

## ***Gas Migration: crystalline and mudrocks***

**Description:** Large volumes of gases may be generated from some waste inventories by a number of processes. These include anaerobic corrosion of metals to form hydrogen, microbial degradation of organic materials to form methane and carbon dioxide, and radiolysis of water. Gas generation is principally an issue for the more reactive and heterogeneous ILW/LLW wastes. A range of natural and anthropogenic analogues are available that relate to processes associated with the migration of gases from a deep repository. For simplicity the processes may be considered under the following topics.

- *Overpressurisation.* This relates to the build-up of gas pressure within the repository to such an extent as to compromise the integrity of backfill, host rock or seals in the access tunnels.
- *Crystalline Rocks.* Analogues for gas leakage from repository caverns constructed in fractured crystalline rocks are available from hydroelectric power station air cushion surge chambers (used to damp pressure fluctuations in water flowing to the power station), natural gas storage caverns and borehole injection tests. Results from a number of such facilities in Norway constructed in fractured crystalline rocks have been summarised in Swit et. al. (2003). Gas leakage was shown to be a function of the nature of the rock mass, water pressure, cavern geometry and most importantly the rock permeability. While there is some ambiguity, it appears that gas leakage occurs at pressures less than the hydrostatic water pressure acting on the caverns. This is a valuable observation since it confirms that gas overpressurisation is unlikely to occur in repositories constructed in fractured crystalline rocks. A second source of information relevant to the overpressurisation in crystalline rocks is provided by oil and gas reservoirs where igneous rocks overly the reservoir rock and presumably provide or contribute to the reservoir top seal. A compilation of such occurrences has recently been published (Schutter 2003). In these situations the dominant rock types involved are bedding parallel basaltic lava flows and dolerite intrusions. The extent to which these rocks provide the top seal is not stated but would be worthy of further investigation within the context of overpressurisation.
- *Mudrocks.* Mudrocks are known to be able to limit gas migration and may form the caprocks to natural gas accumulations. The driving force for gas migration through a mudrock are the buoyancy forces of the gas. These are resisted by the capillary forces preventing gas from entering the very small pores typical of mudrocks (Stenhouse & White 1997). Gas may migrate through a mudrock if the buoyancy forces exceed the capillary pressure or where the capillary pressures are so high that the buoyancy forces can build up to exceed the mechanical strength of the mudstone and fractures form (Clayton and Hay, 1994; Watts, 1987). In practice mechanical failure may be expected only when gas pressures exceed 80% of lithostatic pressure. At depths below ~1.5 km such fractures are likely to reseal due to the high lithostatic pressure, so that only shallower than ~1.5 km is fracturing considered an important gas leakage mechanism (Clayton and Hay, 1994). Precedence from gas and condensate fields in the North Sea show that those fields, where seismic evidence suggests they are leaking, have gas pressures considerably less than 80% of lithostatic and are therefore probably leaking by capillary leakage rather than fracturing (Clayton and Hay, 1994). Note however that most of the observations are from fields deeper than ~1.5 km where capillary leakage is considered the likely mechanism of gas leakage. Elsewhere in the North Sea the flux of gas at the seabed has been measured in the range 400-1000 l m<sup>-2</sup> y<sup>-1</sup> (Clayton and Dando, 1996). This is believed to be sourced from underlying gas reservoirs and has been taken to represent typical gas fluxes through mudrock caps. As such they provide examples of the gas permeability of thick mudrock sequences relevant to repositories constructed in such rocktypes.

### ***Rate of Gas Migration***

Vertical gas migration may be very rapid. Evidence for leakage from a 1 km deep gas storage reservoir into shallow water wells inside one year is given by Coleman et. al. (1977). Gas leakage from an underground coal gasification reactor at a depth of 180 m has been recorded at between 2-15 days (Jones and Burtell, 1996). These rapid vertical migration rates are consistent with the

observation that radon can be transported from depth despite the short half lives of the radon isotopes.

#### *Gas attenuation*

A number of processes can lead to the attenuation of gases as they migrate through the geosphere. The most obvious is physical trapping by low permeability rocks and is well known from the preservation of accumulations of natural gas and other non-commercial gas deposits. In addition, gases such as methane and carbon dioxide can physically sorb to coals and coal-rich mudstones. Typically 6-7 times as much gas can be sorbed on these rock types as held in the pores of a conventional porous reservoir. Commercial extraction of sorbed methane is the basis of the coalbed methane industry. Where a repository is constructed within or below sedimentary rocks consideration should be given to whether either of these processes may attenuate the gas emission at the surface.

#### *Gas sparging*

Sparging or stripping is a process used in the environmental remedial industry. It works by pumping gas (usually compressed air) through contaminated water. Contaminated species, especially dissolved gases in the water, preferentially partition into the gas phase and colloidal particles sorb onto the bubble surface (Goodfield and Rodwell, 1998). This coupled with the natural buoyancy of the injected gas removes the contaminant from the water. Experimental evidence suggest that both hydrophilic and hydrophobic species may sorb at the bubble surface and once attached the sorption is essentially irreversible (Wan and Wilson, 1994).

#### *Gas-induced redox changes*

Methane seeps are sometimes associated with diagenetic changes that involve change of local redox state to become more reducing. This may be evidenced by the formation of magnetic Fe(II) minerals, iron sulphides, bleaching of reddened sediments (Fe(III) reduced to Fe(II)) and the precipitation of U(IV) minerals due to the reduction of U(VI) (Schumaker, 1996). Magnetic anomalies attributed to the reduction of iron minerals have been found above landfill sites in which methane gas is leaking (Ellwood and Burkart, 1996).

**Relevance:** These analogues provide evidence for processes and rates that help to inform the consideration of gas migration from repositories. They are of particular relevance to deep repositories with a significant inventory of reactive materials.

**Position(s) in the matrix tables:** near-field and geosphere matrices, radionuclide transport.

**Limitations:** The nature and significance of gas migration may be affected by the presence of barriers to near-vertical buoyancy-driven flow which are site specific.

**Quantitative information:** Quantitative data is provided for the pressures necessary for the entry of gases into crystalline and mudrock host rocks. Semi-quantitative data is provided on the rates at which gas can migrate through a rock mass. In practice, specific site conditions may affect the values quoted above and they should be used as illustrative only.

**Uncertainties:** There are inevitably unstated uncertainties with the numerical data quoted above.

**Time-scale:** Gas migration timescales can occur on human timescales (0 – 100 years) but the time when gas migration commences depends on the nature of the wastes and packaging and may extend into historical (100 – 1000 years) or archaeological (1000 – 10 000 years) timescales.

**PA/safety case applications:** No previous uses of the analogue studies in a PA or safety case are known.

**Communication applications:** No cases of the use of these types of analogues are known in communication and dialogue material.

**References:**

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**Added value comments:** None identified

**Potential follow-up work:** Additional data on those cases where igneous sills or lava flows appear to form caprocks to gas reservoirs would be helpful within the context of gas overpressurisation.

**Keywords:** gas migration, overpressurisation, sparging, gas sorption, redox controls.

**Reviewers and dates:** Les Knight, Nirex (February 2004).