EUROPEAN COMMISSION

Community research

safe solutions for radioactive waste

Implementing Geological Disposal for Radioactive Waste - Technology platform

IGD-TP Exchange Forum n°6

November 3-4th, 2015

London, UK

Presentations and outcomes

This event is co-funded by the European Union under the 7th Euratom Framework Programme,
Grant agreement number 323260 - SecIGD2 project

Forewords

Annually, the **IGD-TP Exchange Forum** (EF) gathers the geological disposal of radioactive waste community in order to i) informally exchange around common interests in research, development and demonstration (RD&D), ii) highlight IGD-TP ongoing activities and EC projects, iii) initiate or deepen collaborations with other organisations, iv) explore new ideas that could complement the IGD-TP Strategic Research Agenda and v) prepare future activities and projects that may be developed in the framework of the EC Euratom work programme.

The **6th Exchange Forum (EF6)** was held on **3-4th November 2015 in London, UK** and gathered **about 160 participants** from 18 different countries (Europe, US and Japan). Specific Key-notes were given in plenary sessions on:

- Siting Process in UK
- H2020 WP 2016-2017 and future Euratom programmes
- Radiation Protection Research in Europe
- Integration Group for the Safety Case (IGSC) Interaction with the IGD-TP
- State of high-level waste disposal in the U.S

For this 6th edition, it was decided to **review EC projects** that were completed in 2014. These are PEBS, MODERN, FIRST-Nuclides and REDUPP projects. The aim was to present the outcomes and assess the achievements of these projects and presented how they have helped to reach the IGD-TP's vision.

Furthermore, the three **technical project accepted by EC in the framework of the Horizon 2020 Euratom 2014-2015 Work programme** *i;e.* MODERN 2020, CEBAMA and MIND were presented to the EF6 participants..

In addition to the plenary sessions, **four parallel technical sessions** was organised around four topics with the objective to discuss 4 topics that could be submitted as EC project in the forthcoming call:

- WG1 - Novel thermal treatments for waste
- WG2 - Bentonite homogenization
- WG3 - Cement Organics Radionuclide Interactions
- WG4 - Spent fuel dissolution & chemistry in container

This document presents the abstracts of the presentations made during EF6 as well as the outcomes of the four working group sessions.

All presentations are available on the IGD-TP website www.igdtp.eu.

Role of the IGD-TP

- Share information, promote debate and understanding between member WMOs in the field of geological disposal RD&D;
- Define RD&D priorities that could lead to project s of European added value with the support of the European commission;
- Identify projects of European added value which may be undertaken as joint collaborative projects for the benefit of all programmes.

IGD-TP Exchange forum

- The Exchange Forum is the yearly meeting of the IGD-TP, gathering participants and stakeholders that are committing with our vision;
- The forum is intended to give an overview of on-going activities and to promote discussions on how to prioritize different activities to reach the Vision 2025;
- It may act as an incubator to new projects and collaborations in the field of geological disposal

Domain of activities

- The RD&D activities oriented toward geological disposal for high level and long lived waste should remain the driver of the work of the IGD-TP;
- The Strategic Research Agenda offers the possibility to enlarge the scope of the work toward radioactive management issues such as the waste forms and their behaviour
- The IGD-TP platform acts as an information exchange platform with other initiatives and fora such as SNETP, IGSC-NEA, MELODI, ENTRAP…

Some figures

11	Waste Management Organisations
124	participating organisations committing with the vision
9	FP7 projects (4 completed) (Total budget: 61 M€ - EC grant: 28 M€)
4	Horizon 2020 projects (Total budget: 21,3 M€ - EC grant: 15,1 M€)
5	proposals under discussion (WP 2016-2017)

Main activities in2015

Publications

- Review of the Strategic Research Agenda
- Proceedings of the 5th Exchange Forum
- Master deployment plan 2015
- RD&D Planning Guide

Joint Activities

Follow up outcomes of 5 technical projects

10 active working groups this year – 4 leading to EC projects

EC H2020 2015-2016 Work Programme: 5 technical project proposals are under discussion

Events PLANDIS workshop (PLANning geological DISposal of radioactive waste in Europe), May 2015, Bucharest 36 attendees from 12 European countries (RO, SK, FR, EC, UK, LT, SI, HU, CH, CZ, GER, GR)

Working group with SNETP Publication of the factsheet on Geological disposal

Preparing a Joint Programming Contribution to a project on Joint Programming on R&D with Technical Support Organisations and Research Entities

www.igdtp.eu

IGD-TP 6th Exchange Forum - Highlights

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Plenary session 1 – Key note speeches

Status of the Horizon 2020 Euratom Research and Training Framework Programme in the Management of Ultimate Radioactive Waste

Christophe Davies, EC DG Research and Innovation, Fission Energy

The Commission has now implemented the first Work Programme (2014-2015) of the Research and Training Programme of the European Atomic Energy Community (2014-2018), "Euratom Programme" complementing the Horizon 2020 Framework Programme for Research and Innovation.

The presentation will include an overview of the results of the call for proposals for the fission part of the programme and in the activity area "Contribute to the Development of Solutions for the Management of Ultimate Radioactive Waste"

In the meantime, the Commission published its second Work Programme (2016-2017) on 14 October 2015. The deadline for submitting proposals is on 05 October 2016. Following independent evaluation of the proposals, the selected projects are expected to start in mid-2017. The indicative budget for the area Management of Ultimate Radioactive Waste is € 18.89 million covering three topics. The rationale and objectives of the topics will be presented.

Development of Joint Programming of Member States's research programmes in the field of radioactive waste management and disposal solutions is central to EC policy. The JOPRAD EC funded project was launched in 2015 to develop a proposal by 2017 for implementation of an integrated programme document. The Commission's current perspective in this work will be presented.

Radiation Protection Research in Europe: Reaching out to IGD TP

Hildegarde Vandenhove & Nathalie Impens, SCK•CEN, Belgium

Nathalie Impens[a], Hildegarde Vandenhove[b], Frank Hardeman[c], Werner Rühm[d], Jacques Repussard[e], Thierry Schneider[f], Sisko Salomaa[g], Thomas Jung[h], Jean-René Jourdain[i].

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Radiation protection (RP) of workers, the public and wildlife is a corner stone of all activities in nuclear and other industries in which radioactive material is used. To develop a strategic roadmap for RP research in Europe the Radiation Protection Research Community has invited actors in the nuclear field alongside with other users of radioactive substances and ionizing radiation to participate in a stakeholder process. This will increase interactions and synergies with other organisations and platforms that are active in research domains that have facets in common with RP research. EURATOM supports these activities of interaction, amongst others through the FP7 project OPERRA (Open Project for the European Radiation Research Area). OPERRA successfully enhanced the necessary interactions between the RP research platforms, and organised a stakeholder conference with actors from industry, consumer protection and others.

The Radiation Protection Research Community and the progress made to develop the European Joint Programme "CONCERT" will be highlighted. The H2020 CONCERT project will manage the long-term European programmes in RP Research and will organise open calls for research and integration activities. The CONCERT structure and organisation will be explained.

Next, selected topics of potential joint interest to IGD-TP will be highlighted. These topics will be extracted from the Strategic Research Agendas (SRA) of the European research platforms ALLIANCE, EURADOS, MELODI and NERIS active in radioecology, dosimetry, effects and risks of low dose ionising radiation and emergency preparedness, respectively1. There are several links between nuclear safety and RP and the science underlying these disciplines. First of all, international nuclear safety guidelines are based on recommendations on RP, and RP recommendations in turn are based on scientific knowledge on radiation and its effects. As for RP practice, occupational RP in nuclear installations, environmental surveillance around nuclear power plants and preparedness for nuclear accidents are clearly areas of joint interest. Furthermore, there are RP issues across the whole nuclear fuel cycle, from uranium mining to final disposal of nuclear waste. At the more technological level, radiation measurements and technological applications are of shared interest for various purposes, ranging from safety, safeguards to security applications.

In addition there are some emerging research fields in which CONCERT intends to support the development of SRAs such as societal and ethical aspects of RP, risk perception and communication, and safety culture, of potential interest to IGD-TP. Finally we will present the plans of CONCERT to support the implementation of the revised European Basic Safety Standards by performing research.

This presentation could be the first step in initiating the interactions between IGD-TP and the Radiation Protection Research Community. We also hope that in depth discussions will follow this initiative, in order to select areas of common interest and, if relevant, to define potential modes of collaboration.

Acknowledgement: This abstract has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under OPERRA, Grant Agreement number 604984.

NEA IGSC Interaction with the IGD-TP

Lucy Bailey, RWM, UK

The OECD-NEA Integration Group for the Safety Case (IGSC) comprises senior technical specialists and managers from national waste management programmes, regulatory agencies and research and technical support institutions. The IGSC mission is to build and document the technical and scientific basis for developing and reviewing safety cases as a platform for dialogue amongst technical experts and as a tool for decision making.

There is clearly considerable synergy between the work of the IGSC and that of the IGD-TP. In areas of direct application to safety case development, the IGSC may be best placed to lead work in terms of access to the relevant experts.

A specific area of interest to the IGD-TP, where the IGSC has expertise, is the handling of uncertainty in post-closure safety cases. This talk will present the outcomes of a workshop on the handling of uncertainty in safety cases, hosted by RWM on 23 / 24 September 2015. The workshop addresses three main themes:

1. The quantification of uncertainty in uncertain parameters for modelling. The goal is to review existing approaches, demonstrate how bias may affect uncertainty quantification and consider practical tools to aid uncertainty quantification.

[1] ALLIANCE (the Radioecology Alliance http://er-alliance.org/); EURADOS (European Radiation Dosimetry Group; http://www.eurados.org/), MELODI (Multidisciplinary Low Dose Initiative; http://www.melodi-online.eu/index.html) is the European low-dose Association that took the initiative for the OPERRA project; NERIS (European Platform on preparedness for nuclear and radiological emergency response and recovery; http://www.eu-neris.net/)

2. Modelling aspects in the context of handling uncertainties including a review of the use of the outcomes of the EC PAMINA project and what has been developed since.
3. Sensitivity analysis – recent developments and applications of sensitivity analysis methods to repository performance assessment models.

The potential for future collaboration between the IGSC and IGD-TP on this topic, and other relevant topics, will be discussed.

State of High-level Waste Disposal in the U.S. – A Regulatory Perspective

James Rubenstone, US Nuclear Regulatory Commission

The national strategy for the ultimate disposition of high-level radioactive waste and spent nuclear fuel in the United States remains focused on deep geologic disposal, but agreement within the government is limited on the specific implementation. The U.S. Nuclear Regulatory Commission (NRC) is engaging in multiple activities for management of high-level waste and spent fuel to fulfil its mission while acknowledging the policy uncertainties. In response to direction from the U.S. Court of Appeals in 2013, the NRC resumed its review activities for the proposed repository at Yucca Mountain, Nevada. The NRC staff completed its Safety Evaluation Report in January, 2015, and in August issued for public comment a draft supplement to the Department of Energy's Environmental Impact Statement that provides additional analysis of potential impacts on groundwater. In parallel, the NRC staff is conducting focused technical studies to maintain and enhance its capabilities for future reviews of deep disposal in other geologic environments, including possible separate repositories for commercial spent fuel and high-level waste from defense activities. The technical studies include work on performance assessment, engineered barrier materials, waste forms, and coupled processes, as well as participation in international collaborations.

RD&D Planning Guide, Conclusion of the PLANDIS Workshop and future activities

Ray Kowe, RWM, UK

One of the roles of the Implementing Geological Disposal of Radioactive Waste Technology Platform (IGD-TP) SecIGD2 project whose remit is "Coordination and Support Action under the 7th Framework programme" is to support the IGD-TP through its Secretariat to address, at the European level, the networking and structuring of RD&D programmes and competences in countries with less advanced geological disposal programmes including those in the new European Union Member States.

This has included setting up a working group specifically to investigate the needs of new member states and to organise two international conferences (2014, 2015) for disseminating the scientific and technical information and results derived from the IGD-TP's Joint Activities as outlined in its Strategic Research Agenda (SRA) [1] and from other RD&D efforts in the field of geological disposal.

The working group has produced a guide to support RD&D Planning for geological radioactive waste disposal [2]. The Guide is specifically aimed at helping to develop a response to the RD&D related aspects of the Council Directive 2011/70/EURATOM Articles 12 (1,F) and 12 (1,J). [3]. It sets out the key steps in developing a geological disposal facility programme and strategy based on advanced waste management organisations experience and signposts open documentation and guidelines for specific technical areas.

The guide was communicated at a one day workshop (PLANning geological DISposal of radioactive waste in Europe – PLANDIS) which was held on 26 May 2015 and was hosted by the Institute for Nuclear Research, Piteşti in Romania. The workshop was an opportunity for new member states to gain experience of prioritising their potential RD&D work to meet their needs. They also had the opportunity to meet the more experienced RD&D planners from other countries.

[1] Implementing Geological Disposal Technology Platform (IGD-TP): Strategic Research Agenda (SRA), 2011.

[2] EURATOM FP7 IGD-TP, RD&D Planning Towards Geological Disposal of Radioactive Waste - Guidance for less-advanced Programmes, Deliverable (D-N°:2.3), 2015.

[3] OJEU, The Council Directive 2011/70/EURATOM, establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste resulting from civilian activities ("Waste Directive"), Official Journal of the European Union 2.8, 22 August 2011.

Plenary session 2 – New H2020 technical projects

Development and demonstration of monitoring strategies and technologies for geological disposal - Modern2020

Johan Bertrand, Andra, France

Modern2020 is a research and innovation action granted by the H2020 Euratom programme in support of the implementation of the first-of-the-kind geological repositories. Started 1st of June 2015, Modern2020 aims at providing the means for developing and implementing an effective and efficient repository operational monitoring programme, taking into account the requirements of specific national programmes.

The work allows advanced national radioactive waste disposal programmes to design monitoring systems suitable for deployment when repositories start operating in the next decade and supports less developed programmes and other stakeholders by illustrating how the national context can be taken into account in designing dedicated monitoring programmes tailored to their national needs. The work is established to understand what should be monitored within the frame of the wider safety cases and to provide methodology on how monitoring information can be used to support decision making and to plan for responding to monitoring results. Research and development work aims to improve and develop innovative repository monitoring techniques (wireless data transmission, alternative power supply sources, new sensors, geophysical methods) from the proof of feasibility stage to the technology development and demonstration phase. Innovative technical solutions facilitate the integration and flexibility of required monitoring components to ease the final implementation and adaptation of the monitoring system. Full-scale in-situ demonstrations of innovative monitoring techniques will further enhance the knowledge on the operational implementation of specific disposal monitoring and will demonstrate the performance of the state-of-the-art, the innovative techniques and their comparison with conventional ones. Finally, Modern2020 has the ambition to effectively engage local citizen stakeholders in the R&D monitoring activity by involving them at an early stage in a repository development programme in order to integrate their concerns and expectations into monitoring programmes.

Cebama – A collaborative project on cement-based materials, properties, evolution, barrier functions, within the EC/H2020 frame

Xavier Bourbon, Andra, France

Cebama is a research and innovation action granted by the European Atomic Energy Community in support of the implementation of the first-of-the-kind geological repositories. The 4-year project, started 1st of June 2015, is carried out by a consortium of 27 partners consisting of large Research Institutions, Universities, one TSO (Technical and Scientific Support Organizations), and one SME (small medium enterprise) from 9 EURATOM Signatory States, Switzerland and Japan. National Waste Management Organizations support Cebama 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.

Cebama addresses 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 builds on joining the best expertise available to tackle these problems and emphasizing how the knowledge can be applied in the Safety Analysis and Safety Case. Cebama will extend the state-of-the-art with respect to integration of key scientific and long-term safety issues. Progress beyond the state-of-the-art is achieved by providing basic and trustworthy knowledge, modeling tools and arguments for the Safety Case.

Information about Cebama, such as key project events, main scientific results, open PhD positions and research highlights are available on the project website (www.cebama.eu).

The overall strategic objective of Cebama is to support the implementation of geological disposal by significantly improving the knowledge base for the Safety Case for European repository concepts. The scientific/technical research of Cebama is largely independent of specific disposal concepts and addresses different types of host rocks, as well as bentonite. Cebama is not focusing on one specific cementitious material, but aims at studying a variety of important cement-based materials in order to provide insight on general processes and phenomena which can then be easily transferred to different applications and projects. Specific objectives of Cebama are summarized as follows:

- **Perform experimental studies to understand the interface processes between cement-based materials and the host rocks (crystalline rock, Boom Clay, Opalinus Clay (OPA), Callovo-Oxfordian (COX)) or bentonite backfill and assess the impact on physical (transport) properties.**
  - Understand how chemical reactions affect porosity, and water and gas transport properties at the interface for the following systems.
    - Low pH cementitious component - crystalline rock
    - Low pH cementitious component - bentonite
    - Low pH cementitious component - OPA, COX
    - High pH cementitious component - crystalline rock
    - High pH cementitious component - bentonite
    - High pH cementitious component - OPA, COX, Boom Clay.

  - These aspects are investigated by laboratory tests and up-scaling by utilization of in-situ tests (both ongoing and new tests).

- **Study radionuclide retention processes in high pH concrete environments. Radionuclides which have high priority from the scientific and applied perspective are selected.**
  - Analyze the retention of some specific radionuclides in high pH concrete environment, especially: Be, C, Cl, Ca, Se, Mo, I, Ra.
  - Assess the impact of chemical alterations (e.g., high pH concrete ageing, carbonation, transition from oxidizing to reducing conditions) on radionuclide retention.

- **Improve validity of numerical models to predict changes in transport processes as a result of chemical degradation. Support advanced data interpretation and process modelling, covering mainly issues responsible for the changes in transport properties.**
  - Allow improved interpretation of experiments on chemical interactions affecting porosity, and water and gas transport properties at both the bulk cementitious material and its interface with different host rocks by process level and mechanistic modelling.
  - Extrapolate modelling to system-level to modelling for Safety Case application.

Further objectives cover dissemination of key results to scientific and non-scientific oriented stakeholders as well as training and education of young professionals for carrying over the expertise into future implementation programmes.

Work in Cebama is organized in 3 scientific/technical work packages (WP): WP1 – Experiments on interface processes and the impact on physical properties (leader: E. Holt, F. Claret, U. Mäder; WP2 – Radionuclide retention (B. Grambow); WP3 – Interpretation & Modelling (A. Idiart). In addition, WP4 is on Documentation, Knowledge Management, Dissemination and Training (J. Perrone) and WP5 on Management (M. Altmaier, V. Montoya).

Cebama is offering the opportunity of external groups to join the project within the status of Associated Groups (AG). AGs will participate in Cebama at their own costs with specific scientific/technical contributions or particular information exchange functions. The AGs will be invited to the Annual Project Workshops and receive access to the public deliverables and scientific technical information obtained in the project (contact: marcus.altmaier@kit.edu).

A key activity of Cebama, open to all interested to participate, are the Annual Project Workshops which serve as an important forum for dissemination of the research performed within the project. The next Annual workshop will be organized by Amphos21, over at least 2 days in the week from May 8th 2016, in Barcelona, Spain. Exact dates and registration will be available in 2016 at Cebama website.

Acknowledgement: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 662147.

Microbiology In Nuclear waste Disposal (MIND)

Birgitta Kalinowski, SKB, Sweden

The MIND project is a multidisciplinary 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. 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 waste-form evolution in situ, multi-barrier integrity and ultimately radionuclide migration from the repository. The MIND project targets a number of "high urgency" and "high importance" topics identified in the most recent IGD-TP Strategic Research Agenda, focusing specifically on the influence of microbial processes on waste forms and their behaviour, and the technical feasibility and long-term performance of repository components.

The project brings together, 15 European groups from 8 countries working on the impact of microbial processes on safety cases for geological repositories across the EU, focusing on key questions posed by waste management organisations. The emphasis will be on quantifying specific measureable impacts of microbial activity on safety cases under repository-relevant conditions, thus altering the current view of microbes in repositories and leading to significant refinements of safety case models currently being implemented to evaluate the long-term evolution of radioactive waste repositories.

The Scientific Technical Work Programme is divided into two operative Work Packages focussing on ILW and HLW respectively. The third Work Package concerns data implementation and communication and the forth deals with project management. MIND will distribute knowledge on general geomicrobiology and the outcome of the experimental work packages to a broad audience, including students, professionals, the scientific community, stakeholders and the lay community.

Plenary session 3 – Evaluation of completed FP7 technical projects

Evaluating the Performance of Engineered Barriers- Outcomes of the PEBS project

Annika Schäfers, BGR, Germany

The evolution of the engineered barrier system (EBS) of geological repositories for high level radioactive waste (HLW) and spent fuel (SF) has been the subject of many national and international research programmes during the last years. The emphasis of the research activities was on the elaboration of a detailed understanding of the complex coupled thermo-hydro-mechanical and –chemical (THM-C) processes, which are expected to evolve in the early post closure period in the near field. From the perspective of radiological long-term safety, an in-depth understanding of these coupled processes is of great significance, because the evolution of the EBS during the early post-closure phase may have a non-negligible impact on the radiological safety functions at later stages of the repository's lifetime. For repositories in crystalline and argillaceous host rocks, exceptional process interactions during the resaturation phase (heat pulse, gas generation, non-uniform water uptake from the host rock) could impair the homogeneity of the safety-relevant parameters in the EBS (e.g. swelling pressure, hydraulic conductivity, diffusivity).

Remarkable advances have been made in previous projects to broaden the scientific understanding of THM-C coupled processes in the near field of the waste canisters. Less successful, however, was the attempt to use this in-depth process understanding for constraining the conceptual and parametric uncertainties in the context of long-term safety assessment. An integrated approach was required to set-up the scientific validation procedures in a context which is relevant for the performance assessment (PA) purposes. Thus, there was a need for validation experiments on the real scale (in-situ experiments, large scale mock-up experiments) to avoid scale effects. Furthermore, the assessed THM-C processes, the experimental conditions and the experimental times needed to be specified by the requirements of PA.

The 7th Framework EURATOM project PEBS (Long-term Performance of Engineered Barrier Systems) was initiated in 2010 and completed in 2014. It was carried out by 17 partners from 7 countries. The project aimed at evaluating the performance of clay-based EBS, and thereby deepening the knowledge and understanding of the THM and THM-C evolution of the EBS system with time, providing a more quantitative basis for relating the evolutionary behaviour to the safety functions, and clarifying further the significance of residual uncertainties for long-term performance assessment. The project approach included experiments, model development and consideration of the potential impact on long-term safety functions.

The presentation will give an overview of the main outcomes of the PEBS project including the work and the recommendations of the High Level Expert Committee (HLEC) which accompanied the project. It can be concluded that uncertainties for processes occurring in the resaturation period have been better constrained through PEBS studies and the uncertainties in the long-term performance of bentonite barriers have thus been reduced in some important areas. Improvements are in the areas of evolution of materials properties and model development and testing. Existing in-situ experiments in underground research laboratories may play an important role in further confirming bentonite performance over periods of 10-20 years. The presentation will comprise an evaluation of the scientific progress achieved by PEBS and the implication for future research activities.

Outcome of the 7th FP Collaborative Project FIRST Nuclides

Bernhard Kienzler, KIT-INE, Germany

The EURATOM FP7 Collaborative Project “Fast / Instant Release of Safety Relevant Radionuclides from Spent Nuclear Fuel (CP FIRST-Nuclides)” aimed on providing for “instant release fractions (IRF)” for relevant radionuclides from high burn-up spent nuclear UO2 fuel (SNF). The project supported the needs of safety analysis for different host rocks but also for the variety of SNFs to be disposed of in each repository. The project was implemented by a consortium of 10 European beneficiaries. 13 Associated Groups jointed the project being involved in FIRST-Nuclides related fields. National Waste Management Organizations (WMO) participated in the End User Group guiding the Project with respect to the usefulness of the project achievements for the purpose of improving confidence in the Disposal Safety Case.

After completion of the CP FIRST-Nuclides, a significantly broadened knowledge is achieved by investigations covering 12 different types of high burn-up LWR SNF, IRF measurements at 45 different time steps, for up to 3 sample preparations, and up to 20 isotopes. The experiments were performed in a standard leachant guaranteeing comparable results. The data comprise the dissolution based radionuclide release for different samples, sample sizes and preparations from PWR and BWR SNF under aerobic, anaerobic and reducing conditions. The obtained results include cumulative gap and grain boundary releases for caesium and iodine as well as the relevant rates. Additionally, the chemical state of Se was analyzed by micro X-ray absorption near-edge structure (XANES) spectroscopy. In order to provide for procedures for estimating the IRF for complete populations of UO2 fuel rods in a disposal, correlations were derived relating the IRF for Cs and I to the burnup, power rating and calculated fission gas release of the fuel.

The outcome of the project is an important part of the Safety Assessment independent on the host rocks or disposal concepts. The project has a direct impact on the European nuclear power community, including authorities representing public safety interests. The obtained results from the CP FIRST-Nuclides lower the uncertainties, increase the process understanding and maintain an improved description of the source term for radionuclides from SNF. The results improve the trust in the safety analysis for geological disposals. Up to now, 166 reports, publications and presentations at conferences document the achievements and results of FIRST-Nuclides.

Evaluation of 7th FP Collaborative Project REDUPP

Lena Evins/ Johan Andersson, SKB, Sweden

The EURATOM FP7 Collaborative Project REDUPP (Reducing Uncertainty in Performance Prediction) aimed at reducing the uncertainty in the spent nuclear fuel dissolution rate to be used in the safety case and thereby increase the confidence in our ability to assess the safety of a future final repository. A second objective of this work is to provide for the training of young research workers who can continue to support the research needed in the future concerning radioactive waste disposal. The project was implemented by a consortium of 5 European beneficiaries in 3 countries: SKB, Posiva, VTT, Uppsala University and University of Sheffield, and engaged an appointed 3-person scientific advisory board, to ensure scientific excellence.

Two main uncertainties are addressed by this project: 1) effects of chemistry of natural groundwaters, and 2) effects of changes in surface morphology on experimentally measured dissolution rates. This was done by investigating how the surfaces of dissolving fluorite-type materials solid change during the course of dissolution, using both experiments and first-principles modelling. Coupling the analysis of the bulk solution with the studies of the surface, the most reactive sites at the surface are identified. Some conclusions are that the evolution of the grain boundaries plays an important role in the observed changes of the dissolution rate. There are also indications that there is a crystallographic control and variable “local solubility”, with dissolution

occurring in coincidence with precipitation and/or sorption in the vessel. The study with natural groundwaters indicates a slightly elevated dissolution rate compared to previous experiments; these observations may be related to a higher solution volume to surface area ratio. Reactions of the fluorite-type surfaces with H2O have been described using Ab Initio Molecular Dynamics, and atomistic thermodynamics. This is the first step in mechanistically describing, from first-principles, the dissolution reaction. Overall, measured dissolution rates are affected both by surface properties and by fluid composition. Notably, the crystallographic structure of the exposed surface also influences the interfacial reactions.

Scientifically, the project has strengthened the Safety Case by improving our knowledge regarding processes that occur at surfaces of dissolving solids, as well as highlighting potential effects of variations in surface characteristics and environmental conditions, such as groundwater composition. The training objective has been met by employing early-career scientists and directly involving students in the activities, as well as through the REDUPP lecture series, a set of 9 lectures given by research leaders in the field. The project has also contributed to the improvement of analytical skills and data bases. As of today, the publication output from REDUPP comprise 8 scientific articles, 4 articles in Conference Proceedings (Euradiss and EURADWASTE), 3 Posiva Working reports, 5 Newsletters, as well as the periodic and final FP7 reports. In addition the project has reported to a wider audience through 3 articles in professional magazines. A project overview and links to publications are given on the website: www.skb.se/REDUPP.

The MoDeRn Project: Monitoring Developments for safe Repository operations and staged closure

Johan Bertrand , Andra, France

The Monitoring Developments for Safe Repository Operation and Staged Closure (MoDeRn) Project was a four-year collaborative research project within the European Commission Seventh European Community Framework Programme (FP7). The overall objective of the MoDeRn Project was to develop and document the collective understanding of repository monitoring approaches, technologies and stakeholder views to provide a reference framework to support the development of specific national repository monitoring programmes.

MoDeRn included development and testing of a structured approach to monitoring, the MoDeRn Monitoring Workflow, in which safety functions, and features, events and processes are used to identify monitoring parameters. The use of a range of monitoring strategies was tested in a series of case studies. These included the use of dummy canisters, deployed alongside waste packages or in specialised monitoring galleries, and the use of sacrificial cells and pilot facilities.

A better understanding of the views of public stakeholders on the role of monitoring in geological disposal was achieved through research that included both national workshops and visits to underground research laboratories. Many stakeholders expressed the opinion that monitoring should be a checking process with a commitment to maintain a watch over repository performance.

Some technological developments focused on innovative monitoring systems for engineered barrier systems (EBS) were achieved included seismic tomography, microseismics and acoustic emission, high- and low-frequency data transmission systems.

The presentation will give an overview of the main outcomes of the project in order to assess the results and impacts of the MoDeRn approach.

Working Group 1 - Novel thermal treatments for high activity wastes

Rapporteurs: C. Padovani, Jonathan Martin

Thermal treatments from the immobilisation of radioactive materials in a form suitable for geological disposal have been typically employed for the immobilisation of highly radioactive materials such as reprocessing liquors (i.e. High Level Waste, HLW). Progress is being made in some countries (e.g. in the US and, more recently, in the UK) to evaluate and deploy a variety of thermal treatment types to wastes traditionally treated through other routes (e.g. ILW sludges) or for which disposal concepts are not yet fully developed (e.g. plutonium residues). The application of thermal treatments to specific waste types has not only the potential to result in the production of highly stable wasteform but also to achieve substantial reductions in volumes and chemical reactivity (for example for ILW with high organic content). This session will present key examples of thermal treatments being developed in the nuclear industry to achieve immobilisation of a variety of waste types and will provide a forum for information sharing and discussion.

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WG1 - Novel thermal treatments for high activity wastes - Abstracts

Collaboration on the Thermal Treatment of Waste

Anthony Banford/ Sean Clarke, National Nuclear Laboratory, UK

An integrated project team has been formed to demonstrate and evaluate the thermal treatment of Intermediate Level Waste (ILW) currently consisting of Sellafield Ltd., National Nuclear Laboratory and the Nuclear Decommissioning Authority.

The project will establish an active demonstration facility on the Sellafield Site (NNL Central Laboratory) for thermal treatment processes through which a variety of waste streams will be fed and evaluated. The waste streams include PCM, wet ILW and future decommissioning wastes.

The objectives of this project will comply with NDA strategy i.e. all waste conditioning needs to take into careful consideration the application of the Waste Hierarchy with a focus waste minimisation, whilst demonstrating the disposability of the treatment product. To support a future detailed Business Case, a number of factors are important and their relative importance will be evaluated, which will include: cost and affordability, safety and environment impact, schedule and technology insertion, scope, applicability, deployability, passivation, volume reduction, niche vs bulk and disposability.

Thermally treating active waste will allow the technology readiness level of the various processes to reach a level where they can be seriously considered as an alternative to traditional immobilisation techniques such as cementation.

Within the UK it has been estimated that thermal treatment of waste provides opportunities to make significant reductions in packaged ILW volume of between 16% and 50%. This in turn could lead to significant cost savings in ILW packaging and storage costs, potentially of several £100 million to more than £1 billion.

An opportunity now exists for the work streams within this project to be aligned with other EU partners with similar needs. Collaboration through such a project would build on individual thermal programmes and would allow a collective international approach to form. The project would provide a stepping stone to facilitate and accelerate progress from the current position, with its various independent thermal treatment initiatives, to a future integrated programme with functioning thermal treatment facilities, available to a wider variety of waste producers.

The project will provide valuable research data on the conditioning of candidate wastes through active thermal demonstration rigs, such as passivation, volume reduction factors and superior product quality. The project would also allow advances to be made in the understanding of how radioactive waste behaves in thermal systems both in terms of the product and the process including issues such as off-gas management.

Novel treatments to improve radioactive waste disposal

Laurence Petit, Andra, France

In France, Andra is in charge of the long-term management of all radioactive waste, under the supervision of several ministries. This work is mainly focused on the development of long-term repository solutions. However, in order to provide an optimal management of waste disposal capacities and an overall consistency of waste management, it is of importance to take an overview of waste life cycle, from their production until their disposal. This implies collaboration between Andra, radioactive waste producers and potential intermediate parties.

In 2010, the French government attributed to Andra, through the 'Investissements d'Avenir' program, a 75 M€ endowment to promote its activities upstream of repository. The main goal was to allow Andra to work together with waste producers on innovative R&D projects so as to optimize radioactive waste disposal. These projects fulfill three main purposes:

- Optimization of disposal capacities by reducing waste volume to be disposed of;
- Optimization of disposal safety by processing waste to make them as inert as possible under disposal conditions;
- Optimization of waste take over and distribution between the different waste disposal facilities already existing or planned, in particular for waste with no management solution.

Since 2010 several R&D projects have been launched, including development of thermal treatment processes. Examples will be given in the presentation.

Application of Joule Heated Ceramic Melter (JHCM) Technology for Stabilization of Radioactive Wastes in the United States

Eric Smith, EnergySolutions, United States

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In the United States, JHCM vitrification technology has been developed and deployed for the stabilization of high level radioactive wastes (HLW), as well as lower activity radioactive wastes. JHCM technology has been adopted as the reference technology for the treatment of HLW in the United States, Japan, Germany, China and Russia due to its robust nature, and flexibility in being able to accommodate diverse waste chemistries. This presentation will review the various U.S. based projects utilizing this technology, and the corresponding wasteform performance requirements for each. Projects reviewed will include high level wastes at West Valley, Savannah River and Hanford; low activity waste at Hanford; and mixed – low level waste at Savannah River.

The innovative plasma tilting furnace for industrial treatment of radioactive waste

Jan Deckers, Belgoprocess, Dessel, Belgium

The operation and maintenance of nuclear power plants, the nuclear fuel cycle in general, research laboratories and pharmaceutical, medical and industrial facilities generate large amounts of low-level radioactive wastes which, along with the historical radioactive wastes from past nuclear activities, need to be treated to minimise the volume to be disposed of. Plasma technology offers a very effective way of treating this waste with a high volume reduction factor (VRF), free from organics, liquids and moisture, and meets without doubt the acceptance criteria for safe storage and disposal. By means of a plasma beam of approximately 5000°C, the inorganic materials are melted into a glassy slag containing the radioactive isotopes while the organic material is gasified and afterwards oxidized in an afterburner and purified in an off-gas cleaning system.

This paper describes the principles of plasma, the different waste feed systems, off gas treatment, operational experience and future plasma plants. In particular a new full-scale plasma facility for the treatment of radioactive waste at the Kozloduy Nuclear Power Plant in Bulgaria is described. This facility is designed and now under construction by the Joint Venture Iberdrola Ingeniería y Construcción and Belgoprocess.

Application of Hot Isostatic Pressing to disposal of UK radioactive wastes

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The current concept for disposal of higher activity radioactive wastes in England and Wales is a single Geological Disposal Facility for all Intermediate Level Wastes (ILW) and High Level Wastes (HLW) arising from current and historic nuclear operations. Reference to the UK Radioactive Waste Inventory 2013, shows the projected volume of ILW generated by current and historic nuclear fuel cycle operations to be 286,000 m3 (i.e. excluding wastes from nuclear new build). The strategy for treatment of ILW in current Lifecycle Baseline Plans is by encapsulation in an ordinary portland cement matrix, combined with super-compaction where appropriate. Since the waste incorporation rates of encapsulation processes are generally low, the estimated final volumes of conditioned and packaged ILW swell to 458,000 m3; contained within 216,000 individual packages.

In contrast to encapsulation processes, thermal treatment technologies, such as Hot Isostatic Pressing, offer the potential to reduce conditioned and packaged waste volumes due to the removal of entrained water, minimisation of void space and destruction of combustible materials. Depending on the waste to be treated and technology platform selected, the thermally conditioned waste volumes may be reduced by a factor of between 2 to 100, compared to the volume of unconditioned waste. Clearly, therefore, thermal treatment of ILW would be expected to translate into considerable financial, environmental, safety, and security benefits, arising from the lower volume and number of waste packages requiring disposal.

Hot Isostatic Pressing (HIPing) utilises a combination of high temperature (generally, up to 1300 oC) and applied pressure (argon gas, 10-200 MPa) to achieve incorporation of radionuclides into a ceramic or glass host phase, by melting or solid state reaction, with simultaneous exclusion of

entrained porosity to achieve near theoretical density of the final packaged product.. The key advantages of HIP technology include:

- Batch processing of radioactive wastes, this allows for accurate accountancy of materials, of key importance for criticality control.
- Containment of the radioactive inventory during processing, by utilisation of a sealed container. This eliminates volatile losses during high temperature consolidation and minimises the production of secondary wastes.
- Insensitivity to the physical properties of the wasteform, e.g. electrical and thermal conductivity (which are key constraints, in a joule heated glass melter).
- Flexibility of operation, in principle a single HIP facility could treat a wide spectrum of wastes under tailored processing conditions, with minimal secondary waste generation.

In this presentation, I will present an overview of recent strategy development in UK thermal treatment of radioactive wastes and discuss illustrative examples of the application of HIP technology to conditioning of plutonium residues, ion exchange materials, and radioactive sludges, relevant to decommissioning activities in the UK and worldwide. I will show how HIP technology allows conditioning of such wastes in a single one-pot processing step and produces robust glass, ceramic, glass-ceramic and composite wasteforms suitable for direct geological disposal.

Geological disposal of silicon-rich vitrified ILW products in a cement-based engineered barrier system: addressing key uncertainties

Steve Swanton, NNL, UK

The use of high-temperature (e.g. vitrification) processes for the conditioning of certain types of ILW has been under consideration in the UK. One option for the disposal of the resulting waste products would be to place them in a geological disposal facility (GDF) in a high-pH environment with cemented ILW and a cement-based backfill. In this concept, two key requirements of the backfill are: to maintain an alkaline environment in which many key radionuclides have low solubility; and to provide a high sorption capacity and so control the rate at which many radionuclides can migrate into the host rock. In this concept, the leaching behaviour of a vitrified wasteform could provide additional controls on the release rates of key radionuclides in the near field.

Placing vitrified ILW in a highly alkaline environment raises two questions:

1) How will the vitrified ILW behave?
2) What impact would emplacement of vitrified ILW have on the properties and performance of the cementitious backfill?

This presentation will give an overview of research undertaken on the RWM programme to evaluate the leaching behaviour of a range of ‘non-optimised’ vitrified ILW products and their potential impact on a cement-based backfill. The work has included:

- dissolution studies of a number of illustrative vitrified ILW products under both near-neutral and high-pH conditions;
- dynamic leaching studies of low calcium to silicon ratio C-S-H (calcium silicate hydrate) gels and thermodynamic modelling studies related to the impact of silicon rich vitrified ILW on the long-term chemical barrier performance of a cement-based backfill.

The results of scoping studies to date indicate that, even in a high pH, cementitious environment (high pH is generally expected to result in higher dissolution rates for the glass), vitrified ILW products may display relatively low dissolution rates. It has been found that C S-H gel systems are resilient in their capacity to buffer pH to alkaline values even at low calcium to silicon ratios that might result from the interactions of silicon-rich materials with a cement backfill. The overall buffering capacity of the backfill

is not expected to be reduced by such interactions; rather the buffering will be at a lower pH, but for an extended period; moreover the overall sorption capacity of the backfill is predicted to increase. These findings support the view that placing vitrified ILW alongside cemented ILW would be a potentially viable disposal option.

Nano Flex HLW / spent fuel rods recycling and permanent disposal

Dimitre Assenov, Nano Flex HLW, Bulgaria

The Nano Flex HLW technology resolves all existing contamination issues related to the resulting production of High-Level Waste (HLW) to include:

- Spent fuel rods from nuclear reactors
- Radioactive liquid and solid waste
- Consolidated HLW in storage
- Depleted uranium
- Liquid and solid isotope industrial/ medical byproducts
- Nuclear disasters and/or detonation cleanup
- Toxic chemical and/or reactive HLW
- Mine tailings
- Coal fired power plant solid/liquid waste

The process consists of converting all of the above-listed waste in a controlled environment to a very low radiation level, quasi-natural state or artificial feldspar mineral, followed by immediate unrestricted and permanent disposal. The radiation level of the final product is controlled to achieve a level matching that of a selected disposal site, thereby preserving the natural equilibrium. As such, this approach eliminates the need for waste vitrification and deep geologic repositories and instead, produces common engineering fill. This effectively removes all of the current disposal site restrictions in place for existing solutions due to radioactive waste proliferation, intrusion or resulting exhumation restrictions.

This invention achieves an efficient flow that includes simplified liquid-to-liquid separation of uranium (U) and plutonium (Pu) in a specially designed vortex apparatus, enhanced by cryogenic cooling and gas isotope separation via volatilization in isolation. The vortex apparatus is simple and safe to operate, and is used for the separation of U and Pu from other transuranic (TRU) isotopes, including all undissolved metal particles. The process does not require electricity and has no moving parts. Upon separation, all collected liquid and dry (filters) HLW is converted into a very low radiation level, quasinatural artificial feldspar minerals.

There are two options for conversion: 1) Industrial Continuous flow/batch reactor, or 2) the use of unique, natural phenomena known as dry fumaroles. The latter option is unique because it also allows for the immediate deposit/disposal of the feldspars. The natural design of dry fumaroles can accommodate all known worldwide HLW production in one location. The phenomena are several miles long, never appear on the surface, have been established during a long geologic time (10K years to 15K years) with very stable thermodynamics within the host rock, and prevent any formation of perched water. Ideally, the separation process should be performed at the disposal site, thereby avoiding all issues and concerns of waste transportation and handling. The separated U and Pu in solid form are ready for enrichment and re-use.

Note that the entire process does not produce any byproducts that require additional purification (as is the case with all existing technologies – ref. AREVA-France, SRS – USA and other European/Asian recycling facilities). The production flow diagram includes the use of mobile detachable, interconnected production units temporarily buried under isolation soil berms. This scaled down, inexpensive, and green design replaces existing heavy and expensive facilities that ultimately leave at decommissioning a substantial environmental footprint.

Feldspars are natural carriers of isotopes and comprise more than 50% of the Earth's crust. They are subject to a very slow, natural metamorphosis transition with the only exception being when they are exposed at the Earth's surface or come into contact with running water, where they are converted to clay. The artificial feldspars are produced in a wide variety of structures, ranging from pellets to molded block that can be disposed of as common engineering fill (85% to 87% of MDD at OMC, reference ASTM or AASHTO) or dry masonry. While placement can be done most anywhere, it is more cost-effective to deposit the fill in the empty spaces of underground mines (subject to remediation and closed for exploration), open pit mines, quarries, berms, dikes and/or trenches.

The feldspar conversion process includes the use of crystalline precursors that are inexpensive industrial waste byproducts, available worldwide and without significant practical application (e.g. fly ash). After mixing (according to a specific job mix formula) with the HLW sludge, some setting time is required for the formation of alumina-silicate crystalline clusters that contain the isotopes in trace amounts. Once completed, the mixture is introduced to the Continuous Flow/Batch Reactor at a controlled temperature and time (ref. to Bowen Reaction series), then converted to one of the four major feldspar mineral groups - Calcium, Sodium, Potassium or Barium- [M(Al,Si)O2]. Barium feldspar is produced from the decay of the Cesium to Barium via a complex solid dissolution process of alumina silicate tetrahedral. All isotopes and their decay daughters are held permanently in the large vacancies of the feldspar crystalline alumina silicate tetrahedral lattice – resolving all existing issues and concerns related to isotope transition volume expansion. This duplicates naturally occurring, geologic processes.

The feldspar type selection is controlled by the consumer and depends on the disposal location; it is recommended that the feldspar type match the host environment. Because the radiation level of the artificial feldspar matches or is below the host site, no restrictions for disposal are needed. It is simply used as ordinary engineering fill and protected from surface water via a 2-3 ft high plastic clay cap, which is common in civil engineering fill and works to avoid surface radiation sky shine. Once this is completed, a minimum depth of 2 ft of crushed stone rejects is put in place to protect against flash floods. The rejects are easily obtained from stone production quarries and facilities. The final surface is covered with topsoil and agriculturally ready for planting.

The resulting very low radiation artificial feldspar has two predetermined properties:

1) At high temperatures and quick crystallization there is a reduction of the initial water content in the feldspar to less than 4 molecules (instead of 8), thereby repeating the exact process that occurs in nature. Thus, solute transport is only permitted from the host to the fill until the equilibrium of 8 water molecules is reached. In nature this process takes 10,000 to 100,000 years.

2) A natural silicon coating (similar to volcanic glass) is produced by the quick crystallization, which prevents any absorption and dissolution for an extensive geologic time.

The economics of NANO Flex HLW are significant when reviewing the estimated costs of existing HLW treatment and storage facilities. International spent fuel processing costs range from $1,400-$2,200/kg with another $18-$22 billion dollars in storage costs that includes glass vitrification, non-corrosive storage containers, casks, temporary transfer storage and deep geologic disposal facilities. Add to all of this unknown maintenance costs for 10,000 years. By contrast, the NANO Flex HLW solution incurs a one-time cost of $160/kg of waste, including spent fuel recycling and permanent disposal. The cost of the mobile processing facility varies based on capacity from $6-$20 million with no decommissioning cost because the used modules are also converted to artificial feldspar at the closing of processing.

The detachable mobile production modules have extensive, inexpensive safety features currently employed by military explosive and rocket fuel production installations (e.g. ATK USA). They are comprised of large, detachable cargo containers, buried under a 3-5 ft. soil berm, which is the most efficient and inexpensive protection against radiation sky shine, fire, explosion and/or industrial accidents. Finally, the production modules are easy to isolate without shutting down an entire facility,

and require minimal operational staff because 85 % of the production process is gravitational and hydraulically, remote controlled.

The TRU separation process is simplified in one step versus existing multi-step processes, which makes it the first solution to employ cryogenic cooling during separation of the spent fuel from cladding. This avoids known hazards associated with hydrogen explosions and/or radioactive metal dust. This is due to a more stable radioactive environment with a natural dropping of electromagnetic wave length radiation at temperatures at or below -150 °C.

The Feldspar conversion process uses off-the-shelf, mobile continuous flow/batch furnaces already in use in urban wastewater treatment facilities that require only a feeding tune up (several furnace types developed and used in the market today are fueled by, gas, kerosene or electricity).

The last that need to be point is the volume of existing waste converting/disposal technologies vs. Nano Flex HLW. The combined volume of any of existing recycling / disposal technologies (including waste temporary storage, reprocessing, vitrification, canister, casks, transfer storage and deep geologic repository) is almost 3 times greater than the artificial Feldspar Nano Flex HLW produces.

In conclusion, NANO Flex HLW is the first comprehensive and cost effective technology for the treatment and recycling of all types and forms of High Level Waste (HLW). Accordingly, the technology is substantially cheaper and more efficient when compared to existing mining, enrichment and recycling processes for uranium, plutonium and thorium, and produces a safe product that duplicates what currently exists in nature today.

Available reference:
US Patent 8,987,541 B2
WO 2013158196 A2
www.Nanoflex-hlw.com

Plasma Vitrification of nuclear wastes

Mark Rogers, Costain, UK

Costain and Tetronics International have completed trials of a new system which promises to significantly reduce the volume of various nuclear wastes from the nuclear industry compared with alternative treatment approaches.

Following a two year programme of process development and equipment design, a full-scale test rig incorporating nuclear features was operated, successfully processing waste simulants covering a range of properties including Magnox ponds sludges and demolition debris. A novel wasteform was produced during these full scale trials.

Costain and Tetronics collaborated in order to adapt and enhance Tetronics' existing plasma furnace technology for the nuclear industry. Tetronics has 50 years' experience in supplying direct current plasma arc systems for a range of applications, with this latest variant drawing on Costain's considerable nuclear industry experience. Costain's and Tetronics' investment in this project was supported by Innovate UK, with the Department of Energy and Climate Change and the Nuclear Decommissioning Authority (NDA) also contributing.

The furnace operates at around 1000 C to 1400°C, taking between six and 12 hours to reduce waste to a glass-like substance. Tetronics built test facilities at Swindon over two years, with the trials taking two months. The wasteform produced was for all waste types a block of glass in a disposable refractory lined steel crucible, suitable for emplacement in a standard waste container.

Organic and carbonaceous material in the ILW is vaporised by the extreme heat produced by the plasma torches. This waste gas is cleaned using standard processess and released, with any

secondary waste fed back into the reaction chamber of the furnace for vitrification. The inorganic material in the ILW, together with additives that reduce its melting point and increase fluidity, forms a pool of melted material in a water-cooled container. The material is cooled to form a stable, vitrified waste. The solid material will be physically and chemically stable over the long term and, importantly, has demonstrated very low levels of leachability.

Following this full scale demonstration the collaboration is actively pursuing opportunities to implement the approach, both immediate work on available waste streams, and longer term studies. A project has just begun in partnership with the University of Manchester and MDecon looking at the fundamental science and implementation of retrieval and thermal treatment of reactor core graphite.

The ability to greatly reduce the volume of ILW would immediately ease the burden on the UK's interim waste storage facilities and could mean considerable savings, both in building future storage and in other areas of ILW treatment. Billions of pounds could be saved by the nuclear industry over the coming decades.

The THOR process and the leachability of the THOR residues

Maria Lindberg and Adam Foster, Studsvik, Sweden

The THOR process that has the capability to successfully treat a wide variety of radioactive wastes including those with high organic content, high nitrate and nitrite content, high solids content, and heavy metal bearing. The process produces a dry stable waste form with no liquid effluents and environmentally compliant off-gas emissions, while reducing the overall waste volume.

Prior to processing additives are used to produce a leach resistant final solid product by reacting with alkalis (Na, K, Li, and Cs) to form alkali-alumino-silicate (NAS) minerals. Halogens (Cl, F, Br, and I), sulfates (SO42-), and phosphates (PO43-) from the waste are bound in the solid product as part of the NAS mineral structures that form in the fluidized bed. These NAS minerals also provide host phases to accommodate radionuclides and various hazardous species. The NAS mineral phase are anhydrous feldspathoid phases, such as sodalite, are unique because they have cage-like structures. The cage structures are typical of sodalite and/or nosean phases where the cavities in the cage structure retain anions and/or radionuclides that are ionically bonded

In the THOR NAS mineral waste form, the molecular structure of the waste controls the release of radionuclides through a unique distribution of ion exchange sites and hydrolysis sites, and by controlling the access of water to said sites. As a granular product, the mineral waste form has been shown to be more durable than glass during testing with ASTM C-1285-02 known as the Product Consistency Test, testing with the Single Pass Flow-Through Test, and during subsequent performance assessment modeling.

WG1 - Novel thermal treatments for high activity wastes
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Outcomes

The session featured talks from Waste Management Organisations, technology providers and research organisations2. The aims of the session were: to build a common understanding of the 'appetite' of different member states to deploy thermal treatments for radioactive waste with relatively high activity (e.g. intermediate level waste), available technologies, and the science and technology underpinning geological disposal (and to a lower extent surface storage) of thermally-treated waste forms; and to identify the key elements of a future proposal for collaborative work in this area, including the possibility of submitting a proposal to the EC under the Horizon 2020 Framework.

Key topics of discussion included the nature of specific waste streams for which thermal treatments may produce the greatest benefits, the benefits of different technologies, their state of development and, for operating facilities, the experience with specific type of wastes. Overall, the level of participation indicated a broad interest in these technologies reinforced the idea that collaborative work in this area would bring substantial benefits to many European (and possibly non-European) countries. Given the different level of maturity, across different countries, of plans to treat, store and/or dispose of higher activity wastes, any proposal for joint working would need to feature a strong strategic element, exploring the needs of different countries, the wastes and technologies of greatest interest, and important issues such as costs and transport/logistics of samples, wastes and treatment facilities. Further benefits would be achieved through the active demonstration of specific technologies on key waste streams, and additional research to underpin the expected behaviour of the waste form during disposal (and possibly during surface storage).

[2] The session also featured a talk, by HLW Nano-Flex, on the disposal of high level waste (HLW) after dilution and incorporation of radionuclides in feldspars. Given the nature of the approach proposed (based on a principle of radioactivity dilution, not compatible with the agreed international vision of the key principles underpinning geological disposal of HLW) and the fact that, in European countries which pursued fuel reprocessing strategies, stocks of reprocessing liquors have already largely been vitrified, this approach is not currently endorsed by the IGD-TP. In addition, the IGD-TP fundamentally disagrees with many of the statement and observations contained in the information presented by HLW Nano-Flex, including those on the expected behaviour of vitrified HLW in a geological disposal facility.

Novel Thermal Treatments for High Activity Wastes (TWG1) - Summary

Cristiano Padovani

Date: 04/11/2015

Radioactive Waste Management

Objectives of the Session

- Develop a common understanding of:
  - European WMO's appetite in thermal treatments for high activity waste (e.g. ILW)
  - Available technologies, their characteristics and state of development
  - Science underpinning the disposability of treated products
- Build a platform for discussion to identify opportunities for future collaboration, including opportunities to develop a proposal for European funding

Radioactive Waste Management

Scope

Higher activity wastes for which thermal processes are not currently used and for which substantial benefits may exist:

- **Some ILW**
- Some LLW
- Some ‘unconventional’ higher activity wastes/materials (e.g. plutonium stocks)
- *Alternative approaches to HLW management?*

Radioactive Waste Management

Agenda

Title	Organisation
Collaboration on the Thermal Treatment of Waste	NNL/Sellafield Ltd
Novel Treatments to Improve Radioactive Waste Disposal	Andra
Application of Joule Heated Ceramic Melter (JHCM) Technology for Stabilization of Radioactive Wastes in the United States	Energy Solutions
The Innovative Plasma Tilting Furnace for Industrial Treatment of Radioactive Waste	Belgoprocess
Hot Isostatic Pressing of glass and ceramic wasteforms for UK higher activity wastes	University of Sheffield
Nano Flex HLW/ Spent Fuel Rods Recycling and Permanent Disposal	Nano Flex HLW
Geological Disposal of Silicon- rich Vitrified ILW Products in a Cement- based Engineered Barrier System: Addressing Key Uncertainties	AMEC-FW
Plasma Vitrification of Nuclear Waste	Costain
THOR and the Leachability of THOR Residues	Studsvik

European WMO's appetite

There is a strong interest in the UK and in France to evaluate the use of thermal treatments for specific waste types including:

- Organic wastes contaminated with plutonium
- Sludges
- Wastes with high metal content
- Bitumised wastes
- *Graphite?*

There is likely to be interest in other countries given that either:

- They are already using these techniques to treat some wastes
- Plans for disposal do not exist, are more uncertain or are down the line – importance of producing unreactive wasteforms

Radioactive Waste Management

Available techniques

A variety of techniques are available, including:

- Joule Heater Ceramic Melting
- Plasma-based techniques
- Electrode-based techniques
- Hot isostatic pressing
- Thermal oxidation/Pyrolysis
- *Alternative treatments for disposal of HLW*

Overall, one or more techniques can be used to treat a variety of wastes types. Key benefits are:

- Volume reduction (and associated potential cost reduction)
- Reduction in chemical reactivity

Radioactive Waste Management

Science Underpinning Disposal

Work has been carried out in many countries to scope/evaluate the disposability of different type of products. The results tend to show that:

- Low leaching rates can be obtained with suitable processing
- The presence of high silicon in the waste is unlikely to have a detrimental effect on a cement/based EBS, if such wastes *were* to be disposed of in conventional ILW concepts
- In highly α-contaminated materials, radiation damage may affect the characteristics of the wasteform after very long times.

Overall, thermal treatment may bring benefit to disposal as well as upstream

Radioactive Waste Management

Way forward

A good European basis of end users, suppliers and research institutes exists to enable collaboration at European level, including developing a proposal for European funding. Such a proposal would need to consider:

- The need of strategic coordination at European level, including waste types and technologies of greatest interest, strategic benefits (costs, risk-reduction, etc.), and logistic issues associated with transport of wastes, samples and treatment plants
- An element of active demonstration for key waste types
- Consideration of both upstream (treatment) and downstream (disposal) outstanding technical questions

Radioactive Waste Management

Working Group 2 - Bentonite homogenization

Rapporteurs: P. Sellin - J.C. Mayor

The proposed project will address key technical issues related to bentonite mechanical time evolution and homogenization that must be tackled to support the implementation of planned geological disposal projects for higher-level radioactive wastes across the EU. The overall objective of the project is to evaluate the performance of an inhomogeneous bentonite barrier. This will be achieved by cooperation between design and engineering, science and performance assessment. The evolution from an installed engineered system to a fully functioning barrier will be assessed. This will require an increased understanding of material properties as well an increased understanding of the fundamental processes that leads to homogenization and improved capabilities for numerical modelling. The output will be a verification of the performance of current designs for buffers, backfills, seals and plugs and an improved handling of mass losses in long term assessments.

- **Introduction** – Patrik Sellin/Juan Carlos Mayor

Strategic issues: feedback to Design and Safety assessment

- **Proposal for a project focussed on bentonite homogenization – some examples of ongoing activities in the area** – Patrik Sellin, SKB
- **Bentonite Homogenization: the safety relevance of the even distribution of bentonite buffer properties** - Olivier Leupin, NAGRA, Switzerland
- **Posiva's plans to assess bentonite homogenisation** - Kari Koskinen, POSIVA, Finland
- **Development of a Design Basis for Bentonite Homogenization: Lessons from the DOPAS Project Applied to WG2 Bentonite Homogenization** – Matt White, GSL, UK

Large and field scale experiments

- **Homogenization of bentonite plugs- what are the issues?** - Jean Talandier, Andra, France
- **State of a barrier of bentonite blocks after 18 years of operation** – María Victoria Villar, CIEMAT, Spain
- **Examples of Finland's experiments for assessing buffer-backfill-pellet homogenization and performance** - Erika Holt, VTT, Finland
- **Impact of the sand/bentonite homogenization on the performance of an EGTS** – Niels Giroud, NAGRA, Switzerland
- **Geophysical monitoring of evolutions of buffer materials and EBS** - Kristof Schuster, BGR, Germany
- **An impact of bentonite homogenization on its changes by degradation processes** – Jiri Mikes, TERAMED s.r.o., Czech Republic

Laboratory experiments

- **Understanding the homogenisation behaviour of bentonite** – Jon Harrington, British Geological Survey, UK
- **The Affect of Accessory Minerals on Bentonite Erosion Rates** – Rebecca Lunn, University of Strathclyde, UK
- **Saturation and mechanical properties of clays with defined composition** – Vaclava Havlova, UJV Rez, a.s., Czech Republic
- **Bentonite homogenization : Experimental contribution of CEA/LECBA** – Claude Gatabin, CEA, France
- **Bentonite homogenization: laboratory tests to answer open questions related to the German disposal concept in claystone** - Artur Meleshyn GRS Braunschweig, Germany

Modelling - Conceptual model/ processes understanding

- **Bentonite homogenization: processes and modelling** – Antonio Gens, Universitat Politecnica Catalunya, Spain
- **A Poroplastic Model of Structural Reorganisation in Porous Media** – Gabriel Wittum TechSim, G-CSC, U Frankfurt Germany
- **Hydromechanical behaviour of bentonite under in situ conditions** – Robert Charlier, University of Liege, Belgium
- **Proposal for a project focussed on bentonite homogenization – some examples of ongoing activities in the area** - Vasileios Mantikos, Imperial College London, UK
- **Constitutive mechanical modelling of bentonite behaviour in THEBES project** - Markus Olin, VTT Technical Research Centre of Finland Ltd, Finland
- **SEALEX In-Situ Experiments-Performance Tests Of Repository Seals: Experimental observations and modelling -** Nadia Mokni, IRSN, France
- **Relevance of hydrodynamic and hydrogeochemical reactions on buffer homogeneization** - Javier Samper, University of A Coruña, Spain

WG2 – Bentonite homogenization
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Abstracts

Proposal for a project focussed on bentonite homogenization – some examples of ongoing activities in the area

Patrick Sellin, SKB, Sweden

The overall objective of the proposed project is to evaluate the performance of an inhomogeneous bentonite barrier. This will be achieved by cooperation between design and engineering, science and performance assessment. The evolution from an installed engineered system to a fully functioning barrier will be assessed. This will require an increased understanding of material properties as well an increased understanding of the fundamental processes that leads to homogenization and improved capabilities for numerical modelling. The output will be a verification of the performance of current designs for buffers, backfills, seals and plugs and an improved handling of mass losses in long term assessments. Further research and demonstration activities are required in the following areas:

A: Strategy aspects:

- A1) Review of currents designs for bentonite barriers in the European disposal concepts. This will include performance targets as well as manufacturing and installation aspects.
- A2) Review of the assessment strategy for the evaluation of the performance of the bentonite barriers, with special attention given to the treatment of remaining inhomogeneities.
- A3) Definition of the technical basis for the design of the barriers

B: Assessment aspects

- B1) Definition of case studies for the verification of the performance of current barrier designs
- B2) Definition of case studies for the verification/validation of quantitative models, based on results from laboratory an field tests

C: Scientific aspects

- C1: Development of conceptual approaches for the mechanical evolution of a bentonite barrier
- C2: Laboratory testing to gain understanding of material properties
- C3: Modelling of cases for the verification/validation of quantitative models.
- C4: Evaluation of data from (existing) field scale experiments
- C5: Investigation of a natural analogue, e.g. a drill core through a bentonite deposit

D: Practical implementation

- D1: Feedback to design/engineering, are current designs adequate or can they be improved?
- D2: Feedback to safety assessments: how should the homogenisation process be described and how should an inhomogeneous system be treated?

In the KBS-3 concept, the primary function of the buffer is to ensure that the transport of various substances from the rock to the canister and from the canister to the rock is dominated by diffusion. The swelling pressure in the bentonite is expected to seal all gaps and ensure that the rock and the buffer are in good contact with each other. It is therefore important that the swelling pressure is maintained. The buffer's capacity to homogenize and fill cavities is crucial for its function in the repository.

This is particularly true for:

1. Homogenization of buffer blocks and pellets in connection with water saturation after installation.

The degree of homogenization is directly linked to the requirement on installed density and configuration.

2. Self-healing capacity after piping with erosion. This is indirectly linked to the requirements on inflows.

3. Self-healing capacity after colloid formation with erosion.

Simplified material models have previously been used in the analyses of homogenisation processes.

However, there are uncertainties in the models and the models need to be checked and improved, if necessary. A program with laboratory studies to provide data to improve the models.

Bentonite Homogenization: the safety relevance of the even distribution of bentonite buffer properties

Olivier Leupin, NAGRA, Switzerland

Most of the European repository concepts for radioactive waste are using bentonite for sealing or backfilling of tunnels and drifts or as buffer around the waste containment. It is a communality of all bentonite based repository concepts that the bentonite has to fulfill requirements related to long-term safety. For the safety assessment the required safety relevant properties of bentonite are for reasons of simplicity and in general assumed to be evenly distributed without considering its evolution regarding resaturation or thermal history. In other words, it is assumed that the final THM characteristics of the bentonite will be independent of the actual stress path, thermal path and saturation path, which has been experienced in the early phase of the nearfield evolution. Evidences from large scale experiments however showed that occasionally variations of material densities persist for the duration of the experiments independently of the degree of saturation and thermal gradient within the bentonite. A high enough dry density of bentonite ensures a sufficiently high swelling pressure and a low hydraulic conductivity two key criteria for fulfilling the long term safety requirements. This paper explores on the basis of our current understanding of buffer evolution to what degree dry density variation might vary and impact safety and whether observed variations in material densities may disappear to a certain degree with time.

Posiva's plans to assess bentonite homogenisation

Kari Koskinen, POSIVA, Finland and Xavier Pintado (B+Tech Oy)

Posiva submitted construction license application (CLA) for a spent nuclear fuel repository at the end of the year 2012. Therein homogenisation of density differences between compacted bentonite blocks and pellets in the KBS-3 concept was assessed only using computer simulations. Validation of the different computer software implementations including those used in CLA was committed within EBS Task Force and THERESA project (a European Commission funded project during the years 2007-2009) during the late 2000's. Even though the computer implementations were calibrated with some selected relevant experimental data, a validation facilitating use of computer simulations in dimensioning different block-pellet systems was not reached. Therefore, a validated method to assess homogenisation of density differences in block-pellet systems needs to be developed. In KBS-3 concept the main focus is in assessing recovery from defects.

Objective of the work is to justify allowable ranges of KBS-3V relevant block-pellet systems' design parameters. These parameters for blocks and pellets are montmorillonite content, dry density, block filling ratio, and thickness of pellet filled and air slots.

The work comprises of five (5) key tasks: 1) definition of the prototype, 2) review of conceptual models, 3) experimental work, 4) improvement of the conceptual models, implementation in a computer code and computer simulations, and 5) justifying guidelines for design parameters.

The prototype is defined such that at least KBS-3 concept's buffer and backfill conditions are assessed. Only isothermal conditions will be considered as well as Olkiluoto type brackish water. The main focus will be in the extent of homogenisation of density differences whereas assessment of time-dependent mechanical evolution is of secondary interest.

While reviewing conceptual models available, attention will be recognising the shortcomings.

Regarding experimental data, there is a massive body data from field and laboratory experiments that need to be reviewed. Based on the recognised shortcomings new tests to assess performance of the prototypes and produce some data for validation and some missing parameters will be executed. To begin with the performance of the prototype will be assessed using down-scaled setups. The foreseen maximum duration of the tests is two (2) years.

Computer simulations will be committed using existing software implementations. No new conceptual models will be developed but existing models will be improved in order to be able to assess the homogenization process. The improvements will be implemented, validated and verified.

Progress in computer simulation methods to assess the prototypes has been limited during the past few years. Should this be recognised to be the case, it has to be made sure that relevant physical experiments have been committed. Since reaching steady state in prototype scale setups takes several years, the assessments of prototype performance has to be based on down-scaled experiments and on applying scaling rules. To justify the guidelines for design parameters a standard operation procedure (or industry standard method) to assess homogenisation is sought to be developed, validated and tested to assess the prototypes.

Prototypes will be defined to a great extent by waste management organisations. One PhD student is to commit the conceptual models and computer simulations related work and another PhD student the experimental work. The work is to be supervised by a Finnish university but, say, half of these pieces of work will be done in other European universities. Furthermore, in addition to a supervising professor a part time senior scientist is needed to support PhD students and a senior design engineer is needed to formulate the SOP (or ISM). This latter work needs to be carried out during the course of the work but the biggest contribution is to be done during the last 6 months.

The work can begin immediately and the results need to be published before Posiva submits operation license application for spent nuclear fuel repository at mid-2020.

Development of a Design Basis for Bentonite Homogenization: Lessons from the DOPAS Project Applied to WG2 Bentonite Homogenization

Matt White, Galson Sciences Limited, UK

Full-scale experiments, laboratory tests, and performance assessment studies of plugs and seals are being implemented in Sweden, Finland, the Czech Republic, France and Germany within the Full-Scale Demonstration Of Plugs And Seals (DOPAS) Project. The project is a European Commission (EC) programme of work jointly funded by the Euratom Seventh Framework Programme and European nuclear waste management organisations. The project runs from 2012-2016.

The design basis for each test has been collated as part of the project. The design basis consists of the set of requirements and conditions that are taken into account when designing repository system

components. It specifies the required performance and the conditions under which this component performance must be achieved.

Significant work has been undertaken in DOPAS on identifying the requirements on bentonite seals, and structuring these requirements so that safety functions can be linked to design and quality control procedures. Such work is of direct relevance to the proposed work areas of the proposed Bentonite Homogenization Project, including:

A: Strategy aspects:

A1) Review of currents designs for bentonite barriers in the European disposal concepts. This will include performance targets as well as manufacturing and installation aspects.

A2) Review of the assessment strategy for the evaluation of the performance of the bentonite barriers, with special attention given to the treatment of remaining inhomogeneities.

A3) Definition of the technical basis for the design of the barriers

D: Practical implementation

D1: Feedback to design/engineering, are current designs adequate or can they be improved?

For example, the call for ideas for the Bentonite Homogenization Project discusses several of the issues that have been addressed as part of the design basis work in DOPAS. These include:

- The need to structure requirements on both temporal and spatial scales. For example, specifying the requirements on bentonite hydraulic conductivity/density on emplacement and following saturation.
- The need for design specifications to be explicitly linked to safety functions to ensure that they are appropriate and benefit both the implementation process, and licensing and on-going regulatory oversight.
- The need to appropriately express requirements so that they can be translated into construction procedures and quality control processes.
- The need to write good requirements, that allow for variability in product quality, and the practicalities of underground working.

This presentation will provide suggestions for inputs to the Bentonite Homogenization Project from the perspective of systems engineering.

The research in DOPAS has received funding from the European Atomic Energy Community's (Euratom) Seventh Framework Programme FP7/2007-2013 under grant agreement no 323273, the DOPAS project.

Homogenization of bentonite plugs – what are the issues?

Jean Talandier, Andra, France

Bentonite has been considered by most of the agencies in charge of radioactive waste management as the principal component of engineered barrier in underground repository for high and intermediate level wastes. The most important roles for this kind of material is: (i) to ensure low permeability and geochemical favorable environment around the waste, (ii) to limit water flow along the drifts and shafts, (iii) to fill the voids left during the construction of the tunnels providing a good contact due to its swelling property with the drift wall.

Several compositions and forms of bentonite have been studied in the past such as pellets mixture, pre-compacted block or bentonite/sand mixture depending on the required specifications essentially linked with its emplacement in the repository and the safety assessment requirements.

A lot of experiments showed a good homogeneity of the material after hydration in terms of average properties (swelling pressure, water permeability, density…). Many data have been provided by these

experiments and led to the development of predictive models. Nevertheless, locally it is possible to have some variations in those properties with sometimes lower density, which could have some consequences on water permeability and radial stress applied on the host rock. These local heterogeneities could appear in some particular zones such as interfaces and technologic voids. They could result also from non-uniform water hydration history around the drift. In this context, three issues should be addressed:

- After full saturation of the engineered barrier has been reached, understanding the role of local heterogeneity zones on water and gas flow through the engineered barrier. The consequences of localized heterogeneities in terms of preferential pathways should be investigated.
- During hydration phase, understanding the physical processes and reorganization of swelling clay need to be improve, especially for pellets mixture. One consequence could be heterogeneous distribution of loading on components around the bentonite such as retaining concrete plugs, concrete liners or host rock.
- Control the initial properties of the material introduced in the facility with a focus on bentonite density variability. What are the technics available to control the initial variability of dry density when pellets are used? This topic is essential for predicting under good conditions the behavior of the engineered barrier.

State of a barrier of bentonite blocks after 18 years of operation

María Victoria Villar, CIEMAT, Spain

The FEBEX in situ test was running under natural conditions for 18 years before its dismantling, which is currently being carried out. Numerous on-site determinations of the bentonite barrier dry density and water content have been performed. Significant differences between the barrier sections around the heater simulating the waste container and the cold sections have been observed, not only in terms of water content, but also concerning density changes. Since half of the original experiment was dismantled after 5 years of operation, the comparison of the results obtained at that time and those obtained now will help understand the evolution of a bentonite barrier in terms of gap closure, dry density and water content changes over time.

Examples of Finland's experiments for assessing buffer-backfill-pellet homogenization and performance

Erika Holt, VTT, Finland

This presentation summarizes some of the large-scale demonstrations on-going in Finland to assess the bentonite homogenization in the KBS-3V concept. The experiments include in-situ demonstrations at ONKALO, such as the 40% scale buffer test (ongoing since 2012), the buffer-backfill interaction test at VTT (ongoing since March 2015), and the next steps for full-scale insite demonstrations. The material parameters include studies of compatibility and performance of various types of bentonite used for buffer, backfill and pellet products. Some of the main outcomes are shared, as well as scope of upcoming work and needs for future international cooperation on this topic.

The presentation is a joint effort between experts from VTT (Jutta Peura, Harri Kivikoski, Erika Holt) and Posiva Oy (Ville Heino & Pasi Rantmäki).

Impact of the sand/bentonite homogenization on the performance of an EGTS

Niels Giroud, NAGRA, Switzerland

Gas production from corrosion of metals and from degradation of organics in the low and intermediate waste results in a gas pressure build-up that must be limited to avoid irreversible damages to the technical and natural barriers. Thus engineered gas transport systems are designed to lower the pressure build in the emplacement caverns by easing the gas transport towards the construction tunnels. Sand/bentonite mixtures in gas permeable seals are designed to have a low gas entry pressure while providing sufficiently low hydraulic conductivities. The parameters in sand/bentonite mixtures, which control the gas transport capacity of the material, are the sand/bentonite ratio and the emplacement density. With low bentonite content, the hydraulic properties of the mixture are very sensitive to the emplacement density; and as the bentonite content increases, the effect of the emplacement density decreases accordingly. Evidences from large-scale experiments show that the emplacement process may result in a grain size segregation associated with stratified grain size distribution and anisotropic transport properties. Preferential flow paths for water or reduced gas transport properties depending on the direction of flow may result from anisotropic transport properties. In order to assess the performance of the gas permeable seal, the optimisation of the emplacement technique is critical in order to reproduce at full-scale the properties measured in cm-scale laboratory experiments, which produce typically air entry values in the order of 10 to 40 kPa above the pore pressure. This paper presents results from the dismantling of the FORGE mock-up experiment at the Grimsel Test Site, highlighting the significance of the emplacement process as a controlling factor for gas transport capacity of S/B mixtures.

Geophysical monitoring of evolutions of buffer materials and EBS

Kristof Schuster & Markus Furche, BGR, Germany

Knowledge of the evolution of buffer materials like bentonite or sand-bentonite mixtures, especially observed under in-situ conditions, is of great importance and interest for engineers and modeler. Geophysical methods offer a great potential for an appropriate, even nearly non-destructive observation. BGR gained many experiences with this kind of investigations within the framework of several EC projects. The sensitivity of the methods could be shown at several occasions, e. g. during power failures where the heating of a dummy canister was interrupted and the seismic parameters in the ambient rock as well as in the buffer material reacted immediately and significantly. Based on these experiences we would like to encourage the integration of geophysical methods, especially seismic transmission and electrical resistivity tomography in future sealing experiments.

As a retrospect we focus on two projects where beside the EDZ evolution especially the long-term evolution of the backfill materials were monitored and interpreted with the help of changing geophysical parameters. As part of the EC funded PEBS Project three geophysical long-term as well as one short lasting experiment were performed successfully in the related Heater Experiment (HE-E, scale 1:2) and Engineered Barrier Emplacement Experiment (EB, scale 1:1) in the Mont Terri Rock Laboratory (Switzerland). In both experiments a dummy canister was emplaced in the Opalinus Clay (OPA) and bentonite or a sand-bentonite mixture was used for the proper sealing. The EB-Experiment started in 2001 and became part of the PEBS-Experiment in 2010. The HE-E Experiment was initiated in 2010 and started in 2011.

In order to support the process understanding related to different stages of a real repository closure seismic and geoelectrical methods were used. Geophysical parameters as seismic velocities and geoelectrical resistivities react very sensitive to changes in materials as used in these experiments, OPA as host rock and bentonite or sand-bentonite mixture as backfill. The geophysical long-term monitoring was performed on a daily basis which results in a huge data set. Main results are:

1) With the help of seismic transmission methods over four and a half year the compaction/consolidation of the sand-bentonite backfill (65/35, MX80/sand) could be visualized very well. Furthermore, varying seismic parameters give very clear indications for the creation as well as the sealing of EdZ/EDZ features caused in the vicinity of the interface between the backfill and the Opalinus Clay.

2) A 12 years lasting emplacement experiment started with two years of seismic long-term monitoring which were continued after a pause of 8.6 years. The extracted seismic parameters show the continuation of the sealing process in the EDZ and once again the stepwise creation of the EdZ/EDZ as a consequence of the dismantling process in the final stage of the experiment.

3) One year before the dismantling activities started the drilling of two pilot boreholes was performed. In addition to the sampling of backfill material one borehole was used for seismic and geoelectrical borehole measurements. These measurements showed that the bentonite, which was emplaced ten years before and hydrated artificially, seemed to be homogenized in the inspected area.

4) Furthermore, in the final stage of the experiment a circular geoelectrical profile which was used for the initial characterization of the emplacement niche with resistivity parameters was reactivated for the daily monitoring for the last nine months. Resistivity data show a convincing inverse relation to the water content of the bentonite (FEBEX, Almería, Spain) and a rather top – down homogenised bentonite. The resistivity data show also EdZ/EDZ related features in the OPA caused by the dismantling activities.

An impact of bentonite homogenization on its changes by degradation processes

Jiri Mikes, TERAMED s.r.o., Czech Republic

From geomicrobiological point of view, an inhomogeneous bentonite barrier creates potentially different conditions for comparing with the situation when bentonite is homogeneously distributed around the canister (heater). Different milieu in both above mentioned situation creates a unique system for the assessment of its impact on microbial (biogeochemical) activity, especially this which is represented by sulphate and iron reducing bacteria as two examples of corrosion active biota.

In this contribution, the ROCKLAB facility (operated with CTU Prague) will be presented in detail due to emphasis on all advantages for studying of material corrosion and geological environment interactions under specific conditions. Furthermore, the presentation shows intended proposal of experiments and methodical approach for comparison of changes in microbial consortium (especially from its functional aspects – sulphate reduction, iron transformation, hydrogen consumption, etc.) of inhomogeneous and homogeneous bentonite milieu.

Understanding the homogenisation behaviour of bentonite

Jon Harrington, British Geological Survey, UK

Laboratory and field scale experiments provide data at different scales on the homogenisation behaviour of bentonite. However, data from these studies show significant differential stresses arise during hydration of the clay. The apparent longevity of these features can lead to 'locked in stresses' and while their origin and longevity remains unclear, the localised time-dependent development of porewater pressure is an important contributory factor in the development of these stresses. Understanding the evolution in saturation and its impact on the final equilibrium state of the clay is of fundamental importance to predicting barrier performance. Key to this is a detailed understanding of the processes and mechanisms governing the development of stress, porewater pressure and their coupling to the hydromechanical and transport behaviour of the. Data from recent laboratory scale experiments, combined with that from the Lasgit field test will be examined and suggestions made for future studies to improve process understanding.

The Affect of Accessory Minerals on Bentonite Erosion Rates

Rebecca Lunn, University of Strathclyde, UK

In the deep geological disposal of nuclear waste in crystalline rock, erosion of the bentonite buffer may occur during periods of glaciation. Previous researchers have examined the mechanism and rates of extrusion and erosion for purified montmorillonite samples in smooth planar fractures. In this paper, we compare erosion rates from pure montmorillonite with those using, as delivered, MX-80 material (i.e. including accessory minerals) for both smooth walled planar fractures and variable aperture fractures. We construct bespoke fracture flow cells, in which the swelling pressure of the bentonite can be monitored. We also conduct gravimetric analysis on the effluent and use XRD to determine the composition of both the eroded material and the material retained within the fracture. Quantitative image analysis of the extrusion process is used to quantify the extent of the extruded bentonite and location of the accessory minerals. The experiments using MX80 demonstrate that erosion occurs through a 3-stage cyclic process: (1) an accessory mineral ring forms at the edge of the extruded material (2) bentonite swelling pressure increases, resulting in a breach of the accessory mineral ring (3) the breach results in a period of increased erosion during which accessory minerals are transported to the edge of the extruded bentonite and the breach is subsequently healed. This cycle is repeated resulting in a gradual increase in the thickness of the accessory mineral ring until it is sufficiently strong that it remains intact. A comparison of erosion rates with MX80, and those we conduct using pure montmorillonite, shows that the presence of accessory minerals results in a significant reduction the erosion rate. The implications of our findings for bentonite erosion in a full scale repository are discussed.

Saturation and mechanical properties of clays with defined composition

Vaclava Havlova, UJV Rez, a.s., Czech Republic

As it is stated in Collaborative project proposal, bentonite exhibits a quite complex mechanical behaviour showing a degree of irreversibility, leading to backfill heterogeneity. However, mechanical properties are directly connected with chemical and mineralogical composition and the vise versa. So

do the property changes. Moreover, bentonites contain different alkali groups that determine the material property, however not fully predictably.

Therefore a set of experiments has been performed in UJV Rez, a.s. lab, concerning chemical and transport properties of clays with defined composition, representing the end members of bentonite groups. Physical models of saturation of such clay end-member types can be constructed complemented with determination of mechanical property and others. Such a set of information could enable to determine and explain behavior of mixed type bentonites.

Bentonite homogenization: Experimental contribution of CEA/LECBA

Claude Gatabin , CEA, France

For many years, the Laboratory of Concrete and Clay from CEA (CEA / LECBA), in collaboration with Andra, is studying the (T) HM behaviour of bentonites in disposal conditions. This encompasses the design and the realization of multiscale characterization tests, of mock-up, the design and implementation of engineered barriers, clay core for seals and plugs, up to full scale. Depending on the type and the function assigned to the engineered component, different techniques for formatting of swelling clay materials are possible. The use of granular bentonite based materials, assemblages of pellets, for example, has been tested or is now being considered in many disposal concepts. Thus, the LECBA participated in a few important large-scale projects: Bacchus 2, RESEAL, and more recently FSS (2012-2014) included in the European DOPAS project. To achieve the sealing core of the FSS seal, a specific formulation of material was developed. It consists in a 70%30 assembling of quasi spherical pellets, of 32 mm in diameter, and crushed pellets. This mixture, set up in the laboratory, is currently tested in two mock-ups, equipped with relative humidity and total pressure sensors, in order to measure hydro-mechanical parameters during hydration phase.

During the implementation of the FSS seal core technological gaps could be filled only partially, in particular in the uppermost part or in the growths of the simulated test tunnel. Thus, density differences emerged during the filling of the upper part of the seal. A difference of density was measured between the lower part, representing the 2/3 of the volume of the core, regarded as homogeneous, and the upper part, visually heterogeneous, including technological gaps.

Study of swelling clay materials inevitably passes through the knowledge of their hydro-mechanical behaviour under hydration. However, the time required to saturate these materials is fatal once it exceeds the decimeter scale. Only the simulation can solve this temporal aspect.

In the context of the upcoming European project, the CEA/LECBA proposes to consider, at the laboratory scale, the problems of homogenization of heterogeneous materials, the filling of technological gaps and the interfaces contacts, with initially a phenomenological approach. Qualitative and quantitative visual tests will be realized in glass cells. Tests will be settings with the modeling teams to definite dimensions and geometry, material to study, presence of technological gaps, various scenarios of hydration (injection of water on a large surface or on a point), filling cavities or growths, traps filled with gas or water, etc...

After definition of a reference test with modelers, we mean to realize a small instrumented mock-up, its implementation, and the following-up of the test.

The LECBA also proposes to study the problem of the creep of bentonite on a selected material. The laboratory owns a press control loading (capacity 20 tons) and a device specifically adapted to this type of long term measurement.

For large scale component, control of the initial homogeneity of the bentonite mixture is essential. Especially initial distribution of dry density will influence the capacity of the engineering barrier to reach

the specified requirements. To address this issue, the LECBA is currently developing, in collaboration with ENS Cachan, (SATIE laboratory), an original sensor capable of measuring the variations in density and water content in granular bentonite materials.

Bentonite homogenization: laboratory tests to answer open questions related to the German disposal concept in claystone

Artur Meleshyn, GRS Braunschweig, Germany

In the ongoing national R&D project AnSichT, a considerable effort is allocated in Germany to the development of a FEP (feature, events and processes) catalogue accompanied by development of a disposal and closure concept for a generic high-level waste and spent fuel (HLW/SF) repository in claystone. Two disposal site models North and South are considered which take into account inherent differences of Lower Cretaceous and Opalinus claystones in northern and southern Germany such as, e.g., salinities of about 150 g/l and below 23 g/l, respectively. The disposal and closure concept for the disposal site model North envisages the emplacement of HLW/SF waste in 27-m-deep boreholes below the access galleries, whereas in that for the disposal site model South HLW/SF waste is emplaced in galleries (Jobmann & Lommerzheim, 2014; Lommerzheim & Jobmann, 2015). In both concepts clay is to be used as the buffer, backfill and sealing material with, in particular, the buffer (pellets and blocks) to be exposed to temperatures of up to 150°C.

A series of open questions specific to the disposal site models and the disposal concepts were identified so far, some of which are directly related to the homogenization of clay buffer during the saturation phase. These are, e.g., (i) cementation of bentonite due to the interaction with in-situ solutions that may lead to piping effects at 60°C and to a permeability reduction at 90°C (Herbert et al., 2011), (ii) erosion of clay material along the engineering voids as a result of colloid formation or (iii) hydraulic behavior of the buffer as compared to the designed performance during and after the saturation. To cope with the identified issues specific not only to the German disposal concept in claystone, the proposed project should incorporate laboratory experiments (i) at elevated temperatures of up to 150°C (and correspondingly elevated pressures maintaining water in the liquid state in accordance with the expected repository evolution), (ii) with low and high salinities of up to 150 g/l, and (iii) with two bentonites– Ca- and Na- ones – to study the influence of their very different swelling behavior on bentonite homogenization. Dedicated experimental setups will be designed at these conditions to quantify the erosion of compacted bentonite due to the colloid formation and the induced permeability changes as well as to study the effect of the size of compacted bentonite pellets on the permeability and heterogeneity of the bentonite after re-saturation.

Herbert, H.-J., Kasbohm, J., Lan, N. T., Meyer, L., Thao, H. T. M. & Xie, M. (2011): Experiments and modeling of the interactions of bentonites with iron. – GRS mbH, GRS-295: FKZ 02E10538; Braunschweig.

Jobmann, M. & Lommerzheim, A. (2014): FuE-Projekt AnSichT: Endlagerkonzept sowie Verfüll- und Verschlusskonzept für das Endlagerstandortmodell SÜD. – DBE TECHNOLOGY GmbH, TEC-08-2014-Z: FKZ 02E11061B; Peine.

Lommerzheim, A. & Jobmann, M. (2015): FuE-Projekt AnSichT: Endlagerkonzept sowie Verfüll- und Verschlusskonzept für das Endlagerstandortmodell NORD. – DBE TECHNOLOGY GmbH, TEC-08-2015-TB: FKZ 02E11061B; Peine.

Bentonite homogenization: processes and modelling

Antonio Gens, Universitat Politecnica Catalunya, Spain

The degree of homogeneity/heterogeneity of a barrier or a seal at the end of the transient period affects their safety functions. Average dry density is not sufficient to characterize the state of the barrier or seal, maximum hydraulic conductivity will be controlled by the connected zone with the lowest dry density. It should be remembered that hydraulic conductivity is very sensitive to modest changes in dry density.

Although bentonite exhibits a natural tendency towards homogenization, observations at the end of very long term tests such as EB (isothermal) and Febex (non-isothermal) have revealed that, even when the barrier has reached a saturated or near saturated state, a degree of heterogeneity persists.

The sources of heterogeneity can be diverse and the processes associated with them require careful and rigorous modelling. The following sources can be mentioned:

- Combination of pellets and blocks in the same section
- Geometrical features of the barrier
- Non-uniform hydration
- Presence of technological gaps and voids that are filled with the expansion of unsaturated bentonite
- Requirement for self-healing of the saturated bentonite after erosion and /or colloid formation

In addition, thermal effects may enhance heterogeneity as suggested by the dismantling observations of the Febex experiment.

A phenomenon that underlies much of the heterogeneity is the irreversibility of the mechanical behaviour of the bentonite. Irreversibility has been conclusively demonstrated in a series of tests performed by Clay Technology on saturated compacted bentonite samples. Those tests have also showed that existing mechanical models have difficulties reproducing this behaviour. There is less information concerning the equivalent situation under unsaturated conditions although it is likely that irreversible behaviour may be equally significant.

Thus, a major activity in the project should be the development of mechanical constitutive models for bentonite (blocks and pellets) capable of representing irreversibility in a correct and reliable way under both saturated and unsaturated conditions. Non isothermal situations must also be contemplated. This issue has not been addressed specifically in past projects. The resulting constitutive laws would be incorporated in HM and THM analyses to simulate laboratory and in situ experiments that have exhibited heterogeneity. The validated formulation and models can then be applied to generic designs to predict and assess the potential heterogeneity of the barrier or seal at the end of the transient phase.

Finally, there is the possibility that heterogeneity will continue to evolve in the long term due to creep phenomena (bentonite creep only in the case of crystalline rock, bentonite and host rock creep in the case of argillaceous rock). The issue of bentonite creep has never been seriously addressed; it is not straight forward as it involves the very long term behaviour. It could be initially tackled at these levels:

- basic physico-chemical aspects at nano-level (a good understanding at this level may be the only way to extrapolate to the very long term) plus the performance of well-controlled laboratory tests

- parallel development of constitutive models based on the improved understanding of the phenomenon.

A Poroplastic Model of Structural Reorganisation in Porous Media

Gabriel Wittum TechSim, G-CSC, U Frankfurt Germany

We present a model which can serve as a basis for describing the homogenization of bentonite by swelling. The poroplastic model of structural reorganisation in a binary mixture comprises a solid and a fluid phase. The solid phase is the macroscopic representation of a deformable porous medium, which exemplifies heterogenous material. The fluid occupies the interstices of the porous medium and is allowed to move throughout it. The solid phase reorganises its internal structure in response to mechanical stimuli. This process, known as remodelling, is described in terms of 'plastic' distortions, whose evolution obeys a phenomenological flow rule driven by stress. We determine the influence of remodelling on the mechanical and hydraulic behaviour of the tissue, showing how the plastic distortions modulate the fluid flow pattern, fluid pressure, and the distribution of stress. To accomplish this task, we solve the highly non-linear model equations by elaborating a previously developed numerical procedure, which is implemented in the highly flexible, non-commercial Finite Element solver UG4. We show some examples including swelling of the material.

References:

Grillo, Alfio; Raphael Prohl, Gabriel Wittum: A poroplastic model of structural reorganisation in porous media of biomechanical interest. Continuum Mechanics and Thermodynamics, to appear 2015.

Reiter, S., Vogel, A., Heppner, I., Rupp, M., Wittum, G.: A Massively Parallel Geometric Multigrid Solver on Hierarchically Distributed Grids. Comput Vis Sci, 16 (4), pp 151-164, Dec. 2014

Vogel, Andreas; Reiter, Sebastian; Rupp, Martin; Nägel, Arne; Wittum, Gabriel: UG 4 - A Novel Flexible Software System for Simulating PDE Based Models on High Performance Computers. Comput Vis Sci, 16 (4), pp 165-179, 2014.

Hydromechanical behaviour of bentonite under in situ conditions

Robert Charlier , University of Liege, Belgium

In the context of deep geological repositories for nuclear waste, particular attention is paid to the behaviour of bentonite-based materials in relation to their use as engineered barriers. The objective is to create a zone of low permeability that is able to limit water flow around the excavated galleries, and thereby delay the release of radionuclides to the biosphere.

Bentonite-based materials are usually manufactured and emplaced at their hygroscopic water content. Under in situ conditions, the material experiences hydration and swells. During the saturation process, technological gaps between the engineered barrier and the host rock are filled. Contact between the bentonite barrier and the host rock is progressively reached and results in the development of a swelling pressure against the gallery wall.

For several years, a hydromechanical model for compacted bentonite under in situ conditions has been developing to take into account the following aspects:

- The implementation of the Barcelona Basic Model in the finite element code Lagamine. The model is used to reproduce the large strains observed in compacted bentonites upon wetting.
- The extension of the existing hydromechanical formulation to include coupling between
  - The water retention behaviour and the evolving material micro- and macrostructure;

  - The permeability and the material macrostructure.
- The use of a hydromechanical interface element to reproduce the behaviour of technological gaps before reaching contact between the materials, as well as the hydromechanical behaviour of interfaces once contact is achieved.

The hydromechanical behaviour of a bentonite buffer submitted to hydration under in situ conditions has been studied numerically using Lagamine. The investigated problem was directly related to the set of experiments PGZ2 developed in Andra's underground research laboratory.

Micro/Macro model such the one developed in Lagamine is really relevant to describe bentonite pellet mixture during water hydration. ULG propose to improve the model to deal with pellets mixture and to valid it on some specific lab tests. The aim is to be able to handle water saturation of different forms of bentonite including initial technological voids and heterogeneities (density, water content…). Lagamine will used within the framework of the project to simulate experiments at different scale from lab tests to in situ tests. A close collaboration is planned with experimenter groups to design some specific tests to acquire some particular data needs by the model.

Proposal for a project focussed on bentonite homogenization – some examples of ongoing activities in the area

Vasileios Mantikos, Imperial College London, UK

A constant volume column infiltration test, performed under isothermal conditions on compacted MX80 bentonite, was modelled numerically using the Imperial College Finite Element Program (ICFEP). A modified version of the Barcelona Basic Model was used to simulate the behaviour of the buffer, which is inherently partly saturated. The numerical results agree well with the observed experimental data, especially with regard to the advancement of the wetting front, which, however, has proved very sensitive to the adopted relationship between permeability and suction. The analysis results indicate that at any given height, the swelling stress developed due to the hydration of the bentonite depends on the stress history of both the examined point and the rest of the column. A region of localised dilation, advancing simultaneously with the wetting front, induces the contraction of other zones of the material. In addition, local yielding occurs in the q-p plane due to the development of large swelling stresses, followed by yielding in the s-p plane due to suction reduction, causing irreversible strains. As a result, the spatial distribution of the voids ratio changes continuously, leading to significant heterogeneity.

Constitutive mechanical modelling of bentonite behaviour in THEBES project

Markus Olin, VTT Technical Research Centre of Finland Ltd, Finland

The clay barriers are of critical importance in the KBS-3 method. Detailed understanding of their behaviour is pivotal to ensure safe disposal of spent nuclear fuel both in Finland and Sweden.

Several national and EU projects are concentrated on furthering the understanding of the bentonite behaviour in nuclear waste storage applications. However, it is clear that there are still uncertainties which must be carefully investigated before starting the disposal of spent fuel by KBS-3 method. As the disposal is planned to commence in Finland by Posiva in early 20s, the time schedule to complete the bentonite studies reaching acceptable level of uncertainty is pretty tight.

Our proposed approach to investigation of bentonite (applied in the national Finnish project THEBES) is based on a very systematic protocol starting from characterisation and basic experiments followed

by development of a constitutive model based on these observations and data. The developed model is aimed to be validated against more experiments as well as implemented in software and used for prediction of barrier behaviour. In the most ideal case few untested model assumptions would be needed as enough experimental observations should be available. Unfortunately, bentonite is surprisingly intricate material which behaves in a complex manner, which leads to a very challenging research.

THEBES will create not only high quality scientific information but also the know-how and expertise required for the successful application of swelling clay barriers in nuclear waste repositories. In particular, the project will characterise bentonite which is going to be used for creating engineering barriers in spent nuclear fuel repositories in Finland. These investigations will be accompanied by constitutive modelling and simulation of practical cases useful in risk assessment and design of nuclear waste repositories. The project consortium involves four partners: two universities (Aalto and Jyväskylä) as well as VTT Technical Research Centre of Finland Ltd and Numerola Oy.

VTT and Jyväskylä University will investigate the behaviour of bentonite at micro- and nanoscale. Jyväskylä University will perform studies of bentonite with a very accurate x-ray tomography which allows for capturing water transport and swelling deformation of the bentonite. VTT will make systematic tri-axial experiments for obtaining mechanistic behaviour data; in addition, samples are collected for nanolevel structural analysis as well as for microbial acitivity studies (to be carried out in another VTT's project). Furthermore, based on the experimental data, Aalto University, as well as VTT and Jyväskylä University will develop a constitutive model for bentonite. That task will be aided by existing know-how, both at the local and international project partners. The developed constitutive model will be implemented into Numerrin software and validated both using laboratory data and available field studies. The research will allow for more accurate modelling of bentonite and will provide case studies calculations relevant for the design of the nuclear waste repositories. The simulations may, for example, provide estimation of the hydration time of the barrier as well as pressures induced on the canisters by the swelling bentonite.

Authors:

Markus Olin, Matusewicz Michal - VTT Technical Research Centre of Finland Ltd, Finland

Mika Laitinen – Numerola Oy, Finland

Wojciech Solowski, Pulkkanen Veli-Matti – Aalto University, Finland

Markku Kataja - University of Jyväskylä, Finland

SEALEX In-Situ Experiments-Performance Tests Of Repository Seals: Experimental observations and modelling

Nadia Mokni, IRSN, France

The SEALEX project was built with specific focus on long-term hydraulic performance of sealing systems as part of the overall IRSN R&D program that provides the bases for scientific expertise on disposal safety. This work describes observations and numerical analysis of the first SEALEX performance test PT-N1 installed in Tournemire URL. The aim of this large-scale in situ test is to investigate the impact of technological voids on the long term performance of bentonite based seals. The swelling core consists of pre-compacted blocks of MX80 bentonite/sand mixture (70/30 in dry mass). An annular technological gap with a non-uniform thickness exists between the bentonite based core and the host rock. The test is intensely instrumented and it has provided the opportunity to study in detail the evolution of the main HM variables. Material parameters are determined from an extensive laboratory program carried out in the context of SEALEX project.

To ensure an adequate interpretation of the test, the annular technological gap has been appropriately represented. A coupled Hydro-Mechanical (HM) formulation that incorporates the relevant processes involved in the problem under consideration has been adopted to analyse the evolution of the test. The hydraulic and mechanical observations in the bentonite seal are described and discussed. Special attention is paid to the effect of technological gap on swelling pressure evolution and dry density distribution as hydration progresses. The model was able to predict correctly the global HM behaviour of the bentonite based core considering the uncertainties and heterogeneities associated to the fabrication and installation processes of the bentonite based blocks.

Relevance of hydrodynamic and hydrogeochemical reactions on buffer homogeneization

Javier Samper, Universidad de a Coruña, Spain

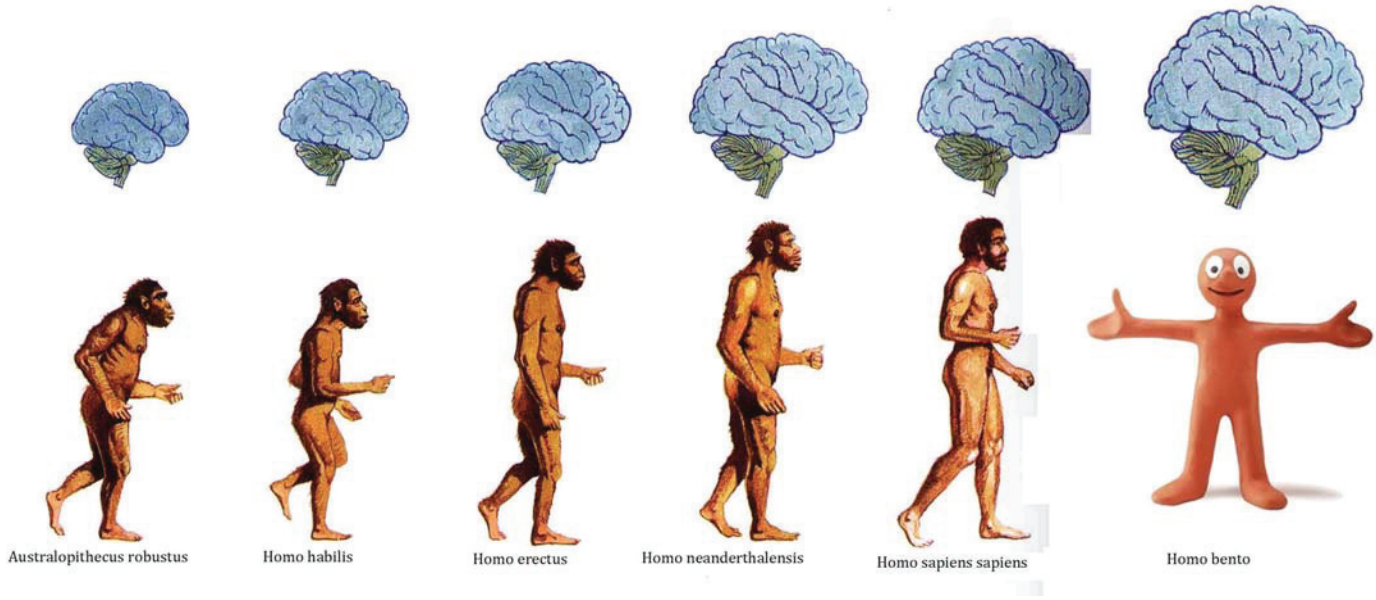
Bentonite homogeneization is usually tackled by analyzing thermal, hydrodynamic and mechanical processes. The role of the bentonite geochemistry should not be disregarded because bentonites are known to be chemically reactive materials. In addition, bentonite hydration and swelling are linked to changes in hydrochemical conditions.

Here we propose to analyze the relevance of the hydrogeochemical reactions for bentonite homogeneization. This analysis aims at improving the understanding of the fundamental processes that lead to homogenization and improved capabilities for numerical modelling. The relevance of geochemical aspects should be analyzed in laboratory and in situ tests as well as for the long-term performance of the bentonite barrier of a high-level radioactive waste repository.

WG2 – Bentonite homogenization
-
Outcomes

Overall idea of HomoBento

Patrik Sellin, SKB



Overview

- Rationales
- Work in other projects
- Available experimental data
- Potential experiments
- Modelling issues
- Summary

Rationales

Safety assessments assumes a homogeneous bentonite material density distribution with a minimum dry density of 1.45 gcm^{-3} at full saturation. This may be an optimistic approach that needs to be verified.

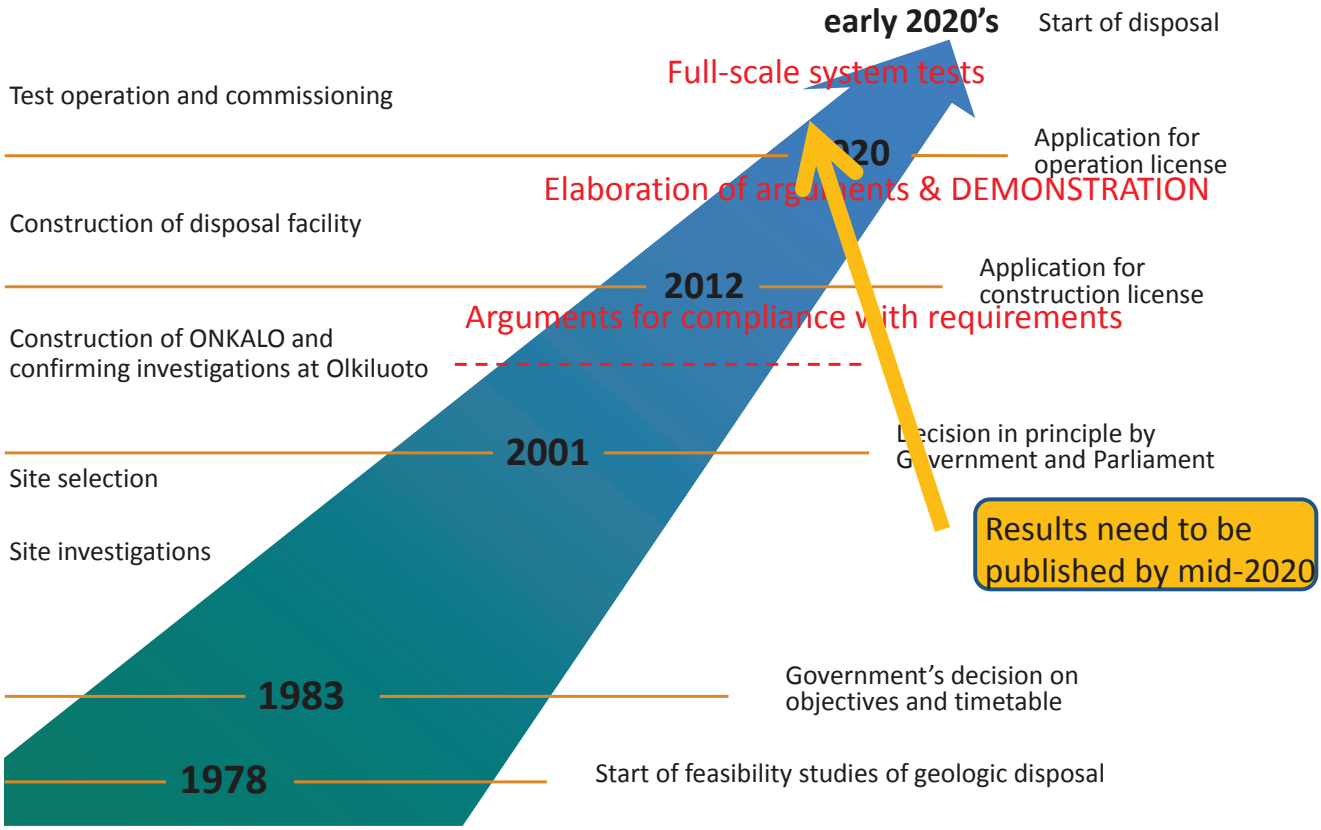
To fulfill this requirement, **it is assumed** that:

1. **Initial material property** differences vanish through resaturation (e.g. blocks and pellets)
2. **Backfill process** induced heterogeneities vanish with resaturation (including technical gaps)
3. **Heterogeneities induced through the nearfield evolution** disappear with resaturation (including chemical interactions at all interfaces)

But based on experimental evidences homogeneity is never fully achieved, thus following questions become pertinent for safety assessment:

1. What phenomena and processes are expected in backfilled repository sections that could be detrimental to safety and that are caused by a heterogeneous backfill?
2. What degree of backfill/buffer homogeneity is needed to ensure long term safety?
3. If heterogeneities are detrimental to the long term safety, how can these be limited or avoided?

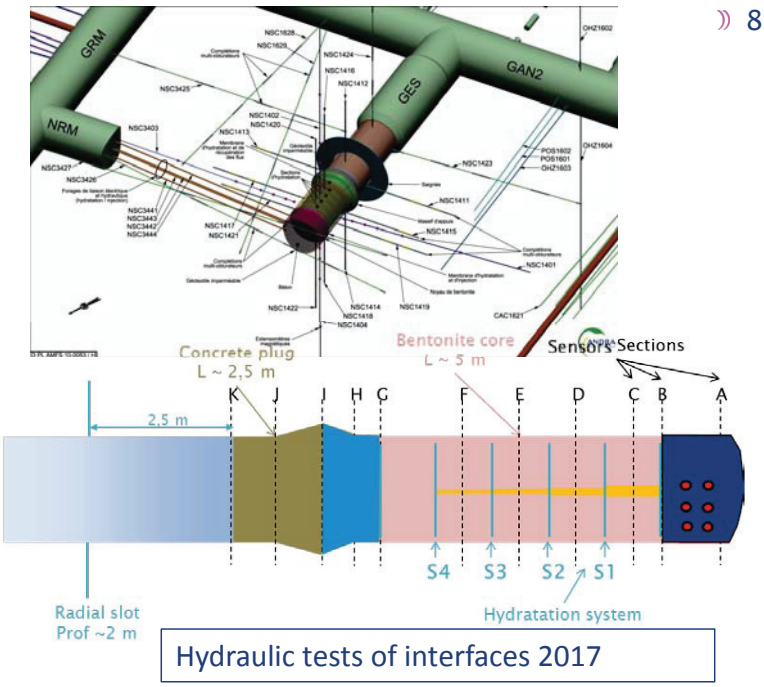
Schedule – Posiva



AVAILABLE EXPERIMENTAL DATA

NSC a large scale sealing experiment

Sand/bentonite bricks
Seal of 5 m long 4,6 m diameter
Pellets/powder mixture to fill interface between host rock and bricks

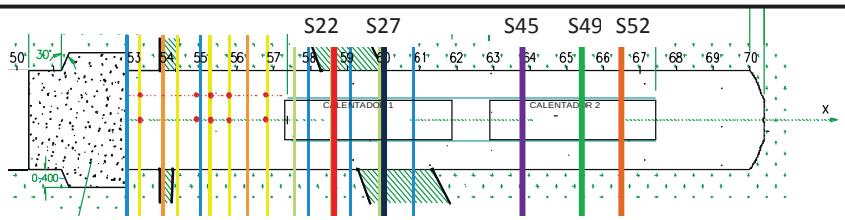


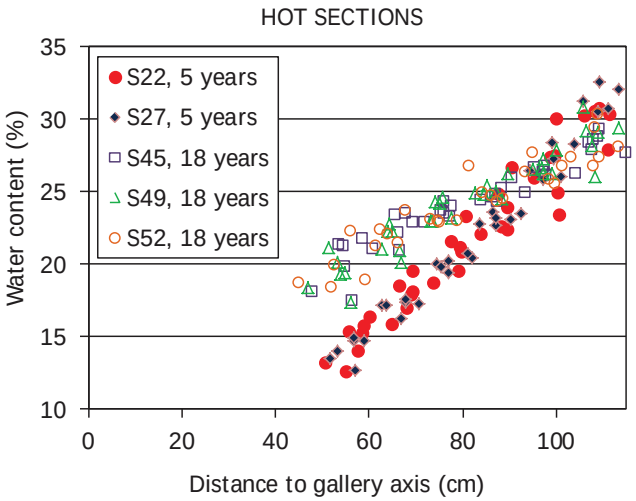
Hydraulic tests of interfaces 2017

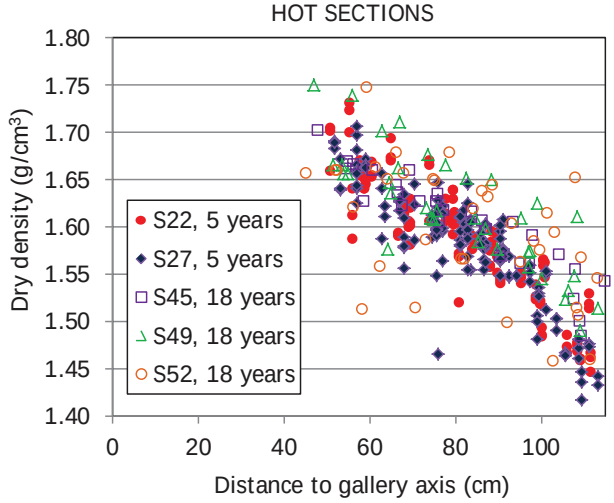
- 318 sensors in the bentonite core
  - Pore pressure :98
  - Load cells :76
  - RH (Capacitive 64, Psychrometer 64, FDR 16)
- 88 sensor in the concrete plug
  - Deformation 36, displacement 16
  - Pore pressure 20
  - tomography(INERIS) 16

Beginning of hydration: January 2014

COMPARISON PARTIAL DISMANTLING







w (%)

S22: 22.6% S45: 25.7%

S27: 22.6% S49: 25.9%

S52: 25.6%

S_r (%)

S22: 85% S45: 98%

S27: 84% S49: 99%

S52: 98%

ρ_d (g/cm³)

S22: 1.57 g/cm³ S45: 1.59 g/cm³

S27: 1.56 g/cm³ S49: 1.59 g/cm³

S52: 1.59 g/cm³

KBS-3V 40% Scale Buffer Demonstrations

Project Schedule

- Site selection & Designing 2010
- Site preparation 2011 then Final installation 10/2011
- Monitoring 2011-> on-going
- Partial Dismantling 9/2013

Project Goals

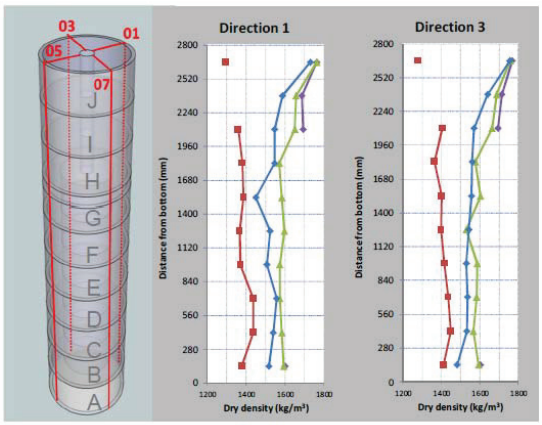
- To perform medium-scale tests in underground conditions
- Learn how to plan, build and monitor tests at repository environment
- Get information from early phase processes of the bentonite buffer

Test basic information

- Two test holes: 800 mm diameter, 3000 mm deep and 4 m from each other
- Buffer blocks, gap filling pellets and heating canisters

Dismantling

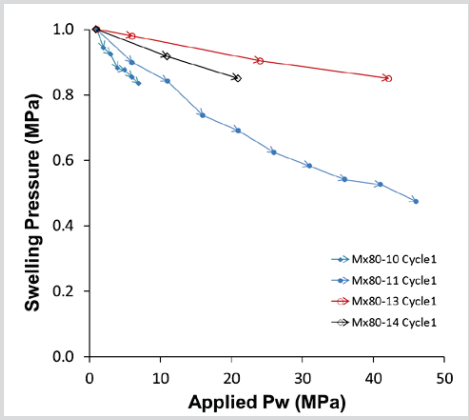
- One experimental test hole was opened and sampled after two years of testing
- A total of 361 water content measurements and 203 density measurements were done during the post-sampling laboratory assessments phase

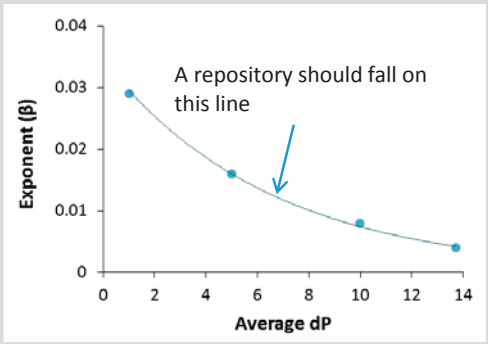


REFERENCE: *Posiva Working Report 2015-08 (Kivikoski et al)*

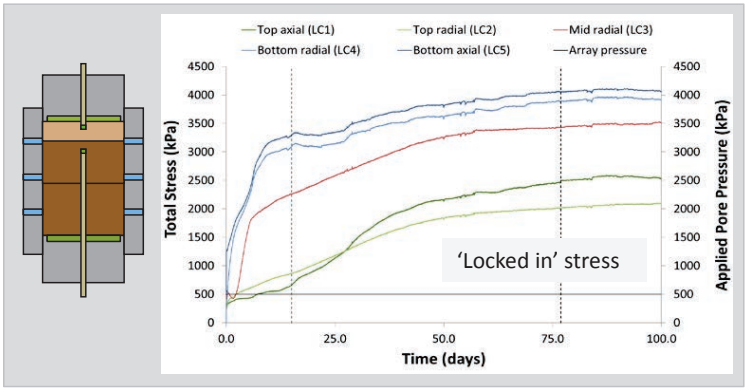
27/10/2015

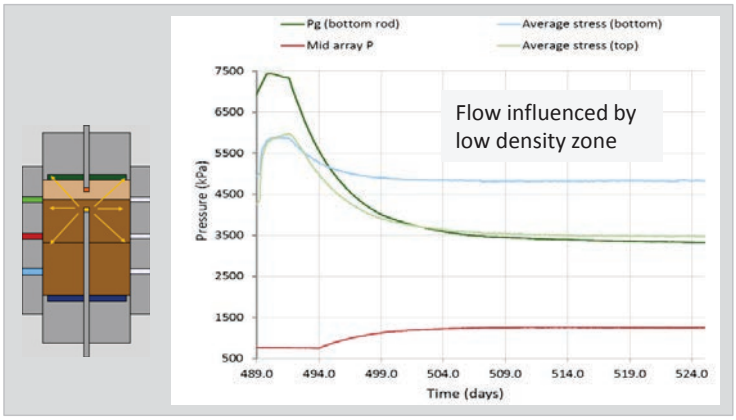
Laboratory experiments – homogenisation under different hydraulics gradients and coupling in dual density systems





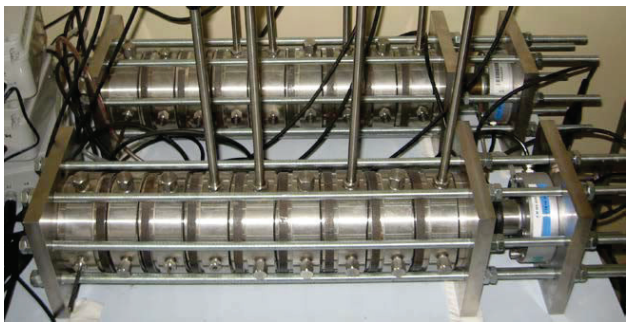
$$\sigma = p_w + \pi_0 e^{-\beta p_w}$$





To be done: Saturation and mechanical properties for homoionic clays

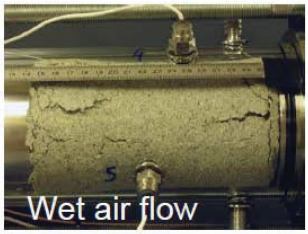
- Hydraulic conductivity
  - Triaxial high pressure chamber – up to 10 MPa
  - Cell without chamber pressure
- Swelling pressure
  - Cell without pressure chamber
- Saturation of homoionic clays:
  THM PHYSICAL MODELS
  - Cells developed within EU FP7 project DOPAS
  - Meaurement:
    - pressure and infiltrated water amount in the beginning of the sample
    - Swelling pressure on the end of the sample
    - Relative saturation in 9 observation points

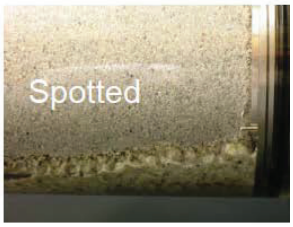


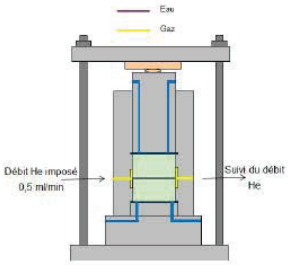
(FP7 EU project DOPAS)

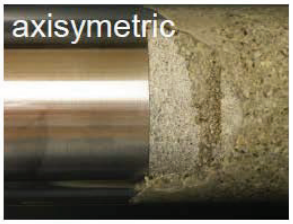
- Qualitative investigation of some specific points, using visual and smart experiments in glass vessels
  - Filling of gaps containing air or water or both : increase of pressure, delay of saturation time…
  - Study of different scenarios, defined with modellers
  - Pressures measurements during the tests
  - Density and water content performed after dismantling
- Influence of a gaz flow on gaps or joints closing, for choosen scenarios (existing equipment).

Some of these tests were reported by Rémi de La Vaissière within EC FORGE project (D3.38-R)









MODELLING ISSUES

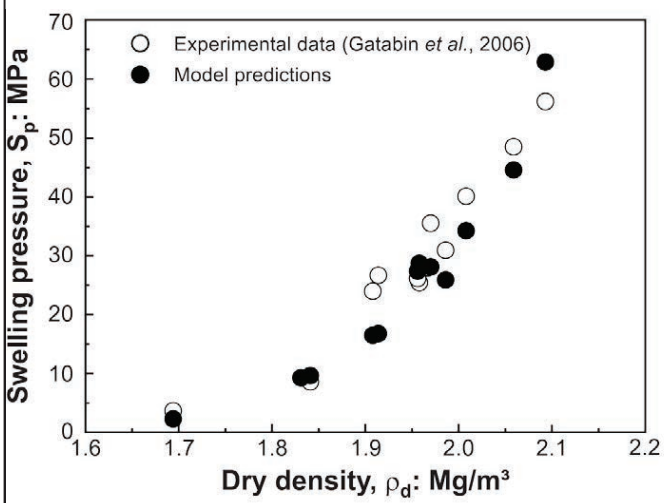
Objectives

- Process understanding requires research on:
  - Effects of initial fabric and its evolution
  - Role of thermal effects
  - Potential role of geochemistry
  - Very long term behaviour (creep)
  - ➢ Well-controlled laboratory tests over a range of conditions and scales are required
- Modelling
  - To develop predictive behaviour
  - Constitutive modelling of the bentonite (including large displacements)
  - Incorporation into coupled HM and THM formulations and codes
  - Ancillary (but important) developments: e.g. gap model
  - ➢ Application to laboratory and field cases (enhanced database with the dismantling of long term tests)
  - ➢ Application to case studies for the verification of performance

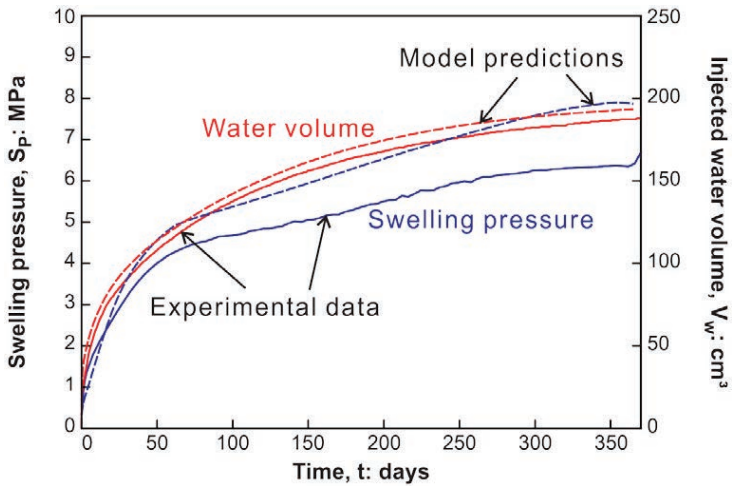
Mechanical aspects

- Elastoplastic model for partially saturated soils = "Extended" BBM

Swelling pressure tests



Infiltration test (BENTOGAZ2)



Experimental data: **70% MX-80 bentonite – 30% sand** - Gatabin et al.

New Project: HomoBento

- Core WG already formed:
  - ANDRA, Enresa, Nagra, Posiva, SKB, RWM, SÚRAO
- Working group discussion at IGD-TP 6th Exchange Forum
- If encouraged by IGD-TP, start-up meeting early 2016
- Potential workpackages:
  - Design and safety assessment
  - Benchmarking/code testing
  - Laboratory experiments
  - Conceptual and mathematical model development

Conditions

- Large amount of data already available
  - Key issue: evaluation of existing data
  - No operation of large- or field scale experiments included in project
- The objective of the modelling with respect to bentonite homogenisation would be
  - Achieve and demonstrate process understanding
  - Attain and demonstrate predictive capabilities
- Focus would be on the mechanical constitutive model that should exhibit irreversibility and stress path dependency and encompass:
  - Saturated and unsaturated material
  - Isothermal and non-isothermal conditions
  - Blocks and pellet-based materials
- The mechanical constitutive model incorporated in coupled HM and THM formulations would be applied to:
  - Well-controlled laboratory tests at different scales (process understanding)
  - Past and ongoing large scale field tests: EB, Febex, SEALEX, CRT…
  - Case studies for the verification of the performance of current designs for buffers, backfills, seals and plugs
- Long term homogeneity/heterogeneity may depend on creep behaviour
  - Laboratory tests (limited duration); fundamental micro or nanoscale studies may be required

Mechanical Homogenization in Bentonite (HomoBento)

- Currently considered in an optimistic way (full homogenization)
  - This has to be verified in the license processes
- Common issue in most programs
  - The working group had strong and common interests to contribute to the issue
- The conceptual understanding of homogenization is incomplete
  - Is the underlying physics correctly represented?
- Available numerical models are not able to predict experimental behavior
- Laboratory and field data is available
  - Possible to continue model improvement
- Strong benefit from a joint effort
- Off-spring from DOPAS, FORGE, LUCOEX and PEBS
- The number of interested partners could be ~30+
  - This includes WMO, TSO, Universities, Research organizations/companies
  - Will be a management challenge

Working Group 3 - Cement Organics Radionuclide Interactions (CORI)

Rapporteurs: M. Altmaier – F. Plas

Organic materials are present in nuclear waste repositories and potentially influence their functionality and performance. Especially in the context of low and intermediate level waste disposal, the amount and chemical diversity of organics will significantly increase relative to what is present as organic additives, e.g. superplasticizers, in the cementitious materials used in a repository. Highly alkaline conditions characteristic for cement based materials are expected to increase the potential impact of certain organics on repository performance. The TSWG CORI is currently discussing relevant issues in the context of Cement-Organics-Radionuclide-Interactions. As decided during the first meeting of CORI in March 2015 where 28 representatives from 4 WMOs and 16 research institutes participated, five topics are prioritized:

- Organics inventories in different countries. Identification of relevant organics in PA
- Degradation of organics => Result of hydrolysis and radiolysis
- Mobility of organics in cementitious environment and their interaction with Fe
- Mobility of organics-RN complexes in a cementitious environment
- Modelling, upscaling, TDB, application to PA

At the IGD-TP EF6, the TSWG CORI will present the results and discussions on Cement-Organics-Radionuclide-Interactions, summarize the present state-of-knowledge and identify the most critical issues and data needs.

- **Introduction** M. Altmaier, KIT- INE
- **Overview of the outcome of the TSWG CORI "Cement Organics Radionuclide Interactions" –** Marcus Altmaier, KIT-INE, Germany
- **CORI-WP - WMOs priorities and expectations –** Eric Giffaut Andra France
- **Degradation of organics - result of hydrolysis and radiolysis-** Johan Vandenborre, SUBATECH, France
- **Mobility of organics in cementitious environment and their interaction with Fe -** Mireia Grivé, Amphos 21 Consulting, S.L., Spain
- **CORI-Work Package on "Mobility of organics-RN complexes in a cementitious environment -** Virginie Blin, CEA, France
- **CORI: WP on "Modelling, upscaling, application to PA"-** Vanessa Montoya, KIT-INE, Germany

WG3 - Cement Organics Radionuclide Interactions (CORI)
-
Abstracts

Overview of the outcome of the TSWG CORI "Cement Organics Radionuclide Interactions"

Marcus Altmaier, KIT-INE, Germany

In this contribution, an overview of TSWG CORI is given, and the main outcome and conclusions from CORI are summarized. Based upon this, the overall approach and tentative content of a latter project proposal on the topics addressed in CORI is presented. TSWG CORI at present consists of 20 research institutes and has received input from with 7 Waste Management Organizations.

The TSWG CORI was established to discuss relevant issues in the context of Cement-Organics-Radionuclide-Interactions. Organic materials are present in nuclear waste repositories and potentially influence their functionality and performance. Especially in the context of low and intermediate level waste disposal, a significant amount and chemical diversity of organics is present. Highly alkaline conditions characteristic for cement based materials are expected to increase the potential impact of certain organics on repository performance. The most critical topics and data needs required to better assess Cement-Organics-Radionuclide-Interactions were identified within CORI and an integrated approach to address these issues in the frame of a collaborative research initiative was developed. Detailed information on the identified key topics will be given in separate contributions by the respective work package leaders and include

- WP "Degradation of organics - result of hydrolysis and radiolysis"
- WP "Mobility of organics in cementitious environment and their interaction with Fe"
- WP "Mobility of organics-RN complexes in a cementitious environment"
- WP "Modelling, upscaling, application to PA"

CORI-WP - WMOs priorities and expectations

Eric Giffaut, Andra, France

E. Giffaut (Andra), V. Cloet (Nagra), B. de Blochouse (Ondraf/Niras), A. Shelton (RWM), K. Källström (SKB)

All waste management organizations that were actively involved in setting up the CORI Working Group have identified a list of common organic compounds present in low and intermediate level radioactive waste. Organic waste inventories are a first input in the definition of the systems of interest, setting the scope of CORI to a 'reasonable' selection of materials. Bituminized wastes represent a significant mass but are not considered here because of the important knowledge acquired from various previous programs. Total mass of the other organics can go up to 12.000 tons in inventories managed by the various WMOs. The organics that contribute most to the total mass are PVC, ionic exchange resins, cellulose, polyacrylate and polyethylene. EDTA is included in the list of organic compounds of interest for its chelating properties, even though it is only present in low quantities. Other organic compounds are also identified but are considered less relevant as a function of their respective total masses and potential to influence radionuclide mobility.

Another source of organic compounds in a geological disposal facility is the use of cement admixtures such as superplasticizers in particular polycarboxylates. Typically, these compounds make up

between 0.5% and 1.5% of mass of cement, which could correspond in the context of the whole system to a total organic mass equivalent to those of organic wastes.

Finally, a last concern is the behaviour of 14C-bearing organic molecules released from graphite, ion exchange resins or activated steel ends and hulls. The EU-project CAST studies the identity of the small organic molecules released in an alkaline environment. However, the transport of these molecules remains unknown.

In the engineered (concrete) barrier system of the geological disposal facilities, the agencies expect to gain more insight into three main issues:

1. Radiolytic/hydrolysis degradation of solid organic compounds (wastes, superplasticizers) : gas and aqueous species characterization and production rates;
2. Chemical and transport behaviour of the dissolved organic degradation products;
3. Influence of these latter on radionuclide behaviour.

The first issue is a major challenge considering analytics techniques necessary to support determination of aqueous speciation. In most cases, no to poor characterization is available for dissolved species (excepted for cellulose). The second issue is mostly focused on strong organic ligands considering (i) their mixtures with other organics also released, (ii) evolution of cement materials. Same studies (methodology, technics) could be applied both to complexing molecules and to 14C-bearing organic molecules. Finally the third issue is directly supporting performance assessment by evaluating sensitivities to organic inventories and to segregation/mixture of waste types in disposal caverns.

CORI-WP: Degradation of organics - result of hydrolysis and radiolysis

Johan Vandenborre, SUBATECH, France

CORI has identified that the degradation of organic products by radiolysis and hydrolysis at high pH is insufficiently known. Consequently, a workpackage is proposed dealing with the radiolytic and/or hydrolytic degradation of selected organics of interest. The key topic of this WP is the kinetic study of degradation rates (hydrolytic/radiolytic) measurements vs. time (irradiation or chemical) and the identification of the resulting organic substances with the intention to constitute a source term for relevant organic molecules. The overall highlights of this WP are:

- At present, 8 partners are interested in the WP (SUBATECH, AMPHOS21, JUELICH, KIT-INE, PSI, SCK-CEN, UPPC, Manchester University). 5 of them have irradiation tools for radiolytic degradation experiments (α and/or γ radiations). CORI intends to establish a consortia combining partners with and without irradiation facilities, in order to perform degradation of organic products by hydrolysis in parallel with radiolytic degradation experiments.
- It is proposed to study two experimental systems with a restricted set of experimental parameter variation (hyper alkaline pH fixed at 12.5, under anoxic atmosphere, with or without initial H2 and with or without radiation) for two systems: (i) binary systems with solution and organic products, (ii) ternary systems with solution, organic products and additional powdered solid cement phases.
- Powdered solid phases will be chosen among the cement phases of interest consistent with CEBAMA project (CSH, Portland…).
- The range of organics products studied needs to be limited. CORI at present intends to prioritise investigations of PVC, cellulose, phtalate/polycarboxylate (representing superplasticiser) and ionic exchange resins.
- Analytical tools available in CORI are devoted to the characterization and/or measurements of organic molecules resulting from the radiolytic/hydrolytic degradation experiments. Specific

analytical tools are available for the measurement of gas production (for example: H2, small volatile organic molecules and others).

- Modelling efforts, in collaboration with the WP "modelling, upscaling, application to PA", will be mainly devoted to hydrolytic/radiolytic degradation rates.
- A strong overlap will be established with the WP "mobility of organics in cementitious environment and their interaction with Fe".

Mobility of organics in cementitious environment and their interaction with Fe (WG3: CORI)

Mireia Grivé, Amphos 21 Consulting, S.L. Spain

The CORI Work Package (WP) entitled "Mobility of organics in cementitious environment and their interaction with Fe" is aimed at improving the understanding of the behaviour of anthropogenic organic molecules within cement systems and quantifying their aqueous concentration in pore water resulting from source terms, chemical interactions and transfer properties. This availability in interstitial waters is a direct input to Performance Assessment (PA) exercises. Thereby, this WP is a straightforward link between the WP dealing with "Source term and kinetics of release" and the one aimed at addressing the "Direct consequences of organics onto RN mobility". Special attention will be paid on the influence of steel from armoured systems and of Fe-bearing cement phases (i.e. Ferrite). The aim is to deepen the understanding of the competitive effect of organic ligands on both, sorption and transfer properties of the small organic molecules onto cement, and iron complexation ability in ternary systems Fe-org-cem. Because of the large list of possible combinations among dissolved organic species, RN and cement degradation states, the priorities for organics of this WP have been ranked with respect to: (i) organic waste inventories, (ii) complexing properties, (iii) organics arisen from the organic 14C fraction dissolved (e.g. basically a third of the aqueous 14C released from graphite). The list of organics to be studied will be adapted following the outcomes of the WP "Source term and kinetics of release".

Cementitious systems:

The use of cement entails the employment of additives and especially superplasticizers (SPL). Thus, cement formulations may comprise a large list of potential organic sources that must be considered in the development of this WP. A promising methodological approach is to select proxies (e.g. one polycarboxylate as proxy for this type of substance) when studying interactions with cement and RN.

Therefore, a scientific development is foreseen from single systems (e.g. C-S-H (with variable C/S ratio), AFm, AFt) up to actual materials to be used in disposal designs. A bottom-up approach will be considered from different cement paste formulations to actual materials, including aggregates and armoured systems.

Organics from technological wastes:

Many studies have been carried out and published on ISA behaviour (mentioned as a typical example), although the response of ISA to cement degradation is still unclear. From a PA point of view, the influence of organic compounds must be considered within a common scenario where a cocktail of species is released as a whole. Interactions between organics are currently ill-defined, including competitive effects for cement surfaces. One direct question that should be addressed in this WP is the behaviour of ISA in the presence of other dissolved organic species. Up-scaling development involves interactions with iron steel and corrosion products (e.g. magnetite), i.e. considering iron as a source for complexation and assessing redox processes of organic compounds.

Organics as 14C release and behaviour:

14C behaviour is directly correlated with its speciation in gaseous and aqueous species. Retardation processes through cementitious materials are then of special relevance, limiting the 14C mobility in the EBS. This WP within CORI project aims at providing specific insights on dissolved organic 14C behaviour interaction with cement-based materials. 14C species to be studied could be identified later following CAST outcomes.

Bottom-up approach and modelling process:

Scientific developments in this WP must be a part of a process which leads to reflect actual disposal components (waste packages, disposal cells). Individual topics are already identified:

- Interactions of single organic molecules with cementitious phases,
- Interactions of mixtures of organic molecules with cementitious phases,
- Interactions with the former systems, but including metallic iron and its corrosion products,
- Up-scaling to realistic materials (cement pastes, concrete, reinforced systems).
- Each subject will be studied from experiments to models (conceptual, numerical).

CORI-Work Package on "Mobility of organics-RN complexes in a cementitious environment"

Virginie Blin, CEA, France

As part of the CORI project, this Work Package is dedicated to strengthen the understanding on organics/radionuclides complexes mobility in cement-based systems.

In the ternary systems composed of cement-based materials, organic molecules and radionuclides, the mobility of the latter can be influenced by several processes such as:

- Radionuclide complexation in the aqueous phase by organic molecules acting as ligands;
- Competition effects for the surface adsorption sites of cement-based materials;
- Or synergic processes.

In Performance Assessment (PA) exercise, the influence of aqueous organic molecules is usually considered as a phenomenon decreasing the adsorption of radionuclides onto solid surfaces. Such an effect is then taken into account by using adsorption "reduction factors" applied to the sensitive radionuclides. It is strongly linked to the nature and amount of organics released into the system, their complexation properties as well as their own mobility in interstitial pore water.

Consequently, the development of this Work Package will benefit from the feedback on both "Degradation of organics" and "Mobility of organics in cementitious environment" Work Packages. Within a consistent overall approach in CORI, the studies will allow to perform a bottom-up approach from simplified to real systems, with selected solid phases and organic molecules. Furthermore, considering the highly alkaline physicochemical conditions expected and the knowledge about adsorption under such conditions, it is intended as a first priority to focus this study on selected radionuclides in cationic form (Ni, Pb, Am, Ln(III), Pu, U have been selected as a first set of elements of interest).

The studies performed will combine experimental and modelling work in order to assess and quantify the mechanisms that take place at microscopic scale in relevant ternary systems in order to support PA calculations. They will also provide new data on adsorption and radionuclide transport to be used in the integrated modelling approach proposed in the Work Package of CORI project "Modelling, upscaling, application to PA".

CORI: WP on "Modelling, upscaling, application to PA"

Vanessa Montoya, KIT-INE, Germany

CORI is addressing the topic of Cement-Organics-Radionuclide-Interactions. In the framework of nuclear waste disposal, understanding of the interactions of cement with radionuclides in the presence of a wide variety of organic components is of high interest. Modeling of radionuclide migration in the presence of organic components requires a detailed mechanistic understanding of chemical phenomena with transport processes as well as specific data and databases. Modeling work within CORI will include:

Reactive transport modeling of organics and RN-organics complexes

- Modelling of selected organics degradation processes
- Upscaling of processes (based upon reference scenarios)
- Application to PA

CORI has identified the need to improve the modelling capabilities by a collaborative approach based upon new experimental data. The aim of CORI is to provide a scientifically convincing integrated modelling approach, also including the important aspect of up-scaling, in support of PA interests. In this presentation, the activities proposed by CORI on this topic are summarized. The expected close link to the experimental work is highlighted, potential synergies with complementary international developments outlined, and an overview of modelling tools and related software packages to be used given.

WG3 - Cement Organics Radionuclide Interactions (CORI)
-
Outcomes

Summary of discussions
"Cement-Organics-Radionuclide-Interactions"
TSWG CORI

- M. Altmaier, KIT-INE, Germany
- Frederic Plas, ANDRA, France

IGD-TP EF6, 3+4.11.2015, London

TSWG CORI (JA6b)

- **TSWG CORI established within IGD-TP:**
  JA6b: Cement-Organics-Radionuclide-Interactions
- *Joint activity launched in EG15*

- *WP activities in 2015*
  - *March: meeting in Karlsruhe,* 28 representatives from 4 WMOs and 16 Research Institutes. Definition of key topics and responsibilities.
  - Spring: distribution of CORI Questionnaire to partners.
  - Summer/Fall: evaluation of questionnaires and input from partners, several follow up meetings.
  - November: presentation of CORI at IGD-TP EF6.
  - Always: highly constructive exchange with WMO representatives!

Presentations and discussions on CORI at IGD-TP EF6

TWG3 – Cement Organics Radionuclide Interactions (CORI)

Rapporteurs: M. Altmaier – F. Plas

Programme

Tuesday 3rd November

14:00 - 17:00	***Introduction*** M. Altmaier, KIT- INE
	Overview of the outcome of the TSWG CORI "Cement Organics Radionuclide Interactions" - Marcus Altmaier, KIT-INE, Germany
	CORI-WP - WMOs priorities and expectations - Eric Giffaut Andra France
	Degradation of organics - result of hydrolysis and radiolysis- Johan Vandenborre, SUBATECH, France
	Mobility of organics in cementitious environment and their interaction with Fe - Mireia Grivé, Amphos 21 Consulting, S.L., Spain
	CORI-Work Package on "Mobility of organics-RN complexes in a cementitious environment - Virginie Blin, CEA, France
	CORI: WP on "Modelling, upscaling, application to PA"- Diederik Jacques, SCK.CEN, Belgium

OUTCOME OF TSWG CORI

- Investigation of cement-organics-radionuclides-interactions is a relevant topic with potential implications for nuclear waste disposal.
- WMOs analysis of relevant organics inventories in repository projects!
- The identified key topics, research tools and strategy allow to develop a R&D approach for investigating the CORI topics.
- *CORI suggests to develop a proposal for the next Horizon 2020 call.*

CONCEPT FOR CORI PROPOSAL

- **CORI includes four R&D oriented Work Packages:**

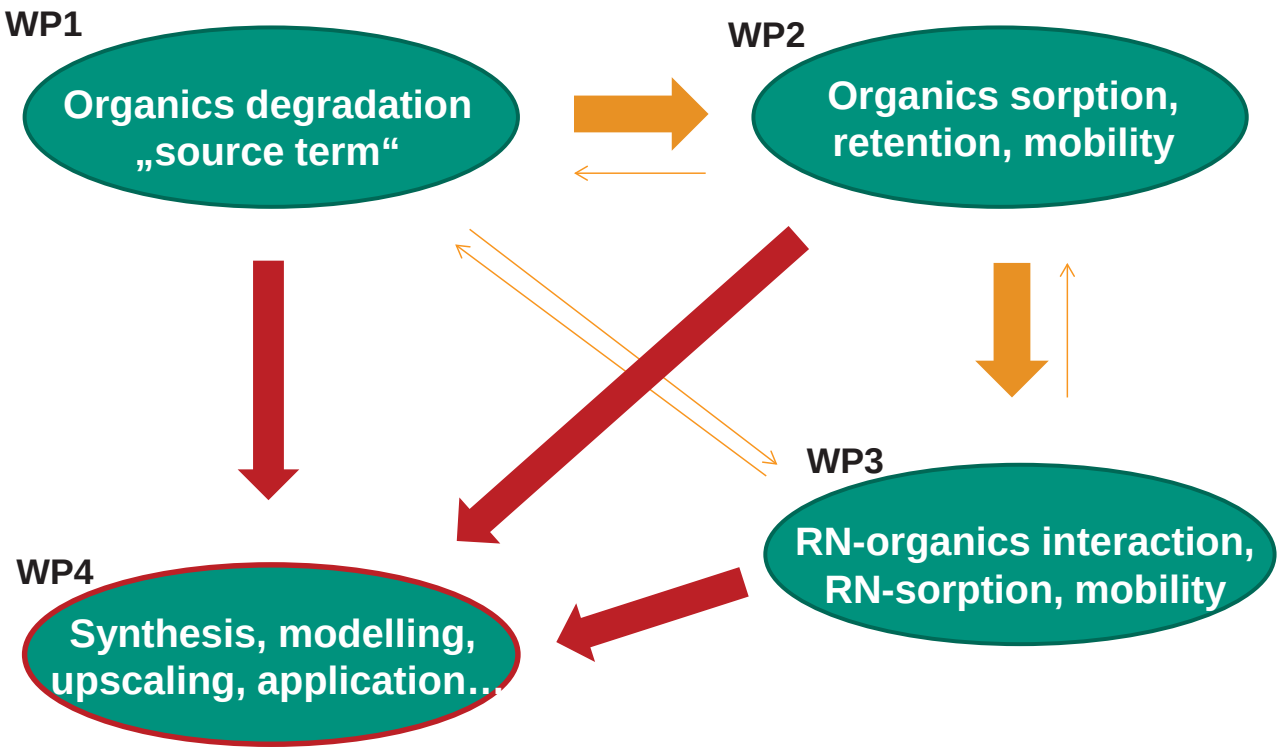
  - WP 1 “Degradation of organics - result of hydrolysis and radiolysis” (*Subatech*)
  - WP 2 “Mobility of organics in cementitious environment and their interaction with Fe” (*Amphos21*)
  - WP 3 “Mobility of organics-RN complexes in a cementitious environment” (*CEA*)

  - WP 4 “Synthesis, modelling, upscaling, application” (*SCK·CEN*)

- Additional WPs on Management (Coord. KIT) + Training/Dissemination

- **Total requested EC contribution: < 4 M€**

CONCEPT FOR CORI PROPOSAL



INTERACTION WITH OTHER PROJECTS

- CORI topics allow strong synergies with ongoing EC projects.
- Complementarity of approaches and complementary research results.

MIND	*Organics degradation via bio-mediated processes studied. => Synergy with CORI WP1.*
CAST	*Chemical speciation and concentrations of ^{14}C from irradiated materials. => Synergy with CORI WP2.*
CEBAMA	*Transport processes and RN sorption studied and modelled in cement based systems. => Synergy with CORI WP4.*

POTENTIAL CORI PROJECT PARTNERS

Potential CORI partners

Amphos21 (ES), Bern Univ. (CH), BRMG (F), CEA (F), CTU (CZ), ENEA (IT), Heidelberg Univ. (DE), Juelich (DE), KIT-INE (DE), Loughborough Univ. (UK), Mainz Univ. (DE), Manchester Univ. (UK), NNL (UK), NRG (NL), Potsdam Univ. (DE), PSI (CH), SCK·CEN (BE), Sheffield Univ. (UK), Subatech (F), TERAMED (CZ), UJV (CZ).

At present: 21 potential partners from 8 countries

CORI is open for additional contributions from new partners focusing on the identified key issues in CORI.

WMOs

ANDRA, NAGRA, ONDRAF/NIRAS, RWM, SKB, SURAO, (ENRESA), …

Main results + arguments from discussions

General Comments

- CORI has three sufficiently linked experimental WPs.
- Good complementarities and synergies with other projects (CAST, MIND, Cebama).
- Investigated cement systems shall be consistent with Cebama.

- Motivation of CORI to develop proposal for Horizon2020 is confirmed.

Main results + arguments from discussions

WP 1: "Degradation of organics - result of hydrolysis and radiolysis"

- Degradation studies in **WP1** under varying conditions (pH, dose).
- Irradiation experiments performed both under α and γ dose (β?). Attention should be made to avoid artefacts at very high doses.
- Balance of work efforts on radiolysis/hydrolysis degradation studies needs to be clarified.
- Analysis of gas production from organics degradation presently included in CORI concept within WP1.

Main results + arguments from discussions

WP 2 "Mobility of organics in cementitious environment and their interaction with Fe"

- **WP2** builds on selected low weight organic molecules (priorities according to inventories and chemical representativity) already identified and adds increasing complexity during project via WP1 input.
  - *Large complexity of expected organics from WP1 systematized according to functional groups and chemical characteristics.*
- Competition effects, e.g. with Fe or between organic molecules, in cementitious environments investigated in WP2.
- Investigation of ^{14}C mobility in cementitious environments from activated materials as identified in CAST included in CORI WP2.

Main arguments from discussions

WP 3 "Mobility of organics-RN complexes in a cementitious environment"

- Radionuclides prioritized in **WP3** include typical representatives for main relevant metal classes. => Ni, Pb, Ln(III), Am, Pu, U , (present).
- CORI intends to derive mechanistic understanding and provide a combination of complementary diffusion and batch experiments.
- Comparison of chemical modelling with K_d approach. (see WP4)

Main arguments from discussions

WP 4 "Synthesis, modelling, upscaling, application"

- Feedback from WMOs required for **WP4** to better define requirements. Exchange between CORI and WMOs is ongoing process (=> EUG).
- CORI aims at providing a synthesis of results on a level that allows integrating the results as input in national programms and PA.
- CORI does not intend to do PA calculations.

CONCEPT FOR CORI PROPOSAL

- **CORI includes four R&D oriented Work Packages:**

➢ WP 1 "Degradation of organics - result of hydrolysis and radiolysis" (*Subatech*)
➢ WP 2 "Mobility of organics in cementitious environment and their interaction with Fe" (*Amphos21*)
➢ WP 3 "Mobility of organics-RN complexes in a cementitious environment" (*CEA*)

➢ WP 4 "Synthesis, modelling, upscaling, application" (*SCK·CEN*)

- Additional WPs on Management (Coord. KIT) + Training/Dissemination

- **Total requested EC contribution: < 4 M€**

Working Group 4 - Spent fuel dissolution & chemistry in container

Rapporteurs: L.Evins – J. Andersson

Within the Key Topic "Waste forms and their behaviour", there is a need to improve understanding of modern fuel behaviour in realistic repository conditions. There is a current trend to change manufactured fuel characteristics in order to improve fuel performance. Experiments are needed to expand the data base to include fuels with dopants such as Cr, Al, and Si, and potentially also research reactor fuel. In addition, whatever groundwater type is expected to be present in a repository, it is required to properly address the interaction between the intruding water and the on-going canister corrosion which is expected to affect the real chemical environment inside a failed canister. Thus, having reached a certain consensus of expected standard fuel behaviour in truly reducing conditions, the idea is now to test the hypothesis that modern spent fuel, in a realistic chemical environment as envisaged inside a failed canister, will not deviate from the expected behaviour as determined from previous experiments. This session aims to bring together and discuss research ideas for further study in the area of dissolution of modern (doped) and non-standard fuel in a failed canister.

- **Introduction Waste form and behaviour: Chemistry and dissolution in a high-level waste container** - JA Leader: SKB (L.Z. Evins, J.Andersson)
- **Leaching of doped irradiated fuel under H2 conditions** , Studsvik (O. Roth)
- **Dissolution rate of MOX and Cr-doped UO2 fuel** , JRC-ITU (D. Wegen)
- **Remaining questions after FIRST-Nuclides** , KIT-INE (B. Kienzler)
- **Thermodynamics as a support for the interpretation of spent fuel leaching experiments**, PSI (E. Curti)
- **Simfuel approaches to understanding spent fuel behaviour** , University of Cambridge (I . Farnan)
- **UO2 interactions inside canister conditions**, VTT (K. Ollila, E. Myllykylä)
- **Corrosion mechanisms of modern LWR-fuels using UO2-based model systems**, FZ Jülich (D. Bosbach)
- **Andra proposal for a future European project dealing with geochemical processes within a HLW/Spent fuel disposal cell, Andra** (C. Martin)

WG4 - Spent fuel dissolution & chemistry in container

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Abstracts

Waste form and behaviour: chemistry and dissolution in a high-level waste container Introduction

Lena Z. Evins, SKB, Sweden

Within the Key Topic “Waste forms and their behaviour”, there is a need to improve understanding of behaviour of the waste form in realistic repository conditions. This means that the chemistry of the High-Level waste form, be it SNF or HLW glass, will affect the dissolution behaviour of the material in direct relation to expected chemistry inside a corroding waste container. The purpose of this introduction is to set the stage for the discussion regarding what are the most pressing matters, in line with the IGDTP vision and Strategic Research Agenda, to include in a future project proposal concerning the dissolution of the HLW waste form. From the spent fuel perspective, we foresee a focus on modern, doped fuels as well as MOX and research reactor fuels, while for all types of waste it is required that the question regarding the expected conditions inside a failed canister is addressed.

Leaching of doped irradiated fuel under H2 conditions

Olivia Roth, Studsvik Nuclear AB, Sweden

Studsvik Nuclear AB is a leading supplier of services to the international nuclear industry. The company has more than sixty years of experience of nuclear technology and services in a radiological environment and the group of nuclear fuel chemistry has more than 30 years research experience on spent fuel leaching and nuclear environmental chemistry.

At the Hot Cell laboratory in Studsvik, the necessary equipment for studies of irradiated fuel under conditions relevant for a future deep repository are available. This includes for example clean Hot Cell environment, spent fuel autoclaves and chemical analysis instruments, such as ICP-MS, for highly radioactive solutions.

Studsvik has a large range of fuel types available for deep repository studies. This enables systematic studies where doped fuel can be compared to standard fuel under identical conditions. Long term spent fuel leaching under aerated conditions can be performed in order to evaluate the matrix dissolution behaviour of doped fuel. Furthermore, leaching under H2 atmosphere can be performed using both doped and standard fuel in order to investigate potential effects of doping on the H2 inhibition of matrix dissolution.

Spent fuel leaching under aerated conditions was performed in the project “First Nuclides” for doped fuel (ADOPT). To complete the picture of the effects of dopants, it is suggested that leaching under H2 atmosphere is be performed using both doped and standard fuel in order to investigate potential effects of doping on the H2 inhibition of matrix dissolution.

Dissolution rate of MOX and Cr-doped UO2 fuel

Detlef Wegen, European Commission, JRC-ITU, Germany

The current European context is characterised by an ever-changing spent nuclear fuel composition due to the requirement for more efficient use of the fissile material, mainly through higher fuel burn-up. MOX and Cr_2O_3-doped fuels are two examples of the evolution of light water reactor fuels.

This proposal aims at decreasing the uncertainty related to the release of radionuclides from irradiated MOX and Cr_2O_3-doped UO_2 fuel. Experiments will be carried out under oxidising and reducing conditions.

The emphasis will be on the fuel matrix dissolution, but some data will also be collected to assess the instant release fraction. There is a scientific knowledge gap affecting the understanding of the relationship between matrix dissolution and fuel power rating (linear heat rate, centreline temperature). In particular, we will investigate the correlation between dissolution rate and the local centreline temperature for a well characterized irradiated fuel sample.

The second part of our proposal is related to the dissolution of irradiated Cr_2O_3-doped fuel under reducing conditions (in presence of H_2). In this case the goal is to determine the long-term dissolution rate and compare it with un-doped UO_2 fuel tested under similar conditions.

Additionally, we will extend the radionuclides investigated by geochemically mobile ß-emitting long-lived ones, such as ^{79}Se.

Remaining questions after FIRST-Nuclides

Bernhard Kienzler, KIT-INE, Germany

The outcome of the CP FIRST-Nuclides covered experiments with 12 different types of high burn-up UO2 LWR SNF. IRFs were measured at ~45 different time steps, for up to 3 sample preparations, and for up to 20 isotopes. From the position of the End-Users, the value of the studies performed in FIRST-Nuclides appears to be high. Nevertheless the partners of the project and End-Users identified a series of open questions to be resolved by future investigations. The 3 years CP FIRST-Nuclides required huge investments to setup the experiments, to implement the required analytical tools and instruments and to get the clearance by the utilities to publish the spent fuel data. Some of the experiments have run only for short time, which does not justify the level of investment. For this reason, we believe that the definition of a long-term project allowing for the continuation of the experiments will maximize the outcome of the efforts invested. This will provide

- Improved statistics for the IRF of additional fission products, especially under reducing conditions.
- In depth investigations of low concentrated but very relevant isotopes such as the FP 79Se and Pd, or activation products 36Cl and 14C.
- Clear correlations of the IRF with nuclear power plant operational parameters (power rates, temperatures, FGR).
- Improved basis for delineating the IRF from long-term radionuclide release.
- Data for additional types of samples including MOX fuel and doped fuels and dependence of IRF on the type and quantity of dopants)
- Some contradictions have been found in the results of FIRST-Nuclides which need to be resolved. These cover

- Contradiction of measured 79Se release with speciation of Se in the UO2 matrix.
- Resolving open questions for some nuclides, such as of 135Cs showing a higher release in comparison to 137Cs.

For this reason, it was proposed to keep the experimental set-up and the materials for an interim period and to apply for a new project.

Thermodynamics as a support for the interpretation of spent fuel leaching experiments

Enzo Curti, Paul Scherrer Institut, Switerland

Nowadays, a large variety of fuels are burnt in nuclear power reactors under a wide range of operating conditions. In order to determine key parameters such as oxygen potential and primary chemical state of actinides and fission products (e.g. redox state, host phase), thermodynamic calculations are the tool of choice rather than time-consuming and expensive experiments. However, the reliability of such calculations depends on the quality of underlying thermodynamic data, as well as on the implementation of mixing models for multicomponent solid solutions (particularly for non-stoichiometric actinide oxides). Recent improvements in data quality and completeness, as well as the development of advanced computer codes (Calphad, GEMS) capable of solving equilibria involving complex solid solutions, make it now possible to carry out realistic calculations for all kinds of spent nuclear fuels.

In the framework of a prospected project we propose to carry out full-system comparative thermodynamic calculations for doped and non-doped UO2 fuels, as well as MOX fuel, both under reactor operating conditions and repository-relevant (wet) conditions. In the former set of calculations, the oxygen potential as well as the primary chemical state and phase distribution of radionuclides will be determined. In the second set of calculations, the objective will be to determine solubility limits for safety-relevant radionuclides in pore water at equilibrium with the spent fuel and the encapsulating materials (Zircaloy, canister corrosion products). To this aim, we will use the in-house GEM-Selektor speciation code with the appropriate thermodynamic databases (PSI-Nagra, HERACLES) both developed and maintained at PSI. Whenever possible, the calculations will be benchmarked with Open Calphad and compared to available experimental results.

Simfuel approaches to understanding spent fuel behavior

Ian Farnan, University of Cambridge, UK

The fabrication and characterisation of depleted uranium simfuels will be described. In particular simfuels designed to simulate UK advanced gas-cooled reactor (AGR) fuels. Examples of their use in separate effects studies to investigate particular aspects of spent fuel behaviour such as the effect of radiation damage on the chemical and structural changes induced by the irradiation; the effect of the dissolved and ex-solved fission products on the dissolution kinetics and the total dissolution of uranium. Developing an understanding of the controls on U dissolution in simfuels through the application of state of the art microscopy and analysis tools.

UO2 interactions inside canister conditions

Kaija Ollila, VTT Technical Research Centre of Finland

The objective is to gain improved understanding of the chemical and redox processes and their effects on UO2 dissolution mechanisms and rates under in-canister conditions after water intrusion. The alpha-doped UO2 simulates the alpha-activity of spent fuel thousands of year after disposal, when the dominant radiation type is -radiation. The availability of alpha- and Cr- (and Al) –doped UO2 will be investigated in order to study the effect of doping. The canister is copper/iron canister. Experiments will be performed to understand the role of iron surface and of groundwater composition (e.g. Si and sulphide). Potential chemical transformation of UO2 fuel matrix will be studied in groundwater with elevated Si content. The formation of uranium silicate (UsiO4) has been suggested.

The redox conditions of the experiments are planned to simulate the redox conditions inside canister as closely as possible. Dissolution experiments will be performed in the presence of magnetite, cast iron and H2. The aqueous phases include synthetic and natural groundwaters with saline groundwater composition.

The compositions are based on Olkiluoto saline groundwater conditions and results from previous bentonite/groundwater interaction investigations.

The experiments will be performed as batch tests in the glove box with argon atmosphere. Tracer methods are probably needed because the concentrations in saline solutions are expected to be low. High Resolution ICP-MS is used for U analyses. A test vessel system (autoclave) is planned for the experiments with H2 to maintain gas phase composition.

Corrosion mechanisms of modern LWR-fuels using UO2-based model systems

Dirk Bosbach, FZ Jülich, Germany

Sarah Finkeldei, Felix Brandt, Guido Deissmann, Dirk Bosbach

Research Center Jülich, Institute of Energy and Climate Research, IEK-6: Nuclear Waste Management.

The current efforts to improve the 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, who might exhibit certain differences in their behaviour in the repository environment compared to conventional spent LWR-fuels. However, the various mechanisms and processes contributing to the long-term (oxidative) matrix corrosion of spent nuclear fuels (SNF) in the nominally reducing repository environment are still not yet fully understood. Due to the chemical and structural complexity of SNF and its high beta- and gamma radiation field, SNF is not suitable to unravel the various concurring corrosion mechanisms entirely. The innovative approach suggested here aims to derive a mechanistic understanding of important SNF corrosion processes by investigating simplified UO2-based model systems to complement studies on irradiated "real" SNF and thus to reduce uncertainties with respect to the matrix dissolution of and the radionuclide from modern doped LWR-fuels.

Within the frame of an ongoing research activity at research center Jülich (FZJ) using UO2-based model systems to unravel specific SNF matrix corrosion processes, we propose to synthesize a variety of UO2-based materials to address effects of (i) dopants (e.g. Cr2O3) and increased fission product concentrations in the matrix of doped fuels with higher burn ups on the long-term matrix corrosion, and

(ii) the effects of the metallic particles, whose composition and microstructure will be slightly different in doped fuels with higher burn-ups, with respect to the scavenging of radiolytic oxidants. The tiered approach suggested here aims at the synthesis and fabrication of, for example, Cr2O3-doped UO2 pellets exhibiting a similar grains size as modern doped fuels, and containing lanthanides as fission product surrogates as well as surrogates for epsilon particles. Careful microstructural and electrochemical investigations complemented by corrosion experiments under realistic conditions expected in a corroding waste container are foreseen, where alpha-doped pellets (e.g. containing U-233 or Pu-238 in addition to the aforementioned dopants) will be used to mimic the alpha radiation field of aged SNF and to produce radiolytic oxidants at the UO2-water interface, leading to an oxidative UO2-matrix dissolution. The groundwater simulants envisaged for the corrosion experiments comprise compositions representative for repositories in crystalline rocks (e.g. similar to Forsmark or Äspö groundwaters) and clay systems (e.g. Opalinus clay porewater).

Andra proposal for a future European project dealing with geochemical processes within a HLW/Spent fuel disposal cell

Christelle Martin, Andra, France

The understanding of geochemical processes within a HLW disposal cell and above all the understanding of interactions with environmental materials are still key R&D topics. That's why Andra supports R&D whose aim is to characterize and model spent fuel (UO2(-Gd2O3) and (U, Pu)O2 matrix) and nuclear glass dissolution in repository conditions considering all the interactions between surrounding materials in a disposal cell.

After closure of disposal cells and overpack failure, spent fuel/nuclear glass alteration is expected to begin in partially saturated conditions due to hydrogen production resulting from carbon steel corrosion in anoxic conditions. Therefore, the spent fuel/nuclear glass should at least partially be hydrated by water vapor during thousands of years until complete saturation. R&D should aim to determine the spent fuel/nuclear glass behavior in such conditions, the influence of the main parameters (temperature, relative humidity) and consequences of vapor hydration on subsequent radionuclides release by water leaching.

However, the main R&D issue remains the influence of the environment on spent fuel/nuclear glass alteration. The water which is expected to leach the spent fuel/nuclear glass is presumably at equilibrium with the nearfield materials, including iron and/or its corrosion products and the surrounding Callovo-Oxfordian clay. The container corrodes first in groundwater and the resulting corrosion products (CP) are characteristic of an anoxic corrosion in clayey environment. As the overpack breaks due to mechanical constraints, part of it remains in the system and its corrosion is then concomitant to spent fuel/nuclear glass alteration at a temperature around 70°C. The spent fuel/nuclear glass alteration rates and the associated radionuclides release will depend on redox conditions resulting from the alpha activity of spent fuel, and/or the redox properties of the host rock, and the anoxic corrosion of the container. The nature of CP is also likely to be influenced by the solution chemistry at the interface between the spent fuel/nuclear glass and the container. Needless to say it is essential to determine how the nearfield materials (including corrosion products, host rock,…) can influence the alteration kinetics of spent fuel/nuclear glass in repository conditions, mainly through interactions with uranium released by the spent fuel dissolution and silica released by nuclear glass dissolution.

The understanding of experiments performed in laboratory, the modeling of situations expected in repository raise different key questions, mainly the scale effect, the transport effects for both spent fuel and nuclear glass, but also highlights some specific topic such as the necessity to define an alteration tracer for the radionuclide release from spent fuel.

WG4 - Spent fuel dissolution & chemistry in container

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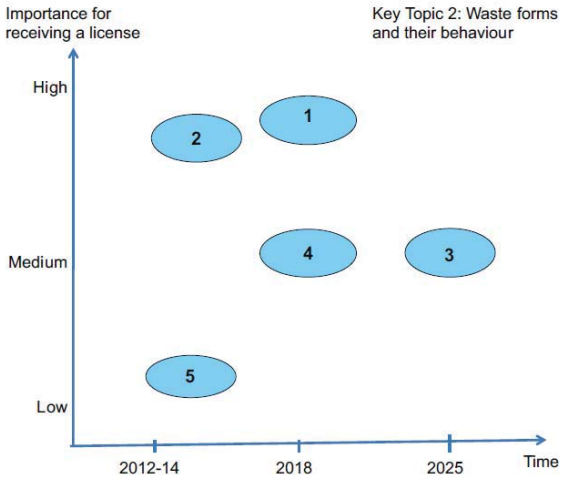
Outcomes

WG 4 - Background, motivation

Spent fuel dissolution and chemistry in a high-level waste container
Needs identified in IGD-TP SRA, Euratom call as well as from research groups.
- Improved understanding of behaviour of the expected waste form in expected repository conditions.
- Test dissolution rate of the waste form in direct relation to expected chemistry inside a corroding waste container.

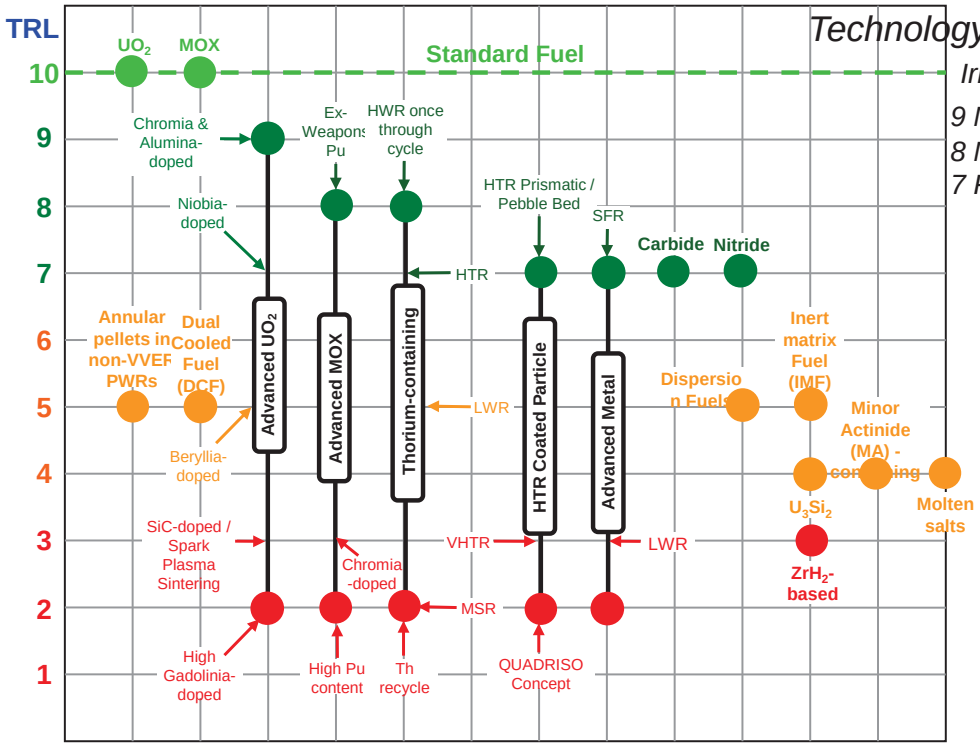


Expected fuel evolution in Sweden (pers. comm. Vattenfall 2011):
2011: doped pellets in one reactor
2016: doped pellets in 50% of reactors
2021: doped pellets in all reactors
NB: doped pellets, made by different manufacturers do not have uniform properties

Fuel evolution

David Hambley, NNL, EF5 2014: Technology Readiness Level / Irradiation Performance Maturity

9 Multiple assemblies/core loads
8 Multiple assemblies/core loads
7 Few assemblies



Availability of doped fuel pellets for dissolution experiments?

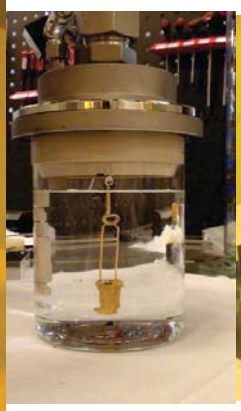
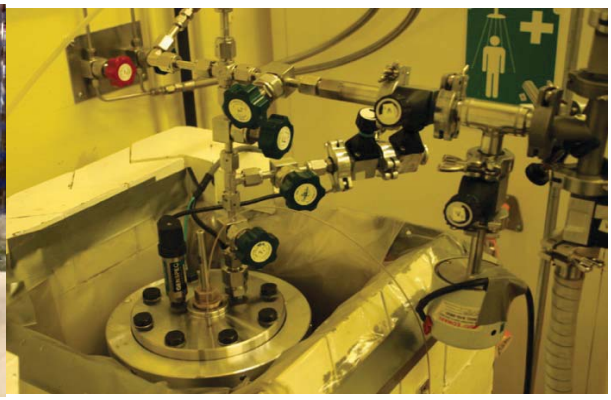
Licensing facilities for existing SNF as well as future SNF, but so far based on standard fuel data…
Requirements to formulate clear waste acceptance criteria

WG 4 - Presentations

WG 4 Spent fuel dissolution & chemistry in container		
03-Nov		Title
14:00	INTRO JA Leader: SKB (L.Z. Evins, J. Andersson)	Waste form and behaviour: Chemistry and dissolution in a high-level waste container
14:15	Studsvik (Olivia Roth)	Leaching of doped irradiated fuel under H2 conditions
14:35	JRC-ITU (Detlef Wegen)	Dissolution rate of MOX and Cr-doped UO2 fuel
14:55	KIT-INE (Bernhard Kienzler)	Remaining questions after FIRST-Nuclides
15:15	PSI (Enzo Curti)	Thermodynamics as a support for the interpretation of spent fuel leaching experiments
15:40	***COFFEE BREAK***	
16:00	University of Cambridge (Ian Farnan)	Simfuel approaches to understanding spent fuel behaviour
16:20	VTT (Kaija Ollila, E. Myllykylä)	UO2 interactions inside canister conditions
16:30	FZ Jülich (Dirk Bosbach)	Corrosion mechanisms of modern LWR-fuels using UO_2-based model systems
16:40	ANDRA (Christelle Martin)	Andra proposal for a future European project dealing with geochemical processes within a HLW/Spent fuel disposal cell
17:00	General Discussion (All)	
17:30	END day 1	

Real spent fuel

Contributors: Studsvik, KIT, ITU, CTM, SCK*CEN, Rez, CEA, (Hungarian contribution?)
Materials: Doped fuel or MOX, UO2 - to close issues from First Nuclides – with possible addition of reactor fuels (Rez)
Conditions: both Reducing and oxidating

Model systems

Contributors: Julich, Cambridge, Sheffield, VTT, Ciemat

Model systems - synthesized materials

Planning needs to be performed in collaboartion with real plans for real SNF samples.

Important coordinate the experimental conditions.This can be done i aseparate work package - sample and system characterisation.

Materials includes UO2 doped with alpha-emitter, as wel as other dopants such as Cr, Al, Si, Cs/volatiles depending on qustion asked

Chemical modelling

Contributors: Amphos PSI, NNL, Andra, Quintessa

Several lines :
1, primary state of spent fuel once discharged, oxygen potential
2, evolution of fuel during dry period, from storage to water contact,
3, effect of the doping agents on the fuel (only fuel system), and molecular modelling of selenium in the UO2 matrix.
4, coupling the fuel and the container under aqueous conditions.

Important with input from experimentalists, and set-up exchange points: once model is set up exchange with the experimentalists

WG 4 Summary

DISCO: Modern Spent Fuel DISsolution and Chemistry in Container
Hypothesis: Modern fuel (advanced fuel and mox) dissolution differs only insignificantly from standard fuel.

General Hypothesis: Modern fuel (advanced fuel and mox) dissolution in real repository condiitions differs only insignificantly from standard fuel. (zero-hypothesis)

Motivation: there are knowledge gaps and need for extended data base for the modern fuels and for the chemical system in a degraded HLW waste canister

3-4 year project. Preliminary work package structure

- WP1 Management, Coordination and Dissemination/Knowledge Management
  SKB (Coord) , Amphos21
- WP2 Sample preparation and characterisation of the chemical systems (All)
- WP3 Fuel leaching experiments WP Leader: (Studsvik /KIT-INE)
  Contributors: Studsvik, KIT, ITU, CTM, SCK*CEN, Rez, CEA, (Hungarian contribution?)
- WP4 Model materials experiments WP Leader: (Univ. Cambridge/FZ Jülich), Contributors: FZ Julich, Univ. Cambridge, Univ. Sheffield, VTT, Ciemat
- WP5 Chemical modelling WP Leader Amphos21/PSI, Contributors: Amphos PSI, NNL, Andra, Quintessa

Appendix I - Useful links

IGD-TP Strategic Documentation:

Vision Report (2009)
Strategic Research Agenda (2011)
Deployment Plan 2011-2016 (2012)
Master Deployment Plan (2015)

Websites:

IGD-TP	www.igdtp.eu
JOPRAD	www.joprad.eu
SITEX	www.sitexproject.eu
SNETP	www.snetp.eu
Cebama	www.cebama.eu
DOPAS	www.posiva.fi/dopas
FIRST-Nuclide	www.firstnuclides.eu
MIND	www.mind15.eu
Modern2020	www.modern2020.eu
PEBS	www.pebs-eu.de
IGSC - NEA	www.oecd-nea.org/rwm/igsc/
MELODI	http://melodi-online.eu/

EC DG Research & Innovation: http://ec.europa.eu/research/

Appendix II – Agenda

IGD-TP
6th Exchange Forum

November 3-4th 2015, London, UK

Venue: Amba hotel

AGENDA

Tuesday 3rd November 2015

Registration	
8:30 - 9:00	Registration
Plenary Session1 - Jonathan Martin, RWM	
9:00 - 9:20	**EF6 meeting objectives** Monica Hammarström, IGD-TP Chair
9:20 - 9:50	**Key Note: Siting Process in UK** Bruce Cairns (DECC)
9:50 - 10:10	**Key Note: H2020 WP 2016-2017 and future Euratom programmes** Christophe Davies, European Commission, DG Research and Innovation, Fission Energy
10:10 - 10:40	**Key Note : Radiation Protection Research in Europe: Reaching out to IGD-TP** Hildegarde Vandenhove, Nathalie Impens, SCK-CEN
10:40 - 11:10	*Coffee Break*
11:10 - 11:40	**Key Note: NEA IGSC Interaction with the IGD-TP** Lucy Bailey, RWM
11:40 -12:10	**Key Note: state of high-level waste disposal in the U.S.** James Rubenstone,Yucca Mountain Directorate
12:10 - 12:30	**RD&D Planning Guide, Conclusion of the PLANDIS Workshop and future activities** Ray Kowe, RWM

12:30 - 12:35	**Organisation of the parallel Sessions -** Jacques Delay, IGD-TP Secretariat
12:35	*Lunch*

Parallel Sessions – Technical Working Groups Session	
14:00 - 15:40	**Technical Working Groups - presentations and discussions -** Rapporteurs WG
15:40 - 16:00	*Coffee Break*
16:00 - 17:30	**Cont. Working Groups' presentations and discussions -** Rapporteurs WG

Wednesday 4th November 2015

Parallel Sessions – Technical Working Groups Session (Cont.)	
09:00 -10:15	**Cont. Working Groups' presentations and discussions** - Rapporteurs WG
10:15 - 10:30	**Conclusion WG session rapporteurs**
10:30 - 11:00	*Coffee Break*

Session 2a : Chairman's and rapporteurs' commission session (Chairman & rapporteurs only)		**Session 2b : Technical session New H2020 technical projects -** Walter Steininger	
11:00 - 12:00	Rapporteurs' meeting - Summary of discussion, draft of WG conclusions	**11:00**	**MODERN2020** Johan Bertrand, Andra
		11:20	**CEBAMA** Xavier Bourbon, Andra
		11:40	**MIND** Birgitta Kalinowski, SKB

Session 3: Evaluation of completed projects -Juan Carlos Mayor	
12:00 -12:25	**PEBS -** Annika Schäfers/Klaus-Jürgen Röhlig/Irina Gaus
12:25 - 13:55	*Lunch*

Session 3: Evaluation of completed projects (cont.) - Tiina Jalonen	
13:55 - 14:20	**FIRST Nuclides -** B. Kienzler / Johan Andersson
14:20 - 14:45	**MODERN –** Johan Bertrand/Frédéric Plas
14:45 - 15:00	**REDUPP –** Lena Evins/ David Shoesmith /Johan Andersson

Session 4: Conclusion and way forward - Philippe Lalieux	
15:00 -15:15	**Rapporteur WG1 - Novel thermal treatments for waste** Cristiano Padovani and Amy Shelton, RWM
15:15 - 15:30	**Rapporteur WG2 - Bentonite homogenization** Patrik Sellin, SKB
15:30 - 16:00	*Coffee break*
16:00 - 16:15	**Rapporteur WG3 - Cement Organics Radionuclide Interactions – (CORI)** Marcus Altmaier, KIT-INE
16:15 - 16:30	**Rapporteur WG4- Spent fuel dissolution & chemistry in container** Lena Evins, SKB
16:30 - 16:55	**Conclusion & way forward for IGD-TP Towards H2020** Monica Hammarström, SKB, IGD-TP Chair
16:55 - 17:00	**Closing IGD-TP 6th Exchange Forum** Monica Hammarström, SKB , IGD-TP Chair
17:00	**End of the EF6**

Parallel sessions – Technical Working Groups (TWGs)

TWG1 – Novel thermal treatments for high activity wastes

Rapporteurs: C. Padovani, A. Shelton

Programme

Tuesday 3rd November

14:00-14:10	**Introduction** C. Padovani, RWM
14:10-14:40	**Collaboration on the Thermal Treatment of Waste,** Anthony Banford, NNL
14:40-15:10	**Novel Treatments to Improve Radioactive Waste Disposal**, Laurence Petit, Andra
15:10-15:40	**Application of Joule Heated Ceramic Melter (JHCM) Technology for Stabilization of Radioactive Wastes in the United States,** Eric Smith, Energy Solutions
15:40-16:00	***Coffee break***
16:00-16:30	**The Innovative Plasma Tilting Furnace for Industrial Treatment of Radioactive Waste,** Jan Deckers, Belgoprocess
16:30-17:00	**Title TBC,** Neil Hyatt, University of Sheffield

17:00-17:30	**Nano Flex HLW / Spent Fuel Rods Recycling and Permanent Disposal,** Dimitre Assenov, Nano Flex HLW

Wednesday 4th November

9:00	**Start of day 2**
9:00-9:30	**Geological Disposal of Silicon-rich Vitrified ILW Products in a Cement-based Engineered Barrier System: Addressing Key Uncertainties,** Steve Swanton, AMEC-FW
9:30-9:55	**Plasma Vitrification of Nuclear Waste,** Mark Rogers, Costain
9:55-10:15	**THOR and the Leachability of THOR Residues,** Maria Lindberg, Studsvik
10:15-10:30	***Conclusion WG session Rapporteur***

IGD-TP Exchange Forum n°6

November 3-4th, 2015, London, UK

Presentations & outcomes

TWG2 – Bentonite homogenization

Rapporteurs: P. Sellin - J.C. Mayor

Programme

Tuesday 3rd November

14:00 -14:10	***Introduction* –** Patrik Sellin/Juan Carlos Mayor
	Strategic issues: feedback to Design and Safety assessment
14:10 -14:35	**Proposal for a project focussed on bentonite homogenization – some examples of ongoing activities in the area** – Patrik Sellin, SKB
	Bentonite Homogenization: the safety relevance of the even distribution of bentonite buffer properties - Olivier Leupin, NAGRA, Switzerland
	Posiva's plans to assess bentonite homogenisation - Kari Koskinen, POSIVA, Finland
	Development of a Design Basis for Bentonite Homogenization: Lessons from the DOPAS Project Applied to WG2 Bentonite Homogenization - Matt White, Galson Sciences Limited, UK
14:35-15:00	***Questions and discussion***
	Large and field scale experiments
15:00-15:35	**Homogenization of bentonite plugs – what are the issues? -** Jean Talandier, Andra, France
	State of a barrier of bentonite blocks after 18 years of operation - María Victoria Villar, CIEMAT, Spain
	Examples of Finland's experiments for assessing buffer-backfill-pellet homogenization and performance - Erika Holt, VTT, Finland
	Impact of the sand/bentonite homogenization on the performance of an EGTS - Niels Giroud, NAGRA, Switzerland
	Geophysical monitoring of evolutions of buffer materials and EBS - Kristof Schuster, BGR, Germany
	An impact of bentonite homogenization on its changes by degradation processes - Jiri Mikes, TERAMED s.r.o., Czech Republic
15:40-16:00	***Coffee break***
	Laboratory experiments
16:00-16:30	**Understanding the homogenisation behaviour of bentonite -** Jon Harrington, British Geological Survey, UK
	The Affect of Accessory Minerals on Bentonite Erosion Rates - Rebecca Lunn, University of Strathclyde, UK
	Saturation and mechanical properties of clays with defined composition - Vaclava Havlova, UJV Rez, a.s., Czech Republic
	Bentonite homogenization : Experimental contribution of CEA/LECBA - Claude Gatabin, CEA, France

	Bentonite homogenization: laboratory tests to answer open questions related to the German disposal concept in claystone - Artur Meleshyn GRS Braunschweig, Germany
16:30-17:30	***Questions and discussion - End of day 1***

Wednesday 4th November

9:00	***Start of the Day***
Modelling - Conceptual model/ processes understanding	
9:00-9:40	**Bentonite homogenization: processes and modelling -** Antonio Gens, Universitat Politecnica Catalunya, Spain
	A Poroplastic Model of Structural Reorganisation in Porous Media - Gabriel Wittum TechSim, G-CSC, U Frankfurt Germany
	Hydromechanical behaviour of bentonite under in situ conditions - Robert Charlier, University of Liege, Belgium
	Proposal for a project focussed on bentonite homogenization – some examples of ongoing activities in the area - Vasileios Mantikos, Imperial College London, UK
	Constitutive mechanical modelling of bentonite behaviour in THEBES project - Markus Olin, VTT Technical Research Centre of Finland Ltd, Finland
	SEALEX In-Situ Experiments-Performance Tests Of Repository Seals: Experimental observations and modelling - Nadia Mokni, IRSN, France
	Relevance of hydrodynamic and hydrogeochemical reactions on buffer homogeneization- Javier Samper, University of A Coruña, Spain
9:40-10:15	***Questions and discussion***
10:15-10:30	***Conclusion WG session Rapporteur***

Yellow = 10 minute presentation

Cyan = Questions and discussion

TWG3 – Cement Organics Radionuclide Interactions (CORI)

Rapporteurs: M. Altmaier – F. Plas

Programme

Tuesday 3rd November

14:00 - 17:00	***Introduction*** M. Altmaier, KIT- INE
	Overview of the outcome of the TSWG CORI "Cement Organics Radionuclide Interactions" - Marcus Altmaier, KIT-INE, Germany
	CORI-WP - WMOs priorities and expectations - Eric Giffaut Andra France
	Degradation of organics - result of hydrolysis and radiolysis- Johan Vandenborre, SUBATECH, France
	Mobility of organics in cementitious environment and their interaction with Fe - Mireia Grivé, Amphos 21 Consulting, S.L., Spain
	CORI-Work Package on "Mobility of organics-RN complexes in a cementitious environment - Virginie Blin, CEA, France
	CORI: WP on "Modelling, upscaling, application to PA"- Vanessa Montoya, KIT-INE, Germany

Wednesday 4th November

9:00 – 10:30	***Discussion***

TWG4 – Spent fuel dissolution & chemistry in container

Rapporteurs: L. Evins – J. Andersson

Programme

Tuesday 3rd November

14:00	***Introduction*** **Waste form and behaviour: Chemistry and dissolution in a high-level waste container -** JA Leader: SKB (L.Z. Evins, J. Andersson)
14:15	**Leaching of doped irradiated fuel under H2 conditions,** Studsvik (O. Roth)
14:35	**Dissolution rate of MOX and Cr-doped UO2 fuel,** JRC-ITU (D. Wegen)
14:55	**Remaining questions after FIRST-Nuclides,** KIT-INE (B. Kienzler)
15:15	**Thermodynamics as a support for the interpretation of spent fuel leaching experiments,** PSI (E. Curti)
15:40	***Coffee break***
16:00	**Simfuel approaches to understanding spent fuel behaviour,** University of Cambridge (I. Farnan)
16:20	**UO2 interactions inside canister conditions,** VTT (K. Ollila, E. Myllykylä)
16 :30	**Title Tbd,** FZ Jülich **(D. Bosbach)**
16:40	**Andra proposal for a future European project dealing with geochemical processes within a HLW/Spent fuel disposal cell,** Andra (C. Martin)
17:00 – 17:30	***General Discussion***

Wednesday 4th November

09:00	***Start & recap of 3rd October***
09:15	**Project proposal preparations**
10:00	***Final discussion***
10:15	***Conclusion WG session,*** Rapporteurs
10:30	***Coffee Break***

Appendix III – List of participants

First name	Last name	Organisation	Country	Att.
Achim	Albrecht	Andra	France	
Marcus	Altmaier	KIT-INE	Germany	
Johan	Anderrsson	SKB	Sweden	
Thuro	Arnold	Helmholtz-Zentrum Dresden-Rossendorf, Institute of Resource Ecology	Germany	
Dimitre	Assenov	Nano Flex HLW	Bulgaria	
Lucy	Bailey	RWM	UK	
Anthony	Banford	NNL	UK	
Behrooz	Bazargan-Sabet	Université de Lorraine	France	
Dirk-alexander	Becker	GRS	Germany	
David	Bennett	TerraSalus Limited	UK	
Johan	Bertrand	Andra	France	
Matthias	Beushausen	BfS	Germany	Excused
Thomas	Beuth	GRS	Germany	
Philippe	Blanc	BRGM	France	
Virginie	Blin	CEA	France	
Dirk	Bosbach	Forschungszentrum Jülich	Germany	
Xavier	Bourbon	Andra	France	
Felix	Brandt	Forschungszentrum Jülich	Germany	
Wernt	Brewitz	IWW Goslar	Germany	
Christophe	Bruggeman	SCK CEN	Belgium	
Gunnar	Buckau	EC JRC ITU	Germany	
Crina	Bucur	Institute for Nuclear Research, Pitesti	Romania	
Bruce	Cairns	DECC	UK	
Colin	Campbell	Environment Agency	UK	
Leena	Carpen	VTT	Finland	
Stéphane	Catherin	Andra	France	
Robert	Charlier	University of Liege	Belgium	
Petra	Christensen	SKB	Sweden	Excused
Francis	Claret	BRGM	France	
Sean	Clarke	National Nuclear Laboratory	UK	
Veerle	Cloet	Nagra	Switzerland	
Joachim	Cobos	CIEMAT	Spain	
Claire	Corkhill	University of Sheffield	UK	
Jean	Croisé	AF-Consult Switzerland	Switzerland	
Diane	Crozes	IRSN	France	
Miguel	Cuñado	ENRESA	Spain	
Enzo	Curti	PSI	Switzerland	
Alexandre	Dauzères	IRSN	France	
Christophe	Davies	EC	EU	
Benny	de Blochouse	ONDRAF/NIRAS	Belgium	
Jan	Deckers	Belgoprocess	Belgium	
Guido	Deissmann	Forschungszentrum Juelich	Germany	

Jacques	Delay	Andra	France	
Daniela	Diaconu	RATEN INR	Romania	Excused
Mark	Dowson	Sellafield Ltd	UK	
Holger	Dr Tietze-Jaensch	Forschungszentrum Jülich ENTRAP representative, RWM	Germany	
Christian	Dr. Müller	DBE TECHNOLOGY GmbH	Germany	
Lara	Duro	Amphos21	Spain	
Stéphane	Esnouf	CEA	France	
Lena Z.	Evins	SKB	Sweden	
Ian	Farnan	University of Cambridge	UK	
Megan	Frame	RWM	UK	
Marie	Garcia	Andra	France	
José-Luis	García-Siñeriz Martínez	AITEMIN	Spain	
Claude	Gatabin	CEA	France	
Irina	Gaus	Nagra	Switzerland	
Antonio	Gens	Universitat Politecnica Catalunya	Spain	
Eric	Giffaut	Andra	France	
Niels	Giroud	NAGRA	Switzerland	
Bernd	Grambow	SUBATECH	France	Excused
Mireia	Grivé	Amphos 21 Consulting, S.L.	Spain	
Mafalda	Guerra	Sogin S,p.A.	Italy	
Lotta	Hallbeck	Microbial Analytics Sweden AB	Sweden	Excused
David	Hambley	National Nuclear Laboratory	UK	
Monica	Hammarström	SKB	Sweden	
Jon	Harrington	British Geological Survey	UK	
Vaclava	Havlova	UJV Rez, a.s.	Czech Republic	
Pierre	Henocq	Andra	France	
Erika	Holt	VTT	Finland	
Pavla	Hudáková	TERAMED s.r.o.	Czech Republic	
Neil	Hyatt	University of Sheffield	UK	
Doug	Ilett	Environment Agency	UK	
Nathalie	Impens	SCKCEN	Belgium	
Merja	Itävaara	VTT	Finland	
Diederik	Jacques	SCK CEN	Belgium	
Tiina	Jalonen	POSIVA	Finland	
Pierre Janssen	Janssen	Bel V	Belgium	
Darius	Justinavicius	Lithuanian Energy Institute	Lithuania	
Birgitta	Kalinowski	SKB	Sweden	
Klas	Källström	SKB	Sweden	
Lucie	Karásková Nenadálová	Research Centre Rez	Czech Republic	
Bernhard	Kienzler	KIT	Germany	
Kari	Koskinen	POSIVA	Finland	
Johannes	Kulenkampff	HZDR	Germany	
Valérie	L'Hostis	CEA	France	
Philippe	Lalieux	ONDRAF/NIRAS	Belgium	Excused

Markku	Leivo	VTT	Finland	
Olivier	Leupin	NAGRA	Switzerland	
Maria	Lindberg	Studsvik Nuclear AB	SE	
Jon	Lloyd	University of Manchester	UK	
David	Lowry	Nuclear Waste Advisory Associates	UK	
Rebecca	Lunn	University of Strathclyde	UK	
Michal	Lupinski	Radioactive Waste Management Plan	Poland	
Norbert	Maes	SCK-CEN	Belgium	
Vasileios	Mantikos	Imperial College London	UK	
Jon	Martin	RWM	UK	
Christelle	Martin	Andra	France	
Albert	Martínez-Torrents	Fundació CTM Centre Tecnologic	Spain	
Juan-Carlos	Mayor	ENRESA	Spain	
Hans	Meeussen	NRG	The Netherlands	
Richard	Metcalfe	Quintessa	UK	
Volker	Metz	KIT	Germany	Excused
Jiri	Mikes	TERAMED s.r.o.	Czech Republic	
Jitka	Mikšová	Research Centre Rez	Czech Republic	Excused
Nadia	Mokni	IRSN	France	
Peter	Molnar	PURAM	Hungary	
Balázs	Molnár	PURAM	Hungary	
Katherine	Morris	The University of Manchester	UK	
Emmi	Myllykylä	VTT Technical Research Centre of Finland Ltd	Finland	
Grégory	Nicaise	IRSN	France	
Simon	Norris	RWM	UK	
Ulrich	Noseck	GRS	Germany	
Markus	Olin	VTT Technical Research Centre of Finland Ltd	Finland	
Kaija	Ollila	VTT Technical Research Centre of Finland	Finland	
Jana	Orzechowski	BfS	Germany	
Hitoshi	Owada	RWMC	Japan	
Jaroslav	Pacovsky	Czech Technical University in Prague	Czech Republic	
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Karsten	Petersen	Micans	Sweden	Excused
Laurence	Petit	Andra	France	
Frédéric	Plas	Andra	France	
Stéphane	Plumeri	Andra	France	
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Michela	Raio	Sogin S,p.A.	Italy	
Ray	Ray Kowe	RWM	UK	
Denise	Ricard	Andra	France	Excused
Antonietta	Rizzo	ENEA	Italy	
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Olivia	Roth	Studsvik Nuclear AB	Sweden	
James	Rubenstone	US Nuclear Regulatory Commission	US	