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INSTITUTUL DE CERCETĂRI NUCLEARE

FISA 2019 • EURADWASTE '19

9th European Commission Conferences on EURATOM Research and Training in

Safety of Reactor Systems | Radioactive Waste Management

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Contact [First name Last name]
E-mail [...]*@ec.europa.eu* *(functional e-mail if existing, and)*
[First name.Last name]*@ec.europa.eu*
RTD-PUBLICATIONS@ec.europa.eu
European Commission
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EUROPEAN COMMISSION

PROCEEDINGS OF EURADWASTE '19

[edited by A. Constantin]

Directorate-General for Research and Innovation
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FOREWORD

It is our pleasure to introduce these proceedings of the 9th European Commission Conferences on EURATOM Research and Training in Safety of Reactor Systems and Radioactive Waste Management. FISA and EURADWASTE conferences have always been a major milestone on the EU/Euratom agenda, gathering on a regular basis research and training organisations, academia, industry, technology platforms, European fora and European civil society, and International Organisations, participating in Euratom Framework Programmes'. The key of their success lies in coherently summarising most activities and highlighting major achievements of the main pillars of the EU/Euratom Fission Programmes, on safety of reactor systems and radioactive waste management. Following the successful edition in 2013, in Lithuania, these two major events are organised jointly with the Romanian Presidency of the Council of the EU in 2019.

All balanced energy mix scenarios elaborated in Europe on a strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy by 2050 include nuclear energy. While it is for each EU country to choose whether to make use of nuclear power, it remains the role of the European Union, together with its Member States and in the interest of all its citizens, to establish a framework to further develop and support EU/Euratom research and training. The European Union has since long recognised its importance and benefits also through international cooperation.

FISA 2019 EURADWASTE '19 plenary introduction and closure provided an opportunity for both communities to gather, to exchange their views on shared challenges and opportunities in EU/Euratom research and training. Stakeholders' and policy makers' participation contributed to setting the scene at EU / national / international levels and illustrating high benefits from cooperation by supporting, among others, today's Energy/Climate/Industrial policies and to tackle today's societal challenges. It also proved EU/Euratom constant success in pursuing excellence in R&D whilst facilitating pan-European collaborative efforts across a broad range of nuclear science and technologies, nuclear fission and radiation protection.

FISA 2019 EURADWASTE '19 parallel sessions facilitated detailed presentations and panel discussions on the latest achievements, main results and success stories, as well as key recommendations in the respective areas, of some 90 projects carried out, since the previous conference edition in 2013, as part of the 7th and Horizon 2020 Euratom Research and Training Framework Programmes (FP). They were aimed at demonstrating that the knowledge base has advanced significantly, and continuity between actions co-funded over time through the Euratom Framework Programmes guarantees a high impact and is of great added value to the scientific community. It also showed a capacity is maintained to suitably respond to any unexpected event or new EU/Euratom legislative Directives requirements such as the implementation of dedicated research and innovation (or coordinated and support) actions in response to the 2011 Fukushima Daichi accident.

With the incentive of Horizon 2020, Framework Programmes enhance further integration towards a European Research Area together with better prioritisation at European level, with the capitalisation of European Technology platforms and in close collaboration with International Organisations or Fora. Evolutions towards European Joint Programmes, together with Member States research and innovation programmes, were successfully illustrating the added value of a concerted European approach in nuclear safety research and training advocated by the European Commission and Member States.

FISA and EURADWASTE were also a unique opportunity for students, PhD, MSc or young professionals to take part in the ENEN PhD Event & Prize, FISA 2019 and EURADWASTE '19 Poster and PhD awards, and FISA 2019 thematic workshops addressing cross-cutting research and innovation areas of common interest and providing recommendations for the future. The finalists were selected and invited by a jury (Programme Committee) and awards were presented at the joint closing plenary session. The awarded paper were published in the European Physical Journal (EPJ N, EPJ Nuclear Sciences & Technologies), alongside this special edition of EPJ-N.

Participants were also able to participate in a technical tour of the nuclear facilities at Institute for Nuclear Research Pitesti (RATEN-ICN), the Nuclear Fuel Plant (FCN Pitesti), the Cernavoda Nuclear Power Plant and waste management facilities, or the Extreme Light Infrastructure – Nuclear Physics (ELI-NP) in Bucharest, one of the most advanced research facilities in the world focusing on the study of photonuclear physics and its applications.

The European Commission would like to thank the Romanian Presidency, the Ministry of Research and Innovation of Romania and the Institute for Nuclear Research (RATEN-ICN) for hosting the conferences in Pitesti and for the co-organisation of these events. We would also like to extend our gratitude to the speakers, chairs and co-chairs, expert reviewers of all papers and presentations, rapporteurs, projects coordinators, panel members, ENS but also all staff involved at any time whose contribution ensured that the FISA 2019 EURADWASTE '19 Conferences were engaged with the audience in an enjoyable, dynamic and interactive way, ensuring success of these conferences!

All reviewed papers were published in a special edition of EPJ-N and they are the result of a common effort of all partners involved. Thanks are due to many researchers, authors and the peer reviewers for the time and effort they spent to make this special issue possible, to Gilles Moutiers and Anne Nicolas, Editors in Chief of EPJ-N, for providing the opportunity to produce a special issue, to Mr Roger Garbil and Christophe Davies of the European Commission in Brussels for their active participation in the editorial process. Finally, Ms Daniela Diaconu of the Nuclear Research Centre RATEN-ICN has to be gratefully acknowledged for making the FISA 2019 EURADWASTE '19 Conferences a reality, in Pitesti, in Romania, and another key milestone of the Euratom Research community!

Roger Garbil and Christophe Davies (EC DG RTD, FISA 2019 - EURADWASTE '19 Co-chairs)

Daniela Diaconu (RATEN-ICN and Romanian Presidency, Co-chair)

Contents

SUMMARY OF THE EURADWASTE '19 CONFERENCE

Prepared by Hans Forsström (General Rapporteur), International independent expert, Sweden

1. Introduction

The EURADWASTE '19 conference, which was the 9th European Commission Conference on EURATOM Research and Training (R&T) in Radioactive Waste Management was organised jointly with FISA 2019 on Research and Innovation for Nuclear Reactors. This provided a good opportunity for cross contacts between those who produce most of the radioactive waste and those who will take care of and dispose of the waste. In the FISA conference, information was provided on the development status for reactor and fuel management systems with the potential to alleviate the long-term challenges for disposal of the radioactive waste, while in EURADWASTE the developments on geological disposal were reported.

Since the earlier EURADWASTE conferences important developments have taken place and good progress has been made both in the actual implementation of management and disposal of radioactive waste in the EU Member States (MS), and in the organization of the cooperation in research and development and training between the EU MS.

In his keynote speech on the status of management and disposal worldwide Mr Pierre-Marie Abadie, CEO for the French waste management organisation ANDRA, made the following observations:

- Low Level Waste is already adequately and safely disposed in many existing facilities throughout the world.
- Intermediate and High Level Waste and Spent Nuclear Fuel can be safely disposed in deep geological repositories (DGRs). The knowledge exists and the development of DGRs is progressing. In three MS, Finland, France and Sweden, the projects are in advanced stages of implementation. Sites have been chosen and operation is planned for 2025/30. Other MS have a longer time schedule and are still in the siting or pre-siting phase. In the USA one repository for Intermediate Level Waste, the WIPP facility, is in operation.
- As more and more nuclear reactors and other facilities will be decommissioned and subsequently dismantled large volumes of Very Low Level and Low Level Waste are foreseen. As they will appear in a fairly short time span an efficient system for characterisation and treatment will be required to optimize the waste routes.
- Some long-lived waste with low activity, but with large volumes (e.g. graphite, depleted uranium and NORM), will require new appropriate disposal routes.
- In non-nuclear countries the most important radioactive waste is radioactive sources used in medicine, research and industry. Special appropriate solutions will be required for these, e.g. disposal in boreholes as developed by the IAEA.

- The long duration of disposal projects (>100 years) will require a strong knowledge management process to transfer knowledge and experiences between generations.

To support the development and implementation of safe management and disposal of different types of radioactive waste substantial R&D has been carried out and further R&D continues to be important. Although most of this R&D is financed nationally the EURATOM R&T programme in radioactive waste management plays an important role to foster collaborative R&D and improve coordination of R&D, as well as to transfer knowledge and experiences between the front runner countries and the countries with a smaller programme and/or a longer time schedule for implementing their disposal programme.

As stated in the EURATOM Framework Programme the objectives of the activities supported by the EURATOM research and training programme are: "Contributing to the development of safe, longer-term solutions for the management of ultimate nuclear waste, including final geological disposal as well as partitioning and transmutation."

Over the years the EURATOM R&T programme has developed from supporting several projects for coordinated R&D on specific issues to an European Joint Programming of the R&D activities in radioactive waste management across Europe involving Waste Management Organisations (WMOs), Technical Support Organizations (TSOs), Research Entities (Res) and representatives from the civil society.

During the conference reports were presented on the activities leading up to the establishment of the European Joint Programming project (EURAD). Also reports on specific research projects supported by EURATOM were reported.

The EURADWASTE '19 conference was thus structured in four oral sessions:

- Overview and policy: International/EU/EURATOM status in radiation protection, safety of reactor systems and radioactive waste management (jointly with FISA 2019).
- Technology: Predisposal and disposal technology developments.
- Science: Radioactive waste source term and science for disposal safety.
- Organisation: Networking of research communities, joint programming of national programmes and integration of radioactive waste producers.

During these sessions the results from several recently finished and on-going research projects were presented orally and in posters. Especially encouraging was the many good quality PhD-posters that were presented, not least in view to ensure human capacity for the future.

2. Main messages from EURADWASTE '19

Recent developments

Since EURADWASTE '13 some important developments have taken place which influences the implementation of radioactive waste disposal and the accompanying R&D. Some of them are:

- The EURATOM Directive on responsible and safe management of spent fuel and radioactive waste has become operational. The first national reports on the implementation of the Directive nationally have been submitted to and evaluated by the European Commission, including the national programmes for management and disposal of all types of spent fuel and radioactive waste. The first report on the implementation of the Directive was presented to the Council and the European Parliament in 2017. A second report is due in 2019.
- The Directive requires that a peer review of the national situation and plans is performed at least every ten years. The IAEA has developed the ARTEMIS peer review service, which has already been used by a number of MS and is planned by others.
- In Finland a construction licence has been issued for a DGR and construction work has commenced. Good progress is being made in Sweden and France towards licensing of DGRs. In other MS progress can be seen on siting programmes.
- More reactors than earlier planned have been, or will in the short term be, shutdown in several MS, which means that the planning to manage and dispose of the waste from dismantling in an efficient way has become very important.
- The progress towards an European Joint Programming involving WMOs, TSOs, research entities and representatives from the civil society has been good and funding has been provided to the EURAD project to propose, plan and manage all EURATOM funded projects in radioactive waste management. For this purpose, a Strategic Research Agenda and a roadmap has been developed.

All these issues were presented and discussed during the EURADWASTE '19 conference.

Main messages

The main messages from the conference can be summarised as follows:

- The EURATOM R&T programme in radioactive waste management remains very important, in spite that more than 90 % of the R&D funding is national. The programme helps to coordinate R&D, to transfer knowledge and experiences, and to foster cross-fertilisation between the front runner countries and the countries with a longer time scale.
- The landscape is changing as several DGRs are being implemented, but this doesn´t stop the needs for further development of science. Recurrent safety assessments will continue to be made. All countries thus need to keep abreast of the knowledge development.

- This development provides more opportunities for cross-fertilisation including transfer of knowledge and know-how to countries with longer time scales.
- The long time schedules for construction and operation of disposal facilities (> 100 years) puts important demands on knowledge management and the need to ensure the availability of capable people in the long future.
- In the context of knowledge management it is important to distinguish between information management, which can be handled with IT tools, and the management of know-how, which requires transfer of knowledge and experiences between people.
- The EURATOM programme has an important role in this regard, both to support R&D and collect important information, and to transfer of know-how through networking and mobility schemes.
- A step change has been introduced in the management of the EURATOM R&T programme in RWM, as the European Joint Programming project EURAD became active in June 2019. This project involves all actors with an official role in their respective national programme in R&D for radioactive waste management, i.e. WMOs, TSOs, Research Entities and representatives from the civil society. EURAD has developed a Strategic Research Agenda and a road-map for implementation of activities of European added-value between Member States with support of the EURATOM Programme.
- The development of EURAD has a long history starting with the co-operation between WMOs through Implementing Geological Disposal – Technology Platform (IGD-TP), followed by similar cooperation between TSOs in the SITEX project. Both activities, which were originally supported with EURATOM funding, are now continuing through self-sustained fora. Also, the research entities have organised themselves and set up EURADSCIENCE.
- IGD-TP, SITEX and the Research Entities have developed their own Strategic Research Agendas, which have been introduced into EURAD. Input has also been given by civil society groups.
- The latest EURATOM R&T programmes have mostly dealt with issues connected to deep geological disposal. Taking into account interest expressed by several actors the programme is now being widened to also include pre-disposal radioactive waste management, decommissioning and legacy waste management.

In the following the main outcomes and conclusions from the different sessions are described. More details are given in separate reports later in this book.

3. Overview and policy session

The session on International/EU/EURATOM status in radiation protection, safety of reactor systems and radioactive waste management covered several topics:

- Implementation of the different EU/EURATOM Directives
- EU R&T programme in nuclear area and in particular on radioactive waste
- The view of the EURATOM Scientific and Technical Committee (STC), and
- A keynote speech on European and International status on RW management and disposal and challenges ahead.

The highlights and main messages were:

Waste Directive

- The purpose of the Waste Directive is to ensure appropriate national arrangements for a high level of safety and to avoid imposing undue burdens on future generations. It should also ensure public information and participation.
- Each MS shall have a national programme for the management and disposal of all types of spent fuel and radioactive waste.
- The first national reports on the implementation of the Directive and the national programmes were made to the European Commission in 2016, The Commission subsequently reported to the Council and European Parliament in 2017.A new report is due in 2019.
- Together with the EC, the IAEA has developed a peer review service, ARTEMIS, which has been used already by several States as required in the Directive.

Development of European Joint Programme

- Since its start in 1975 the EURATOM R&T programme on radioactive waste management has progressed from a large number of uncoordinated projects to the call for one European Joint Programme in 2018, which brings together WMOs, TSOs, REs and representatives from the civil society.
- This closer cooperation has developed successively over a long period, starting in the early 2000s between WMOs and then through platforms and networks like the IGD-TP for the WMOs, SITEX for TSOs and recently EURADSCIENCE for the REs.
- In the European Joint Programme advanced programmes will be able to address specific cutting-edge science, while less advanced programmes will be able to plan, structure and implement the necessary R&D, with guidance, training and transfer of competence and knowledge from advanced programmes.

Views of EURATOM Scientific and Technical Committee (STC)

- In its opinion in 2018 the STC advocated for an increased budget for nuclear R&D given the need to maintain capability in the nuclear field to ensure that nuclear gets an important role in the road-map towards a zero carbon society.

Keynote speech

- The keynote speech was delivered by Mr Pierre-Marie Abadie, CEO of ANDRA.
- In addition to describing the status of radioactive waste management, as mentioned above in the introduction, Mr Abadie highlighted the usefulness of international cooperation through IAEA, NEA and EC.
- In particular as concerns RD&D the support by the EC is important and the developments towards a European Joint Programming are very good and

the efforts of the EC to promote the sharing of ideas and plans between all actors concerned is commendable.

4. Predisposal and technology session

The session on predisposal and disposal technology included one keynote on the role of Research Entities in advancing knowledge, solutions and technologies for the management and disposal of RAW seen from the Czech perspective and five project presentations, three on pre-disposal and two on disposal technology:

- Nuclear site characterization for radioactive waste minimization - INSIDER
- Characterization of conditioned nuclear waste - CHANCE
- Thermal treatment for radioactive waste minimization - THERAMIN
- Tunnel plugs and shaft seals demonstrations - DOPAS
- Monitoring strategies & technologies for geological disposal - MODERN2020

The session was concluded with a panel discussion on remaining research needs in pre-disposal.

The highlights and main messages were:

- Pre-disposal is becoming a new pillar in the EURATOM programme. The results achieved in the pre-disposal project are promising and show that further improvements in characterization, minimization and treatment of waste can be achieved. This might lead to a higher safety and also have commercial benefits.
- Waste Acceptance Criteria are important and should be developed in dialogue between all concerned parties (WMOs, waste producers, regulatory bodies and other stakeholders). In this way, one can avoid creating a category of waste that cannot be taken care of.
- Specific waste streams, like bituminized waste, graphite and powder waste from the back-end require further investigations with regard of their disposability and long-term behaviour.
- Waste packages are important not only for long-term purposes but for transport and handling in the repository operational period as well. Few examples of real waste packages for SNF/HLW exist today. Continued R&D on the design and construction of such waste packages will be useful.
- The activities performed during construction and operation of a DGR will have an important impact on the long-term safety, e.g. plugs for tunnels and drifts as investigated in DOPAS.
- It is also important to be able to monitor the function of specific elements of the disposal facility. As was shown in Modern 2020 this is not only a technical issue. Here the involvement of representatives of civil society has been very useful.

5. Radioactive waste source term and science for final disposal

The session on Radioactive waste source term and science for disposal safety included one keynote on the role of science for the safety case now and in the future, and how to maintain knowledge and competence until final closure seen from the Swedish perspective and five presentations on R&D projects:

- Spent fuel dissolution - REDUPP and DISCO
- Carbon-14 source term generation and release from irradiated metals, ion-exchange resins and graphite - CAST
- Research and Innovation action on cement-based materials, properties, evolution and barrier functions - CEBAMA
- Bentonite erosion and Bentonite mechanical evolution - BELBAR and BEACON
- Microbiology in nuclear waste disposal - MIND

The session was concluded with a panel discussion on remaining challenges in science for the safety case of geological disposal.

The highlights and main messages were:

- The development of the safety case provides the platform to integrate the scientific and technical knowledge in a systematic and traceable manner to show the long-term safety of a repository. For licensing a DGR a sound scientific and technological basis and the ability to compile a convincing post-closure safety case is needed.
- Also, after receiving licenses and starting operation safety analyses will continue to be needed for periodic updates based on latest state of knowledge.
- As science will continue to develop also after the start of operation of a repository, there is a need to maintain oversight and knowledge in those areas of science that are important to post-closure safety until closure of the repository. This also includes the capability to compile a safety case. These are issues where future cooperative activities can play an important role.
- The work done in the reported projects increases the knowledge (both scientific and technical) to be used for the licensing of the first HLW/SNF repositories in the advanced MS. This knowledge will also support the other MS in advancing their national programmes as rapidly as possible.
- All projects could to some extent build upon available experience and results from earlier projects. None of the projects did fundamentally change earlier understanding, but refinements have been made in all projects.
- Most projects include experimental work and modelling activities. This is important as adequate models help to transfer the evidence from experiments to the in-situ conditions of the repository analysed. The models also support the extrapolations for long-term evolution if needed and can provide information for sensitivity studies as part of the post-closure safety case.
- After completion of the reported projects some uncertainties will remain and should be specified. Whether these are acceptable or not, needs to be analysed within specific performance assessments and post-closure safety cases as the importance of remaining uncertainties depends upon the whole repository system and cannot be judged for one process alone in isolation.
- The time schedule from the start of a DGR project until the closing of the repository could be 100 years or more. Knowledge management was thus a key topic brought up during the science session. Knowledge management is also an important component in the new EURAD project.

- The difference between information and knowledge how to use the information should be recognised. For preservation of information different IT tools can be utilised. For preserving the knowledge how to use the information, active involvement in the work is needed. Here the recurrent safety assessments foreseen are important.
- The challenge to engage young people in R&D on radioactive waste management in the future remains. Challenging tasks are needed to attract young researchers and engineers.

6. Networking and organisation of future work

The session called Networking of research communities, Joint Programming of national programmes and Integration of radioactive waste producers mainly dealt with how the different actors have evolved and adhered to the concept and joined forces in the European Joint Programme on Radioactive Waste Management (EURAD) and the remaining issue to also integrate the waste producers.

Presentations were made of IGD-TP, representing the WMOs, SITEX, representing the TSOs and EURADSCIENCE, representing the Research Establishments.

Presentations were also made on the possible interaction with IAEA and OECD/NEA and on the interests and needs from countries with longer time scales for implementation.

Finally, a keynote speech was given from EDF on how to include the pre-disposal activities in the Joint Programme and in particular to ensure harmonization of standards in Europe to allow cross-country activities.

The highlights and main messages were:

- EURAD is a step change in the implementation of EURATOM R&T programme in radioactive waste management. Instead of many smaller R&D projects the Commission is now funding a large project that will be based on a European Joint Programming (EJP).
- EURAD involves all actors concerned in radioactive waste management R&D, i.e. WMOs, TSOs, Research Entities and representatives from the civil society. EURAD will implement its Strategic Research Agenda of activities of European added-value between Member States with support of the EURATOM Programme. In a second step also waste producers may be included.
- The development of EURAD has a long history starting with the co-operation between WMOs through IGD-TP, followed by similar cooperation between TSOs in SITEX. Both projects, which were originally supported with EURATOM funding, are now self-sustaining fora. The creation of EURAD is an achievement and has been successful thanks to the continuous support of the EURATOM programme over a decade.
- IGD-TP, SITEX and the Research Entities have developed their own Strategic Research Agendas, which have been introduced into EURAD as a basis for EURADs SRA. Input has also been given by civil society groups.
- In a first round EURAD will run 7 collaborative R&D projects, 2 strategic studies and 3 knowledge management projects.

- For WMOs focus remains on geological disposal, but the missions of EURAD are proposed to be expanded to also accommodate more upstream interests and cover a wider inventory (e.g. sealed sources and borehole disposal). However, it is important to recognise that WMO's R&D programmes have a much wider scope of activities than the commonly agreed EURAD strategic research agenda will address.
- For TSO/SITEX community, the condition for participating to an EJP is to develop the high quality expertise function independent from WMOs as well as expanding interaction with Civil Society towards integration in R&D projects, meaning that CS may express their view on the need for R&D activities.
- The European research organisations involved in RWM have organised themselves in a network, called EURADSCIENCE, with the vision of acting as an independent, cross-disciplinary, inclusive network providing scientific excellence and credibility to national radioactive waste management programmes.
- An important component of EURAD is knowledge management. These parts should lead to attract and train new competencies and new high level researchers, to allow a cross fertilization of ideas and to ensure that the competencies will be present all along the duration of the disposal project until closure of the disposal facilities.
- The involvement of representatives from the civil society is important in programming projects for radioactive disposal. Extensive support of past EURATOM programmes has enabled to define the key requirements and methods for involvement of civil society in radioactive waste disposal programmes.
- Civil society organizations were consulted in the preparations of EURAD, primarily through SITEX and the TSOs, but also in an advisory role to the project. The role of these organizations, however, needs to be clearly defined. Primarily they have a role to influence the Strategic Research Agenda. They can also assist in making the R&D results understandable by the public at large. In certain projects with a social impact direct participation can also be considered.

7. Summing up

EURADWASTE '19 has been very successful with very high quality and interesting presentations and quite vivid panel discussions. The R&D activities presented have shown a high scientific content and are very valuable for the continued implementation of radioactive waste management and disposal. Most projects have been connected to the safety of disposal of intermediate and high level waste and spent nuclear fuel. Some projects also cover the management of low-level waste (especially waste from decommissioning). Further such projects are foreseen to be included in the future programme.

As concerns the organisation of the R&D activities good progress is being made towards an efficient continued implementation involving all important stakeholders through the EURAD European Joint Programming project. The European Joint Programming is an efficient way of utilising capacities of different types in Europe, including EURATOM funding. It will also provide a tool for transfer of knowledge and experiences from the countries with an advanced programme to countries with a longer time schedule as well as to new generations of scientists. The EURAD project has many important challenges, especially concerning the decision-making process, but the structure is built to get the best results out of the work and the funding provided.

JOINT INTRODUCTION
FISA 2019
EURADWASTE ’19

PATRICK CHILD

FISA 2019 – EURADWASTE '19

Keynote of Mr Patrick Child (EC, DG RTD), Deputy Director General, Research and Innovation, European Commission:

Euratom Research and Training and Horizon Europe framework programmes

Dear Minister,
Dear Senator,
Dear Honourable members,
Ladies and gentlemen,

Thank you, Honourable Minister Hurduc for Research and Innovation of Romania, and the Institute for Nuclear Research (RATEN ICN) for co-organising together with the European Commission these events taking place this week, in Pitesti, in Romania, under the auspices of the Romanian Presidency of the Council of the EU.

It is a great honour to be here among so many of the world's leading scientific experts. Today I will speak to you about three things. Firstly, about the EU's ambition to become the world's 1st major economy to go climate neutral by 2050; Secondly, about Euratom as a platform to work together and the results we have achieved so far; and finally, I will speak to you about the new features of the future Euratom program.

Decarbonisation: Clean Planet for All

The alarming findings of the recent International Panel on Climate Change (IPCC) special report call for unprecedented efforts and much higher emissions reductions in order to limit the global warming to 1.5 degrees Celsius.

This is a wake-up call to the world – policy-makers and business community alike. The powerful mobilisation of citizens, including youth, for the case of climate action cannot remain answered.

The EU committed to lead by example

With its 2050 decarbonisation strategy 'A Clean Planet for All', the EU unveiled the ambition to become the world's 1st major economy to go climate neutral by 2050.

This calls for a range of new ground-breaking solutions and makes research and innovation a cornerstone to a carbon neutral world.

Member States have very different views on nuclear energy

Through the European Strategic Energy Technology Plan (SET-Plan), the implementation plan for nuclear energy is supported only by several member states.

Yet in the 'Clean Planet for All' communication, the European Commission recognises a continued contribution from nuclear energy to decarbonise the economy by 2050.

EURATOM as a platform to work together

EURATOM provides us a platform to work together on objectives where we do agree: ensuring the safe and sustainable use of peaceful nuclear energy technologies.

EURATOM has been the framework in which, for more than 60 years, knowledge and competence in nuclear science and technology have been developed in Europe, and through International Cooperation together with, among others, the OECD, the Nuclear Energy Agency and the International Atomic Energy Agency.

EURATOM would not have been possible if Europe was not continuously maintaining high competences, underpinned by sound and advanced research.

Today, all EU Member States meet equally high standards of safety, radiation protection, safeguards and security.

The EU became the first major regional actor with a legally binding regulatory framework for nuclear safety following the implementation of the latest Directives on safety, waste and basic safety standards.

As such, we can ensure that Member States can rely on one another, respect each other's choices and citizens in different Member States can rely on their neighbours across the border.

I would like to highlight a couple of benefits of the EURATOM Research and Training programme:

It focusses on basic and fundamental research but also on technological and industrial developments, as these are essential to face and overcome the Energy and Climate Change challenges that are lying ahead of us.

In the field of decommissioning we need to transfer the fundamental research into successful industrial projects while ensuring adequate training opportunities are available for this growing market.

In the field of waste management, we need to implement solutions that can help the society to understand issues linked to waste disposal and agree on the acceptability of proposed solutions.

The European Commission is proud to support the launch of a third COFUND European Joint Programme with co-funding of EUR 32 million from Euratom, supporting further integration of Waste Management Organisations, Technical Support Organisations and other Research Organisations in Joint Programming at European level.

Following the Council Regulation establishing the Euratom Research and Training Programme for 2019-2020, a specific 2 years' work programme has been published. The Fission call that opened on 15 May 2019 will benefit from a total budget of 139.9 million euros. Fusion actions include the extensions of EUROfusion and the contract of operation of JET with a total budget of 328 million euros.

This work programme focuses on the safety of nuclear systems, radiation protection and radioactive waste management. As in the previous work programme, education and training will be supported in two ways: through specific actions and through the requirement that each research and innovation action in this work programme dedicates at least 5 % of the total budget to education and training activities for PhD students, postdoctoral researchers and trainees.

This work programme gives particular attention to innovations in the safety of reactors and in decommissioning by supporting technology transfer from the research community to industry.

On radiation protection, the work programme focuses on further integration of research, preparation of a research roadmap for medical applications, and ensuring the safe use of these medical applications.

For research infrastructure, this work programme launches important actions aiming to maximise the safety of existing and future research reactors.

The work programme introduced two pilot actions with JRC on knowledge management and on open access to JRC nuclear research facilities with the objective to address better synergies between direct and direct actions.

Future Euratom programme and Horizon Europe

The new Euratom program will continue to improve safety, security and radiation protection and to contribute to the decarbonisation of the energy system in the long term. The budget we proposed is EUR 2.4 billion (2021-27), EUR 1.675 billion (2021-25).

The new elements that the European Commission are proposing in the next Euratom program include:

- non-power applications such as the uses of ionising radiation, not only for medical applications, but also for industry, agriculture and space research.
- the creation of stronger synergies between nuclear research and other research areas through joint activities within the new research and innovation framework for 2021-2027, Horizon Europe.

- a single set of objectives, combining the indirect and direct action and we will also offer to all projects the possibility for access to our Joint Research Centre facilities and expertise.
- One overarching element of research is the human capital. It is imperative that we maintain and further enhance the number, the competences and the excellence of our research community, especially in the nuclear sector. For this reason, the Marie Skłodowska-Curie Actions will be opened up to Euratom researchers.

<u>Conclusion</u>

I have unveiled to you today that with the 2050 decarbonisation strategy 'A Clean Planet for All', the EU unveiled the ambition to become the world's 1st major economy to go climate neutral by 2050. We see nuclear energy as part of the future energy mix to achieve this.

Even though there are clear differences between Member States about the role of nuclear energy, the Euratom program has given us a platform to work together on objectives we do agree on: ensuring the safe and sustainable use of peaceful nuclear energy technologies.

EURATOM has been the framework in which, for more than 60 years, knowledge and competence in nuclear science and technology have been developed in Europe.

The current programme focusses on safety of nuclear systems, radiation protection and radioactive waste management. Education and training is supported too.

In the new Euratom programme we introduce a some new elements: a focus on non-power applications for medical and industrial use, a signle set of direct and indirect objectives, clear synergies with Horizon Europe and we will open up Marie Skłodowska-Curie Actions to nuclear researchers.

I would like to conclude by expressing all my gratitude for organising these successful events and I personally look forward to hear from the results of this dialogue.

Thank you, Chairman, Honourable Members, Ladies and gentlemen.

CHARLINA VITCHEVA

FISA 2019 – EURADWASTE '19

Keynote of Ms Charlina Vitcheva (EC, DG JRC), Deputy Director-General of the Joint Research Centre, European Commission:

JRC role in Euratom Research and Training and Horizon Europe

Dear Minister,
Dear Senator,
Distinguished guests,
Ladies and gentlemen:

I am very glad to be here today in this joint opening session of the FISA 2019 and EURADWASTE'19 conferences.

I sincerely believe that bringing together the key stakeholders in nuclear research under these conferences, to discuss on where we stand with regards nuclear research, to identify the key challenges (at national, European and international levels) on research and innovation policies, as well as to exchange on synergies, partnerships, and future perspectives is fundamental to shape the future of European nuclear research.

Thank you, Honourable Minister Hurduc for Research and Innovation of Romania, and also to the Institute for Nuclear Research for hosting and making it possible.

The European Commission's Joint Research Centre

My name is Charlina Vitcheva and I am Deputy Director-General of the European Commission's science and knowledge service: the Joint Research Centre.

We support EU policies with independent multidisciplinary evidence throughout the whole policy cycle, as part the European Commission, in areas such as agriculture, food security, environment, climate change, innovation, growth, as well as in nuclear safety, safeguards and security.

Our researchers provide EU and national authorities with solid facts and independent support to help tackle the big challenges facing our societies today.

Established as the Joint Nuclear Research Centre by the Euratom Treaty 60 years ago, the JRC has broadened its field of research to non-nuclear disciplines, which now cover around 75 % of its research programme. We are dealing with large spectrum of activities such as Growth and Innovation; Energy, Transport and Climate; Sustainable Resources; Space, Security and Migration; Health, Consumers and Reference Materials; and Nuclear Safety and Security; We have a new focus on Knowledge Management and Competences.

The JRC is spread across six sites in five different countries within the EU: Brussels and Geel in Belgium, Petten in The Netherlands, Karlsruhe in Germany, Ispra in Italy, and Seville in Spain.

The JRC is funded by the EU's framework programme for research and innovation: Horizon 2020, and by its EURATOM Research and Training Programme for its work in the nuclear field.

JRC research in nuclear safety, safeguards and security.

Our Directorate for Nuclear Safety and Security employs about 460 scientists, technicians and administrative personnel in Petten, Karlsruhe, Geel and Ispra.

The JRC multi-annual work programme for nuclear activities fully reflects the specific objectives of the Direct Actions of the Euratom programme. It is structured in about 20 projects, allocating:

- 48 % of its resources to nuclear safety, waste management, decommissioning and emergency preparedness;
- 33% to nuclear security, safeguards and non-proliferation,
- 12% to reference standards, nuclear science and non-energy applications and
- 7% to education, training and knowledge management.
- From these areas of activity, one part is dedicated to supporting the policy of the Union on nuclear safety and security.

But we do not work alone. We do not work in silos, in an isolated fashion. Collaboration is the essence of the scientific effort.

And in our case, it is not just for the sake of scientific curiosity, but to align with and complement research and training in the Member States. Indeed, the JRC is continuously interacting with the main research and scientific institutions in the EU, such as the Technology Platforms SNETP, IGDTP, and ESARDA; with research institutions of Member States and third countries, and with international organisations such as the IAEA.

Globally, we work together with over a thousand organisations worldwide in more than 150 networks, both nuclear and non-nuclear.

JRC carries out research, training and knowledge management activities in nuclear safety, radioactive waste management, nuclear security and safeguards, nuclear data, reference materials and measurements, standardisation, and nuclear science applications.

JRC is the Euratom implementing agent of the Generation IV International Forum.

In addition to its competent staff, the JRC owns and operates scientific research infrastructure which is rare, and in occasions unique.

Students and researchers can access JRC nuclear research facilities through several programmes enabling them to perform research projects as part of their curricula. This will be enhanced in the future Horizon Europe framework programme.

Based on its relevant competence, infrastructures, its independence and neutrality of judgement, the JRC provides the scientific basis for nuclear-related Union policies across entire EU policy-making cycle, from policy anticipation and impact assessment up to policy implementation, monitoring and evaluation.

What lies ahead of us?

In spite of the different national options regarding the electricity mix, all scenarios considered in the forward looking for a low carbon economy in Europe include nuclear energy as a source of electricity generation in the long term.

The long-term safe, secure and sustainable use of nuclear energy must be ensured by a consistent approach to safety (implementation of appropriate and commensurate common principles, rules and standards); safeguards (verification, reporting and non-proliferation commitments such as export controls) and security (prevention, detection and response), as well as international acceptance and mutual trust (transparency).

This can only be based on sound scientific evidence, reliable nuclear measurements and appropriate control tools, as well as on public involvement, which at the same time can only be guaranteed if competence and technology leadership are maintained within the EU (research, education, training, and knowledge management).

The Commission's proposal for the next Euratom Research and Training Programme, which is currently being discussed at the Council aims at focusing in the same key research areas as the current programme, i.e. nuclear safety, security, radioactive waste and spent fuel management, radiation protection and fusion energy.

At the same time, the programme intends to expand research into non-power applications of ionising radiation, and make improvements in the areas of education, training and access to research infrastructure (including JRC's), as well as to better exploit the complementarity between research carried out by Member States scientific institutions, and research carried out by the Joint Research Centre.

Ladies and gentlemen, we are ready for that. We are ready to continue our cutting-edge research in nuclear safety, security and safeguards, putting at the disposition of the research community our competence, and our infrastructure. Ready to work together with you, the scientific community, in these very important topics for the future of Europe.

I wish you very successful conferences, and I am looking forward to hear from their outcomes.

Thank you very much.

NICOLAE HURDUC

FISA 2019 – EURADWASTE '19

Keynote of Mr Nicolae Hurduc (Minister, RO)

Ministry of Research and Innovation of the Republic of Romania

Dear participants,

Romania has an installed capacity of around 17 GWe characterized by a balanced mix, high share of low carbon electricity, availability of own natural resources, and independency

The national energy policies were oriented to capitalize: (1) the advantages of important internal energy resources (oil, natural gas, and coal), (2) the considerable potential for hydro-energy, solar, wind and bio-mass, (3) the existing uranium reserves. A well balanced energy mix was developed based on diversity and stability offering independence, security of supply, and capability to operate properly.

In the last decades the national electricity consumption was affected by three factors:

- restructuration of the economy (closing large consumers, growing up of the low intensive energy industry),
- demographic decline from 22 million (1990) to 19 mil. (2016) inhabitants,
- energy efficiency measures.

After a decline of consumption (from 60 TWh in 1990 to 40 TWh in 1999) it stabilized around 49 TWh (2016) with a trend of 1-2% annual growth.

Nuclear power contributes with 18-20% to the total electricity production. It is a stable, reliable and price affordable electricity. The peculiarity of nuclear sector in Romania is the natural uranium based on CANDU technology. The security of supply is strengthened by the fact our industry produces the nuclear fuel, the heavy water, nuclear equipment and a lot of services.

Very important is to note the contribution of the national research to this achievement. The nuclear fuel is a result of the national efforts, also the heavy water, and now the Tritium issue was deeply approached to find valuable solutions. Romanian research organizations have developed technics, methods, instruments and tools to support the national nuclear power. An important research infrastructure was developed together with research groups, teams and organizations, and important efforts were devoted to build the education and training system.

Nowadays the Romanian nuclear Agenda includes:

- operational safety of the the Nuclear Power Plant and other nuclear installations,
- the continuation of works at Cernavoda Unit 3 and Unit 4,
- Plant life extension for Cernavoda NPP Unit 1,
- Radioactive waste management (LILW repository construction, geological disposal strategy),
- ALFRED GenIV demonstrator implementation,
- Mining and environmental issues (site remediations).

On the short term the plant life extension of the nuclear units from Cernavoda NPP is a major decision to preserve the current share of free carbon electricity in the national system. The refurbishment of Unit 1 was approved and entered in the preparation phase. The project consists of the re-tubing of the CANDU core and it will be implemented from December 2026.

The continuation of the works at the Unit 3 and Unit 4 is considered as a feasible and optimal approach to significantly increase the free-carbon electricity production and a set of dedicated measures are included in the national energy strategy.

From the long term perspective, the National Strategy for Research, Development and Innovation (NSRDI) is oriented to stimulate the development of advanced technologies including nuclear technologies able to face the societal and climate challenges. The development of the lead-cooled fast reactors technology (LFR) is seen as an optimal option for the implementation of nuclear systems with great performances in safety, security, economics, and waste management. At the same time the synchronism of the national research with the major European themes, the enhancing of collaboration, the growth of the spin-off capacity, and the job creation are targeted.

Based on NSRDI, a separate subprogram (5.5 Program for research, development and innovation of 4th generation reactors-ALFRED) was started, in 2019, to support preparatory activities for the implementation of the LFR demonstrator. ALFRED project is also mentioned in the national energy strategy as an important development for the consolidation of the nuclear sector in Romania and for the development of advanced system able to cope with the societal, market, and climate challenges.

ALFRED is a European project, emerged from the Euratom supported projects. Our vision is to combine the European structural funds with national funds and industry contribution in order to transform the vision into a real infrastructure. After a large national consultation of the stakeholders, today ALFRED is present in the main national strategic documents. Based on thrm, the Ministry of research supports the efforts to include ALFRED in the planning of the future EU budget and to fulfill the full procedure to declare it as a major project.

FISA and EURADWASTE conferences will approach the success of the collaborative research in the frame of Euratom programme, how the critical mass on different very focused topics was created and worked, what kind of outcomes were produced, what are the directions for the future.

I hope the collaboration on the main topics of nuclear safety and radioactive waste management will be more and more fruitful producing valuable solution and helping the nuclear power to be more and more accepted by the society as a powerful contributor to de-carbonization of the energy sector.

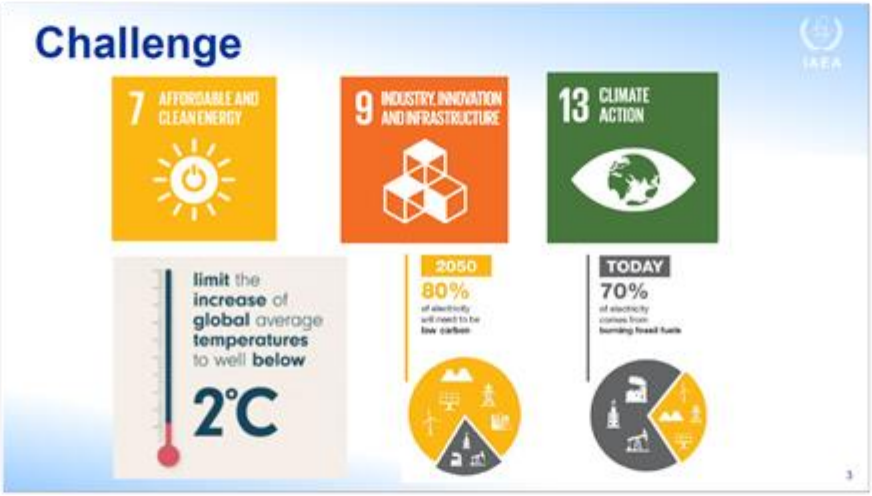
I wish a great success for your debate!

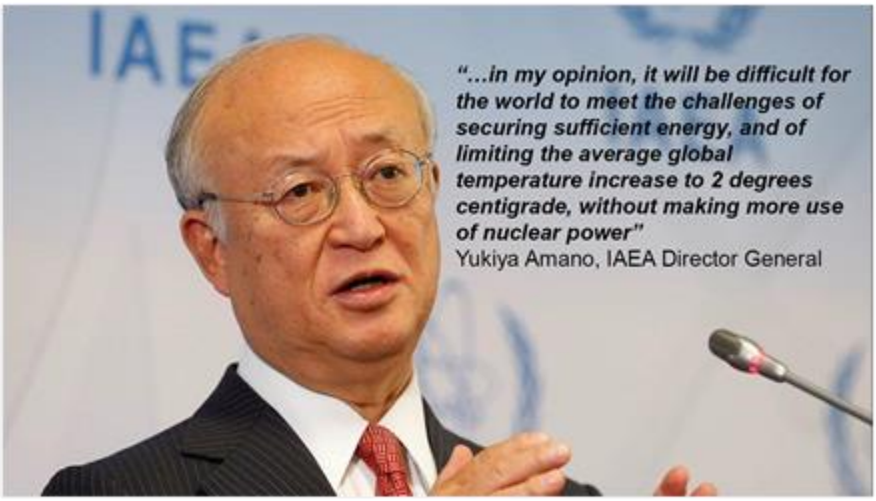
STEFANO MONTI

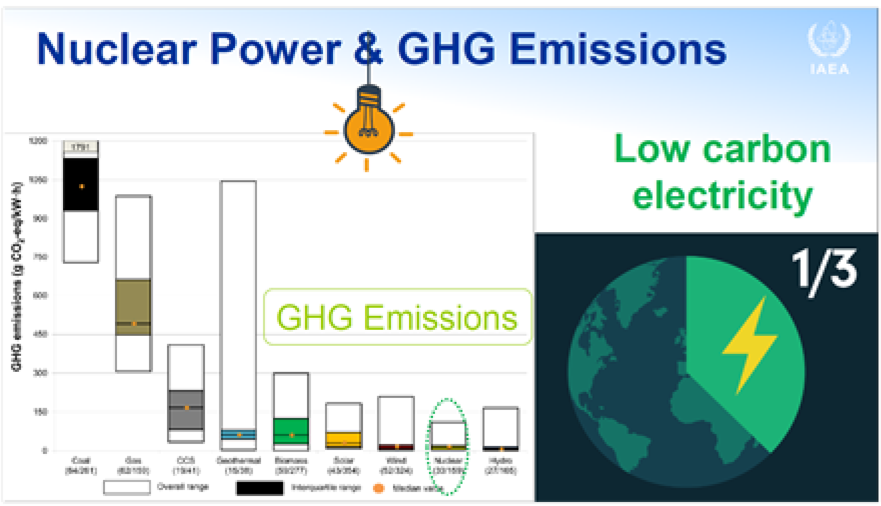
FISA 2019 – EURADWASTE '19

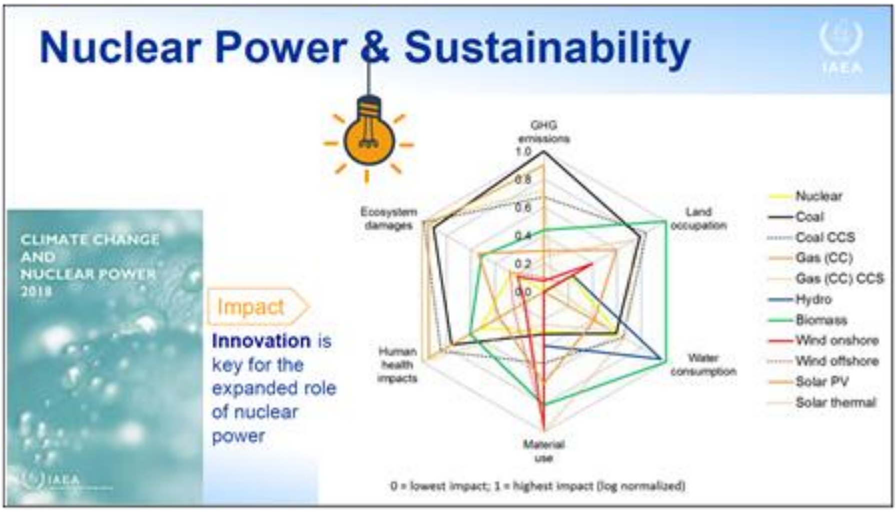
Keynote of Mr Stefano Monti (IAEA), Section Head, Nuclear Power Technology Development section, Division of Nuclear Power, Department of Nuclear Energy:

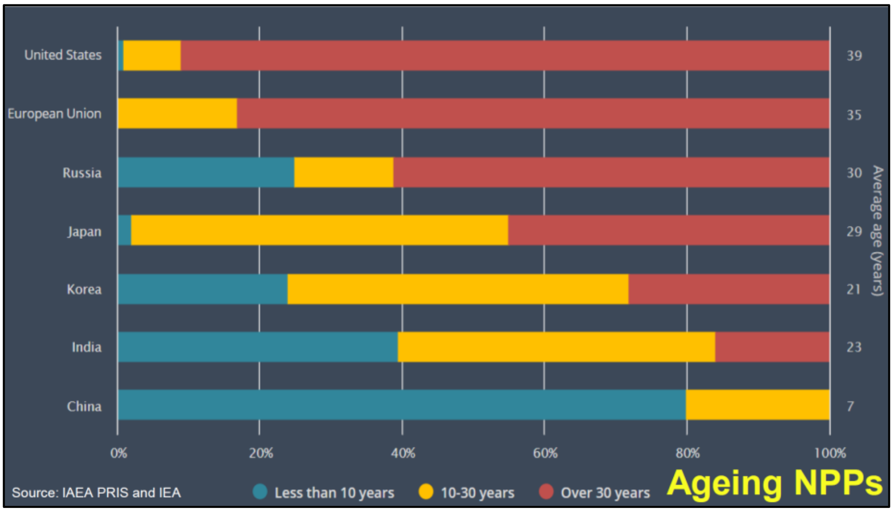
Research and Innovation for a safe, secure and safeguarded nuclear power in support of the UN Sustainable Development Goals


Challenge
7 AFFORDABLE AND CLEAN ENERGY
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
13 CLIMATE ACTION
limit the increase of global average temperatures to well below
2°C
2050
80%
TODAY
70%


"…in my opinion, it will be difficult for the world to meet the challenges of securing sufficient energy, and of limiting the average global temperature increase to 2 degrees centigrade, without making more use of nuclear power"
Yukiya Amano, IAEA Director General

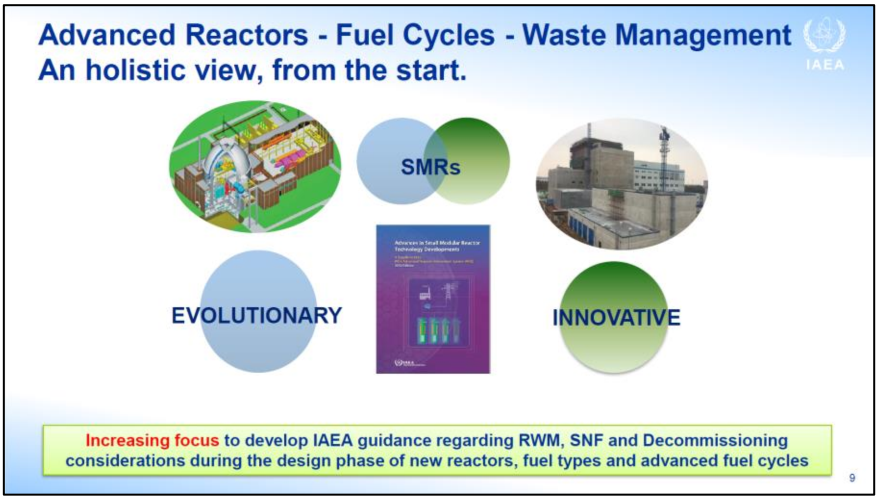

Nuclear Power & GHG Emissions
GHG Emissions
Low carbon electricity
1/3

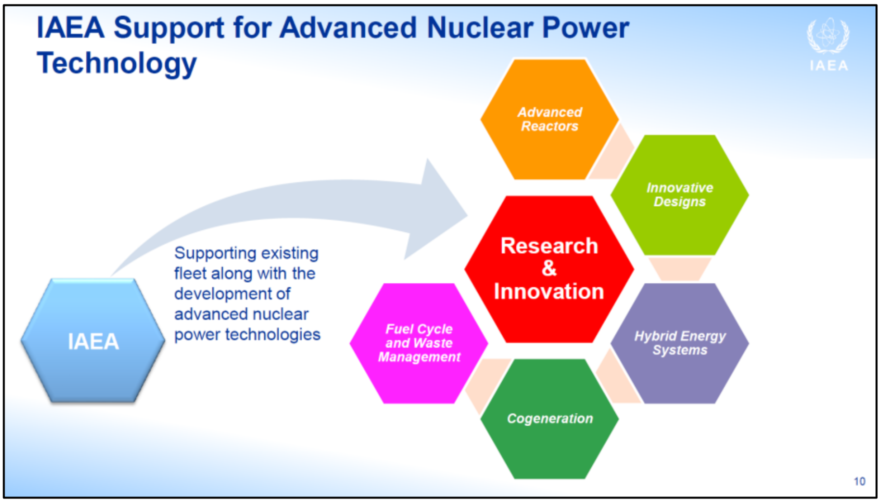




IAEA support of technical innovations to improve existing NPP fleet sustainability

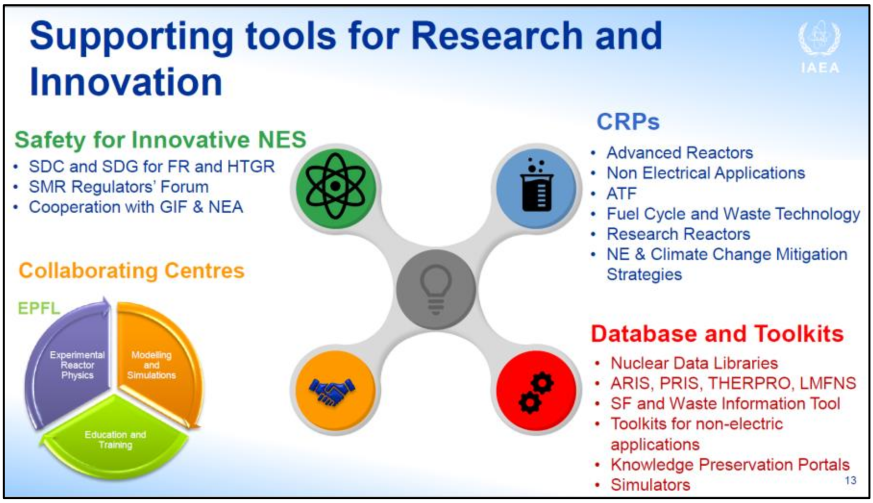
- Non-Baseload operation
- Transitioning toward a future integrated grid
  - Energy storage, H2 production, district heating and other examples of loosely integrated energy systems relevant to the current fleet of reactors
- Modernization
  - Deployment of wireless technology (CRP completed)
  - Digitalization (TWG-NPPI&C)
  - Condition-based monitoring and maintenance (TWG-NPPLM)
  - Innovative human-factors engineering
- Overcoming supply-chain atrophy
  - Additive manufacturing
  - Innovations to improve procurement and supply logistics
- International Partnership: Innovation for the future of Nuclear Energy, A Global Forum 10-12 June, Gyeongju, South Korea


Advanced Reactors - Fuel Cycles - Waste Management
An holistic view, from the start.
IAEA
SMRs
EVOLUTIONARY
INNOVATIVE
Increasing focus to develop IAEA guidance regarding RWM, SNF and Decommissioning considerations during the design phase of new reactors, fuel types and advanced fuel cycles
9


IAEA Support for Advanced Nuclear Power Technology
IAEA
Supporting existing fleet along with the development of advanced nuclear power technologies
IAEA
Advanced Reactors
Innovative Designs
Research & Innovation
Fuel Cycle and Waste Management
Hybrid Energy Systems
Cogeneration
10


Supporting tools for Research and Innovation
IAEA
Technical Cooperation
CRPs
Database & Toolkits
Collaborating Centers
International Forums & TWGs
ICERR
Safety & Security for innovative NES
11

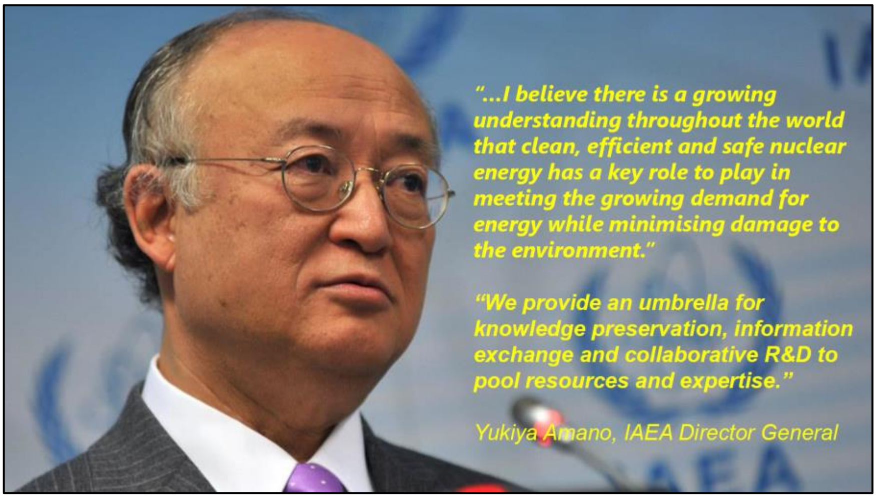
Coordinated Research Activities
IAEA
Uniting the World through Research
4
3%
44
36%
74
61%
~130 active CRPs (30 in NE), ~1600 research institutions involved
Nuclear Techniques for Development and Environmental Protection
Nuclear Power, Fuel Cycle and Nuclear Science
Nuclear Safety and Security
12



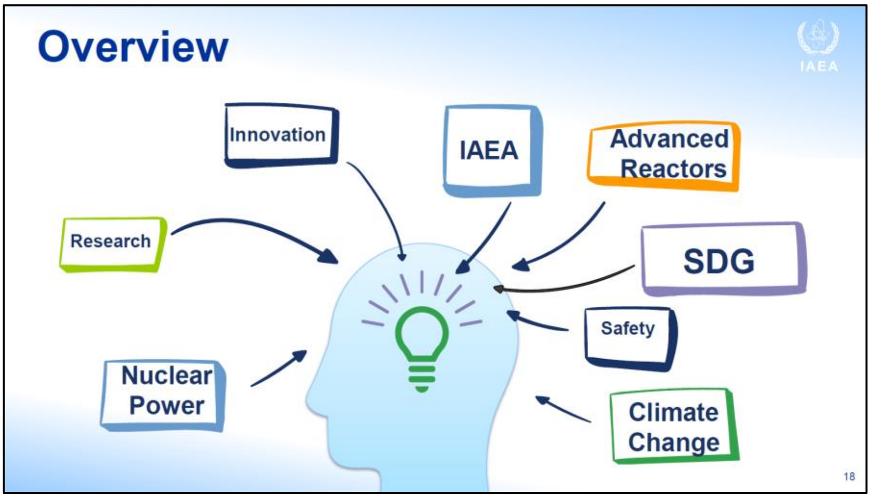
Supporting tools for Research and Innovation
IAEA
Safety for Innovative NES
• SDC and SDG for FR and HTGR
• SMR Regulators' Forum
• Cooperation with GIF & NEA
Collaborating Centres
EPFL
Experimental Reactor Physics
Modelling and Simulations
Education and Training
CRPs
• Advanced Reactors
• Non Electrical Applications
• ATF
• Fuel Cycle and Waste Technology
• Research Reactors
• NE & Climate Change Mitigation Strategies
Database and Toolkits
• Nuclear Data Libraries
• ARIS, PRIS, THERPRO, LMFNS
• SF and Waste Information Tool
• Toolkits for non-electric applications
• Knowledge Preservation Portals
• Simulators
13

Global Scenario
• Scenario modelling, decision analysis and road-mapping tools
01
Collaborative Projects
• Investigate innovations in selected nuclear energy technologies, related R&D
• Innovative institutional arrangements to facilitate their development and deployment.
02
INPRO
Sustainability assessment & strategies
• Nuclear Energy System Assessment (NESA) using the INPRO Methodology
03
Dialogue and Outreach
• INPRO Dialogue Forum
• Regional Trainings
04


International Conference on
Climate Change and the Role of Nuclear Power
7–11 October 2019
Vienna, Austria
#Atoms4Climate
Atoms4Climate@iaea.org
1. Advancing energy policies that achieve the climate change goals
2. The increasing contribution of nuclear power in the mitigation of climate change, including synergies with other low-carbon power generation sources
3. Development and deployment of advanced nuclear power technologies to increase the use of low-carbon energy
4. Shaping the future of the nuclear industry in regulated and deregulated energy markets to address climate change
5. Enhancing international cooperation and partnership in nuclear power deployment
6. Public and non-nuclear stakeholders' perception of the role of nuclear power in climate change mitigation
CN-275


"...I believe there is a growing understanding throughout the world that clean, efficient and safe nuclear energy has a key role to play in meeting the growing demand for energy while minimising damage to the environment."
"We provide an umbrella for knowledge preservation, information exchange and collaborative R&D to pool resources and expertise."
Yukiya Amano, IAEA Director General


8 December 1953
1 to 23 October 1957
11 December 1957
1959
10 December 2005
1958 to 1979
IAEA
23 August 1979
Thank you for your attention!
Contact:
Stefano MONTI
S.Monti@iaea.org
Atoms for peace and Development...

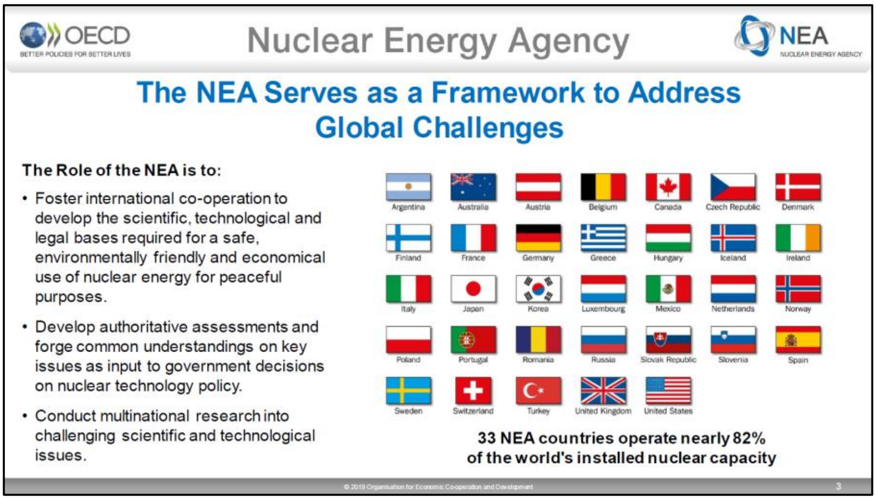

Overview
IAEA
Innovation
IAEA
Advanced Reactors
Research
SDG
Safety
Nuclear Power
Climate Change
18

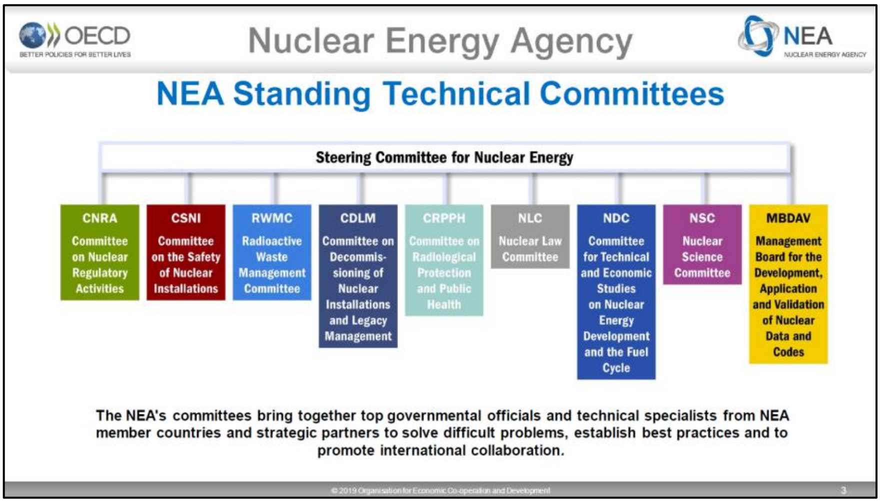
DANIELA LULACHE

FISA 2019 – EURADWASTE '19

Keynote of Ms Daniela Lulache (OECD/NEA, FR), Head of Office of Policy and Coordination, OECD Nuclear Energy Agency

Nuclear Research and Innovation successes and accomplishments looking to the future


OECD
BETTER POLICIES FOR BETTER LIVES
Nuclear Energy Agency
NEA
NUCLEAR ENERGY AGENCY
The NEA Serves as a Framework to Address Global Challenges
The Role of the NEA is to:
• Foster international co-operation to develop the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes.
• Develop authoritative assessments and forge common understandings on key issues as input to government decisions on nuclear technology policy.
• Conduct multinational research into challenging scientific and technological issues.
Argentina
Australia
Austria
Belgium
Canada
Czech Republic
Denmark
Finland
France
Germany
Greece
Hungary
Iceland
Ireland
Italy
Japan
Korea
Luxembourg
Mexico
Netherlands
Norway
Poland
Portugal
Romania
Russia
Slovak Republic
Slovenia
Spain
Sweden
Switzerland
Turkey
United Kingdom
United States
33 NEA countries operate nearly 82% of the world's installed nuclear capacity
© 2019 Organisation for Economic Co-operation and Development
3


OECD
BETTER POLICIES FOR BETTER LIVES
Nuclear Energy Agency
NEA
NUCLEAR ENERGY AGENCY
NEA Standing Technical Committees
Steering Committee for Nuclear Energy
CNRA
Committee on Nuclear Regulatory Activities
CSNI
Committee on the Safety of Nuclear Installations
RWMC
Radioactive Waste Management Committee
CDLM
Committee on Decommissioning of Nuclear Installations and Legacy Management
CRPPH
Committee on Radiological Protection and Public Health
NLC
Nuclear Law Committee
NDC
Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle
NSC
Nuclear Science Committee
MBDAV
Management Board for the Development, Application and Validation of Nuclear Data and Codes
The NEA's committees bring together top governmental officials and technical specialists from NEA member countries and strategic partners to solve difficult problems, establish best practices and to promote international collaboration.
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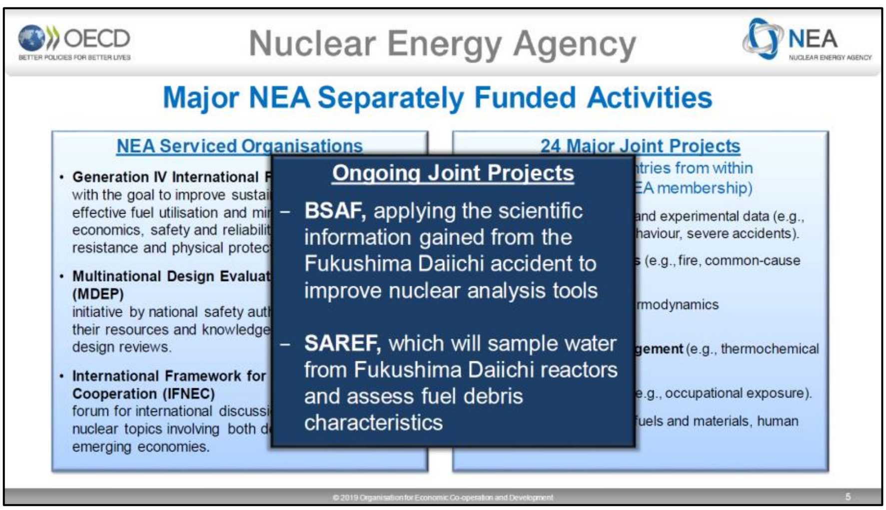
3


OECD
BETTER POLICIES FOR BETTER LIVES
Nuclear Energy Agency
NEA
NUCLEAR ENERGY AGENCY
Major NEA Separately Funded Activities
NEA Serviced Organisations
• Generation IV International F
with the goal to improve sustai
effective fuel utilisation and mi
economics, safety and reliabilit
resistance and physical protec
• Multinational Design Evaluat
(MDEP)
initiative by national safety aut
their resources and knowledge
design reviews.
• International Framework for
Cooperation (IFNEC)
forum for international discussi
nuclear topics involving both d
emerging economies.
24 Major Joint Projects
tries from within
A membership)
nd experimental data (e.g.,
haviour, severe accidents).
(e.g., fire, common-cause
rmodynamics
gement (e.g., thermochemical
.g., occupational exposure).
uels and materials, human
Ongoing Joint Projects
– BSAF, applying the scientific information gained from the Fukushima Daiichi accident to improve nuclear analysis tools
– SAREF, which will sample water from Fukushima Daiichi reactors and assess fuel debris characteristics
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5

OECD BETTER POLICIES FOR BETTER LIVES — Nuclear Energy Agency — NEA NUCLEAR ENERGY AGENCY

NEA: leading the way towards a robust nuclear energy future

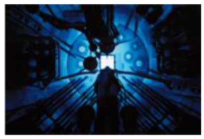
An overview of current NEA projects/initiatives:

- **Nuclear Innovation 2050 (NI2050)**:
  focussing on increasing momentum in R&D and market deployment of new nuclear technologies
- **Multinational NEA Framework for In-pile Fuel and Material Testing**: focussing on future experimental capabilities
- **Nuclear Education, Skills and Technology (NEST) Framework**: focussing on the future generation

 6

OECD BETTER POLICIES FOR BETTER LIVES — Nuclear Energy Agency — NEA NUCLEAR ENERGY AGENCY

Nuclear Innovation 2050: moving ideas into reality



- Need for new nuclear technologies which are:
  - able to compete in future global energy markets
  - cheaper
  - more flexible and faster to deploy
- NI2050 involves industry and safety authorities to facilitate the transformation of R&D to market readiness → **all stakeholders need to be on board**

Three major barriers to overcome:

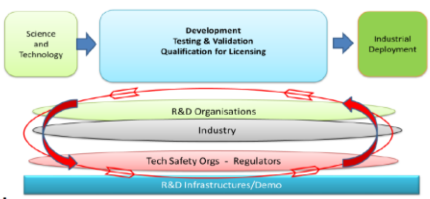
- Financing: nuclear innovation timeline is long; industry and private investors need to contribute
- Regulatory framework: not active in the technology development process; national dimension of regulatory processes can hinder wider market deployment
- Availability of infrastructure to support nuclear technology development

 7

OECD BETTER POLICIES FOR BETTER LIVES — Nuclear Energy Agency — NEA NUCLEAR ENERGY AGENCY

NEA "Nuclear Innovation 2050" (NI2050) Initiative

- **Goals and added value**
  - building a cooperative framework enabling innovative fit-for-purpose nuclear fission technologies
  - applying multilateral strategies to support more effective deployment of innovative nuclear technologies
- **Selected topical areas**
  - **accident-tolerant fuels**
  - **advanced fuels and materials**
  - **advanced modelling and simulation**
  - severe accident knowledge management
  - passive safety systems
  - management of ageing structures
  - heat production and cogeneration, etc.



- **NI2050 is supported by other NEA initiatives in the development, safety and science areas**

 8

OECD BETTER POLICIES FOR BETTER LIVES

Nuclear Energy Agency

NEA NUCLEAR ENERGY AGENCY

New Multinational NEA Framework for In-pile Fuel and Material Testing

- **Motivation**
  - Strengthen fuel- and material-related experimental capabilities for the benefit of industry, safety and science
  - Address the post-Halden situation
  - Develop a coordinated approach and a new paradigm for experimentation
- **Goals and added values**
  - Create and maintain awareness regarding experimental capacities
  - Perform key experiments using facilities around the world using mechanism of NEA Joint Projects
  - Coordinate the analysis, preservation and management of experimental data
  - Enable training and education via NEST project

OECD BETTER POLICIES FOR BETTER LIVES

Nuclear Energy Agency

NEA NUCLEAR ENERGY AGENCY

Proposed Framework Structure

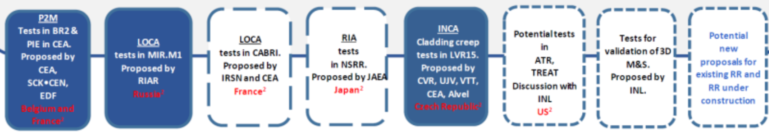
Pursuant to Article 5 of the NEA Statute, the Framework will be established as an international joint undertaking

Framework for IrraDiation ExperimentS – FIDES[1]

- Being designed to provide stable, sustainable, reliable platform and an incentive for innovations for fuels and materials testing
- Encompasses **Joint Experimental Programmes** and the **Cross-cutting Activities**

Joint ExpErimental Programmes (JEEPs)

- **Enable in-pile experiments in test reactors and PIE**



[1] Fides (Latin: Fidēs) was the goddess of trust and bona fides (good faith)

[2] Country of the host organisation

OECD BETTER POLICIES FOR BETTER LIVES

Nuclear Energy Agency

NEA NUCLEAR ENERGY AGENCY

New NEA Framework: Added value and cross-cutting activities

The Framework is currently being established in order to

- provide continuity and sustainability in the strategic field
- build a collective awareness of needs and capabilities
- identify gaps requiring investments and facilitate related implementations
- create opportunities for cross-cutting activities
  - State-of-the-art instrumentation and modelling & simulation
  - **Preservation and quality management of experimental data**
  - Professional development and educational activities
- in collaboration with IAEA, address collectively practical issues of nuclear fuel transport and waste management

Nuclear Energy Agency

NEA Nuclear Education, Skills and Technology (NEST) Framework

NEA member countries together represent the world's best nuclear expertise in the use of nuclear technology…

HOWEVER

…the scientists, engineers and technologists needed to ensure the safe and efficient use of nuclear technologies are declining in many countries leading to a potential loss of nuclear expertise and knowledge.

NEST Framework aims to:

- Attract, train and facilitate skills development of students and young professionals through transmission of practical knowledge and hands-on training
- Aid countries to maintain and strengthen academic nuclear-related education programmes by establishing international exchanges and collaborative activities between universities and other organisations (e.g., research institutions, regulatory bodies, etc.)

Nuclear Energy Agency

NEST: an investment in the next generation

Tacit knowledge needs to be preserved, transferred and shared with the next generation

To achieve this:

- Young generation needs to be exposed to challenging projects and real-world problems through hands-on training
- Leading experts in the field will work alongside the NEST Fellows (Masters, PhD, Postdoc students and young professionals)
- NEST Fellows will work within a network of organisations encouraging cross-fertilisation of ideas and development of new projects to advance new innovative nuclear technology

Photo Credit: Dean Calma / IAEA

Nuclear Energy Agency

Entry into force of the NEST Agreement: 15 February 2019

OECD Nuclear Energy Agency NEA

NEST current projects

NEST HYMERES (HYdrogen Mitigation Experiments for Reactor Safety, Phase 2) project:
- addresses safety relevant phenomena in containments during accidents; hands-on training at PANDA, one of the world's most advanced containment test facilities

SMR project:
- aims to integrate SMR research projects from individual participating organisation countries into a broader and more impactful program

NEST-CLADS (Collaborative Laboratories for Advanced Decommissioning Science) project:
- dedicated to advanced remote technology for decommissioning under intense gamma-ray radiation environments (e.g robotics, virtual reality).

NEST-PDC UGR (Pilot & Demonstration Center for Decommissioning of Uranium-Graphite Nuclear Reactors) project:
- addresses main issues of i-graphite management, including characterisation, decontamination and disposal

OECD Nuclear Energy Agency NEA

Global issues require global solutions

What we know:
- Clima…
- Nucl… …UT it need…
- Much… …gies. Innov…

What c…
- Increa… …pertise has more value than a go-it-alone approach

The NEA can help lead the way

The NEA offers an ideal forum to advance the future of nuclear bringing together international experts who share and disseminate state-of-the-art knowledge in the field of nuclear energy.

The NEA's existing framework supports expertise and resources needed to enable multilateral co-operation.

OECD Nuclear Energy Agency NEA

Thank you for your attention

More information @ www.oecd-nea.org
All NEA reports are available for download free of charge.
Follow us:

 17

TEODOR CHIRICA

FISA 2019 – EURADWASTE '19

Keynote of Mr Teodor Chirica (FORATOM, BE), President of the European Nuclear Industry Association

Research and Innovation benefits for a low-carbon economy, Industrial Competitiveness and sustainable development

Membership

The membership of FORATOM is made up of 15 national nuclear associations representing more than 3,000 companies.

- Belgium
- Bulgaria
- Finland
- France
- Hungary
- Italy
- Netherlands
- Romania

- Slovakia
- Slovenia
- Spain
- Sweden
- Switzerland
- Ukraine
- United Kingdom

CEZ (Czech Republic) and PGE EJ 1 (Poland) are Corporate Members

Key topics

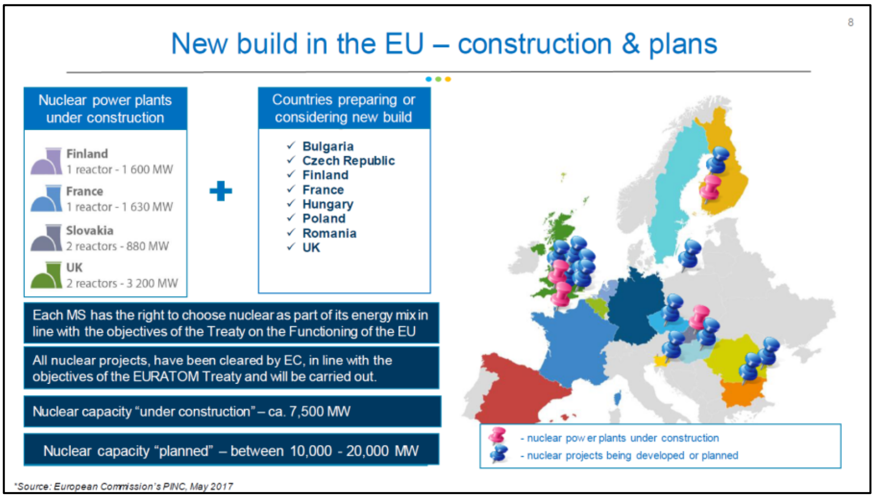
EU Energy Policy:
- Economics of nuclear
- EU energy mix
- Environment
- Euratom Treaty
- Security of energy supply
- Special projects - Brexit

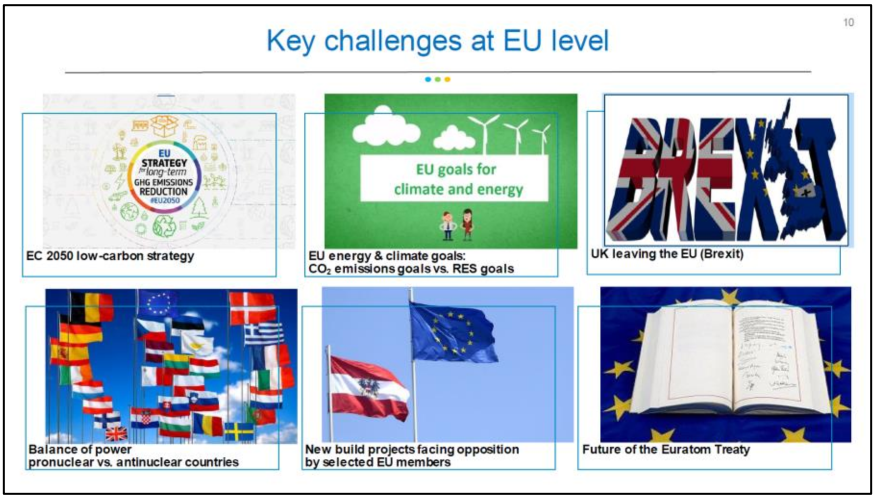
Nuclear technology:
- Nuclear safety
- Nuclear transport
- **IRD**
- Supply Chain
- Waste disposal

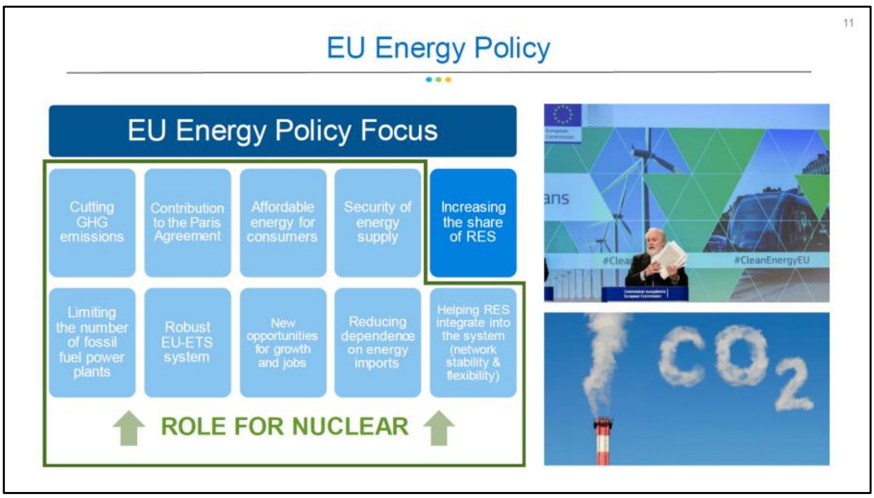
Communication:
- Nuclear advocacy
- Perception of nuclear energy
- Promotion of nuclear energy
- Young generations in nuclear

What does nuclear contribute to the EU's economy?

126	100	1,100,000	26%	50%
NUCLEAR REACTORS IN OPERATION	TURNOVER € BILLION/YEAR	JOBS	ELECTRICITY PRODUCTION	LOW-CARBOM ELECTRICITY


8
New build in the EU – construction & plans
Nuclear power plants under construction
Finland
1 reactor - 1 600 MW
France
1 reactor - 1 630 MW
Slovakia
2 reactors - 880 MW
UK
2 reactors - 3 200 MW
Countries preparing or considering new build
✓ Bulgaria
✓ Czech Republic
✓ Finland
✓ France
✓ Hungary
✓ Poland
✓ Romania
✓ UK
Each MS has the right to choose nuclear as part of its energy mix in line with the objectives of the Treaty on the Functioning of the EU
All nuclear projects, have been cleared by EC, in line with the objectives of the EURATOM Treaty and will be carried out.
Nuclear capacity "under construction" – ca. 7,500 MW
Nuclear capacity "planned" – between 10,000 - 20,000 MW
- nuclear power plants under construction
- nuclear projects being developed or planned
*Source: European Commission's PINC, May 2017


10
Key challenges at EU level
EU STRATEGY for long-term GHG EMISSIONS REDUCTION #EU2050
EC 2050 low-carbon strategy
EU goals for climate and energy
EU energy & climate goals:
CO_2 emissions goals vs. RES goals
UK leaving the EU (Brexit)
Balance of power
pronuclear vs. antinuclear countries
New build projects facing opposition
by selected EU members
Future of the Euratom Treaty


11
EU Energy Policy
EU Energy Policy Focus
Cutting GHG emissions
Contribution to the Paris Agreement
Affordable energy for consumers
Security of energy supply
Increasing the share of RES
Limiting the number of fossil fuel power plants
Robust EU-ETS system
New opportunities for growth and jobs
Reducing dependence on energy imports
Helping RES integrate into the system (network stability & flexibility)
ROLE FOR NUCLEAR
#CleanEnergyEU
CO_2

Nuclear energy in the EC strategy (Nov 2018)

EC Communication*:

"Renewables together with nuclear energy will be [the backbone of a carbon-free European power system](https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_en.pdf)"

EU STRATEGY for long-term GHG EMISSIONS REDUCTION #EU2050

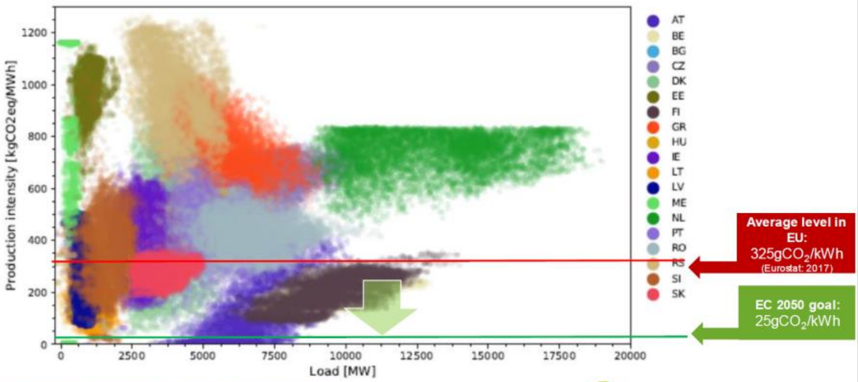
EC in-depth analysis:**

- Nuclear will **remain an important component** in the EU 2050 energy mix
- Capacity of nuclear in 2050 – **between 99-121 GW**
- Share of nuclear in the electricity mix in 2050 – **ca. 15%**
- *"The consumption of **natural gas** is expected to be severely reduced by 2050 in all scenarios"*
- *"In the baseline, **hydrogen** use develops only as a niche application for road transport and industry"*

Authors of the strategy referred directly to the study commissioned by FORATOM

** https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_en.pdf*
*** https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf*

Hourly production intensity vs. hourly load by EU MSs



https://www.researchgate.net/publication/329734236_Real-Time_Carbon_Accounting_Method_for_the_European_Electricity_Markets

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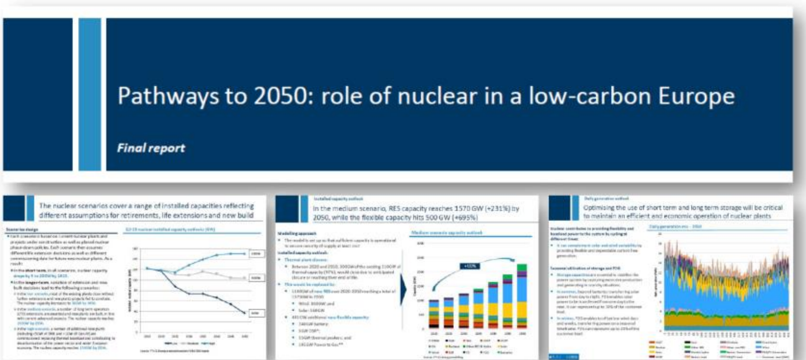
FTI CL Study (commissioned by FORATOM)



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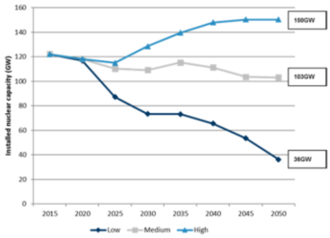
3 nuclear scenarios



3 nuclear scenarios:
1. **High** – 150 GW, **share ~25%** (maintaining the current one)
2. **Medium** – 103 GW, share ~15% (in line with the EC strategy)
3. **Low** – 36 GW, share ~4%

The study assesses the impact of each scenario on the key dimensions of Europe's energy policy:
1. security of supply
2. sustainability
3. economics

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Benefits of having a 25% nuclear share in 2050*

Sustainability

- ✓ Allowing the EU to meet its **climate goals**
- ✓ **700 million t.** of CO_2 avoided per year (it emits **30x** less CO_2 than gas, **65x** less than coal, **3x** less than solar)
- ✓ Compliance with **air quality** standards
- ✓ **No need** for vast volumes of land / raw materials

Energy security

- ✓ **85-90%** capacity factor = a reliable source of electricity
- ✓ **Decreased dependence** on fossil fuels imports
- ✓ **System flexibility** much needed to support the RES developments
- ✓ **Limited reliance** on yet-to-be-proven technologies

Economy

- ✓ High residual investment value (avoiding reducing the value by **€1 trillion**)
- ✓ Mitigation of the cost impact of the low-carbon transition on customer cost by **€350bn**
- ✓ Reducing network & balancing costs by **160bn€**
- ✓ Positive & significant impact on **jobs, GDP, revenues,** etc.

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Deloitte Study (commissioned by FORATOM)

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19

Key findings

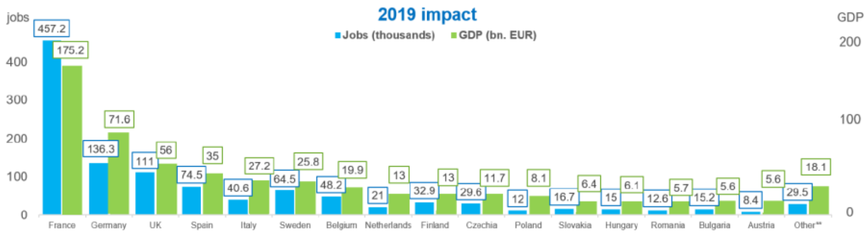
2019 Impact of the nuclear sector on EU economy	
1,129,900*	numbers of jobs
47%	of the total numbers of jobs in the nuclear sector are highly skilled, equaling a number of 531,900
€507.4 bn	in EU GDP, which equals – 3-3.5% share of 2019 EU GDP
€383.1 bn	disposable household incomes
€124.2 bn	public revenues generated through tax payments
€1,092.3 bn	investments undertaken in the EU
€18.1 bn	trade surplus within the EU

*This figure does not include the full spectrum of jobs in fission R&D, therefore the actual number is even higher…

20

Nuclear energy's economic impact

2019	2050
• 1,129,900 jobs in the EU • €507.4 billion in EU GDP	• 1,321,600 jobs in he EU • €576 billion in EU GDP*



*Deloitte study "Nuclear energy: powering the economy – carbon-free growth, jobs and leadership in innovation

** Other = Ireland, Denmark, Greece, Slovenia, Luxembourg, Croatia, Lithuania, Latvia, Estonia, Cyprus, Malta combined

22

Different approaches towards nuclear R&D

Strategic areas for existing and future related technologies Small Modular Reactors (SMR) and Accident Tolerant Fuel (ATF).

over €1.1bn in 2019

R&D programmes & near-term innovation (floating nuclear reactor technology, advanced fuel cycle programme, focusing on the full recycling of fuel)

€1bn per year

Nuclear R&D (SMRs, advanced materials manufacturing, digitalization, large nuclear systems & component testing facilities, advanced fuel R&D programmes)

"Heavy investments" in R&D, but difficult to precisely estimate

?

Significantly less ambitious and of multiple orders of magnitude less than what is needed!!!

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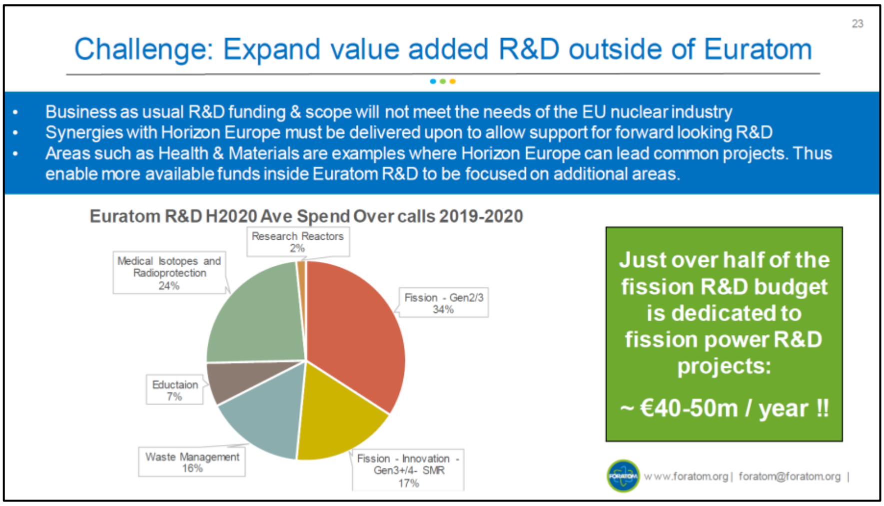

23
Challenge: Expand value added R&D outside of Euratom
• Business as usual R&D funding & scope will not meet the needs of the EU nuclear industry
• Synergies with Horizon Europe must be delivered upon to allow support for forward looking R&D
• Areas such as Health & Materials are examples where Horizon Europe can lead common projects. Thus enable more available funds inside Euratom R&D to be focused on additional areas.
Euratom R&D H2020 Ave Spend Over calls 2019-2020
Research Reactors 2%
Fission - Gen2/3 34%
Fission - Innovation - Gen3+/4- SMR 17%
Waste Management 16%
Eductaion 7%
Medical Isotopes and Radioprotection 24%
Just over half of the fission R&D budget is dedicated to fission power R&D projects:
~ €40-50m / year !!
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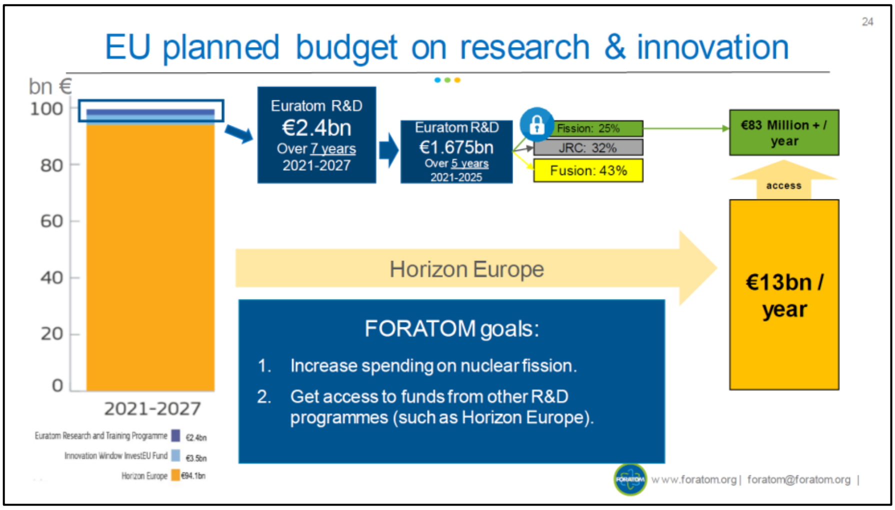

24
EU planned budget on research & innovation
bn €
100
80
60
40
20
0
2021-2027
Euratom Research and Training Programme €2.4bn
Innovation Window InvestEU Fund €3.5bn
Horizon Europe €94.1bn
Euratom R&D
€2.4bn
Over 7 years
2021-2027
Euratom R&D
€1.675bn
Over 5 years
2021-2025
Fission: 25%
JRC: 32%
Fusion: 43%
€83 Million + / year
access
€13bn / year
Horizon Europe
FORATOM goals:
1. Increase spending on nuclear fission.
2. Get access to funds from other R&D programmes (such as Horizon Europe).
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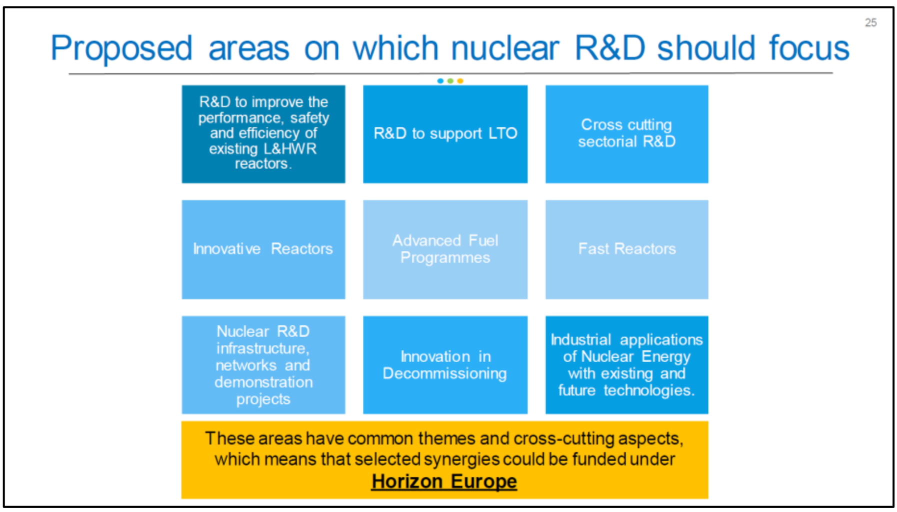

25
Proposed areas on which nuclear R&D should focus
R&D to improve the performance, safety and efficiency of existing L&HWR reactors.
R&D to support LTO
Cross cutting sectorial R&D
Innovative Reactors
Advanced Fuel Programmes
Fast Reactors
Nuclear R&D infrastructure, networks and demonstration projects
Innovation in Decommissioning
Industrial applications of Nuclear Energy with existing and future technologies.
These areas have common themes and cross-cutting aspects, which means that selected synergies could be funded under Horizon Europe

26

Colaboration outside of the Nuclear Sector: Case study – RIMA project

RIMA | Robotics for inspection and Maintenance

RIMA - European project to drive innovation in robotics for I&M by establishing a pan-European network of Digital Innovation Hubs.
The objective of RIMA is to **reinforce the leadership of Europe** in I&M robotics by connecting technology to industrial/sectorial needs and foster efficient cross border cooperation in Europe.

Project funded under the Digitising European Industry Call of **<u>Horizon 2020</u>**

FORATOM role

- Member of the RIMA consortium
- Bridge the gap between:
    - **<u>SMEs within the robotics community</u>**
    - Potential **<u>end users within the nuclear industry</u>** (licencees, I&M service providers, operators, etc.)

28

Importance of investing in nuclear R&D

The EU is lagging behind in nuclear R&D when compared to other international actors…
In order for the EU to maintain its technological leadership, which can help the EU decarbonise its power sector in line with the Paris Agreement:

1. Euratom 2021-2025 funding for fission R&I <u>should be increased</u>

2. Horizon Europe & Euratom 2021-2025 <u>should be set up to complement each other</u> (common themes & cross-cutting aspects)

3. <u>Cohesion</u> and <u>synergy</u> with R&D in the SET Plan Action 10 'Nuclear' <u>must be considered</u> & <u>support given for shared benefits</u> across R&D programmes

4. The scope of the WP Euratom 2021-2025 <u>should be reflective of the direction of Member States, industry & academia stakeholders</u>

29

FORATOM IRD WG planned activities

Release of a PP on "Opportunities for Euratom R&T 2021-2025 & Horizon Europe Programmes"

Innovation, Research & Development Working Group's industry view on the priority areas of R&D (9 fiches)

Position paper on IRD to meet the EU objectives (Q4 2019)

Direct engagement with key stakeholders (promotion of agreed messaging)

Participation in events (promotion of agreed messaging)

Participation in various projects, such as RIMA (promotion of agreed messaging)

Thank you

FORATOM

NuclearEurope 2019

Join us on **26 June 2019** in **Bucharest** to discuss key challenges affecting EU's energy sector, the role of long-term operation of nuclear power plants and how to ensure that the industry has access to the skills it needs.

Registration: *events.foratom.org/nuclear-in-a-changing-world/*

Official hashtag: *#NuclearEurope2019*

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PIERRE JEAN COULON

FISA 2019 – EURADWASTE '19

Keynote of Mr Pierre Jean Coulon (EESC, EU), President of the Transport Energy and Networks section, European Economic and Social Committee

Research and Innovation missions and benefits to Civil Society to tackle today's Societal Challenges

MISSING

DORU VISAN

FISA 2019 – EURADWASTE '19

Keynote of Mr Doru Visan (Secretary of State, RO)

Mr Minister,
Dear representatives of the European Commission,
Dear Participants,
Ladies and Gentlemen,

Today, I am pleased to represent the Ministry of Energy at the Open Session of the FISA and EURADWASTE Conferences, jointly organized by the European Commission and the Romanian Presidency of the Council of the EU in 2019.

I am honored that the Institute for Nuclear Research, entity under the authority of the Ministry of Energy, was entrusted with the co-organization of this event, as a proof and acknowledgment of its contribution to the EURATOM projects.

Established in 1971, RATEN ICN has continuously provided the technical and scientific support for the National Nuclear Program from its launch until its implementation, by commissioning Units 1 and 2 from Cernavoda, delivering equipments and services for the safety of operations.

The outstanding performance of the Cernavoda Nuclear Power Plant is also due to the contribution of the ICN researchers, starting with the manufacturing of the first CANDU fuel elements, their testing in the TRIGA research reactor, the performance analysis in the post-irradiation examination laboratories.

Through their experience and competence gained over the years, RATEN, through its subsidiaries ICN and CITON, is now ready to respond to the current priorities of the Nuclear Power Program regarding the refurbishment of Cernavoda Unit 1, the construction of the near surface disposal and the implementation of the ALFRED demonstrator in Romania.

RATEN participation in the EURATOM Framework Programs has supported the national nuclear energy priorities, particularly in the field of nuclear safety, life time extension of the nuclear installations, radioactive waste management, transfer of knowledge and dissemination of research results.

I am convinced that this scientific event will summarizes research results that has been achieved so far and will identify new research directions, thus for the nuclear energy to meet the objectives of the European Union's policy initiative "20-20-20", through security, sustainability and competitiveness.

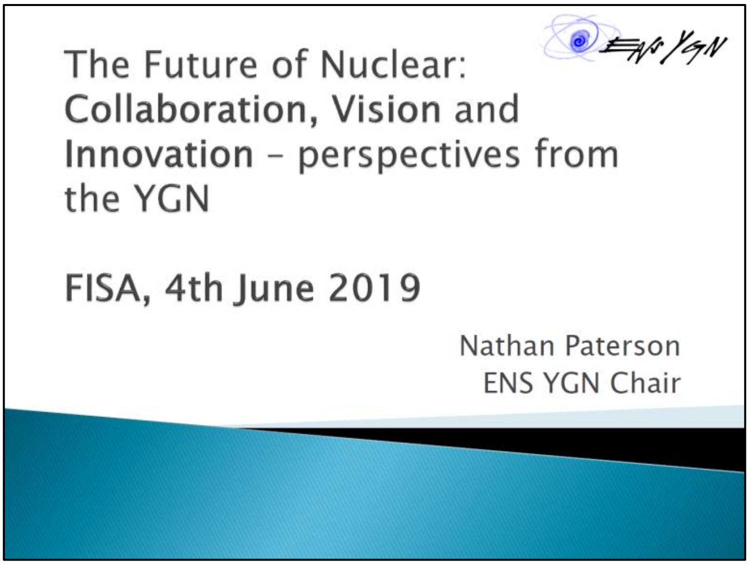
I wish a successfully Meeting!

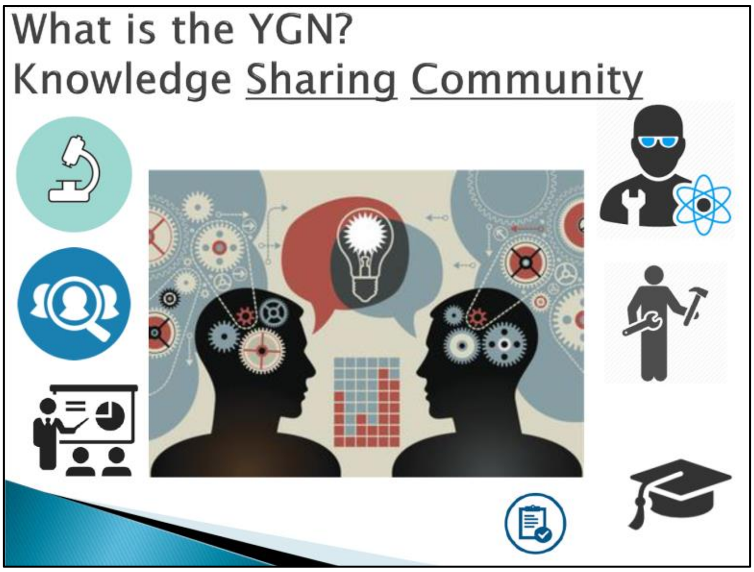
NATHAN PATERSON

FISA 2019 – EURADWASTE '19

Keynote of Mr Nathan Paterson (ENS YGN, BE), Chair European Nuclear Society Young Nuclear Generation

The future of Nuclear: Collaboration, Vision and Innovation – perspectives from the YGN





ENS YGN

21 Member Societies

Observer Partners

WANO | global WiN Women in Nuclear | World Nuclear Association | IYNC | IAEA

3

Who are we and what we stand for!!

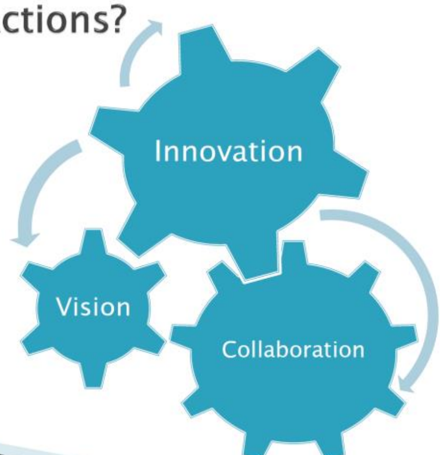
The global population is growing and the demand for **safe, clean** and **reliable electricity** is more important than it has ever been.

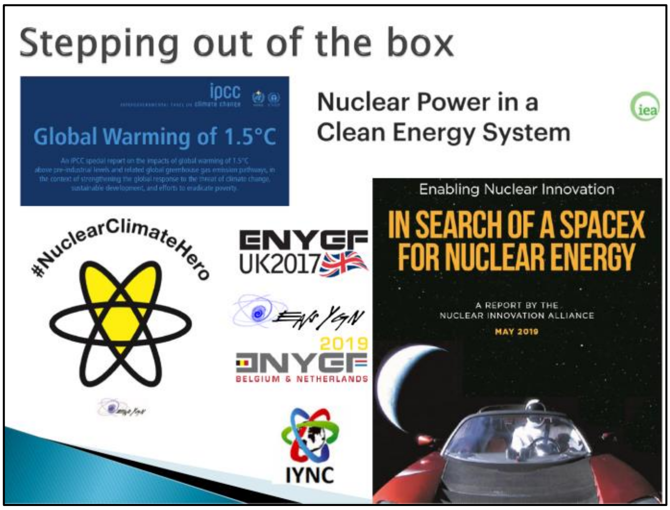
We must continue developing the global **nuclear industry** and strive for more **collaboration**, **innovative technologies** and **harmonization** of **best practices** to meet the needs of our **future**.

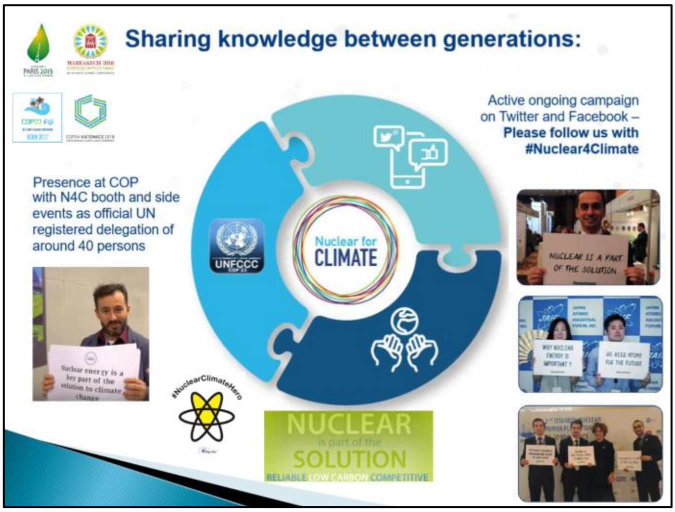
UN SDGs Extract

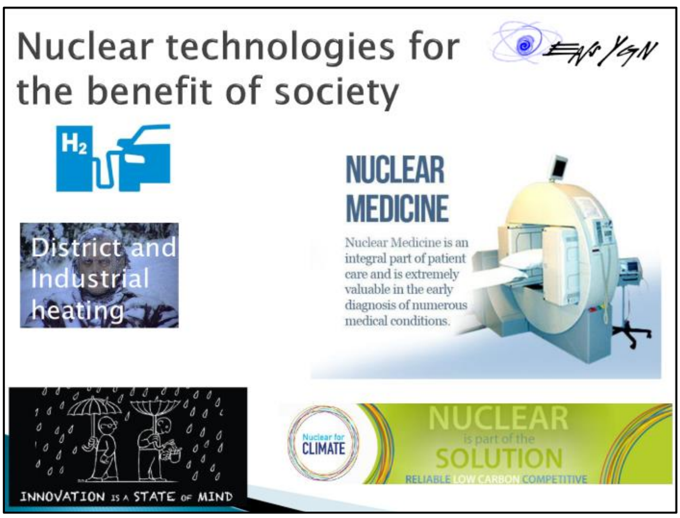
7 AFFORDABLE AND CLEAN ENERGY | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE | 13 CLIMATE ACTION

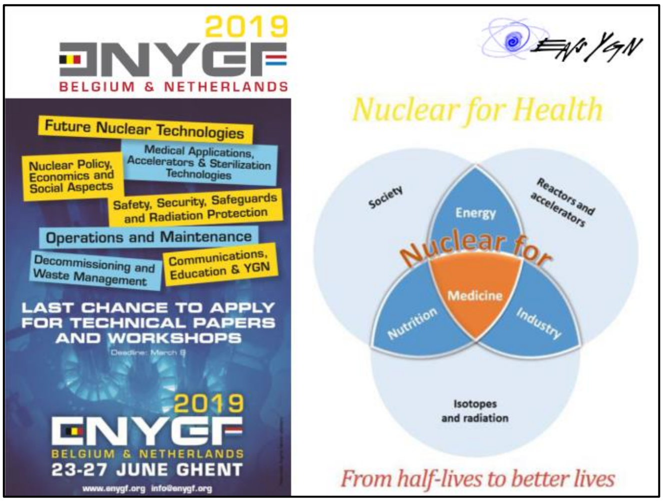
Words or Actions?




Stepping out of the box
ipcc
Global Warming of 1.5°C
Nuclear Power in a
Clean Energy System
iea
Enabling Nuclear Innovation
IN SEARCH OF A SPACEX FOR NUCLEAR ENERGY
A REPORT BY THE NUCLEAR INNOVATION ALLIANCE
MAY 2019
#NuclearClimateHero
ENYGF UK2017
2019
ENYGF
BELGIUM & NETHERLANDS
IYNC


Sharing knowledge between generations:
Active ongoing campaign
on Twitter and Facebook –
Please follow us with
#Nuclear4Climate
Presence at COP
with N4C booth and side
events as official UN
registered delegation of
around 40 persons
UNFCCC
Nuclear for
CLIMATE
NUCLEAR IS A PART OF THE SOLUTION
#NuclearClimateHero
NUCLEAR
is part of the
SOLUTION
RELIABLE LOW CARBON COMPETITIVE


Nuclear technologies for
the benefit of society
H_2
District and
Industrial
heating
NUCLEAR
MEDICINE
Nuclear Medicine is an
integral part of patient
care and is extremely
valuable in the early
diagnosis of numerous
medical conditions.
INNOVATION IS A STATE OF MIND
Nuclear for
CLIMATE
NUCLEAR
is part of the
SOLUTION
RELIABLE LOW CARBON COMPETITIVE


2019
ENYGF
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Future Nuclear Technologies
Medical Applications, Accelerators & Sterilization Technologies
Nuclear Policy, Economics and Social Aspects
Safety, Security, Safeguards and Radiation Protection
Operations and Maintenance
Decommissioning and Waste Management
Communications, Education & YGN
LAST CHANCE TO APPLY FOR TECHNICAL PAPERS AND WORKSHOPS
Deadline: March 8
2019
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23-27 JUNE GHENT
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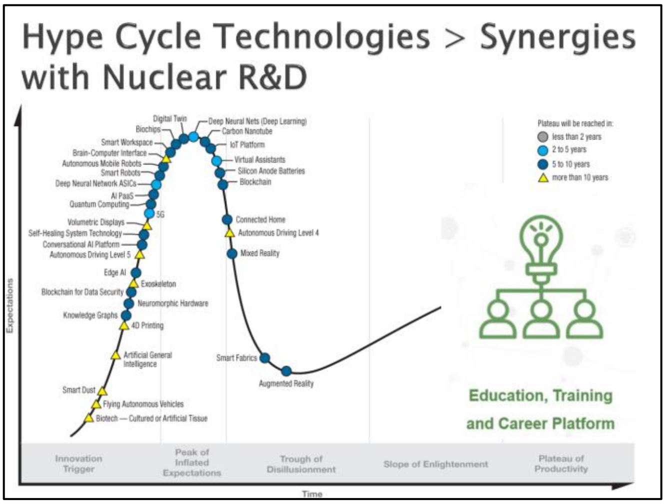
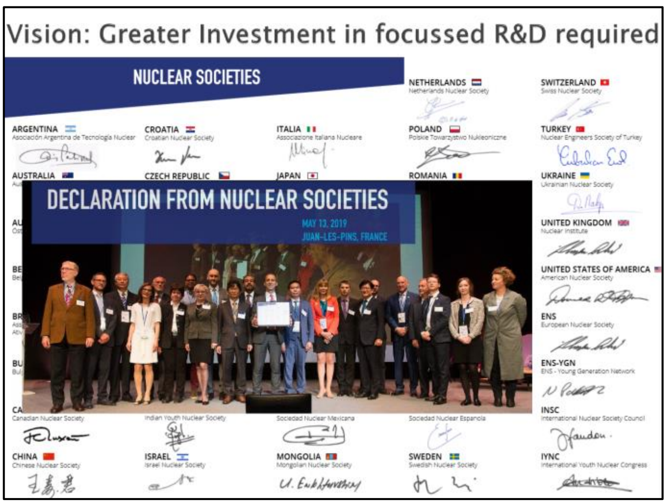
ENS YGN
Nuclear for Health
Society
Reactors and accelerators
Energy
Nuclear for
Medicine
Nutrition
Industry
Isotopes and radiation
From half-lives to better lives


Hype Cycle Technologies > Synergies with Nuclear R&D
Digital Twin
Biochips
Deep Neural Nets (Deep Learning)
Carbon Nanotube
Smart Workspace
IoT Platform
Brain-Computer Interface
Autonomous Mobile Robots
Virtual Assistants
Smart Robots
Silicon Anode Batteries
Deep Neural Network ASICs
Blockchain
AI PaaS
Quantum Computing
5G
Connected Home
Volumetric Displays
Self-Healing System Technology
Autonomous Driving Level 4
Conversational AI Platform
Autonomous Driving Level 5
Mixed Reality
Edge AI
Exoskeleton
Blockchain for Data Security
Neuromorphic Hardware
Knowledge Graphs
4D Printing
Artificial General Intelligence
Smart Fabrics
Augmented Reality
Smart Dust
Flying Autonomous Vehicles
Biotech — Cultured or Artificial Tissue
Plateau will be reached in:
less than 2 years
2 to 5 years
5 to 10 years
more than 10 years
Education, Training and Career Platform
Expectations
Innovation Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
Time


Vision: Greater Investment in focussed R&D required
NUCLEAR SOCIETIES
NETHERLANDS
SWITZERLAND
ARGENTINA
CROATIA
ITALIA
POLAND
TURKEY
AUSTRALIA
CZECH REPUBLIC
JAPAN
ROMANIA
UKRAINE
DECLARATION FROM NUCLEAR SOCIETIES
MAY 13, 2019
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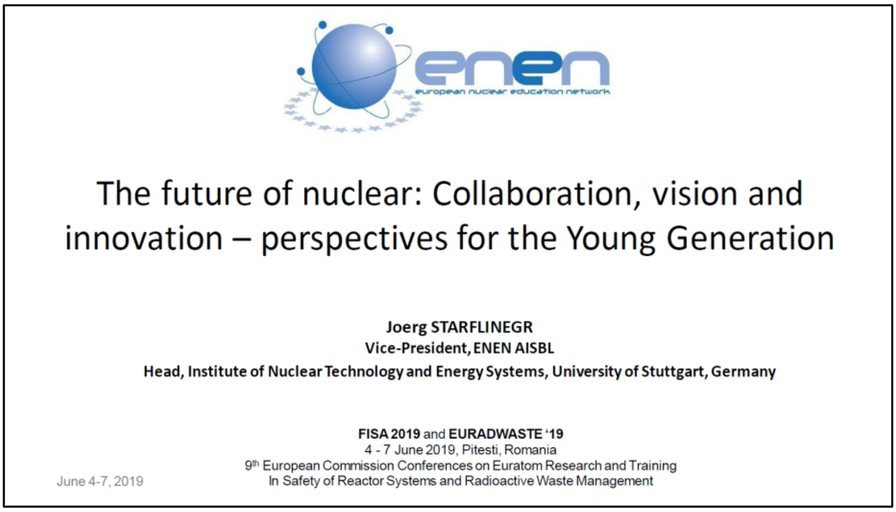
NETWORK
TRANSPARENCY
EUROPE
CLEAN
POWER
ATOM
OPENNESS
HI-TECH
INSPIRING
DEVELOPMENT
Young Generation
creating the future

JOERG STARFLINGER

FISA 2019 – EURADWASTE '19

Keynote of Mr Joerg Starflinger (ENEN, BE), Vice-president of ENEN, University of Stuttgart, Germany

The future of Nuclear: Collaboration, Vision and Innovation – perspectives for the Young Generation



ENEN: European Nuclear Education Network

ESTABLISHED in 2003

Steady support by European Commission through projects

OBJECTIVE

Preservation and further **development** of expertise in the nuclear fields by higher Education & Training.

ENEN Members in 2018

76 Members from 25 Countries:
5 Research Centers, 9 Companies, 48 Universities, 1 TSO and 9 international institutions

Selected Achievements of ENEN

Established

- Exchange of information, best practices, teachers and students
- Voluntary accreditation in academic education (quality control, quality assurance)

Ongoing: Projects ANNETTE, ENEN+

- Facilitating communication and cooperation between nuclear stakeholders and access to research infrastructures, to projects and internships
- Innovative teaching an learning methods (MOOCs, flipped-classroom approaches, etc.)
- Coordination of ETKM activities (Education, Training, Knowledge Management) among different NUCLEAR communities

PhD Event & Prize and Mobility

- Key success indicators:
  - ENEN+ mobility program „living the European idea of exchange and networking“ **1,000,000 €** for mobility of B.Sc., M.Sc., Ph.D. and teachers **plus.enen.eu**
  - ENEN PhD event (Wednesday at FISA19)

- The number of students is decreasing. **Is Nuclear E&T a cause of concern?** See you E&T workshop at 14h in "Ametist Room"

Thank you for your attention

www.enen.eu

European Nuclear Education Network AISBL
Rue d'Egmont 11, 1000 Brussels, Belgium

Telephone: +32 484 20 15 04
Email: secretariat@enen.eu

June 4-7, 2019 FISA conference, Pitesti, Romania 7

SERBAN CONSTANTIN VALECA

FISA 2019 – EURADWASTE '19

Keynote of Mr Serban Constantin Valeca (RATEN ICN, RO), President of the Scientific Council in RATEN ICN, Professor at University of Pitesti, Romania

Dear guests, dear participants, in fact, dear nuclear workers, both those with long experience and the younger ones who are at the beginning,

Is a great honour for me to have some opening remarks and to chair the first session.

First of all, I wish you welcome in Romania and in Arges County, a county that in history has 2 very old capitals of our country. At the same time for Pitesti, the capital of Arges County the first documentary attestation is from 630 years ago.

Dear participants in FISA and EURADWASTE conferences,

The nuclear power is an important pillar of the Europe Union energy mix having a significant contribution to the reduction of the emissions, security and stability of the supply, and to affordable prices of electricity.

At the same time, the debate on the nuclear continued to express a set of opinions in relation with the challenges, difficulties, and opportunities of the nuclear power development in terms both of the global economy aspects and of the national contexts.

A strong stimulation of renewable (especially for the variable renewables: wind and photovoltaic), occurred mainly in the EU, are impacting the nuclear development. Today nuclear power has no enough capabilities to support the variable production and is necessary to work complementarily with them in order to ensure a complete free-carbon electricity production.

In Romania we discuss very openly on the equal treatment of nuclear power and renewables as energy options without carbon emissions. The Ministry of Energy proposed a common support scheme for all free carbon electricity. In this manner we intend to support nuclear on the basis of the same principle.

Despite of the complications of the decision making process, it is clear that the nuclear represents an important solution to be managed in an appropriate way. The nuclear research and development has new opportunities such as the new systems (Gen III+, GenIV, and SMR) or challenging solutions for safety of the NPPs, geological disposal, etc.

FISA 2019 and EURADWASTE '19 conferences in Safety of Reactor System and Radioactive Waste Management represent an opportunity to find some answers to these challenges through the proposed objectives:

- To present progress since the previous conference edition in 2013
- To stimulate discussions on the state of play of R&D, key challenges addressed at national, European and international levels
- To address the latest EC proposal for a new Framework Programme for Research and Innovation for the next period 'Horizon Europe' and 'Euratom Research and Training' programme.

In 2018 the Special Report of Global Warming of 1.5°C done by the Intergovernamental Panel on Climate Change above preindustrial levels and related global geenhouse gas emission pathways, in the context of strenghteningglobal response of to the threat of climate change, sustainable development and efforts to eradicate poverty, the report state that limiting the global temperature increase to 1.5°C will prevent the worst impact of climate change, but will require rapid, far-reaching and unprecedent action on decarbonisation. Gen IV of nuclear reactors promise to be part of solution.

In this respect, Romania is deeply involved in the implementation of ALFRED LFR demonstrator. As hosting country we are preparing the licensing and siting process, the education and training process for the future workforce, and participating in finding valuable solution for the open issues.

At decision-making level the proposed funding scheme is based on a mix of European structural funds (for Romania), the national and industry contribution. Important steps were achieved by introducing ALFRED in the most important national strategic documents. Now the main effort will be devoted to negotiate the presence of ALFRED in the future EU budget, and the declaration as major project in the future EU-Romania partnership Agreement.

Dear participants,

The two EURATOM conferences will approach the most important achievements in the last years in nuclear RDI. Beyond of these I wish you a fruitful process to identify the best ways for new collaborations to drive the nuclear power toward a better future in the benefit of a more united Europe, based on independence in energy supply, and with zero carbon emissions.

I wish a full success for all the sessions of the conferences and to have a wonderful experience in Pitesti and Romania.

INTERNATIONAL / EU / EURATOM STATUS IN RADIATION PROTECTION, SAFETY OF REACTOR SYSTEMS AND RADIOACTIVE WASTE MANAGEMENT

SUMMARY OF THE SESSION ON INTERNATIONAL/EU/EURATOM STATUS IN RADIATION PROTECTION, SAFETY OF REACTOR SYSTEMS AND RADIOACTIVE WASTE MANAGEMENT

Prepared by:

Horia Grama (Chair), Agentia Nucleara si pentru Deseuri Radioactive, Romania
Massimo Garribba (Co-chair), European Commission, DG Energy
Hans Forsström (Rapporteur), SKB International, Sweden

This report summarises the outcome of the session on International/EU/EURATOM Status in Radiation Protection, Safety of Reactor Systems and Radioactive Waste Management.

The Chairman introduced the session by highlighting the importance of the Euratom Directives for safe operation of the nuclear facilities and for defining and implementing strategies for spent fuel and radioactive waste management.

The session had three parts, Status of EU/EURATOM Directives, Radioactive Waste Management and Safety Reactor Systems.

In the first part presentations were made by Michael Hübel and Massimo Garribba from the Commission on the development the Euratom Directives on Basic Safety Standards (BSS) (2013), Nuclear Safety of Nuclear Installations (2014) and Spent Fuel and Radioactive Waste Management (2011), and on the implementation of the latter Directive. In addition, a presentation was made by the Andrew Orrell from IAEA on the ARTEMIS peer review service which is widely used by Member States to review their compliance with the spent fuel and radioactive waste Directive.

The main messages from these presentations were:

– Euratom provides a comprehensive framework to ensure a high level of radiation protection and nuclear safety across Europe.
– Significant changes have recently been introduced in the BSS and the Nuclear Safety Directives. In particular the BSS has been reworked to incorporate older Directives connected to radiation protection and conformity checks of MS legislations are underway. In the Nuclear Safety Directive Topical Peer Reviews (TPR) have been introduced in the revised Directive 2014, and the first TPR on ageing management has taken place. As a result, national plans are being established to follow up on the TPR outcomes.
– The purpose of the Directive on Responsible and Safe Management of Spent Fuel and Radioactive Waste is to ensure appropriate national arrangements for a high level of safety and to avoid imposing undue burdens on future generations. It should also ensure public information and participation. An

important component of the Spent Fuel and Radioactive Waste Management Directive is the requirement for countries to have a national programme for the management of all types of spent fuel and radioactive waste from generation to disposal. The first report on the implementation of the Directive was presented to the Council and European Parliament in 2017 and a new report is due in 2019. It notes the activities and plans of the MS, especially as concerns the timing of disposal of spent fuel or high level waste.

- The Spent Fuel and Radioactive Waste Management Directive requires that MS arrange for self-assessments of their national framework, competent regulatory authority, national programme and its implementation, and invite international peer review at least every ten years. Together with the EC, the IAEA has developed a peer review service, ARTEMIS, which includes both components of audit that the MS are fulfilling the requirements in the Directive and components of peer review and advice on the planned programme. Until now 6 EU MS have used the ARTEMIS. ARTEMIS is flexible in design and has also been utilised by non-EU countries for specific reviews.

The second part on Radioactive Waste Management consisted of a keynote presentation by Pierre-Marie Abadie from ANDRA, France on the European and International status on the management and disposal of radioactive waste, and a presentation by Christophe Davies from the European Commission on the Euratom research and training programme in radioactive waste management.

The main messages from the keynote presentation were:

- LLW from NPP operations are disposed of adequately in many existing facilities throughout the world.
- HLW, ILW and SNF can be disposed of in Deep Geological Repositories, and development of three such facilities is progressing in Finland, France and Sweden with ongoing or planned licensing, while siting activities are going on in several other countries, based on the availability of a strong scientific/technical knowledge base.
- Large volumes of waste from decommissioning will require optimisation of the management, where characterisation is a key point.
- Some long-lived radioactive waste with low level of radioactivity (e.g. graphite or depleted uranium and NORM) will require new appropriate disposal routes, which might depend on national policies.
- The long duration of disposal projects (>100 years) will require a strong knowledge management process.
- The activities of IAEA, OECD/NEA and EC strongly contribute to national efforts in a complementary and consistent way.
- In particular as concerns RD&D the support by the EC is positive and the developments towards a Joint European Programming are very good. This is also the case for the broadening of the activities from geological disposal to also include management of other wastes, including predisposal and decommissioning. The EC has also promoted the sharing between all actors (Waste producers, Waste Management Organisations (WMOs), Technical Support Organisations (TSOs), Research Establishments (Res) and the Civil Society) in developing a Joint Strategic Research Agenda, collaborative

R&D, joint knowledge management and training processes and joint strategic studies.

In the presentation of the Euratom R&T programme on radioactive waste management it was shown how the programme since the start in 1975 has progressed from a large number of uncoordinated projects to the call for one European Joint Programme in 2018, which brings together WMOs, TSOs, REs and representatives from the Civil Society.

The Joint Programming (JP) is in line with the strategy of the European Research Area, which is promoted by the European Commission since the early 2000's. JP should provide EU-added value, leverage and benefit to all national programmes. In working together, as part of a European Joint programme, advanced countries will be able to address specific cutting-edge science on very deep scientific topics, while less advanced programmes will be able to plan, structure and implement the necessary R&D, with guidance, training and transfer of competence and knowledge from advanced programmes.

This closer cooperation within the Euratom programme has developed successively over a long period, starting in the early 2000s between WMOs and then through platforms and networks like the IGD-TP for the WMOs, SITEX for TSOs and recently EURADSCIENCE for the REs.

In the latest calls also pre-disposal activities and decommissioning have been reintroduced in the Euratom programme in line with the recommendations from EURADWASTE '13.

The last part of the session called Safety of Reactor Systems included a report by Martin Murray from the Euratom Scientific and Technical Committee (STC) and a broader presentation of all activities in the Euratom programme in addition to radioactive waste management by Roger Garbil from the European Commission.

The STC is an advisory body within the Euratom Treaty providing advice to the Commission and the Council. In their latest opinion paper in 2018 they highlighted inter alia:

- Nuclear plays an important role as a component of low carbon electricity supply and should be a part of the road-map to a zero carbon society.
- Nuclear R&D is needed to maintain capability in the nuclear field and provide the basis for high standards of safety and non-proliferation and ensure competitiveness of the European industry. Education and training is an important component in the R&D.
- It is of interest for all EU MS as the impacts of nuclear energy pass borders.
- Given this situation it is time to increase the EU funding for nuclear R&D, but also to find funding possibilities in other EU programmes, e.g. concerning health and materials.
- Not only should the work on fusion and fission for electricity production be pursued but also work on non-electricity applications in industry and on production of radioisotopes for medical and industrial uses.
- Given the controversy about nuclear power and nuclear applications socio-economic research is needed.

In June 2018 the Commission proposed a new Euratom R&T programme for 2021 – 2025. It has four headings:

- Improve the safe and secure use of nuclear energy and non-power applications of ionizing radiation, including nuclear safety, security, safeguards, radiation protection, safe spent fuel and radioactive waste management and decommissioning.
- Maintain and further develop expertise and competence in the Union.
- Foster the development of fusion energy and contribute to the implementation of the fusion roadmap.
- Support the policy of the Community on nuclear safety, safeguards and security.

The budget proposed is 1,675 billion € for a 5 –year period (2021 – 25). About 43 % will go to fusion research, 37 % to the JRC and the remaining 20 % for the co-operative research on safety of reactor systems, radiation protection, radioactive waste management and decommissioning. The proposal is now discussed in the European Parliament.

The issues covered in safety of reactor systems include:

- Safety of existing reactors
- Development of advanced reactors
- P&T and closed fuel cycle
- Cross-cutting research
- Other applications

At the end of the session a short panel discussion was held on the Role of the Euratom R&T programme and the Directives. In particular the added value of the programme was raised, and it was concluded that although most of the nuclear R&D is performed nationally the Euratom contribution makes it possible to build a common vision and to continue the work in a coordinated way across Europe. The example of the activities in P&T was given where it has been possible to go from lab scale towards semi-industrial application. Other topics raised to the panel concerned the need to increase activities on non-power applications to help develop the carbon free society and the need to look at the social impact of nuclear, not least in connection with transports.

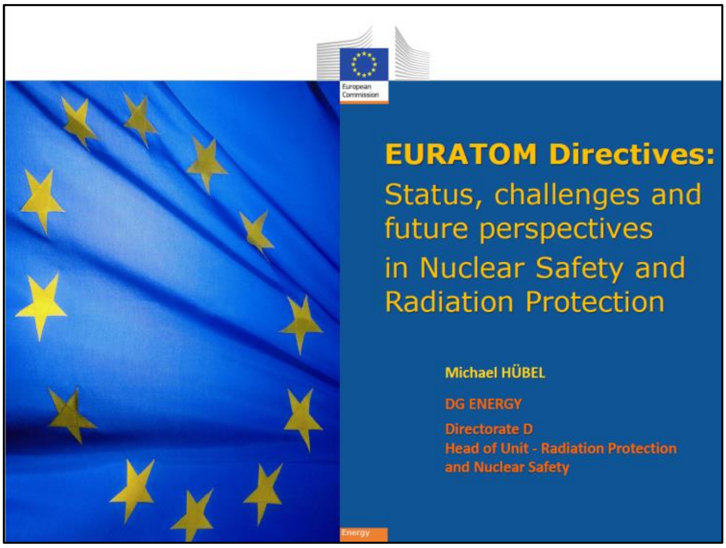
STATUS OF EU/ EURATOM DIRECTIVES

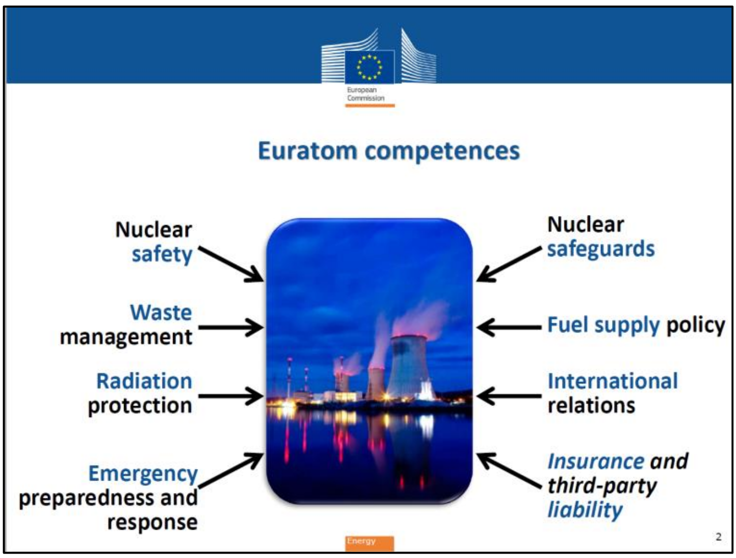
MICHAEL HUEBEL

FISA 2019 – EURADWASTE '19

Presentation of Mr Michael Huebel (DG ENERGY, DIRECTORATE D), Head of Unit - Radiation Protection and Nuclear Safety

EURATOM Directives: Status, challenges and future perspectives in Nuclear Safety and Radiation Protection





Strengthening the legal framework

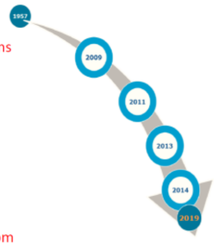
Directive 2009/71/Euratom
Nuclear Safety of nuclear installations

Directive 2011/70/Euratom
Spent Fuel and Waste Management

Directive 2013/51/Euratom
Euratom Drinking Water Directive

Directive 2013/59/Euratom
Basic Safety Standards

Directive 2014/87/Euratom
amending Directive 2009/71/Euratom



Energy

Nuclear Safety
Follow up to Fukushima nuclear accident

European Council 24-25 March 2011

2 mandates

- **Risk and safety assessments of nuclear power plants ("stress tests")**
- **Review of the legal and regulatory framework for the safety of nuclear installations – amended Directive**

Energy

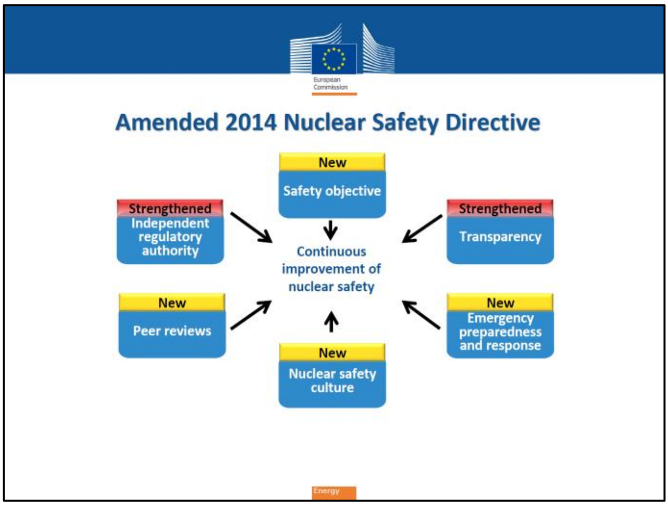
EU Stress Tests in 2012

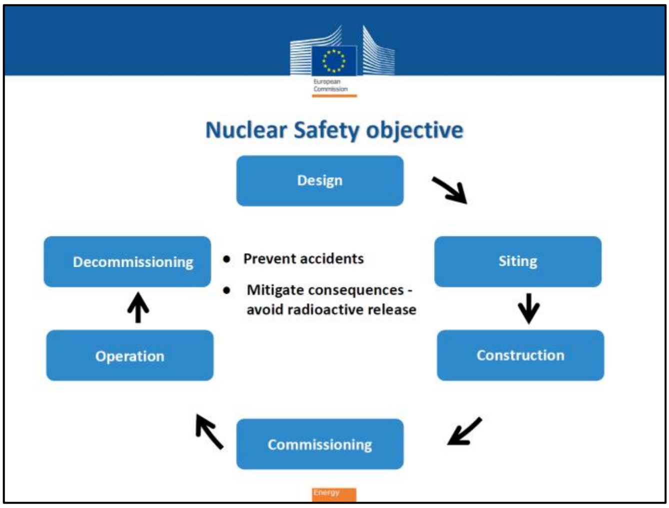
ENSREG
European Nuclear Safety Regulators Group

All 14 EU Member States that operate nuclear power plants, plus Lithuania, Switzerland, Ukraine. Additionally, Taiwan (2013), Armenia (2016) and Belarus (2018).

Planned in Turkey and Iran.

Energy


European Commission
Amended 2014 Nuclear Safety Directive
New
Safety objective
Strengthened
Independent regulatory authority
Strengthened
Transparency
Continuous improvement of nuclear safety
New
Peer reviews
New
Emergency preparedness and response
New
Nuclear safety culture
Energy


European Commission
Nuclear Safety objective
Design
Siting
Construction
Commissioning
Operation
Decommissioning
Prevent accidents
Mitigate consequences - avoid radioactive release
Energy


European Commission
Main measures to achieve the safety objective
as provided for in the Directive
Defence-in-depth
Nuclear safety culture
Safety objective
Initial assessments and periodic safety reviews
Emergency preparedness and response
Energy

European system of Topical Peer Reviews

- Introduced by amended Nuclear Safety Directive → every 6 years (and following severe accident)
- Inspired by EU stress tests
- 1st Topical Peer Review in 2017/18 - Ageing management of nuclear reactors - final report published October 2018, National Action Plans to follow

http://www.ensreg.eu/sites/default/files/attachments/hlg_p2018-37_160_1st_topical_peer_review_report_2.pdf

Energy

TPR 2018 findings, challenges

- Ageing management programmes in place for all nuclear power plants, based on IAEA safety standards and WENRA reference levels, although some differences of national approach.
- Ageing management of research reactors to be brought in line with that for NPPs.
- Challenges remain on means to evaluate the effectiveness of Ageing Management Programmes.
- Use of international Peer Review Services is a good practice.
- National Action Plans to be prepared by September 2019.

Energy

Basic Safety Standards Euratom Treaty (1957)

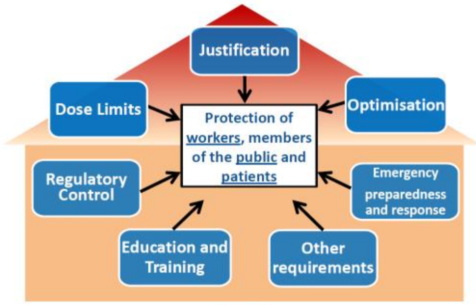
Chapter on health and safety

- Establish uniform basic safety standards for the protection of the health of workers and the general public against dangers arising from ionising radiations
  - ✓ ... and ensure that they are applied.

Energy

Radiation Protection

Basic Safety Standards Directive (2013)



Energy

Motivation and Objective of the 2013 Revision

Modernisation

- Take account of latest scientific findings (e.g. ICRP 2007), technological development as well as operational experience since 1996
- Cover all radiation sources – including natural radiation
- Cover all exposure situations – planned, existing, emergency
- Integrate protection of workers, members of the public, patients and the environment
- Harmonise, to the extent possible, numerical values with international standards

Consolidation and streamlining *– repealing :*

- ✓ *Basic Safety Standards, Directive 96/29/Euratom*
- ✓ *Medical Exposures, Directive 97/43/Euratom*
- ✓ *Public Information, Directive 89/618/Euratom*
- ✓ *Outside Workers, Directive 90/641/Euratom*
- ✓ *Control of high-activity sealed radioactive sources and orphan sources, Directive 2003/122/Euratom*
- ✓ *Radon, Commission Recommendation 90/143/Euratom*

Energy 15

Council Directive 2013/59/Euratom provides

- ✓ **Better protection of**
  - ✓ workers,
  - ✓ medical staff,
  - ✓ emergency workers and
  - ✓ workers in workplaces with natural radiation sources (indoor radon; activities processing naturally occurring radioactive material (NORM));
- ✓ **Better protection of the public, in particular from:**
  - ✓ radon in dwellings,
  - ✓ exposure from NORM activities and building materials
  - ✓ deliberate exposure for non-medical purposes;
- ✓ **Better protection of patients, in particular with regard to the avoidance of incidents and accidents in radio diagnosis and radiotherapy;**
- ✓ **Strengthened requirements on emergency preparedness and response, especially with a view to the lessons learned from the Fukushima accident.**

Energy 16

Medical applications - radiology challenges

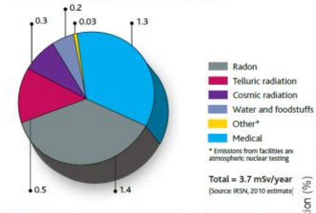
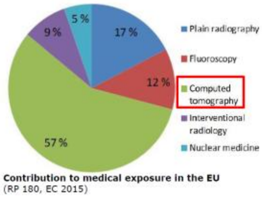
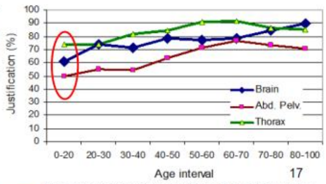


Figure VIII.1 - Average exposure to ionizing radiation of the population in Fran





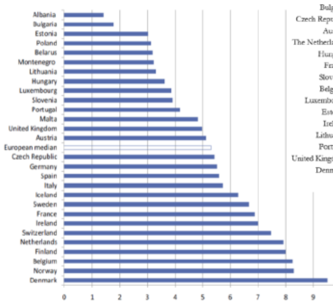
W. Leitz, A. Almén, S. Richter, A study on justification of CT examinations in Sweden

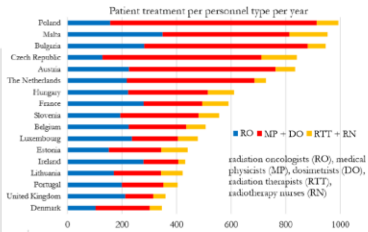
- BSS 2013/59/Euratom
- Commission COM/2010/0423
- Council Conclusions 2015 (LU)
- Implementation support

Energy 17

Medical applications – radiotherapy challenges

Radiotherapy machines per million inhabitants






LE FIGARO·fr

À Épinal, 5 500 personnes ont été victimes de surirradiation

Energy 18

BSS medical – main changes

Justification

- Transparency of justification for types of practice
- Equipment information – link with EU Medical Devices law
- Asymptomatic – guidelines, documenting, info to the 'client'

Optimization

- DRLs – mandatory, regular review, applicable to IR

Responsibilities / Procedures

- Stronger MPE involvement in IR, CT, paediatric, screening
- Information to patients on benefits and risks

Equipment

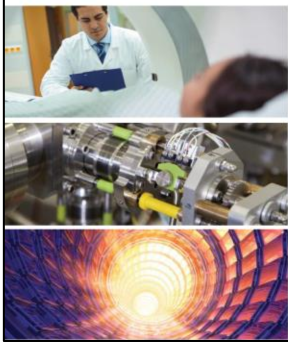
- Dose-related information, transfer to examination record

Accidental and unintended exposures

- Risk assessments, recording, reporting, dissemination

Energy

SAMIRA = Strategic Agenda for Medical, Industrial and Research Applications



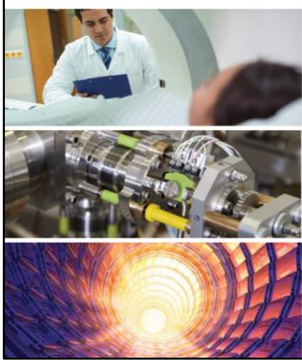
Objectives: *systematically* ***identify issues*** *relating to the use of nuclear and radiation technology outside the nuclear energy sector and* ***propose actions*** *to address them*

Cover: *security of* ***supply of radioisotopes****, radiation protection and safety, research and innovation*

20

Energy

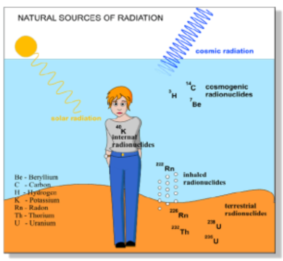
Towards SAMIRA Action Plan



- **Where action is most needed**
- **EU could add real value to Member State actions**
  - Concentrated largely in the medical field
- **Secure supply of radioisotopes for Europe**
- **Improve radiation protection and safety for patients and medical staff**
- **Facilitate innovation in the medical practice**
- **Strengthen human resources and facilitate capacity building**

Protection from natural radiation sources

- Radon in dwellings and workplaces
  - ✓ *Establishment of a national reference level for indoor radon concentration in workplaces ≤ 300 Bq/m³*
- Practices involving naturally-occurring radioactive material (NORM)
  - ✓ *If worker doses liable to exceed 1 mSv /year – relevant occupational exposure requirements apply*
- Existing exposure situations involving naturally-occurring radioactive material
- Gamma radiation from building material
  - ✓ *Reference level of 1 mSv/year from indoor external exposure to gamma radiation (above outdoor external exposure)*
- Cosmic rays (air crew & space crew)



Energy

National radon action plan

- Establishment of a national radon action plan addressing long term risks from radon exposures (Article 103)
  - ✓ in dwellings, buildings with public access and workplaces
  - ✓ from any source of radon ingress – soil, building material, water
- National action plan needs to take into account the issues set out in Annex XVIII of the BSS Directive
- Ensure appropriate measures to prevent radon entry into new buildings, e.g. through specific requirements in building codes
- Identify areas with a significant number of buildings expected to exceed the national reference level

Energy

Emergency preparedness and Response

The BSS Directive

Provisions of Basic Safety Standards Directive

- Assessment of emergency situations
- Management emergency exposures,
- Emergency response plans, protective measures, notification, emergency workers
- Cooperation across Member States
- Information to the public
- Transition from emergency to existing exposure situation

Council Conclusions on EP&R (Dec 2015)

- *Coherent protective measures along adjacent national borders,*
- *MS's cooperate closely on EP&R,*
- *MS's intensify efforts for joint training and emergency exercises,*
- *Better cross-border coordination of protective measures*

Energy

Emergency Preparedness and Response

The Amended Nuclear Safety Directive

- **Includes requirements on on-site EP&R, periodically reviewed, exercises, external assistance**
- **Establishes requirements for organisational structure, coordination between parties, and ensuring consistency and continuity with the BSS provisions (Art 8d)**
- **Enhances the requirements on transparency on nuclear safety matters by prompt information to the public (Art 8)**

Energy

Emergency Preparedness & Response

Commission role

- **Information exchange**
  - ✓ inform Member States (ECURIE)
  - ✓ EUropean Radiological Data Exchange Platform (EURDEP)
- **Protection:**
  activate emergency measures
  (Food/feed Regulations)
- **Response:**
  Contribute to EU-level response (civil protection, medical…)

Energy

26

The Euratom perspective

- Euratom provides a comprehensive framework to ensure a high level of radiation protection and nuclear safety across the EU
- NSD and BSS Directives – significant changes, strengthened legal framework
- Conformity checks of Member States' legislation and application are underway – will identify areas where joint actions are needed
- Science based provisions – research outcomes feed into the development of the legal framework

Energy

THANK YOU

https://ec.europa.eu/energy/en/home

Energy

MASSIMO GARRIBBA

FISA 2019 – EURADWASTE '19

Presentation of Mr Massimo Garribba (DG ENER, EUROPEAN COMMISSION)

Responsible and safe management of spent fuel and radioactive waste. The Community framework


European Commission
"WASTE & SPENT FUEL" DIRECTIVE
(Council Directive 2011/70/Euratom)
Major challenges addressed:
Sustainability
Safety
Transparency
Avoid imposing undue burdens on future generations
Appropriate national arrangements for a high level of safety
Public information and participation
Energy


DIRECTIVE ON RESPONSIBLE &
SAFE MANAGEMENT OF SPENT FUEL AND RADIOACTIVE WASTE
Euratom Directive 2011/70 aims to improve the safety of radioactive waste and spent fuel disposal without undue burden on future generations.
Protects workers and EU citizens
Helps turn political decisions into actions
Avoids undue burden on future generations
Continued improvement of management systems, transparency, safety and public involvement
Commits Member States (MSs) to implement sustainable solution
Spent fuel and waste under the responsibility of the generators until disposal
WHY
EURATOM DIRECTIVE 2011/70
All MSs generate radioactive waste
21 manage spent fuel on their territory
14 MSs with 126 nuclear power reactors in operation
50 to be shut down by 2025
10 MSs plan new NPP projects
1 MS plans the first geological disposal expected around 2024
WHO
3 481 000 m³ of radioactive waste
58 000 tHM of spent fuel generated in the EU by 2016
WHAT
HOW
NATIONAL POLICIES
NATIONAL FRAMEWORK
NATIONAL PROGRAMMES
Energy


European Commission
COUNCIL DIRECTIVE 2011/70/Euratom
MEMBER STATES
Establish national policies
Have ultimate responsibility
Establish a national legislative, regulatory and organisational framework
Establish a competent regulatory authority
Ensure the licence holders' prime responsibility
Policy
Framework
Programme
Reports
EUROPEAN COMMISSION roles:
Guardian of the Treaties
Legislative initiative
Ensure compliance with EU regulatory framework
Facilitate dialogue and cooperation between MS
Report to other EU Institutions
COUNCIL OF EUROPEAN UNION role:
Legislator
EUROPEAN COURT OF JUSTICE role:
Jurisdiction

NATIONAL POLICIES have to ensure:

- AVOID
- REDUCE
- REUSE
- RECYCLE
- RECOVER
- TREAT
- DISPOSE

- Generation kept to the **minimum** which is **reasonably practicable**
- **Interdependencies** shall be taken into account
- **Safely management**, including in the **long term** with **passive safety features**
- **Graded approach**
- **Costs** borne by **those who generated those materials**
- Evidence-based and documented **decision-making process**

Disposal in the Member State in which the waste was generated, unless an agreement is in force between the Member State and another country to use a disposal facility in its territory

Energy

1st COMMISSION REPORT

- Provides a **comprehensive overview** to the Council, European Parliament and EU citizens
- Brings the principle of **avoiding undue burden on future generations**
- Recognises MS' efforts and encourage pursuing them in several areas; **policies**, **cost estimations**, **financing provisions** and concrete projects for **waste disposal**.

- Main report COM(2017)236
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52017DC0236
- Staff Working Document SWD (2017)159 on MS implementation
https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1531085795800&uri=CELEX:52017SC0159
- Staff Working Document SWD (2017)161 on inventories, prospects
https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1531085865514&uri=CELEX:52017SC0161

Energy

WAY FORWARD

Energy

IMPORTANCE OF THE R&D ON THE DIRECTIVE

Member States shall ensure that the national framework (for spent fuel and radioactive waste management):

Article 5 Obligations (5.2)

- is improved ...taking into account … **the development of relevant technology and research**.

Article 8 Expertise and skills

- require all parties to make arrangements for …**research** and development activities to cover the needs of the **national programme…**

Article 12 Contents of national programmes (12.1(f))

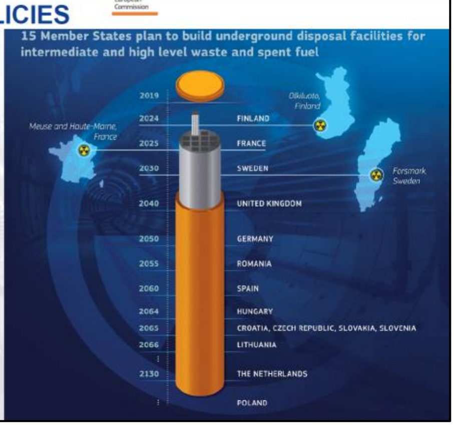
… shall include:
the **research**, development and demonstration activities that **are needed in order to implement solutions**

Energy

UNDERGROUND RESEARCH LABORATORIES

NATIONAL POLICIES

DEEP GEOLOGICAL DISPOSAL



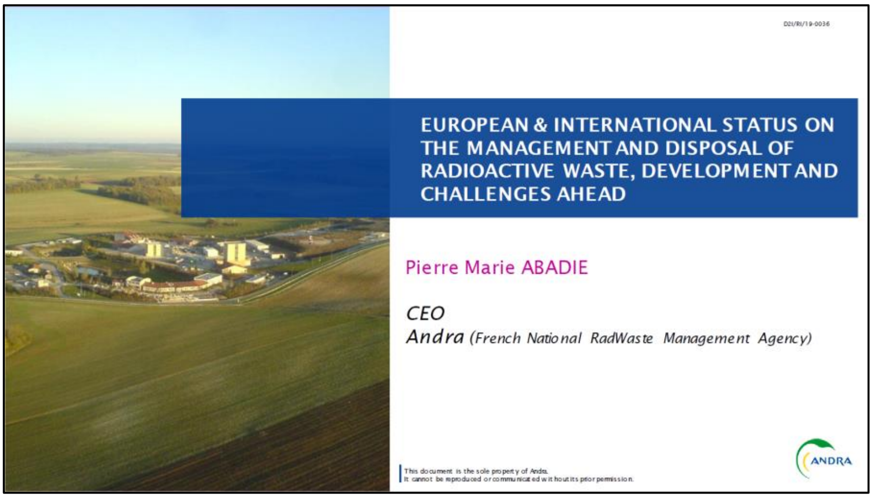
RADIOACTIVE WASTE MANAGEMENT

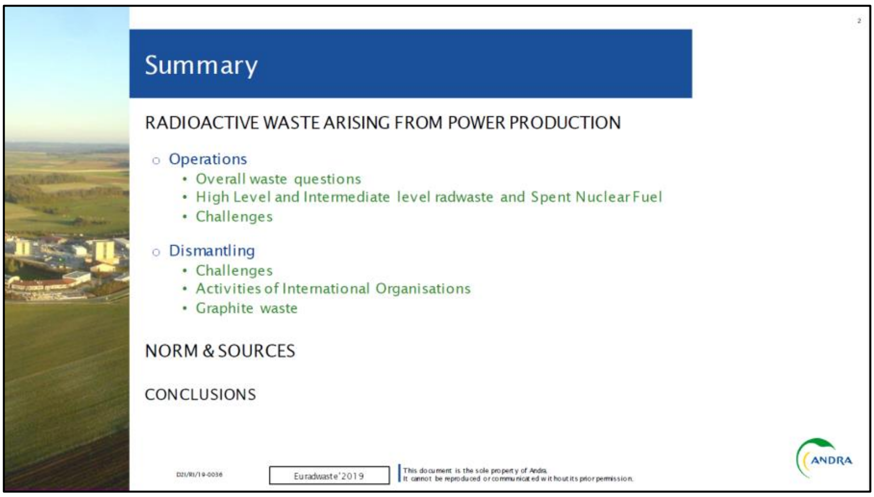
PIERRE MARIE ABADIE

FISA 2019 – EURADWASTE '19

Presentation of Ms Pierre Marie Abadie (ANDRA, FR), CEO

European and International status of the management and disposal of radioactive waste, developments and challenges ahead





The overall waste question (I)

Currently **446 reactors operating worldwide** in **31 countries**, and 4 new comers are in the process of joining that club (Turkey, United Arab Emirates, Bangladesh and Belarus)

Radwaste arising from operations:

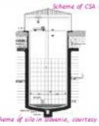
- Operating waste, mainly low activity (LLW), and mainly short lived
- Spent Nuclear Fuel and/or waste from reprocessing mainly high activity and including a significant amount of long lived elements

Radwaste management **routes** and many **disposal facilities exist for Majority of LLW** (short lived), but different concepts:

- **Surface disposal**, centre de l'Aube (France) **(1)**
- **Shallow disposal**, silo (planned in Slovenia) **(2)**
- **Underground** type, SFR (Sweden) **(3)**

Scheme of CSA in France

(1)


Scheme of silo in Slovenia, courtesy of ARAO

(2)


Scheme of SFR in Sweden, courtesy of SKB

(3)

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The overall waste question (II)

Long term management of spent nuclear fuel and/or radwaste from reprocessing: a challenge for the industry since the birth of nuclear power generation

A main consensus for long term management: Deep Geological Repository as appropriate solution

- This solution does not burden future generations. In this sense long term storage, although technically sound, does not completely answer the question
- Other possible envisaged solutions such as partitioning and transmutation do not completely satisfy requirements either
- Acceptance of such a DGR by local and national populations: a constant issue

A large set of knowledge available on DGR, resulting for more than 40 years of research

- mainly focussed on long term safety of a DGR and construction (clay, granite…): host rock, engineered barriers (buffer, backfill, seal, plugs), radwaste…

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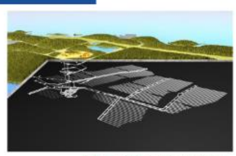
HLW, ILLW and Spent Nuclear Fuel: Situation regarding the DGR at 2019

Significant variety of situations

- For 3 countries, established projects for disposal exist:
  - Finland has a license for excavating a facility (SNF in Crystalline host rock)
  - Sweden has applied for a license and the approval is pending (SNF in Crystalline host rock)
  - France has a target date for submitting a license application in 2020 (HLW and ILLW in clay host rock)
- Other countries have started the sitting process/work:
  - UK: government (BEIS) kicked off the sitting in December 2018
  - Switzerland: sitting process ongoing
  - Japan: METI produced a map of suitable sites in the summer of 2016
  - China and Russia: Underground Research Laboratories (URL) are being excavated in Crystalline rock
  - And URL's exist in Belgium, Switzerland and Hungary.

With different schedules (can be very distant)


Scheme of DGR in Finland (Courtesy of posiva)


Scheme of Cigéo project in France

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7

The challenges a waste manager faces

In all cases, the management of HLW/SNF lead up to R&D intensive projects:

- A common development/realisation project duration: > 20-30 years
- A common long operational duration: > 100 years
- A significant oversight cost in the tens of billion Euro range, depending on inventory size

It also leads to managing an organisation that will have to adapt to the successive project phases:

- Phase 0 : policy, framework and program establishment
- Phase 1 : Site evaluation and site selection
- Phase 2 : Site characterization and Design
- Phase 3 : Facility construction
- Phase 4 : Facility operation and closure
- (Phase 5 : Post-closure)

- The feedback from the Swedish, Finn and French projects all point to the transition from 2 to 3
  - There is a needed adaptation of the organisation to go from science to design to realisation
  - This in turn requires changes in both skills and organisation
    - But RD&D/innovation remains for optimization and adaptation of DGR, long term Knowledge Management…

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10

Dismantling - Challenges (I)

The challenges differ between facilities

- One of kind dismantling operations (ex. research facilities)
- Repetitive dismantling of an homogeneous fleet of NPP's

However in all cases, **characterization** is a key issue

- for a better sorting and an identification of the most suited management route

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11

Dismantling - Challenges (II)

Strong need for **optimization of waste stream**

- Optimization based on safety, waste volume and cost criteria

Requirement for a holistic approach of waste management chain and strong interaction between waste producer, operator and waste manager

Options that lead to optimization cover:

- Waste valorization (of scrap metal, of rubble)
- Volume reductions (metal fusion, incineration and compaction) including at the waste generation phase
- Reorientation of waste streams to more appropriate solutions (ex. In situ disposal)
  - Options to be assessed as to their technical, economic, environmental efficiency and to their social acceptability
  - Existence of clearance levels must also be taken into account
  - These options are supported by a significant R&D effort

George Besse facility (France)

Disposal of a vapour generator at French surface disposal centre for VLLW (CIRES)

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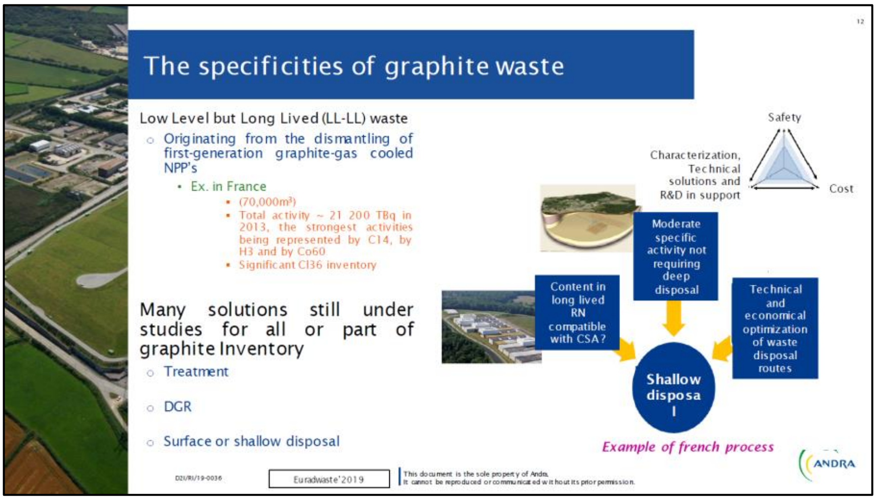
12
The specificities of graphite waste
Low Level but Long Lived (LL-LL) waste
Originating from the dismantling of first-generation graphite-gas cooled NPP's
Ex. in France
(70,000m³)
Total activity ~ 21 200 TBq in 2013, the strongest activities being represented by C14, by H3 and by Co60
Significant Cl36 inventory
Many solutions still under studies for all or part of graphite Inventory
Treatment
DGR
Surface or shallow disposal
Safety
Characterization, Technical solutions and R&D in support
Cost
Moderate specific activity not requiring deep disposal
Content in long lived RN compatible with CSA?
Technical and economical optimization of waste disposal routes
Shallow disposa l
Example of french process
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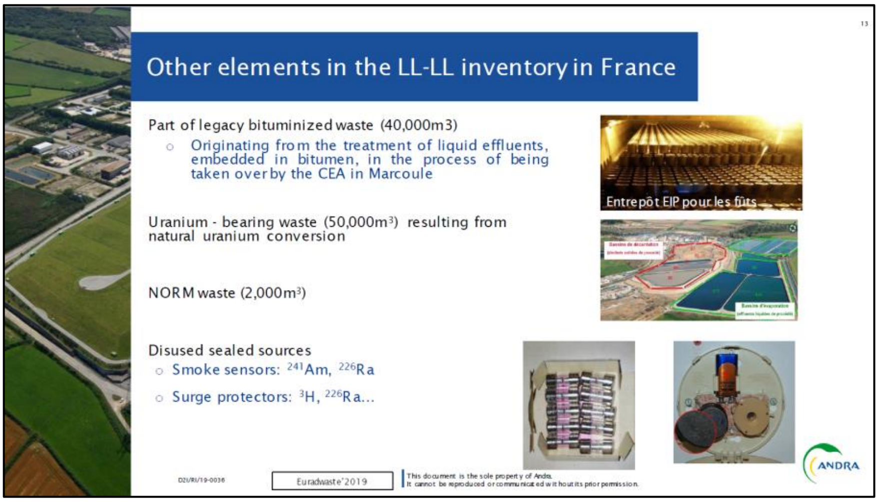
13
Other elements in the LL-LL inventory in France
Part of legacy bituminized waste (40,000m3)
Originating from the treatment of liquid effluents, embedded in bitumen, in the process of being taken over by the CEA in Marcoule
Entrepôt EIP pour les fûts
Uranium - bearing waste (50,000m³) resulting from natural uranium conversion
NORM waste (2,000m³)
Disused sealed sources
Smoke sensors: ^{241}Am, ^{226}Ra
Surge protectors: ^{3}H, ^{226}Ra...
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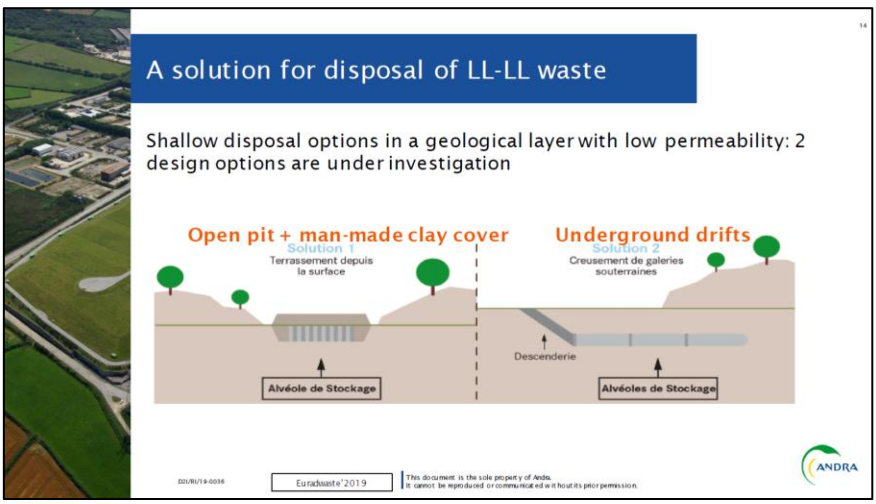
14
A solution for disposal of LL-LL waste
Shallow disposal options in a geological layer with low permeability: 2 design options are under investigation
Open pit + man-made clay cover
Solution 1
Terrassement depuis la surface
Alvéole de Stockage
Underground drifts
Solution 2
Creusement de galeries souterraines
Descenderie
Alvéoles de Stockage
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16

Sources and NORM (I)

NORM and sources are present in many countries

- Sources:
  - Generally sources that have been used either for industrial or health linked applications (Disused Sealed Sources)
  - Classified by IAEA on 1-5 scale (level 1 being the most active)
  - To be dealed in countries that are not nuclear countries
- NORM waste
  - Waste arising from the processing of natural materials that are naturally rich in radionuclide content but that are not used for their radioactive properties
    - extracting materials from the underground (water, oil, coal, rare earth…) or from the ground (phosphate…),
    - Processing materials (coal, rare earth…)
    - …

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17

Sources and NORM (II)

Difficulty to Handle these different categories of waste in countries were the nuclear and radioactive waste management culture is not present

In addition the volumes can range from very small to significant

Promising solutions are being investigated by the IAEA for Disused Sealed Sources, based on borehole technology.

- Solution that also could be used for small volumes of other type of waste, and this is being examined by the IAEA

Issues to identify solutions that are adapted to these waste streams:

- Environmentally safe
- Affordable for the country
- Adequate proportionality from a waste management point of view (holistic view)

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19

Conclusions (I)

LLW from NPP operations are disposed adequately in *many existing facilities* throughout the world

HLW, ILLW and SNF from NPP operations can be disposed of via *DGR*'s, and the development of this type of solution is progressing with ongoing or planned license applications in 3 countries and siting projects in many countries

- A strong knowledge base is available
- The evolution of project from design and demonstration to construction and operation requires deep evolution of skills and organization
- The long duration and the progressive development of projects allow optimization and innovation, supported by RD&D

Forecast Radioactive waste from decommissioning of NPP's is a significant issue, for the next decades, according to large volume: *characterization* is a *key point to optimize the waste routes in an holistic approach (recycling, disposal)*

- R&D on characterization, treatment and conditioning is required to support optimization

Low Level but Long Lived radwaste, such as graphite, (should) remain(s) an issue to address the *appropriate route*, depending of country policy (long term storage, DGR, shallow or surface disposal)

Other types of waste (NORM, DSSS…) are to be considered: frequent in all countries and appropriate solutions are to be deployed in particular in *countries without nuclear culture/NPP* (borehole…)

Whatever type of radwaste, but in particular HLW/ILLW and SNF, the *long duration of projects* (more than a century) highlights the need of a **strong Knowledge Management process**

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Conclusions (II)

In addition to efforts produced by each country, international organizations strongly contribute in a complementary and consistent way

- to radioactive waste management:
  - IAEA: numerous initiatives (joint convention, production of safety standards and guides, supporting exchange networks…)
  - NEA: Radioactive Waste Management Committee that in turn has organized many instances to share information on waste management (The Integration group for the safety case (IGSC) ; Forum on Stakeholder Confidence (FSC)…
  - EC: Directive, Euratom R&D projects
- in dismantling:
  - IAEA: recent Decommissioning & Environmental Remediation Section inside the department of nuclear energy
  - NEA: creation of an independent Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM) since 2018
  - EC: Directive, Euratom R&D projects

In addition, international initiatives exist to address the complex subject of the disposal of HLW, ILLW or SNF for countries with a limited inventory (Netherlands, Slovenia…)

- The previously mentioned significant financial needs associated to such projects naturally lead to looking at the sharing of such facilities

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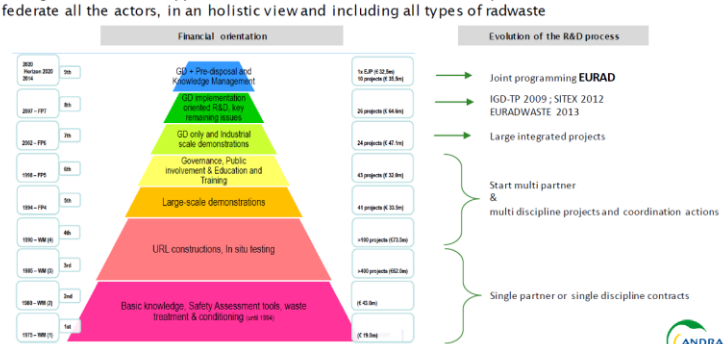
Conclusions (III.1)

Strong effort of EC to support R&D on radwaste since more than 40 years and an evolution to federate all the actors, in an holistic view and including all types of radwaste



Courtesy of EC

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Conclusions (III.2)

A positive evolution of EC support to RD&D:

- To consider all Radwaste types
  - Including countries without NPPs
- To consider all management solutions
- To consider radwaste routes from cradle to grave
  - From predisposal to disposal
- To federate all actors: Radwaste Producers, WMOs, TSOs, and REs, in close link with Civil Society
  - To promote sharing between all actors
    - Joint Strategic Research Agenda
    - Collaborative RD&D
    - Joint Knowledge Management and Training processes
    - Joint Strategic studies
- To be complementary with IAEA and NEA and to promote common work on Knowledge Management, Training and Strategic studies

⇨Toward an **European community on Radwaste**, whatever each national policy and level of progress

- EURAD Joint Programming
- (future) project on predisposal (characterization/treatment/conditioning) in close link with EURAD

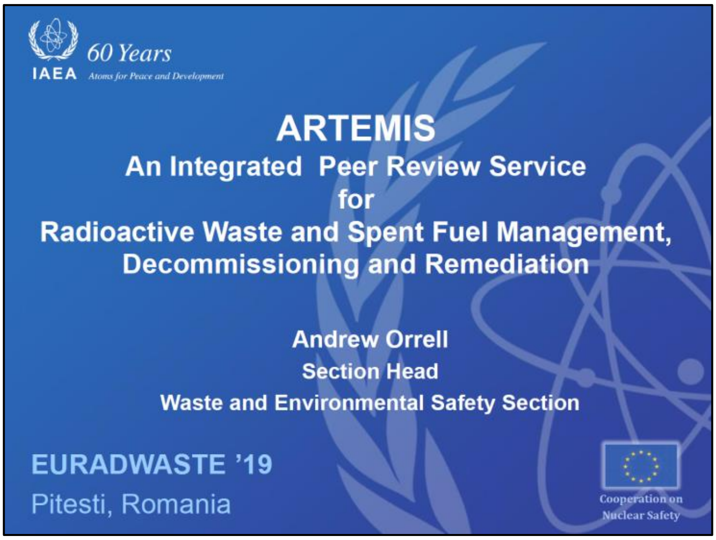
ANDRA

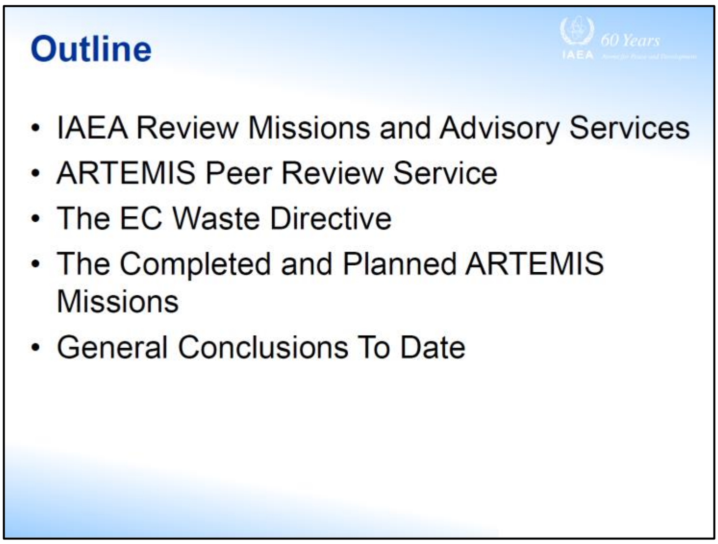
ANDREW ORRELL

FISA 2019 – EURADWASTE '19

Presentation of Mr Andrew Orrell (IAEA), Section Head of Waste and Environmental Safety

ARTEMIS in Europe, the Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation





IAEA Review Missions and Advisory Services

IAEA offers Member States a wide array of review services

- ImPACT (an integrated mission of PACT otherwise referred to as an imPACT Review)
- Operational Safety Review Team (OSART)
- International Physical Protection Advisory Service (IPPAS)
- Integrated Regulatory Review Service (IRRS)
- Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation (ARTEMIS)
- Safety Aspects of Long-Term Operation (SALTO)
- Integrated Nuclear Infrastructure Review (INIR)
- Quality Management Audits in Nuclear Medicine Practices (QUANUM)
- Occupational Radiation Protection Appraisals (ORPAS)
- Construction Readiness Review (CORR)
- Emergency Preparedness Review (EPREV) Service
- Integrated Safety Assessment of Research Reactors (INSARR)
- Site and External Events Design Review Service (SEED)
- Independent Safety Culture Assessment (ISCA)
- Knowledge Management Assist Visit (KMAV)
- Education and Training Appraisal (EduTA)
- Operation and Maintenance Assessment for Research Reactors (OMARR)
- Technical Safety Review (TSR)
- State Systems of Accounting for and Control of Nuclear Material mission (ISSAS)
- Quality Improvement Quality Assurance Team for Radiation Oncology (QUATRO)
- Safety Culture Continuous Improvement Process (SCCIP)
- Independent Engineering Review of I&C Systems (IERICS)
- International Nuclear Security Advisory Service (INSServ)
- Quality Improvement Quality Assurance Audit for Diagnostic Radiology Improvement and Learning (QUAADRIL)
- Integrated Nuclear Infrastructure Review for Research Reactors (INIR-RR)
- Advisory Mission on Regulatory Infrastructure for Radiation Safety (AMRAS)
- Uranium Production Site Appraisal Team (UPSAT)
- Safety Evaluation of Fuel Cycle Facilities during Operation (SEDO)
- Transport Safety Appraisal Services (TranSAS)

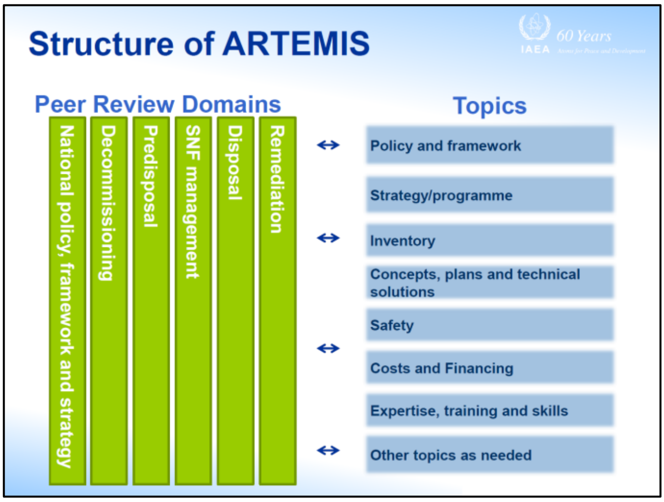
https://www.iaea.org/services/review-missions/calendar

ARTEMIS Review Service

- Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation (ARTEMIS)

ARTEMIS

Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation



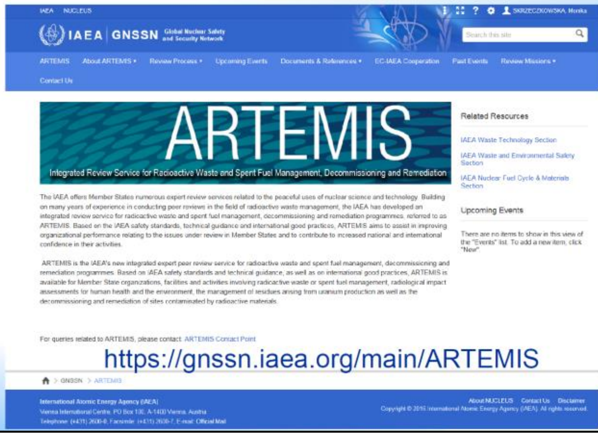
ARTEMIS Review Process

- General process overview and familiarization
  - Objectives, principles, benefits, costs
  - Forming the request
- Planning Phase
  - Terms of Reference agreed to
  - Logistics, financing, Points of Contact, draft schedule
- Preparation Phase
  - Review Team – selection, organization, contracting
  - Self-assessment
  - Reference material gathered and distributed
  - Preparatory Meetings
  - Discussions with MS on self-assessment or expert questions
- Conduct the Review
  - Entrance Meeting
  - Review of mission specifics per the ToR
  - Drafting the mission report
  - Exit Meeting
- Reporting
  - Final report provided
  - Follow-up as requested
  - Release to public as permitted

Definitions

- ***Recommendations***
  - Recommendations are proposed where aspects relative to the IAEA Safety Requirements and additional supporting documents agreed as basis for review such as other IAEA documents, Conventions, Code of Conduct or other supporting documentation are missing, incomplete, or inadequately implemented. … In the case of peer review in relation to the obligations under the European Council Directive 2011/70/EURATOM to review the national programmes and frameworks, the review and recommendations made should also be based on this Directive.
- ***Suggestions***
  - Reviewers may identify opportunities for improvement not directly related to inadequate conformance with IAEA Safety Requirements, but which should be shared with the host country (e.g. a more efficient way of utilizing staff resources). Suggestions are means of achieving improvements. … In general, suggestions should stimulate the management and staff to consider new or different approaches to technical, regulatory and policy issues that may enhance performance. … Each suggestion shall have a basis either in IAEA Safety Requirements, Safety Guides or other relevant IAEA documents or international commitments (e.g., Codes of Conduct, Conventions, etc.).
- ***Good Practices***
  - A good practice is identified in recognition of an outstanding organization, arrangement, programme or performance superior to those generally observed elsewhere. A good practice goes beyond the fulfilment of current requirements or expectations. It will be worthy of the attention of other organizations or entities as a model in the general drive for excellence.

ARTEMIS on GNSSN Platform



https://gnssn.iaea.org/main/ARTEMIS

The EC Waste Directive

The EC Waste Directive

- Article 14, Item 3, Reporting of the EC 2011 'Waste Directive':
  - Member States shall periodically, and at least every 10 years, *arrange for self-assessments* of their national framework, competent regulatory authority, national programme and its implementation, *and invite international peer review of their national framework, competent regulatory authority and/or national programme with the aim of ensuring that high safety standards are achieved* in the safe management of spent fuel and radioactive waste. The *outcomes of any peer review shall be reported to the Commission and the other Member States, and may be made available to the public* where there is no conflict with security and proprietary information.

Article 5 National framework

1. Member States shall establish and maintain a national legislative, regulatory and organisational framework ('national framework') for spent fuel and radioactive waste management that allocates responsibility and provides for coordination between relevant competent bodies. The national framework shall provide for all of the following:

(a) a national programme for the implementation of spent fuel and radioactive waste management policy;

(b) national arrangements for the safety of spent fuel and radioactive waste management. The determination of how those arrangements are to be adopted and through which instrument they are to be applied rests within the competence of the Member States;

(c) a system of licensing of spent fuel and radioactive waste management activities, facilities or both, including the prohibition of spent fuel or radioactive waste management activities, of the operation of a spent fuel or radioactive waste management facility without a licence or both and, if appropriate, prescribing conditions for further management of the activity, facility or both;

(d) a system of appropriate control, a management system, regulatory inspections, documentation and reporting obligations for radioactive waste and spent fuel management activities, facilities or both, including appropriate measures for the post-closure periods of disposal facilities;

(e) enforcement actions, including the suspension of activities and the modification, expiration or revocation of a licence together with requirements, if appropriate, for alternative solutions that lead to improved safety;

(f) the allocation of responsibility to the bodies involved in the different steps of spent fuel and radioactive waste management; in particular, the national framework shall give primary responsibility for the spent fuel and radioactive waste to their generators or, under specific circumstances, to a licence holder to whom this responsibility has been entrusted by competent bodies;

(g) national requirements for public information and participation;

(h) the financing scheme(s) for spent fuel and radioactive waste management in accordance with Article 9.EN 2.8.2011 Official Journal of the European Union L 199/53

Article 6 Competent regulatory authority

1. Each Member State shall establish and maintain a competent regulatory authority in the field of safety of spent fuel and radioactive waste management.

2. Member States shall ensure that the competent regulatory authority is functionally separate from any other body or organisation concerned with the promotion or utilisation of nuclear energy or radioactive material, including electricity production and radioisotope applications, or with the management of spent fuel and radioactive waste, in order to ensure effective independence from undue influence on its regulatory function.

3. Member States shall ensure that the competent regulatory authority is given the legal powers and human and financial resources necessary to fulfil its obligations in connection with the national framework as described in Article 5(1)(b), (c), (d) and (e).

Article 11 & 12 National Programmes

1. Each Member State shall ensure the implementation of its national programme for the management of spent fuel and radioactive waste ('national programme'), covering all types of spent fuel and radioactive waste under its jurisdiction and all stages of spent fuel and radioactive waste management from generation to disposal.

2. Each Member State shall regularly review and update its national programme, taking into account technical and scientific progress as appropriate as well as recommendations, lessons learned and good practices from peer reviews.

Contents of national programmes

1. The national programmes shall set out how the Member States intend to implement their national policies referred to in Article 4 for the responsible and safe management of spent fuel and radioactive waste to secure the aims of this Directive, and shall include all of the following:

(a) the overall objectives of the Member State's national policy in respect of spent fuel and radioactive waste management;

(b) the significant milestones and clear timeframes for the achievement of those milestones in light of the over- arching objectives of the national programme;

(c) an inventory of all spent fuel and radioactive waste and estimates for future quantities, including those from decommissioning, clearly indicating the location and amount of the radioactive waste and spent fuel in accordance with appropriate classification of the radioactive waste;

(d) the concepts or plans and technical solutions for spent fuel and radioactive waste management from generation to disposal;

(e) the concepts or plans for the post-closure period of a disposal facility's lifetime, including the period during which appropriate controls are retained and the means to be employed to preserve knowledge of that facility in the longer term;

(f) the research, development and demonstration activities that are needed in order to implement solutions for the management of spent fuel and radioactive waste;

(g) The responsibility for the implementation of the national programme and the key performance indicators to monitor progress towards implementation;

(h) an assessment of the national programme costs and the underlying basis and hypotheses for that assessment, which must include a profile over time;

(i) the financing scheme(s) in force;

(j) a transparency policy or process as referred to in Article 10;

(k) if any, the agreement(s) concluded with a Member State or a third country on management of spent fuel or radioactive waste, including on the use of disposal facilities.

2. The national programme together with the national policy may be contained in a single document or in a number of documents.

ARTEMIS Reviews Status

60 Years
IAEA Atoms for Peace and Development

Mission	Member State	Date
ARTEMIS Mission to SOGIN	Italy	3-Jul-17
ARTEMIS Mission to Poland	Poland	1-Oct-17
ARTEMIS Mission to France	France	14-Jan-18
ARTEMIS Mission to Bulgaria	Bulgaria	10-Jun-18
ARTEMIS Mission to SOGIN	Italy	24-Jun-18
ARTEMIS Mission to Luxembourg	Luxembourg	24-Sep-18
ARTEMIS Mission to Eletronuclear	Brazil	1-Oct-18
ARTEMIS Mission to Spain	Spain	14-Oct-18
ARTEMIS Mission to Estonia	Estonia	24-Mar-19
ARTEMIS Mission to Germany	**Germany**	**22-Sep-19**
ARTEMIS Mission to Latvia	**Latvia**	**3-Dec-19**
ARTEMIS Mission to Denmark	**Denmark**	**7-Jun-20**
ARTEMIS Mission to Romania	**Romania**	**2019 Q4***
ARTEMIS Mission to Cyprus	**Cyprus**	**2020 Q4***
ARTEMIS Mission to Slovenia	**Slovenia**	**2021 Q1***
ARTEMIS Mission to Hungary	**Hungary**	**2021 Q2***
ARTEMIS Mission to Lithuania	**Lithuania**	**2021 Q2***
ARTEMIS Mission to Croatia	**Croatia**	**2021 Q3***
ARTEMIS Mission to Ireland	**Ireland**	**2021 Q3***
ARTEMIS Mission to Sweden	**Sweden**	**2022 Q1***
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- Slovenia 2021
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General Conclusions

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INTEGRATED REVIEW SERVICE FOR RADIOACTIVE WASTE AND SPENT FUEL MANAGEMENT, DECOMMISSIONING AND REMEDIATION (ARTEMIS)

MISSION

TO

FRANCE

PARIS, FRANCE

14 to 24 January 2018

DEPARTMENT OF NUCLEAR SAFETY AND SECURITY
DEPARTMENT OF NUCLEAR ENERGY

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CONTENTS

60 Years
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Thank you!

ARTEMIS.Contact-Point@iaea.org

CHRISTOPHE DAVIES

FISA 2019 – EURADWASTE '19

Extended abstract of Mr Christophe Davies (EC, DG RTD), Euratom Fission, Project & Policy Officer

Euratom research and training programme in radioactive waste management: Overview status, vision and future perspectives

Euratom Research and Training (R&T) on radioactive waste management began in 1975. It is one of the first, European Commission research programmes. The purpose of this extended abstract is to take stock of the evolution the Euratom (R&T) programme underpinning the strategic vision and plan of the European Commission for its continued role and support in the field of radioactive waste management.

Over the nine successive programmes, Euratom went through all the R&D phases needed to manage and dispose all types and categories of radioactive waste including decommissioning, pre-disposal (characterisation, treatment, conditioning), fuel cycle (reprocessing, partitioning and transmutation-P&T) and disposal (basic science on key processes; performance assessment calculations; site, host rock and geological investigations plus natural analogues; underground research laboratory constructions and in situ testing for performance investigations, constructions and disposal concept feasibility and technology development); policy and waste management strategies; and social science and humanities (SSH) for public perception and acceptance.

R&D on dismantling was gradually stopped in the mid-2000's due to the industrial maturity of the dismantling projects. Working groups to maintain and exchange knowledge in this domain are operating at the two international organisations (OECD Nuclear Energy Agency and IAEA). At Euratom level, the need to re-open R&D on decommissioning for advanced and innovative techniques and technologies is being investigated in a Coordination & Support Actions (CSA), SHARE, to identify any need for a decommissioning R&D roadmap for activities of EU added-value.

Near-surface disposal of short-lived and intermediate level waste is being widely implemented across Europe, hence activities supported by Euratom in this field were discontinued during Framework Programme (FP7, 2007-2013). Support to characterisation and waste treatment for these wastes was reopened during the Horizon 2020 FP as part of the Work Programme 2016-17.

R&D on P&T is conducted mostly by the research community close to reactor systems, hence in Euratom this domain of research is managed within the part of the programme on reactor safety.

In the early 2000's, after 25 years of R&D, there was still no scheduled date for start of operation of the first underground repositories in Europe and no country was still foreseeing a date of submission of an operation license application to its regulatory authority. Disposal of high-level and long-lived radioactive waste

(HL&LL W) and spent fuel (SF) in deep underground repositories was and still is the most important challenge in all national programmes, which have to manage SF.

Being a priority in EU Member States (MS), Euratom gradually focussed its support on this domain and lower priority was given to R&D on pre-disposal.

Geological Disposal (GD) is a complex multidisciplinary scientific, technical, organisational and societal issue. R&D in this domain being mostly non-commercial and open science the Commission started to advocate for increase and close collaboration and joint activities within the respective research communities involved in the safety case (SC) of GD. Although the principle for EU support is competitive project proposals, this principle had to be adapted to the specific situation of radioactive waste disposal, so that even if scientific excellence is the objective in R&D, collaboration instead of competition can bring more benefits to all MSs, which face the same challenges. This approach also avoids unnecessary duplication of research. The question has been and remains to which extent and scope collaboration in all domains of the SC for GD is of EU added-value as opposed to specific requirements in each MS national programme. And it is also necessary to identify which R&D has to be done in any case in each national programme.

Only competitive projects may not be the most effective working method both for the Commission and the research actors on GD. Evidence of unfruitful competition was exemplified by the failure, in 2007, of two large competitive project proposals on gas led on the one side by Technical Support Organisations (TSO) and the other side by Waste Management Organisations (WMO): GASCONI and GASMIG. Both proposals were rejected at the evaluation stage and both communities had lost time and effort. The underlying argument leading to this competition was that TSOs considered that they need to remain independent to draw conclusions on the outcome of the project. This argument was challenged during evaluation saying that the purpose of the projects was to develop scientific knowledge and understanding on the processes of gas in underground repositories and that the interpretation of the results for the performance of the repositories remains of the responsibility of the respective communities. Fortunately, a joint project (FORGE) was developed the year after with fruitful collaboration and did set the pace for future method of work of the different research communities for disposal.

In the mid-2000's, one of the steps taken by the EC to increase collaboration and joint activities within the respective research communities was to introduce new types of project contracts: Integrated Projects, Network of excellence and European Technology Platforms (TP), to help speed up industrialisation of research outputs and to help establish the European Research Area (ERA). The first initiative in Euratom was the start of work towards integration / coordination of WMOs. A number of projects were conducted between 2002 and 2009 with the Network of excellence NET.EXCEL, then CARD, which eventually led to the establishment of IGD-TP, the Implementing Geological Disposal –Technology Platform, in 2009, between 11 WMOs.

In line with the strategy of ERA, the EC/Euratom aim is to provide EU-added value, leverage and benefit to all national programmes. Therefore, beyond collaboration within the research communities, EC policy to achieve this objective has been to gradually bring together the different research communities generating knowledge for the safety case of disposal with the end-users of the results, i.e; Waste Management Organisations (WMO), TSOs and academic and research organisations.

In the early 2010's, the context at the EU level and in the MSs continued to evolve in a way justifying, reinforcing EC strategy towards integration of the different research communities, but furthermore to develop Joint Programming activities between MSs at EU level.

In 2011 and 2012, the first two license applications for underground repositories were submitted in Sweden and Finland demonstrating maturity of knowledge for the SC in countries with advanced programmes for GD. This could have been understood that continued support from Euratom could be questioned. However, at the EC EURADWASTE '13 conference, two key conclusions provided evidence of the continued role for Euratom.

The first conclusion was that each underground repository is a first of the kind because of many different conditions including geological formations, disposal concept, etc… .

The second conclusion was that knowledge underpinning the SC needs to be continuously improved in order to be in a position to update the operating license, respond to uncertainties in processes measured during operation and to regulatory questions, to optimise the repository concept and facility, to provide competence to next generations of scientists due to the long operational time of repositories (up to one hundred years), etc… .

At the same time, the Council Directive 2011/70/Euratom establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste (the waste Directive) was adopted by the MSs.

The Directive requires each MS to establish and maintain national policy, and legislative, regulatory and organisational framework for managing all types of radioactive waste from generation to disposal. This includes establishing a national programme with significant milestones and clear timeframes, as well as RD&D activities needed in order to implement technical solutions. Therefore, a R&D programme is needed in each MS concerned with radioactive waste management.

The role of Euratom is considered as reinforced, when considering the different time scheduled between MSs on the start of their respective repositories. Advanced countries like Finland, Sweden and France plan operational starts in the next decade, while many other MSs have longer implementation timescales, i.e. commissioning dates of deep geological repositories planned around 2055-2065. These countries in early stage will need to go through all the research steps undertaken in advanced countries. Therefore, there is a central role for Euratom in organising cooperation between all national programmes so that all countries can benefit from joint work.

In working together, as part of a European Joint Programme, advanced countries will be able to address specific cutting-edge science on very deep scientific topics, while less-advanced programmes will be able to plan, structure and implement the necessary R&D, with guidance, training and transfer of competence and knowledge from advanced programmes and not having to redo and duplicate R&D effort for which there is state of the art knowledge.

From a regulatory support point of view, given the on-going and forthcoming license applications Euratom began to support networking and R&D activities of TSOs for their necessary competence in the review of Safety Cases. The two SITEX projects, started in 2011, led to establishment of the SITEX Network in 2018.

Recently, the community of research entities (RE), taking into account the EURADWASTE '13 key messages, also started to structure and coordinate at European level in order to contribute to the long-term R&D challenges of, in particular, GD as part of a European Joint Programme and to be in a position to provide a flowerbed for education and training of the needed scientists for the future. In 2018, this community launched its own network called EURADSCIENCE.

In response to the evolving context described above, the Commission initiated the process of integration of MSs' national programmes in a Joint Programming at EU level via the use of the new contractual instrument: Joint Programme co-fund.

Preparatory work for a European Joint Programme was discussed intensively between IGD-TP and SITEX and eventually in effective cooperation within the JOPRAD project in the years 2015 to 2017. One important criterion for collaboration was preserving independence of the TSO. The three R&D communities took part and elaborated a common Strategic Research Agenda (SRA) for joint implementation at European level. The SRA is the basis for joint collaborative activities based on agreed prioritisation and decisions of the Joint programme governing board. The SRA structure, being built to address research on scientific technical gaps, and on acquisition of basic science allows joint work between communities. This method is considered as respecting independence between implementers and reviewers, which can use separately the results obtained, to respectively develop their safety case and implement their review process. Non-technical stakeholders were also involved to provide input on their view of the needed R&D to be performed.

Integration of the actors of the disposal communities (WMO, TSO and RE) at European level, which have an official role in their respective national programme has delivered the EURAD European Joint Programme (EJP) to be launched in mid-2019 for five years.

One of the benefits of Joint Programming should be effective close collaboration and avoid undue competition on topics of common interest. The question will be whether R&D leading to industrial and commercial activities could be included in Joint Programming, which is mostly working on open science.

Regarding the national programmes with longer GD implementation timescales and those with small radioactive waste inventories, including those from central and eastern Europe, their participation in Euratom research projects has over the years been limited. Therefore, taking into account this situation, that of advanced knowledge on GD and that their R&D priorities could be, for the time being, on pre-disposal management of radioactive waste Euratom has reopened R&D topics on other categories than HL&LL W and SF. The scope of activities include, the development of methods, processes, technologies and demonstrators for characterisation, quality control / checking, treatment and conditioning of unconventional, legacy waste, operational wastes, waste arising from repair or maintenance and decommissioning/dismantling waste or other waste streams for which there is currently no industrial pre-disposal and or disposal mature processes.

These activities are generally carried by waste producers and owners and the projects issued from this Euratom call domain are separate from the EURAD EJP. However, EC strategy is to gradually involve and integrate this community in future Joint Programming at EU level. The justification is that if characterisation, treatment and conditioning processes are developed together with the disposal community based on co-developed waste acceptance criteria, there will be efficiency, optimisation and benefits on both sides. The current limitation of the types of activities to be included in the EJP, considered by Euratom, is that decommissioning activities up to pre-treatment for stabilisation and packaging of dismantled waste are more of the responsibility of utilities. Also, dismantling are commercial and competitive markets, which does not seem compatible with the open-science approach in the EJP. This could be considered as an obstacle to open cooperation. Recent evidences can be found in project proposals received in the category Innovation actions (IA). A large numbers of technical reports were classified as confidential. Although an objective of the EC in the research programmes is to contribute to economic growth and employment, observation is made that when a project includes activities covering innovative products, processes or services and prototyping, testing, demonstrating, piloting, large-scale product validation and market replication of advanced and new technologies, the results are of direct benefit to a small number of organisations with IPR for commercial use.

The question for the EC is, whether these activities should be included in Joint Programming. In the domain of waste treatment, the current EC idea is to allow inclusion of development of new processes and technologies for waste types or streams common to several MSs or eventually for which there could be co-ownership of the process and possible common exploitation facilities. Otherwise, other research proposals based on existing technologies or new ones which are or would be property of a single company should be subject to competitive call for proposals.

Public acceptance and political decision to select a site to construct a repository or an underground research laboratory (URL) is a sensitive issue. Already early, a number of applications for site investigations and URLs had been refused due to local and public opposition. Euratom opened the domain of SSH to increase public perception and acceptance around 2000. A series of projects were supported to investigate communication, stakeholders' engagement, governance aspects and public involvement, mainly at local level: RISCOM2, TRUSTNET, COWAM series, OBRA, ARGONA, IPPA and InSOTEC. General principles and recommendations on communication and stakeholder involvement were produced by the projects.

The results are available for use in national programmes and in working groups of the OECD NEA, the Stakeholder Forum for Confidence (SFC). Therefore, the need to continue social science on its own as part of Euratom did not appear as justified. Instead the Euratom programme on radioactive waste management proposed, in some way an innovative approach for public participation by suggesting to involve public non-technical stakeholders in scientific / technical R&D projects when a clear task/contribution can be identified for them. A series of projects implement this approach: MODERN 2020, SITEX II, JOPRAD, MIND and Beacon. Lessons learnt from these projects need to be drawn and a number of questions need to be addressed to clarify which role and task could public and non-technical stakeholders play in future Euratom research activities.

The future involvement of public, non-technical stakeholders in R&D projects and Joint Programming at European level thus needs analysis. Civil Society Organisations (CSO) and Non-Governmental Organisations (NGO) have defined their role as interaction with civil society in following the research to give civil society the opportunity to follow, discuss and give feedback on the research conducted in the projects and to create the conditions for civil society local and national representatives to interpret, discuss and give feedback on the research result and other information made available by the projects. CS experts also wish to perform social science (SC) activities within scientific technical projects.

On the role of CSOs and NGOs to follow the projects to discuss and give feedback on the research conducted, trials have been tested in on-going projects. Scientific experts have been used to comment of the work performed by the projects. The content of the deliverable is similar as that requested from the external advisory boards composed of end-users (WMOs and TSOs). Therefore, the EC considers that if CSOs and NGOs wish to make scientific comments on the projects work, this should be carried jointly with the other external experts in the advisory boards.

On the role to create the conditions for civil society local and national representatives to use the project results and other information in future situations where there are consultation processes as a part of safety case reviews and licensing decisions, this could be considered as training and performed as such in the form of deliverables presenting the project results in understandable way for the public.

Social science activities are performed extensively as part of the OECD NEA SFC forum, therefore SC as individual projects in the field of RWM are not justified also because such activities on their own usually address strategic issues as nuclear energy and radioactive waste management policies, which are not part of the Euratom R&T programme scope.

Summary:

- The European Commission via the Euratom R&T programme on radioactive waste management has a role in fostering close cooperation and joint implementation of R&D on radioactive waste management,
- The criteria for supporting research is cutting-edge science on issues of common EU added-value for Member States. However, the wide gaps in the status of the national programmes towards implementation of geological repositories for high-level and long-lived radioactive waste (HL&LL W) and spent fuel implies a central role for Euratom in the management of scientific and technical knowledge on RWM for exchange between organisations across the MSs and to transfer to new generations of scientists to ensure the long-term safety of disposal,
- The European Joint Programme tool for R&D at EU level appears to be the most effective way to jointly prioritise and implement R&D at the European level between the main actors of the disposal community (WMO, TSO and RE) representing their official MS national programme,
- Public non-technical stakeholders may contribute in R&D activities at Euratom level whenever a clear and genuine task can be identified and does not diverge from the programme of their country of origin,
- The needs for R&D on pre-disposal at EU level may be justified as long as the criteria for cooperation are clear and that benefit is acknowledged for several MSs as opposed to activities leading to competitive and commercial markets of benefit to single entities.

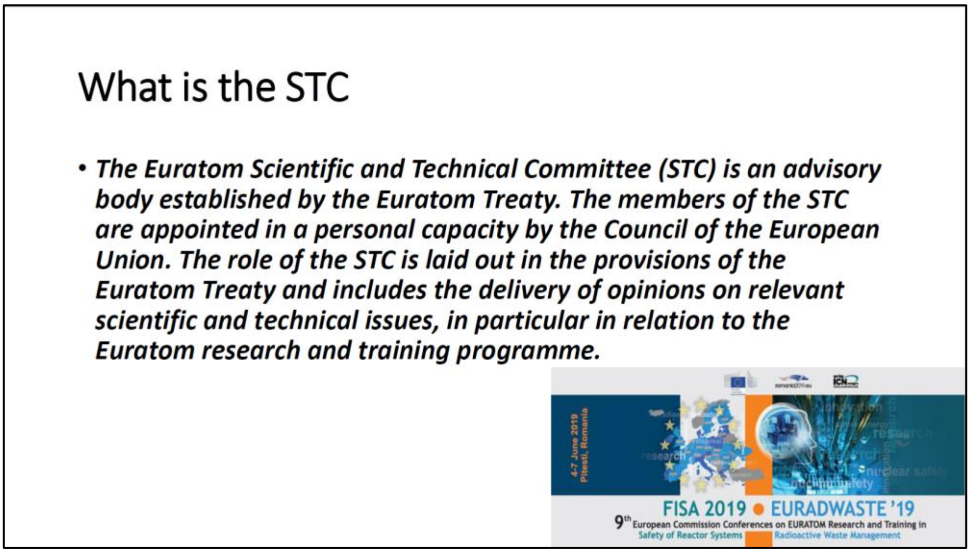
SAFETY OF REACTOR SYSTEMS

MARTIN MURRAY

FISA 2019 – EURADWASTE '19

Presentation of Mr Martin Murray (Environment Agency, UK)

EURATOM Scientific and Technical Committee Legacy messages from the 2013-2018 Mandate



How long have we existed

- The Euratom Scientific and Technical Committee (STC) is the only scientific and technical advisory body formally enshrined in the Euratom Treaty (Article 134) and active since 1957.
- For over 60 years, the STC has provided independent, authoritative advice and opinion on all aspects of nuclear technology. Its members are appointed from all Member States, for a five-year renewable term, as independent experts in nuclear medicine and radiation protection, in nuclear fission reactor systems and fuel cycles, waste management and thermonuclear fusion. The STC is also responsible for nominating the experts advising the Commission on the basic standards for radiation protection (the Article 31 Expert Group) and on the assessment of the health impact of radioactive release from nuclear facilities (the Article 37 Expert Group).

Our Work 2013 - 2018

- The 2013-2018 STC provided a detailed, multifaceted Opinion covering Future Fission Systems and Fuel Cycles, Radiological Protection, Infrastructure, Waste Management and Decommissioning and a separate stand-alone Opinion on the Fusion Roadmap.
- Recognises nuclear energy in a number of Member States is and will be a component of low carbon electricity supply
- Makes the point that all EU Member States, even those without nuclear power plants, have an interest in ensuring nuclear safety throughout the EU;

Why do we need research

- Maintain Capability – Intelligent Client role if not Leadership
- Nuclear safety security and environmental impacts cross national and international boundaries
- Need to influence and ensure high standards of safety
- Climate Change – non fossil fuelled generation – enable mixed energy economy
- Safe decommissioning and disposal of current and future wastes
- Sustainability and inter generational equity
- Future provision of medical radio-isotopes

Research Priorities

- Fusion
- Fission
- Nuclear Materials
- Medical and Industrial uses of radiation/radio isotopes
- Maintain Skills
- Develop Capability
- Enable Leadership

Future Opportunities : Limited Future Funding

- Climate Change 4, 3,2, or 1.5 degree increase in temperature
- Nuclear Power as part of the roadmap to zero carbon
- Sustainable use and supply of radio-isotopes for industrial and medical uses
- Leadership in Generation III and IV reactor Systems
- Small Modular Reactors
- Fusion
- Decommissioning

Looking forward

- Socio economic research
- Safety and Operation of Nuclear Reactors: technology, safety culture and human factors
- Fusion Roadmap Assessment
- The Joint Research Centre (JRC) Direct and Indirect actions
- A balanced view : Research in support of radiological protection, notably regarding medical and industrial applications of radiation and radioactive material

Opening up other research fields for Euratom research

- The outgoing STC has indicated for a number of years that the budget for fission research within the Euratom Framework Programme is insufficient to enable the most important topics to adequately progress. It has sought to encourage and recommend that synergy is sought from cross-cutting initiatives in other EU research fields, *inter alia* materials and medicine and from the basic research programme as well from the fusion programme.
- The Opinion also highlighted the need and appetite for funding for activities that can and should be pursued in parallel to ITER and are of critical importance at the DEMO and reactor stage for fusion energy.

ROGER GARBIL

Euratom Success Stories in Facilitating Pan-European Education and Training Collaborative Efforts

R. Garbil[1] et al.

[1] European Commission (EC), DG Research and Innovation, Euratom, Brussels, Belgium

E-mail contact of main author: roger.garbil@ec.europa.eu

Abstract. The European Atomic Energy Community (Euratom) Research and Training framework programmes are benefitting from a consistent success in pursuing excellence in research and facilitating Pan European collaborative efforts across a broad range of nuclear science and technologies, nuclear fission and radiation protection. To fulfil Euratom R&D programmes key objectives of maintaining high levels of nuclear knowledge and building a more dynamic and competitive European industry, promotion of Pan-European mobility of researchers are implemented by co-financing transnational access to research infrastructures and joint research activities through Research and Innovation and Coordination and Support Actions' funding schemes. Establishment by the research community of European technology platforms are being capitalised. Mapping of research infrastructures and E&T capabilities is allowing a closer cooperation within the European Union and beyond, benefiting from multilateral international agreements and from closer cooperation between Euratom, OECD/NEA, IAEA and international fora. 'Euratom success stories' in facilitating Pan-European E&T collaborative efforts through Research and Training framework programmes show the benefits of research efforts in key fields, of building an effective 'critical mass' and implementing European MSc curricula, of promoting the creation of 'Centre of Excellence' with an increased support for 'Open access to key research infrastructures', exploitation of research results, management of knowledge, dissemination and sharing of learning outcomes.

Key Words: Education and Training, Research and Innovation, Centers of Excellence, Nuclear knowledge.

1. Introduction to the European landscape

Nuclear power plants (NPP) currently provide 30 % of the overall European electricity generated and 15 % of the primary energy consumed in the European Union. In 2016, 126 NPPs are in operation in Europe, representing a total installed electrical capacity of 137 GWe and a gross electricity generation of around 850 TWh per year. Nuclear fission is a major contributor already today as a low-carbon technology in the Energy Union's strategy to reduce its fossil fuel dependency and to fulfil its 2020/2030/2050/COP21 energy and climate policy objectives [1] however the sector is currently facing several challenges: a) one concerns the plans of most EU Member States (MS) to extend the design lifetime of their nuclear power plants; b) other countries, such as France, Finland, Czech Republic, Hungary and the UK, are planning new builds; c) while others, like Germany, are either considering or have excluded nuclear energy from their energy mix for now; d) a bigger share of renewables should be fostered at European level; and e) fierce international competition is taking place on a global level. Interest in nuclear power is boosted by the need to ensure a secure and competitive supply of energy and by concern over climate change. Finally, whether or not Member States will continue to use nuclear for their electricity production, for both energy and non-energy applications, Europe will need to keep and train highly qualified staff across the whole continent and share its knowledge worldwide.

2. Euratom Treaty and EU/Euratom legislative framework [2]

The Euratom Treaty provides the legal Framework to ensure a safe and sustainable use of peaceful nuclear energy across Europe and helps non-EU countries meet equally high standards of safety and radiation protection, safeguards and security. With legally binding Nuclear Safety Directive (2009/71/Euratom) and its latest amendment (2014/87/Euratom), EU nuclear stress tests, including safety requirements of the Western European Nuclear Regulators Association (WENRA) and the International Atomic Energy Agency (IAEA), the EU became the first major regional nuclear actor with a legally binding regulatory framework as regards to nuclear safety. Furthermore, this legal framework has been recently complemented by the Directive (2011/70/Euratom) that establishes a Community framework for the responsible and safe management of spent fuel and radioactive waste (both from fission and fusion systems), and the Directive (2013/59/Euratom) laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. Directives on Nuclear Installations' Safety (Art.7), Nuclear Waste Management (Art.8), Basic Safety Standards (Ch.4) and IAEA Convention on Nuclear Safety, all emphasize that each MS shall take the appropriate steps to ensure that sufficient numbers of qualified staff with appropriate education, training and re-training are available for all safety-related activities in - or for each - nuclear installation throughout its life. 'Conclusions' were issued at: a) 'EU Competitiveness Council in November 2008 encouraging Member States and the EC to establish a 'review of EU professional qualifications and skills' in the nuclear field; and b) a 'Second Situation Report on EU E&T in the Nuclear Energy Field' was published in 2014 by the European Human Resources Observatory in the Nuclear Energy Sector (EHRO-N, the latest created in 2009 by the European Nuclear Energy Forum (ENEF)).

The EC promotes and facilitates through the Euratom Framework Programmes (FP) [3] nuclear research and training activities within MS and complements them through its specific Community FP. R&D activities supporting the enhancement of the highest nuclear safety standards in Europe are mainly promoted by EC DG RTD indirect actions together with JRC direct actions. JRC has also been providing for 30 years internationally recognized scientific and technical support e.g. training courses, educational modules, support to the European Safeguards R&D Association (ESARDA), and CBRN risk areas of chemical, biological, radiological and nuclear. European and International safeguards authorities such as Euratom, MS and IAEA benefitted from JRC's dedicated R&D and operational support in collaboration with other EC DGs, ENER, TRADE, DEVCO and EEAS [4]. Beyond EU borders, DEVCO manages the 'Instrument for Stability (IfS)' and the 'Instrument for Nuclear Safety Cooperation (INSC)' where among others an initiative on Training and Tutoring (T&T) provided post graduate professional education to expert staff at Nuclear Regulatory Authorities (NRA) and Technical Support Organizations (TSO), both in terms of management and of technical means in the areas of nuclear safety and radiation protection which proved to be very successful in strengthening local organizations and regional cooperation.

3. EU/Euratom initiatives are being capitalized

The European Commission helps to stimulate joint funding from Member States and/or enterprises, and benefits are being capitalised from the increasing interaction between European Technology Platforms (ETPs) [5] launched during the 7th Framework Programme (2007-2013), namely the 'Sustainable Nuclear Energy Technology Platform' (SNETP incorporating NUGENIA Generation II III water cooled reactor technology, ESNII Generation IV fast reactors aiming at closing fuel cycle, and NC2I Cogeneration of electricity and heat), the 'Implementing Geological Disposal of Radioactive Waste Technology Platform' (IGDTP), the 'Multidisciplinary European Low Dose Initiative' (MELODI association), the European Energy Research Alliance (EERA) Joint Programme in Nuclear Materials (JPNM), the Strategic Energy Technology Plan (SET-Plan) [6] and other EU stakeholders (ENEF, ENSREG, WENRA, ETSON, FORATOM, etc.) [7] as well as OECD/NEA, GIF and IAEA at international level [8].

Euratom Fission Training Scheme (EFTS) coordination actions aimed at structuring Higher University Education Master of Science (MSc) training and career development benefitting from a European Credit Transfer and Accumulation System (ECTS) initiated by the Bologna Process in 1999 for higher academic education. European Credit System for Vocational Education and Training (ECVET) launched in Copenhagen in 2002 is also promoted today for lifelong learning in the field of nuclear and successfully tested across a wide range of industrial sectors. It is further promoting transparency, mutual trust, continuous professional development based on a modular course approach and recognition of learning outcomes that refer not only to knowledge but also to management of skills and competences [9].

Successful Euratom EFTS - selected on a competitive basis and promoted through the scientific community (detailed information on all projects is available on CORDIS [10]) - covered highly relevant E&T needs for industry (energy and non-energy including medical) and associated end-users: ECNET (2011-13), EU-China nuclear cooperation; ENEN-III (2009-13), Generation III and IV engineering training schemes for nuclear systems suppliers and engineering companies; TRASNUSAFE (2010-14) nuclear safety culture in health physics (e.g. ALARA principle applied to both industrial and medical fields); CORONA-II (2015-18) on the creation of a regional center of competence for VVER technology and nuclear applications; CINCH-II (2013-16) cooperation establishing a European MSc in nuclear and radiochemistry; EUTEMPE-RX (2013-16) for Medical Physics Experts in Radiology and focusing on the implementation of the BSS Directive; GENTLE (2013-16) delivering graduate and executive nuclear training and lifelong education with a focus on synergies between industry and academia; NUSHARE (2013-16) on nuclear safety culture competences for policy makers, regulatory authorities and industry; PETRUS III (2013-15) a program for a European RadWaste MSc, E&T research on underground storage addressing mainly radiation waste management agencies; ENEN-RU-II (2014-17), ETKM MSc cooperation with Russia, ROSATOM and MEPhi and VVER technology; and ENETRAP-III (2014-18) MSc in radiological protection addressing mainly nuclear regulatory authorities and TSOs. Some of the above EFTS are developing European Passport (Europass) based on personal transcripts of records and learning outcomes modules obtained through various paths (traditional face-to-face, virtual classroom, training and tutoring, internships, workshops, webinars, on-line or blended learning tools such as e-learning or today's Massive Open Online Courses (MOOC)). IT technologies are being set to transform today the higher education system, benefitting from the huge capabilities of computer simulations and virtual reality accessible anywhere and at any time, however it will never constitute per se a license of a practice or an official authorization to operate or to supervise nuclear facilities from national nuclear regulatory authorities but complementary IT tools benefits for E&T and KSC management have to be acknowledged.

Support from Euratom to key research infrastructures has proven to be highly beneficial to the scientific community at facilitating Pan-European mobility of researchers, engineers or scientists, transnational access to large and unique infrastructures, promoting joint research activities and collaborative efforts across a broad range of nuclear science and technologies in most fields covered by Euratom is supporting today's Euratom portfolio of success stories. Increased cooperation in research in Europe is benefitting from H2020 cross-cutting support from all EU financial instruments available: ERASMUS+ education and training actions (MSC, Engineers, Bachelors, Lifelong learning funding schemes across the globe), Marie Slodowska Curie Fellowships (PhDs), European Research Council on 'Excellent Science' (ERC), Fusion and ITER, JRC ETKM support using its world class laboratories, and the European Institute of Technology Knowledge Innovation Centre (EIT KIC InnoEnergy). The latest promoted a highly successful European Master in Innovation in Nuclear Energy (EMINE) involving major industrial partners AREVA, EDF, ENDESA and VATTENFALL, but also CEA (FR) and universities KTH (SE), University of Catalonia (UPC, ES), INP (Grenoble, FR) and Paris-Saclay (FR) [11].

A publication from EHRO-N in 2012 'Putting into Perspective the Supply of and Demand for Nuclear Experts by 2020 within the EU-27 Nuclear Energy Sector' [12] also confirmed today's EU challenging gap in covering 50% of nuclear experts training needs by 2020 (estimated at around 2000 a year) due to retirement by then. Faced with the challenge of shortages of skilled professionals, the nuclear fission community has called for a steady upgrade of the level of knowledge, skills and competences while striving to attract a new generation of experts to cover the entire life cycle of new nuclear power plants from design and construction to dismantling and green field. The European Union is urged to speed up implementation of EU Directives emphasizing that each MS (governments together with professional organisations and universities ensuring any adequacy between competences needed and jobs available) shall take the appropriate steps to ensure that sufficient numbers of qualified staff with appropriate education, training and re-training are available for all safety-related activities in - or for each - nuclear installation throughout its life.

4. EU/Euratom E&T in support to sustainable Fast Reactor and closed fuel cycle technologies: from technological workshops and international schools to EU training Centers of Excellence

The OECD/NEA Generation-IV International Forum (GIF) [13] has stimulated innovation towards sustainable nuclear reactor technologies since the year 2001 such as Sodium-cooled Fast Reactor (SFR), Lead-cooled Fast Reactor (LFR), Very High-Temperature Reactor (VHTR), Gas-Cooled Fast Reactor (GFR), Supercritical Water Cooled Reactor (SCWR) and Molten Salt Reactor (MSR). On the basis of an EU Commission Decision, EU/Euratom acceded to GIF by signing in July 2003 the 'Charter of the Generation IV Forum' and the International 'Framework Agreement' existing between all Members of the Generation IV International Forum. The Joint Research Centre (JRC) of the European Commission is the Implementing Agent for EU/Euratom within GIF. In November 2016, EU Commissioner T. Navracsics has signed on behalf of EU/Euratom the agreement to extend for another ten years the Framework Agreement for an International Cooperation on Research and Development of Generation IV Nuclear Energy Systems. EU/Euratom contributions shall also be extended towards all respective six GIF Systems Arrangements as Fast Neutron Reactor systems are considered as key for the deployment of sustainable nuclear fission energy. EU/Euratom framework programmes constantly promote research and training, innovation and demonstration of nuclear fission technologies to achieve EU SET-Plan objectives being: by 2020, (1) to maintain the safety and competitiveness in fission technology, and (2) to provide long-term waste management solutions; and by 2050, (3) to complete the demonstration of a new generation (Gen-IV) of fission reactors with increased sustainability namely via the European Sustainable Nuclear Fission Industrial Initiative (ESNII), and (4) to enlarge nuclear fission applications beyond electricity production through the Nuclear Cogeneration Industrial Initiative (NC2I).

The European Commission has also promoted since 2007 the establishment of technology platforms such as the Sustainable Nuclear Energy Technology Platform (SNETP) gathering today around 100 key stakeholders mainly from research organisations, industry and academia. Its latest 2013 Strategic Research and Innovation Agenda (SRiA) and 2015 Deployment Strategy gave prioritization between all GIF systems to the three most advanced. Sodium Fast Reactor (SFR) is the reference technology since it already has substantial technological and operations feedback in Europe and today's French ASTRID demonstrator lead by CEA is promoted. Lead Fast Reactor (LFR) technology has significantly extended its technological base. It can be considered as the shorter-term alternative technology with support first from MYRRHA (Multi-purpose hYbrid Research Reactor at SCK CEN (BE), even the leading ESNII industrial demonstration project following the French government's decision to delay the construction of ASTRID, a Pb-Bi Accelerator Driven System) and later ALFRED projects. Gas Fast Reactor (GFR) technology is considered to be a longer-term alternative option and ALLEGRO is supported by the Visegrad 4 central European countries (CZ, SK, HU and PL). With innovative emerging technologies fostering increased efficiency, competitiveness and enhanced safety through design, one could expect: a) by 2025, a licensed SMR and/or cogeneration (V)HTR design(s) available in the EU, with operating demonstrator(s) by 2030; and b) by 2030, at least one Gen-IV demonstrator fast reactor in Europe, including associated fuel cycle facilities.

Gen-IV innovative nuclear reactors are very attractive to young students, scientists and engineers engaging in a nuclear career thanks to the related scientific challenges characterized by higher operating temperatures, studies on high temperature materials, corrosion effects, heavy liquid metal thermodynamics, innovative heat exchangers, fast neutron fluxes for both breeding and enhanced burning of long-lived wastes. Development, fabrication and testing of entirely new nuclear fuels, advanced fuel cycles, fuel recycling concepts including partitioning and transmutation are required, all promoting excellent topical opportunities for internships or PhD studies within R&D laboratories. Beyond the obvious educational merit for young engineers investing on average into additional two years' fast reactor studies, scientists and engineers would also have a broader expertise when working on enhanced LWR technology and cross-cutting safety, core physics, engineering and materials areas. Also, a successful Gen-IV design team would highly benefit from 'systemic' and 'interdisciplinary' specialists in the various scientific disciplines involved such as neutronics, thermal-hydraulics, materials science, coolant technologies together with 'assembling' engineers capable to perform optimized integrations of all topical results into 'realistic' reactor components and 'most efficient' balance of plants.

Successful EU/Euratom projects - selected on a competitive basis and promoted through the scientific community (detailed information on all projects is available on CORDIS) - covered highly relevant E&T needs for research organisations, industry and associated end-users. EU/Euratom fission work programmes supported 'GIF concept-oriented' projects, in line with the strategy implemented by the European Commission together with EU leading Member States, but also key cross-cutting fields of nuclear safety, fuel developments, thermal hydraulics, materials research, numerical simulation, design activities of future reactor technologies, partitioning and transmutation, support to infrastructures, education, training and knowledge management, and international cooperation. EU/Euratom framework programmes consistently co-funded dedicated collaborative 'Research and Innovation' (E&T evaluated at around 5% of the total budget for each projects) and 'Coordination and Support Actions' (E&T could be up to 100% of the total budget for each projects) in the area of advanced nuclear systems. All R&D projects incorporated E&T tasks, workshops focused on R&D progress but also training courses for Higher University MSc and PhD students co-organised in collaboration with industrial and research laboratories. They are usually open to participants from partner institutions outside the project and third countries. Coordination support from ENEN is systematically provided to strengthen its international visibility and ensure the highest impact of dissemination and sharing of knowledge among the European scientific community.

Some projects were 'concept-oriented' such as: CP-ESFR (2009-13) Collaborative Project on European Sodium Fast Reactor; LEADER (2010-13) Lead-cooled European Advanced Demonstration Reactor; HELIMNET (2010-12) Heavy liquid metal network; GOFASTR (2010-13) European Gas Cooled Fast Reactor; VINCO (2015-18) Visegrad Initiative for Nuclear Cooperation; ESNII+

(2013 17) Preparing ESNII for HORIZON 2020; EVOL (2010-13) Evaluation and Viability of Liquid Fuel Fast Reactor System; SAMOFAR (2015-19) A Paradigm Shift in Reactor Safety with the Molten Salt Fast Reactor, MYRTE (2015-19) MYRRHA Research and Transmutation Endeavour and ESFR-SMART (2017-21) European Sodium Fast Reactor Safety Measures Assessment and Research Tools.

Other projects addressed cross-cutting research and innovation areas such as: GETMAT (2008 13) Gen-IV and Transmutation MATerials; MATTER (2011-14) MATerials TEsting and Rules; MATISSE (2013-17) Materials' Innovations for a Safe and Sustainable nuclear in Europe; FAIRFUELS (2009-15) FAbrication, Irradiation and Reprocessing of FUELS and targets for transmutation; F BRIDGE (2008-12) Basic Research for Innovative Fuels Design for GEN IV systems; THINS (2010-15) Thermal-hydraulics of Innovative Nuclear Systems; SEARCH (2011-15) Safe ExploitAtion Related CHemistry for HLM reactors; SESAME (2015-19) Thermal hydraulics Simulations and Experiments for the Safety Assessment of MEtal cooled reactors; SACSESS (2013-16) Safety of ACtinide Separation processes; GENIORS (2017-21) GEN-IV Integrated Oxide fuels recycling strategies; CINCH-II (2-13-16) Cooperation in education and training In Nuclear Chemistry; ASGARD (2012-16) Advanced fuelS for Generation IV reActors: Reprocessing and Dissolution; TALISMAN (2013-2016) Transnational Access to Large Infrastructure for a Safe Management of ActiNide; ARCAS (2010-13) ADS and fast Reactor CompArison Study in support of Strategic Research Agenda of SNETP; JASMIN (2012-16) Joint Advanced Severe accidents Modelling and Integration for Na-cooled fast neutron reactors; and SARGEN-IV (2012-13) Towards a harmonized European methodology for the safety assessment of innovative reactors with fast neutron spectrum planned to be built in Europe.

As an illustration of the consideration brought to E&T in the above-mentioned projects, E&T activities within FP7 CP-ESFR included five European Sessions dedicated to SFR and have been organized by the ESML (Ecole du Sodium et des Métaux Liquides) at CEA-Cadarache in France, University of 'La Sapienza' (IT), Karlsruhe Institute of Technology (KIT, DE) and the University of Madrid (ES). More than 120 trainees and PhD students were welcomed during these five Sessions. Within the following H2020 project ESNII+, a large effort dedicated to Fast Neutron Reactors cooled by Sodium, Lead and Gas has been foreseen. Eight Seminars and two Summer Schools are being organized between 2014 and 2017 and dedicated to various topics such as: a) Fuel properties and fuel transient tests; b) Core neutronic safety issues; c) Instrumentation for Fast Neutron Reactors; d) Thermal-hydraulics and thermo-mechanical issues; e) Mitigation of seismic risks; e) Coolant physico-chemistry and dosimetry, and quality control strategy; f) Safety Assessment of Fast Neutrons Reactors; g) Severe accidents in Fast Neutron Reactors; and h) Sitting and Licensing of Fast Neutron Reactors.

One should also highlight the FP7 ENEN-III project which has elaborated Training Schemes for the development and pre-conceptual design of Gen-IV nuclear reactors. All six Gen-IV reactor types were considered; however, emphasis has been given the three concepts (SFR, LFR and GFR) prioritized within the EU/Euratom framework. Gen-IV training schemes are more research oriented and they have a broader scope than Gen II III training schemes. Following basic principles and introductory courses common to all Gen-IV concepts, dedicated schemes for experts and using supporting research facilities have been identified, and learning outcomes classified accordingly.

To ensure any continuity between implementation of such FP7 ENEN-III training schemes, organizing EU/Euratom projects workshops on R&D progress and international schools could be challenging if they would be exclusively supported by Euratom due to a risk of a lack of continuity between projects selected on a competitive basis following yearly of bi-annual call for proposals. Euratom is highly recognized as a framework benefitting from a high European added value fostering increased cooperation and joint programming activities between EU and Member States, Public and Private investments involving industry, research centres, academia and technical safety organisations capitalizing international partnerships and any use of key infrastructures.

EU/Euratom Education, Training, Skills and Competences sustainable objectives are fulfilled as national and European 'Technological schools' are today evolving successfully towards 'International training platforms' (or Centers of Excellence) [14] [15] e.g. in France, Belgium, Germany, Italy, Sweden or the UK. Courses and training schemes further benefit from a consolidated pedagogical support, a database of lecturers, a management of course materials with a certified Quality Assurance process including evaluation procedures, regular updates and better harmonisation, communication and logistical organization, and an increasing mutual international recognition of certificates or diploma. The availability of attractive research infrastructures in support to Education, Training, Skills and Competences has to be underlined as they highly contribute to quality hands-on training in nuclear technology such as research reactors, critical assemblies, thermal-hydraulic facilities, fuel cycle related laboratories and hot-cells, computer based simulators and state-of-the-art computer codes.

As an illustration where EU/Euratom projects have contributed in a relevant way other the years by supporting dedicated E&T activities, France is providing an important nuclear teaching platform organized around engineering schools, universities, research laboratories, technical schools but also nuclear companies or dedicated entities for professional training. Within this context, the Institut National des Sciences et Technologies Nucléaires (INSTN), with its own Nuclear Engineering Master level (or specialization) degree and a catalogue of more than 200 vocational training courses, is a major nuclear E&T operator in Europe. The International Institute for Nuclear Energy (I2EN) launched in 2010 is federating French entities delivering high level curricula in nuclear engineering and science and is promoting the French offer for education and training in partner countries. With the objective to build ASTRID in France, an important and a rapid increase of R&D work orientated towards the design and conceptual evaluations has taken place. Two reactors are currently being dismantled namely PHENIX and SUPERPHENIX, and it was therefore necessary to further support E&T initiatives delivered at the Ecole du Sodium et des Métaux Liquides (ESML). The Ecole des Combustibles (EC) is also located in CEA Cadarache with the support of INSTN for the development of SFR technology. Trainees usually belonged to French companies such as CEA, EDF, AREVA, IRSN, or any companies involved in sodium activities and belonging (or not) to the nuclear industry. Specific training sessions were also provided to German operators (1983), Japanese operators for the first start-up of the Monju reactor (1990) or in support to PFR and DFR decommissioning projects (UK). Specific sessions were provided to the chemical industry such as UOP (USA). And more recently, ESML in association with the plant operator from PHENIX has extensively increased its offer to foreign institutes such as trainees from CIAE in China, ROSATOM in Russia on Reactor technologies, safety and operation, or IGCAR in India dedicated to Safety. The pedagogical approach consists of combining lectures, discussions and hands-on training on Sodium loops. Since 1975, more than 5000 trainees benefitted from a training at the Sodium School.

In Belgium, SCK•CEN Academy for Nuclear Science and Technology was established at the beginning of 2012 benefitting from sixty years of research into peaceful applications of nuclear science and technology, material and fuel research performed today at the BR2 reactor. With such an extensive experience and involvement in the development of an innovative Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA), major nuclear installations and specialist laboratories are available today on site, SCK•CEN is well placed to take on the role of an international education and training platform on Heavy Liquid Metal (Pb-Bi). In addition, IAEA and SCK•CEN Academy have agreed in 2015, CEA-INSTN and SCK•CEN have also signed in September 2016 cooperation framework agreements on E&T.

EU/Euratom Education and Training initiatives are increasingly being organized with the support of the European Commission to the European Nuclear Education Network (ENEN), and within the frame of projects co-funded through the Euratom Framework Programmes. ENEN was established in 2003 as a French non-profit association to preserve and further develop expertise in the nuclear fields through Higher Education and Training. ENEN has currently over 60 members, mainly in Europe but also from Japan, Russia, South Africa, Canada, Ukraine including strengthen cooperation with IAEA. This objective is realized through the co-operation between universities, research organizations, regulatory bodies, the industry and any other organizations involved in the application of nuclear science and radiation protection and by fostering students' mobility schemes within Europe and beyond. National and international organizations currently undertaking E&T activities in support to Fast Reactor and closed fuel cycle technologies are all very keen to cooperate and to share their resources, to open key research infrastructures in support to common challenging initiatives to the highest benefit of the entire nuclear community (IAEA initiative on the creation of International Centers of Excellence on Research Reactors (ICERR) is very welcome), supporting international mobility of young scientists or researchers and mutual recognition of competences, giving overall a new impetus, high incentives and perspectives for E&T within Europe and beyond.

5. EU/Euratom research perspectives and outreach

The 'Euratom experience' with the Framework Programmes has been one of consistent success in pursuing excellence in research and facilitating pan-European collaborative efforts across a broad range of nuclear science and technologies including nuclear safety, safeguards and security within EU and non-EU countries. Associated education and training activities are in line with Horizon 2020's key priorities, but also in the proposal of Horizon Europe (2021-27), excellent science, industrial leadership, and societal challenges, one of the latter being the secure, clean and competitive energy challenge for Europe in the context of the Energy Union.

Nuclear 'Research and Innovation and Demonstration' needs a policy-driven programmatic approach, to meet the strategic objectives of EU 2020/2030/2050/COP21 Energy and Climate policies. Lack of coordinated research leads to national or bilateral programmes in countries with large capabilities, threatening smaller countries with scientific isolation and loss of expertise. In nuclear medical applications, proliferation vigilance and waste management, non-participating countries risk to become second-class.

In contrast to earlier approaches characterised by a bottom-up projects' selection on a competitive basis and their following implementation, future nuclear R&D should be policy driven. A programmatic approach involving all relevant stakeholders and fora at an early stage - rather than a project approach - should be called for, to meet the strategic objectives of EU energy and climate policies: sustainability, security of supply and competitiveness for a future low-carbon economy. EU energy R&D should satisfy all three policy pillars simultaneously, in a coordinated and output oriented manner. This type of structured R&D organisation should nevertheless not exclude some funding being reserved for good ideas by small research groups (technology watch), since creative solutions often emerge from unexpected initiatives.

National laws and EU Directives should play a bigger role in the organisation of research and training (typically through a roadmap, deployment strategies and priorities), with national organisations (e.g. for nuclear waste management, with the launch of a European Joint Programme EURAD in June 2019) taking the lead in R&D programmes which should be coordinated at the EU level.

It seems appropriate to use different partnerships for collaboration depending on the subjects treated. Public- public partnerships between the European Commission and EU Members States remain crucial to long term R&D (especially infrastructures, demonstration and prototype plants, and basic nuclear education, training, skills and competences) and to societal R&D (such as external costs and radiation protection). In contrast, public-private partnerships are more appropriate for short-term work (design and operation of reactors and waste facilities, regulation, procedures and practical training). For management and operation of large infrastructures of common interest, legal schemes such as a joint technological initiative or European research consortiums should be considered. In addition, use of all H2020 funding instruments available should be capitalised together with the KIC InnoEnergy of the EU's European Institute of Innovation and Technology, and where needed, of EU structural funds in combination with H2020.

The attractive and challenging scientific topics associated to innovative and sustainable Fast Neutron Reactors create a new and highly incentive context for students and young scientists with high potential to embark on a nuclear career. The perspective of new build, innovative Small and Modular Reactors (SMR), construction of SFR, LFR or GFR demonstration reactors or prototypes are key drivers. EU/Euratom Education, Training, Skills and Competences sustainable objectives are fulfilled as national and European 'Technological schools' are today evolving successfully towards 'International training platforms' (or Centers of Excellence). An exemplary and precursory approach in France has allowed a preservation of knowledge on SFR and know-how gained during the past four decades. INSTN, I2EN, SCK•CEN and ENEN are among others respectively increasingly capitalising the practical and sustainable implementation of training schemes, any complementary skills and competences in addition to knowledge, for the qualification and mobility of workers, scientists and engineers. Promoting any further use of key experimental infrastructures, research reactors, irradiation facilities and hot laboratories, simulation platforms and computer codes are highly valuable, and a long-term investment supporting international cooperation.

The dynamic and fast-evolving nuclear industry and its research activities need to be supported by an up-to-date education and training system based on mutual trust, on a certified quality assurance process, on transparency and integration of pan European needs that will deliver an increased number of highly skilled and trained personnel. This updated system could be based on the combination of traditional learning paths and, innovative ones, such as virtual classrooms and MOOCs, to be most effective. All EU stakeholders, from policy-makers, academia, research organisations, regulators, and industry are unanimous in stating that 'a common pan European approach is the way forward', benefitting from EFTS, ECTS and ECVET in combination to 'Open Access to key or world class infrastructures'. For the funding of education and training, beyond the usual programmes in schools and universities, creative instruments could be envisaged. For example, should the minimal educational and training be better specified within national law or by a Euratom Directive? Also, it could maybe be reasonable to set up a common education and training fund jointly managed by the European Commission and Member States and, similarly to the funds for waste management, financed by a mandatory levy on nuclear generators based on nuclear MWh produced if we wish to ensure the meeting of all challenging targets.

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MELODI Multi-disciplinary European Low Dose Initiative
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SESSION 1
PREDISPOSAL AND DISPOSAL TECHNOLOGY DEVELOPMENTS

SUMMARY SESSION 1 – PREDISPOSAL AND DISPOSAL TECHNOLOGY DEVELOPMENTS

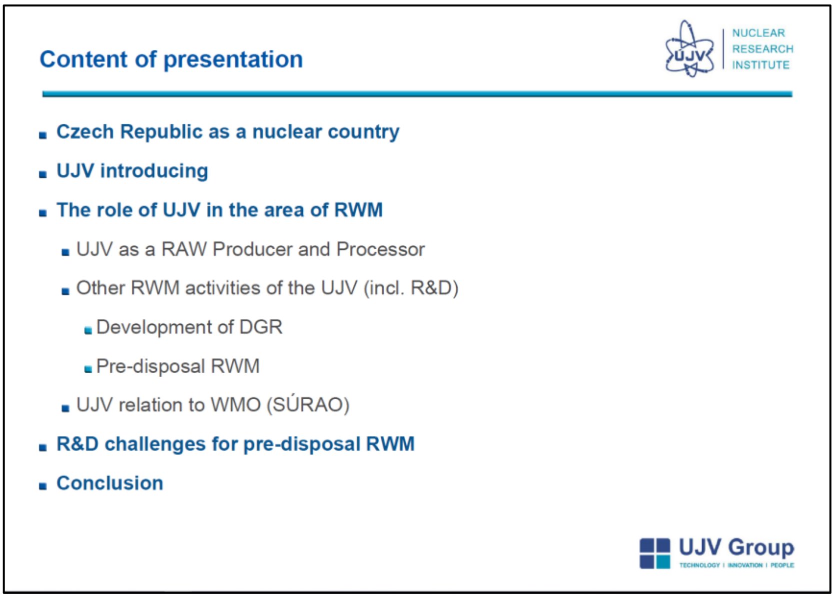
Chair: Jon MARTIN (RWM, UK)
Expert rapporteur: Wilhelm BOLLINGERFEHR (BGE, DE)

RADEK TRTILEK

FISA 2019 – EURADWASTE '19

Presentation of Mr Radek Trtilek (UJV Řež, CZ)

KEYNOTE: ROLE, CONTRIBUTION, CHALLENGES AND PERSPECTIVE FROM RESEARCH ENTITY IN ADVANCING KNOWLEDGE, SOLUTIONS, TECHNOLOGIES FOR RAW MANAGEMENT



General overview of the situation in the Czech Republic

NUCLEAR RESEARCH INSTITUTE

WMO = SÚRAO
Authority = SÚJB
TSO = SÚRO
NPP operator = ČEZ

UJV Group

Briefly about UJV – Nuclear Research Institute

NUCLEAR RESEARCH INSTITUTE

- **Milestones of the UJV / NRI history**
  - 1955 UJV established
  - 1957 reactor VVR-S (power 2 MW) in operation /today LVR-15 (power 10 MW)
  - 1972 reactor TR-0 (zero power) in operation /today LR-0
  - 1992 transformation to a joint-stock company and privatization
  - 2012 UJV Group established
  - 2011 – 2017 infrastructural project „Sustainable Energy – SUSEN“ [1] carried out

1 - Financed by EU/EC and the Ministry of Education, Youth and Sport

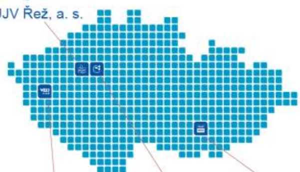
UJV Group

UJV Group

NUCLEAR RESEARCH INSTITUTE

UJV Group revenue in 2018 – € 98 mil
1200 employees

ÚJV Řež, a. s.



VZÚ PLZEŇ
Research and Testing Institute Plzen

Research Center Rez

ÚAM BRNO
Institute of Applied Mechanics, Brno

UJV Divisions

Nuclear Safety and Reliability

Integrity and Technical Engineering

Radioactive Waste and Decommissioning

ENERGOPROJEKT PRAHA

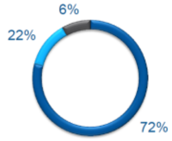
Radiopharmaceuticals

UJV Group

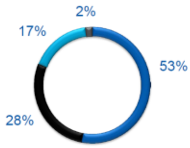
ÚJV Řež, a. s.

NUCLEAR RESEARCH INSTITUTE

- **Geographical revenue breakdown, 2018**



- **Shareholder structure**

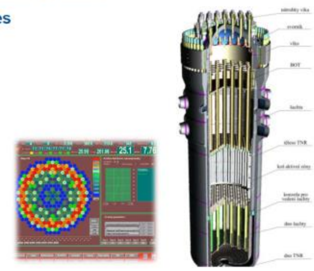


UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

Main areas of the UJV activity

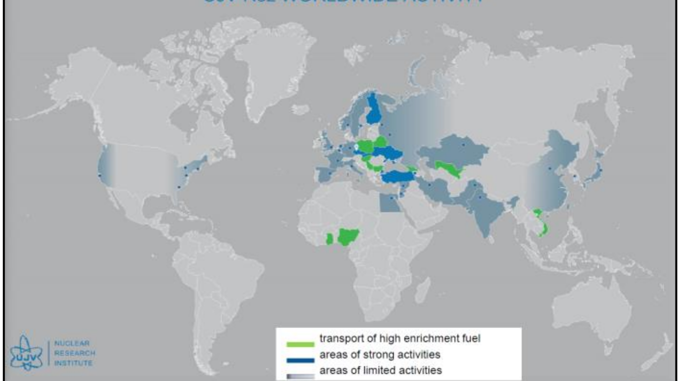
NUCLEAR RESEARCH INSTITUTE

- **Technical and engineering support of safe operation of NPPs**
- **Design and engineering services for energy sector**
- **Radiopharmaceutical and PET centres**
- **Radioactive waste management**
- **R & D:**
  - R&D support to main activities
  - Construction materials
  - Sorption materials
  - Hydrogen technology
  - Systems using renewable sources
  - Gen IV reactor technologies
  - DGR safety issues



UJV Group
TECHNOLOGY | INNOVATION | PEOPLE

UJV Rez WORLDWIDE ACTIVITY



NUCLEAR RESEARCH INSTITUTE

ARMENIA, BELGIUM, BELARUS, BULGARIA, CHINA, EGYPT, FINLAND, FRANCE, GHANA, GEORGIA, CROATIA, INDIA, ITALY, JAPAN, SOUTH KOREA, JORDAN, HUNGARY, GERMANY, NIGERIA, NETHERLANDS, NORWAY, NEW CALEDONIA, POLAND, RUSSIA, PAKISTAN, SLOVAKIA, SPAIN, SERBIA, SWEDEN, TURKEY, UKRAINE, USA, UZBEKISTAN, GREAT BRITAIN, VIETNAM

UJV as a RAW producer and processor

NUCLEAR RESEARCH INSTITUTE

- **Processing of institutional RAW in the Czech Rep. (more then 95%)**
  - Mostly „drum-in-drum“ technology is used
- **Waste characterization and radiological monitoring**
- **Decommissioning of old facilities (environmental liabilities)**
- **Clearance measurement after decommissioning**
- **Services and technologies for processing of RAW**
- **Expertise and concepts**

UJV Group TECHNOLOGY | INNOVATION | PEOPLE

Institutional RAW processed in the UJV in 2014 - 2018

NUCLEAR RESEARCH INSTITUTE

Producer	RAW form	unit	2014	2015	2016	2017	2018
ÚJV	solid	m^3	25,2	20,3	24,4	41,4	18,9
	liquid		60,3	9,9	8,0	9,2	9,4
External producers	solid		16,3	9,7	9,7	21,0	20,7
	liquid		4,23	14,4	23,9	14,0	5,4
Historical liabilities	solid		55,8	63,9	98,1	36,2	84,4
	liquid		2,95	4,3	9,2	3,0	3,0
Processed RAW together			164,8	122,5	173,3	124,8	141,8
Packages to dispose *	solidified	pcs	639	479	547	418	717

* Usually drum of 200 l volume, in some cases non-standard package (fence palette, etc.)

UJV Group TECHNOLOGY | INNOVATION | PEOPLE

Scope of other RWM activities

NUCLEAR RESEARCH INSTITUTE

- **Operational support of NPPs**
  - Testing of final waste form
  - Processing of spent resins and sludge [1]
- **Shipment of spent nuclear fuel from RR**
  - RRRFR and MNSR Programs
  - 17 shipments from 12 countries
- **Radiochemical analyses**
  - Accredited testing lab
  - IAEA safeguard labs net
  - Support of characterization and D&D
- **R&D for the DGR Project**
  - Barriers, interactions, diffusion, migration
  - Modelling, WAC development, SA
- **R&D of matrices and RW technology**
  - Bitumen, cement, geo-polymer, mixed
  - Treatment of liquid waste after a severe accident
  - Nanomaterials applications

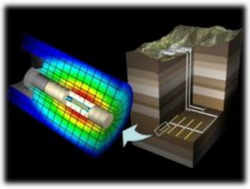
UJV Group TECHNOLOGY | INNOVATION | PEOPLE

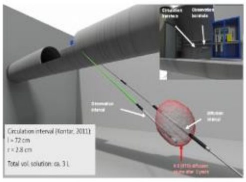
1 – In consortium with Chemcomex a.s. and CEZ Energoservis s.r.o.

RWM – R&D activities

DGR development and L&ILW disposal

NUCLEAR RESEARCH INSTITUTE





- **Applied research on safety issues of DGR and engineering support for existing repositories**
  - Barriers development and testing:
  - Corrosion, diffusion, chemical interactions
  - Anaerobic conditions
  - Radionuclides migration
  - Hydrogeology and transport modelling
- **General engineering support of DGR project**
  - Designing
  - Communication
  - Safety assessment, safety scenarios, WAC development
- **Participation in EU/EC projects**
- **URL Bukov Experimental Programme**
- **Engineering support for existing repositories**

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RWM – R&D activities

Pre-disposal - 1

NUCLEAR RESEARCH INSTITUTE

- **Applied research for pre-disposal WM and technology**
- **Bitumen matrix**
  - > 24,000 drums disposed (NPPs chemical concentrate)
  - Complex testing of the concentrate - bitumen composition
  - Developed a matrix composed of pure raw materials [1]
- **Geopolymer matrix**
  - > 4,700 drums disposed (NPPs resins and sludge)
  - Mixed cement-polymer matrix developed using suitable properties of both matrices [1,3]
- **Development of advanced technologies:**
  - Molten Salt Oxidation (MSO) [1,2]
  - Polysiloxan matrix [1,2]
  - Application of nanostructures to sorption and to improve matrix properties [1,2]

1 - Funded by the Ministry of Industry and Trade, Project No. FR-TI3 / 245
2 - It continues to be funded by public funds
3 – Cooperation with Chemcomex a.s.

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RWM – R&D activities

Pre-disposal - 2

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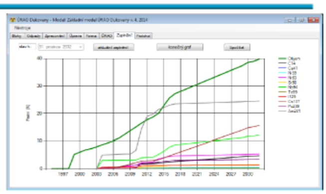
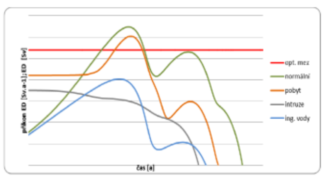
- **The Dukovany repository filling model depending on:** [1]
  - Operation of NPPs
  - Decommissioning time of NPPs
  - Time to commission of new units
- **Model VLLW landfill and criteria** [1]
- **Development of new radioanalytical methods and their certification** [1,2]
- **Decontamination methods for D&D processes** [1]
- **Treatment of a large volume of ilquid waste after a severe accident** [2]





1 - Funded by the Ministry of Industry and Trade, Project No. FR-TI3 / 245
2 - It continues to be funded by public funds

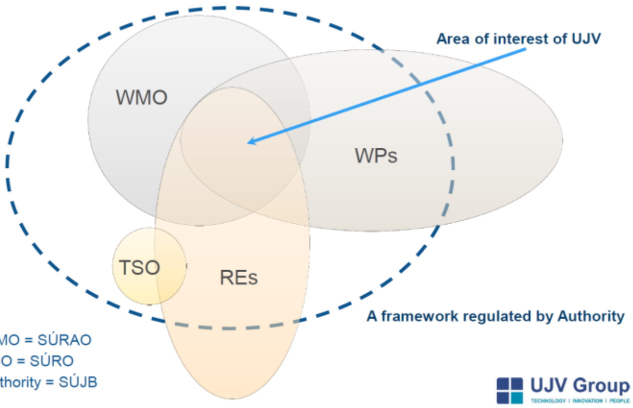
UJV Group

UJV relation to WMO

- **Unique UJV Group know-how in the Czech Rep.**
  - Complex research infrastructure
  - Working with open sources IR, irradiated and nuclear material
- **RAW collection and processing (WP)**
  - Incl. seizures of abandoned and orphan sources
  - NPPs operation support
- **Long-term continuity in collaboration and support**
  - Support for the establishment of the WMO (SÚRAO)
  - DGR Reference Design
  - Safety assessment, monitoring and upgrading of repositories
  - Studies for the National RAW and SNF Management Policy /Frame
- **International collaboration and participation in > 20 EU/EC projects**

→ **Frame Agreement on collaboration in applied research between SÚRAO and UJV, the FA includes both pre- and disposal management activities.**

Relations of interests in the Czech Rep.



WMO = SÚRAO
TSO = SÚRO
Authority = SÚJB

R&D challenges for pre-disposal RWM

Objective	Task
Post-operational safety of repositories	Long-term stability of matrices
LTO of repositories	Ageing of structures and barriers
	Modernization and equipment up-grade
Waste from D&D and remediation historical liabilities	Final forms for waste unacceptable to existing repositories
	VLLW management and landfill
New builds	Technology selection
	Final product(s) testing and licensing
	Analysis and modeling of repositories capacity
Long-term SNF storage	Fuel properties (source inputs for DGR)

Conclusion

NUCLEAR RESEARCH INSTITUTE

- **The Czech Republic remains a nuclear country**
  - Institutions and resources are established
  - RAW management is coherent and conceptual
  - L&ILW are continuously processed and disposed
- **A strong development and research base is available at UJV Group**
  - Includes RWM support (pre- and disposal) and Institutional RAW processing
  - Working at a broad international level
- **WMO, WPs and REs interests:**
  - Complementary and coordinated
  - WMO and key WPs jointly define R&D needs and objectives
  - Guided by the principles of long-term safety and sustainability

→ **Reflected in the proposals for R&D tasks including involvement in Horizon2020 projects (EJP1, NFRP10,event. 9)**

UJV Group

DANIELE ROUDIL

NUCLEAR SITE INTEGRATED CHARACTERIZATION FOR RADIOACTIVE WASTE MINIMIZATION: THE INSIDER PROJECT

D. ROUDIL[1*], P. PEERANI[2], S. BODEN[3], B. RUSSELL[4], M. HERRANZ[5], M. CROZET[1], L. ALDAVE DE LA HERAS[2]

[1] CEA DEN, DMRC, CETAMA, BP 17171 F-30207 Bagnols sur cèze, France
[2] European commission Joint Research Centre, Rue de la Loi 200, Brussels 1049, Belgium
[3] SCK-CEN, Belgian Nuclear Research Centre, Boeretang 200, B-2400 Mol, Belgium
[4] NPL National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW
[5] University of the Basque Country (UPV/EHU), Nuclear Engineering and Fluid Mechanics Dpt., EI Bilbao, Pza. Ing. Torres Quevedo 1, 48013 Bilbao, Spain
[*] Main Author: *danielle.roudil@cea.fr*

Abstract. The H2020 EURATOM project INSIDER (Improved Nuclear Site Characterization for waste minimization in Decommissioning and Dismantling under Constrained EnviRonment) was launched in June 2017. This 4 year project has 18 partners, and aims at improving the management of contaminated materials arising from Decommissioning and Dismantling (D&D) operations by proposing an integrated methodology for radiological characterization. This methodology is based on advanced statistical processing and modelling, coupled with adapted and innovative analytical and measurement methods, with respect to sustainability and economic objectives. In order to achieve these objectives, the approaches will be then applied to common case studies. To assess the analytical method performance, interlaboratory or inter-team comparisons on matrix representative reference samples and on real samples are organized. Assessment of the outcomes will be used for providing recommendations and guidance resulting in pre-standardization texts.

1. Introduction

Decommissioning and Dismantling (D&D) operations are strongly dependent on the facilities history and on the inventory of present radionuclides. These D&D projects produce large volumes of materials with different radioactivity concentration levels. The material management is a major technical and societal challenge, strongly being subject to economical optimization. Under constrained environments, new methodologies are necessary for a more accurate initial estimation of the contaminated materials, resulting waste volumes and timely planning [1].

The radiological characterization of a facility prior to performing any D&D and remediation operations is a crucial step in the definition of a viable decommissioning scenario [2]. This scenario must be robust and optimized not only with regards to technical issues, produced waste amount and workers dosimetry, but also with regards to costs, deadlines and safety. Today, information can be gained from the reconstitution of a 3D vision of a facility or of the components to be characterized.

The European project called INSIDER has been accepted by the European Commission and launched the 1st of June 2017. INSIDER is coordinated by

CETAMA (CEA Nuclear Energy Division) and includes 18 European partners from 10 member states. An End User Group (EUG) will provide user requirements and feedback from the beginning of the project.

The project will focus on radiological characterization, including the sampling strategy and sampling design, through waste-led integrated approaches. Its objectives are thus to improve the management of waste coming from nuclear sites or facilities under D&D with medium (MA) and high radioactivity (HA) levels and/or other constrained environments with respect to operational decommissioning efficiency, safety and costs. It will increase confidence in the quantities and characteristics of resulting radioactive waste in particular concerning subsequent storage and disposal end points.

2. Objectives and ambitions

2.1. Technical objectives and general approaches

The project aims at improving knowledge of the radiological state of nuclear facilities under decommissioning operations in constrained environment, i.e. with limited data set.

The heart of the technical innovative part of the project is to improve the sampling strategy coupled to in-situ and in-lab available techniques and methods, to take into account different types of measurement data, with different but known levels of accuracy [2],[3].

To face the problem of radiological characterization in constrained environments, where very limited amount of available data is particularly challenging, and specific statistical strategy needs to be implemented in order to limit the variability and sensibility to outliers.

In-situ analysis techniques are of paramount importance for initial cartography. In constrained environment they must be complemented by more detailed off–site measurements. Realistic knowledge of their performance is important, without systematic optimization.

An essential consideration for the INSIDER project is that it must be possible to demonstrate that any measurements carried out to characterize the waste materials are traceable to the international measurement system. Such traceability enables nuclear sites to demonstrate that measurements are accurate, fit for purpose and scientifically rigorous, to give regulators and the general public confidence in any results. The INSIDER project involves the characterization representativity problematics of nuclear decommissioning sites.

The main characterization challenges are thus:

- Choosing suitable measurement techniques, well adapted to sampling requirements or expectations
- Adapting to constrained environments of corresponding in-situ and remote laboratory analysis techniques in a cost effective perspective

– Increasing the reliability of characterization data and of interpretation models.

It applies on three main specific use cases, fuel cycle facility, nuclear power plant and post accidental remediation. Each one is representative for different kind of constraints and analytical challenges.

To illustrate and qualify the project-integrated approaches, the methodologies will be applied to the use cases in the form of three different benchmarking exercises. An interlaboratory comparison (ILC), both proficiency testing [4] and possibly method validation [5] on synthetic similar samples will be organized at the same time to assess the performance of the laboratories and their analytical methods in representative but ideal configurations, namely analyzing fit for purpose certified reference materials.

The benchmark will deal directly on real, past or present, D&D selected worksites.

INSIDER has the ambition to develop a common applicable methodology, for hostile environments and to provide guidelines in support to D&D industrial, stakeholders and R&D community, and to future standardization studies.

2.2. Expected impact and ambitions

Recent international reports and standards [8][9][10] highlight the key role of the characterization step in decommissioning operation, planning and cost evaluation. It is central to the optimisation plans. The INSIDER project can contribute to great extent to the international scheme and further identified needs [8].

Currently, real improvement of some analytical or measurement methods is difficult due to the lack in suitable reference materials. INSIDER will support the process development and validation of specific common reference materials and associated fabrication process.

Analytical microsystems or mobile laboratories will take part in different ILC and benchmarking exercises, with increasing representability to D&D operations. They will likely benefit of an increase in TRL level for future R&D and industrial applications.

Through this radiological modelling integrated concept, the project should also contribute to 3D modelling and virtual reality approaches, which are essential areas considered for decommissioning and dismantling task improvement in constraint environments.

3. Organization of the project and status of the workpackages

Five specific technical axes are addressed by the five work packages (WP) of the project, in accordance with the organization described in figure 1. The WP7 is devoted to result exploitation and dissemination to facilitate and emphasize the developments.

The validation of the integrated approach using benchmarking practices activates multiple interfaces between the various work packages. Precise synchronisation and a rigorous scheduling monitoring are indispensable to achieve the common project ambition.

FIG. 1. INSIDER Project organization.

3.1. WP2: User requirements and validationWP2 places itself at the front-end of the INSIDER project, but it extends practically till the end.

Four tasks are devoted to actual practices and requirement reviews. The WP started with the identification of the needs of end-users and requirements imposed by boundary conditions with particular emphasis on the legislative framework. Then a state-of-the-art and associated gap analysis has followed with the purpose to identify topics for R&D; this task, led and composed by research organisation, provides an input to the three technical Work Packages of the project (WP3, WP4 and WP5). Aligned with the global project objective to improve decommissioning of nuclear facilities, different methodologies and practices applied to structure and site characterization connected with the intent of optimizing the management of wastes resulting from the associated operations (decontamination, dismantling and site-clean-up) are investigated. Regarding waste management particular emphasis is devoted to estimation and documentation of volume and characteristics of radioactively contaminated material to be produced. Strategies for waste minimization include volume reduction, segregation, in terms of material composition activity levels and half-lives of the relevant radionuclides and eventually the use of the clearance concept.

Globally, WP2 deals with setting the main requirements and objectives of INSIDER, with defining a benchmark exercise of the methodology developed during the project and evaluating the results.

The backbone of the WP is task 2.4 aiming to identify, design and organise the experimental benchmarks on the selected usage cases:

- UC1: decommissioning of a back/end of fuel cycle and/or research facility: JRC-ISPRA tank farm;
- UC2: decommissioning of a nuclear reactor (NPP or RR): BR3 reactor biological shield at SCK-CEN;
- UC3: post-accident remediation of a site: Contaminated soil from a CEA R&D soil.

3.2. WP3: Sampling & strategy

The main objective of WP3 is to draft a strategy for data analysis and sampling design for initial nuclear site characterization in constraint environments before decommissioning, based on a statistical approach. The process followed consists of four main steps: status, development, implementation and guidance.

The first step resulted in a report that provides an overview on sampling design methods and state-of-the-art statistical techniques for preliminary analyses and data processing. Many of the currently available standards and guides in the specific field of decommissioning focus on the back end of decommissioning (e.g. waste acceptance or release from regulatory control). Within the INSIDER project we aim to anticipate by concentrating at the front end (pre-decommissioning characterization), already applying a waste-led approach. Today, many of the generic currently applied sampling design techniques and state-of-the-art statistical techniques used in preliminary analyses and data processing are often considered as stand-alone methods.

3.3. WP4: Reference materials and radiochemistry

The first aim of this work package is to produce a set of reference materials, to be used in WP 6 for the interlaboratory comparison exercise. This WP involves expert laboratories from the nuclear industry working in collaboration with national measurement institutes to develop and characterize the materials; particular attention will be paid to the uncertainty budget. Two reference materials, characterised for radionuclide content (fission products and activation products) will be provided.

The second aim is to assess radiochemical measurement techniques and identify those most suited for use on D&D samples. The review will concentrate on existing measurement techniques, but in general analysis of specific radionuclides in samples requires several sample preparation steps to purify and/or isolate the target radionuclides. Some of these steps would benefit from reducing the sample and reagent volume by using miniaturized devices in order to considerably reduce the harmfulness of the analytical operations, the sample shipment constraints and the environmental impact due to analytical wastes or chemical reactants.

One novel technique to overcome this problem will therefore be validated and taken into account in the assessment.

3.4. WP5: On site measurements

This WP5 dealing with "In situ measurements techniques" mainly for constrained environments started its task in the early moment of the project but they will continue until the end of it.

In line with the general objectives of the INSIDER project, this WP5 is devoted to the definition and implementation of practical considerations about "in situ" radiological characterization. It works closely with WP2, WP3, WP4 and WP6. In addition, the results of the in situ intercomparison exercises carried out under this WP5 will be processed and perform by WP6.

The partners of the WP5 will participate in the interlaboratory comparison campaign for analytical methods of different radionuclides in real samples that are being prepared by WP4.

The main objectives of WP5 are:

- The identification and revision of the available in situ measurement techniques to be applied to constrained environments;
- The classification and categorization of these constrained environments, taken into account the impacts they generated,
- The application of the suitable techniques to real situations according to the results of the intercomparison campaigns in the three UC identified, and of "in lab" intercomparisons exercises on real samples.
- Finally, the elaboration of guidelines containing the requirements for method implementation and validation.

The first activities belonging to the inventory of radiological characterization methodologies, and of European companies involved in characterization of nuclear facilities undergoing decomminissioning have already been accomplished.

3.5. WP6: performance assessment and uncertainty evaluation

The objective of WP6 is to evaluate the performance of methods/ laboratories/ teams to measure and to try to establish a complete uncertainty budget.

Performance is assessed through interlaboratory/interteam-comparisons on site or in laboratories. For each of the UC site, WP6 will organize a comparison on on-site measurements in collaboration with WP5. For interlaboratory comparisons organized in collaboration with WP4, measurements shall be made either on real samples from UCs whose homogeneity and stability have been characterized or on synthetic Certified Reference Materials. CRMs will be produced for this purpose by WP4, one is a solution, the other is a concrete. Comparisons on real samples are called "benchmark" and comparison on synthetic materials are called "Interlaboratory comparisons ILC".

For each comparison, measurands are defined by teams involved in WP5, for measurement on site and by WP4 for in laboratory measurements.

3.6. WP7: dissemination and exploitation

The INSIDER Project is making use of new and innovative dissemination and communication approaches. Beyond the classical dissemination & communication (i.e. web page and newsletters), a new approach to Knowledge Management is implemented, used as the basis for disseminating and communicating the achievements of the project.

In INSIDER the management and dissemination of knowledge of the State-of-Knowledge for the key topics dealt with in the project will be enabled in the JRC open-access Integrated Knowledge Management System (IKMS) under the EU Science Hub. IKMS will allow the presentation of the knowledge ensuring the knowledge transfer to future trainees, students, and workers. In addition, transfer of competence in this field will be implemented through the European Learning Initiatives for Nuclear Decommissioning and Environmental Remediation (ELINDER) training programme in nuclear decommissioning.

The IAEA CONNECT platform, available to all IAEA professional networks or communities of practice and its members, is intended to promote capacity building, facilitate collaboration and share information and experience both within and among the several networks and their members. E-Learning, nuclear education and training, discussion forums, on-line interactions, are some of the features explored in INSIDER WP7.

The overall objectives of the WP7 are to manage the outcome of the project, including documentation, generation of guidelines, pre-standards and recommendations, and assessment, dissemination and communication. The objectives thus cover different aspects to ensure that (i) the work meets the end-user expectations, (ii) the State-of-Knowledge is open-access documented and updated along the Project, (iii) Guidance and Pre-Standards are generated based on the State-of-Knowledge, (iv) Recommendations are established, (v) the outcome is disseminated to the concerned expert and user community, and finally (vi) that the project outcome is communicated also to a broader interested community.

4. INSIDER major developments and short term outlook

4.1. Integrated approach set up

The INSIDER strategy promotes an integrated and overall approach of pre-decommissioning characterization which notably consists in evaluating historical data, making on-site measurement campaigns, sampling and analysing, developing scaling factors and applying numerical codes. Therefore, we developed a strategy for sampling in the field of initial nuclear site characterization in view of decommissioning, with the most important goal to guide the end user to appropriate statistical methods and approaches to use for data analysis and sampling design. The proposed strategy has been structured by using different diagrams. All the different steps to take are described in a way that should be sufficient for the end user to make well-founded decisions. To aid the end user in applying the proposed strategy, an application presenting the strategy in a user-friendly way has been developed (Fig. 2).

The strategy, making use of the user-friendly application, is currently being implemented on the three use cases.

The ILC and benchmark aim at a realistic assessment of the measurement uncertainties and so at an improvement of the cartography sensitivity without affecting the number of samples and analyses [11],[12].

The return of experience, supplemented with global uncertainty calculations and sensitivity analysis, will allow to refine the strategy and result in a comprehensive data analysis and sampling design strategy guide.

A classification and categorization of the constrained environments regarding impacts generated on in situ measurement techniques will complete and support this process.

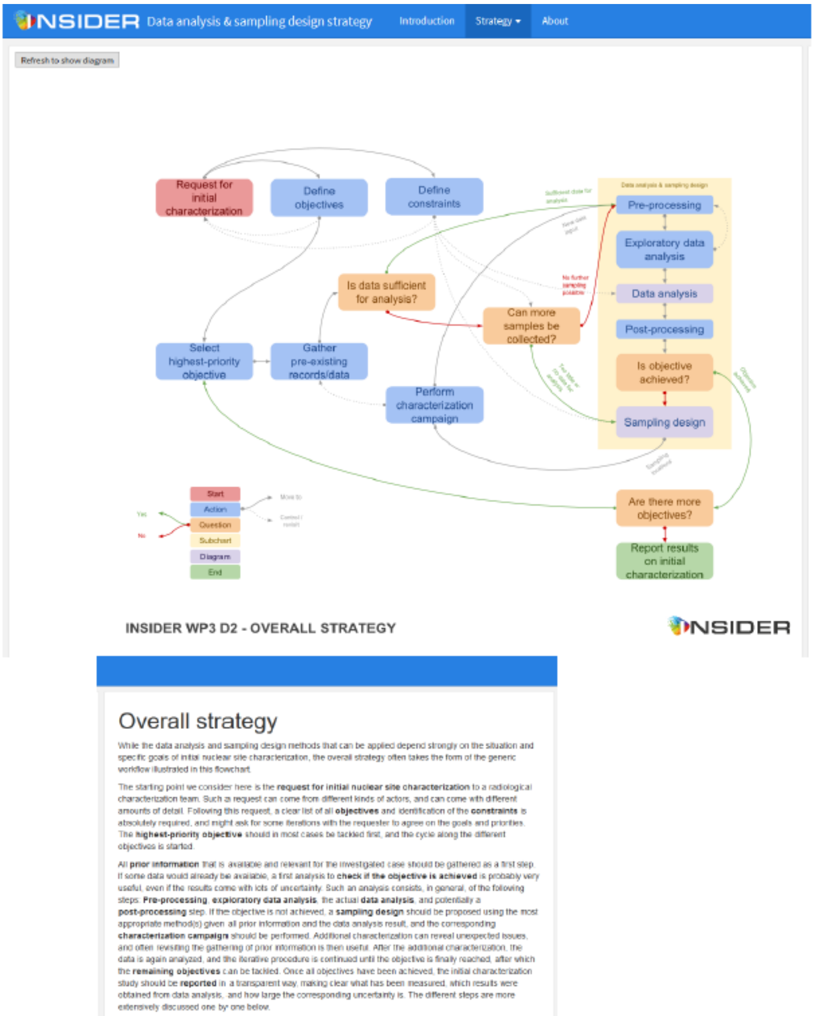


FIG. 2. Screenshot of the user friendly application for the INSIDER data analysis and sampling design strategy.

4.2. Experimental benchmark status

4.2.1. Global approach

The benchmark will help the project to meet some of the INSIDER project main objectives [13], in particular:

- Definition of an improved sampling strategy for waste production optimization by demonstrating the feasibility in realistic cases.
- Validation of rapid / cost effective analytical methods (in lab and in-situ) in realistic conditions
- Performance assessment of available measurement techniques (methods & tools) to establish a science base for decision-making.

The criteria of selection, for each use cases were discussed in relation with the presentation of the sites under decommissioning. They concern:

- Availability of the worksite for sampling and on-site measurements
- Availability of historical and/or characterization data
- Matrix and radionuclides types
- Radioactive activity level
- Shipment feasibility

Interlaboratory comparisons approaches are powerful tools used in the project to assess the performance of the analysis methods and to compare the performances of the different methods and teams. ANOVA approaches are used to prove the ability of methods used and to assess different uncertainty components.

Matrix certified reference materials are essential for a realistic evaluation of measurement uncertainties and for methods calibration.

Real samples are then paramount to compare the performance reached by the on-site teams and by the analytical labs.

4.2.2. UC1: ISPRA worksite description and benchmarking preparation

The facility selected for the case study UC1 is the liquid waste storage facility at the JRC site of Ispra (Italy), generally denominated "Tank Farm". This is a building (Fig. 3 - Left), commissioned in 2010, designed to collect all remaining liquid waste present on site, mostly stored in tanks in the old liquid effluent treatment station (STRRL), to be routed for cementation or other solidification treatment. Most of the liquid waste is contained in two double walled tanks.

The building is easily accessible, and it is possible to perform in-situ measurements around the large tanks, even though accessibility is convenient only for half of their length or from the top, due to the presence of shielding walls (Fig. 3 - Right). The large tanks are provided with a system for sampling. Stirrers are present to ensure homogeneity of samples.

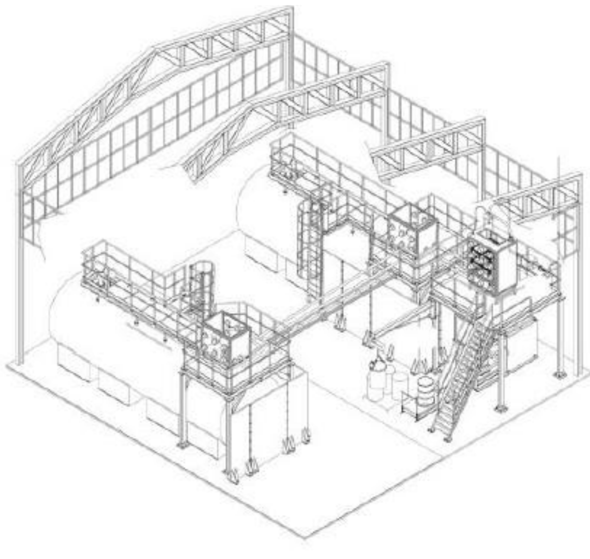


FIG. 3. (Left) "Tank farm" building at JRC Ispra. (Right) Photograph of the effluent tank for liquid effluents.

The liquid waste in the tanks has been already characterised and available information cover physical, chemical and radiological parameters.

Objective of the experimental benchmark will be to reproduce the complete radiological characterisation of at least one tank, through both in-situ measurements from WP5 partners and samples shipped to analytical laboratories of WP4.

For the in-situ benchmark, the teams will be asked to measure dose rates and gamma spectrometry in locations to be defined in the sampling strategy, developed within WP3. The measurements before and after effluent homogenization is essential in this case in terms of sampling strategy.

For the analytical laboratory inter-comparison, the measurements will include gamma spectrometry and different alpha and beta emitters among those already present.

4.2.3. UC2 worksite and benchmarking status

UC2 is dedicated to a pre-decommissioning characterization within a nuclear power plant. The worksite selected is the Belgian Reactor 3 (BR3), located at the SCK•CEN (Belgian Nuclear Research Centre) site in Mol. Today, the focus of this PWR decommissioning project lies on the building structure, since all the main installations including the complete primary circuit have already been dismantled. The high density concrete of the reactor pool is activated, except for the part surrounded by a neutron shield tank. The main goal of the radiological characterization program is to economically optimize the bioshield dismantling strategy, using a waste-led approach. Radiological measurements performed in the past on drill core samples, gave a first idea on the most important radionuclides present, namely Ba-133, Eu-152, Co-60 and Eu-154 (figure 4).

We implemented the strategy developed in WP3. Original plans, operational history, neutron activation calculations and former characterization programs were used for designing a preliminary 3D activity concentration distribution map, still showing considerable uncertainties. The subsequent sampling plan, mainly based on a systematic approach, exploited the expected symmetry and was supplemented by a few samples targeting expected trend extremes and a few judgmental samples. The 30 samples were taken by wet core drilling and sliced. Radiological measurements of the slices are ongoing [7].

FIG. 4. Pictures from the inside of the reactor pool before and after the removal of the pool liner (left). 3D models of the biological shield indicating the sampling locations (blue = 30 samples; orange = additional samples WP4/WP5) and the preliminary activity concentration distribution map: green: 0.1 to 10 Bq/g Ba-133; purple > 10 Bq/g Ba-133 (right).

Within WP5, six EU measurement teams (MTA EK, UPV/EHU, PSI & KIT, Tecnatom, Mirion and SCK•CEN) performed an in-situ measurements comparison exercise in the BR3 reactor pool consisting of dose rate, total gamma and gamma spectrometry measurements at different locations. The results are being processed by WP6.

The various measurement results enlarge the existing dataset, which will be again analyzed and checked against the objectives.

For the in-situ benchmark, the teams were asked to measure in at least three same locations (corresponding to different levels of radioactivity). Gamma-spec will be carry out in only one position.

For total gamma measurements all the teams should perform a calibration "in situ" using a Cs-137 point source and results will be expected to be provided in Bq equivalent to such a Cs-137 point source.

Results from Gamma-spec measurements are expected in Bq/kg of the main radionuclides present in the pool walls. Each team should calibrate their own equipment.

For the analytical laboratory inter-comparison the measurements will cover gamma spectrometry and some long live β emitters determination.

Additionally, drill core samples at two different activated locations and blank samples were provided to NPL (WP4) in view of their homogenization, the benchmarking exercise and the production of reference samples for the organization of an interlaboratory comparison (WP6).

4.2.4. UC3 Contaminated soil site description

Since it was not possible to identify an ideal site with all the characteristics for a meaningful post incidental site remediation exercise, it was decided to execute anyway a limited UC3 benchmark with the best available conditions.

The exercise proposed apply on nuclear site devoted to R&D activities. The historical analysis showed that leaks of active solution occurred in the tank room. Several contamination pathways to reach the soil were consider.

The soil appears to be contaminated with actinides and fission products.

A preliminary initial characterization campaign has been conducted, based on:

- non-destructive measurements, (total gamma and X doses), on drills at different depth;
- radiochemistry and chemistry analysis on extracted cores, in the most active zone of the core.

The soil samples present a large inhomogeneity. Radioactivity should be concentrated in small particles.

The contamination level is generally very low, typically below 0.1 Bq/g, but with hotspots up to hundreds of Bq/g. The main radionuclides to be consider are: Sr-90, Np-237, Pa-233 and Cs-137.There is no chemical pollution in these samples.

Seven drills are available for the INSIDER project in a horizontal plan. Samples can be derived for laboratory analysis. The drills could be also subject to NDA measurements.The sampling strategy and sampling plan will be defined by WP3, depending on the cartography optimisation objectives, knowing that new re-sampling operation will not be possible.

4.3. Next validation steps and needs

A data evaluation methodology on real cases will be performed under WP6.

The inter-comparison exercise has two different goals:

- Proficiency test (task T6.2)
- Uncertainty budget estimation (task T6.3)

To date, measurements concerning the first in situ comparison of UC2, i.e. in situ measurements made at BR3, have been made. The analysis of the teams' results is in progress.

In 2019 the ILC on the 2 CRMs (concrete and liquid) will be organized as well as the in-lab intercomparisons on BR3 concrete samples.

The practical organization of the measurement campaign at the UC1 worksite is planned for June-September of 2019. Different groups belonging to European companies/institutions will realize on site dose rate and gamma-spectrometry measurements.

Based on the comparisons results, the analysis methods will be graded and a most effective method will probably emerge, taking into account all the constraints encountered.

In order to quantify confidence in the measurement result for the initial batch, it is important to establish a complete uncertainty budget that also includes the sampling step. This will be done in collaboration with WP4, WP5 and WP3. It could be done, for example, on concrete cases proposed by WP3.

Within WP6, we also foresee to perform a global uncertainty calculation and sensitivity analysis of the entire process from initial characterization towards the assessment against objectives. Return of experience from the UC2 case will, together with the other two use cases, lead to a guide on the data analysis and sampling design strategy that has been developed within WP3 of the INSIDER project.

5. Conclusions

"Statistical modelling to optimise sampling" is one of the highest priority identified by the NI (Nuclear Innovation) 2050 expert group of the Organization for Economic Cooperation and Development (OECD) and the Nuclear Energy Agency (NEA). The novelty and originality of the INSIDER project is represented by the development of a site radiological modelling integrated concept. It is based on the coupling between advanced statistical processing approaches, measurement/analysis results obtained by existing techniques adapted for hostile or severe environment. Maximum and optimal use of existing techniques will be favored. Applicability and effectiveness of the methodologies, after implementation, will be given by the different validation step, from laboratory scale to representative environment. Performance assessment and uncertainty budget estimation at each step of the concept are crucial in constrained environments to perform a reliable characterization. They necessitate analytical and metrological specific developments shared by different laboratories joining their competences: statistics and metrology expertise, reference samples fabrication process, characterization means, adaptation and qualification of novel methods.

The second and third year of the project is devoted to benchmarking and interlaboratory comparison organizations, including two reference material fabrication and certification, and homogenization of collected real samples.

The fourth year will focussed on performance assessments and uncertainty budget evaluations, thanks to analysis results statistical processing.

The practical project implementation includes documenting, testing, verifying and assessing characterization methodologies for the selected test cases. The INSIDER project is working towards recommendations and guidelines for improving decision making of the industrial implementation for decommissioning and remediation activities Thereby, a key contributor is effective knowledge sharing within the scientific community.

Final assessment of the outcome will strengthen the recommendations and guidance, and promoting and sharing European expertise through guide and pre-normative texts.

Acknowledgment

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DENISE RICARD

THE CHANCE PROJECT "CHARACTERIZATION OF CONDITIONED NUCLEAR WASTE FOR ITS SAFE DISPOSAL IN EUROPE"

A. SCHUMM[1], M. RABUNG[2], G. MARQUE[3], J.J. HAMALAINEN[4]

D. RICARD[1], L. BOUCHER[2], C. BUCUR[3], C. BRUGGEMAN[4], G. GENOUD[5], D. KIKOLA[6], A. KOPP[11], C. MATHONAT[7], A. RIZZO[8], P. STOWELL[10], H. TIETZE-JAENSCH[9], L. THOMPSON[10], J. VELTHUIS[11], G. ZAKRZEWSKA-KOLTUNIEWICZ[12]

[1] Andra, 1/7 rue Jean Monnet, Parc de la Croix-Blanche, F-92298 Châtenay-Malabry, France
[2] CEA/DEN/DTN Cadarache, F-13108 Saint-Paul-Lez-Durance, France
[3] RATEN, strada campului 1, Mioveni 115400, Romania
[4] SCK•CEN, Boeretang 200, 2400 Mol, Belgium
[5] VTT, Technical Research Centre of Finland Ltd, Tekniikantie 1, 02150 ESPOO, Finland
[6] Politechnika Warszawska, plac politechniki 1, Warszawa 00 661, Poland
[7] KEP Nuclear, 7 rue de l'Oratoire, 69300 Caluire, France
[8] ENEA, Research Centre. Via Martiri di Monte Sole, 4, I-40129 Bologna, Italy
[9] Forschungszentrum Jülich, Wilhelm Johnen Strasse, Jülich 52428, Germany
[10] University of Sheffield, Department of Physics and Astronomy, Sheffield S3 7RH, United Kingdom
[11] University of Bristol, Tyndall Avenue, Bristol BS8 1TH, United Kingdom
[12] Instytut Chemii i Techniki Jadrowej, Dorodna 16, Warszawa 03-195, Poland

Abstract. The CHANCE project aims to address the specific issue of the characterization of conditioned radioactive waste (CRW). The first objective of CHANCE is to establish, at the European level, a comprehensive understanding of current CRW characterization and quality control schemes. The second objective of CHANCE is to further develop, test and validate techniques already identified that will undoubtedly improve the characterization of CRW. Specifically, these technical tasks will focus on calorimetry as an innovative non-destructive technique to reduce uncertainties on the inventory of radionuclides; Muon Tomography to address the specific issue of non-destructive control of the content of large volume nuclear waste; Cavity Ring-Down Spectroscopy (CRDS) as an innovative technique to characterize outgassing of radioactive waste. An overview of the project and the current results are presented and discussed.

1. Context and objectives of the project

The CHANCE project aims to address the specific issue of the characterization of conditioned radioactive waste (CRW). The characterization of fully or partly conditioned radioactive waste is a specific issue because, unlike for raw waste, its characterization is more complex and needs specific non-destructive techniques and methodologies. There are different and varying reasons for this: 1) conditioned waste may no longer be in its initial form (e.g., due to incineration), 2) conditioned waste is typically embedded or surrounded by a matrix, 3) conditioned waste may contain wastes coming from different primary sources and therefore the radiological spectrum might become more complex.

CHANCE focus on these categories of waste as described in [1]:

– Very Low Level Waste (VLLW);

- Low Level Waste (LLW);
- Intermediate Level Waste (ILW);

The first objective of CHANCE is to establish at the European level a comprehensive understanding of current conditioned radioactive waste characterization and quality control schemes across the variety of different national radioactive waste management programmes, based on inputs from end-users such as Waste Management Organizations and storage operators.

The second objective of CHANCE is to further develop, test and validate techniques already identified that will improve the characterization of conditioned radioactive waste, namely those that cannot easily be dealt with using conventional methods.

To address these specific issues, the CHANCE project proposes R&D actions to develop three innovative technologies for conditioned radioactive waste packages, namely:

- Calorimetry as an innovative non-destructive technique to reduce uncertainties on the inventory of radionuclides;
- Muon Tomography to address the specific issue of non-destructive control of the content of large volume nuclear waste;
- Cavity Ring-Down Spectroscopy (CRDS) as an innovative technique to characterize outgassing of radioactive waste.

The activities performed and the results obtained within the project CHANCE are integrated, communicated and disseminated both between the project partners as well as with the broader European community involved in radioactive waste disposal. Dissemination of results and progress is an integral part of the CHANCE project. Generally stated, the goal of communication is to raise awareness concerning the CHANCE research topics and developments, and to inform the CHANCE stakeholders about the project's progress and achievements. The main communication tool to reach this goal is CHANCE website http://www.chance-h2020.eu/.

The final ambition of CHANCE is to improve the efficiency of the characterization of conditioned radioactive waste and therefore to improve the safety of the global radioactive waste management process throughout the full storage cycle, including transport, interim storage and final disposal operational and long-term stability.

2. Project overview

CHANCE is structured into six work packages (Fig.1):

- Management and coordination (WP1)
- Methodology for conditioned radioactive waste characterization: Problematic wastes and R&D proposal (WP2)
- Calorimetry associated with non-destructive assay techniques and uncertainties study (WP3)

– Muon imaging for innovative tomography of large volume and heterogeneous cemented waste packages (WP4)
– Innovative gas and outgassing analysis and monitoring (WP5)
– Dissemination activities (WP6)

Activities related to these WP are detailed in following paragraphs.

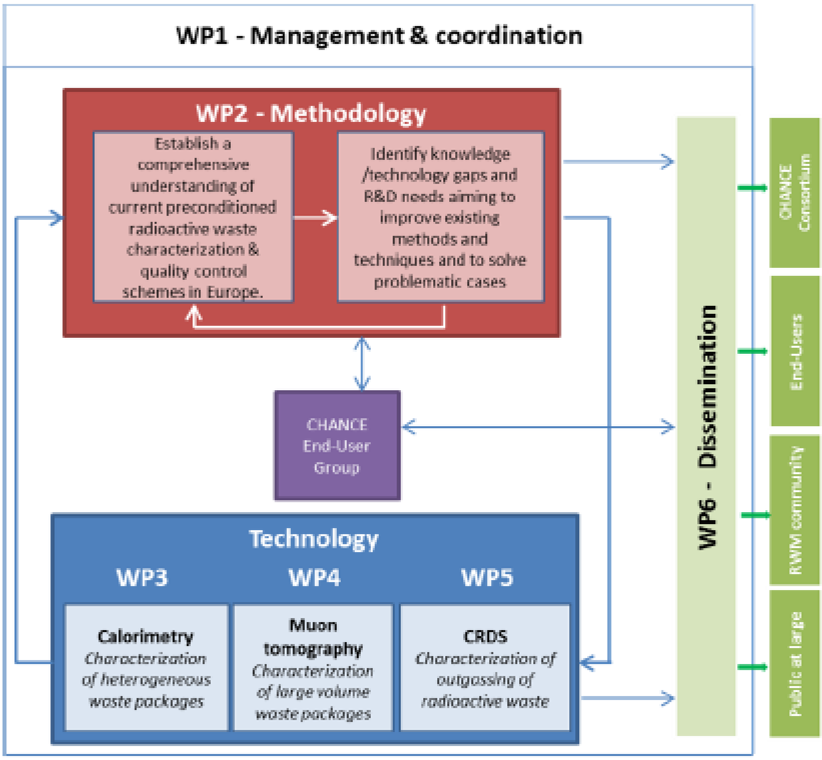

FIG. 1. CHANCE structure.

2.1. Methodology for CRW characterization: Problematic waste and R&D proposal (WP2)

End-users requirements concerning CRW characterization are driven by radioactive waste properties (VLLW, LLW, ILW or HLW) and specific waste acceptance criteria (WAC) for each disposal concept (surface, sub-surface or geological).

One of the tasks is dedicated to the identification of links and overlaps between WAC and actual waste characterization technologies available in order to allow CHANCE to identify specific methodology issues. In order to enhance the efficiency of conditioned radioactive waste characterization methodology, CHANCE proposes to identify:

– key parameters that need characterization;

- technologies commonly used for conditioned waste characterization;
- specific problematic issues for the characterization of conditioned radioactive waste;
- knowledge and technology gaps for radioactive waste package characterization methodologies.

This will be based on a survey of characterization methodologies currently used by European waste producers, disposal operators and waste management organisations, and by coupling these methodologies to the available waste conformity criteria for the different disposal solutions present in EU countries.

Based on the identified gaps, R&D will be proposed aiming to improve existing or introduce novel methods and techniques and to solve problematic cases. These R&D proposals will fuel future common research calls on waste characterization concerns.

2.2. Calorimetry associated with non-destructive assay techniques and uncertainties study (WP3)

An exhaustive study of uncertainties related to the use of existing and widely used techniques for the characterization of waste packages (gamma spectrometry and passive neutron measurement) in conjunction with calorimetry will be carried out.

Calorimetry provides a most powerful way to estimate the overall quantity of nuclear material over a wide range of masses, from a few milligrams up to kilograms of radionuclides, and volumes from one up to 385 litres, by measuring the overall thermal power (or heat flux) from radioactive decay inside the waste contained in metallic drums or various matrices (concrete, bitumen,...). It has many advantages: it is a non-destructive method, adapted to heterogeneous waste packages because it is independent of both the matrix effect and chemical composition, though chemical reaction heating must be ruled out from the preconditioning process. Calorimetry is sensitive to alpha and beta emitters, possibly hidden inside the material matrix or shielded, which cannot be addressed otherwise by gamma or neutron scanning and dose rate measurements.

In this WP, development, manufacturing and tests of a new 200 litres calorimeter with lowered detection limit will be performed. Development means radiological, thermal and mechanical modelling to optimize the performance of the instrument.

2.3. Muon imaging for innovative tomography of large volume and heterogeneous cemented waste packages (WP4)

A mobile muon tomography system will be developed to address the as-yet unsolved problem of the non-destructive assay of large volume nuclear waste packages, such as large spent fuel casks and large concrete waste packages with heterogeneous waste.

Muons are natural occurring particles with a flux at ground level of around 1 cm-2min-1; they are capable of passing through several hundred metres of rock. When they interact with matter, they scatter depending on the atomic number, Z, of the material. Hence, if muon trajectories are measured before and after traversing a volume, an image of the different materials in that volume can be produced. This mature and well-established technique is known as 'muon tomography' (MT). It has been successfully utilised in e.g. cargo screening for nuclear contraband. MT is fully passive and works for heavily-shielded volumes; it is also highly complementary to gamma and neutron tomography. The technique is particularly useful to detect heavy elements like lanthanides and actinides, but can also be applied to detect density gradients or differences within a matrix. In order to fully exploit the power of the tomography technique excellent position resolution and timing resolution is required.

A large-area demonstrator system will be developed which will utilize two different technologies, namely plastic scintillator (providing timing resolution) and resistive plate chambers (providing position resolution). The system will initially be operated at a dedicated test facility using test volumes comprising materials of different Z (e.g. metal pieces, U rods, cellulose, air enclosures), encased in concrete or bitumen (simulated inactive waste drums). The performance of the system in identifying the composition and placement of the different materials will be evaluated.

2.4. Innovative gas and outgassing analysis and monitoring (WP5)

An extremely sensitive technique, called cavity ring-down spectroscopy (CRDS), will be used to determine the outgassing amount and rate of selected radioactive molecules from nuclear waste. This isotopically selective laser spectroscopic technique provides the highest sensitivity, allowing for the detection of extremely small amounts of radioactive gases, and thus detection of the smallest leaks.

CHANCE will explore the potential of CRDS for waste package monitoring, since this technique has not been used in this context before and has several advantages over conventional techniques. Gaseous emissions from waste usually mostly consist of tritium and radiocarbon, mainly emitted in the form of water vapour (HTO), carbon dioxide ($^{14}CO_2$) and methane ($^{14}CH_4$). $H^{36}Cl$ is also of interest in the particular case of graphite waste. Even though tritium detection is important, it was decided in CHANCE to focus on radiocarbon and ^{36}Cl isotopes, as the participants had most expertise and interest in detecting those isotopes.

The work package consists of two main parts. First, a novel instrument for the detection of $H^{36}Cl$ based on CRDS will be developed. This will be the first time that CRDS is used to detect this molecule, which is highly relevant in the case of outgassing from graphite waste. Secondly, an already-developed CRDS instrument for the detection of radiocarbon compounds will be used to study in detail their outgassing rate on various types of waste. The instrument was developed within the Euramet funded MetroDecom project and its predecessor, and for the first time will be used to provide valuable information about the radiocarbon release kinetics using this novel technique. The speciation will include methane and carbon dioxide, with reference to the outcomes of the ongoing European project Carbon-14 Source Term (CaST).

This work will therefore result in a major step forward in the development of the use of CRDS to detect radioactive gas emissions as well as demonstrate a direct application of CRDS to the characterization of the outgassing from radioactive waste.

3. Results and discussion

Main results are presented by WP in the following paragraphs.

Methodology for CRW characterization: Problematic waste and R&D proposal (WP2)

A questionnaire has been produced to obtain a broad overview on the end-users needs for the characterisation of conditioned radioactive waste. It also includes questions pertaining to Work Package 6, related to underlying socio-technical and ethical frameworks of radioactive waste characterisation practices and policies.

List of questions include the following subjects:

- Existing and planned disposal solutions for radioactive waste.
- Waste acceptance specification for each solution (including potential free-release).
- Technologies used for conditioned radioactive waste characterization.
- Potential ongoing R&D programme on the topic of conditioned radioactive waste characterization.
- Interest on R&D actions included in CHANCE (WP3, WP4 & WP5).

The questionnaire is available in the Website of Chance (http://www.chance-h2020.eu/en/Deliverables), deliverable D2.1 [2].

This questionnaire was distributed to operators of radioactive waste disposal in Europe, notably through the End-User Group. Questionnaire answer has been received and analysis are in progress. A synthesis of commonly used methodologies for conditioned radioactive waste characterization is expected for first quarter of 2019.

Calorimetry associated with non-destructive assay techniques and uncertainties study (WP3)

An overview of the existing calorimeter was carried out; the main designs of calorimeters and specific parts of the calorimetric system were detailed with their advantages and drawbacks. Their performances were evaluated depending on their mode of operation.

A review of the main characteristics concerning mature NDA techniques has also been produced. The following techniques has been considered:

- Gamma methods: Gamma spectrometry, Segmented Gamma Scanning, Tomographic Gamma Scanning;
- Neutron methods: Passive Neutron Coincidence Counting, Active Neutron Interrogation.

The performances of the different techniques were evaluated through a study of the neutron and gamma ray signal that can escape various 200 L waste drum matrices and through a comparison of the published plutonium and uranium Minimum Detectable Masses (MDM) of existing systems. The results suggest that the most interesting cases would be polyethylene, bitumen and concrete matrices. Due to the limitations of the experimental program, however, only the latter will probably be available to perform experiments. While escaping radiation can be largely hampered with these matrices, the heat flux is unaffected, thus demonstrating the usefulness and complementarity of calorimetry in these cases and in general.

Further simulations with heterogeneous and homogeneous distribution of activities within the drums showed that the neutron and gamma measurements are very sensitive to the source distribution, leading to uncertainties that can reach two orders of magnitude, depending on the matrix composition. In case of gamma emission, the two orders of magnitude are obtained for concrete, while for neutron emission it is only a factor of two, leading to a factor four in the neutron coincidence rate measurement. The first Monte Carlo simulations of the calorimeter suggest that the uncertainty related to the energy deposition, based on uncertainty on the distribution of activities within a drum, is much smaller than the two orders of magnitude. Therefore, we also demonstrated the usefulness of calorimetry in cases with unknown distribution of activities within drum.

These overviews and simulations results are presented in the CHANCE deliverable 3.1 [3] that is available in the Website of Chance (http://www.chance-h2020.eu/en/Deliverables).

A large volume calorimeter with one measurement cell opening in two half shell has been developed (Fig. 2). The manufacturing is under progress and almost completed (Fig. 3).

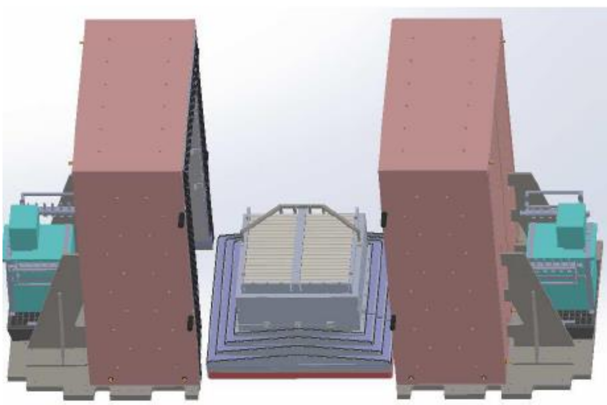

FIG. 2. 3D view of the CHANCE Calorimeter.

FIG. 3. CHANCE Calorimeter manufacturing.

Muon imaging for innovative tomography of large volume and heterogeneous cemented waste packages (WP4)

The muon system consists of a drift chamber system combined with additional Resistive Plate Chamber (RPC) layers. The two detector systems have been merged into one system. The detector system is currently being commissioned (Fig. 4) with first data expected soon.

FIG. 4. Commissioning of Muon detector system.

Monte Carlo simulation has been done. This includes studies about modelling the hybrid system, how to optimally combine the data of the two subsystems, comparison studies of the performance of different reconstruction algorithms to determine the contents of the waste drums focusing both of high-Z materials and gas bubbles, studies of the smallest structures we can distinguish. This has led to the development of a unique approach using figures of merit to enable performance comparisons between different algorithms and/or instrumentation techniques. The Fig. 5 show a comparison of different algorithm outputs when imaging a 10 cm long Uranium cube for 25 days of muon exposure. The inclusion of momentum information and metric distances in the BC algorithm leads to an image with higher contrast and clarity than a simple PoCA approach.

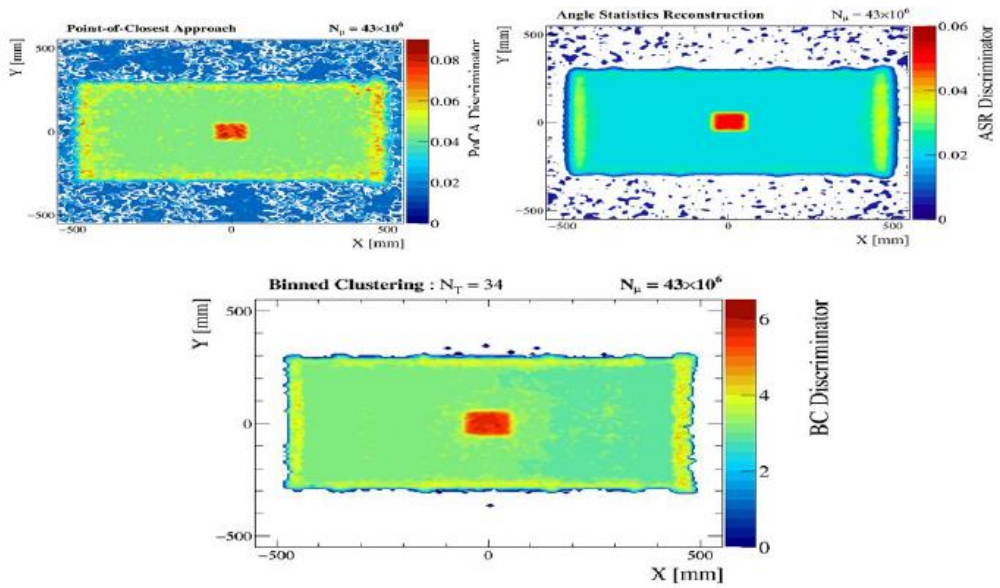

FIG. 5. Comparison of different algorithm outputs when imaging a 10 cm long Uranium cube for 25 days of muon exposure.

Innovative gas and outgassing analysis and monitoring (WP5)

The construction of a prototype of CRDS instrument dedicated to $H^{36}Cl$ measurement is under progress. $H^{36}Cl$ isotope rotation-vibration frequencies has been calculated. The optimum transition for detection by laser spectroscopy is located between the $H^{35}Cl$ and $H^{37}Cl$ transitions, with a line position of 5737.15 ± 0.1 cm-1 (Fig.6). In parallel, studies about chemical transformation of $Na^{36}Cl$ into $H^{36}Cl$ has been performed. This is an important step since CRDS can only measure ^{36}Cl in form of $H^{36}Cl$ gas, but ^{36}Cl standards are only available as $Na^{36}Cl$ solutions.

Development of a new sampling line to be used in connection with a C-14 CRDS prototype has been carried out to study C-14 outgassing from irradiated waste. As a first step CO_2 outgassing from non-radioactive graphite has been carried out. Graphite outgassing at room temperature is very small, and by heating to a few hundred's degrees the amount of released CO_2 was increased (Fig. 7) which will improve the feasibility of future studies. Measurement of C-14 from irradiatied graphite will be carried out soon.

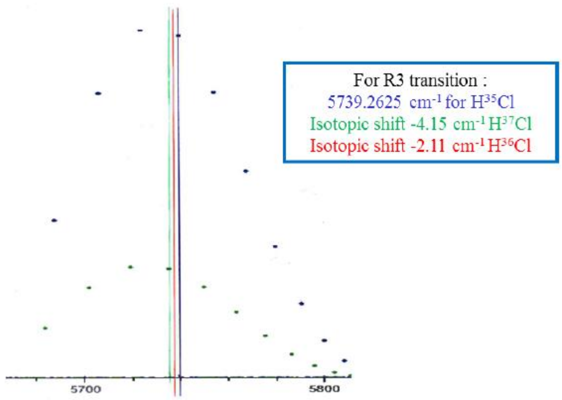

FIG. 6. Positions of the main transitions of HCl isotopes.

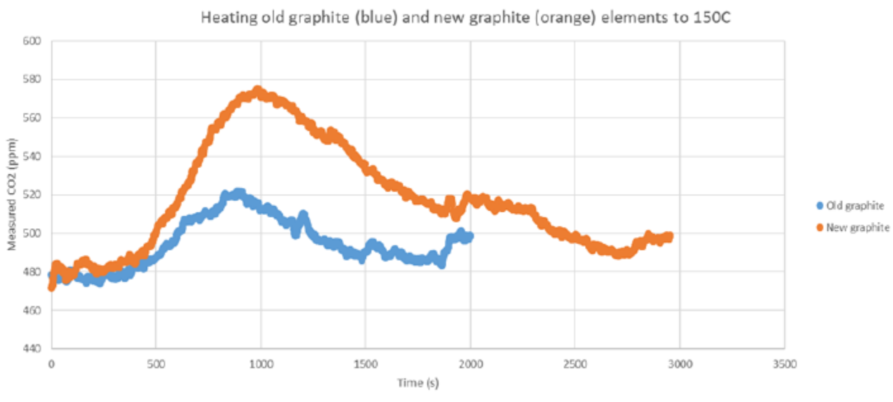

FIG. 7. Heating of graphite (blue) and new graphite (orange) elements to 150°C. The "new" graphite exhibits more outgassing due to CO_2 present on the surface.

Acknowledgment

"This project has received funding from the Euratom research and training programme 2014-2018 un-der grant agreement No 755371".

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MATTI NIEMINEN

THERMAL TREATMENT FOR RADIOACTIVE WASTE MINIMISATION

M. NIEMINEN[1], M. OLIN[1], J. LAATIKAINEN-LUNTAMA[1], S.M. WICKHAM[2], S. DOUDOU[2], A.J. FULLER[2], J. KENT[2], M. FOURNIER[3], S. CLARKE[4], C. SCALES[4], N.C. HYATT[5], S.A. WALLING[5], L.J. GARDNER[5], S. CATHERIN[6]

[1] VTT Technical Research Centre of Finland Ltd, Tietotie 4C, FI-02044 VTT (Espoo) – Finland
[2] Galson Sciences Ltd, 5, Grosvenor House, Melton Road, Oakham, Rutland LE15 6AX, UK
[3] CEA, DEN, DE2D, SEVT, F-30207 Bagnols sur Cèze – France
[4] National Nuclear Laboratory, Sellafield, Seascale, UK CA20 1PG
[5] Department of Materials Science & Engineering, The University of Sheffield, Mappin Street, Sheffield, S1 3JD – UK
[6] Waste Packages and Material Department, R&D Division, ANDRA, 1-7 rue Jean Monnet, 92298 Châtenay-Malabry cedex – France

Abstract. Safe management of radioactive waste is challenging to waste producers and waste management organizations. Deployment of thermal treatment technologies can provide significant improvements: volume reduction, waste passivation, organics destruction, safety demonstration facilitation, etc. The EC funded THERAMIN project will provide an EU-wide strategic review and assessment of the value of thermal technologies applicable to a broad range of (Low and Intermediate Level) waste streams (ion exchange media, soft operational waste, sludges, organics, and liquids). THERAMIN will compile an EU-wide database of treatable wastes and document available thermal technologies. Applicability and benefits of technologies to the identified waste streams will be evaluated through full-scale demonstration tests by project partners. Safety case implications will also be assessed through the study of the disposability of thermally treated waste products. This paper will communicate the strategic aims of the ongoing project and highlight some key findings and results achieved to date.

1. Introduction

The waste hierarchy sets out guidelines for waste managing in order to minimise environmental impact. Priority is on waste prevention and the lowest priority is on disposal. Disposal should be applied when no other alternatives are available and, in this case, the amount of waste to be disposed should be minimised. The principles of the waste hierarchy should also be applied for radioactive waste, though with due regard to safety standards and regulation.

Especially in the case of Low and Intermediate Level Waste (LILW), materials are typically contaminated by a very small amount of radioactive isotopes, while the majority of the waste material is not radioactive. For example, in the case typical operational Low Level Waste (LLW) the actual volume of radioactive isotopes is very low but the total volume of waste is usually large; this is also true for many LILW fractions. The guidelines of the waste hierarchy could be followed to minimise the waste volume to be disposed by thermal treatment of these LILW fractions.

Numerous technologies for thermal treatment of radioactive waste are available or in development worldwide, and more especially in the European Union. These technologies may be applied to a wide range of different radioactive waste streams, including non-standard waste types that present specific waste management challenges. Thermal treatment can result in significant volume and hazard reduction, both of which are beneficial for safe storage and disposal. Thermal treatment further removes organic material, which can form complexing agents and make radionuclides more mobile in a repository.

The European Commission funded THERAMIN project was established in order to improve awareness and understanding of capability of thermal treatment technologies to treat radioactive waste prior disposal. The overall objective of THERAMIN is to provide improved long-term safe storage and disposal of both ILW and LLW streams suitable for thermal processing. The work programme provides a vehicle for coordinated EU-wide research and technology demonstration designed to provide improved understanding and optimisation of the application of thermal treatment in radioactive waste management programmes across Europe and will move technologies higher up the Technology Readiness Level (TRL) scale. The Consortium assembles a European-wide community of experts on thermal treatment technologies and radioactive waste management and disposal, who will work together with the aim of identifying efficiencies in national waste management and decommissioning programmes across Europe.

2. THERAMIN project

The THERAMIN project will achieve an EU-wide strategic review and assessment of the value of thermal technologies applicable to a broad range of waste streams (ion exchange media, soft operational wastes, sludge, organics and liquids) and compile an EU-wide database of thermally treatable wastes, document the strategic benefits of thermal treatment, and identify the opportunities, synergies, challenges, timescales and cost implications to improve radioactive waste management. The most essential activity of the project is to evaluate the applicability and achievable volume reduction of the technologies through 'first-of-a-kind' active and non-active full-scale demonstration tests. Finally, the disposability of the product materials and residues will be assessed.

The project benefits from the large financial and resource investments made by partners in thermal treatment R&D facilities, which will be used to maximize the benefit across member states. THERAMIN also benefits from close engagement with an End User Group (EUG) consisting of waste producers and waste management organisations.

The THERAMIN project comprises the following core strands of research (1) strategic review of radioactive waste streams, (2) demonstration of selected thermal treatment technologies in order to evaluate viability of treatment routes for selected waste stream/technology combinations and (3) assessment of disposability of treated waste products by characterising the products and residues from demonstration trials against various Waste Acceptance Criteria, which are not harmonised in EU. In addition to these technical topics the project is also actively disseminating the results including a training program in order to enhance knowledge on thermal treatment technologies and on their benefits.

The project was started in June 2017 and has just passed the halfway point thus a substantial fraction of experimental demonstration program has not yet completed and thus the final results of the project are not yet available.

2.1. Strategic review of radioactive waste streams and potential thermal technologies

One of the first activities of the project was to identify wastes that could potentially be treated using thermal techniques, or where thermal techniques could offer strategic benefits. As a result of this evaluation the following waste categories were identified:

- Ion exchange resins, organic and inorganic, where there is significant volume and organics reduction potential.
- Soft operational waste including plutonium contaminated material (PCM), where there is also significant volume reduction potential.
- Wet wastes such as sludges and liquid wastes.
- Wastes with a significant organic content (could include bituminised waste in some countries such as Belgium or Lithuania) with the potential to be chemically reactive and/or give rise to significant gas generation, and which may contribute uncertainty to the post-closure safety case for geological disposal.
- Certain types of metallic wastes (e.g., reactor internals, cladding) that are known to cause significant gas generation by corrosion and may contribute uncertainty to the post-closure safety case for geological disposal.
- Some types of packaged waste that may have become unacceptable for geological disposal owing to package degradation.

In addition to suitability for thermal treatment, the volume of waste has an essential impact on the assessment of the potential and importance of thermal treatment techniques. The review and assessment of waste volumes turned out more challenging than was expected. Data on low and intermediate radioactive wastes is not easily available in all EU counties and thus the results from the survey are not fully comprehensive. Nevertheless, the survey demonstrated that the need and market potential for thermal treatment technologies is already significant in those countries from which the data were available.

Once the wastes of interest had been identified, an assessment on the thermal facilities available across Europe that could potentially treat these wastes was done. Following a thorough survey, the identified European thermal technologies were grouped into three high level processes: thermal treatment for volume reduction and passivation, conditioning by immobilisation in glass, and conditioning by immobilisation in ceramic or glass-ceramic matrices. For each facility information on its technical capabilities and availability to treat waste streams were summarised.

- Treatment for volume reduction and passivation included incineration (with burner and refractory walls), Rotary kiln incineration, pyrolysis, gasification, calcination, underwater plasma incineration, hydrothermal oxidation and induction metal melter.

– Conditioning by immobilisation in glass included Joule-Heated In-Can Vitrification, Joule-Heated Ceramic Melter (JHCM), Cold crucible induction melter (CCIM), Advanced CCIM (A-CCIM), Indirect induction (metallic wall - hot metal pot), Coupled cold wall direct metal induction melting and plasma burner, Coupled cold wall direct glass induction melting and plasma burner and Refractory wall plasma burning and melting.
– Conditioning by immobilisation in ceramic, glass or glass-ceramic included Hot Isostatic Pressing (HIP).

Once the technologies and facilities were identified, and the technical details of the thermal processes were assessed, this information was utilised to establish the advantages and limitations of each of the treatment facilities. From this it was possible to map the identified waste groups to the most suitable or promising technologies. During this mapping exercise each technology was assessed as either being a viable method for treating the given waste, having some potential (either untested, or only with modification) or not being applicable. From this exercise it was clear that there are a wide range of facilities spread across Europe that could potentially treat the identified wastes.

2.2. Viability of treatment routes for selected waste stream/technology combinations

The most essential and largest activity of the THERAMIN project is the assessment of the viability of different thermal treatment routes for selected waste stream/technology combinations. This activity is based on experimental demonstrations with six different technologies. The waste materials to be used in the demonstration test trials were selected based on the results from strategic review of radioactive waste streams (presented above) and assessment of suitability of the technologies for certain wastes. In addition, one selection criterion was to cover several different waste streams, which are suitable for thermal treatment. The selected waste streams and demonstration technologies are presented in Table 1.

TABLE 1. Demonstration technologies and waste materials of the THERAMIN project.

Technology	Demonstrator	Waste stream	Waste category	Product
Shiva	CEA/Orano, France	Organic ion exchange resin	Unconditioned wastes	Vitrified
In Can	CEA/Orano, France	Ashes	Unconditioned wastes	Vitrified
Geomelt 1	NNL, United Kingdom	Cementitous wastes	Conditioned wastes	Vitrified

GeoMelt 2	NNL, United Kingdom	Heterogeneous sludges	Unconditioned wastes	Vitrified
Thermal gasification	VTT, Finland	Organic ion exchange resin	Unconditioned wastes	Solid residue
VICHR	Vuje/Javys, Slovakia	Chrompik	Liquid wastes	Vitrified
HIP	USFD, United Kingdom	Uranium containing sludges	Unconditioned wastes	Vitrified/Ceramics

Until now the first test trials have been completed. All thermal treatment facilities to be used in the project have been have been installed already before the THERAMIN project and financed by other sources but made accessible for the project. The first demonstrations in the autumn 2018 were carried out using following technologies:

- The SHIVA process: cold wall direct glass induction melting and plasma burner (CEA/Orano);
- In-Can Melting process: metallic crucible melter heated in a simple refractory furnace using electrical resistors (CEA/Orano);
- GeoMelt: In Container Vitrification (NNL);
- Thermal treatment process based on thermal gasification (VTT);
- HIP: Hot Isotopic Pressing (NNL and UFSD).

The SHIVA process (CEA/Orano)

SHIVA is an incineration-vitrification process (Fig. 1) well suited for the treatment of organic and mineral waste with high alpha contamination and potentially high chloride or sulfur content. This technology is specifically designed to operate in a hot cell for high or intermediate level waste. It allows, in a single reactor, waste incineration by plasma burner and ashes vitrification. SHIVA consists of a water-cooled, stainless steel cylindrical reactor, equipped with a flat inductor at the bottom and a transferred arc plasma system in the reactor chamber (Figure 2). The gas treatment consists of an electrostatic tubular filter and a gas scrubber. The waste can be in solid or liquid form but must not contain metals. The SHIVA process has a technology readiness level (TRL) of 5-6 as a full-scale inactive pilot which has been tested by the CEA since 1998 for various wastes. TRL 5-6 means a technology validated/demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies).

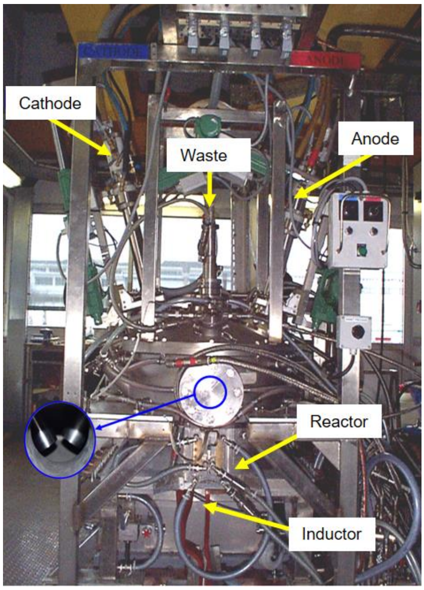

FIG. 1. SHIVA process.

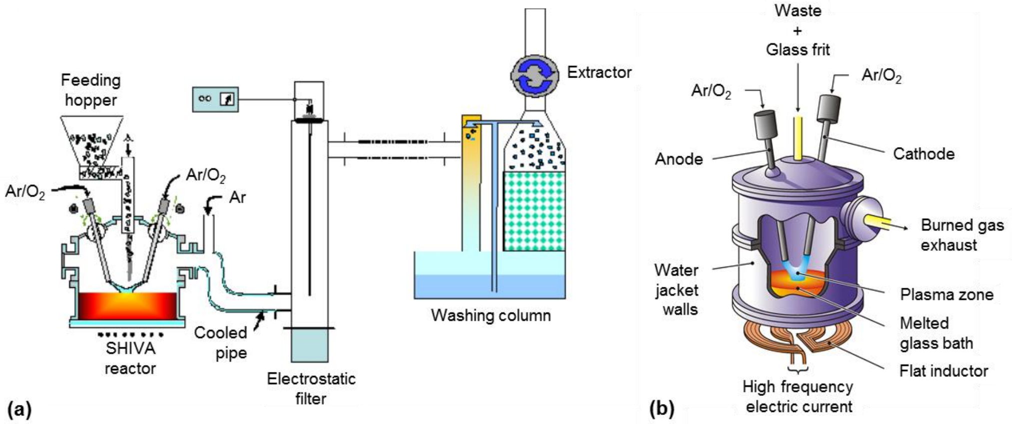

FIG. 2. (a) Simplified diagram of the SHIVA process and (b) artist's view of the reactor.

The waste selected for the THERAMIN trial is a 25 kg mixture of inorganic and organic ion exchange media composed of zeolites, diatoms, strong acid IXR, and strong base IXR. Inputs of SHIVA process composed of 38.5 wt-% of waste and 61.5 wt-% of glass frit.

The end-product of the process is an alumino-borosilicate glass which is macroscopically (millimetre scale: visual inspection) homogeneous (Figure 3).

Thus, the SHIVA trial conducted in the framework of the THERAMIN project showed the success of this process for the thermal treatment of a mixture of organic and mineral waste composed of zeolites, diatoms and ion exchange resins. The waste load of 38.5 % is high and could probably be increased in the future. Indeed, during this feasibility trial, it was not sought to maximize the waste load and the processing capacity. The waste product is a alumino-borosilicate glass, macroscopically homogeneous, whose long term behaviour could be characterized according to proven methodologies, which makes it possible to consider with confidence its disposability.

FIG. 3. Waste glass sample from the SHIVA trial.

In Can (CEA/Orano)

The In-Can Melter is a metallic crucible melter heated in a simple refractory furnace using electrical resistors (Fig. 4). The can is renewed after each filling.

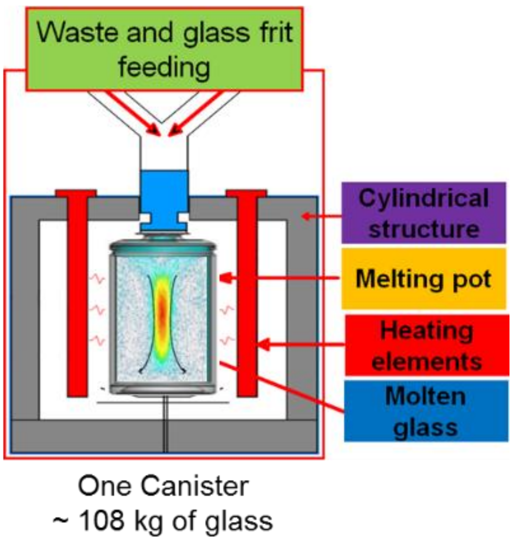

FIG. 4. Simplified diagram of the In-Can Melter process.

The process can support either liquid or solid waste feeds. With the current gas treatment process, it can only tolerate small amounts of organics. It can also accept a small fraction of metal in the waste. The design ensures that the process can operate remotely for high-activity waste. The design can also be adapted for dealing with plutonium containing material in gloveboxes. The end product can be glass, glass ceramic or simply a high-density waste product.

To prepare the THERAMIN trial preliminary tests were conducted at the laboratory-scale to select the best operating conditions in order to obtain an optimized waste load and a good quality end-product. These tests aim to demonstrate the feasibility of the confinement in a vitreous matrix of by-products coming from existing incineration processes. The preliminary tests consist of bringing into contact - at 1 100 °C during 2 hours - different amounts of ashes and glass frit, in the presence or absence of an adjuvant. These tests are carried out using a few grams of materials. At the end of the tests, the crucibles are cut after immobilization in epoxy resin and the products obtained are observed under a binocular magnifier. The criteria for the choice of the optimum conditions are the obtaining of a homogeneous glass and the limitation of the expansion during the elaboration.

The preliminary tests at the laboratory-scale showed the feasibility of ashes vitrification with a high load of 50 wt.% in the end-product. They also showed the interest of adding a sugar-based or a bentonite-based adjuvant up to 10 wt.% to avoid volatile dust and ensure the best reactivity.

Thermal treatment process based on thermal gasification (VTT)

VTT has developed, constructed and tested a thermal gasification based treatment method, especially for organic IXR. Technically the method can also be used for reduction of volume of low level operational waste containing organic matter but the waste has to be crushed before treatment. The technology has been designed for compact process, which can be operated at nuclear power plant site. The process has been designed primarily for reduction of volume of high organic matter containing radioactive waste.

The primary product from thermal gasification is fine dust collected by high temperature filter In addition to the filter dust the process produces some bottom ash, which consists mainly of bed material. Both filter dust and bottom ash are powders and thus the final residues have to be immobilised (cementation, vitrification, etc.) after waste processing before final disposal.

The development of thermal gasification based treatment of LILW has been based on so called bubbling fluidised-bed (BFB) gasification. In BFB gasifier bed material is fluidised by blowing gasification air or other gas from the bottom through the air distributor. The other type of fluidised-bed reactor is so called circulating fluidised-bed (CFB) reactor, which uses significantly higher fluidising velocity enabling thermal capacity per cross-sectional area. Both reactor types can be applied for thermal gasification of LILW and are used in THERAMIN demonstration test trials. A schematic diagram of the VTT's pilot-scale Circulating Fluidised-Bed (CFB) gasifier is shown in Fig. 5.

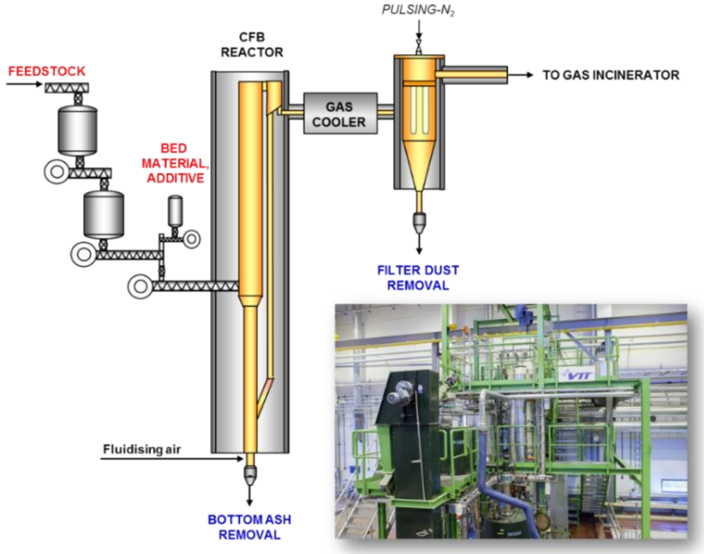

FIG. 5. Pilot-scale Circulating Fluidised-Bed (CFB) gasification test rig.

The first test trial was carried out with the pilot scale CFB gasification test facility. Organic IXR was treated in total of 325 kg during three test trial days. Total duration of the operation was 26.5 hours of which a steady-state period was measured during 12.5 hours.

Carbon conversion was calculated after the test trials. Calculation is based on the carbon mass balances and it describes how efficiently input carbon is converted to gas. The carbon conversion to gas and tars was 92-96 wt-%, which means that the removal of the organic material from the IXR succeeded very well.

Test trials with Circulating Fluidised-Bed (CFB) gasification pilot plant proved that CFB reactor is very efficient in removal of organic matter from ion exchange resin and thus reduce significantly volume of the organic ion exchange resin. The advantages of CFB compared to bubbling fluidised-bed (BFB) reactor are related to treatment capacity per cross-sectional area of the reactor. In addition, the heat and mass transfer are also better in CFB.

GeoMelt (NNL)

NNL and Veolia Nuclear Solutions have formed a collaboration to establish an active GeoMelt In-Container Vitrification (ICV) system at Sellafield. This facility is currently used to demonstrate the treatment of a wide range of UK based waste streams. The GeoMelt system installed at the NNL Central Laboratory is shown in Fig. 6.

The melter consists of a steel container lined with refractory materials containing the melt. The refractory lining consists of a 200-L cast refractory box (CRB) surrounded by refractory silica sand.

As part of the THERAMIN project, two appropriate waste streams were selected for thermal treatment demonstration using the GeoMelt system. The streams selected for demonstration using were:

- TH01- A cementitious stream representative of sea dump drums or failing cement wastes packages
- TH02- A sludge stream made up of a naturally occurring zeolite (clinoptilolite), sand, Magnox storage pond sludge and miscellaneous contaminants known to arise in a range of UK feed streams.

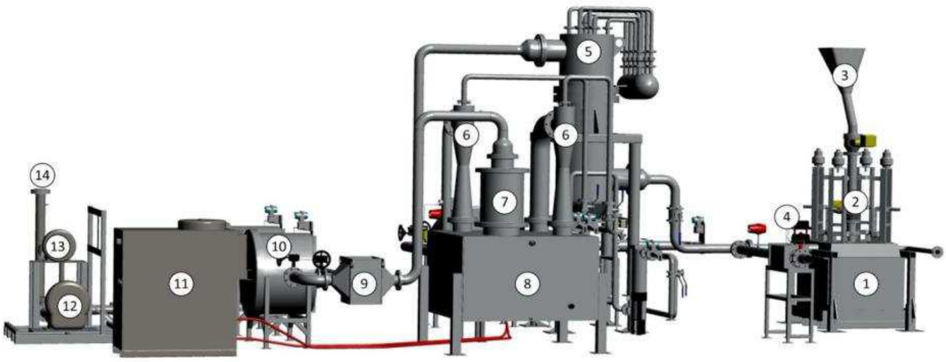

FIG. 6. The GeoMelt system installed at the NNL Central Laboratory. (1. ICV melter, 2. feed chute, 3. feed hopper, 4. connection to off-gas, 5. sintered metal filter, 6. scrubber column, 7. demister, 8. scrubber tank, 9. off-gas heater, 10. HEPA filtration, 11. cooler, 12. off-gas blower, 13. back-up blower and 14. vent discharge).

Thermal treatment of 279 kg of representative cementitious waste stream (TH-01) with a pre-treatment waste loading of 49% has been successfully demonstrated using the GeoMelt ICV system. Macroscopic observation of the product indicated that a glassy monolith with broad homogeneity has been produced. Visual inspection of the product suggests it should be disposable against all key disposability criteria. Observations made during product sampling indicate that at least some of the original metallic objects present in the simulated waste remained on completion of processing. All plant operating parameters observed during this melt were within expected norms.

FIG. 7. GeoMelt container.

Similarly thermal treatment of 238kg of a sludge stream consisting of clinoptilolite, sand and Magnox sludge (TH-02) with a pre-treatment waste loading of 72% has also been successfully demonstrated. The product manufactured from this experiment also had a glassy appearance which appeared to be homogenous.

Hot Isostatic Pressing (NNL and USFD)

The HIP is used to consolidate a pre-prepared waste feed sealed in a HIP can resulting in a monolithic waste form produced through the application of pressure and temperature while in the HIP vessel. The product will then be in a form suitable for ongoing storage and ultimate disposal. A schematic is shown in Figure 8. The HIP assembly consists of a monolithic steel pressure vessel surrounded by a water jacket for cooling. Inside the vessel is a molybdenum furnace surrounded by a thermal barrier/heat shield to protect the vessel from the high temperatures required. The work piece (e.g. canister) is placed inside the furnace and the vessel closed before applying pressure through the use of compressed argon and temperature through power to the molybdenum furnace.

In the THERAMIN project NNL and USFD are focusing on HIP technology. USFD in 30 g scale and NNL in 8 l scale. USFD are currently the only facility in the UK with capabilities to fabricate and process radioactive HIP waste forms. At USFD the waste forms were based on the immobilisation of magnesium hydroxide sludges, where five waste forms used triuranium octoxide (U_3O_8) to simulate waste streams present on the Sellafield Ltd site. At NNL Workington two HIP runs have been carried out on sludge feeds.

Prior to any characterisation and analysis, some conclusions can be drawn from the observation of the trial at NNL. The primary aim was to consolidate the waste feeds into a form that may be suitable for ongoing storage and disposal. From a visual observation the cans consolidated as expected. From this it can be concluded that the pressure temperature cycle was appropriate. The visual observation of the product would suggest that the product of the trials, THERAMIN HIP 1 and HIP 2, would both be suitable for disposal.

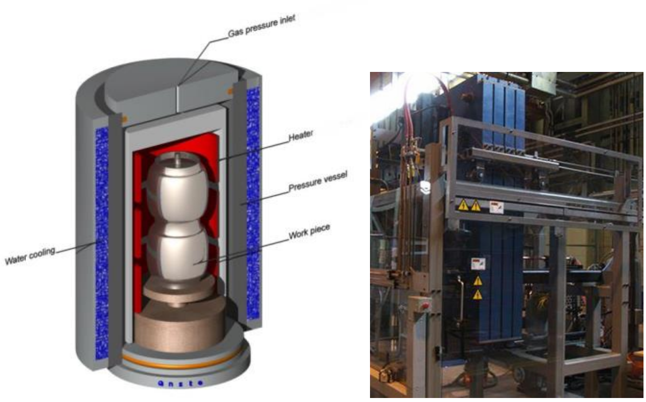

FIG. 8. Schematic of HIP (left: courtesy of ANSTO) and HIP installed at NNL Workington (right).

Seven conceptual waste forms were successfully prepared and HIPed at USFD. The primary aim was to utilise a unique active furnace isolation chamber (AFIC) system that allows processing of radioactive waste simulants in the HIP without risk of contamination to the processing equipment. This target was achieved with five of the waste forms produced using U3O8 to simulate Magnox sludges located at the Sellafield Ltd site. The pre-calcination, canister packing and bake-out steps were completed with no operational issues. However, the HIP processing of waste forms MBS-U low, NNL-U and NNL-Ce had difficulty achieving and maintaining the target pressure of 100 MPa. Once the HIP repairs were completed, the target pressure for the remaining waste forms was reduced to 75 MPa in order to have a comparable suite of samples.

2.3. Development of generic disposability criteria

Samples from each demonstration, but also samples from thermal treatment processes not tested in the project, will be characterised in order to evaluate the impacts of thermal treatment on the disposability of radioactive waste. The first step of this evaluation was the identification of the relevant criteria, also called Waste Acceptance Criteria (WAC). Each participating country provided data through a questionnaire. Then, some generic disposability criteria were developed based on examination of these data. These generic disposability criteria can be used to evaluate any products from any form of thermal treatment for disposal at any type of facility, and regardless of the political, regulatory or socio-economic context. They reflect typical characteristics of thermally treated waste products. The characterisation of thermally treated waste products are currently ongoing.

3. Dissemination

Dissemination and training are also an essential activity of the THERAMIN project. For example all public deliverables can be found and downloaded from the web site http://www.theramin-h2020.eu/. In 2020 the project will also organise an international conference focusing on thermal waste treatment technologies.

In addition, a training replacement program is a way to promote thermal treatment technologies. The first round of training replacements has been completed and the second will be implemented in 2019.

Acknowledgements

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JOHANNA HANSEN

TUNNEL PLUGS AND SHAFT SEALS DEMONSTRATIONS - DOPAS

J. HANSEN[1], M. PALMU[1], P. KOHO[1], M. WHITE[2], J-M. BOSGIRAUD[3], R. FOIN[3], A. RÜBEL[4], M. DVOŘÁKOVÁ[5], D. GENTLES[6], P. GRAHM[7], J. SVOBODA[8], M. JOBMANN[9]

[1]Posiva Oy, Olkiluoto, 27160 Eurajoki, Finland
[2]Galson Sciences Limited, Melton Road Grosvenor House 5, Oakham, LE156AX, UK
[3]ANDRA, 1-7 rue Jean Monnet - CHATENAY MALABRY, 92298 France
[4]Gesellschaft Für Anlagen- Und Reaktorsicherheit (GRS) MBH, Schwertnergasse 1, 50667 Köln, Germany
[5]SURAO, Dlazdena 6, 110000 Prague, Czech Republic
[6]Radioactive Waste Management, Building 587, Curie Avenue, Harwell Oxford Didcot, OX11 0RH, UK
[7]Swedish Nuclear Fuel and Waste Management Company, Evenemangsgatan 13, 16979 Solna, Sweden
[8]Czech Technical University, Thakurova 7, 16629 Prague 6, Czech Republic
[9]DBE TECHNOLOGY GmbH, Eschenstrasse 55, 31224 Peine, Gerrmany

Abstract. The goal of the Full-scale Demonstration of Pugs and Seals (DOPAS) project was to improve the industrial feasibility of plugs and seals, the measurement of their characteristics, the control of their behaviour in repository conditions, and their performance with respect to safety objectives. The DOPAS project delivered improvements in the process used to develop the design basis, in the design bases for different plugs and seals, in reference designs, in strategies to demonstrate the compliance of reference designs to the design basis, in technology, in materials, in construction; and on performance assessment of the materials and components. Five demonstration experimental programmes were implemented as part of these development activities.

1. Introduction

The Full-scale Demonstration of Pugs and Seals (DOPAS) project was undertaken in the period September 2012 – August 2016. Fourteen European waste management organisations (WMOs), and research and consultancy institutions from eight European countries participated in the project. A set of five full-scale experiments, materials research projects, and performance assessment studies of plugs and seals for geological repositories were undertaken in the course of DOPAS. The plugs and seals demonstrated in DOPAS were the Full-scale Seal (FSS) experiment, undertaken by Andra in a surface facility at St. Dizier, France [1], the Experimental Pressure and Sealing Plug (EPSP) experiment undertaken by SÚRAO and the Czech Technical University at the Josef underground research centre an underground laboratory in the Czech Republic [2], the Dome Plug (DOMPLU) experiment undertaken by SKB and Posiva at the Äspö Hard Rock Laboratory in Sweden [3], and the Posiva Plug (POPLU) experiment undertaken by Posiva, SKB, VTT and BTECH at the ONKALO® Underground Rock Characterisation Facility in Finland [4]. Additionally, in situ tests related to seals in vertical shafts complemented by materials research projects were conducted for the ELSA shaft seal project in Germany [5]. The DOPAS work was implemented in seven Work Packages (WPs). WP1 included project management and coordination. WP2, WP3, WP4 and WP5 addressed, respectively, the design basis, construction, compliance testing, and performance assessment modelling of the full-scale experiments and materials research projects. WP6 and WP7 addressed cross-cutting activities common to the whole of DOPAS through review and integration of results [6, 7, 8, 9, 10], and their dissemination to other interested organisations in Europe and beyond.

2. DOPAS project's main objectives

The work in the DOPAS project provided an updated European-level state-of-the-art for the plugs and seals studied in the project, through consideration of the following issues:

- Design basis processes: How are requirements on plugs and seals structured, and how can compliance with requirements be demonstrated? Can the learning from development of design bases for plugs and seals be applied to other repository elements? [6]
- Conceptual designs of plugs and seals: What conceptual designs exist for plugs and seals and what are their roles within the overall safety concept? [6]
- Plug and seal materials, and detailed design: What materials can be practically used to deliver the required functions of plugs and seal components as part of the detailed experimental designs? [7]
- Siting and excavation of plug/seal locations: How are the locations of plugs and seals selected? Further development of methods for the excavation of plug and seal locations. What operational safety issues are posed by the excavation of plug and seal locations and how can one overcome these? [7]
- Installation of plugs and seals: Further developments in the technology for emplacing plug and seal materials. What are the operational safety and logistical issues posed by the installation of plugs and seals? [7]
- Monitoring of plugs and seals: Does suitable technology for monitoring the performance of plugs and seals exist. What are the issues with monitoring of plugs and seals? [8]
- Performance of plugs and seals: How do plugs and seals perform with respect to detailed requirements on their performance? [8, 9]
- Compliance of plug and seal designs with their functions: To what extent can the current designs of plugs and seals be considered to meet their overall and safety functions? [9]
- Project management during plug and seal construction and full-scale testing: What learning has the DOPAS project provided with respect to the management of plug and seal implementation, conducting of full-scale tests and repository operations? [10]
- Dissemination about and integration of learning on plugs and seals: Have the dissemination activities in the DOPAS project been successful, and can the approaches adopted in the DOPAS project be applied elsewhere? [10, 14, 15]
- Technical readiness level of plugs and seals and remaining issues: What further development including testing of plugs and seals is required before designs are ready for implementation in operating repositories, and how can the plugs be implemented efficiently during the operational period in an industrial manner? [8, 10]

3. Design basis processes for plugs and seals

Work on the design basis in the DOPAS project has allowed assessment of current practice with regard to both the process used to develop and describe the design basis and the content of the design basis of plugs and seals. The design basis is developed in an iterative fashion with inputs from regulations, technology transfer, tests and full-scale demonstrations, and performance and safety assessments. The learning provided by design basis compilation has been used to describe a generic process for development of the design basis for plugs and seals called the "DOPAS Design Basis Workflow" (Fig. 1). The workflow integrates the project work package content related to construction, compliance testing, and performance assessment modelling of the full-scale experiments and material research projects. [6]

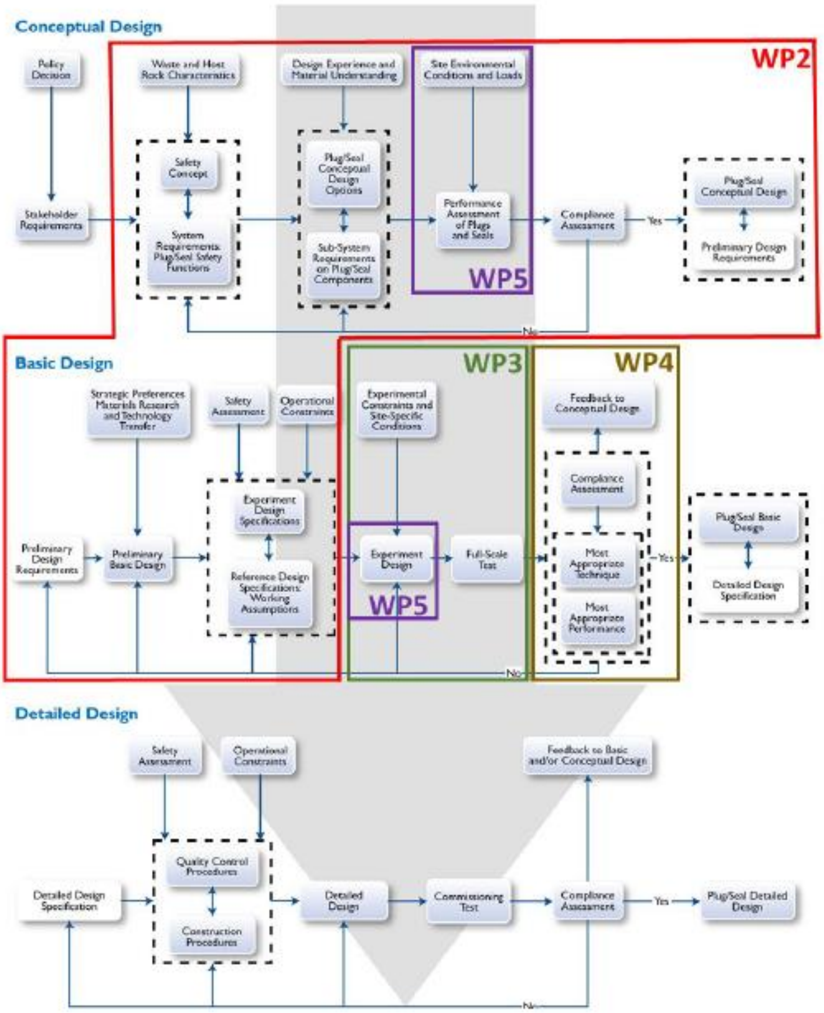

FIG. 1. The DOPAS Design Basis Workflow illustrating the iterative development of the design basis [6].

4. Implementation of plugs and seals in DOPAS project

4.1. FSS Experiment (Full-Scale seal demonstrating the Cigéo design plug)

The main objective of the experiment was to demonstrate the industrial feasibility of the construction of a large-scale swelling clay core seal (internal diameter 7.6 m), which forms part of drift and intermediate-level waste (ILW) disposal vault seal for the Cigéo repository design. Work on the FSS experiment within the DOPAS project included the design, construction and monitoring and dismantling of the experiment [1, 6, 7, 8, 9]. The components of the FSS experiment are illustrated in Figure 2.

For FSS, design work was undertaken in the period August 2012-April 2014, the upstream containment wall was cast in July 2013, the swelling clay core was emplaced in August 2014 and the downstream shotcrete plug was emplaced in September 2014. Investigations of FSS were undertaken in the period October 2014 to July 2015, and the dismantling and rehabilitation of the experimental surface facility was completed in December 2015.

The FSS experiment was not hydraulically pressurised. Instead the FSS experiment was dismantled during the duration of the DOPAS project. The dismantling of the FSS experiment included the collection of observations about the success of the construction and materials and additional information related to the properties of the installed components.

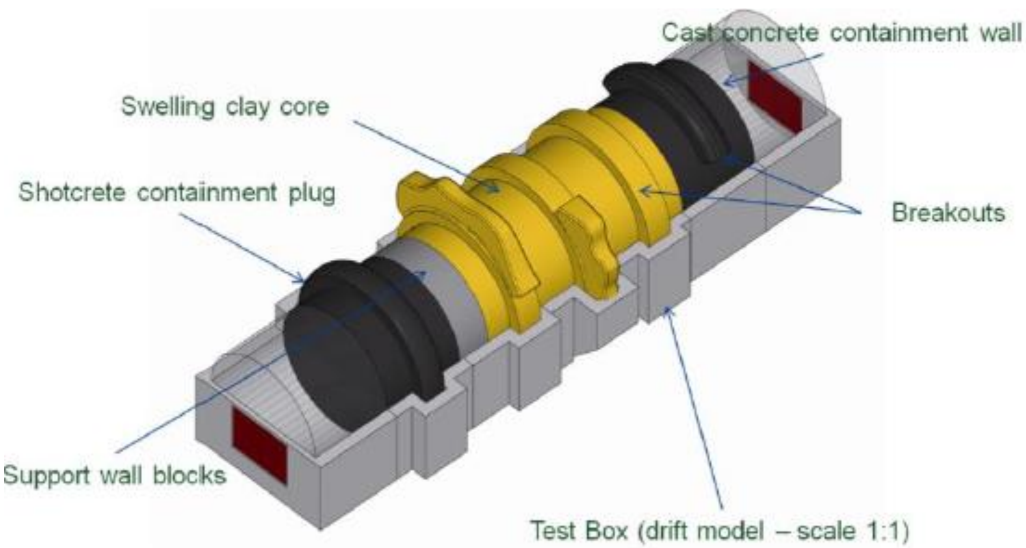

FIG. 2. FSS schematic design.

4.2. EPSP Experimental pressure and seal plug in Josef Gallery

The key objectives of the EPSP experiment were to test materials and technology, extending laboratory experience to the underground environment and to full scale, and to build the practical expertise of the SÚRAO personnel and other partners. In addition, the experiment demonstrated the successful use of shotcreting method in constructing a small-diameter experimental plug (the cross-section of the tunnel was approximately 15 m2. Work on the EPSP experiment within the DOPAS project included the design, construction and initial monitoring of the experiment [2, 6, 7, 8, 9]. The components of the EPSP experiment are illustrated in Fig. 3.

The location of the EPSP plug was selected in the period September 2012 - December 2012, and ground works were undertaken in the period January 2013 - August 2014. The EPSP's inner plug was shotcreted in November 2014, the bentonite core was emplaced in June 2015 and the outer plug was shotcreted in June 2015.

Experimental testing and pressurisation of EPSP started during the construction process. The inner plug was pressurised to check the water tightness of the concrete and to determine if grouting was needed through injection of water and air into the injection chamber up to 0.5 MPa. A series of short water injection tests followed by long-term tests at various pressure levels (starting at 0.1 MPa going gradually to up to 1 MPa) were undertaken once the outer plug had cured. The testing sequence was then interrupted and the bentonite sealing section was saturated by injection of water into both the filter and the pressurisation chamber to allow swelling pressure to develop. A short pressure test was then undertaken involving injection of bentonite slurry into the pressurisation chamber at pressures up to 3 MPa (2.5 MPa being the original target value). The pressurisation chamber was then cleaned up, and water pressurisation of the experiment through the pressurisation chamber was resumed. Further pressurisation and monitoring of the EPSP experiment, and evaluation of the results are still on-going in Josef Gallery.

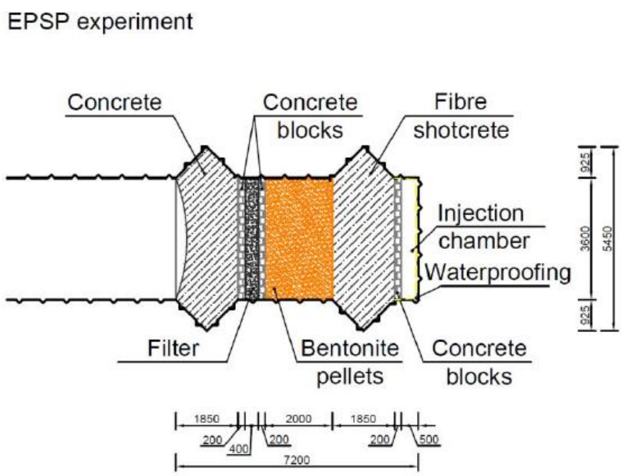

FIG. 3. EPSP plug design.

4.3. DOMPLU Experiment (Dome shaped plug in crystalline host rock)

The DOMPLU experiment was a full-scale test of the reference KBS-3®V deposition tunnel plug in Sweden and Finland at the time of the DOPAS project. The DOMPLU experiment was part of an on-going SKB testing and demonstration programme. The cross-section of the experiment is approximately 18 m2. The overall objective of the test was to reduce uncertainties in the performance and description of the initial state of deposition tunnel plugs. The components of the DOMPLU experiment are illustrated in Fig. 4.

Work on the DOMPLU experiment within the DOPAS project included the management, final installation and monitoring of the DOMPLU experiment up to 30 September 2014, and its evaluation and technical reporting [3, 6, 7, 8, 9]. The main part of the design and construction work for the DOMPLU experiment was not part of the DOPAS project. Excavation work for the DOMPLU experiment was undertaken between February and October 2012. The DOMPLU experiment's concrete dome was cast in March 2013 and the contact grouting was undertaken in June 2013. Monitoring was undertaken from March 2013.

Pressurisation of the system was started in December 2013 by injection of water into the filter and backfill, followed by saturation and development of swelling pressure in the watertight seal and backfill transition zone. The water pressure was artificially increased in steps inside the plug until it reached 4 MPa in February 2014. The water pressure was kept at this level for the remainder of the testing reported here. Further monitoring of the DOMPLU experiment, dismantling of the experiment, and evaluation of the results were carried out after the completion of the DOPAS project.

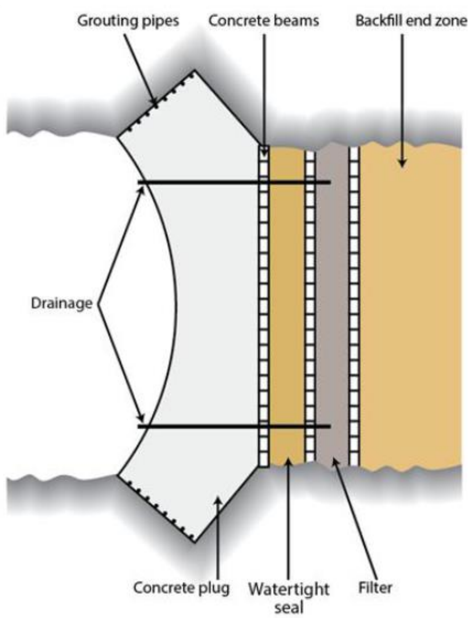

FIG. 4. DOMPLU schematic design.

4.4. POPLU Experiment (wedge shaped plug in crystalline host rock)

The goal of the POPLU experiment's goal was to implement an alternative plug design for the KBS-3V disposal concept reference plug and the work on both DOMPLU and POPLU has led to further development of Posiva's plug in the current demonstration of full-scale in-situ test in ONKALO®. The cross-section of the experiment is approximately 14.5 m^2. Work on the POPLU experiment within the DOPAS project included the concrete recipe design and performance evaluation, bentonite tape and filter system planning, slot excavation planning and implementations, monitoring and pressurisation systems' design and implementation, modelling of water tightness and mechanical integrity, pressurisation of the experiment plug and its performance assessment [4, 6, 7, 8, 9]. Some aspects of the plug design, tunnel excavation and construction of the experiment were not part of the DOPAS project. The components of the POPLU experiment are illustrated in Fig. 5.

The design of the POPLU experiment was undertaken between November 2012 and September 2013. Excavation of the demonstration tunnels (one for the plug experiment and one for its monitoring data collection) and then the slot were undertaken in the period September 2013-February 2015. The first section of the POPLU concrete wedge was cast in July 2015 and the second section was cast in September 2015. Grouting of the plug-rock interface was undertaken in December 2015. Pressurisation of the plug commenced in mid-January 2016.

Once the filter section was filled with water, pressurisation of the plug could commence. In the early stage of pressurisation, the water pressure in the filter was increased to 1.4 MPa over a one-month period, and a shorter duration higher pressure test. Based on the results achieved to date, it was decided to re-grout the plug interface with an improved grout mix and methodology. It is expected that the pressurisation and performance evaluation will be undertaken again with pressures up to 4.2 MPa after the re-grouting is completed. The POPLU experiment is available for further monitoring and for potential future dismantling in ONKALO®.

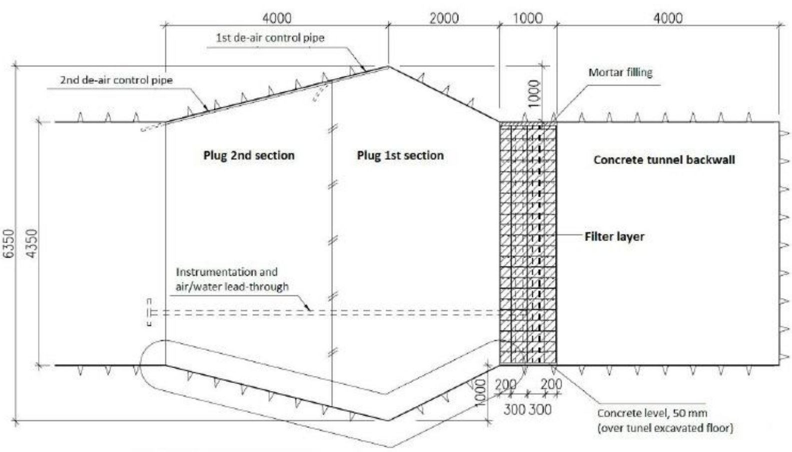

FIG. 5. POPLU plug design.

4.5. ELSA Programme for shaft seal design with related material studies

No full-scale test as part of the German ELSA project has been carried out within the DOPAS project. However, the work consisted of several smaller comparative experiments carried out at different sites. The aims of the experiments were to develop generic design concepts for sealing elements to be used in shaft seals in both salt and clay host rocks that comply with the requirements for a repository for high-level waste, and to carry out the preparatory work in shaft seal design. [11, 12].

4.6. Expert evaluation of outcomes and the dissemination of DOPAS results

The DOPAS project deliverables went through an extensive expert elicitation [13, 10] to ensure the soundness of the different work package reports and their results. A total of 16 geological disposal experts with various areas of expertise in the field, and who were not directly involved in the DOPAS work, contributed to this expert evaluation in four different elicitation processes. The outcomes of the process included external experts' review of drafts of the main WP2 - WP5 summary reports (DOPAS Deliverables D2.4, D3.30, D4.4 and D5.10) [6, 7, 8, 9].

FIG. 6. DOPAS seminar participants in Turku, Finland, May 2016. Photo: Elina Heikkilä, TVO.

In addition, the DOPAS project results were shared on tens of technical and research forums and articles, in the regular DOPAS newsletters, and in a dedicated training workshop for young professionals and students in geological disposal carried out in the Czech Republic [15]. Additionally, the DOPAS project organised three staff exchanges for competence exchange between the experiments and the participating organisations' staff. However, the main dissemination highlight was the final DOPAS seminar [14] where the project's results were disseminated to a wide audience of over 110 participants from 50 different organisations and 16 different countries, including participants from the European Union, Russia, Japan, and Australia (Fig. 6).

5. Assessment of plugs and seals

The DOPAS project contributed significantly to the further development of plugging and sealing material recipes and design, to the practical industrial installation work of the plugs and seals and finally to the safety cases for radioactive waste repositories by bringing forward the plug and sealing concepts in the three main host rock types considered in Europe: crystalline rock, clay rock and salt rock. Process modelling work performed in DOPAS contributed to the preparation and execution of the experiments and helped in interpreting the results [9]. The full-scale experiments have contributed to the safety assessment and development of safety case in following ways (see also Fig. 7):

- **Gain in process understanding and improvement of models for safety assessment by evaluation process modelling of laboratory experiments**: Process modelling of laboratory experiments in the DOPAS project was able to predict and interpret the results enhancing the confidence in the suitability of the models used to describe the observed processes. The process models were partly converted into abstract models that could be included in integrated safety assessment models to achieve a better process representation in the future total system performance assessments. Future comparison of the performed predictive modelling on mid-scale experiments with experimental results contributed in the confidence of the validity of the up-scaling of process modelling results from the small scale to the metric scale.
- **Advancement of the sealing concept**: The process modelling of laboratory and mid-scale in situ experiments contributed to the updating of sealing concepts and to the choice of sealing materials. The predictive process modelling of the in situ experiment directly supported and influenced the layout and construction of the experiment.
- **Confidence in concepts and models**: Future comparison of the predictive modelling with experimental results will further contribute to the confidence of the validity of the up-scaling of process modelling results from the small scale to the large scale.
- **Proof of constructability**: All aspects described before are jointly contributing to the confidence that plugs and seals can be constructed as planned, and will be able to meet their designed function in the overall repository concept.

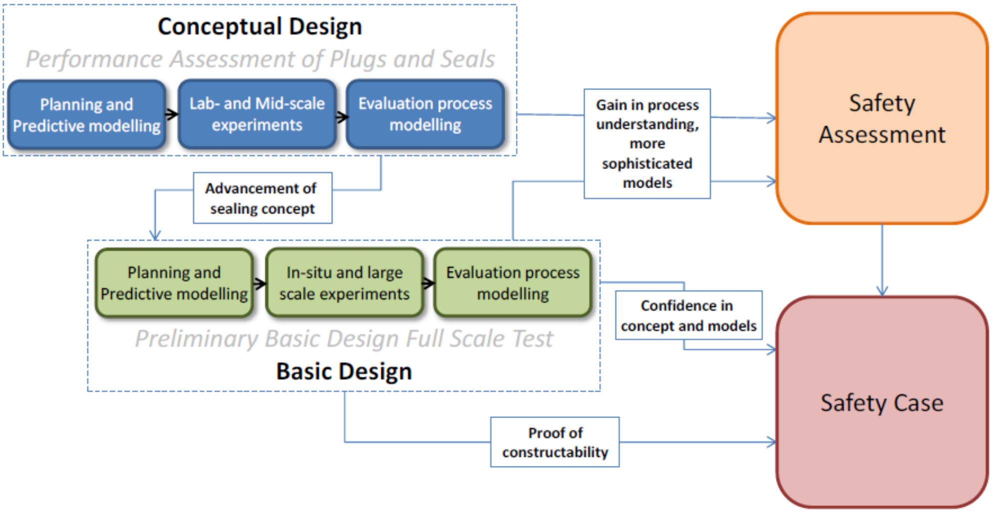

FIG. 7. Safety assessment and the development of the safety case as part of the full scale testing of plugs and seals [9].

6. Outcomes of the DOPAS project

The main outcome for defining the design basis and requirements for plugs and seals were the requirements on plugs and seals considered in the DOPAS project, conceptual and basic designs including material development work, and the strategy adopted in programmes for demonstrating compliance with the design basis. The design basis is presented for both the repository reference design, i.e., the design used to underpin the safety case or licence application, and for the full-scale experiment design, i.e., the design of the plug or seal that is being tested in the DOPAS project. The strategy is presented in Workflow outlining how the design basis and designs of plugs and seals are developed throughout a programme at an increasing level of detail (Fig. 1).

The main outcome from design and construction feasibility for plugs and seals are the lessons learned from the detailed design, site selection and characterisation, and construction of the experiments. These include the four full-scale demonstrators, materials research and its up-scaling, and the learning provided by the practical experience in constructing the experiments. Appraisal of plug and seal systems' function considers what can be concluded from the experiments conducted in the DOPAS project with respect to the technical feasibility of installing the reference designs, the performance of the reference designs with respect to the safety functions listed in the design basis, and identifies and summarises achievements from starting the conceptual design and leading to the full-scale demonstrator. It is essential to collect the feedback from the implemented structures back to the design basis, while development is usually an iterative process and it is important to consider the aspects on the way for industrialisation and implementing the structures in repository. In the DOPAS project, performance assessment was taken to cover the performance of plugs and seals following the installation of the plug/seal materials in the experiment/repository. This included, therefore, the saturation of the materials following installation, their long-term thermal, hydraulic, mechanical and chemical (THMC) behaviour, and their representation in safety assessments.

Integrating analysis including cross-review of each other's work also included the use of an applied Expert Elicitation (EE) process to integrate critical analyses of the achievements and results from the implementation and monitoring of the DOPAS project's plugs and seals. Concluding the integration the DOPAS project, a final public technical summary report (Deliverable D6.4) [10] was published at the end of the project and the DOPAS seminar was held in May 2016 bringing together WMOs and research organisations to widely discuss about the role of plugs and seal in repository context [14].

Acknowledgements

The DOPAS project with full-scale experiments provides the basis for future needs related to plug and seal technologies for nuclear waste management. The research leading to these results received funding from the European Union's European Atomic Energy Community's (Euratom) Seventh Framework Programme FP7/2007-2013 under Grant agreement no 323273, the DOPAS project".

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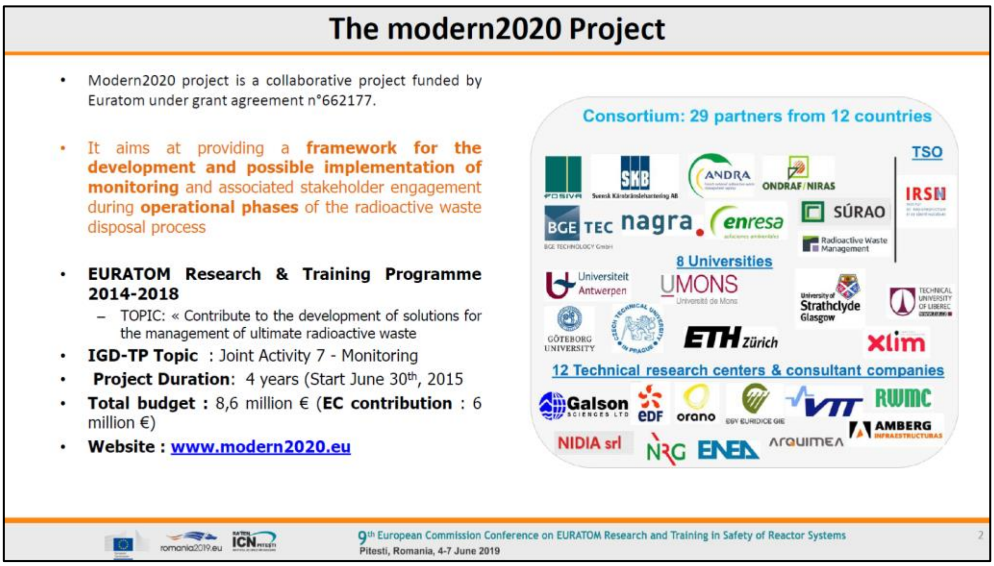
JOHAN BERTRAND

FISA 2019 – EURADWASTE '19

Presentation of Mr Johan Bertrand (ANDRA, FR)

DEVELOPMENT AND DEMONSTRATION OF MONITORING STRATEGIES AND TECHNOLOGIES (MODERN2020)



Modern2020 Structure

- **WP2 Strategy** lead by **SKB (Mansueto Morosini)**
  - Linking of monitoring objectives to the safety case and decision-making strategies.
- **WP3 Technologies** lead by **Amberg infraestucturos (José-Luis Garcia-Sineriz)**
  - Research and development on monitoring technologies
- **WP4 Demonstration and Practical Implementation** lead by **Euridice GIE (Jan**
- **Verstricht)**
  - Demonstration of monitoring technologies at full-scale and under *in situ* conditions.
- **WP5 Societal concerns and Stakeholder Involvement** lead by **the University of Antwerpen** (Anne Bergman)
  - Development and evaluation of ways for integrating public stakeholders concerns into national repository monitoring programmes

content

1. Introduction
2. WP2 : monitoring strategies
3. WP3: Monitoring technlogies
4. WP4: in situ demonstration
5. WP5: Public stakeholders
6. WP6: dissemination
7. Conclusion
8. Futher works

Background

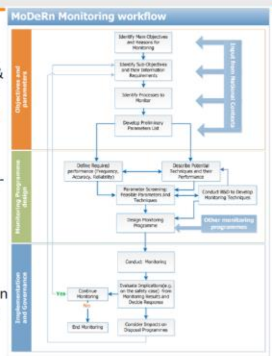
Extensive « literature » on monitoring (20 years)

- National legislation and regulatory demands
  - **STUK YVL Guide D.5**
  - **French ASN-2008 Geological Disposal Safety Guide,**
- Guiding principles from international organizations (IAEA, NEA, EU)
  - **IAEA TECDOC 1208 (2001)**
  - **IAEA Safety Requirements WS-R-4 (2006)**
  - (….see paper)
- Generic process for scoping, designing and implementing a repository monitoring programme - the MoDeRn-FP7 project (2010-2014)

Objectives & Parameters
What?

Programme-design
How?

Implementation & Governance
Use?



MoDeRn (2013a), *Monitoring During the Stages Implementation of Geological Disposal: The MoDeRn Project Synthesis.* MoDeRn Deliverable D6.1.

Approach

- All programmes agree that it is impractical to monitor all of the repository
- High-level strategies will be used to monitor specific parts of the repository during the operational period
- In Modern2020 a strategy consists of the following elements:
  - **What:** waste packages and near field; dummy packages and near field; specific EBS elements; the geological barrier; the biosphere
  - **Where:** preparation main repository, pilot repository, underground rock characterisation facility
  - **When:** during construction (baseline for operations); during emplacement; after emplacement; during closure; after closure
  - **How:** the types of technologies used, including *in situ* sensors; borehole-based sensors; surface –based technologies; air-based technologies
  - **"Whom":** operator, regulators, lay stakeholders...

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  - **How:** the types of technologies used, including *in situ* sensors; borehole-based sensors; surface –based technologies; air-based technologies
  - **"Whom":** operator, regulators, lay stakeholders...

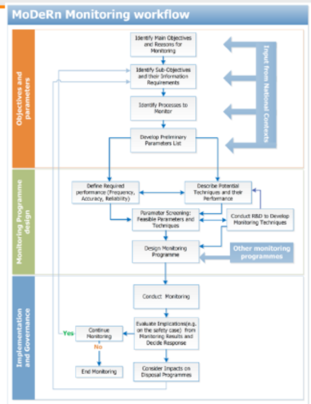
Why to monitor?

- Definition of **monitoring** (IAEA Safety Standards): "continuous or periodic observations and measurements to help evaluate the behaviour of the components of a waste disposal system and the impact of the waste disposal system on the public and the environment"
- The emphasis placed on different reasons for monitoring the near field during the operational period differ from programme one to another
  - Monitoring may provide an opportunity to demonstrate understanding of the thermal, hydraulic, mechanical and chemical processes occurring, thereby demonstrating WMO **understanding and building further confidence**
  - Monitoring programmes might focus on the short-term evolution of the repository system to show that this **evolution is consistent with the safety case**
  - Monitoring may also provide the means for **continuing to engage with stakeholders** and check the evolution of the disposal system following waste emplacement

WP2 MONITORING STRATEGIES

What to monitor?

- The MoDeRn Project formulated a reference framework and a generic workflow for developing and conducting a monitoring programme
- Further work was required to consider explicitly **how monitoring parameters could be identified**



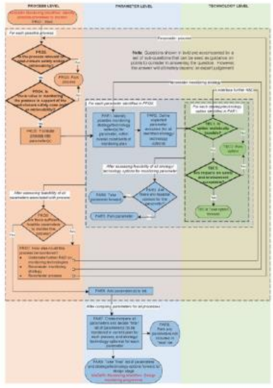
Recommendation from the Nuclear Energy Agency

Monitoring of Geological Disposal Facilities: Technical and Societal Aspects" (NEA, 2014)

- *The current, and justifiable, tendency is to measure as many parameters as possible*
- *With the transition from the repository development stage to implementation, it becomes necessary to optimise the selection of the parameters*
- *The identification of those parameters which would sufficiently demonstrate the attainment or approach to the passive safety status of the disposal system would be of substantial benefit*
- The recommendations of the NEA have been addressed in Modern2020 through the development of a generic structured approach to the selection of parameters
  - The Modern2020 Screening Methodology

The Modern2020 Screening Methodology

- The Methodology is presented as three strands: processes, parameters and technologies
- Starting point is list of processes or parameters that have been proposed for monitoring
- Basis for decisions are judgements based on existing knowledge
- The Methodology is a stepwise process to allow for **traceability and transparency**
- Judgements used as a basis for decisions may change, so processes and parameters are parked and not rejected



Decision making process (use of monitoring Data?)

- Consider how a waste management organisation might plan for responding to monitoring results
- Develop recommendations and observations on responding to monitoring results
  - General guidance and principals, rather than specific plans
- Develop a generic process for responding to monitoring results
- Terminology on performance measures and response plans
- Decision making is a complex process where monitoring is only one input

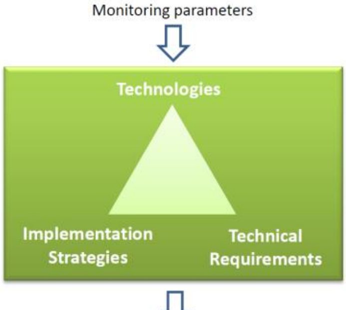
Generic Response	Explanation
Desk-based responses	
Evaluate sensor performance	Re-checking of the raw data from sensors to check that the sensor readings are valid.
Check results	Re-checking the analysis of sensor readings to check that the interpretation of the raw data is valid.
Report results	Notifying stakeholders (including regulators) of results.
Root cause analysis	Evaluating the reasons behind particular monitoring results, focused on results that are not consistent with expectations. This might include, for example, literature review.
Revise models / safety assessment	Modifying THMC and safety assessment models to incorporate new process understanding and/or parameter values.
Update monitoring plan	Revising the monitoring programme, taking into account the results from the monitoring programme to date (and any other information generated during the period since the monitoring programme was last updated).
Monitoring Programme Responses	
Continue monitoring in the same way	Continuing the operation of the monitoring programme using the same method (e.g. using the same number and type of sensors, in the same locations, and with acquisition of data at the same frequency).
Change monitoring	Changes in the monitoring programme could relate to changes in the frequency of data acquisition using the current monitoring system, monitoring the same parameter(s) with additional sensors of the same type (additional redundancy), monitoring the same parameter(s) with different sensors (increased diversity), or monitoring of different parameters.
Disposal Programme Responses	
Change operations	The emplacement of waste could be altered by, for example, placing a temporary halt on emplacement operations, or only emplacing waste of a specific type. Monitoring can also support decisions to move from one phase of repository operations to the next.
Change design	Evaluation of the results from the monitoring programme may be used to underpin decisions to change the design of the repository.
Engineering intervention	Changing the properties of the repository near field through engineering measures such as grouting, in situ vitrification and construction of new barriers.
Reversal / retrieval	Reversal is removing the waste from the disposal location by reversing the original emplacement process (the term is also used to denote the ability to reverse decisions). Retrieval is removing the waste from the disposal location by any means.

WP3 : MONITORING TECHNOLOGIES

How to monitor?

Monitoring technlogies

- Technologies exist but with evident limitation
- Actions to carry out before repository monitoring starts
  - **Adaptation** of the technologies to specific monitoring objectives, host rocks and repository concepts
  - **Innovate** of technologies for monitoring specific parameters
  - **Improvement** of the long-term performance.
- Objectives
  - Accelerate the development of suitable monitoring technologies VS needs
  - Guidance for the monitoring system qualification



Monitoring technologies (1/3)

Wireless Data Transmission systems

Improve existing <u>short range</u> (tens of meters) wireless systems based on high or medium frequencies (*Arquimea, ENRESA, IRSN & VTT*)

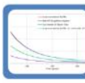
Improve existing <u>long range</u> (hundreds of meters) wireless systems based on low frequencies (*Andra & RWMC*)

Evaluate the use of a <u>combination</u> of different range wireless systems to provide a complete data transmission solution (*Amberg, Andra, Arquimea, ENRESA, EURIDICE, IRSN, NRG, RWMC & VTT*)

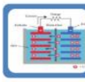
Alternative power supply sources

Nuclear batteries (Orano)

Induction (10m, VTT)



energy harvesting from small thermal gradients (NRG)

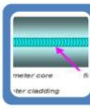


Chemical batteries + ceramic capacitor (Arquimea)

Monitoring technologies (2/3)

Optical fiber technology

Distributed CFO (Andra, EDF,Xlim/CNRS)
- Brillouin, raman, rayleigh
- For temperatute, strain, H2,

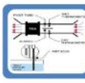


Bragg CFO (Umons)
- pH, H2

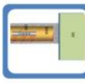
Calibration method (Nagra)

Active DTS: Heatable fiber-optic cable
- **Distributed FO system for thermal and mechanical monitoring.**

Innovative sensors



Psychrometer (Amberg, Arquimea)
- Water content



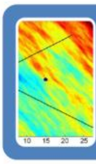
Non-contact displacement measurement (ENEA)

Chemical measurements: selection of ion electrode and prelimenary evaluation

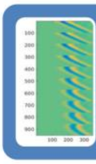
- Smart cell THMC

Monitoring technologies (3/3)

Improvement of seismic full waveform inversion technologies



Seismic waveform inversions (ETH)



Anomaly detection algorithms (TUL)

Development of a method based on combined Electrical Resistivity Tomography and Induced Polarisation Tomography, VTT & U. Strathclyde

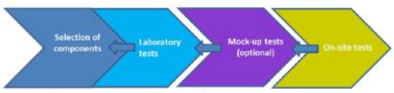
Combined (3D/4D) Electrical Resistivity and Induced polarization Tomography (ERT/IPT) techniques in order to monitor water content changes in 3D in the buffer-backfill-bedrock systems, (VTT)

Diffuse non-intrusive monitoring of the EBS based on combined Electrical Resistivity Tomography (ERT) and Induced Polarisation Tomography (IPT), (U. Strathclyde)

Guidance for the monitoring system qualification

a common multi-stage qualification methodology

- Strong synergy between Energy, Space fields and DGR needs with a qualification process in 3 stages: i) Selection of components, ii) The laboratory qualification and iii) On-site qualification



Global sketch for the qualification of monitoring components in DGRs

Proposal of an Approval DOCument (ADOC) for a monitoring component qualification

WP4 IN SITU DEMONSTRATIONS

How to monitor?

Why Demonstration ?

Implementation of monitoring set-ups at real scale, and at (geotechnical) conditions similar to a repository, offers a tangible environment to assess the topics investigated / developed in the Modern2020 project

- the monitoring strategy concepts
- the (innovative) monitoring technologies
- the (public) stakeholder engagement

In addition, it provides, in itself, also relevant input on the factors that determine the succesful performance of a monitoring system, such as:

- installation and interaction with construction
- long-term management of monitoring systems

- Evaluate monitoring system
  - Using monitoring technologies with high Technological readiness level (TRL)
  - With innovative solution

EBS monitoring plan (KBS-3V, Posiva)

AHA experiment (monitoring THMC evolution on HLW cells prototype ,Cigeo concept, Andra)

LRTBM (monitoring seals, IRSN)

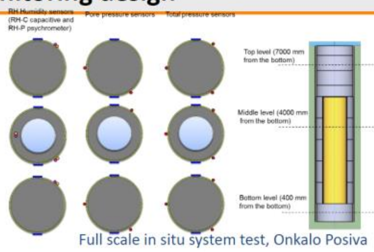
FE experiment (monitoring of the THM evolution of the EBS and the host rock, Nagra)

Evaluate possible monitoring design

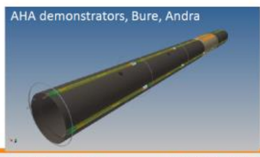
Evaluate possible monitoring design

Implement monitoring design using monitoring technologies with high Technological readiness level (TRL)

- Evaluate practical aspect (duration, implementation methods)
- Evaluate cost
- Evaluate of the monitoring on the safety



Full scale in situ system test, Onkalo Posiva

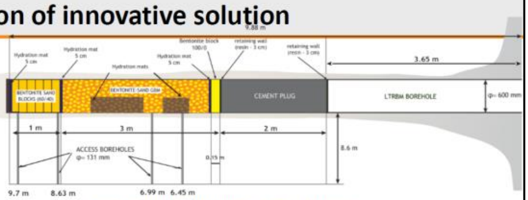


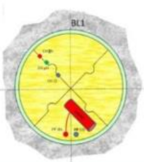
AHA demonstrators, Bure, Andra

Evaluation of innovative solution

Long-Term Rock Buffer Monitoring experiment (LTRBM)

Objectives: LTRBM experiment is intended to test new monitoring solutions developed in WP3 of Modern2020 to assess their performance under real in situ conditions, e.g. inside an Engineered Barrier System (EBS), to demonstrate a full wireless data transmission from the EBS borehole to the earth's surface and to assess commercial sensors that have never been tested in a bentonite buffer

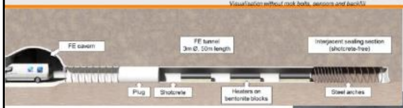




New measuring instruments from partners

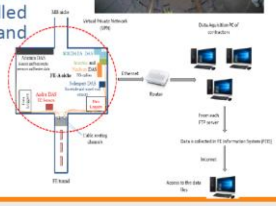
- ***Chemical sensor*** *based on measurements of potential difference between an ion-selective electrode and a reference electrode (measuring electrodes pH, Eh and Cl⁻) provided by* ***VTT_WP3***
- ***Thermocouple Psychrometers*** *(measures suction using dew point method) attached to a wireless transmitter provided by* ***ARQUIMEA*** *(4 units)*_**WP3**
- ***THMC smart sensor*** *(measures total pressure, pore pressure, temperature and relative humidity) provided by* ***CTU_WP3***
- ***Total pressure*** (based on fibre optic technology) *provided by* ***Andra*** *(4 units)*
- ***Pore water sensors*** *(vibrating wire for pore pressure measurements and electrical resistivity for temperature) attached to a wireless transmitter provided by* ***Andra*** *(2 units)*

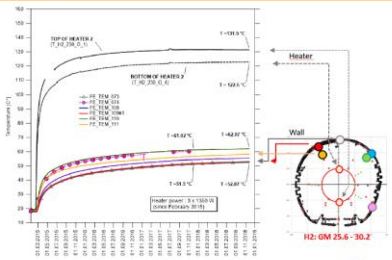
FE experiment

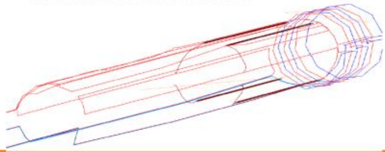


- Fibre-optic cables for distributed strain and temperature sensing (cables with single and/or multimode fibres) were installed at FE tunnel wall and in boreholes.

- Challenge on data treatment







WP5: public Stakeholders

- To **actively engage** local public stakeholders (people in concerned communities) in repository monitoring RD&D within the Modern2020 project, and to **analyse the impact** this has on both the participating stakeholders' and the project partners' understanding of, and expectations regarding, repository monitoring

- To **define** more specific **ways for integrating public stakeholder concerns and expectations** into specific repository monitoring programs

- To **develop ideas on how to ensure accessibility and transparency of monitoring data** (of the type gathered through in-situ monitoring) to public stakeholders

- To **learn lessons** on how local stakeholder groups could be engaged effectively with RD&D programs and projects **at EU level**.

Responsible research and innovation (RRI)

Responsible research and innovation (RRI)

- RRI pushed by the EU
- RRI: "societal actors work together during the whole research and innovation process in order to better align both the process and its outcomes with the values, needs and expectations of society" (Horizon 2020 website)
- RD&D should be anticipatory, inclusive, responsive, reflective, and sustainable
- Modern2020 has tried to adapt to RR

- ‘Home engagement activity’ (making use of existing configurations; in collaboration with respective NWMO)
  - Municipality of Eurajoki (Finland), Municipality of Östhammar (Sweden), Local partnerships in Mol and Dessel (Belgium), Clis de Bure (France)
  - Belgium and Sweden from the start; Finland and France to follow later
  - ‘Activity level’ influenced by national programme (cf. environmental court process in Sweden)

STORA

MONA Mols Overleg Nucleair Afval vzw

ÖSTHAMMARS KOMMUN – EN DEL AV ROSLAGEN

Clis Comité Local d'Information et de Suivi du Laboratoire de Bure

EURAJOKI 150 vuotta

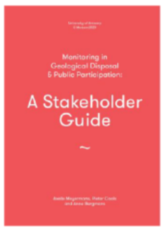
Specific outputs

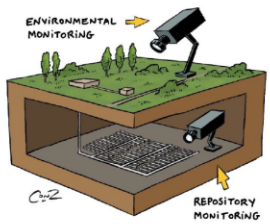
More reflective and analytical

- Monitoring the Underground: Specific Challenges for Engaging Concerned Stakeholders (D5.1)
- Lessons learned from engaging with local citizens in an international R&D project (D5.3)

More practical

The Stakeholder Guide to Repository Monitoring (D5.2)





Dissemination

2nd International Conference on Monitoring in geological disposal of radioactive waste

Strategies, technologies, decision making and public involvement

150 participants 15 countries
90 organizations 43 speakers

All presentation is available on Modern2020 website

Training school about monitoring

Learning unit 1 : Nuclear fuel cycle and geological disposal concept
Learning unit 2 : Monitoring : objectives, process and parameters
Learning unit 3 : Monitoring program design
Learning unit 4 : Implementation and governance

Conclusion

- The Modern2020 Project has enhanced our ability to implement, both strategically and technically, repository monitoring during the operational phase to build further confidence in the post-closure safety case
  - international consensus on strategies, parameter-selection methodologies and plans for responding to monitoring result
  - Identify and accelerate the R&D on monitoring technologies
  - Real test cases
  - the work on stakeholder engagement in the Modern2020 Project has been successful and has identified innovative methods for early engagement of stakeholders in the development of monitoring programmes
    - Both groups benefitted from the interaction, especially as it was a long-term interaction over the course of the four-year Project

Further Work

- The key requirement now, is for the guidance to be applied in specific programmes, and for detailed operational phase monitoring programmes to be developed.
  - Common strategy : Pilot phase, industrial pilot phase, first emplacement field, Full-Scale *In Situ* System Test….always heavy monitoring system
- the new monitoring techniques provide much more information (huge amounts of digital or analog data) that the standard data acquisition systems can not properly handle. Furthermore, the fast spreading of the BIM (Building Information Modelling) technologies to all kind of civil works will demand to integrate the monitoring data as part of the digital model of the future repository.

Acknowledgement

ANDRA, POSIVA, SKB, nagra, enresa, SÚRAO, ONDRAF/NIRAS, RWMC, Radioactive Waste Management, BGE TEC, GÖTEBORG UNIVERSITY, ESV EURIDICE GIE, Universiteit Antwerpen, ARQUIMEA, AMBERG INFRAESTRUCTURAS, NRG, IRSN, UMONS, University of Strathclyde, orano, ETH Zürich, VTT, TECHNICAL UNIVERSITY OF LIBEREC, xlim, Galson Sciences Ltd, ENEA, EDF

SESSION 2
RADIOACTIVE WASTE SOURCE TERM AND SCIENCE FOR DISPOSAL SAFETY

SUMMARY SESSION 2 – RADIOACTIVE WASTE SOURCE TERM AND SCIENCE FOR DISPOSAL SAFETY

Chair: Antonio GENS (UPC, ES)
Co-chair: Jean-Paul GLATZ (DG JRC, EC)
Expert rapporteur: Piet ZUIDEMA (Zuidema Consult GmbH, CH)

JOHAN ANDERSSON

KEYNOTE: SCIENCE UNDERPINNING THE SAFETY CASE OF DEEP GEOLOGICAL REPOSITORIES – CHALLENGES IN THE PAST AND IN THE FUTURE AND HOW TO MAINTAIN KNOWLEDGE AND COMPETENCE DURING OPERATION

J. ANDERSSON

Unit of Nuclear Fuel Repository, Swedish Nuclear Fuel and Waste Management Co. SKB, Box 3091, SE-169 03 Solna – Sweden

Abstract. Final repositories for spent nuclear fuel are approaching implementation. A prerequisite for these advancements is that it has been shown that the repository can be constructed and operated in practice in such a way that safety can be assured both during operation and over very long time scales. The success rests on decades of structured and objective driven research and development. A key element of the research strategy has been to ensure adequate in-house competence and expertise. Also openness and international cooperation are essential. Workable procedures for data qualification, version control as well as internal and external peer review have gained importance. When the programmes now enter a new phase of construction and operation new challenges will arise. Even if the implementing organizations would need to keep a core competence on post closure safety assessment international cooperation will be even more important on developing, sharing and managing the knowledge needed.

1. INTRODUCTION

Final repositories for spent nuclear fuel are approaching implementation. In 2011, SKB applied for a permit to build a KBS-3 type final repository for spent nuclear fuel at the Forsmark site. The application has now been examined by the Swedish Radiation Safety Authority (SSM) under the Act on Nuclear Activities and by a Swedish Land and Environmental Court under the Environmental Code. On January 23 2018, SSM and the Court both issued their statements to the Swedish Government. SSM recommends the Government to grant permission for a final repository at the Forsmark site. It also points to issues that SKB needs to resolve in coming phases of the step-wise licensing process under the Act on Nuclear Activities. The Land and Environmental Court approved in its statement parts relating to the choice of Forsmark as the site for the repository, post-closure aspects related to the rock and the buffer and the environmental impact assessment. It also considered that supplementary information regarding five issues related to the long-term integrity of the copper canisters be presented and evaluated before permission is considered. In March 2019 SKB submitted supplementary material, as requested by the Government, demonstrating that these issues do not jeopardize the post-closure safety of a KBS-3 repository at the Forsmark site. The matter now rests with the Government. Construction of the repository may start around 2023 and operation may start early 2030, provided the Government grants a decision during 2020. In Finland, a KBS-3 type repository for the spent fuel has obtained a construction license in 2015. Provided licenses are approved operation may start around 2024.

An application to expand the repository for low-level operational waste was submitted in 2014. In January 2019 SSM recommended approval of license in its statement to the Land and Environment Court. The main hearing in Environmental Court will take place in late September 2019, statements to the Government may follow late 2019 and a government decision may be at hand during 2021. Regarding the long-lived intermediate level wastes a safety assessment of a conceptual repository design will be presented during 2019. This will form the basis for further development of the engineered barriers, waste acceptance criteria, and the siting process.

A prerequisite for these advancements is that it has been shown that the repository can be constructed and operated in practice in such a way that safety can be assured both during operation and over very long time scales. The success of the programmes rests on decades of structured and objective driven research and development including both theoretical assessments and practical test in the laboratory and in full scale. This has been possible by a dedication to bring the repository programme to a conclusion with a structured siting strategy, sufficient and long term funding, and a clear strategy for research and development

2. Research strategy

2.1. Objectives

Research has been, and still is, one of the pillars in SKB's programme since its start in the 1970s. The objective of SKB's research programme is to secure safe management and final disposal of nuclear waste by ensuring access to the knowledge that is needed in order to assess a site, design, licence, construct and operate existing and planned facilities. This means that the research should:

– provide sufficient knowledge of post-closure safety and make sure that safety can be assessed for SKB's existing and planned facilities also in the future,
– provide sufficient information for the continued technology development and planning that is needed in order to obtain efficient and optimised solutions that at the same time provide safety both during operation and after closure of SKB's final repository.

2.2. Iterative development of safety case, requirements and design

SKB's programme has developed iteratively where repository designs are evaluated in safety assessments that in turn provide feedback to technology development, design and requirements, see Fig 1. At early stages, i.e. at the presentation of the KBS-3 concept [1] initial conceptual design and low resolution site data from study areas were used as inputs to safety assessments that in turn provided guidance for the future R&D. Since the start of the siting programme around 1992 safety assessment also provided input to determining siting factors [2] and guidelines to the surface based site investigations carried out during the years 2002 to 2008 [3].

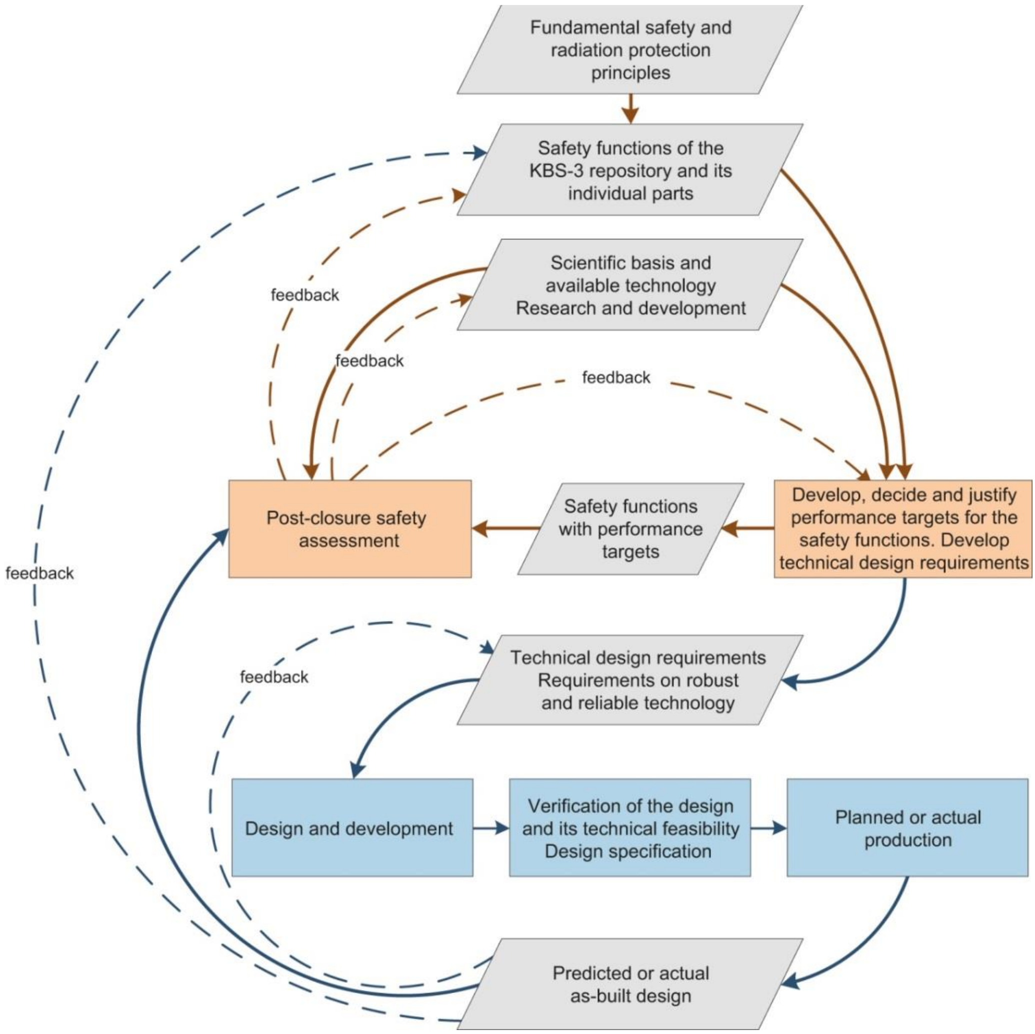


FIG. 1. The iterative process of design and safety assessment [4].

At the time of the submittal of the license application SKB presented a complete safe case, SR-Site [5] constituting the basis of the application. The SSM has reviewed the safety case and while they recommend a license SSM has also identified a long list of detailed issues that need to be resolved prior to operation [6]. Provided SKB's application is accepted by the Swedish Government SKB will then update this safety case into a formal Preliminary Safety Analysis Report (PSAR) also supported by updated requirements and more detailed designs, to be submitted to SSM as a basis for obtaining a license to start underground excavation.

At later stages the PSAR will be updated to a safety analysis report (SAR) that will form the basis for the construction and operation of the repository. Each decision step for a final repository requires an assessment of post-closure safety and prior to each decision the regulator (SSM) is expected to judge whether the knowledge base concerning post-closure safety is sufficient for SSM to approve that SKB should proceed to the next step.

2.3. In-house competence

A key element of the research strategy has been to have sufficient in-house competence in order to maintain its ability to assimilate the knowledge that is present in the community of importance for management and final disposal of nuclear waste, and to be a skilled research client. While a repository programme will need input from a very wide range of scientific and technical disciplines the core of the in house competence has been to maintain a coherent group of professionals with knowledge of the methodology for the assessment of post-closure safety with both wide and deep interdisciplinary insight on how the different processes that affect repository safety interact. Furthermore, by conducting its own research, SKB has ensured this maintenance of competence.

2.4. Openness

Another bearing principle has been that all research should be publicly available and a strive to publish results in open peer reviewed journals. In communicating with the public though media, open seminars or other event SKB also makes sure to let the internal experts be the main spokespersons and to foster a frank and open discussion. Openness and an strive to demonstrate that there is nothing to hide, is judged a basis for developing confidence with the public, the research community and authorities.

2.5. International cooperation

In building up and maintaining competence international cooperation has been essential. This cooperation entails direct cooperation with sister organisations and using experts trained in other programmes as well as participation in the work of International organisations like the IAEA, OECD/NEA and the European Commission. These different international bodies all have their different benefits.

Direct cooperation with sister organisations, like the close cooperation between SKB in Sweden and Posiva in Finland or NWMO in Canada, allows for sharing resources and ensuring that the expertise involved reaches critical mass. Both IAEA and NEA have provided platforms for interaction with peers from sister organisations and also allowed interaction with regulators from other countries. Over the years these interactions have strongly advanced the understanding on how to conduct a repository development programme and how to carry out safety assessments. While the direct funding of research projects by the European Commission has primarily not been an important means of funding, it has allowed networking on a detailed level directly with a broad range of researchers and other experts.

3. Knowledge management tools developed

As the programme developed from feasibility studies and basic research into site characterisation, and repository design, requirements management, workable procedures for data qualification, version control as well as internal and external peer review gained importance. These knowledge management aspects imply a major undertaking and needs to be planned.

3.1. Data qualification

Safety assessment and design work involves several different teams using data on e.g. fundamental processes, site characteristics and design solution and these data originate from various sources of different quality. Furthermore, different teams may need data on the same aspects and phenomena.

When SKB updated the safety assessment methodologies in the mid 1990:ies it was realised that it is necessary to ensure that different teams use the same data for describing the same things and that the quality of the data are assessed as well as their uncertainties [7]. Strict procedures for data and uncertainty qualification were introduced by the concept of data reports [8].

3.2. Site descriptive modelling

When surface-based site investigations were commenced in 2001 the concept of Site-descriptive modelling (SDM) was introduced to provide a description of the investigated sites to be used both as input to the safety assessment and to the engineering design work [9, 10, 11]. Developing an SDM entails transfer of the information from quality-assured databases produced by the site investigations to discipline-specific descriptions applicable to various subdivisions of the system made up of surfaces and volumes. The underlying field data is in its nature often point-wise, varying both spatially and temporally. Evaluation of uncertainties in values of parameters describing the material properties and states of the studied system and the realism in the subdivision of the studied system are central in the analyses. Included in the SDM work is control of primary data, followed by disciplinary and interdisciplinary integrated modelling providing basic geometrical descriptions and parameterisations of the bedrock and the surface system. Due to its nature and its uses, development and updating an SDM forces interaction, not only between experts from different geoscientific disciplines, but also between these experts and designing engineers and safety assessment teams.

3.3. Peer review

Both internal and external peer review are essential quality assurance tools. Starting with the site descriptive modelling works in 2001 SKB has developed and applied strict protocols for these reviews. Review plans are established defining the review criteria and the qualification of the reviewer. A review is conducted using standardized protocols where the reviewer both makes an overall assessment against the review criteria stated in the review plan and provides detailed comments. In completing the reviewed document the reviewee needs to respond to every such comment in writing. While these procedures may have been regarded as tedious in the beginning, they are now seen as essential and a safeguard against the many mistakes that otherwise would have been made.

3.4. Requirements and quality control of production and installation

Confidence in the post-closure safety assessment rests upon

- a sufficient understanding of the Thermo, Hydro, Mechanical, Chemical and Biological processes determining the evolution of the repository system, thereby providing a necessary basis for demonstrating the repository's ability to provide adequate containment and retention, and
- a demonstration that the installed engineered barriers and the underground construction work conforms to stated technical design requirements.

For the former, the thorough process understanding achieved by decades of research is complemented by a research program tailored to the specific conditions at the chosen site. For the latter a Quality Control programme is being developed. This implies possibilities to find potential manufacturing or installation errors or other deviations in material, equipment and handling. Before and during waste emplacement, quality control provides the main source for ensuring that the as-built stage complies with stated design requirements.

The basis for the Quality Control is that there are well-defined technical design requirements against which the compliance can be checked. Formulation of design requirements is not trivial. From the Safety Assessment perspective they should be sufficient to yield a safe repository. From the designers perspective they need to be possible to implement and verify. It is easy to formulate rules that would lead to safety, but are impossible to implement and verify. Iteration and "negotiations" between safety assessment and design work is needed.

An initial set of design requirements were specified in SKB's license application for the spent fuel repository [12]. These concern what mechanical loads the barriers must be able to withstand, limitations concerning the composition and properties of the barrier materials, acceptable deviations in the dimensions of the barriers and acceptance criteria for the various underground openings.

Together with Posiva, SKB has presented revised technical design requirements for the KBS-3 barriers [4] based on the findings from the Swedish and Finnish Safety Cases on how the repository conditions affect the evolution of the safety functions, and experiences from the ongoing technology development. A Technical Design Requirement concerns the characteristics an engineered barrier or underground opening shall fulfil to be approved as a part of a KBS-3 repository. They should be derived such that if an as-built repository fulfils the technical design requirements it would help to show that safety function will be upheld in the long-term evolution. The requirements must be technically achievable and possible to verify at the latest at the time of final installation, deposition or backfilling.

4. R&D challenges in coming phases

When the programmes now enter a new phase of construction and operation new challenges will arise. While the fundamental questions regarding post closure safety should be resolved there is nevertheless a need to be prepared for and adopt new findings that might, somehow, jeopardise long term safety.

Furthermore, implementation and optimisation of the new technologies may present new challenges where new research may provide essential input, although not necessarily in subject areas that traditionally have been judged important. With respect to the previous approach for producing a safety case there are some new aspects to consider.

4.1. Safety case needs to be up to date during the entire operational time

Although a central milestone in the level of knowledge is achieved when SKB obtains permissibility and licence to construct a new facility, the need to be able to make assessments on the safety of final repositories both during operation and after closure does not disappear. These assessments entail requirements of knowledge regarding how both the engineered barriers and the natural processes in the rock and on the ground surface interact and evolve in time. Furthermore, research and new findings regarding the long term properties will continue, both as projects driven by SKB, projects within other implementing organisations and in the scientific community at large. There has to be a readiness to assess the safety implications of such new findings. According to the regulations, the Safety Assessment Report (SAR) should be constantly kept up-to-date. In addition, a periodic overall evaluation of the safety and radiation protection of each facility should be made every ten years according to the requirements of the Nuclear Activities Act.

4.2. Access to detailed data from the underground and local adaption of the repository

Once construction starts there will be new possibilities for characterization and monitoring. Underground construction implies that volumes of the host rock that are hard to characterize from the surface will be accessible to mapping and (short) borehole investigation from the excavated underground galleries [13]. Furthermore, during operation parts of the repository will already have been constructed, characterised and filled with deposited canisters, whereas other parts are yet to be excavated (Fig. 2).

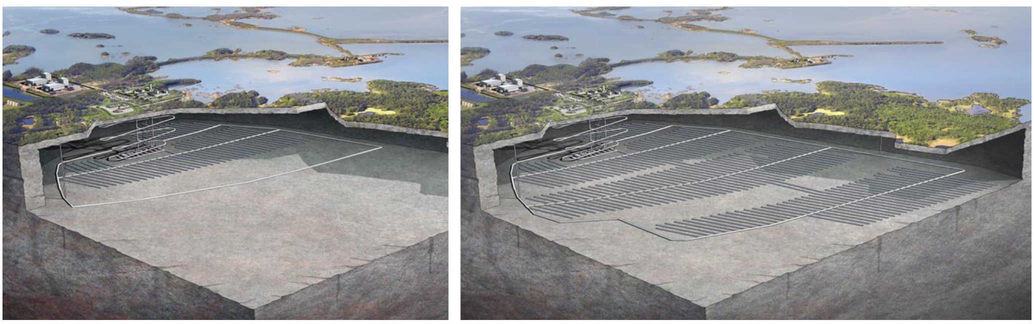


FIG. 2 During operation parts of the repository will already have been constructed, characterised and filled with deposited canisters, whereas other parts are yet to be excavated.

The importance of detailed characterization depends on host rock and repository concept. Crystalline formations are strongly spatially variable in the sense that they are intersected by fractures and deformation zones that never will be fully characterized. Data from detailed characterization are there essential for local adaptation of the location of deposition tunnels and deposition holes and ultimately to confirm site suitability since suitability would depend to what extent such local adaption is possible.

During underground construction in crystalline formations it will be possible to adapt the location of deposition tunnels and deposition holes with respect to local rock conditions. The inclusion and evaluation of such local adaption will be an important part of the safety case. Issues to consider for crystalline rock repositories include distance of the major deformation zones, location of deposition holes to ensure that these are not intersected by large fractures or fractures with potential for high water flow, selection of deposition tunnel orientation and geometry in relation to rock mechanical conditions, and to select a sufficient distance between the canisters to ensure that the bentonite temperature does not exceed the maximum allowed temperature.

Information will be continuously obtained while the repository is constructed and characterised. Pilot holes are planned to be drilled and assessed as a basis to decide whether to excavate a deposition tunnel in a particular part of the repository volume. Excavated tunnels will be mapped and characterised. Pilot holes will be drilled and characterised in potential locations for deposition holes.

While scientific issues and much of the technology to be used for this detailed characterisation is the same as was applied during surface-based operation, there is a difference in scale and resolution to consider. Conditions underground, in particular recognising that characterisation will take place jointly with excavation work, imply practical limitations to characterisation such as limited time, high water pressures and confined spaces. Workers safety need also be handled and the methods applied need to be applicable in practice. Also the speed of interpretation and modelling is essential to ensure that findings from the characterisation really can affect the decisions they are supposed to support.

4.3. Monitoring during construction and operation

Underground construction will also disturb the host rock. Monitoring these disturbances and comparing them with the prediction of disturbances made from the understanding based on the surface data, may provide essential information on the site properties and ongoing processes. In addition, monitoring aspects of the evolution during operation may provide further insights. While monitoring results essentially never can relate to direct safety impacts, a management structure should be in place to handle situations when monitoring results deviate from expectations.

This implies an increased need to understand also the short term changes due to the excavation. A challenge with this approach is that many disturbances caused by underground construction are of a short term transient behaviour and would often be irrelevant once the repository is finally sealed and drainage is ceased. Nevertheless, these short term issues need further attention while still maintaining the basic principle that research should focus on issues relevant to safety.

4.4. Relation between operational safety and post-closure safety

Actions during operation should not only consider impacts on operational safety, but also consider how they might affect post-closure safety. While these two aspects of safety are usually not in conflict, there are a few examples of the opposite. For example, stable rock reinforcement is needed both for workers' protection and to ensure that there are no mishaps during canister emplacement, and the standard means of rock reinforcement may be detrimental to post-closure safety. Further research and development could be justified to resolve such potential conflicts.

4.5. Proved quality control as an essential part of the safety case

As described in section 3.4, Technical Design Requirements (TDRs) have been updated for all barrier components. However, it is still a challenge to ensure that the TDRs are technically achievable and possible to verify at the latest at the time of final installation, deposition or backfilling. Ongoing and future technology developments focus on these aspects.

Quality control implies an assurance that the requirements made on the facilities during operation and after closure of the spent fuel repository are satisfied. Important activities in this process are to establish:

- principles for safety and quality classification,
- what is to be quality-managed and quality-controlled, and
- when quality management and control are to be performed and by whom in terms of first, second and third parties.

This needs to be established in order to qualify processes, methods, equipment and personnel for fabrication and installation, testing and inspection.

Establishing and qualifying all aspects of the quality control system for the spent nuclear fuel repository is a considerable undertaking since many of the quality needs and requirements will be unique for the repository. With respect to the canister, this implies carrying out numerical design and damage tolerance analyses. The results are used to establish dimensions and material properties (including acceptable defect frequencies and sizes) required to provide sufficient resilience to mechanical loads in the repository.

These more specific requirements are used as input to manufacturing specifications and to define the defects that need to be detected in the production and to be controlled during manufacturing, encapsulation and deposition. Among issues to consider for the bentonite components there is a need to establish practical laboratory procedures for establishing that a specific bentonite shipment confirms to the empirical (but brand-independent) TDR:s. Challenges relating to underground construction and local adaptation have already been addressed in section 4.2, above.

4.6. Implementation and optimisation

While SKB has established a technically feasible reference design and layout, detailed designs adapted to an industrialised process designed to fulfilling the specific requirements on quality, cost and efficiency need still to be developed. These updated designs should result in at least the same level of safety as the current reference design and should be implemented in the various production systems needed for the repository. These include canister production, encapsulation of spent fuel, transport, bentonite production, underground excavation and deposition activities.

Constructing and operating the repository implies that many procedures will have to operate in conjunction. While each component and each subsystem may have been tested many times new challenges will arise when all these system should operate together and in accordance with the practices of operating a nuclear facility. This means that new development needs, or even needs to revise requirements, will arise during implementation and operation.

Optimisation is another driver for additional research and development. Due to the complexity of the technical and scientific issues at hand research and development up to the license application primarily focus on developing a repository that is both safe and constructible, whereas questions regarding what is most economically optimal need to come second. Since the submittal of the license application SKB has now entered a phase of "value engineering". Value engineering is a systematic and organized approach to provide the necessary functions in a project at the lowest cost without sacrificing functionality. Issues considered include size of the underground openings, excavation methods, thermal dimensioning and deposition sequence logistics with associated need of machinery and storages. While optimisation studies appear to be very promising, they cannot be undertaken too early in the repository programme. On overall system understanding, a complete set of detailed safety functions and technical design requirements and understanding of the logistics is needed before such studies are meaningful. Otherwise there is a great risk of arriving at sub-optimal solutions.

4.7. Knowledge management and in-house competence needed

Research and development will need to continue also after a license to construct a repository is granted. There is also a need to apply, maintain and develop the knowledge management tools already established.

Workable procedures for information handling and QA are already developed and successfully applied but wealth of information and pressure to act quickly will increase when construction and operation starts. A structure for requirements management and quality control of production and installation is established and workable requirements are formulated, but the application during construction and operation still lies in the future. These tools will also be used by even larger groups of experts.

Due to the complexity of issues at hand implementing organisations would need to keep a core competence on post closure safety assessment including at least on overall understanding on how the repository components evolve over time. An important part in each assessment of post-closure safety is the evaluation of the knowledge base both with regard to processes and input data in the assessment. Safety assessments are thus fundamental for the prioritisations of the research programme. However, it may be more difficult to attract a new generation of researchers and to justify funding the R&D when the fundamental issues are less acute.

4.8. Role of international cooperation

In the future international cooperation will be even more important on developing, sharing and managing the knowledge needed. Guidelines and other recommendations issued by the international agencies will not only be important for developing programmes but would also serve as a fundamental memory in more developed programmes when the experts ones being authoring such guides now have retired or soon will retire. International cooperation is also essential for sharing competences where the national contexts is too small, especially on issues essentially only of interest to the nuclear waste community. Participation in international work may also be an inspiration and reason to carry on for internal staff, as well as researches at universities, to consider the work sufficiently interesting.

5. Conclusions

SKB is closing the back end of the fuel cycle, but research and development would need to continue, although with a new focus. There is also a need to apply, maintain and develop the knowledge management tools already established. In the future international cooperation will be even more important on developing, sharing and managing the knowledge needed.

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LENA ZETTERSTROM EVINS

SPENT NUCLEAR FUEL DISSOLUTION RESULTS FROM COMPLETED PROJECT REDUPP AND ONGOING PROJECT DISCO

L.Z. EVINS[1], L. DURO[2], A. VALLS[2], C. CORKHILL[3], E. MYLLYKYLÄ[4], I. FARNAN[5], D. BOSBACH[6], V. METZ[7], P. MALDONADO[8]

[1]Research and Post-Closure Safety, Swedish Nuclear Fuel and Waste Management Co., Evenemangsgatan 13, Box 3091, SE-169 03 Solna – Sweden
[2]Amphos 21 Consulting S.L. c/ Veneçuela, 103. 2nd floor. 08019 Barcelona – Spain
[3]Department of Materials Science and Engineering, The University of Sheffield, Mappin Street, Sheffield, S1 3JD – United Kingdom
[4]VTT Technical Research Centre of Finland Ltd, P.O. Box 1000, FI-02044 VTT, Espoo – Finland
[5]Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB2 3EQ – United Kingdom
[6]Nuclear Waste Management (IEK-6), Forschungszentrum Jülich GmbH, Wilhelm-Johnen-Strasse, D-52428 Jülich – Germany
[7]Karlsruhe Institute of Technology - Institute for Nuclear Waste Disposal (KIT-INE), Hermann-von-Helmholtz-Platz 1, DE-76344 Eggenstein-Leopoldshafen – Germany
[8]Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala – Sweden

Abstract. This contribution summarizes results and progress in two projects: REDUPP and DisCo. REDUPP finished a few years ago while DisCo is on-going and only initial, preliminary results are available. The projects focus on processes occurring at the interface between spent nuclear fuel and aqueous solution. This includes redox reactions but also dissolution from high-energy sites and processes occurring at or near equilibrium. Uncertainties investigated here are if additives in modern fuels, such as Cr or Cr+Al, or, as in the case of MOX fuels, Pu, can influence these processes significantly. Reducing conditions are expected overall although local repository environment will influence the water composition. Therefore, experiments and models are set up to test the effect of different water chemistries. Real spent nuclear fuel experiments, complemented with studies on model materials, provide further insight in the detailed mechanisms involved in spent nuclear fuel dissolution.

1. Introduction

The safety assessments for the planned spent nuclear fuel and high level waste repositories in Europe can be considered to rely on two main principles: first to keep the radionuclides contained in the waste package, and secondly, in case of a container breach, to retard the outward migration of radionuclides. The second part starts with release from the waste itself to the transporting medium, normally water. Due to its central part in the safety assessment, dissolution of spent nuclear fuel in a repository environment has therefore been investigated for many years within the framework of Euratom in a succession of collaborative projects. This paper involves two projects: REDUPP and DisCo. REDUPP started in FP7 and was finished 2014, while DisCo is an ongoing H2020-project. Both projects deal mainly with issues concerning matrix dissolution of spent nuclear fuel: in light of very low matrix dissolution rates stemming from the dissolution inhibiting hydrogen effect, certain aspects need to be better understood, such as the effect of the solid phase characteristics on the oxidative and non-oxidative dissolution in reducing conditions. The results of REDUPP are available in the open literature, while the DisCo results are currently being produced and only preliminary data are available at the time of writing.

1.1. REDUPP

REDUPP (Reducing Uncertainty in Performance Prediction) investigated two remaining uncertainties regarding dissolution data used in safety assessments: the effect of surface characteristics of the solid state, and the effect of natural groundwater compared to synthetic. Any solid sample surface is characterised by varying amounts of so-called "high-energy sites". These may be found on different scales: atomic and nanoscale, microscopic, and macroscopic. Previous data indicated that the history of UO_2 fragments used in experiments affected the calculated dissolution rates [1]. The reason seemed to be that the high-energy surface sites disappeared and the surface matured and evolved towards equilibrium in the successive experiments. This hypothesis was investigated in the REDUPP project by using analogue materials avoiding the complex redox behaviour of uranium: CaO_2 and ThO_2. In addition, the effect of natural groundwater on the dissolution of UO_2 was investigated. Commonly, dissolution experiments are performed using some kind of simplified aqueous solution. Natural ground waters have a more complex composition which may affect aqueous speciation and the dissolution process. This was also investigated in the REDUPP project using alpha-doped UO_2 in three different ground waters.

1.2. DisCo

Several decades of research into spent nuclear fuel dissolution has built a firm knowledge base for standard UO_2 fuel, including high-burnup fuels. Still, some uncertainties remain. The DisCo (Modern spent nuclear fuel Dissolution in failed container Conditions) project focuses on another uncertainty that has become more relevant in later years. As a way to utilise nuclear fuel more efficiently, nuclear power plants use modern types of nuclear fuel which contain additives (also called dopants) [2]. Most common dopants are Gd, Cr and Cr with Al. In addition, mixed-oxide fuel containing a certain amount of Pu (MOX) is also being used in some countries. Fuel developers are also looking into possibilities of using Th in the nuclear fuel. How these changes in chemical composition affect the characteristics of the spent nuclear fuel in repository environment is uncertain. The DisCo project therefore focuses on the experimental study of the dissolution of these types of materials and the development of models to enhance our understanding of these modern fuels in comparison with traditional fuels.

2. Methods

The details of the experimental methods are given in specific publications. Here we only present the general principles behind the approach, methods and experimental set-ups used in the projects discussed.

One approach in both REDUPP and DisCo is to use analogue materials to reduce some of the complexity of the spent nuclear fuel from the experiments. This allows the investigation of single parameters and their influence on the results. This is done to complement spent nuclear fuel dissolution experiments. The manufacturing of analogue materials can be done using different approaches, such as dry or wet synthesis followed by calcination and classic sintering, or sintering using Hot Isostatic Pressing; in the end, all routes aim for a final homogenous material with similar density and grain size as the spent nuclear fuel. This initial sample preparation step is quite time and resource consuming. Some analogue materials also employ an alpha-emitter (Pu-238) which requires a tried, tested and optimized synthesis route before final material is made. It is also of central importance that the initial state of the solid sample is sufficiently characterised, to identify changes caused by water contact. Methods used are for example X-Ray diffraction and electron microscopy using various features such as electron back-scatter diffraction patterns.

The core of the experimental investigations is the dissolution experiments. Since the aim is to investigate processes relevant to repository environments, most experiments are performed in reducing conditions. The expected Eh in a KBS-3-type repository, as envisaged by SKB and Posiva, is between -400 and -200 mV at near neutral pH conditions and regulated by the anoxic corrosion of Fe(0) and consecutive hydrogen production due to reduction of groundwater. This means that the experimental systems require very low pO2 and elevated hydrogen concentration, respectively, to be representative of the near-field environment of the repository environment. These conditions are commonly achieved by using autoclaves with controlled atmosphere. In an appropriate inert-gas glove box this environment can also be achieved if an additional reducing agent is used to remove traces of oxygen. For spent nuclear fuel experiments in autoclaves, hydrogen or hydrogen mixed with an inert gas is used to achieve representative, reducing conditions in the close vicinity of the spent nuclear fuel surface. In an anaerobic glove box, corroding iron is used to produce hydrogen and Fe(II) in solution which results in the required low Eh. Some experiments are performed also to observe the dissolution under higher Eh: that is in oxic conditions with or without hydrogen peroxide which accelerates the oxidation of UO_2. In the REDUPP project, dissolution was also performed in acidic conditions, in order to produce observable effects during the planned experiment.

The composition of the aqueous solution is analysed at various times during the experiment to determine the concentration of uranium and other relevant elements. This is normally done by inductively coupled plasma mass spectrometry (ICP-MS). It should be noted that the materials investigated are, in neutral and reducing conditions, insoluble or very sparingly soluble, and the concentration in solution is very low. This requires high resolution instruments with low detection limits. For some radionuclides, radiometric methods are also used. When dissolution experiments are finished, the samples are investigated with various techniques such as Scanning and Transmission Electron Microscope, to be compared with the initial state of the samples.

The dissolution process is also explored through different modelling approaches. In REDUPP, modelling was performed from first principles so look at dissolution at an atomic scale. This was combined with thermodynamics to analyse the effects of the different water reactions on UO_2 surfaces when exposed to water environments. In DisCo, thermodynamic modelling approaches are used both to investigate the solid (oxygen potential, solid solution model), and to develop reactive transport models involving both the dissolution of the solid and the transport in the failed container environment. Specifically, the codes used are GEM-Selektor, Chemisimul, PhreeqC coupled with Comsol Multiphysics, CHESS-HYTEC. In addition, an electrochemical mixed-potential model is developed for the modelling of corrosion of fuel in storage ponds.

3. Results

An overview of final results of REDUPP and initial, preliminary results of DisCo are provided below. In general, the results point towards the importance of including solid state characterisation both before and after dissolution experiments to improve interpretation of aqueous concentration data collected during the experiment.

3.1. REDUPP

Results from the REDUPP project have been published both as open reports and scientific, peer-reviewed articles. REDUPP was presented at Euradwaste 2013 in Vilnius, and an overview of results up to that point is given in the conference proceedings [3]. The project finished in 2014 and the final project report [4] gives an overview of the achievements. Some results have been published at a later date.

Experiments on CeO_2 show fast initial leaching rates that are decreasing as dissolution proceeds. The use of polycrystalline samples show that initial dissolution is focused on grain boundaries. Grain boundaries with high misorientation angle retreats more rapidly than those with low misorientation angles. A strong crystallographic control was exerted. It was also noted that sample preparation may induce defects and strain which enhances the dissolution rate [5]. To further explore the importance of intrinsic defects, oxygen vacancies were introduced in the CeO_2 material through treatment in a reducing atmosphere form CeO_{2-x}. This material was then dissolved in nitric acid at 90°C. The results show that replacement of vacancy sites by oxygen during dissolution caused changes in the lattice volume and strain. This process increased dissolution rate and caused grain boundary decohesion. The results indicate the importance of defect sites and grain boundaries on dissolution kinetics [6].

The dissolution rate of ThO_2, with a very low solubility at the experimental conditions, is seen to be clearly affected by pH and complexing ligands. By using an isotopic tracer (Th-229) in some of the experiments, information was gained regarding the surface processes. At apparent chemical equilibrium, a continued isotopic exchange indicates that both dissolution and precipitation is occurring (Fig 1). The dissolving material provides the Th-232 to the aqueous solution, indicating that the original solid surface keeps dissolving, while precipitation also occurs in the vessel [7]. An alpha-spectrometry study of the ThO_2 surface after the experiments indicated the presence of a surface layer, maximum 0.1 µm thick, which had been affected by the dissolution precipitation reactions [8].

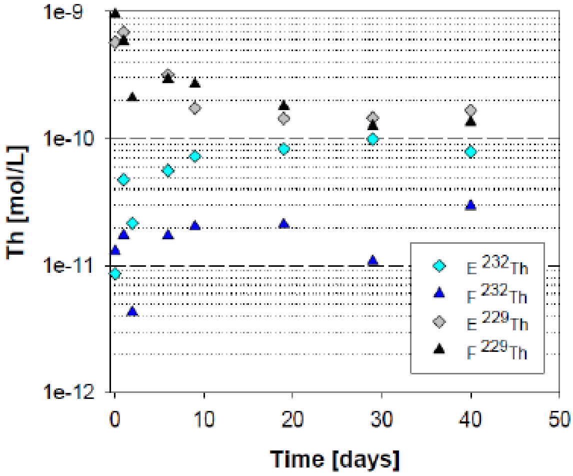

FIG. 1. Isotopic exchange observed in experiments with ThO_2, using Th-229 as a tracer. From Figure 4-6 by Myllykylä et al., in the final REDUPP report [4].

The results point to the importance of surface characteristics at least for initial dissolution rates in experimental conditions. A closer look at the solid surface and solid-liquid interface can reveal crucial information regarding the dissolution processes is of interest. In the REDUPP project, surfaces of minerals with fluorite structure were modelled using Ab Initio methods. The focus was the reactivity towards H2O, and this was explored using Ab Initio Molecular Dynamics, combined with atomistic thermodynamics. The results show that a hydroxylated surface is formed through dissociative chemisorption of water and this is stable at all environmentally relevant conditions [9]. This adjustment of the surface is predicted for certain surfaces and for varying environmental conditions, ie temperature and pressure (Fig. 2).

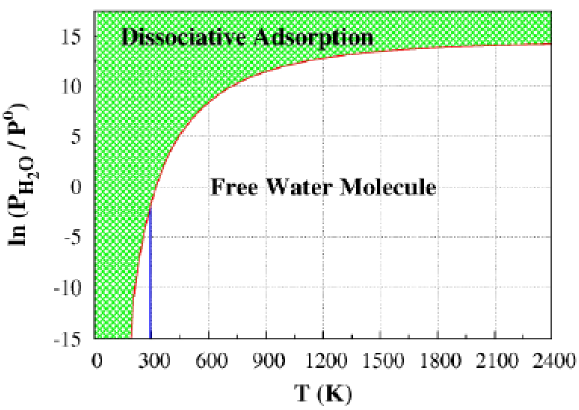

FIG. 2. Phase diagram computed from first principles showing the temperature and pressure where dissociative adsorption of water (green area) is expected on the (111) UO_2 surface. From Figure 7-2 by Maldonado et al, in the final REDUPP report [4].

Aqueous fluids in contact with dissolving solids contain various components that may influence speciation, solubility and interfacial reactions. Effects of three different natural ground waters were seen as a slight elevation of the calculated dissolution rates of UO_2; the effect is most pronounced for fresh groundwater which had the highest carbonate and silicate content of the different waters [4, 10]. The lowest rates were found for the most saline ground water (Fig. 3). Experiments using an isotope tracer (U-235 in aqueous solution), showed that isotope exchange occurred during the experiment when the system was close to chemical equilibrium. This isotope exchange is a result of dissolution and precipitation and/or sorption in the reaction vessel. The measured concentration of uranium in fresh groundwater was, after ca 250 days, between 10-11 and 10-12 M. Some precipitates, found on the Fe-strips used in the experiments, contained both U and Si [4], but it was not possible to perform X-ray diffraction on these small precipitates.

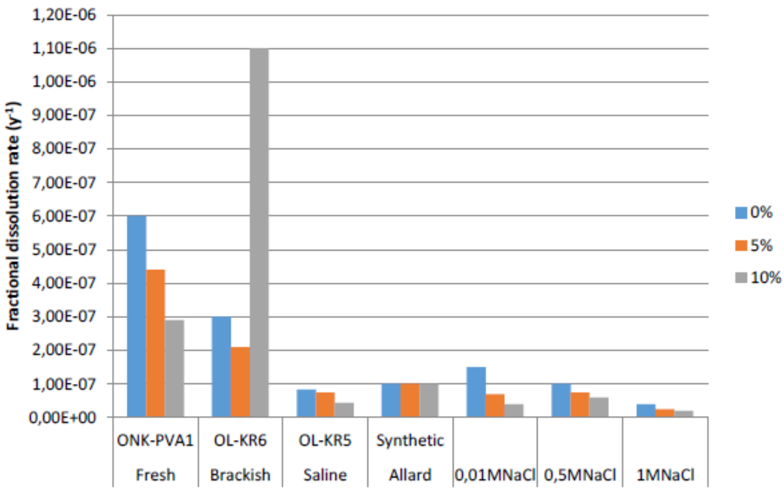

FIG. 3. Fractional dissolution rates calculated from isotope dilution experiments using UO_2 doped with 0%, 5%, and 10% U-233. Data is taken from Table 5-3 and 5-4 of Ollila et al. in the final REDUPP report [4]. Results from natural ground waters are given for the higher surface to volume ratio data.

3.2. DisCo

At the time of writing, the DisCo project has been running for 20 months. Initial results have been presented at the first Annual Meeting, the proceedings of which are available for download at the project web page (www.disco-h2020.eu). During the first part of the project most work has been focused on synthesis and characterisation of fuel analogue materials as well as on preparation and characterisation of specimen sampled from real irradiated fuel rods, in preparation for the dissolution experiments. Information regarding samples and sample characterisation is found in Deliverable D2.1 [11]. The preparation of samples of real spent nuclear fuel is done by means of remote handling in shielded cells. Irradiated fuels investigated are standard UO2 fuel (as reference), Cr-doped UO_2 fuel, (Cr+Al)-doped UO_2 fuel and MOX fuel, (i.e. (U, Pu)O_2 fuel).

Samples destined for dissolution are prepared either as segments of an irradiated fuel rod, with the cladding still present, or as fragments with the cladding removed (Fig. 4). Samples are also prepared for ceramography (microscopic characterisation) and for determination of chemical inventory and burn-up. In order to use the autoclaves in the dissolution experiments, they have been modified to enable remote handling by manipulators in shielded cells, intensively cleaned, and tested for air tightness.

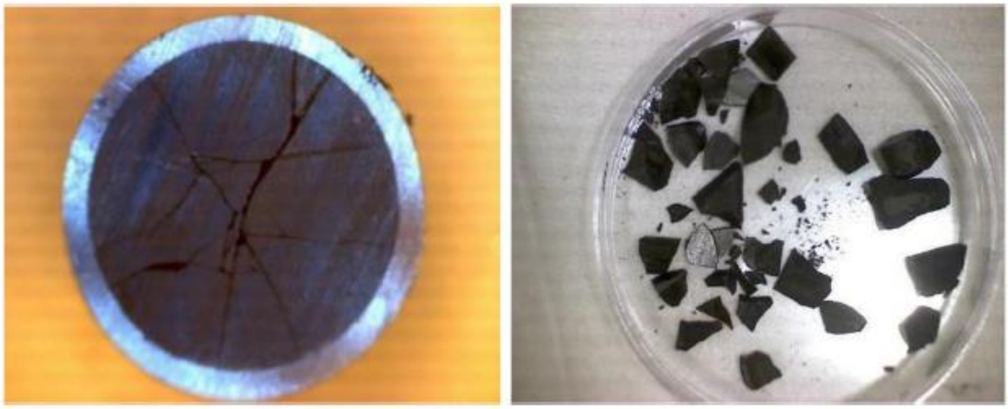

FIG. 4. Spent MOX fuel (38 GWd/t burn-up) prepared at KIT-INE (Fig. 2.1.1 in [11]).

Synthesis of analogue materials involves characterisation, such as testing for density and grain size, during the process to ensure optimized final products. The following materials have been synthesized and characterised: UO_2 (as reference), UO_2+Gd, UO_2+Cr, UO_2+Cr+Al, (U,Th)O2. UO_2 doped with U-233 and unirradiated, homogenous (U, Pu)O_2 were already available. Using a wet coating technique, Cr-doped UO_2 has been produced with enhanced grain size, as is desired (Fig. 5). X-ray diffraction of the final product suggests that introducing Cr and Al into the UO_2 produces a contraction of the cubic lattice.

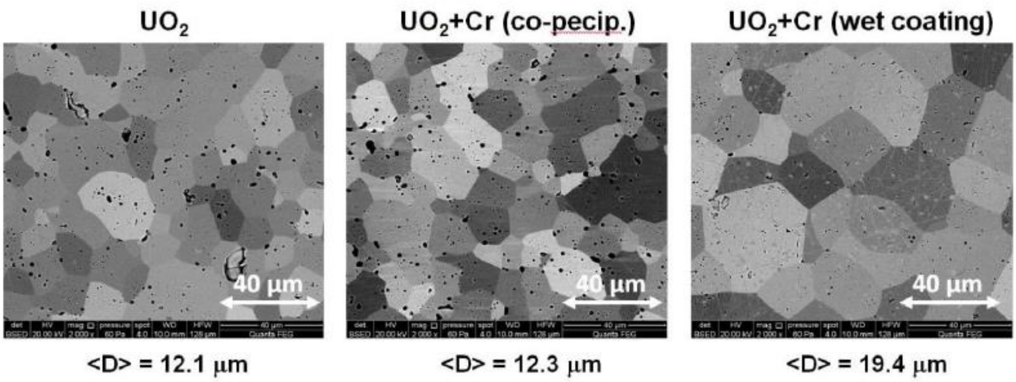

FIG. 5. UO_2 and Cr-doped UO_2 prepared at Forschungszentrum Juelich (Fig. 3.1.4 in [11]).

The preparation of UO_2 doped with Pu-238 to mimic aged spent nuclear fuel is on-going at the time of writing. An overview of planned and started dissolution experiments is given in Table 1. Some initial, preliminary results from the dissolution experiments are presented below.

TABLE 1. Experimental matrix for DisCo. Status at the time of writing (February 2019). BW= Bicarbonate water. YCWCa= Young Cement Water with C., GW= Ground Water. Cox = Callovo-Oxfordian Water.

Reducing (H_2, mix H_2+ Ar/N_2, or anoxic with corroding Fe)				
Water type	**BW**	**YCWCa**	**Natural GW+Fe**	**Synthetic Cox+Fe**
Solid				
UO_2 (reference)	**Started**	**Started**	Planned	
UO_2+Gd	**Started**	**Started**		
UO_2+Cr	**Started**	**Started**	Planned	
UO_2+Cr+Al	**Started**	**Started**		
$(U,Th)O_2$	Planned	Planned		Planned
UO_2 ref - $^{238}Pu/^{233}U$	Planned	Planned	Planned	
UO_2+Cr- ^{238}Pu	Planned	Planned	Planned	
$(Pu,U)O_2$				**Started**
Spent nuclear fuel UO_2	Started	Planned		
Spent nuclear fuel Cr&Al-UO_2	Started			
spent nuclear fuel Cr- UO_2	Planned			
MOX	Started			
Oxidizing/Anoxic (Ar, H_2O_2, or Air)				
Water type:	**BW**	**YCWCa**	**Natural GW+Fe**	**Synthetic Cox+Fe**
Solid				
UO_2 (reference)	**Started**	**Started**		
UO_2+Cr	**Started**	**Started**		
Spent UO_2 fuel		**Started**		
Spent MOX fuel	Planned			

Standard UO_2 fuel dissolved in young cement water with Ca (YCWCa, high pH) has been performed in air-saturated conditions. Preliminary results show rapid initial release of radionuclides followed by slower dissolution. Comparing with results from previous experiments performed with bicarbonate water and neutral pH, two observations can be made: 1) higher initial Mo release in YCWCa 2) lower U release and U concentration in YCWCa.

Oxidative dissolution of UO_2 has been investigated using pure and Cr-doped UO_2 in hydrogen peroxide containing aqueous solutions. A successive decrease in uranium concentration is observed in each successive experimental run. This decrease appears to be independent of the initial hydrogen peroxide concentration. Preliminary experiments imply that the dissolution rate of Cr-doped pellets is independent of the doping method (co-precipitates or wet-coating). The direct view on dissolution is unclear because of the apparent passivation of the pellet surface due to the formation of precipitates. Further experiments will clarify the process of surface passivation for comparison between pure UO_2 and Cr-doped UO_2 materials.

Homogenous, unirradiated MOX pellets with a high amount of Pu (ca 25%, $2.2 \cdot 10^{9}$ Bq/g) have been dissolved in synthetic Callovo-Oxfordian (COx) water, pre-conditioned with corroding Fe. The radioactivity of the sample is expected to cause radiolysis and thus produce oxidants such as hydrogen peroxide. The experiment was run with an atmosphere of an Ar/CO_2 gas mixture. Preliminary results indicate that the Fe has a significant effect on the oxidative dissolution; uranium concentration after several months is less than 1 µg/L, i.e. less than ca $4.2\ 10^{-9}$ M.

Thermodynamic calculations of Cr-doped UO_2, simplified as an ideal solid solution, have been performed. This results in slightly lower oxygen potentials than the pure Cr and Cr_2O_3 systems. Calculations involving a full model spent nuclear fuel composition results in much higher oxygen potentials. These initial, preliminary results indicate that the stable oxidation state for Cr in the spent nuclear fuel will be Cr(III), and that the oxygen potential of the Cr-doped and spent nuclear fuel will be similar. It should be noted that this is based on the assumption of ideal solid solution.

For spent nuclear fuel dissolution, a model involving the catalytic effect of metallic aggregates (simulated with Pd) on the electron transfer from hydrogen to uranium is being developed. A first version was presented at the first annual DisCo meeting. The model employs the Chemsimul code to simulate the water radiolysis. The results from Chemsimul is then used in a reactive transfer model implemented in iCP (interface coupling COMSOL Multiphysics and PhreeqC). Validation of this first version of the model, using existing data (Fig. 6), shows that including the hydrogen activation results in a more realistic description of the spent nuclear fuel dissolution process.

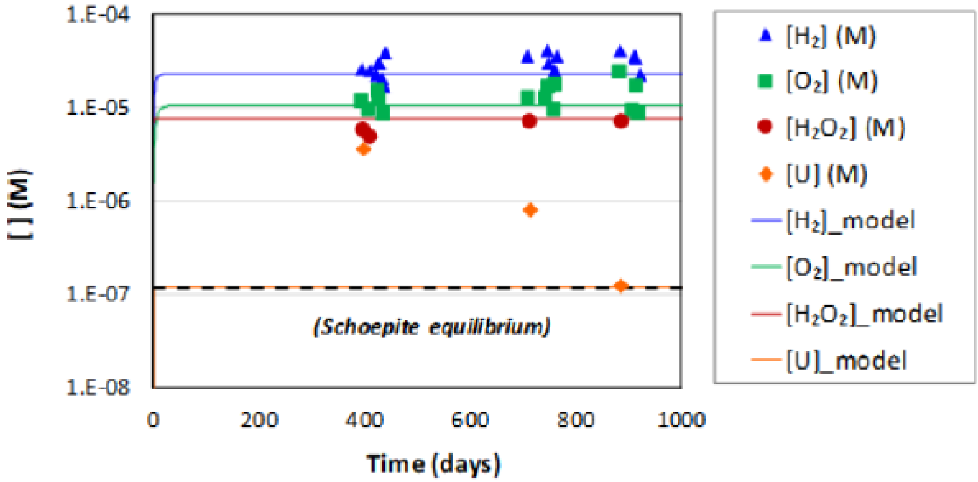

FIG. 6. Experimental data from Cera et al [12] and model results from the DisCo project (Fig. 2 in Riba et al., in [13]).

The development of the electrochemical model is on-going and results not yet available. However, it has been noted that, after some adjustments to remedy observed issues with previous models, the model now is able to produce the expected responses to the presence of hydrogen, noble metal particles, iron and alpha radiolysis.

The effect of Fe, observed in dissolution of unirradiated MOX fuel in synthetic COx water, has been successfully modelled by a preliminary version of the CHESS-HYTEC model. The model considers the kinetics of the reaction expected at the pellet surface, resulting in a progressive decrease of pellet dissolution and hydrogen peroxide concentration over time.

4. Discussion

Based on results from decades of research, there is now a general understanding and an accepted view of what processes control the rate of spent nuclear fuel dissolution. Most important is the oxidation of the fuel matrix; in an oxidizing environment, uranium will oxidize and UO_2 will transform, through dissolution and precipitation, to various minerals containing U(VI). This oxidation can be quite rapid and thus has the potential to control the overall dissolution rate of spent nuclear fuel. However, in experiments using alpha-doped material, used to simulate aged spent nuclear fuel, it is noted that when the alpha-radiation is below a certain value, there is no observable oxidation. Suppression of the oxidation of spent nuclear fuel with an overpressure of hydrogen has been experimentally observed. In the repository environment, at the time when water comes in contact with fuel, both of these situations will be expected: aged spent nuclear fuel, and hydrogen overpressure from the anoxic corrosion of iron. Therefore, the situation where UO_2 oxidation caused by radiolysis is negligible, or occurs at a rate which is not observable on an experimental time scale, is not unreasonable but rather expected, c.f.[14]. This is the view developed from studies made on standard UO_2 fuel in simple groundwater simulates. The question is if this is applicable also on doped fuels and MOX fuels?

The interfacial reactions that are at the core of these processes involve electron transfers. In the case of the dissolution inhibiting hydrogen effect, electrons are transferred from the hydrogen to the UO_2 matrix via the particles of metallic fission products (so-called ε-phases). Galvanic coupling of H_2 oxidation on metallic particles to UO_{2+x} reduction on the fuel surface appears to reverse the U oxidation at the U(V) stage [15]. The use of modern fuels which employs additives such as Cr or Cr and Al, may interfere with the UO_2 lattice and these electron transfer processes, potentially affecting the efficiency of the hydrogen effect. This is also possible for MOX fuels. Preliminary results from DisCo shows that the hydrogen effect can be incorporated in the models and when experimental data are available, this will be tested.

The chemical composition of the waters in the repositories may also influence these processes. In oxidizing conditions with real spent nuclear fuel, such as tested in DisCo, lower uranium concentrations are found in cementitious water (YCWCa) compared to bicarbonate water. It is hypothesized that this is due to the formation of a secondary phase. If saturation is reached with regards to a secondary uranium phase it is not possible to use the change in uranium concentration over time as an indicator of dissolution rate, or rate of radionuclide release. A secondary phase precipitated on the surface of UO_2 might also have formed in the DisCo experiments employing hydrogen peroxide to accelerate UO_2 oxidation; in this case, the secondary phase appears to have affected the reactivity of the original surface. Uranium concentrations above the expected U(IV) solubility indicates U(VI) in solution. As long as the concentration measured is below saturation level of a U(VI) solid, a continuous rise in concentration can be interpreted as oxidative dissolution and a dissolution rate can be estimated. Uranium speciation is affected by both pH and various components in the water, so these aspects need to be taken into account when interpreting the data. For example, in the case of natural groundwater, it was observed during REDUPP that calculated rates were higher for the fresh water with higher carbonate and silicate contents. Some secondary phases were observed that contained both U and Si; thus, it is possible that uranium speciation and solubility limiting phases (potentially coffinite) was affected by the different groundwater compositions.

In the case of low level alpha radiation, as in aged fuel, or when there is hydrogen and iron present that keeps the Eh low even at the surface of the fuel, the rate of oxidation may be lower than the rate of dissolution of UO_2 driven by the degree of deviation from equilibrium, ΔG_r. If so, one has to consider processes relevant for when the system is close to equilibrium. This was the focus of the Euratom project SKIN and discussed by Grambow et al. [16]. The radionuclide release in this situation can be controlled by the removal of U from the water either through advection (water flow) or through the precipitation of a more stable phase, keeping the water unsaturated with regards to the spent nuclear fuel matrix. The latter process can be recrystallisation or chemical alteration of the spent nuclear fuel matrix. There are isotopic exchange data that indicate that this process occurs [1,7,16]. Results from REDUPP show that during the initial phase of dissolution, the sample surface adjusts to a lower energy state. This occurs by dissolving sites with higher energy such as defects and grain boundaries, but also higher surface energy crystallographic faces will preferentially dissolve. It seems, however, for UO_2 and ThO_2 that the amount altered during the experiment is limited to only a part of the sample surface [16]. The REDUPP results indicate that the high-energy sites at the sample surface are indeed releasing material to solution at a rate which is initially fairly rapid, but which slows as the experiments proceeds. The DisCo experiments, involving both pre- and post- dissolution characterisation, will enhance our understanding not only of the effects of additives, but of how the sample surface is changed by dissolution.

5. Concluding remarks

This contribution aims to provide an overview of the final results of the REDUPP project and some initial results of the DisCo project. The research performed in these projects enhances our understanding of the processes involved in spent nuclear fuel dissolution. Based on knowledge gained from previous Euratom projects, it is possible to focus specifically on processes expected during reducing conditions, and test how solid and fluid state composition may affect these.

We have shown that during the initial stages of dissolution experiments, there is an interval where the solid surface adjusts towards a state of lower energy. This happens also when the experimental system is close to equilibrium. Surfaces with a fluorite structure, such as CeO_2, ThO_2 and UO_2, are predicted to cause dissociation of water to form a hydroxylated surface. In this process, depending on which crystallographic structure is being exposed, the surface structure will be adjusted on an atomic scale. Surface defects and grain boundaries are also show to be preferentially dissolved during this initial stage, which is characterised by a higher dissolution rate. The dissolution is accompanied by precipitation when the system is close to equilibrium. This dissolution-precipitation is observed through isotopic exchange in experiments with UO_2 and ThO_2. A clear crystallographic control and effects of surface characteristics on an atomic scale indicates that anything that may affect the crystal lattice, may also affect these processes. Therefore, the effect of additives is being studied in the DisCo project.

The initial results from the DisCo project presented here relates mainly to the successful production of analogue materials, preparation of specimen sampled from irradiated fuel rods and the characterisation and control of the experimental systems. The synthesis of these various materials has been optimized. By characterising the final solid product by X-ray diffraction, the effect of additives on the cubic lattice can be observed: doping UO_2 with both Cr and Al produces a homogeneous material but with slightly contracted lattice. Regarding dissolution, some reference experiments have been performed, such as UO_2 and spent nuclear fuel dissolution in oxidizing environments in different aqueous solutions. Observed differences in results are now being interpreted. Experiments and models concerning Pu-rich unirradiated MOX in synthetic, Fe-calibrated Callovo-Oxfordian water have produced some initial results. The redox reaction between iron in solution and hydrogen peroxide is central in the system, and the preliminary results indicate that uranium is kept reduced. Preliminary modelling also suggests that the hydrogen effect can be included in the models and successfully predict experimental results.

The research presented here will have an impact on the safety assessments of the spent nuclear fuel repositories in different environments. The results will reduce some remaining uncertainties in the parameters of the assessments and be informative for future discussions concerning the possible challenges of disposal of the newly developed fuels before they are included in the nuclear fuel cycle on a large scale. This is important for the steps taken towards implementation and licensing of the repositories.

Acknowledgements

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SIMON NORRIS

OVERVIEW OF CAST PROJECT

S. NORRIS[1], M. CAPOUET[2]

[1]CAST project co-ordinator, Radioactive Waste Management Limited, B587, Curie Avenue, Harwell Campus, Didcot, Oxon, OX11 0RH, United Kingdom
[2]Ondraf Niras, Avenue des Arts 14, 1210 Brussels, Belgium

Abstract. The European Commission CAST project (CArbon-14 Source Term) aimed to improve the scientific understanding of carbon-14 (radiocarbon, ^{14}C) release mechanisms and associated release rates from the corrosion of irradiated steels and Zircaloys and from the leaching of ion-exchange resins and irradiated graphites, under geological disposal conditions. The project considered the release of carbon-14 as dissolved and gaseous species from these materials, evaluating new understanding in the context of national safety assessments and disseminating this understanding to stakeholders. This paper provides an overview of the CAST project and its output.

1. Introduction

Carbon-14 (radiocarbon, 14C) is present in important amounts in the radioactive waste inventories of many national waste management programs, particularly in irradiated steels, irradiated Zircaloys, spent ion-exchange materials (resins) and irradiated graphites. The knowledge regarding the chemical form and the release mechanism of carbon-14 from these wastes in disposal conditions — be they surface-based or an underground geological repository — is limited. Therefore, in precedent safety assessments it is often assumed that carbon-14 is released from irradiated metals in a single chemical form at a rate dependent on the corrosion rate of the metal and the inventory of carbon-14. Similarly, estimates of the rate of release from irradiated graphite may be based on simple assumptions about the proportion of the carbon-14 that is 'labile' and on short-term leaching results. Such conservative treatments possibly give rise to over-estimated radiological impacts.

The European Commission CAST project (CArbon-14 Source Term) aimed to improve understanding of the potential release mechanisms of carbon-14 from radioactive waste materials under conditions primarily relevant to disposal to underground geological disposal facilities. The project focused on the release of carbon-14 as dissolved and gaseous species from irradiated metals (steels, Zircaloys), from spent ion-exchange materials and from irradiated graphites.

Carbon-14 shows different behaviours in typical repository environments depending on whether it is in inorganic or organic form. As carbonate, carbon-14 shows excellent retention in cementitious and clay environments due to isotopic exchanges, whereas it is an unretarded element, possibly in the gaseous phase, when it is an organic species.

The primary focus of CAST was thus to discriminate experimentally between these two different forms, with possibly a more precise characterisation of the speciation of the carbon-14 bearing compounds released from these wastes investigated in this project.

The CAST consortium brought together 33 partners with a range of skills and competencies in the management of radioactive wastes containing carbon-14, geological disposal research, safety case development and experimental work on gas generation. The consortium consisted of national waste management organizations, research institutes, universities, and commercial organizations. Although CAST was funded by the European Commission, the participation of non-EC partners was welcomed.

The interested reader is also directed to the CAST website (www.projectcast.eu) and the special issue of the Radiocarbon journal dedicated to CAST (Volume 60, Number 6, 2018), where further project deliverables are publicly accessible.

2. Summary of project output

For steel and Zircaloy, exhaustive literature reviews and experimental studies on their corrosion rates were carried out in CAST, to bound the carbon-14 source term.

Steel corrosion rates in alkaline conditions are very low because of the presence of a passivation layer [1, 2]. Many experimental studies have shown that uniform corrosion rates for carbon steel in anoxic, alkaline conditions are below 0.1 µm/yr. Recently, an increasing number of studies indicate upper values in the range of few tens of nm/yr. Uniform corrosion rates for stainless steel are very low. In anoxic, alkaline conditions, recent studies reported measured values below 0.01 µm/yr. The corrosion rates of stainless and mild steels are higher in neutral conditions than in alkaline conditions. This might affect the carbon-14 release in a pessimistic scenario where the alkalinity of the near field decreases i.e., because of ageing of the cementitious environment. However, the radiological impact remains limited since the pH decreases significantly only in the long-term when most carbon-14 has decayed. The experimental studies indicate an early, fast release of carbon-14 from steel between a negligible fraction up to a few percent. There is no consensus on how to abstract these observations in safety assessment.

The experimental works conducted on the corrosion of Zircaloy in CAST tends to confirm the data reported in the literature with corrosion rates in the order of a few nm/yr at the most at low temperature, in alkaline or neutral conditions [3, 4]. CAST allowed progress in the knowledge of the corrosion mechanism of Zircaloy. Should the corrosion regime change in disposal conditions (transition to pseudolinear kinetics), it is not expected to lead to higher rates. Further, the CAST results on Zircaloy confirm the hypotheses formulated 15 years ago by the Japanese program of a mechanism in which carbon-14 is not released immediately by Zircaloy corrosion but is retained inside the oxide film. Indeed, the total leached fraction of carbon-14 from long-term Japanese experiments of several years on pressurized water reactor (PWR) and boiling water reactor (BWR) cladding samples is less than 0.1%. The carbon-14 released in this experiment seems to originate from the oxide layer [5]. These experimental results suggest that the 20% instant release fraction (IRF) used traditionally in safety assessment is overconservative. Unfortunately, there are not enough data and currently no consensus over the release mechanism of carbon-14 from the oxide layer to abstract these very low fractions in quantitative safety assessments. In addition, the influence of hydrides on the corrosion behaviour on the long term in disposal conditions remains uncertain. Lastly, it is to be noted that the review work performed in CAST in relation to the Zircaloy inventory in the claddings reduced the uncertainties on the concentration of the nitrogen impurity [3, 6]. However, uncertainty remains in relation to the carbon-14 inventory in reprocessed waste (vitrified and compacted waste). The assumptions regarding the carry-over fractions of carbon-14 inventory from the different components of the assemblies need to be consolidated. Also, accounting for an accessible carbon-14 in the oxide layer in compacted waste (after acid treatment) is still a matter of debate [6].

The measurements of carbon-14 speciation released from steel show that both organic and inorganic compounds are present in the liquid phase [2]. Methane and minor contributions of CO are found in the gas phase. However, applying this speciation to long-term releases of carbon-14 in disposal conditions is debatable. The oxygenated species measured in experimental conditions might in fact result from the radiolysis induced by the activated materials. It could thus be expected that the carbon-14 speciation will shift to reduced compounds, such as—gaseous—hydrocarbons, when the radiolysis becomes ineffective in the disposal system. Carbon-14 from Zircaloy shows the same behaviour in terms of speciation: the liquid phase is shared between inorganic and small oxygenated organic compounds. Methane, ethane, and CO_2 were mainly detected in the gas phase. Precise distribution as an input to safety assessment is still challenging at this stage, nevertheless, it can be concluded that the organic form of carbon-14 released from Zircaloy and steel is present in non-negligible fractions.

Spent ion-exchange resins (SIERs) are a heterogeneous source term. The range of activity of SIERs depends on specific factors such as reactor and circuit type, history of the physicochemistry in the fluid as well as pre-disposal storage conditions and conditioning processes of the resins. Likewise, carbon-14 speciation is expected to be influenced by these factors. In the case of BWR, more than 90% of carbon-14 was found under the form of inorganic carbon. For PWR, the situation is more contrasted. CANDU reactors seem to induce a major part of inorganic carbon-14, whilst for PWR around 20% of carbon-14 was obtained [7]. The speciation of the organic fraction suggests formic acid as the main organic form in SIERs. The conditioning matrix of SIERs (epoxy and cement) is assigned a safety function of water ingress limitation and possibly retardation in safety assessment [6]. Experimental studies brought to light the lability of carbon-14 in—unconditioned—SIERs during predisposal processing: the presence of atmospheric air during storage, temperature increase, transient decrease in the pH upon contact with alkaline solutions as well as drying procedures of the SIERs seems to cause a release of inorganic carbon [7, 8]. SIERs are a telling example illustrating the strong dependency between predisposal and long-term disposal management strategies.

The study of carbon-14 in irradiated graphite in CAST is, to an extent, a continuation of work undertaken in the preceding European Commission CARBOWASTE project. A certain number of outcomes were highlighted in [9].

First, regarding the release rate, a substantial fraction of the carbon-14 in irradiated graphite is not releasable. Some carbon-14 will initially be released rapidly, and some will be released more slowly at a rate that decreases over time. 99% of the carbon-14 that is released in the inorganic form. Carbon-14 can be released to both the gas and aqueous phases. A number of different species, including organic species (e.g., CH_4), CO_2 and CO may exist in the gas phase. For high pH conditions, the proportion released as gaseous carbon dioxide is small in comparison to the fractions released as carbon monoxide and methane. CAST provided a consensual parameterisation of the carbon-14 source term in irradiated graphite as basis for safety assessment. However, these data should be considered with care as the release rate and speciation of carbon-14 is a function of the graphite type used in different reactors and the disposal concept and conditions.

3. Upscaling to geological disposal systems

Due to its relatively short half-life (5,730 years), the carbon-14 radiological release from the waste through the host rock is sensitive to the release and migration processes in the disposal system.

Clay-based disposal systems provide an excellent performance regarding carbon-14, provided transport times in the disposal system are of the order of a few tens of thousands of years. The carbon-14 activity releases from the geological barrier (whatever its chemical form) are barely sensitive to the instant release fractions (IRF) up to 20% due to the spreading effect of the diffusive transport [10]. Sensitivity studies show that, in the present state of knowledge reported by PSI in CAST, the possible uptake capacity of the carbon-14 bearing organic compounds identified in CAST is too weak to influence the carbon-14 transport [6]. The impact of organic carbon-14 might become more relevant in scenarios where diffusion through the geological barrier is cut short, as could occur for example in the case of a scenario that considers transport of groundwater and dissolved species by advection. The impact of this scenario is very dependent on the uncertainties pertaining to corrosion rates, amount of metals and their specific surfaces. Reducing these uncertainties would make it possible to better estimate the source term of both the hydrogen carrier and carbon-14. Different design strategies can also be applied to limit the impact of both the hydrogen pressurisation and the advective transport of carbon-14 [10].

Locating the repository caverns in crystalline rocks away from any major fracture zones at a sufficient depth limits the groundwater flow through and in the vicinity of the repository caverns. This provides favourable near-field conditions for the engineered barrier system, limits the radionuclide transport, and isolates the waste from the biosphere. In crystalline rocks, any open fractures can provide pathways for both gas and aqueous transport. The release and migration of carbon-14 in organic gaseous form is expected to occur at a rate comparable to the migration of organic carbon-14 dissolved in groundwater. Sensitivity analyses carried out in CAST of carbon-14 releases from a repository located in a crystalline rock indicate a strong impact of the near field processes, i.e., groundwater flow rates and sorption, on the release rates. Consequently, the transport and retardation properties of the ageing cementitious environment are critical. Radiological impact in crystalline rock is more sensitive to IRF and (potential) low distribution coefficients (assigned to cement and host formation) than in clay. Reducing the uncertainties related to the metal corrosion rate as well as a good knowledge of the cementitious evolution is of primary importance for crystalline systems [10].

A repository for radioactive waste in a salt formation is characterized by mostly dry conditions. Therefore, radionuclide transport occurs dominantly through the gas phase. The convergence of the backfill starts as soon as the repository is closed. This process can be the driver of an advective transport of gases though the EBS up to the biosphere. A potential release of carbon-14 from the repository in salt depends thus on the amount of gaseous carbon-14 made available in the early few hundreds of years after repository closure, due to corrosion by water brought in inside waste packages alongside the waste itself during the operational period or due to initial canister failure. The experimental conditions of CAST (saturated and alkaline) are not directly representative of the conditions prevailing in a salt disposal (unsaturated & high saline brines). Water being a limiting factor, the impact in salt is very sensitive to the gaseous IRF. Although conditions are different, the literature (First Nuclides) relevant for salt system is in line with CAST. It shows increasing indications that the gaseous release of accessible carbon-14 from Zircaloy (oxide layer), spent fuel rods and steel are relatively low (1% altogether). The highest priority for salt disposal systems is to reduce the uncertainty on the release behaviour of gaseous carbon-14. This is mainly related to three questions: (1) What is the percentage of carbon-14 which can be released in volatile form? (2) What is the temporal distribution of this release? (3) Is water necessary to transfer carbon-14 into a volatile form or does this occur in dry conditions? [10].

4. Key messages to safety case

In conclusion, the experimental studies of CAST have confirmed the release of a non-negligible fraction of carbon-14 organic compounds from steel, Zircaloy and Spent Ion Exchange Resins in alkaline and anoxic conditions.

Regarding Zircaloy and steels, hydrocarbons, and carbon monoxide were found in the gas phase whereas the aqueous phase contained small oxygenated organic compounds. The mechanism of formation of these organics remains uncertain, in particular the source of oxygen. Although the organic nature of carbon-14 products generated from steel and Zircaloy corrosion has been confirmed, long-term generation of carbon-14 in disposal conditions might give a different picture with respect to its organic speciation and compound distribution. Consequently, conservative treatment still applies in safety assessment regarding specific organic speciation. CAST gave the opportunity to reinforce the understanding of the corrosion mechanisms of these metals, in alkaline, anoxic conditions. As a result, the confidence that these corrosion mechanisms will remain generally unchanged in the long term (within a certain Eh/pH window of the near field) has increased. Also, the interplay of the oxide layer in the carbon-14 release mechanism of Zircaloy is now acknowledged. The literature review carried out in CAST confirms the low corrosion rates for these metals as well as the general trend to even lower rates as observed in more recent studies.

CAST emphasized the heterogeneous character of irradiated graphite and spent ion exchange resins. The relative importance in the safety case of carbon-14 (aqueous) versus carbon-14 (gaseous) for these wastes varies by disposal concept, predisposal activities, and power plant operational conditions. Applying the results determined from few specific samples to broad inventories of waste with various operational and predisposal histories must be done with caution. This generalisation process might bring a certain level of uncertainty to be accounted for in the safety case. Safety assessment studies carried out in CAST highlighted the critical influence of the chemical and physical evolution of the cementitious environment on different aspects of the carbon-14 source term (e.g., corrosion rates, carbon-14 release rates), but also on more global aspects pertaining to the confinement properties of a geological disposal (e.g., fate of the hydrogen produced by corrosion, near field hydraulic properties). Carbon-14 in the form of a mobile organic compound will give a more relevant radiological impact than if considered in the inorganic form, and this particularly in rapid transport scenarios. Reducing the uncertainty on carbon-14 speciation shifts the conservatism introduced in safety assessment of carbon-14 release to the corrosion and transport rates.

The results from CAST will be evaluated in the context of national safety assessments and disseminated to interested stakeholders. The new understanding should be of relevance to national safety assessment stakeholders. CAST provided an opportunity for training for early career researchers.

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MARCUS ALTMAIER

CEBAMA: RESEARCH AND INNOVATION ACTION ON CEMENT-BASED MATERIALS, PROPERTIES, EVOLUTION AND BARRIER FUNCTIONS

M. ALTMAIER[1], V. MONTOYA[2], L. DURO[3], A. IDIART[3], A. VALLS[3], F. CLARET[4], B. GRAMBOW[5], E. HOLT[6], U. MÄDER[7]

[1]Karlsruhe Institute of Technology, Institute for Nuclear Waste Disposal, PO Box 3640, 76021 Karlsruhe – Germany
[2]Department of Environmental Informatics, Helmholtz Centre for Environmental Research, 04318 Leipzig – Germany
[3]Amphos 21 Consulting S.L. c/ Veneçuela, 103. 2nd floor. 08019 Barcelona – Spain
[4]BRGM, 3 av. Claude-Guillemin - BP 36009, 45060 Orléans Cedex 2 – France
[5]SUBATECH (IMT Atlantique, CNRS-IN2P3, Université Nantes) and ARMINES, 4, rue Alfred Kastler, BP 20722, F- 44307, Nantes cedex 03 – France
[6]VTT Technical Research Centre of Finland, Box 1000, 02044 VTT – Finland
[7]University of Bern, Geological Sciences, Baltzerstrasse 3, CH-3012 Bern, Switzerland

Abstract. CEBAMA is a research and innovation action granted by the EC within the HORIZON2020 programme in support of the implementation of the first-of-the-kind geological repositories. The 4-year project started the 1st of June 2015 and lasted until 31st May 2019. It was carried out by a consortium of 27 partners consisting of large Research Institutions, Universities, one Technical and Scientific Support organization (TSO), and one small-medium enterprise (SME) from 9 EURATOM Signatory States, Switzerland and Japan. IGD-TP and the National Waste Management Organizations supported CEBAMA, for instance by co-developing the work plan, participating in the End-User Group, granting co-funding to some beneficiaries, and providing for knowledge and information transfer.

The overall strategic objective of CEBAMA was to support the implementation of geological disposal by significantly improving the knowledge base for the Safety Case for European repository concepts. R&D in CEBAMA was largely independent of specific disposal concepts and addressed different types of host rocks, as well as bentonite. CEBAMA was not focusing on one specific cementitious material but aimed at studying a variety of representative cement-based materials for nuclear waste disposal in order to provide insight on general processes and phenomena which can then be transferred to different applications at national and international levels. Specific objectives and research activities of CEBAMA are summarized as follows:

- Experimental studies analysing interface processes between cement-based materials and potential host rocks (crystalline rock, Boom Clay, Opalinus Clay (OPA), Callovo-Oxfordian (COX), Toarcian mudstone, Borrowdale Volcanic Group) or bentonite backfill, and assessing the impact on physical and chemical properties.
- Investigation of radionuclide retention and migration processes in high pH cementitious environments, focusing on radionuclides which have high priority from the scientific and applied perspective.
- Improved validity of numerical methods to predict changes in transport processes as a result of chemical degradation, including advanced data interpretation and process modelling.

In this contribution, the main results and scientific highlights from the CEBAMA project are presented, and the potential impact of CEBAMA on the Safety Case discussed. It is also indicated which project events were organised and how the individual technical results from CEBAMA can be accessed, i.e. via peer-reviewed publications, public Deliverables,

Annual Workshop Proceedings, etc. The experimental and modelling work in CEBAMA was to a significant extent performed by young researchers and within PhD theses. This contributes to the continuing availability of highly trained specialists for implementers and regulators.

1. CEBAMA, project aims and overview

The HORIZON 2020 EURATOM Collaborative Project "Cement-based materials, properties, evolution, barrier functions (CEBAMA)" was developed to support the implementation of nuclear waste disposal in deep underground facilities. Radioactive waste poses potential health hazards and risk to the biosphere including humans. The best way to handle and dispose this material is a topic of broad public debate and concern. Supporting safe options for the long-term disposal of nuclear waste is therefore a key component in developing sustainable strategies to implement nuclear energy as part of the energy mix in Europe but also within decisions taken by some countries to finally phase out the use of nuclear energy.

Cement-based materials are highly relevant for nuclear waste disposal safety, because they are widely used in a repository, e.g. as waste matrix, liners and structural components or backfill / sealing materials. In order to make reliable assessments of the potential evolution and performance of a repository with time, it is important to understand the specific chemical and physical processes affecting cement materials and their effect on radionuclide behaviour and migration. Previously to CEBAMA, significant advances were already achieved in extensive experimental programs at all scales as well as in model development and application. The ambition of CEBAMA was to considerably improve the state-of-art on several topics which were still open for discussion. Specific technical objectives tackled within CEBAMA were chosen to answer key questions and organized into three Work Packages:

WP1: Experiments on interface processes and their impact on physical properties. *How do cement-based materials affect the isolation properties of other barriers, like the host rock and the clay backfill material? Experimental studies were performed in CEBAMA to understand the interface processes between cement-based materials and the host rocks (crystalline rock, Boom Clay, Opalinus Clay, Callovo-Oxfordian, etc.) or bentonite backfill and assess the impact on physical and geochemical properties.*

New experimental studies on interface processes and the impact on physical properties evolution constituted the main working effort in CEBAMA. The multifold studies were considering several different interfaces and a large variety of specific cement-based materials. The main work was focused on the characterisation of different interfaces between cement-based samples and applying new methodologies. Additionally, partners were characterising and investigating the specific CEBAMA reference material (low-pH concrete and paste) prepared and distributed within the CEBAMA consortium.

WP2: Radionuclide retention. *How do specific radionuclides or toxic elements of interest behave in the presence of cement-based materials considering as well that these materials will alter under long-term repository conditions?*

Experimental investigations focused on the behaviour of elements (Be, C, Cl, Tc, Se, Mo, I, Ra, Sr) which have high priority from the scientific and applied perspective in environments dominated by presence of cementitious materials.

Processes were investigated at high pH environments, considering various cement pastes and relevant individual hydrated cement phases and alteration products. The studies performed addressed sorption, diffusion, solid solution formation and solubility experiments. The information derived can be incorporated in complex models to predict radionuclide retention or mobilization processes in a repository.

WP3: Interpretation & Modelling. *How well are we able to predict changes in transport properties coupled with chemical and physical processes on the cementitious matrix or in the cement host rock interface? Modelling work performed in CEBAMA supported advanced data interpretation and process modelling, covering mainly physical and chemical processes responsible for the changes in transport properties and extrapolate the models to different scales for application in Safety/Performance assessment.*

Modelling approaches and modelling tools were developed in CEBAMA in order to analyse and predict processes that can impact the physical and chemical properties of cementitious materials and the interface between cement-based materials and host rocks or bentonite. Work was performed in close connection to the experimental studies conducted in CEBAMA, for instance within the joint studies focusing on the CEBAMA reference material. Work by the partners in CEBAMA also included the development of modelling tools for pore-scale applications, and the modelling of physical and chemical processes related to other experimental studies performed in WP1 and WP2 of CEBAMA. A Common Modelling Task was developed for organising the integration of the reactive transport modelling approaches and experimental data of the reference material in CEBAMA and to benchmark the reactive transport codes. Modelling in CEBAMA also established a close link with the Safety Case and Performance Assessment requirements.

In addition to the above three R&D Work Packages, WP4 was on Documentation, Knowledge Management, Dissemination and Training, and WP5 on Management. Detailed information on CEBAMA is available at the project website at www.cebama.eu.

2. Experimental Workplan and R&D programm (WP1, WP2, WP3)

The specific objectives in CEBAMA were separated into three main scientific and technical topics (WP1, WP2 and WP3, see above), which are interconnected with each other. In the following sections, the experimental Workplan and R&D program of CEBAMA is summarized. For WP1 and WP3, joint activities organised within CEBAMA, emphasising the specific advantages of performing research within a large international consortium with complementary expertise and experiences, are highlighted.

WP1: Experiments on interface processes and the impact on physical properties.

The largest amount of resources (~50%) and the most work effort was used for WP1 with 19 institutions participating, led by VTT (Finland), BRGM (France) and the University of Bern (Switzerland). The main objectives were: (i) to perform experimental investigations to better understand and quantify the alteration processes between cement-based materials and different host rocks of interest to Waste Management Organizations (i.e. crystalline rock, Boom Clay, Opalinus Clay (OPA), Callovo-Oxfordian (COX), Toarcian mudstone, Borrowdale Volcanic Group) or engineered barrier components (bentonite backfill) and (ii) to assess their impact on physical (i.e. diffusivity, hydraulic conductivity, porosity, strength,…) and chemical (i.e. porewater composition, mineralogy) properties.

Two types of cementitious materials (based on ordinary Portland cement (OPC), and/or "low-pH cement") were studied, which were in contact with either aged or fresh interfaces (i.e. claystone, bentonite, other rock types) or with model pore water / groundwater solutions. A key source for aged interface materials were ongoing experiments from existing underground research labs (URLs, samples up to 10+ years old) from 6 European URLs in Switzerland, France, Czech Republic and Belgium (i.e. Grimsel test site, Mont Terri laboratory, HADES, Tournemire, Meuse/Haute, Josef) and from Japan. The work of the partners in WP1 focused on five main topics:

- Quantifying transport parameters of altered and unaltered cement-based samples by performing through- and in-diffusion experiments and development of new non-invasive techniques (i.e. GeoPET method).
- Study of hydro-mechanical processes in the interface cement - Callovo Oxfordian claystone, measuring the evolution of flow and strength properties of different cementitious-based materials (i.e. low-pH concrete).
- Study of thermo-hydro-geochemical processes in the interface cement-clay, measuring changes on transport properties due to mineralogical alteration and microstructure changes (e.g. Ca leaching, carbonation).
- Analyses of interface reactions, with respect to changes in mineralogy and porosity evolution, between different materials in contact with solutions with different compositions (i.e. pH, redox, carbonate, sulphate concentration, salinity) by percolation and leaching experiments.
- Manufacturing and characterisation of the reference materials of the CEBAMA project as a benchmark to other studies by various partners.

As reference materials within the CEBAMA project, ternary low-pH concrete (RCM) and a paste (RPM) were manufactured, setting a specific focus on high-performance low–pH materials. Mixtures were cast at VTT in March 2016 and distributed among several CEBAMA partners early in the project. This reference material was also used in WP 2 and WP 3 of CEBAMA, thus further exploiting synergies between the partners and different WPs in CEBAMA.

The reference mix designs and materials were characterised by different partners in CEBAMA using several techniques (i.e. XRD, XRF, TG/DTA, ^{29}Si and ^{27}Al MAS NMR, X-CT, SEM/EDX, XAS, ICP-OES, etc.) providing complementary information on mechanical, chemical, transport properties and microstructure. Table 1 provides an overview of the applied characterisation methods used by the partners. Most of the results were in agreement but also some disparities were observed. Mineralogical composition, diffusion coefficient and pore solution pH were determined with multiple methods. The results enable comparison between different experimental set-ups and increases cohesion of individual experiments. Low diffusion coefficients (RPM: $10^{-(12\text{-}13)}$ [mol(HTO)/(m^2s^{-1})] and high compression strengths (RCM: 115 MPa, RPM: 150 MPa) were determined with multiple methods. The results confirmed that nanoporosity has a large effect in high performance cementitious materials' total porosity and thus long term performance. In the studies, the importance of curing temperature on pH development was observed, meaning that pH decreases significantly slower in cold environments.

TABLE 1. CEBAMA reference concrete and paste characterisation methods.

Quality	**Partner**	**Paste (RPM)**	**Concrete (RCM)**
Fresh-stage properties			
Workability	VTT	yes	yes
Air Content	VTT	no	yes
Heat of hydration	USFD	yes	no
Setting	USFD	yes	no
Mechanical properties			
Compression strength	VTT, USFD, CTU, UJV	yes	yes
Chemical composition			
X-ray diffraction (XRD)	KIT, USFD, JUELICH, SURREY, CSIC, UAM	yes	yes
X-ray fluorescence (XRF)	SURREY	initial materials	
Thermogravimetry (TG/DTA)	KIT, USFD, CSIC, UAM	yes	yes
^{29}Si and ^{27}Al MAS NMR	KIT	yes	no
Energy dispersive microscopy (SEM, Back Scattering+ EDS)	KIT, CSIC, USFD, JUELICH	yes	yes
X-ray absorption spectroscopy (XAS, Fe and Cl K-edge)	KIT	yes	yes
Pore solution pH	KIT, VTT, CSIC	yes	yes
Microstructure			
Scanning electron microscopy (SEM)	KIT, CSIC, USFD, JUELICH	yes	yes
Porosity	CSIC, USFD, UJV, BRGM	yes	yes
X-ray computed tomography	USFD	yes	no
Transport properties			
Leaching	VTT	yes	yes
Percolation	USFD, SURREY, CSIC, CTU, UJV	yes	yes
Diffusion	JUELICH, CSIC, UAM, KIT	yes	yes
Other			
Density	VTT, USFD	yes	yes
Spectral induced polarization (SIP)	JUELICH and BRGM	yes	no

WP2: Radionuclide retention.

There were 10 institutions working in WP2 of CEBAMA which was led by ARMINES/SUBATECH (France). The work of the partners in WP2 was focused on radionuclide retention/migration processes. The main efforts were dedicated to (i) high pH cementitious environments characteristic for cementitious materials, (ii) relevant individual hydrated cement phases and cement pastes and (iii) aged cement pastes. Additionally, the low-pH reference materials of the CEBAMA project as developed in WP1 were considered. The investigations in WP2 include retention or sorption, diffusion, solubility and co-precipitation studies. Focus was put on elements and nuclides for which only insufficient information was available before CEBAMA was started and rather large related uncertainties existed. Work performed by partners in WP2 is divided into the following topics:

- Detailed solid characterisation performed on the experiments with radionuclides using several complementary analytical techniques. (e.g. XRD, XRF, BET, SEM/EDS, TG-DSC and ^{29}Si NMR).
- Solubility experiments with Be, Mo and Se under high pH conditions. Providing for realistic solubility limits and radionuclide speciation schemes was a prerequisite for meaningful sorption studies allowing to derive advanced models on radionuclide retention.
- Sorption/desorption experiments were carried out using various radionuclides or toxic elements (i.e. Be, Mo, Ra, Tc, I^-, IO_3^-, SeO_3^{2-}/SeO_4^{2-}, Cl^-, Ra, Sr and ^{14}C) and various hardened cement paste formulations as well as individual cement phases.
- Solid solutions formation between various radionuclides in a range of oxidation states (Se, I and Mo) and main components (OH, S, Cl…) in cementitious phases (AFm).
- Diffusion experiments were performed with various anionic species ($^{36}Cl^-$, $^{99}TcO_4^-$, $^{125}I^-$, ^{14}C) or sorbing radionuclides (Ra, Sr) through saturated hardened cement pastes considering as well partially water saturated conditions.

As examples of research performed within WP2 of CEBAMA, studies on Se and Be retention are summarised in Fig. 1. The joint research performed by CEBAMA partners offered a significantly improved description of Se retention in a variety of systems, while studies on Be within CEBAMA give clear experimental evidence of a strong Be retention in cementitious system, contrary to previous assumptions.

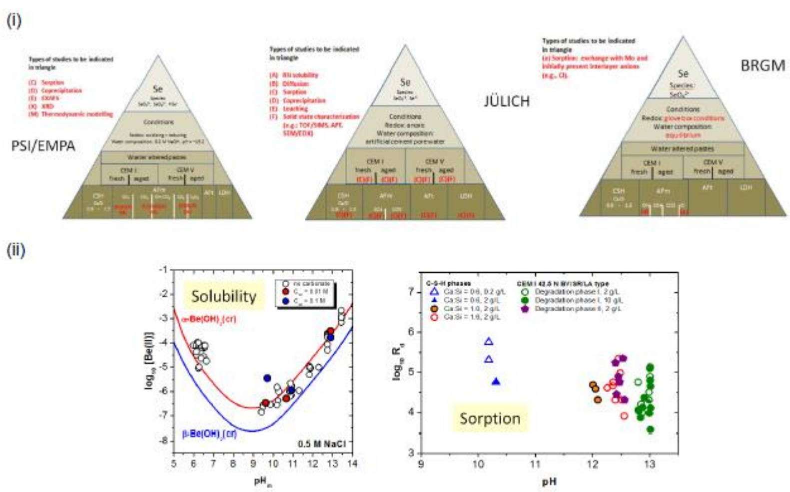
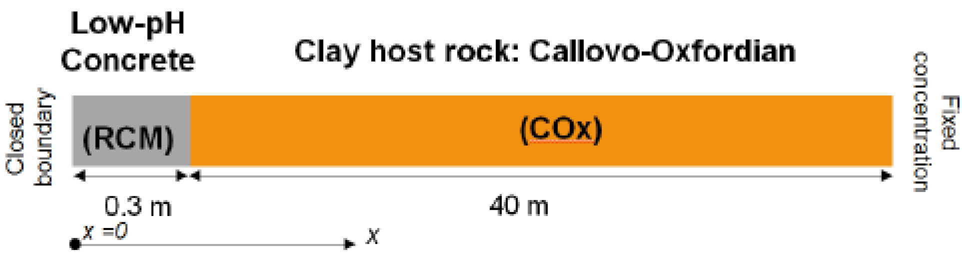


FIG. 1. (i) Overview on the specific systems studied in CEBAMA on Se retention by PSI/EMPA, JUELICH and BRGM. (ii) Studies on Be retention by KIT indicate strong Be retention in cementitious systems.

WP3: Interpretation & Modelling.

In WP3 of CEBAMA, advanced modelling approaches were developed and improved to predict coupled THMC processes at the interface between cement-based materials and engineered or natural barriers in crystalline and argillaceous host rocks. A total of 13 partners were working in this WP led by AMPHOS21. Activities within this WP were mainly dedicated to the modelling and interpretation of experimental data, also generated within CEBAMA in WP1 and WP2. WP3 was additionally contributing to extrapolate modelling to system-level for Safety Case applications and validate different modelling tools. Main modelling work was focused on four main tasks:

- Development of modelling tools with pore- and continuum-scale applications including new capabilities (i.e. Poisson-Nernst-Planck equations, Poisson-Boltzmann equations, coupling with geochemical solvers, coupling between chemistry and mechanics, etc.) in already existing or new codes (i.e. iCP, ORCHESTRA, MATLAB, iPP, Yantra, etc.).
- Modelling work with application to WP1 and WP2 experiments (i.e. through-diffusion tests, leaching tests, cement-clay interaction, etc.), including reactive and mass transport simulations, cement hydration models, solubility calculations and hydromechanical simulations.
- Long-term modelling of concrete-clay interactions including reactive transport and hydro-mechanical-chemical coupled analyses.



Material	Porosity	Pore diffusivity (m^2/s)	Effective diffusivity (m^2/s)
COx claystone	0.18	$1.44 \cdot 10^{-10}$	$2.60 \cdot 10^{-11}$
Low-pH concrete	0.04	$2.50 \cdot 10^{-11}$	$1.00 \cdot 10^{-12}$

FIG. 2. Geometry and key parameter of the system investigated within the Common Modelling Task.

To optimize the integration of different modelling approaches and the experimental data obtained in CEBAMA, a Common Modelling Task was developed within the project. The goal of this task, which was supported by 8 different partners, was to cluster WP3 activities around a common long term simulation case, using a low-pH cement (CEBAMA reference material) / clay interface, based on the set-up shown in Fig. 2. The figure shows the geometry used in the simulations. The interface investigated is resolved with cm-scale elements at both sides of the interface. Initial properties and composition of the low-pH cement used in the simulation were based on the experimental findings obtained for the reference ternary low-pH concrete. The Common Modelling Task helped to increase confidence in the consistency of the different modelling approaches (see contribution to EURADWASTE by A. Idiart et al.) for the simulation of the long-term behaviour of low-pH cementitious materials with reactive transport tools.

3. CEBAMA Results, Application to Safety Case and Future Recommendations

CEBAMA addressed key issues of relevance for long term safety and key scientific questions related to the use of cement-based materials in nuclear waste disposal applications. The scientific quality and impact of the project built on joining the best expertise available to tackle these problems and emphasising how the knowledge can be applied in Performance Assessment and the Safety Case. According to IAEA (2012) [1] the Safety Case is the collection of scientific, technical, administrative and managerial arguments and evidences in support of the safety of a disposal facility, covering the suitability of the site and the design, construction and operation of the facility, the quantitative assessment of short and long term risks as well as more qualitative safety indicators and assurance of the adequacy and quality of all of the safety related work associated with the disposal facility. Safety Assessment, an integral part of the Safety Case, is driven by a systematic assessment of radiation hazards.

CEBAMA has improved the knowledge base for the Safety Case via the following specific items: (i) safety impact of microstructural and porosity changes of cementitious materials (i.e. cement paste, mortar and concrete), (ii) safety impact of cement degradation, (iii) creation of long-term models, (iv) decrease of uncertainties in radionuclide retention processes, (v) development of modelling expertise and methodologies and (vi) upscaling modelling in time and space. A specific focus was put on the (vii) investigation of low-pH cement-based materials, and hence conclusions can be drawn from the work within CEBAMA on the potential use of this relatively new material in waste disposal applications. In the following, potential links between CEBAMA to new activities within the new EURAD joint research program (2019-2024) are indicated.

To ensure that the project was directed towards implementation and application, the End User Group (EUG) represented the view of the main users of the research performed in CEBAMA. The organisations taking part of the EUG of CEBAMA were: NAGRA (CH), ANDRA (FR), POSIVA (FI), SKB (SE), COVRA (NL), ONDRAF/NIRAS (BE), RMW (UK), ENRESA (ES) and SURAO (CZ). These waste management organisations come from countries in very different stages of implementation, so that the implication that the results of CEBAMA have on their interests may vary from case to case.

Regarding the **study of the cement-clay interfaces (bentonite and clay host-rocks)** related to WP1, the results obtained within CEBAMA provide evidences of the effect of different cement formulation on the clay-cementitious materials interfaces. Experiments have included in-situ large-scale long-term data gathered from Mont Terri and Grimsel in Switzerland, HADES in Belgium, Bure in France as well as laboratory tests.

The studies provided evidence of a relatively good understanding of key processes in all systems, also resulting from the wide range of mature and tested analytical and experimental techniques available. The most relevant results are summarised below.

- At low temperature (25°C), whatever the concrete mixture formulation, both very little clay and concrete alterations were observed during the early phases (0-13 years) with respect to mineralogical changes being limited to the mm scale. The cement-internal extent of alteration in low-pH material was at least as extensive as in OPC (although rather difficult to compare due to many relevant parameters). However, it needs to be realised that another advantage of "low pH" cements compared to OPC is a low-heat hydration temperature, which minimises the microcracking that can have negative consequences on the cement's long-term durability. Therefore, mineralogy is not the only driver to consider for cement-based materials formulation.
- Regarding porosity (and mass) re-distribution at small scale, an only partially coherent pattern was observed, indicating a potential tendency of permeability reduction.
- According to the results and with specific focus on radionuclide mobility, low pH cementitious materials did not minimise the extent of reaction between bentonite and cementitious materials in the "high-performance" materials investigated (having dense paste structure). There also was no significant reduction of the mobility of highly mobile anionic radionuclides like $^{36}Cl^{-}$ and $^{129}I^{-}$ in cement (see contribution by N. Ait Mouheb et al. to EURADWASTE).

Based upon the R&D performed within CEBAMA WP1, recommendations were derived to provide input for future research activities. It was noted that there is still a relatively small database for measured hydro-mechanical-diffusion (H(D)M) properties with interfaces, a problem which could be elaborated with new in-situ experiments (i.e. CI-D at MontTerri, Switzerland). Some experiments seem to indicate that the concrete-clay interface does not appear to be a weak zone of permeability, contrary to previously accepted hypothesis. However, the mechanical stability of mm-scale porosity-reduction zones is difficult to assess (impact of skin on transport, i.e. performance with hydraulic differential pressure induced by gas overpressure). The impact of interfaces on gas transport need to be further investigated (which is the scope of the new EURAD-GAS project). Rather little information is available on the increased amounts of organic additives associated with low-pH cements (which is the scope of the new EURAD-CORI project). The question of upscaling results and models will be partially addressed in the new EURAD-DONUT project, and thus these additional activities seem justified for future added value to the end users. In terms of extrapolation of time from decades to centuries and millennia, the CEBAMA methods may be used to assess natural analogues. Moreover, there is a rather thin database on temperature effects potentially impacting the above interface processes.

The results obtained within WP2 of CEBAMA provide an increased understanding of the **behaviour of several safety relevant radionuclides** within cementitious barriers in the repository environment, thus decreasing uncertainties with respect to relevant radionuclide retention processes. The results can be used to substantiate and justify assumptions made with respect to the radionuclide migration behaviour in Safety Assessments. The excellent collaboration between the different research teams involved was key to the success. The collaborative approach for instance featured many research visits and exchanges between laboratories (RATEN/SUBATECH, BRGM/KIT, AMPHOS/JUELICH, USFD/JUELICH, CTU/JUELICH) and the organisation of a focussed anion cluster meeting. The experiments performed and the interactions between partners contributed to identify new research directions of less advanced projects. WP2 has realised an important step forward in the understanding of retention processes on cementitious materials, in particular for anionic species, based on the largely coherent scientific results obtained by the different groups. Key findings are:

- For the uptake of anions in AFm phases a continuous solid solution was found between the end members Se(IV)-AFm and S(VI)-AFm, with a continuous peak shift towards higher basal spacing with increasing amount of SO_4^{2-}. Solid solution formation was also observed between the pairs I-OH and I-OH_CO_3. At an iodide fraction of 0.1 a miscibility gap is observed. In the I-OH_CO_3 pair no miscibility gap is observed. The solid solution formation between the I-AFm and monocarbonate (CO_3-AFm), is incomplete and a miscibility gap with the composition $0.5 \leq CO_3/(2I+CO_3)$ exists. The thermodynamic properties of each of the pure Se- and I-AFm phases and of AFm phases containing binary mixtures of Se and I with the common anions present in cement, were determined.
- Due to the higher amounts of aluminate phases in HCP based on CEM I, the retention capacity for the selenite and selenate is higher in this case compared to the low–pH CEBAMA reference paste.
- Flow-through studies have shown that the Se(VI)/Cl exchange on AFm-Cl is rapid and reversible. The exchange can be modelled by 2 anion exchange sites. Exchange constants were obtained with associated selectivity coefficient based on the Gaines and Thomas convention. Accurate rate laws were determined implementable in reactive transport modelling.
- CEBAMA has provided a first set of sorption parameters of Beryllium onto cementitious phases. In contrast to the traditional hypothesis of very weak Be sorption, assumed on the basis of the negative charge of the Be(II) species at high pH values, a strong uptake has been confirmed for all investigated systems. This finding helps decreasing the conservativism when conducting calculations supporting Performance Assessment and decreases previously existing uncertainties. (see contribution by X. Gaona et al. to EURADWASTE).
- Project studies have shown that the sorption of molybdenum in cementitious environments is not associated with ettringite, in contrast to what has been traditionally assumed. This finding has important implications on sorption analogies - the project recommends not to use arsenic as analogue for molybenum in sorption estimations, as it has been done in previous exercises.
- CEBAMA results showed a significantly higher retention of Ra than that of Sr onto cementitious materials. This again, decreases uncertainty and conservativism, and leads to a recommendation to revise sorption analogies used in SC to date. (see contribution by J. Kittnerova et al. to EURADWASTE).

- A strong reduction of sorption of ^{14}C(inorg) has been observed with the increased degradation of cement pastes. In contrast, Ra sorption increases with increased degradation.

Looking beyond the work in CEBAMA, future recommendations were identified. Regarding quantitative description, the thermodynamic models developed in the present project with individual cement phases should be validated in real cement-based material systems. Future studies should also extend to include Fe(II)-bearing phases, which might significantly affect the behaviour of redox-sensitive radionuclides, and focus on the kinetics of mineral dissolution and precipitation. In this context, differences in data from various teams (i.e. regarding kinetics, pH, S/L ratio, etc.) should be resolved and eventually interpreted beyond the Kd-concept to clearly identify a boundary between adsorption and solid solution phenomena and to include advanced molecular level understanding. As capacities to assess the effect of competition have advanced, considering other anionic species (sulphate…) or organics (ISA, gluconate…) on radionuclide retention is needed (link to EURAD-CORI). A better understanding of the pH effect in AFm/AFt interactions with radionuclides would be positive. Stability of AFm phases at the claystone concrete interface should be clarified. Last but not a least, quantification of transport and retention in unsaturated conditions still is challenging. With view towards EURAD, work performed in CEBAMA shall be included in state-of-the-art (SOTA) documents.

CEBAMA has represented a step forward in **model development on the behaviour of cementitious materials and the cement-clay interfaces** in WP3. Models have included new thermo-hydro-mechanical (THM), chemo-mechanical (CM) and reactive transport developments. Overall, a very good level of collaboration between the different partners and with WP1 and WP2 in CEBAMA was reached. In general, good agreement between results obtained by different models and the available experimental data was observed. Interpretation of CEBAMA experiments with WP3 models has served to increase confidence in system understanding and identify remaining gaps. It also supported development of modelling tools and incorporation of new features in existing codes. The outcomes of WP3 represent a significant step forward in the quantitative assessment of physical and chemical processes of cementitious materials and their interface to clayey host-rocks. Results showed a high level of understanding of governing processes and the good agreement between reactive transport codes, which is essential for the use of these tools in a Safety Case. The specific focus put on low-pH cement-based materials, allows drawing conclusions on their potential use for nuclear waste management. CEBAMA has improved the knowledge base for the Safety Case by improving the following modelling aspects: (i) impact of cement degradation, microstructural and porosity changes of cementitious materials, (ii) development of long-term and upscaled models, (iii) development of modelling expertise and methodologies. CEBAMA clearly represents a step forward in modelling the behaviour of cementitious materials and cement-clay interfaces.

Some of the most prominent results are detailed below:

- THM models of clay-concrete interfaces, based on elasto-plasticity, have been developed that can now be used in future assessments of the behaviour and evolution of interfaces between concrete and different host rocks.
- New model features developed and implemented in WP3 include: diffusion-porosity changes couplings, electro-chemical multi-component diffusion capabilities, homogenization schemes for mechanical and transport properties, more efficient pore-scale reactive transport tools, and extended membrane polarization models for porosity and pore size distribution.
- CM models have been developed to predict the impact of chemical interaction of concrete with other materials in the repository on the mechanical integrity of cement-based barriers (i.e strength, stiffness, pore space). Additionally, new couplings were established regarding electrochemistry, diffusion-porosity couplings, CM models, HM coupling of clay/concrete interfaces, etc.
- New insights on newly developed low-pH cement and concrete were derived, including: hydration modelling in low-pH and low w/b ratio systems; assessment of diffusion properties from microscopic considerations; pore structure (pore-scale reactive transport models, homogenization models and membrane polarization models); assessment of thermodynamic data in low-pH systems: C-S-H, C-(A)-S-H, Fe speciation, alkali uptake, etc.; and hydro-mechanical behaviour of clay/concrete interfaces.
- For the first time, reactive transport models have explicitly considered the hydration of low-pH cement and how water consumption during hydration impacts the final mineralogical composition. This information is essential in Safety Assessments to determine the initial state and the early evolution in the post-closure period.
- The Common Modelling Task of CEBAMA has built confidence on the reactive transport tools used when simulating the long-term behaviour of an interface between low-pH concrete and a clayey host rock. The results show not only the high level of understanding of the governing processes but also the good agreement obtained with different codes, which is essential to demonstrate for the use of these tools in Safety Assessments (see contribution by A. Idiart et al. to EURADWASTE).

In view of open questions for future research, more validation work in general is needed, also including the development of more quantitative data of mineralogical changes in the cement/clay interface or in low-pH cement-based materials (M-S-H, low C:S C-S-H, C-(A)-S-H), also considering associated changes in transport properties (pore-structure, effective diffusion, permeability) and porewater composition, and the consideration of aggregates and superplasticizer chemical interactions. Numerical capabilities and efficiency of models should be further improved, especially for repository-scale or pore-scale simulations in 3D. Upscaling from pore-scale to continuum scale modelling is still not trivial. Further development of conceptual modelling of Ra uptake in cement-based materials is needed. Evaluation of long-term HCM behaviour of interfaces still needs to consider time-dependent deformations of clay and concrete. Surface complexation modelling is still needed to interpret zeta potential results on RCM.

4. Project dissemination and indicators

CEBAMA featured several dedicated activities to disseminate the results of the project to the technical/scientific community and all interested stakeholders making use of several complementary tools. The project website at www.cebama.eu served as a successful platform for information exchange within the project partners and with interested stakeholders. CEBAMA distributed a Newsletter on a regular basis to inform on project activities and selected research highlights, specifically targeting non-technical stakeholders.

Key events in the project were the four Annual CEBAMA Workshops (2016 – Barcelona, Spain, hosted by AMPHOS21; 2017 – Espoo, Finland, hosted by VTT; 2018 - Nantes, France, hosted by ARMINES; 2019 – Karlsruhe, Germany, hosted by KIT). The Annual CEBAMA Workshops were clustering several activities, including information exchange, monitoring of work progress, dissemination of results, interaction with End Users and other stakeholders, amongst others. The technical presentations were summarised in the Workshop Proceedings, made available at the project website and published at KIT Scientific publishing following a peer-review process involving the End User group (EUG) including persons affiliated with European Waste Management Organizations. Specific topical sessions were integrated into the Workshops, with the Socio-political Stakeholder panel discussion organized by E. Holt (VTT) of CEBAMA focusing discussion on the Finnish repository project, or the Session on the significance of cement-based materials in decommissioning organised at Nantes meeting being two of the highlights. In order to enhance the visibility of CEBAMA for the interested international scientific community, the Final CEBAMA Workshop was organised in connection to the 5th International Workshop on "Mechanisms and Modelling of Waste / Cement Interactions" in Karlsruhe, March 2019, gathering more than 100 participants. CEBAMA partners were invited to present results generated in the project to this conference and submit manuscripts for publication in a special issue of a peer-reviewed scientific journal.

FIG. 3. Participants at CEBAMA Final Workshop, March 2019, Karlsruhe, Germany.

In addition to these dissemination actions, a comprehensive set of public Deliverables was prepared by CEBAMA and made available at the project website. These documents provide plenty technical details and allow an in-depths view on the R&D carried out in the project, but also include Deliverables prepared with the aim of integrating results and outcomes. Key Deliverables allowing an integrated view on the CEBAMA project results are mainly D1.7, D2.6 and D3.8 (manuscripts for peer-reviewed publications on the results generated within WP1, 2, 3, respectively), and D4.20 (report on the relevance of the outcome of CEBAMA for the Safety Case).

Significant efforts were also devoted by the individual project participants to disseminate the technical information and knowledge generated in the frame of this project. More than 60 articles have been published, submitted or are in preparation (as of February 2019) for their submission in several peer review scientific journals. A list of publications is available at the CEBAMA website. Additionally, researchers have attended to different international conferences and workshops to present their work by either oral talks or in poster sessions. CEBAMA has produced 90 presentations (oral talks and posters) at conferences and meetings, highlighting the results of partners including joint contributions between partners in CEBAMA. Additional presentations were given by the members of the Coordination Team on the overall CEBAMA project.

The CEBAMA project has gathered together more than 100 participants, including renowned senior researchers, a significant number of students and young PostDoc researchers, as well as technicians and administrative staff. About 50% of the participants in CEBAMA hold a PhD. In terms of gender, a good balance was achieved in the project with 47% female participants, however, gender inequality exists when analysing category profiles. Some examples can be found when looking at gender indicators of professors/main investigators vs. administrative, the former dominated by men (80%) and the latter by women (88%). Project external partners joining in the frame of an Associated Group Agreement were Moscow State University (MSU), Russia, Los Alamos NL Carlsbad Office (LANL-CO), USA, and the Swiss Federal Nuclear Safety Inspectorate (ENSI), Switzerland.

A very important point is that CEBAMA has been very successful in training young scientists: 7 students did their master thesis and 14 students performed their PhD thesis within the CEBAMA project. Several early career PostDoc researchers were likewise working in CEBAMA. The young researchers were specifically supported by targeted mobility measures, giving the opportunity for working at hosting CEBAMA organisations with special tools or expertise, following an internal proposal system. Specific PhD sessions at the Annual CEBAMA Workshops or PhD workshops organized by one of partners (i.e. PSI) put a further focus on supporting young talent.

5. Summary and impact

As main outcome and key impact of the scientific studies carried out in the CEBAMA project, advanced modelling approaches were developed which allow predicting the performance of cement-based materials in contact with the engineered and natural barriers of repositories in crystalline and argillaceous host rocks and the retention of radionuclides by cement-based materials. These improved models may be applied for high level waste disposal but also for scenarios in low and intermediate level waste disposal, currently implemented in several countries. CEBAMA has enhanced the publicly available knowledge on the performance and reliability of the engineered barrier systems (EBS) for nuclear waste repositories. This has impact on the public debate on nuclear waste disposal, also by keeping non-scientific stakeholders informed.

CEBAMA established cooperative international research for basic understanding of EBS systems, with main highlights addressing design issues, safety assessment issues, radionuclide retention and modelling. CEBAMA influences several design issues (which thus (i) impact optimisation of repository dimensioning; (ii) aid specification/selection of material parameters, material compatibility, evolution; (iii) aid specifications for experimental methods, i.e. for material quality control). CEBAMA has likewise advanced several safety assessment issues (which thus (i) provide evidence that interfaces (concrete-bentonite-host rock) can co-exist safely; (ii) provide better understanding of impacts from material interface processes for realistic description of the system performance affecting strength, flow properties, etc. and transport processes variation with time; (iii) evidence porosity changes – if and when clogging occurs; (iv) offer improved accuracy in robustness and weighting of safety functions; increased modelling accuracy with new data and process understanding (WP3)), accounting for evolution of the system. With the view on radionuclide retention the results can be used in particular by WMO, TSOs or regulators for the evaluation and assessment of radionuclide migration in cementitious repository near fields by (i) decreasing uncertainties and increasing safety margins with respect to relevant radionuclide retention processes, (ii) substantiating and justifying assumptions made with respect to the radionuclide migration behaviour in Safety Assessments, and (iii) improving sorption databases for cementitious environments for so far less studied systems and different stages of system evolution (i.e. cement-based material degradation) in the long-term. Furthermore, there is a direct input to case studies like for the LLW-ILW repository Bratrství (Czech Republic) and the licensing process for the near surface repository in the proximity of Cernavoda NPP (Romania). Regarding modelling, CEBAMA increases the level of confidence in reactive transport models for further use in Safety Cases for near-field applications. The project provided improved reactive transport modelling tools, available as open source or upon request, to quantify how bentonite barrier or clayey host rocks could affect the integrity of normal and low-pH cementitious materials. The developed models can be used by end users to study the impact of reactive transport processes, but also other THMC coupled processes on the long-term performance of the near-field, including low-pH cement-based materials. Pore-scale reactive transport models can be used as process models in support of the Safety Case to enhance understanding of the impact of alteration of cement-based materials on their transport properties.

Besides pure scientific and technical based impacts in terms of generating specific knowledge and decreasing uncertainties, the enhanced cooperation/exchange and knowledge transfer between different institutions on an international level is highly valuable. This is including cooperation between research institutions in different fields (i.e. Geosciences, Environmental Engineering, Radiochemistry and Computational Sciences) with access to specific sophisticated state-of-art analytical equipment and modelling tools. CEBAMA Consortium members thus became aware of the respective complementary competencies, and, based on this experience, will likely tackle future challenges in a focused, cost-saving, collaborative approach.

The experimental and modelling work in CEBAMA was to a significant extent performed by young researchers and within PhD theses. The dedicated support of young talent actively involved in the CEBAMA project contributes to the maintenance of competences, aiming to ensure continued availability of highly trained specialists for implementers and regulators.

Last but not a least, CEBAMA has contributed to European integration by bringing together experts from several European member states and Japan. The involvement from experts coming from countries at very different stages of implementation likewise poses a positive achievement, for instance in view of sharing of expertise and resources and integrating new member states.

Acknowledgements

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PATRICK SELLIN

BEACON: BENTONITE MECHANICAL EVOLUTION

P. SELLIN[1], M. WESTERMARK[1], O. LEUPIN[2], S. NORRIS[3], A. GENS[4], K. WIECZOREK[5], J. TALANDIER[6], J. SWAHN[7]

[1]Svensk Kärnbränslehantering AB (SKB), Evenemangsgatan 13, Box 3091, 169 03 Solna, Sweden
[2]Nagra, Hardstrasse 73, Postfach 280,5430 Wettingen, Switzerland
[3]Radioactive Waste Management, Building 587, Curie Avenue, Harwell Oxford, Didcot, Oxfordshire, OX11 0RH, United Kingdom
[4]Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya (UPC) – BarcelonaTech, Jordi Girona 1-3, Edifici D-2, 08034 Barcelona, Spain
[5]Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Abteilung Standortauswahl, Bereich Endlagerung, Theodor-Heuss-Str. 4, 38122 Braunschweig, Germany
[6]ANDRA, 1/7, rue Jean Monnet, Parc de la Croix-Blanche, 92298 Châtenay-Malabry Cedex, France
[7]Miljöorganisationernas kärnavfallsgranskning (MKG), Första Långgatan 18, 413 28 Göteborg, Sweden

Abstract. BEACON aims at the development of understanding fundamental processes that lead to material homogenization, as well as improved capabilities for numerical modelling. In earlier assessments of bentonite EBS, the mechanical evolution of the installed bentonite was neglected, and an "ideal" final state was optimistically assumed. Key features of the project are:

– Re-evaluation of the existing database to extract the important information to compile the qualitative and quantitative observations and to develop the conceptual understanding.
– Enhanced, robust and practical numerical tools firmly grounded on a good conceptual understanding, which have the required predictive capabilities concerning the behaviour of engineered barriers and seals.
– A complete experimental database for the need of the assessment models.
– Verified models based on experimental results from experiments in different scales.

The BEACON project is needed for the pan-European aims at building confidence amongst regulators and stakeholders regarding the performance of safety barriers in a geological repository.

1. Introduction

The overall objective of the project is to develop and test the tools necessary for the assessment of the mechanical evolution of an installed bentonite barrier and the resulting performance of the barrier. The goal is to verify the performance of current designs for buffers, backfills, seals and plugs. For some repository designs mainly in crystalline host rock, the results can also be used for the assessment of consequences of mass loss from a bentonite barrier in long term perspective.

The driver for this project is repository safety, and the demands of waste management organizations to verify that the material selection and initial state design fulfil the long-term performance expectations. For this project, the initial state refers to the period at installation of the barrier, while long-term performance refers to the period for barrier saturation and evolution of the hydro-mechanical state, which could range from 10 to 1000s of years. In current and future applications for repositories, the regulators will expect the applicants to have a sufficient predictive capability of the barrier evolution from the installed to the final state.

BEACON is focused on the direct application to real assessment cases in actual repository systems. A few cases from relevant repository systems have therefore been selected as test examples. The systems intended to be evaluated in Beacon include three cases: 1) a tunnel plug based on The ANDRA design, 2) a disposal cell from the Nagra concept, 3) the KBS-3 deposition tunnel backfill. These are representative of the primary areas of uncertainty in density homogeneity. These examples cover a broad range of issues and the results should be applicable to other concepts and systems as well. The cases are illustrated in Fig. 1, Fig. 2 and Fig. 3 below.

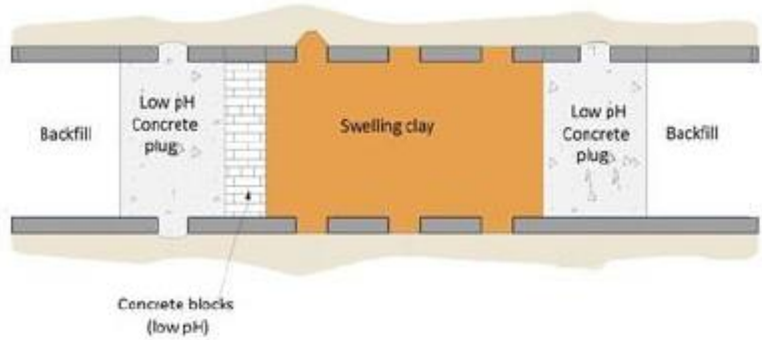

FIG. 1. Tunnel plug in the ANDRA concept.

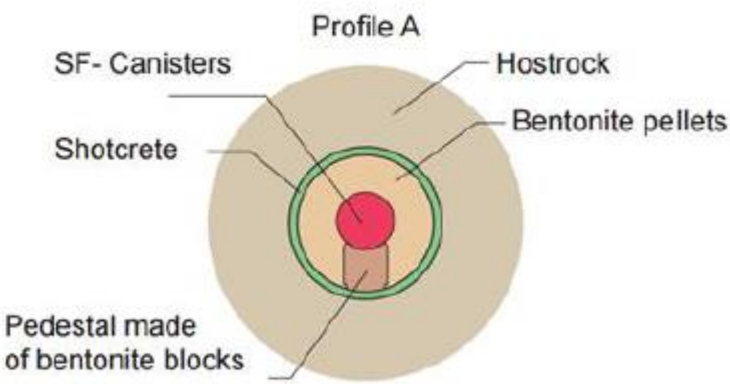

FIG. 2. Disposal cell in the Nagra concept.

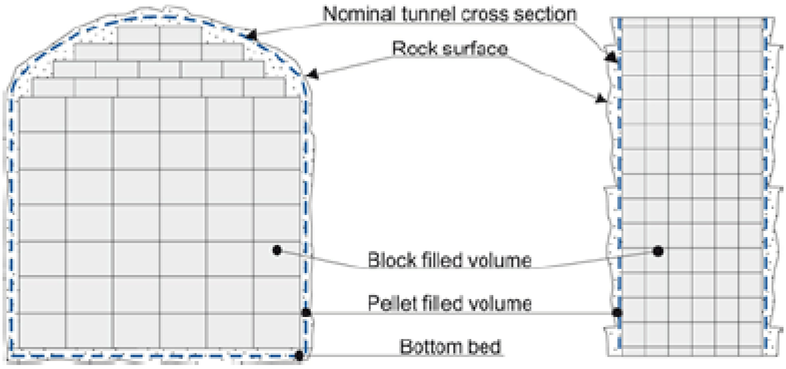

FIG. 3. KBS-3 Tunnel backfill.

BEACON builds upon experience by waste management organizations from different countries and technology providers over the past 30+ years. Great gains have been made in understanding individual bentonite components through experimental and modelling work. Yet shortcomings in the state-of-the-art knowledge exist which still inhibit confidence toward repository operation.

The sealing ability is essential for the engineered clay (bentonite) barriers in all geological repository concepts. This is normally achieved by a swelling pressure and a low hydraulic conductivity. The swelling pressure may also impact the barriers in the repository. The mechanical properties of the installed EBS, that may consist of a mixture of blocks, pellets and engineering voids, will be entirely different from the situation after full saturation. It is therefore important to understand:

- The mechanical evolution during the saturation phase;
- The final situation after reaching equilibrium.

A good knowledge of the mechanical evolution is necessary to ensure that a given design is adequate to meet the performance targets.

The scientific-technical work in Beacon is structured in five work packages (WP1-5), dissemination and training is handled in two work packages (WP6-7) while coordination and project management is covered in one single work package (WP8). The interconnections between the work packages are illustrated in Figure 4.

WP1 is the main driver for the entire project. The waste management programs involved are all represented in WP1, through the implementer or equivalent organization. The objective of WP1 is to define the important issues concerning the mechanical properties of bentonite and to define how these should be treated.

In WP2 the existing knowledge base is treated. The key objective of WP2 is the sharing of knowledge and experience. The partners will distribute information and results from earlier assessments, design considerations, experiments and modelling tasks.

A strong driver for a joint project is the current limitations in the predictive capability in the numerical models. The issue of homogenisation and swelling is challenging both from a conceptual and a numerical point of view. The purpose of WP3 is to identify and resolve the shortcomings of current models.

Although there is a substantial experimental database available for the project, it will be necessary to perform additional experiments to support the model development in WP3 and the model testing in WP5. The experimental work will be coordinated in WP4. WP4 will consist of experienced experimental groups, which have the flexibility to adapt the experimental work to support the needs of WP3 and WP5.

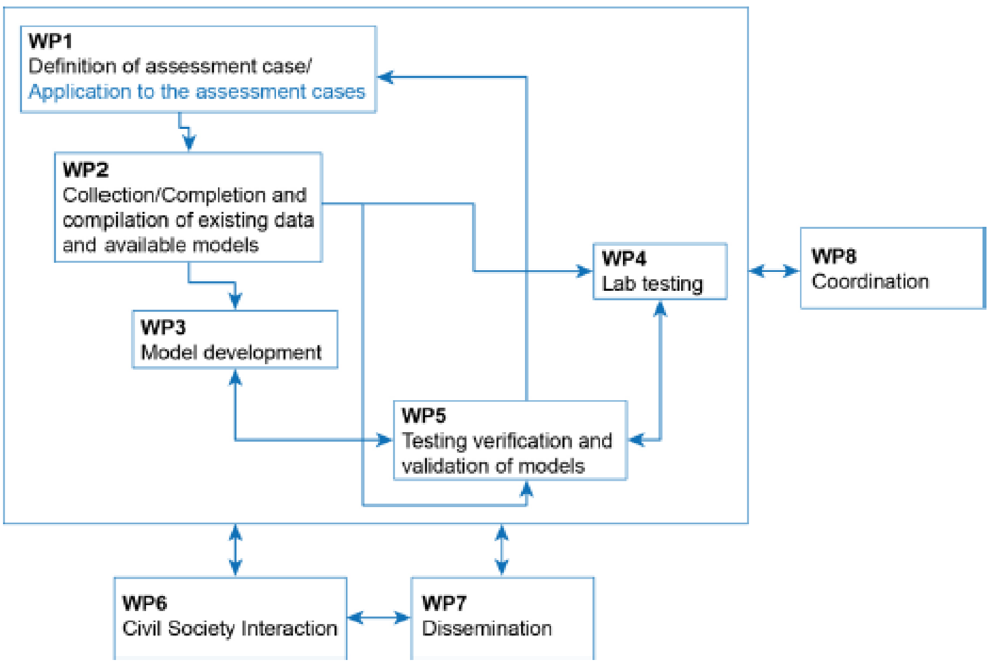

FIG. 4. Interconnections between the work packages in BEACON.

The core component of Beacon is WP5. The main effort will be performed in this work package. The overall objective of WP5 is to simulate the assessment cases defined by WP1. In order to do this, the available models have to be tested first on results from laboratory experiments and later on results from large scale field tests to gain confidence in their predictive capability. The next step is to actually test the predictive capability, by means of "blind" predictions of experimental results. Finally, the models will be used to evaluate the assessment cases.

2. WP1 Definition of assessment case/Application to the assessment cases

In the framework of WP1, the needs of safety assessment regarding the evaluation of nonhomogeneous backfill properties are addressed, in particular to what extent non-homogeneous material property distributions comply with safety requirements. The outcome of this work package is planned to be a (hydro)-mechanical assessment of the case studies, given a range of uncertainties in the boundary conditions based on empirical and numerical evidence, that, based on a probabilistic approach, would ultimately result in a set of requirements under consideration of the host rock and the repository design.

The first deliverable was a report compiled with the answers to a questionnaire that was distributed to the different WMOs or their representatives. The questionnaire aimed at reflecting the state-of-the-art regarding the treatment of heterogeneous bentonite density distribution and properties in the safety case. The questionnaire consisted of three different parts: (1) application of bentonite in the specific design (2) the required performance of bentonite (3) detailed characterization of the required properties of the bentonite.

The conclusions from the answers to the questionnaire were that occurrence of heterogeneity in the repositories could impact the safety functions of bentonite components. Therefore, it needs to be determined to what extent this could affect the safety case of the repositories. Heterogeneity can occur in the initial material, through the emplacement or the re-saturation phase as well as on the long term after re-saturation of all repository components. The heterogeneities in the initial state, i.e. after installation of the EBS, are mainly due to density differences. Inhomogeneous saturation and swelling of bentonite could cause irreversible damage. The role of uncertainties related to these bentonite heterogeneities is addressed in most repository concepts using a deterministic approach, defined with a preferred density value. There are several natural properties of bentonite that may impact the degree of homogenization. Most waste management organizations consider water content, original exchangeable cations, bulk density, swelling pressure and hydraulic conductivity as relevant natural properties for the bentonite regarding heterogeneity, while organic carbon or thermal conductivity seem to be incidental to the homogenization process.

All participating waste management organizations agree that the most valuable output from

Beacon would be material models that are accurate enough to be used as a tool for design and engineering purposes, i.e. to assess the behaviour and performance of the bentonite-based EBS both on the short- and long-term under variable design and environmental conditions. It is expected that, if preparation of the sealing material (e.g. pellets) and emplacement method are performed properly, heterogeneity will not be problematic for safety cases and that the buffer material can be represented in the safety assessment by a well-chosen homogeneous material.

3. WP2 Collection and compilation of existing data and available models

The primary deliverable of WP2 so far was a report that documents the information that has been made available to the BEACON project by the project partners and associated organisations. The information relates to experiments at a variety of scales and also modelling studies that have been undertaken. The report uses information supplied by Beacon partners on experiments that have been carried out in previous projects, to build a database of experiments which can be used during the Beacon project and beyond. The report documents the available data but does not attempt to propose any experiments for consideration within the BEACON project. This will be left to the Work Package leaders to undertake, based on the information contained herein. The report provides a summary of information on a range of experiments, as well as clear referencing to the underlying reports which contain further information, to facilitate the process of selecting datasets for modelling within BEACON. The process for collecting and compiling information into the database involved:

- Designing a data form to collect appropriate information;
- Requesting that Beacon partners and associated organisations fill out the data form for any studies they feel could be relevant to BEACON;
- Collation of the completed data forms into a preliminary database;
- Discussion of the database at a workshop and definition of additional fields that would aid future selection of experiments for study within BEACON;
- Request for additional information to complete additional fields in database;
- Finalisation of the database.

The process relies on the judgement of the Beacon participants as to which experimental datasets may be relevant to Beacon. The data forms have been entered into the database in three categories: laboratory experiments, mock-up experiments and in-situ experiments. The laboratory experiments include experiments designed to measure material properties, as well as experiments that simulate scaled-down repository conditions. There are many experiments listed in the database, at a range of scales (from bench top laboratory experiments to full scale field experiments), a small number of which were designed specifically for studies of bentonite homogenisation, but the majority of which were originally designed for other purposes. Nevertheless, these experiments provide a valuable source of information on the mechanical properties of bentonite and the likely mechanical evolution of bentonite within a repository. The database contains information on the type of bentonite considered in the experiments, the boundary conditions and heterogeneities within the experiments and also the range of measurements taken in the experiment. This will allow Beacon partners and especially Work Package leaders to interrogate the database and find experiments of interest for consideration in the Beacon project. Furthermore, knowing experiments that have been undertaken previously, decisions on new experiments to be undertaken within the Beacon project itself can be taken in the light of understanding derived from international work on bentonite derived to date.

4. WP 3 Model development

Work Package 3 plays a central role in the structure of the project as it is devoted to the development of the constitutive models for describing the hydro-mechanical behaviour of the bentonite in an appropriate manner. It is recognized that current models face limitations in their predictive capabilities and significant advances are required. The models must prove their predictive capabilities, reliability and robustness and they should preferably be grounded on a good understanding of the phenomena involved. To this end, they will be validated using several laboratory and field-scale tests. Ideally, those constitutive models should consider the following cases:

- Saturated and unsaturated materials
- Compacted bentonite (Blocks) and granular bentonite (e.g. pellet-based)
- Isothermal and non-isothermal conditions

although it is recognised that not all models will necessarily have this comprehensive level of generality.

To facilitate a more common assessment of the models, the teams were asked explicitly what the model capabilities were concerning a number of features of behaviour:

- Dependence of swelling strain on applied stress and on dry density;
- Irreversibility of strains in wetting/drying cycles;
- Behaviour during swelling stress test. Dependence of swelling pressure on dry density;
- Stress path dependence from an unsaturated to a saturated state (Fig. 5);
- Stress path dependence from a saturated to an unsaturated state ;
- Dependence of strains developed in a temperature cycle (increase/decrease) on OCR (Overconsolidation Ratio) (or stress).

The first five items correspond to an isothermal formulation whereas the sixth one requires the incorporation of temperature effects. The features selected for this purpose are those that are deemed, in principle, most relevant to explain the evolution of engineered barriers and seals during the transient phase.

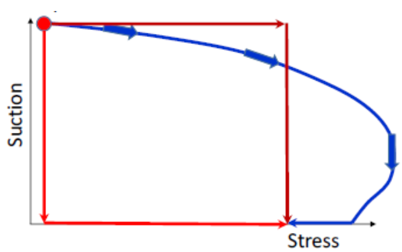

FIG. 5. Suggested suction-stress paths to check stress path dependency from an unsaturated to a saturated state. Stress may be vertical total stress (in oedometer tests) or mean total stress (in isotropic loading tests).

The model capabilities at the beginning of the project are available as deliverable 3.1.

5. WP4 Lab testing

The objectives of the Beacon experimental studies are to provide input data and parameters for development and validation of models and to reduce uncertainties about conditions and phenomena influencing bentonite homogenisation. Both the homogenisation of an initially inhomogeneous bentonite system and the persistence or development of inhomogeneities in the bentonite systems under various mechanical and hydraulic conditions are investigated. Eight experiment teams perform tests involving different bentonite materials and hydraulic and mechanical boundary conditions. As an example, CIEMAT's hydration tests in large-scale isochoric cells are presented here.

The work focuses on the conceptual understanding of the evolution of bentonite fabric and microstructure upon hydration and the factors affecting them. To accomplish this, hydration tests are being performed in isochoric cells (Fig. 6) to analyse the fabric and microstructure evolution of initially inhomogeneous FEBEX bentonite. In the tests half of the sample was composed of bentonite pellets (initial dry density 1.3 g/cm^3) and the other half of a bentonite block (initial dry density 1.6 g/cm^3). The two samples were prepared in the same way, but one of them was hydrated under a constant flow rate of 0.05 cm^3/h (MGR22) and the other one under a constant injection pressure of 14 kPa (MGR23). The first boundary condition tried to simulate a host rock with limited water availability, whereas the other one simulated a repository with plenty of water in which the water intake is controlled by the bentonite permeability. The axial pressure development in the two tests is shown in Fig. 1. There was a significant difference in swelling development kinetics, but although it took much longer to reach an equilibrium value for the test performed under low water inflow (MGR22), the final swelling pressure value, once the samples were saturated, was the same in the two cases, about 3 MPa, which is the expected value for a granular FEBEX sample compacted to the average dry density of the block/pellets set (1.42 g/cm^3).

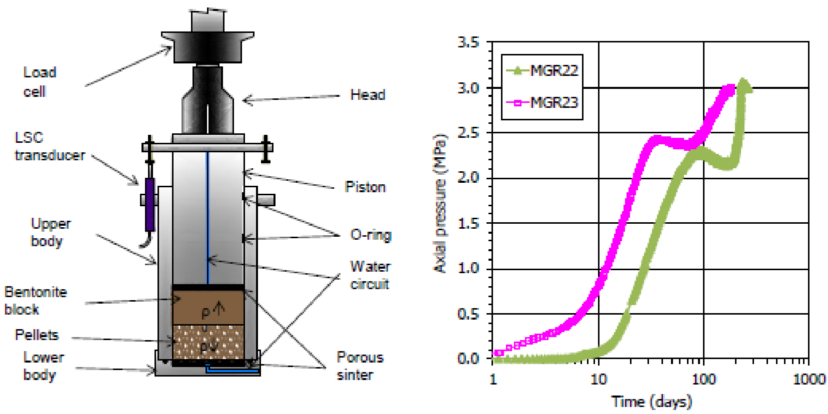

FIG. 6. Isochoric cell for hydration tests on bentonite block/pellets and swelling pressure evolution in two tests.

Once the sample from test MGR22 was dismantled, its physical state was checked by determining the water content, dry density and pore size distribution at different positions. The final appearance of the clay was homogeneous, with no discernible pellets. There was a slight decrease of water content from the hydration surface to the top of the sample (from 35 to 30%), while the dry density increased in this sense (from 1.39 to 1.46 g/cm^3). The average dry density of the bentonite block considerably decreased as a consequence of saturation and that of the pellets part increased. The degree of saturation was close to 100% in every position. The pore size distribution significantly changed with respect to the original samples: the macroporosity of the pellets decreased, whereas the microporosity of both the pellets and of the block increased.

6. WP5 Testing verification and validation of models

One of the objectives of Beacon project is to improve models to simulate bentonite component evolution along the repository life. In this context, a specific work package is dedicated to verification and validation of models.

Based on an inventory performed within the project identifying experiments in link with mechanical evolution of repository bentonite barrier materials, a selection of test cases has been made. The test cases are based on experiments performed at several scales: from lab tests (cm) to field tests (scale 1) which are relevant in regards of the BEACON objectives.

Partners involved in WP5 make simulations on the chosen test cases and produce specified results. The objective of those simulations is not only to reproduce the experimental results which most of the time could be done by identifying some relevant parameters but also to detect where the difficulties in terms of modelling are. The aim is to be able to improve our capacities of prediction of long-term behaviour for bentonite-based components. Comparisons of results and analyses of the differences will lead to an improvement of the physical and numerical models creating a strong link with WP3 (model development) and should give a feedback to the experimentalists involved in the dedicated work package (WP4).

The strategy was to select tests at laboratory scale where homogenization processes have been highlighted, and which will constitute elementary bricks to tackle bentonite evolution modelling at a larger scale. The selected tests are:

- Swelling pressure tests for compacted plugs with free volume available TEST B1.7 from Clay Technology AB;
- Swelling pressure tests for pellets mixture TEST B1.16 from CEA, Andra;
- Swelling pressure tests for block and pellets structure TEST B1.6 from Posiva.

The first test modelled during this exercise concerns a pure MX-80 bentonite at an initial dry density of 1655 kg/m^3 and have two successive phases (Fig. 7). It consists first in a classical swelling pressure test at constant volume. When the swelling pressure is stabilized, the upper piston is moved upwards and fixed with spacers admitting a certain volume for the swelling. A second stage of swelling starts, bentonite filling the created void.

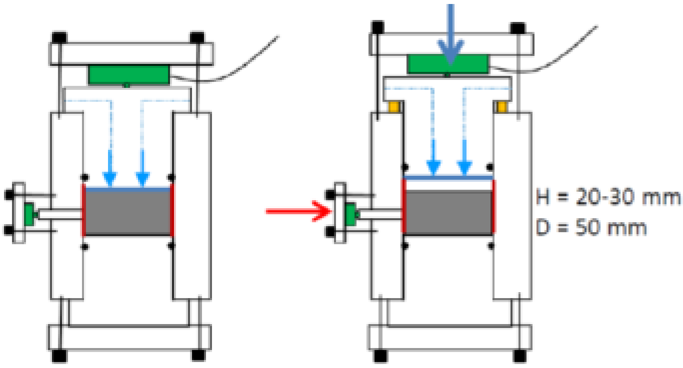

FIG. 7. Set-up used for the axial swelling tests. The red lines represent the lubricated surfaces and the blue lines represent filters and water supply. The radial pressure transducer is placed 10 mm from the bottom end of the specimen.

After finished swelling and homogenization, i.e. when no or negligibly small changes are noticed in the swelling pressure with time, the specimen is dismantled and cut in slices for determination of the water content and density distribution in the direction of swelling.

Several partners modelled the test obtaining results in good agreement with the measurements at the end of the first stage for the axial swelling pressure (Fig. 8). The exercise shows the difficulties of the models to represent the transient phase that is constituted mainly by water saturation and development of swelling pressure.

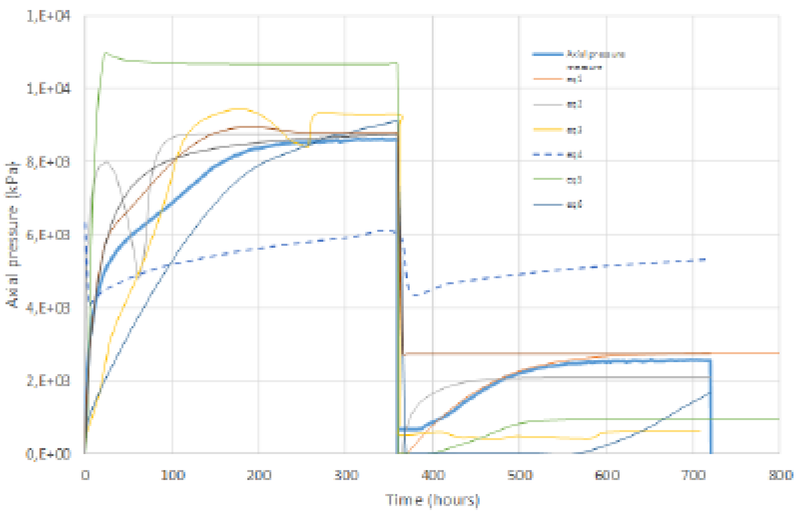

FIG. 8. Axial pressure evolution – comparison between the experiment and the models.

At the top of the sample, dry density and water content at the end of the test are higher due to the introduced void during the test. The water content obtained at the end of the test when the sample was dismantled is compared to the numerical results (Fig. 9) showing that the general trend for water content is well reproduced. Models seem able to reproduce the final heterogeneity of properties observed at the end of the test.

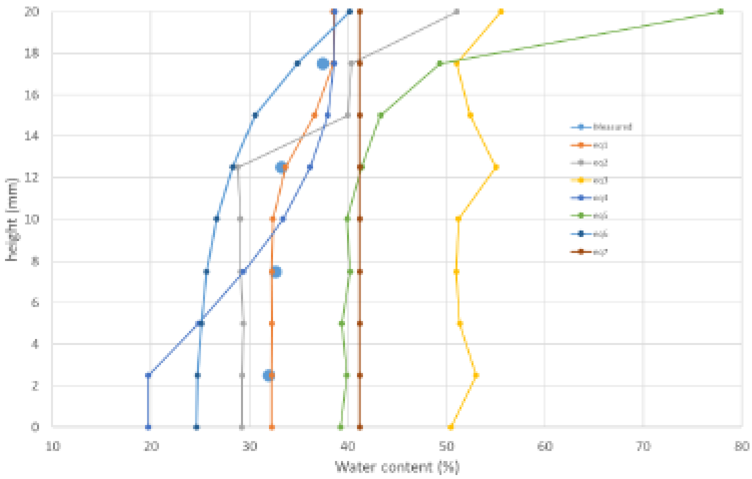

FIG. 9. Water content at the end of the test – comparison between the experiment and the models.

The first analysis was very useful to identify some specific points that need to be investigated and on what the model evolutions should be focused. The second test, in the list above, performed on pellets highlighted the same kind of conclusions. The hydration phase is always difficult to capture with the models.

The next task will be to model large scale field tests to show the capacity of the models to reproduce in situ experiments. Three experiments have been selected:

– EB - Engineered Barrier Emplacement Experiment (Mont Terri),
– FEBEX - Full-scale Engineered Barrier Experiment in Crystalline Host Rock (Grimsel),
– CRT - Canister Retrieval Test (Äspö).

7. Civil society interaction, dissemination and coordination

The overall aim of WP6 is to give civil society the opportunity to follow, discuss and give feedback on the research conducted in the project by the development, using previous experience, of a relevant interaction framework.

The work package will facilitate the translation of scientific results and other output from WP1-5 to the public and create the conditions for civil society local and national representatives to interpret, discuss and give feedback on the research results and other information made available by the project. This will enhance the possibilities of civil society participation in future situations where there are consultation processes as a part of safety case review.

The BEACON project has arranged one specific training course during the project, within WP7. The course took place at the Universitat Politècnica de Catalunya (Spain). The course aimed to give an overview of the current approaches and capabilities concerning the constitutive and numerical modelling of the hydro-mechanical behaviour of bentonite and other swelling clays. The context of the course was the field of nuclear waste management; however, the concepts and methods that were presented have a much wider scope of application. The topics of the course were:

- The fundamental science behind the mechanical and hydraulic properties of bentonite;
- Current constitutive modelling approaches;
- Numerical modelling and examples of application;
- The issues around the mechanical evolution of bentonite in nuclear waste management;
- Hands-on training with a computer code.

The course had 36 participants and was addressed to the nuclear waste management community as well as to students in areas of soil and material science and civil, environmental and mechanical engineering.

8. Conclusions

BEACON is now about half way into the project. So far the work has been both focused and according to plan. The State of Art reports from WP2 and WP3 are important summaries of the knowledge that never has been collected in a similar manner before. They will both be an important foundation for current and future mechanical assessments of bentonite. The benchmark tests in WP5 have also been very successful: they have pointed out that there are real challenges, but also have shown that there are model concepts available that should be able to meet those challenges.

Acknowledgement

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PATRICK SELLIN

BENTONITE EROSION: EFFECTS ON THE LONG-TERM PERFORMANCE OF THE ENGINEERED BARRIER AND RADIONUCLIDE TRANSPORT – THE BELBAR PROJECT

P. SELLIN[1], M. WESTERMARK[1], L. BAILEY[2], T. MISSANA[3], T. SCHÄFER[4], R. ČERVINKA[5], K. KOSKINEN[6]

[1]Svensk Kärnbränslehantering AB (SKB), Evenemangsgatan 13, Box 3091, 169 03 Solna, Sweden
[2]Radioactive Waste Management, Building 587, Curie Avenue, Harwell Oxford, Didcot, Oxfordshire, OX11 0RH, United Kingdom
[3]Radioactive Waste Management, Physical Chemical of Actinides and Fission Products Unit CIEMAT, Avda. Complutense 40, 28040 Madrid, Spain
[4]Applied Geology Friedrich-Schiller-Universität, Jena Burgweg 11, D-07749 Jena, Germany
[5]Chemie palivového cyklu 2402 / Fuel Cycle Chemistry Department, ÚJV Řež, a. s., Hlavní 130, 250 68 Husinec – Řež, Czech Republic
[6]Posiva Oy, Olkiluoto, 27160 Eurajoki, Finland

Abstract. BELBAR was a Collaborative Project within the Seventh Framework Programme of Euratom for nuclear research and training activities. The main aim of BELBaR was to increase knowledge of the processes that control clay colloid stability, generation and its ability to transport radionuclides (RNs). More specifically the aim of BELBaR was to reduce uncertainties in the description of the effect of clay colloids on the long-term performance of the engineered barrier and on RN transport. This was done by:

- improving the understanding of when bentonite colloids are unstable — for a given site/site evolution, to determine whether or not clay colloids need to be included in the long-term assessment;
- improving the quantitative models for erosion on the bentonite barrier for cases when the colloids are stable;
- improving the understanding of how RNs attach to clay colloids — this information is used to formulate improved transport models for the assessment of RN transport.

1. Introduction

The Collaborative Project was based on the desire to improve the long-term safety assessments for repository concepts that combine a clay EBS with a fractured rock. The formation and stability of colloids generated from the EBS may have a direct impact on the assessed risk from the repository in two aspects, as illustrated in Fig. 1:

- generation of colloids may degrade the engineered barrier;
- colloid transport of RNs may reduce the efficiency of the natural barrier.

An increased understanding of processes will have an effect on the outcome of future assessments.

2. Background and the problem

Clay colloid chemistry and the properties of bentonites and smectites have been studied intensively over a long time, both within and outside the waste management community. There is a sound theoretical basis for the forces acting on and between smectite particles in gels and suspensions and how these are influenced by water chemistry. Much experience has been gathered on practical use of bentonite suspensions used as drilling muds and as additives to various products including paints to give them thixotropic properties.

Nevertheless, there are areas where the behaviour of smectite gels and sols, which have important impact on the possible erosion of a bentonite buffer, are not sufficiently understood.

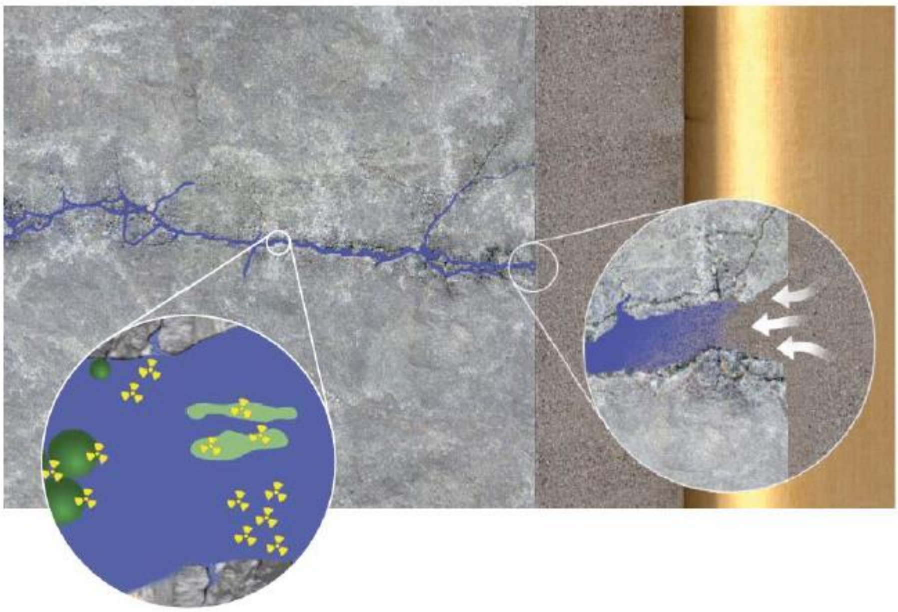

FIG. 1. Generation of colloids from a bentonite buffer and radionuclide transport in fractures.

The uptake of water and resulting swelling of the bentonite buffer is counteracted by the walls of the deposition hole, and a swelling pressure is developed in the bentonite. Fractures intersecting the deposition hole mean that rigid swelling restrictions are not present everywhere, and that localised swelling continues into the fractures until an equilibrium or steady state is reached. This free swelling may lead to separation of individual montmorillonite layers (dispersion) and part of the buffer could be transported away by groundwater.

Clay colloids released could be a carrier of RNs. Colloid mobility is strongly dependent on fracture geometry (aperture size distribution and fracture surface roughness) as well as chemical heterogeneity induced by the different mineral phases present in the fracture-filling material and the chemistry of the matrix porewater. In the case where bentonite colloids are stable, the high concentrations of colloids that may be present in the water may have a significant impact on the RN transport in the geosphere.

3. Concept and methodology

The main aim of BELBAR was to reduce uncertainties in the description of the effect of clay colloids on the long-term performance of the engineered barrier and on RN transport. This was done by:

– improving the understanding of when bentonite colloids are unstable for a given site/site evolution — this is critical information since it determines whether or not clay colloids need to be included in the long-term assessment;
– improving the quantitative models for erosion on the bentonite barrier for cases when the colloids are stable;
– improving the understanding of how RNs attach to clay colloids — this information is used to formulate improved transport models for the assessment of RN transport in the geosphere.

To meet the main aim, a number of experimental and modelling activities were undertaken within the project.

With respect to the erosion of a bentonite EBS and the RN transport with colloids in a fractured host-rock far-field, and application to the associated safety assessments, the work plan aimed at:

– identification of the key issues in safety assessments;
– implementation of a training package;
– survey of modelling needs and current capabilities;
– review of the understanding of the clay colloid stability field;
– definition of the need for data and observations from the experimental programmes;
– implementation of extensive experimental work in the relevant fields;
– development of improved conceptual and mathematical models;
– formulating the results based on its use for decreasing uncertainty in safety assessment;
– encouragement of publications of results in peer-reviewed journals;
– provision of overall project management.

BELBAR consisted of six RTD WPs and one project management WP. The focus of the RTD WPs was on:

WP1: Safety assessment;
WP2: Erosion;
WP3: Radionuclide and host rock interactions;
WP4: Colloid stability;
WP5: Conceptual and mathematical models.

There was also one WP on knowledge management and dissemination and training (WP6). The targeted training package was closely associated with the

RTD programme through the project workshops and exchange of researchers among partners. The last WP was on 'Project Management' (WP7).

4. WP1 Safety assessment

This WP collected and presented the current treatment of the relevant processes in safety assessments in a report. The report achieved the following:

- The current treatments of colloid issues in performance assessments PA (on the basis of national organisations involved in BELBAR only) was described;
- The limitations of previous studies and uncertainties related to colloids was noted;
- The needs for additional studies of colloids issues, and their PA relevance, was discussed;
- Such additional studies were linked to planned work in the BELBAR project, and the relevance of, and expected benefit from, BELBAR WPs 2–5 were identified.

Each of the three national WMOs represented in BELBAR WP1 produced a description of how it currently considered colloids in PA — the current state of the art. This information has subsequently been used to identify current issues affecting the treatment of colloids in PA in national programmes.

At the end of the project WP1 provided a synthesis (Shelton et al 2017) of the progress that was made as a result of the work undertaken within the BELBAR project along with recommendations for the potential to review the treatment of colloids in performance assessment.

The following points represent a summary of recommendations:

1. With respect to the safety assessment, the results of BELBAR suggest that assumptions made by WMOs relating to the dependency of mass loss rate on groundwater flow velocity could potentially be reviewed under highly 'erosive' conditions. It has been shown that bentonite erosion overall is driven more significantly by chemical forces rather than mechanical forces and thus it is recommended that the current treatment could be reviewed with respect to the driving mechanism controlling bentonite erosion.
2. All exchanger sites in the clay are currently assumed to be occupied by Na^+. This assumption leads to high erosion rates and overly pessimistic mass loss calculations since the current modelling capability is not able to take into account the effects of divalent cations such as Ca^{2+}. However, in a natural system, it would be difficult to exclude that the Na content of clay is less than the 20-25% threshold that favours colloid generation and thus the current treatment is considered to be appropriate within the overall system uncertainties.
3. The presence of different cations in solution can effect coagulation, with divalent cations being more effective than monovalent ions as coagulants. It is currently assumed that mass loss ceases when groundwater salinity exceeds a stability limit of 4-8 mM NaCl for Na-bentonite. Should the assumed composition of the clay be reviewed (Recommendation 2) then

consideration should also be given to addressing the conservatism that would be inherent in the assumed bentonite stability limit. However, within the bounds of the current knowledge, it considered that this assumption remains appropriate.

4. In terms of the ionic strength of groundwater assumed, given that deionised water may not be representative of a real dilute groundwater, it may be considered that the maximal zero charge limit is an overly conservative scenario. However it is considered that this assumption remains appropriate within the overall system uncertainties, particularly with regard to the need to address the potential for a change on groundwater composition for example due to glacial meltwater.
5. With respect to the angle of the fracture aperture, it is observed that the mass loss mechanisms between a horizontal and sloped fracture are different. Current performance assessment assumptions assume a horizontal fracture and thus the results observed suggest that this treatment may not necessarily be conservative. It is strongly suggested that this assumption is reviewed and potentially further work is required to account for the observed effects of slope angle/ gravity.
6. Significant retardation of clay colloids in a rock fracture has been observed. However, the uptake of colloids is not complete (i.e. some remain in solution), which means that colloid transport needs to be considered, if colloids are present. It is recommended that colloid retardation could be included in safety assessment calculations. However, the effect may be limited under most conditions and the process could therefore be optimistically neglected.
7. It is clear that the current assumption of linear sorption is valid. Sorption reversibility is nuclide specific and should possibly be treated on a case by case basis. However, for most radionuclides sorption reversibility can be assumed (the exception is potentially tetravalent elements where caution should be taken) over repository time scales.
8. Organic matter (humic or fulvic acid) was demonstrated to be able to stabilise clay colloids in NaCl electrolyte. In all the other electrolytes investigated ($CaCl_2$, $MgCl_2$) and at higher Ionic strength, the clay colloids undergo fast coagulation, independently of the presence of organic matter. This is true in various aqueous media containing different inorganic cations, showing that the ionic strength remains the key parameter. In addition, Ca^{2+} ions alone are able to initiate clay colloid agglomeration even at low concentrations. The presence of Ca, even at only low concentration in natural media, is thus recommended to be considered in performance assessments (as per Recommendations 2 and 3).
9. Regarding validation and advancing the models, sufficient confidence was obtained to predict clay mass loss rate on laboratory scales using numerical simulations, whereas mass loss rate predictions on repository relevant scales remain to be assessed using analytically derived expressions for bounding estimates. According to the bounding estimates referred to, the agglomerate/floc migration rate in fracture is the mass loss rate determining feature.
10. The reasoning of dominant processes was succeeded considering agglomerate migration but was based only on expert judgement for clay swelling and gravity. Moreover, data needs specifications to assess the

relative importance of clay swelling and gravity were raised but only when it was too late to commit experiments within BELBAR.

11. It can be stated that a new bounding estimate is proposed to be used in the safety cases to assess clay mass loss rates; loss of clay at the clay-water interface is limited by migration of newly formed clay agglomerates in fractures. This estimate can be obtained with far less effort and uncertainty than used in the previous safety cases.

5. WP2 Erosion

In WP2 several research groups collaborated to identify the most important mechanisms involved in bentonite erosion and to quantify its possible extent under different environmental conditions. Different possible scenarios were considered: the static system, where the transformation of the hydrated bentonite gel to a sol is mainly a chemically driven process and the dynamic one where other hydraulic aspects, as water velocity or fracture geometry must be considered. In fact, the worst scenario for a HLRW repository in crystalline rocks includes the presence of hydraulically active fractures near the bentonite surface.

In both scenarios, the extent of erosion is expected to depend mainly on the combination of water chemistry and clay properties; however, in the dynamic system, the water flowing at the bentonite surface (the gel-front) may increase colloid detachment.

In order to address the goals of this WP, different experimental sets-up were used by the different organisations. Most of the tests were carried out simulating the potential extrusion/erosion behaviour of bentonite buffer material at a transmissive fracture interface. A schematic of this type of test can be seen in Fig. 2. With this system, the effect of solution chemistry, material composition, flow velocity, fracture geometry (aperture, slope angle) and other parameters could be analysed. In this set-up, the swelling clay material can extrude/erode into an artificial fracture and it was selected for performing the tests of the benchmark exercise, also carried out in WP2.

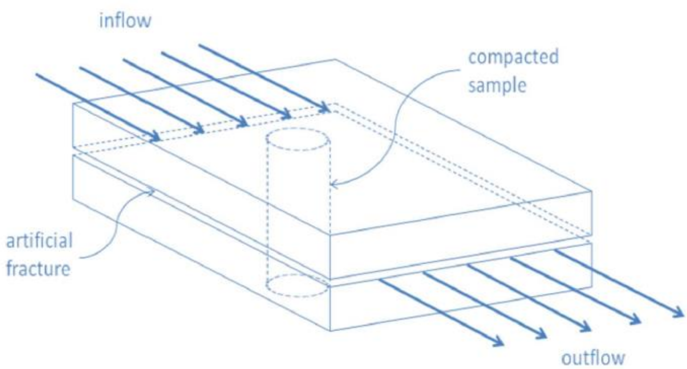

FIG. 2. Schematic representation of the flow-through, artificial fracture test.

To analyse the results obtained from the different organisations and to be sure that the data provided in the Annex are comparable, is important to make clear how the "mass loss" or the "average mass loss rate", needed for quantitatively estimating erosion, is measured in each case. When the clay is confined, with no significant extrusion, the mass loss is limited to the particles dispersed in the liquid phase (or eluted mass) plus some particles retained in the sintered filters, which can be determined by difference from the initial and final weight of the initially emplaced mass. In the artificial fracture tests, the mass loss is determined via post-mortem analysis considering also the material extruded in the fracture.

6. WP3 Radionuclide and host rock interactions

In WP3 of BELBAR in total six partners investigated colloid mobility controlling processes in the geosphere and the effect of the mobile colloidal phase on the transport of radionuclides in the far-field environment of a deep geological repository in crystalline formations.

The work in BELBAR has increased our understanding of bentonite colloid effects on radionuclide transport. It has shown that radionuclides bound by bentonite colloids may be released slowly. In this state, they are bound 'non-exchangeably'. The extent of the effect depends upon the chemistry of the radionuclide. Tri- and tetravalent f-block elements seem to be prone to slow dissociation, with the tetravalent elements able to show slower dissociation than the other species. Actinyl species appear more weakly bound, but may still dissociate slowly. Monovalent and divalent cations show a rather fast dissociation kinetic with the exception of Cs, where the geological origin of the clay mineral triggering the frayed edge sites is determining the reversibility of sorption. The first order dissociation rate constants found in the literature for colloid dissociation have been significantly enlarged through the BELBAR project and already published values have been to a large extent reconfirmed.

7. Colloid stability

Both the erodibility of the clay barrier and colloid transport in the environment are strictly related to the water chemistry and also to the intrinsic properties of colloids and their stability behaviour. Thus, the analysis of the chemical conditions that make colloidal systems stable or unstable is important because the conditions that favour colloid stability are also expected to favour colloid transport and erosion processes. In general, a colloidal system is considered as stable, if suspended particles do not undergo coagulation at least during the observation time.

Because colloid stability depends on the chemistry of the aqueous environment, the stability studies analyse whether or not clay colloids aggregate depending on several chemical and physical parameters, such as pH, ionic strength, temperature, presence of different inorganic ions and organic ligands, amongst other factors. It is also important to understand what intrinsic physico-chemical properties of the bentonite may affect the stability of colloids. So, the knowledge about the stability of clay colloids in the site-specific host rock conditions is important for assessments of long-term performance of radioactive waste repositories.

Based on the analysis in WP1 the main crucial issues for WP4 were identified at the beginning of the project (Fig. 2). Many coagulation studies of colloidal clay dispersions were performed under different geochemical conditions during the last decades. However less attention was given to find the main reason for different behaviour of different clays. In this project some insight was made concerning the trend or correlation between the bentonites characteristics and its stability.

The coagulation of colloids is a fast process, if the conditions are favourable for coagulation (e.g. the concentration of some cation(s) is above critical coagulation concentration for given clay dispersion - CCC). But if we are at the boundary, close to conditions which are favourable for clay colloids coagulation, the aggregation process can be very slow. In this means, the long term experiments are important and were performed in this project. Highlights from WP4 are listed below in accordance with issues from WP1.

Phase transitions of montmorillonite in a repository – the investigations suggest that, provided the ionic strength of the ground water is above the CCC, the highly compacted clay in engineered barriers will act as a swelling repulsive paste and expand. Once the lowest clay concentration at the swelling front is below the clay concentration required for paste formation, the clay will form a gel. The lowest limit appears to be about 60 g/l.

Influence of bentonite properties on its stability – one of the possible causes of the difference in the stability / erosion behaviour could be related to the different mineralogy (mainly clay minerals and its properties) of the different bentonites (trioctahedral vs. dioctahedral clays, different exchange complex, different charge density, and different charge location). In general, those clays having the charge located in the tetrahedral layer form larger colloids: these particles sediment easier being less stable than others even in de-ionized water DI.

Role of inorganic compounds and (ir)reversibility of coagulation process – changing anion has only minor effect on the CCC, provided that the anion does not directly influence the overall clay particle charge, as in the case of polyphosphates and to some extent OH^-. The effect of cations (CCC) was also investigated. It has to be noted, that such tests must be evaluated taking exchange into account. Sodium and potassium, and magnesium and calcium act in a similar way during the coagulation process and in real systems. Their effect can be simplified to the effect of M^{1+} (Na+K) or M^{2+} (Ca+Mg) cations, where M^{2+} are more effective in coagulation.

Role of organic matter – organic matter (like humic or fulvic acids) is able to stabilize clay colloids in NaCl electrolyte (experimental concentration up to 0.1 M NaCl). This means that in presence of organic matter more concentrated NaCl electrolyte is needed to coagulate clay dispersion (the CCC is higher). For example the CCC is four times higher in a suspension containing 0.5 mg/L total organic carbon (TOC) compared to the same suspension without humic acid.

8. WP5 Conceptual and mathematical models

The objectives for WP5 were derived from the main aim of BELBaR that was to reduce the uncertainties in the description of the effect of clay colloids on the long term performance of the engineered barrier and on radionuclide transport. The objective of the development activities was to improve the conceptual and the mathematical models used to predict mass loss of clay in dilute waters, clay colloid generation in particular, as well as clay colloid facilitated radionuclide transport. A target of validating advanced model(s) for the purposes of spent nuclear fuel disposal was set at the beginning. Regarding validation and advancing the models, sufficient confidence was obtained to predict clay mass loss rate in laboratory scales using numerical simulations, whereas mass loss rate predictions repository relevant scales remain to be assessed using analytically derived expressions for bounding estimates. According to the bounding estimates referred to, the agglomerate/floc migration rate in a fracture is the mass loss rate determining feature. The reasoning of dominant processes was succeeded considering agglomerate migration but was based only on expert judgement for clay swelling and gravity. Moreover, data needs specifications to assess the relative importance of clay swelling and gravity were raised but only when it was too late to commit experiments within BELBAR. As to conclude it can be stated that a new bounding estimate is proposed to be used in the safety cases to assess clay mass loss rates; loss of clay at the clay-water interface is limited by migration of newly formed clay agglomerates in fractures. This estimate can be obtained with far lesser efforts and uncertainties than used in the previous safety cases.

9. WP6/WP7 Dissemination and management

To ensure that BELBAR had the appropriate impacts, a specific work package (WP6) was established for dissemination. The purpose was that a range of tools would be used to reach a wide audience. In particular, the results were disseminated to international conferences, and high level publications. A training course on laboratory methods in colloid science was arranged.

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BIRGITTA KALINOWSKI

MICROBIOLOGY IN NUCLEAR WASTE DISPOSAL

B.E. KALINOWSKI[1], P. CHRISTENSEN[1], J. S. SMALL[2], K. PEDERSEN[3], N. LEYS[4], K. MIJNENDONCKX[4]

[1]Swedish Nuclear Fuel and Waste Management Co, Evenemangsgatan 13, SE-169 03 Solna – Sweden
[2]National Nuclear Laboratory, Chadwick House, Birchwood Park, Warrington WA3 6AE - United Kingdom
[3]Microbial Analytics Sweden AB), Mölnlycke Fabriker 9, 435 35 Mölnlycke – Sweden
[4]Belgian Nuclear Research Centre SCK-CEN, Boeretang 200, 2400 Mol - Belgium

Abstract. Microbiology in Nuclear waste Disposal (MIND) is an interdisciplinary project consisting of two experimental work packages and a third one that handles integration of society and policy-oriented studies.

Work package 1 is focusing on the influence of microbial processes on organic containing long-lived Intermediate Level Waste (L/ILW) forms e.g. waste solidified with cement or bitumen. In work package 2 the influence of microbial processes on high level waste (HLW) and spent fuel geological disposal are studied. The emphasis is on quantifying specific measurable impacts of microbial activity on processes and the long-term performance of the system with its barriers under repository-relevant conditions to be considered in safety cases. The remaining uncertainties concerning the release of chemicals, gases and radionuclides that are important to the safety case for L/ILW disposal and near-field safety issues related to the engineered barriers in HLW disposal, are addressed respectively. Work package 3 is oriented towards interaction within (by e.g. sharing experience and results with other experts) and between different groups including both experts and the lay community through education and communication and thereby improving the general awareness of microbial issues.

Microbial activity may have a significant impact on the physical and chemical evolution of repositories for radioactive waste. Therefore, what controls their activity under repository conditions must be well understood.

1. Introduction

The MIND project is a project addressing key technical issues that must be tackled to support the implementation of planned geological disposal projects for higher-level radioactive wastes across the EU. Geological disposal is a challenge as social and technical aspects blend and input from social science with regard to the design, implementation and post-construction management of the installation is required. In this respect the impact of the inclusion of microbiology on expert conceptualisation and public perception of geological disposal have been considered as well. Our current understanding of the impact of microbial metabolism on the safety of geological repositories remains tenuous, even though microorganisms may have controlling influences on organic waste (e.g. solidified with cement or bitumen) evolution in situ, multi-barrier integrity and ultimately radionuclide migration from the repository. The project brings together, for the first time, 15 European groups from 8 countries working on the impact of microbial processes on the evolution/performance of the repository system and its barrier elements to be considered in safety cases for geological repositories across the EU, focusing on key questions posed by waste management organisations. The emphasis has been on quantifying specific measureable impacts of microbial activity on barrier evolution under repository-relevant conditions. The knowledge obtained will be considered when choosing design and materials when constructing repositories for radioactive waste. The MIND project has thus contributed to that microbial processes in repositories are now being taken into account to greater extent than previously leading to significant refinements of safety case models currently being implemented to evaluate the long-term evolution of radioactive waste repositories. The project consists of two experimental work packages, WP1 and WP2 and the third one WP3 handles distribution of knowledge obtained in WP1 and 2 including dissemination and education. WP4 handles project management.

1.1. Work package 1

The overall objective of WP1 is to reduce uncertainty of safety relevant microbial processes controlling radionuclide, chemical and gas release from long-lived intermediate level wastes (ILW) containing organics. Development of gas in a repository for L/ILW has been studied previously by e.g. Wiborgh et al., [1] and more recently by Small et al., [2] who performed experimental and modelling investigations of the biogeochemistry of gas production from low and intermediate level radioactive waste in the GGE (gas generation experiment) in Olkiluoto. Organic waste materials present in ILW include a variety of natural (cellulose, bitumen) and anthropogenic polymers including: polyvinylchloride (PVC), polyethylene (PE) and ion exchange resins (D1.1). Effects resulting from the combined effects of hydrolysis, radiolysis and biodegradation of such organic wastes have been studied under the physical and chemical conditions relevant to organic ILW solidified with cement (waste forms) and disposal concepts. The range of microbial processes that can be fuelled by these organic wastes has been examined to assess the effect on processes of gas generation and radionuclide complexation. Laboratory and in situ large-scale experiments have been performed examining alkaline, cement buffered (pH 10-12.5) conditions and including actual organic waste materials to determine the types of microbially mediated chemical and gas generation processes that may proceed in heterogeneous cementitious waste forms with organic waste. Microbial processes, affecting gas generation (CH_4) and consumption (H_2) have been examined that have relevance to the pressurisation of the repository system and which are also important to the migration of gaseous radionuclides such as ^{14}C. Models of the microbiological, geochemical and transport processes have been developed to assist in the interpretation of the *in situ* experiments.

The main safety issues concerning radionuclide, chemical and gas release from ILW that are addressed by the work package are summarised as:

1. The degradation of anthropogenic polymers (PVC and ion exchange resins) and hence their contribution gas generation and release of soluble organic species.
2. The biodegradation of cellulose hydrolysis products (e.g. ISA) and the overall effect on radionuclide complexation and transport.
3. Microbial gas generation (CH_4) and consumption (H_2) studied under in situ conditions.
4. The effect of high pH on limiting the above microbial processes in cementitious ILW.

1.2. Work package 2

In WP2 the objectives are to better quantify the contribution of microbially produced sulfide in the geosphere and in buffers and backfill to the overall rate of canister corrosion. There is also a need to gain systematic information on the efficiency of specific bentonite buffer in inhibiting microbial activity. Already a few years before MIND started, it was shown that there would exist a threshold density over which sulfate reducers could not be active (e.g. Motamedi et al, [3], Stroes-Gascoyne et al. [4], Masurat et al.,[5]).

Remaining key issues for the geological disposal of HLW concern the factors controlling sulfide production in the geosphere, including man-made artefacts to what extent microorganisms can accelerate canister corrosion in the near-field either by hydrogen scavenging or by sulfide and/or acetate production. Further, it is important to identify conditions more in detail (including buffer density) under which relevant bentonites inhibit microbial activity and to understand whether microorganisms can accelerate degradation of bentonite-based buffers and influence the long-term behaviour of plug systems and seals. To better understand the differences in behaviour between different bentonites.

Microbiology in work package 2 generally addresses near-field safety issues related to the engineered barriers canisters, bentonite clays and concrete. Three main safety issues can be postulated due to bacterial activity in the nearfield.

1. Bacterial sulfide production in buffer and backfill and the concomitant risk for sulfide corrosion of canisters.
2. 2. Bacterial acetate production in buffer and backfill and the concomitant risk for acetate induced stress corrosion cracking of canisters.
3. 3. Bacterial degradation of buffers and backfill, and of concrete constructions such as tunnel plugs.

1.3. Work package 3

The purpose with the third Work Package is to ensure that the output from WP1 and WP2 is well integrated. WP3 will evaluate and integrate microbial processes towards the conceptualization and performance assessment of geological repositories and in the respective state of the art knowledge base. The impact of the inclusion of microbiology on expert conceptualisation and public perception of geological disposal will be estimated. The proper contextualization of results will be ensured and remaining key topics within and beyond the MIND project will be extracted by maintaining an active dialogue with stakeholders.

In WP3 the outcome of the experimental work packages will also be distributed to a broad audience, including students, professionals, the scientific community, stakeholders and the lay community via e.g. Euratom Fission and Training Scheme programme PETRUSIII. Synergies of the MIND program and consortium will be identified and cultivated with ongoing research lines of European laboratories and institutes outside the MIND consortium, with special attention for those in the less advanced member states.

1.4. Work package 4

The project also organises an Implementers Review Board (IRB). The IRB consists of representatives of the Nuclear Waste Management organisations and regulators with interest in in MIND (SKB, Posiva, TVO, Andra, NWMO, Nagra, RWM, ONDRAF/NIRAS, NUMO, LANL, SURAO, CNSC, IRSN). During the course of the MIND project the IRB has advised the Technical Coordinator and the Executive Committee of MIND with critical evaluation concerning research quality and significance of outputs in relation to the implementers needs, highlighted opportunities for networking with other international research activities and raised awareness of our research programme where appropriate. Members of IRB have participated in the MIND Annual Meetings, participated in discussions and also produced written feedback at the end of each annual meeting.

2. Work package summaries

2.1. Work package 1

Outputs from laboratory and in situ experimental systems are reported in WP1 deliverables (D1.1- D1.8) and peer-reviewed journals, as discussed below.

The state of the art knowledge base concerning the biodegradation of organic polymers common in LLW/ILW was reviewed in D1.1, which includes a summary of information concerning the types of organic polymer present in ILW and some disposals of Low Level Waste (LLW) together with information concerning the European repository designs and concepts for their deep geological disposal. Deliverable D1.1 confirmed that the materials selected for study in the MIND project; bitumen, organic ion exchange resins and halogenated polymers (PVC), are present in significant amounts in the national inventories, but that biodegradation of these materials and their hydrolysis and radiolysis products was poorly understood. Cellulose is present in generally lower amounts in most inventories, but it is already established that it is of significance with regard to the strong complexation effect of its alkaline hydrolysis products. Recent findings concerning the biodegradation of the cellulose hydrolysis product isosaccharinic acid (ISA) using an alkaline inoculum from a high pH lime works [6,7] form the basis of further work within MIND WP1 using the inoculum to examine biodegradation of PVC (D1.2) and bitumen hydrolysis products (D1.3) at pH 10-11 conditions.

Deliverable D1.2 presents further studies of cellulose degradation following ^{60}Co ϒ irradiation (1 MGy) and hydrolysis at pH 12.7. Irradiation enhanced the rate of the abiotic alkaline hydrolysis of cellulose, which resulted in the production of higher concentrations of the radionuclide complexant ISA, compared to the unirradiated controls. Irradiation also led to an increase in the concentration of dissolved organic carbon, including ISA, and made the cellulose more bioavailable for microbial degradation at a starting pH value of 12.5. Fermentation of the cellulose degradation products at hyperalkaline pH (pH 12.5) led to the production of H_2, and acetate, while CH_4 was not detected. Fermentation at pH 12.5 is possibly due to the microbial activity in low pH niches associated with the cellulose tissue and which are further developed by acidity generated by fermentation. Characterisation, including 16S rRNA gene sequencing, of the bacteria (Anaerobacillus isosaccharinicus) isolated from the lime works inoculum establishes that it grew at pH 8.5–11, could utilise a number of organic substrates, and was able to reduce nitrate and arsenate (Bassil and Lloyd [8]). Deliverable D1.2 also presents studies of PVC biodegradation of pure PVC polymer (powder) and plasticised PVC sheet, following 1 MGy ^{60}Co ϒ irradiation in saturated Ca(OH)2. Batch microcosm experiments were set up to test the ability of a high pH-adapted lime works inoculum to use these irradiated materials as the sole source of carbon and electron donors for nitrate reduction at pH 10 (Nixon et al [9]). The results from this work demonstrate that PVC plasticiser and fire retardant additives present in the PVC sheet are able to fuel microbial metabolism at pH 10 conditions using nitrate as an electron acceptor. Irradiation of plasticised PVC renders the material less bioavailable at pH 10, but microbial metabolism appears to be supported. No nitrate reduction was observed with non-irradiated PVC powder, although irradiated powder supported minor nitrate reduction. Separate tests on phthalate, the breakdown product of phthalate esters under irradiating and high pH conditions, and a potential radionuclide complexant was not found to support the metabolism tested, although it is clear that other additives present in plasticised PVC were degraded. These results highlight the bioavailability of volumetrically significant plasticised PVC under conditions relevant to its geological disposal in cementitious intermediate level nuclear waste.

Results of studies of bitumen degradation are presented in D1.3. This study concerned the degradation of Eurobitum, which also includes nitrate salts, which have the potential to oxidise the Boom Clay that is being considered as a possible host rock for nuclear waste disposal in Belgium. The study compared the potential of a microbial inoculum from the Boom Clay to metabolise nitrate leached from thermally aged inactive Eurobitum in the presence or absence of known bitumen degradation products (acetate, formate, oxalate). The study examined denitrification at pH 9-12.5 conditions and also included experiments inoculated with the high pH adapted lime works inoculum used in other MIND studies (D1.2, [3,4]). The study demonstrated that the nitrate leaching from Eurobitum rapidly stimulated microbial nitrate reduction. Different rates were observed depending on the organic compounds that were used as the electron donor to fuel the nitrate reduction process. Microbes were also able to use the Eurobitum as an electron donor to reduce nitrate. Microbial nitrate reduction resulted in a significant production of nitrite, which has the potential to oxidise the Boom Clay and thus affect the mobility of some radionuclides. Enhanced rates and extent of nitrate reduction were observed for the high pH adapted inoculum at pH 10.5, but the Boom Clay inoculum was also capable of nitrate reduction up to pH 10.5, reflecting conditions at the interface of the Boom Clay and the concrete liner of the disposal gallery.

Studies of ion exchange resin degradation are in progress in the Czech Republic and Switzerland and interim results are provided in the year 3 synthesis report D3.5. Both studies involve irradiation of cationic and anionic polystyrene based bead resins. Swiss studies have studied irradiation in Opalinus Clay groundwater conditions (pH 8) and under alkaline conditions using an electron linear accelerator (50 kGy) and at higher dose (200 kGy) using a ^{60}Co ϒ source. Analysis of the gas phase reveals the formation of H2 and a number of chlorinated aliphatics, such as bromomethane, chloromethane, dichloromethane, and chloroethane, as well as aromatic compounds, such as benzene and toluene; many of these compounds have potential to fuel microbial processes. Studies in the Czech Republic have undertaken microcosm experiments of irradiated resins in groundwater inoculated with sulfate reducing bacteria. In this case a higher total dose was examined (^{60}Co ϒ, 1 MGy) and the proportion of resin to water varied. Degradation products of polystyrene resins detected in the liquid fraction mainly consisted of trimethylamine and dimethylaminacetatenitrile. Subsequent microbial microcosm experiments showed that the lowest concentration of irradiated anion exchangers (0.2 g/l) caused the highest relative increase in bacterial abundance (14 fold increase). At higher resin content microbial activity appears to have been inhibited by the low pH (3.1 - 3.4) following irradiation. The effect of Cs present in resins on microbial activity has also been examined, with no toxic effect being observed at 0.5 mM of Cs (stable) but with effects evident at higher concentrations of 1 mM and 5 mM Cs.

Deliverables D1.4, D1.5 and published journal papers [10], [11], [12] report specific studies of radionuclide interactions with cellulose degradation products and bio-reduction processes. Deliverable (D1.4) presents results of spectroscopic studies of uranyl (UO_2^{2+}) speciation with ISA and with acetate, the latter representing a typical fermentation product of cellulose and ISA as revealed by studies reported in (D1.2). Uranyl (UO_2^{2+}) - acetate (AcO^-) speciation is described by a 1:1 complex; $[UO_2AcO]^+$ and a 1:2 complex ; $[UO_2(AcO)_2]$, with no evidence for a previously proposed 1:3 complex (D1.4). Fundamental information about the interaction of UO_2^{2+} with ISA were gathered by a variety of spectroscopic techniques: (i) three dominant UO_2^{2+}-ISA-complexes were discovered; (ii) two of the three complexes are probably polynuclear; (iii) 5- and 6-membered rings are the dominant binding motifs; and (iv) the limiting metal to ligand ratio is 1:2 (D1.4).

Studies of Ni interaction and immobilisation with biogeochemical processes associated with the metabolism of cellulose degradation products (e.g. ISA) related to studies reported in [D1.2] have also been published by Kuippers et al [10]. Here it has been shown that in an applied experimental system examining the fate of Ni complexed with ISA that the biodegradation of ISA at neutral pH resulted in the removal of complexed Ni from solution and incorporation in iron sulfide phases that were formed as a consequence of the microbial activity (sulfate reduction) that was stimulated.

High resolution electron microscopy studies have been undertaken, along with detailed microbial studies to characterise new species of bacteria from bentonites that are able to reduce selenate (SeO_4^{2-}) to less soluble forms (D1.5). Ruiz-Fresneda et al. [11] and Sanchez-Castro et al. [12] report about the bacteria Stenotrophomonas bentonitica, that is capable of reducing Se(VI) and Se(IV) to Se(0) forming nanoparticles, which with time crystallise to more insoluble forms morphologies (D1.5).

Methanogenesis has been studied under in situ conditions at the Mont Terri rock laboratory and through the long term LLW gas generation experiment (GGE) at Olkiluoto (D1.6, D1.7, D1.8, Small et al [13]). Studies at the Mont Terri Underground Rock Laboratory (URL) have examined the potential for methanogenesis to develop in Opalinus Clay as a consequence of reaction of H2 with inorganic carbon (CO_2, HCO_3^-). This experiment relates to a scenario where H2 is generated by anaerobic corrosion and radiolysis processes associated with the disposal of ILW and is relevant to consumption of H2 as well as furthering the understanding of methanogenesis. Results of the in situ borehole experiments show that methanogens and acetogens are found at very low abundance (<0.1%) as part of the microbial community, however no change to the relative proportion of these microorganisms was detected throughout the duration of the experiment. Although the sulfate concentration was successfully reduced from 12 mM to less than 4 mM during the in situ experiment no evidence for methanogenesis and acetogenesis was recorded. Microcosm experiments were also setup to examine conditions with lower sulfate concentration. However these microcosms also show no evidence for the onset of methanogenesis. Methane concentrations were measured for the duration of the experiment however no increase in concentration was recorded. There was also no significant increase in the acetate concentration over time suggesting that acetogens were not active in the community. The microbial composition after the incubation period supports these conclusions as it is dominated by one family (Desulfobulbaceae), which accounts for over 98% of the total reads. No methanogenic or acetogenic microorganisms were identified. Further investigation suggests that the onset of methanogenesis is also controlled by the bicarbonate (HCO_3^-) concentration, which was too low in the in situ and microcosm experiments so methanogenesis remained thermodynamically unfavourable.

In situ study of methanogenesis from cellulose containing LLW under initial alkaline conditions has been studied through further microbiological characterisation and modelling studies of an 18 year gas generation experiment (GGE) at the VLJ Repository, Olkiluoto, Finland (D1.6, D1.8,[13]). The GGE was originally set up in 1997 as part of a previous EU project (PROGRESS) and is operated by Teollisuuden Voima Oyj (TVO) and examines microbial gas generation from 16 200 dm^3 drums of cellulose containing LLW from the Olkiluoto power plants, together with a 4 tonne concrete box in a 20 m^3 gas tight vessel initially filled with river water. Interpretation of the geochemical data and modelling (D1.7, D1.8) has shown that an observed decrease in pH of water present in the tank water in contact with the concrete from pH 10 to neutral occurred over a period of 8 years by cellulose degradation processes occurring within the waste drums. A biogeochemical model of the GGE (D1.8, [13]) represents the diffusion of alkali from the concrete and acidity from the waste drums generated by cellulose hydrolysis and fermentation processes. The model accurately represents the observed rate of CH_4 generation during the 18 years of operation (~ 0.5 to 1 m^3 CH_4 per year), including an observed doubling of gas generation that occurred after 8 years. Microbiological characterisation including genomic sequencing studies of samples from the GGE reveal that the increase in gas generation rate coincides with the presence of acetate utilizing Archaea from the family Methanosaeta; methanogens that consume organic carbon. Initially, the microbial community was characterised by sulfate reducers belonging to the order Desulfovibrionales and methanogens that utilise H_2 (Methanosarcinaceae). The increase in CH_4 gas generation rate also coincides with a decrease in concentrations of dissolved organic carbon (DOC) and volatile fatty acids in the tank water. Biogeochemical modelling ([13], D1.8) also simulated the effect of increased methanogenesis as being related to neutralisation of the initial alkaline tank water and delayed consumption of DOC. Consideration of concentrations of sulfide in the tank water [13] also raises the possibility that methanogenesis could be inhibited by sulfide, whose concentration was observed to decrease from 0.2 mM initially to < 3 x 10^{-6} M after 8 years as a result of slow equilibration with of iron sulfide (mackinawite).

Deliverable [D1.8] concerns modelling of microbial processes in in situ experiments such as the GGE and borehole experiments at the Mont Terri URL. Deliverable D1.8 describes the basis to represent the growth of anaerobic microbes through Monod kinetics and coupling to geochemical speciation and solute transport. Examples are provided using the open source geochemical code PHREEQC, for wider application to assist the interpretation of such biogeochemical experiments and to underpin performance assessment models.

2.2. Work package 2

This work package consists of 5 tasks.

1. Microbial production of sulfide in the geosphere;
2. Microbial induced corrosion of canisters;
3. Microbial activity in bentonite buffers;
4. Microbial degradation of bentonite buffers;
5. Microbial activity in backfill and influence on plugs and seals.

Microbial production of sulfide in the geosphere: In the context of microbiological risks related to radioactive waste disposal, the geochemistry of gases in deep groundwater is an integral part of the determination of geochemical constraints of biological activity at disposal depths. Data on gas compositions and concentrations do exist from several separate locations in Finland and two locations in Sweden (D2.1, D2.3). In laboratory experiments with deep groundwater populations, acetate was overall the most efficient activator of the studied microbial communities which indicates acetate's important role as an electron donor for different Olkiluoto deep subsurface groundwater communities. However, there were also activation effects from H_2, CH_4 and NO_3^- (D2.5). The deliverable D2.17 "Sulfide production" will be delivered M45. This deliverable aims at defining the boundary conditions constraining the availability of sulfide in deep geological disposal conditions. Critical process to be analysed is the sulfate reduction to sulfide, which is constrained by the sulfate source and the availability of possible electron donors (e.g., H_2, CH_4 and Fe^{2+}).

Microbial influenced corrosion (MIC) of canisters: This task has produced one deliverable, D2.13 "Anaerobic microbial corrosion of canister material" and D2.18 "Rate of corrosion of carbon steel in bentonite under biotic and abiotic conditions" will be ready in M45. The D2.13 report includes a description of MIC and methods that can be used to study corrosion and microbiology. Anaerobic MIC were studied in experiments with stainless steel and carbon steel in three types of water, granitic water from the VITA source and HV1 source in Frans Josephs underground research facility together with synthetic bentonite porewater which was inoculated with VITA water. Corrosion was studied in inoculated samples and in sterile controls with a range of electro-chemical methods; electrochemical impedance spectroscopy (EIS), open circuit potential and polarization curves. Weight loss studies were done and two DNA-techniques for identification of microorganisms were used. Also surface analyses were performed. Two temperatures, lab temperature and 35°C were used in some studies. The duration of the experiments was from 111 days to 2 years. It was clearly shown that the corrosion rate of carbon steel in the presence of bacteria, SRB, was several times higher than in sterile controls. This was shown by weight loss experiments and illustrated with SEM.

Microbial activity in bentonite buffers: This task was scheduled for 4 deliverables, D2.4 "Threshold densities" (M36), D2.6 "Microbial diversity in bentonite buffer of aged bentonite buffer experiment" (M36), D2.14 "Role of bentonite density on the rate of corrosion of carbon steel" (M42) and D2.15 "Survival of microorganisms in bentonite subjected to different levels of irradiation and pressure" (M42).

The relation between water saturated clays at varying wet density and bacterial sulfide-producing activity is well studied (D2.4). However, wet density is just a value of the total amount of clay and water. That value does not reflect the conditions in compacted clay where several variables of importance for bacterial life can be of importance, such as clay type, pH, temperature, transport conditions, water content, pressure, pore space and pore water composition. These variables need further attention for a full understanding of what conditions control bacterial activity in compacted bentonite clays. Significant acetate formation from natural organic matter present in the clays was detected in the studied bentonites. This production occurred at all wet densities and suggests that bacterial activity, per see, was possible also at densities where sulfide-production could not be detected. Acetate is known to induce stress-corrosion cracking of copper and other metals and the possible formation of acetate should, therefore, be further investigated.

The presence of living microbes on bentonite and on copper surfaces could not be demonstrated in the D2.6 study but microscopy studies revealed living microbial cells in the external water surrounding copper cylinders. According to the IonTorrent sequencing, SRB and IRB were detected in the bentonite matrix, water and the copper surface. SRBs can produce corrosive sulfide and IRBs can have a role in processes that could be linked to the loss of swelling properties in bentonite. Fungal conidia and hyphae were detected by SEM in water and several groups of Ascomycetes and Basidiomycetes were identified by sequencing from bentonite samples. Many of the fungal genera detected are able to produce organic or inorganic acids that help fungi in solubilisation of minerals from rock substrates.

The current results obtained from the in situ experiments in the Opalinus clay in Switzerland, offer a partial view on the microbial activity, and thus the potential impact of microbial processes on canister corrosion, under repository relevant conditions. Continued monitoring of the ongoing experiments may provide further evidence of the role of microbes in sulfide production and steel corrosion and the results will be presented in D2.14.

BaM bentonite is currently being tested at high temperature and pressure for D2.14. Two DNA extraction methods were compared (based on protocols obtained from HZDR and SCK•CEN), another method involving ultrasonic disintegration of the material was also tested. Experiments with inoculated bentonite suspension under pressure 1, 2, 3 and 5 MPa together with atmospheric pressure control were performed. Experimental setup of temperature/pressure experiments is being finalised and the experiments started. Influence of radiation on microorganism's survivability in the bentonite suspension and water is also studied. Experiments are still ongoing; they will be finished in 2019.

Microbial degradation of bentonite buffers: This task comprises 6 deliverables, D2.2 "Design, set up and operation of experimental equipment" (M18), D2.7 "Microbial diversity in aged bentonite" (M36), D2.8 "Long-term stability of bentonite in the presence of microorganisms" (M36), D2.9 "Evolution of stress in biotic and abiotic clay flow cells" (M36), D2.10 "Microbial mobility in saturated bentonites of different density" and D2.16 "Microbial activity and the physical-chemical and transport properties of bentonite buffer" (M44).

Sulfide has been found to reduce ferric iron in bentonites denoted Asha, MX-80 and Calcigel under the formation of elemental sulphur, ferrous iron and iron sulfide. This immobilisation effect can reduce the mass of sulfide that corrode metal canisters over repository life times, but the concomitant reduction of ferric iron may be problematic due to the destabilizing effect of ferrous iron on dioctahedral smectites such as montmorillonites.

The results of the D2.7 analyses showed that there were bacteria present in all of the bentonite samples studied. Surprisingly, the microbial communities detected in the bentonite samples showed a high level of similarity. The bacterial profiles were characterised by the dominance of heterotrophs, aerobes or facultative anaerobes capable of respiring oxygen or nitrates. The majority of detected bacteria belong to common soil microorganisms or ubiquitous microorganisms with wide ecological amplitude enabling them to survive under various conditions. The results suggest that microorganisms found in the bentonite samples in this study were most probably present in the bentonite already before the start of the experiment.

The aim of the laboratory scale D2.2/D2.8 MX-80 bentonite storage experiment was to simulate bentonite behaviour in circumstances that can take place in the interfaces of bentonite, host rock fractures and water flow in nuclear waste geological disposal. After one year, microcosms in MX-80 bentonite initiated both at aerobic and anaerobic conditions, no essential changes in bentonite mineralogy were found compared to the initiation of experiment. However, clear microbial activity in terms of ongoing sulfate reduction and sulfide formation as well as high number of sulphite reductase genes (dsrB) were detected in anaerobic samples. Microbial activity also affected bentonite water-phase chemistry and bentonite cation exchange capacity. These effects were not detected in sterile controls, demonstrating the microbial origin of these changes. The experiment is planned to continue for some years further as potential changes in bentonite mineralogy caused by microbial activity happens slowly in the studied conditions.

Given the limited duration of the D2.2/D2.8 tests, it is not surprising that the alteration of the bentonite was limited to a small zone adjacent to the iron. From a 'flow perspective' this will have little impact, as the bulk of the clay, and therefore the flowing porosity, remains unchanged. To understand the full impact of microbial action on the hydraulic properties of the clay, test durations would need to be increased substantially, or the iron should be dispersed within the entire clay matric to increase reaction rates. Given these findings, the question of whether microbial activity alters the hydraulic behaviour of bentonite remains unanswered. Further work is required beyond the lifetime of this project to fully assess the impact of microbial induced changes on the hydraulic integrity of the clay.

The D2.10 study fulfilled important goals. First, a reliable method for direct detection of bacterial presence (both viable and dead cells) in the bentonite was developed, which has been missing. This method is based on the extraction of bacteria from bentonite using density gradient centrifugation and their subsequent Live/Dead fluorescence staining. Although the method needs further optimization and testing of its general functionality on different bentonite types, it is believed the method will be very useful for future research of bacterial presence in various clay materials.

The D2.16 work is progressing according to the plans. The experimental equipment that is being assembled and tested begins to generate the data needed. Collating data on the evolution of stress in biotic and abiotic flow cells is ongoing. The first two experiments have been dismantled, samples have been taken for DNA analysis, and culture-based enumeration has been set up. Culture-based analysis and DNA analysis is ongoing and assessment of physical, chemical and transport is ongoing as well.

Microbial activity in backfill and influence on plugs and seals: This task comprises 2 deliverables, D2.11 "Cement deterioration boundaries" (M36) and D2.12 "Concrete stability" (M36). The D2.11 study demonstrated that the high pH conditions imposed by the OPC CEM I inhibited microbial sulfate and nitrate reduction. However, SEM analysis indicated the presence of intact cells in the suspension on top of cement and putative biofilm structures on the cement. This suggests that the high pH environment does not completely eliminate the microbial population. Interestingly, in sulfate reducing conditions, a pH decrease from > 12 to pH 10 was observed in one replicate harbouring clearly a larger microbial community in the suspension on top of the cementitious material compared to the other samples. Further studies to confirm this observation and to elucidate the precise mechanism are necessary.

The conclusion of the D2.12 results was that the alkaline solution, leached from the concrete, lead to a deviation in wet density and increased the pH in the bentonite clay. However, the inhibition of microbial activity was dependent of the added carbon source. Induced microbial activity in MX-80 with glucose led to a decrease in pH. A reason might be that natural occurring acetogenic bacteria produced organic acids from the added carbon source. In the future bentonite clay samples should be analysed for acetate and cultivatable acetogenic bacteria to confirm this hypothesis.

2.3. Work package 3

This work package includes 3 tasks:

1. Synthesis, evaluation, abstraction and integration of experimental and computational output;
2. The impact of the inclusion of microbiology on expert conceptualization and public perception of geological disposal;
3. Knowledge and information exchange.

Synthesis, evaluation, abstraction and integration of experimental and computational output:

Within this task of work package 3, all experimental work obtained within WP1 and WP2 was synthesized on a yearly basis and reported in two deliverables: D3.4 and D3.5. The first year, an evaluation of the initial state of the art knowledge base was reported as deliverable D3.1.

In addition, next generation sequencing based on the 16S rRNA amplicon, a technique that is frequently used by most partners to identify the present microbial community was compared and evaluated among different partners. This because it is known that the analysis of microbial communities via next generation sequencing based on the 16S rRNA amplicon can be biased due to the DNA extraction protocol, primer design, PCR amplification, sequencing artefacts and bioinformatics analysis procedures. Therefore, care should be taken in comparing results obtained using different methods. Also within MIND, DNA extraction procedures, sequencing processes and bioformatics pipelines are highly diverse among the different partners. In order to evaluate the impact of the different strategies on the identified microbial community, a commercial microbial community standard of ZymoBiomics, consisting of eight different bacterial species was used (note that all data were analyzed blind i.e. involved partners didn't know the composition of the mock community).

In first instance, the sequencing process and bioinformatics pipelines were compared and evaluated. To this end, the DNA of the mock community was sent around to eight different microbiology laboratories involved in the MIND project. The different laboratories processed these samples with their own sequencing and data analysis tools. In total, five laboratories had sent in their sequencing data. Two different sequencing technologies were used i.e. Illumina MiSeq and IonTorrent, and the V3-V4 or V4 region of the 16S rRNA gene was selected as amplicon. If different labs analyzed their own data and predicted the mock community, variation was observed in the amount of Operational Taxonomic Units (OTUs) between the different research groups, ranging between 10 and more than thousand OTUs. However, the majority of this variation could be explained by the bioinformatics pipeline used, rather than the amplicon region, the quality of the sequencing data or the type of sequencing technology (Illumina MiSeq versus IonTorrent). This could be confirmed by applying the same 16S rRNA gene amplicon sequencing analysis pipelines on the five different datasets as comparable results were obtained from the different datasets. It was also observed that longer amplicons (e.g. V3-V4) returned a higher sequencing error rate than the approaches focusing on one region (e.g. V4). Additionally, most artefacts in the sequencing data originated from the presence of chimeric sequences, even for the best performing bioinformatics pipeline. Overall, it was clear that the different state-off-the-art sequencing and data analysis approaches used by the different partners in the MIND community are adequate and comparable, providing high quality scientific data. Chimera removal should be a point of attention whenever analyzing sequencing data. Knowledge and experience on how to address and process such samples and data was shared among the partners.

In a next step, an experiment was carried out to compare different DNA extraction protocols to recover DNA from a clay-rich environment. This matrix – although hampers the efficiency of DNA extraction – was selected as it is essential to have robust DNA extraction techniques from relevant host rock formations to assess the microbial impact on the safety of deep geological radioactive waste repositories. Seven laboratories received a 10 g aliquot of Opalinus Clay rock collected from the Mont Terri Underground Rock Laboratory in St. Ursanne, Switzerland spiked with the Zymobomics cell mock. Every participating laboratory extracted DNA using their own method. Afterwards, DNA amplification (16S rRNA gene V4 region) was performed by a single laboratory and Illumina MiSeq sequencing was carried out by a single commercial laboratory. In addition, the same bioinformatics pipeline was used to process and compare the DNA sequences obtained. Highly different results were obtained with the different DNA extraction methods. The amount of extracted DNA ranged from 0.66 ng to 418 ng, while in theory ~ 4.5 µg DNA could be obtained. In addition, there was one method outstanding in reassembling the mock community, while for other methods, an over-and underrepresentation of different OTUs was observed. The results of this study will be further elaborated on in future work. Nevertheless, these results indicate that care should be taken with comparison of data obtained with different methods and that testing the efficiency of the used DNA extraction protocol is essential.

The impact of the inclusion of microbiology on expert conceptualization and public perception of geological disposal: In order to understand how MIND experts (MIND researchers, members of the MIND Implementer Review Board) and experts outside the project (e.g. geologists, waste management regulators, policy makers) conceptualize the role of microbes in radioactive waste disposal, social scientists conducted semi-structured interviews with MIND members, participated as observers and presenters at MIND meetings, and analyzed guiding RWM documents within the MIND project. Elicited findings served as inputs for communication with project participants and civil society. To this end, group discussions, interviews and an interactive workshop with implementers, project participants and civil society were organized.

Recurrent issues concerned the possibility and scope of interdisciplinary collaboration within and outside the MIND research community, the importance of public communication (particularly the communication of uncertainty), and the institutional recognition for microbiology in radioactive waste governance at large. In a concluding interactive workshop, members of civil society reproduced and reiterated these issues, while also shedding new light on them, by stressing that communicating uncertainty can generate (rather than erode) public trust in science, and by probing the relationship between MIND research and public safety. These observations should sensitize MIND stakeholders to their own research concepts and practices, including the value all stakeholders, without exception, ascribe to public communication – as research on the role of microbes in radioactive waste is characterized by a considerable degree of exoticness, uncertainty, and ambiguity. Although communication has been recognised as a challenge due to multidisciplinarity, trandisciplinarity, diverse risk perceptions and complexity, the new communication tools and opportunities offer a lot of possibilities to reach out with scientific results and to enable stakeholders to make informed decisions.

Knowledge and information exchange

Education and training activities were initiated (D3.3) to cultivate awareness of the relevance of microbial issues in otherwise typically abiotic fields of expertise, and to dissipate the knowledge gained in the MIND project beyond the known geomicrobiology expert circles. To this end, two courses related to microbiology in nuclear waste disposal were organized during the project, an exchange program for Master and PhD students has been developed and focused communication on these initiatives has been undertaken.

2.4. Work package 4

IRB has developed a table listing potential research gaps regarding Microbiology in Nuclear Waste Disposal. This table is a collation of FEPs on different microbial processes of potential relevance to waste disposal and also addresses to what extent these "FEPs" were addressed in MIND. As a final product the IRB has produced an Evaluation Report (D4.6) where the contributions of MIND are assessed with respect to microbial issues, processes and conditions of relevance to Post Closure Safety of Nuclear Waste repositories.

3. Conclusions

The MIND project was one of the first projects, investigating the impact of microbial processes on organic material in cementitious waste forms and their behaviour, on the technical feasibility and on long-term performance of repository components including clay and canister materials. Research focussed on key questions posed by waste management organisations. Overall, many experiments have been conducted providing further insights into different microbial processes that can be expected during the geological disposal of radioactive waste. Chemical conditions that may limit methanogenesis and hydrogen consumption in LLW/ILW repositories were elaborated on in more detail. The research related to H_2 consumption by sulfate reduction processes is also of relevance to microbial induced corrosion of metal canisters. In addition, the knowledge base concerning the range of organic polymers and additives that may contribute to gas generation from LLW/ILW including the combined effects of irradiation and biodegradation under alkaline conditions was increased. Further knowledge has also been obtained regarding the biodegradation of potential radionuclide complexants, including ISA under alkaline conditions. Furthermore, several experiments showed that enhanced microbial activity could result in solid partitioning of radionuclides, which could affect their mobility in ground water. Furthermore, different experiments resulted a more detailed understanding of microbial activity in backfill material and bentonite buffers. In addition to the experimental work, the MIND project took a lot of time on education and communication. All the expertise gathered within the project is summarized in yearly synthesis reports deliverables [D3.1, D3.4, D3.5] which can be valuable for waste management organizations to define further knowledge gaps that could be elaborated on in future projects.

The evaluation report (D4.6) by the IRB concludes that MIND has been invaluable to assemble the competence on microbiological issues of relevance to repository safety and has helped to clarify what issues are of potential importance and what that mere has scientific interest. Thereby MIND forms an essential platform for how further efforts in the areas should be prioritized.

The findings in the MIND project has contributed to that microbial processes in repository environments are now being considered e.g. when setting the requirements on engineered barriers such as buffer and backfill leading to significant refinements of safety case models currently being implemented.

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SESSION 3

NETWORKING OF RESEARCH COMMUNITIES, JOINT PROGRAMMING OF NATIONAL PROGRAMMES AND INTEGRATION OF RADIOACTIVE WASTE PRODUCERS

SUMMARY SESSION 3 – NETWORKING OF RESEARCH COMMUNITIES, JOINT PROGRAMMING OF NATIONAL PROGRAMMES AND INTEGRATION OF RADIOACTIVE WASTE PRODUCERS

Chair: Piet ZUIDEMA (Zuidema Consult GmbH, CH)
Co-chair: Ian GORDON (IAEA, AT)
Expert Rapporteur: Jacques DELAY (ANDRA, FR)

Context and content of Session 3

Providing that the EURAD is launched and performs adequately, the European Joint Programming (EJP) instrument is expected to be continued in the next Euratom FP and would be the main instrument for EURATOM support for research and training on Radioactive Waste management (RWM). In the meantime, in order to reinforce the R&D on pre-disposal and gradually include the waste producers in the EJP concept, the Commission has opened a topic on pre-disposal as part of WP2019-2020 on:

– #10, developing pre-disposal activities identified in the scope of the European Joint Programme in Radioactive Waste Management.

Session III was comprised of presentations from the three main structured actors in European RWM, i.e. Waste Management Organisations (WMOs), Technical Support Organisations (TSOs), and Research Entities (REs) which decided to merge their efforts and resources.

This session included a presentation of the result of the integration of their selected R&D activities in a single European Joint Programme (EJP) called EURAD. In addition, the Central Eastern countries, operating one to six reactors and dealing with small inventory, presented their view on the study of a shared solution for disposal.

Finally, waste producers presented their views on predisposal R&D and their views on the possibility of their integration into the EJP on waste disposal.

Prior to the panel discussion, the synergies between EURAD and the IAEA and OECD/NEA programmes on the state of knowledge, Guidance on R&D and training and mobility were presented.

Ten years of effort in structuring the RWM community

Structuring networking and support to collaborative research across European countries has been the «raison d'être» of the EURATOM programme for at least two decades. As stated by Alan Hooper in EURADWASTE 13' report, *"the organisational structures established through EURATOM, notably ENSREG, ENEF and the IGD-TP was clearly shown to be contributing strongly to the progress towards the safe an, long term management of Spent fuel and heat generating and long-lives RW in Europe".* Furthermore, the JOPRAD Project engaged within the RWM community led to the possibility and now the start of a European Joint programming.

In 2009, the first step of integration of activities was the support to the IGD-TP that provided a coherent roadmap for collaborative R&D in view of the licensing of disposal facility. In addition, IGD-TP organised "Exchanged Fora" that proved to be an efficient tool to initiate collaborative projects. After the WMOs, the TSOs produced their own SRA in the framework of SITEXII. Emphasis was put on the development of the independent expertise function as well as the means to involve the Civil Society in the process. More recently, the REs have established in the framework of JOPRAD their own Strategic Research Agenda.

Today, the EURAD project gathered mandated actors, i.e. mandated by their government to take part in the work in the RWM domain. The mandated actors are limited to WMOs, TSOs and REs. In addition, EURAD includes observers and non-technical participants who do not have a formal national mandate for research in RWM but who are considered as key interest groups and may benefit from or influence the direction of specific activities undertaken. This includes Civil Society Experts, waste producers, International Organisations and countries not part of EU.

Waste producers

Waste Producers and those with a pre-disposal waste management remit are engaged via the Nuclear Generation II & III Association (NUGENIA). Although not direct contributors or participants of the EURAD initiative Joint Programme, NUGENIA will set a foundation for future collaboration in projects influencing the waste form for final disposal.

Waste Producers and implementers at a national level are well-connected and have existing cooperation activities that should support the integration of Waste Producers RD&D needs (that impact disposal), via the WMOs.

Waste Producers are often responsible for contributing to financing of disposal facilities. Thus, they are involved in the R&D in order to ensure the acceptance of the waste in the future disposal.

The H2020 R&D projects already linked to predisposal activities through calls on waste management are: CHANCE on characterization of conditioned nuclear waste; THERAMIN on thermal treatment for radioactive waste minimisation and hazard reduction, and INSIDER on methodology for characterization to minimize waste and to develop new methodologies for more accurate initial estimation of contaminated materials.

Where do we stand?

One of the main achievements of the EURATOM continuous policy was to create at the EU level, discussion fora where project results and future research development are challenged. Exchange Fora organised by IGD-TP, SITEX meetings, and JOPRAD/EURAD workshops have led to structure the communities and organise research priorities and topics.

Consequently, following the WMOs Strategic Research Agenda published in 2011, all the communities have expressed their priorities in their own documents. The methodology proved to be efficient to fulfil research objectives of real interest for the implementation of a Geological Disposal while avoiding duplication and making efficient use of the financial and human resources.

The methodology to set up of the research agendas and the programmes is mature and well understood. This work has to be renewed to take into account evolution in policies or improvement of knowledge. However, it should be acknowledged that the technical projects linked with safety or demonstration of a waste disposal are not the first priority for most of the European countries. They are dealing more with strategic issues and siting issues, which originally were out of the scope of the implementers for they were considered fundamentally a national issue.

EURAD is opening a new era with the possibility of embarking more activities that are predisposal and a spectrum of strategic studies.

Thus, for the first run of EURAD the SFC project is directly dealing with this activity. Spend Fuel Characterisation and evolution until Disposal (SFC) aims at reducing uncertainties in spent fuel properties in predisposal phases. This will study the properties, behaviour and associated uncertainties of spent nuclear fuel from the time when it is irradiated in the reactor up to the time it is emplaced in a geological disposal facility.

In addition, EURAD proposed strategic and horizontal studies in order to develop good practices, in particular:

- To manage damaged waste packages and set the criteria and methods for reprocessing aged waste,
- To minimise radiological consequences in the event that packages have aged and require re-processing or have become damaged prior to transfer to a geological disposal facility,
- To support the safe management and safety assessment of existing storage facilities and design criteria for new storage facilities, and
- To establish and develop waste acceptance criteria.

Thus, for the first run of EURAD strategic studies, WPs are initiated in order to agree upon and define in some detail the needs for future activities, including further specific thematic studies or RD&D at the forefront of science. This may also be referred to as 'think-tank' or networking activities to determine if there is a RD&D need on an emerging issue, if there is a need of a position paper, or if it is considered mature and suitable for knowledge management activities.

In addition, Knowledge Management is enabled by three permanent WPs that derive directly from EURATOM expectations under WP2018 and that will be implemented through the Annual Work Plan:

- State of Knowledge - Activities under this WP consist of developing a systematic approach of preserving/capitalising on and providing open-access to knowledge generated in the field of RWM research.

- Methodological guidance - Activities under this WP consist of developing a comprehensive suite of instructional guidance documents that can be used by Member-States with RWM programmes that are at an early stage of development with respect to their national RWM programme. Such a WP shall pursue and complement the work initiated with the PLANDIS Guide.
- Training/mobility - Activities under this WP consist of developing a diverse portfolio of tailored basic and specialised training courses for the end-users within EURAD under the umbrella of a "School of Radioactive Waste Management", taking stock of and building upon already existing initiatives (i.e. IAEA and NEA) and creating new initiatives to bridge the identified gaps.

The way forward: NFRP 10 - Developing pre-disposal activities identified in the scope of the European Joint Programme in Radioactive Waste Management – potential technical topics

For EC, the aim is now to reinforce scope of pre-disposal of the EJP SRA by involving waste producers for preparation of future integration in an EJP waste that will follow EURAD. This Framework Programme appears to be dedicated to the waste producer community, although the connections with the RWM community are obvious.

Thus, the NFRP10 activity objective is to develop methods, processes, technologies and demonstrators for treatment and conditioning of wastes for which no or inadequate solutions are currently available. It should be noted that the dismantling is not included in the scope for these activities are the sole responsibility of the waste producers.

In a position letter published in March 19, the IGD-TP, presenting WMO's views, confirmed its strong interest in the project to be developed as the IGD-TP acts as the ultimate end-user of the pre-disposal activities. IGD-TP considered that the major aspect to consider is the development of the waste acceptance criteria (WAC). Based on a survey by the IGD-TP members, policy, treatment routes, and potential pre-disposal treatment techniques have to be developed in cooperation with waste producers. The first priority for the majority of the IGD-TP members lies in the treatment and conditioning of organic wastes, liquid, or solid such as bitumen, exchange resins, and polymers. Depending on IGD-TP members, graphite or metal treatment as well as conditioning of reactive metal could be developed in a shared proposal.

Civil Society involvement

Considering the long time for project design and development, the Civil Society (CS) properly represented in the various management and technical committee designing European R&D programmes, should provide their contribution to the definition of the scientific and technical questions to be solved as well as the ways to positively take into account the outcomes in future project developments. Moreover, the role of Civil Society is key in the strategy to be developed to allow the knowledge transmission amongst generations and European countries. Least but not last Civil society should be the fulcrum to promote the education and training on technical and societal matters in consistent and efficient ways.

Possible ideas to develop to prepare a larger integration of Waste producers need in the EJP

According to EDF the R&D that could be developed is two folds:

- A regulatory consideration, to foster a circular economy in materials management, including waste whatever they are radioactive or not, thanks to the appropriate definition of criteria and rules. In this domain, EC could support work, including coordination action, providing material, data, scientific, technical and economic impact of for example levels of acceptance criteria, in support of regulatory development on the topic.
- New treatment demonstrators or facility in order to reduce waste quantities and improve decommissioning techniques and waste management. The example given is the use of arc melting furnace to decontaminate/homogenize metallic material in the frame of a recycling route. As part of its decommissioning strategy, EDF has launched a decommissioning demonstrator facility project to be in operation by 2022. Following a modular conception, and first envisaged to check the decommissioning operations of Graphite reactors.

Knowledge sharing

IAEA stressed on the knowledge tools and especially the documentation produced in the domain of R&D on RWM. In addition, Technical Cooperation programme including national and regional projects address global needs such as train and share knowledge in all steps of waste managements, and targets all types of waste management steps, scales and needs.

In complement, NEA as presented the objectives and means for competency management for regulators and implementers to ensure development of competences in specific domains as well as proper transmission of knowledge through generation.

Conclusion

- EURAD represent the achievement of ten years of integration of RWM community and the platform for further integration of R&D programmes with waste producers thanks to the continuous support of EURATOM programmes over a decade;
- For WMOs focus remains on geological disposal, but the missions are to be expended to also accommodate more upstream interests and a wider inventory coverage (e.g. sealed sources and borehole disposal). However, it is important to recognise that WMO RD&D programmes have a much wider scope of activities than the commonly-agreed EURAD strategic research agenda will address;
- For SITEX community, the condition for participating to an EJP is to develop the high quality expertise function independent from WMOs as well as expanding interaction with Civil Society towards integration in R&D projects, meaning that CS may have a role on design of shared experiments;

- After decades of collaboration with WMOs and TSOs, European research organisations in radioactive waste management have organised themselves in a network, called EURADScience, with the vision of acting as an independent, cross-disciplinary, inclusive network providing scientific excellence and credibility to national radioactive waste management programmes. It aimed at serving to built an European knowledge platform on RWM;
- The need to harmonization of regulation was emphasised in order to prepare predisposal activities. Actually this activities could be minimized by better integrating waste management activities in the dismantling and decommissioning phases.
- Knowledge management programmes should lead to attract and train new competencies and new high level researchers to allow a cross fertilization of ideas and ensure that the competences will be present all along the duration of the disposal operation.

CHRISTOPHE DAVIES

EURATOM RESEARCH AND TRAINING PROGRAMME IN RADIOACTIVE WASTE MANAGEMENT: OVERVIEW STATUS AND VISION

C. DAVIES

European Commission, DG Research and Innovation, Unit D4, Euratom Research

Extended abstract. Euratom Research and Training (R&T) on radioactive waste management began in 1975. It is one of the first, European Commission research programmes. The purpose of this extended abstract is to take stock of the evolution the Euratom (R&T) programme underpinning the strategic vision and plan of the European Commission for its continued role and support in the field of radioactive waste management.

Over the nine successive programmes, Euratom went through all the R&D phases needed to manage and dispose all types and categories of radioactive waste including decommissioning, pre-disposal (characterization, treatment, conditioning), fuel cycle (reprocessing, partitioning and transmutation-P&T) and disposal (basic science on key processes; performance assessment calculations; site, host rock and geological investigations plus natural analogues; underground research laboratory constructions and in situ testing for performance investigations, constructions and disposal concept feasibility and technology development); policy and waste management strategies; and social science and humanities (SSH) for public perception and acceptance.

R&D on dismantling was gradually stopped in the mid-2000's due to the industrial maturity of the dismantling projects. Working groups to maintain and exchange knowledge in this domain are operating at the two international organizations (OECD Nuclear Energy Agency and IAEA). At Euratom level, the need to re-open R&D on decommissioning for advanced and innovative techniques and technologies is being investigated in a Coordination & Support Actions (CSA), SHARE, to identify any need for a decommissioning R&D roadmap for activities of EU added-value.

Near-surface disposal of short-lived and intermediate level waste is being widely implemented across Europe, hence activities supported by Euratom in this field were discontinued during Framework Programme (FP7, 2007-2013). Support to characterization and waste treatment for these wastes was reopened during the Horizon 2020 FP as part of the Work Programme 2016-17.

R&D on P&T is conducted mostly by the research community close to reactor systems, hence in Euratom this domain of research is managed within the part of the programme on reactor safety.

In the early 2000's, after 25 years of R&D, there was still no scheduled date for start of operation of the first underground repositories in Europe and no country was still foreseeing a date of submission of an operation license application to its regulatory authority. Disposal of high-level and long-lived radioactive waste (HL&LL W) and spent fuel (SF) in deep underground repositories was and still is the most important challenge in all national programmes, which have to manage SF.

Being a priority in EU Member States (MS), Euratom gradually focused its support on this domain and lower priority was given to R&D on pre-disposal.

Geological Disposal (GD) is a complex multidisciplinary scientific, technical, organizational and societal issue. R&D in this domain being mostly non-commercial and open science the Commission started to advocate for increase and close collaboration and joint activities within the respective research communities involved in the safety case (SC) of GD. Although the principle for EU support is competitive project proposals, this principle had to be adapted to the specific situation of radioactive waste disposal, so that even if scientific excellence is the objective in R&D, collaboration instead of competition can bring more benefits to all MSs, which face the same challenges. This approach also avoids unnecessary duplication of research. The question has been and remains to which extent and scope collaboration in all domains of the SC for GD is of EU added-value as opposed to specific requirements in each MS national programme. And it is also necessary to identify which R&D has to be done in any case in each national programme.

Only competitive projects may not be the most effective working method both for the Commission and the research actors on GD. Evidence of unfruitful competition was exemplified by the failure, in 2007, of two large competitive project proposals on gas led on the one side by Technical Support Organizations (TSO) and the other side by Waste Management Organizations (WMO): GASCONI and GASMIG. Both proposals were rejected at the evaluation stage and both communities had lost time and effort. The underlying argument leading to this competition was that TSOs considered that they need to remain independent to draw conclusions on the outcome of the project. This argument was challenged during evaluation saying that the purpose of the projects was to develop scientific knowledge and understanding on the processes of gas in underground repositories and that the interpretation of the results for the performance of the repositories remains of the responsibility of the respective communities. Fortunately, a joint project (FORGE) was developed the year after with fruitful collaboration and did set the pace for future method of work of the different research communities for disposal.

In the mid-2000's, one of the steps taken by the EC to increase collaboration and joint activities within the respective research communities was to introduce new types of project contracts: Integrated Projects, Network of excellence and European Technology Platforms (TP), to help speed up industrialization of research outputs and to help establish the European Research Area (ERA). The first initiative in Euratom was the start of work towards integration / coordination of WMOs. A number of projects were conducted between 2002 and 2009 with the Network of excellence NET.EXCEL, then CARD, which eventually led to the establishment of IGD-TP, the Implementing Geological Disposal –Technology Platform, in 2009, between 11 WMOs.

In line with the strategy of ERA, the EC/Euratom aim is to provide EU-added value, leverage and benefit to all national programmes. Therefore, beyond collaboration within the research communities, EC policy to achieve this objective has been to gradually bring together the different research communities generating knowledge for the safety case of disposal with the end-users of the results, i.e. Waste Management Organizations (WMO), TSOs and academic and research organizations.

In the early 2010's, the context at the EU level and in the MSs continued to evolve in a way justifying, reinforcing EC strategy towards integration of the different research communities, but furthermore to develop Joint Programming activities between MSs at EU level.

In 2011 and 2012, the first two license applications for underground repositories were submitted in Sweden and Finland demonstrating maturity of knowledge for the SC in countries with advanced programmes for GD. This could have been understood that continued support from Euratom could be questioned. However, at the EC EURADWASTE '13 conference, two key conclusions provided evidence of the continued role for Euratom.

The first conclusion was that each underground repository is a first of the kind because of many different conditions including geological formations, disposal concept, etc.

The second conclusion was that knowledge underpinning the SC needs to be continuously improved in order to be in a position to update the operating license, respond to uncertainties in processes measured during operation and to regulatory questions, to optimize the repository concept and facility, to provide competence to next generations of scientists due to the long operational time of repositories (up to one hundred years), etc.

At the same time, the Council Directive 2011/70/Euratom establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste (the waste Directive) was adopted by the MSs.

The Directive requires each MS to establish and maintain national policy, and legislative, regulatory and organizational framework for managing all types of radioactive waste from generation to disposal. This includes establishing a national programme with significant milestones and clear timeframes, as well as RD&D activities needed in order to implement technical solutions. Therefore, a R&D programme is needed in each MS concerned with radioactive waste management.

The role of Euratom is considered as reinforced, when considering the different time scheduled between MSs on the start of their respective repositories. Advanced countries like Finland, Sweden and France plan operational starts in the next decade, while many other MSs have longer implementation timescales, i.e. commissioning dates of deep geological repositories planned around 2055-2065. These countries in early stage will need to go through all the research steps undertaken in advanced countries. Therefore, there is a central role for Euratom in organizing cooperation between all national programmes so that all countries can benefit from joint work.

In working together, as part of a European Joint Programme, advanced countries will be able to address specific cutting-edge science on very deep scientific topics, while less-advanced programmes will be able to plan, structure and implement the necessary R&D, with guidance, training and transfer of competence and knowledge from advanced programmes and not having to redo and duplicate R&D effort for which there is state of the art knowledge.

From a regulatory support point of view, given the on-going and forthcoming license applications Euratom began to support networking and R&D activities of TSOs for their necessary competence in the review of Safety Cases. The two SITEX projects, started in 2011, led to establishment of the SITEX Network in 2018.

Recently, the community of research entities (RE), taking into account the EURADWASTE ’13 key messages, also started to structure and coordinate at European level in order to contribute to the long-term R&D challenges of, in particular, GD as part of a European Joint Programme and to be in a position to provide a flowerbed for education and training of the needed scientists for the future. In 2018, this community launched its own network called EURADSCIENCE.

In response to the evolving context described above, the Commission initiated the process of integration of MSs’ national programmes in a Joint Programming at EU level via the use of the new contractual instrument: Joint Programme co-fund.

Preparatory work for a European Joint Programme was discussed intensively between IGD-TP and SITEX and eventually in effective cooperation within the JOPRAD project in the years 2015 to 2017. One important criterion for collaboration was preserving independence of the TSO. The three R&D communities took part and elaborated a common Strategic Research Agenda (SRA) for joint implementation at European level. The SRA is the basis for joint collaborative activities based on agreed prioritization and decisions of the Joint programme governing board. The SRA structure, being built to address research on scientific technical gaps, and on acquisition of basic science allows joint work between communities. This method is considered as respecting independence between implementers and reviewers, which can use separately the results obtained, to respectively develop their safety case and implement their review process. Non-technical stakeholders were also involved to provide input on their view of the needed R&D to be performed.

Integration of the actors of the disposal communities (WMO, TSO and RE) at European level, which have an official role in their respective national programme has delivered the EURAD European Joint Programme (EJP) to be launched in mid-2019 for five years.

One of the benefits of Joint Programming should be effective close collaboration and avoid undue competition on topics of common interest. The question will be whether R&D leading to industrial and commercial activities could be included in Joint Programming, which is mostly working on open science.

Regarding the national programmes with longer GD implementation timescales and those with small radioactive waste inventories, including those from central and eastern Europe, their participation in Euratom research projects has over the years been limited. Therefore, taking into account this situation, that of advanced knowledge on GD and that their R&D priorities could be, for the time being, on pre-disposal management of radioactive waste Euratom has reopened R&D topics on other categories than HL&LL W and SF. The scope of activities include, the development of methods, processes, technologies and demonstrators for characterization, quality control / checking, treatment and conditioning of unconventional, legacy waste, operational wastes, waste arising from repair or maintenance and decommissioning/dismantling waste or other waste streams for which there is currently no industrial pre-disposal and or disposal mature processes.

These activities are generally carried by waste producers and owners and the projects issued from this Euratom call domain are separate from the EURAD EJP. However, EC strategy is to gradually involve and integrate this community in future Joint Programming at EU level. The justification is that if characterization, treatment and conditioning processes are developed together with the disposal community based on co-developed waste acceptance criteria, there will be efficiency, optimization and benefits on both sides. The current limitation of the types of activities to be included in the EJP, considered by Euratom, is that decommissioning activities up to pre-treatment for stabilisation and packaging of dismantled waste are more of the responsibility of utilities. Also, dismantling are commercial and competitive markets, which does not seem compatible with the open-science approach in the EJP. This could be considered as an obstacle to open cooperation. Recent evidences can be found in project proposals received in the category Innovation actions (IA). A large numbers of technical reports were classified as confidential. Although an objective of the EC in the research programmes is to contribute to economic growth and employment, observation is made that when a project includes activities covering innovative products, processes or services and prototyping, testing, demonstrating, piloting, large-scale product validation and market replication of advanced and new technologies, the results are of direct benefit to a small number of organizations with IPR for commercial use.

The question for the EC is, whether these activities should be included in Joint Programming. In the domain of waste treatment, the current EC idea is to allow inclusion of development of new processes and technologies for waste types or streams common to several MSs or eventually for which there could be co-ownership of the process and possible common exploitation facilities. Otherwise, other research proposals based on existing technologies or new ones which are or would be property of a single company should be subject to competitive call for proposals.

Public acceptance and political decision to select a site to construct a repository or an underground research laboratory (URL) is a sensitive issue. Already early, a number of applications for site investigations and URLs had been refused due to local and public opposition. Euratom opened the domain of SSH to increase public perception and acceptance around 2000. A series of projects were supported to investigate communication, stakeholders' engagement, governance aspects and public involvement, mainly at local level: RISCOM2, TRUSTNET, COWAM series, OBRA, ARGONA, IPPA and InSOTEC. General principles and recommendations on communication and stakeholder involvement were produced by the projects.

The results are available for use in national programmes and in working groups of the OECD NEA, the Stakeholder Forum for Confidence (SFC). Therefore, the need to continue social science on its own as part of Euratom did not appear as justified. Instead the Euratom programme on radioactive waste management proposed, in some way an innovative approach for public participation by suggesting to involve public non-technical stakeholders in scientific / technical R&D projects when a clear task/contribution can be identified for them. A series of projects implement this approach: MODERN 2020, SITEX II, JOPRAD, MIND and Beacon. Lessons learnt from these projects need to be drawn and a number of questions need to be addressed to clarify which role and task could public and non-technical stakeholders play in future Euratom research activities.

The future involvement of public, non-technical stakeholders in R&D projects and Joint Programming at European level thus needs analysis. Civil Society Organizations (CSO) and Non-Governmental Organizations (NGO) have defined their role as interaction with civil society in following the research to give civil society the opportunity to follow, discuss and give feedback on the research conducted in the projects and to create the conditions for civil society local and national representatives to interpret, discuss and give feedback on the research result and other information made available by the projects. CS experts also wish to perform social science (SC) activities within scientific technical projects.

On the role of CSOs and NGOs to follow the projects to discuss and give feedback on the research conducted, trials have been tested in on-going projects. Scientific experts have been used to comment of the work performed by the projects. The content of the deliverable is similar as that requested from the external advisory boards composed of end-users (WMOs and TSOs). Therefore, the EC considers that if CSOs and NGOs wish to make scientific comments on the projects work, this should be carried jointly with the other external experts in the advisory boards.

On the role to create the conditions for civil society local and national representatives to use the project results and other information in future situations where there are consultation processes as a part of safety case reviews and licensing decisions, this could be considered as training and performed as such in the form of deliverables presenting the project results in understandable way for the public.

Social science activities are performed extensively as part of the OECD NEA SFC forum, therefore SC as individual projects in the field of RWM are not justified also because such activities on their own usually address strategic issues as nuclear energy and radioactive waste management policies, which are not part of the Euratom R&T programme scope.

Summary :

- The European Commission via the Euratom R&T programme on radioactive waste management has a role in fostering close cooperation and joint implementation of R&D on radioactive waste management,
- The criteria for supporting research is cutting-edge science on issues of common EU added-value for Member States. However, the wide gaps in the status of the national programmes towards implementation of geological repositories for high-level and long-lived radioactive waste (HL&LL W) and spent fuel implies a central role for Euratom in the management of scientific and technical knowledge on RWM for exchange between organisations across the MSs and to transfer to new generations of scientists to ensure the long-term safety of disposal,
- The European Joint Programme tool for R&D at EU level appears to be the most effective way to jointly prioritise and implement R&D at the European level between the main actors of the disposal community (WMO, TSO and RE) representing their official MS national programme,
- Public non-technical stakeholders may contribute in R&D activities at Euratom level whenever a clear and genuine task can be identified and does not diverge from the programme of their country of origin,
- The needs for R&D on pre-disposal at EU level may be justified as long as the criteria for cooperation are clear and that benefit is acknowledged for several MSs as opposed to activities leading to competitive and commercial markets of benefit to single entities.

ROBERT WINSLEY

THE IMPLEMENTING GEOLOGICAL DISPOSAL OF RADIOACTIVE WASTE TECHNOLOGY PLATFORM (IGD-TP) – EVOLVING INTO OUR SECOND DECADE

R. WINSLEY[1], J. MARTIN[1], I. BLECHSCHMIDT[2], I. GAUS[2]

[1]Radioactive Waste Management, Building 587, Curie Avenue, Harwell Oxford Didcot, OX11 0RH – UK, (Former General Secretary and Chair (respectively) of the IGD-TP)
[2]National Cooperative for the Disposal of Radioactive Waste (Nagra), Hardstrasse 73, Postfach 280, 5430 Wettingen – Switzerland (Current General Secretary and Chair (respectively) of the IGD-TP)

Abstract. The IGD-TP was established in 2009 to initiate joint RD&D activities that support implementation of geological disposal. Our vision is to have the first European geological disposal facilities operational by 2025.
Realization of this vision has been supported by establishing common, needs driven RD&D activities.
A robust knowledgebase now exists that underpins progression towards geological disposal facility licensing and construction. It is however important that we maintain and enhanced this throughout step-wise implementation.
Recently, the European community has been working to establish a European Joint Programme on Radioactive Waste Management (EURAD).
Whilst IGD-TP is supportive of EURAD, it is important to recognize that Waste Management Organization (WMO) RD&D programmes have a wider scope of activities than the commonly agreed EURAD strategic research agenda. IGD-TP therefore also sees value in expanding our remit to co-ordinate aspects of RD&D programmes where WMO collaboration is beneficial. This paper describes the evolution of the IGD-TP as we move into our second decade.

1. Introduction and background

The Implementing Geological Disposal of Radioactive Waste Technology Platform (IGD-TP) was established in 2009 to initiate joint technical activities to facilitate stepwise implementation of safe geological disposal. There are currently 120+ different member organisations and over 600+ individual members. The group was established by the European Commission (EC), but is now led and funded by an Executive Group (EG) comprising representatives from 11 European Waste Management Organisations (WMOs) and organisations responsible for implementation-related research, development and demonstration (RD&D). The IGD-TP's original vision on launch was to have the first European geological disposal facilities (GDF) for spent fuel (SF), high-level waste (HLW) and other long-lived radioactive waste in operation by 2025 (Vision 2025).

The IGD-TP has worked for the last ten years to support delivery of this vision, by steering the development of responses to EURATOM calls in the radioactive waste management and disposal area and in doing so helped to ensure proposals were aligned with implementation and safety case needs. In this time, we have led scope development and needs driven alignment of 17 successful EURATOM programme projects, totalling around €100M (€59M EC funding). In addition, the IGD-TP has worked to build confidence in the policy of geological disposal, minimised duplication, delivered savings and helped to make better use of existing European competence and research infrastructures.

2. Underpinning scientific and technical knowledgebase

The scientific and technical knowledgebase that has been acquired from more than 40 years of collaborative RD&D is considerable and is now sufficient to underpin progression towards licensing and construction of GDFs. For example, Posiva received a construction licence in 2015 and plan to submit their operating licence in 2021, SKB submitted their construction licence in 2011 and Andra are expected to follow in the near future. Significant progress has therefore been achieved. However, it is important that this technical knowledgebase is maintained, enhanced and shared, throughout the step-wise design, development, operation and closure of facilities.

A significant proportion of the underpinning scientific knowledge was developed with EURATOM funding. Recently the EC called for a 'step change' in RD&D cooperation involving all parties (e.g. Waste Producers, Waste Management Organisations (WMO), regulatory Technical Support Organisations (TSO), Research Entities (RE) and Civil Society Organisations (CSO)). To achieve this, the European community has been working together to establish a European Joint Programme on Radioactive Waste Management (called EURAD), founded on agreed common objectives. EURAD aims to deliver an ambitious, cohesive and co-ordinated joint programme.

This paper presents the IGD-TP Executive Group's view that a sustained, co-ordinated and collaborative RD&D programme in the area of radioactive waste management and disposal is vital to ensure that all European countries, at various stages of advancement, continue to progress towards implementation. The main proportion of these RD&D programmes should ideally comprise national programme activities, with a selection of WMO jointly funded activities or international consortia interactions (on topics where it is sensible to cooperate), and finally a programme of activities of common interest co-funded by EURATOM (i.e. the EURAD Joint Programme). IGD-TP will act to identify RD&D work of common interest. Some of these topics might be taken up within EURAD (if they are aligned to the shared Strategic Research Agenda (SRA) [1] and consistent with the established joint programme ground rules). If, however, the topics of WMO interest are not suitable for progression within EURAD, IGD-TP will increasingly take the lead to co-ordinate and deliver these tasks as WMO funded initiatives that are parallel and complimentary to EURAD RD&D. This operational model is illustrated in Fig. 1.

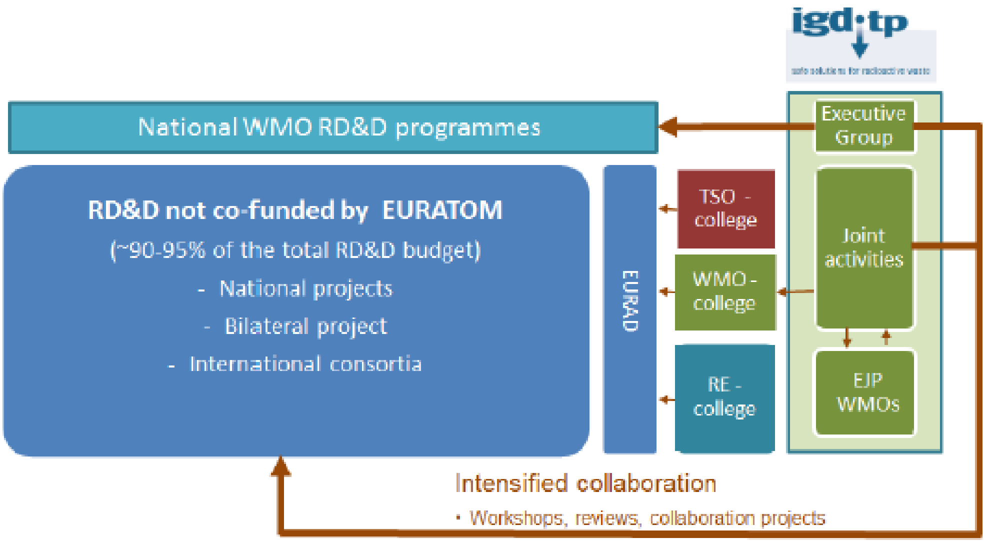

FIG. 1. Illustration of how the IGD-TP inputs to European RD&D programmes (both EURATOM and non-EURATOM funded activities).

The exact mix of RD&D that an individual WMO is involved in will largely depend on the stage of advancement of their national programme. The differing needs for and focus of RD&D at different stages of programme advancement is briefly discussed below. Following this, this paper seeks to explain the IGD-TPs input to EURAD and our intended future activities outside of and in parallel to the EURAD programme.

3. Need for and focus of RD&D at different stages of programme advancement

Geological disposal RD&D serves several purposes. It provides input to system design and optimisation and makes an essential contribution to siting of GDFs. Furthermore, it helps to achieve a sufficient level of system understanding to allow an adequate evaluation of safety. The RD&D priorities depend upon the stage of the programme lifecycle and change as the programme progresses. The current stage of advancement towards HLW/SF disposal facilities for each of the European waste management organisations that comprise the IGD-TP EG is depicted in Fig. 2, along with a broad indication of their RD&D focus, which is closely related to their stage of advancement.

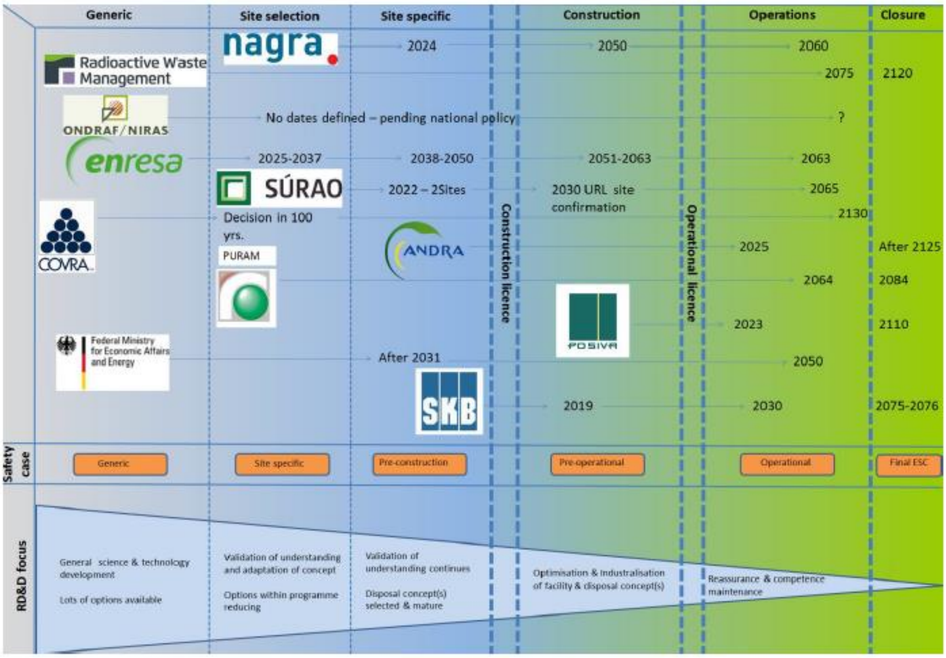

FIG. 2. Overview of European geological disposal facility maturity (for SF/HLW disposal programmes) and associated RD&D focus for IGD-TP member organisations, as of 2017.

In the early generic/site-selection phases the emphasis is on the development of basic concepts, combined with an evaluation of safety and of technological feasibility. These early phases are followed by a site-specific phase where the focus turns towards system optimisation, with an emphasis on post-closure safety and on site-specific geology and design concepts. The system of engineered barriers is increasingly tailored to the specific geological conditions. In the later stages (i.e. construction phase onwards), when moving towards implementation, practical issues become increasingly important, such as construction procedures, operational safety and optimisation of technology (including 'industrialisation' of repository operations). RD&D does not stop following the commencement of facility construction. It will need to continue throughout the construction and early operational phases. RD&D efforts are therefore necessary throughout the entire lifecycle of radioactive waste management and disposal programmes in order to ensure optimisation of management routes in general and of disposal solutions in particular, as well as to comply with Waste Directive obligations. RD&D must also continue in order to address evolving societal and regulatory concerns.

4. IGD-TP input to EURAD – inclusive and unified

For almost a decade the IGD-TP EG has been functioning as a successful and enduring WMO RD&D platform. The group has already acted on behalf of all of the European WMOs when it input consolidated WMO comments into the JOPRAD-developed common SRA [2] and latterly the EURAD SRA [1]. The IGD-TP EG also acted to efficiently co-ordinate WMO review comments on the developing EURAD proposal. Based on this positive track record and well-established structure, the IGD-TP EG has offered to support EURAD more formally by co-ordinating the 'WMO College' within the proposed EURAD governance structure. The role of the IGD-TP/WMO College within the governance of EURAD is shown in Fig. 3.

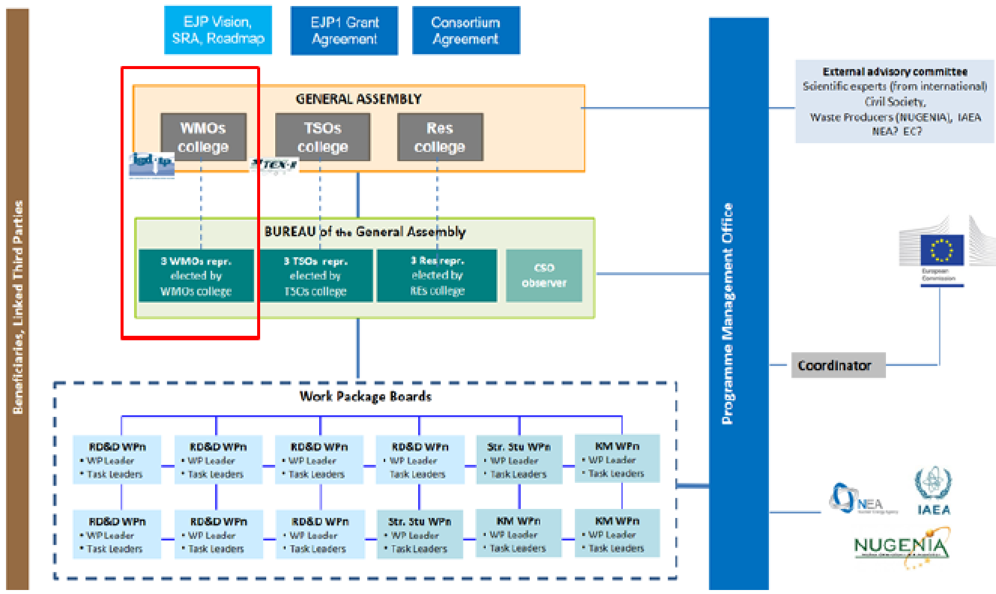

FIG. 3. Overview of proposed EURAD governance structure with the IGD-TP's input highlighted in red.

The proposed governance arrangement for EURAD includes three colleges, one each to represent the mandated WMOs, research entities and regulatory technical support organisations participating in EURAD. The WMO College should represent all 19 of the current mandated WMOs participating in the programme; it is noted that 10 of these WMOs are members of the IGD-TP EG. The IGD-TP EG has acted to ensure inclusivity by inviting all non-IGD-TP EG WMOs who are mandated within EURAD to either join the EG or, alternatively, to reinforce our mandate as the co-ordinator of the proposed WMO college (by supplying their views via a less formal observer/associate member status).

To facilitate the inclusion of further European WMOs, the EG has proposed that the IGD-TP remains focused on geological disposal, with some interest in upstream activities, but progressively expands its remit to also include scope of greater relevance to nations with small programmes/inventories (e.g. disposal of sealed sources etc.). It is intended that this evolution of the IGD-TP remit will allow the group to more adequately represent all European WMOs and in doing so facilitate the IGD-TP EG to also act as an inclusive WMO College within the EURAD joint programme. This will mean that the IGD-TP EG/WMO College will be able to speak with one strong, unified WMO implementer's voice.

5. IGD-TP activities outside of EURAD

The IGD-TP is fully supportive of EURAD. However, it is important to recognise that WMO RD&D programmes have a much wider scope of activities than the commonly-agreed EURAD strategic research agenda will address. This is also the case for our RE and TSO colleagues. This distribution of RD&D needs is nicely depicted by Fig. 4, which was developed as part of the JOPRAD project to represent common areas of interest for Joint Programming. It also serves to highlight the significant RD&D areas that joint programming cannot and in some cases should not seek to address. For example, this could be because:

- the scope is such that it would be inappropriate to collaborate with regulatory bodies (TSOs) due to a perceived conflict of interest;
- the topic area and scope of interest did not gain consensus with other EURAD actor groups (i.e. not of sufficient common interest);
- or the work is of WMO interest/significance, but is not deemed to be sufficiently cutting edge for inclusion within EURAD.

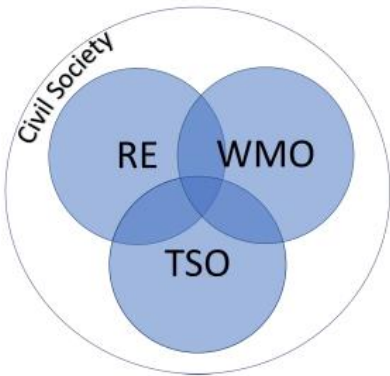

FIG. 4. Representation of common areas of interest for Joint Programming [2].

WMOs publish RD&D programmes at regular intervals, typically 3-5 years. Activities included in national programmes normally require a strict timeline for delivery, are very specific (and therefore would only be relevant to one or a small number of WMOs) and are applied topics that are interlinked with decision making. They almost always have a clear licence-driven purpose (reducing uncertainties, optimisation, robustness, stakeholder requests etc.).

Typical candidates are developing a common WMO view on how to integrate climate modelling in our safety assessments, sharing of the current state-of-the-art on retrievability, canister development aspects, interfaces between operational phase and post-closure phase, etc. These illustrative WMO joint activities could be delivered through, for example, shared RD&D activities, knowledge transfer workshops or the production of IGD-TP position papers.

Therefore, the IGD-TP also sees value in expanding the group's activities to co-ordinate aspects of these RD&D programmes where WMO collaboration is beneficial and sensible. We intend to do this in parallel with ongoing involvement in EURAD, as is highlighted in Fig. 1.

6. Update of the IGD-TP remit, vision and Strategic Research Agenda

In July 2011 the IGD-TP published a SRA [3]. This document identified the main RD&D issues that required a co-ordinated effort over the coming years in order to realise Vision 2025. Key Topics were identified in relation to their priorities, which were established collectively through discussions among numerous European WMOs. The SRA proved to be a good instrument for creating synergies, co-operation and co-ordination, both internally between the IGD-TP participants and with external activities. Because the SRA identified the key topics of RD&D that had the greatest potential to support repository implementation through enhanced cooperation, it provided valuable input to identifying topics for calls in the EURATOM Frameworks. Several of the priorities in the SRA have been addressed in the last 10 years. It further served as a significant element for the development of the shared JOPRAD [2] and subsequent EURAD SRAs [1].

Now that EURAD is a reality and the IGD-TP has decided to expand our remit to facilitate wider membership, it is an opportune time to revisit and revise our common WMO SRA [3]. Furthermore, taking into account the fact that the Vision 2025 is approaching realisation, an updated vision offering a longer term perspective up to 2040 is currently being developed and will be announced on the 10-year anniversary of the IGD-TP in November 2019.

In February 2019, the IGD-TP established a subgroup that was tasked with updating the IGD-TP's SRA and, in effect, producing the first IGD-TP SRA that also takes account of the EURAD SRA responding to the new vision. This task is currently underway, the original IGD-TP SRA structure will be used as a basis and the priorities will be re-assessed, also to take into account the progress that has been achieved in the last 10 years. Then, the areas in the EURAD SRA will be mapped on this update. We will then assign a WMO level of importance, significance and urgency (a prioritisation exercise) to each area. An additional step may well then be to identify any missing research needs and again conduct a prioritisation exercise. By engaging with all European WMOs (i.e. both those represented within the current IGD-TP EG and also all of the others mandated within EURAD) in the end we will be able to ensure inclusion of all WMO research needs, not just those related to deep geological disposal of spent fuel, high level waste and long-lived intermediate level waste.

7. Concluding remarks

The IGD-TP is approaching its second decade and is in a good position to realise its Vision 2025. The IGD-TP SRA proved instrumental in this realisation and fostering international collaboration. The IGD-TP welcomes the EURAD Joint Programme. EURAD will address a range of important WMO needs, but not all of them. The IGD-TP EG will therefore co-ordinate and develop collaborative research activities and deliver them in parallel to EURAD involvement (e.g. via multilateral WMO collaborations). The IGD-TP EG has offered to co-ordinate the views of mandated WMOs within the WMO College, so WMOs can speak with one unified implementer's voice. To achieve this in an inclusive manner the IGD-TP will adapt and evolve as we move into our second decade. We have been openly engaging on this issue for over a year and have now developed an appropriate role within and outside of the EURAD Joint Programme. This process will result in an update of our vision, to be announced at our 10-year anniversary in November 2019 and the publication of the second version of the IGD-TP's SRA soon after.

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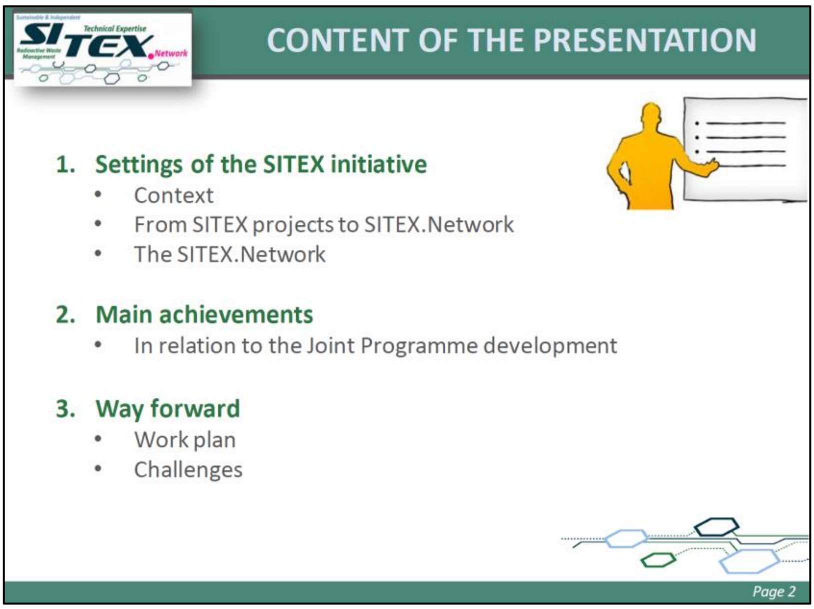
DELPHINE PELLEGRINI

FISA 2019 – EURADWASTE '19

Presentation of Ms Delphine PELLEGRINI (IRSN, FR)

THE SITEX INITIATIVE: SUSTAINABLE NETWORK FOR INDEPENDENT TECHNICAL EXPERTISE ON RADIOACTIVE WASTE MANAGEMENT



1. SETTINGS

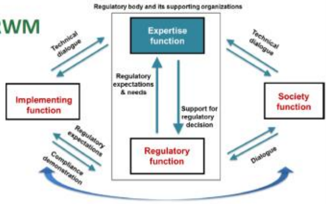
Context - *Functions* interacting in RWM

- The *Expertise Function* key mission is to provide the **technical and scientific basis** for notably supporting the decisions made within *the Regulatory Function.*

The EC Directive 2011/70/Euratom (adressing safety of RWM) states notably:

- member states shall establish and maintain a competent regulatory authority;
- regulatory authority is functionally separate from Waste Management Organizations (WMOs);
- all parties to carry out education, training and R&D activities.

➢ **Independence and competence** of the *Regulatory Function* calls for the support of a competent *Expertise Function*, independent from the *Implementing Function*.



➢ **Typical activities** of the *Expertise Function*:

- Contributing to the establishment of regulatory requirements;
- Developing guidance for meeting these requirements;
- Evaluating Safety Cases related to RWM facilities;
- Develop and maintain its knowledge and skills.

1. SETTINGS

The origin of the SITEX intiative

– *Implementing Function* **(WMOs)** in Europe decided to coordinate their efforts to be able, at horizon 2025, to implement the first geological disposal:
  - **IGD-TP** launched in 2009, funded by the EC

– **Need at the international level for developing and coordinating activities of the *Expertise Function*,** associated to the scientific review process of deep geological disposal safety (as a start):
  - **SITEX** launched in 2012, funded by the EC
  - gathering organizations fulfilling an Expertise Function (TSOs, Research Entities (REs), NRAs) and Civil Society Groups (CS)

  ➢ plurality of actors and views as a way forward to build a strengthened and comprehensive **technical expertise network**

1. SETTINGS

From SITEX projects to SITEX.Network

SITEX project
2012-2013

SITEX-II project
2015-2017

SITEX.Network
Since January 2018

Preparatory phase
- Define needs and missions of the expertise function.
- Define objectives of the future SITEX network.
- Define possible activities and interactions of the network.

Test phase
- Test the practical implementation of activities and interactions.
- Prepare the Terms of Reference of the future SITEX network.

1. SETTINGS

SITEX.Network founded as a non-profit organization, in January 2018

- **What is the overall objective?**
  - Enhance and foster cooperation at international level to achieve a high quality *Expertise Function*,
  - Independent from organizations responsible for the implementation of waste management programmes (*Implementing Function*),
  - Aiming at supporting the Nuclear Regulatory Authorities *(Regulatory Function)* as well as the Civil Society *(Society Function)*,
  - In the field of radioactive waste management, including disposal.

➢ **Types of activities**

➢ **15 members, from 9 countries:**
- Expertise Function: Bel V, EIMV, FANC, GI-BAS, IRSN, PSI, SURO, TS Enercon, VTT.
- Civil Society Function: Clis de Bure, Energiaklub, MKG, Mutadis, NTW, SYMLOG.

Page 6

2. MAIN ACHIEVEMENTS

R&D related activities

- Expertise Function **Strategic Research Agenda (SRA)** in the field of RWM
  - 36 Topics distributed in 7 Main Topics, with:
    - Importance of the main topic to safety
    - Rationale for developing joint activities

➢ For each topic: **Research activities** (experiment and/or modelling works) and/or **Horizontal activities** (SoTA, exchanges on practices/common position, transfer of knowledge/training)

➢ **Conditions for implementation in an EJP** whilst preserving the independence of the Functions, eg. :
- impartiality in establishing SoTA
- transparency of codes/date/results
- independent analysis of the results
- say on the design of shared experiments

Main topic 1: Waste inventory and source term.
Main topic 2: Transient THMBC conditions in the near-field.
Main topic 3: Evolution of EBS material properties.
Main topic 4: Radionuclide behaviour in disturbed EBS and HR.
Main topic 5: Safety-relevant operational aspects.
Main topic 6: Managing uncertainties and the safety assessment.
Main topic 7: Lifecycle of a disposal programme and its safety case.

2. MAIN ACHIEVEMENTS

R&D related activities

- **SITEX was involved in the development of the EJP EURAD proposal:**

  ➢ **SITEX SRA was an input to the JOPRAD project**
  - the TSO group of JOPRAD worked in close collaboration with SITEX
  - based on the SRA's, assessments of commonalities among WMOs, REs and TSOs needs in R&D were done → Programme Document issued by JOPRAD → EURAD SRA

  ➢ **SITEX coordinated the TSOs reviews of EURAD WPs**
  - 2 reviews organized (jan-feb 2018 and May 2018)
  - Internal review by the mandated TSOs
  - External review by other SITEX.Network members (*Expertise* and *Society Functions* separately)

  ➢ **SITEX coordinated the election of the 3 TSO representatives in the EURAD Bureau**

Page 8

2. MAIN ACHIEVEMENTS

Safety review related activities

- A **guidance** for the technical review of Safety Cases for geological disposal facilities was issued;
- **Position papers** were developed on the 4 aspects of geological disposal

  (Not developed here as out of the session topics)

Training activities

- SoTA on practices, experiences and prospective views on training and tutoring
- a **training module** for generalist experts in geological disposal, with the **safety review perspectives**, was developed
- 1-week **pilot** training session implemented in Kaunas (Lithuania) in 2017
- ❑ Proposal by SITEX as an association for the EJP unsuccessful → SITEX/ENSTTI course

2. MAIN ACHIEVEMENTS

Interaction between Expertise and Civil Society functions

- A small group of CSOs was directly involved in SITEX-II and interacted with a larger group of 35 NGOs from 18 European countries (**"double wings" concept**), to explore the possible modes of interaction via 3 specific issues

1. **How could CSOs concerns be integrated in R&D activities of the *Expertise Function*?**
   - CSOs formulated R&D key issues they expected to be covered
   - these issues were discussed with the other SITEX partners and considered to produce the final version of SITEX SRA
   - e.g, based on the input from CSOs, a first list of socio-technical topics for which both technical and societal aspects need to be investigated in an integrated manner, were identified and included in the SRA (eg. conditions for closure)
   - Following notably the successful interactions between *Society, Expertise* and *Implementing Functions*, CSOs are now engaged in :
     - the BEACON R&D project
     - the EJP1 EURAD
   - though initial proposals evolved to account for EC requests
   - Interactions between institutional and non-institutional organizations needed rather than external (one shot) reviews or "communication"

2. MAIN ACHIEVEMENTS

Interaction between Expertise and Civil Society functions

2. **How safety culture for RWM can be shared through different stakeholders, including CS?**
   - commonalities and differences in the vision of safety culture in RWM identified through a questionnaire
   - conditions and means for developing interactions with CS

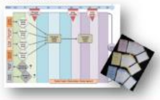
2. MAIN ACHIEVEMENTS

R&D Safety Review Training Civil Society

Interaction between Expertise and Civil Society functions

3. **Issues on intergenerational governance**

   - Review and analysis of the literature on past and on-going research projects devoted to intergenerational aspect of RWM were performed
   - A new approach was developed to stimulate exchanges on the different possible routes (aboveground or underground storages, deep geological repository…) for the long term management of HLW & SF - **a serious game called PEP « Pathway Evaluation Process »** - and implemented:
     - with SITEX-II partners + enlarged group of NGOs
     - for educational purpose by a NGO with students in Czech republic
     - recently by the French Public Debate Commission for 40 students, with the support of SITEX as facilitator



Page 12

3. WAY FORWARD

SITEX.Network Work Programme

- **R&D related activites**
  - update of SITEX SRA produced in 2015, notably in the perspective of the definition of further projects in the framework of the EJP,
  - coordination of the TSO community for the EJP EURAD when needed
  - PhD Day related to recent social sciences on governance
- **Safety review related activities**
  - Benchmark on reviewing approaches (exchange on review practices)
  - State-of-knowledge related to deep borehole disposal
- **Training**
  - on regulatory review and assessment of the safety case for geological disposal : SITEX/ENSTTI course, module 1 on September 23-27, 2019, modules 2&3 in 2020
- **Civil Society**
  - PEP sessions (of two days each) in 2019 proposed to participants, internal or external to SITEX.

https://www.sitex.network/

Page 13

3. WAY FORWARD

- **SITEX.Network, a sustainable technical expertise network**
  - statutes, terms of reference (activities, interaction modes, management…)
  - structured community, producing outputs and able to coordinate actions when required
  - plurality of actors (TSO/Res, NRA, CSO) and views, including so-called less and more advanced programs : an added value
    - thanks to the European Commission funds for its preparation phases
    - Challenge: from EC funds to membership fees
- **Successful interactions toward the EURAD EJP between the *Expertise*, the *Implementing* and the *Society Functions*.** Improvements/feedback :
  - the complexity of RWM issues entails involving both "Social science" and "Citizen science" in future research projects
  - proper integration of CSO in international technical R&D projects is still an issue
  - associations (representatives of enlarged groups) as direct beneficiaries?
  - inclusiveness with a well-balanced participation of the different communities (operators (WMOs, waste producers) – TSOs – RE – Civil Society) is a key aspect
  - gathering all parties as early as possible whatever the project is an advantage !

Page 14


Sustainable & Independent
Technical Expertise
Radioactive Waste Management
SITEX
Network
THANK YOU FOR YOUR ATTENTION !
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CHRISTOPHE BRUGGEMAN

"EURADSCIENCE", A NETWORK OF RESEARCH ORGANISATIONS FOR RADIOACTIVE WASTE MANAGEMENT SCIENCE WITHIN EUROPE

C. BRUGGEMAN[1], M. ALTMAIER[2], D. BOSBACH[3], S. CHURAKOV[4], D. GALSON[5], B. GRAMBOW[6], F. MCEVOY[7], TH. STUMPF[8]

[1]Belgian Nuclear Research Centre SCK•CEN, Boeretang 200, 2400 Mol, Belgium
[2]Institute for Nuclear Waste Disposal (KIT-INE), Postfach 3640, 76021 Karlsruhe, Germany
[3]Forschungszentrum Jülich, Wilhelm-Johnen-Straße, 52428 Jülich, Germany
[4]Paul Scherrer Institute, Forschungsstrasse 111, 5232 Villigen, Switzerland
[5]Galson Sciences Ltd, Grosvenor House, Melton Rd, Oakham LE15 6AX, UK
[6]IMT Atlantique, 4, rue Alfred Kastler - BP 20 722 - 44307 NANTES CEDEX 3, France
[7]British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK
[8]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany

Abstract. Founded in December 2018, EURADScience is an independent, cross-disciplinary, inclusive network with the aim of ensuring long-term scientific excellence and credibility in radioactive waste management. Among the 25 founding members are representatives of nationally funded research organisations, smaller consultancy firms, and academia. EURADScience's Vision is to maintain a holistic view of relevant scientific disciplines and provide scientific excellence to advance progress of national radioactive waste management programmes and establish credibility of waste management concepts.

EURADScience will work closely with complementary networks such as IGD-TP (the Implementing Geological Disposal Technology Platform, established and led by waste management organisations) and SITEX (a network of technical support organisations to national regulators). EURADScience will also cooperate closely with the new European Joint Programme on Radioactive Waste Management (termed EURAD), and will take a lead on developing new research proposals within its sphere of expertise..

1. Introduction

1.1. Context

Research on radioactive waste management and disposal has been ongoing for more than 40 years. Driven by the need to establish national solutions, international co-operation has been supported through the Euratom R&D co-funding programmes, focusing on the pooling of resources, competences and infrastructure to tackle diverse, cross-disciplinary scientific and technical challenges associated with storage and disposal solutions.

Over the past 10 years, this international cooperation has been further developed through the establishment of networks, bringing together, e.g., European waste management organisations (WMOs) and other bodies concerned with implementation of deep geological disposal within IGD-TP (Implementing Geological Disposal of radioactive waste Technology Platform, https://igdtp.eu/), or the technical support organisations (TSOs) fulfilling an expertise function in the field of safety of radioactive waste management, within the SITEX network (Sustainable network for Independent Technical Expertise on radioactive waste management, https://www.sitex.network/).

The next level in integrating the different actors involved in radioactive waste management science and technology on a European level was developed within the JOPRAD project (Towards a Joint Programming on Radioactive Waste Disposal, http://www.joprad.eu/) and the subsequent development of the EURAD proposal, the first European Joint Programme on radioactive waste management, including disposal.

The first geological disposal facility for high-level waste/spent fuel has obtained its construction licence (in Finland), and it is likely that others will follow in the next decade. Thereby, the role and long-term perspective of the associated science and technology is changing. Next to a long-term vision on how to continue development of the state-of-the-art in view of the many additional disposal projects to follow in the next several decades and their long operational lifetimes, a broader spectrum of pre-disposal activities feeding into the final disposal step needs more attention.

1.2. Background

When preparing for the European Joint Programming proposal EURAD during the JOPRAD project, the Research Entities (REs) input was requested in addition to that of the WMOs and the TSOs. However, unlike the WMOs and TSOs, the Research Entities had no representation structure. Thus, facilitated and coordinated by the CNRS (France), a number of research entities organised themselves and generated a Strategic Research Agenda (SRA) as input to the EURAD project. After several meetings (Brussels, June 2015; Paris, September 2015; Nantes, November 2015; Paris, March 2016), a final draft was produced in May 2016 by a working group comprising 22 partners from countries having both advanced and less advanced radioactive waste management programmes, and with both a traditionally strong nuclear research community or only a relatively small RD&D programme. Subsequently, the CNRS facilitated the translation of the Research Entities' SRA into the research organisations' priorities and concerns integrated into the central "Program Document", an important milestone and deliverable within JOPRAD (http://www.joprad.eu/fileadmin/Documents/JOPRAD_Deliverables/JOPRAD_WP4_D4.4_Programme_Document_Final_-_Issue_4_30.05.18-.pdf). This document served as the scientific and technical basis for the development of the proposal for a Joint Programme on radioactive waste management, or EURAD.

During this exercise, but also throughout the development of the EURAD project proposal, it became apparent to many research organisations that their self-organisation through a network could provide added value in the implementation phase of EURAD, as well as contributing to the development of excellent and breakthrough science in the context of safe and sustainable radioactive waste management. Therefore, an initiative was launched in June 2018 to bring together interested research organisations into such a network with a broader objective than only that driven by the need for EURAD implementation. After positive feedback, Research Entities were invited to a joint meeting in Berlin, Germany on 5 December 2018, where such a network was established under the name "EURADScience".

2. Vision and Mission of EURADScience

The key challenge identified is essentially the importance of continuously developing the scientific frontier in view of the extremely long timescales associated with the generation and storage of radioactive wastes, and the development, operating and closing of geological repositories. Correspondingly, and in view of the particular contribution required from the scientific community, EURADScience's Vision is to act as an **independent, cross-disciplinary, inclusive network ensuring scientific excellence and credibility** to radioactive waste management.

This vision is driven by the mission of the EURADScience network and its members, which can be summarised as follows:

- Research organisations are at the centre of developing a long-term vision for the scientific and technical challenges that are inherently linked to safe waste management and disposal, beyond national borders and implementation programmes:
  - Such a link is also addressed by the Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste.
  - Research organisations are in a unique position to provide scientific excellence and credibility to waste management concepts established and implemented within national programmes.
  - Research organisations are also key contributors for providing scientific solutions to meet implementation and safety-driven needs.
  - The organisation within a network facilitates engagement with the wider scientific community outside EURAD, including actors beyond Europe.
- Research organisations have a primary focus on long-term knowledge development and management and are key to maintaining competence and know-how. Research organisations are frequently providing the cradle in which the next generation of experts is trained, and are strongly positioned in providing education and training:
  - In order to attract this new generation of scientists, research organisations need to emphasise and promote important research.
  - Such research can only be sustained when maintaining and developing state-of-the-art infrastructure and expertise, which can be pooled and made available on a European level.
- Nationally funded research organisations identified as Mandated Actors within EURAD form the membership of the Research Entities college:
  - EURADScience can be used as supporting function for this college.
  - As such, EURADScience can be seen as complementary but independent to the existing IGD-TP and SITEX initiatives, with its own emphases and needs.
  - By interaction between the Research Entities college and EURADScience, views of the larger research community (including also Third Parties linked to Mandated Actors within EURAD) can be promoted within EURAD.

3. Interest in EURADScience

Following the December 2018 inception meeting in Berlin, minutes together with accompanying material were distributed to research organisations across Europe in order to attract a sufficiently critical number endorsing the EURADScience vision and mission. As of March 2019, 25 research organisations from 15 countries (Fig. 1) have responded positively to this invitation.

These research organisations include nationally funded research centres, smaller specialist companies, and members of academia, and are located in countries having both larger and smaller waste management programmes. As such, the EURADScience founding membership is already considered to be representative of the range of research actors within the European landscape. Inclusiveness being at the heart of the EURADScience vision, the network is still open to accommodate new interested research organisations and will remain so in the future.

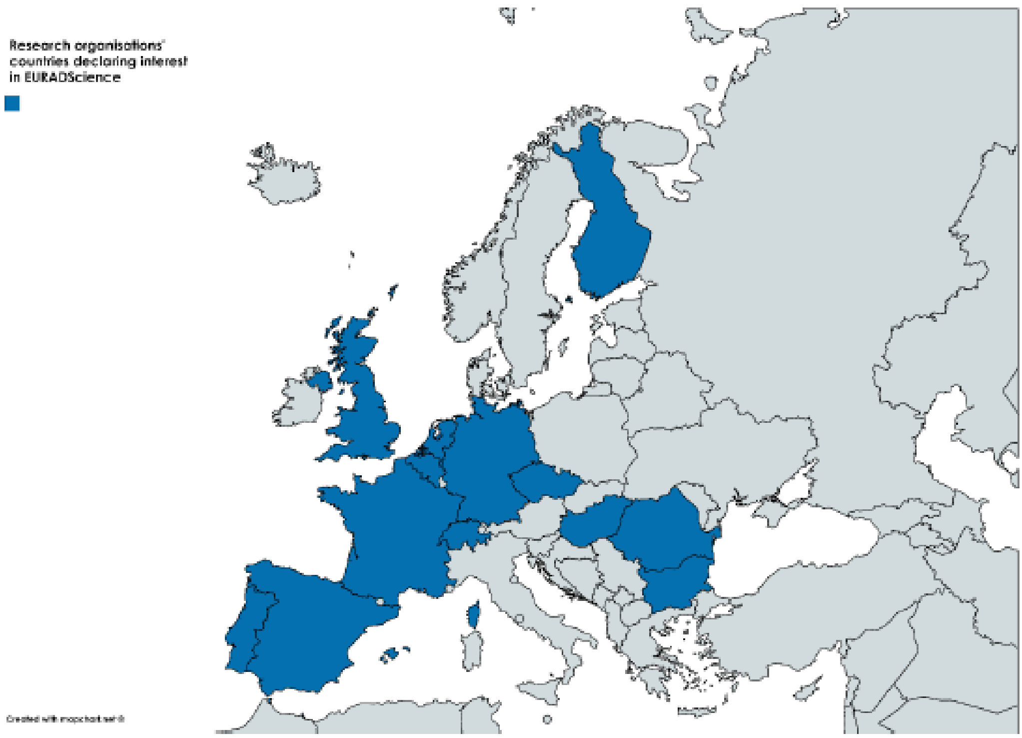

FIG. 1. Country map of organisations responding positively to EURADScience's invitation of endorsing the vision and mission (correct as of March 2019).

4. Organisation of EURADScience

The new EURADScience network needs a management structure with resources and experienced research personnel provided by member organisations. The aim is a lean structure with the potential for expansion, if required in the future. At the 2018 Berlin inception meeting, it was decided to establish an Executive Group responsible for preparing the work to be undertaken within the network, and for communicating with both the wider EURADScience membership and the outside world (including other networks). The tasks allocated to the Executive Group are as follows:

- To prepare processes, documents and meetings within and on behalf of the network, allowing and enabling progress.
- To safeguard the vision, mission and values endorsed by the network.
- To ensure communication between all members, with EURAD, and outside EURAD.

Participation in the Executive Group is on a voluntary basis. A limited number of committed organisations are needed in order to perform these tasks. The eight organisations (and their representatives) who answered positively to the call for becoming a member of the Executive Group are reflected in the author list of the current paper. Membership of the Executive Group is limited to 2.5 years, after which the position is opened again to all EURADScience members. EURADScience members are asked to formally approve the Executive Group membership.

The Executive Group members will chose a Chair to act as spokesperson for EURADScience, which will also be a rotating position.

5. Future of EURADScience

EURADScience plays a dual role (i) as actor and science-stakeholder on a European level, and (ii) as the platform in support of the Research Entities college within EURAD. For its functioning, EURADScience will communicate with all mandated Research Entities, as well as all research organisations who express interest in participating in the network.

The EURADScience network will therefore need to:

- develop and promote a joint vision on common interests, the scientific state-of-the-art, and research priorities of its members;
- effectively support the Mandated Actor group, with their Linked Third Parties, to fulfill their obligations within EURAD and, as such, act in a similar fashion as the already-existing IGD-TP and SITEX networks.

5.1. Roles within EURAD

The specific roles within EURAD will be specified by the forthcoming EC grant agreement, but are expected to include:

- Providing input to updating the EURAD work programme in view of the second wave of activities within the EJP EURAD phase 1 (mid-2019 – mid-2024).
- Providing input to updating the EURAD Strategic Research Agenda and Roadmap by consultation with the Mandated Actors and their Linked Third Parties.

- Assisting in the knowledge management activities within EURAD by suggesting, nominating and/or providing experts in the different research fields for which either the state-of-the-art needs to be established, or in which education and training activities are organised.
- Providing the Research Entities college for operation of the EJP EURAD.
- Electing three representatives of the Research Entities to the Bureau of the EURAD General Assembly.

5.2. Roles outside EURAD

EURADScience as a network will play a wider role within the European RD&D landscape on radioactive waste management. Activities will need to be undertaken to promote its visibility, such as investing in a webpage, and other activities to communicate more widely about its role and work (presentations, flyers, and papers such as this one). Furthermore, EURADScience also aims to promote networking activities such as joint meetings, and the organisation of working groups on certain scientific and/or technical themes. Within the Executive Group, discussions will have to be undertaken regarding the structure best suited to operate such activities, thereby ensuring the commitment of EURADScience and its membership to the founding vision and mission. In the longer term, a scientific secretariat might become desired.

The role as a science-stakeholder on a European level will include providing a forum for research organisations to exchange and develop ideas, strategies and joint R&D. Other aims and activities will need to be further developed.

As one of the first possibilities for establishing and promoting EURADScience as a network, it will provide the necessary support in developing a proposal for the 2019-2020 EURATOM work programme on pre-disposal management (NFRP-10).

The emphasis of EURADScience activities will be within the European Union. In addition, within the context of the implementation of EURAD, it will need to develop mechanisms for interaction with EU candidate and associated countries. With respect to collaboration beyond the EU, objectives, strategies and processes will be discussed within the network and implemented as jointly agreed.

6. Conclusion

For the first time, European research organisations in radioactive waste management have organised themselves in a network, called EURADScience, with the vision of acting as an independent, cross-disciplinary, inclusive network providing scientific excellence and credibility to national radioactive waste management programmes. Twenty-five organisations from 15 countries have already declared interest and have endorsed EURADScience’s vision and mission as agreed during the inception meeting in December 2018.

EURADScience aims to play a complementary role to the already established IGD-TP and SITEX networks, both within and outside EURAD.

Acknowledgments

The EURADScience Executive Group acts on behalf of the EURADScience membership, and acknowledges all of the efforts, ideas and proposals developed by many organisations and individuals to reach the current state of the network.

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BÁLINT NŐS

NEEDS OF COUNTRIES WITH LONGER TIMESCALE FOR DEEP GEOLOGICAL REPOSITORY IMPLEMENTATION

B. NŐS

Strategical and Technical Directorate, PURAM, HRSZ.: 8803/2, H-7031 Paks - Hungary

Abstract. Countries operating nuclear power plants have to deal with the tasks connected to spent fuel and high-level radioactive waste management. There is international consensus that, at this time, deep geological disposal represents the safest and most sustainable option as the end point of the management of high-level waste and spent fuel considered as waste. There are countries with longer timescale for deep geological repository (DGR) implementation, meaning that the planned date of commissioning of their respective DGRs is around 2060. For these countries cooperation, knowledge transfer, participation in RD&D programmes (like EURAD) and adaptation of good international practice could help in implementing their own programmes. In the paper the challenges and needs of a country with longer implementation timescale for DGR will be introduced through the example of Hungary.

1. Introduction and background

1.1. Countries with longer implementation timescale

Nuclear Power Plants are operated since 1970's and 1980's in Central and Eastern European (CEE) countries. This means that these countries have to deal with spent fuel management, including the final disposal of high-level radioactive waste (HLW): spent nuclear fuel or vitrified HLW corresponding to the direct disposal or reprocessing option respectively for the back-end of the nuclear fuel cycle. As it is formulated in the Council Directive 2011/70/EURATOM (Directive) [1]: *"it is broadly accepted at the technical level that, at this time, deep geological disposal represents the safest and most sustainable option as the end point of the management of high-level waste and spent fuel considered as waste".*

Taking into account the above mentioned, most of the CEE countries have to face the challenge of implementing a deep geological repository, the programs for which are in an early stage, so these countries could be named as: 'countries with longer timescale for deep geological repository implementation' (countries with longer implementation timescale). Usually the planned commissioning date for deep geological repositories (DGRs) in these countries is around 2055-2065 (Fig. 1).

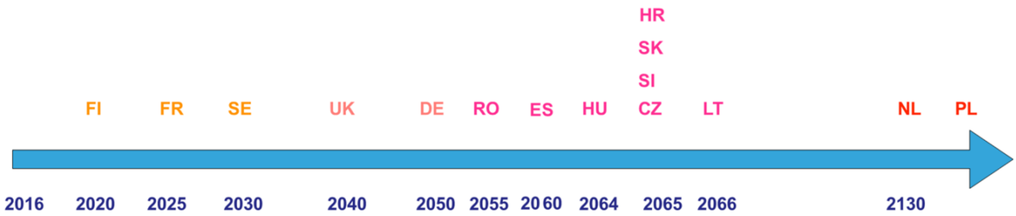

FIG. 1. Planned start of operation of deep geological facilities in the EU [2].

Nevertheless, when a country is in an early stage of implementation, it is essentially important from several aspects (and it is required by the Directive [1]), to develop a long-term programme – and an underpinning RD&D plan – for the implementation of a DGR. A long-term programme, with its technical contents and connected cost calculations is necessary to collect enough funding for the long-term liabilities, meeting the general principle, that requires not to leave undue burden on future generations.

1.2. The need for cooperation and assistance

Because of the small scale of the nuclear industry – including radioactive waste management – in CEE countries, providing the necessary resources (human, technical, financial, etc.) for deep geological repository implementation through decades could be more challenging. Very useful guidance documents exist to assist Member States in the development of their long-term programme and the connected RD&D plan.

The NAPRO working group of the European Nuclear Energy Forum has drafted a guide (NAPRO Guide [3]) with the aim of assisting the Member States in the establishment of their National Programmes, addressing among others guidance on how to develop a comprehensive programme for all waste streams, showing the management routes from the generation until the final disposal in dedicated repositories. From all waste streams, the biggest challenge is to find a management route and implement the programme for the disposal of HLW and spent nuclear fuel.

The Directive [1] prescribes that, "the National Programmes shall include (…) the research, development and demonstration activities that are needed in order to implement solutions for the management of spent fuel and radioactive waste". The NAPRO Guide [3] contains some general guidance on how to meet this requirement. More specific assistance on RD&D planning can be found in the PLANDIS Guide [4], which was developed by the SecIGD2 Project. The PLANDIS Guide was intentionally focused on the needs of the countries with longer implementation timescale (or countries with less-advanced programmes).

Cooperation at the international level can assist these countries in facing some of these challenges. Some of the CEE countries follow the so-called 'dual track approach', meaning that they are considering the possibility of shared solutions for disposal either as a preferred or as an alternative option. From the technical and financial point of view, the shared disposal option is a rational idea to solve the problems, however, beside the technical issues, more complex legal, financial and political questions have to be answered.

Another important circumstance is the fact, that there are countries with mature, advanced DGR implementation programmes. These countries accumulated a vast amount of information and experience during the past few decades. This knowledge base could be adapted by countries with longer implementation timescale for their own situations, within their boundary conditions. In this respect, the EURAD project (European Joint Programme on Radioactive Waste Management) could play an important role in collecting the state of knowledge and developing training modules in different areas.

In the next chapters, the example of Hungary is used to illustrate the specific boundary conditions, current situation of a programme and R&D needs of a country with longer implementation timescale.

2. Programme boundary conditions

2.1. National policy

The Hungarian Parliament, in accordance with the requirements of the Directive, adopted the national policy document on the management of spent nuclear fuel and radioactive waste (national policy). The national policy summarizes the principles applicable to the management of spent nuclear fuel and radioactive waste. Most of these principles were promulgated in the Hungarian legal regulation - mainly in the Act CXVI of 1996 on nuclear energy (Atomic Act) and its implementing decrees - before the adoption of a national policy, but have also been recast according to the requirements of the Directive in a systematic manner. Some of the important principles from the national policy – which are relevant for the DGR implementation programme – are highlighted below:

- During the use of atomic energy, safety has priority over any other aspects.
- The Hungarian state shall assume ultimate responsibility for the management of spent fuel and radioactive waste generated in Hungary (with some special exemptions for spent sealed radiation sources and research reactor spent nuclear fuel).
- The primary responsibility for safety rests with the license holder of the facility or activity.
- During the use of atomic energy, the safe final disposal of the generated radioactive wastes and spent nuclear fuel shall be provided in line with the latest justified scientific results and the international recommendations and experience in such a way that no undue burden is transferred to future generations.

According to the national policy, the final decision concerning the back-end of the fuel cycle of power reactors is not yet necessary to be made, but it is important to state that the country must address the management of high-level radioactive waste regardless of the chosen back-end option. The most suitable and most widely accepted solution to this is final disposal in a deep geological disposal facility. The policy concerning the back-end of the fuel cycle follows the "do and see" principle, meaning that an open fuel cycle i.e. direct, domestic disposal of spent fuel originating from nuclear power plants has been determined as the reference scenario, which provides the basis of the relevant cost estimates concerning the currently operating four units. Domestic and international developments concerning the back-end of the fuel cycle must be followed ("see") and, if necessary, must be incorporated into the policy of the back-end of the fuel cycle, while at the same time progress must be made on the site selection of the domestic deep geological disposal facility ("do"). [5]

2.2. National framework

The Hungarian Atomic Energy Authority (HAEA) was established in Hungary, as an independent regulatory body, responsible for the supervision and licensing of nuclear facilities and radioactive waste repositories, from nuclear safety, radiation protection and physical protection point of view.

In accordance with the Atomic Act, the Hungarian government appoints an organization to carry out the tasks related to:

- the preparation of the national policy and national programme,
- the final disposal of radioactive waste,
- the interim storage of spent fuel and the back-end of the nuclear fuel cycle,
- the decommissioning of nuclear facilities.

In 1998, the legal predecessor of Public Limited Company for Radioactive Waste Management (PURAM) – the waste management organization of Hungary – was established to cover the above mentioned tasks and responsibilities.

On the basis of the Atomic Act, a segregated state financial fund, the Central Nuclear Financial Fund (Fund) was created in 1998. This provides funding for the management of radioactive waste and spent fuel, and for the tasks related to the decommissioning of nuclear facilities. The costs of managing spent fuel and radioactive waste are to be borne by those who produced these materials – through making payments into the Fund.

2.3. Main milestones of DGR implementation

The national programme of Hungary for spent nuclear fuel and radioactive waste management was adopted by the Hungarian government. At the level of the national programme, the coherence and interrelations between the management of the different waste streams were taken into account, and the main milestones of DGR implementation were set.

After consecutive phases of surface-based investigations (Fig. 2), the site is selected and an underground research laboratory is planned to be constructed from 2032 at that site. During the operation of the URL, the in-situ underground investigation, site confirmation activities will take place in the first period, while in the second period, the focus will move to the demonstration programs with the aim of preparing the construction and operation. The start of the construction of the DGR is scheduled for 2055 and the operation for 2064.

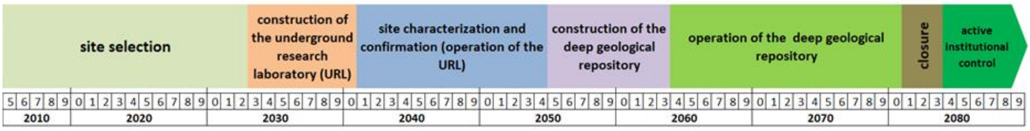

FIG. 2. Time schedule of the Hungarian DGR implementation programme.

The first conceptual plan [6] describing the disposal system of the DGR was developed in 2005. This plan contained the first cost calculations of the whole programme. In 2008, the technical and financial update of the long-term investigation programme of the Boda Claystone Formation [7] was compiled. In principle the time schedule of the implementation programme for the DGR and the cost estimate are based on this document. The long-term investigation programme was reviewed by the Swiss NAGRA, who had given useful comments on the document.

At this early stage of site selection, it is necessary also for countries with longer implementation timescale to develop a long-term implementation programme and a connected R&D plan, in order to have an idea about the technical content and the cost implications of the project. This is important, because on the basis of the cost calculations enough money has to be collected in the fund during the operation of the NPPs. In the Hungarian cost profile, the deep geological disposal project is the most expensive element, so the technical content of the programme has to be justified, and the cost estimates have to be defendable.

Due to the very long timescale of the implementation of deep geological disposal programme, maintaining the core competences within a waste management organization and keeping educated, skilled and experienced workforce for decades could be a challenge mainly for countries with longer implementation timescale. Participation in international R&D projects could be a good instrument to attract young people into the radioactive waste management business and this approach could be justified in those cases as well, when the results of a given R&D task will be used much later in the national programme of the interested country.

3. Development of a R&D framework programme

3.1. Introduction

In Hungary, the preparations for the disposal of spent nuclear fuel and HLW started in 1993. In 1994, an exploration tunnel was excavated in the Mecsek Uranium Mine, reaching the Boda Claystone Formation (BCF), and on-site underground data acquisition began at a depth of ~1050 m. The formation was explored underground by a tunnel extending into the claystone ~500 m. The tunnel was utilized as an Underground Research Laboratory (URL), and a large amount of on-site underground data was collected. During this programme, the Hungarian partners received technical assistance from the experts of the Canadian AECL company. In 1998, the mine was flooded, and the opportunity to perform underground investigations was terminated.

From 2000, based on desktop studies, a nationwide screening was carried out by evaluating the potential host rock formations in detail. Thirty-two lithological formations potentially suitable for a deep geological repository, within the territory of Hungary, were identified (Fig. 3). This comprehensive investigation in 2003 confirmed that the BCF has the highest potential among the suitable host rocks for hosting a DGR.

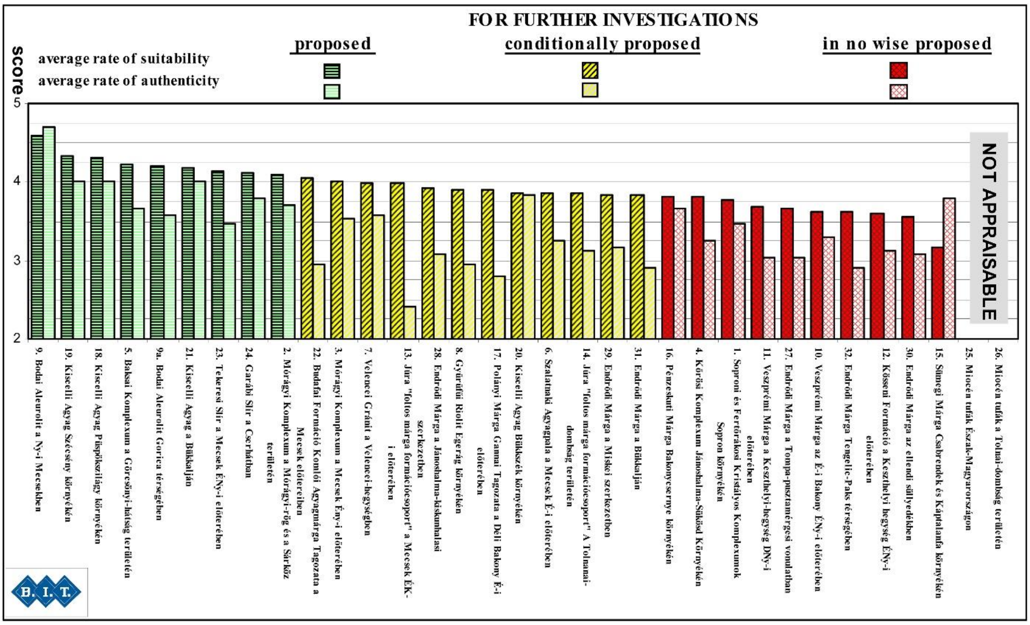

FIG. 3. Ranking of the formations in Hungary during the screening 2000-2003.

Between 2004 and 2017, there were two new starts for the investigations of the BCF, but both programmes were interrupted. This was a typical challenge of a small nuclear country: due to the lack of enough resources it was difficult to run three big programmes (continuous extension of the interim storage facility for spent fuel, construction of an underground repository for l/ILW and site selection activities for a DGR) in parallel.

In 2018, PURAM drafted a new site investigation framework programme for the BCF, based on the recently extended governmental decree, which now contains the requirements for the site selection phase. Both the modified regulation and the new framework programme seriously take into account the recommendations of the PLANDIS Guide [4].

In the development of the site investigation framework programme, PURAM could effectively use the methodological advices of the French waste management organization, ANDRA, which were transferred in the frame of a cooperation agreement between the companies. The cooperation agreement focused on project development planning and functional analyses. It should be emphasized, that it was important for the colleagues of PURAM to understand the methodology, the rationale behind that and implement it within the Hungarian boundary conditions. The experts of ANDRA also promoted this kind of adaptation (instead of copying) and mentoring programme, which provided a real added value for PURAM from a country with longer implementation timescale.

3.2. Structure of the site investigation framework programme

The long-term safety of the disposal facility relies on multiple barriers (and multiple safety functions). In case of a deep geological repository, the host formation and the geological barrier play an extremely important role in meeting the post-closure safety targets. Accordingly, the site investigation framework programme has an independent annex for geological investigations. In the main text, meeting the regulatory requirements, the R&D activities are structured in the following areas:

- waste inventory - amount, activity content, physical-chemical form,
- waste package (waste form and package) - geometry, properties, long-term behaviour, compatibility with other elements of the disposal system,
- engineered barrier system (buffer, backfill, seals and plugs) - geometry, properties, long-term behaviour, compatibility with other elements of the disposal system,
- geological and natural environment of the facility – properties and long-term evolution of the geological barrier, external natural hazards relevant for the safety of the facility (this area is elaborated in detail in the geological investigation programme, which is an independent annex of the framework programme),
- preliminary design and layout of the surface and underground part of the facility
- operation of the facility, transport and transfer of waste packages, ensuring retrievability / reversibility,
- methods for R&D investigations, models, evaluation,
- data management, and long-term information preservation.

3.3. Phases of the site investigation framework programme

The phases (Table 1) of the R&D activities for the surface-based investigation period (with site selection and preparations for the construction of the underground research laboratory) were defined based on the targets of the geological investigation program.

Table 1. Main goals and durations of the surface-based investigation phases

Surface-based investigation		
investigation phase I	**investigation phase II**	**investigation phase II**
2019-2023	2024-2029	2030-2032
general data acquisition in order to rank candidate areas	Site selection and characterization of chosen site	preparations of the URL

For each phase, a detailed site investigation plan has to be prepared by PURAM and has to be submitted for licensing to the regulatory body (HAEA). At the end of each phase, a final investigation report and on the basis of that a preliminary safety case has to be compiled, and the site investigation framework programme has to be reviewed and updated, if necessary, for the next phase(s). In this preliminary stage of the Hungarian Programme, the safety case is dominantly used (i) to help in understanding the main processes and how the elements of the systems could fulfil their safety functions; (ii) to identify the uncertainties and knowledge gaps, and (iii) through sensitivity analyses to prioritize the R&D needs.

3.4. Investigation area

An investigation area (86.7 km^2) was identified for the site investigation framework programme in such a way that this contains all relevant field investigation locations within its boundary (Fig. 4, green line). The surface projection of the potential disposal zone (32.6 km^2) – the area, where the Boda Claystone Formation can be found at the depth between 500 m and 1000 m – is also shown on this map (Fig. 4, brown line).

The investigation area is important from the public participation point of view as well. In the licensing procedure for the site investigation framework programme and site investigation plan, a public hearing is organized by the HAEA. All interested people can participate and those who own a property within the investigation area have a 'client right' in the licensing process.

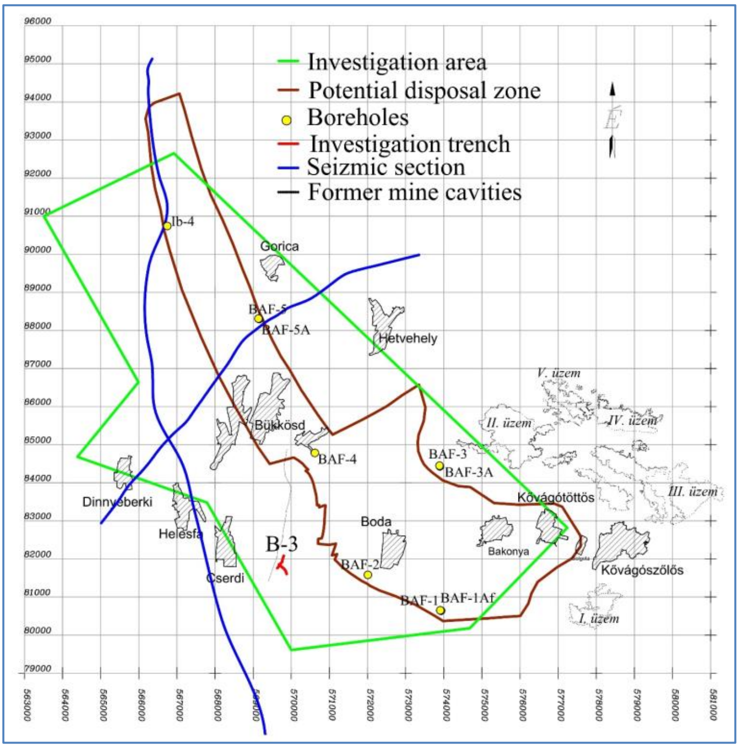

FIG. 4. Investigation area and potential disposal zone.

3.5. Goals of the investigation phases

The general aim of the investigation phase I is data acquisition for site characterization and ranking the candidate areas for phase II. Four special goals were identified for phase I:

- understanding of the geological environment in such detail, that the ranking of the candidate areas can be made;
- evaluation of unfavourable site properties and exclusion criteria and screening out of those;
- detailed investigation of the host formation;
- data acquisition for the preliminary safety case.

Phase II of the investigations will focus on a reduced 10 km^2 area. The general aim of investigation phase II is data acquisition for designating the location of the underground research laboratory. Special goals of investigation phase II are:

- designation and surface-based characterization of the site, confirmation of geological suitability;
- designation of the location of the surface and underground facilities and the underground research laboratory;
- data acquisition for the conceptual design of the facility;
- data acquisition for the preliminary safety case.

The general aim of investigation phase III is data acquisition and the preparation of the underground research laboratory and for the site licence application. Special goals of investigation phase III are:

- characterization of the geological environment of the previously designated location for the surface and underground parts of the facility in such details, that the site licence application could be compiled;
- preparation of the underground research laboratory and planning the investigation program to be conducted in it;
- evaluation of the reference state of the site for the environmental impact assessment;
- data acquisition for the safety case, substantiating the site licence application.

The field investigations of phase III are focused on a few km^2 area of the site.

During the three above mentioned phases, in parallel with the geoscientific investigations, the relevant R&D activities have to be carried out for the different elements of the disposal system: waste inventory, waste form, packaging, engineered barrier system (buffer, backfill, seals and plugs). The preliminary conceptual design of the underground and surface facilities has to be developed.

At the end of investigation phase III., an environmental protection licensing procedure (based on an environmental impact assessment) is considered for the construction and operation of the URL. From nuclear safety point of view, the site licensing procedure will be conducted. In the frame of this licensing step, mainly based on the safety case, the feasibility of the disposal concept is demonstrated.

The decision in principle of the Hungarian Parliament – which is a requirement based on the Atomic Act – will be asked after the site licence is granted.

4. Summary

The execution of the implementation programme for a deep geological repository contains some challenges for countries with longer implementation timescale. There are a lot of preconditions for the success of implementation, like:

- high quality scientific and technical work
- sound political commitment and support;
- adequate funding and financing scheme;
- acceptance of the stakeholders (local people, general society);
- enough educated, skilled and experienced workforce with the necessary competencies covering several disciplines.

Nevertheless, for a country in the early stage of its programme, it is important to develop a long-term implementation programme, in which the milestones are set and clear decision points are defined. The technical content of the programme has to be justified, and the cost estimates have to be defendable. International benchmarking and validation can increase the credibility of the programme, which helps to gain acceptance of the stakeholders (public, regulatory body, politics, waste producers). International good practices can be adapted and incorporated within the given country's boundary conditions. At an early stage of the programme, lessons learned by advanced countries, the rationale (pro's and con's) behind strategical decisions (e.g. the URL is a part of the future DGR or not) and methodological recommendations have a real added value.

Participation in international RD&D programmes (e.g.: European Commission cofounded programmes, like EURAD) on the one hand can support the knowledge transfer from advanced countries to the countries with longer implementation timescale, on the other hand, it is a good instrument to attract young people into the radioactive waste management business, which is necessary to providing educated, skilled and experienced workforce for decades.

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MARIE GARCIA

EUROPEAN JOINT PROGRAMME ON RADIOACTIVE WASTE MANAGEMENT

M. GARCIA[1], T. BEATTIE[2], S. SCHUMACHER[1]

[1]R&D Department, ANDRA, 1-7 rue Jean Monnet 92298 Chatenay-Malabry, France
[2]MCM Environmental Services Ltd, 1 Little King Street, Bristol, BS1 4HW, UK

Abstract. For more than 40 years, considerable scientific and technical knowledge has been acquired in Europe in the field of radioactive waste management, both for near-surface disposal and geological disposal. RD&D will continue to be necessary to develop, maintain and consolidate knowledge throughout the stepwise development, operation and closure of disposal facilities, which will be spread over many decades and make this knowledge available to all end users. Recently, the EC has promoted a step-change in pan-European research cooperation between EU Member States' national programmes by promoting the setting-up of inclusive research joint programmes in Europe gathering those organisations with scientific and technical responsibilities and a national mandate for research in radioactive waste management. Based on the positive achievement of the JOPRAD project (2015-2017), the EC confirmed in 2017 its willingness to co-fund such a Joint Programme in the field of RWM. The RWM community therefore pursued the efforts to establish the Founding Documents (Vision, Strategic Research Agenda, Roadmap, Deployment) and a Work Plan for a first implementation phase of 5-years (2019-2024). In June 2019 the Joint Programme – EURAD – was accepted by the European Commission.

1. Introduction - Successful RD&D collaboration across Europe

For more than 40 years, considerable scientific and technical (S/T) knowledge has been acquired in Europe in the field of radioactive waste management (RWM), in particular for deep geological disposal. This has supported countries to progress towards licensing of geological disposal facilities (e.g. Finland, Sweden and France) and contributed to the progress of numerous Member States' disposal programmes. RD&D efforts in radioactive waste management, including disposal, will continue to be necessary to:

- develop, maintain and consolidate S/T knowledge throughout the stepwise development, operation and closure of disposal facilities, which will be spread over many decades and make this knowledge available to all end users;
- ensure optimisation of waste management routes and of disposal solutions;
- address evolving regulatory concerns;
- bridge the risk of shortage of the skilled, multidisciplinary human resources needed to develop, assess, license and operate facilities for RWM ; and
- help in gaining and maintaining public confidence.

The European Commission (EC) has supported the acquisition of knowledge at the European level by supporting collaborative RD&D projects through the EURATOM programme on RWM and has also enhanced coordination and networking activities by supporting the establishment of the IGD-TP platform - a network for European Waste Management Organisations and the SITEX Network for the regulatory expertise function undertaken by regulatory authorities, regulators, and their technical support organisations, which are both now independently funded.

Recently, the EC has promoted a step-change in pan-European research cooperation between EU Member States' national programmes by promoting the setting-up of inclusive research joint programmes in Europe, attracting and pooling a critical mass of national resources on specific objectives and challenges. The objective for the EC is therefore to promote and co-fund ambitious programmes rather than individual projects, bringing together those legal entities from EU Member-States and associated countries able to direct national funding and/or manage a national research and innovation programme.

2. A feasibility study towards a Joint Programme on RWM – JOPRAD project

The EURATOM JOPRAD project was launched in June 2015 with the objective to assess if the RWM community could be meaningfully integrated in such a Joint Programme, and if so, to prepare its establishment. By identifying those with key responsibility for directing RD&D in the field of RWM, and engaging them in the process of developing a shared Vision and identifying the S/T basis for shared research agenda, JOPRAD has demonstrated the feasibility and the added-value of creating such a Joint Programme in the field of RWM.

2.1. Identifying the categories of organisations

Across Europe, the organisation for how RD&D is managed and completed, in support of the safe management of radioactive waste, varies widely. At the highest level, most Member States have programme owners such as a ministry, national/regional authority or private organisation in charge of setting-up and managing a national programme. This is often followed by varying levels of 'programme managers', who have a formal mandate and delegated responsibility for technical RD&D activities associated with the national programme.

The JOPRAD project identified three distinct categories of organisations, from across 28 EU Member States, Switzerland and Ukraine, with S/T responsibilities and a national mandate for research in RWM, and that are willing to share a Strategic Research Agenda (SRA) for European collaborative RD&D:

- **Waste Management Organisations (WMOs)** having the ultimate responsibility for the implementation of geological disposal (which includes the management of a supporting RD&D programme), and for some other topics of RWM (e.g. waste characterisation, treatment and packaging, interim storage, etc.). WMOs from across Europe form a core part of the Joint Programme and provide a driving force for what is needed for successful and practical implementation from an industrial perspective. WMOs have established a network and coordination framework for RD&D needs of the implementers of geological disposal at the European level via the Implementing Geological Disposal Technology Platform (IGD-TP);
- **Technical Support Organisations (TSOs)** carrying out activities aimed at providing the technical and scientific basis for supporting the work and decisions made by a national regulatory body. As safety cases for waste

processing, storage and disposal develop, so too do the safety case reviews and independent scrutiny responsibility by regulatory organisations in the framework of the decision-making process. This requires specific skills (such as safety case review methodology) from the regulatory expertise function undertaken by safety authorities, regulators, and their TSOs. Several TSOs, together with other organisations fulfilling a regulatory expertise function and Civil Society Organisations have established the SITEX network to support independent technical expertise in the field of safety of geological disposal of radioactive waste; and

- **Research Entities (REs)** working to different degrees on the challenges of RWM including disposal (and sometime in direct support to implementers or WMOs or TSOs), under the responsibility of Member States. This includes national research centres, some research organisations and some universities that could also be funded by other sources. RE's provide scientific excellence and leading-edge research on basic components and generic processes in relation to the management of radioactive waste, and therefore represent an important proportion of the contributions to the Joint Programme.

Furthermore, the following organisations were identified as key interest groups of cooperative research in the field of RWM:

- **Civil Society Organisations (CSOs)** having an interest in RWM.This includes local organisations (associations, local committees of information, local partnerships), national or European civil society organisations willing to take part in interactions with the nationally mandated actors in EURAD;
- **Waste Producers** and those with a pre-disposal waste management responsibility are engaged via the Nuclear Generation II & III Association (NUGENIA);
- **International Organisations** such as the International Atomic Energy Association (IAEA) and the Organisation for Economic Co-operation and Development – Nuclear Energy Agency (OECD-NEA).

2.2. Identifying the S/T basis for a Joint Programme

Each of these three categories of actors (WMOs, TSOs, REs) then identified S/T activities suggested as suitable for inclusion within a potential future Joint Programme and within the different activities considered, they indicated their preferences and priorities based on their own perceived needs.

The following step-wise process was then used to further define and prioritise the S/T domains of common interest of the different categories of actors:

1. Compiling Activities for Inclusion: Drafting a first compilation of combined activities suggested as suitable for inclusion within a potential future Joint Programme. A key part of this step was to organise and coalesce suggested activities (identified from WMO-, TSO- and RE-specific SRAs) into a suitable structure, considering the different types of activities suggested and the adoption of a common terminology and appropriate scope definition for a potential future Joint Programme. Once the first compilation was prepared, it was recognised that this did not represent an

exhaustive list of all the potential activities that could enter into the scope of a potential future Joint Programme. It simply indicated activities for which a sufficient level of common interest has been expressed among the JOPRAD contributors.

2. Surveying Representative Joint Programme Participant Views: Eliciting JOPRAD participants' opinions on their preferences and motivations for prioritising activities. This was completed by issuing a comprehensive questionnaire of suggested activities, allowing JOPRAD participants to comment and express views on activities suggested by all the represented groups for the first time;
3. Identifying Priorities and Activities of High Common Interest between WMOs, TSOs and REs: Analysing the questionnaire responses to identify the themes with high common interest, and the adoption of screening criteria used to prioritise what should be included in the Joint Programme. This step included development of a methodology to cross-check that all prioritised activities met with the established boundary conditions for the Joint Programme (See section 2.3) ;
4. 1st Draft SRA: Drafting a first compilation of the Joint Programme S/T scope with a clear description of prioritised RD&D activities agreed and supported by all JOPRAD participants;
5. SRA Consultation and Finalisation: Consultation of the draft S/T scope within the broader European RWM community. Obtaining feedback and end-user input to facilitate updating of the final Programme Document.

2.3. Defining the governing principles for a Joint Programme

The JOPRAD project has defined the following principles that shall be respected for joint programming.

Positive Participation – Contributors will work positively towards achievement of the Vision. All contributions will be valued. Work will be carried out considerately and respectfully by all, maintaining relationships that respect diversity, different roles and boundaries, and respect the knowledge, insight, experience and expertise of others.

Maintenance of Independence – It is possible for different organisations with different roles in their national programme to work together, without prejudice in relation to their own role in the national implementation process. Most important is the independence between the "expertise function" (fulfilled by TSOs and by some Research Entities) and the "implementer function" (fulfilled by WMOs). Different parties (WMOs and TSOs in particular) can have common agreement of what RD&D should be done and how, and Research Entities may furthermore have a long-term vision of general research needs. All can collaborate in doing the basic research; however, maintaining their independence in developing their own views on the interpretation of the generated research results and data is essential.

Transparent Governance – A transparent, balanced and efficient mode of governance is maintained, taking into account the role and independence of the Joint Programme participants with a national mandate for research in RWM.

Scientific Excellence – RD&D activities shall focus on achieving passive safety (safety of a disposal facility is provided for by means of passive features inherent in the characteristics of the site and the facility and the characteristics of the engineered barriers, together with certain institutional controls, particularly for surface facilities) and reducing uncertainties through excellence in science.

Balanced Programme – Recognising that different Member States have a wide variance in the status of their National Programme, the scope should support programmes at all stages of advancement;

Added Value – Ensuring that the Joint Programming provides real added value (e.g. enhanced coordination and improved information and knowledge transfer between national programs, improved financial arrangements, improved stakeholder understanding and acceptance of outputs, more robust RD&D outputs, etc.). Administration costs should represent a small proportion (including ongoing legal, EC admin., etc.) in comparison to the money spent on the technical and scientific scope;

Inclusiveness – Ensuring that the different categories of actors and groups of interest are involved in the definition and implementation of the Joint Programme;

Equitable Financing – Financial costs (financial/in-kind) should be equitable; participants should contribute what they can afford, or what they consider matches their interest in a project;

Complementary Participation – Participation in Joint Programme is complementary to RD&D activities which will continue to be undertaken nationally or jointly outside of the auspices of the Joint Programme where required; and

Tangible Results – The scope is appropriately prioritised and focused on the objective to achieve tangible results within a reasonable timeframe. A key aspect is that participants recognise that the Joint Programme is a distinct change from past work (and other collaborative working) on radioactive waste management. Translating the scientific, technical and societal challenge of RWM (including disposal) into operational reality requires the generation of new knowledge, combined with the consolidation, maintenance and transfer of existing knowledge.

3. Establishing the European Joint Programme on Radioactive Waste Management - EURAD

Based on the good progress and the positive achievements of JOPRAD, the EC confirmed in 2017 its willingness to co-fund such a Joint Programme in RWM with a dedicated topic included in the EURATOM WP2018 (indicative EC available budget for 5 years: 32.5M€). The RWM community composed of 52 organisations mandated by their Programme Owner (19 WMOs, 13 TSOs and 20 REs) and more than 100 associated research organisations from 23 countries pursued the efforts to establish a Joint Programme in order to be able to submit in September 2018 to the EC its Founding Documents (Vision, Strategic Research Agenda, Roadmap, Deployment mechanisms) and a Work Plan for a first implementation phase of 5-years.

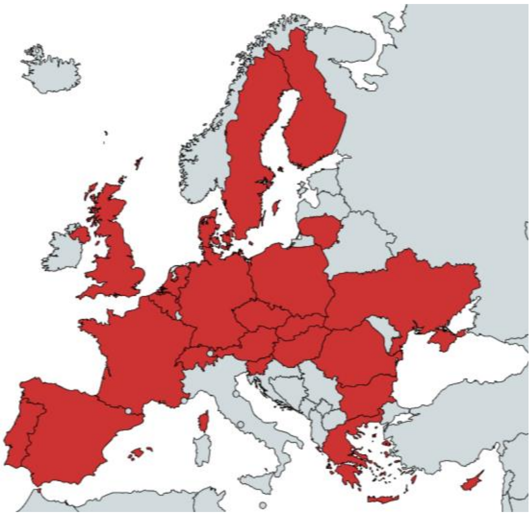


FIG. 1. Representation of countries involved in the joint programming.

3.1. Vision

A step change in European collaboration towards safe 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 Joint Programme participants.

By step-change we mean a new era via a more effective and efficient public RD&D funding in Europe, and a deepening of research-cooperation between Member States. The aim is to implement a joint Strategic Programme of research and knowledge management activities at the European level, bringing together and complementing EU Member State programmes in order to ensure cutting-edge knowledge creation and preservation in view of delivering safe, sustainable and publicly acceptable solutions for the management of radioactive waste across Europe now and in the future.

The Joint Programme shall support the implementation of the Waste Directive in EU Member-States, taking into account the various stages of advancement of national programmes. National RWM programmes across Europe cover a broad spectrum of stages of development and level of advancement, particularly with respect to their plans and national policy towards implementing geological disposal. Programmes differ significantly depending on the national waste inventory, with some member states only responsible for relatively small volumes of medical and research reactor wastes, compared to others that have comparatively large and /or complex waste inventories from large nuclear power (and fuel reprocessing) and defence programmes. Programmes also differ significantly in the way in which they are managed, particularly with respect to the national policy and socio-political landscape with respect to longer-term storage and geological disposal.

Across Europe, the terms 'Advanced Stage Programme', 'Early Stage Programme' (or programmes with longer time scales) and 'Small Inventory Programme' are typically adopted. Regardless of size and stage of implementation, all Member-States are responsible for the safe management of radioactive waste and are required to report periodically on the status of their national programme.

The EURAD therefore gathers Members-States:

- with no nuclear power programme operating, but with research, training or demonstration reactors, and/or other sources of radioactive waste;
- with a nuclear programme;
- with different amounts of radioactive waste to manage;
- at different stages of advancement in the implementation of their national RWM programme; and
- with plans for geological disposal for Spent Fuel, High-level Waste and long-lived intermediate level waste, with different host rocks and different disposal concepts and at different stages of implementation.

3.2. Strategic Research Agenda and Roadmap

The EURAD Strategic Research Agenda (SRA) provides a description of S/T Themes and Sub-Themes of common interest between the participants. These needs are grouped into a number of scientific themes and based upon the scope established by the JOPRAD project. The SRA is structured by seven Scientific Themes, as illustrated in Fig. 1 and should allow to capture all areas relevant for the implementation of waste management solutions. Although all technical in nature, Theme 1 is an overarching theme, Themes 2-5 are predominantly focussed on fundamental science, engineering, and technology, and Themes 6 and 7 include aspects more of an applied science and integration focus.

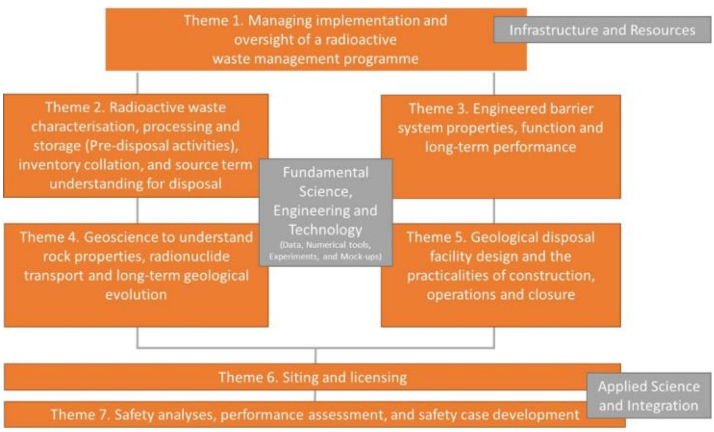


FIG. 2. Scientific Themes of the EURAD SRA.

The S/T scope in the SRA covers cutting-edge S/T activities on RWM from cradle to grave, including predisposal, interim storage and disposal solutions - mainly geological disposal of spent fuel, high level waste and intermediate level waste[1]. The EURAD SRA has been set up as a dynamic and living document that shall be updated periodically in order to integrate outcomes of RD&D activities as well as any emerging collaboration needs identified by the RWM community during the implementation phases of the Joint Programme.

Theme 1: Managing implementation and oversight of a RWM programme

Implementation of a national RWM programme, including geological disposal, requires a national policy reflected in the legal framework, a long-term vision based a sound scientific-technical foundation, appropriate regulatory oversight, funding, organisational infrastructure and sound management systems and processes and formally organized exchange among stakeholders. For programmes in the early phase of establishing national policy or developing a waste management programme, support by international entities (IAEA, NEA) is available and EU-wide good practice and lessons learned can be used to facilitate implementation of suitable organisational structures and strategic decision making.

Theme 2: Radioactive waste characterisation, processing and storage (pre-disposal activities), and source term understanding for disposal.

This involves characterizing and documentation of the various waste types (requiring activation calculations, evaluation of contamination carry-over, development of waste treatment and packing technology, etc.), evolution of waste matrix properties during extended interim storage, developing waste acceptance criteria and developing model predictions about future waste. This also includes development of sufficient interim storage capacity. Source term and radionuclide release mechanisms need to be assessed for different waste forms/waste packages considering the interaction of the various interfaces with the disposal environment. In this broad area of work much information is already available or can be acquired through co-operation. The remaining issues are often site and design specific.

Theme 3: Engineered barrier system properties, functions and long-term performance.

Engineered barriers (overpack, buffer, backfill, seals, etc.) are in a broad sense comparable in many programmes and much basic information is already available today as there have been many European and international projects to-date. Existing needs can be further developed through continued co-operation, which

[1] Specific RD&D required for near-surface or surface disposal and low-level waste (LLW), will be addressed, and is encompassed within the RD&D needs identified for waste characterisation and processing, interim storage and geological disposal of radioactive waste. Nuclear facility dismantling and decommissioning activities are however excluded, although interfaces, and particularly aspects that impact final disposal will be considered.

includes the provision of utilising available Underground Research Laboratories (URL) to conduct large-scale demonstration and verification testing. However, at a National Programme level some specific development work is often necessary to improve the understanding of the system of engineered barriers, optimise it or adapt it to the specific situation at hand. Remaining research issues concern in particular cementitious and to a lesser degree clay-based materials.

Theme 4: Geoscience to understand rock properties, radionuclide transport and long-term geological evolution.

Geoscience focusses on host rocks representative for a broad range of geologies also to better understand long-term geological evolution (and stability), and on the detailed understanding of the relevant properties and behaviour of different types of host rocks. This includes the transport properties of radionuclides and fluids, redox phenomena, coupled phenomena to address facility-induced disturbances, and the impact of gases. This also includes the demonstration and verification that the important coupled geomechanical, thermal, hydrological and chemical phenomena are sufficiently well understood to allow for long term assessment of void space closure, fluid movement and behaviour of the material interfaces, in some cases through full scale experiments in an URL. The broad area of geoscience will require significant activities that are specific to each country (especially regional geology but also the details of specific rocks), but with respect to the properties of rocks, much can be learned from other programmes working on similar rocks and may involve co-operative projects in URLs.

Theme 5: Facility design and the practicalities of construction, operation and closure.

Facility design (covering early conceptual design during early programme phases, right through to detailed design for construction, operation and closure). In the area of geomechanics and excavation, much can be learned from the tunnelling and mining industries and the corresponding science and technology developments. The current focus is on the demonstration of waste and engineered barrier emplacement techniques, and to perform demonstration tests under real 1:1 scale and active conditions. URLs and/or rock characterisation facility experiments, incl. monitoring activities often focus on demonstrating that technical aspects of facility construction and operation are suited for their purpose.

Theme 6: Siting and licensing.

The selection of a site (or sites) and licensing of a geological disposal facility is clearly the most important challenge of the successful implementation of long-term management of radioactive wastes. Site characterisation (exploration of geometrical aspects such as rock layers and structures, and characterisation of key rock properties), acquiring site property parameters through the use of geophysical techniques, hydraulic and geochemical measurements in boreholes and seismic investigations will contribute to the selection of the site. As part of the full development of the selected site, underground testing will be required to allow detailed in-situ confirmation (and/or refinement) of some of the critical data on rock properties and state parameters before and during the construction of the repository. Site selection policies and procedures, regulatory arrangements and licensing requirements vary between member states, reflecting inter alia the socio-political context, geological factors, and the waste inventory. In this broad area of work a large part is of national focus but much can be learned from science and technology e.g. developed for hydrocarbon exploration, and also the wealth of information available from RWM programmes and from previously existing URLs should be considered. For URL-experiments, significant technology developments have been made (testing tools, sensors, etc.) that are essential for underground testing at repository sites. This area is very much suited for co-operation.

Theme 7: Performance assessment, safety analyses and safety case development.

For safety analyses (methodology, numerical tools, compiling all the information and data, drawing the conclusions), a wealth of information is already available. The development of the safety case and the task of integrating all the necessary information will always be specific to the system evaluated and thus, in this area, each country must develop its own capabilities. Nevertheless, information exchange and interaction with experienced experts is considered useful and includes e.g. the exchange on the treatment of uncertainties and development of arguments for confidence building.

There is a need to recognise the need for independence between those supporting and managing safety case development and those supporting or managing the regulatory review and scrutiny of a safety case, this applies to all the SRA Themes, but is especially relevant to Theme 7.

The EURAD SRA has been set up as a dynamic and living document that shall be updated periodically in order to integrate outcomes of RD&D activities as well as any emerging collaboration needs identified by the RWM community during the implementation phases of the Joint Programme.

3.3. Roadmap

The SRA is further complemented by a Roadmap with clear objectives, linking the SRA Themes and Sub-themes to milestones typical for the different phases of a RWM programme as drawn from the IAEA work - *Site evaluation and site selection; Site characterisation; Facility construction; Facility operation and closure; Post-closure* – to which a phase on Policy, framework and programme establishment has been added to recognise the needs of Members-States who are in the process of establishing a waste management programme.

The Roadmap covers the full scope of the Joint Programme and shows the relevance of the different themes for waste management and disposal programmes at different stages of maturity. The Roadmap effectively provides a framework upon which to organise the scientific priorities of the SRA, enabling users and programmes to ‘click-in’, and to access existing information and knowledge and active work or future plans. For each of the phases, the Joint Programme Roadmap explains how e.g. the aspects related to disposal facility design and safety case development (and supporting safety analyses) span across all phases. The Roadmap elaborates further on the how the emphasis of work on each of the themes differs and changes through successive Phases.

The Roadmap also provides a framework for future periodic assessment of the Joint Programme, and to evaluate future priorities as new knowledge is acquired or as new needs are identified, and to communicate completed, ongoing and future work activities to those interested in our work.

3.4. Deployment Activities

The following types of activities will be established within the Joint Programme:

RD&D activities - The main activities of EURAD will consist of RD&D activities aiming at developing and consolidating S/T knowledge of the EURAD Strategic research Agenda and Roadmap. There shall be a balance between operational RD&D in direct link with implementation of repository concepts as well as safety concerns and prospective RD&D such as short and long-term experiments and/or modelling work to demonstrate the robustness of the waste management concepts, to increase understanding and predictability of the impact of fundamental processes and their couplings or to maintain scientific excellence and competences throughout the stepwise long-term management of radioactive waste.

Strategic Studies - Complementary to RD&D activities and in support of the implementation of the Member States' national programmes, Strategic Studies shall give the opportunity to participants and expert contributors to network on methodological and strategic challenging issues that are common to various national programmes and in close link with scientific, technical and issues.

Knowledge management - Beyond RD&D and Strategic Studies, ambitious activities of EURAD are to consolidate efforts across Member-States on Knowledge Management – this includes access to existing Knowledge (State-of-Knowledge), guiding the planning and implementation of a RD&D plan of national RWM programme, and developing/ delivering training/mobility in line with core competencies.

Interaction with Civil Society - The successful implementation of RWM programmes relies on both S/T aspects for a sound safety strategy and scientific and engineering excellence and societal aspects. EURAD shall allow interactions between WMOs, TSOs and REs, and Civil Society Organisations (CSOs) in order to facilitate the translation of S/T results to allow effective interactions with CS and by extension to the public and create the conditions for CSOs to express their expectations and perspectives. Such interactions shall improve the mutual understanding of how and to what extent RD&D on RWM makes sense and contributes to improving decisions. It shall also contribute to developing ideas, propositions and methodologies on how to interact with Civil Society on S/T results, how to deal with uncertainties, and on how to promote mutual benefit of the available knowledge, based on cooperation and sharing.

4. EURAD first implementation phase (2019-2024)

Building on the initial work of the JOPRAD project, taking into account ongoing projects at the EU level, the RWM community has co-developed an initial five-year deployment plan (2019-2024) as illustrated in Fig. 2.

EURAD 1 Work Packages (2019-2024)		Indicative Budget	EURAD Strategic Research Objectives	EURAD Beneficiaries		
		Total Cost (EC + Beneficiary Contributions)	How the Work Package will address objectives, priorities and activities of high common interest in the EURAD Strategic Research Agenda	WMOs	TSOs	REs
				◆ = Beneficiary Organisation; ◇ = Coordinating Beneficiary Organisation		
Programme Management Office		**7%**				
WP1	Administration, Scientific Coordination, Communication and Dissemination	€2.7 M		◆◆	◆	◆◆
Collaborative RD&D		**75%**				
WP2	Assessment of Chemical Evolution of ILW and HLW Disposal Cells (ACED)	€5.1 M	Multiscale approach and process integration to improve long-term modelling and assessments .	◆◆◆◆◆	◆◆◆◆◆	◇◆◆◆◆ ◆◆◆
WP3	Cement-Organics-Radionuclide-Interactions (CORI)	€4.7 M	Improved understanding of the role of 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)	€3.7 M	Improved understanding of the upscaling of THMC modelling for coupled hydro-mechanical-chemical processes in time and space.	◇◆◆◆	◆◆◆◆◆	◆◆◆◆◆ ◆◆◆
WP5	Fundamental Understanding of Radionuclide Retention (FUTURE)	€4.6 M	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)	€5.6 M	To increase understanding and predictability of gas migration in different host rocks.	◇◆◆◆◆ ◆◆	◆◆◆	◆◆◆◆◆ ◆◆◆◆
WP7	Influence of Temperature on Clay-based Material Behaviour (HITEC)	€5.3 M	Improved THM description of clay based materials at elevated temperatures.	◆◆◆◆◆ ◆◆◆◆◆	◆◆	◇◆◆◆◆◆
WP8	Spent Fuel Characterisation and Evolution Until Disposal (SFC)	€5.8 M	Reduce uncertainties in spent fuel properties in predisposal phase.	◇◆◆◆◆	◆◆◆◆◆	◆◆◆◆◆ ◆◆◆◆◆
Strategic Studies to Address Complex Issues and Expert Networking		**10%**				
WP9	Waste management routes in Europe from cradle to grave (ROUTES) *	€1.7 M	Waste Management Routes across Europe considering different waste types and their specified endpoints.	◆◆◆◆◆ ◆◆◆◆◆ ◆◆	◇◆◆◆◆ ◆◆◆◆◆ ◆◆◆	◆◆◆◆◆ ◆◆◆◆◆ ◆
WP10	Uncertainty Management multi-Actor Network (UMAN) *	€1.7 M	Further refinement of methods to make sensitivity and uncertainty analyses and the development of a multi-actor network for uncertainty management.	◆◆◆◆◆ ◆◆◆	◇◆◆◆◆ ◆◆◆◆◆ ◆	◆◆◆◆◆ ◆◆◆◆
Knowledge Management		**8%**				
WP11	KM State-of-Knowledge (SoK)	€1.4 M	To maintain information, knowledge and records over the long lead- and implementation-timelines of geological disposal programmes, from pre-licensing through to the post-operational phase.	◇◆	◆◆	◆◆
WP12	Guidance	€0.5 M	To identify RD&D and knowledge transfer needs in support of defining pre-licensing activities that can support success in the siting and licensing phase/process.	◇◆	◆◆◆	
WP13	Training & Mobility	€0.6 M	Training and competence maintenance of skills and expertise to support safe radioactive waste management including disposal.	◆◆	◆◆◆	◇◆

* Interactions with Civil Society

FIG. 3. EURAD first implementation phase (2019-2024).

5. Conclusion - how EURAD will complement the National Programmes

The Joint Programme is not intended to replace National Programmes, rather it complements the national efforts and enables effective use of resources by sharing RD&D efforts and by making existing knowledge easily available to end-users. Member-States' Programmes are organised and funded independently, and their participation in the Joint Programme is the responsibility, and at the sole discretion, of each national programme owner. By mandating organisations to participate, Member States demonstrate that EURAD has an EU-added value beyond their National Programme. Overall, the following impacts can be expected:

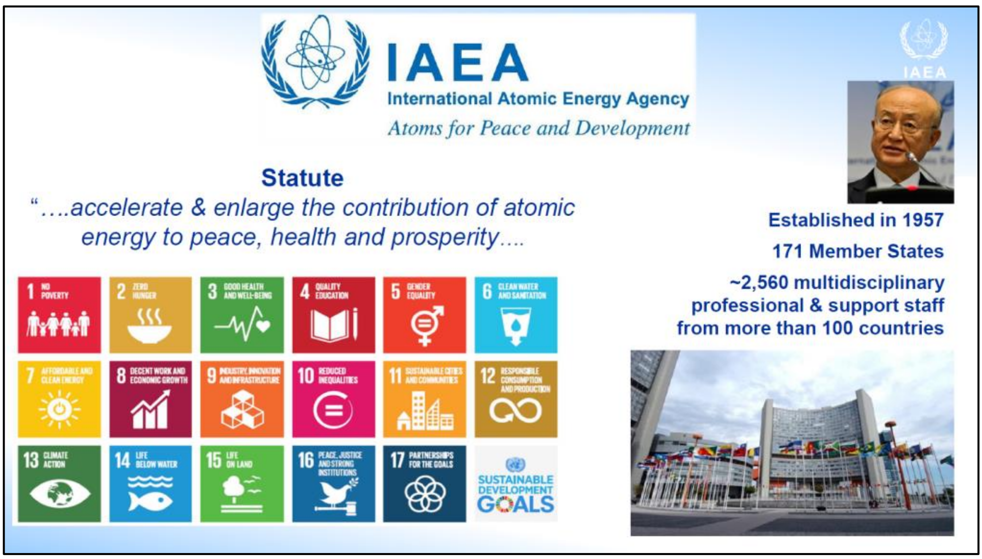
- **Support compliance with European regulations** – by supporting Member States in implementing RD&D, developing skills and providing for transparency in order to develop solutions for their radioactive waste (see, Waste Directive articles 8, 10 and 12.1(f));
- **Support passive safety of radioactive waste management solutions** – by contributing to the responsible and safe management of radioactive waste in Europe, including the safe start of operation of the first geological disposal facilities for high-level and long-lived radioactive waste / spent nuclear fuel as well as improvement, innovation and development of science and technology for the management and disposal of other radioactive waste categories;
- **Help to gain or maintain public confidence and awareness in RWM** – by fostering transparency, credibility and scientific excellence;
- **Support RWM innovation and optimisation** – by supporting the development of solutions for different waste streams and types and continuously improving and optimising waste management routes and disposal solutions, including identifying needs specific to small inventory programmes with their particular challenges with respect to access to critical mass of expertise and developing appropriate disposal options;
- **Contribute to addressing S/T challenges and evolving regulatory concerns** – by prioritising activities of high common interest, and creating conditions for cross fertilization, interaction and mutual understanding between different Joint Programme contributors and participants;
- **Enhance knowledge transfer to early stage programmes** – by providing an opportunity for less advanced programmes, and in particular those in an early stage of geological disposal programme implementation, to benefit from the cross-European integration in radioactive waste management activities;
- **Foster efficient use of the RD&D resources at the EU level** – by sharing and advancing existing knowledge, facilities and infrastructure rather than repeating and duplicating efforts; and
- **Foster a better transfer of knowledge across generations of experts** – by helping to bridge the risk of shortage of the skilled, multidisciplinary human resources and critical infrastructure needed to develop, assess, license and operate RWM facilities, in view of the long lead-times and the intergenerational operational time-spans.

STEFAN MAYER

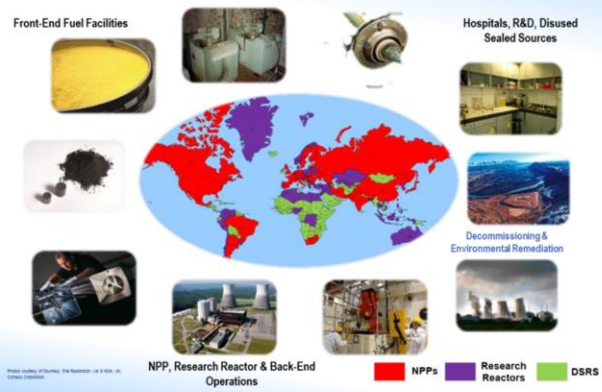
FISA 2019 – EURADWASTE '19

Presentation of Mr Stefan MAYER (IAEA, AT)

RADIOACTIVE WASTE MANAGEMENT: A NATIONAL RESPONSIBILITY AT A GLOBAL SCALE REQUIRING A LOCAL SOLUTION…AND SOME OTHER THINGS IAEA CAN DO TO HELP



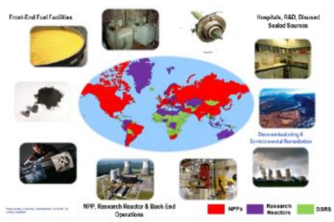
Radioactive Waste World-Wide



Radioactive Waste World-Wide

All MSs have radioactive waste arising from nuclear fuel cycle operations, nuclear power generation, research reactors, radiopharmaceutical production, and/or other uses of nuclear technologies in hospitals, for research, agriculture, industry etc… as well as from the associated decommissioning and environmental remediation needs.

Radioactive Waste World-Wide



All MSs have radioactive waste arising from nuclear fuel cycle operations, nuclear power generation, research reactors, radiopharmaceutical production, and/or other uses of nuclear technologies in hospitals, for research, agriculture, industry etc… as well as from the associated decommissioning and environmental remediation needs.

All countries are responsible to provide solutions for the safe, secure & safeguarded management of their national inventories. From generation to disposal.

Radioactive Waste & SF Inventory

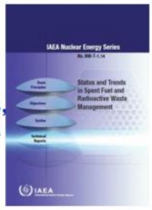
SRIS – Waste Inventory Database

- SRIS is the agency's new waste inventory information tool **Spent Fuel & Radioactive Waste Information System**
- **Developed in collaboration with EC**
- SWIFT – an associated **information tool** that allows Member States to compile their national reports – EC Waste Directive, JC etc.
- Meeting to "beta-test" functionalities in June 2019 – Release planned 2019

Inventory data are reported once and can be used by MSs for several different purposes

Status and Trends in RWM & SF

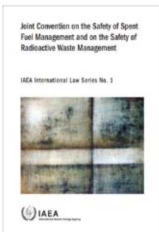
- Provides an international overview of SF & RW inventories, global status and trends
- **Prepared in collaboration with MSs, EC, OECD NEA & WNA**
- The next update will be published in 2020



Provides visibility of shared challenges & proven solutions

International Conventions & Standards

Joint Convention on the Safety of Spent Fuel Management & on the Safety of Radioactive Waste Management



Code of Conduct on the Safety & Security of Radioactive Sources

Euratom Waste Directive

Common challenges – shared frameworks

IAEA's Services & Products

→ Organize meetings and conferences
→ Provide the secretariat for international conventions
→ Develop Standards and Guides
→ Publish documents reflecting experiences and good practices
→ Manage Coordinated Research Projects
→ Provide the secretariat for communities of practices (Networks)
→ Manage databases (SRIS, Intl. Catalogue for Sources and Devices…)
→ Host the worlds largest nuclear information library (INIS)
→ Develop training material (Lectures, Workshops, eLearning)
→ Provide expert missions and training courses (Technical Cooperation)
→ Provide peer review services (Artemis…)
→ And through the Safeguards Department, we are also known as the "nuclear watchdog"

…always with Member States, for Member States

→ PUBLISH DOCUMENTS REFLECTING EXPERIENCES AND GOOD PRACTICES

IAEA

Publications

>120 publications in the area of pre-disposal radioactive waste management
All available on iaea.org

Pre-disposal Handbook Series

IAEA

Part I: **Technical Overview** – provides a concise summary of technical information.
Part II: Annexes* – provide detailed information on technical options, design basis, operational requirements, best practices, lessons learned, emerging technologies

1. Characterization of radioactive waste, waste forms & waste packages — *Draft*
2. Treatment of low & intermediate level liquid radioactive waste — *Draft*
3. Treatment of low & intermediate level solid radioactive waste — *Draft*
4. Conditioning of low & intermediate level liquid, solidified and solid radioactive waste — *Draft*
5. Processing of high level radioactive waste — *Draft*
6. Storage of radioactive waste & conditioned waste packages — *Draft*

Part I published as paper report and Part II will be electronic (CD/network ‘cloud’ based)

Implementing disposal programmes

IAEA

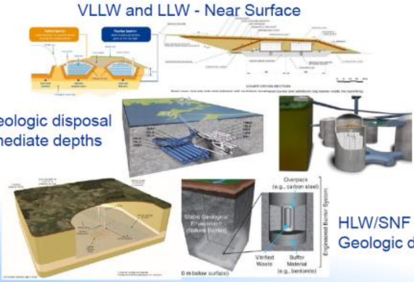
Concepts - Overview — *In Publication*

Cost estimation method — *In Publication*

Stakeholder engagement — *In Publication*

VLLW and LLW - Near Surface

ILW - Geologic disposal at intermediate depths



HLW/SNF – Deep Geologic disposal

Generic DGR Roadmap — *Draft*

Site investigations — *Draft*

Post-accident waste — *Draft*

60 years URF Compendium — *Draft*

Building Capacities - Spent Fuel and Radioactive Waste Management eLearning

The IAEA has an online learning platform (former CLP4Net) available with eLearning materials, free of charge.

The materials on Spent Fuel and Radioactive Waste Management, Decommissioning and Environmental Remediation are organized by thematic areas and distributed into courses for better understanding and use. Altogether, there are currently 45 modules with a total of 93 lectures. Some are available in other languages as well. More are underway.

Access is possible also through the IAEA CONNECT platform, via the professional Networks.

Link to "walk-through" video here

Building capacities - Technical Cooperation

The technical cooperation programme is the IAEA's primary mechanism for transferring nuclear technology to Member States, helping them to address key development priorities in areas such as health and nutrition, food and agriculture, water and the environment, industrial applications, and nuclear knowledge development and management.

Technical Cooperation in RWM/SFM

National Projects
(Pakistan, Croatia, Romania, Brazil, Egypt, Libya, Moldova, Georgia, Serbia, Ukraine ....)

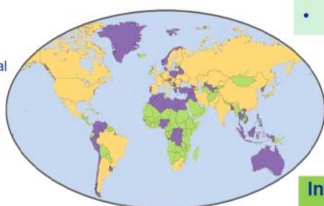
- Policy and strategy
- Planning & siting for disposal
- Waste management optimization
- Characterization
- Legacy waste management
- Modular processing
- Procurement of key equipment

Regional Projects

- Latin America, Africa, Asia-Pacfic, Europe

e.g. TC-RER 2020-23 addressing:

- Life-cycle waste management
- Strategy & planning
- Integrated national RWM plans
- Inventory to disposal



Inter-regional Projects
e.g.: Cradle-to-grave management of disused sealed sources

Nuclear power plants | Research reactors | Use of radioactive sources

Example: Capacity Building Workshops & Training Courses

Courses organized to transfer radioactive waste management knowledge and best practice usually on topics of common interest to MS

Workshop on Problematic Waste from Decommissioning

- Expert lectures
- Group exercises
- Technical visit to FGUP RADON to observe different treatment technologies being applied in practice

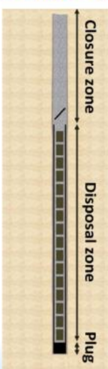
Advanced Training on Management of Large Components with Complex Geometries

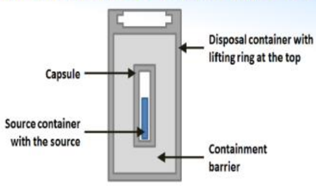
- Provide decommissioning professionals with necessary theoretical and practical basis for the management of large components

Co-ordinated Research Projects (CRPs)

- CRPs are tools to encourage information exchange/cooperation on on-going R&D activities in MS on selected topics of common interest
- Usually participants from 10-15 countries
- Periodic Research Coordination Meetings organized to facilitate exchange of progress, discussions
- Results of CRP published as Agency Reports

DSRS-inventories and the borehole disposal system





DSRS - Disposal: Decision aiding method

Draft

→ Mobile Hot Cell – Mobile Tool Kit
→ Capsules and Disposal Containers
→ Detailed Design
→ Generic Safety Assessment
→ School of Drafting Regulations
→ …

Many Member States' national inventory comprises "only" DSRS

17

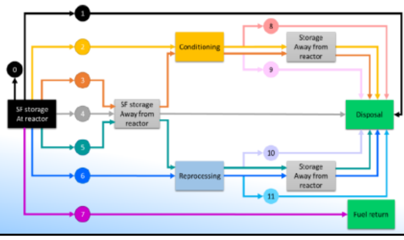
CRP on RR - Spent Fuel Management

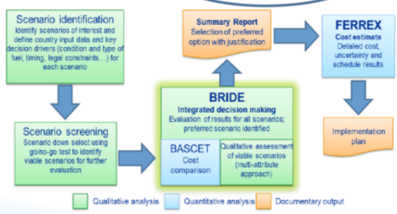
IAEA

Raise Awareness among Member States about RR SNF Management Responsibilities

- Technology options for spent fuel management
- Decision support tool – Scenario from range of options (BRIDE)
- Cost estimation tool (FERREX)

Frances MARSHALL
Research Reactor Fuel Cycle
NE Department - NEFW Division

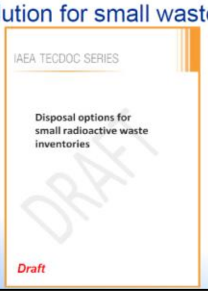




Small inventories of ILW or HLW

IAEA

Exploring a portfolio of disposal concepts that **show potential** of providing a safe and effective disposal solution for small waste inventories.



Access to waste processing facilities - Mobile Processing Systems

IAEA

Mobile Supercompactor

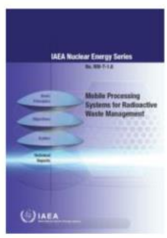
Key benefits:

- Lower capital cost
- Alternative to centralized facilities
- Easy replacement
- Shared use
- Useful for small volume streams
- Potential to cross borders
- Disposability
- Ability to schedule processing campaigns

Unit for drying solids (IX resins, sludges, concentrates)

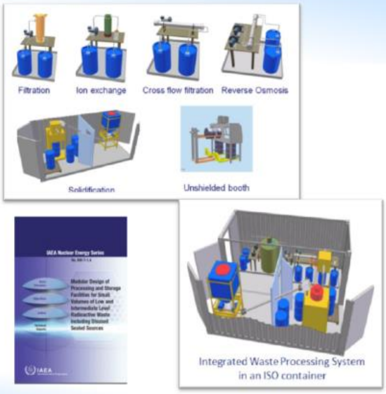
Common uses:

- Smaller volume, problematic waste streams
- Accident/urgent response situations
- Decommissioning & remediation



Access to waste processing facilities - Modular Designs for Small Volumes

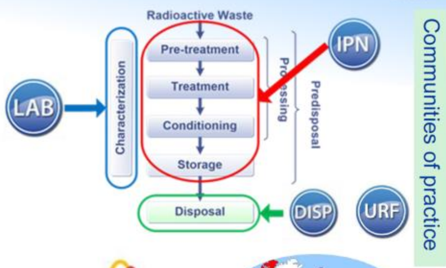
- Ideal for small waste quantities
- Flexible size & configuration
- 11 pre-designed modules that can be assembled & factory-tested off-site before being transported to waste processing/storage site
- **Processing modules** available for:
  - High & low volumes of liquid waste
  - All types of solid waste:
    - compactable & non-compactable
  - Sludges, ion-exchange resins, DSRS
- Can be **combined** to form an integrated process scheme
- **Storage modules** are available for all types of LLW packages/DSRS and sizes of inventory



RWM Wiki

- Decommissioning wiki fully functional on IDN Network
- Currently expanding wiki content to cover all of radioactive waste management
  - Predisposal
  - Disposal
  - Decommissioning
  - Environmental Remediation
- Type of content:
  - Facilities
  - Technologies
  - Lessons Learned
  - Good practices
  - ……

RWM Networks



Tool-kit for predisposal

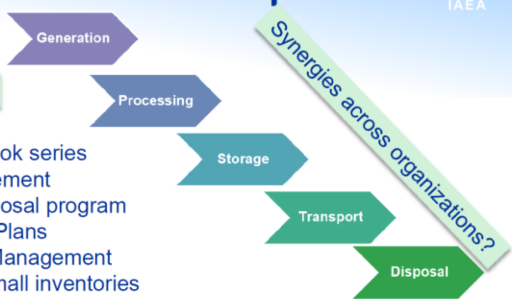
Technologies & Practices

Disposal Facilities World-wide

Guidance, Tools & future developments

Waste | DSRSs | RR SF

Synergies across organizations?



- Pre-disposal technology handbook series
- Optioneering for RR-SF management
- Steps and components of a disposal program
- Integrated Waste Management Plans
- Strategies and tools for DSRS Management
- Cradle-to-grave strategies for small inventories
- Waste Inventory
- Waste Acceptance Criteria

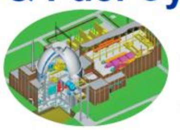
Continuous Improvements – Gap Analysis – RD&D Needs

The future of RWM World-wide

- **Life-cycle radioactive waste management planning** begins **before** any waste is generated
- **Waste hierarchy principles** are adopted (avoid, minimize, recycle, reuse, dispose) to **minimize waste** going to disposal
- **End-of-life plans** are in place for all new sealed sources (i.e. recycle, return, disposal)
- All waste is **characterized** at the **point of generation**
- A **waste inventory** is created and tracked at all life-cycle stages
- **Fit-for-purpose** processing, storage and **disposal** solutions are selected and implemented in a timely manner
- Adequate **provision** is made for radioactive waste management **resources** at all stages – financial, technical and human

Future RWM responsibilities can be planned and provided for.

Management of Waste from Advanced Reactors & Fuel Cycles



SMRs

CAREM-25, HTR-PM, KLT-405, RITM-200, AHWR, NuScale, SMART, 4S, PRISM…

EVOLUTIONARY

ABWR, ACR 1000, AP1000, APWR, Atmea-1, CANDU 6, EPR, ESBWR, WWER 1200, CAP1400, APR1400, HPR1000…

INNOVATIVE

LFR, GFR, SFR, SCWR, VHTR, MSR, ADS

New initiative to develop IAEA guidance regarding radioactive waste management considerations during the design phase of new reactors, fuel types and advanced fuel cycles

IAEA
International Atomic Energy Agency

More information:
https://www.iaea.org/events/management-of-spent-fuel-conference-2019

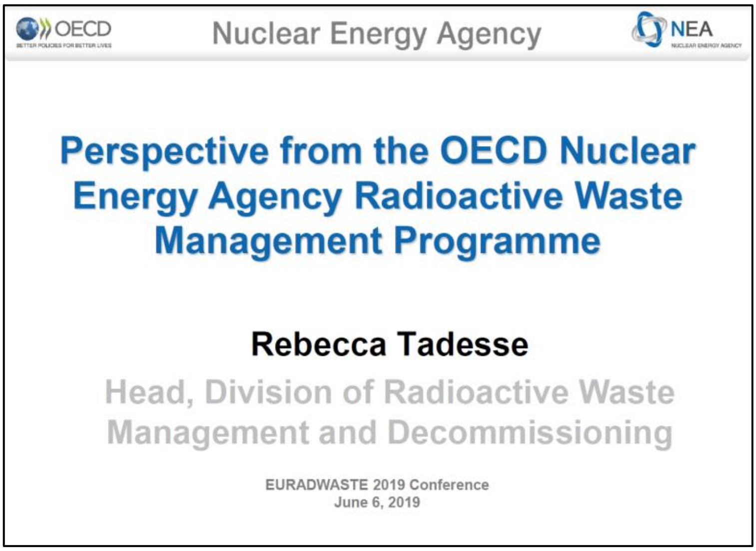
Thank you!

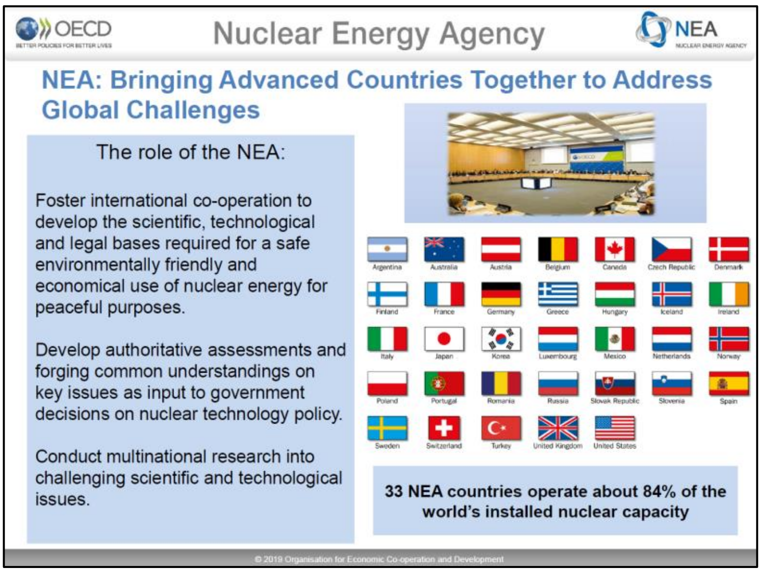
REBECCA TADESSE

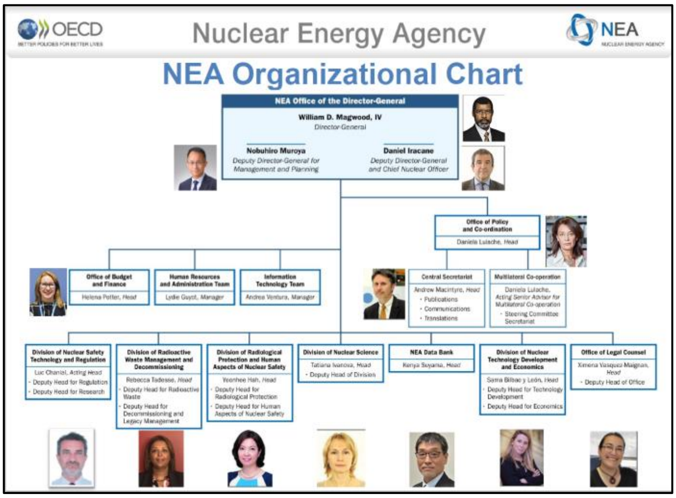
FISA 2019 – EURADWASTE '19

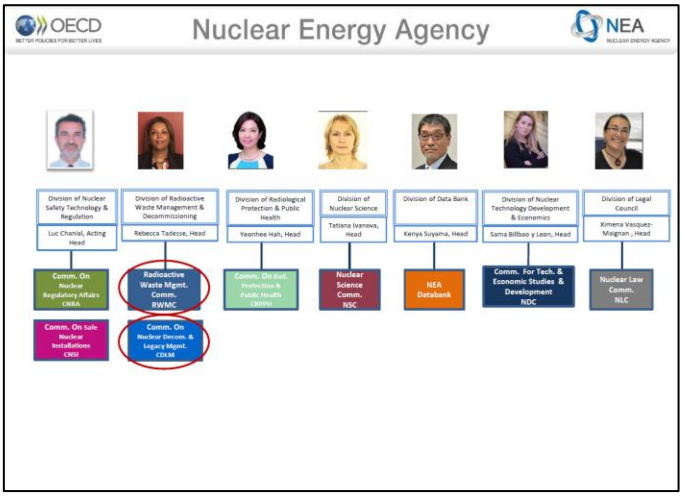
Presentation of Ms Rebecca TADESSE (OECD/NEA, FR)

PERSPECTIVE FROM THE OECD NUCLEAR ENERGY AGENCY RADIOACTIVE WASTE MANAGEMENT PROGRAMME









OECD
BETTER POLICIES FOR BETTER LIVES

Nuclear Energy Agency

NEA
NUCLEAR ENERGY AGENCY

Committee on Nuclear Decommissioning & Legacy Management (CDLM)

- Approved by the NEA Steering Committee in April 2018.
- The CDLM covers the decommissioning of all types of nuclear facilities and reactor types; as well as the management of legacy waste and waste sites from historical nuclear activities.

- **Objectives**
  - share experiences and knowledge;
  - establish best practices in decommissioning and legacy management;
  - improve understanding of decommissioning costs and uncertainty treatment; and
  - identify research needs and collaboration opportunities.
  - IDKM for decommissioning

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RWMC Vision Statement

The RWMC's vision to manage RW using a holistic approach. Specifically:

- Advance the state-of-the-art on technical, economic and societal aspects of radioactive waste management, also to foster exchange information and experience on RWM policies and practices among members;
- Identify and analyse key issues in policy and strategy for optimisation of the management of spent fuel and all types of radioactive waste generated during various activities.
- Promote cooperative efforts such as the setting up of joint international R&D projects or the development of databases, and to promote initiatives to retain relevant competencies and knowledge.
- Offer, upon request, a framework for the conduct of international peer reviews and international expert feedbacks of national activities in the field of radioactive waste management.

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Managing RW using a holistic approach – 3 key aspects

RWMC

Regulators' Forum (RF)

Environmental

Near-term focus:

- Develop best available technologies which can be used to optimize RWM activities,
- effective methods for integrating new technological information in national RWM decision making.
- A new initiative on information, data, knowledge management.

Societal

Near-term focus:

- Continue FSC's work on the social and ethical dimensions of radioactive waste management, nuclear decommissioning and legacy management;
- Its aim is to assist member countries to enhance confidence, communications and understanding of needs and expectations of all involved stakeholders.

Economics

Near-term focus:

- economic factors that affect the selection and optimization of RWM strategies and their subsequent impacts.

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NEA Activities Related Information Data and Knowledge Management

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Why nuclear is interested in IDKM

- Worldwide interest and request for the development of new tools for efficient and performant IDKM on both short and long term;
- Nuclear sector, incl. RWM, is highly demanding in IDKM:
  - Nuclear data, information and knowledge are very expensive in terms of human, time and financial resources due to its intrinsic complexity and nature;
  - The pioneering nuclear generation has now retired, the generation trained during the nuclear expansion period are approaching retirement, and new generations are hard to emerge due to the national policy contrary to, or simply uncertain about, the use of the nuclear energy;
  - Nowadays, there is a high risk to fail (partially or totally) the transfer of the data, information and knowledge, gained with so many efforts, to the next generations (risk of loss).

We "forgot" how to go to the Moon. We should do not forget how to build nuclear power reactors, how we generated or how we disposed waste…

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Why RWM is interested in IDKM

National programmes for RWM tend to run for decades. This timescale is an additional crucial factor for IDKM in this domain:

- ***Data*** – They increase in number, type and quality as national programmes proceed through the successive stages of repository commissioning.
- ***Information*** – Users have to be confident with data and able to access and understand the associated information for the long-term.
- ***Knowledge*** – The (explicit and implicit) knowledge that RWMOs acquire during the national programmes development has to be transmitted from generation to generation of workers to reduce the risk of loss.

In addition to the long development of national programmes, the final repositories are to remain safe from hundreds of years to millennia, while future generations have to be able to take their own-informed decisions…

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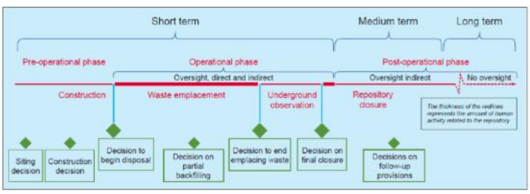
Recent activities at NEA in the IDKM

RepMet (2014-17) homepage

- *Radioactive Waste Repository Metadata Management*;
- Investigation of a family of tools and techniques under the heading of metadata to be implemented in national programmes in order to keep confidence in data and maintain understandable the information in short term.

RK&M (Phase I: 2011–14, Phase II: 2014–18) homepage

- *Preservation of Records, Knowledge and Memory across Generations*;
- Definition of a set of complementary and synergic mechanisms for the preservation of RK&M about a radioactive waste repository on the medium- and long-term (Phase II).



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Recent activities at NEA in the IDKM (2)

EGIRM (Phase I: 2014-16, Phase II: 2017-18) homepage

- *Expert Group on Inventorying Reporting Methodology;*
- Development of an innovative methodology for presenting data and information about spent fuel and radioactive waste national inventories and management strategies in a common, unified and unified format.

RK&M Final Report (coming soon)

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New activities at NEA in the IDKM

- **IDKM Workshop** (22-24 January 2019)
- Development of the "**IDKM Roadmap**", a document collecting activities for which the country member representatives have expressed willingness and interest to carry out under the RWMC auspices
- The NEA Radioactive Waste Management Committee (RMWC) has approved the creation of the "**IDKM Working Party**". It will act as:
  - A group managing and coordinating all of the activities included in the IDKM Roadmap that the same group will maintain and update based on rising needs of RWMOs and innovations in the IDKM area;
  - A *neutral forum* for the exchange of experiences, lessons learned, common needs and challenges in IDKM among RWMOs, nuclear regulators, TSOs and other stakeholders;
  - A *platform* following major innovations and trends, emerging technologies and consolidating best practices in all forms of the dynamic area of IDKM, in order to assist member countries in their understanding and applications to the RWM field.

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NEA Activities Related to Competency Management

OECD Nuclear Energy Agency NEA

Background (1)

- A growing need exists for strong and comprehensive knowledge management programmes for nuclear regulatory bodies, specifically in the areas of radioactive waste management and decommissioning, to ensure long-term safety.
- Considering the long timeframe of radioactive waste management activities, members of the Regulators' Forum (RF) have expressed their concern for the potential loss of current radioactive waste and decommissioning knowledge and expertise.
- A questionnaire developed by the Secretariat and adopted by RF Bureau was disseminated.

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Background (2)

- The questions were designed to collect information on;
  - Current policy and strategy of competency management in RF countries,
  - methodology to foresee a necessary competency in future,
  - activities on competency and knowledge management,
  - training, tools or other information available for others, and
  - the priority level for enhancing competency in regulatory activities.

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Key results from survey (1)

- There is a need to keep necessary competency to address their mission.
- Competency management policy is developed by regulatory bodies or stipulated in the law.
- Regulators rely on the technical competency of their TSO's
- The need for competency management has changed in the last 10 years.
- Need for more focus on knowledge management and development of new expertise to address new responsibilities placed on the regulators (decommissioning, phase-out strategies, new reactor types, and long-term storage and disposal facilities).

Key results from survey (2)

- Need to review necessary competency in line with their missions.
- Need for retiring staff to maintain their knowledge within the organisation and supply necessary competency.
- Participation in international meetings/workshops to gain competencies required in the field of waste management and decommissioning.
- Bilateral or multilateral agreement on staff training is valuable, although it can be difficult if the regulatory systems are different between countries.
- On the job training is important. Challenge is how to transfer “know-how” and “experience”.
- RF is a valuable platform for effective communication/interaction with interested parties; best (most effective) practices in the transfer of knowledge/competencies for regulators.

Competency Management if Regulators Workshop

- Workshop Date February 25-26, 2019 at NEA
- Workshop objective
  - Focus discussion on the core concepts of competency management,
  - Identify effective mechanism for building competency,
  - Identify members needs is support of the development of national framework of regulators’ competency management.

Other NEA Activates related to Radioactive Waste Management

Nuclear Energy Agency

New initiative on the application of RRS in nuclear back-end

RWMC approved the establishment of a new initiative on RRS application in the nuclear back-end.

Objectives:

- Promote the exchange of information on RRS development and application amongst the participants; collection and analysis of inputs from all participants;
- Study the main and emerging challenges for the RRS application. Identify the main factors influencing RRS development and application. Arrange the identified factors and develop a road map (a plan of actions) to support the development in the area of provision of the nuclear back-end programmes with RRS;
- Develop recommendations (road map) to members on establishing a framework, allowing the wider application of RRS in the nuclear back-end area. Strive to achieve shared approaches and standards, where appropriate;
- Support the development and implementation of common procedures, rules, standards, etc. that can facilitate the process of RRS application amongst the potential users of the systems.

Nuclear Energy Agency

Potential participants

Members should be senior technical specialists who have considerable experience and knowledge in the development and application of RRS:

- representatives of decision-makers;
- research and development institutions/organisations in the field of RRS;
- test sites, laboratories and facilities;
- regulatory bodies (various) and technical supporting organisations to the regulatory bodies;
- developers of the main and auxiliary elements for maintenance and repairing of RRS;
- RRS producers, suppliers and service providers;
- soft and electronic elements developers;
- environmental organisations and public communication experts;
- other relevant specialists.

The CDLM will be invited to be part of the initiative as well as the CRPPH and other NEA STCs. Communication with NI-2050.

International organisations (IAEA, EC, WNA, others) and initiatives (e.g. SHARE) will be invited.

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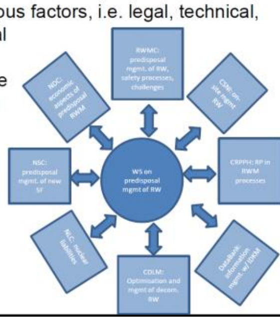
Predisposal Management Workshop

Objectives:

- To review the latest RW treatment/conditioning technologies within the RWM community, R&D needs, technical and social challenges in predisposal management.
- To better understand the impact of various factors, i.e. legal, technical, economics, societal, etc. on predisposal management and future WAC.
- To identify work topics for continuing the RWMC predisposal work, and potential collaborations with relevant STCs.



Next step:

- assemble a PC to plan for an NEA workshop, with all relevant STCs.
- WS to be held in Q1-Q2 2020.

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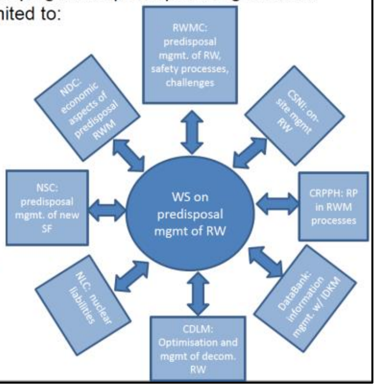
Predisposal Management Workshop

Collect and analyse inputs in developing future predisposal mgmt. work. Inputs may include, but are not limited to:

- RWMC: to present current treatment experiences, R&D needs, challenges
- CDLM: optimization challenges, mgmt. of decom/legacy waste
- CRPPH: radiation protection in RW treatment processes
- NDC: economic aspects of predisposal mgmt.
- CSNI: challenges of on-site RWM and change of ownership
- NSC: predisposal mgmt. of SF from new reactors
- NLC: nuclear liabilities (incl. transportation).
- Databank: data management (jointly w/ IDKM).



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Building Constructive Dialogues Between Regulators and Implementers in Developing Deep Geological Repositories and Other Disposal Projects for Radioactive Waste (RIDD)

- The aim of this new initiative (RIDD) is to develop best practices for structuring stakeholder interactions in the decision-making process of managing radioactive waste.
- Best practices will be defined based on existing national experiences and best practices as identified by international organizations such as the NEA, IAEA, EC, and ICRP.
- Best practices should be in line with the RWMC Statement.
- The main idea is to develop sustainable strategies for the management of all radioactive waste types from their production to final disposal.

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RIDD – Work Scope

- 1st phase 2019-2020: focus on building constructive R-I dialogues in RW disposal projects.
- Proposed mode of operation: regular informal meetings to engage R-I dialogue in a collaborative setting, with opportunities for open discussion. Presentations, discussion outcomes and lessons learned will be documented and used to develop the final report.
- The RWMC may consider dialogues with other stakeholders in other radioactive waste management activities/projects in future phases.
- Future phases will identify best practices for structuring effective stakeholder dialogues in the following project areas:
  - Geological disposal
  - Other types of disposal, i.e. underground and near surface disposal
  - Decommissioning and dismantling
  - Transportation infrastructure development
  - Interim and long-term storage

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The Nuclear Education Skills and Technology (NEST) Framework:

- Building-up practical experience and expertise by exposing the next generation to real-wold problems, through hands-on activities in multi-disciplinary and multi-national contexts;
- International co-operation allows identifying and accessing a critical mass of capacities (infrastructures, construction or decommissioning projects, innovative activities…);
- Establishing links between Universities, Research Institutes, Industry and Regulatory bodies.

• 15 organisations from 10 countries are signatories to the NEST Framework Agreement (entry into force 15 February 2019).

Nuclear Energy Agency

The NEST CLADS Project

Collaborative Laboratories for Advanced Decommissioning Science

NEST-CLADS will be dedicated to advanced remote technology for decommissioning under intense gamma-ray radiation environments.
The proposed project is divided into two stages:
- *a short program* consisting of seminars, site tours, and practical exercise. This will be held at the Nahara Remote Technology Development Centre of JAEA where students will be able use virtual reality to understand the circumstances inside a reactor building, virtual operations by simulated remotely operated robot.
- *a long program* mainly based on research tasks.

Virtual reality and simulation system in Naraha Remote Technology Development Center of JAEA

NEST Management Board

Leading organisation: JAEA/CLADS

NEST Fellows:
Graduate and Postgraduate students and young professionals

Participating Organisations:
The University of Tennessee, US (Prof. William R. Hamel)
Lawrence Berkeley National Laboratory, US (Dr. Kai Vetter)
McMaster University, Canada (Prof. Shinya Nagasak)

Organizations under consideration : University of Birmingham, UK (Prof. Rustam Stolkin), Lancaster University, UK, Savannah River National Laboratory, US (Dr. Jeffery C. Griffin), Platform for Basic Research on Decommissioning, Japan, University of Manchester, UK , NNL, UK, CEA, France, KAERI, Korea…

Nuclear Energy Agency

The NEST PDC UGR Project

POCATOM

The **NEST-PDC UGR** project addresses the main issues of **RW management, including characterization, decontamination and disposal**. It will focus on decommissioning of Uranium Graphite Nuclear Reactors,. Hands-on training will consist of several activities which will make use of the fully-fledged infrastructure, **pilot & experimental facilities** present at the sites:
- Specially-manufactured equipment for i-graphite remote sampling
- Graphite incineration facility
- RW repository mock-up models for investigation of geological barriers

Pilot facilities for testing technology of i-graphite treatment

NEST Management Board

Leading organisation: "PDC UGR" JSC

NEST Fellows:
Graduate, Postgraduate students and young professionals

Interested Participating Organisations

Universities:
- Seversk Technological Institute/MEPhI branch, Russia;
- National Research Nuclear University MEPhi, Russia;
- National Research Tomsk Polytechnic University (TPU), Russia;
- Faculty of Chemistry, Lomonosov Moscow State University (MSU), Russia;
- Politecnico Milano, Italy.

Industry:
- ROSATOM. Russia;
- Sogin Latina NPP, Italy.

Regulator:
- Siberian Department of the Federal Environmental, Industrial and Nuclear Supervision Service "ROSTECHNADZOR", Russia.

Nuclear Energy Agency

Thank you for your attention

More information @ www.oecd-nea.org

All NEA reports are available for download free of charge.

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MICHEL PIERACCINI

A NUCLEAR OWNER/OPERATOR PERSPECTIVE ON WAYS AND MEANS FOR JOINT PROGRAMMING ON PREDISPOSAL ACTIVITIES

M. PIERACCINI, S. GRANGER

[1]EDF Direction des Projets Déconstruction et Déchets (DP2D), 30 Avenue de Wagram 75008 Paris - France

Abstract. Nuclear decommissioning is a worldwide competitive market. It is also the main source of radioactive waste from the nuclear energy field. In order to reduce the waste volume it is necessary to sort the actual radioactive waste to be disposed of and to separate them from other materials that could be recycled.

Since 2015, Electricité de France (EDF) has gathered the waste management and dismantling (WM&D) projects, the related competences and human resources in the WM&D field, in a dedicated directorate (DP2D) and a company group called Cyclife (including waste treatment facilities).

Taking into account the experience gained by carrying out its own WM&D projects as well as contributing to international cooperation, EDF considers that integrating collaborative research and development (R&D) on pre-disposal and waste management could be carried out following four main objectives.

- Alignment of the application of regulatory frameworks through appropriate definition of criteria and rules for radioactive waste to enable sensible worldwide comparison of technics,
- Improvement of technical and organisational aspects of nuclear reactors decommissioning using a demonstrator facility to be in operation, at first for graphite reactors, by 2022,
- Development of new techniques to decontaminate/homogenize metallic materials through a dedicated recycling route. These technics will be implemented in a new treatment facility foreseen to be available by 2030, and
- Increased training of decommissioning operators with the help of new technologies.

All these improvements are aiming, beyond technical and experimental aspects, at reducing environmental impacts of nuclear activities as well as preserving the radioactive disposal volumes, as they are considered by EDF as rare resources.

1. Introduction

As owner/operator of a nuclear fleet with the responsibility of the dismantling of already shutdown NPPs, EDF has acquired a sound and robust experience in WM&D. Since 2015, EDF has created in the WM&D field a dedicated directorate (DP2D) and its holding called Cyclife. These new entities gather all corresponding projects, all necessary human skills and resources as well as technical means. Such new organisation enables DP2D to define and make applied the WM&D strategy for the entire EdF Group and its partners.

The main objective of this new organization is to reinforce EDF’s capacity and leadership in this field. It will allow the integration of R&D aspects such as decommissioning operators' training, testing of innovative technologies (virtual reality, 3D simulation, remote operations) and development of technical demonstrators. Therefore, EDF intends to develop international collaboration directly through industrial cooperation and through participation in collaborative R&D projects. These projects can be carried out under the umbrella of international organisations such as the European Commission, OECD/NEA or IAEA, in which EDF already contributes actively.

To define R&D programmes for improving radioactive waste management during pre-disposal periods, it is necessary to agree on the definition of "radioactive waste" and the various current or potential sources. There is now a global international agreement within the nuclear industry to call "radioactive waste" the ultimate status of a considered material that will require disposal. Thus, to assess the status of waste, all materials to be generated by nuclear activities should be precisely characterized and sorted out in order to reduce significantly the amount of actual radioactive waste to be disposed of.

The importance of reducing the radioactive waste volume has increased over the last decade since repositories are considered as rare resources to be preserved in order to limit environmental impacts as much as possible. This care about reducing waste volume is taken during the four steps of the lifetime of a nuclear facility: design, construction, operation and decommissioning. Then, as users of radioactive disposals, nuclear operators take on their responsibility, by enhancing their expertise as well as increasing their credibility by mastering techniques and costs. In addition, they contribute to avoid spoiling resources by disposing materials that can be reused or recycled.

Defining relevant R&D programs in WM&D require that all aspects of predisposal activities are properly evaluated, considering the great diversity of type, nature and activity of waste generated by decommissioning as well as the involved quantities. Sufficient operational experience and feedback from existing practices help to identify remaining needs, commonly shared at the European or the international level.

2. Strategy on Waste Management and Decommissioning

Experience gained in performing decommissioning on an industrial scale

The last 10 years EDF has acquired experience in the decommissioning of four different types of nuclear reactors. This fruitful learning stage makes it possible to benefit from some lessons learned. They can be summarized as follow:

- For Pressurized Water Reactors (PWRs), which compose the current French operating fleet, the feasibility of the decommissioning process has already been demonstrated. The focus is now on optimizing the sequence of future operations and scenarios.
- For graphite reactors, the remote handling systems to dismantle these huge reactors are still under development. In parallel, the graphite waste management remains a major issue. Considering the size and complexity of this kind of reactors, dismantling design and operation will lead to long timeframes.
- A sound experience in waste management driven decommissioning is the cornerstone to successfully perform the dismantling of a nuclear reactor.

- France can rely on a complete and efficient radioactive waste management system for nuclear waste produced during decommissioning. However, this system could be improved by addressing the issue of clearance levels to allow the recycling of ingots produced after the melting of very low-level radioactive metallic waste.
- Specific care should be given to the use of terms for decommissioning For instance, the term "immediate dismantling" recommended by the IAEA, should not mean that dismantling should be hurried, irrespective of associated risks and costs, but that the decommissioning of the nuclear plant should start soon after its shutdown. This kind of misinterpretation could lead to counterproductive attitudes of counterparts including local stakeholders.

Organisational issues

Taking into account the experience gained, EDF, in 2015, decided to create and structure an entity devoted to decommissioning and waste management with three main objectives:

- Support ongoing EDF dismantling worksites,
- Prepare the decommissioning of the nuclear fleet in operation,
- Become a major actor in the WM&D market, which is emerging but already highly competitive.

This restructuring has been progressively conducted in three parallel phases:

- The creation of a dedicated directorate called DP2D gathering all corresponding projects, resources and skills. It reports directly to EDF Group Board.
- The creation of specialized subsidiaries providing waste treatment services in order to optimise the sorting and the volume of waste to be disposed of. In addition, it has aimed at increasing EDF's technical and financial mastery for its own needs (as a responsible owner/operator of a world nuclear fleet) or those of its partners/customers (who trusts and relies on EDF capacities and skills worldwide to preserve and develop their own competitiveness),
- The establishment of industrial partnerships regarding innovative and key technologies or targeted geographic areas.

In order to take advantage of the ongoing development of digital/numeric methods and techniques and to gain in efficiency, a specific study has been initiated. The aim is to analyse what would be the potential benefits of the implementation of numerical techniques in the organization model; would it be better to address the related topics thanks to a dedicated structure (as it is currently performed) or to consider this specific field as a crosscutting topic with its own strategy and associated business plan?

Regulatory Framework

Currently, technological developments are due to EDF engineering means and capacities, international cooperation (IAEA, OECD/NEA and World Nuclear Association (WNA)), feedback on various worksites as well as the R&D research programmes. One of the lessons learned in this particular field is that the efficiency of a technological development depends not only on the techniques used or the operator's ability and mastery but also on regulatory aspects.

Actually, the application of regulations, originally initiated by international directives (IAEA, EC), can vary from one country to another as they are adapted to local considerations and national policies. This point is critical for neighbouring countries as it may result in a risk of confusion in the perception of the public. For instance, some technique performed in one country could be restricted or forbidden in a neighbouring country only due to regulatory constraints, leading to confusion, weakening nuclear operators' credibility as well as lowering public acceptance.

For example, clearance levels, despite a global common European regulation, are not systematically implemented in national policies. This is an illustration of the national policies heterogeneity, preventing from a more efficient circular economy in waste management, at least at the European Union level.

It would, thus, be advantageous to align and harmonize the application of the internationally agreed regulatory basis. Such a framework shared and applied by all countries with nuclear activities could enable an efficient comparison of the efficiency, the suitability as well as the limits of available techniques being operated in similar situations.

As a consequence, it will become easier to identify the remaining needs of improvements as well as the necessary R&D developments. In addition, a common regulatory basis will help to qualify the decommissioning operators on the common basis of an international shared assessment, which is important as decommissioning is becoming an international business.

Financial issues

Strategic considerations in WM&D and R&D have to take into account the cost issues. This includes accurate cost assessment, funding availability, on time, and the associated mechanisms to provide funds.

Since 2006, France, like most other countries, has developed and structured a rigorous and demanding financial system, to guarantee future financing of WM&D operations. French nuclear operators are on a regular basis audited on their own financial capabilities. The audits include the demonstration of the relevance of the dismantling and waste treatment or conditioning scenarios, the efficiency of the chosen processes as well as the operators' carefulness to maintain them up to date along the years.

3. Ways and means for R&D on predisposal activities

Mainly deduced from EDF observations throughout its decades of experience as worldwide nuclear operator and its strategies developed in WM&D, 4 ideas for international cooperation are presented here after. They could be the starting point for future R&D activities at European or international levels in the frame of predisposal activities development.

These preliminary ideas are not exhaustive, as decommissioning and waste management business, being a competitive and emerging market, constitutes a continuous field of innovation and improvements.

3.1. Alignment of the implementation of the Regulatory Framework

Considering the long timeframe and the complexity of the decommissioning activities, the research and innovation effort makes sense if the application of the regulatory framework is similar or at least coherent amongst the countries. For instance, an appropriate definition of criteria and rules for waste management routes may foster the circular economy in material management at European and international level.

Such improvements in regulations should be developed with the support of IAEA and European Commission through their Research and Innovation (R&I) programmes. Creating exchange forums will help develop the sharing of experiences and competences. Furthermore, it will enable sensible and relevant comparison of techniques efficiency being performed worldwide.

Alignment of decommissioning objectives, regulatory framework and operating rules will help building confidence among the stakeholders mitigating the risk of confusion in population perception of facility dismantling operations and waste management practices.

3.2. Improvement of Technical and Organizational Aspects of Decommissioning Graphite Reactors

In line with its strategy, EDF has already launched the Decommissioning Demonstrator project scheduled to be in operation in 2022. Based on a modular design, the aim of this demonstrator facility is first to check the feasibility of decommissioning scenarios foreseen for graphite reactors. In particular, it will help to improve safety as well as tools and operators' efficiency thanks to an adequate training. This will help to face unexpected situations that will undoubtedly occur during real dismantling as none of the graphite reactors have been designed to be decommissioned. This demonstrator should therefore help to strengthen the technical mastery at appropriate cost. This new flexible facility will enable to test, improve and implement innovative technologies while performing decommissioning on site.

Beyond these objectives, the ambition of the Decommissioning Demonstrator project is to become an international training centre for decommissioning operators. Settled in Chinon (France), this location has the advantage to be at nearly equal distance from most European graphite reactors' locations. This demonstrator will allow operators from foreign countries to share experiences and train themselves on representative mock-ups in safe conditions.

The decommissioning of graphite reactors presents specific characteristics and constraints in terms of scales, dimensions and volumes of waste. Although these specific characteristics are common for all reactors of this type, no real set of decommissioning scenarios and tools are commonly agreed.

Thus, the Decommissioning Demonstrator is a full scale facility with a modular design, ensuring flexibility and adaptability. It will allow the implementation of R&D projects aimed at testing tools as well as training operators. This facility is composed of two main parts: a 3D simulation platform enabling digitalization and virtual reality and a huge experimental hall with scale one representative mock ups. The hall will serve to improve and qualify innovative techniques, such as remote handling and automated operations.

In addition, the experimental activities aim at improving decommissioning operators' confidence and experience in managing unexpected operational situation. They will also help to determine accurately the types and quantities of secondary induced waste produced in dismantling operation. Moreover, complementing the decommissioning scenarios assessment through this new angle will allow the reduction of waste volume and consequently the limitation of the number of waste packages thanks to relevant compromise and choice of tools.

Furthermore, the Decommissioning Demonstrator will allow the development of innovative and applied R&D in an international cooperation framework. The perspective of implementing R&D based on real cases has already drawn the attention and interests of the United Kingdom and Spain, currently involved in graphite reactors decommissioning.

Supporting countries have been invited by EDF to express their own needs regarding their own decommissioning projects, not limited to graphite reactors, such that they can be taken into account during the design of representative mock-ups, operators training programs, or other topics to be addressed with associated priorities.

The Decommissioning Demonstrator will apply for European support through the 2019 - 2021 Euratom work programme and in particular through the launch of a specific European Joint Programme (EJP) comprising R&D as well as training activities.

In addition, considering the expression of interest of some members, the OECD/NEA Nuclear Innovative Program (NI2050) has identified this future facility as one of the 12 selected projects of interest in the nuclear field. This OECD/NEA initiative is aiming at accelerating R&D and market deployment of innovative nuclear fission technologies to go with the necessary energy transition towards a very low carbon energy mix.

Finally, the IAEA has recently expressed its willingness to consider such project becoming a formation centre as soon as its industrial objectives will be achieved.

Beyond improving dismantling operation and ongoing waste management (in operation and in decommissioning), the Decommissioning Demonstrator will positively direct the future NPPs design and associated maintenance operations whatever are their nuclear technologies.

3.3. Development of New Techniques to Decontaminate/Homogenize Metallic Materials

Currently, EDF considers the creation, in France, of a new treatment facility to recycle metals. Based on the circular economy principle, this new plant, foreseen to be available by 2030, will comprise a melting oven and a foundry. The new facility will allow preserving repository capacities thanks to a significant reduction of volumes to be disposed of. It will also preserve source of raw materials such as steel, carbon and nickel.

At the early stage of the project, joint R&D programmes are designed to establish a sound common technical and regulatory basis to design processes that could accommodate metallic waste coming from various countries. In particular, emphasis will be given to study the use of arc melting furnace technology to decontaminate/homogenize metallic materials.

When operating, such unique facility could allow centralizing and regulating metallic flows coming from worldwide decommissioning worksites, particularly from Europe and Asia. Metals could therefore be recycled and further reused thanks to this new sustainable industrial process.

3.4. Increased Training of Decommissioning Operators and implementation of robotics

A specific emphasis will be put on the need to increase nuclear operators training using automated tools. The training and qualification processes should be established on the common basis of an international shared assessment of current and future practices.

The operators' increased ability and effectiveness will be obtained by strengthening their training on representative configurations and mock-ups specifically designed to take into account the various nuclear technologies constraints and requirements,

For example, the development of remote exoskeleton is foreseen, as human skills and expertise appear irreplaceable in some cases with high dose rate exposure. This R&D will pave the way for progressively replacing operators by machines without losing human know-how and mastery.

Such improvements and associated R&D could consequently bring up safety and public acceptance as well as increasing operators' efficiency.

In the future, an operator would be able, safely, from his or her office or a representative mock-up, to operate remotely a humanoid robot present on site. Thanks to 3D and virtual reality, wearing its exoskeleton, the operator will act as if he or she were really operating, adapting his behaviour to the context.

Such evolution in working conditions could lead to several advantages:

– Improvements of the labour efficiency (up to ~2 times), increasing the time of work in conditions of ionized radiation (reduction of the collective dose),

– Reductions of personnel's dose exposure,
– Dismantlement of larger fragments without necessary heavy handling/lifting means,
– Easier worksite preparation with no (or less) need of time-consuming (and waste-producing) preliminary decontamination,
– Reduction of the volumes of secondary induced waste (work clothing, air locks, ...), less washings leading to fewer liquid effluents, and
– A drastic mitigation of the risk of injury, electric shock, falling objects or falling from heights and their consequences.

Last, but not least, it will keep operators' motivation at high level and increase public confidence towards back-end activities by use of cutting-edge technologies. This innovative approach of performing nuclear decommissioning is also foreseen as a means to secure the roadmap by accelerating cutting rates upgrading/modernizing scenarios and technologies. This last characteristic could foster the attractiveness of back-end activities, particularly towards young generations.

3.5. Intellectual Property Rights (IPR) issues

Although IPR is not the prime aim of this paper, it is clear that in a highly technologic area like decommissioning it is important to address IPR since the preliminary phases of discussions, defining R&D programmes.

Several ways exist to address these topics. They usually depend on the level of involvement of each contributor, their respective internal policies and their will to share their own techniques/know-how aiming to improve them. EDF currently implements various possible IPR schemes. All of them lead to specific agreements, defining respective contributors' commitments. The contractual framework and in particular IPR rules in view of commercial applications should be set specifically for each R&D project.

4. Conclusion

The worldwide experience gained from the last decade at decommissioning worksites lead to a first conclusion: ways and means of R&D implementation on dismantling activities and waste management are strongly linked to a suitable application of the regulatory framework.

A sound and efficient application will foster a circular economy in materials, will help to establish a common basis of comparison of techniques efficiency and decommissioning operators' ability and will allow waste volume reduction.

This first point is important for identifying the actual remaining lacks and needs of knowledge and consequently the associated R&D developments requirements.

The second point is to put in coherence at the International level operators' training rules (up to their certification). This goal could be achieved on one hand by the sharing of experiences through international cooperation and, on the other hand, by the use of experimental demonstrators equipped with representative mock-ups.

These experimental demonstrators will help to adapt already existing tools or to identify and implement the required applicable pragmatic innovations. It will increase the efficiency of operators and techniques, mitigating risks (dose exposure, human intervention, secondary induced waste (clothing, wash liquid effluents)) and associated costs while securing the global decommissioning roadmap.

The development of sustainable techniques may have a positive impact on public acceptance as well as stakeholders' confidence.

Achieving these objectives will improve future NPPs' design in order to ease future decommissioning operations and thus, strengthening the nuclear industry credibility.

International cooperation, e.g. through the support of the European R&D work programmes in WM&D will help to reach a global commitment in a sustainable, internationally shared waste management policy and practices.

JOINT CONCLUSIONS
FISA 2019
EURADWASTE ’19

Summary and main conclusions of the FISA2019 Conference

provided by Stefano Monti (IAEA), Section Head, Nuclear Power Technology Development section, Division of Nuclear Power, Department of Nuclear Energy

Despite different energy policies in EU Member States, Europe produces about 25% of its electricity through the operation of 126 reactors. It represents about 50% of European clean electricity production. Moreover, in a number of EU Member States nuclear energy plays a significant role as a component of low carbon electricity supply to address, in particular, the obligations under the Paris Agreement on climate change, also highlighted in the latest 2050 roadmap for carbon-neutral economy.

Nuclear energy also contributes to security of energy supply and competitiveness of European industry.

All the EU Member States, including those with no NPPs, have a primary interest to ensuring nuclear safety throughout the EU. Maintaining a high level of safety and competitiveness is a major challenge and requires the establishment of a coordinated and well-focused R&D programme at European level, grounded on the corresponding national efforts and interconnected at international level, in particular with the International Atomic Energy Agency and the Nuclear Energy Agency of the OECD

Most European countries operating NPPs are now considering prolonging the lifetime of their reactors from an originally foreseen 40 years' operation to 60 years. In order to safely extend the lifetime of these reactors, the nuclear sector – in particular both operators and regulators - needs to have, in addition to a skilled and well-trained workforce, reliable tools to assess the ageing and degradation processes of components and structures, as well as methods and guidelines for their validation and safe management. Reactor performance, system reliability, accident tolerant fuels, advanced numerical simulation and modeling for reactor safety, are also equally important to maintain the current European NPPs fleet safe and competitive with the other carbon-free energy sources. The contribution from the Euratom R&D programme to this top priority must continue and be focused on the expressed needs of the European Member States and their industry.

After a forthcoming period of stagnation, also characterized by the definitive shutdown of the most aged NPPs and by a limited number of new NPP realization, all the medium-, long-term energy scenario studies forecast a new and increasing deployment of nuclear energy after 2050. This is coherent with the maturity of Generation III+ reactors like EPR, as well as with the industrial scale deployment of so-called Generation IV nuclear energy systems expected in Europe around the middle of the current century. As a consequence, European contribution, above all to safety, sustainability, non-proliferation resistance, physical protection and competitiveness aspects of these innovative systems, is key and already clearly recognized at the international level, in particular within the Generation-IV international Forum (GIF). JRC remains the implement agent of Euratom in GIF, whilst specific indirect actions should be aimed at coordinating the contribution from interested Member States, also with the goal to proceed in the next two decades to the realization of GEN-IV experimental and demo plants.

In view of these first realizations, after a first broad-spectrum investigation of all the possible technology options which has characterized the last 20 years of R&D, there is an increasing consensus in the European nuclear community on the need to focus on the most promising innovative nuclear energy systems and associated fuels and fuel cycles for Europe. Concentration of effort, critical mass and synergies between national and European programmes seem to be seem to be necessary conditions for success.

However, Europe should also broaden the available offer to meet national specificities. To this purpose, there is the need to maintain flexibility within current and future Euratom programmes to consider, at appropriate time, other emerging nuclear technologies, including those given high priority in other regions of the world, like for instance Small Modular Reactors, micro-reactors, hybrid energy systems integrating NPPs, renewables, energy storage and non-electric applications. The establishment of a shared R&D programme at European level could lead to a detailed European SMR design – to be integrated with increasing new renewables and based on harmonized European safety standards - by 2025.

Hydrogen production, district heating, several industrial applications, desalination, etc. are of increasing interest in many regions of the world including some EU Member States. The imperative to conjugate extended industrial deployment with decarbonization of the energy sector, offers to nuclear power a unique opportunity to finally penetrate the non-electric energy market. Synergies and integration with chemical industry should be developed and pursued as soon as possible, and related R&D in Europe should be focused on near-term deployment while maintaining a correct balance with the very high temperature applications expected in the second half of the century.

Despite the planned life extension of aging NPPs, a number of NPPs in Europe are expected to be shut-down in coming years. Decommissioning and dismantling industrial-oriented R&D activities have to be appropriately supported by forthcoming Euratom programmes.

Many efforts have been devoted during last decades to develop advanced physical models and computer simulation codes of high fidelity, including in the very challenging area of severe accident Monitoring and Simulation. However new technologies such as artificial intelligence, on-line monitoring, deep-learning, etc. are rapidly being introduced in many advanced technology sectors. Forthcoming Euratom programmes should take into account these new trends and foster the early involvement of European industry and TSOs which represent the final users.

Nuclear applications and technologies, and related competence and expertise, in the fields of medicine, radiation protection and in general non-power applications are recognized of great value for a modern society in all the EU Member States. As a consequence, Euratom programme should be seen as an integral part of the broader Horizon Europe proposal able to capitalise on synergies over a much wider range of research areas. Joint projects between Euratom and Horizon Europe programmes should be pursued whenever possible.

Research and technology development must be accompanied by appropriate actions to further develop and strengthen education and training, infrastructures, cooperation throughout EU and at international level. To this end:

- Ensuring a top-level education & training, involving basic academic education as well as continuous professional development and capacity building, is of paramount importance to create a new generation of nuclear researchers and experts able to maintain high levels of safety in all the fields, as well as address the challenges posed by advanced nuclear power and non-power technologies of European interest;
- It is more and more urgent to assure adequate maintenance and strengthen a robust, enduring and efficient infrastructure base across the EU to underpin all aspects of research and innovation throughout the sector;
- It is highly advisable to capitalize on the European Technology Platforms SNETP- NUGENIA, -ESNII, -NC2I as well as ENEN as for E&T. ETPs have proved to be very effective in fostering and strengthening collaboration between research/academic institutes and industry. This successful mechanism of collaboration should be enhanced and further implemented
- International cooperation and synergies with initiatives launched by other international agencies like NI2050 (Nuclear Innovation 2050) & NEST (Nuclear Education, Skills and Technology Framework) by OECD-NEA, ICERR (International Centre based on Research Reactors), Collaborating Centres and E&T networks by IAEA, GIF task forces on infrastructure and E&T have to be encouraged and intensified.

Finally, there are significant cross-cutting benefits and synergies that can be realised between fission and fusion energy research programmes, as the latter evolves from activities focused on basic plasma physics to ones focused more on technology and safety-related aspects.

- In a number of EU Member States nuclear energy plays a significant role as a component of low carbon electricity supply to address, in particular, the obligations under the Paris Agreement on climate change, also highlighted in the latest 2050 roadmap for a carbon-neutral economy.
- Nuclear energy also contributes to security of energy supply and competitiveness of European Industry
- All the EU Member States, including those with no NPPs, have a primary interest to ensuring nuclear safety throughout the EU
- Despite different energy policies in EU MSs, Europe produces about 25% of its electricity through the operation of 126 reactors. Maintaining a high level of safety and competitiveness is a major challenge and requires the establishment of a coordinated and focused R&D programme at European level, well interconnected with IAEA and OECD-NEA activities

- Most European countries operating NPPs are now considering prolonging the lifetime of their reactors from an originally foreseen 40 years' operation to 60 years. In order to safely extend the lifetime of these reactors, the nuclear sector needs to have, in addition to a skilled and well-trained workforce, reliable tools to assess the ageing and degradation processes of components and structures, as well as methods and guidelines for their validation. The contribution from the Euratom R&D programme to this top priority must continue and be focused on the expressed needs of the European industry
- Industrial scale deployment of so called Generation IV nuclear energy systems is expected around the middle of the 21st Century. European contribution, above all to safety, sustainability, non-proliferation resistance, physical protection and competitiveness aspects of these innovative systems is clearly recognized at the international level. JRC remains the implement agent of Euratom in GIF whilst specific indirect actions should be aimed at coordinating the contribution from interested Member States

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- Limited resources at European level on advanced reactors and related fuels and fuel cycles suggest prioritization on the most promising nuclear systems for Europe
- In the meantime there is the need to maintain flexibility within current and future Euratom programmes to consider, at appropriate time, other emerging nuclear technologies, including those given high priority in other regions of the world, like for instance SMRs, nuclear-renewable hybrid energy systems, etc.
- Non-electric applications of NP, like H2 production, district heating, several industrial applications, desalination, etc. are of increasing interest in many regions of the world including some EU Member States. They have the potential to decarbonize the whole energy sector. Synergies with chemical industry should be developed as soon as possible and related R&D in Europe should be focused on near-term deployment

- Despite the planned life extension of aging NPPS, a number of NPPs in Europe are expected to be shut-down in coming years. Decommissioning and dismantling industrial-oriented R&D activities have to be appropriately supported by forthcoming Euratom programmes
- Many efforts have been devoted during last decades to develop advanced physical models and computer simulation codes of high fidelity, including in the very challenging area of severe accident M&S. However new technologies such as artificial intelligence, on-line monitoring, deep-learning, etc. are rapidly being introduced in many advanced technology sectors. Forthcoming Euratom programmes should take into account these new trends and foster the early involvement of European industry and TSOs which represent the final users
- Nuclear applications and technologies, and related competence and expertise, in the fields of medicine, radiation protection and in general non-power applications are recognized of great value for a modern society in all the EU Member States. As a consequence Euratom programme should be seen as an integral part of the broader Horizon Europe proposal able to capitalise on synergies over a much wider range of research areas. Joint projects between Euratom and Horizon Europe programmes should be pursued whenever possible (mission oriented projects)

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- Ensuring a top-level education & training, involving basic academic education as well as continuous professional development and capacity building is of paramount importance to create a new generation of nuclear researchers and experts able to maintain high levels of safety throughout the sector and address the challenges posed by advanced nuclear power and non-power technologies of European interest
- There is a strong and urgent need to maintain and strengthen a robust, enduring and efficient infrastructure base across the EU to underpin all aspects of research and innovation throughout the sector
- There is the need to capitalize on the European Technology Platforms SNETP- NUGENIA, -ESNII, -NC2I as well as ENEN as for E&T. ETPs are very important to foster and strengthen collaboration between research/academic institutes and industry
- International cooperation and synergies with initiatives launched by other international agencies like NI2050 & NEST by OECD-NEA, ICERR and E&T networks by IAEA, GIF task forces on infrastructure and E&T have to be fostered and strengthened as well

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- There are significant cross-cutting benefits and synergies that can be realised between fission/fusion/non-nuclear (e.g. materials) energy research programmes, as fusion evolves from activities focused on basic plasma physics to ones focused more on technology and safety-related aspects

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EURADWASTE ‘19
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New composite material based on heavy concrete reinforced by basalt-boron fiber for radioactive waste management

I. ROMANENKO[1], M. HOLIUK[1], V. GULIK[1], P. KUTSYN[1], I. KUTSYNA[1], G. ODINOKIN[1], A. NOSOVSKYI[1], Y. CHUVASHOV[2], V. PASTSUK[3], M. KIISK[3], A. BILAND[4]

[1]Institute for Safety Problems of Nuclear Power Plants, Ukraine
[2]Institute for Problems in Materials Science, Ukraine
[3]Institute of Physics, University of Tartu, Estonia
[4]US Basalt Corp., United States of America

Abstract

For safe operation of various sources of radioactivity, it is necessary to have reliable radiation protection. To date, there are many different types of radiation sources in the world, such as conventional fission reactors, fusion neutron sources, D-D and D-T neutron generators, plasma focus devices as neutron sources and many gamma sources. These radiation sources are used for industrial, scientific and medical purposes. At the moment, there are different types of radiation protection. The most widespread - heavy concrete with various additives. Such heavy concrete should have radiation shielding properties, both from neutron and from gamma sources. For example, to protect against gamma radiation, we need to use materials with large values of the atomic number Z. As a result, for protection against gamma radiation, the most widely used are fillers, such natural minerals as barite containing a lot of barium, magnetite - contains titanium and iron, and serpentinite.

In this study, the authors investigate the gamma-ray and neutron attenuation characteristics of two different types of concrete, both reinforced with a novel basalt-boron fiber with varying proportions of natural and enriched boron. The authors focus on the production of specially enhanced basalt fiber.

A new composite material for neutron radiation shielding properties is presented on the basis of heavy concrete with serpentinite aggregate and with basalt-boron fiber with different concentrations of boron oxide, for using in biological shield in nuclear waste management applications. The protective properties of the new composite material were investigated with different neutron source, there are: 1) neutrons with 14 MeV energy; 2) fast fission neutrons for U-235; 3) fast fission neutrons for U-235 after passing a water layer. The simulation of the neutron radiation in presented composite material with adding crushed stone aggregate and serpentinite aggregate is performed with the help of the Monte Carlo Serpent code. It is shown that basalt-boron fibers in concrete are improves the protective properties of concrete from neutron irradiation for neutrons with different energies, but the most effective is the addition of a basalt-boron fiber in the case of thermal neutrons. Also, the basalt-boron fiber samples were produced at laboratory conditions. The several series of tests were carried out for prepared samples. The neutron experiment on radiation shielding properties of concrete reinforced by basalt-boron fiber was performed at Pu-Be neutron source.

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From modelling part of this work, it is found that even though the addition of basalt-boron fiber in concrete has negligible effects for very fast neutrons with energy 14 MeV, considerable shielding improvements are observed for fast fission spectrum neutrons, which means that the use of basalt-boron fiber as reinforcing material in concrete could in fact be a viable shielding material for nuclear reactor facilities both for reactors with fast fission spectrum (e.g. BN-800 (Russia) or FBTR (India)) and for conventional reactors with light water moderator (e.g. LWR). This statement is also supported by the fact that the use basalt-boron fiber could also decrease the thickness of radiation shielding protection at Nuclear Power Plants.

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Effects of the initial granular structure of clay sealing materials on their swelling properties: experiments and DEM simulations

B. DARDE[1], A. M. TANG[1], J. N. ROUX[1], J. M. PEREIRA[1], P. DANGLA[1], J. TALANDIER[2], M. N. VU[2]

[1]Laboratoire Navier, Université Paris-Est, UMR 8205 (Ecole des Ponts ParisTech - Ifsttar - CNRS), Marne-la-Vallée, France, France
[2]French National Radioactive Waste Management Agency (Andra), Châtenay-Malabry, France, France

Abstract

Bentonite-based materials are considered as a sealing material for the isolation of galleries in radioactive waste disposal concepts because of their low permeability, radionuclide retention capacity and ability to swell upon hydration. This latter is an important property to fill technological voids. Within this context, bentonite pellet mixtures have been studied owing to operational convenience. Pellets are installed in a dry state as a granular assembly. The mixture homogenises upon hydration from the host rock pore water. At full saturation, homogenised pellet mixtures are thought to behave as classic compacted bentonite materials. However, before homogenisation, the granular nature of the material controls the macroscopic behaviour of the mixture. Interactions between pellets and their consequences on the macroscopic behaviour of the mixture have to be studied to carry out predictive simulations of the evolution of engineered barriers, especially during the first years following installation.

In this work, the influence of the granular nature of the material is studied through Discrete Element Method (DEM) simulations. A model based on the Hertz law and perfect plasticity at contact is proposed. Friction at contact is described using the Coulomb law. Model parameters such as pellet stiffness, volumetric strain and elastic limit are characterised upon suction decrease in the laboratory. Swelling pressure tests of pellet mixtures, carried out at laboratory scale, are then simulated using the proposed model. The model is shown to satisfactorily reproduce the mixture behaviour upon hydration from 89 MPa (initial state) to 9 MPa of suction, the value below which the granular structure is thought to lose its influence on the mixture macroscopic behaviour.

Results highlight that the swelling pressure evolves in two phases upon suction decrease. The first phase is characterised by the increase of elastic contact forces and is influenced by the sample preparation. The second phase is characterised by the occurrence of plasticity at contacts and is influenced by the progressive decrease of pellet strength and stiffness. Furthermore, it is shown that a low ratio of pressure sensor diameter to pellet diameter induces a significant variability of the measured swelling pressure in experimental tests.

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Direct Method for Determination of ^{14}C massic Activity in Irradiated Graphite

J. GARANKIN, E. LAGZDINA, R. PLUKIENE, A. GUDELIS, A. GARBARAS, L. JUODIS, A. PLUKIS, D. LINGIS, V. REMEIKIS, V.

Center for Physical Science and Technology, Lithuania

Abstract

^{14}C is one of the limiting radionuclides for categorization of radioactive graphite waste. In order to optimize pretreatment or disposal strategy, the precise and fast method for determination of ^{14}C massic activity is needed. Recently we proposed a rapid analysis method for the 14C massic activity determination in small graphite samples of the 1-100 µg range. The proposed method is based on the graphite combustion and subsequent CO_2 and ^{14}C measurements by using the commercial elemental analyzer and the semiconductor detector, respectively. There is no need for sample weighing. The detection procedure for sample containing a higher ^{14}C activity than 20 Bq takes approximately 10 minutes. Although the estimated efficiency of the semiconductor detector system is fairly poor (15%) due to the less than the ideal 4π geometry, the uncertainty of the rapid method is in an acceptable range (10-20%) for radioactive waste characterization purposes.

The proposed method was compared with measurements done by conventional liquid scintillation counter Quantulus-1220 (PerkinElmer, USA) and gas catchers (3M NaOH) to evaluate the accuracy of measurements for very small mass samples with the low ^{14}C activity. LSC measurements were traceable to the national standard of activity. The ^{14}C activity in a graphite sample was calculated taking into account activity determined in the catchers, the counting efficiency, the recovery efficiency and the aliquot volume. The linear approximation function between the activity measurements from the LSC method and the semiconductor detectors was determined. This function could serve as the ^{14}C activity calibration curve and could be used for rapid ^{14}C activity determination in routine measurements. The proposed rapid analysis method could be implemented for the direct radioactive waste characterization by using the scaling factor method or even used in biomedical applications when dealing with the massic activity determination of ^{14}C in a sample.

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Chromium doped UO2-based Model Systems: the Model Materials for the Study of the Matrix Corrosion of Modern Spent Nuclear Fuels

P. KEGLER[1], M. KLINKENBERG[1], A. BUKAEMSKIY[1], G. DEISSMANN[1], D. BOSBACH[1], E. ALEKSEEV[1], R. DELVILLE[2], C. CACHOIR[2], T. MENNECART[2], K. LEMMENS[2], M. VERWERFT[2]

[1]Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research - Nuclear Waste Management and Reactor Safety, Germany
[2]Belgian Nuclear Research Centre, BE-2400 Mol, Belgium

Abstract

The current efforts to improve fuel performance in nuclear power generation resulted in an increased utilization of a variety of new types of light-water reactor (LWR) fuels such as Cr-, Al-, and Si-doped fuels. The corrosion behavior of these types of fuels in the systems relevant to deep geological waste repository has hardly been studied so far. Experiments with spent nuclear fuel (SNF) cannot entirely unravel all of the various concurring dissolution mechanisms due to the chemical and structural complexity of spent nuclear fuel and its high beta- and gamma radiation field and technical restrictions allowing only for a very limited number of experiments. Therefore, within the EU-DISCO project (www.disco-h2020.eu) experiments on irradiated Cr-doped fuels are complemented with systematic dissolution studies carried out with carefully prepared and characterized, simplified UO2-based model materials. A bottom-up approach is followed to understand how the addition of Cr-oxide into the fuel matrix affects SNF dissolution behavior under repository relevant conditions.

Here, we present recent results on the development and optimization of the process steps for a wet-chemical route to produce pure reference UO_2, Cr-doped UO_2 as well as Cr- and alpha doped (^{238}Pu) pellets. A wet chemical route was favored due to the very low doping levels of ^{238}Pu required to mimic fuel ages between 1,000 and 10,000 a later in DISCO. Process optimisation was achieved by a systematic investigation of various process parameters such as calcination temperature and pelletisation pressure. Syntheses were performed by co-precipitation and wet-coating methods and had to be free of any grinding steps to be applicable in a dedicated glove box. In order to provide insights into the effects of the material's micro-structure on the dissolution behaviour (e.g. regarding the larger grain size in doped fuels and contributions of grain boundaries) the model materials are produced in form of sintered pellets. The microstructure (grain size, grain orientation) of and dopant distribution (i.e. either in solid solution within the UO_2 matrix or segregated on grain boundaries) in the model materials were characterised using various methods (e.g. SEM, EBSD, EMPA, ToF-SIMS, XRD).

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LIST OF PARTICIPANTS

ABOUSAHL Said
EUROPEAN COMMISSION - JOINT RESEARCH CENTRE
Belgium
said.abousahl@ec.europa.eu

AGOSTINI Pietro
ENEA
Italy
pietro.agostini@enea.it

AIOANEI Laurentiu Costel
Institute for Nuclear Research
RATEN ICN
Romania
laurentiu.aioanei@nuclear.ro

AÏT ABDERRAHIM Hamid
SCK-CEN
Belgium
haitabde@sckcen.be

AKTAA Jarir
Karlsruhe Institute of Technology (KIT)
Germany
jarir.aktaa@kit.edu

AL MAZOUZI Abderrahim
EDF R&D
France
abderrahim.al-mazouzi@edf.fr

ALEMBERTI Alessandro
Ansaldo Nucleare
Italy
alessandro.alemberti@ann.ansaldoenergia.com

AMBROSINI Walter
Università di Pisa
Italy
walter.ambrosini@unipi.it

ANCUTA Mirela
RATEN ICN Pitesti
Romania
mirela.ancuta@nuclear.ro

ANGHEL Claudia
RATEN ICN PITESTI
Romania
Claudia.anghel@nuclear.ro

APOSTOL Minodora
RATEN ICN PITESTI
Romania
minodora.apostol@nuclear.ro

BARBU Gabriela
RATEN ICN
Romania
Gabriela.barbu@nuclear.ro

BEILMANN Markus
OECD Nuclear Energy Agency
France
Markus.Beilmann@oecd-nea.org

BENTAIB Ahmed
IRSN
France
ahmed.bentaib@irsn.fr

BETTI Maria
European Commission, Joint Research Centre, Directorate G
Germany
maria.betti@ec.europa.eu

BLANC Jean-Yves
CEA
France
jean-yves.blanc@cea.fr

BODI Janos
Paul Scherrer Institut
Switzerland
janos.bodi@psi.ch

BOHNSTEDT Angelika
KIT - Karlsruhe Institute of Technology
Germany
angelika.bohnstedt@kit.edu

BOURG Stephane
CEA
France
Stephane.bourg@cea.fr

BRABETE Virgil
RATEN ICN PITESTI
Romania
plan@nuclear.ro

BRACKE Guido
GRS gGmbH
Germany
guido.bracke@grs.de

BREAZU Elena Madalina
UPIT
Romania
breazuelenamadalina@yahoo.ro

BRUNA Giovanni
Expert
France
gianni.bruna@gmail.com

CAMARCAT Noel
EDF
France
noel.camarcat@edf.fr

CARRE Franck
CEA
France
franck.carre@cea.fr

CARREÑO SÁNCHEZ Amanda María
Universitat Politècnica de València
España
amcarsan@iqn.upv.es

CAZACU Laurentiu
CA RATEN
Romania

CHILD Patrick
EUROPEAN COMMISSION
Belgium
patrick.child1@ec.europa.eu

CHIRIAC Bianca Nicoleta
Universitatea din Pitești
România
chiriacbianca@yahoo.com

CHIRICA Teodor
FORATOM/ Nuclearelectrica
Romania
tchirica@nuclearelectrica.ro

CIOCIRLAN Andrei Bogdan
Universitatea din Pitesti
Romania
ciocirlan.andreibogdan@yahoo.com

COCEA Dumitru
CA RATEN
Romania

CODESCU Dan
CA RATEN
Romania

COECK Michèle
Belgian Nuclear Research Center
Belgium
mcoeck@sckcen.be

COGNET Gérard
NucAdvisor
France
gerard.cognet@outlook.fr

COMSA Olivia
Safetech Innovations
Romania
olivia.comsa@safetech.ro

CONSTANTIN Mihai
RATEN ICN Pitesti
Romania
Mihai.constantin@nuclear.ro

COSTACHE Sofia
RATEN ICN PITESTI
Romania
sofia.costache@nuclear.ro

DANESCU Elena-Alina
UNIVERSITATEA DIN PITESTI
Romania
andronic.lucian@gmail.com

DE HAAS Geert-Jan
NRG
Nederland
g.dehaas@nrg.eu

DERMARKAR Fred
CANDU Owners Group
Canada
Fred.dermarkar@candu.org

DIEGUEZ PORRAS Pedro
ENEN
Belgium
pedro.dieguez@enen.eu

COJOCARU Ileana Valentina
RATEN
Romania
valentina.cojocaru@raten.ro

CONSTANTIN Marin
RATEN ICN
Romania
marin.constantin@nuclear.ro

CONSTANTIN Alina
RATEN ICN PITESTI
Romania
Alina.constantin@nuclear.ro

CRETU Ileana
RATEN ICN PITESTI
Romania
Ileana.cretu@nuclear.ro

DARIE Mariana
RATEN ICN PITESTI
Romania
mariana.darie@nuclear.ro

DEMAZIERE Christophe
Chalmers University of Technology
Sweden
demaz@chalmers.se

DIACONU Daniela
RATEN ICN PITESTI
Romania
Daniela.diaconu@nuclear.ro

DIES Javier
Nuclear Safety Council CSN
Spain
Javier.Dies@csn.es

DINU Alice Daniela
RATEN
Romania
alice.dinu@nuclear.ro

DOBRIN Relu Ion
RATEN ICN
Romania
Relu.dobrin@nuclear.ro

DOMITR Pawel
National Atomic Energy Agency (PAA)
Poland
domitr@paa.gov.pl

DRAGOI George
RATEN ICN Pitesti
Romania
george.dragoi@nuclear.ro

DUMITRESCU Iulia Maria
RATEN ICN-PITESTI
Romania
iulia.dumitrescu@nuclear.ro

DURRANT Aiden
UNIVERSITY OF LINCOLN
UK
adurrant@lincoln.ac.uk

DUVVURU MOHAN Varenya Kumar
Delft University of Technology
Netherlands
v.k.duvvurumohan@tudelft.nl

DŽUBINSKÝ Mykola
European Commission
Belgium
mykola.dzubinsky@ec.europa.eu

ELORZA Franciso Javier
UPM
Spain
Franciscojavier.elorza@upm.es

ENACHE Gabriela
RATEN ICN PITESTI
Romania
gabriela.enache@nuclear.ro

ENE Denisa Valentina
UPIT
Romania
denisavalentina.ene@gmail.com

EPSKAMP Kirsten
European Nuclear Society
Belgium
kirsten.epskamp@euronuclear.org

FAKO Raluca
RATEN CITON
Romania
fakor@router.citon.ro

FAZIO Concetta
JRC
Netherlands
concetta.fazio@ec.europa.eu

FOERSTER Evelyne
CEA
France
evelyne.foerster@cea.fr

GARANKIN Jevgenij
Centre for Physical Sciences and Technology
Lithunaia
jevgenij.garankin@gmail.com

GARBIL Roger
European Commission
Belgium
roger.garbil@ec.europa.eu

GARDIN Ionela - Adriana
University of Pitesti
Romania
gardinionelaadriana@yahoo.com

GENTEA Cristian
RATEN
Romania
cristian.gentea@raten.ro

GEORGES Christine
CEA
France
christine.georges@cea.fr

GEORGESCU Raluca
RATEN ICN
Romania
Raluca.georgescu@nuclear.ro

GHEORGHE Stefan Cristian
Universty of Pitești
România
gstefancristian@yahoo.com

GHITA Cosmin
NUCLEARELECTRICA S.A.
Romania
cghita@nuclearelectrica.ro

GHITESCU Petre
UPB/ENEN
Romania
ppghites@hotmail.com

GILLET Guillaume
EIT InnoEnergy
France
guillaume.gillet@innoenergy.com

GLONT Andrei
UPIT
Romania
andreiglont13@yahoo.com

GONDAC Ileana Violeta
RATEN ICN
Romania
ileana.gondac@nuclear.ro

GONZALEZ ROMERO Enrique Miguel
CIEMAT
Spain
enrique.gonzalez@ciemat.es

GRASSO Giacomo
ENEA
Italy
giacomo.grasso@enea.it

GRISOLIA Christian
CEA
France
Christian.grisolia@cea.fs

GUGIU Elena Daniela
RATEN ICN
Romania
daniela.gugiu@nuclear.ro

GUILLEMIN Julien
Onet Technologies
France
jguillemin@onet.fr

HEBER Katarine Lucia
University of Pitesti
Romania
luciakatharine@yahoo.com

HILALI Wael
University of Stuttgart
Germany
wael.hilali@polytechnique.edu

HURDUC Nicolae
Ministerul Cercetarii si Inovarii
Romania

IONESCU Marian-Nicolae
RATEN ICN
Romania
marian.ionescu@nuclear.ro

IONESCU Victor
Universitatea din Pitesti
Romania
experimentalnewdesign@yahoo.com

IONESCU Viorel
RATEN ICN
Romania
Viorel.ionescu@nuclear.ro

IONITA Catalin Stefanita
University of Pitesti
Romania
s.ionita94@yahoo.com

IORDACHE Roxana
RATEN ICN
Romania
Roxana.iordache@nuclear.ro

JINESCU Gheorghita
Academia de Stiinte Tehnice din Romania
Romania
dilucan@yahoo.com

JINESCU Valeriu V.
Academia de Stiinte Tehnice din Romania
Romania
dilucan@yahoo.com

JOITESCU Elena Roxana
University of Pitesti
Romania
Roxana.2105@yahoo.com

KARIMI SABET Javad
Atomic Energy Organization of Iran
Iran
jvkarimi@aeoi.org.ir

KORITTOVÁ Veronika
Technology Centre CAS
Czech republic
korittova@tc.cz

KOSOWSKI Kai
PreussenElektra GmbH
Germany
kai.kosowski@preussenelektra.de

KRAL Pavel
UJV Rez
Czech republic
pavel.kral@ujv.cz

KWIATKOWSKI Tomasz
National Centre for Nuclear Research
Poland
t.kwiatkowski@ncbj.gov.pl

LATHOUWERS Danny
TUDELFT
Netherlands
d.lathouwers@tudelft.nl

LAZYKINA Anastasia
IAEA
A.Lazykina@iaea.org

LE GALL Claire
CEA
France
legall.claire1@gmail.com

LOPEZ Anabelle
CEA
France
Anabelle.lopez@cea.fr

LOSASSO Marcello
CERN
Switzerland
marcello.losasso@cern.ch

LUCACIU Gheorghe
ROMATOM
Romania
gh.lucaciu@gmail.com

LUCAN Dumitra
Institute for Nuclear Research
Romania
dumitra.lucan@nuclear.ro

LULACHE Daniela
OECD Nuclear Energy Agency (NEA)
France
daniela.lulache@oecd-nea.org

MALERBA Lorenzo
CIEMAT
Spain
lorenzo.malerbo@ciemat.es

MANOLATOS Panagiotis
European Commission DG RTD
Belgium
panagiotis.manolatos@ec.europa.eu

MARGEANU Cristina Alice
RATEN ICN PITESTI
Romania
cristina.margeanu@nuclear.ro

MARIAS Foivos
European Commission
Belgium
foivos.marias@europa.eu

MARIN Tatiana Ionela
Universitatea din Pitesti
Romania
m.oana26@yahoo.com

MARIN Andrei-Alexandru
University of Pitesti
Romania
andreimarin.webevolution@gmail.com

MARTÍN RAMOS Manuel
European Commission Joint Research Centre
Belgium
Manuel.martin-ramos@ec.europa.eu

MARTINEZ-DELCAYROU Alban
CEA/INSTN
France
alban.md@gmail.com

MASCHI Michel
EDF R&D
France
michel.maschi@edf.fr

MATEESCU Maria Magda
UPIT – University of Pitesti
Romania
mateescumariamagda@yahoo.com

MATEI Aneta
MINISTERUL ENERGIEI
Romania

MALUREANU Simona
MCI
Romania

MCGRATH Margaret
PALLAS
Netherlands
margaret.mcgrath@pallasreactor.com

MEDIA Marius
RATEN ICN
Romania
Marius.media@nuclear.ro

MIHAI Ramona
RATEN ICN
Romania
Ramona.mihai@nuclear.ro

MIHALACHE Maria
RATEN ICN-PITESTI
Romania
maria.mihalache@nuclear.ro

MIKITYUK Konstantin
PSI
Switzerland
Konstantin.mikityuk@psi.ch

MIRCEA Stefania Daniela
University of Pitesti
Romania
mirceastefaniadaniela@yahoo.com

MIRESCU Ionut-Alexandru
University of Pitesti
Romania
mirescu.alexandru@gmail.com

MOGA Liviu
UPIT
Romania
demogaliviu012897@gmail.com

MONTI Stefano
International Atomic Energy Agency
Austria
s.monti@iaea.org

MOTTERSHEAD Kevin
Wood
UK
kevin.mottershead@woodplc.com

MOUTIERS Gilles
CEA
France
gilles.moutiers@cea.fr

MULLER Florian
CEA/INSTN
France
florian.muller99@wanadoo.fr

NEACȘU Irina Elena
University of Pitesti
România
irina.neacsu13@yahoo.ro

NECULAE Valentina
RATEN ICN
Romania
Valentin.neculae@nuclear.ro

NEDELCU Elena Carmen
CNE Cernavoda
Romania
cnedelcu@cne.ro

NEIGHBOUR Gareth
Open University
Uk
gareth.neighbour@open.ac.uk

NICOLAE Alexandru-Mihai
RATEN ICN Pitesti
Romania
alexandru.nicolae@nuclear.ro

NITA Iulian
RATEN CITON
Romania
nitai@router.citon.ro

NITOI Mirela
RATEN ICN
Romania
mirela.nitoi@nuclear.ro

NITU Alexandru
RATEN ICN
Romania
alexandru.nitu@nuclear.ro

NUTTALL William
The Open University
United Kingdom
william.nuttall@open.ac.uk

OLARU Valentin
RATEN ICN
Romania
Valentin.olaru@nuclear.ro

PACI Sandro
Pisa University
Italy
sandro.paci@ing.unipi.it

PANA Gigi
MCI
Romania

PATERSON Nathan
FORATOM
Belgium
nathan.paterson@foratom.org

PAUNOIU Constantin
RATEN ICN PITESTI
Romania
constantin.paunoiu@nuclear.ro

PAVEL Gabriel
European Nuclear Education Network
Romania
gabriel.pavel@enen.eu

PETRA Mihaela
RATEN ICN PITESTI
Romania
Mihaela.petra@nuclear.ro

PETREANU Marius
RATEN ICN Pitesti
Romania
mariusc12@yahoo.com

PETRIDIS Athanasios
EC, DG-RTD
Belgium
Athanios.petridis@ec.europa.eu

PIETRIȘ Iulia Maria
Universitatea din Pitesti
Romania
pietris.iulia@yahoo.com

PIRVU Ion
RATEN ICN
Romania
ion.pirvu@nuclear.ro

PÎRVU Andreea Madalina
Universitatea din Pitesti
Romania
pirvu.andreea.madalina1996@gmail.com

PIZZOCRI Davide
Politecnico di Milano
Italy
davide.pizzocri@polimi.it

PLAVETI Victoria
Ramapo College of New Jersey
United states
vplaveti@ramapo.edu

POPA Ionela-Cristina
UPIT
Romania
Cristina_enache@yahoo.com

POPA Mircea
MCI
Romania

POPESCU Ana
Universitatea din Pitesti
Romania
ana_popescu942010@yahoo.com

POPESCU Angelica
RATEN
Romania

POPESCU Lucia
MCI
Romania

PREDA Stefan
RATEN ICN
Romania
Stefan.preda@nuclear.ro

PRISACEANU Claudia
CA RATEN
Romania

PRODEA Iosif
RATEN ICN PITESTI
Romania
vprodea@gmail.com

PROFIR Manuela
CRS4
Italy
manuela@crs4.it

PTACKOVA Katerina
European Commission
Belgium
katerina.ptackova@ec.europa.eu

PURICA Ionut
Romanian Academy
Romania
Ipurica@gmail.com

PUSKA Eija Karita
VTT Technical Research Centre of Finland Ltd
Finland
eija-karita.puska@vtt.fi

QUÉNÉHERVÉ Gilles
LGI / NUGENIA Secretariat
France
gilles.queneherve@lgi-consulting.com

RADU Vasile
RATEN ICN
Romania
vasile.radu@nuclear.ro

RADU Alexandra Gabriela
University of Pitesti
Romania
radu_alexandra1996@yahoo.com

RADU George-Nicolae
University of Pitești
România
Radugeo_2010@yahoo.com

RAVETTO Piero
CIRTEN - Politecnico di Torino
Italy
piero.ravetto@polito.it

RETEGAN Teodora Valeria
Chalmers
Sweden
tretegan@chalmers.se

RIMKEVICIUS Sigitas
Lithuanian Energy institute
Lithuania
Sigitas.Rimkevicius@lei.lt

ROCCHI Federico
ENEA
Italy
federico.rocchi@enea.it

ROCKERAS Pierre
EC
Belgium
Pierre.rockeros@ec.europa.eu

ROKROK Behrouz
Nuclear Science and Technology Research Institute
Iran
brokrok@aeoi.org.ir

ROMOJARO Pablo
CIEMAT/UPM
Spain
pablo.romojaro@ciemat.es

ROSSETTI DI VALDALBERO Domenico
European Commission
domenico.rossetti-di-valdalbero@ec.europa.eu

ROTARI Daniel
University of Pitesti
Romania
daniel_rotari@yahoo.com

ROTH Csaba
Institutul de Cercetari Nucleare Pitesti (RATEN ICN)
Romania
csaba.roth@nuclear.ro

ROTH Maria
Regia Autonoma Tehnologii pentru Energia Nucleara (RATEN)
Romania
maria.roth@raten.ro

SALLAH Mohammed Ibrahim
Mansoura University
Egypt
msallahd@mans.edu.eg

SANCHEZ Ivan
CIEMAT
Spain
Ivan.sanchez@ciemat.es

SANCHEZ Victor
Karlsruhe Institut of Technology
Germany
victor.sanchez@kit.edu

SANDU Cristina
Universitatea din Pitesti
România
Izabela.nicolae@yahoo.ro

SARBU Monica Victoria
University of Pitești
Romania
monicavictoria.sarbu@yahoo.com

SAVU Laura
RATEN ICN
Romania
Laura.savu@nuclear.ro

SCHUMM Andreas
EDF
France
andreas.schumm@edf.fr

SERBANEL Marieta
RATEN ICN Pitesti
Romania
marieta.serbanel@nuclear.ro

SERBANESCU Dan
NUCLEARELECTRICA SA
Romania
dserbanescu@nuclearelectrica.ro

SHENGLI Chen
CEA
France
chenshengli1226@outlook.com

SIMIC Sanja
CNSC
Canada
sanja.simic@canada.ca

SIMION Andreea Daniela
University of Pitesti
Romania
andreea.simion2194@yahoo.com

SIMOLA Kaisa
European Commission Joint Research Centre
Netherlands
kasimola@gmail.com

SLUJITORU Vlad Ilie
University of Pitesti
Romania
slujitoruvlad@yahoo.com

STACUI Cornel
MCI
Romania

STAICU Gheorghe
CITON
Romania
staicug@router.citon.ro

STAN Stefania Florentina
University of Pitesti
Romania
stan.stefania96@yahoo.com

STANCU (POPESCU) Alexandra Irina
Romanian
România
alle_inna3@yahoo.com

STARFLINGER Joerg
University of Stuttgart
Germany
joerg.starflinger@ike.uni-stuttgart.de

STEFAN Vollmer
United Kingdom
Vollmer.stefan@gmail.com

STOENESCU Luiza Diana
RATEN-ICN PITESTI
Romania
diana.stoenescu@nuclear.ro

STOICA Maria
University of Pitesti
Romania
Stoica_maria_victoria@yahoo.com

STYCZEŃ Paulina
Ministry of Science and Higher Education
Poland
paulina.styczen@nauka.gov.pl

SUSALA Elena-Roxana
RATEN ICN
Romania
susalaroxana@yahoo.com

SUTTER Florian
DLR
Germany
Florian.sutter@dlr.de

SZABALCS Szavai
BOY Z. NUMP.Ltd
Hungary
Szabalcs.szavai@bayzolton.hu

TARANTINO Mariano
ENEA
Italy
mariano.tarantino@enea.it

TISELJ Iztok
University of Ljubljana
Slovenia
iztok.tiselj@ijs.si

TOMA Alexandru
Institute for Nuclear Research (ICN)
România
alexandru.toma@nuclear.ro

TORAB MOSTAEDI Meisam
Nuclear Science and Technology Research Institute
Iran
mmostaedi@aeoi.org.ir

TOSOLIN Alberto
Politecnico di Milano
Italy
alberto.tosolin@polimi.it

TRAICU Rodin
NATIONAL COMMISSION FOR NUCLEAR ACTIVITIES CONTROL
Romania
rodin.traicu@cncan.ro

TROMM Th. Walter
KIT, Karlsruhe Institute of Technology
Germany
walter.tromm@kit.edu

TUDOR Gratiela-Irene
RATEN ICN
Romania
Gratiela.tudor@nuclear.ro

TUDOR Roxana Adriana
University of Pitesti
Romania
roxana.tudor@ymail.com

TURCU Ilie
RATEN ICN
Romania
ilie.turcu@nuclear.ro

TURLEA Silviu
RATEN ICN
Romania
Silviu.turlea@nuclear.ro

UDROIU Adriana-Meda
NATIONAL INSTITUTE FOR RESEARCH AND DEVELOPMENT IN INFORMATICS
Romania
meda.udroiu@gmail.com

URJAN Romeo
SNN, AREN
Romania
rurjan@nuclearelectrica.ro

URSU Ioan
IFIN-HH
Romania

VALACHE Cornelia Mariana
CNE Cernavoda
Romania
cvalache@cne.ro

VALANCE Stéphane
CEA
France
stephane.valance@cea.fr

VALECA Serban Constantin
RATEN ICN
Romania
serban.valeca@nuclear.ro

VAN ZEVEREN Jan
ENEN (PongPing)
Belgium
jan@pongping.studio

VARSEEV Evgenii
ROSATOM TECH
Russian federation
evvarseev@rosatomtech.ru

VASILACHE Radu
CAMBERRA PACKARD
Romania
r.vasilache@cpce.net

VILCU Andrei
RATEN ICN Pitesti
Romania
aucliv@gmail.com

VILLABRUNA Giovanni
Ansaldo Nucleare Spa
Romania
villabruna@ansaldo.ro

VISAN Doru
MINISTERUL ENERGIEI
Romania

VITCHEVA Charlina
JOINT RESEARCH CENTRE, EUROPEAN COMMISSION, EU
Belgium
charlina.vitcheva@ec.europa.eu

VITULLO Fanny
École polytechnique fédérale de Lausanne (EPFL)
Switzerland
fanny.vitullo@epfl.ch

VLADA Adrian
Safetech Innovations
Romania
adrian.vlada@safetech.ro

VLADU Georgiana-Teodora
UNIVERSITY OF PITESTI
Romania
georgiana.teodoraa@yahoo.com

WALLENIUS Janne
KTH
Sweden
janne@wallenius.pub

WITHOUCK Steve
ENEN / PongPing Studio
Belgium
steve@pongping.studio

WOAYE HUNE Antony
Framatome
France
antony.woayehune@framatome.com

WROCHNA Grzegorz
NCBJ
Poland
g.wrochna@ncbj.gov.pl

YI Huaiqian
Chalmers University of Technology
Sweden
huaiqian@chalmers.se

ZANIN Egidio
RINA-CSM
Italy
Egidio.zanin@rina.org

ZATLKAJOVA Helena
EC
Belgium
helena.zatlkajova@ec.europa.eu

ZAVOIANU Gina
RATEN ICN
Romania
Gina.zavoianu@nuclear.ro

ZEGRI Jacobo
NUCLEAR SAFETY COUNCIL OF SPAIN
España
jacobo.zegri@csn.es

ZHURAVLEV Pavel
Russian Federation

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