Poster Session

IGD-TP's Eighth Exchange Forum

3rd and 4th December, BMWi, Berlin, Germany

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At 1700 on day 1, the IGD-TP will host an evening poster session that aims to showcase cutting-edge radioactive waste management RD&D that aligns to the IGD-TP's SRA. The session will be held in the main meeting room and light refreshments will be provided.

The table below lists the submitted posters and the poster board number on which they can be found; the rest of this document presents the abstracts submitted for each poster. Where possible, copies of the posters presented at Exchange Forum 8 will be added to the event website in early December 2018 (https://igdtp.eu/event/igd-tp-exchange-forum-8/).

Poster Board #	First Name	Last Name	Poster Title
Posters in connection with technical topic 1: Technical issues in support of retrievability			
1	Philipp	Herold	Retrievability in German SF/HLW Repository Concepts - Technical Solutions and Provisions for Implementation
2	Tomoko	Ishii	R&D on reversibility and retrievability
3	Masataka	Imai	Analytical study on the influence on safety during maintaining retrievability
4	Johan	Bertrand	Ovalization monitoring of High Level waste tunnel
5	Jean-Michel	Hoorelbeke	Retrieval Test of High Level Waste in the Cigéo Project
Posters in connection with technical topic 2: Heat generating waste containers			
6	Tara	Beattie	Robust repository concept selection to enable flexible design adaptation and optimisation
7	Vaclava	Havlova	Canister material corrosion test under in situ conditions (MACOTE experiment)
8	Holger	Tietze-Jaensch	The CHANCE project "Characterization of conditioned nuclear waste for its safe disposal in Europe"
9	Christian	Herold	Project "KoBrA" - Study on Requirements and Concepts for SF/HLW Final Disposal Canisters in Salt, Clay and Crystalline Rock
Posters in connection with technical topic 3: Progress in site investigation and characterisation techniques			
10	Béatrice	Yven	Advanced site characterization from 3D seismic survey and 3D geological modelling

Poster Board #	First Name	Last Name	Poster Title
11	Christophe	Bruggeman	Prediction of the key physico-chemical parameters of geological barriers through detailed mineralogical analysis: case study of the Boom Clay (Belgium)
12	Christophe	Bruggeman	Towards the use of multiple state variables in hydrogeological modelling supporting site characterisation
13	Christophe	Bruggeman	A Multiscale Approach to Model Thermo-Hydro-Mechanical Behaviour of Plain Concrete During Early Stages of Construction.
14	Cornelius	Fischer	Advanced analysis of RN migration in fractured crystalline rock
15	Zbynek	Hlavac	Study of impact of the radiation on concrete structure behaviour
Posters connected with the IGD-TP SRA			
16	Marcus	Altmaier	CEBAMA – EC HORIZON2020 PROJECT ON CEMENT-BASED-MATERIALS
17	Lara	Duro	MODERN SPENT FUEL DISSOLUTION IN FAILED CONTAINER CONDITIONS (DISCO)
18	Hans Jörg Andrea	Kunte Koerdt	Microbial corrosion of iron coupled to methanogenesis by strains from different environments
19	Tim	Heath	Probabilistic modelling of radionuclide release from a cementitious near field
20	Xavier	Gaona	Development and improvement of thermodynamic understanding for the nuclear waste disposal Safety Case
21	Patrik	Sellin	Beacon: Bentonite Mechanical Evolution
22	Megan	Barnett	Microorganisms in a clay-steel system
23	Birgitta	Kalinowski	Microbiology In Nuclear waste Disposal (MIND)
24	Barbara	Ferrucci	Preliminary analysis of gaseous 14 C radiological impact in a geological repository hosted in salt rock
25	Isabel	Paiva	Portuguese Involvement/Engagement in Radioactive Waste Management Related Activities
26	Valentina	Svitelman	Activities of the Russian Nuclear Safety Institute in the context of deep geological disposal safety
27	Marie	Garcia	Modern2020 Project Finalisation
28	Dan	Galson	Theramin update

Poster Abstracts

Topic 1. Technical Issues in Support of Retrievability

1. Retrievability in German SF/HLW Repository Concepts - Technical Solutions and Provisions for Implementation

Philipp Herold, BGE Technology GmbH

Since the revision of the German Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste in 2010, BGE TECHNOLOGY GmbH, also known under its former name DBE TECHNOLOGY GmbH, has been investigating the implementation of retrievability into German repository concepts. The recently concluded R&D project “Development of technical concepts for the retrieval of HLW and spent fuel waste packages from repositories in salt and argillaceous rock formations” (ERNESTA) funded by the Federal Ministry for Economic Affairs and Energy (BMWi) and the Project Management Agency Karlsruhe (PTKA) of the Karlsruhe Institute of Technology (KIT) represents a new milestone of these activities. Within the project, BGE TECHNOLOGY GmbH transferred existing ideas regarding the implementation of retrievability into horizontal drift disposal and vertical borehole disposal in both host rocks into more detailed technical solutions. The work includes the identification of necessary layout modifications of the repository design, conceptual designs, and the preparation of feasibility studies for the retrieval devices. Furthermore, preliminary operational safety analyses for the devices were carried out. This encompassed a detailed description of the operational processes, an analysis of the thermo-mechanical situation inside the retrieval drifts, an analysis of the necessary ventilation and cooling effort during retrieval, and a first preliminary schedule and cost estimation. With its poster BGE TECHNOLOGY GmbH intends to give an overview of the results of the recently concluded R&D project ERNESTA and of the technical concepts for retrievability in Germany.

2. R&D on reversibility and retrievability

Tomoko Ishii, Radioactive Waste Management Funding and Research Center, Japan

A FY 2015 basic policy revision in Japan made the maintenance of reversibility and retrievability a part of geological disposal projects up to the final facility closure stage. In accordance with this policy, RWMC is working on retrievability with focus on the development of recovery technology and on the evaluation of effects from disturbances caused during the retrievability maintenance period.

Related engineering approaches have involved the development and demonstration of recovery technology based on disposal site concepts with focus on vertical emplacement and horizontal PEM. For the former, a buffer material removal device was developed and demonstrated in a mock-up ground test in which the materials were removed in a slurry state after the application of a

saline spray. The latter involves equipment development and demonstration of recovery work in underground environments. The demonstration of tasks such as emplacement, backfilling and removal is planned under this ongoing project.

To evaluate the effects of disturbances caused during the retrievability maintenance period, the information to be quantified was first organized and areas requiring focus were identified. By way of example, there is a need for consideration of work space safety in open tunnel zones during operation. Disturbances occurring during the retrievability maintenance period affect safety, and therefore require quantitative evaluation. Against this background, it is necessary to apply individual methods incorporating consideration of thermodynamics (T), mechanics mechanical (M), hydraulics (H) and geochemistry (C) in numerical analysis. (Please refer to another presentation of the RWMC.) These safety-related evaluation methods need to be developed for use in the selection of radioactive waste disposal sites.

This research project is funded by a grant from Japan's Ministry of Economy, Trade and Industry (METI).

3. Analytical study on the influence on safety during maintaining retrievability

Masataka Imai, Radioactive Waste Management Funding and Research Center, Japan

In Japan, it is required to maintain retrievability up to the final closure of the disposal facility according to the basic policy by the Cabinet in FY2015. Therefore, this study's aim is constructing a quantitative evaluation when maintaining retrievability for a certain period.

It is assumed that a part of the underground disposal tunnel will be maintained open in the period of maintaining retrievability. Therefore, the degree of disturbance of the underground environment is considered to increase with the passage of time.

In this study, to evaluate an influence of the disturbance, it is trying to develop the analysis method to quantify the degree of following two "influence on safety" during maintaining retrievability.

1) Safety of the working space during operation
2) Influence on the barrier function of long-term after closer

For example, to evaluate the soundness of the open disposal tunnel in 1), it is necessary to consider the mechanical stability (M: mechanical influence) of the tunnel that maintaining open for a long time. The mechanical stability is affected by degradation of the tunnel support (C: chemical influence), and the tunnel support is affected by the groundwater flow of host rock (H: hydraulic influence). To consider the mutual influence among these phenomena, an approach based on HMC is necessary. In this study, individual phenomena of HMC are quantitatively evaluated individually by numerical analysis. Also, it is reflected the mutual influence among phenomena as the physical property values of analysis. From the results of these studies, we show how to evaluate the influence on safety and technical issue during maintaining retrievability. In this issue, we will introduce mainly efforts on mechanical and hydraulic influences.

This study is under a grant from the Japanese Ministry of Economy, Trade and Industry (METI).

4. Ovalization monitoring of High Level waste tunnel

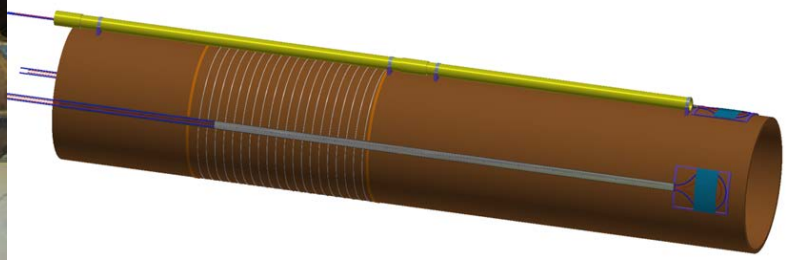
Radwan Farhoud, Sylvie Lesoille and Johan Bertrand, Andra, France

The French National Radioactive Waste Management Agency (Andra) is responsible for the Cigéo project (Industrial underground radioactive waste disposal) dedicated to store high-level radioactive waste in a deep geological disposal facility. The Act of 25 July 2016 defines reversibility as “the capability of future generations either to continue building and operating consecutive phases of a disposal facility or to review the decisions made in the past and modify the management solutions” For waste retrieval to be feasible, institutional arrangements have to be foreseen in order to ensure the condition of retrievability. Andra has launched R&D program in order to evaluate monitoring system and techniques dedicated to the surveillance of high-level waste (HLW) disposal cells. Part of monitoring objectives is to evaluate the condition of retrievability.

The HLW disposal cell consists of a tunnel measuring approximately 70-93 cm in diameter and around 100 m in length. The annular gap between the metal casing and the clay rock is filled by a material imposes corrosion-limiting environmental conditions (cement and bentonite mixed-based grout, etc.). One of the key parameters in HLW retrieval operations is the evolution of the casing’s diameter. In fact, the gap between container and metallic liner should be enough to handle the canister.

Optical fiber sensors (OFS) are one of the fastest growing and most promising researched areas, due to their features of durability, stability, dimension (small diameter, long distance) and insensitivity to external electromagnetic perturbations, which makes them ideal for the long-term health assessment of engineered structure. The thousands of sensing points that the Distributed optical sensors techniques (Rayleigh or/and Brillouin techniques) can provide enables mapping of strain distributions in two or even three dimensions. Thus, real measurements can be used to reveal the global behavior of a structure rather than extrapolation from local point measurements.

In this paper, we present the results obtained on experiment done in the URL of Bure called “AHA1604” dedicated to temperature, strain and load measurements. On such experiment, distributed optical fiber spirally installed directly on the external surface of a particular liner section. Ovalization optical fiber section coupled with three OFS cables installed along three directions on the casing. The implementation includes the design, the docking system and the development of protection system needed when installing the tube section. All OFS sensors have seen successfully installed without any damage (100% survival rate). Dynamic strain and temperature measurements were obtained during installation and grouting phase. It gives clear observation of the filing of the gap between the liner and the rock. Strain distributions along the section analyzed in order to use both 2D and 3D model.



5. Retrieval Test of High Level Waste in the Cigéo Project

Jean-Michel Hoorelbeke, Pascal C. Leverd*,* ***Jean-Michel Bosgiraud****, *Yves Lorillon**

Andra has incorporated in the step-wise design development of Cigéo (the French Deep Geological Repository) various requirements linked to “Retrievability”, at different stages of the repository life cycle (from its construction start-up to its final closure and monitoring). These requirements have an impact on Cigéo’s design, progressive deployment, operation, and partial closure and monitoring. On a shorter term, one must demonstrate that the waste retrieval operations are technically safe and feasible.

The current poster refers to retrievability and reversibility and details how those two combine. The “Retrievability Scale” as proposed by OECD/NEA (and adopted by Andra) is also reminded. The needs for retrieval operations are exposed for HLWwaste containers stored underground in Cigéo within the context of their emplacement configurations (horizontal micro-tunnels) at different stages of the repository life cycle.

The main part of the poster focuses on a practical case story: a technological test (now completed) of HLW container retrieval out of a disposal micro-tunnel. Thanks to a test bench built on surface to simulate (create) the environmental conditions prevailing inside a HLW micro-tunnel at time of retrieval it was possible to check whether the mechanical means developed for the purpose were adequate and efficient.

The test case story is exposed, c/w the problems and challenges encountered (high temperature impairing the retrieval robot’s proper functioning, corrosion products jamming the radioprotection shielding doors…). The trouble-shooting solutions implemented and the final positive results are presented.

This poster concludes with a critical analysis of the methods and equipment used, the results obtained and provides some perspectives of improvement, as now incorporated in the detailed engineering studies currently running.

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Topic 2. Heat Generating Waste Containers

6. Robust repository concept selection to enable flexible design adaptation and optimisation

Tara Beattie, United Kingdom

In the early phases of a disposal programme, when preliminary safety assessments are completed, the selection and use of repository safety concepts becomes an important decision making process. For Early Stage Programmes, adoption of a technically mature concept, for a given rock and waste type, offers a variety of benefits, including the potential of reduced time and cost towards implementation. The clear articulation of requirements at the highest level is a prerequisite to applying a robust and defensible approach to deciding on a mature reference concept, and maintaining ease and flexibility to site-specific design adaption and optimisation.

In this work, we demonstrate the importance of:

- Understanding and evaluating the benefits and constraints of implementing a mature concept, as done exactly elsewhere; and
- Understanding concept variants derived from high level requirements in order to evaluate the benefits and constraints of implementing the same safety concept, but in a different way.

The discussion illustrates a number of tools available that can allow quantitative 'flexing' of a disposal concept to evaluate compatibility for a specific waste type and specific geological setting. It also cites a number of concept variants to consider, including the evaluation of co-disposal of multiple waste types versus single facilities for a specific category of waste, multi-horizon siting, off-shore siting, engineered barrier system emplacement options (prefabricated versus in situ) and sealing, reversibility, and closure options. This work relates to the IGD-TP SRA Key Topic 4: Development Strategy of the Repository [1].

[1] IGD-TP SRA, 2011.

7. Canister material corrosion test under in situ conditions (MACOTE experiment)

Vaclava Havlova, UJV, Czech Republic

Development of the disposal canister for spent nuclear fuel is fully integrated along with research of potential materials corrosion resistance under presumed conditions of a deep geological repository (DGR). Czech disposal concept for spent nuclear fuel is based on a steel canister, which will be surrounded by compacted bentonite in a granitic host rock. The canister is presumed to consist of carbon steel overpack and stainless steel canister, nowadays with presumed maximum temperature 90 °C at the surface during the disposal.

The Material Corrosion Test (MaCoTe), lead by Nagra, is therefore focused on corrosion test in natural granitic host rock in Swiss underground laboratory Grimsel Test Site (GTS). Two types of corrosion tests are performed, non-heated and heated corrosion test. Both types of corrosion tests are long term and metal samples were removed after two years. The poster will show a system of in-situ test that can be certainly upgraded toward updated canister requirements, concerning new disposal concepts or DGR optimization.

Heated corrosion experiment is based on emplaced of corrosion modules with samples in five individual boreholes in a granitic host rock (GTS). Experiment is carried out under anaerobic conditions to simulate the DGR environment. During the sampling campaigns since the start of the heated experiment, all five boreholes have been sampled for groundwater for chemical and microbiological analyses. Up to now, the metal samples has been already taken from 2 boreholes and transferred to the laboratory for post experimental analyses. The remaining sample modules have been left in their respective boreholes and are planned for sampling in the campaigns during the following years of the heated experiment.

The following institutions are involved in MACOTE project: NAGRA, RWM, NWMO, NUMO, SURAO (UJV Rez/Technical University in Liberec).

8. The CHANCE project "Characterization of conditioned nuclear waste for its safe disposal in Europe"

*D.Ricard[1], L.Boucher[2], A.Rizzo[3], H. Tietze-Jaensch[*4], C.Mathonat[5], C.Bruggeman[6], J.Velthuis[7], L.Thompson[8], G.Genoud[9], C.Bucur[10], D.Kikola[11], G. Zakrzewska-Koltuniewicz[12]*

The consortium of CHANCE project addresses some specific issues of the characterization of conditioned radioactive waste (CRW). The first objective of CHANCE is to establish, at the European level, a comprehensive understanding of current CRW characterization and quality control schemes. The second objective of CHANCE is to further develop, test and validate supplementary techniques already identified that will undoubtedly improve the characterization of CRW. Specifically, these methodological/technical tasks will focus on:

i) Calorimetry for large volume waste drums as an innovative non-destructive technique to detect hidden and difficult-to-measure radioactive material and reduce uncertainties on the inventory of radionuclides;

ii) Muon Tomography to address the specific issue of non-destructive identification and visualization of radioactive waste content inside very large volume and heavily shielded nuclear waste casks;

iii) Cavity Ring-Down Spectroscopy (CRDS) as an innovative technique to characterize outgassing namely of ^{3}H, ^{14}C and ^{36}Cl from radioactive waste with the objective to reach a very low level of detection.

We shall present an overview of the project and explain the current state-of-the-art.

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

9. Project "KoBrA" - Study on Requirements and Concepts for SF/HLW Final Disposal Canisters in Salt, Clay and Crystalline Rock

Christian Herold, BAM - FB 3.4, Germany

With the Repository Site Selection Act (StandAG) as of summer 2017 a new procedure for siting a final repository for High Level Waste and Spent Nuclear Fuel has been established in Germany. In this context all three potential host rock formations (salt, clay and crystalline rock) will be taken into account.

A Safety Concept for such a repository relies on the encapsulation and retardation capabilities of natural barriers (host rock, overburden), geotechnical barriers (drift and shaft seals) and technical barriers (containers). The containers have to provide safety functions (containment, shielding, sub-criticality and sufficient decay heat dissipation of the radioactive inventory) during all handling procedures until being finally disposed of. Subsequently, containers have to provide these safety functions depending on the geological boundary conditions and on the design criteria including retrieval and recovery. In this context the German Ministry for Economic Affairs and Energy (BMWi) and PTKA (Karlsruhe Project Management) launched the R&D-Project KoBrA which is carried out by BAM (Bundesanstalt für Materialforschung und-prüfung) and BGE TECHNOLOGY GmbH.

The main objective of KoBrA is to systematically derive requirements for containers for heat-generating radioactive waste and spent nuclear fuel assemblies and to develop generic container concepts. Existing legislation and technical guidelines will be taken into account as well as the international state of the art. And of course, the main safety functions of a container have to be taken into account as well during repository operation on the surface and underground and in the long term. Eventually (end of 2019) the KoBrA-project will deliver suggestions for the implementation of the derived requirements by means of generic container concepts.

Topic 3. Advanced Site Characterisation Techniques

10. Advanced site characterization from 3D seismic survey and 3D geological modelling

Béatrice Yven, Andra, France

During the last 20 years, Andra has conducted research in the North-East part of the Paris basin to build a deep geological disposal facility for the most highly radioactive waste in the very long term.

The geological exploration and site characterization were carried out in different steps following the progress of the project. From the regional scale up to few hundred of km2, the geological characterization (lithology, properties) was performed from deep boreholes (cores and well logging), whereas the structural context was investigated from seismic reflection data (mainly 2D lines). This first stage was completed with the digging of an underground research laboratory at 500 m depth through long-term scientific and technological experiments.
In 2010, a 3D high resolution seismic survey was carried out in a 37 km2 area selected to receive the deep underground facility. The high quality of the seismic data combined with a succession of advanced techniques allowed Andra to develop a 3D high resolution geological model, to study the natural variability of key properties of the target formation and to refine the geometry of the layers (depth, thickness, dip).

This information was used for safety assessment and thermo-hydro-mechanical phenomena simulations. Firstly, special attention was applied in the seismic spread. The density of data was designed to be the most homogeneous as possible in offset, angle and common mid point. The source was a vibroseis source generating a signal in the 14 - 140 Hz frequency bandwidth. The bin size was 10 x 10 m2 and the nominal fold 60. The processing sequence applied to the seismic data set was followed step by step with the main goal to preserve amplitudes. The main steps were amplitude recovery, surface consistent amplitude compensation, statics correction, velocity analysis, pre-stack time migration, noise attenuation and phase conversion, acquisition foot print attenuation and band pass filter. The reliability of the stacked amplitudes was evaluated through stochastic processing of the pre-stack amplitude gathers. Then, the seismic impedances (P-wave and S-wave) were obtained by elastic inversion of the migrated seismic sections from the 3 angle migrated stacks (near, middle, far angles). A geostatistical processing was applied to perform the depth conversion using the Bayesian Kriging method. Another innovative methodology was developed for estimating density and velocity distributions in depth, which are consistent with the depth conversion of seismic horizons and impedances obtained by elastic inversion. Finally, the density and velocity models were used to estimate geomechanical parameters.

11. Prediction of the key physico-chemical parameters of geological barriers through detailed mineralogical analysis: case study of the Boom Clay (Belgium)

Lander Frederickx[1,2], Miroslav Honty[1,], Norbert Maes[1], Christophe Bruggeman[1]*

Geological disposal has been internationally accepted as a feasible and safe solution for the long-term management of medium and high-level radioactive waste. In many countries, the disposal concepts rely on the presence of natural clay formations which act as an ultimate barrier with respect to radionuclide retardation. The mineralogical composition of these clay formations is closely related to some of their important physico-chemical properties, such as density, thermal conductivity, cation exchange capacity, surface area, etc. Since some of these properties heavily affect the sorption and retention of radionuclides, it is important to know their variation in detail over a large scale.

In this paper, we show that there is a strong relationship between quantitative mineralogical composition, grain size distribution and some of the key physico-chemical parameters of the Boom Clay, a potential host formation for disposal of radioactive waste in Belgium. Starting from the grain size distribution, we can already predict bulk mineral proportions, cation exchange capacity and specific surface area. This translates to a significant reduction of time and resources spent on individual analyses at an acceptable loss of accuracy.

In order to further exploit the way a sediment's properties are linked to each other, we are now looking into borehole logging as a way to predict properties of a clay formation in a continuous way. During borehole logging, a continuous data set of parameters such as microresistivity, bulk density and gamma radiation can be measured over the length of the log, while most sorption-relevant properties remain unknown. On-going research is focused on finding a relationship between microresistivity and parameters such as cation exchange capacity and specific surface area. Once this relationship has been established, we will be able to predict a continuous range of these parameters over the entire logged profile. This would mean that a borehole logging campaign, combined with a relatively small sample set to train a statistical model, would suffice to predict key sorption related properties for an entire clay formation.

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12. Towards the use of multiple state variables in hydrogeological modelling supporting site characterisation

Bart Rogiers[(1)], Matej Gedeon[(1)], Koen Beerten[(1,)], Diederik Jacques[(1)], Christophe Bruggeman[(1)]*

Aquifers surrounding geological layers for radioactive waste disposal are an essential element in site characterisation studies. While they are not part of the disposal system itself, and hence do not fulfil any containment, retardation or isolation function, aquifers form the connection between the disposal system and the biosphere. The uncertainty on advection-dispersion of radionuclides potentially released from the disposal system should be reduced as much as possible, although often there is only very limited information available on deep confined or the deeper parts of unconfined aquifers. We will present an overview of advanced techniques that have been tested and are being/will be deployed to address this issue. Developing a model of groundwater water flow and solute transport in the Neogene aquifer, which is overlying the ca. 200 m deep Boom Clay in NE Belgium, addressing challenging conceptual as well as numeric issues should integrate all existing knowledge and data in order to reduce uncertainties. From the poorly constrained model with a simple subsurface geometry that was used several decades ago, we are now entering a new era in model development, targeting the integration of material properties such as hydraulic conductivity, classic state variables such as hydraulic heads and river discharges and alternative state variables. Besides that we aim at coupling unsaturated zone and surface water processes to the groundwater model and perform an advanced uncertainty quantification. Here we discuss some examples of alternative state variables, and how to measure them during an advanced site characterisation, including monitoring well temperature logs, point dilution tests and the use of groundwater age tracer concentrations.

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13. A Multiscale Approach to Model Thermo-Hydro-Mechanical Behaviour of Plain Concrete During Early Stages of Construction.

S. Babaei[(1,2)], S.C. Seetharam[(1,)], B. Craeye[(2)], U. Muehlich[(2)], A. Dizier[(3)], G. Steenackers[(2)]*

This study tackles the coupled thermo-hydro-mechanical behaviour of plain concrete during early stages of construction, especially immediately after hardening. Processes such as (i) thermal expansion, (ii) autogenous/drying or heat-induced shrinkage, and (iii) drying creep may combine to initiate/propagate cracks in plain concrete. These are fundamentally triggered by cement hydration kinetics, thermal/moisture gradients due to internal heat source and/or environmental exposure, and external mechanical load. Such problems are of great relevance in the field of nuclear waste storage and disposal from the point of view of safe design of concrete containers/structures.

The most common approach to study THM problems is via continuum approach, which essentially treats concrete as a homogeneous medium. The main drawback of such an approach is that governing equations representing THM processes are based on phenomenological laws that require parameters to be fitted based on laboratory or in-situ experiments. When the problem is highly nonlinear the phenomenological laws may not always yield satisfactory results. Therefore,

this study aims to tackle this problem via a multiscale framework in which macroscopic properties are determined from microscale models and upscaled via a suitable homogenization approach.

In the first phase of this study, the problem of drying shrinkage is addressed via a multiscale framework. The two most important inputs to predict drying shrinkage strain are the moisture retention curve and bulk modulus of concrete. A novel technique based on combined particle-packing/cement hydration kinetics/pore network model is developed to predict the moisture retention curve for concrete. An effective medium theory, which uses inputs from the cement hydration kinetics model, is then applied to upscale the bulk modulus of concrete. The accuracy of the above framework to predict drying shrinkage strain is demonstrated using various measured data. The second phase of the study will consider multiscale development for temperature dependent parameters and damage formulation of the THM model.

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14. Advanced analysis of RN migration in fractured crystalline rock

V. Havlova, J. Kulenkampff, F. Jankovsky, M. Zuna, C. Fischer

Migration of radionuclides in crystalline rocks is mainly driven by advection processes in fractures. Thus, the safety assessment of deep geological repositories in crystalline rocks relies critically on fracture flow properties and the reliability of transport modelling approaches. Here, we focus on heterogeneity and complexity of transport processes, typically of limited predictability. In order to tackle this issue, we suggest experimental observations by using tomographic methods, as well as feedback with and improvement of existing transport modelling approaches.

As an example, tracer propagation through fractured crystalline rock cores from the Czech Republic (Bukov URL, depth of 500 m below the surface), was studied in collaboration between HZDR (Germany) and UJV (Czech Republic). Spatiotemporal data of the tracer concentration during conservative transport are based on positron emission tomography (PET), and the underlying fracture structure was characterized by µCT-imaging. The latter yields a structural model for reactive transport modelling. The PET data sequences are used for (i) the validation of existing simulation approaches, and (ii) serve as input or the parameterization of advanced simulation concepts.

First results underscore the outlined approach. In particular, the PET measurements clearly show preferential and localized pathways, a feature of the process that significantly reduces the effect of interactions at the fracture surface (and thus retention by adsorption), although repeat experiments are considering that the identified pathways are not constant over the experimental periods.

As a consequence of the combined experimental and simulation approach, we expect (i) advanced model concepts based on experimental insights and (ii) an improved understanding of reactive

transport processes with a focus on temporal heterogeneity of preferential pathways. Further HZDR and UJV joint experimental activities are outlined within the WP FUTURE (Fundamental migration of radionuclides), European joint program project EURAD, submitted in September 2018.

15. Study of impact of the radiation on concrete structure behaviour

Zbynek Hlavac, Czech Republic

Concrete part of the barrier in nuclear waste repository can be affected/can affect the environment by organic radionuclides contained in the concrete compounds as plasticizers or superplasticizers changed by gamma radiation.

The poster shows what happened, when we irradiated concrete prisms by 1 to 2 megagrays of gamma radiation dose. We tested them non-destructively using ultrasonic and resonance methods, as well as destructively, using 3-point bending test and its fragment compression test. Scanning Electron Microscopy was applied to investigate the detail changes in the structure, microcracks etc.

Comparison of the concrete before and after irradiation is provided in the conclusions of the poster.

We will participate in EURAD project, where we provide the gamma irradiation facility which can simulate the repository conditions - temperature, pressure and radiation. We wish to use our experiences with concrete and cement paste with superplasticizers irradiation and testing to complete the project part called CORI cement-organic radionuclide interactions.

Related to the IGD-TP SRA

16. CEBAMA – EC HORIZON2020 PROJECT ON CEMENT-BASED-MATERIALS

Marcus Atlmaier, KIT-INE, Karlsruhe Institute of Technology - Institute for Nuclear Waste Disposal, Germany

In this contribution, main results from the CEBAMA project are presented. Emphasis is put on indicating how the main results from CEBAMA can be accessed, i.e. via peer-reviewed publications, Public Deliverables, Annual Workshop Proceedings, etc. The Final Workshop of the CEBAMA project (March 28th-29th, 2019), which will be held in close connection to the International Workshop “Mechanisms and Modelling of Waste / Cement Interactions” (March 25th-27th, 2019), both hosted by KIT-INE in Karlsruhe, Germany, is also announced.

CEBAMA is a research and innovation action granted by the EC 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, and one SME from 9 EURATOM Signatory States, Switzerland and Japan. IGD-TP and National Waste Management Organizations support CEBAMA, for instance by co-developing the work plan, participating in the End-User Group, granting co-funding to some beneficiaries, and providing for knowledge and information transfer.

Research in CEBAMA focusses on the main activities:

- Experimental studies analysing interface processes between cement-based materials and host rocks (crystalline rock, Boom Clay, Opalinus Clay (OPA), Callovo-Oxfordian (COX), Toarcian mudstone) or bentonite backfill, and assessing the impact on physical (transport) properties.
- Investigation of radionuclide retention processes in high pH concrete environments, focusing on radionuclides which have high priority from the scientific and applied perspective.
- Improved validity of numerical models to predict changes in transport processes as a result of chemical degradation, including advanced data interpretation and process modelling.

For more information on CEBAMA visit: www.cebama.eu.

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17. MODERN SPENT FUEL DISSOLUTION IN FAILED CONTAINER CONDITIONS (DISCO)

Lena Evins, SKB, Sweden (presented by Lara Duro, Amphos21)

DisCo is a H2020 Collaborative Project funded by the European Commission under the Euratom Programme.

Robust safety cases for the geological disposal of spent nuclear fuel require a solid understanding of its dissolution mechanisms over long timescales. Spent fuel dissolution controls the release of radionuclides to the surrounding environment, once the containment fails. The DisCo project represents a logical follow-up from earlier Euratom projects which focused on dissolution and radionuclide release from conventional UO2 spent fuels. This project will fill the knowledge gap on spent fuel dissolution regarding non-conventional fuel types (Cr/Al- doped and MOX). The expected knowledge gain is essential for the Waste Management Organisations and of interest for research organisations and regulators alike.

The work is divided into five work packages:

- WP1: management, coordination and dissemination,
- WP2: Preparation and characterisation of samples and experimental systems,
- WP3: Spent fuel dissolution experiments,
- WP4: Model materials dissolution experiments,
- WP5: Chemical modelling.

The progress has been reported at the first Annual Meeting (May 2018), and the preliminary results presented here are brief excerpts from the proceedings volume (see www.disco-h2020.eu). Spent fuel samples have been prepared as discs and fragments through cutting and decladding, and autoclaves were modified for remote handling, sampling of liquid, gaseous and solid samples, and leak-tested. Samples have been synthesized following the protocols developed for the various analogue materials. Alpha-doped material, produced in Belgium, is expected to be available early 2019. The dissolution tests have started and first preliminary results will be presented at the 2nd annual meeting in 2019. Chemical models have been set up and tested with regards to e.g. kinetic constants used in the coupling between radiolysis and chemistry codes. Oxygen potentials in an ideal Cr-doped UO2 have been calculated, and the importance of Fe2+ on the MOX radiolytic dissolution has been emphasized through Chess-HYTEC modelling.

18. Microbial corrosion of iron coupled to methanogenesis by strains from different environments

Hans-Jorg Kunte and Andreas Koerdt, BAM/Federal Institute for Materials Research and Testing, Germany

Microbially influenced corrosion (MIC) of iron is usually attributed to sulfate-reducing microorganisms (SRM) which act upon the metal by the reactiveness of hydrogen sulfide, and by withdrawal of the available electrons ($Fe \rightarrow Fe2+ + 2e-$; $E° = -0.47$ V) in electrical contact through surface attachment. Also methanogenic Archaea are supposed to cause MIC. Because they do not

produce hydrogen sulfide, withdrawal of electrons may be their main corrosive mechanism; however, mechanistic details and kinetics of the overall process are poorly understood. Precipitation of siderite ($4Fe + 5HCO3^- + 5H^+ \rightarrow 4FeCO3 + CH4 + 3H2O$) can lead to an insulating layer on the metal surface and lower the corrosion rate. Still, the extent of $FeCO3$ precipitation may be significantly influenced by environmental conditions such as pH and advective processes.

To investigate the corrosive potential of methanogens, we studied strains isolated from marine sediments (Methanococcus maripaludis 14266, 2067, Methanobacterium-affiliated strain IM1), crude oil tanks (Methanococcus maripaludis Mic1c10, KA1) and the oral cavity (Methanobrevibacter oralis) in a closed (batch) culture, and in a sand-packed flow-through cell with pH control and simulation of a fluctuating environment. Results indicate that the rates of iron corrosion due to coupled methanogenesis (up to 0.3 mm/yr) are comparable to that caused by SRM. Surface analyses of the metal showed severe pitting. Such knowledge and deeper understanding also from an electrokinetic point of view may not only provide further models in microbial electrophysiology, but also contribute to mitigation strategies in MIC.

19. Probabilistic modelling of radionuclide release from a cementitious near field

Tim Heath, Wood plc, United Kingdom

The IGD-TP's Strategic Research Agenda states that the safety case should describe the evolution of the repository as a reasonable representation of what might happen, and give a clear indication of uncertainties in the description. In the UK, this uncertainty requirement has led RWM to implement a probabilistic approach in the Total System Model (TSM) that underpins its safety case. This approach involves assessing the uncertainty distributions for relevant input parameters in the model and applying a Monte Carlo approach. It allows the identified input uncertainties to be propagated through to uncertainty in the calculated risk. However, where time-dependent parameters are approximated with constant values, real time variability is inevitably wrapped into the assessed uncertainty distributions. This approximation can introduce correlations between parameters that are not accounted for in random sampling of parameter values, leading to erroneous results. To address this issue, either such correlations need to be understood and accounted for or, preferably, the model needs to be refined to represent key processes in terms of time-dependent parameters.

This issue is particularly significant for cementitious ILW concepts in higher-strength rocks, where. near-field solubility and sorption parameters for radionuclides have been treated as time independent quantities. To improve on this assumption, a Near-field Component Model (NFCM) has been developed that provides a more detailed and realistic representation of the system within a framework of the probabilistic Monte Carlo approach. The groundwater chemistry, radionuclide chemistry and backfill reactions are represented explicitly as chemical equilibria. The associated radionuclide equilibrium constants are treated as probabilistic parameters in the NFCM, with uncertainty distributions defined by their previously assessed standard deviations. Comparing the outputs of the NFCM and TSM shows that the results are very similar where the radionuclide

chemistry remains constant (e.g. for uranium(IV) but differ significantly where the chemistry varies (e.g. for uranium(VI)).

20. Development and improvement of thermodynamic understanding for the nuclear waste disposal Safety Case

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Thermodynamic and geochemical model calculations are important tools used in the context of Safety Cases of repositories for nuclear waste disposal. Understanding and properly quantifying the thermodynamic driving forces controlling the mobilization and retention of radionuclides, as well as the degradation of waste matrices and technical barriers, underpins the long-term performance assessment of such disposal systems and increases its credibility. Thermodynamic approaches can sometimes add time-independent boundary conditions into long-term predictions. Further developing thermodynamic databases (TDBs) and underlying scientific understanding of key processes arises as a research need in the context of geological disposal of radioactive waste. In the framework of the JOPRAD Programme Document “The Scientific and Technical Basis of a Future Joint Programme on Radioactive Waste Management and Disposal”, the sub-domain “Chemical Thermodynamics” was rated with the highest level of common interest within the category of “Radionuclide and Chemical Species Migration” [1].

This contribution outlines the specific need for experimental and theoretical investigations providing information for the prediction of processes over long timescales based upon fundamental scientific constants, i.e. via chemical thermodynamics, in key fields for geological disposal of radioactive waste. As a starting point for further discussion, the following topics of interest have been outlined: (i) data gaps identified within the Thermochemical Database project of the Nuclear Energy Agency (NEA-TDB), as well as for other elements / systems of relevance for waste disposal and not covered by NEA-TDB; (ii) radionuclide-organics complexation, including cement additives (beyond CORI), degradation products and small organic ligands disposed of with the waste; (iii) TDB for elevated T conditions and the need of developing advanced methods for the estimation of thermodynamic properties; (iv) solid solutions including relevant end-members for waste disposal, e.g. clay or cement systems, alteration products of waste packages etc.; (v) the interplay of thermodynamic and kinetic effects, in particular with focus on ill-defined solid phases, Ostwald ripening and description of redox processes; and (vi) the link between local equilibrium at small scale or between few components and global disequilibrium. This contribution is intended to trigger the development of a working group on these topics, where of course the list of topics is susceptible to be modified or extended to better adjust to the needs of WMO, TSO, regulators and RE.

The review books within the NEA-TDB and its quality assurance procedures represent a key anchoring point, which provides the most comprehensive international effort for building up a high-quality TDB in the context of nuclear waste disposal, and it is at the core of most national and trans-national TDB initiatives in this field, e.g. ThermoChimie (France, UK, Belgium), THEREDA

(Germany), JAEA-TDB (Japan), WIPP-TDB (US), among others. Beyond the need of maintaining the know-how in the area of thermodynamics, this initiative supports present and future capabilities to perform reliable use of thermodynamic concepts in predictions underpinning the performance of various disposal configurations and the Safety Case.

[1] JOPRAD 2017, Deliverable n 4.2, Programme Document – The Scientific and Technical Basis of a Future Joint Programme on Radioactive Waste Management and Disposal, Work Package 4

21. Beacon: Bentonite Mechanical Evolution

Patrik Sellin, SKB, Sweden

Developing predictive capabilities of the mechanical behaviour of bentonite buffers, seals and backfills are a common need for all radioactive waste management programs that use bentonite in engineered barrier system (EBS) components. Because of the complexity of the objectives networking at European level is key for the development of an integrated system understanding, skills, training and capabilities.

Beacon aims at the development of understanding fundamental processes that lead to material homogenisation, as well as improved capabilities for numerical modelling. In earlier assessments of the long term performance of bentonite EBS, the mechanical evolution of the installed bentonite was neglected and an “ideal” final state was optimistically assumed.

In order to verify the performance of current designs for bentonite barriers the following is ongoing:

1. A well-documented and communicated collection of the available knowledge prior to the project.
2. Re-evaluation of a large part of the existing database to extract the important information, to compile the qualitative and quantitative observations and to develop the conceptual understanding.
3. Enhanced, robust and practical numerical tools firmly grounded on a good conceptual understanding, which has the required predictive capabilities concerning the behaviour of engineered barriers and seals.
4. A complete experimental database for the need of the assessment models.
5. Verified models based on experimental results from experiments in different scales
6. Workshops dedicated to the mechanical issues in bentonite open to the scientific community as well as civil society.

The Beacon project is needed for the pan-European aims at building confidence amongst regulators and stakeholders regarding the performance of safety barriers in a geological repository. It is also cost- and time-effective to progress development of understanding regarding bentonite behaviour in a collaborative manner, and the sharing of precedent information enhances efficiency of overall process.

22. Microorganisms in a clay-steel system

Megan Barnett, British Geological Survey, United Kingdom

Microbial activity has been implicated in the corrosion of steel material and alteration of bentonite clays used in geological disposal facilities for radioactive waste. To understand the limits on microbial growth, and the potential for microbial activity in this environment to affect the swelling behavior of the clay and metal corrosion, a suite of laboratory experiments is being conducted. Experiments conducted in the MIND (Horizon2020) project have been designed to simulate in situ repository conditions by preparing compressed, hydrated clay samples (dry density 1200-1400 kg m-3), with embedded steel. These samples were housed in a constant volume axial flow vessel. A hydraulic gradient was applied using two high pressure pumps. Preliminary results show evidence of corrosion in all experiments and XRD data show an increase in the basal spacings of smectites in the zone immediately surrounding the steel. SEM examination showed that samples inoculated with a sulfate reducing bacterial enrichment culture had evidence of calcium precipitation and calcite crystal formation, accompanied by differences in the iron phases.

These experiments simulate the in situ conditions well, but the complex nature of this experimental design reduces the practicality of performing many repeat experiments and varying the environmental conditions. Therefore, to complement these investigations, a low-tech solution has been implemented with pressurized, hydrated clay batch experiments. The simpler nature of this set-up allows for investigation of more parameters. The freezing of fluid used in the MIND set-up was modeled and formed the basis of a groundwater representative of ‘permafrost’ conditions. The effect of incubation temperature is also being investigated. This combination of high- and low-tech investigations aims to provide insight into microbial behavior under variable realistic conditions. Combined, these experiments will help to understand the influence of microbes in geological disposal facilities and how their behavior may change by external parameters.

23. Microbiology In Nuclear waste Disposal (MIND)

Birgitta Kalinowski, Swedish Nuclear Fuel and Waste Management Co, Sweden

MIND is an interdisciplinary project consisting of two experimental work packages focusing on the influence of microbial processes on waste forms and their behaviour and long-term performance of repository components. The emphasis is on quantifying specific measureable impacts of microbial activity on safety cases under repository-relevant conditions. The third work package handles integration of society and policy-oriented studies in the project, while a study of expert conceptualization, public perception and risk communication concerning microbial influences in geological disposal, improves general awareness of microbial issues.

Work package 1:

- The 18 year data set from Olkiluoto records an increase in CH4 gas generation rate since 2006 that is attributed to neutralisation of pH, declining sulphide concentration and homogenisation of the chemical conditions.

- Microbes have the ability to metabolize organic degradation products of irradiated cellulose, bitumen and PVC at pH conditions relevant to ILW disposal.
- The microbial species Stenotrophomonas bentonitica, isolated from Spanish bentonites have shown to being capable of reducing Se and thereby of reduce the mobility of selenium from repositories.

Work package 2:

- Bacterial sulphide-producing activity in water saturated bentonite correlates negatively with increasing clay density and the specific swelling pressure generated by the respective clay type.
- Biocorrosion of carbon steel canisters was found to be by a factor 2 higher under anaerobic condition in the environment containing sulphate reducing bacteria comparing to sterile control over 240 days.
- Sulphide was demonstrated to react with ferric iron in bentonite with the formation of elemental sulphur, ferric iron and iron sulphide.

Work package 3:

- The bioinformatics analysis procedure that is used to analyse microbial communities was compared among the MIND partners.

Microbial activity may have a significant impact on the chemical evolution of the repositories for radioactive waste. Therefore, what controls their activity under repository conditions must be well understood.

24. Preliminary Analysis of Gaseous 14C Radiological Impact in a Geological Repository Hosted in Salt Rock

Barbara Ferrucci, ENEA, Italy

A preliminary evaluation of gaseous 14C behavior under geological repository conditions for Italian radioactive High Level Waste-Long-Lived and Intermediate Level Waste disposal has been performed. Although in Italy there is still no defined project about geological disposal facility, current work may support future safety assessment studies for a hypothetical repository in deep salt rock. In the Italian context of radioactive waste, the percentage of 14C bearing waste to be disposed in a possible geological repository is low; irradiated graphite is the most important radiological source. Data about the radiological inventory has been collected to simulate production and migration of gaseous 14C in a hypothetical geological repository. Three different conceptual models have been developed and simulated. The first model has considered a preliminary evaluation of the radiological impact referred to the whole inventory; the second and third model have evaluated the impact only due to the irradiated graphite. A preliminary sensitivity analysis has been carried out, highlighting the importance of geometry and of distribution coefficients (Kd) in materials used to seal the disposal underground facility. Results have showed the possibility to

correlate the Kd values, the volume and the location of the sealing materials to the amount of 14C migrating toward the surface.

25. Portuguese Involvement/Engagement in Radioactive Waste Management Related Activities

I. Paiva, P. Vaz, M. Reis, M.M. Madruga and J. Marçalo

Portugal produces radioactive wastes from health, industry, E&T activities and from the 1 MGW swimming pool research reactor. Since FP4th, first as ITN and then as IST, have been involved in the R&D&D activities in support of the fission and radioactive waste management European strategies and policies. It is our objective to give a brief presentation of the involvement of the Country in these activities, within the framework programmes, including its support to the implementation of geological disposal safe solution, both in terms of collaboration in various projects, integration of platforms and links to the IAEA and the creation of a specific curricular unit on radioactive waste management in the IST master's degree MPSR.

26. Activities of the Russian Nuclear Safety Institute in the context of deep geological disposal safety

Valentina Svitelman, Nuclear Safety Institute of the Russian Academy of Sciences, Russia

Nuclear Safety Institute of the Russian Academy of Sciences (IBRAE RAN) was founded by the special Governmental Decree after the Chernobyl accident for basic safety research and independent nuclear and radiation safety analysis.

A balanced combination of fundamental and topical applied research activities in the field of nuclear power safety constitutes the basis for the Nuclear Safety Institute activities.

Main research directions of the Nuclear Safety Institute are:

- Safety analysis of nuclear facilities.
- Radioactive waste and spent nuclear fuel management, decommissioning of nuclear hazardous facilities and remediation of territories.
- Analysis of the nuclear facilities impact on the environment and population.
- Development of radiation monitoring systems for emergency response.
- Development of computer codes.
- Development of the decision-support system for radiation incidents and accidents.

As a part of the Geological disposal implementing program, the Nuclear Safety Institute represent technical support organization for Rosatom. In this regard, the comprehensive research is being

done as an integral part of the development and upgrading the safety case and corresponding safety assessment for the deep geological disposal facilities. This work covers all stages of the disposal project, including design, construction, operation and closure of the disposal facility, as well as relevant research, development and demonstration activities in the underground research laboratory.

The mission of the Nuclear Safety Institute involves a wide variety of activities, including the development of a general safety case methodology, numerical modeling of physical, chemical, biological and other relevant processes, including coupled ones, development of a computational tools and codes, evaluations of radiological and environmental risks and impacts, social and financial consequences.

This poster focuses on recent activities of the Nuclear Safety Institute regarding implementing geological disposal of radioactive waste and relevant nuclear industry issues.

27. Modern2020 Project Finalisation

Marie Garcia, Andra, France

The poster will communicate the upcoming events and project finalisation activities.

28. Theramin Project Update

Dan Galson, Galson Sciences Ltd, UK

The poster will communicate the current activities and upcoming events.