Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.36560

Assessing the hydrogeochemical stability of a Potential Deep Geological Repository for Used Nuclear Fuel: Determining mean pore-fluid helium residence ages.

DALAL SAEED[1], DARREN HILLEGONDS[2], STEFAN MARKOVIC[3], AMY CARTIER[3], LAURA KENNELL[3], SOPHIE GRIFFITH[1], ANNA PATALONG[1] AND CHRIS J. BALLENTINE[2]

[1]Dept Earth Sciences, University of Oxford, UK
[2]University of Oxford
[3]Nuclear Waste Management Organization (NWMO), Toronto, Canada

Helium accumulation in subsurface water from U+Th decay provides a powerful tool for estimating ancient (ka to Ga) groundwater mean residence ages. An Archean-aged biotite granodiorite–tonalite pluton in the northwestern Superior Province, Canada, is a potential site for a geological repository. Porefluid residence age is a key component of the safety case. Recovered core samples provide porefluid helium concentration profiles within the top 1 km [1]. By combining observed U+Th concentration and porosity profiles with calculations that account for in-situ helium production, deeper diffusive input, and loss-to-surface, we estimate both a basal helium flux and a minimum porefluid age. These are 2–3 × 10^{-8} mol m^{-2} yr^{-1} (50–70 times lower than the average steady-state crustal degassing flux) and ~4 Ma, respectively [1,2].

Significant mineral-matrix out-diffusion of helium from the cores continues after porefluid analysis. This out-diffusion is proportional to the analysed rock volume and independent of sample geometry until mineral-scale dimensions are reached. The observation is consistent with sedimentary environments in which minerals such as quartz contain “excess helium” that migrated into their internal helium-accessible volume (HAV) from surrounding porewater [3]. This out-diffusion indicates an additional helium reservoir, in equilibrium with the porefluid, that is not explicitly represented when considering porefluid helium alone. Accounting for this reservoir will substantially increase derived residence ages. HAV diffusive outgassing rates decrease from ~1.5 × 10^{-6} cc(STP)/g to 5.4 × 10^{-7} cc(STP)/g after 812 days, enabling development and testing of a conceptual model that incorporates HAV domain dimensions and helium concentrations. We will present the impact of combining ^{4}He in the HAV with measured porefluid ^{4}He on porefluid age determinations. The ability to estimate mean porefluid residence ages, rather than minimum ages, represents a significant advance in assessing fluid transport within the rock matrix and will provide calibration for effective 2D and 3D fluid migration models supporting evaluation of the hydrogeochemical stability of a proposed deep geological repository.

[1] Cheng et al., (2024) Workshop on porewater chemistry of clayrocks in repository environments NEA/NSC/R(2024) p62
[2] Cheng et al., (2021) EPSL 574, 117175
[3] Tolstikhin et al., (1996) GCA, 60, 1497-1514