TRANSCEND

Transformative Science and Engineering for Nuclear Decommissioning

Inhibiting radionuclide migration using colloidal silica grout

Arianna Gea Pagano, University of Strathclyde

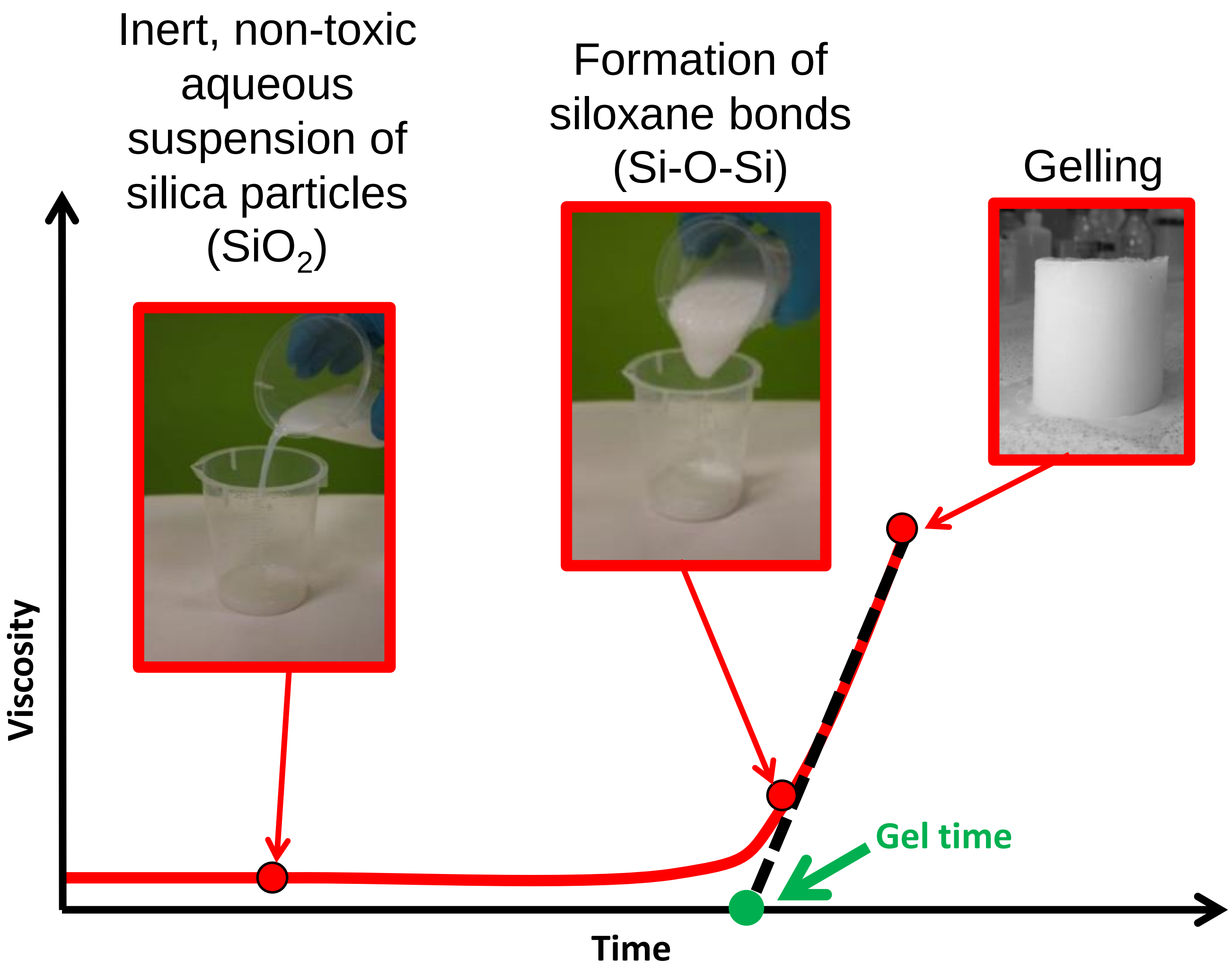
TRANSCEND/NDA/NWDRF Virtual Conference

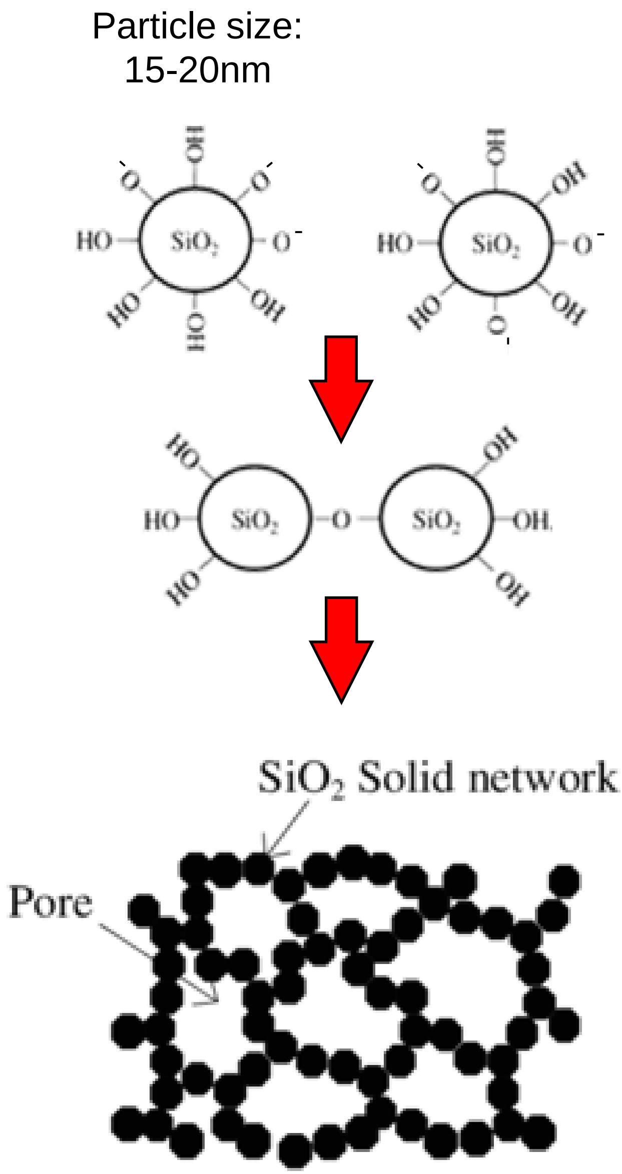
03/12/2020

Energy

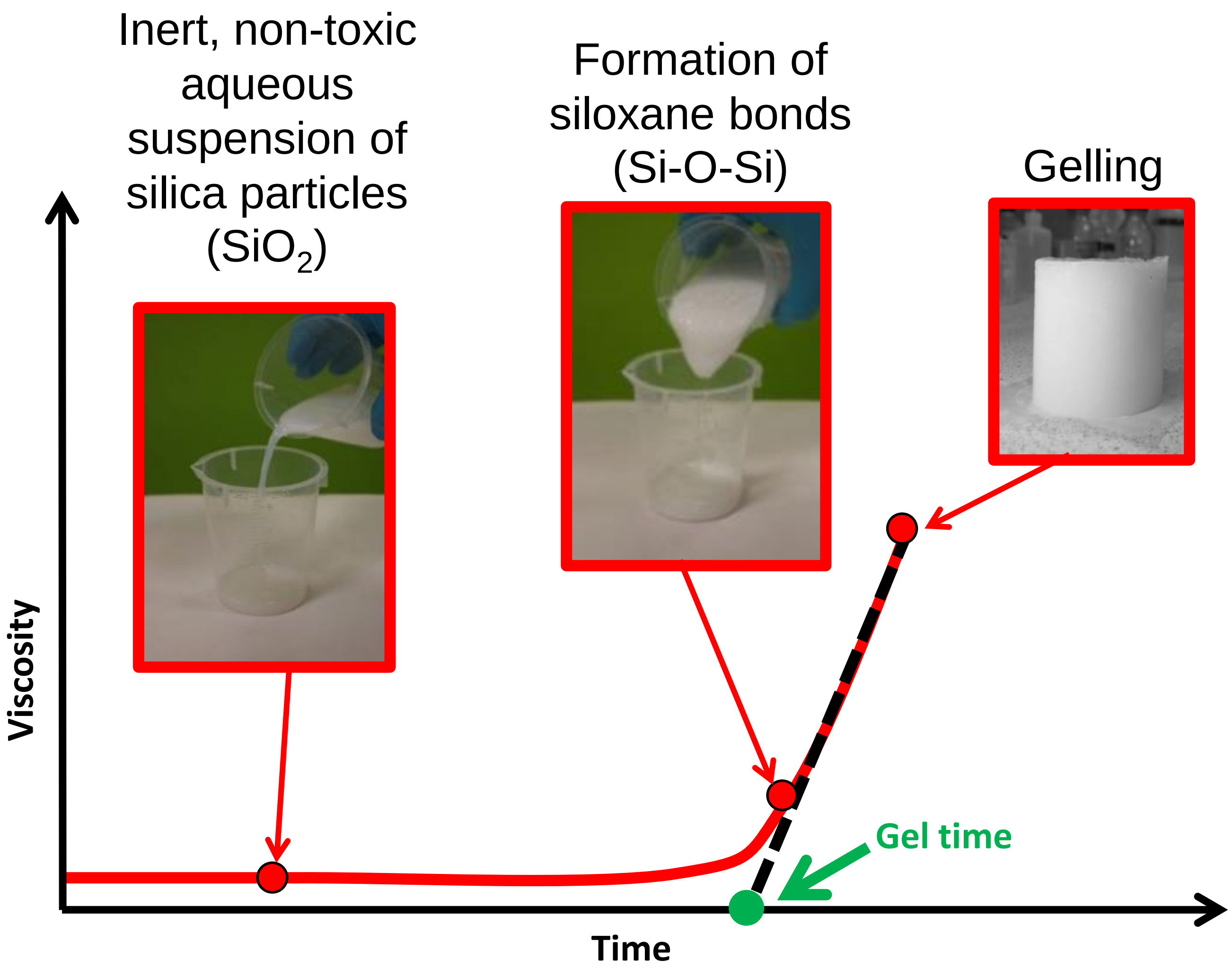
For a Low Carbon Future

What is colloidal silica?





What is colloidal silica?



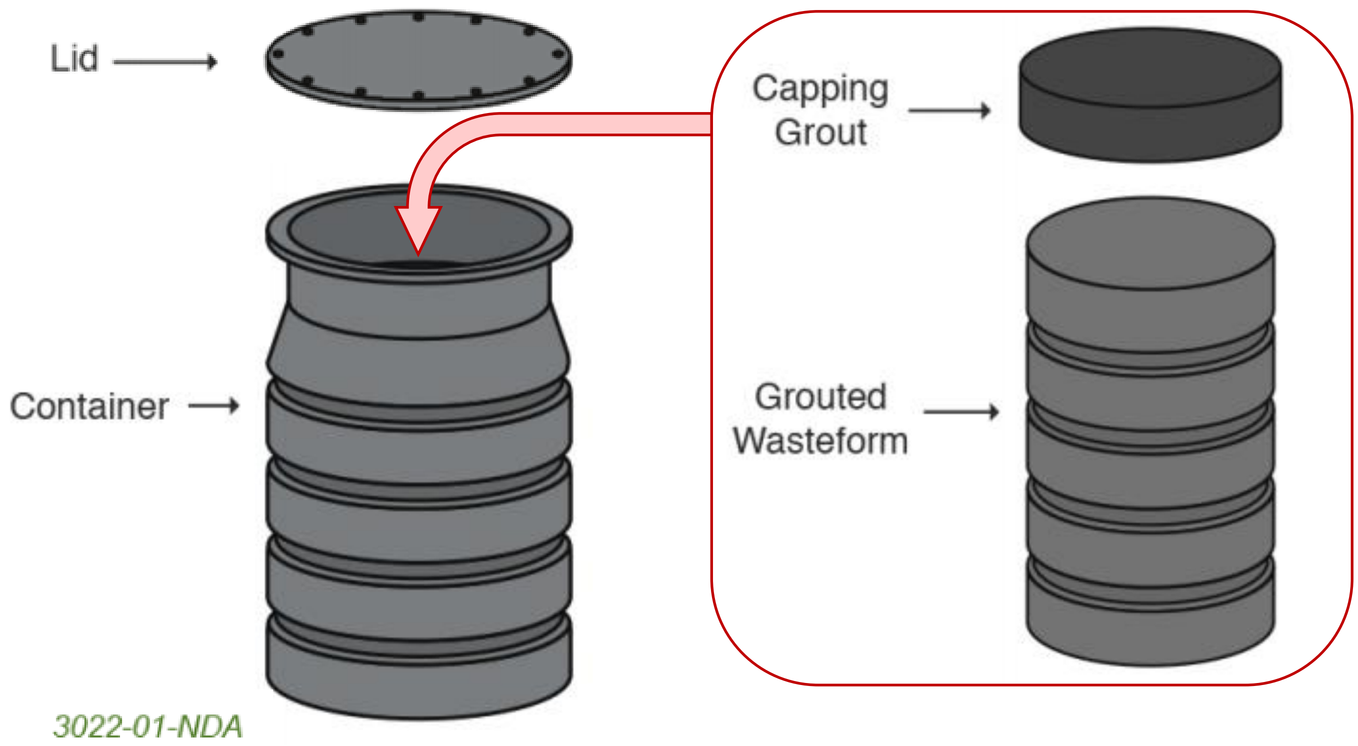
What triggers gelling?

- Electrolyte accelerator
- Change in pH
- Temperature

Colloidal silica treatment for repair of degraded cementitious waste packages

Cement encapsulation of ILW:

- Favoured waste disposal method for ILW in the UK
- Cement provides good shielding against radionuclide migration



- Radioactive waste embedded into a cementitious matrix by pouring grout into 500 L stainless steel drums

Colloidal silica treatment for repair of degraded cementitious waste packages

Cement encapsulation of ILW:

- Favoured waste disposal method for ILW in the UK
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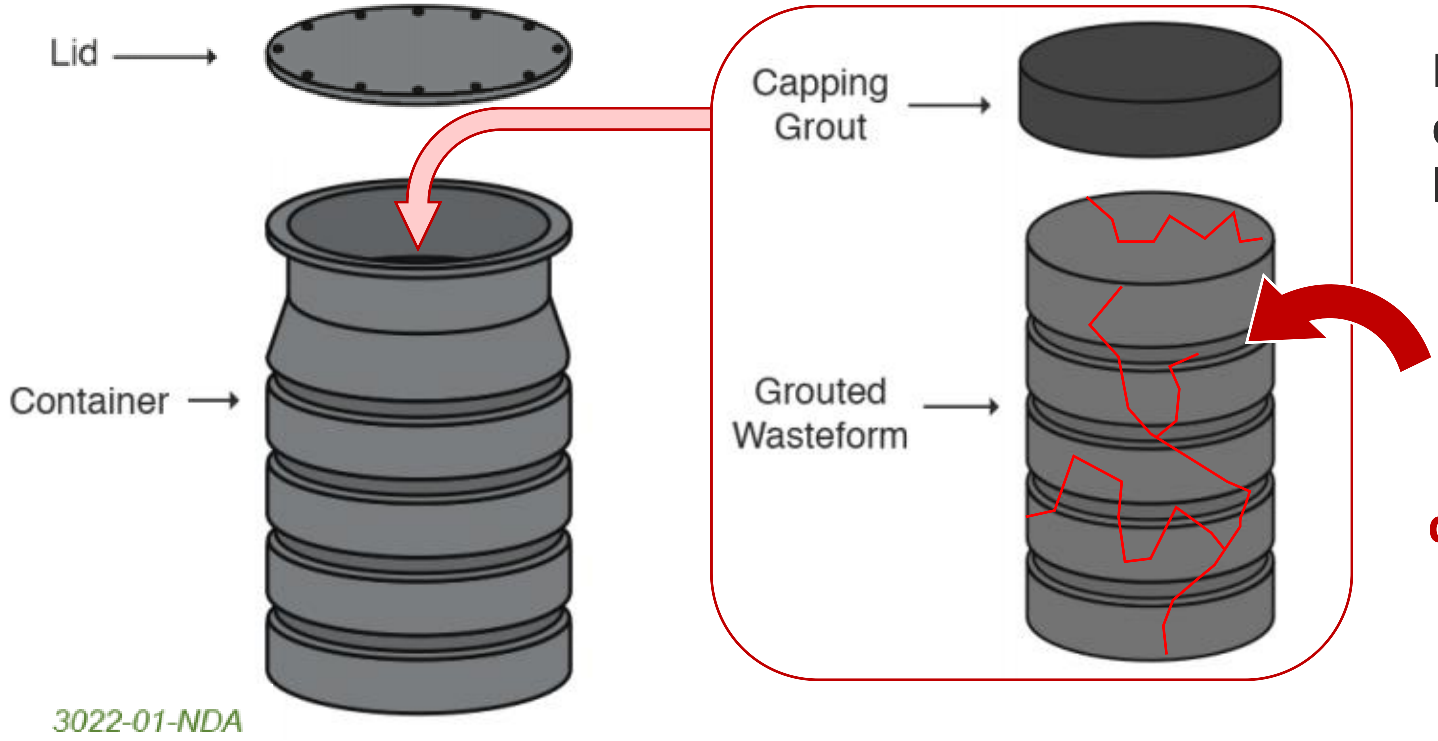

Degradation and cracking of cementitious matrices may lead to <u>radionuclide release</u>

Treatment with colloidal silica grout to repair degraded waste packages

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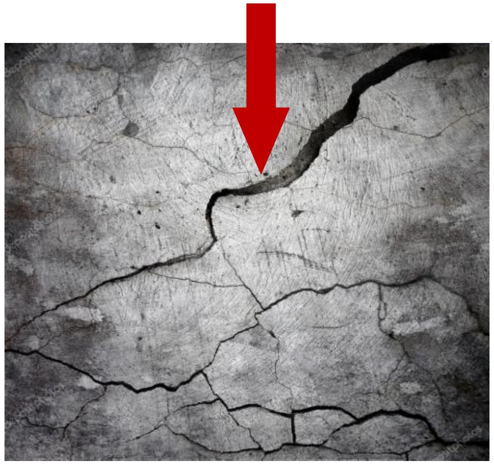
Transformative Science and Engineering for Nuclear Decommissioning

Colloidal Silica treatment for waste packages repair

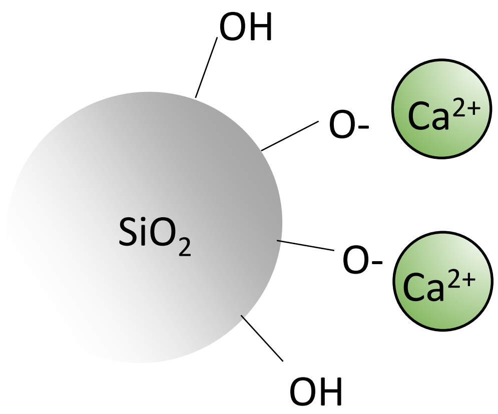
Colloidal silica reactivity with cement

Colloidal silica injection through cement cracks



Abundance of calcium ions within the cracks deriving from cement hydration (portlandite, $Ca(OH)_2$)

Silica Gelling

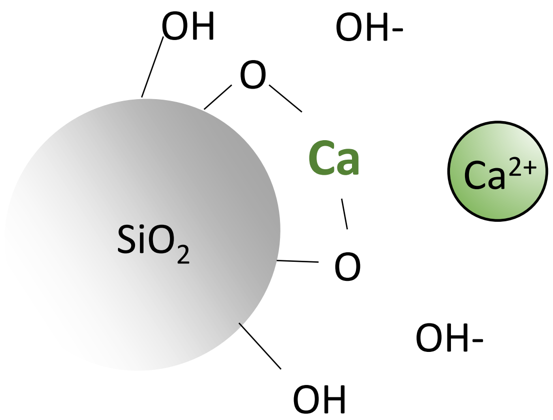


Ca^{2+} ions reduce the negative charge of silica particles

Increased collision rate

Formation of siloxane bonds (**gelling**)

CSH formation



Pozzolanic reaction in the presence of $Ca(OH)_2$:

$Ca^{2+} + 2(OH)^{-} + SiO_2 \rightarrow$ **C-S-H**

Colloidal Silica treatment for waste packages repair

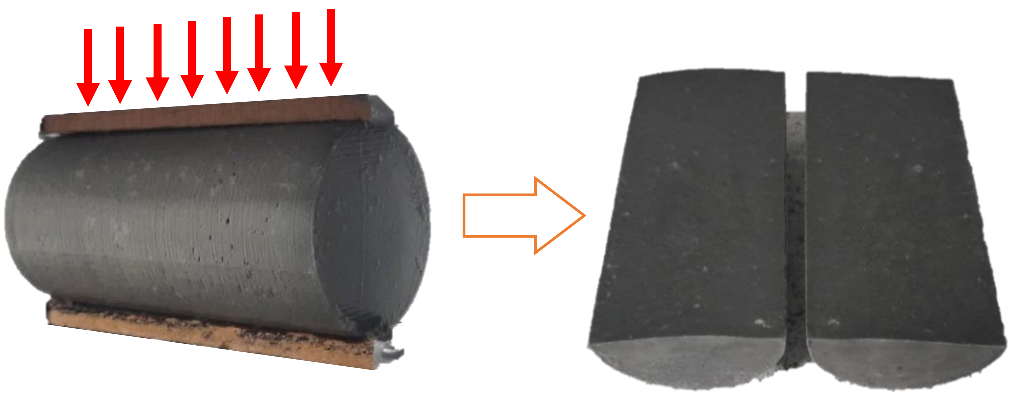
Experimental programme: fractured cement cores for CS treatment

1. Natural fracture network (1 core)

Unconfined compressive strength test (UCS)

2. Single vertical fracture (multiple cores)

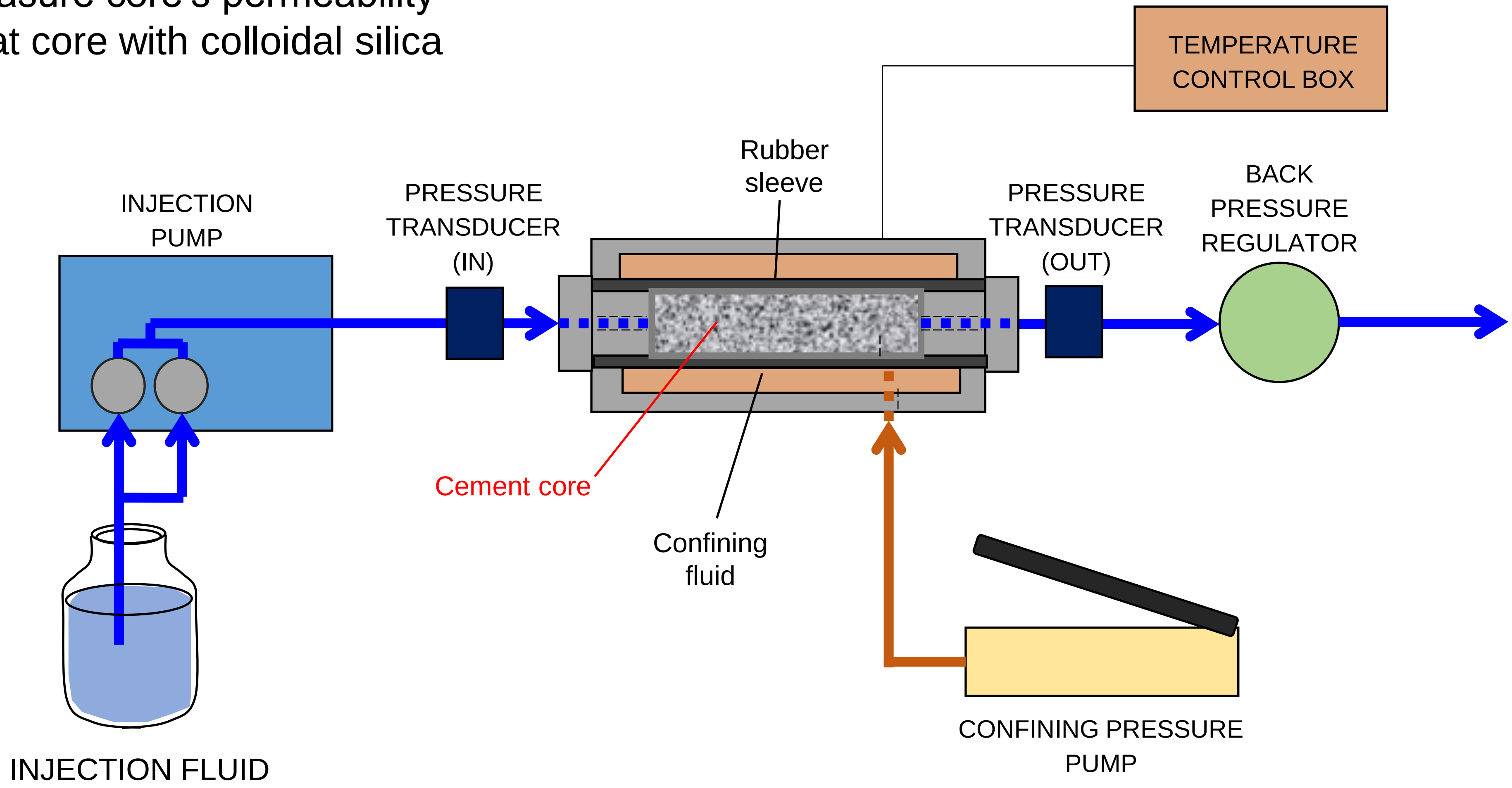
Brazilian tensile splitting test (BTS)



Colloidal Silica treatment for waste packages repair

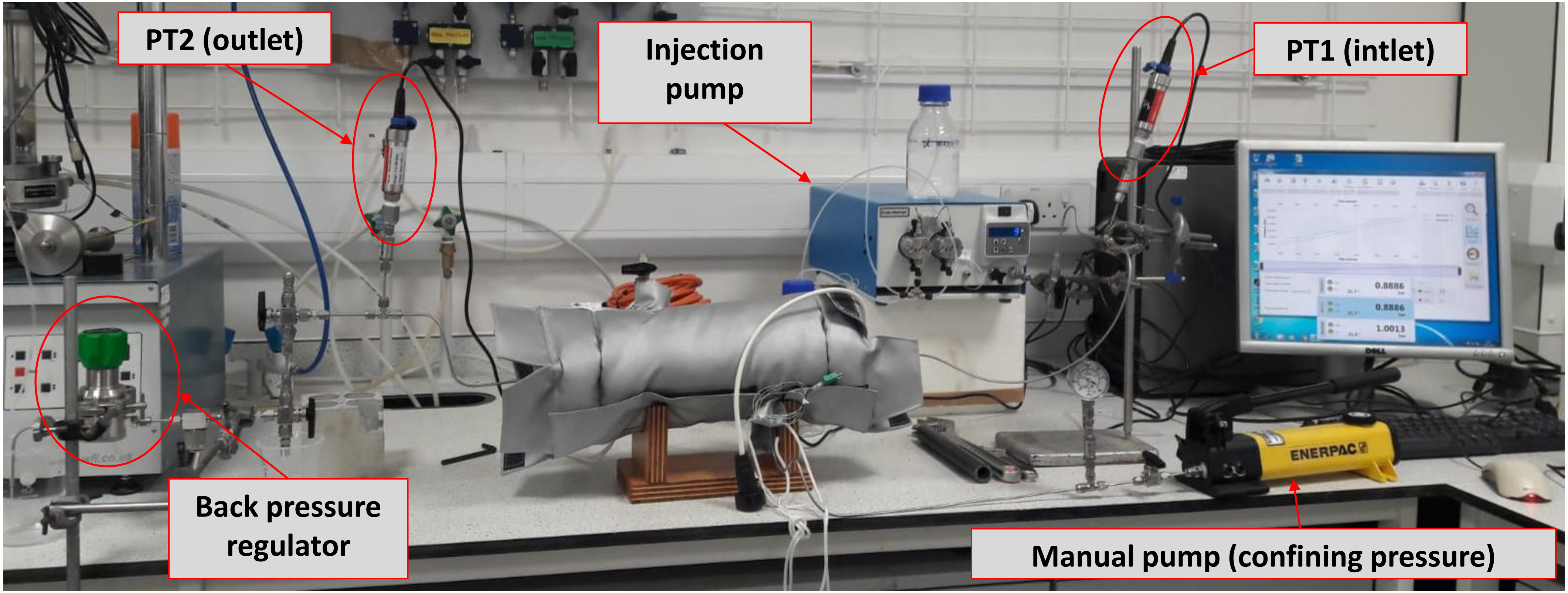
Experimental equipment for CS treatment

Core-holder setup, used to:
- measure core's permeability
- treat core with colloidal silica



Colloidal Silica treatment for waste packages repair

Experimental equipment for CS treatment (2)

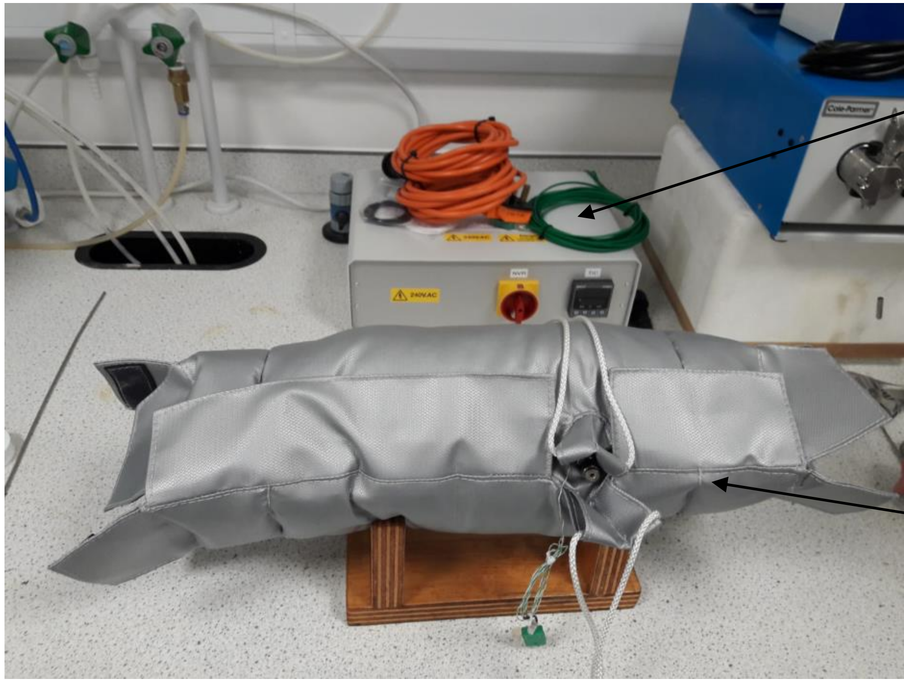


Colloidal Silica treatment for waste packages repair

Experimental equipment for CS treatment (3)

Silicon heater mat

Lagging jacket



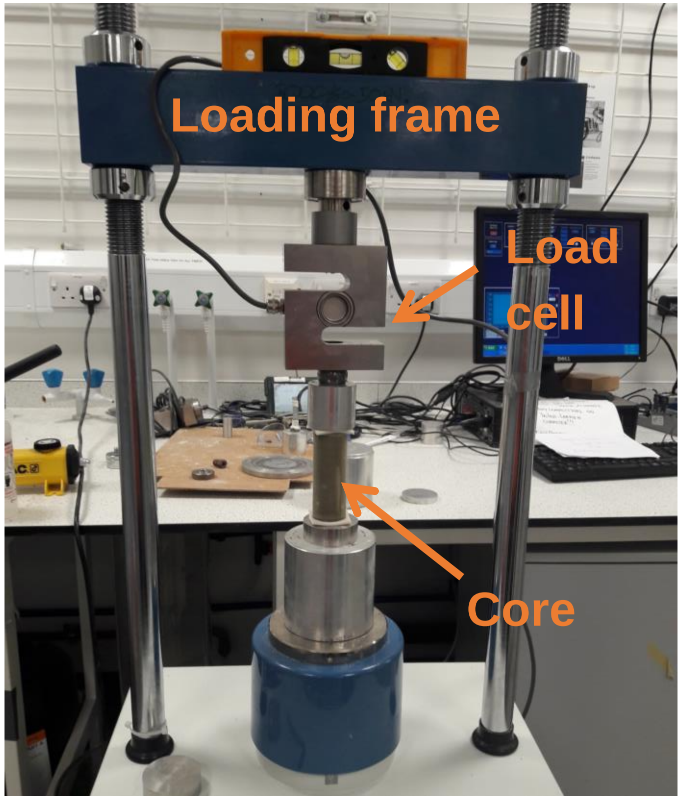
Control box with temperature display

Lagging jacket

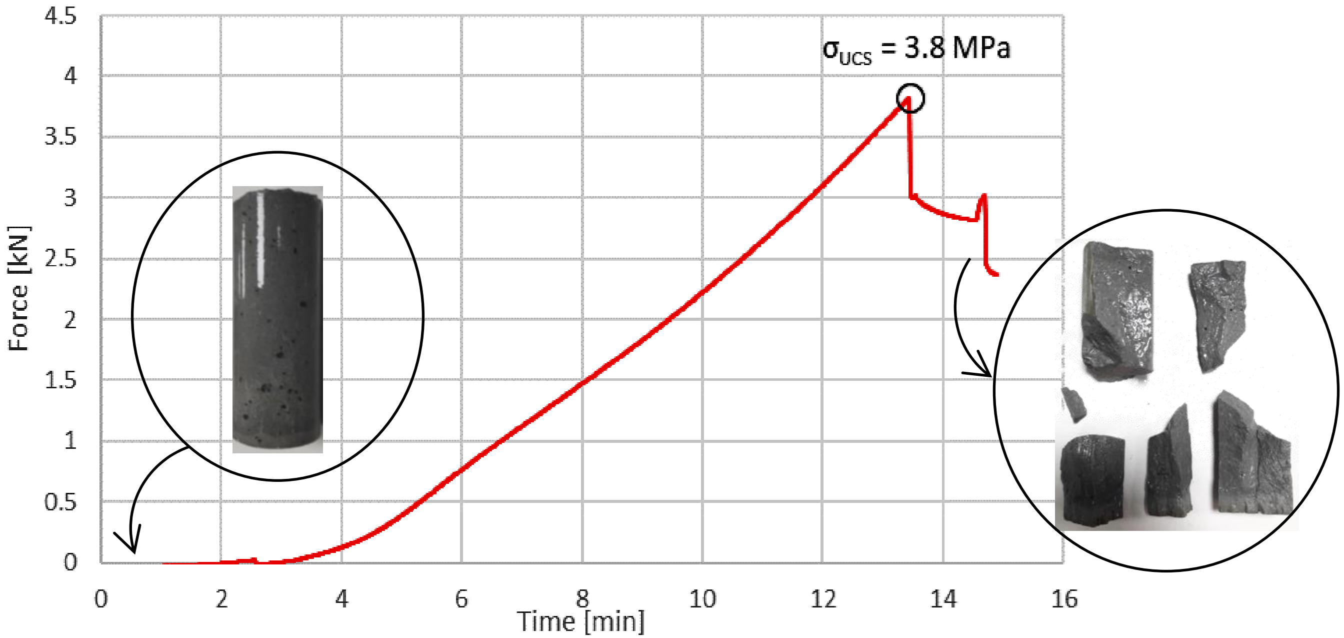
Colloidal Silica treatment for waste packages repair

Experiment 1: natural fracture network

Fracture network creation



The intact core was placed in a loading frame and cracked by performing a UCS test. The applied force was continuously measured during the test to derive the compressive strength of the intact core.

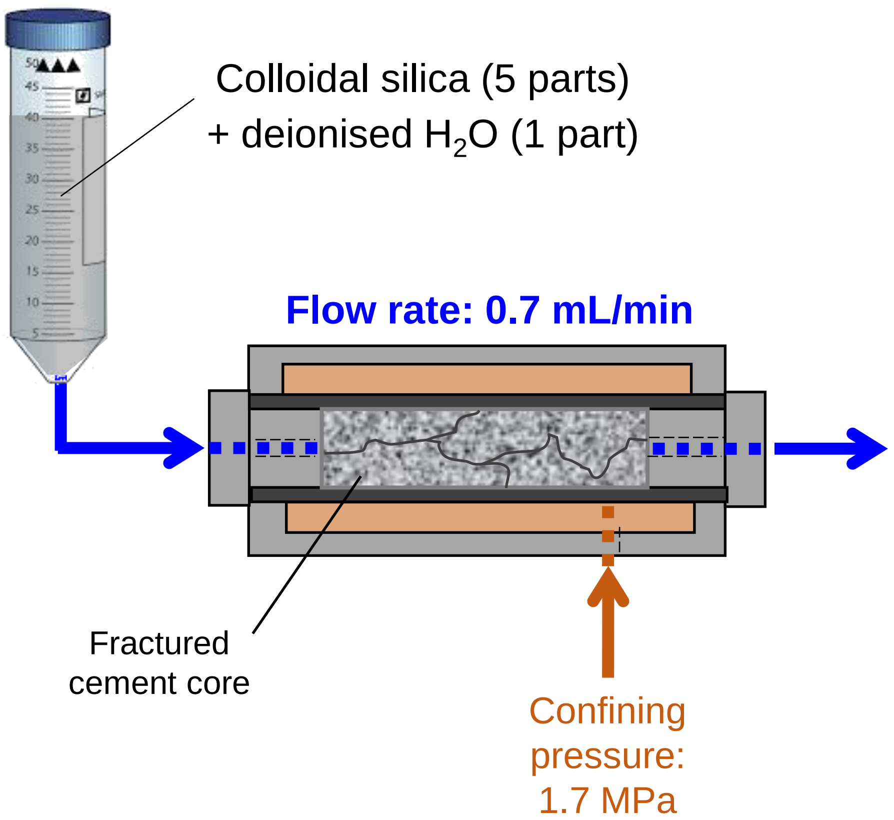


Colloidal Silica treatment for waste packages repair

Experiment 1: natural fracture network

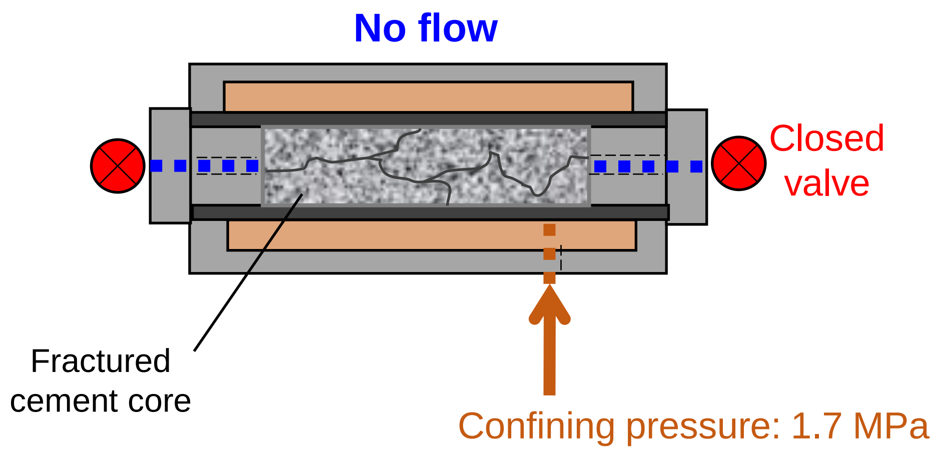
Colloidal silica treatment

1. Colloidal silica grout injection



2. Curing stage (72 hours, 20°C)

- 72 hours, 20°C within core-holder

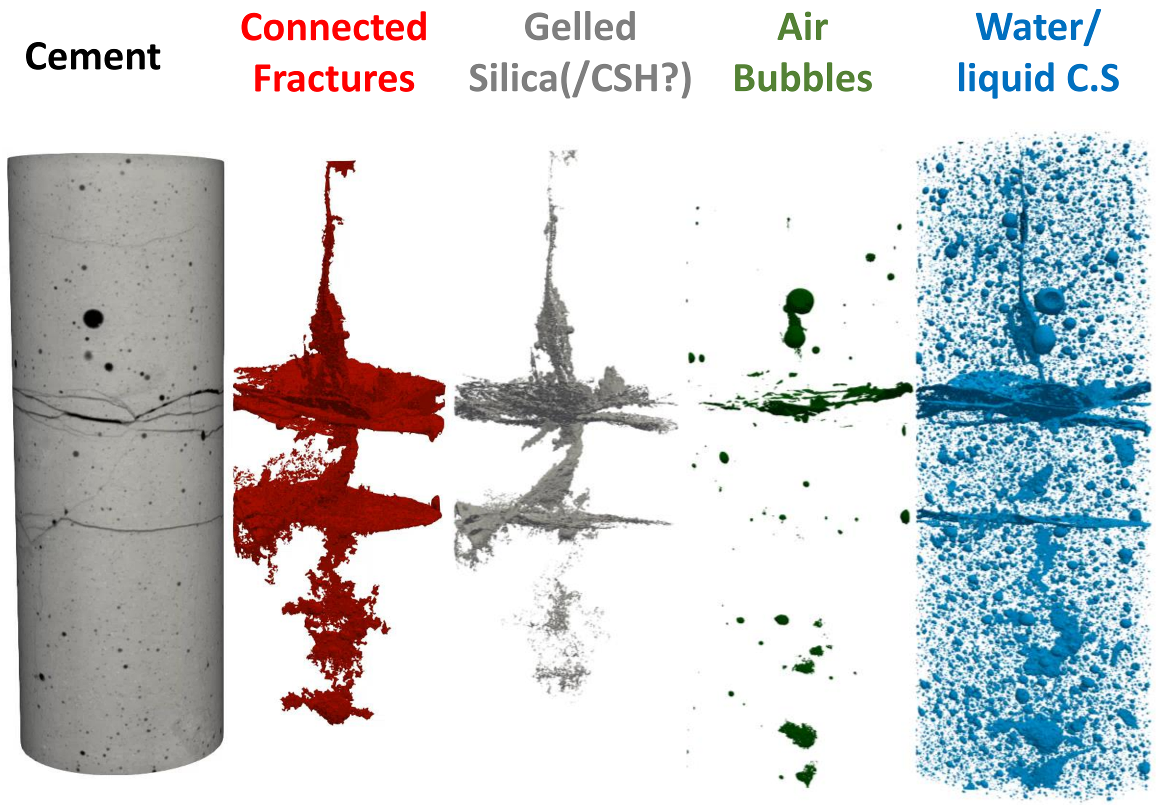


- ≥1 month, 20°C submerged in water

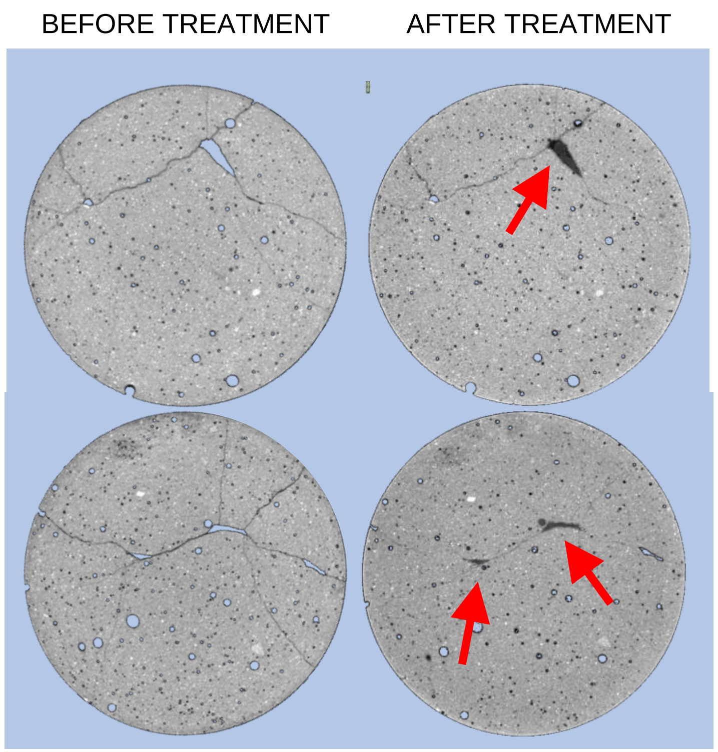
Colloidal Silica treatment for waste packages repair

Experiment 1: natural fracture network

Results (1): Microstructural analysis



X-CT 3D phase reconstruction



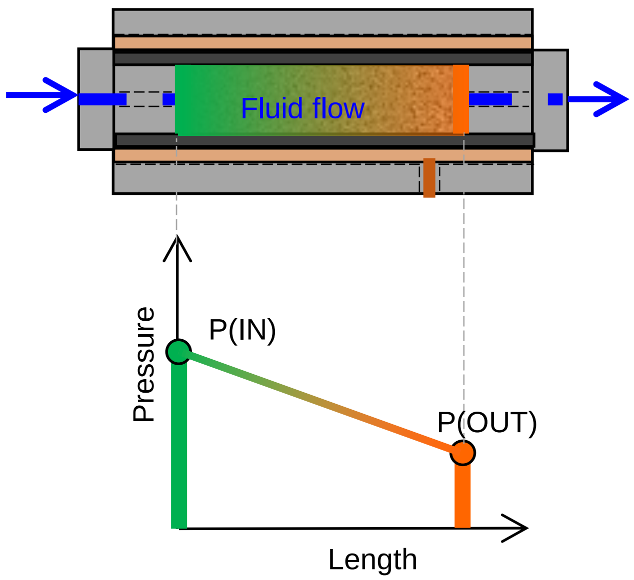
Cross-sections before and after

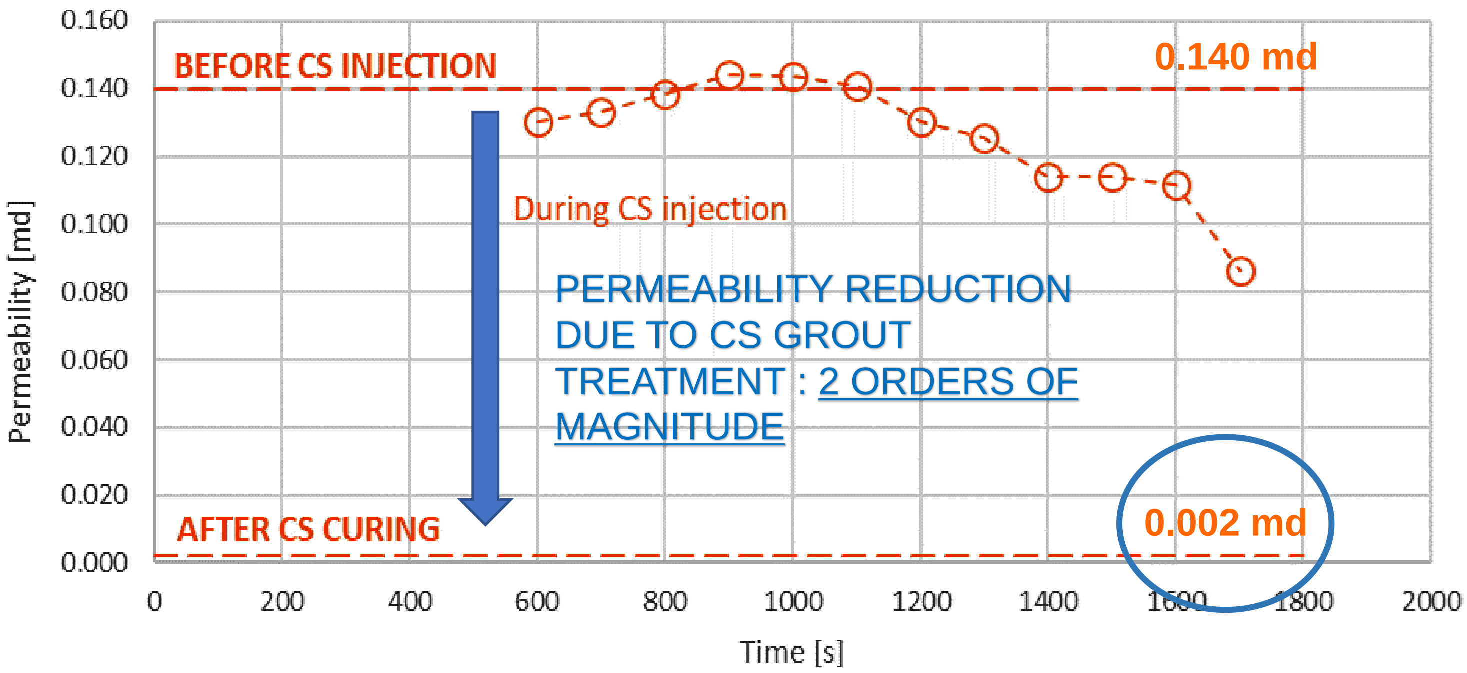
Colloidal Silica treatment for waste packages repair

Experiment 1: natural fracture network

Results (2): Permeability reduction

Permeability measurement:



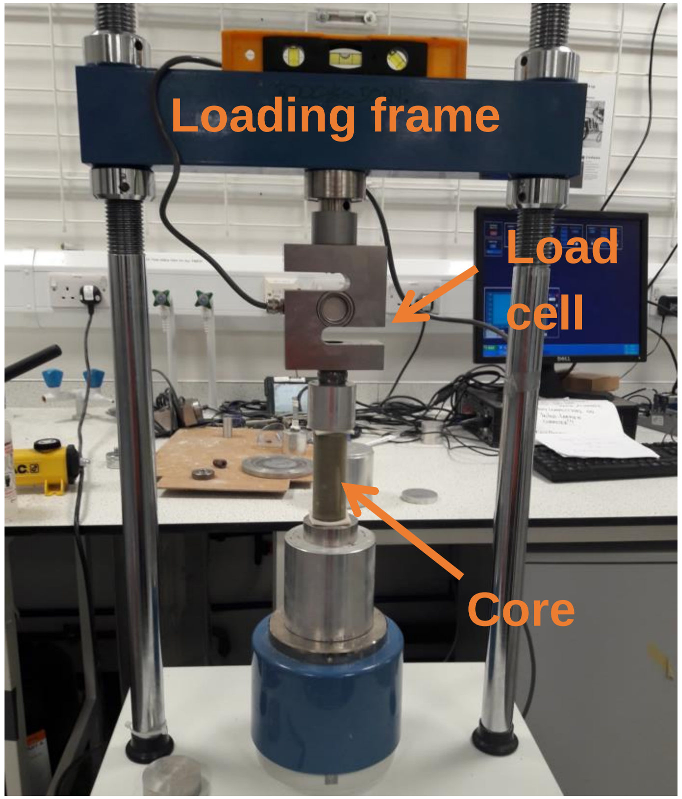


Treatment with colloidal silica resulted in a permeability reduction of two orders of magnitude compared to the permeability of the fractured core before treatment.

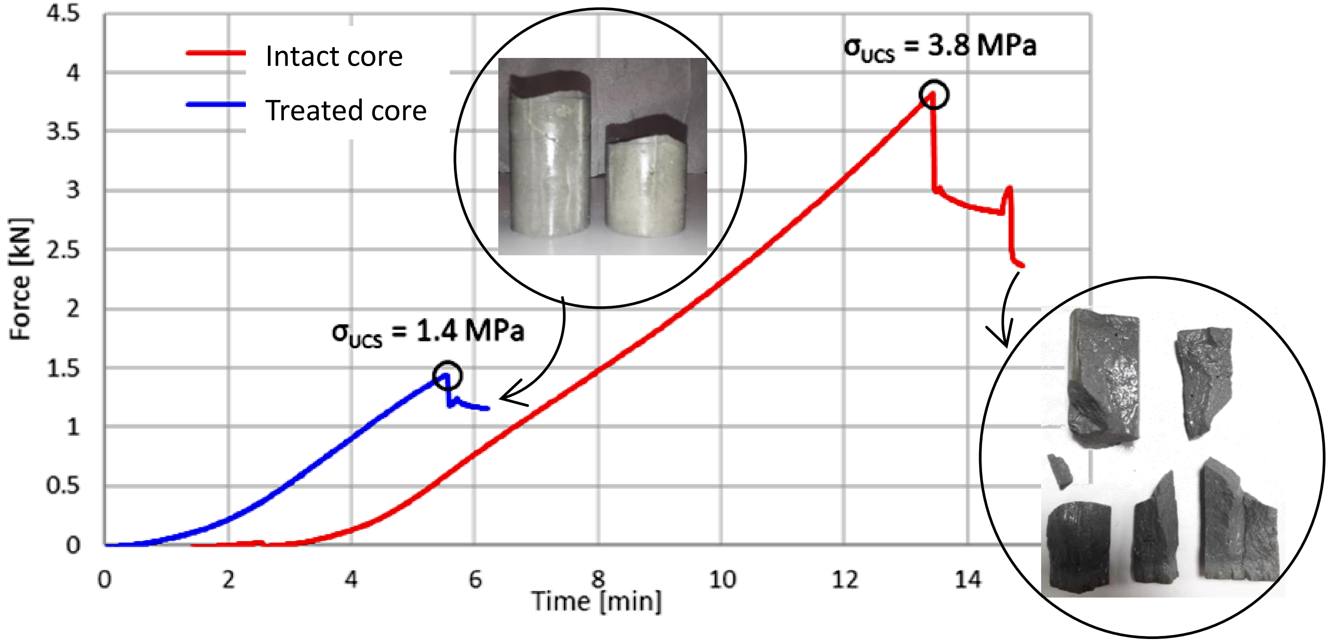
Colloidal Silica treatment for waste packages repair

Experiment 1: natural fracture network

Results (3): Strength recovery

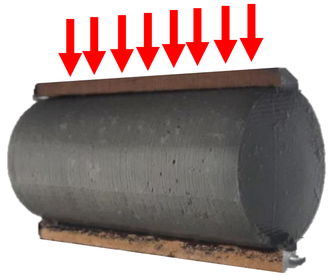


The treated core was placed in a loading frame and cracked by performing a UCS test. The core recovered about 40% of its initial strength (UCS of intact core) after treatment with colloidal silica grout.



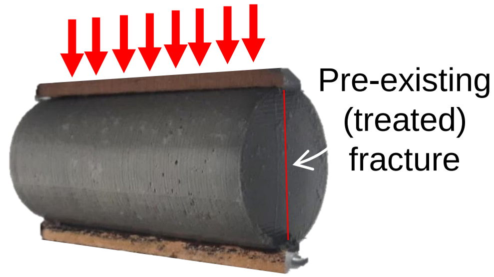
Colloidal Silica treatment for waste packages repair

Experiment 2: single vertical fracture

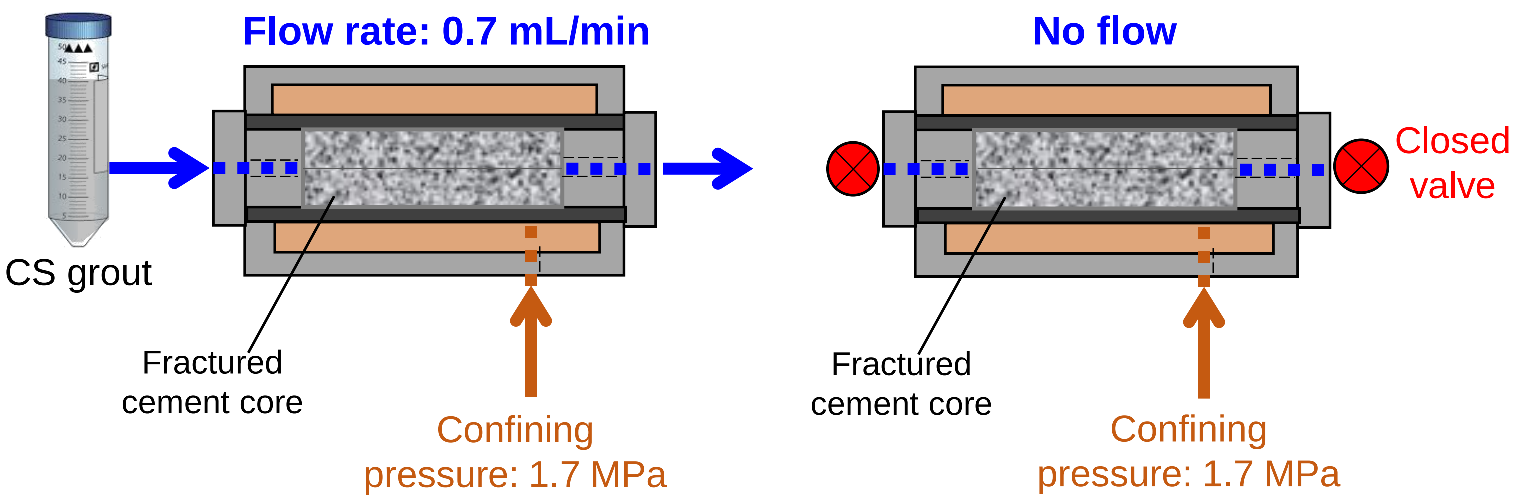


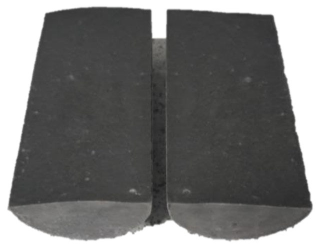
Step 1: Brazilian test on intact cement cores (measure tensile splitting strength)

Step 4: Brazilian test on treated cores (measure strength gain after treatment)



Step 3: Colloidal silica treatment & curing



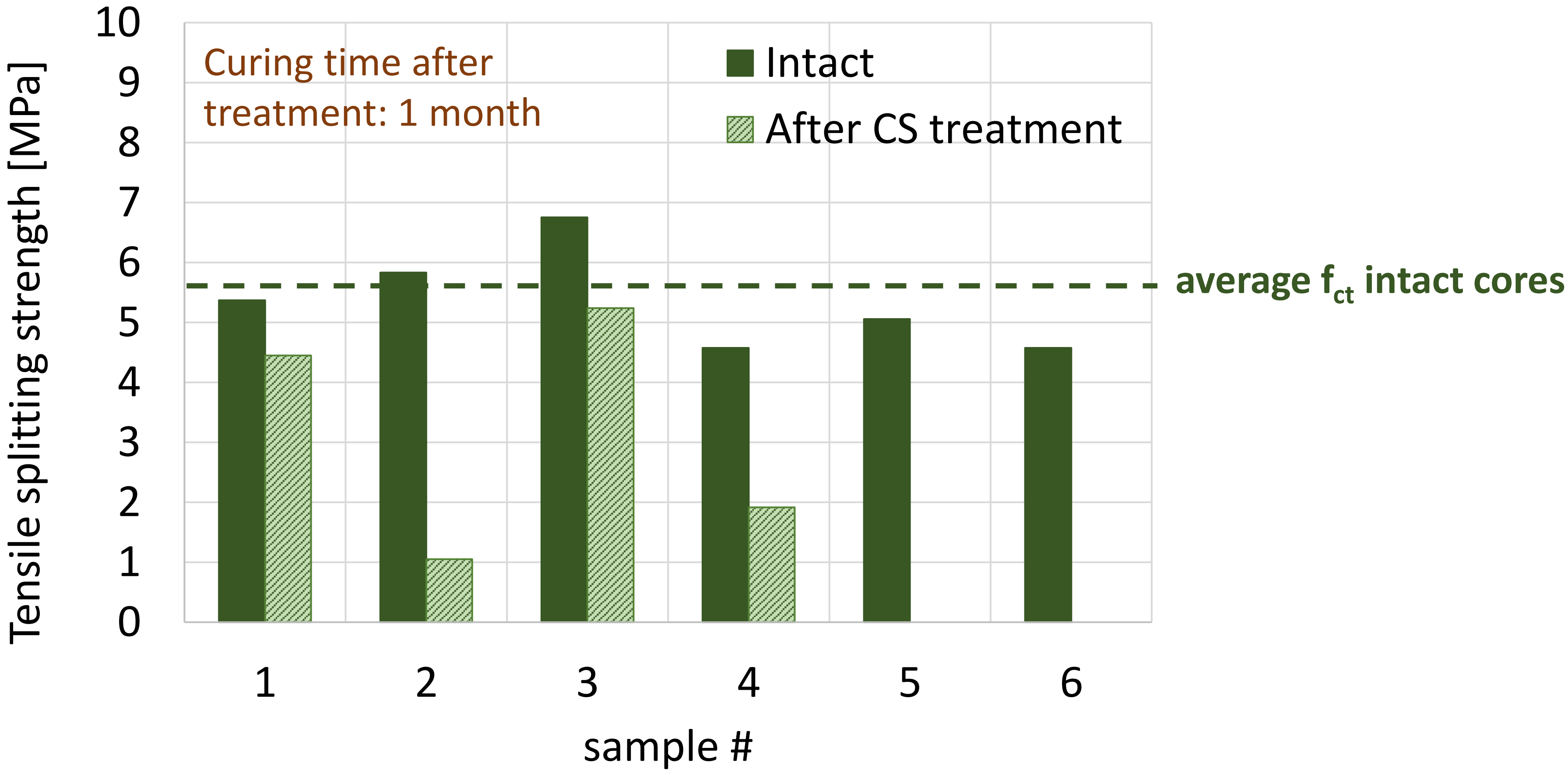


Step 2: Surface roughening of fractured halves

Colloidal Silica treatment for waste packages repair

Experiment 2: single vertical fracture

Brazilian tests results before and after treatment with colloidal silica

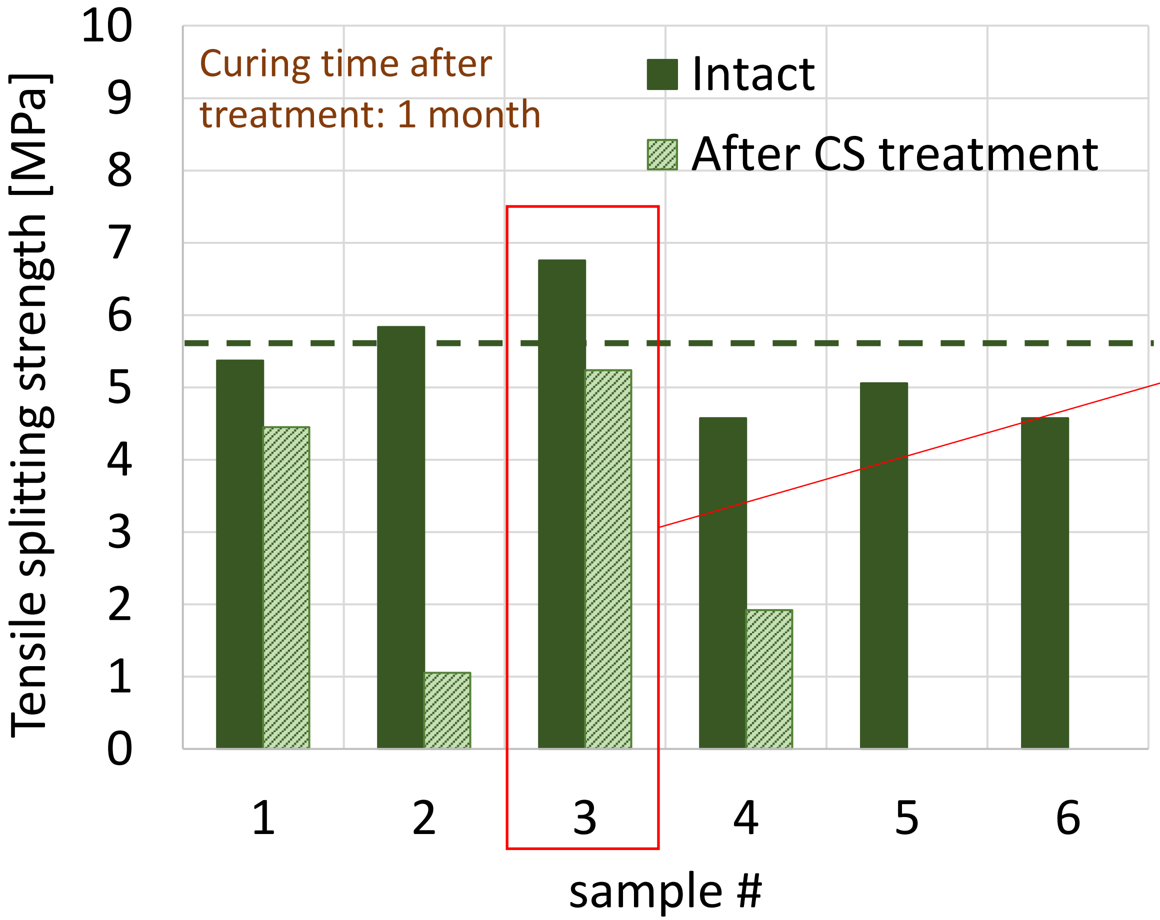


→ *Strength recovery between 20% and 93% of average tensile splitting strength of intact cores!*

Colloidal Silica treatment for waste packages repair

Experiment 2: single vertical fracture

Brazilian tests results before and after treatment with colloidal silica

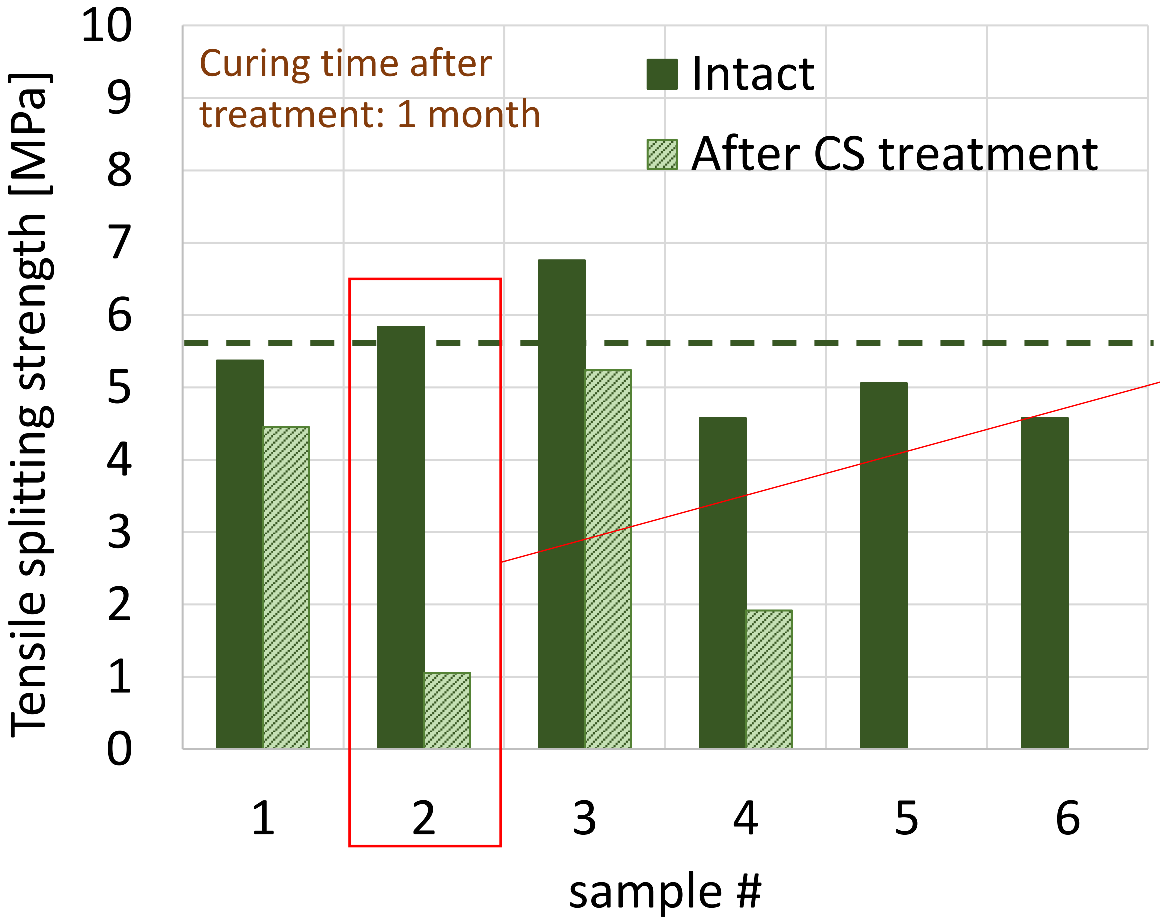


Failure after CS treatment:

Colloidal Silica treatment for waste packages repair

Experiment 2: single vertical fracture

Brazilian tests results before and after treatment with colloidal silica



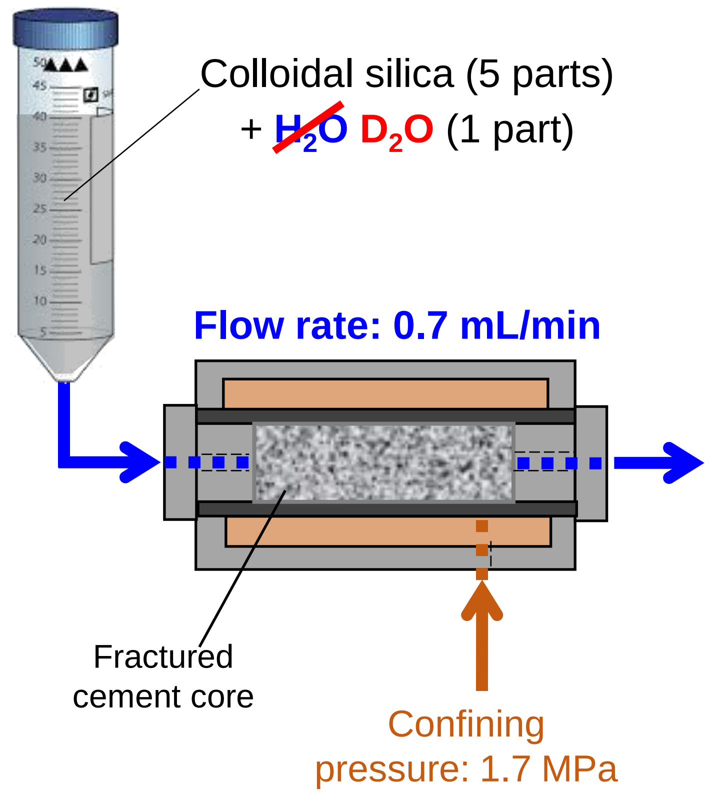
Failure after CS treatment:

Colloidal Silica treatment for waste packages repair

Next steps

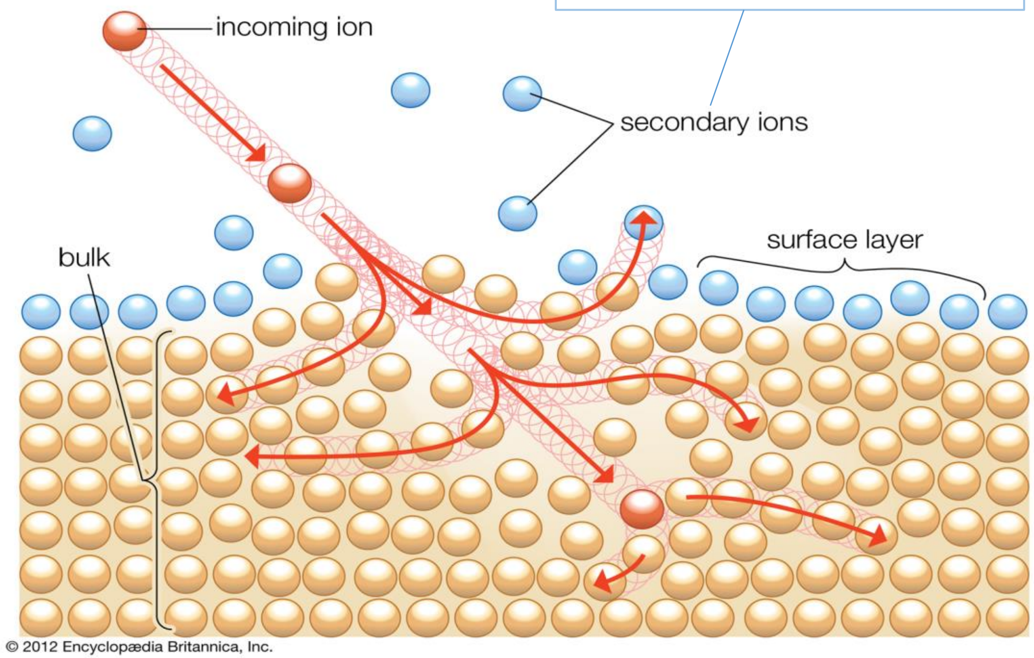
1. Secondary-Ion Mass Spectrometry (SIMS) for C-S-H detection

1. Spike colloidal silica grout with D_2O



2. SIMS for C-S-H detection

Give information on elemental, isotopic, or molecular composition of the surface



Next steps

2. Cement mix for ILW cement encapsulation

Current cement mix

- Ordinary Portland Cement (CEM II/A-L, class 42.5N), w:s = 0.375 by weight

Cement mix for future experiments

Blast furnace slag (BFS) + Ordinary Portland Cement mix:

- SL 3:1 BFS:PC mix, w:s = 0.35
- BEP formulation of 5:1 GGBS:CEM I at a w/s ratio of 0.5

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Transformative Science and Engineering for Nuclear Decommissioning

Thank you

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Transformative Science and Engineering for Nuclear Decommissioning

Electrokinetic Remediation and Combination with Colloidal Silica Grouting

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University of Southampton

JointNuclear (TRANSCEND/NDA/NWDRF) Virtual Conference
2 – 3 December 2020

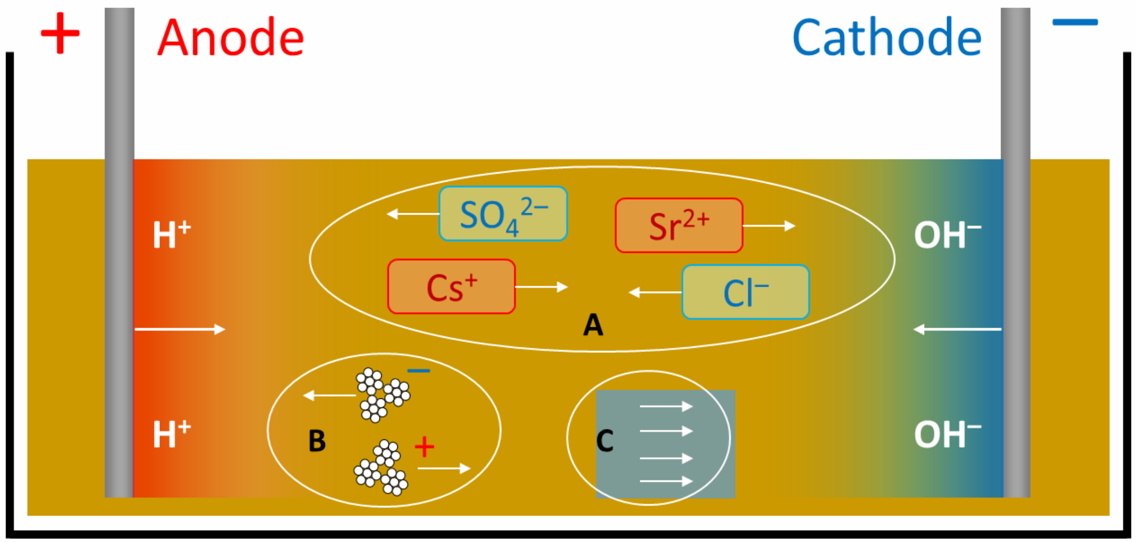
For a Low Carbon Future

Electrokinetic Remediation, EKR

electro kinetic

Electrical — **movement (of ions, …)**

- Soil/groundwater/concrete
- Electromigration (**A**)
  → *movement of ions*
- Electrophoresis (**B**)
  → *movement of particles*
- Electro-osmosis (**C**)
  → *movement of water*



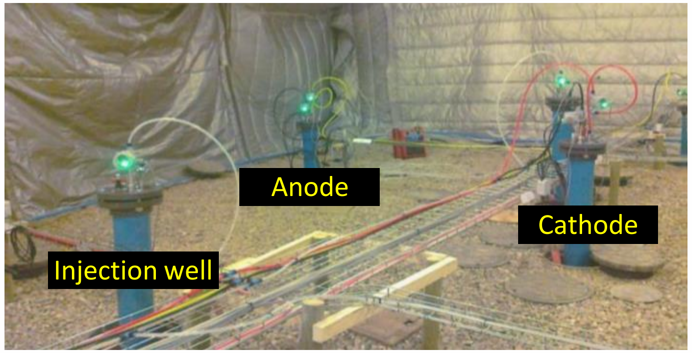
$H_2O \rightarrow 2\,H^+ + \frac{1}{2}\,O_2\,(\uparrow) + 2\,e^-$
$E^0 = -\,1.229$ V

$H_2O + 2\,e^- \rightarrow 2\,OH^- + H_2\,(\uparrow)$
$E^0 = -\,0.828$ V

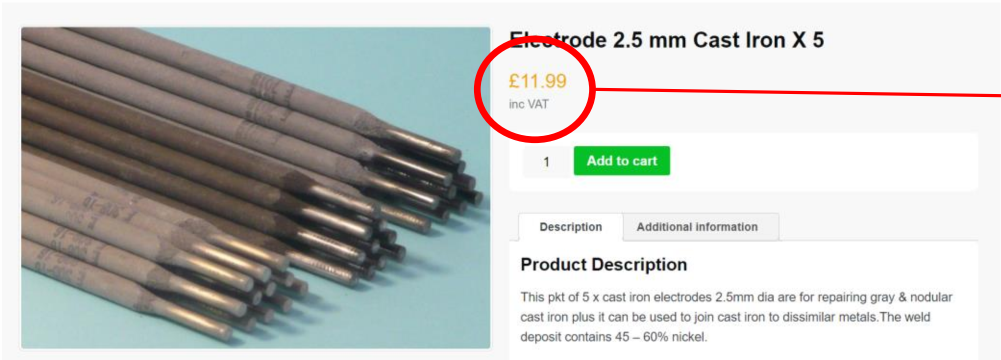
Advantages of EKR

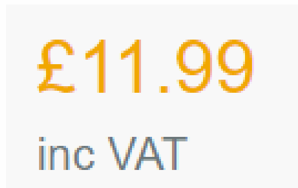
- ***In-situ*** **(or *ex-situ*)**

  Worker safety



- **Cheap**





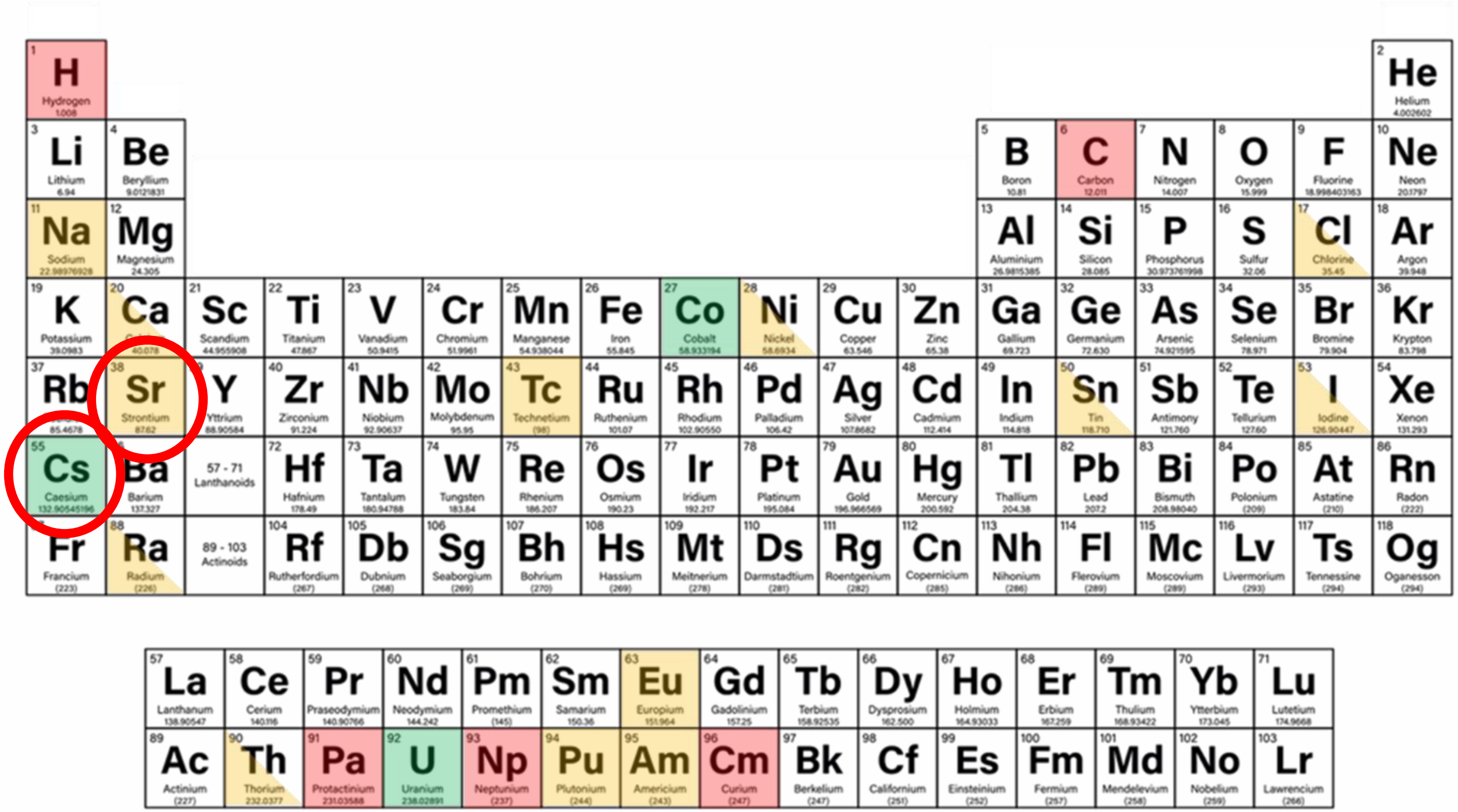
(+ next day delivery!)

- **Adaptable**

Electrode material
Electrode placement
Electrolyte
Voltage

Additives
Duration
(In-)organic + radionuclide
Combination (EKR-Bio…)

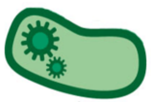
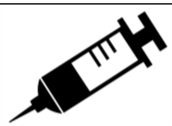
EKR for Nuclear Decommissioning



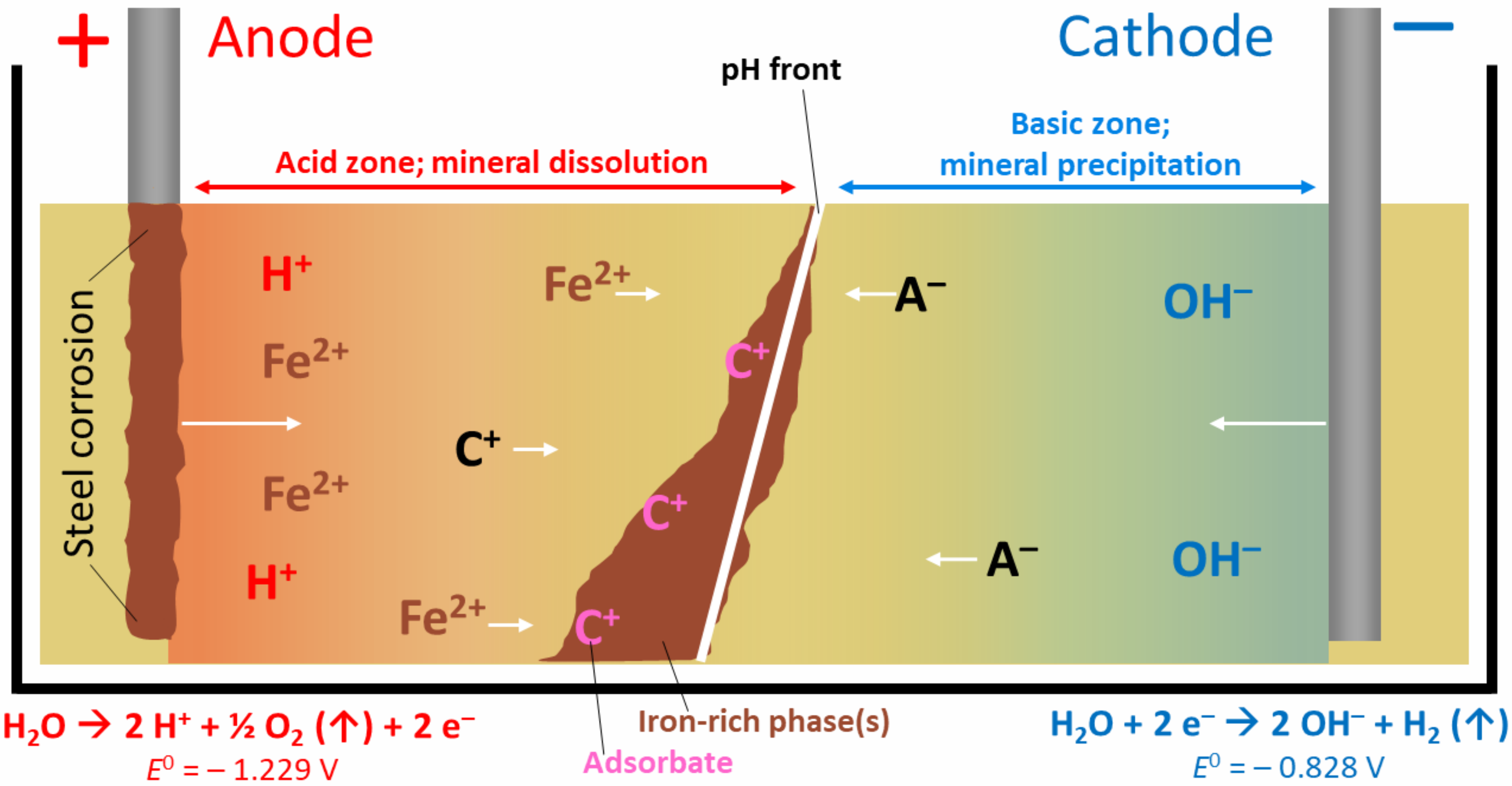
Red further testing; **Yellow** demonstrated, not widespread; **Diagonal yellow** demonstrated, not on radionuclide; **Green** multiple studies. ($t_{1/2} < 1$ y excluded)

Purkis, Hemming, Warwick, Graham, Cundy, submitted to J. Haz. Mater.; Purkis *et al*., Appl. Geochem., in press

EKR for Nuclear Decommissioning

	TRL for nuclear	Duration?	Cost?	Comments	How can EKR help?
EKR 	4 - 6	Variable	Low	✓ Flexible ✗ Unproven	--
Bio-  and Phyto- 	5 - 7	High	Low	✓ Sustainable ✗ Slow	Faster nutrient movement
ISCO 	4 - 6	Low	Variable	✓ Quick ✗ Permeability	***In-situ* barrier generation (FIRS)**
Colloids 	5 +	Variable	High	✓ Immobilisation ✗ Unproven	**Colloidal Silica?**

Ferric Iron Remediation and Stabilisation



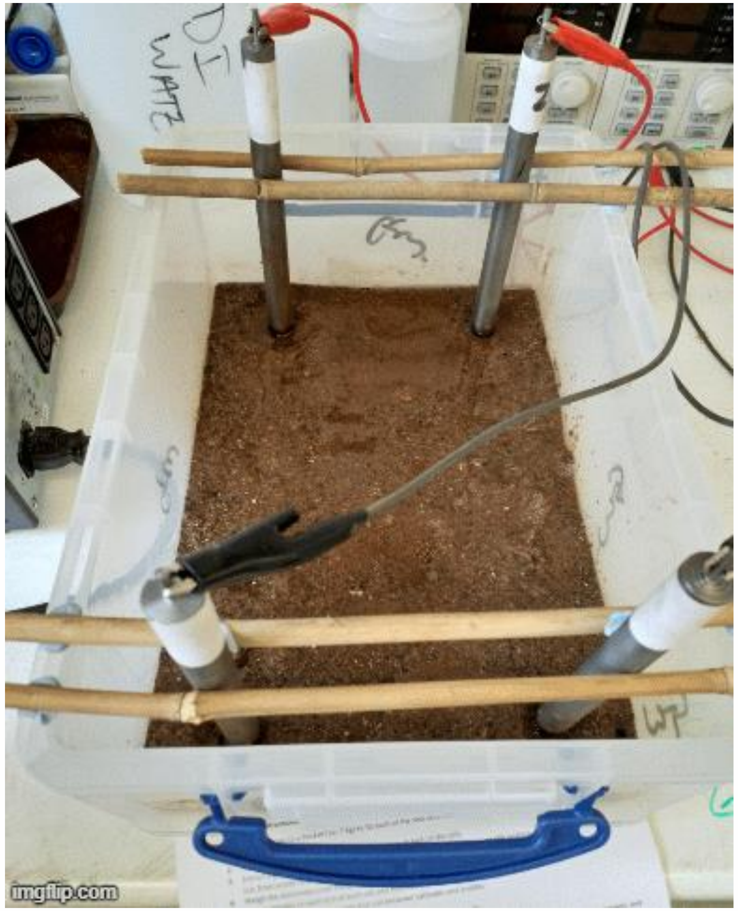
Purkis *et al*., manuscript in prep.; Cundy *et* al., Appl. Geochem., 2005, 20, 841

Case Study – FIRS

- Metre scale in simulated materials
- *In-situ* barrier growth in real materials?

- **Sellafield sand** + simulant groundwater
- Steel electrodes
- Vary:
  - Electrode placement
  - Voltage
  - Duration

- Monitor:
  - **Barrier over time**
  - pH
  - Sorptive properties, *etc*…



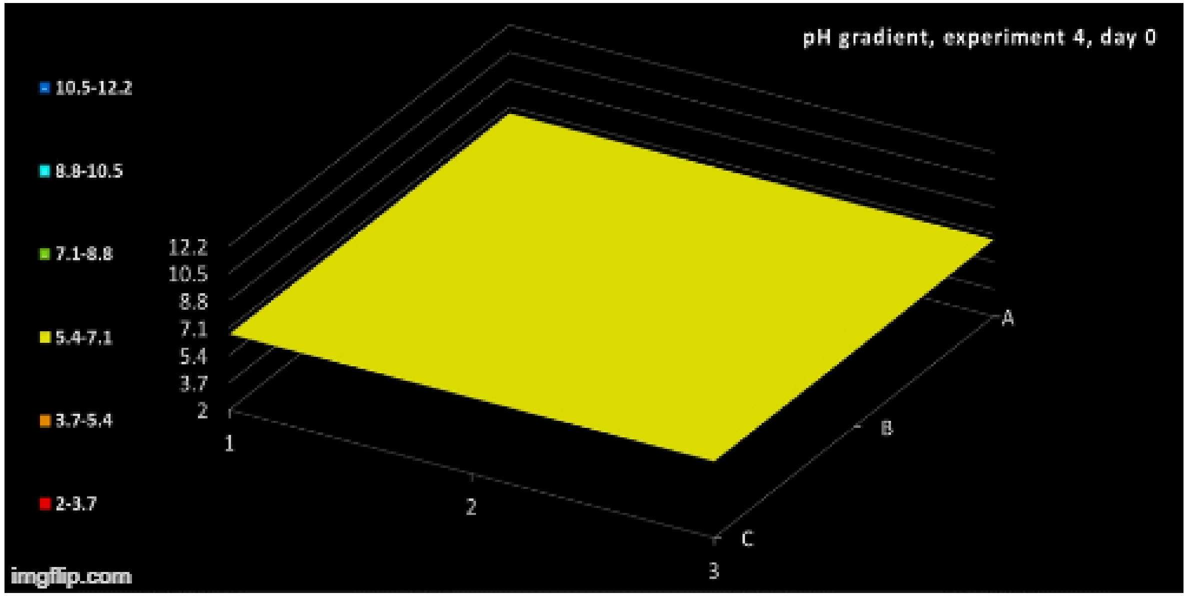
Purkis *et al*., manuscript in prep.

Case Study – FIRS

- *In-situ* barrier growth in soil subsurface?

- Sellafield sand + simulant groundwater
- Steel electrodes
- Vary:
  - Electrode placement
  - Voltage
  - Duration

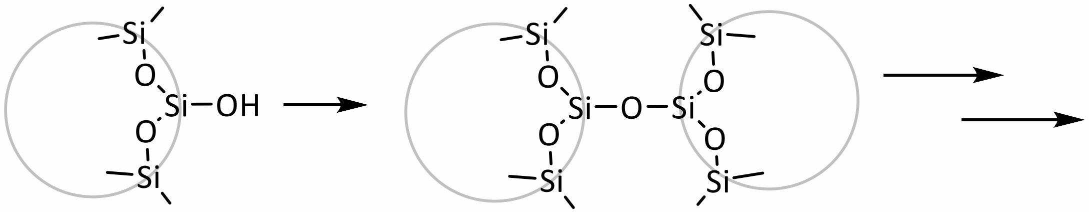
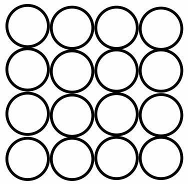
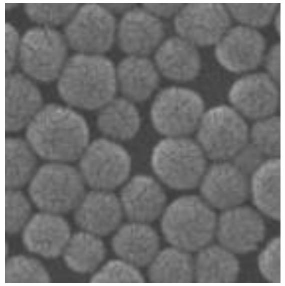
- Monitor:
  - Barrier over time
  - pH
  - Sorptive properties, *etc*…



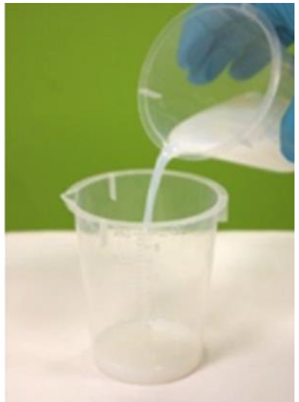
Purkis *et al*., manuscript in prep.; Purkis, Tucknott, Cundy, *et al*., Appl. Geochem., in press

Colloidal Silica Grouting

- (Nano)-Particulate SiO_2

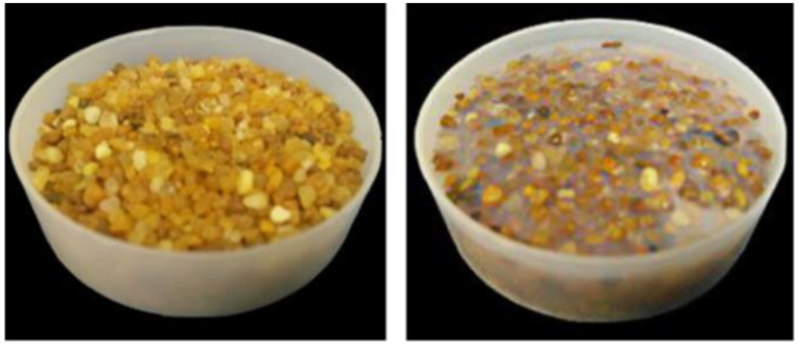

- Gelate with accelerant (NaCl)

 +  =  *minutes* ••• 

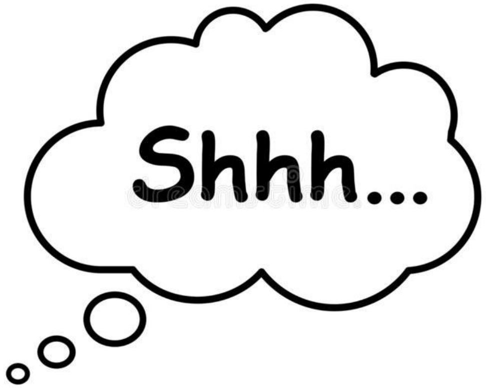
Dallari *et al.,* Sci. Adv., 2020, 6, eaaz2982; Wong *et al.*, Eng. Geol., 2018, 243, 84

Colloidal Silica Grouting + EKR

- Inject into contaminated soil
- Impermeable ($10^{-10} – 10^{-8}$ m.s^{-1})
- Trap radionuclides – combined approach?



Sand before (L) and after (R) grouting

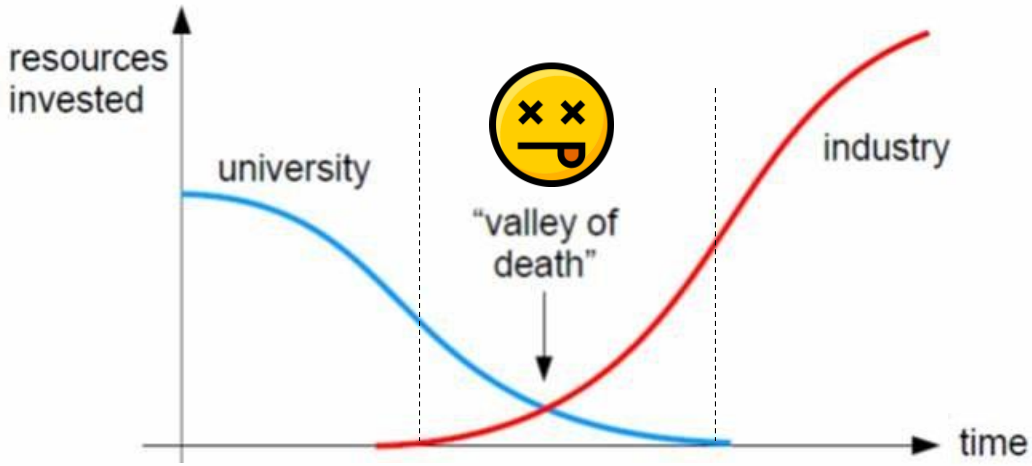


Pedrotti *et al*., Eng. Geol., 2020, 270, 105579

"Valley of Death"

- EKR limited at scale

- Stakeholder engagement?
  - *Decision support tools*



Research Article | Full Access

Developing Effective Decision Support for the Application of "Gentle" Remediation Options: The GREENLAND Project

Andy Cundy, Paul Bardos, Markus Puschenreiter, Nele Witters, Michel Mench, Valerie Bert, Wolfgang Friesl-Hanl ... **See all authors**

First published: 10 June 2015 | **https://doi.org/10.1002/rem.21435** |
Citations: 16

EKR Decision Support Tools

i / ii
Properties of
Substrate **Contaminant**

Electrical conductivity?
Particle size?
Permeability and porosity?
Cation exchange capacity?
Redox chemistry?
Adsorption?
pH and buffering capacity?
Size and speed of contaminant plume?
Effect of biota?
Groundwater flow?
Hydraulic head?
Temperature?
Additives?
Ionic mobility?

↔

iii
Electrical inputs and electrodes

Voltage?
Current?
Electrode placement?
Electrode separation?
Electrode material?
Corrosion resistance?
Strength of pH gradient generated?
Energy consumption?
Electrolyte?
Dead zones?
Borehole engineering?
Electrode installation?
Depth?
Renewable *vs.* fossil fuel?

↔

iv
Cost and sustainability issues

Duration?
Batch *vs.* continuous?
Labour costs?
Source of materials?
Electricity pricing?
Cost saving by remediating?
Safety?
Electrode value?
In-situ vs. ex-situ?
Use of machinery?
Material disposal costs?
Material and labour transport?
Insurance?
Material storage pending remediation?
Possibility to achieve wider socio-economic and environmental benefits?

Purkis, Hemming, Warwick, Graham, Cundy, submitted to J. Haz. Mater.

Conclusions and Acknowledgements

- EKR: *in-situ*, cheap, flexible
- Limited at scale
- Combined approaches
  - *FIRS: iron barriering*
  - *Electro-grouting: colloidal Si*
- Both impermeable (10^{-9} $m.s^{-1}$), sorptive
- DSTs to avoid "valley of death"?






GAU Radioanalytical Laboratories

NATIONAL NUCLEAR LABORATORY

NDA

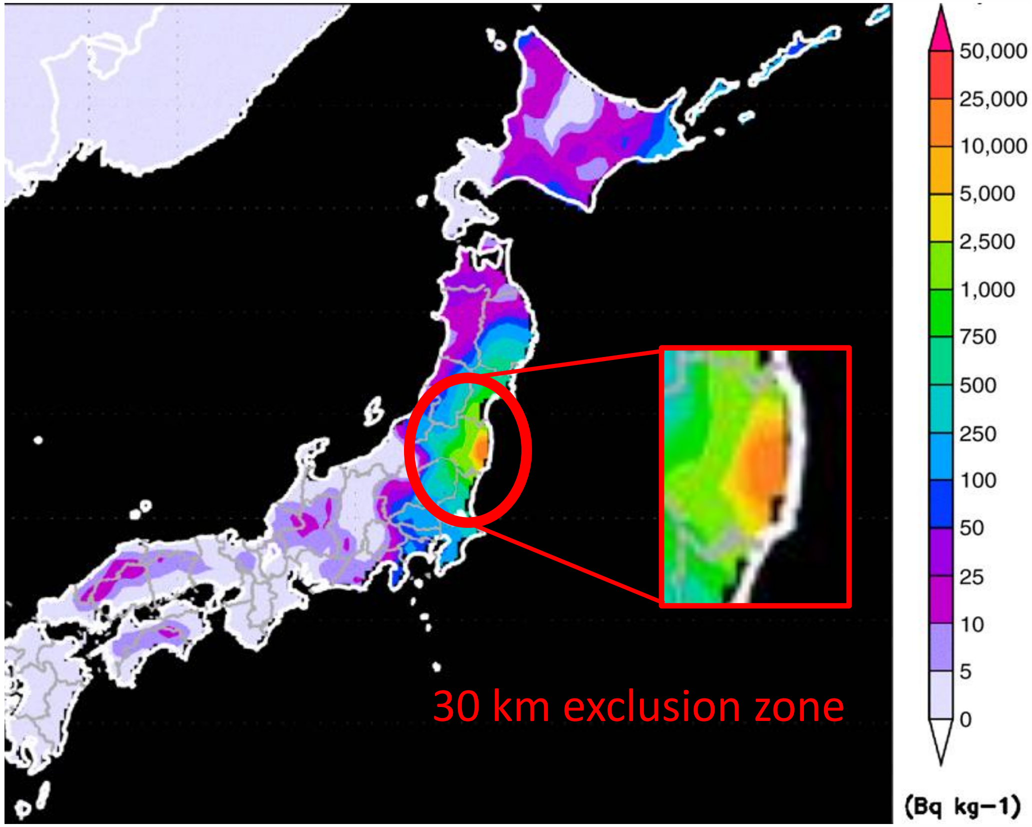
Case Study 2 – Fukushima Simulant

Fukushima, 2011

~ 3 PBq ^{137}Cs & ^{90}Sr in soil (30 km)

160,000 t soil at > 8 KBq/kg (2014)

$50 – 150 billion (2016)

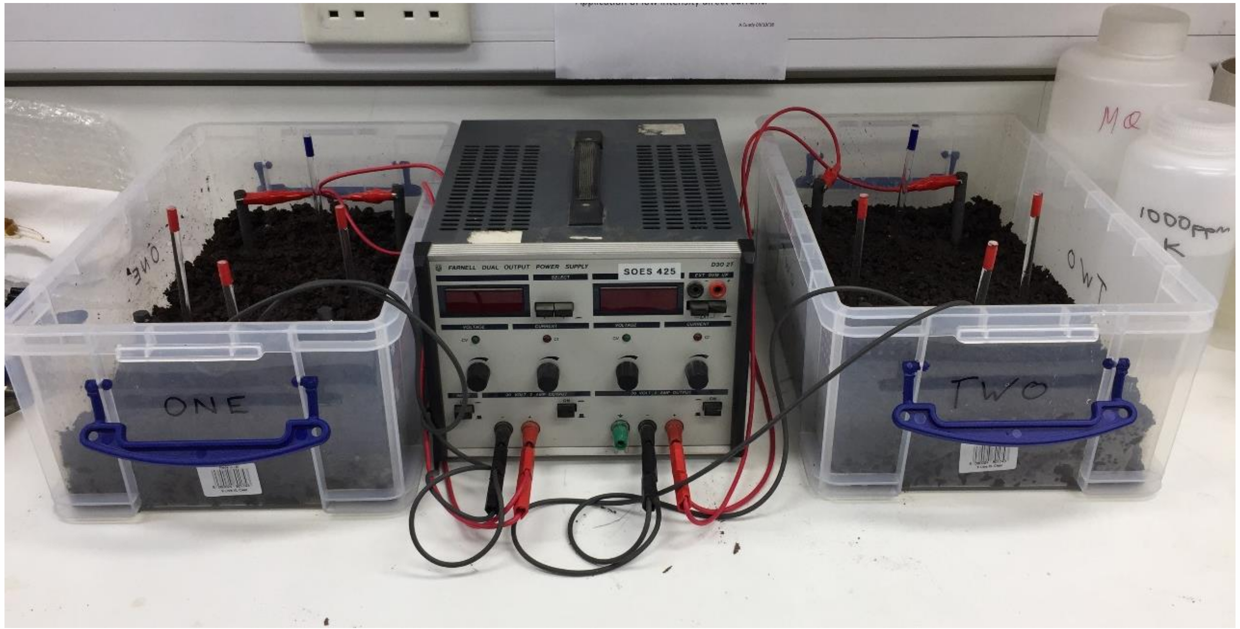


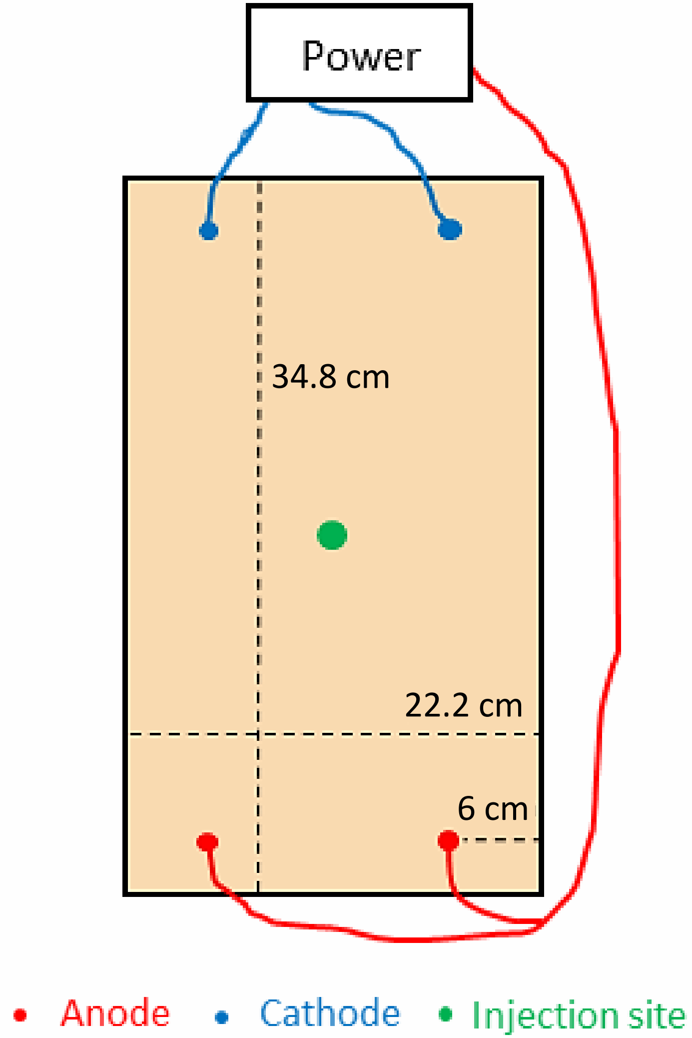
[^{137}Cs], Japan, 19/04/2011
Fukushima: 11/03/2011

PNAS, 2011, 108, 19530; Environ. Sci. Technol., 2014, 48, 13053; J. Environ. Radioactiv., 2016, 151, 512

Case Study 2 – Fukushima Simulant

- 6:1 clay-peat soil (TOC = 11.6 %, pH 5.4)
- 15 or 20 V (0.5 V/cm) → low energy EKR
- Monitor: pH
  [Cs] and others by XRF





Purkis, Tucknott, Cundy, *et al.*, Appl. Geochem., in press

Case Study 2 – Fukushima Simulant

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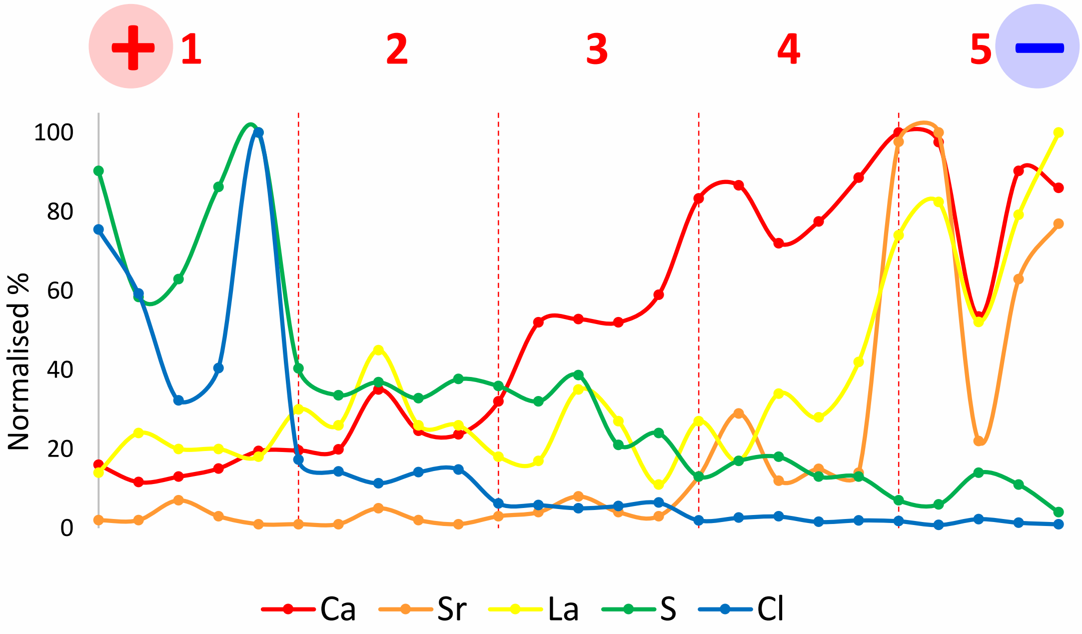

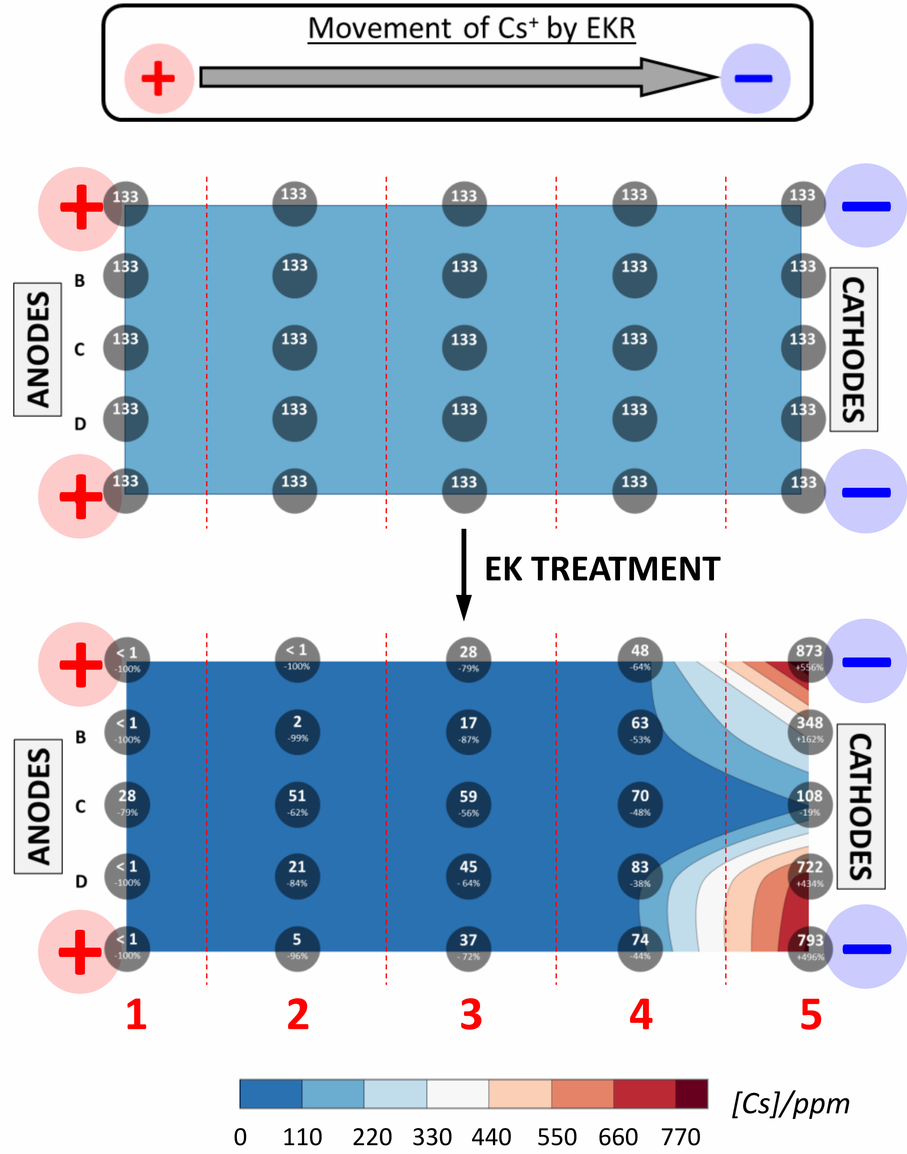

Purkis, Tucknott, Cundy, *et al.*, Appl. Geochem., in press

Transformative Science and Engineering for Nuclear Decommissioning

Predicting Gamma Dose Rates from Underground Contaminated Structures with Limited Information

Luke Lee-Brewin: l.lee-brewin@surrey.ac.uk

University of Surrey

Transcend Virtual Conference

03/12/2020

For a Low Carbon Future

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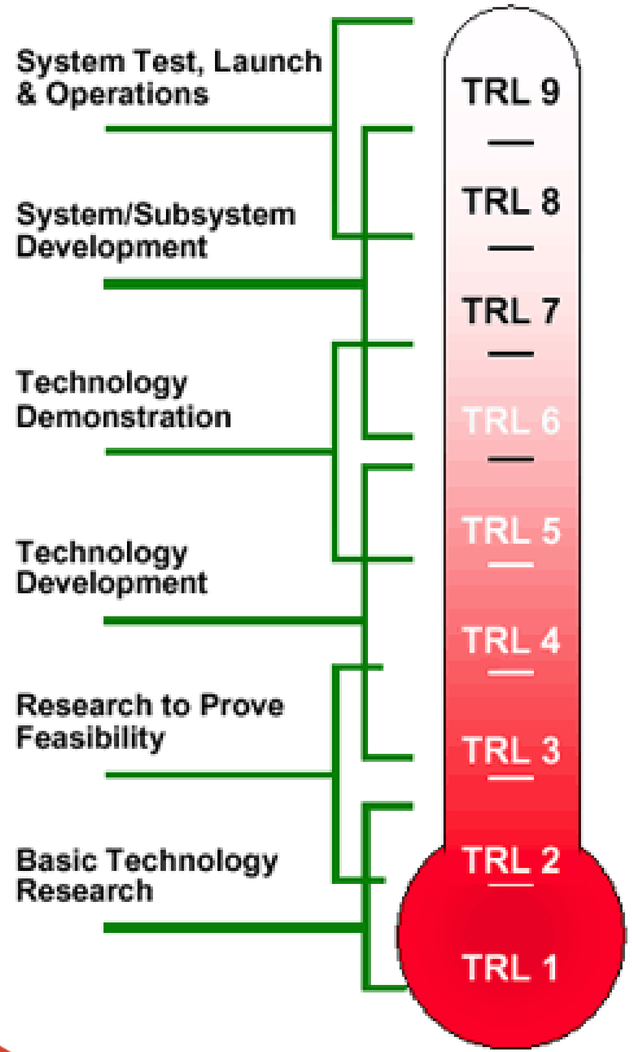
Project Overview

- Develop a non-intrusive method to analyse gamma signals from underground contaminated pipes to TRL: Level 6
- Identify radioisotopes present within gamma signals
- Determine dose rate at a given depth for a given structure



https://en.wikipedia.org/wiki/Technology_readiness_level

Project Overview

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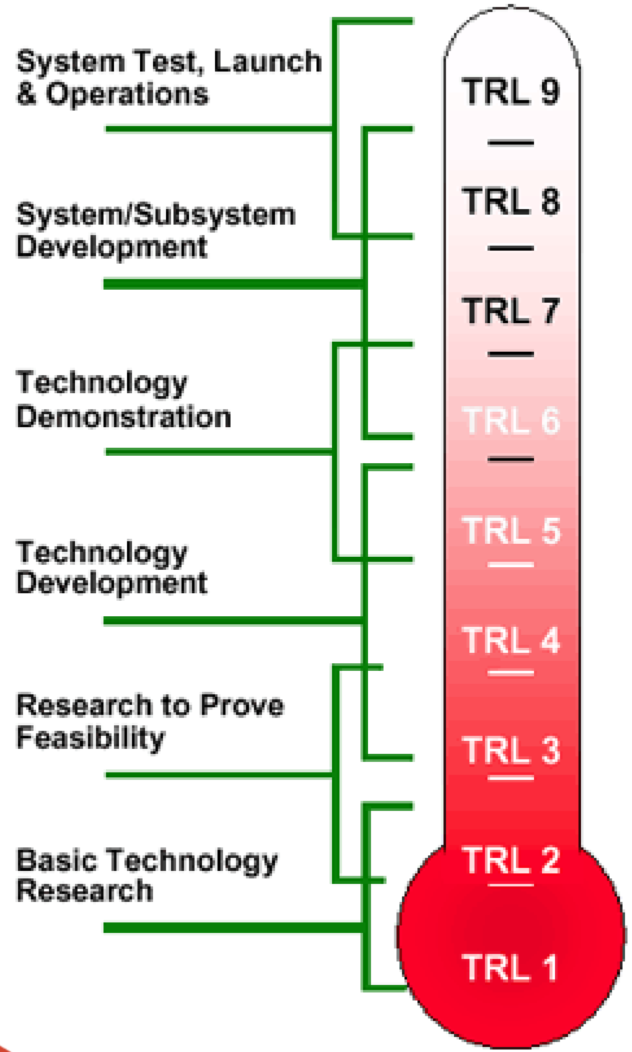


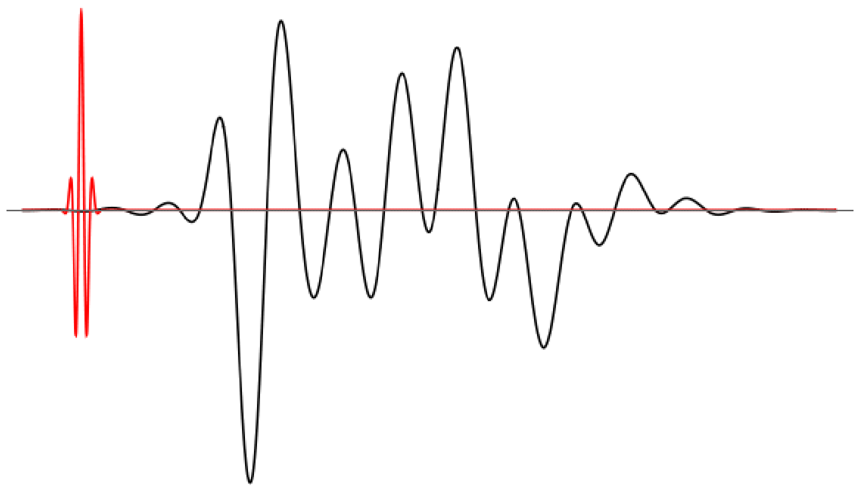
https://en.wikipedia.org/wiki/Technology_readiness_level

Key Challenges

- Large, unknown distances between the contaminated structure and detector
- Multiple, unknown numbers of isotopes present within the contaminated structure
- This results in low signal to noise ratio gamma spectra with overlapping photopeaks

Wavelet Analysis: Theory

- Wavelet analysis offers a method of identifying the location of low SNR signals in photopeaks
- A wavelet is a short wave-like oscillation with an amplitude that begins and ends at 0
- Transforms a signal into the energy scale domain
- Scale is a "pseudo wavelength" for a wavelet, small scales respond strongly to high frequency events such as noise. Large scales respond to lower frequency events such as photopeaks.
- Performing multiple wavelet transforms over a range of scales creates a scaleogram which is used for analysis



$$T(E,s) = \int f(t)\Psi^{*}_{E,s}(t)dt$$

https://en.wikipedia.org/wiki/Continuous_wavelet_transform

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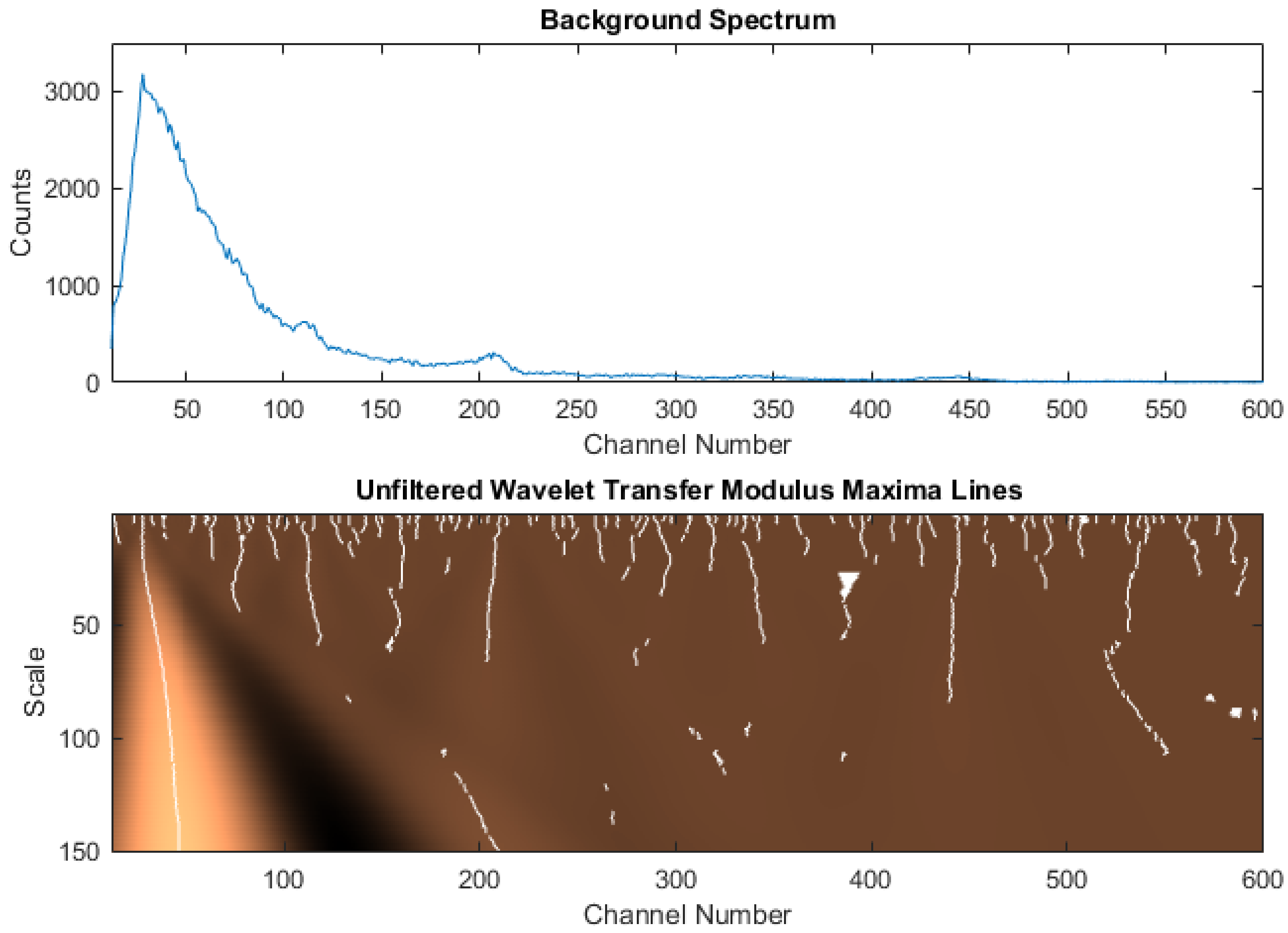
Wavelet Analysis: Results



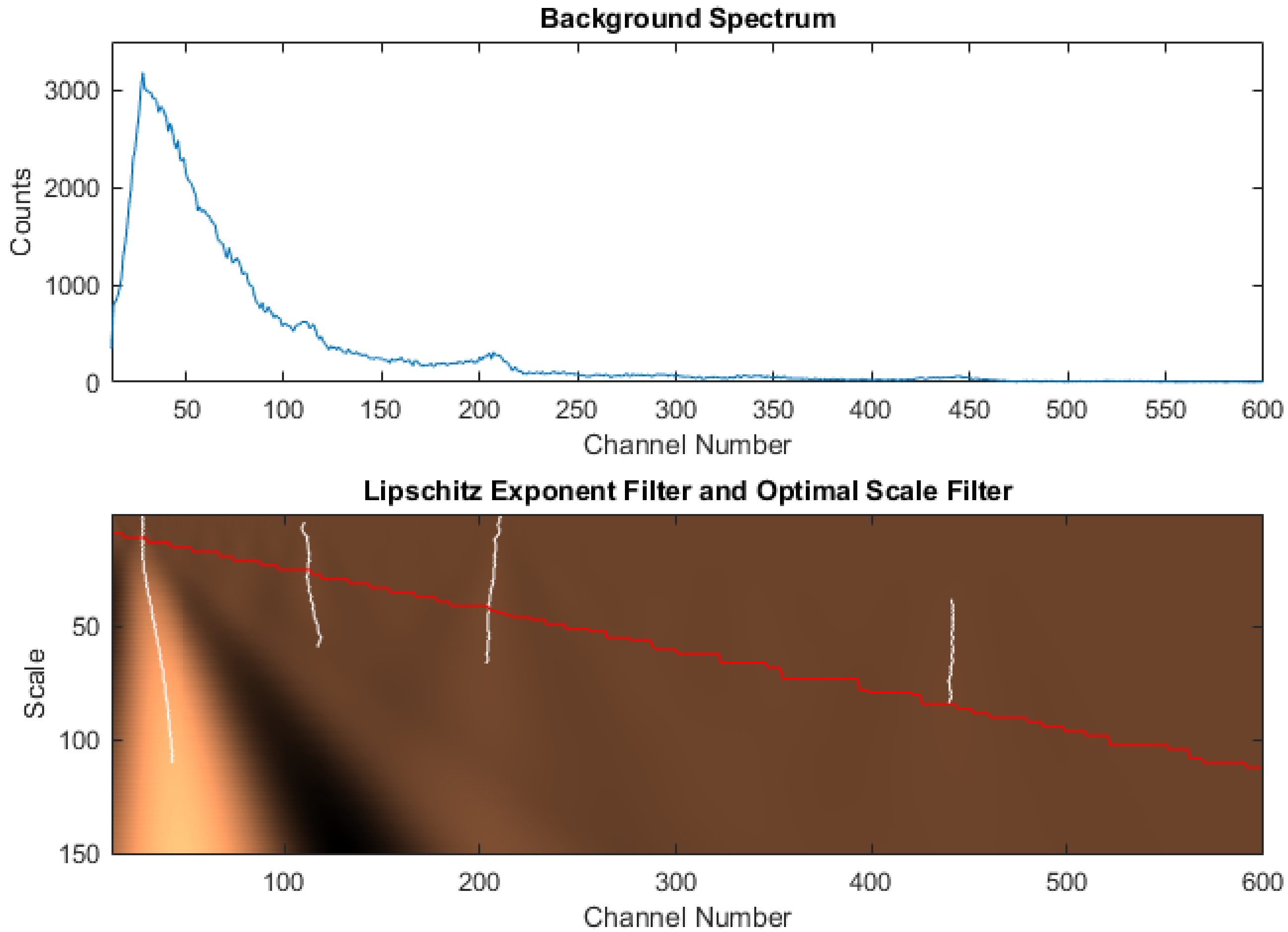
Maxima Lines

White lines on the scaleogram are the local maxima of each transform

Interpreting the Scaleogram

- Shorter lines at low scales represent noise
- Larger lines correspond to larger features e.g. photopeaks and the Compton continuum

Wavelet Analysis: Results



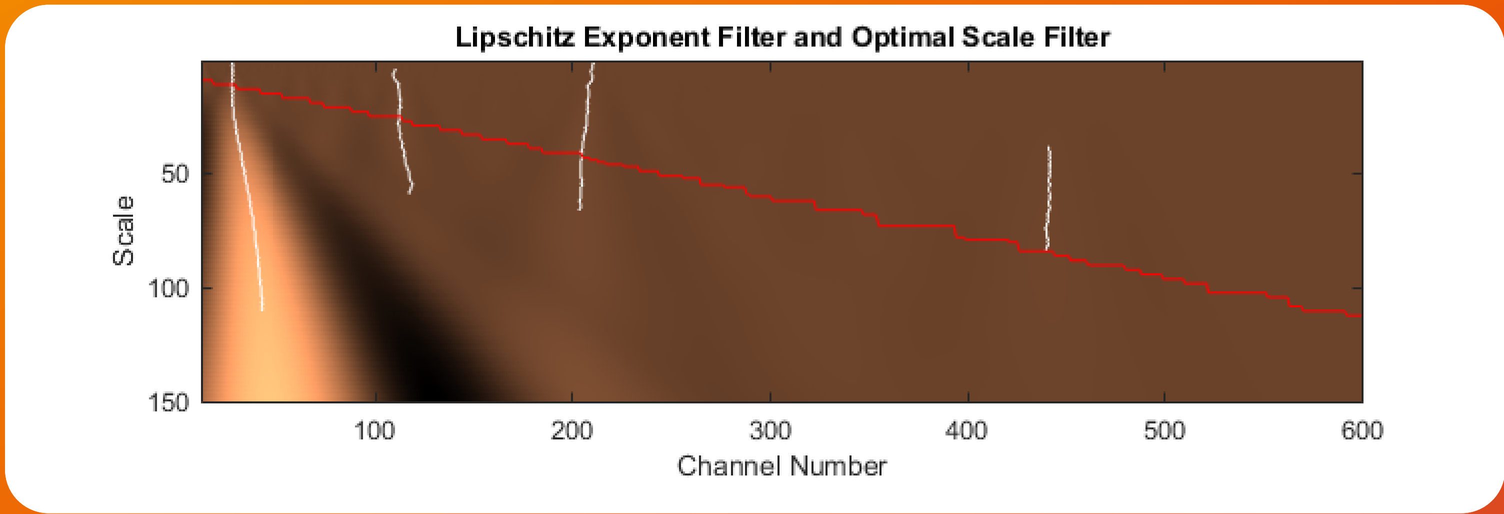
Lipschitz Filter

Measures differentiability of the line. Gaussians are differentiable therefore any line that isn't cannot be a photopeak

Optimal Scale Filter

Red line shows the energy resolution, any line wholly above the red line corresponds to a feature too thin to be a photopeak

Analysis



Line 1:

Energy: ~30-70 keV

Source: Background X-rays

Line 2:

Energy: ~350 keV

Source: ^{152}Eu left in safe

Line 3:

Energy: ~670 keV

Source: ^{137}Cs left in safe

Line 4:

Energy: ~1450 keV

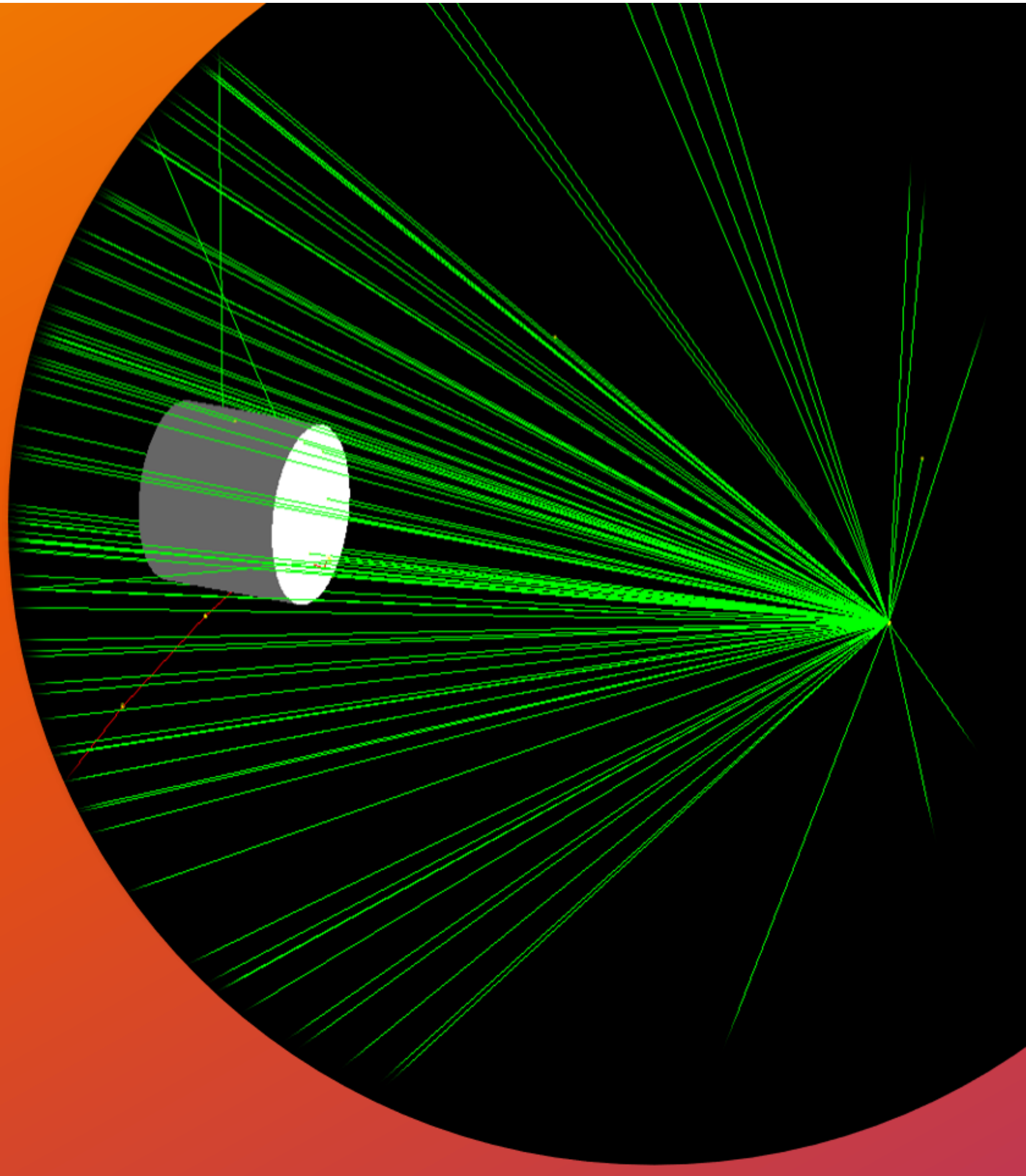
Source: Background ^{40}K

Identifying Isotopes

- A machine learning algorithm is in development to convert the output from the wavelet program into a prediction of isotopes present in a spectrum

- Supervised ANN’s require a large training set. Collecting these spectra experimentally would be impractical

- To address this, a GEANT4 simulation has been used to create this training set



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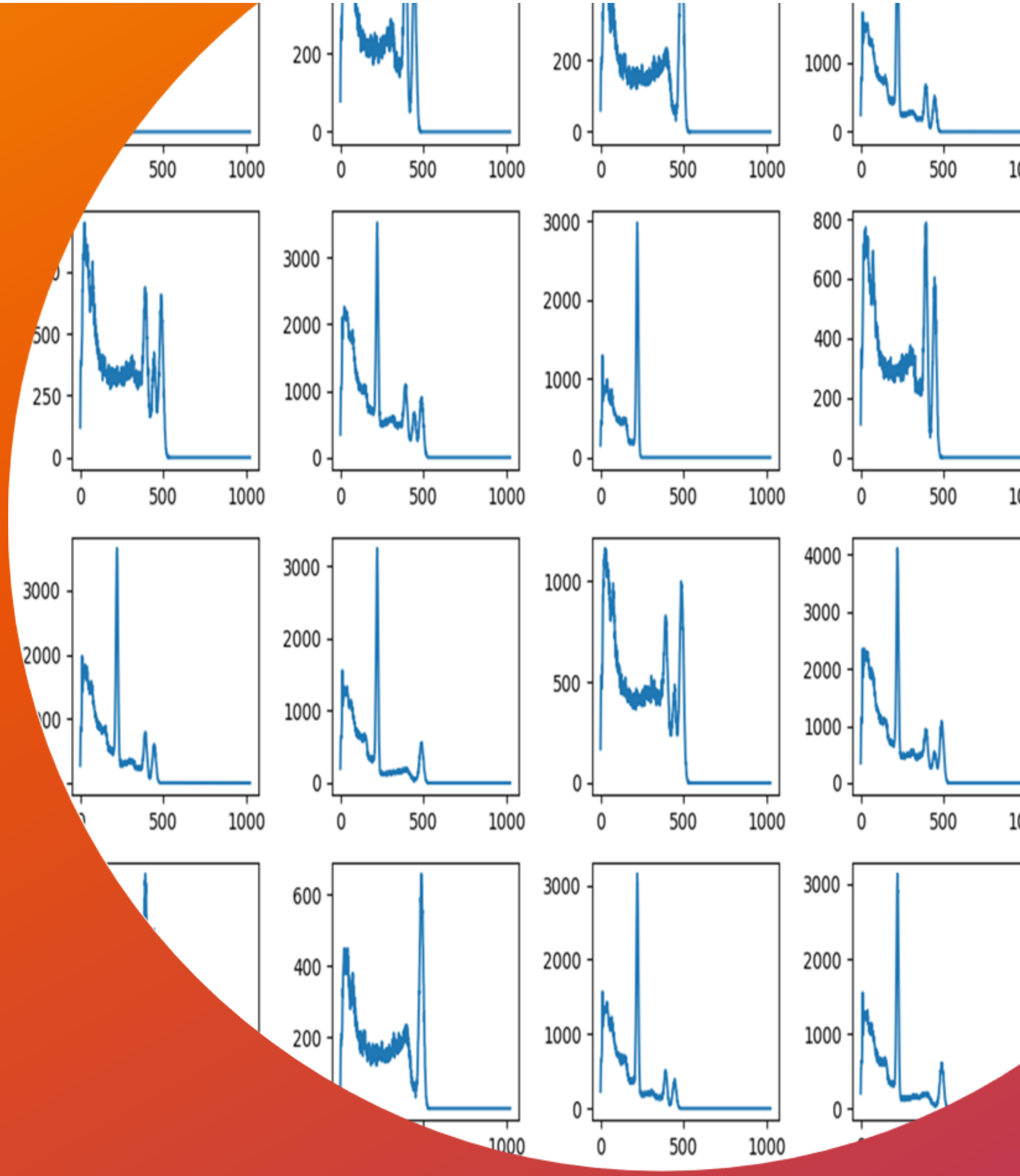
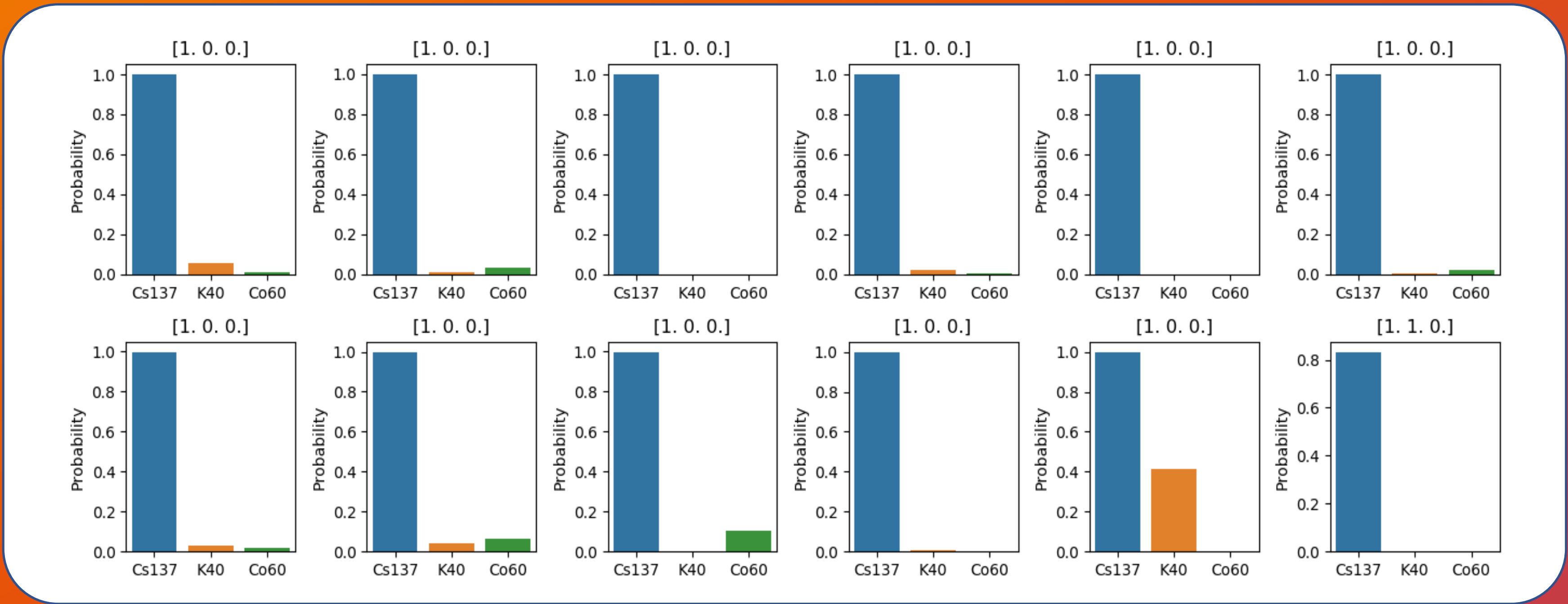
Creating the Training Set

- A training set of 5000 spectra was created
- The training set was comprised of ^{137}Cs, ^{60}Co and ^{40}K
- Equal numbers of each of the 8 possible combinations of isotope were created
- This training set was used to train a neural network by inputting the normalised counts for each channel
- The set was then wavelet analysed and used to train a second neural network for comparison



Results: Neural Networks

Normalised Counts Network	Simulated Data Accuracy: 85%	Experimental Accuracy: 0%
Wavelet Analysed Network	Simulated Data Accuracy: 75%	Experimental Accuracy: 100%



Conclusions

- The wavelet analysed training set created an algorithm capable of identifying spectra collected experimentally
- By removing information such as noise and the Compton continuum from a training set it might be possible to create a neural network capable of identifying isotopes in spectra collected from various environments
- The testing set used was very small. This was because they were the only available spectra during lockdown when access to the lab was restricted

Future Work

- Quantify the effectiveness of these programs with larger experimentally generated testing sets
- Compare different types of neural network and different levels of "filtering" unhelpful information (noise etc.) from gamma spectra before training a network on the data
- Use these methods on data from an underground contaminated pipe at Winfrith and quantify the effectiveness of these methods against more intrusive sampling methods

Acknowledgements

Supervisors: Caroline Shenton-Taylor:

c.shenton-taylor@surrey.ac.uk,

David Read: d.read@surrey.ac.uk

I would like to thank the Transcend consortium for funding and technical discussions supporting this study

Thank you

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Transformative Science and Engineering for Nuclear Decommissioning

Application of low-energy electrokinetic clean-up techniques to problem nuclear contaminants and sites

Shaun Hemming

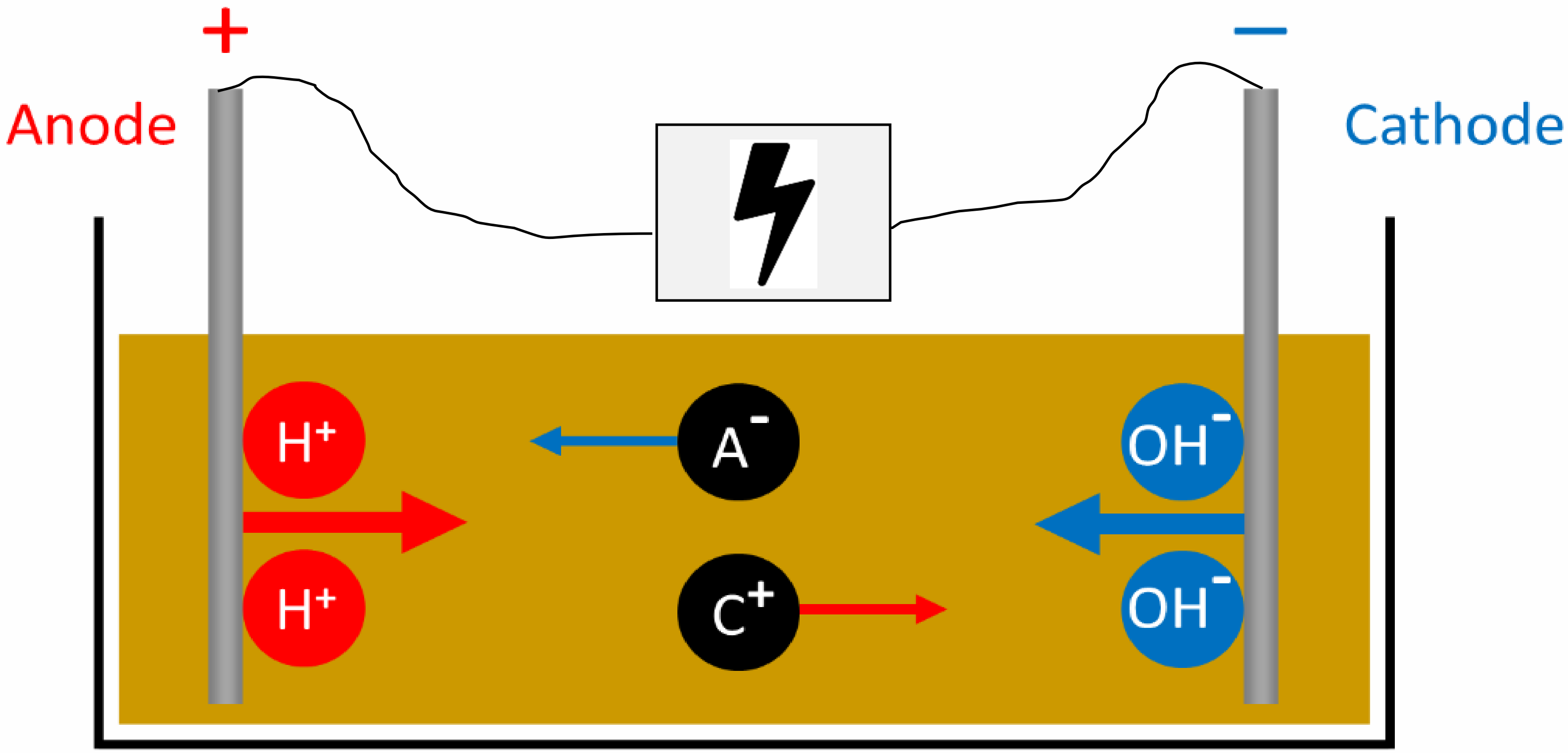
University of Southampton

JointNuclear (TRANSCEND/NDA/NWDRF) Virtual Conference
2-3 December 2020

Energy
For a Low Carbon Future

MSci Geology
University of Southampton
2016-2020

PhD
University of Southampton
2020-2024



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

$E^0 = -\ 1.229\ V$

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

$E^0 = -\ 0.828\ V$

Difficult to Measure Radionuclides:

- Iodine-129
- Chlorine-36
- Technetium-99
- Carbon-14
- Strontium-90
- Tritium

Project Aims

- **Apply electrokinetic remediation to:**

  - **Radionuclides with no/few remediation options**
    - **DTMs**
  - **Different materials found at nuclear sites**
    - **soils, concrete, sludges and other materials**

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Any questions?

sdh1g16@soton.ac.uk

UNIVERSITY OF Southampton

GAU Radioanalytical Laboratories

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Transformative Science and Engineering for Nuclear Decommissioning

TRANSCEND/NDA/NWDRF
Virtual Conference
2-3 December 2020

An advanced blind-tube monitoring instrument to improve the characterization of subsurface radioactive plumes

PhD student: Soraia S C Elisio

Academic supervisor: Malcolm J Joyce

Industrial supervisors:

James Graham
Central Laboratory, National Nuclear Laboratory Ltd.

Barrie Greenhalgh
Radiometric Systems Group, Sellafield Ltd.

Lancaster University

NATIONAL NUCLEAR LABORATORY

Sellafield Ltd

Energy
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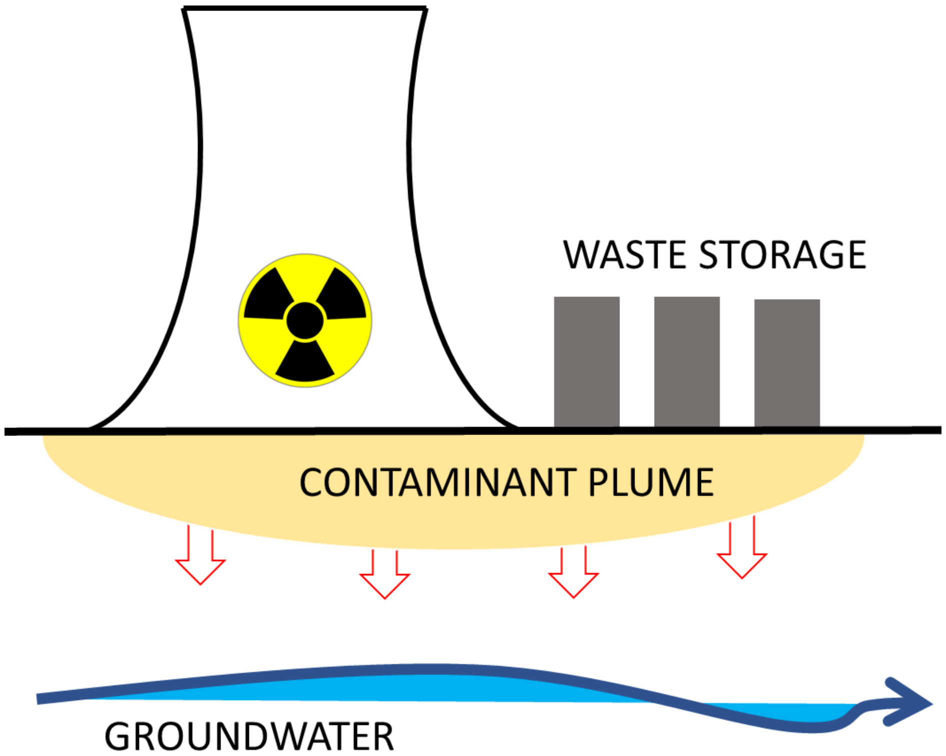
Outline of Presentation

- Context to the problem: why is this important?
- Case study: Magnox Swarf Storage Silo (MSSS)
- Subsurface contamination: current practice
- Challenges and aims
- Possible Solution
    - Radiometric logging detector
    - Concept and components
- Validate and calibrate the system
    - Concept and components
- Future work



CASE STUDY

Magnox Swarf Storage Silo (MSSS) at Sellafield Nuclear Reprocessing Plant

Taken from *Priority programmes and major projects performance report (Data as at end September 2015)*

Taken from *Sellafield Ltd, "The Magnox Swarf Storage Silo: Making our most hazardous facility a safer place," Youtube, 2017*

Active ground leaks

Maximum anticipated dose rate

1 Gy/h

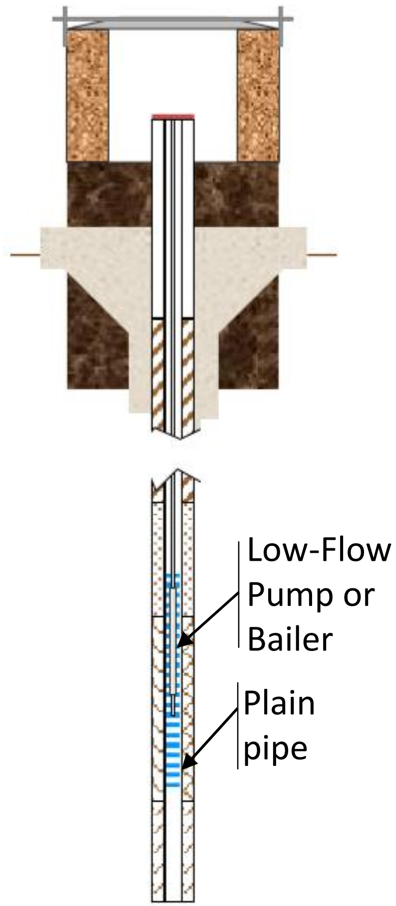
Current practice

Rock core samples

Taken from *The Sellafield Contaminated Land and Groundwater Management Project*

Water samples

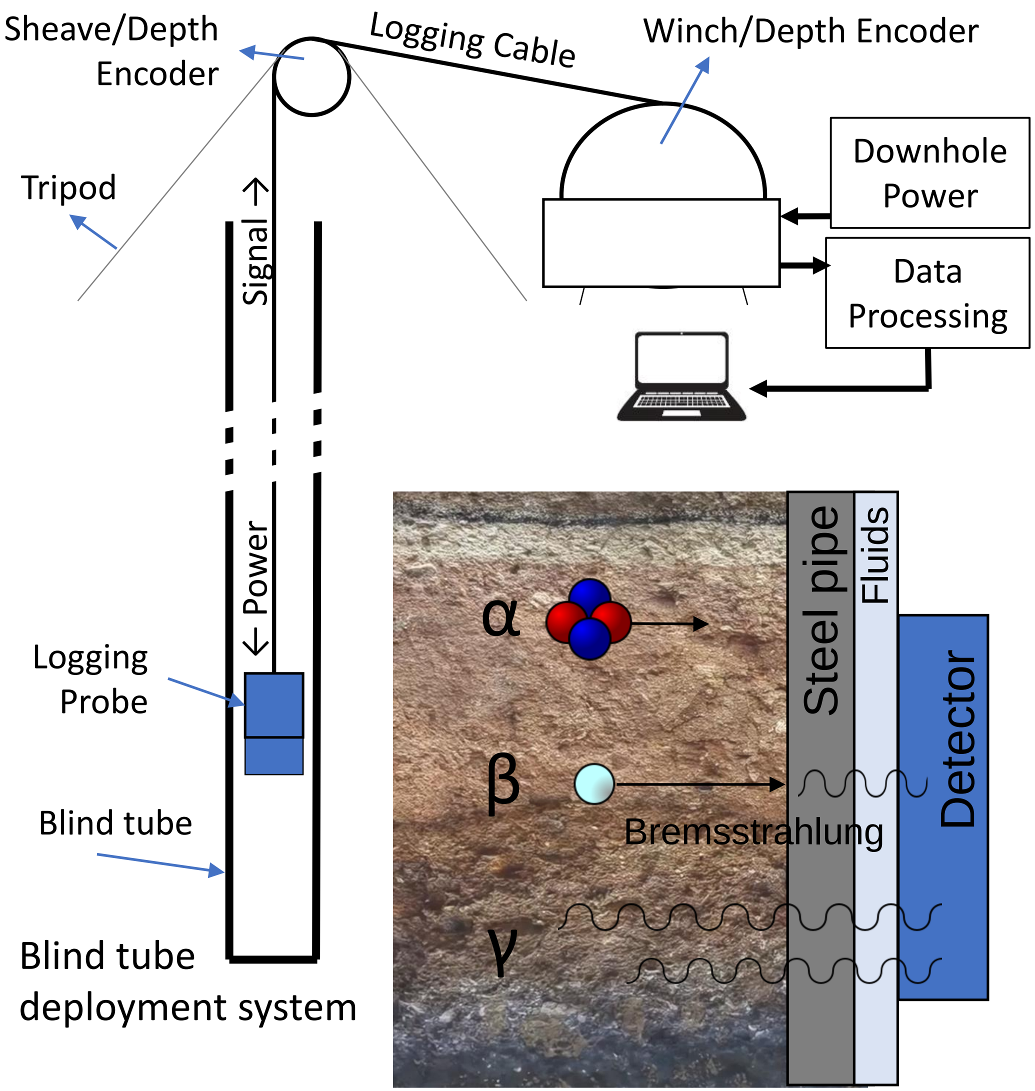
Schematic of a typical groundwater monitoring well



Taken from *Groundwater monitoring at Sellafield: Annual data review, 2016*

Radiometric logging probes

Borehole geophysical logging



Blind tube deployment system

Gamma Radiation Detection System

Sensing element

e.g.
Geiger counter
NaI:Tl
HPGe
CdZnTe

Signal conditioning

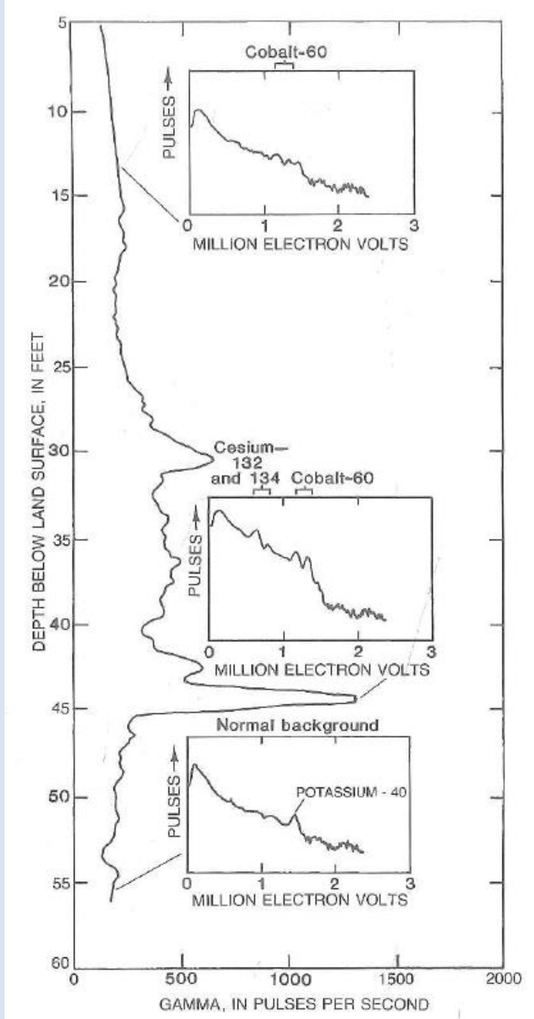
e.g. Preamplifier

Signal processing

e.g. Analog and Digital Pulse height analysis

Visualisation of data

Counts versus depth
Spectra display



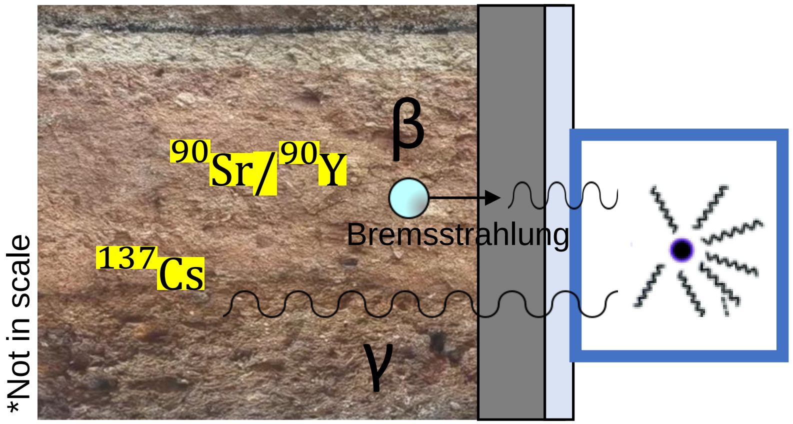
Gamma log at Maxey Flats site (Keys, 1997)

CASE STUDY

Challenges/aims:

Characterisation of sub-surface contamination within MSSS

- To be deployed in a real environment
- Continuous monitoring system
- Existing in-ground assets:
  - Steel tubes
  - Ø 75 mm
- Sub-surface high radiation levels: 1 Gy/h
- Discrimination of key radionuclides
  (Gamma-ray photons + Bremsstrahlung photons)

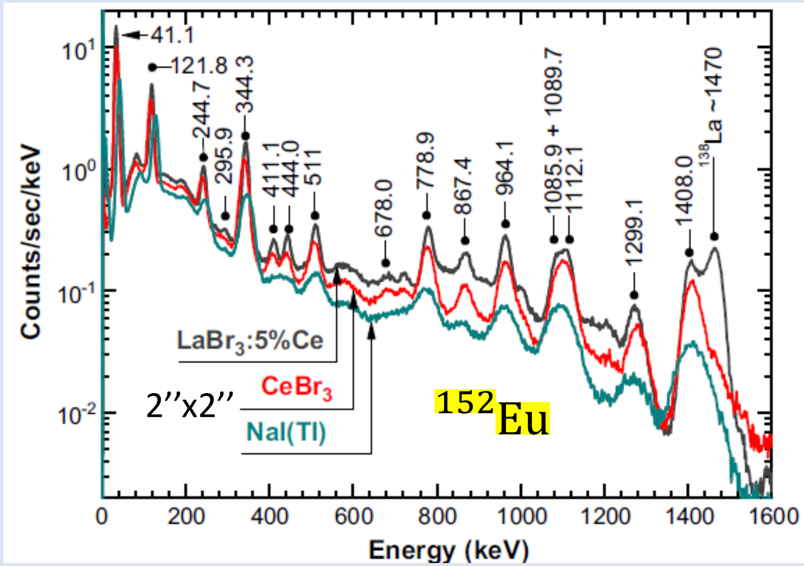


Possible Solution: Gamma Radiation Detection System

Sensing element → Signal conditioning → Signal processing → Visualisation of data

Scintillation detector

Ø10 x 10 mm $CeBr_3$ (Scionix)
Good energy resolution: 4 % @ 662 keV
Fast decay 17 ns
Radiation hardness up to 100 kGy
Residual intrinsic activity



Quarati, F. G. A. *et all* (2013), Scintillation and detection characteristics of high-sensitivity $CeBr_3$ gamma-ray spectrometers

CASE STUDY

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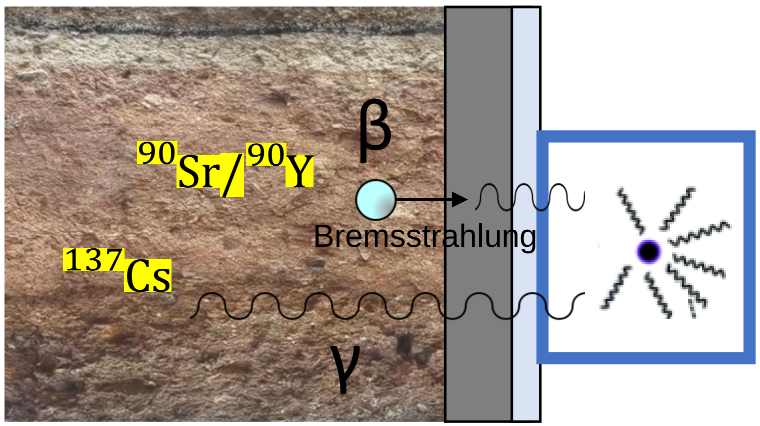


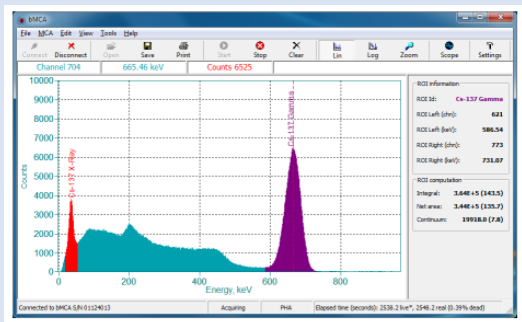
*Not in scale

Possible Solution: Gamma Radiation Detection System

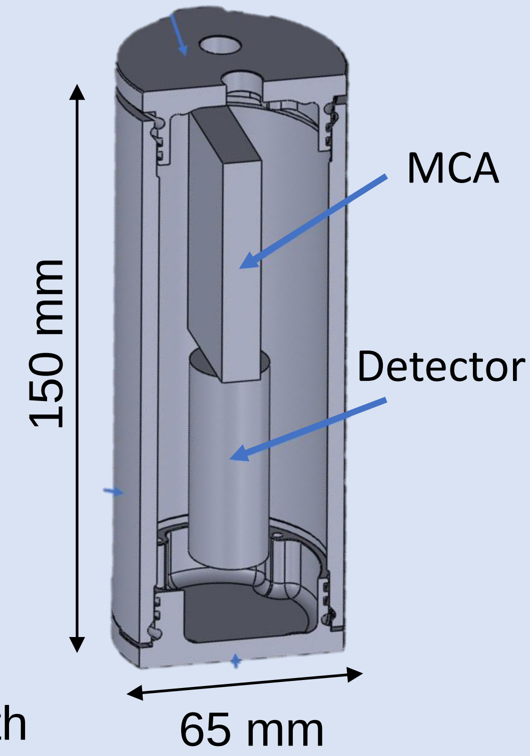
Sensing element → Signal conditioning → Signal processing → Visualisation of data

TOPAZ-SiPM
miniature digital MCA

Gamma-ray spectroscopy software – bGAMMA

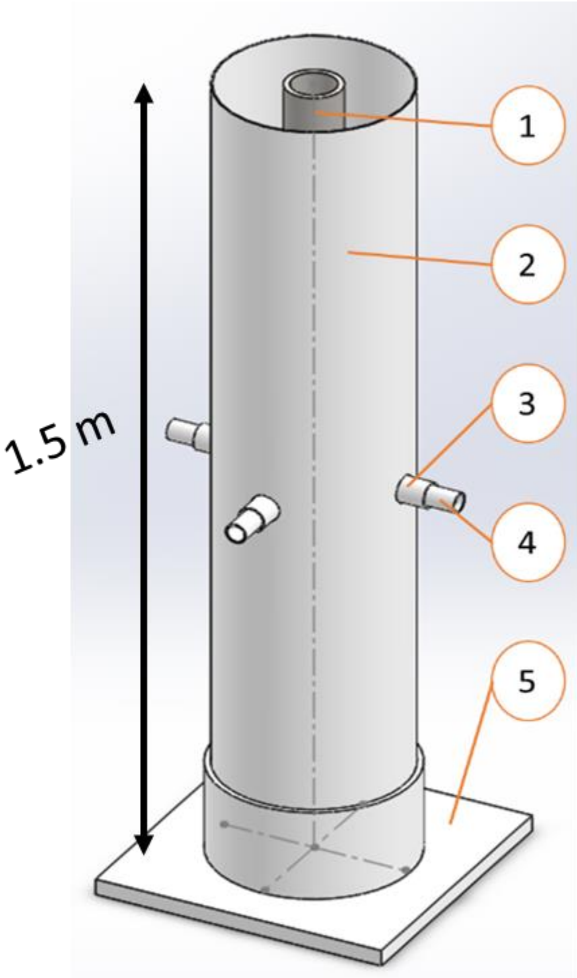


Depth profiles: counts vs depth



Validate the concept and calibrate the system

- Construction of test pipe



1. Blind tube (steel)
2. Sand retaining tube (plastic)
3. 'Void' tubes (plastic)
4. Source holders (plastic)
5. Base support

Non-toxic pit sand

Validate the concept and calibrate the system

What's next?

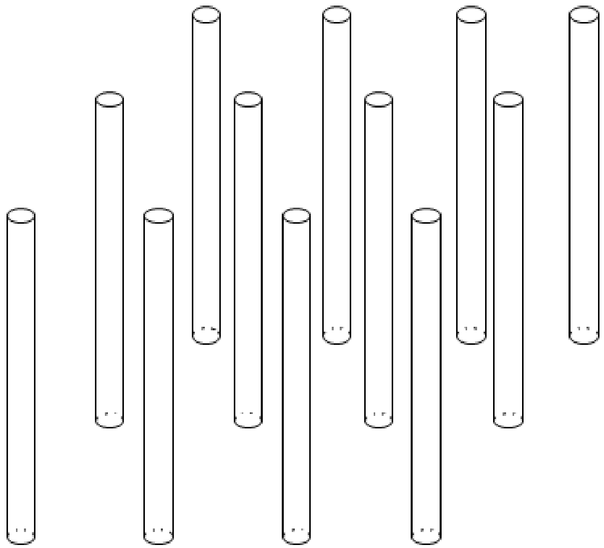
A. Radiological testing

A. Temperature dependence, waterproofing, vibration tests, etc

B. Extension of a single detector to a blind tube string network -> 3D underground mapping

C. Create a 3D picture of sub-surface heterogeneity within MSSS at the Sellafield site

1 m^3 Tank soil



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GAME CHANGERS

Characterisation and monitoring using in-ground assets

Hybrid Instruments

Thank you

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Lancaster University

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Transformative Science and Engineering for Nuclear Decommissioning

Assessing the strength of biomineral strategies for concrete repairs

Thanos Karampourniotis, University of Strathclyde

Theme 2: Site Decommissioning and Remediation

3 December 2020

For a Low Carbon Future

WHAT IS THE PROBLEM WE ARE ADDRESSING?

- The UK's nuclear infrastructure is ageing and many structures are past their original design life.
- Concrete assets in nuclear sites are exposed to harsh environmental conditions.
- The degradation and cracking of concrete in these sites.
- We have to guarantee the safety of the structures, until the decommissioning process is completed.

WHAT THE SOLUTION WE ARE PROPOSING IS

Limitations of the traditional concrete-repair techniques:

Cement: Big particle size, which makes it difficult and not efficient to treat micro cracking.

Resins: A short-term solution in concrete-repair that does not provide any mechanical strength.

Microbially Induced Carbonate Precipitation:

At the University of Strathclyde we are working on a novel concrete-repair strategy which focuses on bringing concrete to its original condition.

A long-term repair technique that can:

- Decrease concrete's permeability
- Increase its mechanical strength.

THE AIMS OF THIS PHD ARE

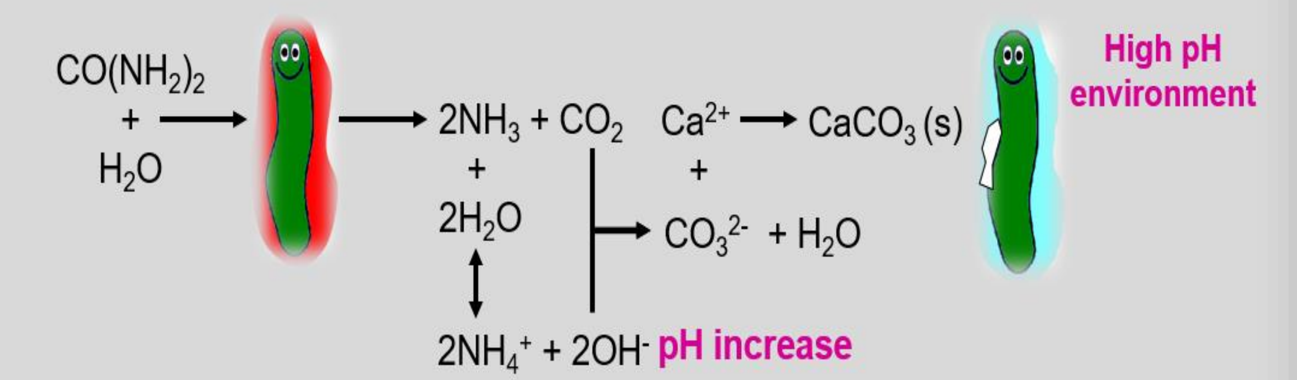
- To help repair concrete structures in nuclear sites so that they are fully functional and safe for the duration of the decommissioning process.
- To help with the research the University of Strathclyde is conducting on bio-mediated repair techniques.
- To contribute to the field trials that will take place at docks located in Devonport, Plymouth
- To develop a modelling strategy, validate it and show it can predict the mechanical behavior of MICP-treated concrete.
- To optimize the repair strategy which is investigated.

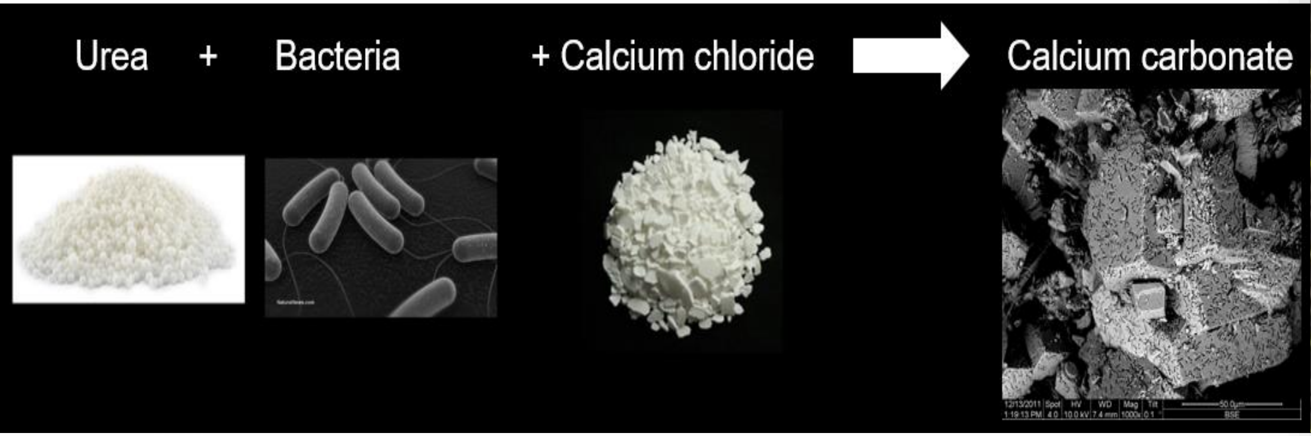
cavendish nuclear

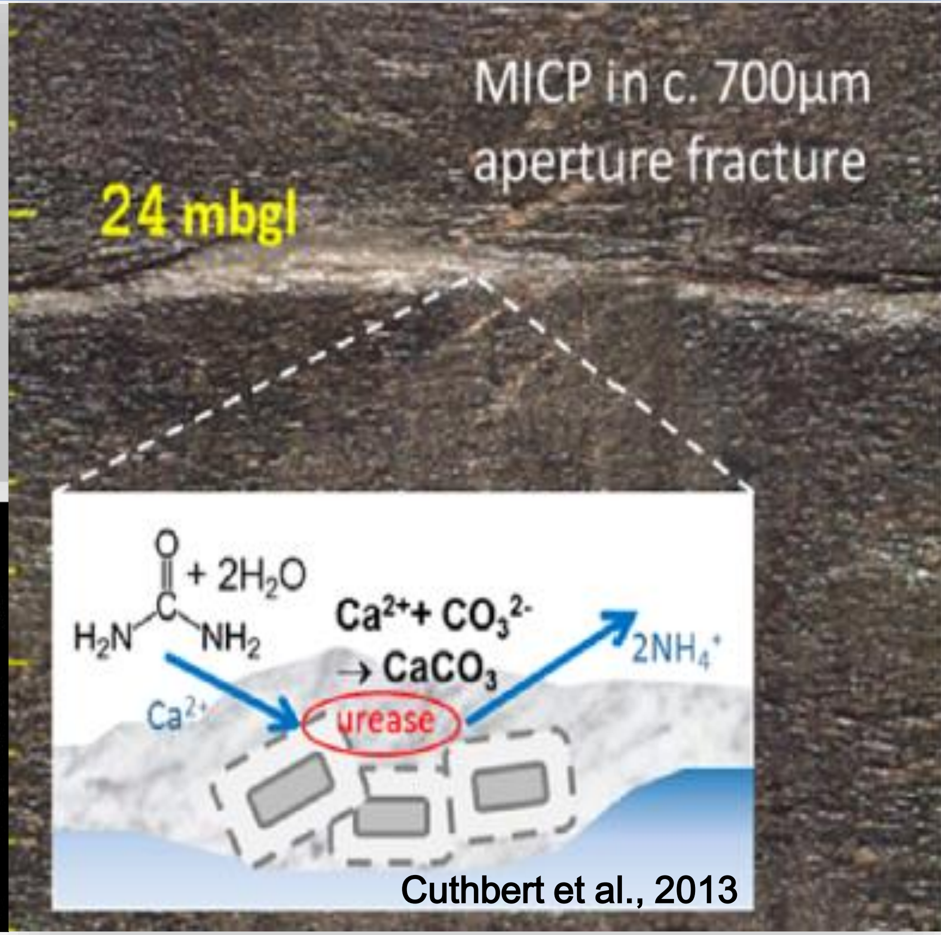
Degraded concrete in Devonport

MICP VIA UREA HYDROLYSIS

Bacterial ureolysis using ***Sporosarcina pasteurii***







FINITE ELEMENTS MODEL

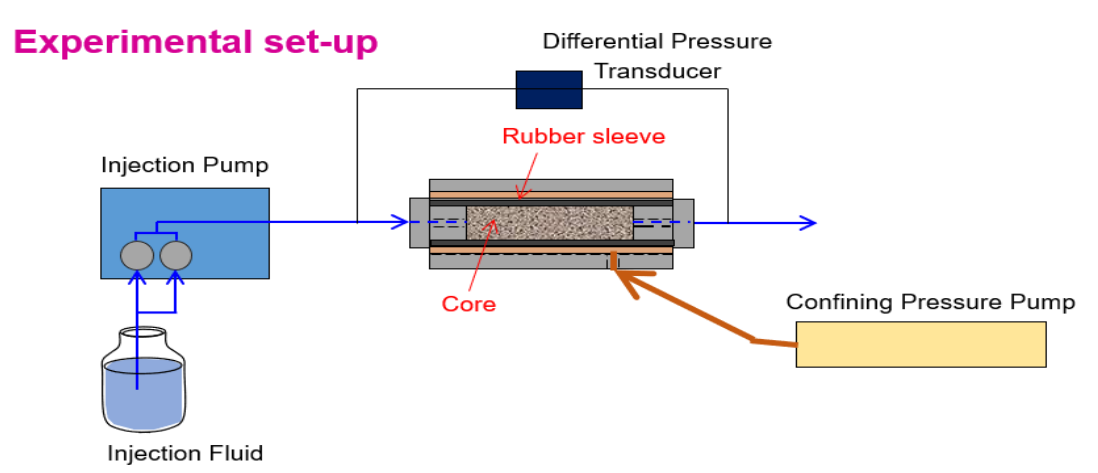
During the first year of this PhD research:

A Finite Elements Model using the meso-scale approach has been developed and calibrated against experimental results.

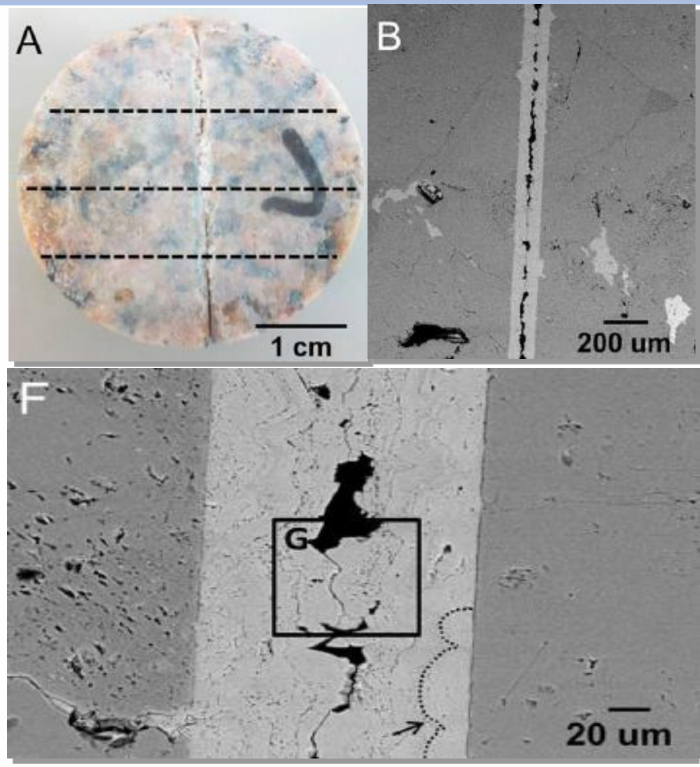
The experimental results are extracted from Dominique Tobler's (2018) research and used to calibrate the Finite Elements Model.

This model has been used to explore the importance of the calcite (calcium carbonate) geometry on the final shear strength of the repair.

GRANITE CORES AND BSE IMAGING



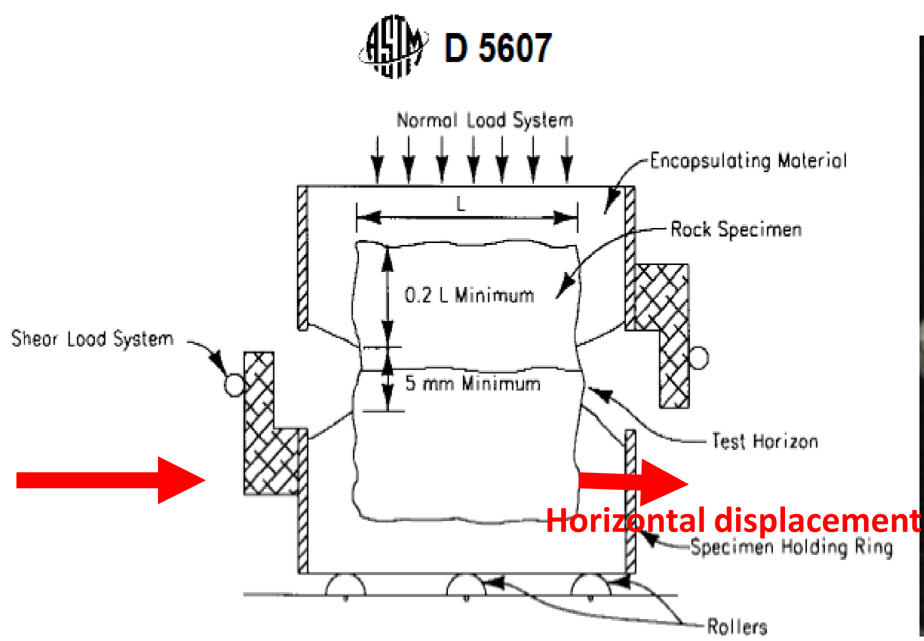
Calcite crystals bridged the fracture
after the MICP treatment was implemented



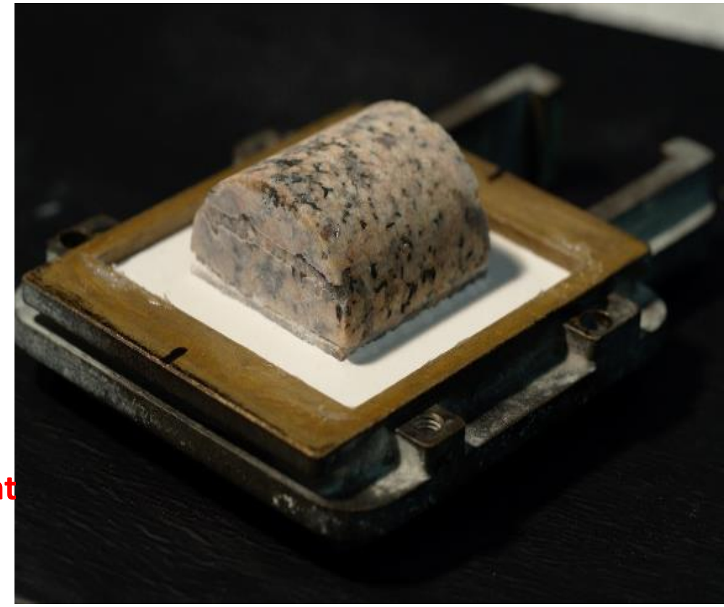
BSE imaging of the 4th granite core that was treated with the MICP repair technique

DIRECT SHEAR TESTING

Direct shear box



Schematic test setup

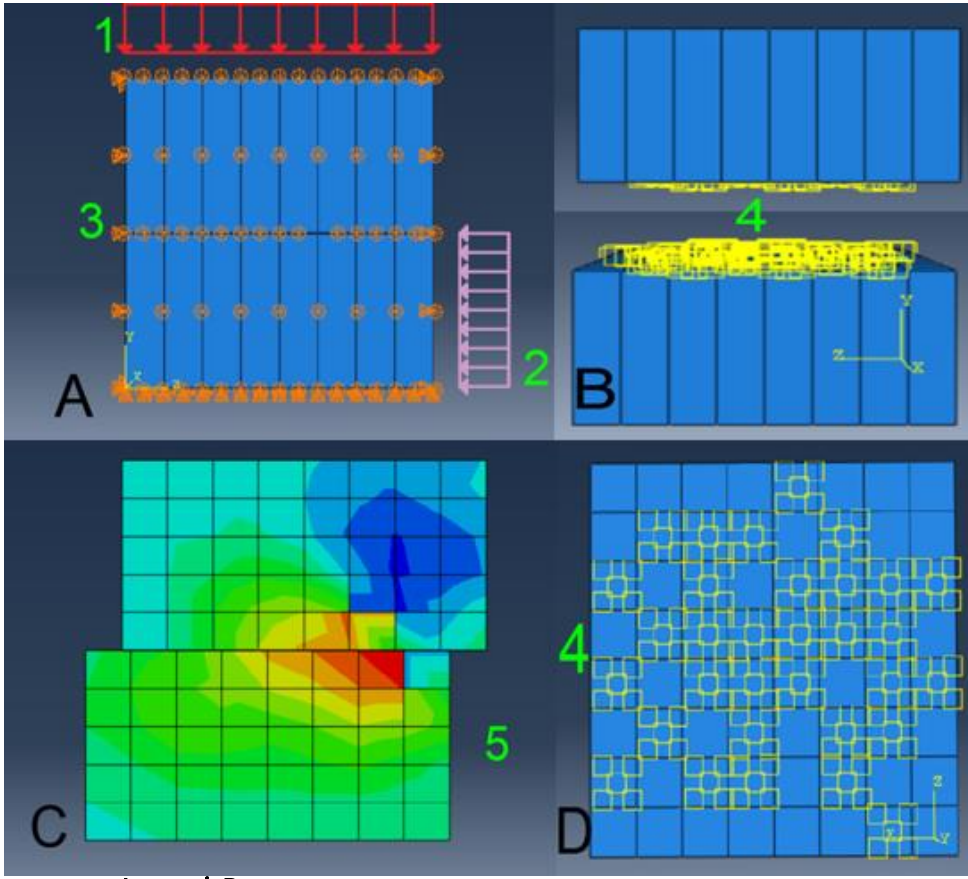


After the direct shear test

THE FINITE ELEMENTS MODEL CREATED

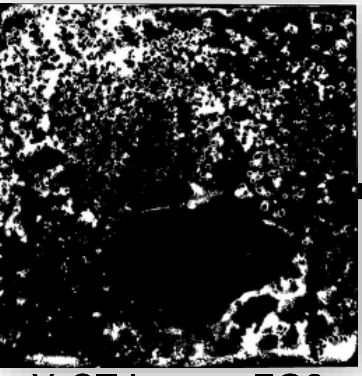
1) Vertical load on the top face of the half-core
2) Displacement rate on the second half-core
3) Horizontal fracture
4) Calcite distribution on half-cores' surfaces
5) Displacement

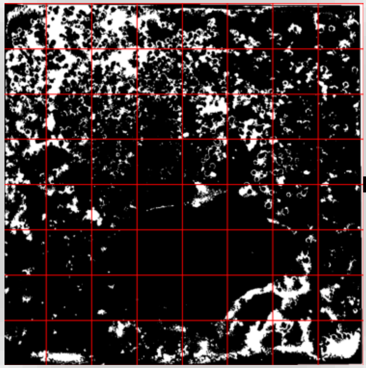
3 December 2020

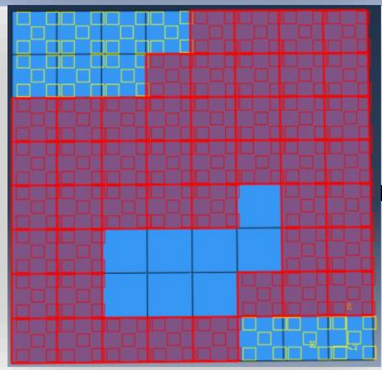


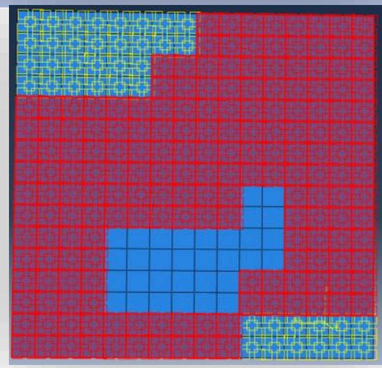
Images A and B: Loading and boundary conditions on the rock core, consisting of two rock sections (top and bottom half). *Y-Z axes view*
Image C: Shear stress distribution and displacement. *Y-Z axes view*
Image D: Simulating calcite (yellow patches) as a cohesive component in different geometrical patterns on the rock's surfaces. *X-Z axes view*

MODELING THE CONNECTED REGIONS OF THE HALF-CORES

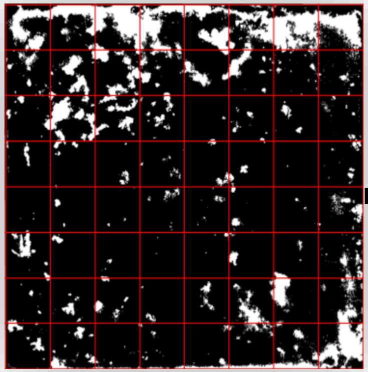

X-CT Image, FG2 Core

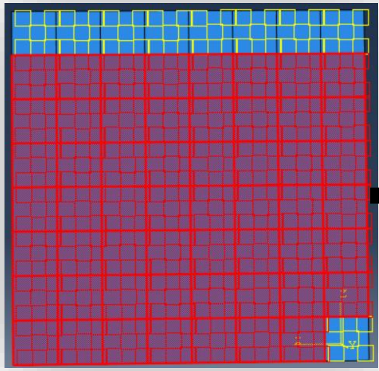

64 elements Grid, FG2 Core

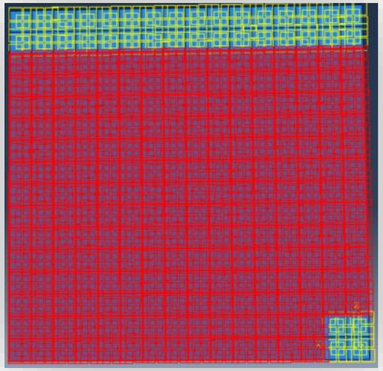

64 elements Model, FG2 Core


256 elements Model, FG2 Core


X-CT Image, FG4 Core


64 elements Grid, FG4 Core


64 elements Model, FG4 Core


256 elements Model, FG4 Core

Yellow elements:

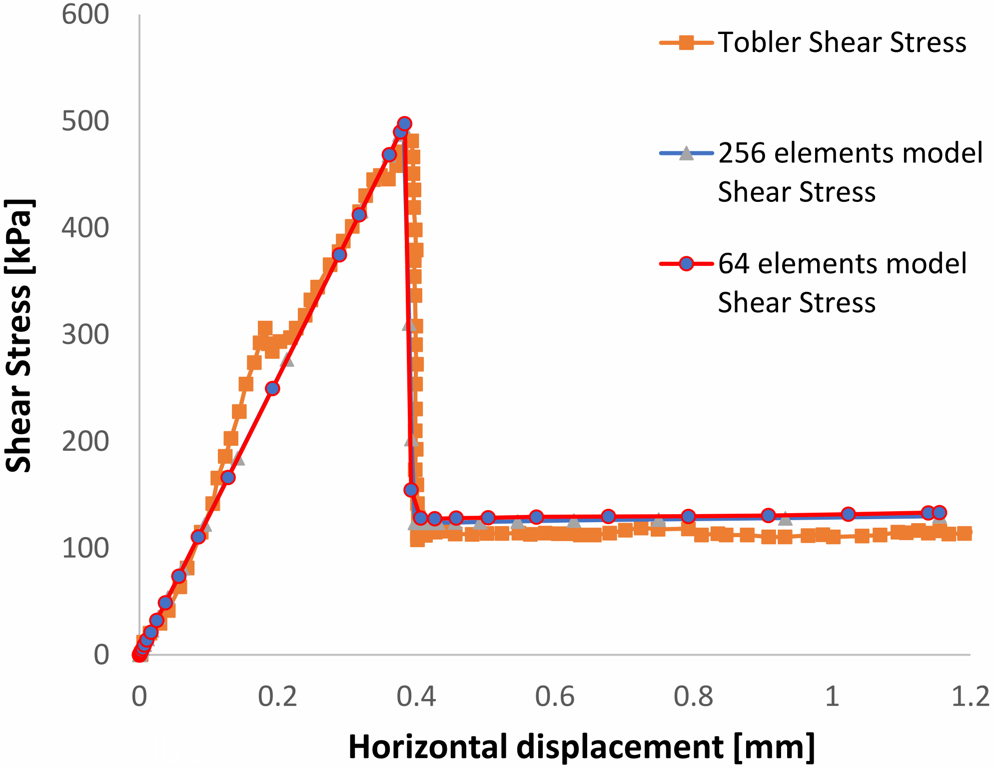
Cohesive behavior assigned

Red elements:

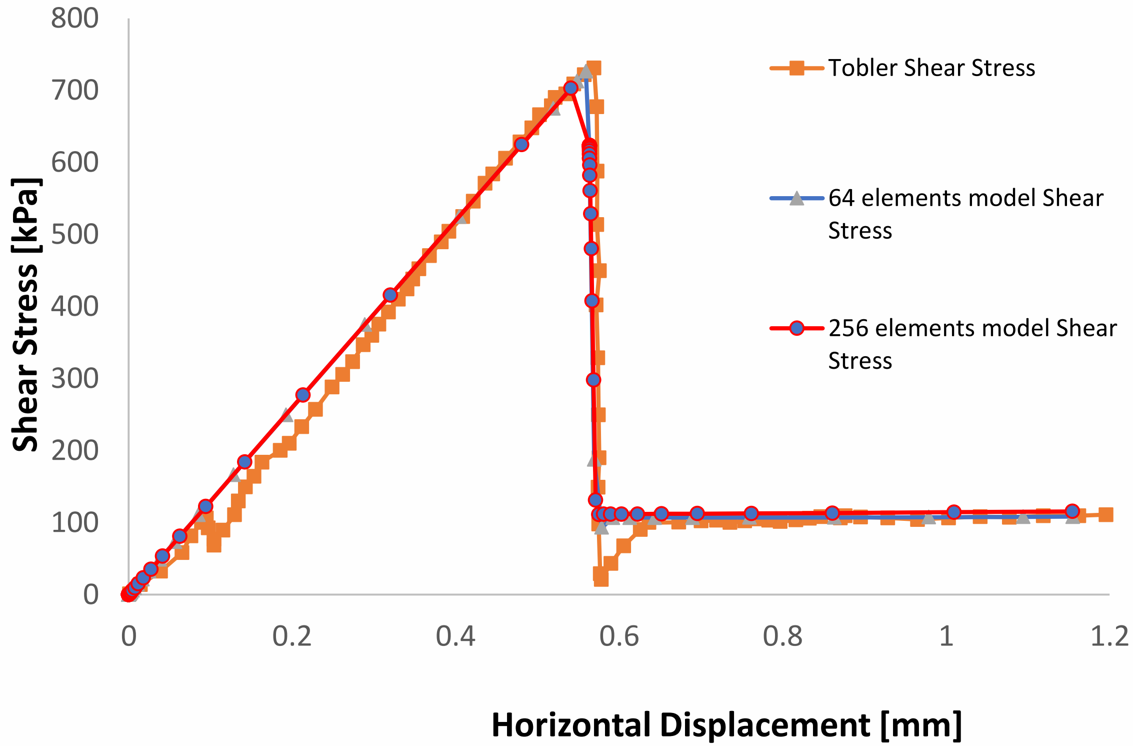
Frictional behavior assigned

CALIBRATION OF THE MODEL - MESH DEPENDENCY

FG2 Core

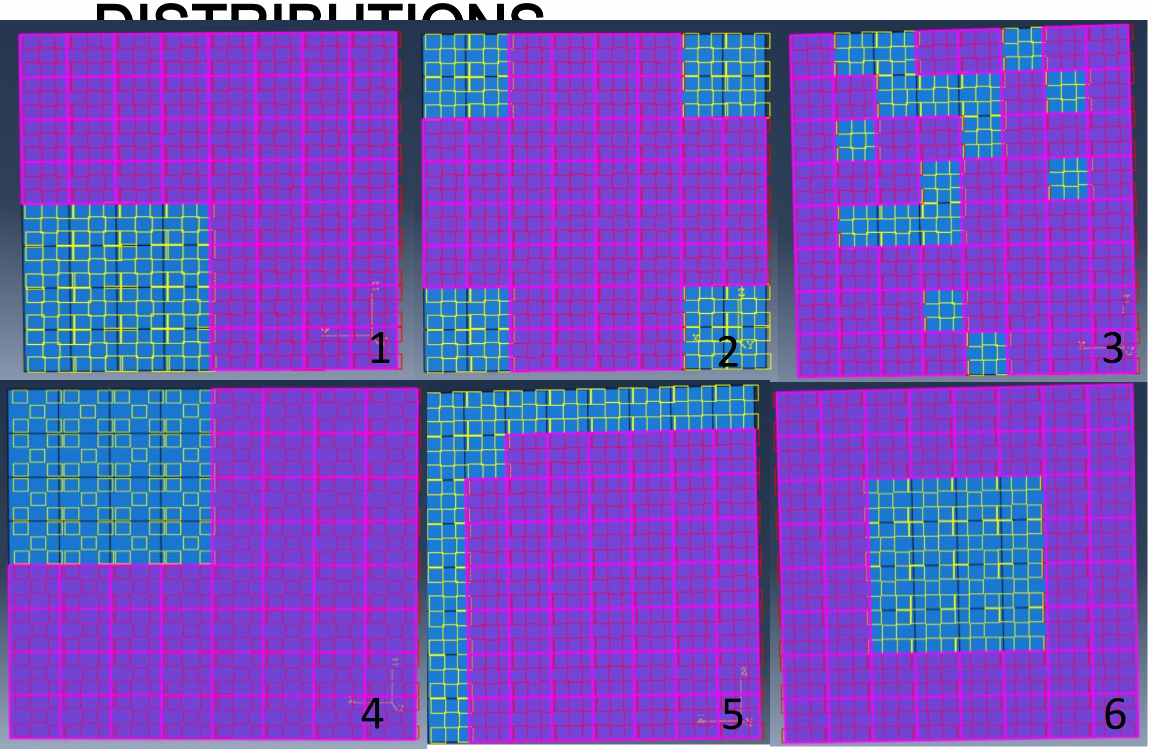


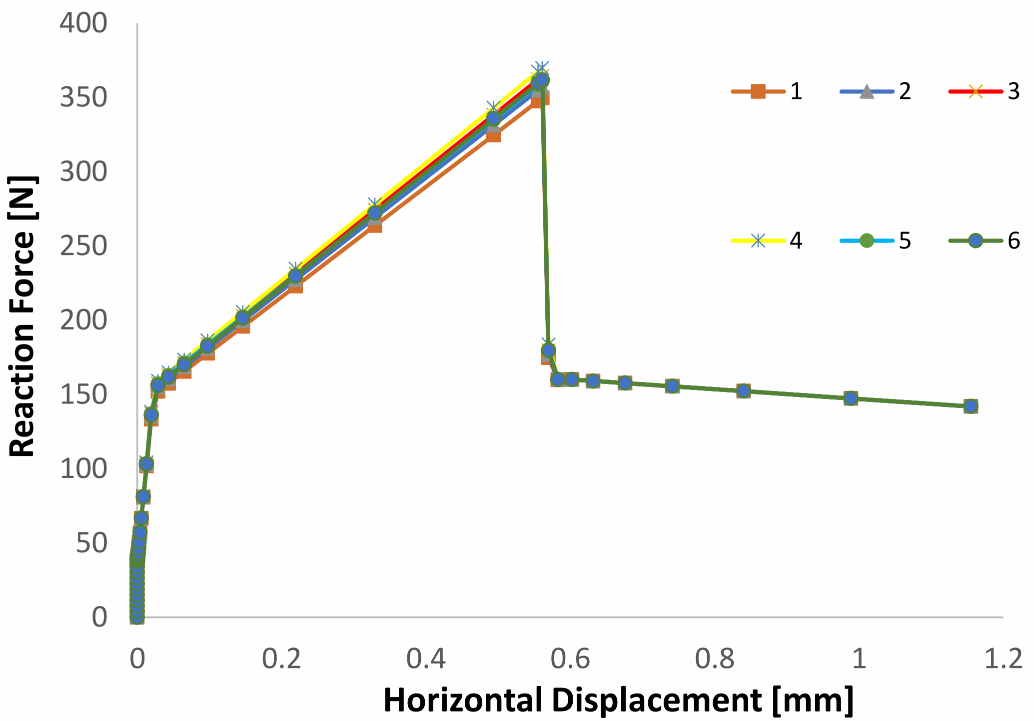
FG4 Core



CALCITE DISTRIBUTION STRATEGIES

DIFFERENT CALCITE DISTRIBUTIONS



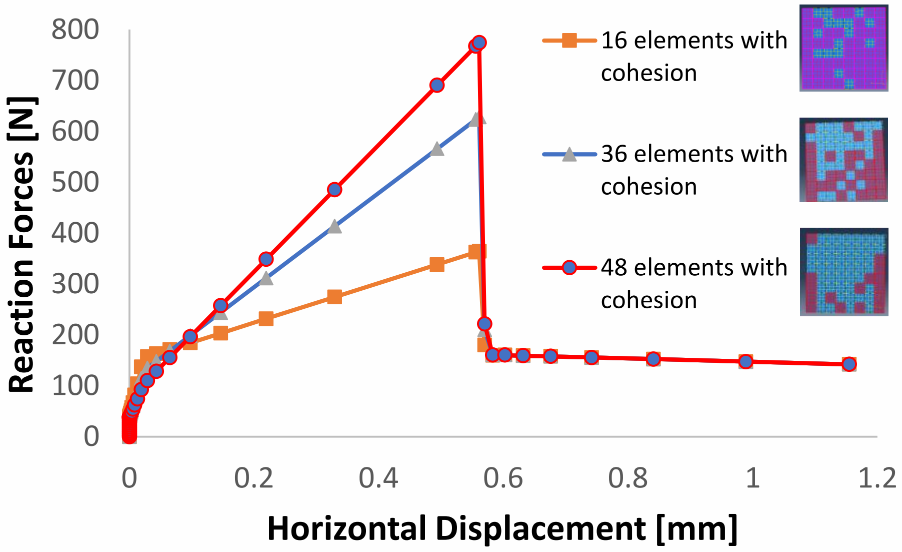


Yellow elements: Cohesive behavior assigned

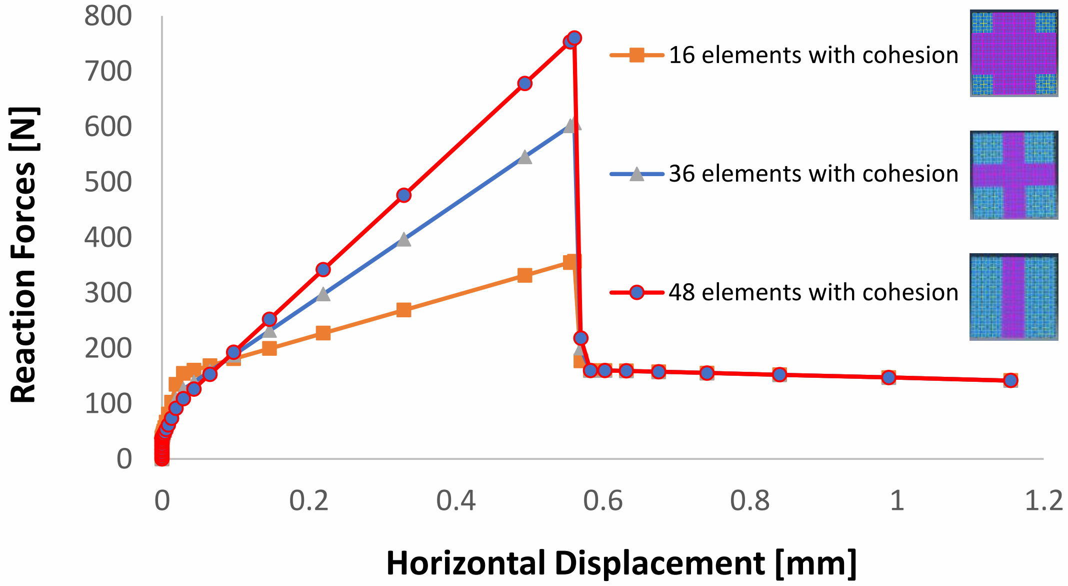
Purple elements: Frictional behavior assigned

DIFFERENT AMOUNT OF CALCITE CONNECTING THE TWO REGIONS

"Random distribution" of calcite models



"Pillars distribution" of calcite models



CONCLUSIONS

- A Finite Elements Model has been developed and calibrated against experimental data, showing that it can predict the behavior of the experimental cores.

- According to the sensitivity analyzes that took place, the model shows that there is relatively little effect on the geometry of the calcite and that strength is largely governed by the size of the contact area.

FUTURE WORK

Design and conduct our own experiments using the MICP repair strategy using concrete specimen in:

- Tensile testing
- Compressive testing
- Shear testing

And compare the obtained results with the ones that the Finite Elements Model provides us with.

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University of Strathclyde Glasgow

cavendish nuclear

TRANSCEND

Thank you

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