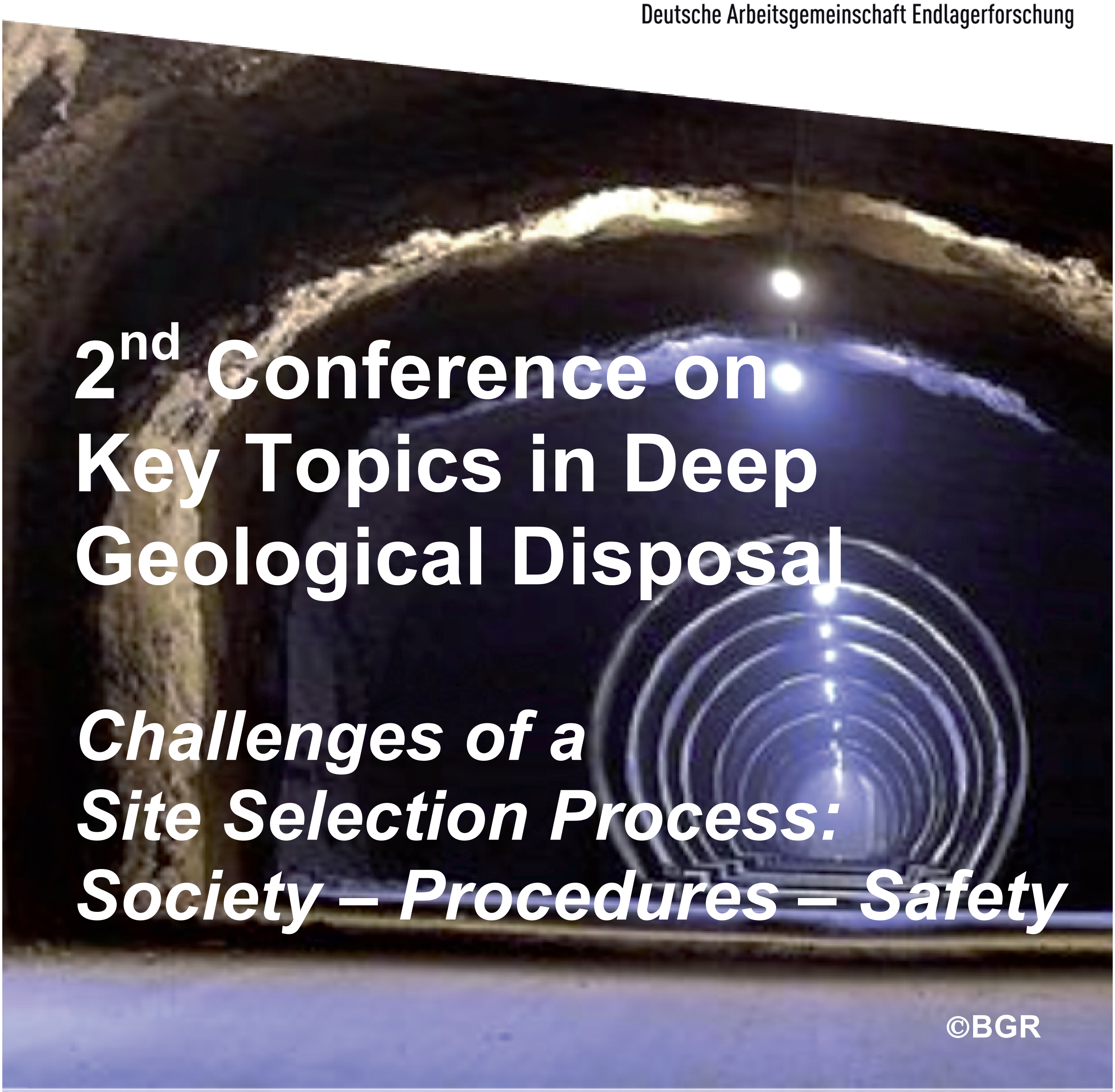
DAEF

Deutsche Arbeitsgemeinschaft Endlagerforschung



2nd Conference on Key Topics in Deep Geological Disposal

Challenges of a Site Selection Process: Society – Procedures – Safety

©BGR

Cologne, 26 – 28 September 2016

BOOK OF ABSTRACTS

Table of Content

SESSION 1 INTERNATIONAL EXPERIENCES IN DESIGNING AND IMPLEMENTING SITING PROCESSES – MASTERING SOCIAL AND TECHNICAL CHALLENGES (TOPIC 1) – PART 1

Chairs: B. Kallenbach-Herbert (Germany) and R. Ewing (USA)

S1-01 THE ROLE OF THE OECD-NEA INTEGRATION GROUP FOR THE SAFETY CASE 9
*L. Bailey (**Keynote**), G. Kwong (UK)*

S1-02 DESIGNING A PROCESS FOR SITING A DEEP-MINED, GEOLOGIC REPOSITORY FOR HIGH-LEVEL RADIOACTIVE WASTE AND SPENT NUCLEAR FUEL 11
D. Metlay, R. Ewing (USA)

S1-04 PARTICIPATORY DISPOSAL POLICY – AN EVALUATION OF REGIONAL PARTICIPATION PROCEDURES IN THE SEARCH FOR SUITABLE DEEP GEOLOGICAL REPOSITORIES FOR RADIOACTIVE WASTE 12
C. Alpiger (Switzerland)

SESSION 2 SCIENTIFIC ASPECTS OF THE NUCLEAR WASTE DISPOSAL SAFETY CASE (TOPIC 3) – PART 1

Chairs: J. Krone (Germany) and C. Davies (EU)

S2-01 50 YEARS OF RESEARCH AND DEVELOPMENT FOR NUCLEAR WASTE DISPOSAL AT KIT 13
B. Kienzler, H. Geckeis (Germany)

S2-02 DESIGN OF DRIFT SEALS COMPLEMENTING A CRZ OF AN HLW REPOSITORY IN CRYSTALLINE ROCK – STATUS OF INVESTIGATION 14
N. Müller-Hoeppe, M. Jobmann (Germany)

S2-03 MICROPHYSICAL PROCESSES OF GRAIN BOUNDARY FLUIDS IN ROCK SALT AND THEIR ROLE IN PREDICTING THE LONG-TERM DEFORMATION AND TRANSPORT PROCESSES IN HOST ROCKS FOR HEAT-GENERATING NUCLEAR WASTE 16
J. L. Urai, G. Desbois, J. Schmatz (Germany)

SESSION 3 DEVELOPMENT AND APPLICATION OF SCIENCE BASED SITE SELECTION CRITERIA (TOPIC 2) – PART 1

Chairs: *P. Landais (France) and B. Thomauske (Germany)*

S3-01 GEOSCIENTIFIC ARGUMENTS IN SUPPORT OF THE SAFETY CASE FOR A DEEP GEOLOGIC REPOSITORY IN SOUTHERN ONTARIO, CANADA – AN EXAMPLE OF REGULATORY RESEARCH AND ASSESSMENT 17
T. S. Nguyen, J. Brown, Z. Li, O. Nasir (Canada)

S3-02 RETRIEVABILITY IN CONNECTION WITH THE REQUIREMENTS FOR A FINAL REPOSITORY FOR HEAT-GENERATING, HIGH-LEVEL RADIOACTIVE WASTE AND SPENT FUEL 18
P. Herold, S. Dörr (Germany)

S3-03 RETRIEVABILITY AND SURVEILLANCE OF RADIOACTIVE WASTE AS HOST ROCK SELECTION CRITERIA 20
T. J. Schröder, J. Hart, A. D. Poley (The Netherlands)

SESSION 6 POSTER SESSION

TOPIC 1: INTERNATIONAL EXPERIENCES IN DESIGNING AND IMPLEMENTING SITING PROCESSES – MASTERING SOCIAL AND TECHNICAL CHALLENGES

P1-01 PARTICIPATORY DISPOSAL POLICY – AN EVALUATION OF REGIONAL PARTICIPATION PROCEDURES IN THE SEARCH FOR SUITABLE DEEP GEOLOGICAL REPOSITORIES FOR RADIOACTIVE WASTE 21
C. Alpiger (Switzerland)

TOPIC 2: DEVELOPMENT AND APPLICATION OF SCIENCE BASED SITE SELECTION CRITERIA

P2-01 ARE CRITERIA FOR SITE SELECTION APPLICABLE FOR DISPOSAL OF HIGH-RADIOACTIVE WASTE IN DEEP BOREHOLES? 22
G. Bracke, F. Schilling (Germany)

P2-02 SEISMICITY AND PROBABILISTIC SEISMIC HAZARD ASSESSMENTS OF GERMANY 23
G. Grünthal, D. Stromeyer, C. Bosse, F. Cotton (Germany)

P2-03 SPANNEND – PROVIDING STRESS DATA AND GEOMECHANICAL MODELLING TOOLS FOR THE SITE SELECTION PROCESS IN GERMANY 24
O. Heidbach, A. Henk, B. Müller, K. Reiter, T. Hergert, F. Schilling (Germany)

P2-04 DETERMINATION OF GEOLOGICAL CRITERIA AND IMPLEMENTATION OF SAFETY INVESTIGATION DURING THE SITE SELECTION PROCESS 25
E. Krapf (Germany)

P2-05 R&D NEEDS FOR IMPLEMENTING THE CHALLENGES OF THE GERMAN REPOSITORY SITE SELECTION ACT (STANDAG) 26
S. Kwiaton, Nicole Schubarth-Engelschall (Germany)

P2-06 METHODS FOR THE DEVELOPMENT OF GEOTECHNICAL AND ROCKMECHANICAL BASIC PRINCIPLES FOR SITE SELECTION IN CLAY AS HOST ROCK 28
D. Wittenberg, J. te Kook, A. Studeny, D. Gutberlet (Germany)

TOPIC 3: SCIENTIFIC ASPECTS OF THE NUCLEAR WASTE DISPOSAL SAFETY CASE

P3-01 EU(III) REACTIVE TRANSPORT MODELLING: APPLICATION OF THE «SMART KD -APPROACH» 29
S. Britz, U. Noseck, W. Durner, S. Iden, D. Zachmann, V. Brendler, M. Stockmann, J. Lützenkirchen

P3-02 MINING OF ANTEI URANIUM DEPOSIT (RUSSIA): EXPERIENCE FOR SAFETY ASSESSMENT OF RW DISPOSAL IN CRYSTALLINE ROCKS 31
V. Petrov, V. Poluektov, J. Hammer (Germany)

P3-03 EVALUATION OF CURRENT KNOWLEGDE FOR BUILDING THE DUTCH SAFETY CASE FOR A DISPOSAL CONCEPT IN ROCK SALT 32
J. Hart, J. Prij, T. J. Schröder, G.-J. Vis, D.-A. Becker, J. Wolf, U. Noseck, D. Buhmann (The Netherlands)

P3-04 EXTENSION OF THE WIPP PERFORMANCE ASSESSMENT USING MODERN 3D MODELING TOOLS 33
T. R. Zeitler (USA)

P3-05 THE EFFECT OF STAGNANT WATER ZONES ON RETARDING RADIONUCLIDE TRANSPORT IN FRACTURED ROCKS: AN EXTENSION TO THE CHANNEL NETWORK MODEL 34
P. Shahkarami, L. Liu, L. Moreno, I. Neretnieks (Sweden)

P3-06 EFFICIENT MANAGEMENT OF SAFETY ASSESSMENT CALCULATIONS – ELECTRONIC INPUT DATA AND RESULTS APPLICATION (EDR) 35
T. U. Kaempfer, G. Mayer, A. Poller (Switzerland)

P3-07 IMPACT OF EARTHQUAKES ON GEOTECHNICAL BARRIERS 36
C. Müller, V. Burlaka, P. Herold, N. Neubert (Germany)

P3-08 THE ROLE OF CALCITE IN NUCLEAR WASTE DISPOSAL SITES 37
S. E. Hellebrandt, S. Hofmann, N. Jordan, M. Schmidt (Germany)

P3-09 SEALING BEHAVIOUR OF CLAYSTONE-BENTONITE-MIXTURE 38
Chun-Liang Zhang and Klaus-Peter Kröhn (Germany)

P3-10	INVESTIGATION OF CH AND HM MATERIAL BEHAVIOUR OF CEMENT BASED SEALING MATERIALS IN ROCK SALT *Oliver Czaikowski, Kyra Jantschik, Helge C. Moog, Klaus Wieczorek (Germany)*	40
P3-11	INTERACTION OF LONG-LIVED SAFETY RELEVANT RADIONUCLIDES WITH CEMENTITIOUS MATERIALS *S. Lange, J. Peele, G. Deissmann, D. Bosbach (Germany)*	42
P3-12	GEOLOGICAL DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTES IN BOOM CLAY IN THE NETHERLANDS: EVALUATION OF WASTE FORM CORROSION BEHAVIOUR FOR THE GENERIC OPERA SAFETY CASE *G. Deissmann, K. Haneke, A. Filby, R. Wiegers, D. Bosbach (Germany)*	43
P3-13	SITE CHARACTERISATION AND SYNTHESIS INTO SDMS – DEVELOPMENT OF NUMO'S PRE-SELECTION SITE-SPECIFIC SAFETY CASE (NUMO 2015 SAFETY CASE)	44
P3-14	DAEF INITIATIVE ON CRUSHED SALT COMPACTION *K. Wieczorek, O. Czaikowski, U. Düsterloh, U. Heeman, C. Lerch, C. Lüdeling, N. Müller-Hoeppe, T. Popp, Ralf Wolters (Germany)*	45
P3-15	HISTORIC INTRAPLATE EARTHQUAKES IN NORTHERN CENTRAL EUROPE ARE CAUSED BY GLACIAL ISOSTATIC ADJUSTMENT *C. Brandes, H. Steffen, R. Steffen, D. C. Tanner, J. Winsemann, P. Wu (Germany)*	47
P3-16	REACTIVE TRANSPORT MODEL IN THE NEAR FIELD OF DIFFERENT GENERIC SPENT NUCLEAR FUEL REPOSITORY OPTIONS: EFFECT OF THE RADIONUCLIDE SOURCE TERM *V. Montoya, D. Fellhauer, V. Metz, H. Geckeis (Germany)*	48
P3-17	LESSONS LEARNT FROM THE EC ACTINET AND TALISMAN PROJECTS PERFORMED AT KIT-INE *M. Altmaier, Th. Schäfer, J. Rothe, B. Schimmelpfennig, H. Geckeis (Germany)*	49
P3-18	CEBAMA – A EC HORIZON 2020 FUNDED COLLABORATIVE RESEARCH PROJECT ON CEMENT-BASED-MATERIALS *M. Altmaier, V. Montoya, L. Duro, A. Valls, E. Holt, F. Claret, U. Mäder, B. Grambow, A. Idiart (Germany)*	51
P3-19	FROM MICROSCOPIC PORE STRUCTURES TO TRANSPORT PROPERTIES IN SHALES: A WORKSHOP CO-ORGANIZED BY THE NEA-OECD CLAYCLUB *T. Schäfer, R. Dohrmann, C. Greenwell (Germany)*	52
P3-20	MODELLING OF INDIVIDUAL DOSIMETRY IN FACILITIES FOR HEAT-GENERATING WASTE: SPENT NUCLEAR FUEL EMPLACEMENT IN A ROCK SALT REPOSITORY *B. Pang, H. Saurí Suaréz, F. Becker, V. Metz, H. Geckeis (Germany)*	53
P3-21	PORE MORPHOLOGY, GRAIN MICROSTRUCTURE AND DEFORMATION MECHANISMS IN CLAYSTONES: RELEVANCE FOR PREDICTING THE LONG-TERM DEFORMATION AND TRANSPORT PROCESSES IN HOST ROCKS FOR HEAT-GENERATING NUCLEAR WASTE *J. L. Urai, J. M. Klaver, B. Laurich, G. Desbois, S. Hemes, J. Schmatz (Germany)*	54

P3-22 THEREDA – URANIUM RELEASE 55
M. Altmaier, F. Bok, V. Brendler, H. Moog, A. Richter, T. Thoenen, W. Voigt (Germany)

P3-23 MICROSTRUCTURE AND DEFORMATION OF OPALINUS CLAY FROM THE MAIN FAULT IN THE MONT TERRI ROCK LABORATORY (CH) – SOME SELECTED INSIGHTS FROM ELECTRON MICROSCOPY 56
B. Laurich, J. L. Urai, C. Vollmer, C. Nussbaum (Germany)

P3-24 THERMODYNAMIC MODEL FOR THE SOLUBILITY OF TETRAVALENT $TCO_2 \cdot XH_2O(AM)$ IN THE AQUEOUS TC^{4+}–NA^{+}–MG^{2+}–CA^{2+}–H^{+}–CL^{-}–OH^{-} SYSTEM 57
E. Yalcintas, A. Baumann, X. Gaona, M. Altmaier, H. Geckeis (Germany)

P3-25 ESTIMATION OF RADIONUCLIDE SOURCE TERMS FOR GENERIC NUCLEAR WASTE DISPOSAL OPTIONS WITHIN THE ENTRIA PROJECT 59
D. Fellhauer, V. Montoya, X. Gaona, J. Schepperle, V. Metz, M. Altmaier, Horst Geckeis (Germany)

P3-26 FLUID DYNAMIC PROCESSES WITHIN A CLOSED REPOSITORY WITH OR WITHOUT LONG-TERM MONITORING 60
K.-H. Lux, R. Wolters, J. Zhao, J. Feierabend, T. Pan, M. Rutenberg (Germany)

SESSION 7 SCIENTIFIC ASPECTS OF THE NUCLEAR WASTE DISPOSAL SAFETY CASE (TOPIC 3) – PART 2

Chairs: *C. Bruggemann (Belgium) and V. Bräuer (Germany)*

S7-01 FRENCH GEOLOGICAL DISPOSAL PROJECT: FROM SITING TO CIGÉO 61
*P. Landais (**Keynote**), G. Ouzounian (France)*

S7-02 THE RELEVANCE OF SOLID SOLUTION – AQUEOUS SOLUTION SYSTEMS TO THE SAFETY CASE FOR DEEP GEOLOGICAL DISPOSAL OF NUCLEAR WASTES 63
D. Bosbach, F. Brandt, M. Klinkenberg, V. Vinograd, G. Deissmann (Germany)

S7-03 APPLICATION OF THE TECHNOLOGY READINESS ASSESSMENT (TRA) PROCESS TO DEEP GEOLOGIC REPOSITORY SYSTEMS 64
S. D. Sevougian, R. J. MacKinnon (USA)

S7-04 CURRENT STATE OF KNOWLEDGE ON ZIRCALOY CLADDING PROPERTIES UNDER CONDITIONS OF PROLONGED DRY INTERIM STORAGE 66
V. Metz, M. Herm, E. González-Robles, H. Geckeis (Germany)

SESSION 8 SCIENTIFIC ASPECTS OF THE NUCLEAR WASTE DISPOSAL SAFETY CASE (TOPIC 3) – PART 3

Chairs: W. Steininger (Germany) and D. Bosbach (Germany)

S8-01	TOWARDS A JOINT PROGRAMME 'CO-FUND ACTION' OF EU MEMBER STATES' AND EURATOM RESEARCH PROGRAMS IN THE MANAGEMENT AND DISPOSAL OF RADIOACTIVE WASTE *C. Davies (**Keynote**) (EU)*	67
S8-02	THE SAFETY CASE FOR THE MORSLEBEN REPOSITORY – EVALUATION OF SUITABLE TIME FRAMES FOR POST-CLOSURE SAFETY ASSESSMENT *M. Ranft, J. Wollrath, M. Niemeyer (Germany)*	69
S8-03	SMART KD-CONCEPT FOR REALISTIC DESCRIPTION OF SORPTION PROCESSES *M. Stockmann, D. Becker, J. Flügge, J. Schikora, U. Noseck, V. Brendler (Germany)*	71
S8-04	HIGH-RESOLUTION CHARACTERIZATION OF THE EDZ IN THE CALLOVO-OXFORDIAN CLAY USING TIME LAPSE HYDRAULIC TOMOGRAPHY *T. Kämpfer, R. Brauchler, R. de La Vaissière, J. Croisé, R. Schwarz, R. Thöny, R. Mettier (Switzerland)*	73
S8-05	REDOX DEPENDENT INTERFACIAL REACTIVITY OF HEXAVALENT RADIONUCLIDES *S. Hellebrandt, K. E. Knope, S. S. Lee, A. J. Lussier, J. E. Stubbs, P. J. Eng, L. Soderholm, P. Fenter, M. Schmidt (Germany)*	74
S8-06	LONG-TERM DURABILITY OF LOW ALKALI CEMENTS: COMPARISON OF NOVEL NATURAL AND ARCHAEOLOGICAL ANALOGUE DATA *W. R. Alexander, H. M. Reijonen (Switzerland)*	75

SESSION 9 INTERNATIONAL EXPERIENCES IN DESIGNING AND IMPLEMENTING SITING PROCESSES – MASTERING SOCIAL AND TECHNICAL CHALLENGES (TOPIC 1) – PART 2

Chairs: L. Bailey (Switzerland) and P. Hocke (Germany)

S9-01	RESET OF UNITED STATES NUCLEAR WASTE MANAGEMENT STRATEGY AND POLICY *R. Ewing (**Keynote**) (USA)*	76
S9-02	PUBLIC PARTICIPATION AND SAFETY – CONSIDERING DIFFERENT NOTIONS OF RISK IN THE SAFETY ASSESSMENT OF POTENTIAL SITING AREAS? *A. Eckhardt (Switzerland)*	77
S9-03	EXPERIENCE OF GEOLOGICAL DISPOSAL SITE SELECTION IN THE UK *N. Ala, C. Tweed (UK)*	78

SESSION 10 DEVELOPMENT AND APPLICATION OF SCIENCE BASED SITE SELECTION CRITERIA (TOPIC 2) – PART 2

Chairs: *P. Zuidema (Switzerland) and J. Mönig (Germany)*

S10-01 THE SWISS SECTORAL PLAN FOR NUCLEAR WASTE DISPOSAL SITE SELECTION: STEP-WISE (GEO-)SCIENCE BASED DECISIONS 80
*C. Schlüchter (**Keynote**) (Switzerland)*

S10-02 ROLE OF PRELIMINARY SAFETY EVALUATION IN THE SITE SELECTION PROCESS 81
N. Schubarth-Engelschall (Germany)

S10-03 REVISED SITE SELECTION PROCESS FOR HIGH-LEVEL RADIOACTIVE WASTE DISPOSAL SITES IN JAPAN - SCIENTIFICALLY PREFERABLE AREAS - 83
H. Saegusa, H. Hyodo, A. Deguchi, H. Umeki (Japan)

S10-04 THE ROLE OF STRESS AND GEOMECHANICAL MODELLING BEFORE SITE SELECTION 84
A. Henk, O. Heidbach, B. Müller, K. Reiter, T. Hergert, F. Schilling (Germany)

The role of the OECD-NEA Integration Group for the Safety Case

S1-01

Lucy Bailey[1], Gloria Kwong[2]

[1] IGSC Chair and RWM, UK, lucy.bailey@nda.gov.uk
[2] OECD-NEA Secretariart, Paris, France, Gloria.Kwong@oecd.org

The OECD-NEA Integration Group for the Safety Case (IGSC) builds and documents the technical scientific basis for developing and reviewing safety cases as a platform for dialogue amongst technical experts and as a tool for decision making. The IGSC is the technical advisory body to the Radioactive Waste Management Committee, which addresses strategic and policy aspects of radioactive waste management. The IGSC comprises senior technical specialists and managers from national waste management programmes and regulatory bodies.

At its last annual meeting, the IGSC held a topical session on the role and use of geoscientific arguments within the siting process, with the objectives to:

- explore how members are planning or have used geoscientific arguments to identify suitable sites for geological disposal facilities;
- compile what geoscientific safety arguments have been used or are planned for use;
- explore how particular geoscientific safety arguments were received by stakeholders (both technical and non-technical) in countries where the siting process is advanced; and
- evaluate regulatory views / experience on using geoscientific safety arguments for siting.

Regulatory requirements on the use of geoscientific arguments in the siting process vary widely. For example, in Switzerland, the Sectoral Plan for Deep Geological Repositories is a clearly described site selection process strongly based on geoscientific arguments. However, in Sweden there is no specific emphasis on geoscientific arguments, rather a focus on the safety function of the whole disposal system. In the US the disposal system is required to have at least one natural and one engineered barrier, but there are no natural subsystem regulatory requirements. In the UK, national geological screening is being used as a precursor to provide geological information for a consent-based site selection process.

The topical session also discussed favourable attributes of a stable geological system and favourable hydrogeological properties of the host rock ; and the role of socioeconomic aspects in the siting process. It was recognised that there is a need to fulfil both geoscientific and societal criteria for a successful siting process.

Other ongoing activities of the IGSC and joint projects include:

- Development and maintenance of the OECD-NEA FEP database – used as a point of reference in many national safety cases;
- Maintenance of a state-of-the-art chemical thermodynamics database for key radionuclides;
- Clay Club – a forum for sharing and developing expertise regarding geological disposal facilities in argillaceous host rocks, including maintaining a Clay Club Catalogue;
- Salt club – a forum for disposal facilities in salt environments;
- Crystalline club – a newly formed group, building on the success of the Clay and Salt Clubs;
- Operational safety – an expert group dedicated to defining best practice in operating geological repositories;
- RepMet – the NEA Radioactive Waste Repository Metadata Management initiative aims at supporting national programmes

in managing their repository data, information and records; and

- Safety case communication – considering how best to communicate the technical complexities of a safety case to non-technical audiences.

The IGSC has just received an extension of its mandate to continue its important role until December 2020.

Designing a process for siting a deep-mined, geologic repository for high-level radioactive waste and spent nuclear fuel

S1-02

Daniel Metlay[1], Rodney Ewing[2]

[1] Senior Professional Staff, U.S. Nuclear Waste Technical Review Board, Washington DC, metlay@nwtrb.gov
[2] Chairman, U.S. Nuclear Waste Technical Review Board, Washington DC, ewing@nwtrb.gov

Efforts to site a deep-mined, geologic repository for high-level radioactive waste (HLW) and spent nuclear fuel (SNF) date from the early 1960s. Since that time, sites have been selected in Finland, France, Sweden, and the United States.[1] But most siting attempts have been unsuccessful.

This paper is based on a report prepared by the U.S. Nuclear Waste Technical Review Board, a technical overseer of the Department of Energy's radioactive waste management program (NWTRB 2015). The document examines two dozen efforts to site a deep-mined, geologic repository in ten countries over the last half-century.

The paper adopts the report's fourfold conceptual framework. First, repository siting involves the passage of potential locations through *both* a technical suitability and a social acceptability filter. These filters typically represent tests established in laws and regulations. The siting process is staged and iterative ; locations pass through the filters more than once. At the early stages, the filters tend to be applied informally and heuristically. At the later stages, the filters are more formal and legalistic.

Second, the two filters are not independent of each other. Judgments about technical suitability can be influenced by views on social acceptability and vice versa. For example, attitudes about nuclear power can affect evaluations of a potential site's technical suitability. By the same token, the persuasiveness of claims about technical suitability can influence the level of social acceptability. The natural analogue of elemental copper nodules found in ancient granite formations is an example of this interdependence.

Third, national site-suitability criteria can be grouped into three catagories. *Exclusion* criteria eliminate sites because they are too close to faults, volcanoes, or exploitable natural resources. *Host-rock specific* criteria are used when an *a priori* decision has been made that a repository will be located in a specific formation, such as salt, clay, or crystalline rock. *Generic* criteria provide the basis for evaluating the suitability of sites in different formations.

Fourth, developing a deep-mined, geologic repository produces two types of impacts on the community where it is located. *Standard effects* arise from changes, among other things, in taxes, employment, and traffic. *Special effects* arise because of perceptions of things nuclear. Examples include the stigmatization of agricultural products and tourist destinations. Implementers tend to look for sites in locations where there will be strong positive standard effects and weak negative special effects.

Based on this framework, the paper advances observations about how siting efforts play out and provides insights into increasing the likelihood that they will be successful.

Reference

Nuclear Waste Technical Review Board (2015): Designing a Process for Siting a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Detailed Analysis. Washington, DC.

[1] The world's first deep-mined, geologic repository (for transuranic waste) operates near Carlsbad, New Mexico. A site for an HLW and SNF repository was selected at Yucca Mountain in Nevada but its development remains in limbo.

Participatory Disposal Policy – An Evaluation of Regional Participation Procedures in the Search for Suitable Deep Geological Repositories for Radioactive Waste

S1-04

Claudia Alpiger[1]

[1] Institut für Politikwissenschaft, Universität Bern, Political Scientist MA, Fabrikstrasse 8, CH-3012 Bern, claudia.alpiger@ipw.unibe.ch, +41 31 631 32 86

Our "*Participatory Disposal Policy*" project best fits into the conference's theme no. 1 on "International experiences in designing and implementing siting processes – mastering social and technical challenges". In our project, we evaluate the regional participation structures (called "Regionale Partizipation") in the communities which are situated within the six potential siting regions for deep geological repositiores for radioactive waste in Switzerland. These participatory structures aim at including the wishes and concerns – e.g. in terms of written statements on the issues at hand – of regional politicians, the local interest groups, and the concerned citizens of the regions into the overall process.

The project's main goal is, first and foremost, to evaluate the process of public involvement in the site selection procedure using predefined evaluation criteria. The implemented criteria draw on the well-established 'criteria to evaluate participation processes' by Linder and Vatter (1996) and their revised version by Vatter (1998) which were established to analyse the construction of nuclear power plants and special waste incinerator plants in Switzerland by means of qualitative case studies. The revised version (Vatter 1998), including 14 criteria, were updated on the basis of insights from the new participatory literature, added more specialized sub-criteria, and were divided in 4 groups (process properties (1), participants (2), information/resources (3) and effects (4)) to give them a structure.

On the basis of the evaluation results, our second aim is to give the Swiss Federal Office of Energy (lead of the process) advices and recommendations on how to improve the participation procedures in the six regions.

For testing the the fulfillment of the updated 14 evaluation criteria (and the 55 sub-criteria), we draw on existing documents (protocols, annual reports,etc.) of the Swiss Federal Office of Energy and the participatory board. In addition, we carried out interviews with important stakeholders and leading persons, and, further, conducted a online survey with the participants of the "Regionale Partizipation".

We may conlude that most of the criteria are partially fulfilled, whereupon some were mostly or hardly fulfilled. There were almost no differences between the six analysed regions. Notably, the most striking deficiency of the process is the missing suitability for the choosen system, where non-professionals as well as laymen, participate and work voluntarily. Besides this, there are also other aspects to improve, in particular the low participation of women and young persons in these processes.

For the poster presentation on the DAEF-conference I (Claudia Alpiger) would like to present the implemented evaluation criteria to assess the public involvement in the site selection procedure for a deep geological disposal and show the main results of the current evaluation.

References

Linder, W. & Vatter, A. (1996): Kriterien zur Evaluation von Partizipationsverfahren. – In: Selle, K. (eds.): Planung und Kommunikation. Gestaltung von Planungsprozessen in Quartier, Stadt und Landschaft. Grundlagen, Methoden, Praxiserfahrungen. Bauverlag, 181-190, Wiesbaden/ Berlin.

Vatter, A. (1998): Politik. – In: Rehmann-Sutter, C., Vatter, A. & Seiler, H. (eds.): Partizipative Risikopolitik. Westdeutscher Verlag, 167-320, Opladen.

50 years of research and development for nuclear waste disposal at KIT S2-01

Bernhard Kienzler, Horst Geckeis

Karlsruhe Institute of Technology (KIT), Institut für Nukleare Entsorgung (INE), Hermann-von-Helmholtz Platz 1
76344 Eggenstein-Leopoldshafen, Germany, bernhard.kienzler@kit.edu

Research and development (R&D) activities in the field of nuclear waste management and disposal started at the Nuclear Research Center Karlsruhe (KfK now KIT) shortly after foundation and construction of the FR2 research reactor. R&D in this field related to estimates of radioactive waste types and volumes from different sources and their treatment. Final disposal issues including disposal options, long-term waste isolation from the biosphere, and regulatory requirements were investigated already in the early 1960s.

Since 1964 a working group was established at KfK discussing and developing adequate solutions for the waste problem. One important topic was dedicated to the safety of final disposal of nuclear wastes. In the beginning, engineering solutions with respect to the development of robust and economic technologies had highest priority. This strategy was strongly driven by the closed-nuclear-fuel-cycle concept implying spent fuel reprocessing. This concept was considered the preferred option at that time and was defined by law. The outcome of R&D was documented in reports (gray literature) or was occasionally presented at special conferences. Publications of results in peer-reviewed journals as it is usual today, were rare at this time. The retrospective reconstruction of research activities during those early days is exacerbated by the fact, that many results are just summarized in annual or project reports or in so-called "primary reports", which were/are not freely accessible or are not any more available.

Over time, societal, political and scientific views to the problem of nuclear waste disposal changed significantly. An attempt is made to classify R&D performed at KfK considering the respective temporal context with respect to the political and economic situation, and to elaborate its influence on specific decisions.

Nuclear waste management R&D activities at KfK evolved, starting with development of waste treatment and solidification processes, followed by focusing on radioactive waste disposal emplacement concepts for the Asse II salt mine in close cooperation with the Gesellschaft für Strahlen- und Umweltforschung (GSF). Later on, R&D was dominated by reqirements of the Project Reprocessing and Waste Management (PWA). Since about 1990, R&D on the safety of nuclear waste disposal at KfK was considered as provident research for the sustainable protection of man and nature against radioactive burdens induced by a repository for radioactive waste focusing on long term safety aspects.

During the 50 years of R&D, KIT-INE accumulated understanding, know-how and data for many disposal relevant aspects, which achieved world-wide recognition:

- steel canister corrosion,
- thermo-mechanics of rocksalt,
- radionuclide source terms,
- radionuclide solubility, complexation and effects of colloids,
- mobilization and retention of radio-nuclides in the multbarrier systems of different host rocks

The retrospective analysis of nuclear waste management research programmes clearly points to the close relationship of research priorities and changes in societal and political perceiption of nuclear energy and nuclear waste issues.

The presentation covers timetables, short overviews of KIT's involvement in national and international R&D and presents some scientific highlights.

Design of Drift Seals Complementing a CRZ of an HLW Repository in Crystalline Rock – Status of Investigation – (Topic 3)

S2-02

Nina Müller-Hoeppe[1,2], Michael Jobmann[1]

[1] DBE TECHNOLOGY GmbH, Eschenstraße 55, 31224 Peine, Germany
[2] email: muellerhoepp@dbe.de, phone: +49 (0) 5171 43 1529

In 2013, the German Federal Government started a new site selection process for a repository to dispose of all heat-generating radioactive waste, both existing and still being generated by German NPPs. The site selection procedure is based on the Site Selection Act (StandAG, 2013). The aim is to use a sound scientific and transparent basis to select the site that guarantees the highest possible level of safety for a time period of 1 million years.

Based on the "Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste as at 30 September 2010" (BMU 2010), a repository concept for the Gorleben site was developed in the past that also included a closure system. According to the safety requirements, the radioactive waste is to be safely confined in a so-called containment providing rock zone (CRZ), from which only insignificant release of radionuclides is tolerated. For certain repository designs, the integrity of the rock salt barrier was shown as well as the functionality of the closure system. The latter complements the CRZ with technical measures, because the rock salt barrier is impaired by the access routes into the repository. As a result, a CRZ was defined from which only insignificant radionuclide release below tolerated values may occur and only under conditions with a low probability (GRS 2013). Thus, according to current knowledge, the safety requirements can be met for sites showing salt structures comparable to the Gorleben site. As the best possible safety is required according to (StandAG 2013), the results of the premilinary safety analysis Gorleben represent a reference to rate alternative host rocks as the safe containment of radioactive waste is a realistic option at salt sites.

In several countries; e.g. Sweden, Finnland, Canada, and the Czech Republic, crystalline rock is to serve as host rock for heat-generating radioactive waste. Crystalline rock is generally fractured and therefore aquiferous cracks and clefts within the host rock are taken into account in the repository design. To meet the safety requirements of radiation protection (dose and risk constraint), the waste containers and the surrounding bentonite buffers constitute the main barriers. As a consequence, the design premises of drift and shaft seals in a crystalline host rock differ from those of sealing systems that are to complement a host rock to form a CRZ. First, the design premises for drift and shaft seals in crystalline rock are specified and then, an overview of practical experience on their performance from in-situ experiments is given.

In (DBETEC 2016), it was shown that in a hypothetical repository in granite in Germany the temperature limit of 100° C at the waste container surface can be met although MOX waste with very high heat generation has also to be taken into account. As undisturbed granite is very tight, it is currently discussed whether individual, local CRZs can be defined in crystalline rock that are joined to form the repository (Jobmann et al. 2016).

In the Finnish URL ONKALO, investigations showed that even in crystalline rock local, undistured dry areas exist. As in rock salt, the seals of man-made access routes are important components for defining a local CRZ in this case. As the seals in Sweden, Finland, Canada, and the Czech Republic are designed to limit radionuclide release and water intrusion to meet the radiation protection goals dose and risk constraint, it is currently being investigated if the seals can be modified in such a way that they are able to complement a local CRZ in crystalline rock. First results will be presented.

References

BMU (2010): Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste as at 30 September 2010, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Berlin, 2010

DBETEC (2016): Flächenbedarf für ein Endlager für wärmeentwickelnde hoch radioaktive Abfälle, Gutachten, TEC-09-216-G, DBE TECHNOLOGY GmbH, Peine.

Fischer-Appelt, K., Baltes, B., Buhmann, D., Larue, J. & Mönig, J. (2013): Vorläufige Sicherheitsanalyse für den Standort Gorleben, Bericht zum Arbeitspaket 13, Synthesebericht für die VSG, Gesellschaft für Anlagen und Reaktorsicherheit (GRS): Köln, 2013

Jobmann, M., Becker, D.A., Hammer, J., Krone, J., Lommerzheim, A., Müller-Hoeppe, N., Noseck, U., Weber, J.R., Weitkamp, A., Wolf, J. (2016): Machbarkeitsuntersuchung zur Entwicklung einer Sicherheits- und Nachweismethodik für ein Endlager für Wärme entwickelnde Abfälle in einer Kristallingesteinsformation in Deutschland, F&E-Projekt CHRISTA, Abschlussbericht, DBE TECHNOLOGY GmbH, BGR, GRS, Peine, Hannover, Braunschweig (in Vorbereitung).

StandAG (2013): Gesetz zur Suche und Auswahl eines Standortes für ein Endlager für Wärme entwickelnde radioaktive Abfälle, Standortauswahlgesetz vom 23. Juli 2013 (BGBl. I.S. 2553), das durch Artikel 309 der Verordnung vom 31. August 2015 (BGBl. I S. 1474) geändert worden ist.

Microphysical processes of grain boundary fluids in rock salt and their role in predicting the long-term deformation and transport processes in host rocks for heat-generating nuclear waste

S2-03

Janos L. Urai, Guillaume Desbois, Joyce Schmatz

Structural Geology, Tectonics and Geomechanics, RWTH Aachen University, Lochnerstrasse 4-20, D-52056 Aachen, Germany, j.urai@ged.rwth-aachen.de, www.ged.rwth-aachen.de

Reliable modeling of the deformation and fluid transport in rocksalt under the very low strain rates characterizing long term engineering conditions or tectonic deformation requires extrapolation of experimentally derived constitutive equa-tions to strain rates much lower than those attainable in the laboratory. This extrapolation must be based on an understanding of the microscale deformation mechanisms operating in the experimentally deformed samples, integrated with studies of natural laboratories where deformation took place under much lower strain rates. The engineering creep laws generally used in the salt mining industry are based on dislocation creep processes quantified in laboratory experiments of necessarily limited duration. However, a large body of evidence clearly demonstrates that grain boundary dissolution-precipitation proces-ses, such as solution-precipitation creep and dynamic recrystallization, commonly play a significant role in natural rock salt and rock salt backfill. In this contribution, we first briefly review the microphysics of grain boundary water related solution-precipitation processes in halite, together with the constitutive relations associated with these processes, and we discuss the contribution of these mechanisms to the strain rate during long-term creep.

In many current engineering studies the effects of water-activated grain boundary processes are neglected, and this omission leads to errors in prediction of displacement rates, especially over long term. Geomechanical modeling can be significantly improved by improving constitutive equations based on microphysical models for solution-precipitation creep, fluid-assisted re-crystallization and surface energy driven grain boundary healing on flow and transport properties. Recent development of methods to study microstructures in rock salt include (i) transmitted light microscopy of Gamma- decorated thin sections, (ii) subgrain size paleo-piezometry of polished and chemically etched samples using reflected light microscopy, (iii) micro-CT analysis of grain boundary fluid inclusions, (iv) analysis of grain boundary structure and microchemistry by cryogenic BIB-SEM and (v) X-ray or EBSD orientation imaging.

There is a growing understanding of on deformation mechanisms and constitutive behavior and fluid flow in naturally deforming rocksalt from a wide range of geological settings including data from inverting surface displacement measure-ments and thermodynamically controlled connectivity of grain boundary triple junction channels in rock salt at increasing pressure and temperature. Integrating this knowledge base provides an improved basis for making predictions of the evolution of host rocks for heat-generating nuclear waste less uncertain.

References

Závada, P., Desbois, G., Schwedt, A., Lexa, O. and Urai, J.L. (2012). Extreme ductile deformation of fine-grained salt by coupled solution-precipitation creep and microcracking: Microstructural evidence from Perennial Zechstein Sequence (Neuhof salt mine, Germany). Journal of Structural Geology 37: 89-104.

Li, S., Abe, S., Urai, J., Strozyk, F., Kukla, P. and Van Gent, H. (2012). A method to evaluate long-term rheology of Zechstein salt in the Tertiary. in: Berest et al., (eds): SaltMech7 - The mechanical behaviour of salt VII, Paris: p. 215-220.

210. Desbois, G., Urai, J.L. and de Bresser, J.H.P. (2012). Fluid distribution in grain boundaries of natural fine-grained rock salt deformed at low differential stress (Qom Kuh Salt Fountain, Central Iran): Implications for rheology and transport properties. Journal of Structural Geology 43: 128-143.

Geoscientific arguments in support of the safety case for a deep geologic repository in Southern Ontario, Canada – An example of regulatory research and assessment

S3-01

Thanh Son Nguyen[1], Julie Brown[1] , Zhenze Li[1] and Othman Nasir[2]

[1] Canadian Nuclear safety Commission, 280 Slater, Ottawa, Ontario, Canada K1P 5S9, son.nguyen@canada.ca
[2] Geofirma Engineering Ltd., 1 Raymond, Ottawa, Ontario, Canada K1R1A2

Currently in Canada, both sedimentary rocks of the Michigan Basin and crystalline rocks of the Canadian Shield are being considered as potential host rock types for the deep geological disposal of radioactive wastes. The Canadian Nuclear Safety Commission (CNSC), the Canadian regulator, has carried out independent research to identify and assess key issues related to the safety of geological disposal in both types of rock. This paper summarizes our research findings to date, focussing on our understanding of the Michigan Basin sedimentary rocks and their ability to ensure the surface environment, including the Great Lakes, would be protected.

The Michigan basin is an intracratonic basin characterized by carbonate - dominant sedimentary sequences that were deposited onto the Precambrian Shield over several episodes between ~500 – 300 million years ago. The last major tectonic event to have affected the basin occurred during the culmination of Appalachian mountain building, ~250 million years ago. During the last million years, the region experienced nine glacial (glaciation-deglaciation) cycles, one cycle occuring roughly every 120,000 years. The last glacial cycle began ~120,000 years ago; at glacial maximum, the maximum ice thickness reached ~4km, imposing pressures of up to 4 MPa on the lithosphere, depressing the crust by up to 500m, and also gouging and carving out deep valleys. The Great Lakes began to form ~14,000 years ago at the end of the last glacial period when glacial meltwater filled depressions left behind by glaciers. Multiple lines of evidence show that porewaters in the Ordovician host rocks at the site of a proposed deep geological repository (DGR) for low and intermediate level wastes have remained isolated from the surface waters for hundreds of millions of years:

- The porewater in the Ordovician rocks is a brine, with salinity of up to 300 g/l. Those same porewaters have been shown to be ancient. Both characteristics suggest that porewaters have remained stagnant for hundreds of millions of years.
- Ordovician formations, including the proposed Cobourg limestone host rock and several overlying layers of shale, have remained mechanically unaffected by glaciation, and few fractures have been detected during site investigations to date.
- The Ordovician rocks are under-pressured relative to hydrostatic conditions. This underpressure was likely due to the depressurization after glacial retreat, and subsists to the present time because of very low rock permeability.

A mathematical model that couples mechanical, hydraulic, and chemical processes was developed to simulate glacial cycles that occurred over the last million years. The model was able to confirm that Ordovician porewaters have remained unconnected to surface waters and shallow groundwaters. The model was then used to assess the movement of a tracer released from the proposed DGR during the next 120,000 years, under the combined effects of DGR excavation, gas generation, and a future glacial cycle. The model showed that a tracer would remain confined in the host rock, isolated and unconnected to surface waters such as the Great Lakes.

Retrievability in connection with the requirements for a final repository for heat-generating, high-level radioactive waste and spent fuel S3-02

Philipp Herold[1, 2], Sabine Dörr[1]

[1] DBE TECHNOLOGY GmbH, Eschenstraße 55, 31224 Peine, Germany
[2] email: philipp.herold@dbe.de, phone: +49 (0) 5171 43 1613

The German disposal strategy dealing with heat-generating, high-level waste and spent fuel has been in the public debate. This discusssion is often reduced to the necessity of reversing decisions and the requirement of retrievability. Retrievability is one partial aspect of reversibility and represents an additional tool within the general disposal strategy.

The pros and cons of retrievability include a wide range of social and ethical, economic, safety and technical aspects. In recent years, the general opinion has established that retrievability should be implemented. This corresponds to the work of the "Commission on the storage of highly radioactive materials", according to §3 StandAG, which designates the final disposal with retrieval option as the preferred disposal strategy in Germany (Kom, 2016).

In addition to this, the "Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste" (BMU, 2010) determine the safety level for such a repository. Here, retrievability is stipulated as a licensing requirement. The safety requirements correspond to an administrative regulation that subtantiates the German Atomic Energy Act. All measures to "... prevent damage resulting from the construction and operation of the system ..." (§ 7 II Nr. 3 AtG), including the planned technical measures to ensure retrievability must evidently comply with the state of science and technology.

The development of technical retrieval concepts is affected by additional design requirements: "Measures taken to secure the options of recovering or retrieval must not impair the passive safety barriers and thus the long-term safety" and the number of mine openings and the influence on the host rock have to be minimized. Furthermore, it is determined that the "... number of open emplacement zones should be kept to a minimum" and "should be promptly loaded, then backfilled and reliably sealed from the mine building" (BMU, 2010).

All German repository concepts include the parallel realization of the three major operational processes emplacement, backfilling, and closure. This ensures that the waste packages are quickly transferred to the passive safety system of the repository. This strategy is in accordance with the safety requirements.

The retrieval of waste packages corresponds to an extraction from the passive safety system and returning them back into human care. Suitable technical solutions for the implementation of retrievabiliy into underground operations have to cover all three main processes. From the underlying requirements for retrievability a "Re-Mining" strategy can be described as a suitable approach for the technical implementation. This strategy includes emplacement as designed. To ease retrieval, conceptual and technical adjustments can be made. It is also possible to make adjustments to ensure favorable conditions during the retrieval period. Finally, the requirement of retreivability will affect the repositoy design and underground oeprations significantly. Retreivability creates a design-determinating factor, which influences the full repository system including further operations on the surface.

Within this contribution, retrievability is explained as defined and laid down in current German legislation. In addition, general strategies for technical implementation grown out of this understanding are illustrated and the effects on underground operations, surface operations and all facilities are pointed out.

References

AtG, 2015: Atomic Energy Act published on 15 July 1985 (BGBl. I S. 1565), last change by Article 1 of the Law of 20 November 2015 (BGBl. I S.2053)

BMU, 2010: Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste as at 30 September 2010, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Berlin, 2010

Kom, 2016: Final report Commission storage of highly radioactive waste materials, Draft Version from 31th March 2016, K-Drs. 202

Retrievability and surveillance of radioactive waste as host rock selection criteria

S3-03

Thomas J. Schröder[1], Jaap Hart[1], and Arjen D. Poley[1]

[1] Nuclear Research and consultancy Group (NRG), P.O. Box 25, 1755 ZG Petten, The Netherlands, schroder@nrg.eu

The selection of a host rock and disposal concept for deep geological disposal of radioactive waste is a challenging task in radioactive waste management. Such decisions should be based on multiple selection criteria, reflecting safety related, geotechnical, societal, socio-economic, and cost aspects. Retrievability of waste is an important requirement in the Netherlands, and we argue that the level of retrievability and surveillance that can be realized in the different host rocks provides a meaningful selection criterion for a future decision on host rock and disposal design.

Reasons for national programmes to include retrievability in their waste management strategy can be summarized as (1) an attitude of humility or open-mindedness towards the future; (2) provision of additional assurance of safety; and (3) to heed desires of the public not to be locked into an "irreversible" situation (NEA 2011). Despite the general requirement on retrievability that is prescribed in the Netherlands since 1993, there is insufficient agreement on the scope of retrievability: although there is a common understanding that the principal concept of retrievability answers to general concerns and inherent uncertainties, different views exist on how to weigh benefits, costs and risks of retrievability in the pre- and post-closure phase. Retrievability and surveillance of waste are also important aspects in argumentation lines on principal choices for radioactive waste disposal (Rip et al. 1995), and the various views on retrievability reflect societal views and concerns on radioactive waste disposal in general.

As part of the Dutch radioactive waste disposal research programme *OPERA*, a more concrete approach was proposed in order to come to a closer definition and societal agreement on the scope of retrievability. The general objectives for retrievability were decomposed, and a working definition of the term was defined.

One important observation was a strong interrelation between retrievability and monitoring, resulting in the definition of the overarching concept of "surveillance" as the ability to observe and to react on potential deviating evolutions in a disposal facility. As discussed in the EU-FP7 project MoDeRn (NDA et al. 2013), *in-situ* monitoring in the pre- and post-closure phase is technically challenging. The feasibility to provide sufficient robust evidence for a far-reaching decision as the retrieval of waste by monitoring is uncertain, and it is expected that the host rocks considered in the Netherlands, i.e. rock salt and Boom Clay, clearly differ with respect to their "monitorability". Retrievability and the ability to maintain surveillance are therefore suitable candidate criteria for the selection of host rock and disposal concept, if based on a robust definition of the general concept and terminology.

References

Nuclear Energy Agency (NEA; 2011): Reversibility and Retrievability (R&R) for the Deep Disposal of High-Level Radioactive Waste and Spent Fuel. Final Report of the NEA R&R Project (2007-2011). NEA report NEA/RWM/R(2011)4, Paris.

NDA, Nagra, & NRG (eds.; 2013): MoDeRn Monitoring Reference Framework report. MoDeRn Deliverable D1.2.

Rip, A., W.A. Smit, B.J.R. van der Meulen (1995): Radioactive Waste Disposal: Taking Societal Views Into Account, In: Nuclear Energy Agency (NEA), Environmental and ethical aspects of long-lived radioactive waste disposal. Proceedings of an International Workshop, Paris, 1-2 September 1994, NEA/OECD, Paris, 1995, p.184-201.

Participatory Disposal Policy – An Evaluation of Regional Participation Procedures in the Search for Suitable Deep Geological Repositories for Radioactive Waste

P1-01

Claudia Alpiger[1]

[1] Institut für Politikwissenschaft, Universität Bern, Political Scientist MA, Fabrikstrasse 8, CH-3012 Bern, claudia.alpiger@ipw.unibe.ch, +41 31 631 32 86

Our "*Participatory Disposal Policy*" project best fits into the conference's theme no. 1 on "International experiences in designing and implementing siting processes – mastering social and technical challenges". In our project, we evaluate the regional participation structures (called "Regionale Partizipation") in the communities which are situated within the six potential siting regions for deep geological repositiores for radioactive waste in Switzerland. These participatory structures aim at including the wishes and concerns – e.g. in terms of written statements on the issues at hand – of regional politicians, the local interest groups, and the concerned citizens of the regions into the overall process.

The project's main goal is, first and foremost, to evaluate the process of public involvement in the site selection procedure using predefined evaluation criteria. The implemented criteria draw on the well-established 'criteria to evaluate participation processes' by Linder and Vatter (1996) and their revised version by Vatter (1998) which were established to analyse the construction of nuclear power plants and special waste incinerator plants in Switzerland by means of qualitative case studies. The revised version (Vatter 1998), including 14 criteria, were updated on the basis of insights from the new participatory literature, added more specialized sub-criteria, and were divided in 4 groups (process properties (1), participants (2), information/ resources (3) and effects (4)) to give them a structure.

On the basis of the evaluation results, our second aim is to give the Swiss Federal Office of Energy (lead of the process) advices and recommendations on how to improve the participation procedures in the six regions.

For testing the the fulfillment of the updated 14 evaluation criteria (and the 55 sub-criteria), we draw on existing documents (protocols, annual reports,etc.) of the Swiss Federal Office of Energy and the participatory board. In addition, we carried out interviews with important stakeholders and leading persons, and, further, conducted a online survey with the participants of the "Regionale Partizipation".

We may conlude that most of the criteria are partially fulfilled, whereupon some were mostly or hardly fulfilled. There were almost no differences between the six analysed regions. Notably, the most striking deficiency of the process is the missing suitability for the choosen system, where non-professionals as well as laymen, participate and work voluntarily. Besides this, there are also other aspects to improve, in particular the low participation of women and young persons in these processes.

For the poster presentation on the DAEF-conference I (Claudia Alpiger) would like to present the implemented evaluation criteria to assess the public involvement in the site selection procedure for a deep geological disposal and show the main results of the current evaluation.

References

Linder, W. & Vatter, A. (1996): Kriterien zur Evaluation von Partizipationsverfahren. – In: Selle, K. (eds.): Planung und Kommunikation. Gestaltung von Planungsprozessen in Quartier, Stadt und Landschaft. Grundlagen, Methoden, Praxiserfahrungen. Bauverlag, 181-190, Wiesbaden/ Berlin.

Vatter, A. (1998): Politik. – In: Rehmann-Sutter, C., Vatter, A. & Seiler, H. (eds.): Partizipative Risikopolitik. Westdeutscher Verlag, 167-320, Opladen.

Are criteria for site selection applicable for disposal of high-radioactive waste in deep boreholes? P2-01

Guido Bracke[1], Frank Schilling[2]

[1] GRS gGmbH, Schwertnergasse 1, 50667 Cologne, guido.bracke@grs.de
[2] Karlsruher Institut für Technologie (KIT), Institut für Angewandte Geowissenschaften, Adenauerring 20b, 76131 Karlsruhe, Germany, frank.schilling@kit.de

Disposal of radioactive waste in deep boreholes has been discussed in several workshops as a possible alternative to disposal in an underground mine (Bracke et al. 2015), (Nuclear Waste Technical Review Board (NWTRB) 2016). A recent expertise (Bracke et al. 2016) to the "commission storage of high radioactive waste" propsed a concept and recommended further research and development on disposal in deep boreholes in order to generate a feasible technical alternative and to reconsider the requirement of a recovery for 500 years.

The discussion on the criteria for the site selection procedure is not finished. Therefore we will present a review of their applicability on generic site(s) for disposal in deep boreholes in a more general manner.

1. In a first approximation, the drafted criteria (of the "commission storage of high radioactive waste") for the **exclusion of regions / sites** can be directly adopted, since these criteria are independent of the concept and technical means for geological disposal. However, storage in deep boreholes would allow to store the waste (comparable to storage options in mines) in much deeper formations.
2. Also the drafted **minimum requirements** can be adopted easily for sites considered for deep borehole disposal at a first glance.
3. The drafted **criteria and requirements for consideration of sites** have to be evaluated in detail for their adaptability. Most of these requirements could be adopted to sites for deep borehole disposal and are considered to be assessed positively in site specific cases.

The rating of the weighing requirement "Good compatibility for gases" with the indicator "Low gas generation" is strongly dependent on the concept, since a steel casing in addition to the containers and a fluid is used in current generic concept for bore hole disposal. At least as a hazard – corrosion of casing - has to be taken into account and will lead to the generation of gas. Therefore, a trap for gases is considered in the proposed generic concept.

An overview on the possible adaptability of the final criteria of the site selection procedure will given based on a generic concept deep borehole disposal.

References

Bracke, Guido; Charlier, Frank; Geckeis, Horst; Harms, Ulrich; Heidbach, Oliver; Kienzler, Bernhard et al. (2016): Tiefe Bohrlöcher. Hg. v. Kommission Lagerung hoch radioaktiver Abfallstoffe gemäß § 3 Standortauswahlgesetz. GRS gGmbH. Köln (K-MAT 52). Online verfügbar unter http://www.bundestag.de/blob/413166/73c4148a71bb98611305958662204e23/kmat_52-data.pdf, zuletzt geprüft am 15.03.2016.

Bracke, Guido; Schilling, Frank; Müller, Birgit; Hurst, Stephanie; Merkel, Broder (Hg.) (2015): Proceedings of the Workshop "Final Disposal in Deep Boreholes Using Multiple Geological Barriers: Digging Deeper for safety". Berlin, June 2015. Köln: GRS gGmbH (GRS-405).

Nuclear Waste Technical Review Board (NWTRB) (2016): Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program. A Report to the U.S. Congress and the Secretary of Energy. Hg. v. Nuclear Waste Technical Review Board (NWTRB). Arlington, Virginia, zuletzt geprüft am 08.02.2016.

Seismicity and Probabilistic Seismic Hazard Assessments of Germany P2-02

Gottfried Grünthal, Dietrich Stromeyer, Christian Bosse, Fabrice Cotton

Helmholtz Zentrum Potsdam, Deutsches GeoForschungsZentrum GFZ Potsdam, Telegrafenberg, 14473 Potsdam, gruenthal@gfz-potsdam.de

The level of seismicity is in general relatively low in Germany, but there are certain regions with elevated seismic hazard, such as the Rhine Graben and parts of the Swabian Jura, where the largest instrumentally recorded earthquake occurred in 1911 with a moment magnitude M_w 5.8. However, also events with $M_w > 6$ can be expected when longer return periods are considered. Although the probability of such events is small, the impact could be dramatic on critical infrastructures. The Probabilistic Seismic Hazard Assessment (PSHA) is the most resilient method to calculate where and which ground shakings might occur in future at which hazard level. These outcomes are directly used as seismic load parameters at given sites for seismic building codes or other antiseismic design provisions (Grünthal et al., 2013). The resulting seismic hazard curves from a PSHA are also the key input for the Probabilistic Safety Assessments (PSA) which are required for nuclear facilities.

For Germany, the still valid building-code related seismic zoning was provided already by Grünthal and Bosse (1996) and is described by Grünthal (2005) on occasion of the implementation of the new version of the DIN 4149 as construction law. The assignment of all German settlements to one of the three seismic zones of the DIN 4149 and the classification to the corresponding geological underground can be searched using the GFZ online service (http://gfz-potsdam.de/DIN4149). Also, seismic load parameters for the DIN 19700 in form of uniform hazard spectra are available for four hazard levels for any coordinate pair (http://gfz-potsdam.de/DIN19700. Still challenging is the comprehensive involvement of all uncertainties in models and parameters into a PSHA (Stromeyer and Grünthal, 2015; Cotton et al., 2006). This provides a rational framework for facilitating uncertainties in a transparent way and is, in particular, important in areas of low seismicity.

A consequent implementation of this requirement has been accomplished for the new national seismic hazard assessment on behalf of the Deutsches Institut für Bautechnik (DIBt) and launched by the respective national committee on standardization (DIN). We present the results of this work which is a key information in the site selection process of a nuclear waste disposal site in Germany. However, further research and data are needed to improve our assessments for very low probabilities; e.g. in form of high-quality neotectonic data to better characterize seismic sources.

The expertise to perform seismic hazard analyses according to international standards is nationally available. New methods are developed to ensure an improved, standardized and robust treatment of the epistemic uncertainty emerging from hazard, alternative models implementation, and exploration of the tails of distributions, taking into account the diverse range of views and opinions of experts. The results of PSHA and PSA should also be linked to a physics-based assessment of the criticality of the crustal stress state. The latter is an additional measure and key parameter in the geological selection of sites of nuclear waste disposal (cf. abstracts from Heidbach et al., Henk et al. for this conference).

References

Cotton, F., Scherbaum, F., Bommer, J. J., Bungum, H. (2006): Criteria for selecting and adjusting ground-motion models for specific target regions: Application to Central Europe and rock sites. - Journal of Seismology, 10, 2, p. 137-156.

Grünthal G., Bosse C. (1996): Probabilistische Karte der Erdbebengefährdung der Bundesrepublik Deutschland - Erdbebenzonierungskarte für das Nationale Anwendungsdokument zum Eurocode 8. Scientific Technical Report STR 96/10, GFZ Potsdam, 24 pp.

Grünthal, G. (2005): Die Erdbebenzonenkarte als Bestandteil der neuen DIN 4149. In: Tagungsband der DGEB/DIN-Gemeinschaftstagung, Auslegung von Bauwerken gegen Erdbeben - die neue DIN 4149, Beuth Verlag, Berlin, 3-24.

Grünthal, G., Stromeyer, D., Heidbach, O. (2013): Probabilistische seismische Gefährdungsabschätzungen. In: System Erde, 3/1, p. 54-61.

Stromeyer, D., Grünthal, G. (2015): Capturing the Uncertainty of Seismic Activity Rates in Probabilistic Seismic-Hazard Assessments. – Bulletin of the Seismological Society of America, 105, 2A, p. 580-589.

SpannEnD – providing stress data and geomechanical modelling tools for the site selection process in Germany

P2-03

Oliver Heidbach[1], Andreas Henk[2], Birgit Müller[3], Karsten Reiter[2], Tobias Hergert[2], Frank Schilling[3]

[1] Deutsches GeoForschungsZentrum GFZ, Sektion 2.6 Erdbebengefährdung und Spannungsfeld, Telegrafenberg, 14473 Potsdam, Germany, heidbach@gfz-potsdam.de

[2] Institut für Angewandte Geowissenschaften TU Darmstadt, Schnittspahnstraße 9, 64287 Darmstadt, Germany,

[3] Karlsruhe Institut für Technologie, Institut für Angewandte Geowissenschaften, Adenauerring 20b, 76131 Karlsruhe, Germany

SpannEnd stands as an acronym for «Geomechanisch-numerische Modellierungen zur Charakterisierung des tektonischen **Span****n**ungszustandes für die **En**tsorgung radioaktiver Abfälle in **D**eutschland». It is an initiative of various German research institutions with the aim to set-up of a comprehensive data base for the crustal state in Germany and the further development of 3D geomechanical-numerical modelling tools for robust stress predictions in areas where no stress data exist. Thus, SpannEnd provides fundamental information and basic techniques generally required for the site selection process of a geological disposal site for radioactive waste.

At present, only the orientation of the tectonic stress field in Germany, i.e., the orientation of the maximum horizontal stress S_{Hmax} has been compiled in a systematic manner and ranked according to an international quality ranking scheme (Reiter et al., 2015). These data are derived, among others, from well bore data (e.g. borehole breakouts, hydraulic fractures), earthquake analysis as well as geological information and overcoring data. However, only 277 of the 757 data records compiled for Germany have an acceptable quality (Reiter et al., 2015). For the stress magnitude data, which is the essential information to assess the criticality of the stress field, such as database does not exist for Germany. Furthermore, given the sparse and incomplete knowledge of the stress field geomechanical-numerical models have to predict the full stress tensor at arbitrary points in the subsurface.

To provide a stress prognosis for a potential disposal site, i.e., prior to drilling or excavation, a toolbox of 3D geomechanical-numerical models has to be developed. We propose that this model should be Germany-wide with dimensions of $1200 \times 900 \times 80$ km³ to capture the geometry and mechanical properties of the main lithological units that control the overall pattern of the crustal stress field. This model has to be calibrated using a stress magnitude stress data base. Such a model allows for a physics-based interpolation between individual stress measurements and stress prognosis at points not covered by stress observations, respectively. Furthermore, the Germany-wide model, that simulates the large-scale variations of the stress field, would also deliver reliable initial- and boundary conditions for regional and local scale 3D geomechanical-numerical models. Both, the set-up of the stress magnitude data base as well as development of the modelling tools has to be started now in order to provide the necessary fundamental information on the local tectonic stress field once the site-selection process will be started in Germany.

Besides the recently published new stress map of Germany (Reiter et al., 2015) we present an example of a new 3D geom.-num. model concept applied in southern Germany that shows a fast and automated calibration process as well as the derivation of boundary conditions from regional models for local site models. The aforementioned initiative SpannEnd proposes to extend this concept for Germany, to set up a fundamental stress magnitude database and to integrate the expert knowledge of the stress field modelling in Germany in order to provide geomechanical measures needed in the course of the selection process.

References

Reiter, K., Heidbach, O., Reinecker, J., Müller, B. & Röckel, T. (2015). Spannungskarte Deutschland 2015. Erdöl Erdgas Kohle, 11, 437-442.

Ziegler, M., Heidbach, O., Reinecker, J., Przybycin, A., Scheck-Wenderoth, M. (2016): 3D stress field simulation for Greater Munich, Germany. Geophys. Res. Abstr., Vol. 18, EGU2016-3872, EGU Gen. Ass. 2016, Vienna, 18.-22. April 2016.

DETERMINATION OF GEOLOGICAL CRITERIA AND IMPLEMENTATION OF SAFETY INVESTIGATION DURING THE SITE SELECTION PROCESS

P2-04

Eva Krapf[1]

[1] TU Clausthal, Insitute of Disposal Research, Adolph-Roemer-Str. 2a, 38678 Clausthal-Zellerfeld, Germany, eva.krapf@tu-clausthal.de

For the selection of a site for exploration from above ground the German Site Selection Act (StandAG) claims according to §§ 13, 14 the definition of geoscientific exclusion criteria and geological minimum requirements. The decision on relevant criteria and minimum requirements should be made by the Commission Storage of Highly Radioactive Waste (§ 4). Furthermore a representative preliminary safety investigation for the considered sites has to be made. The main target is the determination of possible sites and further the decision about sites for the exploration from above ground.

The exploration from above ground now provides concrete data and gives better insight especially into the overlaying geology, hydrology, shape and structure of the host rock. Therewith the fulfillment of a part of the defined criteria and minimum requirements can be verified. According to § 16 an advanced preliminary safety investigation has to be made. The difference in comparison with the safety investigations of the first step of the siting process is also the gain of concrete information. Now, there is a possibility to further develop the safety investigation or to decide which safety aspect can be verified or what kind of further certainty can be achieved.

Aspects of a Ph.D.-study which is related to the special requirements, criteria and safety investigations during the site selection process will be presented here. The focus is laid on domal salt as host rock. The following method is recommended:

Starting point are those regions which stay in the process after implementation of exclusion criteria and minimum requirements. The Safety Assessment Gorleben (VSG) is taken as a basis for the considerations presented here, in particular with regard to the safety concept for disposal in domal salt.

At first all issues which can have an influence on safety functions of the disposal system are defined. Differentiations can be made whether an impact on the Confining Rock Zone and/or on the far field takes place and how this impact can be characterised. Moreover it has to be clarified how safety aspects are affected and if there is an increase or decrease of impact due to combination of the safety relevant issues. As a consequence all relevant criteria at a certain point of the process and their relevance for the later consideration in the process can be identified.

At this point of the process the capability of ensured statements and possible uncertainties has to be determined. Moreover the method of safety investigations and also the points of the process at which a safety statement can generally be made have to be clarified.

As an expample, the geothermal gradient is considered: It is a safety relevant aspect and should be known as early as possible. With the known regional heat flux density and the measured thermal conductivity of the overlaying lithology the temperature gradient can be calculated without drilling into the host rock. With this method the temperature gradient for every possible site can be determined at an early stage of the selection process.

References

StandAG (2013): Gesetz zur Suche und Auswahl eines Standortes für ein Endlager für Wärme entwickelnde radioaktive Abfälle (Standortauswahlgesetz – StandAG); Berlin

R&D needs for implementing the challenges of the German Repository Site Selection Act (StandAG) P2-05

Silke Kwiaton[1], Nicole Schubarth-Engelschall [1]

[1] Federal Office for Radiation Protection, Willy-Brandt-Straße 5, 38226 Salzgitter, skwiaton@bfs.de, nschubarth-engelschall@bfs.de

The Repository Site Selection Act (StandAG) states the tasks of the implementer. One of the most outstanding challenges is to identify suitable regions and sites for a repository for high-level radioactive waste.

Thus the Commission on disposal of high radioactive waste (Endlagerkommission) was established. During the commissions work in the last 2 years important questions of principle for the site selection process were reviewed and assessedommission. In its final report the Commission describes in detail the implementers tasksin different steps. It ist clear that from the beginning of the site selection process the implementer has to work out and provide all scientific-technical needs to narrow sites down.

To achieve this aim the implementer has to follow the three main phases of the site selection process, including e.g. the application of geoscientific exclusion criteria, minimum requirements and weighing criteria. The first phase of the site selection process is carried out in three subsequent steps and aims at identifying regions for surface site investigation. A preliminary safety evaluation is applied first in the third step of the first phase. Each phase concludes with an safety evaluation.

Clear R&D needs for the site selection process considering different possible host rocks (bedded salt, salt domes, clay and crystalline) have to be identified prior to and in course of site selection process. This in particular is the immediate task of the implementer as he is responsible for providing scientific and technical expertise also based on R&D findings to give reasons for his proposals on suitable regions and sites according to the state-of-the-art. Previous experience has shown, that it isn`t possible alone on a generic basis. The main aspect for the implementer in defining RD&D needs is to provide tools for efficient

exploration,

evaluation, and

comparison.

This regards methods for implementation and evaluation of safety analysis as well as data collection and evaluation of exploration data.

To frame his R&D needs open questions relating to e. g. application of "isolating rock zone" concept and or vs. canister concepts, retrievability and recoverability as well as weighting factor for comparison criteria need to be answered.

Generally all work related to R&D has to be set as early as possible. So the results can be considered in the ongoing process of the site selection.

Considering the aims of the site selection procedure a realignment of the german exploration focus is necesary. Increased R&D investigation is identified in the field of clay/claystone and crystalline. In foreign countries existing knowledge of this host rocks can be used.

Exemplarily, some main subjects are given which are seen as essential for the process:

- development of host rock specific safety and verification concept
- development of repository concepts for radioactive waste for all discussed host rocks (salt, clay, crystalline)
- development of (host rock specific) canister concepts to meet the demands on retrievability and recoverability
- implementation of safety-case idea in a site selection process

- development of methods for characterisation of sites and rocks, esp. non-invasive methods
- development of methods for data acquisition and evaluation
- development of methods for comparison of regions and sites on the basis of field data and safety evaluation
- development of a method handling uncertainties at characterization of geosphere
- advancement of young academics and methods for knowledge transfer and reciept
- socio-scientific aspects for a succesful public involvement

Some results of these R&D topics are required at an early stage or even prior to of the site selection process. Therefore, a systematic research approach is necessary.

As safety is set as the main standard to evaluate the suitabiliy of regions and sites, at the beginning a documentation concept according to the safety case idea and to fulfil the safety standards needs to be developed. Furthermore, a concept for handling unvertainties is needed.

In the next steps, more host rock specific topics have to be addressed. First, a specific safety and verification concept for long-term safety for each host rock has to be developed. Based on these concepts, in a second step the development of host rock specific repository concepts and a canister concepts is necessary. Finally, the reliability and verfication concept has to be developed in the third step. The results of these R&D topics are an important basis for identifying suitable regions for above ground exploration and therefore have to be completed at the end of the first phase of the process.

The long term of the site selection process and the ongoing development of the state-of-the-art of science and technology require also a continous advance in development of concepts and methods. Demonstration projects become relevant in a later stage of the process when more site specific findings and decisions (repository concept, canister concept, safety concept) are relevant.

Furthermore, R&D linked to the site selection process needs an effective and constructive frame. For example, questions deal with documentation system, handling uncertanties (e.g. quality and quantity of field data) and the implementation of a self checking system. All institutions involved in the site selction process need to communicate and coordinate their research needs to confine their resposibilities and to gain benefit.

To increase the quality and efficient use of research results a comprehensive coordination and regulation of R&D acitvities in Germany is necessary. Implementer and regulater have to define practice research according to there tasks and research areas in coordination with each other. The aim is to coordinate R&D needs easier and faster in the future.

References

BMU (2010): Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste. 30 September 2010. - Berlin.

Endlagerkommission (2016): Abschlussbericht der Kommission Lagerung hochradioaktiver Abfallstoffe – Vorabfassung. K-Drs. 268. 4. Juli 2016.

StandAG (2013): Gesetz zur Suche und Auswahl eines Standortes für ein Endlager für Wärme entwickelnde radioaktive Abfälle und zur Änderung anderer Gesetze (Standortauswahlgesetz – StandAG) vom 23. Juli 2013. – Bundesgesetzblatt Jahrgang 2013 Teil I Nr. 41, ausgegeben zu Bonn am 26. Juli 2013.

Methods for the Development of Geotechnical and Rockmechanical Basic Principles for Site Selection in Clay as Host Rock

P2-06

Dieter Wittenberg[1], Jürgen te Kook[1], Axel Studeny[1], Daniela Gutberlet[1]

[1] DMT GmbH & Co. KG, Am Technologiepark 1, 45307Essen, Germany, daniela.gutberlet@dmt-group.com

Group 2 of the geoscientific consideration criteria of the Permanent Disposal Site Commission, describes in its final report the criteria for the final disposal site selection that enables to evaluate to which extent rock mass can sustain its containment capacity against stresses caused by the construction and operation of subsurface cavities meant to be used for a final repository. The aim is to develop a ranking of suitability of various sites for final disposal, for their comparison thereafter. This evaluation will be based on the knowledge of the fracturing and deformation behaviour of the observed rock formation. The fracturing and deformation behaviour results from a complex interaction of rock mass characteristics, depth (stress condition), mine design, size and form, and applied support system of the underground mine openings to be constructed. Since the geoscientific suitability evaluations of different sites accrue at an early stage of the decision making process, the necessary fundamentals, experience values, and evaluation possibilites must be compiled in this knowledge area as early as possible.

In Germany it is assumed that usingsalt and clay stone host rock formations, as a natural barrier (effective containment zone, ECZ) is a key component for the long-term safety of a repository. In order to maintain integrity of the geological barriers an effective protection of the ECZ is necessary. The result is, that not only structuraly stable and deformation-free underground mine openings for a repository must be developed_ but also rock mass decompaction as well as crack formation around the workings must be prevented.

Experiences in the field of permanent waste disposal site in clay rock formations are only available for depth of a maximum of 500 m. Many of the clay stone deposits in Germany planned to be investigated exceed this value. However, for producing mines, extensive knowledge for claystones is available for depths up to 1500 m.

In order to transfer the existing experience to potential sites for permanent waste disposal, empirical and analytical methods can be applied. Additionally, there are techniques of physical and numerical modelling that have been calibrated for the deformations in challenging boundary conditions. The interaction between rock mass characteristics, stress conditions, and the applied support systems can be determined at every stage of the analysis by the means of parameter variation. This is of great importance, since a variety of support systems that are usually installed in mining operations such as steel and mortar material containing cement cannot be used. Thus, extensive knowledge of alternative solutions is required.

The decision-making tools, such as for example an assessment matrix, characterizing the fracture and deformation behaviour of claystones in combination with installed support systems in potential permanent waste disposal sites can be delivered as the result of further research acitivities. Based on this it can be identified which permanent waste disposal sites are suitable to meet two main criteria of secure operations and long-term stability and which ones should be excluded from consideration.

References

Kommission Lagerung hoch radioaktiver Abfallstoffe (2016): Abschlussbericht, K-Drs 268, Berlin.

Eu(III) reactive transport modelling: Application of the «smart K_d - approach»

P3-01

S. Britz[1], U. Noseck[1], W. Durner[2], S. Iden[2], D. Zachmann[2], V. Brendler[3], M. Stockmann[3], J. Lützenkirchen[4]

[1] Gesellschaft für Anlagen- und Reaktorsicherheit GRS gGmbH, Theodor-Heuss-Str. 4, 38122 Braunschweig, Germany, susan.britz@grs.de, phone: +49 531 8012 292
[2] Technische Universität Braunschweig, Institut für Goökologie, Braunschweig, Germany
[3] Helmholtz-Zentrum Dresden-Rossendorf, IRE, Dresden, Germany
[4] Karlsruhe Institute of Technology, INE, Eggenstein-Leopoldshafen, Germany

Spatially and temporally constant sorption coefficients (K_d-values) are currently applied in long-term safety analysis for radioactive waste repositories. However, temporally and spatially variable geochemical conditions occurring in natural systems may lead to significant changes in sorption processes of e.g. radionuclides (RN). To account for geochemical variability constant K_d-values are replaced by so-called "smart K_d-values" which consider the impact of selected geochemical parameters on sorption behavior such as e.g. pH, pCO_2, ionic strength, complexing and competing ions.

The smart K_d-concept describes complex geochemical and mineralogical systems through detailed geochemical characterization of major components (component additivity approach): Complex sediments are separated into sorption-relevant components to describe sorption processes as a sum of element- and mineral-specific surface reactions through surface complexation parameters (SCP).

SCP are applied to calculate sediment- and element-specific smart K_d-values as a function of varying geochemical parameters and are stored in multidimensional smart K_d-matrixes (Fig. 1). The state-of-the-art performance assessment code d^3f++ [1, 2] combines hydrogeological information with geochemical information provided in multidimensional smart K_d-matrixes to simulate transport and density driven flow of RN through the geosphere over long time periods.

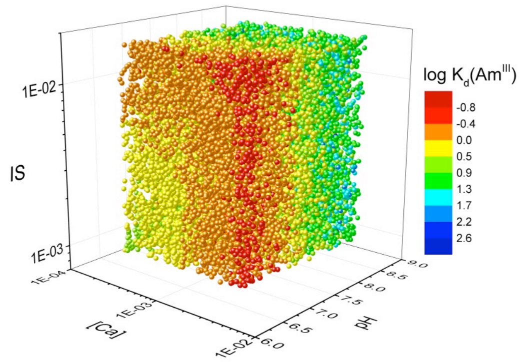


Fig. 1: Multidimensional smart K_d-matrix of Am(III) sorption as a function of pH, [Ca], and ionic strength [IS] (K_d in $m^3\ kg^{-1}$, log-scale).

This contribution aims to illustrate the verification of the developed smart K_d-approach. To verify the developed concept, experiments were conducted in single-mineral systems and complex sediments to investigate Eu(III) migration under varying geochemical conditions. Quartz, mica, feldspar as ubiquitously sediment minerals of Northern Germany were investigated. Eu(III) serves as a homologue for long-term safety relevant trivalent actinides such as Cm(III) and Am(III).

SCP of Eu(III) SCP were derived from batch and titration data simulation with PHREEQC [3]. Application of these Eu(III) SCP to simulate Eu(III) migration under varying geochemical conditions through a natural quartz sediment will be presented. A comparison of Eu(III) transport through quartz, muscovite and a natural sediment will be provided.

Reactive transport was modeled using the geochemical speciation code PHREEQC [3]. CXTFIT [4] was applied to assess initial estimates of effective transport parameters. Analysis provides a first validation of the smart K_d-concept.

References

[1] Schneider, A. (ed.) (2016): Modeling of data uncertainties on hybrid Computers – In: GRS 392, Braunschweig, Germany, in preparation.

[2] Noseck, U. et al. (2012): Realistic Integration of Sorption Processes in Transport Codes for Long-Term Safety Assessments – In: GRS 297, Braunschweig, Germany.

[3] Parkhurst, D. L. and Appelo, C. A. J. (2013): Description of input and examples for PhreeqC version 3-A computer program for speciation, batch-titration, one-dimensional transport, and inverse geochemical calculations – In: U.S. Geological Survey Techniques and Methods, Book 6, chap. A43, Denver, USA.

[4] Toride, N., Leij, F. J, van Genuchten, M. Th. (1999): The CXTFIT Code for Estimating Transport Parameters from Laboratory or Field Tracer Experiments – In: Research Report No: 137, U.S. Salinity Laboratory, U.S. Department of Agriculture, Riverside, USA.

Mining of Antei uranium deposit (Russia): experience for safety assessment of RW disposal in crystalline rocks

P3-02

Vladislav Petrov[1], Valery Poluektov[1], Joerg Hammer[2]

[1] IGEM Russian Academy of Sciences, Staromonetny per. 35, 119017 Moscow, Russia, vlad@igem.ru
[2] BGR, Geozentrum Hannover, Stilleweg 2, D-30655 Hannover, Germany, joerg.hammer@bgr.de

The experimental data from underground research laboratories (URLs) located in granitic massifs of Sweden (Äspö), Canada (Whiteshell), Switzerland (Grimsel), Finland (ONKALO), and Japan (Mizunami) is important for safety assessment, design and construction of disposal facilities in crystalline rocks, e.g. in Russia within the Nizhnekanskiy granitoid massif in Krasnoyarsk region.

Additionally to URL experience (tracer, geomechanical, filtration, heating tests, etc.) data from uranium deposits are helpful for estimating transport mechanisms of radionuclides (actinides) in fractured-porous environment at different stressed-strained states, depths and redox conditions of host rocks. Under specific conditions uranium deposits are natural analogues of features, events and processes, which as expected will occur within the bounds of HLW and SNF (containing 95% of UO2) disposal facilities located in deep seated geological structures. Uranium deposits as El Berrocal, Spain (Pérez del Villar et al. 2003), Palmottu, Finland (Suksi et al. 2002), Sanerliu, China (Min et al. 1998), and Kamaishi, Japan (Yoshida et al. 2000) are such natural analogues in granitic massifs.

However URLs, uranium deposits and disposal facilities are often situated in different geotectonic, hydrogeological, redox, etc. conditions that leads to uncertainties and inconsistencies for performance and safety assessment. It is possible to remove some of these ambiguities if generic URL is organized at an uranium deposit where ore bodies are located at depth of RW disposal facility levels.

During last decade the intensity of studies of uranium deposits as natural analogues is significantly reduced. More over, in the frame of some current concepts and plans for radioactive waste disposal the data gained on uranium deposits is frequently not mentioned.

The Antei vein-stockwork uranium deposit in the southeastern Transbaikalian region combines features of an URL and natural analogue. The deposit is located in Palaeozoic granite at depth from 400 m to 1000 m where pitchblende ore bodies are opened by highly branched workings. The distribution of uranium ores is controlled by intersecting polystadial fault zones. In combination with the big vertical extent of exposures this gives very good opportunities for studies of uranium mobilization and transport as well as of mining conditions in deep and fractured granites.

The main aim of this contribution is to present new geological data and to outline directions of further R&D programme of the URL and exploration of further RW disposal facility in Krasnoyarsk region of Russia.

This study was supported by the Russian Academy of Sciences Programme No. I.15P.

References

Min, M.Z., Zhai, J.P., Fang, C.Q. (1998): U-series radionuclide and element migration around the Sanerliu granite-hosted U deposit in southern China as a natural analogue for HLW repositories. Chem. Geol. No 144. P. 313-328.

Pérez del Villar, L., Reyes, E., Delgado, A. et al. (2003): Argillization processes at the El Berrocal analogue granitic system (Spain): mineralogy, isotopic study and implications for the performance assessment of RW geological disposal. Chem. Geol. No 193. P. 273-293.

Suksi, J., Rasilainen, K., Ruskeeniemi, T. et al. (2002): Natural U occurrences as a paleohydrogeological indicator: observations from the Palmottu natural analogue site, Finland. Uranium Mining and Hydrogeology. Freiberg, Germany. P. 227-236.

Yoshida, H., Aoki, K., Semba, T. et al. (2000): Overview of the stability and barrier functions of the granitic geosphere at the Kamaishi Mine: relevance to radioactive waste disposal in Japan. J. Engineer. Geol. No 56. P. 151–162.

Evaluation of current knowlegde for building the Dutch safety case for a disposal concept in rock salt

P3-03

Jaap Hart[1], Jan Prij[1], Thomas J. Schröder[1], Geert-Jan Vis[2], Dirk-Alexander Becker[3], Jens Wolf[3], Ullrich Noseck[3], Dieter Buhmann[3]

[1] Nuclear Research and consultancy Group (NRG), P.O. Box 25, 1755 ZG Petten, The Netherlands, schroder@nrg.eu

[2] Netherlands Organization for applied scientific research (TNO), Princetonlaan 6, 3584 CB Utrecht, The Netherlands, geert-jan.vis@tno.nl

[3] Gesellschaft für Anlagen und Reaktorensicherheit mbH (GRS), Schwertnergasse 1, 50667 Cologne, Germany, Dirk-Alexander.Becker@grs.de

The Dutch five-year research programme for the geological disposal of radioactive waste, OPERA (Dutch acronym for Research Programme into Geological Disposal of Radioactive Waste), started in June 2011. OPERA aims to develop first preliminary Safety Cases for disposal concepts in an argillaceous host rock, the Boom Clay, and in rock salt. The OPERA Safety Cases are generic, i.e. not site-specific, and conditional since only the long-term safety of a generic repository will be assessed.

The poster provides an overview of the performed evaluation for building the Safety Case of the final disposal of radioactive waste in rock salt in the Netherlands. The evaluation was performed within the OPERA project OSSC, "OPERA Salt Safety Case", by a consortium consisting of GRS from Germany, and TNO and NRG from the Netherlands (Hart et al., 2015). Basis of the evaluation is the abundant available Dutch and international scientific and technical information, especially from the German and US programmes, about the final disposal in rock salt.

The evaluations have shown that in order to build a Dutch Safety Case for the final disposal of radioactive waste in rock salt, several Safety Case elements need to be developed or integrated within the current Dutch context. For example, the characteristics of the Dutch radioactive waste intended for disposal has changed since the last Dutch research programme ("CORA") has ended in 2000 (Hart, 2014). This implies that the previously considered Dutch facility concepts for disposal in rock salt have not yet been adapted to the newly regarded waste types such as spent fuel from research reactors and depleted uranium. Introducing these aspects into the next iteration of the salt Safety Case would also require an update of the post-closure safety assessment.

The OSSC project resulted in an updated mapping of salt deposits in the Netherlands, and recommendations for future development of the Dutch Salt Safety Case by reconsidering and revising the Safety Case aspects treated in the project. A roadmap was provided on how to build a first salt Safety Case in three consecutive steps within a period of 4 to 5 years. The recommendations comprise all aspects of a modern Safety Case and are intended to serve as a basis for a subsequent iteration of the Salt Safety Case for the disposal of radioactive waste in the Netherlands.

References

Hart, J. (2014) Report on the determination of the inventory, OPERA-PU-NRG1112A, Petten, 21 February 2014.

Hart, J. (2015), Prij, J., Schröder, T.J., Vis, G.-J., Becker, D.A., Wolf, J., Noseck, U., Buhmann, D., Evaluation of current knowledge for building the Safety Case for salt based repositories, OPERA-PU-NRG221A, 15 July 2015.

Extension of the WIPP Performance Assessment using Modern 3D Modeling Tools

P3-04

Todd R. Zeitler[1]

[1] Sandia National Laboratories, Carlsbad, NM 88220, USA, tzeitle@sandia.gov

The Waste Isolation Pilot Plant (WIPP) has been developed by the U.S. Department of Energy (DOE) for the geologic (deep underground) disposal of transuranic (TRU) waste. Containment of TRU waste at the WIPP is regulated by the U.S. Environmental Protection Agency (EPA). The DOE demonstrates compliance with the EPA containment requirements by means of performance assessment (PA) calculations. WIPP PA calculations estimate the probability and consequence of potential radionuclide releases from the repository for a regulatory period of 10,000 years after facility closure.

The WIPP has received and emplaced TRU waste since 1999 in rooms mined out of a bedded salt formation 2,150 feet below the surface. The geomechanical and hydrogeological behavior of salt are key components of the repository's ability to safely sequester waste from the accessible environment. Salt properties such as creep and extremely low permeability make salt a natural barrier (Hansen and Leigh 2011). While the WIPP does not have a formal safety case, considerations of radionuclide releases to the surface and groundwater via various features, events, and processes (FEPs) are implicit to the PA approach (van Luik, et al. 2013). The PA methodology is key to a postclosure safety assessment and focuses on the quantitative evaluation of safety through the repository performance (MacKinnon, et al. 2012).

To date, WIPP PA calculations have relied on symmetry to enable the use of two-dimensional computational grids to describe the three-dimensional repository. Using these 2-D grids makes fluid and gas flow calculations highly efficient and the resulting system has an acceptable spatial resolution for compliance calculations. However, advances in computational power have sparked the creation of efficient 3-D subsurface flow codes that can take advantage of parallel computing platforms.

PFLOTRAN is an open-source, state-of-the-art massively parallel subsurface flow and reactive transport code. A version of this code is being developed specifically for WIPP PA in order to maintain the capabilities of the current flow and transport codes, as well as being expanded to include new capabilities such as miscible multi-phase flow and heat transfer. The use of the PFLOTRAN code represents a major change to PA software capabilities and is one that will allow simplification of the PA code structure, greater spatial resolution in the computational grids, as well as flexibility in possible repository reconfiguration. The result of the modernization effort will be a state-of-the-art subsurface flow and transport capability that will serve WIPP PA into the future.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. This research is funded by WIPP programs administered by the Office of Environmental Management (EM) of the U.S Department of Energy.

References

Hansen, F. D. & Leigh, C.D. (2011): Salt Disposal of Heat-Generating Nuclear Waste. SAND2011-0161. Albuquerque, NM, USA: SNL.

MacKinnon, R. J., et al. (2012): Towards a Defensible Safety Case for Deep Geologic Disposal of DOE HLW and DOE SNF in Bedded Salt. SAND2012-6032. Albuquerque, NM, USA: SNL.

van Luik, A., et al. (2013): Continuous Improvement and the Safety Case for the WIPP Geologic Repository. Proceedings of the 2013 Waste Management Symposia: Phoenix, AZ, USA.

The Effect of Stagnant Water Zones on Retarding Radionuclide Transport in Fractured Rocks: An Extension to the Channel Network Model

P3-05

Pirouz Shahkarami[1], Longcheng Liu, Luis Moreno, and Ivars Neretnieks

[1] Department of Chemical Engineering and Technology, KTH Royal Institute of Technology, S-100 44 Stockholm, Sweden, pirouzs@kth.se

An essential task of performance assessment of radioactive waste repositories is to predict radionuclide release into the environment. For such a quantitative assessment, the Channel Network Model and the corresponding computer program, CHAN3D, have been used to simulate radionuclide transport in crystalline bedrocks. Recent studies suggest, however, that the model may tend to underestimate the rock retarding capability, because it ignores the presence of stagnant water zones, STWZs, situated in the fracture plane. Once considered, the STWZ can provide additional surface area over which radionuclides diffuse into the rock matrix and thereby contribute to their retardation.

The main objective of this comminication is to extend the Channel Network Model and its computer implementation to account for diffusion into STWZs and their adjacent rock matrices.

The overall impact of STWZs in retarding radionuclide transport is primarily investigated through a deterministic calculation of far-field releases at Forsmark, Sweden. Over the time-scale of the repository safety assessments, radionuclide breakthrough curves are calculated for increasing STWZ width. It is shown that the presence of STWZs enhances the retardation of most long-lived radionuclides except for ^{36}Cl and ^{129}I.

The rest of the study is devoted to the probabilistic calculation of radionuclide transport in fractured rocks. The model that is developed for transport through a single channel is embedded into a network of channels and new computer codes are provided for the CHAN3D. The program is used to I) simulate the tracer test experiment performed at Äspö HRL, STT-1 and II) investigate the short- and long-term effect of diffusion into STWZs. The required data for the model are obtained from detailed hydraulic tests in boreholes intersecting the rock mass where the tracer tests were made.

The simulation results fairly well predict the release of the sorbing tracer ^{137}Cs. It is found that over the short time-scale of the tracer experiment, the effect of diffusion into STWZs is not as pronounced as that of matrix diffusion directly from the flow channel, and the latter remains the main retarding mechanism. Predictions for longer time-scale, tens of years and more, show that the effect of STWZs becomes strong and tends to increase with transport time. It is shown that over the long times of interest for safety assessment of radioactive waste repositories, STWZs can substantially contribute to radionuclide retardation, though for the short time-scales the impact is not very strong and is not expected to affect the results of short-term field experiments.

References

Shahkarami, P., Liu, L., Moreno, L., Neretnieks, I., 2015. Radionuclide migration through fractured rock for arbitrary-length decay chain: Analytical solution and global sensitivity analysis. Journal of Hydrology, 520, 448-460.

Liu, L., Moreno, L., Neretnieks, I., Gylling, B., 2010. A safety assessment approach using coupled NEAR3D and CHAN3D - Forsmark. SKB Rep. R-10-69, Swedish Nuclear Fuel and Waste Management Company, Stockholm, Sweden.

Gylling, B., Moreno, L., Neretnieks, I., 1999. The channel network model-A tool for transport simulation in fractured media. Ground Water 37, 367–375.

Efficient Management of Safety Assessment Calculations – Electronic Input Data and Results Application (EDR)

P3-06

Thomas U. Kaempfer[1], Gerhard Mayer[1], Andreas Poller[2]

[1] AF-Consult Switzerland Ltd, Taefernstrasse 26, 5405 Baden, Switzerland, thomas.kaempfer@afconsult.com
[2] National Cooperative for the Disposal of Radioactive Waste (Nagra), Wettingen, Switzerland

Quantitative analyses based on deterministic or probabilistic model calculations are one fundamental building block for assessing the post-closure safety of deep geological repository systems (NEA, 2013). Results may also be incorporated into site selection processes as e.g., in Stage 2 of the Swiss Sectoral Plan for Deep Geological Repositories (Nagra, 2014) or as discussed more generically in the VerSi project (AF-Consult, 2010).

Generally, deterministic and even more so probabilistic modeling approaches for safety analyses are bound to lead to a large number of numerical simulations to be managed. In order to satisfy the requirements on traceability and transparency of safety assessments (e.g., IAEA, 2012), it is thus critical to keep track along any simulation chain from the original input to its final output and to ensure the consistency between generic conceptual models, their mathematical and numerical implementation, the model input data, the simulation results, the post-processed results, and the reporting.

The electronic input data and results application (EDR) is a specifically designed web-based application used to browse through the input data and results of safety assessment calculations. The application runs in a web browser and may be supplied online or on a data carrier for offline use. It features interactive charts, which may be exported as high resolution graphics for insertion into technical reports.

By providing easy access to calculation cases, input data, input files and post-processed results, it satisfies the above-mentioned requirements on traceability and transparency. It has become a valuable tool in the context of the Swiss Sectoral Plan for Deep Geological Repositories (Nagra, 2014), where it serves multiple stakeholders:

- Modelers performing quality assurance of calculations,
- the implementer when compiling the post-closure safety assessment, and
- regulatory authorities when evaluating the implementer's safety assessment calculations.

The EDR facilitates tremendously the systematic comparison of calculation results and has thus proven particularly useful for gaining a thorough systems understanding and for consistency checks. In order to cope with evolving data in the course of a safety assessment project, updating of the EDR is automated as much as possible, thus guaranteeing consistency from input data to output graphics and reporting at all stages. Even though the link from data release to input files must be assured manually, the simple features for input file comparison and input data access are improving the associated quality assurance.

Experience with the EDR in Switzerland demonstrates its strength as a common communication base among mutliple stakeholders.

References

AF-Consult & GRS (2010): WS2044 – VerSi – Methode für den quantitativen Vergleich von Endlagersystemen, AF 1313/27, GRS A-3545, Bundesamt für Strahlenschutz; Deutschland.

IAEA (2012): The safety case and safety assessment for the disposal of radioactive waste: specific safety guide, IAEA safety standards series, ISBN 978–92–0–128310–8; Vienna, Austria.

Nagra (2014): Provisional Safety Analyses for SGT Stage 2, Models, Codes and General Modelling Approach, Technical Report NTB 14-09; Wettingen, Schweiz.

NEA (2013): The Nature and Purpose of the Post-closure Safety Cases for Geological Repositories, NEA/RWM/R(2013)1; OECD.

Impact of Earthquakes on Geotechnical Barriers

P3-07

Christian Müller[1], Victoria Burlaka[1], Philipp Herold[1], Natalie Neubert[1]

[1] DBE TECHNOLOGY GmbH, Eschenstraße 55, 31224 Peine, Germany, muellerch@dbe.de

In order to prevent that fluids get in contact with radioactive waste emplaced in an underground repository, the integrity of the geotechnical barriers under different safety-relevant scenarios needs to be demonstrated. One possible safety-relevant scenario is the impact of an earthquake on the geotechnical barrier.

Earthquakes are tectonic movements caused by fracture formations in the earth's crust. The sudden energy release of the fracturing processes generates transient, elastic waves that propagate and can cause massive tremors. According to current designs, gravel is to be implemented in several sections of the shaft sealing elements to act as porous reservoirs. At the same time, the gravel column can act as abutment for bentonite sealing elements installed on top of it. Sealing elements made of bentonite are not installed cohesively with the rock contour and, thus, need an abutment to ensure their effectiveness. The tremors of an earthquake can further compact the gravel, which leads to a settling of the material, which in turn can compromise its effectiveness as an abutment. For a proper functioning of the bentonite sealing element it is, thus, necessary to limit the settling of the underlying gravel column to appropriately small dimensions.

The settling of granular material can be calculated analytically using the silo theory, and the additional settling due to the impact of an earthquake can be determined to some extent. However, an analytical assessment has several disadvantages. The objective is to determine to what extent the settling of a gravel column due to an earthquake can be estimated by means of computer codes. This would allow the verification of existing estimates and the evaluation of the suitability of new technical concepts.

The particle-based code PFC^{2D} was used for calculation. PFC^{2D} is able both to simulate granular media and to solve the equations of motion of individual particles by taking the dynamics into account.

First, representative particle samples were generated consisting of gravel particles of different sizes and shapes. Photo-optical analysis was preformed to derive important input parameters for model generation, and the so-called clumps were used to simulate the sizes and shapes of the gravel particles. Then, calibration work was performed to simulate the friction and displacement behavior of the gravel particles realistically.

To validate the model, the gravitational settling behavior and the silo effect of a 45-meters-high gravel column was calculated and compared with the analytical solution. It was shown that the processes that are responsible for the silo effect are simulated realistically. The characteristic stress gradient across the height of the column is comparable with analytical results based on Janssen's equation (1895).

Finally, dynamic simulations were carried out using a realistic seismic load on the gravel column generated. With increasing distance from the base toward the top of the gravel column, wave amplitudes are weakened continuously due to displacement and damping processes. Particle movements within the gravel column decrease significantly and the system approaches a static state after dynamic excitation. In the upper area, particle movements occur due to settling arising from particle movements in the underlying parts. Overall, a settling of about 16 cm can be measured 30 s after dynamic excitation.

References

Janssen (1895): Versuche über Getreidedruck in Silozellen. – In: Zeitschr. d. Vereins deutscher Ingenieure, 39(35):1045-1049.

The Role of Calcite in Nuclear Waste Disposal Sites

P3-08

Sophia E. Hellebrandt[1], Sascha Hofmann[1], Norbert Jordan[1], Moritz Schmidt[1]

[1] Helmholtz-Zentrum Dresden-Rossendorf, IRE, Bautzer Landstr. 400, 01328 Dresden, Germany, sophia.hellebrandt@hzdr.de, sascha.hofmann@hzdr.de, n.jordan@hzdr.de, moritz.schmidt@hzdr.de

In the safety assessment of nuclear waste disposal sites we have a look on different geochemical processes in the near and far field of a conceivable disposal site. These processes include sorption and incorporation as possible mechanisms of radionuclide retention in a worst case scenario of an ingress of groundwater. Various minerals in the host rocks as well as primary and secondary phases in the geotechnical barrier were investigated under these conditions elsewhere. Calcite ($CaCO_3$) can be found in every section of the containment and has a couple of features, which makes it interesting for further investigations. A high retention potential because of high sorption capacity as well as the possibility to incorporate guest ions into the crystal lattice at the Ca-ion position is distinctive for calcite [Schmidt 2008, Marques Fernandes 2008]. The long-lived radionuclides (e.g. Pu, Am) determine the long-term radiotoxicity, which defines the considered timespan of the safety analysis. The trivalent radionuclides have an affinity to calcite because of their chemical properties (ionic charge and radius).

To investigate this affinity we conducted different experiments – coprecipitation and batch studies over various periods of time. We can show, that the incorporation of radionuclides and their homologues is dependent on several parameters: i.e. the grain size and specific surface area of calcite, amount and composition of impurities in the calcite and in the background solution. To investigate the structural incorporation we used site-selective timeresolved laser-induced fluorescence spectroscopy with Europium, which serves as a homologue for the trivalent radionuclides because of its great spectroscopic usability [Binnemans 2015] and its similar chemical behavoir. With this method we can distiguish between sorption of the Europium ion onto the calcite surface and incorporation into the crystal bulk by figuring out the amount of water molecules in the first coordination shell of the Europium ion – if there is no water left, incorporation took place. Furthermore we perform X-ray surface diffraction with two high resolution methods, crystal truncation rod and resonant anomalous X-ray-reflectivity. Our experiments were run *in situ*, which means we have a thin solution film above the crystall. We can demonstrate the influence of different background electolytes (sodium nitrate and sodium iodate) on calcite, which cause a significant surface destabilisation and hence a modification or prevention of sorption and incorporation mechanism. These results are important to examine sorption and structural incorporation on calcite as a process of radionuclide retention in the near and far field of nuclear waste disposal sites.

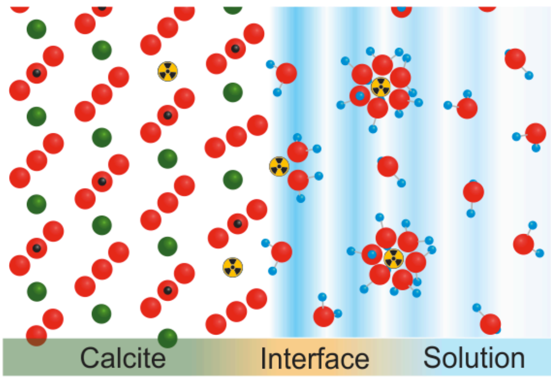


Fig. 1: Schematic diagram of radionuclides adsorbed or incorporated onto/into calcite

References

Binnemans, K. (2015): Interpretation of europium(III) spectra. Coord. Chem. Rev., 295, 1-45.

Schmidt, M. et al. (2008): Charge Compensation in Solid Solutions. Angew. Chem., Int. Ed., 47, 5846-5850

Marques Fernandes, M. et al. (2008): Incorporation of trivalent actinides into calcite: A time resolved laser fluorescence spectroscopy (TRLFS) study. Geochim. Cosmochim. Acta, 72, 464-474.

Sealing Behaviour of Claystone-Bentonite-Mixture

P3-09

Chun-Liang Zhang[1] and Klaus-Peter Kröhn[1]

[1] Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Theodor-Heuss-Strasse 4, 38122 Braunschweig, Germany, chun-liang.zhang@grs.de and klaus-peter.kroehn@grs.de

As a potentially superior material for sealing radioactive waste repositories in clay formations, a mixture of excavated claystone and bentonite was investigated.

Experimental results

The Callovo-Oxfordian claystone excavated from the Bure-URL was mixed with the expansive bentonite MX80 in different ratios. These claystone-bentonite mixtures were comprehensively characterized with respect to sealing properties such as compacted density, water uptake and retention capacity, swelling potential, hydraulic conductivity, and gas migration after full water saturation. The mixtures with a low bentonite content of 20% and 40%, respectively, were compared with pure bentonite and a bentonite-sand mixture with a high bentonite content of 70%. The main results are summarized in the following table.

Properties of the studied sealing materials

Compacted seal mixtures	claystone-bentonite (80/20)	claystone-bentonite (60/40)	bentonite-sand (70/30)	bentonite (MX80)
Dry density (g/cm³)	1.90	1.90	1.80	1.56
Water permeability (m²)	$1 \cdot 10^{-19}$	$6 \cdot 10^{-20}$	$2 \cdot 10^{-20}$	$5 \cdot 10^{-21}$
Swelling pressure (MPa)	2.5	3.5	6.0	7.5
Gas breakthrough pressure (MPa)	1.2	2.5	6.0	>7.5
Assembled seals	claystone-bentonite (60/40)		bentonite-sand (70/30)	
Dry density (g/cm3)	1.88		1.80	
Water permeability (m2)	$1 \cdot 10^{-19}$		$1 \cdot 10^{-20}$	
Swelling pressure (MPa)	2.0		2.0	
Gas breakthrough pressure (MPa)	3.1 - 4.0		8.2 - 9.0	

The test results indicate a favourable sealing behaviour of the claystone-bentonite mixture. While this mixture is comparable with the other materials in terms of compacted density, water permeability, and swelling pressure, it shows a particularly low gas breakthrough pressure after full water saturation. In contrast, the gas breakthrough pressures of the compacted bentonite and the bentonite-sand mixture were found to be quite high, either at the swelling or confining pressures or even above. This implies that gases produced by anoxic corrosion of waste containers and other metallic components within the repositories cannot pass the bentonite-based seals until the pressure exceeds the high gas breakthrough threshold. The major concern about high gas pressures compromising the integrity of the geological-engineered barrier system can thus be disregarded utilising claystone-bentonite mixtures for sealing.

Modelling results

Based on the experimental results, adequate constitutive models and parameters were derived for the sealing materials if necessary. Their hydro-mechanical behaviour observed in the experiments was modelled using the computer code CODE_BRIGHT. The resulting material models and parameters were then used for a preliminary prediction of the long-term performance of a drift seal.

The model predictions concerned a drift seal of 40 m length and a diameter of 9.5 m at a depth of 500 m. The EDZ surrounding the seal was characterized by relatively high permeabilities decreasing in three steps from $5 \cdot 10^{-18}$ m^2 to $1 \cdot 10^{-19}$ m^2 with distance from the drift wall up to a depth of 3 m (Fig. 1). The intact rock had a permeability of $1 \cdot 10^{-20}$ m^2. Equivalent separate models were used to study the sealing behaviour of the claystone-bentonite mixture, pure bentonite and bentonite-sand mixture.

The following operational phases related to a drift seal in a repository were regarded in the models:

1. Excavation and support of the drift within 6 months
2. Operational phase of the drift over 100 years
3. Removal of the support lining within a month
4. Installation of the seal and long-term interaction with the EDZ and the rock.

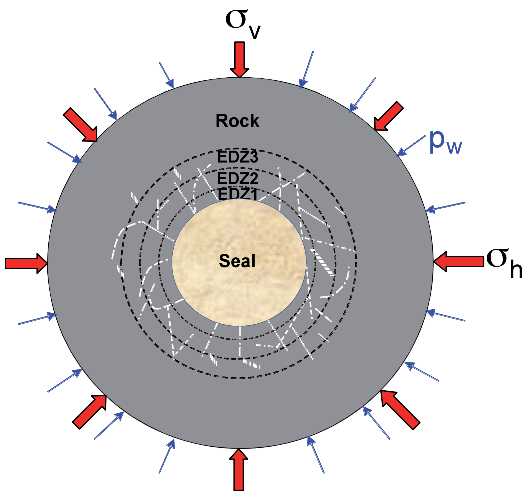


Fig. 1 2D-Model of a drift seal in clay rock

The most important process is the water uptake of the seal, with which the sealing functions develop. Fig. 2a illustrates the evolution of water saturation in the seal centre of the selected sealing materials. The water saturation of the bentonite increases rapidly to 85% during the first 400 years, while the saturation of the other two mixtures are relatively slow showing after the same time period only a saturation of 70% for the clay-stone-bentonite seal and of 63% for the bentonite-sand seal. Full saturation requires a much longer time, namely over 2600 years for the claystone-bentonite seal, 2800 years for the bentonite and 2900 years for the bentonite-sand seal. The saturation durations are comparable for all the sealing materials.

In correspondence with the water saturation, swelling pressure built up in each seal (Fig. 2b). After 400 years of water uptake, different swelling pressures are reached in the seals: 3 MPa in the bentonite, 2 MPa in the clay-stone-bentonite and 1.2 MPa in the bentonite-sand seal. The maximum values achieved after full water saturation were 4.5 MPa for the bentonite and 3.0 MPa for the bentonite-sand seal as well as for the claystone-bentonite seal. A fast development of swelling pressure is desired to ensure an early high degree of sealing in the EDZ.

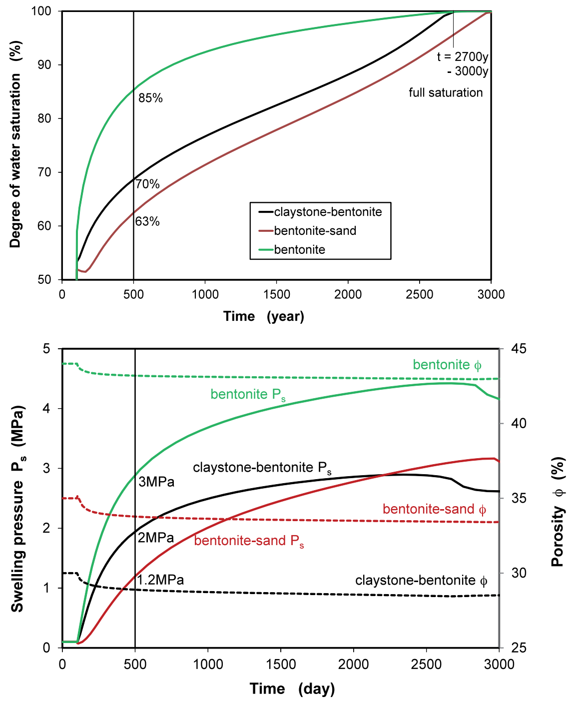


Fig. 2 Long-term sealing performance of a drift seal in terms of water saturation (a) and swelling pressure as well as porosity (b) for the compacted bentonite, bentonite-sand and claystone-bentonite mixtures

Conclusions

The laboratory investigations and the model predictions suggest that the claystone-bentonite mixture is a favourable alternative material to pure bentonite and bentonite-sand mixtures for the safe sealing of re-positories in clay formations.

Acknowledgements

The research work was co-funded by the German Federal Ministry of Economics and Technology (BMWi) under contract number 02E10377 and by the European Commission (EC) as the part of the Euratom's Seventh Framework Programme FP7/2007-2013 under grant agreement no. 323273 for the DOPAS project. The support from ANDRA for provid-ing the test material and for the fruitful discussions is also gratefully acknowledged.

Investigation of CH and HM material behaviour of cement based sealing materials in rock salt

P3-10

Oliver Czaikowski[1], Kyra Jantschik[1], Helge C. Moog[1], Klaus Wieczorek[1]

[1] Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Theodor-Heuss-Strasse 4, 38122 Braunschweig, Germany, oliver.czaikowski@grs.de

For the safe disposal of heat emitting radioactive waste in Germany the disposal in deep geological formations is foreseen. Main tasks are the isolation of the radioactive waste from the biosphere and the permanent safe enclosure of the waste in the containment providing rock zone (CRZ) as stipulated by the safety requirements of the former German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety from September 2010.

The geological barrier is inevitably disturbed by mining activities during repository construction, thereby providing potential pathways for the migration of radionuclides. In order to ensure the safe containment of the waste, drifts and shafts have to be sealed with plugs consisting of adequate construction materials. The sealing capability of these plugs depends on the structurally engineered properties of the material itself and on the long-term interaction between the plug and the host rock. Furthermore, the sealing capability is influenced by potentially inflowing brines.

In the DOPAS Full-Scale Demonstration of Plugs and Seals project, 14 partner organisations from 8 European countries co-operate to perform important demonstration activities in plugging and sealing. These activities are also a part of each participant's national long-term R&D programmes and are therefore jointly funded by Euratom's Seventh Framework Programme and national funding organisations. The demonstration experiments are partially or entirely implemented during the DOPAS project lifetime from 2012 to 2016.

On behalf of BMWi, the national funding organisation for R&D work related to radioactive waste management, GRS is investigating sealing and backfilling materials planned to be utilised in salt and clay formations. The programme aims at providing experimental data needed for the theoretical analysis of the long-term sealing capacity of these materials. According to current R&D work on the salt option, the shaft and drift seal components considered in Germany comprise seal components consisting of MgO and cement based salt concrete.

Hence, GRS is investigating cement- and magnesium oxide-based sealing materials in several chemical-hydraulic tests. These tests aim at analysing diffusive and advective transport mechanisms and their influence on the corrosion of concrete in contact with NaCl- and Mg-rich brines. Tests are executed on two types of specimens, i.e. pure concrete samples and combined samples which consist of a concrete core placed in a rock salt hollow cylinder.

The combined system represents a sealing system in rock salt at laboratory scale. NaCl-solution was axially injected into a combined sample with a salt concrete core at constant hydrostatic loading. When the permeability of the contact zone was reduced from its initial value of 1.0EXP-13 m^2 to around 1.0EXP-18 m^2, the injection fluid was changed to a Mg-rich-solution and hydrostatic loading was reduced. Subsequently permeability decreased by one order of magnitude. This phenomenon results from precipitation of brucite as evidenced by former investigations at GRS. As a consequence pores are clogged by brucite and the pH of the pore fluid decreases to 8-9.

After two months of contact with Mg-rich-solution the permeability starts to increase again. Due to the pH decrease, portlandite becomes instable and dissolves. After complete dissolution of portlandite, the pH decreases further and stabilizing CSH-phases dissolve /NIE 14/.

Experiments using combined samples with a salt concrete core have shown that the presence of NaCl-solution can result in a complete closure of the contact zone. If the contact zone is not closed completely Mg-rich-solutions lead to a corrosion of salt concrete as described and the sealing element loses its sealing function.

Another question, which is currently investigated, is if a permeability increase can also occur after a complete closure of the contact zone. This is currently investigated. The knowledge and understanding of corrosion processes of cement-based sealing materials and at the contact zone between sealing element and host rock is of essential importance for the forecast of the sealing capacity of a disposal system. Especially the corrosion at the contact zone by saline brines could generate a preferred pathway for radionuclides and could compromise the sealing function. Hence, chemical-hydraulic corrosion processes need to be considered in a safety case for deep geological repositories.

/NIE 14/
Niemeyer, M.; Wilhelm, S.; Hagemann, S.; Herbert, H.-J. (2014): Stilllegung ERAM - Zusammenfassende Auswertung von Experimenten und Modellrechnungen zur Korrosion von Salzbeton mit IP21-Lösung. BfS, 2014.

Interaction of long-lived safety relevant radionuclides with cementitious materials

P3-11

Steve Lange[1], Justin Peele[1], Guido Deissmann[1], Dirk Bosbach[1]

[1] Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research: Nuclear Waste Management and Reactor Safety (IEK-6), Wilhelm-Johnen-Str, 52425 Jülich, Germany, s.lange@fz-juelich.de

Cementitious materials are widely used in nuclear waste management, for example for the solidification of low and intermediate level wastes, as construction and backfill material in underground and surface repositories, or in certain waste containers, for example, as buffer in the Belgian Supercontainer. The migration behaviour of radionuclides in cementitious materials is controlled by radionuclide solubility phenomena, diffusion, interface processes such as surface complexation, or incorporation of radionuclides into solid phases, including the formation of solid solutions. Within the frame of the EC-funded Horizon2020 research project CEBAMA (www.cebama.eu), we study the uptake of selected safety relevant long-lived fission and decay products such as I-129, Tc-99, Se-79, and Ra-226 in cementitious systems, using advanced micro analytical and spectroscopic tools. The objective of these investigations is to enhance the mechanistic understanding of the radionuclide uptake and retention in cementitious materials and to evaluate the relevance of cement alteration processes, such as carbonation, on the solid speciation of radionuclides in aged concrete. Within this context, a bottom-up approach is being pursued, studying the radionuclide interaction with synthesised cement phases (model phases), such as calcium silicate hydrates (CSH) with different Ca/Si ratios, monosulfate (AF_m) and ettringite (AF_t) phases on the one hand, and hardened cement pastes with different compositions (e.g. CEM I and CEM V) on the other.

In this paper, we report initial results of the uptake of Ra-226, Tc-99, and molybdenum by single model phases, namely CSH, $AF_{t/m,}$ and hydrogarnet. The phases were synthesised under argon atmosphere, using well established procedures (e.g. Atkins et al. 1991, 1992; Baur et al. 2004). The sorption/uptake kinetics of radium, molybdenum and technetium by the model phases were studied in static batch experiments under anoxic conditions. Experiments performed for up to 50 days indicate a very strong retention of radium by CSH phases, whereas the interaction in systems with AF_t and AF_m is significantly weaker, exhibiting also slower uptake kinetics. In contrast, only a negligible uptake of technetium, present as Tc^{VII} in solution, by the various model phases was observed. Micro analytical investigations of the radionuclide distribution in the solids by TEM, ToF-SIMS, and APT are in progress.

The results of this ongoing study will lead to a better understanding of the uptake and retention mechanisms of safety relevant radionuclides in cementitious barriers and materials and thus contribute to the scientific basis of the safety case for deep geological disposal of nuclear wastes.

Acknowledgement

The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 662147 (CEBAMA).

References

Atkins, M., MacPhee, D., Kindness, A. & Glasser, F.P. (1991): Solubility properties of ternary and quaternary compounds in the calcia-alumina-sulfur trioxide-water system. Cem. Concr. Res. 21: 991-998.

Atkins, M. Glasser, F. P. & Kindness, A. (1992): Cement hydrate phases: solubility at 25 °C. Cem. Concr. Res. 22: 241-246.

Baur, I., Keller, P. Mavrocordatos, D., Wehrli, B. & Johnson, C. A. (2004): Dissolution-precipitation behaviour of ettringite, monosulfate, andcalcium silicate hydrate. Cem. Concr. Res. 34: 341-348.

Geological disposal of high-level radioactive wastes in Boom Clay in the Netherlands: Evaluation of waste form corrosion behaviour for the generic OPERA safety case

P3-12

Guido Deissmann[1], Kirsten Haneke[2], André Filby[2], Rob Wiegers[3], Dirk Bosbach[1]

[1] Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research: Nuclear Waste Management and Reactor Safety (IEK-6), Wilhelm-Johnen-Str, 52425 Jülich, Germany, g.deissmann@fz-juelich.de

[2] Brenk Systemplanung GmbH, Heider-Hof-Weg 23, 52080 Aachen, Germany, a.filby@brenk.com

[3] IBR Consult BV, De Giesel 14, 6081PH Haelen, The Netherlands, r.wiegers@ibrconsult.nl

Focal point of the Dutch research programme into geological disposal of radioactive waste (OPERA – Onderzoeks Programma Eindberging Radioactief Afval) is the development of conditional safety cases for a generic repository in the Tertiary Boom Clay and Zechstein rocksalt formations in the Netherlands. The generic disposal concept for high-level radioactive waste (HLW) in Boom Clay pursued within OPERA is based on the Belgian supercontainer concept (Verhoef et al. 2014). In this concept, the engineered barrier system makes extensive use of cementitious materials (i) in the supercontainer buffer, (ii) as backfilling grout, and (iii) in the disposal gallery linings. Thus the near-field conditions in the post closure phase will be controlled by the interaction of Boom Clay porewater with cementitious materials, leading to anoxic and highly alkaline conditions in the long-term.

The HLW inventory for the OPERA safety case comprises in particular vitrified wastes (HLW glass), i.e. predominantly R7T7 glasses from spent nuclear fuel reprocessing in La Hague, France, and, to a lesser extent, glasses from the reprocessing of commercial nuclear fuels in Sellafield, UK. Spent research reactor fuels relevant within OPERA are aluminium cladded plate-shaped dispersion type fuels consisting of uranium-aluminide (UAl_x) or uranium-silicide (U_3Si_2) fuel particles dispersed in an aluminium matrix, containing high-enriched uranium (up to 95 wt.% ^{235}U) or low-enriched uranium (up to 20 wt.% ^{235}U), respectively. Moreover, spent uranium targets from molybdenum isotope production, and non-heat generating wastes such as compacted hulls and ends from fuel assemblies, are included in the HLW inventory.

In this paper we present and discuss the results of the evaluation of the corrosion behaviour of and the radionuclide release from vitrified HLW and spent research reactor fuels under the disposal conditions expected in a geological repository in Boom Clay in the Netherlands. The overall aim of this project was to assess relevant waste form degradation processes and mechanism, and to derive and quantify waste form corrosion rates and source terms for safety relevant radionuclides for the disposed HLW, in support of the generic OPERA post closure safety assessments. The results address directly the safety function "delay and attenuation of releases" relevant after the failure of the waste canisters (i.e. after the physical containment phase) when the waste forms come into contact with the near-field water.

Acknowledgement

The research leading to these results has received funding from the Dutch research programme on geological disposal, OPERA. OPERA is financed by the Dutch Ministry of Economic Affairs and the public limited liability company Elektriciteits-Produktiemaatschappij Zuid-Nederland (EPZ), and is coordinated by COVRA.

References

Verhoef, E.V., Neeft, E.A.C., Grupa, J.B. & Poley, A.D. (2014): Outline of a disposal concept in clay. OPERA-PG-COV008_rev1. COVRA, Vlissingen, 18 pp.

Site characterisation and synthesis into SDMs – Development of NUMO's pre-selection site-specific safety case (NUMO 2015 Safety Case)

P3-13

Kunio Ota, Takanori Kunimaru, Hiromitsu Saegusa, Saori Yamada

Nuclear Waste Management Organization of Japan (NUMO), 108-0014 Tokyo, Japan, kota@numo.or.jp

In the aftermath of the natural disaster and nuclear accidents in 2011, the social environment of development of a geological disposal project has changed dramatically in Japan. NUMO has been required to develop the technical basis for such changes within the boundary conditions for the national geological disposal project. This is coupled to a more detailed consideration of how any such sites would be characterised in order to ensure their suitability. Whilst the government initiatives to identify scientifically suitable areas have been ongoing, NUMO has developed a pre-selection site-specific safety case (NUMO 2015 Safety Case). This provides a comprehensive overview of the technical basis required to demonstrate the feasibility and long-term safety of geological disposal at sites whose availability results from either open volunteering or the acceptance of government encouragement. As such, it is required to demonstrate a state-of-the-art knowledge base of all relevant geological environments in Japan and a clear ability to characterise them to the degree required and develop a repository concept to the conditions identified. Preliminary repository design and safety assessment are undertaken on the basis of realistic models of potential host rock settings.

During the process of identifying a suitable repository site over the three stages (*ie* literature survey, preliminary investigation and detailed investigation) specified in the relevant national law, focus concentrates on precluding potentially significant impacts of natural disruptive events and processes on the geological environment and, in parallel, characterising the long-term stability of the host geological environment. Basic strategies and advanced methodologies for both preclusion and characterisation have thus been demonstrated in a logical fashion.

The relevant site information required for the subsequent repository design and safety assessment has been integrated into consistent site descriptive models (SDMs) representing the key characteristics and processes (includeing their temporal and spatial evolution) at a range of sites. Five major rock types that commonly occur with sufficient spatial extent in Japan have been characterised in the light of structural and THMC (thermal, hydrological, rock mechanical and geochemical) features – which are of significance to geological disposal – that include potential groundwater pathways, thermal conductivity, hydraulic conductivity, uniaxial compressive strength, chemical buffering capacity *etc*. They have then been categorised into three groups (plutonic rocks, Neogene sedimentary rocks and Pre-Neogene sedimentary rocks) by focussing on distinct characteristics and properties. Geological and hydrogeological SDMs have been developed stepwise for each of the types of potential host rock settings, first, at a scale of several tens of kilometres to allow definition of the location and layout of a repository, second, at several kilometres for assessing groundwater flow through the potential host rock and, third, at several hundreds of metres for more precisely designing the repository. Critical information (*eg* fracture density and hydraulic conductivities) represented quantitatively in the SDMs is derived from a realistic and comprehensive dataset of deep geological environments at particular sites in Japan. In addition, the temporal evolution of the sites has been conceptualised, which serves as a basis for deriving scenarios of how they will evolve further into the future.

DAEF Initiative on Crushed Salt Compaction

P3-14

Klaus Wieczorek[1], Oliver Czaikowski[1], Uwe Düsterloh[2], Ulrich Heeman[3], Christian Lerch[4], Christoph Lüdeling[5], Nina Müller-Hoeppe[4], Till Popp[5], Ralf Wolters[2]

[1] Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Theodor-Heuss-Straße 4, 38122 Braunschweig, Germany, klaus.wieczorek@grs.de
[2] Technische Universität Clausthal (TUC), Adolph-Roemer-Straße 2A, 38678 Clausthal-Zellerfeld, Germany
[3] Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Stilleweg 2, 30655 Hannover, Germany
[4] DBE TECHNOLOGY GmbH, Eschenstraße 55, 31224 Peine, Germany
[5] Institut für Gebirgsmechanik (IfG) GmbH, Friederikenstraße 60, 04279 Leipzig, Germany

Design, analysis and performance assessment of potential repositories for high-level radioactive waste in rock salt formations require knowledge of thermal, mechanical, and fluid transport properties of reconsolidating granular salt (Hansen et al. 2014) which is the candidate backfill material. The current German regulation stipulates that the radioactive waste must be contained safely in a defined rock zone surrounding the mine openings. This represents a substantial change from safety considerations in the past. As a result the time-dependent barrier function of granular salt backfill has gained more attention. Over time the crushed salt will be consolidated by convergence of the rock. It needs to be demonstrated irrevocably that a porosity in the range of a few per cent or less is reached and, thus, a permeability low enough to fulfill the barrier function.

Mechanical and hydraulic properties of reconsolidating salt are functions of porosity. Requirements for reliable porosity predictions are:

- A sound understanding of the phenomena occurring in backfill consolidation, including both instantaneous effects and time-dependent deformation. The relevant microscopic processes (e.g. grain breakage, dislocation creep, pressure solution) are influenced by material properties and initial conditions (mineralogy, grain size distribution, initial porosity, solution content) and boundary conditions (stress state, deformation rate, temperature),
- constitutive models that enable us to adequately simulate these processes, and
- a good experimental database to validate and calibrate the models.

A group of DAEF partners (GRS, DBE TEC, IfG and TUC) have teamed up with BGR to form an initiative on crushed salt compaction. The objective of this group is to take an inventory of the existing material models and experimental database and to develop a strategy for future investigations. The ultimate aim is to enable a reliable prediction and assessment of the thermo-mechanical behaviour of crushed salt and the consequence on its hydraulic behaviour.

The capabilities of existing constitutive models for the thermo-mechanical behaviour of crushed salt were last evaluated in 1995 (Callahan et al. 1995). Later, in the frame of the Bambus project, several models were compared with measurement results of the in-situ experiment. (Bechthold et al. 1999, 2004). Ever since, several models have been modified or further developed, e.g., the models of Sjaardema & Krieg, Hein, Heemann, Olivella & Gens, and Zhang. For some of them, different modifications are available.

While these models differ in terms of their mathematics and capabilities, they have one restriction in common: They have only been partially calibrated and qualified for the intermediate porosity range (down to 10%), but not for the low porosities (<5%) that are crucial for the barrier function of the backfill.

This shortcoming is connected to the scarcity of reliable and systematic experimental data in the low porosity range. In the DAEF working group, the existing data are collected and organized. The data requirements for model validation and data shortcomings are identified to develop a strategy for completing the database with laboratory experiments conducted under conditions that ensure maximum reliability, comparability, and usefulness for model improvement, validation and calibration. This applies to sample preparation, experiment set-up and conduction.

A review of the current state of scientific knowledge of crushed salt consolidation is currently in preparation, focusing on the following topics:

- Classification of available experimental data sets regarding their reliability in the low porosity range and suitability for model validation and calibration,
- Recommendations for completing the experimental database,
- comparison and classification of available constitutive models, and
- development of a strategy to calibrate, benchmark and improve the models.

This presentation will describe the outcome of the initiative's work.

Bechthold, W.; Rothfuchs, T.; Poley, A.; Ghoreychi, M.; Heusermann, S.; Gens, A. & Olivella, S.: Backfilling and Sealing of Underground Repositories for Radioactive Waste in Salt (BAMBUS Project). Final Report EUR 19124 EN. Luxembourg: CEC, 1999

Bechthold, W.; Smailos, E.; Heusermann, S.; Bollingerfehr, W.; Bazargan Sabet, B.; Rothfuchs, T.; Kamlot, P.; Grupa, J.; Olivella, S. & Hansen, F.D.: Backfilling and Sealing of Underground Repositories for Radioactive Waste in Salt (BAMBUS-II Project). Final Report EUR 20621 EN. Luxembourg: CEC, 2004

Callahan, G.D.; Loken, M.C., Van Sambeek, L.L.; Chen, R.; Pfeifle, T.W.; Nieland, J.D.; Hansen, F.D.: Evaluation of Potential Crushed-Salt Constitutive Models, Sandia Report SAND95_2143, 1995

Hansen, F.D.; Popp, T.; Wieczorek, K. & Stührenberg D.: Salt reconsolidation principles and applications. Nuclear Energy Agency Report. SAND2014-4502P. Sandia National Laboratories, Albuquerque, NM., 2014

Historic intraplate earthquakes in northern Central Europe are caused by glacial isostatic adjustment

P3-15

Christian Brandes[1], Holger Steffen[2], Rebekka Steffen[3], David C. Tanner[4], Jutta Winsemann[1], Patrick Wu[5]

[1] Institut für Geologie, Leibniz Universität Hannover, Callinstraße, 30167 Hannover, Germany
[2] Lantmäteriet (IGR), Lantmäterivägen 2c, 80102 Gävle, Sweden
[3] Department of Earth Sciences, Uppsala University, Villavägen 16, 75236 Uppsala, Sweden
[4] Leibniz Institute for Applied Geophysics (LIAG), Stilleweg 2, D-30655 Hannover, Germany
[5] Department of Earth Sciences, The University of Hong Kong, Pokfulam Road, Hong Kong

Northern Central Europe is considered as a low seismicity area, but there are several historic earthquakes with intensities of up to VII that have occurred in this region during the last 1200 years (Leydecker, 2011) for which the trigger has not been sufficiently investigated yet. Our study combines historic earthquake epicentres with the most recent fault maps and shows that the historic seismicity is related to major reverse faults of Late Cretaceous age. The spatial and temporal distribution of earthquake epicentres (episodic clusters that migrate) indicates that northern Central Europe behaves like a typical intraplate tectonic region, as demonstrated for other intraplate settings such as China or the eastern USA (Liu et al., 2011). We suggest that many faults in Central Europe (like the Osning Thrust, the Gardelegen Fault and the Haldensleben Fault) are so-called postglacial faults (pre-existing faults that were reactivated due to stress changes induced by the decay of the Pleistocene ice-sheet), though they developed outside the glaciated area.
We tested our hypothesis with finite-element models that describe the process of glacial isostatic adjustment (GIA). The change in Coulomb failure stress (δCFS) was calculated to determine the minimum stress required to reactivate the fault. A negative δCFS value indicates that the fault is stable, while a positive value means that GIA stress is potentially available to induce faulting or cause fault instability or failure unless temporarily released by an earthquake. The modelling results suggest that most earthquakes are related to GIA since almost all graphs for northern Germany show a change from negative to positive values during the deglaciation phase (Brandes et al., 2015). This is supported by geological field evidence of deglaciation seismicity (Brandes et al., 2012, Brandes & Winsemann, 2013). We have developed the first consistent model that can explain the occurrence of deglaciation seismicity and the historic earthquakes in northern Central Europe. Analysing the causes of intraplate earthquakes in northern Central Europe is of great societal relevance and an understanding of the driving mechanisms behind this type of seismicity is an important step towards a hazard risk evaluation.

References

Brandes, C., Steffen, H., Steffen R. and Wu, P. (2015): Intraplate seismicity in northern Central Europe is induced by the last glaciation. Geology, 43, 611-614

Brandes, C., Winsemann, J., Roskosch, J, Meinsen, J., Tanner, D.C., Frechen, M., Steffen, H. and Wu, P. (2012): Activity of the Osning thrust during the Lateglacial: ice-sheet and lithosphere interactions. Quaternary Science Reviews, 38, 49-62

Brandes, C. and Winsemann, J. (2013): Soft sediment deformation structures in NW Germany caused by Late Pleistocene seismicity. International Journal of Earth Sciences, 102, 2255-2274

Leydecker, G. (2011): Erdbebenkatalog für die Bundesrepublik Deutschland mit Randgebieten für die Jahre 800-2008. Geologisches Jahrbuch, Reihe E, 198 pp.

Liu, M., Stein, S. and Wang, H. (2011) 2000 years of migrating earthquakes in north China: How earthquakes in midcontinents differ from those at plate boundaries. Lithosphere, 3, 128-132.

Reactive transport model for the near field of different generic spent nuclear fuel repository options: effect of the radionuclide source term

P3-16

Vanessa Montoya, David Fellhauer, Volker Metz, Horst Geckeis

Karlsruhe Institute of Technology, Institute for Nuclear Waste Disposal (KIT-INE), Karlsruhe, Germany, vanessa.montoya@kit.edu

In August 2015, the German government approved the national programme for the responsible and safe management of spent fuel and radioactive waste proposed by the Federal Ministry for the Environment, Nature Conservation, Building and Reactor Safety, following a strategic environmental assessment and public consultation. However, a decision on the disposal concept for high-level waste is pending and an appropriate solution has to be developed with a balance in multiple aspects from the view of different stakeholders. In the decision process, evaluation of the risk of different waste management options and scenarios play a big role in the discussion. In this sense, quantitative calculations of radionuclide release and migration are necessary to evaluate the function of the various (geo-) engineered barriers included in the considered geological disposal concepts.

The objective of this work is to develop reactive transport models accounting for geochemical and physical processes taking place in the near-field of repositories for spent nuclear fuel (SNF) in deep geological formations under the presumed scenario that water intrusion takes place and radionuclides can be released. The modelling approach considers coupled processes which potentially occur during a period of thousands of years. The studied systems are implemented in the iCP interface (Nardi et al., 2014), which couples two different codes: COMSOL Multiphysics (COMSOL, 2014) and PHREEQC (Parkhurst and Appelo, 2013).

The multi-barrier systems considered are emplaced in two different host rocks (i.e. rock salt and claystone) and are composed of the waste form (SNF), steel canister, backfilling (crushed rock salt and bentonite, resp.), concrete liner (in claystone) and cement sealing (Ordinary Portland Cement and Sorel Cement, resp.) as well as the adjacent host rock. Simulation calculations are performed in a fully saturated isothermal system (298 K) assuming solubility limited aqueous concentrations for Th, U, Np, Pu, Am and Tc as radionuclide source term in the vicinity of the waste canisters. Various geochemical initial boundary conditions are considered.

Geometrical and transport parameters (i.e. diffusion), including the discretization of the system, are implemented in 2D in COMSOL. The geochemical conceptual model (e.g. redox conditions, pH, salinity and composition of intruding solutions and porewater) is set up in PHREEQC. Chemical reactions of major components and radionuclides at equilibrium are simulated using parameters and data from the appropriate thermodynamic database (i.e. ThermoChimie or Thereda). Steel corrosion is considered to be kinetically controlled. Radionuclide sorption (cation exchange and surface complexation) and competition effects with the major species of the background (e.g. Ca, Mg, Fe) is also assessed.

A mechanistic migration model is defined independently for each radioactive element in each barrier. As an example, the Am(III) source term in the claystone system is modelled by assuming carbonate or hydroxide phases as limiting solubility phases. Sorption and precipitation in the different barriers is taken into account. The results show that the migration of Am(III) is significantly retarded by sorption in the interface between the bentonite buffer material and the canister corrosion products.

References

Nardi A., et al. (2014) Comput. Geoscis, 69, 10-21.

COMSOL (2014) COMSOL-Multiphysics. V.5.0, www.comsol.com

Parkhurst D.L., Appelo C.A.J. (2013) U.S. Geological Survey Techniques and Methods, book 6, 497p.

Lessons learnt from the EC ACTINET and TALISMAN projects performed at KIT-INE

P3-17

M. Altmaier, Th. Schäfer, J. Rothe, B. Schimmelpfennig, H. Geckeis

Karlsruhe Institute of Technology, Institute for Nuclear Waste Disposal, KIT-INE, PO Box 3640, 76021 Karlsruhe, marcus.altmaier@kit.edu

In order to assess the long-term safety of nuclear waste disposal options, geochemical expertise is often indispensible as many geochemically driven processes will decisively control the release of radionuclides from a repository. Over the last decades, the scientific understanding of radionuclide mobilization and retention processes was significantly improved, largely owing to the use of advanced spectroscopic and analytical techniques. The use of innovative technical tools allows researchers to derive the required process understanding at the molecular level which is at the very core of reliable and robust geochemical predictions. Research work on radioactive substances additionally requires dedicated facilities which are properly licensed and equipped to handle the potentially highly hazardous materials.

The need of ensuring access for a wide user and research community to selected large experimental infrastructures equipped with state-of-art analytical equipment dedicated to working with radionulides was identified previously. Consequently, a series of projects were developed on an international level, namely the ACTINET and the recently finalized TALISMAN (http://www.talisman-project.eu) projects. All these projects received funding from the European Commission. As these projects were not entirely restricted to studies pertaining to the Nucleear Waste Disposal Safety Case, a significant portion of the activities were clearly related to this topic.

The 36 months TALISMAN project (start January 2013) was following the positive experiences gained in the previous Actinet projects. TALISMAN featured a proposal system to fund and grant access of researchers to work at the 9 TALISMAN facilities, INE -Radlabs and INE-Beamline being two of them. In addition to the Joint Research Projects (JRP) in which the main experimental research was performed and which were usually developed bilaterally between the visiting scientists and the collaborating Pooled Facility experts, a series of summer-schools and workshops were organised in TALISMAN with a clear focus of dissemination and education.

KIT-INE was involved in both the ACTINET and TALISMAN projects as a Pooled Facility. The experience gained during the projects and the many Joint Research Projects realized with external partners at KIT-INE are very positive, both from a genuine scientific perspective and in view of increased networking, exchange and productive synergies. JRP activities at KIT-INE were using the radiochemical laboratories of KIT-INE equipped with spectroscopic and analytical tools and the INE-beamline for Actinide Research at ANKA with a unique technical infrastructure.

Within this contribution to DAEF, selected R&D highlights from JRPs performed at KIT-INE will be presented in order to exemplify the remarkable output and excellent scientific quality. Topics restrict to the nuclear waste disposal context and cover (i) fundamental actinide chemistry relevant to assess radionuclide source terms, (ii) XAS studies at ANKA on repository relevant systems, (iii) use of analytical tools to investigate radionuclide chemistry in real systems, and (iv) an example from the context of decommissioning of nuclear facilities. Further activities at KIT-INE focussing on computational actinide chemistry with the aim of strengthening links and synergies between theory and experimental studies, are also presented.

The main lesson learnt from the participation of KIT-INE in the ACTINET and TALISMAN projects is, that there is definitely a strong need of both the national and international research communities to have advanced and technically innovative experimental tools and infrastructures available, allowing dedicated research in support of the Nuclear Waste Dispsal Safety Case. In the specific applied context of the German “Energiewende” this demand is further accentuated by the need to establish scientifically justified options for the safe disposal of nuclear waste and support the development of optimized decommissioning technologies, i.e. targeting waste volume reduction.

Main conclusions:

- It is mandatory that large innovative experimental infrastructures and advanced radiochemical laboratories are maintained and further developed on a national level. This is a key component in support of the Nuclear Waste Disposal Safety Case, largely independent of the potential host rock formations and repository concepts.
- An excellent tool to support young researchers during PhD work or early PostDoc careers is offering access to advanced experimental research infrastructures. This is valuable both in view of extending the available scientific methods, and in the broader context of knowledge maintenance and promoting young talent.
- The EC funded ACTINET and TALISMAN projects highlight the significant scientific and technical synergies gained from improved networking on an international, i.e. European, level. Based upon the sharing of resources, expertise and experience within the frame of collaborative R&D actions, there is a clear added value and positive feedback meeting the specific requirements of national programms.

CEBAMA – a EC Horizon 2020 funded collaborative Research Project on Cement-Based-Materials

P3-18

M. Altmaier[1], V. Montoya[1], L. Duro[2], A. Valls[2], E. Holt[3], F. Claret[4], U. Mäder[5], B. Grambow[6], A. Idiart[2]

[1] KIT-INE, Germany (marcus.altmaier@kit.edu), [2]Amphos[21], Spain, [3]VTT, Finland, [4]BRGM, France, [5]Universität Bern, Switzerland, [6]ARMINES, 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.

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. R&D in 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 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), Toarcian mudstone) or bentonite backfill and assess the impact on physical (transport) properties.

- Study radionuclide retention processes in high pH concrete environments. Radionuclides which have high priority from the scientific and applied perspective are selected.

- 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.

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 (A. Valls, L. Duro) 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 participate in Cebama at their own costs with specific scientific/technical contributions or particular information exchange functions. AGs are 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).

Information on Cebama and on upcoming Cebama project events is available at the project website at www.cebama.eu.

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

From microscopic pore structures to transport properties in shales: a workshop co-organized by the NEA-OECD ClayClub

P3-19

Thorsten Schäfer[1], Reiner Dohrmann[2], Chris Greenwell[3]

[1] Karlsruhe Institute of Technology (KIT), Institute for Nuclear Waste Disposal (INE), P.O. Box 3640, D-76021 Karlsruhe, Germany, thorsten.schaefer@kit.edu

[2] Federal Institute for Geosciences and Natural Resources (BGR), State Authority of Mining, Energy and Geology, Stilleweg 2, D-30655 Hannover, Germany, reiner.Dohrmann@lbeg.niedersachsen.de

[3] Department of Earth Sciences, Durham University, South Road, Durham, UK, chris.greenwell@durham.ac.uk

A wide spectrum of argillaceous media are being considered in Nuclear Energy Agency (NEA) member countries as potential host rocks for the final, safe, disposal of radioactive waste, and/or as major constituents of repository systems in which waste will be emplaced. In this context, the NEA established in 1990 a Working Group on Argillaceous Media, known informally as the "Clay Club". The Clay Club examines those various argillaceous rocks that are being considered for the deep disposal of radioactive waste, ranging from soft clays to indurated shales. These rocks exhibit a wide spectrum of characteristics which make them useful as barriers to the movement of water and solutes. Studies include clay media characterization and modeling. The one-day workshop was organized in conjunction with the EUROCLAY 2015 conference in Edinburgh and initiated by the NEA Clay Club, The Clay Minerals Society, and the Euroclay conference series. It was a follow- up of the 1st workshop organized in Karlsruhe in 2011 (NEA, 2013) and was intended to document the progress made over the last four years. Additionally, the shale gas and oil community is interested in the characterization of sediments and black shales from the core- to nano-scale, focusing on clay/ brine/organic interfaces and understanding how pore space evolves and effects the production potential of the shale system. Through characterizing fundamental properties such as nano-/micropore connectivity, all the way up to understanding transport and mechanical fracture properties of whole rock units, both communities (radioactive waste disposal community and shale gas community) are studying the geological materials with a shared set of tools, from quantum mechanics computer simulations, through advanced microscopy and diffraction methods, up to triaxial mechanical tests and large-scale transport models. The results show, that water flow, solute and gas transport and mechanical properties are largely determined by this microstructure, the spatial arrangement of the minerals and the chemical pore water composition. At the current level of knowledge, there is a strong need to improve the nanoscale description of the phenomena observed at the macroscopic scale. This presentation will give an overview of the outcome of the workshop discussing the current state-of-the-art of spectromicroscopic methods as well as modeling approaches and will point out to new developments in the field; details can be found in Schäfer et al. (2016). For a generic safety case this type of fundamental understanding and quantification of geochemical and physical processes that influence the mobility of the radionuclides in the geochemical environment imposed by the host rock is building confidence in the safety of a geological disposal facility.

References

NEA (2013): Clay characterization from nanoscopic to microscopic resolution: NEA CLAY CLUB Workshop Proceedings, Karlsruhe, Germany, 6-8 September 2011, report NEA/RWM/CLAY CLUB(2013)1, pp.168, (http:// www.oecd-nea.org/rwm/docs/2013/ rwm-clay club2013-1.pdf)

Schäfer, T. Dohrmann, R., Greenwell, H.C. (editors) *"Filling the Gaps – from Microscopic Pore Structures to Transport Properties in Shales"* (2016), CMS Workshop Lectures, 21. The Clay Minerals Society, Chantilly, Virginia, USA; ISBN - 978-1-881208-46-4.

Modelling of individual dosimetry in facilities for heat-generating waste: Spent nuclear fuel emplacement in a rock salt repository

P3-20

Bo Pang[1,2], Héctor Saurí Suaréz[1], Frank Becker[1], Volker Metz[1], Horst Geckeis[1]

[1] Institute for Nuclear Waste Disposal (INE), Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

[2] Corresponding author: bo.pang@kit.edu, +49-721-60828797

A responsible and safe management of radioactive residues, especially heat-generating waste from commercial nuclear power plants, is a complex subject of social controversies, unresolved conflicts and uncertainties. The interdisciplinary research platform "ENTRIA" (Röhlig et al. 2014) has been established to develop evaluation principles for comparison of different options for the management of heat-generating waste. Three generic disposal and storage concepts are studied in the research platform, i.e. controversies in deep geological formations with monitoring and retrievability measures, deep disposal without retrievability measures, and prolonged surface storage. Certain working scenarios in the storage / disposal facilities might lead to an enhanced level of radiation exposure for workers. Hence, a realistic estimation of the personal dose during individual working scenarios is desired.

In this study, individual dosimetry of personnel involved in emplacement of canisters with spent nuclear fuel (SNF) in a repository is modelled. In our model, POLLUX-10 casks (Janberg and Spilker 1998), each loaded with SNF discharged from pressurized water reactors, are emplaced in a horizontal drift of a repository in a deep rock salt complex. Geometrical and material parameters are adopted from a generic reference concept for disposal in rock salt (Stahlmann et al., 2014). An average waste inventory consisting of fuel rods of nine UOX and one MOX fuel assemblies are considered.

In our simulation method, the radiation field around the POLLUX-10 cask is calculated in terms of the ambient dose equivalent *H*(10)* with the general-purpose Monte Carlo N-Particle code MCNP6 (Pelowitz et al. 2013). For the waste inventory considered in this study, the radiation field inside the drift is dominated by neutrons. In addition, a strong impact on the total dose due to backscattered radiation by surrounding rock salt is determined in the simulations. As basis to estimate the personal exposure during individual working scenarios, a movable whole-body phantom (Pang et al. 2016) has been developed to describe individual body gestures of the workers during motion sequences. Our simulation method is applied to the working scenario for emplacement of a POLLUX-10 cask in a rock salt repository. The personal exposure was calculated with MCNP6 in terms of the personal dose equivalent $H_p(10)$. Due to the backscattered radiation, the usage of only one dosimeter in front of the chest can underestimate the personal dose, if the worker is not facing the direct radiation incidence, i.e. the POLLUX-10 cask. To reduce this effect, it is proposed to wear a second dosimeter at the back of the upper part of the body and to sum up the results of both dosimeters.

In continuation of this study, our simulation method will be applied to working scenarios regarding disposal of SNF in a POLLUX-3 cask in a generic repository in claystone and storage of SNF in CASTOR® in a generic surface facility.

References

Janberg, K. and Spilker H. (1998): Radioactive Waste Management and Disposal 121, 136-147.

Pelowitz, D. B. et al. (2013): MCNP6 User Manual. LA-CP-13-00634, Rev. 0.

Pang, B. et al. (2016): Radiation Protection Dosimetry, in print.

Röhlig et al. (2014): Entria: Memorandum zur Entsorgung hochradioaktiver Reststoffe, Hannover.

Stahlmann, J., Leon Vargas, R., Mintzlaff, V. (2014) Technische Universität Braunschweig.

Pore morphology, grain microstructure and deformation mechanisms in claystones: relevance for predicting the long-term deformation and transport processes in host rocks for heat-generating nuclear waste

P3-21

Janos.L. Urai, Johannes M. Klaver, Ben Laurich, Guillaume Desbois, Susanne Hemes, Joyce Schmatz

Structural Geology, Tectonics and Geomechanics, RWTH Aachen University, Lochnerstrasse 4-20, D-52056 Aachen, Germany, j.urai@ged.rwth-aachen.de, www.ged.rwth-aachen.de

A microphysics-based understanding of mechanical and fluid flow properties in mudrocks provides a sound basis for extrapolating constitutive equations beyond the time scales accessible in the laboratory, so that predictions of the evolution of host rocks for heat-generating nuclear waste can be made less uncertain. This requires imaging the microstructure at a range of scales as the microstructures are small heterogeneous. Broad Ion Beam (BIB) milling followed by Scanning Electron Microscopy (SEM) imaging pro-vides access to these microstructures at nm resolution in large cross sections of up to several mm^2. BIB-SEM of naturally and experimentally deformed or Wood's Metal injected samples allows study of defor-mation mechanisms and pore connec-tivity, respectively. The pore fluid distri-bution can be studied by integrating BIB-SEM with cryogenic techniques.

This contribution will show examples of these studies with Boom Clay, Opalinus Clay and Callo- Oxfordian clay, the three major potential host rocks in Europe. Our current work on deformation mechanisms focuses on experimental deformation with the integration of micro-CT based digital image correlation (DIC) techniques and BIB-SEM imaging of deformation microstructures to understand deformation mechanisms. Understanding of deformation mechanisms provides a micro-physical basis to explain the measured stress-strain curves, and also allows comparison with samples deformed in natural laboratories, to provide a basis for extrapolating laboratory-derived constitu-tive equations to long-term deformation.

Mudrocks display a poorly understood deformation behaviour transitional bet-ween rocks and soils. Although as a first approximation their plasticity can be described by similar pressure dependent failure envelopes, our results indicate that the full constitutive models describing their deformation and transport properties, especially over the long term should be quite different, due to the different deformation mechanisms. In weak, uncemented mudrocks with increasing effective stress the material's compressive strength increases and the tendency for the formation of dilatant fractures decreases, finally resulting in strongly localized strain in non-dilatant shear zones. Deformation mechanisms are bending of clay plates and sliding along clay-clay contacts, with shear zones anastomosing around strong silt grains. Shear zones develop strong preferred orientation and we propose an important contribution of a poorly understood flow of nano-scale clay aggregates. There is no evidence for intragranular cracking.

In cemented, indurated mudrocks micro-cracking, brittle fractures, and cataclastic deformation is dominant even at high confining pressure. BIB-SEM shows a complex interplay of microcracking, bending and kinking of phyllosilicates, and grain refinement. Although with increasing confining pressure the tendency to dilate decreases, the gouge shows evidence of porosity development even at high confining pressure, requiring high strains for the development of a clay-rich gouge which can re-seal the initial dilatant fractures.

References

Desbois G, et al., (2014) Nanometer-scale pore fluid distribution and drying damage in pre-served clay cores from Belgian clay formations inferred by BIB-cryo-SEM. Engineering Geology 179, 117-131

Laurich B et. al. (2014) Microstructural evolution of an incipient fault zone in Opalinus Clay. Journal of Structural Geology 67, 107-128.

THEREDA – uranium release

P3-22

M. Altmaier[1], F. Bok[2], V. Brendler[2], H. Moog[3], A. Richter[2], T. Thoenen[4], W. Voigt[5]

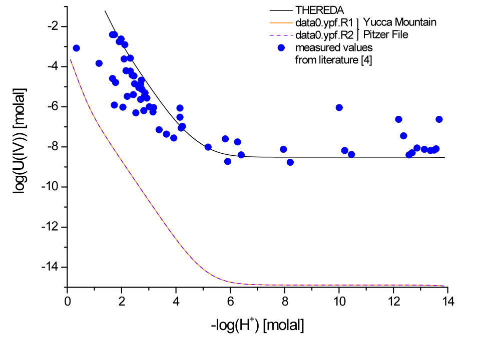
[1] Karlsruhe Institute of Technology, Institute for Nuclear Waste Disposal, Karlsruhe, Germany
[2] Helmholtz-Zentrum Dresden-Rossendorf, Institute of Resource Ecology, Dresden, Germany
[3] Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Braunschweig, Germany
[4] Paul-Scherrer-Institute, Laboratory for Waste Management, Villigen, Switzerland
[5] TU Bergakademie Freiberg, Institute for Inorganic Chemistry, Freiberg, Germany

THEREDA [1], a thermodynamic reference database desingned to support the safety asessment of radioactive waste disposal in Germany: www.thereda.de. Namely it provides a mutually accepted base for predictive geochemical modeling of the solubility of all relevant toxic components in complex, high-saline aqueous solutions. Special emphasis is put on thermodynamic data along with suitable Pitzer coefficients. Registered users may either download single thermodynamic data or ready-to-use parameter files for the geochemical speciation codes EQ3/6, PHREEQC, Geochemist's Workbench, and CHEMAPP.

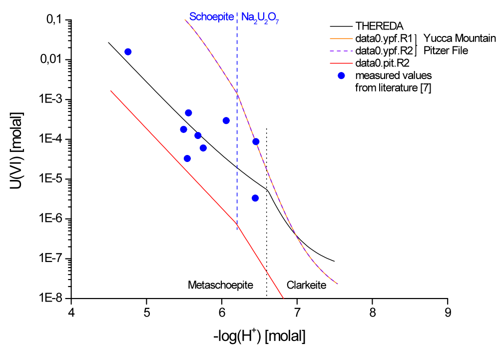
The most recent data release (for 298.15 K) R09 covers U(IV/VI) in solutions of Na, Mg, Ca, K, Cl, SO_4, CO_3, HCO_3, Si, thus being the first one combining two different oxidation states. It contains thermodynamic data for 25 solid phases (among them many secondary phases found in anthropogenic and natural analogues) and 24 aqueous complexes.

Data releases are accompanied by a set of benchmarks that not only help to track affects of database changes on predictive model results (and thereby also comparing the different speciation codes). These benchmarks, where the following two examples are drawn from, also highlight the quality of the released data.

The first example compares experimental results for the solubility of U(OH)4(am) in 1 m NaCl solution at 25 °C with predictions based on THEREDA and on the most recent Yucca Mountain Project database (YMP - one of the very few comprehensive thermodynamic database of actinides under brine conditions). Contrary to THEREDA, the latter does con-



cerning U(IV) not contain thermodynamic data for aqueous species and only very few for minerals, with strastic implications for the predictive capabilities under reducing conditions.



The second example deals with solubility of Metaschoepite (a secondary U(VI) mineral) in 5 m NaCl solution. Deviating solubility constants ($\Delta \log K°_{sp} \approx 0.52$) as well as different or missing data for the aquatic uranium(VI) speciation in the YMP database turned out to be the major reason for the observed discrepancies.

References

[1] Moog, H., Bok, F., Marquardt, C. M., Brendler, V. Applied Geochemistry, 55 (2015), 72-84.

Microstructure and Deformation of Opalinus Clay from the Main Fault in the Mont Terri Rock Laboratory (CH) – Some selected insights from electron microscopy

P3-23

Ben Laurich[1,2], Janos L. Urai[2], Christian Vollmer[3], Christophe Nussbaum[4]

[1] Now at: Federal Institute for Geosciences and Natural Resources (BGR), Stilleweg 2, D-30655 Hannover, Germany, ben.laurich@bgr.de

[2] Structural Geology, Tectonics and Geomechanics, RWTH Aachen University, Lochnerstrasse 4-20, D 52056 Aachen, Germany, j.urai@ged.rwth-aachen.de

[3] Institute for Mineralogy, University Münster, Correnstraße 24, D-48149 Münster, Germany, christian.vollmer@wwu.de

[4] Swiss Geological Survey, Federal Office of Topography Swisstopo, Seftigenstrasse 264, CH -3084 Wabern, Switzerland, christophe.nussbaum@swisstopo.ch

Numerous geoscience disciplines evaluate the suitability of the Opalinus Clay formation (OPA) to host a repository for nuclear waste. Most of them benefit from or even rely on insight of the OPAs' microstructure. In particular, hydro-mechanical studies profit from the understanding of microstructural processes.

In our poster contribution, we present a summary of our results in observing, describing and quantifying the microstructure of naturally and synthetically deformed OPA. Plus, we deduce its microstructural evolution and its underlying deformation mechanisms (Laurich, 2015; Laurich et al., in prep., 2016, 2014).

There are five major deformation features in OPA from the so-called Main Fault in the Mont Terri Rock Laboratory: (1) slickensides, which are in cross-sectional view associated to (2) a µm-thin zone of slickenside-parallel oriented particles, (3) gouge, (4) calcite and celestite veins and (5) scaly clay. We found a significant loss of porosity in gouge, veins and the thin shear zones compared to the protolith. Despite the small offset, we see indicators for all major deformation mechanisms. Most impact on strain is attributed to frictional sliding and rigid body rotation. However, trans-granular fracturing, dissolution-precipitation of calcite, clay particle neoformation and grain deformation by intracrystalline plasticity have also a significant contribution to the fabric evolution.

We provide a microphysical basis to relate microstructures to macroscopic observations of strength and permeability.

Numerical modellers of long-term deformation behaviour of clays should not rely on laboratory derived parameters only, but implement more time-dependent processes to obtain realistic hydro-mechanical properties, resulting in a viscous long-term deformation. Our findings are also relevant to earthquake research, in particular to scaly clay fabrics in accretionary prisms.

References

Laurich, B., 2015. Evolution of microstructure and porosity in faulted Opalinus Clay. RWTH-Aachen University.

Laurich, B., Urai, J.L., Desbois, G., Vollmer, C., Nussbaum, C., 2014. Microstructural evolution of an incipient fault zone in Opalinus Clay: Insights from an optical and electron microscopic study of ion-beam polished samples from the Main Fault in the Mt-Terri underground research laboratory. J. Struct. Geol. 67.

Laurich, B., Urai, J.L., Nussbaum, C., 2016. Microstructures and deformation mechanisms in Opalinus Clay: insights from scaly clay from the Main Fault in the Mont Terri Rock Laboratory (CH). Solid Earth Discuss. 1–30.

Laurich, B., Urai, J.L., Vollmer, C., Nussbaum, C., in prep.: Microstructure of gouge from the Main Fault in the MT URL: Insights from optical and electron microscopy.

Thermodynamic model for the solubility of tetravalent $TcO_2 \cdot xH_2O(am)$ in the aqueous Tc^{4+}–Na^+–Mg^{2+}–Ca^{2+}–H^+–Cl^-–OH^- system

P3-24

E. Yalcintas, A. Baumann, X. Gaona, M. Altmaier, H. Geckeis

KIT-INE, Germany (marcus.altmaier@kit.edu).

Technetium–99 is a β–emitting radionuclide produced in nuclear reactors by the fission of ^{235}U and ^{239}Pu. Due to its significant inventory in spent fuel, long half-life ($t_{½}$ ~211.000 a) and redox-sensitive character, ^{99}Tc is an important radionuclide in Performance Assessment exercises of repositories for radioactive waste disposal. Under sub-oxic/oxidizing conditions, technetium exists as the highly soluble and mobile pertechnetate anion (TcO_4^-). In reducing environments Tc(IV) prevails, forming sparingly soluble hydrous oxides ($TcO_2 \cdot xH_2O(s)$). The later redox state is expected to dominate the aqueous chemistry of Tc under the reducing conditions predicted for deep geological repositories. In this framework, an appropriate understanding of the solubility and hydrolysis of Tc(IV) in dilute to concentrated saline systems is required for an accurate assessment of technetium source term in repositories for radioactive waste disposal.

The solubility of Tc(IV) was investigated in a comprehensive experimental approach from undersaturation conditions in 0.1–5.61 m NaCl, 0.1–4.58 m KCl, 0.25–5.15 m $MgCl_2$ and 0.25–5.25 m $CaCl_2$ solutions in the pH_m range 1.5–14.6. Experiments were performed at 22 ± 2°C in Ar gloveboxes with < 2 ppm O_2. Strongly reducing conditions (pH + pe < 4) were fixed in each independent solubility sample with $Na_2S_2O_4$, $SnCl_2$ or Fe powder. Technetium concentration, pH_m and E_h values were monitored at regular time intervals over several months. Thermodynamic equilibrium was assumed after repeated measurements with constant [Tc] and pH_m. After attaining equilibrium conditions, the redox speciation of technetium in the aqueous phase was quantified for selected samples using solvent extraction with TPPC and XANES analysis. Solid phases of selected batch experiments were further characterized by XRD, SEM–EDS and quantitative chemical analysis. Additional solubility experiments were conducted in “simulated systems”, based on reported ground water and cementitious pore water compositions with complex mixtures of NaCl–KCl–$MgCl_2$–$CaCl_2$.

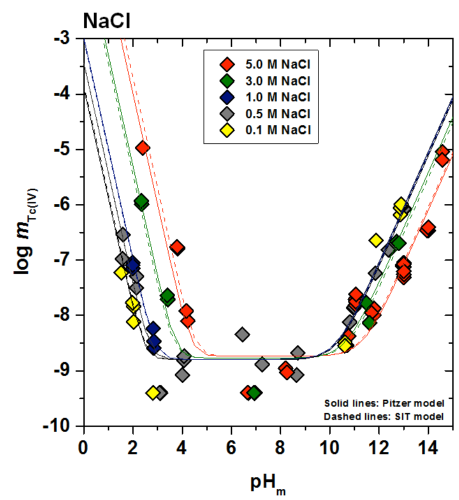


Fig. 1: Solubility and Pitzer Model for Tc(IV) in dilute to concentrated NaCl solutions.

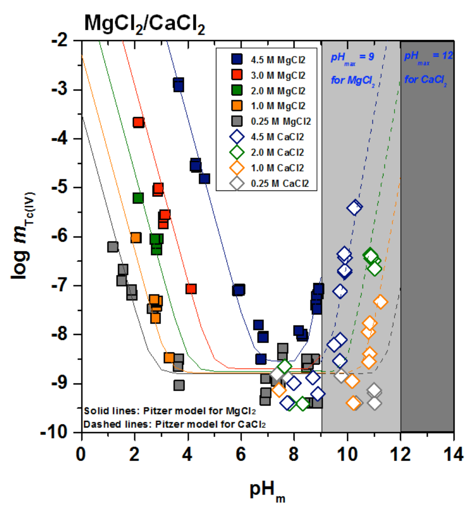


Fig. 2: Solubility and Pitzer Model for Tc(IV) in dilute to conc. $MgCl_2$ and $CaCl_2$ solutions.

Solid phase characterisation and solubility data indicate that $TcO_2 \cdot 0.6H_2O(s)$ is the solid phase controlling the solubility of Tc(IV) in all the evaluated systems. The combination of solvent extraction and XANES analysis confirms the predominance of Tc(IV) in the aqueous phase, independently of the salt system and concentration. The solubility of $TcO_2{\cdot}0.6H_2O(s)$ decreases with a well-defined slope (log [Tc] vs. -log $[H^+]$) of –2 in acidic dilute systems. The same slope is retained in concentrated brines, although a very significant increase in the solubility (up to 4 orders of magnitude) is observed with increasing ionic strength. A newly derived chemical model based on these solubility data in combination with spectroscopic evidences reported in the literature, best explains this increase considering the formation of the previously unreported trimeric technetium species $Tc_3O_5^{2+}$. In the near-neutral pH region, the pH-independent behaviour of the solubility is consistent with the chemical reaction $TcO_2{\cdot}0.6H_2O(s)$ + 0.4 H_2O ↔ $TcO(OH)_2(aq)$ with a $\log_{10}{}^{*}K^{\circ}_{s,TcO(OH)2}$ in good agreement with the current NEA–TDB data selection. The amphoteric behaviour of Tc(IV) is confirmed by the formation of the species $TcO(OH)_3^-$ in dilute NaCl and KCl systems with $pH_m \geq 11$. The same speciation is retained in concentrated alkaline NaCl and KCl solutions, although a decrease in solubility compared to dilute systems takes place due to ion interaction processes. Changes in the aqueous speciation are observed in concentrated alkaline $MgCl_2$ and $CaCl_2$ brines, where the formation of $Mg_3[TcO(OH)_5]^{3+}$ and $Ca_3[TcO(OH)_5]^{3+}$ ternary species are proposed based on the slope analysis of the corresponding solubility curves and the comparison with previous observations available for An(IV) and Zr(IV) in concentrated $CaCl_2$ solutions. The formation of these species has been recently validated by quantum chemical calculations performed at KIT–INE. Based on the newly generated experimental data, comprehensive chemical, thermodynamic and activity models using both SIT and Pitzer approaches are derived for the system Tc^{4+}–Na^+–K^+–Mg^{2+}–Ca^{2+}–H^+–Cl^-–OH^-–H_2O at 25°C. The comprehensive thermodynamic models derived in this work, allow the calculation of solubility limits and Tc(IV) speciation in aquatic systems covering the characteristics of all host rock formations potentially under discussion in Germany.

Tc(IV) solubility investigated in selected "simulated real systems" taken from literature is in good agreement with qualitative predictions based on pure systems as shown in Fig.3.

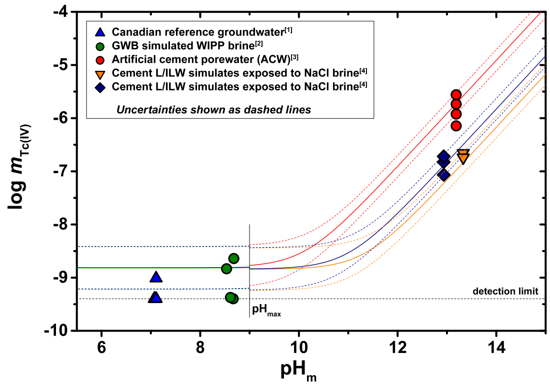


Fig. 3: Comparison of thermodynamic Tc(IV) model with experimental solubility data for simplified reference solutions.

[1] [Duro et al. 2010], [2] [Lucchini et al. 2007], [3] [Wieland et al. 2003], [4] [Bube et al. 2013]

This work has been performed within the BMWi funded VESPA project (02E10800/KIT-INE). The chemical, thermodynamic and activity model parameters derived within this work using the Pitzer approach are scheduled to be implemented into the THEREDA (Thermodynamic Reference Database) project in 2016/17.

Estimation of radionuclide source terms for generic nuclear waste disposal options within the ENTRIA project

P3-25

David Fellhauer[1], Vanessa Montoya[1], Xavier Gaona[1], Julian Schepperle[1], Volker Metz[1], Marcus Altmaier[1], Horst Geckeis[1]

[1] Institute for Nuclear Waste Disposal, Karlsruhe Institute of Technology, P.O. Box 3640, 76021 Karlsruhe, Germany, david.fellhauer@kit.edu

As a consequence of the decision to phase out nuclear power production in Germany, the identification of a safe disposal option for radioactive wastes comes more and more into focus. It is apparent that an appropriate solution, which is accepted by a major part of the public, will have to be an unbiased balance of multiple aspects, and goes far beyond mere technical aspects. ENTRIA (*http://www.entria.de*) is an interdisciplinary project funded by the German Federal Ministry of Education and Research (BMBF) where scientist from various academic disciplines (e.g. physical, applied and social science) jointly evaluate criteria to support future decision-making considering different disposal options for nuclear waste in Germany. A subtask of ENTRIA focuses on a comparison of the risks that several generic (i.e. non-site specific) disposal options may pose, namely the final disposal in deep geological formations (i) with and (ii) without the intention and consequent arrangements for a potential retrieval of the waste, respectively, as well as (iii) the long-term interim storage in engineered facilities at the surface.

In this context, one important aspect is a comparative assessment of the potential release of radionuclides from the defined generic repository options into the geosphere due to water intrusion. The principle procedure is as follows: in a first step the decisive geochemical parameters (e.g. redox conditions, pH and salinity of intruding solutions) that are expected to be representative for the generic repository systems are evaluated. Based on that, source terms for relevant radionuclides are estimated, i.e. robust limiting values of the aqueous radionuclide concentration in the vicinity of the waste canisters (near-field). For most of the radionuclides considered here, in particular the highly radiotoxic actinide elements like plutonium, the free concentrations in aqueous solutions are determined from the solubility limits using reliable experimental data and quality assured thermodynamic constants and parameters (as summarized e.g. in recent reviews of the NEA-TDB (*www.oecd-nea.org/dbtdb*) or the German THEREDA project (*www.thereda.de/de*) to which KIT-INE is contributing). The obtained thermodynamic data further serve as input parameters for reactive transport models to further assess a potential migration into the far-field of the emplacement waste. The latter is discussed in more detail in our related poster contribution by V. Montoya *et al.*.

In this contributions results of our recent solubility studies with the actinide elements plutonium and neptunium are presented. The experimental work is performed under various solutions conditions, that are representative for the boundary conditions of the different repository options in Germany (and for the generic ENTRIA options). For example, the solubility studies are systematically performed as function of the total NaCl concentration in solution, and cover both dilute (typical for clay rock and crystalline rock formations) and saline conditions (typical for salt rock as well as certain clay rock formations). The overall intention is to obtain a fundamental process understanding of radionuclide behavior in aqueous solutions and fill relevant gaps and reduce uncertainties in the thermodynamic databases used for the estimation of radionuclide source terms.

References

Acknowledgement. This work has been financially supported by the *German Federal Ministry of Education and Research* in the frame of the *ENTRIA* project (funding reference 02S9082E).

Fluid dynamic processes within a closed repository with or without long-term monitoring

P3-26

Karl-Heinz Lux, Ralf Wolters, Juan Zhao, Jörg Feierabend, Tianjie Pan, Michael Rutenberg

Clausthal University of Technology (TUC), Clausthal-Zellerfeld, Germany

Regarding the disposal of high-level radioactive waste within a repository in deep geological formations, different concepts are discussed in the international community. These concepts are not only different because of different availability of host rock formations in different nations, but also due to different demands on a long-term monitoring option to check the repository's behaviour over time. In Germany, according to its final report, the "Endlagerkommission" prefers a repository in deep geological formations, but reversibility of decisions as well as retrievability of waste canisters implied by significant improvements of scientific knowledge and technology or by an unexpected development of the repository system should be possible for future generations. A long-term monitoring option should be implemented into the repository concept to provide data about the time-dependent physical as well as the chemical situation within the repository system.

A long-term monitoring could be performed only within special observation parts of the repository, like it is considered in the Swiss concept, but in this case there will not be any data available about the situation within the main part of the repository system. Due to this, a long-term monitoring of at least preselected representative parts of the main repository or even of every single emplacement drift seems to be more suitable. This second approach is investigated in the framework of the ENTRIA-project for the drift emplacement concept, analyzing the influence of a long-term monitoring not only on the repository system's load-bearing behaviour during operational phase and during a limited monitoring phase afterwards by project partner TU Braunschweig, but also on the fluid dynamic processes as well as on barrier integrity within the emplacement drifts on the smaller scale and the whole repository system on the bigger scale by Chair in Waste Disposal and Geomechanics of Clausthal University of Technology.

For analysis of the time- and space-dependent development of fluid dynamic processes occurring in the totally backfilled emplacement level as well as in the rest of a repository system with or without implementation of a long-term monitoring option built in a salt rock or claystone formation based on physical modelling and numerical simulation, a complex simulation tool has been developed at Chair in Waste Disposal and Geomechanics of Clausthal University of Technology within the framework of the ENTRIA-project.

French Geological Disposal project: From siting to Cigéo

S7-01

Patrick Landais, Gérald Ouzounian

Andra 1-7 rue Jean Monnet. 92298 Châtenay Malbry cedex. France

The Law of 30 December 1991 constituted the first real framework for HLW research in France. Innovating approaches were pre-scribed by the Law:

- a stepwise decision-making process;
- the study of alternative solutions;
- independent assessment;
- information;
- the independence of the agency.

A public consultation was then organized with a view to seeking potential implementation sites for underground research laboratories (URL). In 1993, four candidate sites were selected: a granite site (Vienne) a deep marl (Gard), as well as two sites located in Callovo-Oxfordian argillites (Meuse and Haute-Marne). Those two last sites were rapidly combined in the Meuse/Haute-Marne Site.
1994-1996 was dedicated to geological investigations. Concurrently, local information and oversight committees and incentive funds were set in place. Based on the conclusions of its studies, Andra submitted three applications to authorize the implementation of URLs on the Vienne, Gard and Meuse/Haute-Marne Sites. In 1997, the applications were the subject of public inquiries.
The government's decision following the review of the applications confirmed the continuation of operations in the Meuse/ Haute-Marne with the creation of a URL in Bure. On the other hand, both the Gard and Vienne Sites were abandoned. In parallel, the government set in place a research mission in order to find a new granite site, but the project was not met with any local support and was finally terminated in 1999. The construction Meuse/Haute-Marne URL was initiated and the first experiments took place from 2001. The accumulated information served as the basis for the *Dossier 2005 Argile* was submitted to the government in mid-2005. The scientific and regulatory assess-ments of the *Dossier* emphasized the quality of the work and concluded to the feasibility of a deep geological repository.
The government also wished that a national debate be organised concerning the long-term management of radioactive waste. In its final report, the Commission stressed the existence of a general demand for:

- all waste categories to be taken into account by the legislation;
- the need to improve governance regarding radwaste management;
- the advantages of a stepwise decision-making process;
- the need for a true economic-incentive programme for the territories.

The 2006 Planning Act mainly aimed at reduc-ing/avoiding the burden on future generations and promoting a National Plan for the man-agement of radioactive materials and waste (PNGMDR) is promoted
On the basis of a 250 km² area defined around the laboratory, in which the results obtained on the clay layer in the laboratory can be transposed, Andra proposed in 2009 an area of interest of approximately 30 km² in which detailed geological investigations were con-ducted. In parallel, several implementation scenarios of surface facilities were investi-gated. The results were presented during a public debate in 2013. Due to a strong local opposition the tools used for the debate were adapted and allowed to identify necessary evolutions to the project:

- The integration of an industrial pilot phase into the facility startup phase;
- A master plan for Cigéo operation and closure to be regularly revised;
- More involvement of Society;

A new proposal regarding reversibility was included in the May 2016 law indicating that: Reversibility is the ability for successive gene-rations either to continue construction and operation of the repository or to reassess the choices previously defined and change man-agement solutions.

Based on the scientific and conception data available, Andra proposed a project calendar is mainly based on the following steps:

- 2016: Safety Demonstration, Retrievability options file, first draft of the master plan;
- 2018: full license application, and beginning of amenity works;
- 2021: licensing;
- 2025: commissioning, starting with the industrial pilot phase.

The last 25 years of hard work that recently resulted in the promulgation of a new Act were marked with several significant developments with regard not only to scientific and technical expertise, but also to human behaviour and governance, especially in the context of complex social challenges. 25 years after the 1991 law was passed and Andra created, several success factors can also be identified:

- Political framework with independent review bodies;
- Independence of Andra;
- Step by step approach paved by some major milestones and safety assessments;
- Site selection on the basis of voluntary sites;
- Iterative but progressive design approach based on a robust and evaluated scientific basis;
- Mobilization and involvement of national and local elected representatives;
- Strong involvement of Andra in local participation, dialog with local and national stakeholders;
- Participation of waste producers;
- Local development project/scheme and funds for it;
- A sustained information programme for the sound conduct of such projects;
- Information and Oversight Committee.

The relevance of solid solution – aqueous solution systems to the safety case for deep geological disposal of nuclear wastes

S7-02

Dirk Bosbach[1], Felix Brandt[1], Martina Klinkenberg[1], Victor Vinograd[1], Guido Deissmann[1]

[1] Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research: Nuclear Waste Management and Reactor Safety (IEK-6), Wilhelm-Johnen-Str, 52425 Jülich, Germany, d.bosbach@fz-juelich.de

The waste containers emplaced in geological disposal facilities for nuclear wastes built in crystalline rocks or clay formations will inevitably come into contact with ground water post-closure, after resaturation of the repository. Even in repositories in salt rocks, the presence of water cannot be completely ruled out for less probable scenarios, for example, an early failure of shaft seals and plugs. As a consequence, after container failure due to aqueous corrosion, radionuclides can be released from the degrading waste forms into the near-field water and subsequently migrate into the geo-/biosphere via the water pathway.

The migration behaviour of radionuclides released from the wastes into the repository near- and far-field is controlled by various processes such as sorption onto minerals and colloids (e.g. by surface complexation or ion exchange), precipitation/dissolution of solid phases, as well as entrapment in, or solid solution formation with other minerals. The latter process leads to the structural incorporation of radionuclides in a host structure. Such solid solutions are ubiquitous in natural systems – most minerals in nature are solid solutions and pure compounds are rather the exception. Also materials present in the engineered barrier system of a repository such as cementitious materials or bentonite clays can either themselves be described as solid solutions, and/or the radionuclide uptake and retardation by these materials is due to solid-solution formation. Moreover, many nuclear waste-forms such as spent nuclear fuels, cemented wastes, and crystalline ceramic waste forms discussed for the conditioning of plutonium or mobile fission products are basically radionuclide bearing solid solutions.

In many cases the formation of solid solutions leads to a thermodynamically more stable situation compared to the formation of pure compounds, due to a negative excess Gibbs energy of mixing. However, the aspect of solid-solution thermodynamics and the effects of solid-solution formation on radionuclide solubility and mobility are considered only rarely in specific cases in long term safety assessments for nuclear waste repository systems at present (e.g. Bruno et al. 2007).

Here, we present and discuss the development and application of thermodynamic models for solid solution – aqueous solution systems and their relevance to nuclear waste management and safety assessments for deep geological repositories, emphasizing the significance of complementary experimental and state of the art computational approaches (e.g. atomistic modelling). Using the uptake of radium by barite ($BaSO_4$) as well as radionuclide-cement interactions as examples, it is demonstrated that an improved mechanistic understanding of solid solution thermodynamics and its consideration in performance assessments leads to a more realistic and scientifically corroborated picture on release, solubility, and subsequent migration of safety relevant radionuclides in the repository near- and far-field. Thus the development and application of thermodynamic models for relevant solid solution – aqueous solution systems can contribute to the scientific basis of the safety case, allowing for the evaluation of safety margins, and enhancing the confidence in the safety case reasoning.

References

Bruno, J., Bosbach, D., Kulik, D. & Navrotsky, A. (2007): Chemical thermodynamics of solid solutions of interest in nuclear waste management. OECD, Paris, 266 pp.

Application of the Technology Readiness Assessment (TRA) Process to Deep Geologic Repository Systems

S7-03

S. David Sevougian and Robert J. MacKinnon[1]

[1] Sandia National Laboratories, PO Box 5800, MS 0747, Albuquerque, NM 87185, sdsevou@sandia.gov

Technology Readiness Assessment (TRA) is a formal process to aid in defining the remaining research and development (R&D) effort to bring a new technology system to full technical maturity or operational readiness (DOE 2013). The TRA process assigns a technology readiness level (TRL) to key components of a system, called Critical Technology Elements (CTEs). The major uses of the TRA process are to not only minimize technical risk associated with deployment and operation of (often) one-of-a-kind complex systems and technologies, but also to inform the assignment of capital and manpower in a logically laid-out project development schedule—i.e., to optimize resource deployment.

Because a repository or geologic disposal system is comprised of both engineered barriers and natural (or geologic) barriers, the established TRA process must be adapted. In particular, although it is engineered technologies (such as tunnel construction and waste emplacement) and physical components (such as buffer materials/design and waste package materials/design) that must be assessed and matured for the repository engineered barrier system (EBS), it is *knowledge* of the initial state and altered states (e.g., the disturbed rock zone) that must be assessed and matured for the natural barrier system (NBS). Long-standing precedence employs a Repository Safety Case as the preferred vehicle for assembling all facets of knowledge and confidence bases to make a determination of system safety and deployment readiness. However, modifications of the TRA process, as proposed here, all its application to major subsystems and technologies associated with a geologic disposal system.

Two observations about geologic repositories help to determine how a TRA process may be applied to various repository subsystems and technologies:

1) Technology development and related RD&D activities for geologic repositories have a natural "temporal" division into technologies related to *pre-closure* activities and technologies related to *post-closure* system evolution.
2) Technologies and RD&D activities related to the *post-closure* performance of geologic repositories have a natural "spatial" or physical division into two key subsystems or components: engineered barriers and natural barriers.

Most major *pre-closure* technologies (e.g., construction, excavation, and testing technologies) are candidates for a formal TRA, with CTEs defined and rated according to a well-established TRA process for equipment-based (or man-made) technologies (DOE 2013).

Regarding maturation of the *post-closure* repository system, we propose a union of the traditional features, events, and processes (FEPs) approach (Freeze et al. 2014) with the formal TRA process, to assess the maturity of major *post-closure* repository subsystems and technologies. In particular, the major steps of the TRA process are retained, i.e., definition of CTEs, evaluation of TRLs or a similar technical maturity metric, and the development of a technology maturation plan to organize the future RD&D needed to increase the system TRL. However, the selection of CTEs is based on FEPs, and the TRL assessment process for the chosen repository CTEs is simplified for those major post-closure subsystems influenced strongly by natural processes, to reflect that their technical maturity is based on knowledge maturation rather than engineered component maturation.

This abstract is Sandia publication SAND2016-3085A. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

References

DOE (US Department of Energy) 2013. *Technology Readiness Assessment (TRA)/Technology Maturation Plan (TMP) Process Implementation Guide, Revision 1*, U.S. Department of Energy Office of Environmental Management, Washington, D.C., August 2013.

Freeze, G., S. D. Sevougian, C. Leigh, M. Gross, J. Wolf, J. Mönig, and D. Buhmann 2014. "A New Approach for Feature, Event, and Process (FEP) Analysis of UNF/HLW Disposal – 14314," in *Proceedings of the WM2014 Conference*, March 2 – 6, 2014, Phoenix, Arizona USA.

Current state of knowledge on Zircaloy cladding properties under conditions of prolonged dry interim storage

S7-04

Volker Metz[1], Michel Herm[1], Ernesto González-Robles[1], Horst Geckeis[1]

[1] Karlsruhe Institute of Technology, Institute for Nuclear Waste Disposal (KIT-INE), Karlsruhe, Germany, volker.metz@kit.edu

Currently, spent nuclear fuel (SNF) assemblies discharged from German power reactors are stored in dual purpose metal casks (CASTOR®). The SNF management concept is based on the presupposition that sufficient disposal capacity will be available in a deep geological repository until 2050 (NaPro, 2015). However, due to considerable delays in the development of a selection process for a disposal site and an estimated duration of the construction and commissioning of a repository of at least two decades, a significant amount of SNF has to be kept in the twelve existing dry storage facilities for 65 to 100 years (ESK, 2015). The expected duration of SNF dry storage in facilities on-site of the nuclear power plants exceeds by far the initially planned and licensed storage period of up to forty years. Therefore, all safety relevant issues have to be reviewed on basis of the present state-of-art which might differ from the initial safety demonstrations, aimed for few decades of dry SNF storage (Wolff et al., 2013).

Besides other aspects, the long-term integrity of the Zircaloy cladding of irradiated fuel rods is of concern. The integrity of the cladding is decisive for any handling of the irradiated fuel rods after interim storage. In case, the cladding integrity will not be ensured, reloading of fuel assemblies from CASTOR® to disposal containers will be considerably aggravated, in order to prevent any release of volatile radionuclides in the interim storage facilities.

This contribution highlights main issues of the current state of knowledge on physicochemical properties of Zircaloy under conditions of prolonged dry interim storage During irradiation in the nuclear reactors, the cladding is affected both (a) by interactions with the cooling water, causing to some extent oxidation of the outer cladding surface and hydride precipitation within the Zr alloy, and (b) by corrosion with volatile fission products (e.g. iodine compounds) at the cladding / fuel pellet interface. These chemical reactions leads to embrittlement and weakening of the cladding mechanical properties. Due to the built-up of fission products during irradiation, lattice swelling of the nuclear fuel occurs, which exerts mechanical stress on the cladding. After discharge of SNF from reactors, delayed hydride cracking is relevant for the Zircaloy integrity. Moreover, alpha-decay results in continuous He accumulation, displacement of atoms inside the fuel matrix, enhanced lattice swelling, which enlarge the mechanical stress on the cladding with time. The tendency towards creep and stress corrosion cracking is stronger for spent MOX fuels relative to spent UOx fuels and increases with the respective burn-up and storage time. Present experimental studies focus on chemical interactions between Zircaloy and precipitates of volatile fission products at the plenum of an irradiated fuel rod, where pellet-cladding-interactions cannot occur.

References

ESK (2015): Diskussionspapier zur verlängerten Zwischenlagerung bestrahlter Brennelemente und sonstiger Wärme entwickelnder radioaktiver Abfälle. Entsorgungskommission, Bonn, Germany, October 2015.

NaPro (2015): National programme for the responsible and safe management of spent fuel and radioactive waste. Federal Ministry for the Environment, Nature Conservation, Building and Reactor Safety, Berlin, Germany, August 2015.

Wolff, D., Völzke, H., Wille, F., Droste, B. (2013) Extended storage after long-term storage. Proc. 17th Int'l Symp. Packaging Transportation Radioactive Materials, PATRAM, San Francisco, USA, August 2013.

Towards a Joint Programme 'co-fund action' of EU Member States' and Euratom research programmes in the management and disposal of radioactive waste

S8-01

Christophe Davies

European Commission, DG Research and Innovation, Fission Energy, Christophe.davies@ec.europa.eu

Since 1975 the European Commission (EC) has been implementing, under the provisions of the European Atomic Energy Community (Euratom) Treaty, Research and Training (R&T) programmes on radioactive waste management, in which all European Union (EU) Members States participate.

The current R&T Programme (the 'Euratom Programme') (2014-2018), complementing the Horizon 2020 Framework Programme for Research and Innovation (R&I), is the ninth continuous programme in this field.

In 2011, the role and mandate for EU support to joint collaborative research on nuclear fission was reinforced with the adoption by the Member States (MSs) of the Council Directive 2011/70/Euratom establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste (the waste Directive). The Directive requires each MS to establish and maintain national policy and legislative, regulatory and organisational framework for managing all types of radioactive waste from generation to disposal. This includes establishing a national programme with significant milestones and clear timeframes, as well as Research Development & Demonstration activities needed in order to implement technical solutions.

R&I activities of the Euratom programme are implemented in two ways, by participants in the MSs called 'indirect actions' with co-funding by the EU programme and by the Commission through its Joint Research Centre (the 'JRC') the 'direct actions'.

A key principle of the Euratom programmes indirect actions is to perform joint and/or coordinated cutting-edge research, to support knowledge creation and knowledge preservation. The aim is eventually to promote the development of a common Union view on the main issues related to waste management from discharge of fuel to disposal in order for MSs to implement safe, sustainable and publicly acceptable solutions in the processing and disposal of radioactive waste. Criteria for Euratom support to research activities are scientific excellence, impact of the research and quality and efficiency of implementation of the project or action.

Over the years, the scope and focus of the Euratom programmes has evolved with the state of knowledge and needs in the participating MSs. The programmes have covered all waste categories, from low level short-lived to high-level long-lived waste and spent fuel and on the associated management solutions including pre-disposal (treatment and conditioning), site characterisation, near surface and geological disposal.

From the nineties, as the management methods, technologies and disposal solutions for short-lived and intermediate level waste became widely implemented, research was gradually directed to geological repositories and high level and long-lived waste and spent fuel. A large number of projects were and continue to be implemented in underground research laboratories.

In addition to scientific, technical research projects the Euratom programme provides for coordination and support actions (CSAs) on specific issues and topics. Interest in several MSs has therefore led to implementation in the period 2003 to 2009 of two CSAs which aim was to promote and support the networking and coordination of activities on shared EU radioactive waste storage and disposal. The possibility for MSs willing to cooperate on the sharing of facilities for spent fuel and radioactive waste management, including disposal facilities, is mentioned in the 2011 waste Directive as a potentially beneficial, safe and cost-effective option when based on an agreement between the Member States concerned.

During the sixth Euratom Framework Programme (FP) of the EC, FP6 (2002-2006), focus was gradually placed on addressing key remaining issues and uncertainties for implementation of geological repositories as well as on increased integration of the activities and the research community through support of large integrated projects.

In FP7 (2007-2013) in order to make decisive progress towards geological disposal the EC fostered the launch of the Implementing Geological Disposal – Technology Platform (IGD-TP) led by "Implementers" responsible for geological disposal of higher radioactive waste. Focus of FP7 was then placed on implementation oriented research for the actual implementation of the first repositories in Europe by 2025.

At the start of Horizon 2020, after forty years of support to research the Euratom programme can be considered as a very mature programme having covered research on all radioactive waste management aspects and disposal solutions. Actual implementation of the first geological repositories by 2025 is now in sight with approval of the first steps in 2015 and 2016 towards final authorisation by the regulatory authorities to construct and operate such facilities in Finland and Sweden.

Therefore, the purpose, focus and implementation method of the Euratom R&T programme activities deserve to be reviewed to ensure continued effective and efficient support for the twenty eight MS national programmes in addressing the societal challenges of the management of radioactive waste in the coming decades.

Operation of geological repositories is expected to last in excess of 100 years. This implies that in parallel to implementation-oriented research long-term science and innovation -oriented research should be reinvigorated in order to continue improve understanding, knowledge and tools on cutting-edge topics, processes and solutions of radioactive waste management from predisposal to disposal. At the same time, a large gap is now observed between the so called advanced programmes and those in MSs in which plans and progress towards geological disposal is much less mature and/or in which start of operation is scheduled only in several decades from now. In the meantime, existing and expected increase in the coming years in the number of requests to safety/regulatory authorities for authorisation to build geological repositories calls for increase coordination and exchange of best practices and appropriate research activities by technical support organisations (TSO) for the development and maintenance of adequate competence to review the safety cases. Past examples of Euratom projects has shown that implementers and TSOs are able to participate in the same project with specific independent objectives, while respecting independence in their respective role regarding repository safety cases. Finally, in consideration of the above situation Euratom as a community has a key role to play in the development of an Integrated Knowledge Management System (IKMS). In developing text books on science in Radioactive Waste Management, guidance for research at different stages of programmes, organising related training and dissemination and addressing strategic topics, such IKMS will avoid unnecessary duplication of research and greatly facilitate transfer of knowledge and expertise on the one hand from the generation who have designed the radioactive waste management and disposal concepts and solutions to those that will operate and ultimately close them and on the other hand from more mature programmes to the less-advanced programmes.

Given the above considerations, the range of common issues in MSs, the advanced practice of collaboration and joint actions between actors in the field and the role of Euratom programme the EC considers timely to support the launch of an integrated and coordinated joint programme of EU added-value research activities between MSs.

The JOPRAD EC funded project (Towards a Joint Programming on Radioactive Waste Disposal) launched in 2015 is investigating the feasibility and preparing the technical and organisational background for implementation of such common research programme between MSs national programmes.

The Safety Case for the Morsleben Repository – Evaluation of Suitable Time Frames for Post-Closure Safety Assessment

S8-02

Matthias Ranft[1], Jürgen Wollrath[1], Matthias Niemeyer[2]

[1] Federal Office for Radiation Protection (BfS), Willy-Brandt-Straße 5, 38226 Salzgitter, Germany, mranft@bfs.de, jwollrath@bfs.de

[2] ÅF-Consult Switzerland Ltd, Täfernstraße 26, 5405 Baden, Switzerland, Matthias.Niemeyer@afconsult.com

The former Morsleben radioactive waste disposal facility (ERAM) in Saxony-Anhalt, near Helmstedt, Germany is located in a salt formation. The 525 m deep Shaft Bartensleben connects 4 main mining levels between 386 m and 596 m b.g.s. and the 520 m deep Shaft Marie connects two main levels. Due to rock salt and potash production, many cavities exist in this former mine with dimensions of up to 100 m in length, 30 m in width and in height. The total volume amounts to about 8,000,000 m^3 of underground cavities.

In 1971 the operation of the ERAM for predominantly short-lived low-level radioactive waste started. Different areas of the mine were used to dispose of the waste using different techniques (dumping of solid waste and drums, stacking of drums and cylindrical concrete containers, and in-situ solidification of liquid waste). By the end of the operational phase in September 1998 a total waste volume of about 37,000 m^3 with a total activity of approx. $9.3 \cdot 10^{13}$ Bq (as of 2014) has been disposed of.

The licensing procedure of the closure of the ERAM has been initiated and the respective documents have been issued to the licensing authority in 2009. Due to a recommendation of the German Nuclear Waste Management Commission (ESK) issued in 2013 the BfS has to discuss the time frames suitable for the post-closure safety assessment.

Based on the evolution of the radiotoxicity with time two time frames have been proposed by BfS: a first time frame ranging from 0 to 100,000 years and a second time frame ranging from 100,000 to 1,000,000 years. The radiotoxicity of the radioactive waste disposed of in ERAM is reduced by three orders of magnitude in the first 100,000 years and stays nearly constant for the rest of the 1,000,000 years time frame. The radiotoxicity in the time frame ranging from 100,000 years to 1,000,000 years is dominated by the natural Uranium. Therefore, based on the specific inventory of the ERAM, it is allowed to split the timeframe into the two proposed periods.

Nevertheless the radiotoxicity cannot be linked directly to the protection goals of limiting the radiation exposure given by the German Commission on Radiological Protection (SSK 2010). Therefore, the safety of the ERAM in the first time frame will be evaluated by a comprehensive safety assessment that is based on a scenario development procedure according to the German Safety Requirements Governing the Final Disposal of Heat Generating Radioactive Waste (BMU 2010). The safety in the second time frame will be demonstrated by simpler calculations referring to the simplified radiological statement without modelling the dispersion of substances in the overburden and adjoining rock (see Section 7.2.2 of BMU 2010).

These calculations resulting in the assessment of radiological consequences will complement statements about the site characteristics and the closure concept that will substantiate the minimisation of the probability of radionuclides reaching the accessible environment and therefore contributing to the robustness of the safety of the disposal system. The arguments will be based on comprehensive geomechanical calculations investigating the integrity of the salt barrier surrounding the waste emplacement areas and the avoidance of weaknesses in the salt barrier that might lead to the inflow of liquid into the remaining openings in the former salt mine.

References

SSK (2010): Radiological Requirements for the Long-Term Safety of the Morsleben Repository for Radioactive Waste (ERAM). http://www.ssk.de/SharedDocs/Beratungsergebnisse_E/2010/Radiologische_Anforderungen_Morsleben_ ERAM.html?nn=2876402

BMU (2010): Safety Requirements Governing the Final Disposal of Heat Generating Radioactive Waste. http://www.bmub.bund.de/en/topics/nuclear-safety-radiological-protection/nuclear-safety/details-nuclear-safety/artikel/safety-requirements-governing-the-final-disposal-of-heat-generating-radioactive-waste/?tx_ttnews[backPid]=256&cHash=bbf5f172f9319eca690ad46518411c1c

Smart K_d-concept for realistic description of sorption processes

S8-03

M. Stockmann[1], D. Becker[2], J. Flügge[2], J. Schikora[1], U. Noseck[2], V. Brendler[1]

[1] Institute of Resource Ecology, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

[2] Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Braunschweig, Germany

Sorption on mineral surfaces is an important retardation process to be considered in safety assessments of both chemotoxic and radioactive waste repositories. Most often conventional conservative concepts with temporally and spatially constant distribution coefficients (K_d-values) are applied in reactive transport simulations.

This work describes, for the first time, a new methodology, where temporally and spatially variable distribution coefficients, so-called smart K_d-values were calculated for a more realistic description of sorption processes. This concept is based on a Bottom-Up approach (Davis 1998) of a competitive mineral-specific sorption of dissolved species on surfaces, combining surface complexation models with ion exchange and precipitation in a quasi-thermodynamic manner. The respective multi-dimensional matrices are computed a-priori to any run of the reactive transport codes (here: r³t, Fein 2004). During the run of such transport codes respective calls to the K_d–matrix with an appropriate averaging deliver parameter-specific K_d–values.

Three computer codes were coupled to form one tool: PHREEQC, UCODE and SIMLAB. This strategy has various benefits: (1) One can calculate smart K_d-values for a reasonable number of environmental parameter combinations; (2) It is possible to perform uncertainty and sensitivity analysis based on such smart K_d-matrices; (3) The approach is highly flexible with respect to chemical reactions and environmental conditions; (4) The overall methodology is much more efficient in computing time than a direct coupling of the geochemical speciation code with reactive transport codes.

The capability of this new methodology is demonstrated for the sorption of radioactive waste repository-relevant elements such as U, Am, or Np on a natural sandy aquifer. This served as a proof-of-concept for the new methodology to describe the sorption behavior in dependence of changing geochemical conditions. Results were compared to conservative K_d–values from literature used so far.

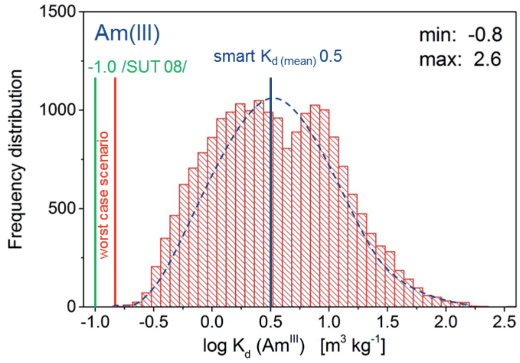


Fig 1: K_d histogramm for Am(III) in the upper aquifer of the Gorleben cap rock

Sensitivity and uncertainty analysis for the nuclides revealed the importance of ternary interaction effects, the non-concervatism of some generic distribution coefficients used so far, and the effects of input parameter correlation. Moreover, a ranking of the sensitivity of the environmental parameters nearly always put pH value, dissolved inorganic carbon and the content of matrix cations (either as complexants or competitors on the sorption sites) in the first places. The effects of organics will be considered in the next project phase as there both model design and parameterization is very challenging. In any case, the mechanistic processes involving them (and their error distribution functions) should deserve higher attention in future research schemes.

References

Davis, J. A., Coston, J. A., Kent, D. B., Fuller, C. C. (1998): Application of the surface complexation concept to complex mineral assemblages. Environ. Sci. Technol. 32, 2820-2828.

Fein, E. (2004): Software Package r^3t. Model for Transport and Retention in Porous Media. Report GRS-192, Braunschweig.

High-resolution characterization of the EDZ in the Callovo-Oxfordian Clay using time lapse hydraulic tomography

S8-04

Ralf Brauchler[1], Rémi de La Vaissière[2], Jean Croisé[1], Rainer Schwarz[1], Reto Thöny[1], Ralph Mettier[1]

[1] AF-Consult Switzerland Ltd, Taefernstrasse 26, 5405 Baden, Switzerland, ralf.brauchler@afconsult.com
[2] Andra, Département Recherche & Développement, Service Mécanique des Fluides et des Solides, Route Départementale 960, 55290 Bure, France, Remi.Delavaissiere@andra.fr

The Meuse / Haute Marne Underground Research Laboratory (URL) provides the location for an experiment, designed to investigate the induced fracture network around open or sealed drifts. The aim of this experiment, called the CDZ-experiment (Compression of the Damaged Zone) is to study the effects of mechanical loading and unloading on the mechanical and hydraulic properties of the EDZ (Excavation damaged zone). In the context of this experiment, a large number of gas permeability tests were performed between six closely spaced wells prior to and after the mechanical loading of the EDZ. The tests allow for the characterization and quantification of the effect of the mechanical loading on the hydraulic (pneumatic) properties of the EDZ (de La Vaissière et al., 2014).
The gas tests were first analyzed based on the pressure and flowrate data recorded solely at the source boreholes using the numerical borehole simulator Multisim, which was developed by AF-Consult Switzerland Ltd. Multisim is particularly suited for the analysis of hydraulic tests performed in low permeability media.
In a second step, the cross-hole pressure responses of the gas permeability tests were analyzed with a travel time based tomographic approach proposed by Brauchler et al. (2003). The inversion is based on the transformation of the transient ground water flow equation into the eikonal equation using an asymptotic approach. The eikonal equation can be solved with ray tracing techniques or particle tracking methods, which allows the inversion of large data sets in a short time with relatively low computational effort (common PC). The main feature of this procedure is a travel time integral relating the square root of the peak travel time, assuming a Dirac point source at the origin, to the inverse square root of the hydraulic diffusivity.
The reconstructed three-dimensional hydraulic diffusivity distribution displays the different zones of the EDZ with a high level of detail and provides important information about the spatial distribution of hydraulic parameters within the EDZ. Particularly, the reconstructed diffusivity distribution reflects the different zones of the excavation-induced fracture network described by Armand et al. (2014), wherein the fracture network was characterized in great detail, based on drill-core logging and resin injection. The comparison of the hydraulic tomographic results prior and after the mechanical loading allow for a quantification of the change in hydraulic properties caused by mechanical loading with a spatial resolution not possible with conventional test analysis techniques. It could be shown that the effect of the mechanical loading on the spatial distribution of the hydraulic properties is in good agreement with the predicted induced stress field.

References

Armand, G., Leveau, F., Nussbaum, C., de La Vaissiere, R., Noiret, A., Jaeggi, D., & Righini, C. (2014). Geometry and properties of the excavation-induced fractures at the Meuse/ Haute-Marne URL drifts. Rock mechanics and rock engineering, 47(1), 21-41.

Brauchler, R., Liedl, R., & Dietrich, P. (2003). A travel time based hydraulic tomographic approach. W, 39(12), 1370.

de La Vaissière, R., Morel, J., Noiret, A., Côte, P., Helmlinger, B., Sohrabi, R. & Nussbaum, C. (2014). Excavation-induced fractures network surrounding tunnel: properties and evolution under loading. Geological Society, London, Special Publications, 400(1), 279-291.

Redox dependent interfacial reactivity of hexavalent radionuclides S8-05

Stefan Hellebrandt[1], Karah E. Knope[2,†], Sang Soo Lee[2], Aaron J. Lussier[3], Joanne E. Stubbs[4], Peter J. Eng[4], L. Soderholm[2], Paul Fenter[2], Moritz Schmidt*[,1]

[1] Helmholtz-Zentrum Dresden-Rossendorf, Institute of Resource Ecology, Bautzner Landstraße 400, 01328 Dresden, Germany, S.Hellebrandt@hzdr.de, Moritz.Schmidt@hzdr.de

[2] Argonne National Laboratory, Chemical Sciences and Engineering Division, 9700 Cass Ave, 60439 Lemont, IL, USA, Karah.Knope@georgetown.edu, sslee@anl.gov, ls@anl.gov; Fenter@anl.gov

[3] University of Notre Dame, Department of Civil & Environmental Engineering & Earth Sciences, 46556 Notre Dame, IN, USA, Aaron.J.Lussier.4@nd.edu

[4] University of Chicago, Center for Advanced Radiation Sources, 5801 S. Ellis Ave, 60637 Chicago, IL, USA, Stubbs@cars.uchicago.edu, Eng@cars.uchicago.edu

[*] Current address: Georgetown University, Department of Chemistry, 20057 Washington, DC, USA.

A solid comprehension of the geochemical behavior of radionuclides on a molecular level is essential to make reliable long-term predictions about the safety of a nuclear waste repository. The mobility of radionuclides in the environment and thus their hazard potential will also be controlled by the reactivity at the water/mineral interface. In order to understand these processes analytical methods shall ideally be both surface specific and sensitive. X-ray reflectivity techniques, particularly resonant anomalous X-ray reflectivity (RAXR) and crystal truncation rod (CTR) measurements have proved to be a successful combination to investigate geochemical interfacial regimes (Fenter 2002).

Plutonium is one of the most important radionuclides in term of nuclear waste disposal due to its long half-life period and high radiotoxicity. That's why it has been subject of different studies over the last decades. While these studies could show an enhancement of the mobility of plutonium in the presence of colloidal matter, the formation of Pu(IV)-nanoparticles is still content of ongoing research (Walther & Deneke 2013). Recently, Schmidt et al. suggested a surface-catalyzed formation due to an enhanced concentration of Pu(III) at the surface in equilibrium with a small amount of Pu(IV). Part of the current study was to proof the viability of this mechanism, but also to investigate the interfacial reactivity of Pu's various oxidation states.

The interaction of UO_2^{2+} and PuO_2^{2+} with muscovite mica and the effect on the actinides' different redox properties were investigated using a combination of surface X-ray diffraction, alpha spectrometry and grazing-incidence X-ray adsorption near-edge structure (GI-XANES) spectroscopy. Although, U(VI) often is used as a homologue for Pu(VI), this study show a completely different behavior of Pu(VI) and U(VI). Starting with a Pu(VI) solution, Pu(IV)-nanoparticles were formed and adsorbed on the mineral surface. The suggested formation mechanism is similar to that of Pu(III). No such adsorption or nanoparticle formation was observed for U. Our results reveal major differences between Pu and U concerning redox and adsorption behavior, influencing their mobility in the environment. Regarding the prediction of the fate of these contaminants' in aqueous systems their different interfacial behavior is of importance. This in turn significantly effects the quality of predictions of the allocation of these contaminants in aqueous systems.

References

Schmidt, M., et al. (2013): Surface-Mediated Formation of Pu(IV) Nanoparticles at the Muscovite-Electrolyte Interface. Environ. Sci. Technol., 47; 14178-14184.

Walther, C., & Denecke, M. A. (2013): Actinide Colloids and Particles of Environmental Concern. Chem. Rev., 113, 995-1015.

Fenter, P. (2002): X-ray Reflectivity as a Probe of Mineral-Fluid Interfaces: A User Guide. Rev. Mineral. Geochem., 49, 149-221.

Long-term durability of low alkali cements: comparison of novel natural and archaeological analogue data

S8-06

W. Russell Alexander[1] & Heini M. Reijonen[2]

[1] Bedrock Geosciences, Veltheimerstrasse 18, 5105 Auenstein, Switzerland. russell@bedrock-geosciences.com
[2] Saanio & Riekkola Oy, Laulukuja 4, 00420 Helsinki, Finland. heini.reijonen@sroy.fi

Bentonite makes an important contribution to the performance of the engineered barrier system (EBS) in many repository design concepts. The choice of bentonite results from its favourable properties for isolation and containment of the waste and its stability in relevant geological environments. However, bentonite – especially the swelling clay component (smectite) that contributes to its essential barrier functions – is unstable under high pH conditions (pH > 11). Consequently, there has been increased interest in utilising low alkali cements (with a leachate pH of 9 to 11) in areas of a repository which will contain bentonite backfill or seals.

However, there are little data available which address the likely long-term durability of such cements. But this this could be examined through the combined investigation of appropriate archaeological and natural analogues of low alkali cement.

For the former example, low alkali cement is essentially the same as the pozzolanic cements developed by the Romans in the 3rd century BC. The Romans particularly used the pozzolan cements in positions where it was important to prevent the penetration of water or damp, such as lining water channels and tanks (e.g. lining parts of the aquaduct Aqua Marcia near Rome in 144 BC). The cement also offered good resistance to seawater and so was used extensively for Roman marine structures. Consequently, to offer a comparison with natural cements, recently reported data from the analysis of a wide range of Roman pozzolanic cement will be presented. Overall, the project aims included:

- analysis of the concrete matrix to determine size, material, and proportions of micro and macro-aggregate
- comparison of the relative compressive strength and density of the various natural and archaeological concretes
- identification of indications of leaching and general degradation of the concretes

Of course, comparison with the original properties of the cement is not possible and while any leaching or reaction of these cements is difficult to ascertain, it is likely that the different methods of handling the Roman cements when compared to modern low alkali cements plays a role in any differences. However, the above noted differences could be tested in two simple ways:

- make modern low-heat cements using the Roman handling methods
- make Roman cements using today's handling methods

and then compare the physical and mechanical properties, allowing a rapid assessment of any handling-related differences which could be subtracted from the properties described here.

For the case of natural analogue data, it has been speculated that the production of natural concrete, formed when calcium carbonate saturated groundwaters seeped through pozzolana, may have suggested the formula for hydraulic mortar to Roman engineers. Samples of this natural material have been recovered and will be examined with a focus on the durability of the cement.

These data can then be combined with that from the Roman cements discussed above and the results presented in a manner which will allow their utilisation in a repository safety case which requires additional, non-traditional support for the long-term durability of low alkali cement.

RESET of United States Nuclear Waste Management Strategy and Policy

S9-01

Rodney Ewing[1]

[1] Center for International Security and Cooperation, Stanford University, Stanford, CA 94304
rewing1@stanford.edu

In 2015, Stanford University* initiated a series of meetings: *Reset of U.S. Nuclear Waste Management Strategy and Policy*: http://cisac.fsi.stanford.edu/research/nuclear-waste-reset-initiative

The motivation for these meetings is that the U.S. nuclear waste management program is stymied on multiple fronts – from the disposal of HLW and transuranic waste of defense programs, to spent nuclear fuel from commercial nuclear power plants, and even, the disposition of fissile material from dismantled nuclear weapons.

In 2002, Congress approved President George W. Bush's decision that a site at Yucca Mountain in Nevada be selected for the nation's repository for high-activity radioactive waste. In 2008, the DOE submitted an application to the Nuclear Regulatory Commission to construct that facility. Two years later, the Administration concluded that developing a repository at Yucca Mountain was "unworkable." The *Blue Ribbon Commission on America's Nuclear Future* (BRC) was charged to make recommendations on what steps should be taken next. The BRC issued its final report in January of 2012. DOE responded favorably to the report in January, 2013. Bi-partisan legislation to implement at least some of the BRC's recommendations has been introduced in the Senate, and hearings were held. But the measure never came to a committee vote.

Today, a stalemate prevails between those who continue to maintain that the Yucca Mountain project is "unworkable" and those who maintain that the selection of the site has been enacted into "law". The stalemate shows no sign of being broken soon.

Against this background, the first meeting assembled a steering committee whose members had extensive experience with nuclear waste management programs (http://cisac.fsi.stanford.edu/sites/default/files/bios_steering_committee_march_7.pdf).

The charge of the committee was to identify the critical issues that must be addressed and understood in order to move the U.S. program forward. The issues identified in order of priority were:

- ✓ Creation of a new waste management organization - structure, properties, and characteristics
- ✓ Definition of a consent-based process for siting nuclear facilities
- ✓ Integration of the back-end of the nuclear fuel cycle - from production to disposal
- Review of regulations and risk assessment methodologies
- Risk assessment of the *status quo* of the U.S. system over the immediate future (100 to 200 years)

To date, meetings have been held to address the first three topics. The fourth meeting on regulations and risk methodologies will be at Stanford University on October 27, 2016. This presentation will describe the meetings and provide preliminary comments on the discussions at each meeting.

*Support has been provided by the Freeman Spogli Institute for International Relations, the Precourt Institute for Energy, both at Stanford University, and the MacArthur Foundation.

Public participation and safety – Considering different notions of risk in the safety assessment of potential siting areas?

S9-02

Anne Eckhardt[1]

[1] risicare GmbH, Bühlstrasse 22, 8125 Zollikerberg, Switzerland, anne.eckhardt@risicare.ch

When siting areas for repositories for radioactive waste are selected, the primacy of safety generally is not contested. However, what does safety mean in this context? And who should decide how safety is defined? Research on risk perception and the evaluation of risks reveals that safety is a rather complex construct – for scientific and technical experts as well as for members of the general public. Individual persons have differentiated notions of safety and risk. These notions are determined by the source of the risk, the societal framework, and characteristics of the persons themselves (Marti 2016).

Experiences with the site selection process in Switzerland, so far demonstrate that the interest of the concerned population in safety issues is considerable. The Technical Safety Forum, which has been set up under the auspices of the sectoral plan, up to now has treated more than 120 technical and scientific questions on the disposal of radioactive waste (ENSI 2016). Safety is a recurrent topic in the potential siting regions. These regions even established working groups specializing in safety on their own initiative. In this context, the interest of dedicated individuals living in a potential siting region or of local and regional organisations to have a say in questions of safety seams comprehensive.

The NEA Forum on Stakeholder Confidence formulated the recommendation to achieve ownership of communities in the siting process. Ownership means that a community is empowered to define problems and their solutions. In acting this way, the community should work together in partnership with other responsible actors (OECD/NEA 2013). To what extend this ownership should also cover the field of safety, needs to be discussed.

An important question which arises, therefore, is: To what extend can and should different notions of safety and risk become part of safety assessments? In answering this question we presume that safety assessments must not only be accepted but also acceptable for present and future generations

Investigations on notions of risk commonly generate results, which are analytical and descriptive. They are not oriented towards normative obligation. Different notions of risk reflect different value systems but also characteristics and influences which are irrelevant from a normative point of view. An example of this is the habituation to a source of risk.

From an ethical point of view, it is therefore not justified to integrate different notions of risk which are widespread in the concerned communities in risk assessments of potential sites for repositories directly. It is worth reflecting, however, about the normative content of these notions. Furthermore, in many cases it is possible to build bridges between conflicting positions on the safe disposal of radioactive waste in public and scientific discourse when differing notions of risk are considered seriously (Eckhardt & Rippe 2016).

References

Eckhardt, A. & Rippe, K. P. (2016): Risiko und Ungewissheit bei der Entsorgung hochradioaktiver Abfälle, vdf Hochschulverlag; Zürich.

ENSI (2016): Technisches Forum Sicherheit. http://www.ensi.ch/de/technisches-forum-sicherheit/?noredirect=de_DE. 20.4.2016.

Marti, M. (2016): Risikoansichten. ENTRIA-Arbeitsbericht; Hannover.

OECD/NEA (2013): Stakeholder confidence in radioactive waste management, an annotated glossary of key terms, NEA No. 6988; Paris.

Experience of Geological Disposal Site Selection in the UK

S9-03

Natalyn Ala[1]

[1] Radioactive Waste Management, Curie Avenue, Harwell-Oxford, Didcot, OX11 0RH, natalyn.ala@nda.gov.uk

A geological disposal facility (GDF) is a highly-engineered facility capable of isolating radioactive waste within multiple protective barriers, deep underground, to ensure that no harmful quantities of radioactivity ever reach the surface environment. To identify potential sites where a GDF could be located, the UK Government favours a consent-based approach, working with communities that are willing to participate in the siting process. Within the UK, Radioactive Waste Management (RWM) has been established as the organisation to deliver a GDF.

The policy framework to which the UK is working was published in 2014 within the Government White Paper *Implementing Geological Disposal: a framework for the long-term management of higher activity radioactive waste* (DECC 2014). This White Paper establishes a number of consent-based principles to which RWM as the GDF developer is working.

To identify potential sites where a GDF could be located, the policy framework sets out the consent-based approach. Following the "launch" of the process (expected 2017) RWM is preparing to be in a position to respond to requests for information from communities that want to find out more about the benefits of hosting a GDF. Decision-making whether to engage with RWM in order to find out more about hosting a GDF, whether to coninue in the process and ultimately whether to commit to hosting such a facility will rest with the community who will also hold the right of withdrawal until such time that a test of public support has been undertaken. A GDF is likely to bring significant economic benefits to a community that hosts it in the form of long-term investment and infrastructure development. Government has also committed to providing short-term additional investment to those communities that constructively engage in the siting process.

As part of the preparations leading up to the launch of the siting process, RWM is undertaking a national geological screening exercise based on known geological information that is relevant to the long-term geological safety case. Government is also developing the policy for how communities that may be interested can engage. This includes an approach to community representation and engagement with the developer, providing information on community investment and establishing methods by which communities can seek independent third-party advice during the process.

The UK preference for a consent-based approach can be traced back to experience in the 1990s when the search for a site for disposal of intermediate level waste was halted due to the rejection of the planning application for a pre-cursor rock characterisation facility. In order to inform the development of future policy, Government established an independent advisory committee (the Committee on Radioactive Waste Management) and asked them to review options for the management of higher activity radioactive wastes and to make recommendations for the future. The Committee's report (CoRWM 2006) included a number of recommendations which were accepted by Government (DECC 2006). It was accepted that experience had shown that non-consensual approaches had not been successful and that future policy should be built on the premise of partnership working between the developer and a willing community. Government also accepted that participation by this willing community should be supported by the provision of investment packages designed both to facilitate participation in the short term and to ensure that a radioactive waste facility is acceptable to the host community in the long term (i.e. participation should be based on the expectation that the well-being of the community will be enhanced).

These principles were reflected in the 2008 White Paper (DECC 2008) and expressions of interest were received from two Borough

Councils and the associated County Council. Unfortunately this process came to a halt in January 2013 when the County Council failed to support the proposed move to the next stage of RWM undertaking non-intrusive geological studies to better understand the geology within the communities. A lesson-learned from this experience was that communities would have increased confidence to commence dialogue with the developer if there was a national compendium of geological information available that could be consulted to determine, albeit at a high level, the potential suitability of an area to host a GDF.

In 2014 RWM launched the national geological screening exercise designed to bring together exsting national-scale information about aspects of geology that are relevant to the long-term safety of a GDF and make it available in an accessible form. RWM sought expert advice from an independent review panel established by the Geolocical Society of London to help with the production of the Guidance that would define the geological attributes to be considered and the form of the outputs. Recognising that it was important to engender public trust in this enterprise, discussions with the independent review panel were held in public and the Guidance was subjected to public consultation before finalisation.

The Guidance was finalised in April 2016 (RWM 2016) which has allowed work to start on production of the screening information and outputs. The national geological screening outputs will provide authoritative information for England, Wales and Northern Ireland and is intended to support early discussions with communities about their geological potential to host a GDF.

It is planned that the national geological screening outputs will be available to support the launch of the siting process in 2017.

References

CoRWM (2006): Managing our radioactive waste safely. CoRWM's recommendations to Government.

DECC (2014): Implementing geological disposal: a framework for the long-term management of higher activity radioactive waste.

DECC (2006): Response to the report and recommendations from the Committee on Radioactive Waste Management (CoRWM).

DECC (2008): Managing radioactive waste safely: a framework for implementing geological disposal.

RWM (2016): Implementing geological disposal. Providing information on geology. National geological screening guidance.

The Swiss sectoral plan for the nuclear waste disposal site selection: step-wise (geo-)science based decisions

S10-01

Christian Schlüchter

Swiss Federal Nuclear Safety Commission (KNS), Gaswerkstrasse 5, CH–5200 Brugg, Switzerland

Sectoral plans („Sachpläne“) as defined in Art. 13 of the Swiss federal law for spatial development are approved instruments for the federal coordination of spatial development in Switzerland. Such plans are, depending on the subject, usually elaborated by a designated federal office in close collaboration with other relevant institutions and the Cantons and finally approved by the federal government. – The search for safe geological repositories for radioactive waste in Switzerland has experienced its up and downs. Plans for a repository for low- and intermediate-level waste at Wellenberg (Canton of Nidwalden), were rejected in cantonal voting in 1995 and in 2002. In 2006, the Federal Council, the Swiss federal government accepted the evidence of feasibility of a repository for spent fuel, vitrified high-level waste and long-lived intermediate-level waste („Entsorgungsnachweis HAA“). However, focussing on the proposed site in the northern part of the Canton of Zürich with Opalinus-Clay as host rock had been rejected and a geologically and geographically more diverse approach was requested. As a consequence, preparatory work for a sectoral plan for site selection of a radioactive waste diposal site was initiated in 2007 and by April 2008 the sectoral plan for deep geological repositories was accepted by the Federal Council. This sectoral plan defines the site selection process and will result in the general licence application for the proposed repositories. The sectoral plan for deep geological repositories comprises 3 stages, of which the first is designed and planned for the selection of potential geologically safe areas. The goal of stage 2 is the designation of two possible sites for high-level and two sites for low- to medium-level waste within the designated areas decided upon in stage 1. In stage 3, the final decision for one site for a high-level waste repository and one site for a low- to intermediate-level waste repository (or one repository for both types of waste) will be taken. Currently, the Swiss Federal Nuclear Safety Inspectorate (ENSI) is reviewing the documentation of stage 2, which has been submitted by Nagra (Swiss National Cooperative for the Disposal of Radioactive Waste). At the same time detailed planning of stage 3 with preparatory geophysical investigations are taking place.

Role of preliminary safety evaluation in the site selection process

S10-02

Nicole Schubarth-Engelschall[1]

[1] Federal Office for Radiation Protection, Willy-Brandt-Straße 5, 38226 Salzgitter, nschubarth-engelschall@bfs.de

The site selection process according to the German Repository Site Selection Act (StandAG) aims at finding a site to establish a repository which is considered as best possible to provide safety for a period of one million years.

For this reason, safety evaluation in the site selection process plays an important role to support decisions in the ongoing process, e.g. which regions and sites remain in the site selection process and are to be investigated in more detail. Furthermore, safety evaluation is needed to supplement the application of site selection criteria for ensuring a science-based and transparent procedure. Safety evaluation is also the basis for the comparative determination of a site which is in compliance with the requirements of the state of the art of science and technology. In the end, safety evaluation is the basis to decide in favor of one specific site where a repository is to be established.

The site selection process according to the German Repository Site Selection Act is divided into three main phases. Each phase concludes with a safety evaluation which is thus an important part of the decision process. Each decision is the premise for the next phase. The first phase is carried out in three subsequent steps and aims at identifying regions for surface site investigation. Safety evaluation is applied first in the third step of the first phase.

The main aspect for the implementer to perform his task is to explore, evaluate und compare different regions and sites. This concerns methods for carrying out safety evaluation and for a comparison. For this, the implementer has to apply tools that need to be ready in time and must be supported by R&D activities.

All safety evaluation in the process are in each phase based on a more or less comparable data base, which need to be completed, adjusted and improved in the ongoing process. The data bases are e.g. geoscientific data base, waste inventory, host rock specific concepts concerning safety and proof-of-evidence, repository concepts and canister concepts.

By using and evaluating the existing data base for each region or site it is evident, that in phase 1 a more generic approach for safety evaluation is necessary. By advancing in the subsequent phases during the site selection process, each safety evaluation is based on more detailed and resilient site specific data and thus becomes more representative.

Of course, preliminary safety evaluation for the site selection process differs from a long term safety assessment in a licensing procedure under the directive of Atomic Energy Law. Though it can be expected, that the methodoligical approach for safety evaluation proposed by the German Repository Site Selection Act is very similar to those of long term safety assessment (safety case). Therefore, the safety evaluation will consume a clear amount of time during the selection process.

According to the recommendations made by the “Kommission Lagerung hoch radioaktiver Abfallstoffe” all preliminary safety evaluation need to be carried out according to the state-of-the-art of science and technology. Also, modifications and advances development of the state-of-the-art need to be considered and safety analses have to be updated decennial. This procedure leads to the necessity to re-evaluate preliminary safety evaluation and as a consequence, early decisions and commitments may be questioned again. This is a challenging part in the site selection process and clear regulation is needed to avoid instability of the process. This concerns also the question, which kind of modification and change in state-of-the-art leads to a re-evaluation of previous safety evaluation and to which depth the re-evaluation has to be carried out. This procedure is without precedence.

Therefore, it is very important, that an aim is defined for each safety evaluation and how it can contribute to the decision process. For this reason, an important aspect by carrying out safety evaluation is to define the aim and the significance of each safety evaluation as well as to be aware of the resilience and robustness of the results of safety evaluation in each phase of the process.

Major aims of safety evaluation are related to

- demonstrate feasibility to build a repository at the sites in question,
- check and verify underlying data bases,
- identify uncertainties and how to cope with remaining uncertainties,
- identify needs for geoscientific exploration and for adjusting unequal data bases,
- identify RD&D needs.

With all this, the implementor has to show and prove that the protection objectives are met.

Considering the basic requirements for preliminary safety evaluation it is obvious, that - in addition to site specifific geological conditions - the definition of safety-oriented aims for each rock type as well as the defintion of amount and characteristics of the waste in question are essential for developing safety and repository concepts and need to be determined.

The robustness and significance of safety evaluation increases in the ongoing process. This is attributed to increasing and new data bases, continous and advanced development of underlying concepts and by narrowing the focus on site specific circumstances. There is a need to give clear terms and definitions for each safety evaluation in each phase to clarify the role of every safety evaluation as well as the task of the implementor, e.g. safety evaluation, safety assessment, safety analyses, etc.

To achieve a resilient and robust comparison of repository systems by using site specific safety evaluation it is favourable to use criteria which are based on safety indicators. For phases 2 and 3 those indicators can also be used to assess radiological consequences.

It is also necessary to communicate the safety evaluations aims and significance with stakeholders to avoid misunderstanding and missing of expectations. Those definitions need to be established in advance of each phase or even at the beginning of the process.

At the same time, safety evaluation must be in compliance with Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste.

References

BMU (2010): Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste. 30 September 2010.- Berlin.

StandAG (2013): Gesetz zur Suche und Auswahl eines Standortes für ein Endlager für Wärme entwickelnde radioaktive Abfälle und zur Änderung anderer Gesetze (Standortauswahlgesetz – StandAG) vom 23. Juli 2013.- Bundesgesetzblatt Jahrgang 2013 Teil I Nr. 41, ausgegeben zu Bonn am 26. Juli 2013.

Revised site selection process for high-level radioactive waste disposal sites in Japan - scientifically preferable areas -

S10-03

Hiromitsu Saegusa[1], Hideaki Hyodo[1], Akira Deguchi[1], Hiroyuki Umeki[1]

[1] Nuclear Waste Management Organization of Japan, 1-23, Shiba 4-Chome, Minato-ku, Tokyo 108-0014 Japan, hsaegusa@numo.or.jp

In Japan, selection of high-level radioactive waste disposal sites has not advanced significantly over 10 years since establishment of a legal system for final disposal of radioactive waste. The government of Japan decided to reinforce drastically measures for achieving solutions and promoting final disposal of high-level radioactive waste (without putting off implementing measures into the future) through the "Strategic Energy Plan" published on April 2014. In association with this decision, a new process for selecting a repository site in which the government would differentiate the whole of Japan into three categories, "Areas probably preferable", "Areas probably suitable" and "Areas probably unsuitable" before initiating legal siting process was added to the basic policy in May 2015. The legal siting process will be conducted in a stepwise manner with a literature survey, preliminary investigation and detail investigation stages.

Scientific factors to distinguish areas into the three categories have been assigned taking into account geological characteristics (and their long-term stability), pre-closure safety and waste transport safety in September 2015. The discussion will continue further to include socio-scientific viewpoints. From the viewpoint of the geological characteristics and their long-term stability, the following risks were taken into account:

- Magma intrusion into and eruption through underground facilities of repository;
- Direct damage to underground facilities of repository and changes to hydraulic properties in/around faults caused by fault movement;
- Significant reduction in the thickness of the geological barrier caused by uplift and erosion ;
- Alteration of waste buffer material caused by geo-thermal heat;
- Increase of corrosion rate of waste overpack due to changes in groundwater conditions caused by penetration of volcanic thermal water and/or deep-seated fluid to repository.

The currently existing geological information available nationwide has been used for the assessment. The areas are distinguished as "Areas probably unsuitable" in case of corresponding to exclusion criteria described below:

- Near the volcanoes/active faults to the site ;
- Significant uplift/erosion, high geo-thermal condition, existence of volcanic thermal water/deep-seated fluid in the vicinity of the site ;
- Areas where there is a danger that surface facilities are damaged by future pyroclastic flow ;
- Areas where unconsolidated bedrock is too thick to assure the structural stability of underground facility in the construction phase.

After this first screening exercise, those areas which are not defined as "Areas probably unsuitable" are defined as "Areas probably suitable". Then, any area which is sufficiently close to the coast is defined as "Areas probably preferable". As such, the coastal area (including the off-shore) is the focus as a potential siting area.

The government of Japan will present the outputs of "scientifically preferable areas" by the end of 2016.

The role of stress and geomechanical modelling BEFORE site selection S10-04

Andreas Henk[1], Oliver Heidbach[2], Birgit Müller[3], Karsten Reiter[1], Tobias Hergert[1], Frank Schilling[3]

[1] Institut für Angewandte Geowissenschaften TU Darmstadt, Schnittspahnstraße 9, 64287 Darmstadt, Germany, henk@geo.tu-darmstadt.de

[2] Deutsches GeoForschungsZentrum GFZ, Sektion 2.6 Erdbebengefährdung und Spannungsfeld, Telegrafenberg, 14473 Potsdam, Germany

[3] Karlsruher Institut für Technologie, Institut für Angewandte Geowissenschaften, Adenauerring 20b, 76131 Karlsruhe, Germany

The local tectonic stress field and the mechanical properties of the host rock are important factors for the site selection process and safe radioactive waste disposal in the subsurface, respectively. Earthquakes, reactivation of tectonic faults, hydraulic properties of natural and induced fractures, geotechnical aspects of construction of a deep depository and extent of the excavation damage zone are just a few examples which highlight the relevance of geomechanics for deep geological disposal. The National Cooperative for the Disposal of Radioactive Waste of Switzerland estimates that about 40% of their site selection criteria are affected by the crustal stress state (Nagra, 2008). As a consequence knowledge of the in situ stresses is an important aspect for site characterization. Furthermore, a first robust stress prediction has to be already available prior to detailed exploration (drilling, mining) of a specific site as the stress state may be crucial for the ranking of competing sites providing criteria for exclusion due to unfavourable or critical stress states.

The required stress prognosis has to be simulated with 3D geomechanical-numerical models, which allow incorporating complex geometries of faults and lithological layers as well as non-linear rock mechanical behaviour (e.g., Fischer & Henk, 2013; Hergert et al., 2015). These models have to be site-specific as magnitude and orientation of the local stress field are not uniform, but influenced by local discontinuities like tectonic faults and lithological changes. Model results provide, among others, the complete 3D stress tensor for any arbitrary point in the model domain. This information is not only needed to characterize the stability of underground openings or faults, but also to derive the stress state prior to construction of a deep depository. Furthermore, it can be used to study the short- and mid-term stress changes in relation to the excavation process and self-sealing mechanisms. In addition they deliver the crucial initial conditions for the required scenario simulations that cover geological time spans (ten thousands to one million years) to assess the long-term safety and stability of a radioactive waste disposal site. Examples are the assessment of the reactivation and fracture potential of tectonic faults as well as the quantification of the long-term impact of tectonic processes, thermal and ice loads.

We present the results of 3D geomechanical numerical models for potential nuclear waste disposal sites in Northern Switzerland and the impact of geological structures and rock properties on the local stress field variability. Given the important role of stress and geomechanical modelling for the characterization of potential disposal sites, we present briefly the initiative SpannEnD that has been established to set up and advance the necessary data bases and modelling tools for robust stress predictions in Germany so that they could be made available once the actual site selection process will be started (see also Heidbach et al., this conference, for further details).

References

Fischer, K. & Henk, A. (2013). A workflow for building and calibrating 3-D geomechanical models-A case study for a gas reservoir in the North German Basin. Solid Earth, 4(2): 347–355.

Hergert, T., Heidbach, O., Reiter, K., Giger, S. B., & Marschall, P. (2015). Stress field sensitivity analysis in a sedimentary sequence of the Alpine foreland, northern Switzerland. Solid Earth, 6(2): 533–552.

Nagra (2008). Vorschlag geologischer Standortgebiete für das SMA- und das HAA-Lager. Begründung der Abfallzuteilung, der Barrierensysteme und der Anforderungen an die Geologie. Bericht zur Sicherheit und technischen Machbarkeit, NTB 08-05, ISSN 1015-2636, Nagra, Wettingen, Schweiz.