TRANSCEND

Transformative Science and Engineering for Nuclear Decommissioning

Electrokinetic Remediation and Decommissioning – an update on current work

Dr Frances Burrell

Frances.Burrell@noc.soton.ac.uk

University of Southampton

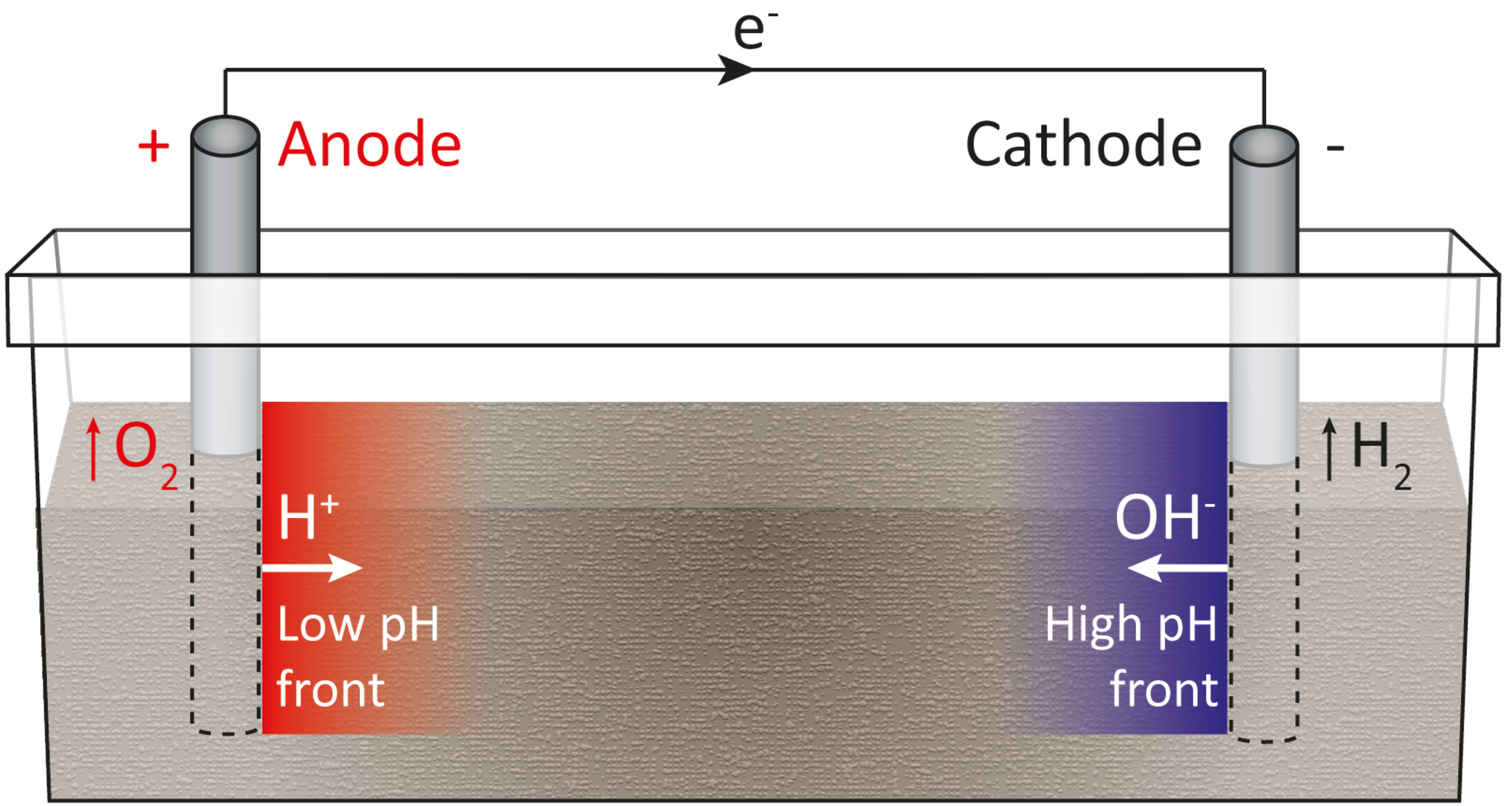
TRANSCEND 2022 Annual Meeting
Glasgow, November 2022

Energy
For a Low Carbon Future

In this presentation…

- **Reminder of the principles of electrokinetics**
- **Benefits and potentials**
  - As a combined technique
- **Real-world challenges**
- **Current work**

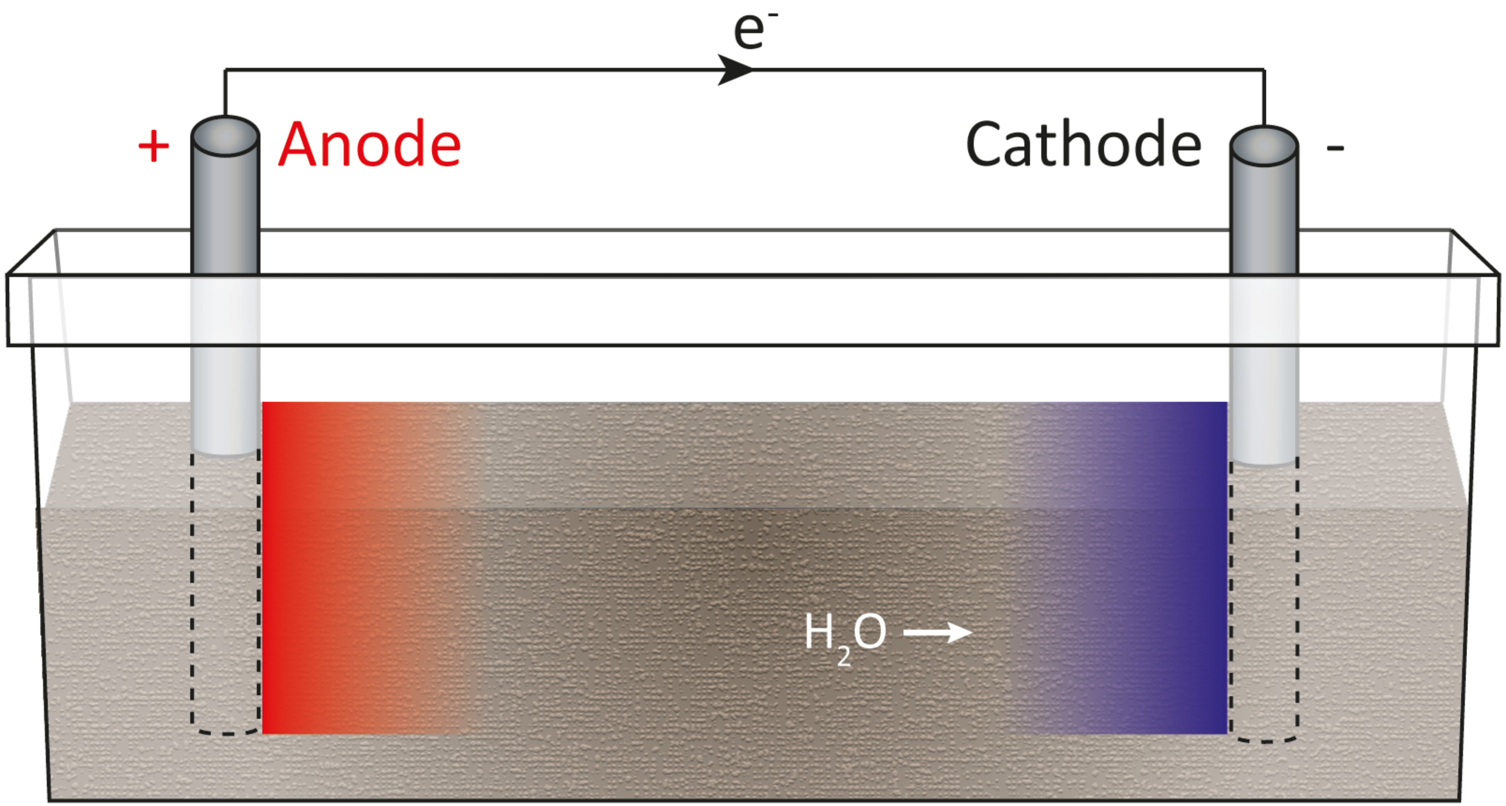
Electrokinetic Remediation



$H_2O \rightarrow 2\ H^+ + \frac{1}{2}\ O_2\ (\uparrow) + 2\ e^-$

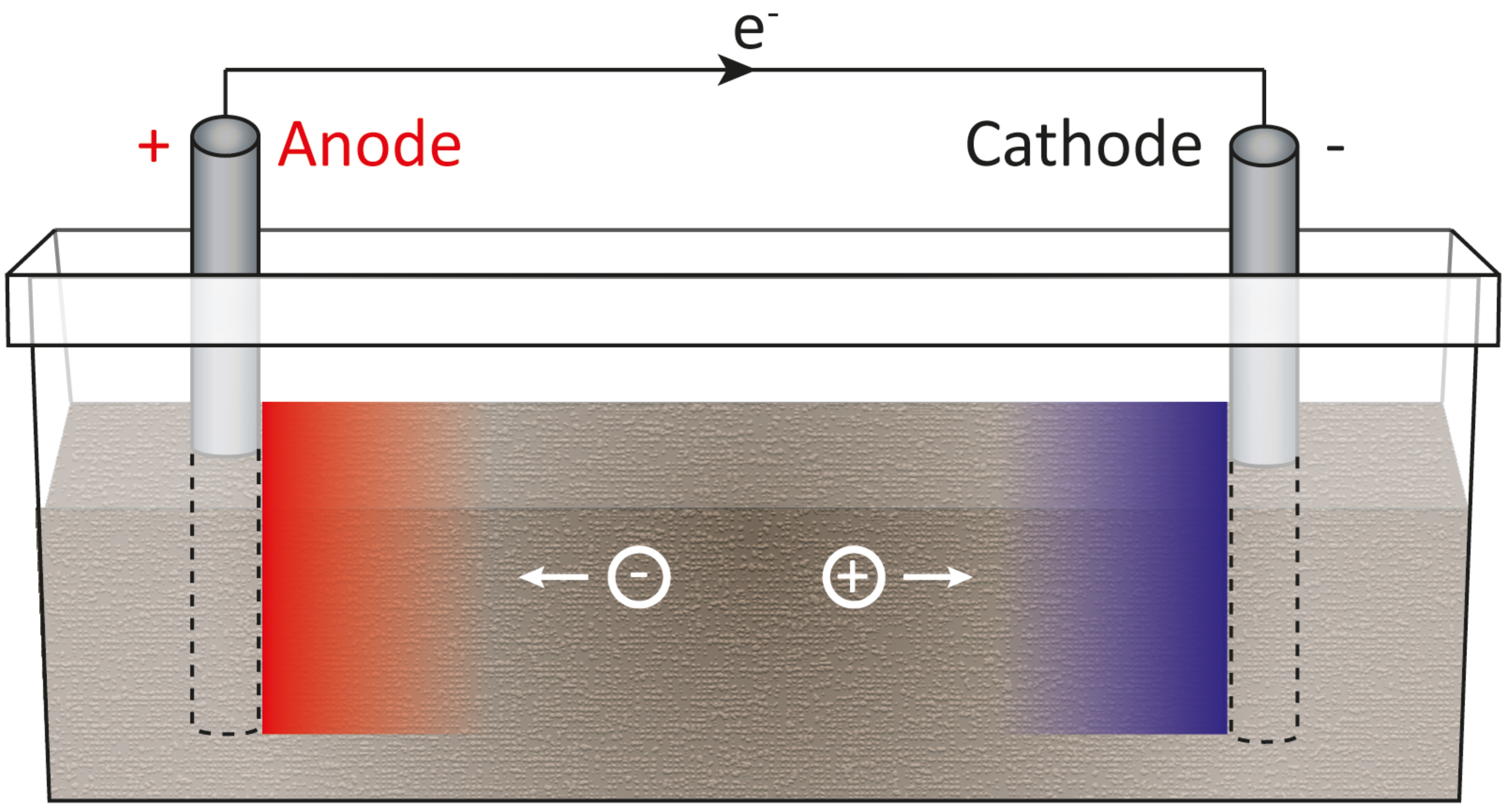
$2H_2O + 2e^- \rightarrow 2OH^- + H_2\ (\uparrow)$

Electrokinetic Remediation



Electro-osmosis:
Movement of water (towards the cathode only)

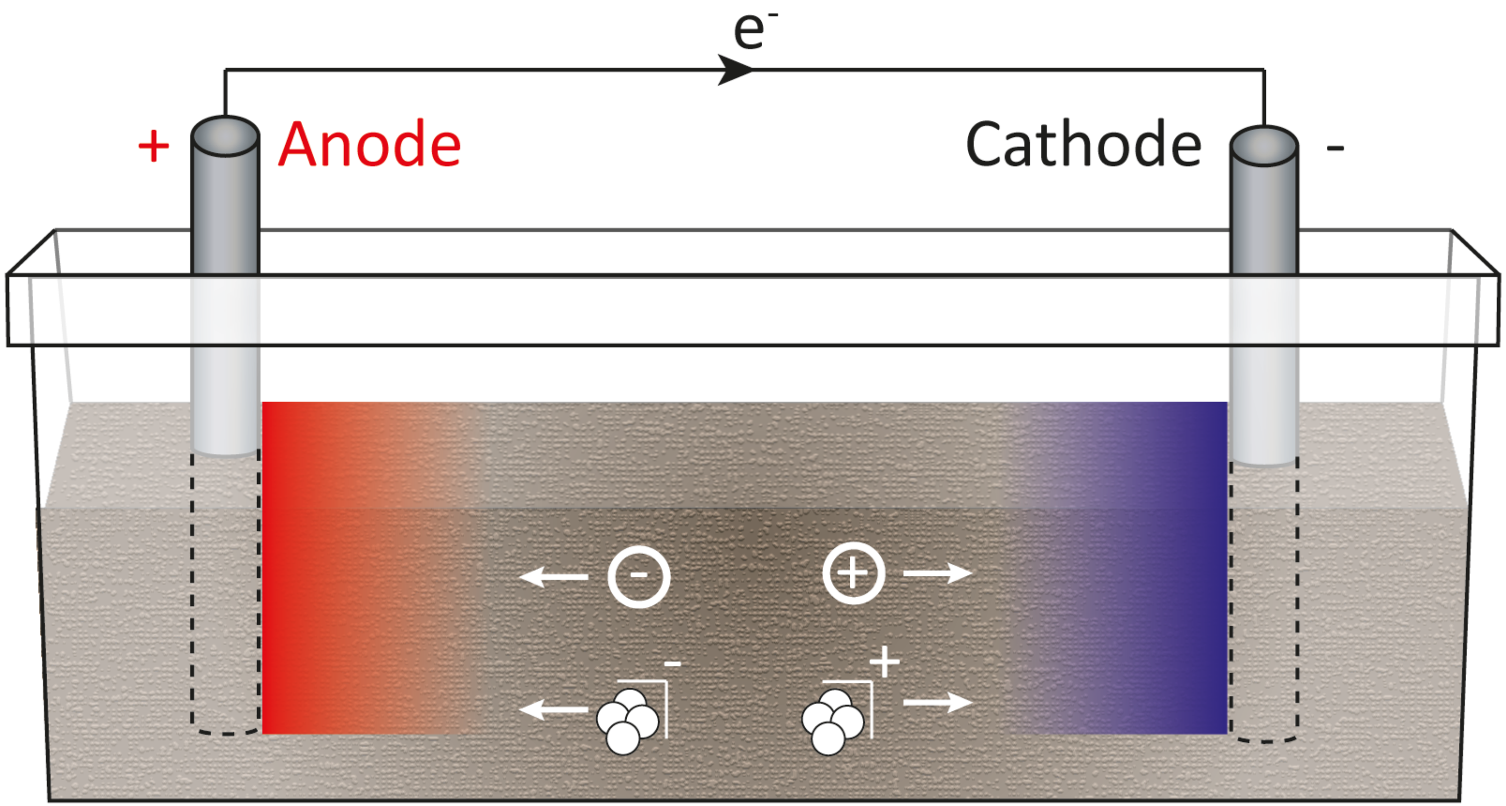
Electrokinetic Remediation



Electromigration:
Movement of ions

Cations (+) → cathode (-)
Anions (-) → anode (+)

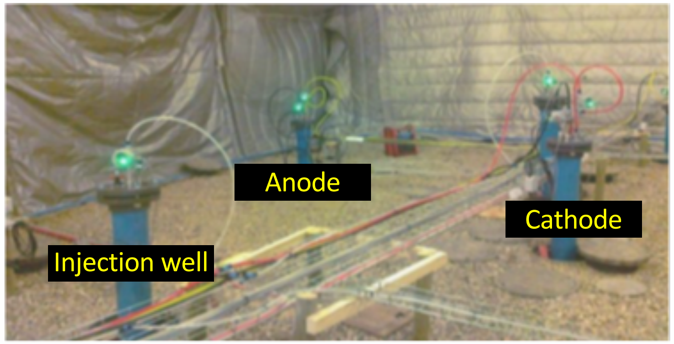
Electrokinetic Remediation



Electrophoresis:
Movement of particles

+ charged particles → cathode
- charged particles → anode

Advantages of Electrokinetic Remediation

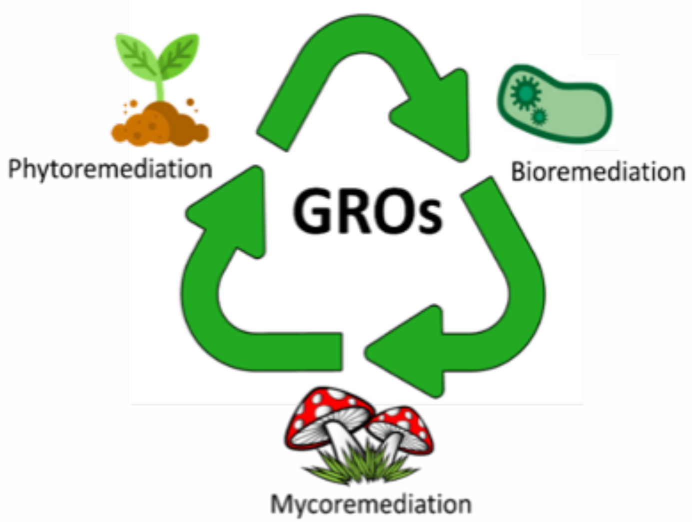


- ***<u>In-situ</u>*** **(or *ex-situ*)**
  - No need to remove/disturb material
  - Worker safety
- **Cheap (power, labour and consumables)**
- **Adaptable**
  - Electrode material
  - Electrode placement
  - Electrolyte
  - Voltage
  - Additives
  - Duration
  - (In-)organic + radionuclide

⇒

- **Combine with**
  - Bio/phyto
  - Chemical oxidation
  - In-situ barrier formation
  - EKR fencing
  - Colloidal grouting

Combination with biological treatment



Journal of Environmental Management 308 (2022) 114620

Contents lists available at ScienceDirect

ELSEVIER

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Developing field-scale, gentle remediation options for nuclear sites contaminated with ^{137}Cs and ^{90}Sr: The role of Nature-Based Solutions

Jamie M. Purkis [a], R. Paul Bardos [b,c], James Graham [d], Andrew B. Cundy [a,*]

[a] School of Ocean and Earth Science, University of Southampton, National Oceanography Centre (Southampton), European Way, Southampton, SO14 3ZH, United Kingdom
[b] Centre for Aquatic Environments, University of Brighton, Brighton, BN2 4AT, UK
[c] r3 Environmental Technology Ltd., Reading, United Kingdom
[d] National Nuclear Laboratory, Sellafield, Cumbria, CA20 1PG, UK

Combination with gentle remediation options?

- Speed up movement of nutrients and/or pollutants

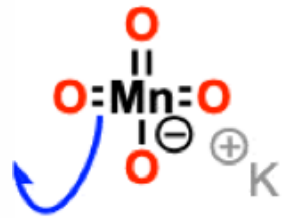
Effect of electrokinetics on biota?

In-situ Chemical Oxidation (ISCO)

Relatively well-established technique for the degradation of organic pollutants

⇨ soluble oxidants are injected into a substrate

⇨ EKR used to enhance transport



Issues:

- Residual toxicity
- Oxidation of radionuclides could increase mobility

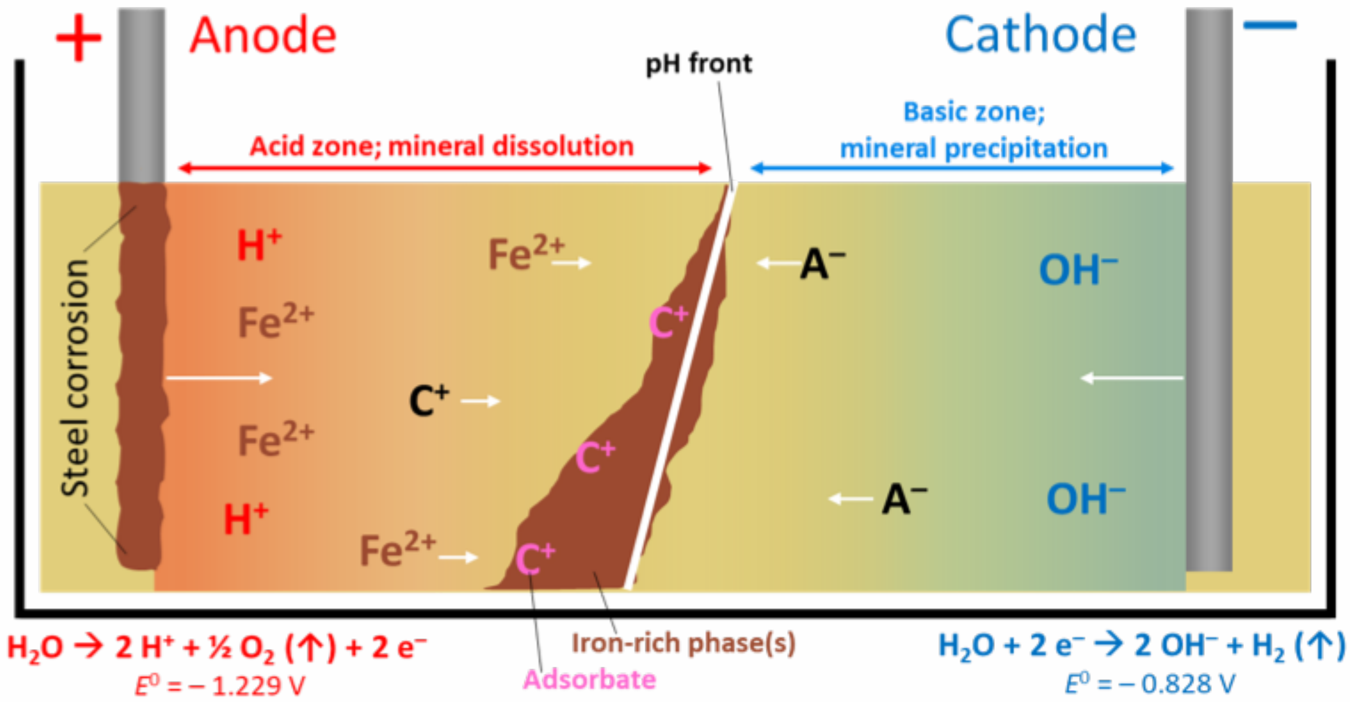
Non-radiological contaminants (e.g. PAHs) at nuclear sites are becoming increasingly important

Ferric Iron Remediation and Stabilisation

Sacrificial iron-rich electrodes ⇨ *in-situ* generation of iron-rich barriers for soil or sub-surface stabilization and contaminant containment

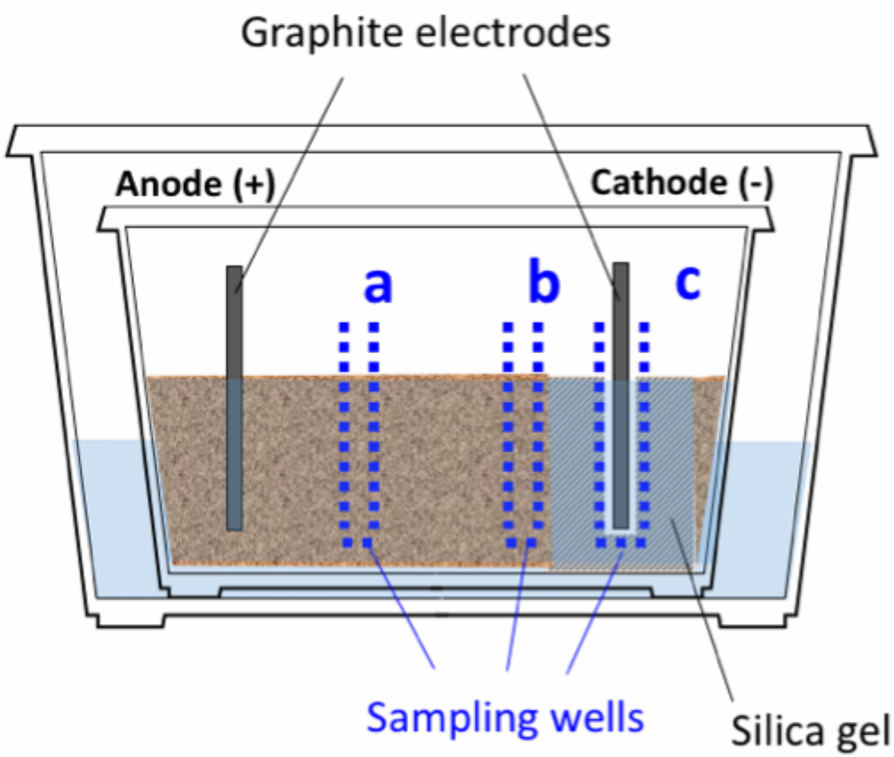
Experimental results:

- Barrier growth over realistic timescales (months)
- Low cost (Single-digit to tens of USD)
- Low energy (< 1 $V.cm^{-1}$)
- Scalability: 1m +



Purkis *et al.*, in prep; Cundy *et* al., Appl. Geochem., 2005, 20, 841

Colloidal Silica Grouting



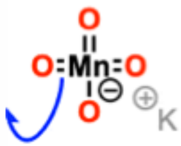
University of Strathclyde

Colloidal silica properties well characterised by University of Strathclyde

- Immobilisation of radionuclides
- Initial electrokinetic tests show potential for "purge and trap" applications

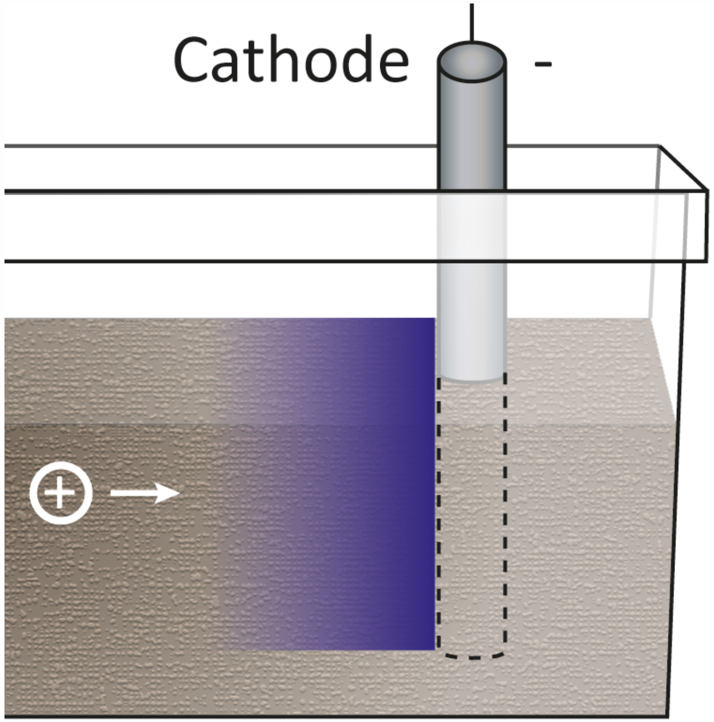
Preliminary results show that Cs and Sr can migrate through colloidal silica block

Technology readiness level

		TRL for non-nuclear	TRL for nuclear	Duration?	Cost?	Comments
EKR		6 - 9+	3 - 6	Variable	Low	✓ Flexible ✗ Limited nuclides tested
Bio- / Phyto-		6 - 7	3 - 5	High	Low	✓ Sustainable ✗ Slow
ISCO		4 - 6	2 - 3	Low	Variable	✓ Quick ✗ Toxicity
Nano / Colloids		4 - 7	3 - 6	Variable	High	✓ Immobilisation ✗ Unproven

Purkis *et al.*, J. Hazard. Mater., 2021, 413, 125274

Real-world challenges



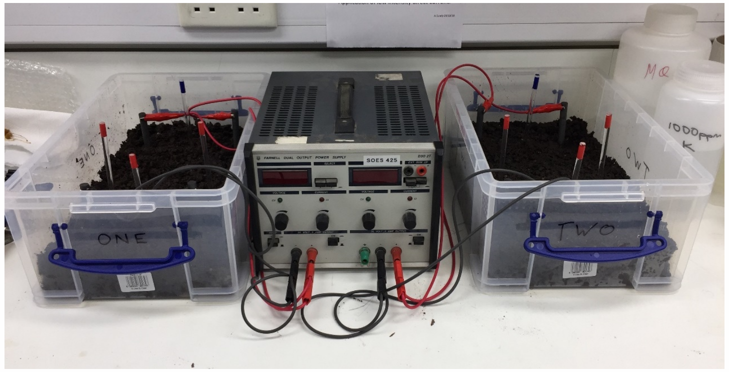
Factors that may affect movement:

- pH front – redox reactions – solubility
- Reactions at the cathode – gas generation, corrosion
- Substrate – permeability, active sites?
- Other ions – competition, ionic strength
- Organic ligands / colloids – complexation, solubility
- Pore water / groundwater – flowing?
- Precipitation / evaporation
- Biota – bioturbation, effect on organisms?

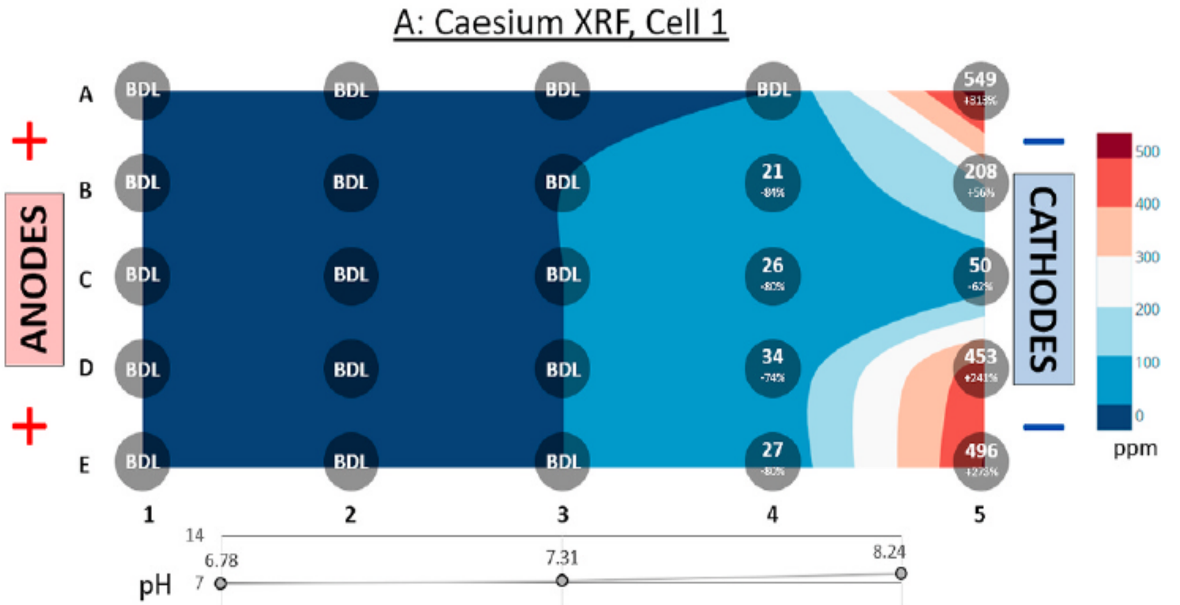
Wider range of experimental conditions to explore in order to increase TRL of electrokinetic remediation for nuclear applications

Treatment of organic-rich soils

- Stable Cs and Sr
- Clayey, organic-rich soil ⇨ simulating material found in the Fukushima exclusion zone



Purkis et al. (2021) Applied Geochemistry, 125, 104826



- Caesium and strontium mobilised by electromigration towards the negatively charged cathodic region
- 80%+ reduction in Cs across much of (2/3) cell
- Cs becomes increasingly intractable with longer maturation times

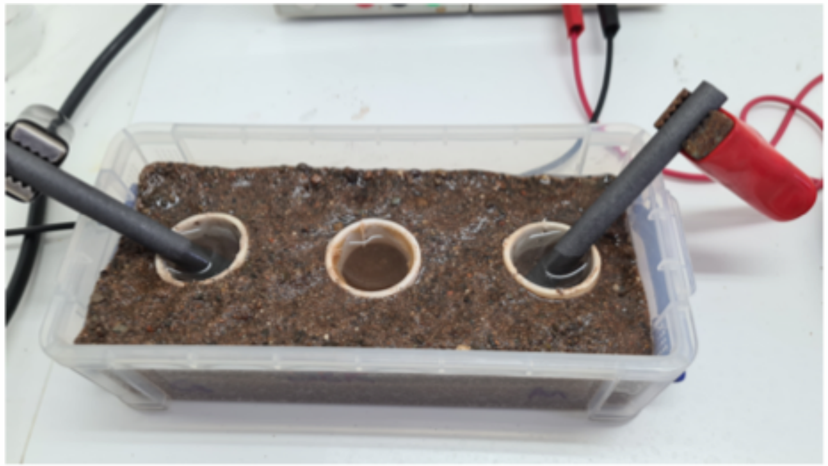
Effect of hydrodynamics & hydraulic head

Lab-based electrokinetic study:

- Movement of Sr, I, Re through sand and sand/clay
- Cells exposed to cycles of evaporation followed by localised reintroduction of water
- Direction of re-saturation of substrate worked against electrokinetics

Future work:

- More realistic environmental conditions
- Quantify competition between electrokinetics and simulated groundwater flow



Deployment considerations: Hydrodynamics at location, time of year, climate, extreme weather events, shelter / protection?

Treatment of invasive plant species?

Potential benefits:

- More environmentally friendly than chemical herbicides
- Targeted, with no run-off of chemicals
- Effective at all times of year even when weeds are not actively growing
- In-situ treatment is important as physical removal / disturbing soil may not be desirable at radiologically contaminated sites

Treatment of invasive plant species?

rootwave

Commercially available electrical treatment of weeds:

- High AC voltage at frequencies of 18kHz and above
- Generator or tractor powered
- Short contact time (5-10 seconds)
- Energy turned into heat
- Plant is boiled from inside out
- Independent assessment by RSK ADAS Ltd shows similar % reduction in weeds as herbicide after 3 electrical treatments

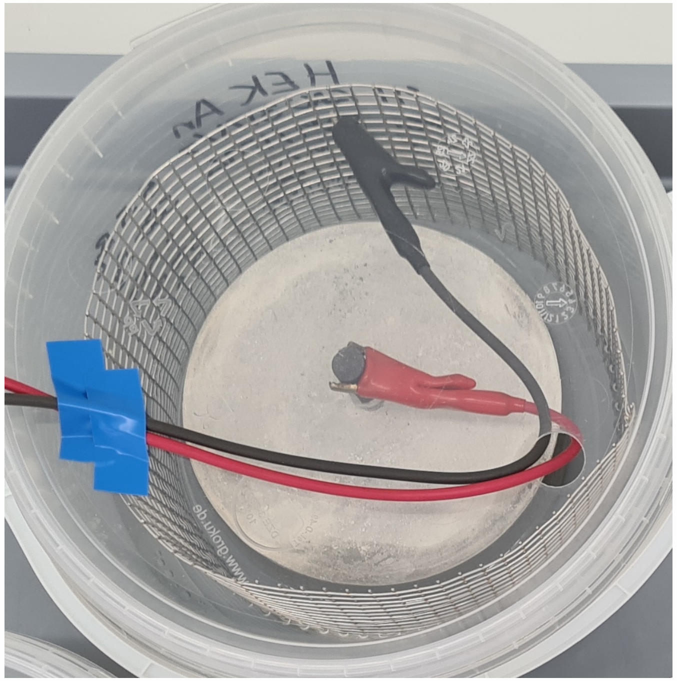
New approach currently being trialled in collaboration with two external SMEs:

- A safer, variable voltage
- Longer contact time – set up and walk away
- Heat not expected to be the dominant mechanism

Difficult-to-measure radionuclides in cementitious materials

<u>Increasing the TRL for nuclear:</u>

- Relevant material for decommissioning
  - Solid matrix
  - Embedded electrode
  - Electrolyte
- Simultaneous study of 5 radionuclides
- DTM radionuclides less commonly studied
- Two mechanisms for radionuclide contamination included
  - Sorption
  - Incorporation



NNUF National Nuclear User Facility

NNUF EXACT

UNIVERSITY OF LEEDS

Future work on combined method with colloidal silica grouting

Initial electrokinetic tests at University of Strathclyde promising
- Voltage gradient important to prevent degradation of silica grouting

Future work (Southampton):
- Explore differently charged analytes
- Add clays/organics into the sand
- Incorporate sand/clay into the silica gel
- Simulated Sellafield groundwater as electrolyte

Conclusions

- EKR: *in-situ*, cheap, flexible
- Value in combined approaches
    - FIRS: iron barriering
    - Electro-grouting: colloidal Si
    - Biological control
- Current work focusing on increasing the TRL for nuclear applications

Looking beyond TRANSCEND

Focus: integration of electrochemical / electrokinetic and microbiological interventions for remediation and critical metal recovery from U mining and other radionuclide-impacted sites and wastes in central Europe

Call: HORIZON-WIDERA-2021-ACCESS-03
(Twinning)

Acknowledgements

- Collaborative research using industrial and academic partnerships has been crucial in this research
- Drawing on expertise from around the UK and internationally will be needed to take EKR forward at scale

University of Southampton
University of Strathclyde
NNUF National Nuclear User Facility
NNUF EXACT
GAU Radioanalytical Laboratories
UNIVERSITY OF LEEDS

Acknowledgements: financial support of the UK Research and Innovation-EPSRC under grant EP/S01019X/1, and for the additional support provided NNL, and the National Nuclear User Facility EXACT (Next Generation Accelerated Characterisation Technologies) laboratory and team, via the UK Engineering and Physical Sciences Research Council (grant EP/T011548/1)