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PU	Public	X
RE	Restricted to a group specified by the partners of the [acronym] project	
CO	Confidential, only for partners of the [acronym] project	

EURATOM

Fate of Repository Gases

Various gases will be generated in a repository including hydrogen (from metal corrosion) and methane and carbon dioxide (both from decomposition of organic materials contained in some wastes). Understanding where and how these gases form and how they move through the repository and surrounding rocks is the focus of the FORGE project. By using small scale laboratory experiments, large scale field tests (performed at a number of underground research laboratories throughout Europe), data and numerical modelling the results from FORGE is providing information to help guide repository design and predict future radionuclide migration.

The understanding and prediction of the evolution of repository systems over geological time scales requires a detailed knowledge of a series of highly-complex coupled processes. There remains significant uncertainty regarding the mechanisms and processes governing gas generation and migration in natural and engineered barrier systems. It is important to understand a system to an adequate level of detail to allow confidence in the assessment of site performance, recognising that a robust treatment of uncertainty is desirable. Of particular importance to the European radioactive waste management programmes are the long-term engineering performance of bentonite buffers, plastic clays, indurated mudrocks and crystalline formations. To reduce uncertainty, further experimental data are required to address:

- Corrosion and gas generation rates in repository environments;
- Key issues relating to the migration and fate of repository gases;
- Validation of numerical codes;
- Derivation of new methodologies for up-scaling from laboratory to field to repository scales;
- Optimisation of repository concepts through detailed scenario analysis.

FORGE is now in its final year and emerging results so far from the project are noted below.

Initial results of a series of long-term laboratory experiments to examine the mechanisms controlling gas flow and pathway sealing in the Callovo-Oxfordian Claystone (COx), the proposed host rock for the French repository, demonstrate that advective gas flow is accompanied by dilation of the samples (i.e. the formation of pressure induced micro-fissures) at gas pressures significantly below that of the minimum principal stress. Flow appears to occur through a local network of inherently unstable pathways, whose properties vary temporarily and spatially within the claystone. The coupling of parameters results in the development of significant time-dependent effects, impacting many aspects of COx behaviour, from gas breakthrough time, to the control of deformation processes. Variations in gas entry, breakthrough and steady-state pressures are indicative of microstructural heterogeneity which may exert an important control on the movement of gas.

As data continues to be acquired and our understanding of these processes improves, a new conceptual model for advective gas flow in COx is beginning to emerge, one in which the onset of gas flow and the hydromechanical response of the material are integrally linked. The importance of pathway dilatancy during gas flow has now been clearly demonstrated and is driving the development of new experimentation to continue the development of the conceptual model for gas flow in COx.

Data collected so far during from a study of gas migration in bentonite clearly demonstrate a strong coupling between total stress, pore-pressure and applied gas pressure. In both tests so far completed, the evidence is for gas migration through the saturated bentonite by way of dilational pathways. This provides more evidence that, in some circumstances, gas flow through clay rich materials is at least partially through dilatants pathways.

In an initial set of tests, the general pressure and flow response in compacted bentonite (MX-80) and pure montmorillonite (Na- and Ca-form) due to externally applied water and gas pressure gradients was examined. A quite large number of different geometries and applied pressure ranges were explored. One of the main results of these tests is that they showed, very systematically, that the criterion for inducing breakthrough events – where the clay body is disrupted and the fluid flow increases by many orders of magnitude – is given by

$P \geq P\_ext$

Where:

P denotes the total pressure of the sample

P_ext is the externally applied fluid (water or air) pressure.

Furthermore, the excess pressure required for breakthrough (P_ext- P) was shown to be dependent on both geometry and the type and density of clay.

Additional tests, where the pathways of the fluid during breakthrough were explored, showed that these usually follow the interface between clay body and test cell.

Recently, a set of "proof-of-concept" experiments have been performed in order to demonstrate the osmotic character of a saturated and confined swelling clay, and that this character governs the hydromechanical response. For example, gas breakthrough events have been induced by lowering the total pressure of the clay sample by flushing a highly concentrated salt solution on the opposite side, and the response due to pressurisation with kerosene – basically a non-polar liquid – have been shown to be very similar to the response due to gas pressurization.

A macroscopic model have been developed which treats confined bentonite as an osmotic system, taking into account the montmorillonite interlayers only (these pores dominates any compacted bentonite system). Within this approach the equations describing flow- pressure- and density response due to externally applied pressures have been deduced.

The theory has been successfully applied to several of the performed tests. In particular, the theory gives the same criterion for breakthrough events as found experimentally (see above), but also quantitative agreement is found e.g. for the water flow response due to applied water pressure gradients in an axial symmetric geometry, as illustrated in the figure below (test made on Na-montmorillonite of length 5 mm, and an initial swelling pressure of approximately 0.6 MPa).

A main conclusion from the theoretical work is that gas migration processes in bentonite is not a two-phase flow phenomena – i.e. gas is not replacing water in a static pore structure. Breakthrough events are, on the contrary, induced when gas dynamically "creates" its own volume by consolidating the clay body.

Experimental validation of critical stress theory applied to repository concepts has greatly increased our understanding and database of fracture flow properties. This study has highlighted the importance of stress-history on the flow properties of fractures because these systems display considerable hysteresis. Shearing has been seen to be a very effective self-sealing mechanism. Repeat gas injection testing has shown repeatability in "gas entry" values, but considerable differences have been seen in gas peak pressures.

The effect of healing of the interfaces between manufactured bentonite blocks has been demonstrated by measuring the shear strength properties of the healed interface. The observation of significant cohesion confirms the “real” healing of the interface.

FORGE publications during the period

Granet, S. Meunier, S. « Numerical modelling on in situ experience of gas injection : PGZ1 », Proceeding of Transfert 2012. ECL/LML 2012.

Justinavicius D., Poskas P., 2012, Gas migration modelling in the disposal cell of conceptual geological repository for high-level radioactive waste, Power Engineering (accepted for publication), (in Lithuanian).

Amaziane, B.; Antontsev, S.; Pankratov, L.; Piatnitski, A. Homogenization of immiscible compressible two-phase flow in porous media: application to gas migration in a nuclear waste repository. Multiscale Modeling and Simulation: A SIAM Interdisciplinary Journal Vol. 8 no 5 (2010) pp. 2023–2047.

Svoboda, J. - Smutek, J.: Centre of Experimental Geotechnics Teaching Activities Related To Radioactive Waste Storage Based On Research Experience. In *Nuclear Energy for New Europe 2010 - PROCEEDINGS [CD-ROM]*. Ljubljana: Nuclear Society of Slovenia, 2010, ISBN 978-961-6207-31-7.

Svoboda, J. - Smutek, J.: The experimental study of gas migration in crystalline rock. In *Transfert 2012 - actes de colloque*. Lille: Ecole Centrale Lille, 2012, p. 390-397. ISBN 978-2-915913-28-6.

Svoboda, J. - Smutek, J.: Research of Rock Mass Gas Conductivity with respect to Geological Disposal and the EDZ. In *Scientific Basis for Nuclear Waste Management XXXV: Volume 1475 (MRS Proceedings)*, 2012. 6 pages. DOI: http://dx.doi.org/10.1557/opl.2012.607. Available from: http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=8521449&fulltextType=RA&fileId=S1946427412006070 Proceedings details: Hardcover: 624 pages Publisher: Cambridge University Press (12 Jun 2012) Language: English ISBN-10: 1605114529 ISBN-13: 978-1605114521

Villar, M.V.; Martín, P.L.; Romero, F.J., Barcala, J.M. & Gutiérrez-Rodrigo, V. 2012. Gas transport through bentonite: influence of dry density, water content and boundary conditions. In: Skoczylas, F.; Davy, C.A.; Agostini, F. & Burlion, N. (eds.): Propiétés de Transfert des Géomatériaux. Transfert 2012, Actes du Colloque: 379-389.

Gutiérrez-Rodrigo, V.; Villar, M.V.; Martín, P.L. & Romero, F.J. 2012. Determinación de las propiedades de transporte de gas en bentonita. Macla 16: 126-127.