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Geological disposal of radioactive waste: underpinning science and technology

18^{th}–20^{th} October 2011, Burleigh Court Conference Centre, Loughborough University, Loughborough, UK

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The Royal Society of Chemistry, the Geological Society, the Institution of Civil Engineers, the Nuclear Institute, the Institution of Chemical Engineers, the Royal Academy of Engineering and the Mineralogical Society organized a wide-ranging conference themed around the geological disposal of radioactive waste from 18^{th}–20^{th} October 2011 at the Burleigh Court Conference Centre, Loughborough University, Loughborough, UK. One of its principal objectives was to showcase and publish research relevant to radioactive waste storage and disposal. The event was supported by the Nuclear Decommissioning Authority (NDA) and the Energy Generation and Supply Knowledge Transfer Network (KTN) for the Nuclear Sector, and kindly sponsored by AMEC and the National Nuclear Laboratory (NNL).

The conference brought together scientists, engineers and other interested specialists to discuss the chemical, biological, geological, hydrological, materials, engineering and other scientific and technological challenges associated with the long-term management of radioactive waste in the UK. The scientific committee peer-reviewed all abstracts received prior to the conference, and determined those best for oral and poster presentation. Papers presented in this issue of *Mineralogical Magazine* were subsequently subjected to a detailed and independent peer-review process.

The organizing committee consisted of Nick Evans (chair), Loughborough University; Katherine Morris, The University of Manchester; Neil Smart and Gordon Turner, Nuclear Decommissioning Authority; Nic Bilham, Geological Society; Glen Owen, Institution of Civil Engineers; Claire Gallery-Strong, Nuclear Institute; Sam Shaw, Mineralogical Society; Steve Lancaster, Royal Society of Chemistry; Richard Ploszek, Royal Academy of Engineering; and Richard Shaw, British Geological Survey. The organizing committee would like to place on record its thanks to the sponsors (see back cover) and exhibitors.

The conference was organized in thematic sessions and this volume is presented in the same manner. Each of the sections begins with a peer-reviewed paper from the NDA outlining its view on the state-of-the-art in a particular discipline. There then follow papers from academia, industry and the supply chain. A major objective of this conference was to make the latest independent research on the geological disposal of radioactive waste, principally related to the current UK scenario, publicly available. It should be stressed that although the NDA supported the conference financially and in other ways, it played no part in the selection of papers for presentation or publication. The sessions were as follows: (1) introduction from the NDA; (2) waste forms, criticality and containment materials; (3) engineered barriers (near field); (4) geosphere (far field); (5) biosphere and microbial sciences; (6) gas; (7) radionuclide transport; (8) international; (9) general issues.

Section 1: introduction

A broad introductory contribution (Tweed, 2012), which follows this editorial outlines the NDA's position that the safe implementation of geological disposal requires sound science.

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Section 2: wasteforms, containment materials and criticality

The first major section on wasteforms, containment and criticality begins with an introduction to package evolution and criticality research studies relevant to the UK disposal programme by Cristiano Padovani and co-workers of the NDA (Padovani *et al*., 2012). There follow papers which describe: waste container durability by Nick Smart (AMEC) and co-workers (Smart *et al*., 2012); the corrosion and expansion of grouted Magnox waste by James Cronin and Nicholas Collier (NNL) (Cronin and Collier, 2012); the durability of potential plutonium wasteforms under repository conditions by Guido Deissmann (Brenk Systemplanung) and co-workers (Deissmann *et al*., 2012), the chemical durability of vitrified wasteforms and the effects of pH and solution composition by Stephen Swanton (AMEC) and co-workers (Utton *et al*., 2012); three-dimensional imaging of inhomogeneous lithologies using X-ray computed tomography in the characterization of drill core from the Borrowdale Volcanic Group by Dirk Engelberg (The University of Manchester) and co-workers (Engelberg *et al*., 2012); the release of uranium from candidate wasteforms by Nicholas Collier (National Nuclear Laboratory) and co-workers (Collier *et al*., 2012); the development of criticality safety controls on intermediate-level waste packages by Tim Hicks (Galson Sciences Ltd) and co-workers (Hicks *et al*., 2012*b*); an experimental study to evaluate the effect of polymeric encapsulants on the corrosion resistance of intermediate-level waste packages by Robert Winsley (AMEC) and co-workers (Winsley *et al*., 2012); the site-bond modelling of porous quasi-brittle media by Andrey Jivkov (The University of Manchester) and co-workers (Jivkov *et al*., 2012); the break-up testing of waste-form materials by Martin Metcalfe (NNL) and co-workers (Metcalfe *et al*., 2012); and initial studies on the effects of radiation, thermal ageing and aqueous environments on the stability and structure of candidate polymeric encapsulant materials by John Dawson (AMEC) and co-workers (Dawson *et al*., 2012).

Section 3: engineered barriers (near field)

The discussion of engineered barrier systems begins with an overview of near-field evolution research in support of the UK geological disposal programme by Tara Beattie and Steve Williams of the NDA (Beattie and Williams, 2012). There follow papers which describe: the deep borehole disposal of higher burn up spent nuclear fuels by Fergus Gibb (University of Sheffield) and co-workers (Gibb *et al*., 2012); the reaction of bentonite in low-alkali cement leachates: an overview of the Cyprus Natural Analogue Project (CNAP) by William Alexander (Bedrock Geosciences) and co-workers (Alexander *et al*., 2012); long-term leachate evolution during flow-through leaching of a vault backfill by Ed Butcher (NNL) and co-workers (Butcher *et al*., 2012); modelling coupled processes in bentonite by David Holton (AMEC) and co-workers (Holton *et al*., 2012); pH buffering in a cementitious near field by Timothy Heath (AMEC) and co-workers (Baston *et al*., 2012*a*); modelling pH evolution in the near field of a cementitious repository by Andrew Hoch (AMEC) and co-workers (Hoch *et al*., 2012); cracking in a cementitious backfill, and the implications for flow and chemistry by Ben Swift (AMEC) and co-workers (Swift *et al*., 2012); europium interaction with a vault backfill at high pH by Nicholas Bryan (The University of Manchester, UK) and co-workers (Telchadder *et al*., 2012); and uranium uptake onto Magnox sludge minerals by Arjen van Veelen (The University of Manchester) and co-workers (van Veelen *et al*., 2012).

Section 4: geosphere (far field)

The discussion of the far field begins with an introduction to geosphere research studies for the UK geological disposal programme by Simon Norris of the NDA (Norris, 2012). There follow papers on: observations of stable high-pressure differentials in clay-rich materials; implications for the concept of effective stress by Robert Cuss (BGS) and co-workers (Cuss *et al*., 2012); coupled hydro-mechanical-chemical process modelling in argillaceous formations by Alexander Bond (Quintessa Ltd) and co-workers (Bond *et al*., 2012); a comparison of a post-closure transient criticality models with the Oklo natural reactors by Robert Mason (AMEC) and co-workers (Mason *et al*., 2012*a*); the consequences of hypothetical post-closure criticality by Robert Mason (AMEC) and co-workers (Mason *et al*., 2012*b*); critical stress theory applied to repository concepts; the importance of the stress tensor and stress history in fracture flow by Robert Cuss (BGS) and co-workers (Sathar *et al*.,

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2012); the comparison of discrete fracture network and equivalent continuum simulations of fluid flow through two-dimensional fracture networks for the DECOVALEX-2011 project by Colin Leung (Imperial College, London) and co-workers (Leung *et al*., 2012); radionuclide diffusion into undisturbed and altered crystalline rocks by Václava Havlová (Nuclear Research Institute) and co-workers (Havlová *et al*., 2012); and the adsorption and diffusion of Sr in simulated rock fractures by Roy Wogelius (The University of Manchester) and co-workers (Ohe *et al*., 2012).

Section 5: biosphere and microbial sciences

Discussion of the biosphere begins with a paper describing the representation of the biosphere in post-closure assessments for the UK geological disposal programme by Ray Kowe and Simon Norris of the NDA (Kowe and Norris, 2012). There follow papers which describe: biosphere studies supporting the disposal system safety case by Russell Walke (Quintessa Ltd) and co-workers (Walke *et al*., 2012); international collaboration in biosphere research for radioactive waste disposal by Karen Smith (Eden Nuclear and Environment Ltd) and co-workers (Smith *et al*., 2012*b*); the comparison of modelled uptake to cereal crops of carbon-14 from gaseous or groundwater mediated pathways also by Karen Smith (Eden Nuclear and Environment Ltd) and co-workers (Smith *et al*., 2012*a*); a comparison of microbiological influences on the transport properties of intact mudstone and sandstone and its relevance to the geological disposal of radioactive waste by Heather Harrison (BGS) and co-workers (Wragg *et al*., 2012); and the potential impact of anaerobic microbial metabolism during the geodisposal of intermediate-level waste by Jon Lloyd (The University of Manchester) and co-workers (Rizoulis *et al*., 2012).

Section 6: gas

Discussion of gas begins with an overview of gas research in support of the UK geological disposal programme by Steve Williams of the NDA (Williams, 2012). There follow contributions which describe: gas migration experiments in bentonite and their implications for numerical modelling by Caroline Graham (BGS) and co-workers (Graham *et al*., 2012); the rate and speciation of volatile carbon-14 and tritium releases from irradiated graphite by Graham Baston (AMEC) and co-workers (Baston *et al*., 2012*d*); gas flow in Callovo-Oxfordian clay including results from laboratory and field-scale measurements by Jon Harrington (BGS) and co-workers (Harrington *et al*., 2012*a*); the comparison of alternative approaches to modelling gas migration through a higher strength rock by Andrew Hoch and Martin James (AMEC) (Hoch and James, 2012); evidence for gas-induced pathways in clay using a nanoparticle injection technique by Jon Harrington (BGS) and co-workers (Harrington *et al*., 2012*b*); multi-component gas flow through compacted clay buffer in a higher activity radioactive waste geological disposal facility by Shakil Masum (Cardiff University) and co-workers (Masum *et al*., 2012); the migration and fate of $^{14}CH_4$ in subsoil: tracer experiments to inform model development by George Shaw (The University of Nottingham) and co-workers (Atkinson *et al*., 2012); a data analysis toolkit for long-term, large-scale experiments by Daniel Bennett (Geoenvironmental Research Centre) and co-workers (Bennett *et al*., 2012); and understanding the behaviour of gas in a geological disposal facility by George Towler (Quintessa Ltd) and co-workers (Towler *et al*., 2012).

Section 7: radionuclide transport

The discussion of radionuclide transport begins with an overview of radionuclide behaviour research for the UK geological disposal programme by Sarah Vines and Rebecca Beard of the NDA (Vines and Beard, 2012). There follow papers which describe: the effect of cellulose degradation products on thorium sorption onto hematite including studies of a model ternary system by Stephen Swanton (AMEC) and co-workers (Baston *et al*., 2012*b*); uranyl binding to humic acid under conditions relevant to cementitious geological disposal of radioactive wastes by Anthony Stockdale and Nick Bryan (The University of Manchester) (Stockdale and Bryan, 2012); the sorption of radionuclides to a cementitious backfill material under near-field conditions by Mónica Felipe-Sotelo (Loughborough University) and co-workers (Felipe-Sotelo *et al*., 2012); the sorption properties of aged cements by Graham Baston (AMEC) and co-workers (Baston *et al*., 2012*c*); the effect of competition from other metals on nickel complexation by α-isosaccharinic, gluconic and

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picolinic acids by Nicholas Evans (Loughborough University) and co-workers (Evans *et al*., 2012); and the complexation of Tc(IV) with EDTA and picolinic acid at high pH by Nicholas Evans and Ricky Hallam (Loughborough University) (Evans and Hallam, 2012).

Section 8: international aspects

A short section on international issues begins with towards an 'implementing geological disposal technology platform' in Europe by Tara Beattie of the NDA and co-workers (Palmu *et al*., 2012). There follows a description of the long-term cement studies project which describes the UK contribution to model development and testing by Claire Watson (Quintessa Ltd) and co-workers (Watson *et al*., 2012).

Section 9: general issues

The final section on general matters begins with a contribution which describes the framework for an environmental safety case for geological disposal in the UK from Mike Poole and Ray Kowe of the NDA (Poole and Kowe, 2012). There follow papers which describe: research in support of the 2011 environmental safety case for the low level waste repository by Andrew Baker (Eden Nuclear and Environment Ltd) and Richard Cummings (Low Level Waste Repository Ltd) (Baker and Cummings, 2012); interactions between the co-located intermediate-level waste/low-level waste and high-level waste/spent fuel components of a geological disposal facility by Tim Hicks (Galson Sciences Ltd) and co-workers (Hicks *et al*., 2012*a*); performance assessment and the safety case: lessons from the European Commission PAMINA project by Daniel Galson (Galson Sciences Ltd) and Lucy Bailey (NDA) (Galson and Bailey, 2012); planning to 'remember to forget'? by Shelly Mobbs (Eden Nuclear and Environment Ltd) (Mobbs, 2012); and geological disposal programme design and prioritization in the face of uncertainty: use of structured evidence support logic techniques by Alan Paulley (Quintessa Ltd) and co-workers (Paulley *et al*., 2012).

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