Radioactive Waste Management

RSO Workshop *Gas Generation, Migration and Reactivity in Radioactive Waste Disposal*

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18th September 2020

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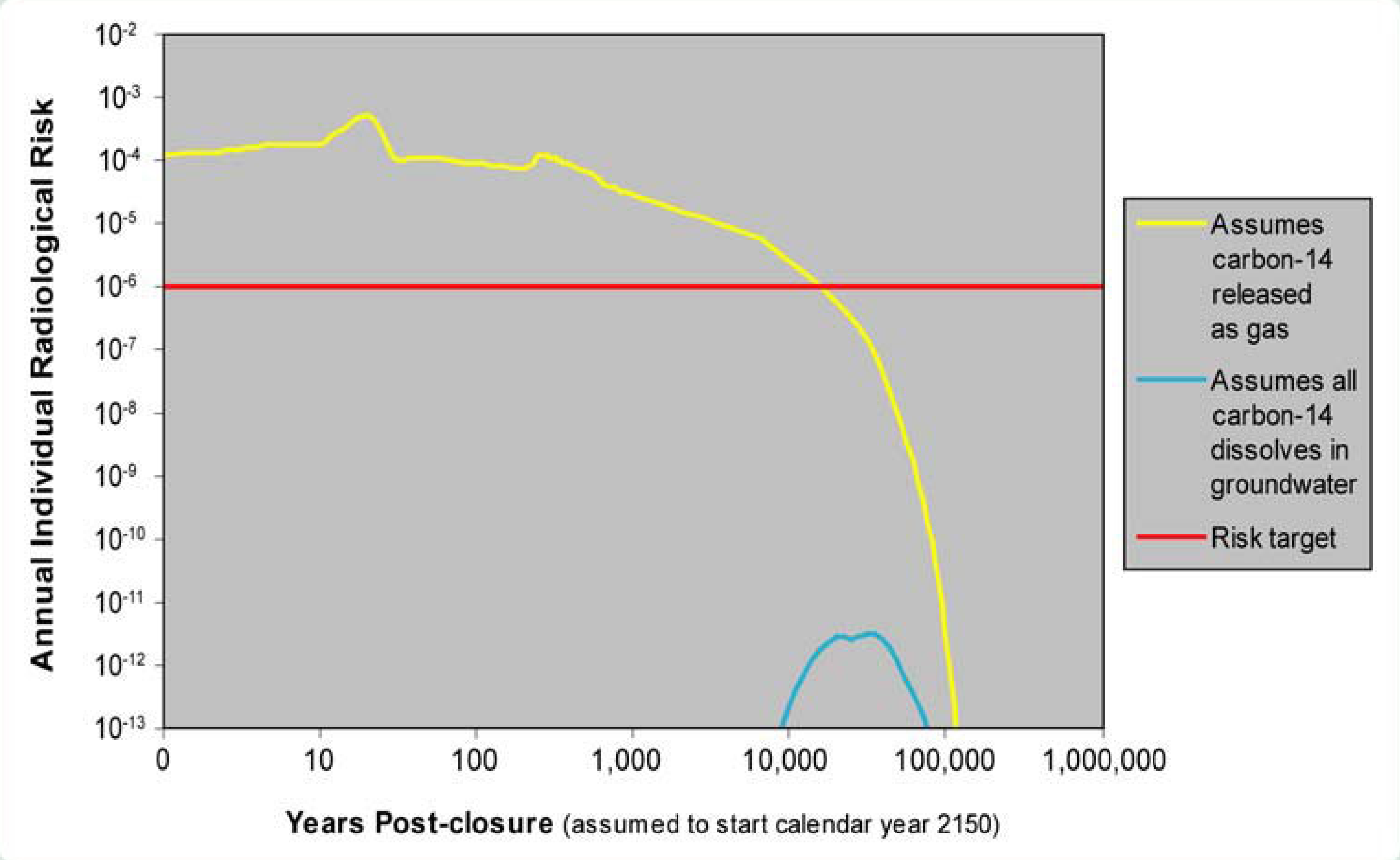
Figure 29
Annual individual risk vs time for carbon-14 dissolved in groundwater and for the scoping calculation for carbon-14 released as gas



- Gas generation from Low-heat and High-heat Generating Wastes in the UK Radioactive Waste Inventory is inevitable
- Bulk gases – primarily hydrogen
- Radioactive gases (C-14)
- Non-radiological gases
- Cross-cutting topic
- Site specific
- Influence on site selection

https://rwm.nda.gov.uk/publication/the-viability-of-a-phased-geological-repository-concept-for-the-long-term-management-of-the-uks-radioactive-waste-nirex-report-n122-november-2005/

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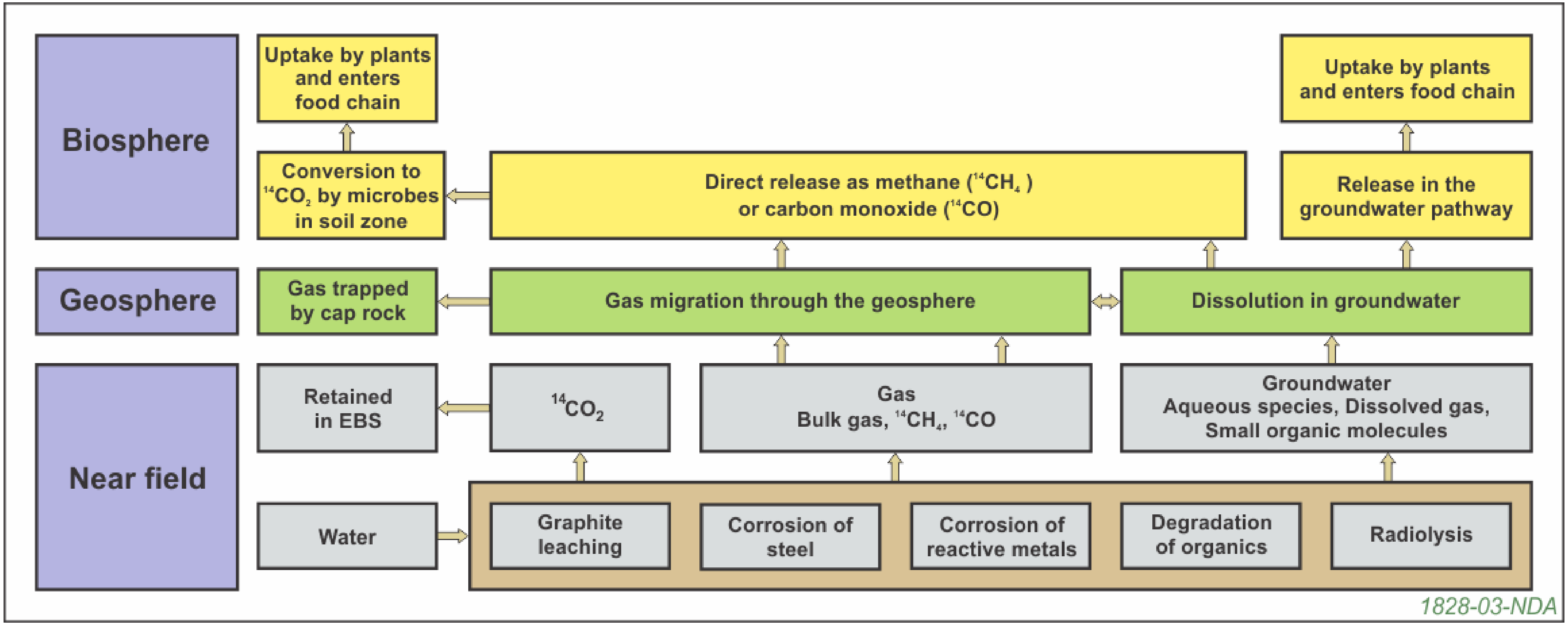
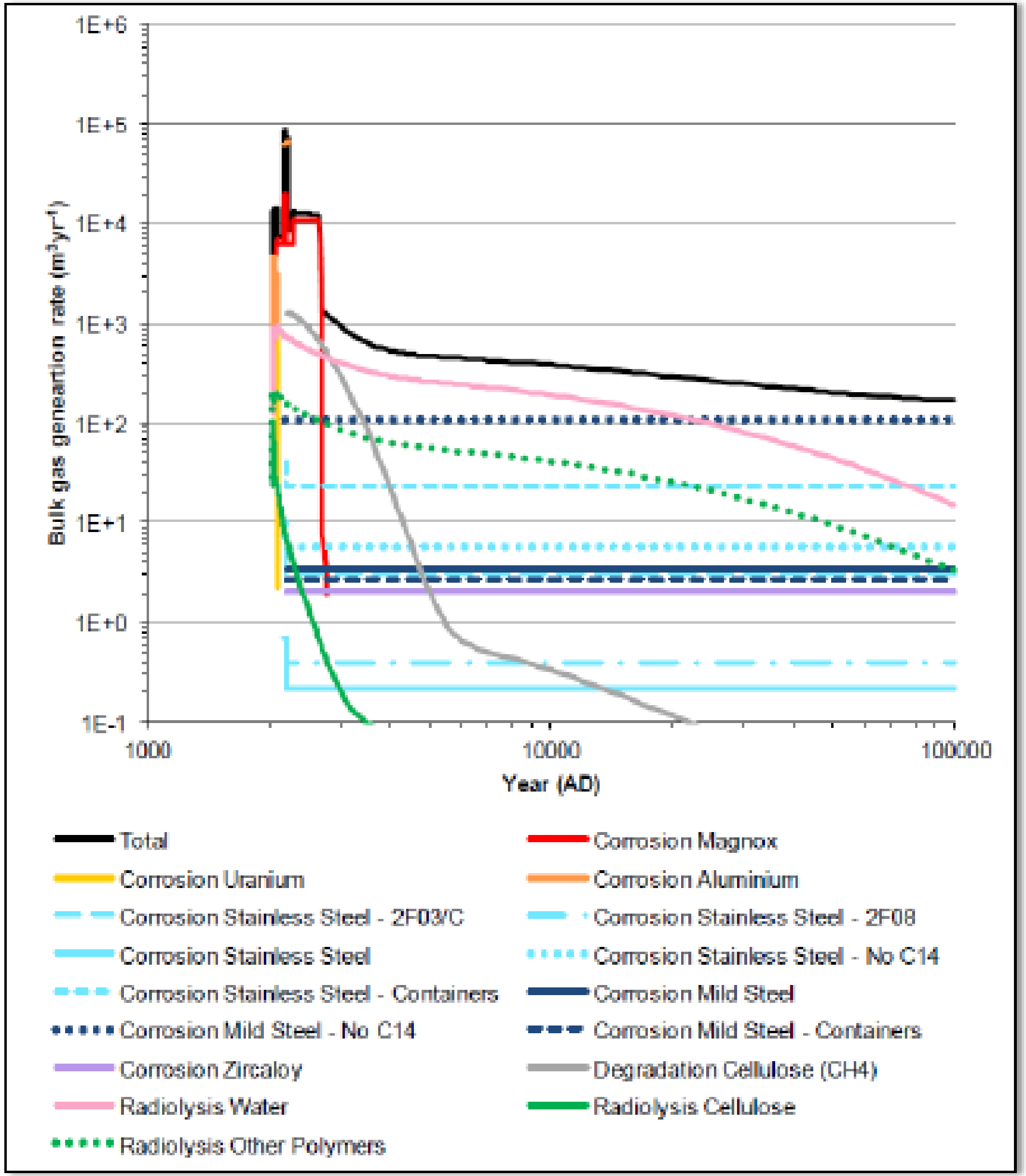


- Cementitious backfill is designed to allow gas movement whilst providing a chemical barrier to radionuclides transported in groundwater
- Bentonite buffer permits gas migration via dilatant pathways that exhibit spatio-temporal evolution; clay believed to fully reseal with time
- Gas migration in higher strength rocks is via fractures; dissolution in groundwater will occur but some ‘free’ gas may remain
- Difficult to create a gas flow into an intact clay host rock as the gas entry pressure and water retention are very high – diffusive transport and transient dilatant pathways
- Gas as an issue still needs to be considered in halite host rock (permeability evolution, plugs/seals)
- Gas behaviour in evolving excavation damaged & disturbed zones

Calculated Bulk Gas Generation Rates by Process from UK RWI Legacy Unshielded Intermediate and Low Level Wastes



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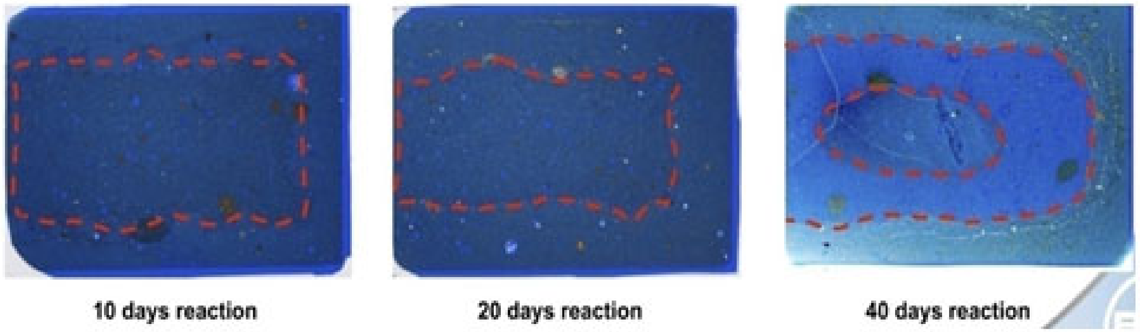
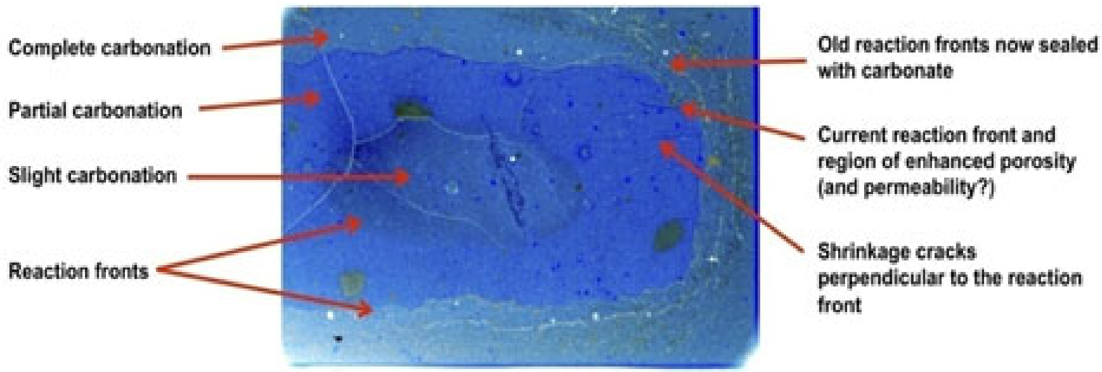
https://rwm.nda.gov.uk/publication/carbon-14-project-phase-2-modelling/

Gas–Engineered Barrier System: Interaction with Cementitious Material

- Substantial body of evidence supporting view that carbonation will occur (cementitious materials react with carbon dioxide)
- In GDF context, carbon-14 bearing carbon dioxide will be immobilized as solid carbonate minerals



Progressive migration of carbonation reaction fronts through 25mm diameter samples of NRVB cement



Partially carbonated cement sample showing zones having different degrees of carbonation together with associated reaction fronts

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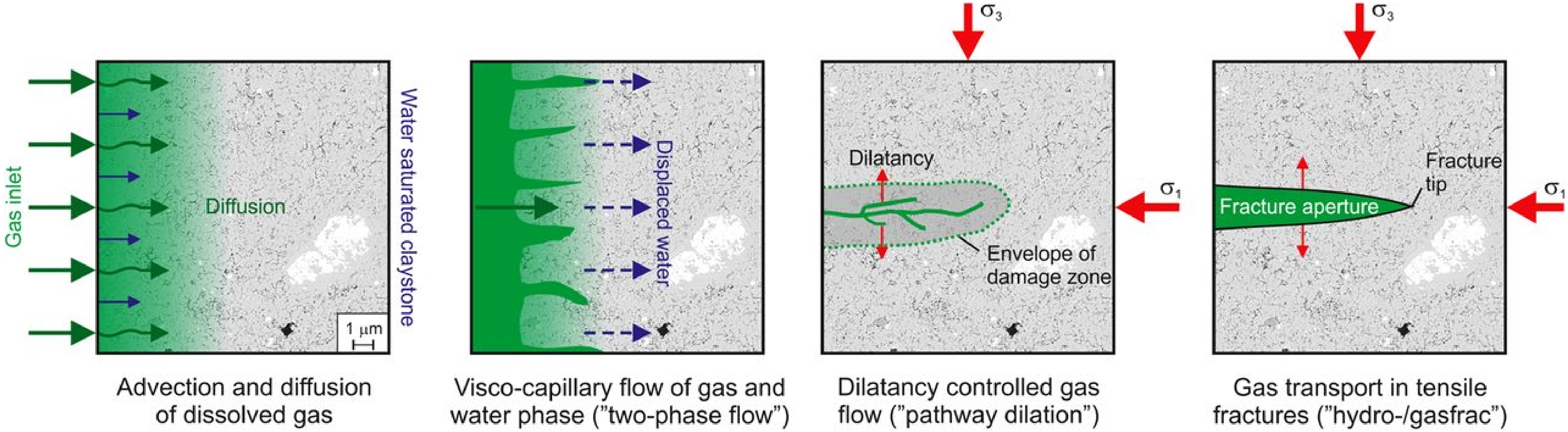
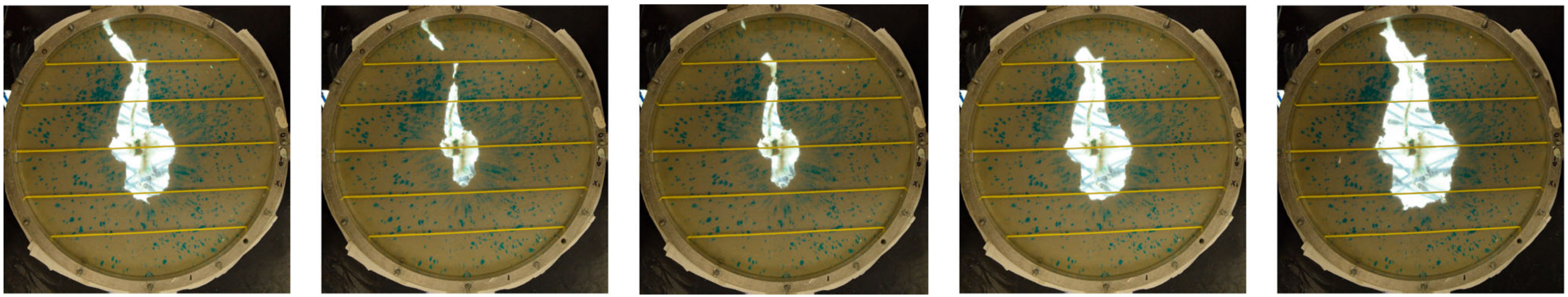
Gas-Clay Interaction, EBS and Host Rock





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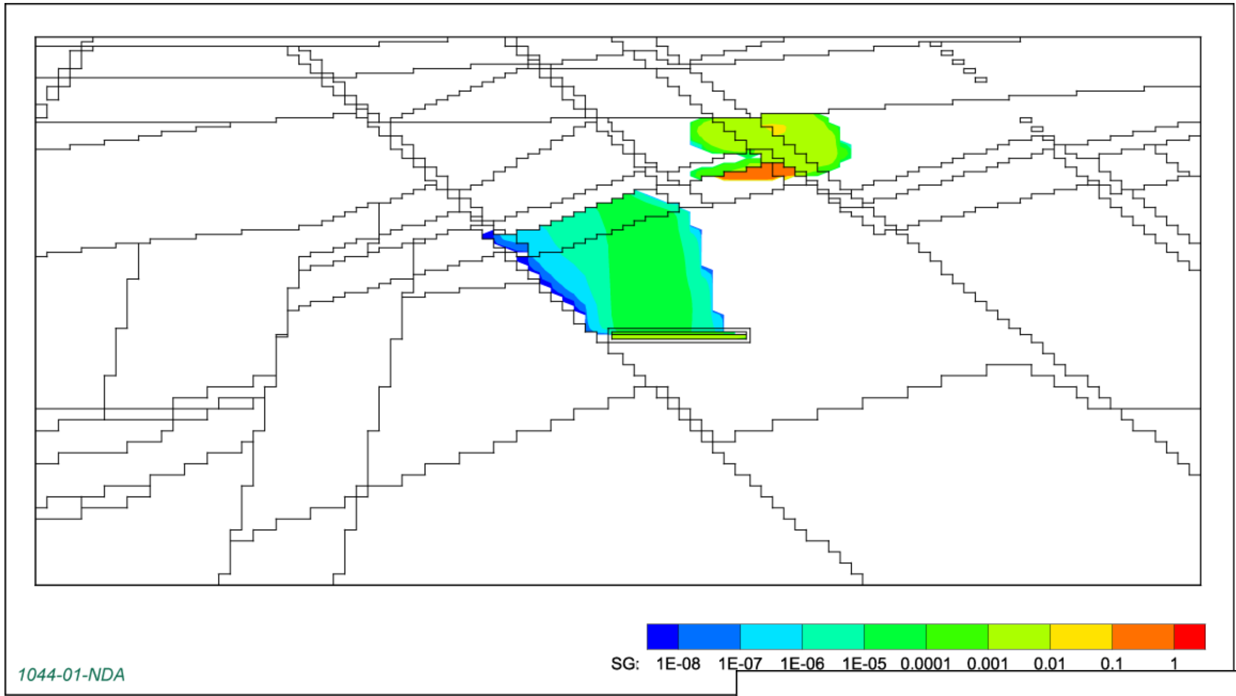
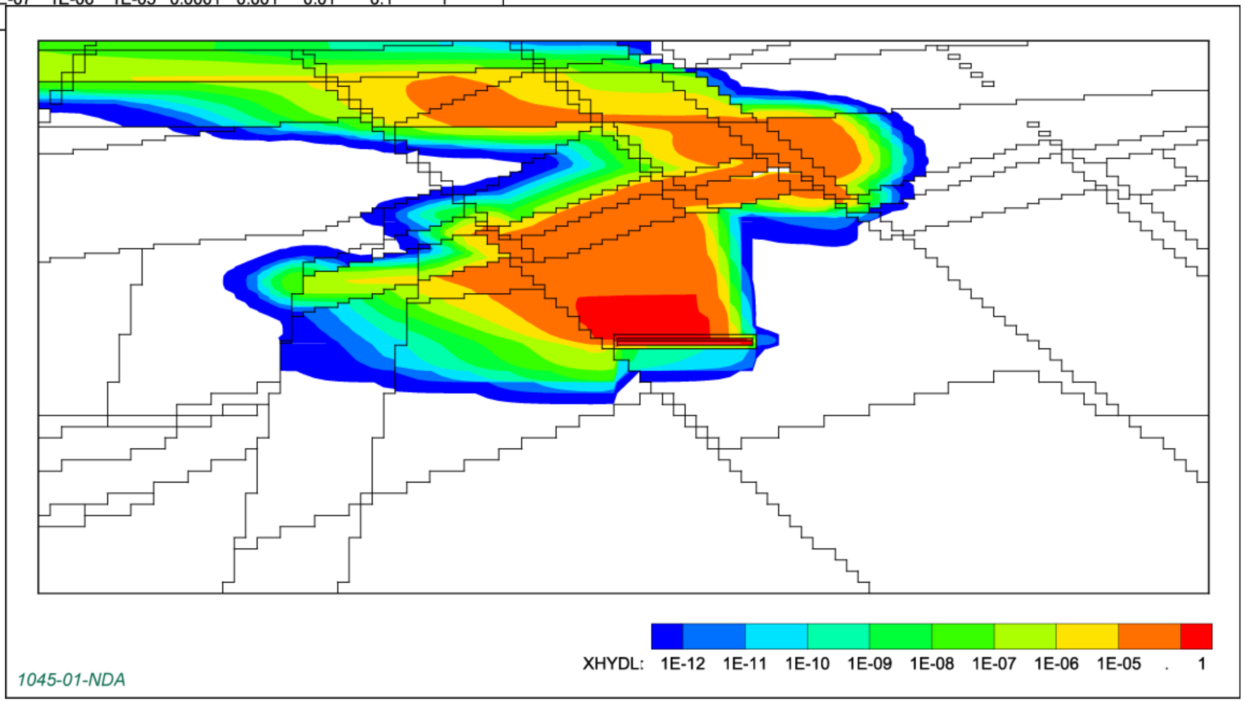
S. Rocco, A.W. Woods, J.F. Harrington and S. Norris, (2016), *An experimental model of episodic gas release through fracture of fluid confined within a pressurized elastic res*ervoir, Geophysical Research Letters, 43, 1–9, doi:10.1002/2016GL071546.



Modelled fraction of pore space occupied by gas at 240 years after closure for gas migration from the GDF in a higher strength rock

Modelled mass fraction of dissolved gas at 240 years after closure for gas migration from the GDF in a higher strength rock



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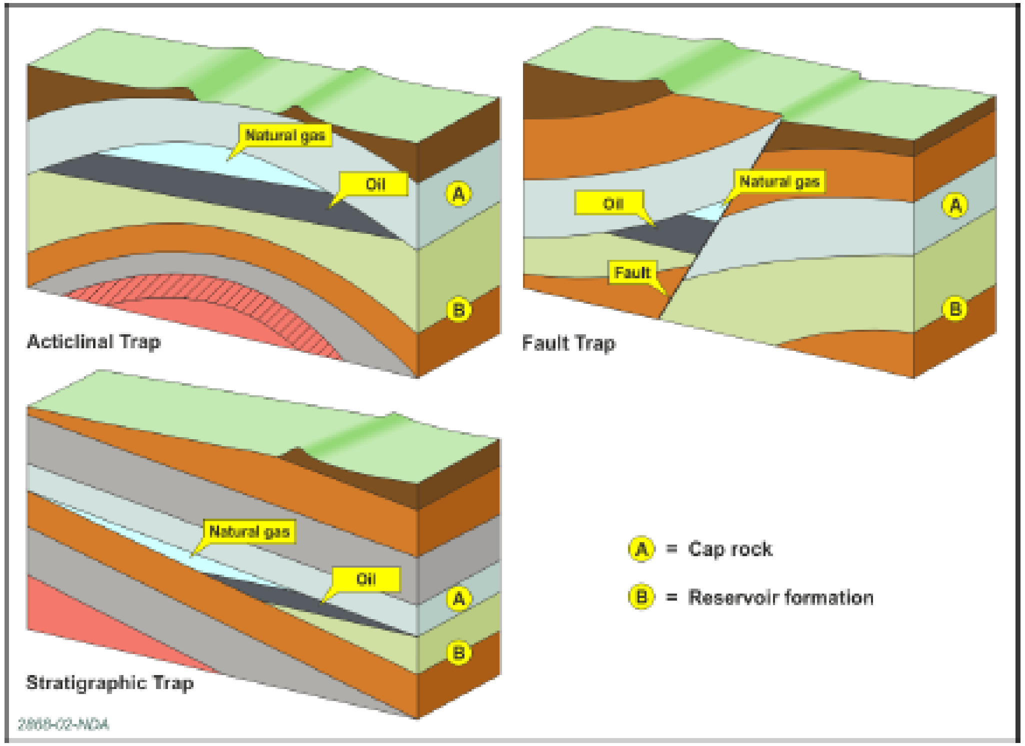
https://rwm.nda.gov.uk/publication/geological-disposal-gas-status-report/



ID	Description	Delay Time (^{14}C ½-lives)	Release Area (m^2)
A	Higher-strength host rock where gas is released over an area similar to the footprint of the GDF ILW/LLW vaults	0	10^5
B	Environments where there is a low permeability formation limiting gas migration	No release	No release
C	Higher-strength host rock where there are features that focus the release of gas to an area much less than the footprint of the GDF ILW/LLW vaults	0	10^4
D	Higher-strength host rock where there are features that distribute the release of gas to an area greater than the footprint of the GDF, e.g. as a result of dissolution	0	10^7
E	Lower-strength host rock where gas migrates slowly across the lower strength sedimentary host rock and is released over the footprint of the GDF ILW/LLW vaults	1	10^5
F	Lower-strength host rock where gas migrates slowly across the lower strength sedimentary host rock and there are features that distribute the release of gas to an area greater than the footprint of the GDF, e.g. as a result of dissolution	1	10^7

- Post-closure risks from GDF-derived gas will be site specific.
- Generic geologies considered to date – range of radiological risks derived in relation to GDF gas (some substantially above the risk guidance level)
- Recognizing this issue, National Geological Screening Guidance* has a long-term safety requirement of "**Any gas generated in the GDF will not compromise safety**"
- NGSG also notes "*The host rocks and the surrounding rocks together must contribute to providing an environment in which harmful quantities of radionuclides or toxic substances will not reach the surface environment by movement in groundwater or in gases generated within the GDF. They must also control the release of any gas generated in the facility to avoid any damage being caused to the containment properties of the multi-barrier system.*"

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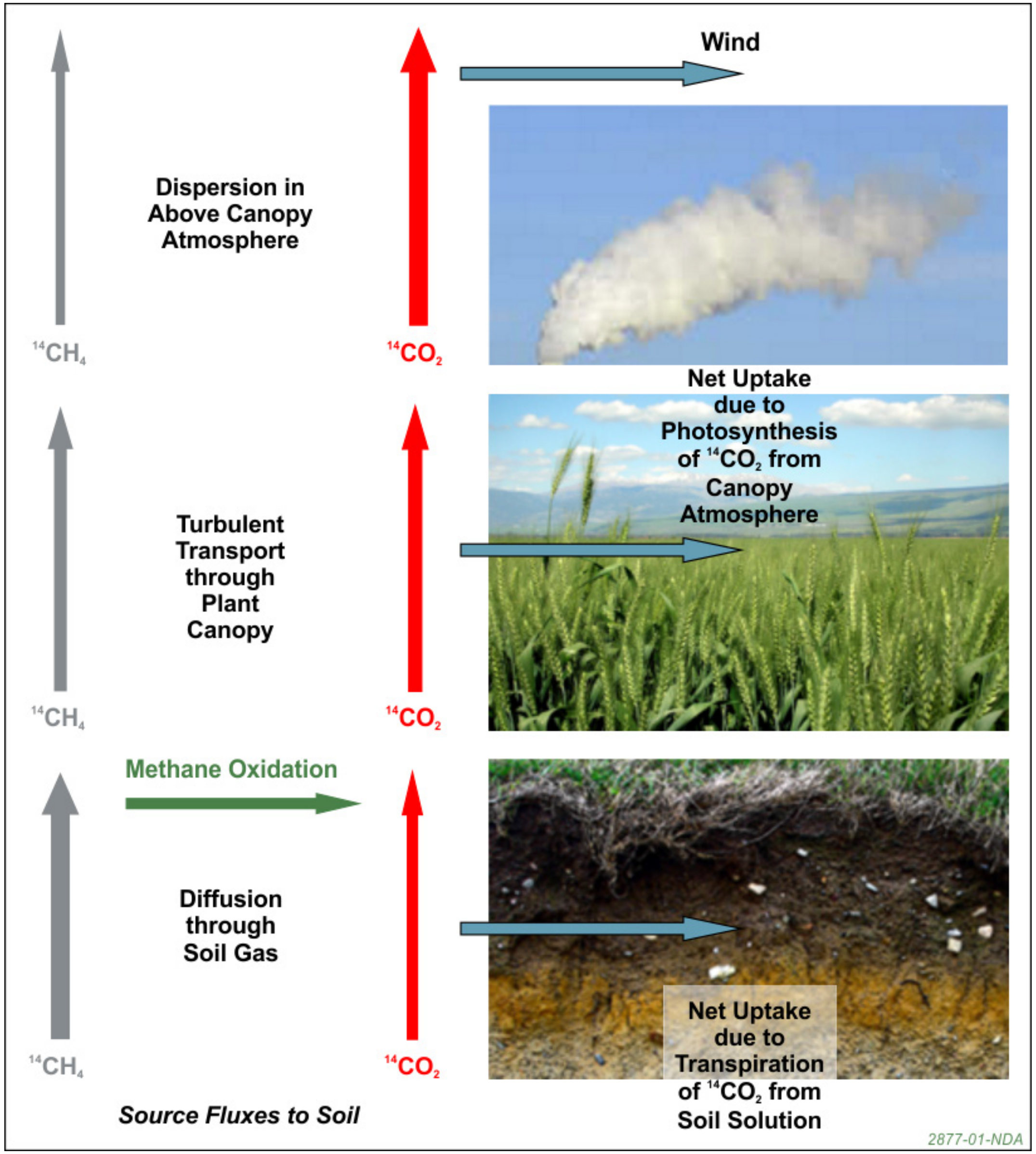
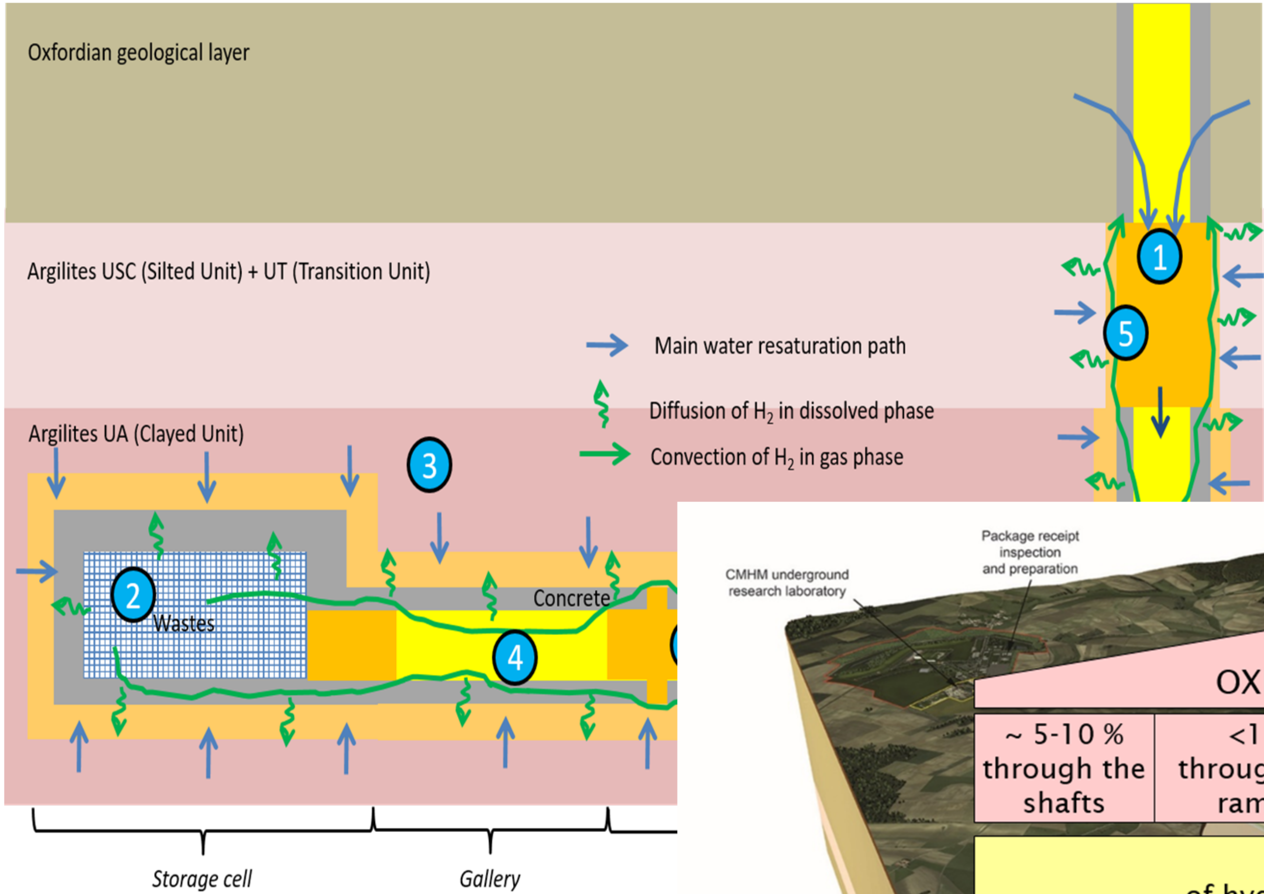
* https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/510678/ngs-guidance.pdf



- Bulk methane may be generated in GDF, mainly by microbial degradation of organic materials
- Carbon-14 bearing methane produced in small amounts in GDF from reactions involving irradiated graphite and irradiated metals
- Microbial conversion of methane to e.g. $^{14}CO_2$ may occur the biosphere, with subsequent plant uptake and entrance to food chain
- This process is of importance as $^{14}CO_2$ represent a greater radiological hazard than $^{14}CH_4$



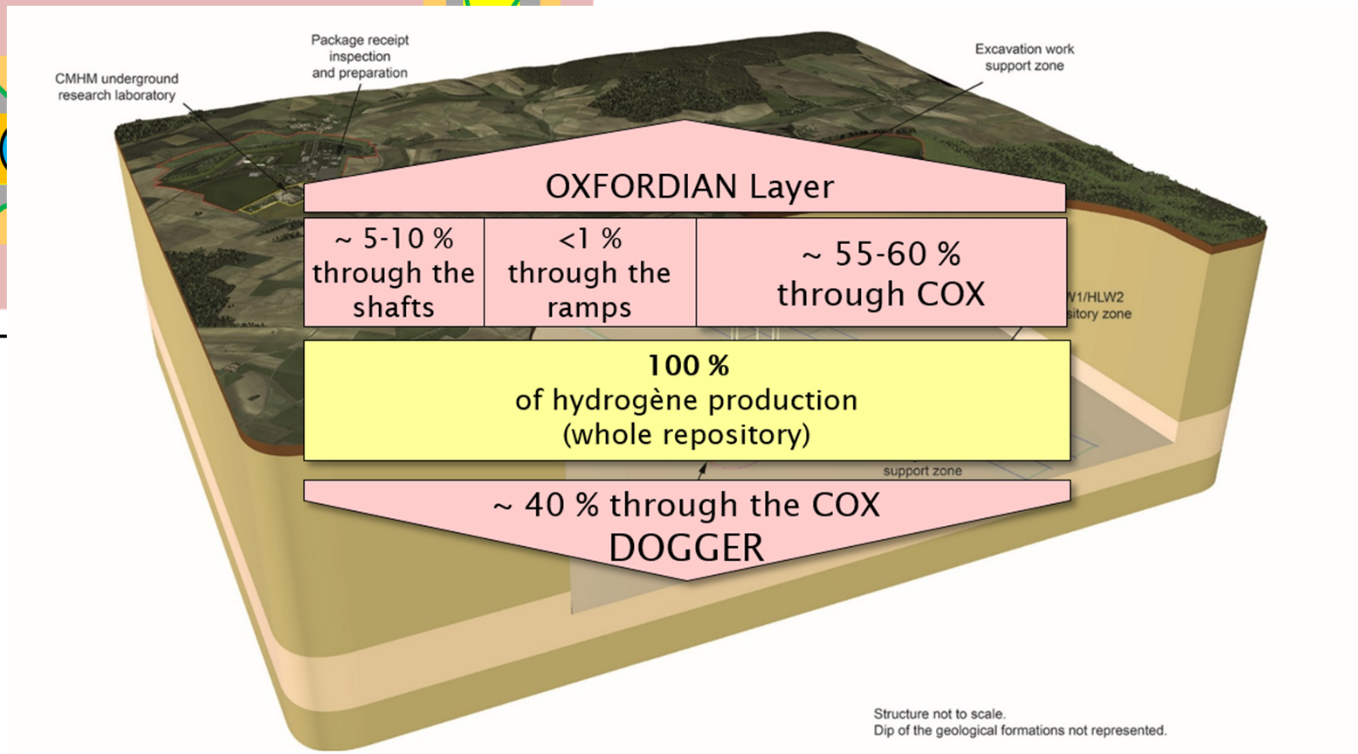


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Illustration of the balance of the distribution of hydrogen migration between upper and underlying aquifers via the host rock or the shafts/ramps after one million years

Process	Cause	T	H	M	C	G
T	Radioactive decay; exothermic reactions. Climate change.		Thermal impact on resaturation timescale and flow paths.	Thermal stresses & strains affect EBS integrity. Spalling.	Solubility, sorption, diffusion, corrosion rate, etc.	Rate and mechanism of gas-generating reactions.
H	Resaturation. Climate change. Future human intrusion.			Changes in saturation alter stresses. Glaciation causes cracking.	Mass transfer, diffusion, EBS degradation, etc. ADZ/CDZ.	Supply of water for gas-generating reactions. Multi-phase flow.
M	Excavation; rock creep. Glaciation; fault reactivation.		Changes to groundwater heads, flow pathways or properties.		Changes in water-rock contact areas and chemistry in a cracked backfill affect solubility or sorption.	
C	Release and migration of solutes, colloids, complexes. Changes to groundwater chemistry.		Precipitation & dissolution reactions alter permeability and porosity. Changes in groundwater salinity affect flow direction.		Solute, complexant or colloid migration change groundwater composition, pH or Eh.	Supplies reactants or catalysts for gas-generating or gas-consuming reactions.
G	Corrosion, microbial degradation, radiolysis. CO_2 release.		Gas transfer and gas-driven groundwater flow.	Induced stress/strain alters flow paths and/or permeability.		

Coupled processes:

T Thermal
H Hydraulic / Hydrogeological
M Mechanical
C Chemical
G Gas

Also sometimes:
B Biological

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Summary / Pointers

- Seeking RSO suggestions for further gas-related issues
- Don’t be confined by work to date!
- Givens – Higher Activity Wastes in UK Radioactive Waste Inventory, Geological Disposal
- Site not chosen; consider host rock, surrounding geology, engineered barrier system, approaches to sealing vaults / tunnels / shafts as ‘variables’
- Waste-stream basis / LHGW inventory basis / HHGW inventory basis / ‘all in’ basis
- Management of gas generated in operational period, including engineering approaches
- Post-closure gas generation, and gas migration in / via GDF ‘furniture’ & geosphere; evolution with time in rates of processes, properties….
- Caveats:
  - Remember gas-related couplings!
  - A significant part of the UK RWI is already packaged – will this realistically ever be subject to re-working?
  - If considering upstream optimisation, need to consider all inputs (e.g. if Process X when applied to the inventory creates “Gas-Perfect” Product A and a load of secondary wastes, need consideration all process outputs – no ‘sweeping under the carpet’)

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Workshop Session AIMS

Research Support Office

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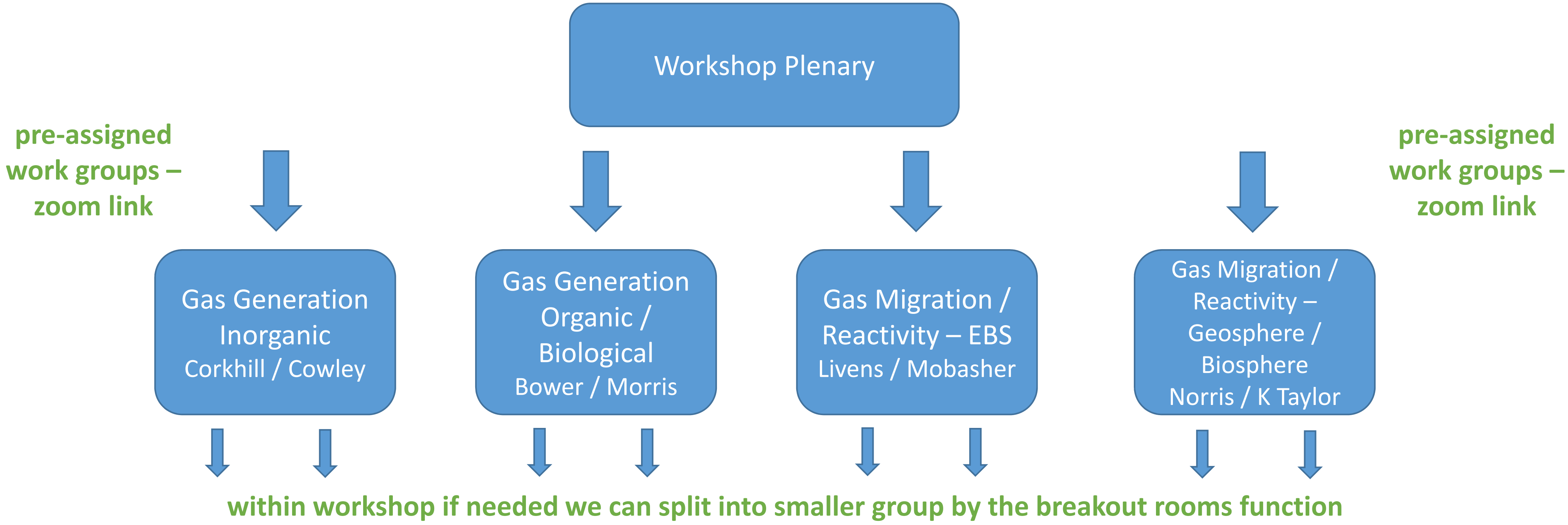
Participants will work in groups to develop ideas for strategic research proposals <u>which will be used to shape an RWM RSO Funding Call</u> in the area of Gas Generation and Gas Migration by:

- 1. Considering their group's strategic research area, purpose, objectives, timescales & methods, including ALL resource needs;
- 2. Outlining the proposed research context including statement of the research community needs;
- 3. Identifying existing and possible research proposal partners and potential funding bodies;
- 4. Sharing any significant learning with members of the research community on developing research ideas, proposals & plans; and
- 5. Agreeing any next steps around the project, including any lead or support roles to progress proposal(s) as the RWM RSO Funding Call is issued.

Workshop Session Ground Rules

- Non-essential devices off
- Please mute unless speaking, in workshop
- Consider “Hand up” function in zoom with facilitators / scribe depending on size of group
- One person speaks at a time – be concise, polite and stay on topic
- Scribe is point of communication for workshop outputs – please respect their task
- Please keep to time – facilitators will assist you in this

Workshop Session A Logistics



- Scribe in each session with pro-forma
- Workgroups of approximately 8 people

Workshop Session B Logistics

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Starts at 11:30

pre-assigned work groups – zoom link in invite and chat

pre-assigned work groups – zoom link in invite and chat

- Gas Generation Inorganic
  Corkhill / Cowley
- Gas Generation Organic / Biological
  Bower / Morris
- Gas Migration / Reactivity – EBS
  Livens / Mobasher
- Gas Migration / Reactivity – Geosphere / Biosphere
  Norris / K Taylor

within workshop if needed we can split into smaller group by the breakout rooms function

please move back into plenary for 13:00

Workshop Plenary

please move back into plenary for 13:00

Appendix

Summary of Recent / Ongoing Work

- C-14 integrated project team; EC CARBOWASTE project; EC CAST project; RWM work – numerous strands to our work on waste-derived gas
- A number of issues are site-specific; pursue at generic level only now (site-specific work will be undertaken in the future)
- View of international participants at conclusion of European Commission **F**ate **O**f **R**epository **G**as**E**s project (2009-2013, 25 participating organisations, regulators, implementers, academia, industrial):
  - "*Based on studies undertaken in the EC FORGE project, and on input from complementary studies, we have enhanced our understanding of repository-derived gas in relation to a range of concepts for the geological disposal of radioactive waste. Such understanding provides a justification for increased confidence in analyses of the gas issue as undertaken within the safety case.*"
- EC GAS project ongoing (gas-clay interactions)
- Ongoing programme of research

RSO RWM SME Gas

- Simon Norris, RWM Principal Research Manager
- With RWM and precedents for 26 years
- Responsibilities include:
  - Geosphere research lead / Geosphere Status Report
  - Gas research lead / Gas Status Report
    - Gas : Engineered Barrier System interaction – cement and bentonite
    - Gas migration through clays (EBS and natural) and evaporites
  - EC CArbon-14 Source Terms (CAST) project (WP lead, to-be co-ordinator)
  - EC Fate Of Repository GasEs (FORGE) project (WP lead)
  - EC EURAD GAS project
  - Owner of Simple Model of Gas Generation ("SMOGG") software with associated Disposability Assessment process responsibilities
- PhD geophysics with geology
- CGeol, CPhys, CSci

Co-authored Gas-related Journal papers

- *On the Role of Caprock and Fracture Zones in Dispersing Gas Plumes in the Subsurface*, A.W. Woods and S. Norris, Water Resources Research, Volume 46, W08522, 2010.
- *Understanding the Behaviour of Gas in a Geological Disposal Facility: Modelling Coupled Processes and Key Features at Different Scales*, G. Towler, A. E. Bond, S. Watson, S. Norris, P. Suckling, and S. Benbow, Mineralogical Magazine, December 2012, v. 76, p. 3365-3371, published online 29 January 2013, doi:10.1180/minmag.2012.076.8.49.
- *EC FORGE project: Updated Consideration of Gas Generation and Migration in the Safety Case,* S. Norris, doi:10.1144/SP415.8. In *Gas Generation and Migration in Deep Geological Radioactive Waste Repositories*, Geological Society Special Publication 415, edited by R.P. Shaw, http://sp.lyellcollection.org/online-first/415, 2015.
- *An Experimental Study of the Flow of Gas along Synthetic Faults of Varying Orientation to the Stress-field; Implications for Performance Assessment of Radioactive Waste Disposal.* R.J. Cuss, J.F. Harrington, D. Noy, S. Sathar and S. Norris. Journal of Geophysical Research - Solid Earth, doi: 10.1002/2014JB011333, American Geophysical Union, 2015.
- *Multi-scale gas transport modelling for the EC FORGE project* , A. E. Bond, K. E. Thatcher and S. Norris, Mineralogical Magazine, 2015, v. 79, p. 1251-1263, doi:10.1180/minmag.2015.079.7.01.
- *Dispersion and dissolution of a buoyancy driven gas plume in a layered permeable rock,* Woods, A. W., and S. Norris (2016), Water Resources Research, 52, doi:10.1002/2015WR018159.

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Co-authored Gas-related Journal papers

- S. Rocco, A.W. Woods, J.F. Harrington and S. Norris, (2016), *An experimental model of episodic gas release through fracture of fluid confined within a pressurized elastic re*servoir, Geophysical Research Letters, 43, 1–9, doi:10.1002/2016GL071546.
- J.F. Harrington, C.C. Graham, R.J. Cuss and S. Norris, *Gas network development in a precompacted bentonite experiment: Evidence of generation and evolution*. Applied Clay Science 147 (2017) 80–89. **http://dx.doi.org/10.1016/j.clay.2017.07.005**. 2017.
- R.J. Cuss, J.F. Harrington, S. Sathar, S. Norris and J. Talandier. *The role of the stress-path and importance of stress history on the flow of water along fractures and faults; an experimental study conducted on kaolinite gouge and Callovo-Oxfordian mudstone*, Applied Clay Science 150 (2017) 282–292, **http://dx.doi.org/10.1016/j.clay.2017.09.029**, 2017.
- J. F. Harrington, C. C. Graham, R. J. Cuss, and S. Norris, *Gas Network Development in Compact Bentonite: Key Controls on the Stability of Flow Pathways*, Geofluids, vol. 2019, Article ID 3815095, 19 pages, 2019. https://doi.org/10.1155/2019/3815095.
- N. Chittenden, S. Benbow, A. Bond, S. Norris. Development of an upscaled HM model for representing advective gas migration through saturated bentonite. International Journal of Rock Mechanics & Mining Sciences 133 (2020) 104415, https://doi.org/10.1016/j.ijrmms.2020.104415.

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RWM Bibliography Reports

- Update of the GPA(03) assessment of the consequences of gas
- Specification for SMOGG Version 5.0: Simplified model of gas generation from radioactive waste
- SMOGG (Version 5.0), a simplified model of gas generation from radioactive wastes: User guide
- Gas migration calculations
- Scoping calculations to determine if gas generated in a repository might migrate to the biosphere
- Gas and the human intrusion pathway
- Comparison of results from the MAGGAS and SMOGG gas generation models
- Comparison of gas generation and gas transfer analyses for Nirex, Nagra and Andra ILW, HLW and SF repository concepts, GSL 0573-1 V2, TW Hicks & TD Baldwin
- Buoyancy Driven Gas Dispersion along an Inclined Low Permeability Boundary A Simple Software Tool
- Post-closure Performance Assessment: Example Approaches for Gas Modelling of Generic Environments, SERCO/TAS/000472/001 Issue 2 May 2010 (delayed from FY2008-09)
- Investigation of Gas Generation and Resaturation Issues: Input to EC FORGE Project, QRS-1378ZC-R2, Version 2.0, July 2011
- Assessment of Issues Relating to Pre-closure to Post-closure Gas Generation in a GDF QRS-1378ZP-R1, Version 3.0, June 2012
- Determination of G-values for use in SMOGG Gas Generation Calculations, AMEC/200615/001 Issue 3, July 2015
- Sealing Site Investigation Boreholes: Phase 2. Task 5: Techniques used in the oil and gas industry for placing materials in boreholes. Potential application to generic sealing concepts for the RWM Siting Programme, Amec Foster Wheeler report to RWM, 202580/04 Issue A, December 2016.
- Sealing Site Investigation Boreholes: Phase 2. Task 14: Impact of Gas, Amec Foster Wheeler report to RWM, 202580/005 Issue A, December 2016
- Specification for SMOGG Version 7.0: A Simplified Model of Gas Generation from Radioactive Wastes, AMEC/204651/001, Issue 2, January 2016
- User Guide for SMOGG Version 7.0: A Simplified Model of Gas Generation from Radioactive Wastes, AMEC/204651/002, Issue 2, January 2016
- Gas Generation Data to Support the 2016 Generic Operational Environmental Safety Assessment, AMEC/204651/003, Issue 3, March 2016
- Effects of Gas Release from Vented Waste Packages during Backfill Emplacement on the Properties of the Backfill, Nuclear Technologies R1492 NNL(17) 13807, Issue 5, January 2017.
- RWM Coupled Processes Project First Annual Report for DECOVALEX-2019, A. Bond, N. Chittenden and K. Thatcher, QRS-1612D-R1, V1.2, December 2017
- RWM Coupled Processes Project Second Annual Report for DECOVALEX-2019, A. Bond, N. Chittenden and K. Thatcher, QRS-1612D-R2, V2.1, February 2019
- Gas Migration Experimentation, C.C. Graham, B.T. Swift, D. Holton, N.L. Jefferies and J.F. Harrington, RWM/02/045, 208299/001, Issue 1.1, 29th November 2019
- GDF Pre-closure to Post-closure Waste-derived Gas Generation and Migration, B.T. Swift, A.R. Hoch, V. Tsitsopoulos, B. Lanyon, P. Marschall, RWM.02.029, 207503/001, Issue 1.1, 17th December 2019
- RWM Coupled Processes Project Third Annual Report for DECOVALEX-2019, A. Bond, N. Chittenden and K. Thatcher, QRS-1612D-R3, V1.2,February 2020
- RWM Coupled Processes Project Final Report for DECOVALEX-2019, A. Bond, N. Chittenden and K. Thatcher, QRS-1612D-FR, V1.0, October 2019
- Review of understanding of gas generation and recommendations for updating its treatment in assessments, B.T. Swift, S.W. Swanton, D.A. Lever, S.A. Myers, S.J. Williams, P.N. Humphreys, A. Adeogun, N. Diomidis, A. Poller and T. Nagel, Wood report to RWM 208517/001, Issue 1, March 2020

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