Talking about gas generation

DR RICHARD SHAW

Dr Richard Shaw currently dedicates his work to a long-term view of radioactive waste management, specifically trying to understand how its waste gases move in deep geological repositories. Here, he explains the huge scope of the FORGE project, and its heavily collaborative approach

What are the objectives of the Fate of Repository Gases (FORGE) project? From what context has the project emerged?

FORGE has been looking at a range of gas-related issues in an attempt to improve our understanding of the processes involved and their impacts. The team has examined some of the processes that affect gas generation, mainly hydrogen production from the corrosion of metals and radiolysis of water. We have tried to firmly ascertain how gas may move through the engineered barrier systems that are designed to contain the waste, through the disturbed zone arising from the construction of a repository, and then into undisturbed host rocks surrounding a facility, which form part of the containment of the wastes in a repository.

FORGE counts 24 organisations from 12 European countries among its members. Can you outline the range of stakeholders involved?

The members of FORGE include a number of national waste management organisations (WMOs), who manage radioactive waste in their countries and its ultimate safe disposal; regulators who are responsible for the oversight of the WMOs and will approve/license the disposal facilities; and finally, universities and research organisations who are involved in scientific research. This wide representation from across the various sectors of the industry has ensured that the research undertaken in FORGE has been focused on the most important safety issues.

Could you offer a summary of the project's activities? How do the work packages complement one another?

There are five scientific work packages in FORGE. The first is The Treatment of Gas in Performance Assessment, which undertook a state-of-the-art report on gas, in a repository context, at the start of FORGE. It successfully identified areas that would merit further consideration. The second was a relatively modest research programme called 'Gas Generation'. This has been undertaken on hydrogen generation under simulated repository conditions to determine, for example, how irradiation and temperature effects on bentonite backfill materials in contact with metals can affect rates of gas production.

Next is Engineered Barrier Systems, under which laboratory-scale and underground research laboratory experiments have been undertaken to study gas transport through the engineered parts of a repository. These include bentonite based back fills, cement based backfills and the interfaces between, for example, host rock clay or 'granite' and backfill materials.

Disturbed Host Rocks is another package which, again, uses laboratory-scale and underground research laboratory experiments to study gas transport through potential clay hosts rock that have been disturbed as a result of the excavation of a repository. These include a study of gas flow though fractures in clay rocks and the effect of stress on fracture flows. Complementary to this is the final work package – Undisturbed Host Rocks. This also uses laboratory-scale and underground research laboratory experiments to study gas transport through potential clay hosts rock, but this time concentrating on those that have not been affected by the excavation of a repository. They include gas injection experiments into *in situ* rock formations, gas breakthough in plastic clays and gas flow through indurated clays.

By what means is the project supporting the training of young researchers?

FORGE has held a number of workshops attended by a range of researchers including postgraduate students and has supported a week long training course in Romania on bentonite and gas-related issues. This was attended by final year undergraduate engineering students, postgraduate students and staff from a number of regulatory bodies. Attendees, from the UK, Italy, Korea, Bulgaria, Spain, Belgium as well as Romania, also had the opportunity as part of the course to undertake some experimental procedures on bentonite.

Finally, what would you highlight as the key findings of the FORGE study?

While there are uncertainties related to gas generation and migration that require further work to continue to improve the understanding, FORGE demonstrates that there are no gas issues that are 'show stoppers' as far as the deep geological disposal of radioactive waste is concerned. Gas needs to be considered at an appropriate level in the development of any repository safety case.

Laying waste

Understanding and addressing gas migration issues in the context of deep geological respositories could hold the key to improving radioactive waste management. A group of scientists working on the FORGE project are on the cusp of unlocking this potential

Large diameter horizontal borehole in the Mont Terri underground research laboratory, Switzerland. © Chris Rochelle (BGS)

NUCLEAR POWER IS an ever-developing and successful energy alternative to fossil fuels. However, in spite of its success in providing approximately 13 per cent of the world's electricity per year with minimal production of greenhouse gases, it is not a problem-free energy solution. Sustained nulear fission produces radioactive waste which, if left inadequantely managed, is potentially damaging to both the health of humans and the environment. Thus, the use of nuclear power must go hand in hand with the responsibility of managing and disposing of the radioactive waste.

As radioactivity gradually diminishes, such management typically consists of isolating and storing the waste until it no longer poses a risk. Long-term radioactive waste management usually employs final disposal in a deep geological repository. These facilities will consist of an engineered barrier system that works alongside the surrounding host rocks to minimise the migration of radioactivity. Problematically however, as the repository system evolves, waste gases can be produced as a result of the corrosion of metals, from the radioactive decay of some of the waste and degradation of organic materials in some waste.

It is crucial that knowledge about how gases are formed from the wastes – and their movement through a repository and the surrounding rock mass – is improved. However, better 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. Fortunately, it is this area of research to which scientists from the Fate Of Repository Gases (FORGE) project are dedicating their time. The project was initiated to address key gas migration issues in repository performance assessment and boasts experts in the fields of radioactive waste management, waste regulation and academia – including contributors based at the British Geological Survey (BGS).

WHAT IS FORGE?

FORGE's aims can be broken down into three key areas. Firstly, the team conducted an assesment of the impact of gas migration on repository infrastructure and engineering performance. Next, they developed models to describe the mechanisms and processes that characterise gas, water and radionuclide movement in repository components; and finally, they are providing groundbreaking insights into the engineered barrier systems (EBS) properties and engineered disturbed zone (EDZ) behaviour.

Forming the backbone of this complex research is the generation of various gases – including hydrogen (from metal corrosion), methane and carbon dioxide (usually caused by decomposition of organic materials) in a repository. The scientists will try to establish where and how these gases form and how they move through the repository and surrounding rocks. Further research has been undertaken using both small-scale laboratory experiments and larger-scale field tests. Next, the researchers will carry out data and numerical modelling of all the recorded results which, they hope, will provide adequate information to influence future repository design, as well as improving the ability to predict radionuclide migration.

The knowledge that the group seeks to accrue demands a detailed knowledge of a series of highly-complex coupled processes and necessitates a wide range of expertise. In order to tackle the ambitious research, FORGE includes a wide range of multidisciplinary participants.

UNCERTAIN TERRITORY

What makes this line of enquiry important – and increasingly complex – is the fact that the mechanisms and processes governing gas generation and migration in natural and engineered barrier systems remains shrouded in mystery. It is vital that FORGE facilitates the full understanding of the processes that occur within this context. Consequently, this will ensure that future gas issues will be managed in a way that does not affect the safety functions of a repository, and results in successful containment. This work will also have widespread, international repurcussions as, in dealing with the disposal of radioactive waste, a safety assessment is undertaken by all countries considering the deep geological disposal of waste. It considers how a repository will evolve over the first million years after closure, so that the amount of radioactivity reaching the surface environment over this time scale is within the low limits set in regulations. FORGE's findings and enhanced knowledge could significantly improve this procedure.

Another consideration is the speed at which gas may be generated. As such, it may not be able to move away from the repository quickly enough, potentially causing disruption to the engineered barriers, affecting groundwater flow and causing

FORGE

FATE OF REPOSITORY GASES

OBJECTIVES

FORGE is a pan-European project with links to international radioactive waste management organisations, regulators and academia, specifically designed to tackle the key research issues associated with the generation and movement of repository gasses with partners from 24 organisations in 12 European countries.

PARTNERS

Agence Nationale Pour la Gestion des Dechets Radioactifs, France; **British Geological Survey**, UK; **Centre Internacional de Metodes Numerics en Enginyeria**, Spain; **Centre National de la Recherche Scientifique**, France; **Centro Deinvestigaciones Energeticas, Medioambientales Y Tecnologicas**, Spain; **Ceske Vysokeuceni Technicke V Praze**, Czech Republic; **Commissariat Energie Atomique**, France; **Ecole Centrale de Lille**, France; **Electricite de France**, France; **Eidgenössisches Nuklearsicherheitsinspektorat**, Switzerland; **Federal Agency for Nuclear Control**, Belgium; **Gesellschaftfuer Anlagen- Und Reaktorsicherheit**, Germany; **Institut Deradioprotection et de Surete Nucleaire**, France; **Institut Für Gebirgsmechanik**, Germany; **Lietuvo Senergetikos Institutas,** Lithuania; **Nationale Genossenschaft Fuer die Lagerung Radioaktiver Abfaelle**, Switzerland; **Nuclear Decommissioning Authority**, UK; **Posiva Oy**, Finland; **Radioactive Waste Repository Authority**, Czech Republic; **Regia Autonoma Pentru Activitati Nucleare Drobeta Tr. Severin Ra Sucursala Cercetari Nucleare Pitesti**, Romania; **Studiecentrum Voor Kernenergie,** Belgium; **Svensk Kaernbraenslehantering**, Sweden; **Ustav Jaderneho Vyzkumu Rez**, Czech Republic; **Université de Liège**, Belgium

KEY COLLABORATORS

Centrale Organisatie Voor Radioactief Afval, The Netherlands; **Nuclear Waste Management Organization**, Canada; **Obayashi**, Japan; **Radioactive Waste Management Committee**, Japan

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DR RICHARD SHAW is a mining geologist (C. Geol; Eur. Geol) with over 22 years' experience in radioactive waste management. He has extensive knowledge of potential UK geologies for deep geological disposal of radioactive waste with particular emphasis on their geological characteristics, site characterisation and potential geological issues.

the displacement of contaminated groundwater. These effects may reduce the efficacy of a repository. Thus, better understanding of how gases are produced and move through a repository system could result in new facility design that reduces the rate of gas generation.

SUCCESS TO DATE

The project has already enjoyed some significant success. In a set of early studies, the group examined gas migration in bentonite – more specifically, the general pressure and flow response in compacted bentonite and pure montmorillonite caused by externally applied water and gas pressure gradients was examined. Some of the datasets collected from these have already clearly demonstrated a strong relationship between total stress, pore-pressure and applied gas pressure. Additional tests, where the pathways of the fluid during breakthrough were explored, showed that these sometimes follow the interface between clay body and test cell. Furthermore, in certain other tests, the evidence indicates that gas migration occurs through saturated bentonite by way of dilational pathways.

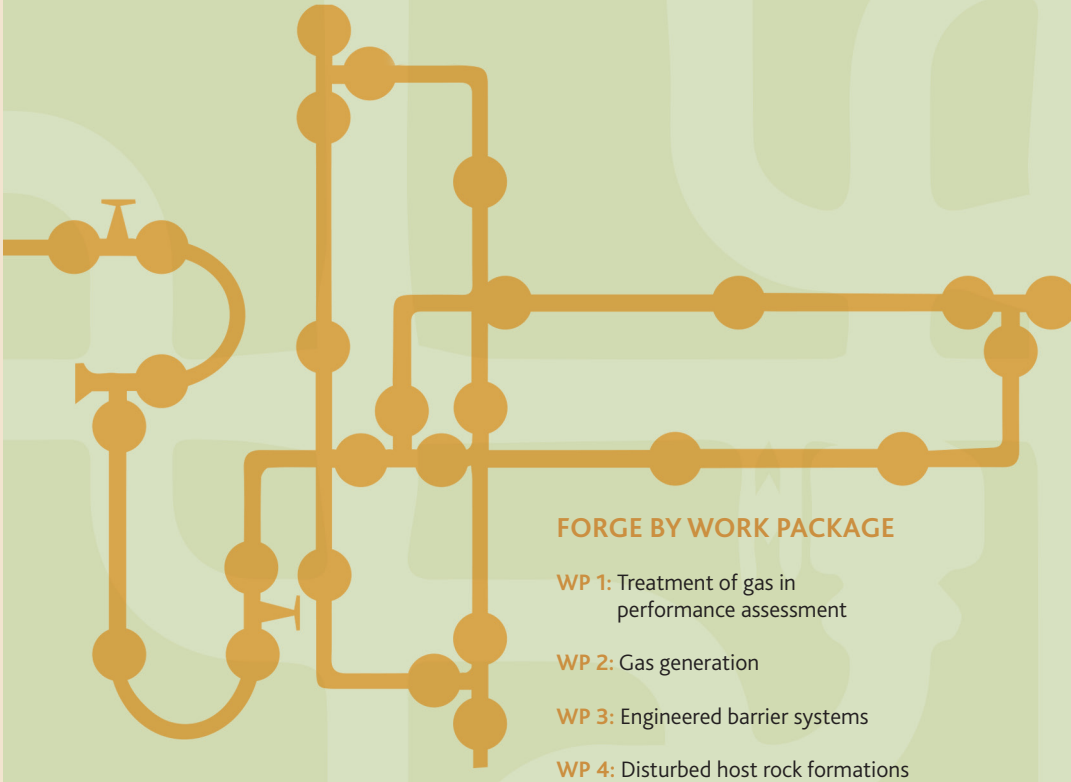
Crucially, these results have provided key evidence that, in some circumstances, gas flow through clay rich materials happens, at least partially, through dilatant pathways. This will also have a bearing on how the gasflows in a repository system may be differently modelled in future. For example, most current modelling approaches use a two-phase flow concept whereby gas and/or fluid phases move through the bulk mass porosity, thereby displacing existing pore fluids. In this instance, where flow moves through specific pathways, the current modelling approach may not fully represent the situation may require further development in order to better represent the situation.

LOOKING FORWARD

Though the members of FORGE are still undertaking the mass evalualution of all their results, plans for further research beyond the scope of the FORGE project are underway. Project leaders believe that many areas of current research could profit greatly from further investigations. For example, further examination of dilatant pathways, through both bentonite backfill material and clay host rocks – as well as the development of codes that can model gas flow through such pathways – would be hugely beneficial and are both possibilities for future development. Furthermore, some researchers will explore ways in which microbiological activity may affect gas generation and movement.

> It is crucial that knowledge about how gases are formed from the wastes – and how these may move through a repository and the surrounding rock mass – is improved

Some of the outstanding issues will only be relevant to specific situations, and will therefore be taken forward by the specific organisations interested in the outcomes. Nonetheless, key strands of results from FORGE are of broad interest and another strongly collaborative project may well be on the horizon.



FORGE BY WORK PACKAGE

WP 1: Treatment of gas in performance assessment

WP 2: Gas generation

WP 3: Engineered barrier systems

WP 4: Disturbed host rock formations

WP 5: Undisturbed host rock formations