Thermal Treatment for HAW Immobilisation

TRANSCEND

C R Scales

April 3rd 2019

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Higher Activity Waste

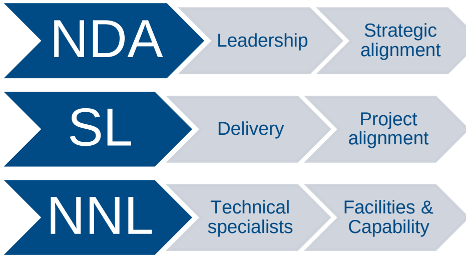
- **LLW**
  - Graphite
- **ILW**
  - **Graphite**
    - Graphite
  - **Solid/immobile**
    - Activated metals
    - Activated other materials
    - Contaminated metals
    - Contaminated other materials
    - Fuel cladding & miscellaneous wastes
    - Fuel element debris
    - Fuels & uranium residues
    - Mixed wastes
    - Plutonium contaminated materials
    - Uranium & thorium contaminated material
    - Wastes being conditioned
  - **Wet/potentially mobile**
    - Contaminated other materials
    - Desiccants & catalysts
    - Flocs
    - Fuel cladding & miscellaneous wastes
    - Inorganic ion exchange materials
    - Mixed wastes
    - Organic ion exchange materials
    - Raffinate
    - Sludges
    - Uranium & thorium contaminated material
- **HLW**
  - High level waste

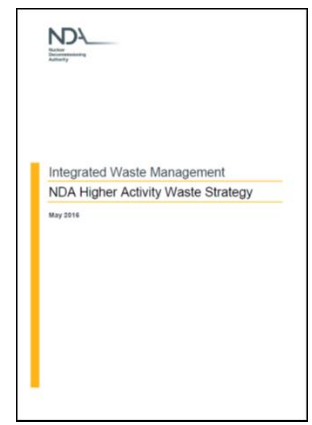
>150,000m^3 future arisings of ILW
75% at Sellafield

Thermal Treatment Integrated Project Team

IPT launched to support the development of thermal treatment technologies to the degree that they can be considered a technically credible option for the treatment of ILW across the NDA estate and across the UK Nuclear industry.

Thermal Technologies		
"Could we?" Technical arguments	Capability of technologies	e.g. Waste analysis, Technology evaluation, Demonstrators
	Alignment with decision calendars	e.g. Understanding waste producer insertion points Touch points and format of deliverables
Implementation		
"Should we?" Business case	Benefits	e.g. Volume reduction, waste product quality
	Affordability	e.g. Understand requirements for industrial application





TTIPT Work Programme

- Robust strategic level DQO process to identify and prioritise target waste streams (independently led)
- Direct technology supply chain engagement against specific requirements
- Stakeholder and Regulator engagement throughout the study
- Direct engagement of other NDA estate and non-NDA estate waste owners
- Active demonstration programme delivered in NNL's Central Laboratory under site licence conditions
- Development of compelling case to change to thermal treatment based on strategic, technical, economic and environmental criteria
- Support key future treatment decisions at Sellafield Ltd
- Identify missions to treat and dispose off-site wastes on an opportunity cost basis

Waste Selection and Information gaps

- DQO process prioritised:
  - SIXEP clino, sand and sludge
  - FGMSP / SPP1 sludge
  - PCM
  - Uranium bearing materials
  - Decommissioning wastes
- Generated long list of issues, knowledge gaps & questions, categorised into those which
    - SL can answer
    - Are best answered by supply chain
- OJEU PIN process used to engage supply chain
- Answers to the PIN questions were objectively assessed by TTIPT, interaction with programme reps
- Allows IPT to answer the question:

"Is thermal treatment a technically viable option for specific waste streams"

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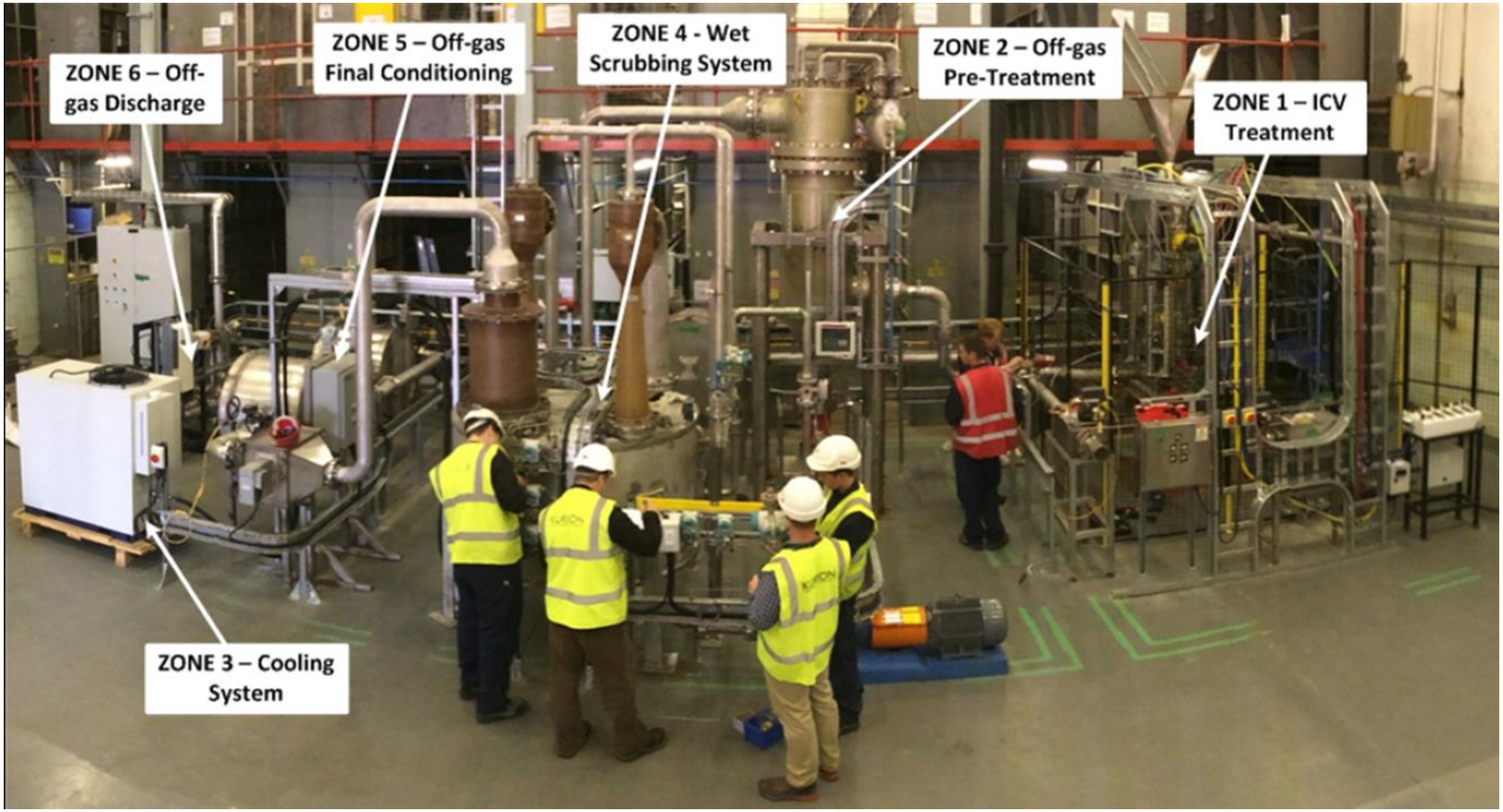
Melt Demonstrations

- Assess thermal treatment as an option for a range of generic waste streams
- Series of 6 pairs of melts: inactive & active
  - Cs-137 & Sr-85 and natural uranium as active feeds
  - All products < 200Bq/g to facilitate disposal as VLLW or LLW
- Use of Geomelt ICV installed in NNL Central Lab.
- Output aimed at making a generic case for thermal treatment
- Any future technology choice for thermal treatment will be made by Sellafield Ltd as part of a commercial process

Geomelt ICV



ZONE 6 – Off-gas Discharge
ZONE 5 – Off-gas Final Conditioning
ZONE 4 - Wet Scrubbing System
ZONE 2 – Off-gas Pre-Treatment
ZONE 1 – ICV Treatment
ZONE 3 – Cooling System

Initial Trials Programme

Melt	Feeds	Waste Stream Analogues
1	Pond skip containing Mg(OH)2 sludge.	Pond skips containing Magnox sludge, opportunity to process skips and sludge is a single step
2	Inorganic ion exchange materials	Sellafield Ion Exchange Effluent Plant (SIXEP) clinoptilolite.
3	Mg(OH)2 sludge (similar to material in Melt 1 without skip containment).	Sludge derived from corroded Magnox cladding also analogous to wastes present at other NDA sites
4	Scrap metal, concrete, soil, wood	Decommissioning waste containing contaminated or activated metals, concrete and other materials, large volume waste streams present at all nuclear sites
5	Uranium "pennies" and "top hats" in cement	Materials containing uranium metal (or another heavy metal), streams present at many sites
6	PVC and other organic materials	Organic soft waste associated with operation and decommissioning, typically plutonium-contaminated materials (PCM) at both Sellafield and AWE

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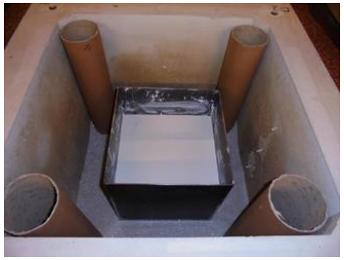
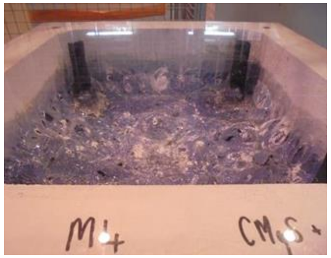
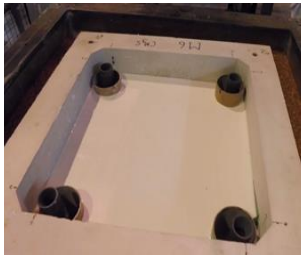
Example Melts Before and After Processing

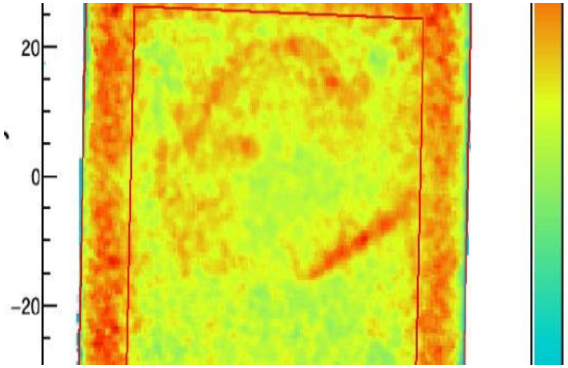








Sampling and Analysis

- Retention of Cs-137 in melted product varied across the melt types related to waste feeds and operational parameters Note: demonstration melts not optimised!
- > 99% retention in vitreous product and sintered metal filter, solids form SMF can be fed back into melt
- Homogeneity of wasteforms good, some residual metallic material from skips and top hats.
- Residual metal from skips and top hats encapsulated in product. Two phase wasteform not necessarily a detriment to disposal.



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Further Melt examples

- Uranium Melt – 11.5kg uranium pennies in skip supports Legacy Ponds treatment

- Surrogate sea dump drums – carried out as part of the EU Theramin programme

Summary

- Successful demonstration on inactive and active surrogates of NDA estate wastes under site license conditions at NNL Central Lab
- Trials have demonstrated the feasibility of thermal treatment for a range of waste feeds across the NDA estate
- Further understanding of melt chemistry and radionuclide retention against varied feeds will be required if systems are to be deployed
- Further melt trials are planned – potentially with real wastes
- DQO process and subsequent supply chain engagement has established thermal treatment as a credible option for sludge and ion exchange feeds (pumpable)
- Similar engagement process is ongoing for PCM
- Choice of technology will depend on factors such as developing appropriate feeds systems and waste packages to meet RWM requirements and reduce storage volumes

Theme 1: Integrated Waste Management
Theme Overview

Claire Corkhill, University of Sheffield

Joe Hriljac, University of Birmingham

3rd April 2019
Bath

1st Annual Meeting

Theme Topics

1. Application of the waste hierarchy and categorisation
2. Novel waste treatment to achieve passive safety and volume reduction including orphan wastes
3. Material decontamination, effluent and gas treatment
4. Process control, product monitoring, prediction and handling
5. Waste package design and optimisation

These came out of the Bristol meeting and align with various strategy documents including the Technology Opportunities from the *NDA Technical Baseline* (Oct 2016) and NNL *Nuclear Industry Guidance for Research in Academic Institutions* (Sep 2017)

Theme Technical Challenges

Research in this theme will focus on underpinning science and engineering in three areas of relevance to **hazard reduction and decommissioning**:

Removal of radionuclides from effluent

Enhanced characterisation and modelling the behaviour of sludges in the Sellafield ponds and silos

Development and evaluation of new wasteforms

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Research Objectives

This theme aims to develop an **enhanced understanding of materials, processes and wasteforms used in hazard reduction and decommissioning**. The ultimate goal is to underpin new technologies for safe and efficient management of legacy waste. The objectives are to:

Develop new materials for the removal of radionuclides from effluent that can be deployed in plant, e.g. to replace or supplement the clinoptilolite in SIXEP at Sellafield, or on site.

Develop first principles modelling techniques on particle-laden flows that can be used to improve their flow, mixing and separation properties.

Transform the understanding and predictive capability of the role of radiation-driven processes in nuclear waste sludges

Develop a better understanding of the production & physical properties of a toolbox of wasteforms including cementitious, vitrified and ceramic materials

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Theme Researchers

4 Postdoctoral Researchers:

University of Birmingham	University of Leeds	Imperial College London	Manchester 1824 – The University of Manchester
3 year PDRA	3 year PDRA	3 year PDRA	2 year PDRA

12 PhD researchers over 7 Universities:

University of Birmingham

University of Strathclyde Glasgow

The University Of Sheffield.

Manchester 1824 – The University of Manchester

University of Leeds

Imperial College London

Sheffield Hallam University

7.5 PhD projects funded by Universities. 4.5 from industry:

NDA – Nuclear Decommissioning Authority

Sellafield Ltd

LLWR Ltd

Work Packages Overview

WP1: New Materials and Methods for Decontamination of Effluent

- x1 PDRA at Birmingham University
- x1 PDRA at Imperial
- x2 PhDs at Birmingham (1 sponsored by Sellafield Ltd.)

WP2: Modelling and Experiments for Understanding Pond and Silo Sludge Behaviour

- x1 PDRA at Leeds University
- x1 PDRA at Manchester University
- x2 PhDs at Leeds, x 1 PhD at Manchester

WP3: Wasteform Development

- x7 PhDs at: Imperial (1); Manchester (1); Sheffield (3); Strathclyde (1); Sheffield Hallam (1) (2 sponsored by NDA, 1 by SL, 0.5 by LLWR)

WP1: Effluent Decontamination

New Ion Exchange Materials and Methods
Supervisors: Joe Hriljac & Phoebe Allan

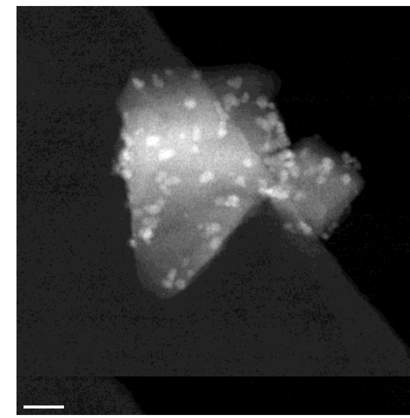
UNIVERSITY OF BIRMINGHAM

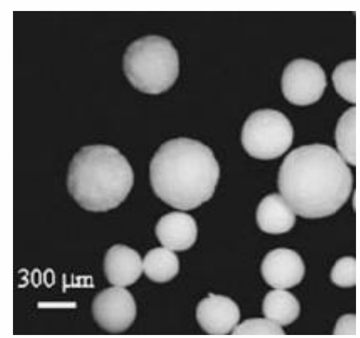
The objectives of the project are to:

(1) continue and expand our work from DISTINCTIVE on developing new ion exchange systems for Cs and Sr removal (e.g. $K_{1.75}[Sn_{0.75}Nb_{0.25}Si_3O_9]\bullet H_2O$) from effluent under realistic legacy pond and decontamination conditions;

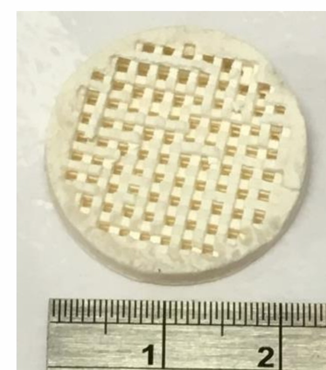
(2) develop our work on producing magnetized inorganic ion exchange materials in collaboration with the NNL and SL who have produced a test rig for magnetic retrieval post use;

(3) investigate new means to deploy ion exchangers such as *via* the production of monoliths or pellets that avoid problems using fine powders in applications.





Sebastien et al., Adv. Funct. Mater. 2008



3 year PDRA: Hiring for 1st July start

WP1: Effluent Decontamination

Imperial College London

Nanotechnology for effluent treatment and RN assay

Supervisors: Luc Vandeperre & Mary Ryan

This project will build on work from the DISTINCTIVE consortium, where it was shown that phosphate functionalised paramagnetic iron oxide particles had a surprisingly large capacity and selectivity for uranium sorption.

The objectives are to:

(1) clarify why the multi-layer structures developed have such a large capacity;
(2) study the feasibility of widening the same approach to other radionuclides of interest;
(3) develop particles that can act in acidic environments; and
(4) investigate the magnetic steering of silica coated paramagnetic particles for concrete repair.

3 year PDRA: Hiring for June / July start

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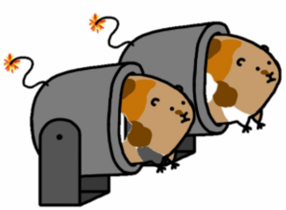
WP1: Effluent Decontamination

1. Birmingham (Joe Hriljac/Phoebe Allen/Mark Read)

In situ ion exchange studies of zeolites. The focus of this project is synchrotron X-ray diffraction experiments coupled with atomistic modelling studies to better understand the ion exchange process in zeolites and other silicates. This will include studies of clinoptilolites from various sources, including that used in SIXEP, to determine how the differences in composition are related to the selectivity. This will be informally co-supervised by Diamond Light Source beamline scientists.

2. Birmingham (Joe Hriljac, Sellafield Ltd. funded)

***Scoping studies of new ion exchange materials for likely Sellafield effluent*.**
Survey of as-received and pre-treated materials to develop an understanding of key factors affecting performance for ion exchange



2 PhD students:

(1) Hannah Parish (see poster!) Start date: 1st October 2018

(2) James Read. Start date: 1st October 2019

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WP2: Pond & Silo Sludge Behaviour

Particle-laden flow characterisation and prediction

Supervisors: Mike Fairweather & Tim Hunter

UNIVERSITY OF LEEDS

The objectives of the research are to:

(1) establish the impact of behavioural modification techniques, implemented using additives, on particle-laden flows to provide opportunities to intervene and improve the flow, mixing and separation properties of wastes during retrieval and POCO activities;

(2) provide recommendations as to the most appropriate techniques for use on plant, including how such interventions can be applied and controlled to positively impact on wastes for disposal;

(3) provide benchmark numerical solutions that can be used to assess the accuracy of design tools that are used in industry;

(4) further develop the acoustic backscatter technique for the in situ characterisation of wastes for deployment on plant.

3 year PDRA: Lee Mortimer. Start date: 1st November 2018

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WP2: Pond & Silo Sludge Behaviour

Radiation induced changes in effluents/sludges

Supervisors: Fred Currell & Aliaksandr Baidak

MANCHESTER 1824
The University of Manchester

The overarching aim of this work is to transform our understanding and predictive capability of the role of radiation-driven processes in nuclear waste sludges (e.g., but not limited to, brucite).

The objectives are to:

(1) determine the physical/chemical changes induced in effluent sludges/slurries found in nuclear waste, including H_2 production and changes in zeta-potential;
(2) determine rates for diffusive transport of hydrogen through sludges;
(3) develop methodology to test remediation of chemical production and change in the zeta potential by the use of additives.

2 year PDRA: Mel O'Leary. Start date: 1st Feb 2019.

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WP2: Pond & Silo Sludge Behaviour

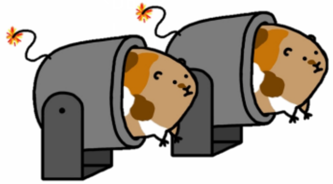
1. Leeds (Mike Fairwea

Simulation of behaviou ***spension waste pipe flows.***
This project will use firs delling techniques that have been developed at Leed ows with extreme accuracy. These will include, for e r additives that reduce agglomeration and/or c n agents to reduce downstream sedimenta

Advertising!

2. Leeds (Tim Hunter &

Advanced characterisa ***polymeric behavioural modifiers.*** The project s s being encountered in suspension transfer via e in two ways – the development of an onli nique for remote characterisation of part nline, and the use of polymer additives to modify slurry characteristics enabling safe and efficient slurry transfer.



2 PhDs: Start date October 2019

WP2: Pond & Silo Sludge Behaviour

3. Manchester (Fred Currell & Jorge Kohanoff (QUB))

Modelling nanoscale radiation physics/chemistry processes in sludges.

The aim of the project is to provide mechanistic support for the work of the Manchester PDRA. A combination of kinetic Monte Carlo radiation transport and (if necessary) atomistic simulation approaches will be used to investigate the energy transfer processes at work when brucite is irradiated in water.

1 PhD: Ella Schafer. Start date: 1st October 2019.

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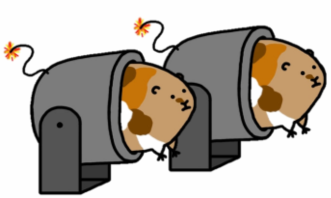
WP3: Wasteform Development

1. Imperial (Luc Vandeperre & Hong Wong)

Durability of magnesium silicate cements made from brucite. Magnesium silicate hydrate (M-S-H) based cements exploit the strength generated when MgO is made to react with a soluble silica source to form a mostly amorphous hydrated gel of magnesium silicate. The project will explore using these as the basis for wasteforms for pond sludges as the brucite can be converted to a M-S-H gel under the right circumstances, focussing on the durability and long-term behaviour.

2. Manchester (Laura Leay & Brian O'Driscoll)

Radiation effects on wasteforms. The project will focus on studying radiation effects on glasses including the use of γ-irradiation, heavy ions and He^{2+} using the particle accelerator at the DCF.



2 PhDs, Start Date: 1st October 2019

(1) Mercedes Baxter Chinery

(2) In application stage

WP3: Wasteform Development

3. Sheffield (Neil Hyatt) / NDA bursary-part support

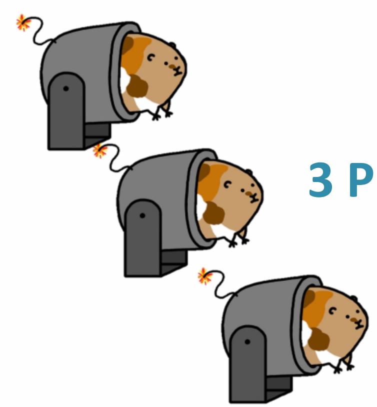
Encapsulation of orphan wastes using magnesium phosphate cements. The focus will be on mercury wastes, building on a previous NDA-sponsored PhD.

4. Strathclyde (Jo Renshaw) / LLWR

Novel approaches to encapsulation of low level waste. The project will study alternatives for the PFA currently in use.

5. Sheffield (Claire Corkhill) / NDA

Characterisation of thermal treatment products. The project will investigate radionuclide speciation and partitioning in thermal products, aiming to understand radiation stability and durability.



3 PhDs

Advertising for Oct 2019

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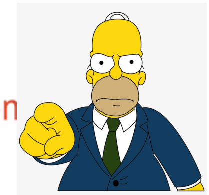
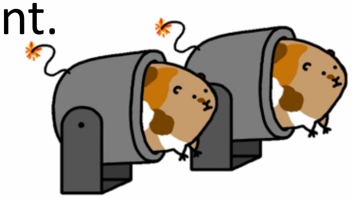
WP3: Wasteform Development



Advertising for Oct 2019

6. Sheffield Hallam (Paul Bingham) / NDA

Process monitoring of thermal treatment of nuclear wastes. A key issue for novel thermal treatment processes (e.g. GeoMelt or plasma treatments) is the production of off-gases and the need to develop better means to deal with these. The primary objective of this project is to develop new, more responsive methods for on-line, real-time monitoring of off-gas emissions. The secondary objective will be to develop new methods of controlling, limiting or inhibiting off-gas emissions of volatile compounds during thermal treatment.



2 PhDs

7. Sheffield (Russell Hand & Neil Hyatt) / Sellafield Ltd

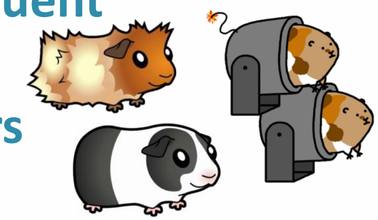
Understanding glass melt chemistry in thermal treatment of nuclear waste. The aim of this project is to develop a better understanding of how glass melt chemistry can be used to maximise waste incorporation while minimising volatilisation. The project will look at behaviours of conventional borosilicate, aluminosilicate (greater capacity for chloride) and titanosilicate (potentially for high soda and molybdate) glasses.

IWM Theme Summary

WP1. New Materials and Methods for Decontamination of Effluent

2 × PDRA (Birmingham, Imperial)
2 × PhD (both at Birmingham)

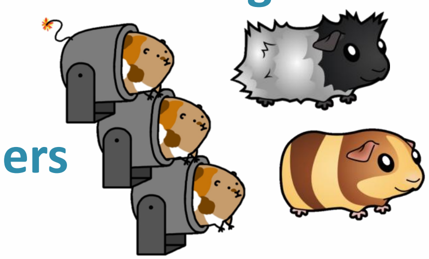
4 researchers



WP2. Modelling and Experiments for Understanding Pond and Silo Sludge Behaviour

2 × PDRA (Leeds, Manchester)
3 × PhD (2 Leeds, 1 Manchester)

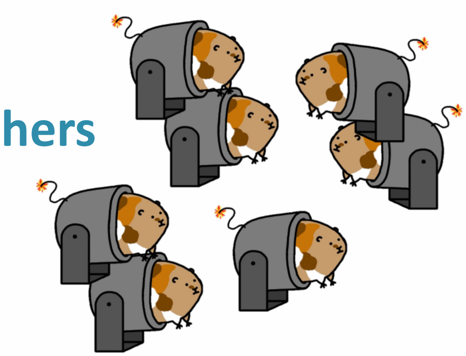
5 researchers



WP3. Wasteform Development

7 × PhD (Imperial, Manchester, 2 Sheffield, Strathclyde, Sheffield Hallam)

7 researchers



EPSRC – 11 PDRA Years
University studentships – 7.5
Industry studentship – 4.5

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Thank you

j.a.hriljac@bham.ac.uk

Transformative Science and Engineering for Nuclear Decommissioning

Particle-laden Flow

Characterisation and Prediction

Lee Mortimer, University of Leeds

TRANSCEND ANNUAL MEETING 2019

3rd April 2019
Bath, England

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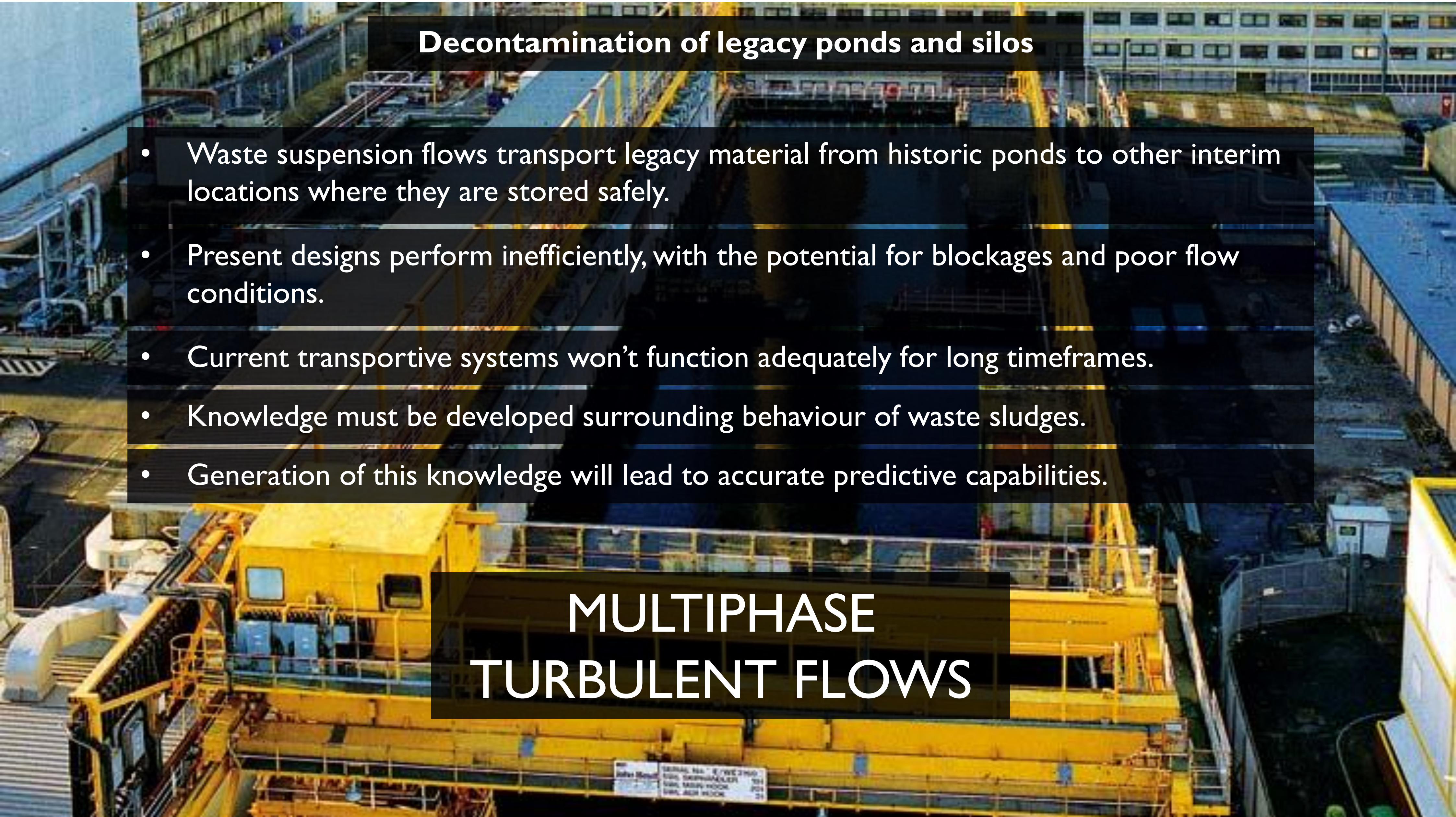
Transformative Science and Engineering for Nuclear Decommissioning

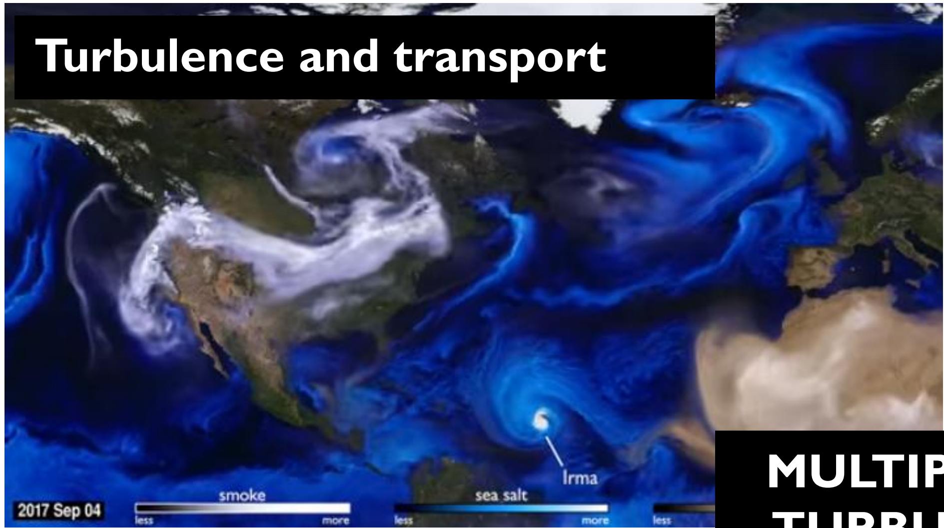


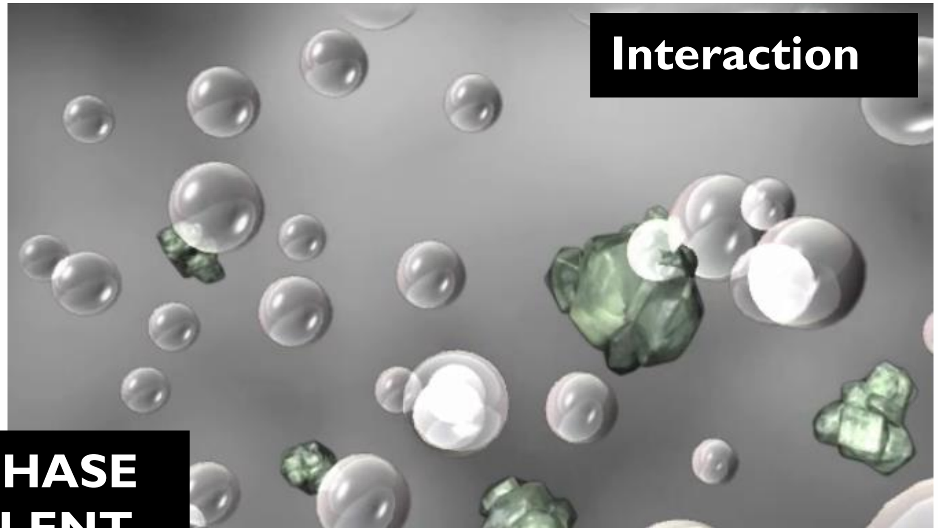
Decontamination of legacy ponds and silos

- Waste suspension flows transport legacy material from historic ponds to other interim locations where they are stored safely.
- Present designs perform inefficiently, with the potential for blockages and poor flow conditions.
- Current transportive systems won’t function adequately for long timeframes.
- Knowledge must be developed surrounding behaviour of waste sludges.
- Generation of this knowledge will lead to accurate predictive capabilities.

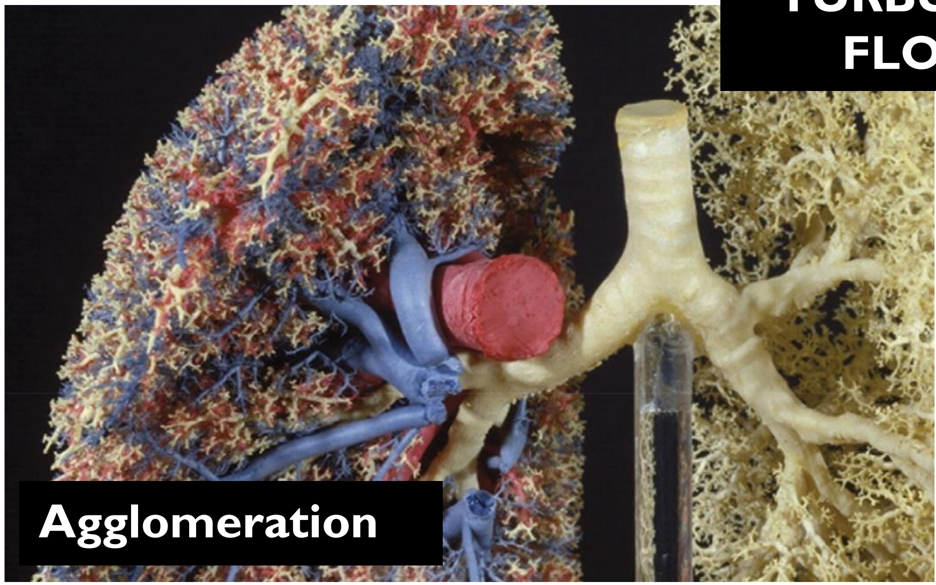
MULTIPHASE TURBULENT FLOWS

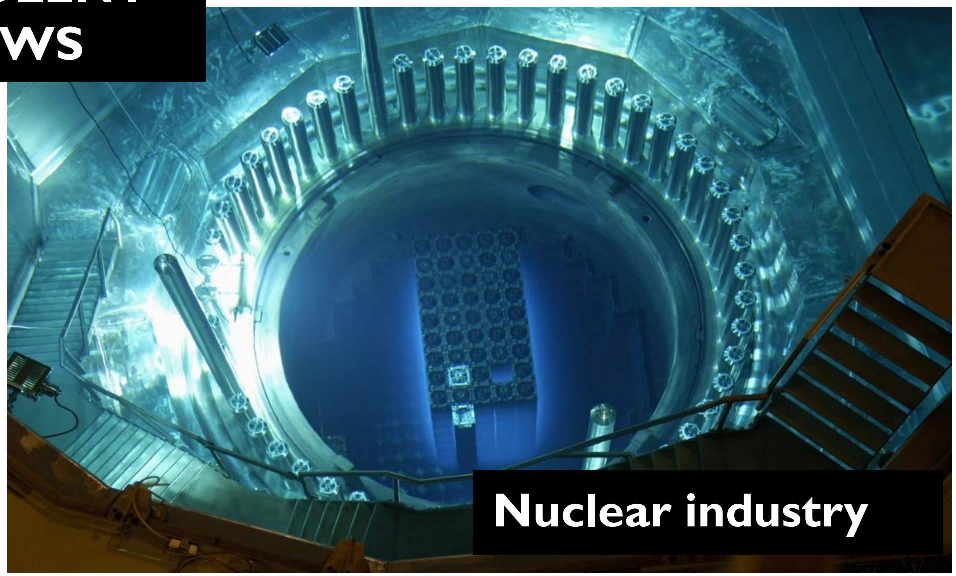
Transformative Science and Engineering for Nuclear Decommissioning





MULTIPHASE TURBULENT FLOWS





Multiphase fluid simulation at Leeds

- Range of technical tools for both the fluid and particle phases

FLUID PHASE

Direct numerical simulation (DNS):

- All turbulent length and timescales are resolved.
- Provides most accurate representation of a turbulent system.
- Computationally intensive but code is parallelised.

PARTICLE PHASE

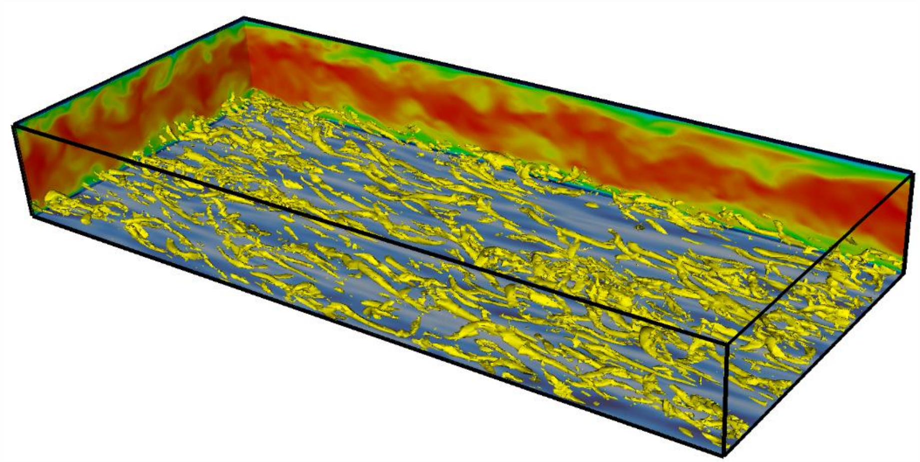
Lagrangian particle tracking (LPT):

- Particles modelled as point spheres.
- Useful for large ensembles of particles.

Immersed boundaries method (IBM):

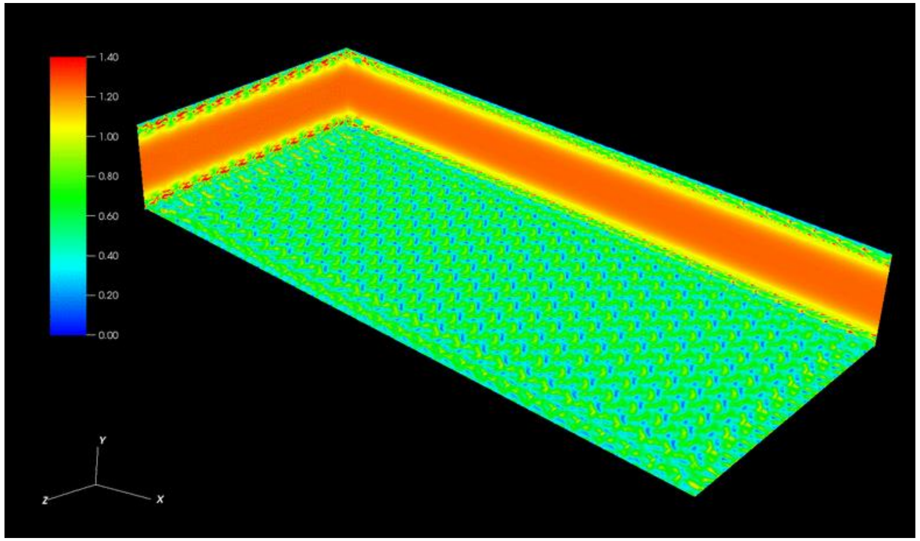
- High fidelity resolution of particle-fluid boundary.
- Limited by particle number

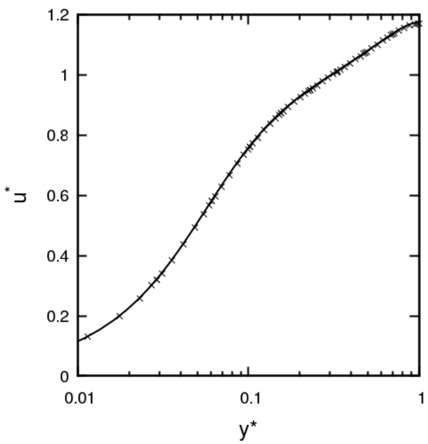
Single phase turbulent channel flow at Reτ = 180

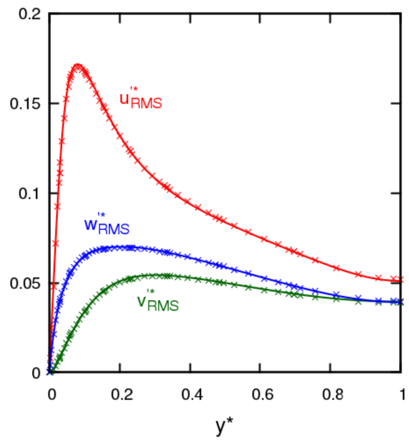


NEK5000 SEM SOLVER

(27 x 18 x 23) 7th order spectral elements







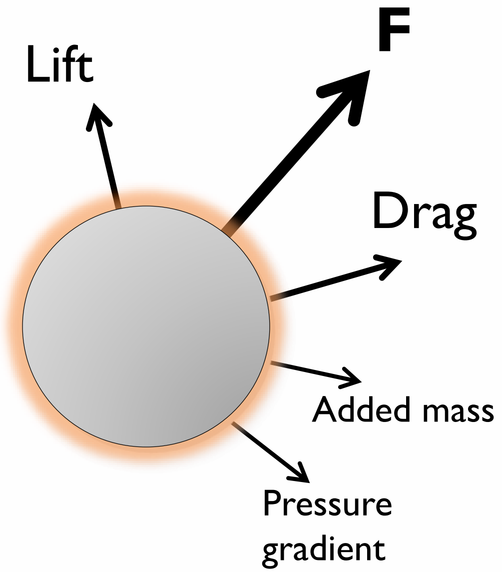
Crosses: Present work

Solid line: Vreman and Kuerten (2014) [1]

[1] - Comparison of direct numerical simulation databases of turbulent channel flow at Re_τ = 180. *A.W. Vreman and J.G.M. Kuerten, Phys. Fluids* ***26****, 015102 (2014).*

Lagrangian particle tracking

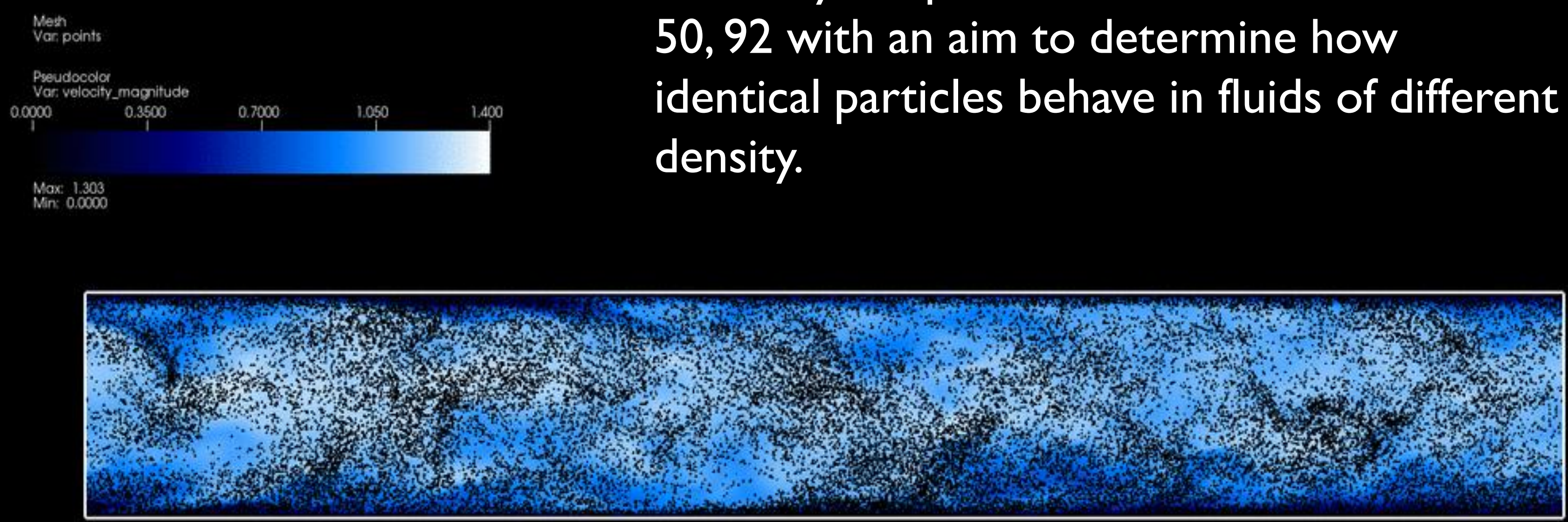
- Particle dynamic properties updated each timestep due to inertial effects of the surrounding flow field.
- Resultant force is the summation of individual forces acting on the particle.
- Runge-Kutta 4th order integration algorithm run concurrently with fluid solver.
- Momentum coupling using particle source in cell (PSIC) method (two-way coupling).
- Elastic hard-sphere collision model (four-way coupling).
- Deterministic agglomeration model.



$$\frac{\partial u_P^*}{\partial t^*} = \underbrace{\frac{3C_D|\mathbf{u}_s^*|}{4d_p^*\rho_P^*}\mathbf{u}_s^*}_{Drag} + \underbrace{\mathbf{g}^*(1-\rho^*)}_{Gravity/Buoyancy} + \underbrace{\frac{3}{4}\frac{C_L}{\rho_P^*}(\mathbf{u}_s^* \times \boldsymbol{\omega}_F^*)}_{Lift} + \underbrace{\frac{1}{2\rho_P^*}\frac{D\mathbf{u}_F^*}{Dt^*}}_{Virtual\ Mass} + \underbrace{\frac{1}{\rho_P^*}\frac{D\mathbf{u}_F^*}{Dt^*}}_{Pressure\ Gradient}$$

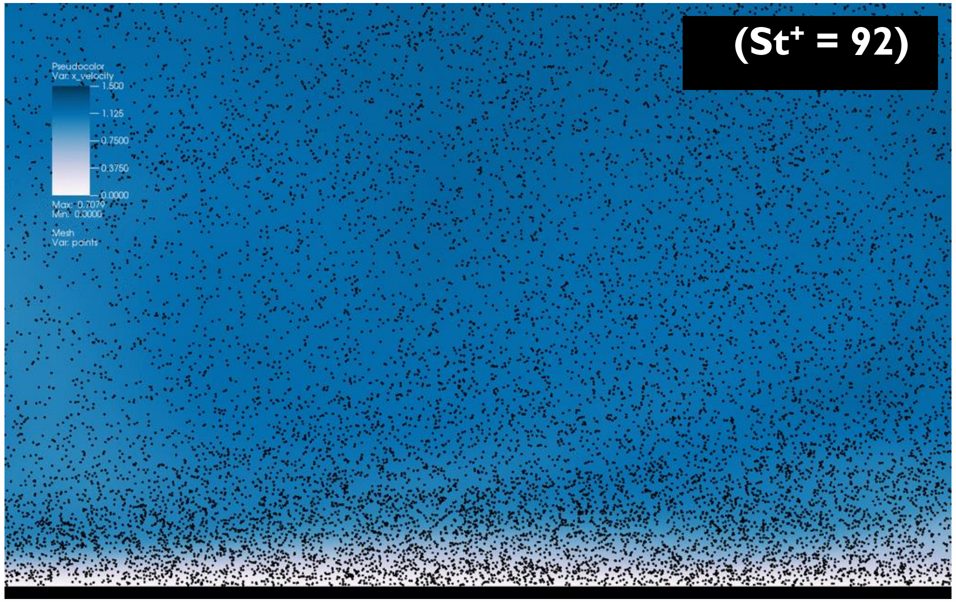
Dilute transportive flows

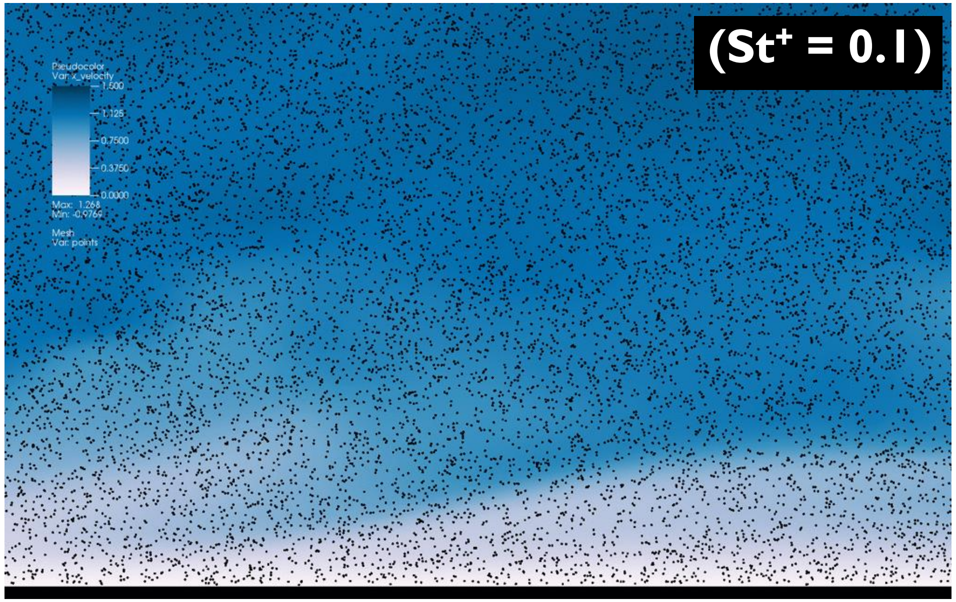
- One-way coupled simulations at St^{+} = 0.1, 50, 92 with an aim to determine how identical particles behave in fluids of different density.



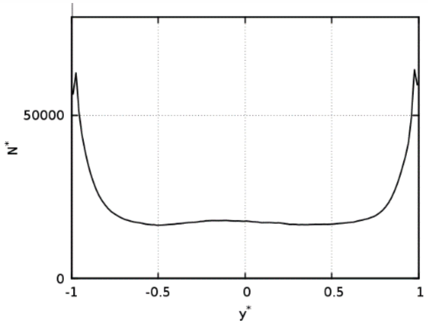
- Stokes numbers beyond range studied in previous work were considered.
- Variation of density ratio rather than diameter was studied. (Carrier fluid)
- Explanation for near-wall increased turbulence intensities based on rapid inter-layer migration due to interaction with coherent turbulence structures.

Effect of changing density ratio on particle dynamics

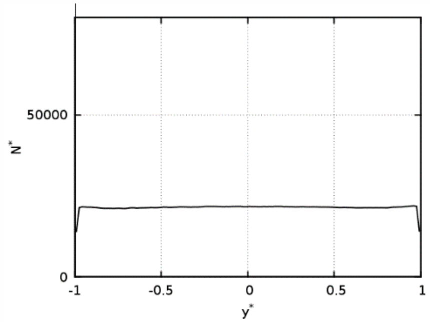




- Increased particle concentration near the wall.
- Particles near the wall seem to have a slow and fast regime?

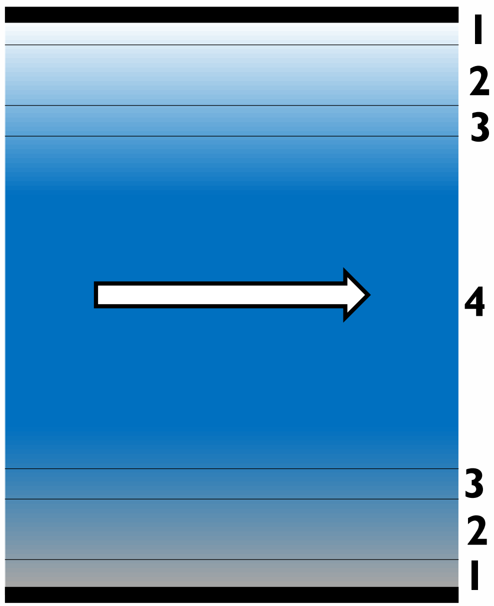


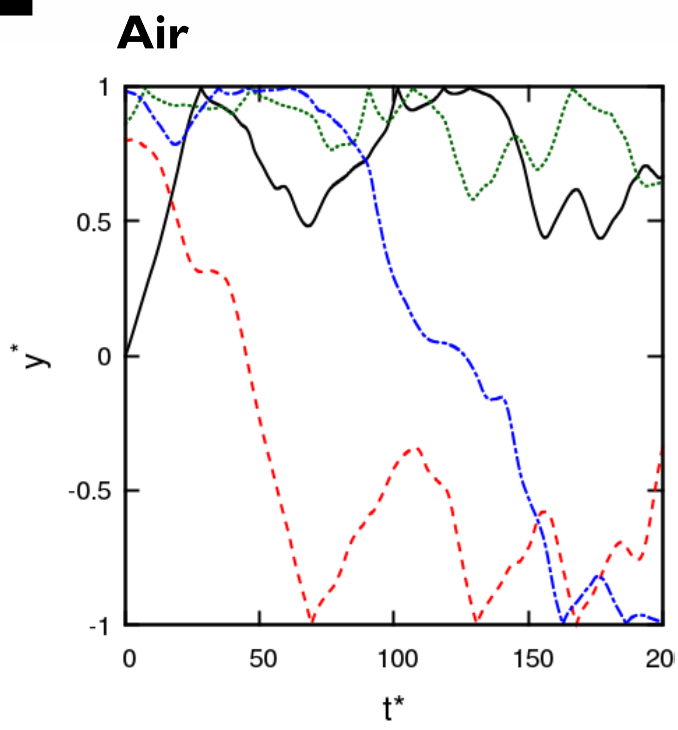
- Particle concentration is homogenous across the channel
- Particle motion both towards and away from wall.

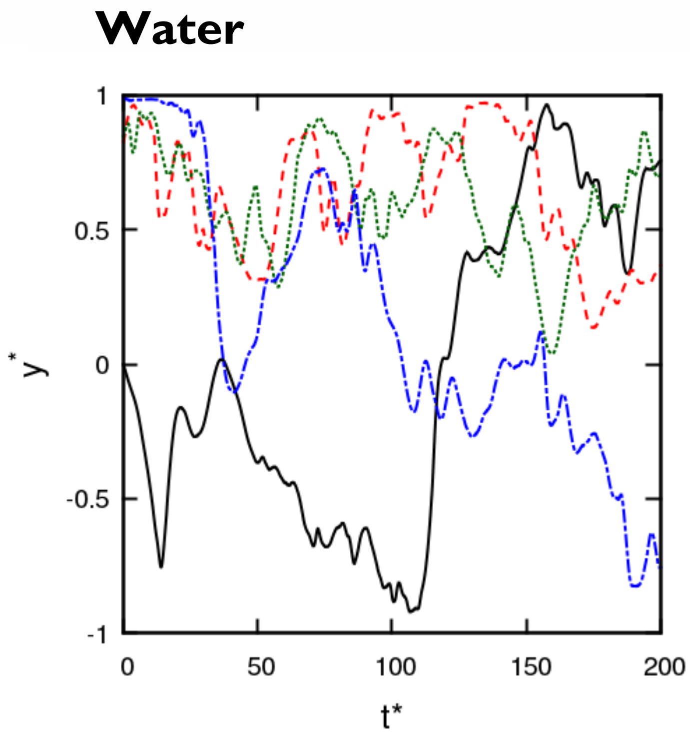


Particle trajectories

Regions:





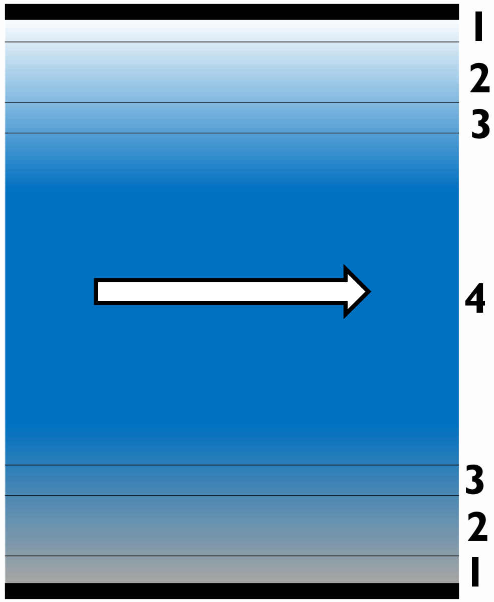


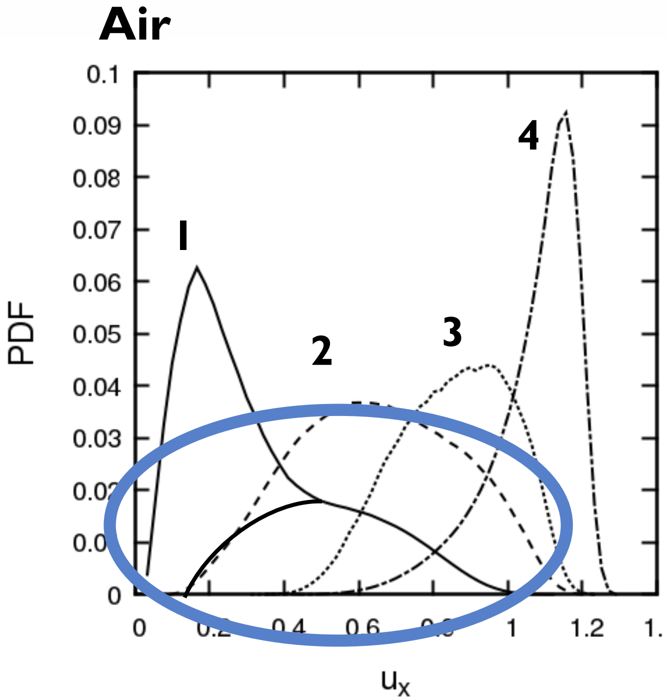
Layer
1. Viscous sublayer
2. Buffer layer
3. Log-law region
4. Bulk flow region

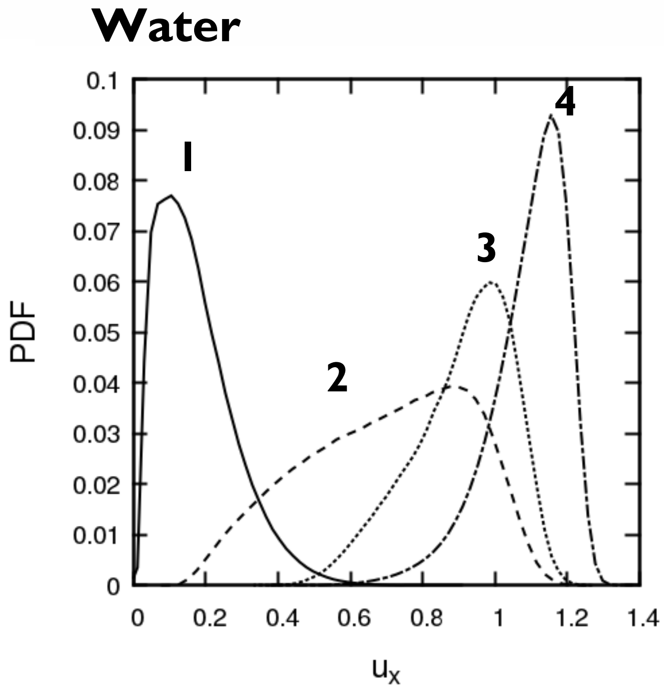
Particles with high density-ratio demonstrate more frequent wall-collisions and smoother trajectories

Mean particle streamwise velocity PDFs

Regions:



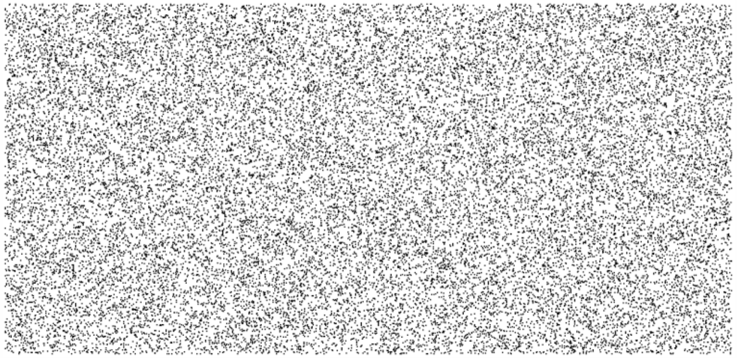




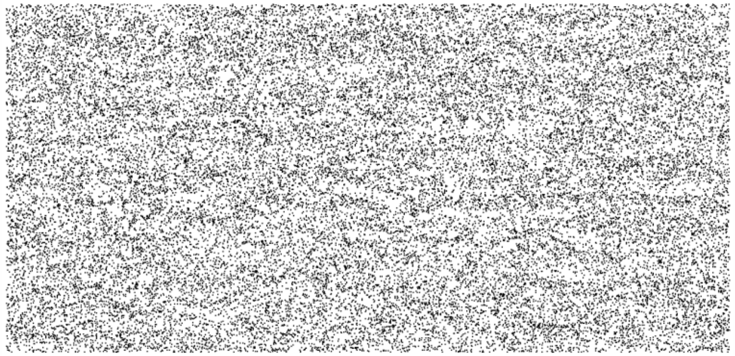
Layer
1. Viscous sublayer
2. Buffer layer
3. Log-law region
4. Bulk flow region

Particles with high density-ratio have two regimes of streamwise velocity distributions

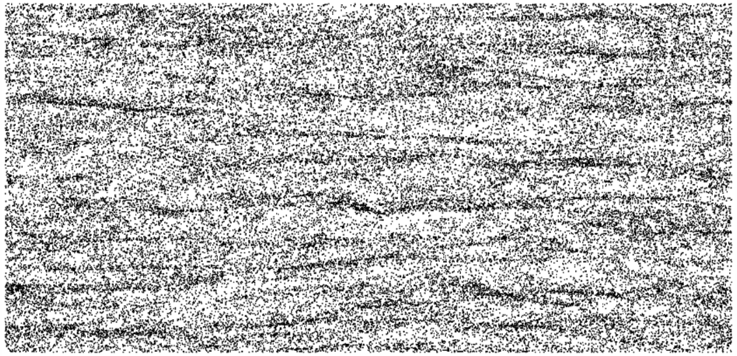
St = 0.1



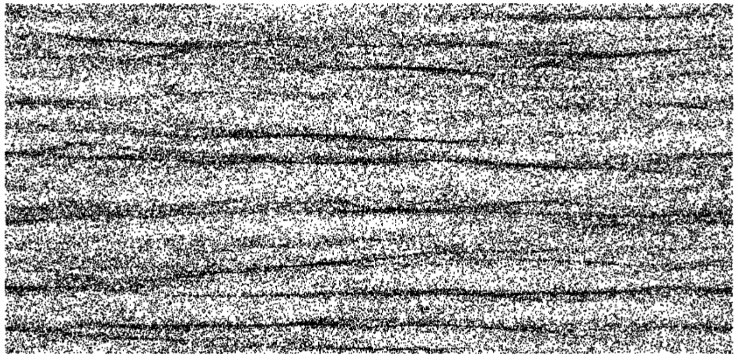
St = 1



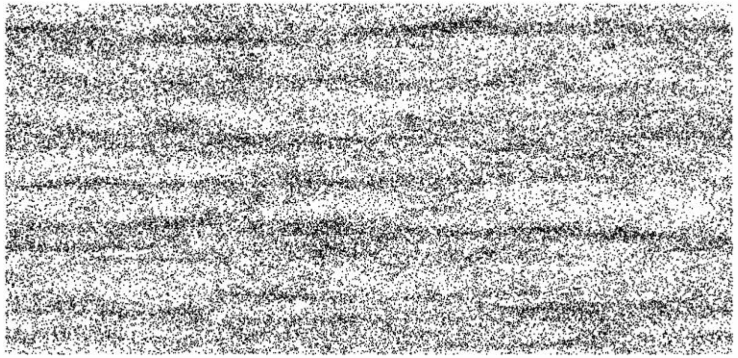
St = 5



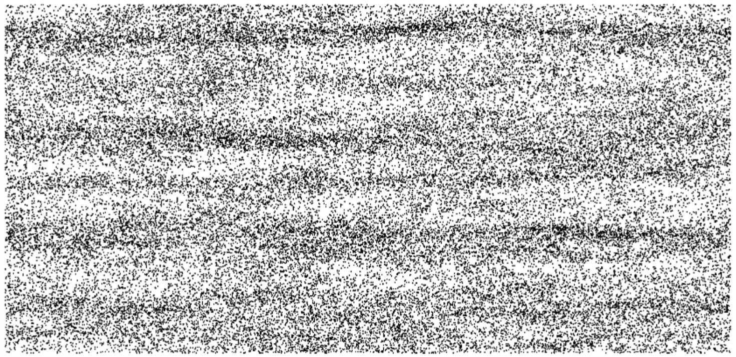
St = 25



St = 50

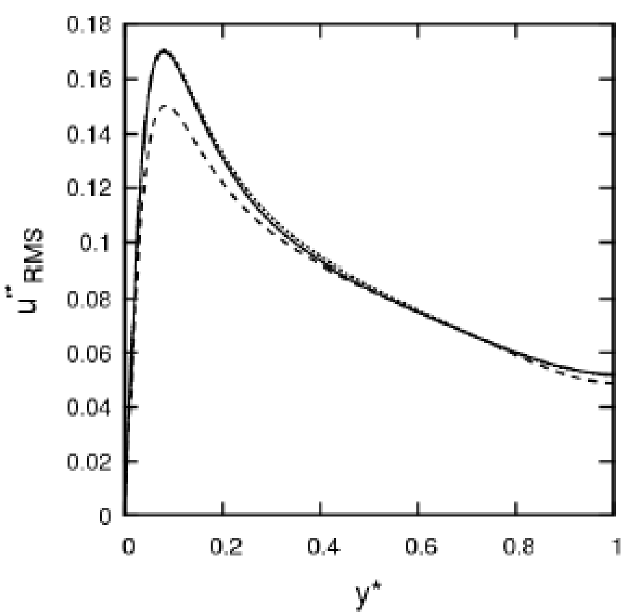


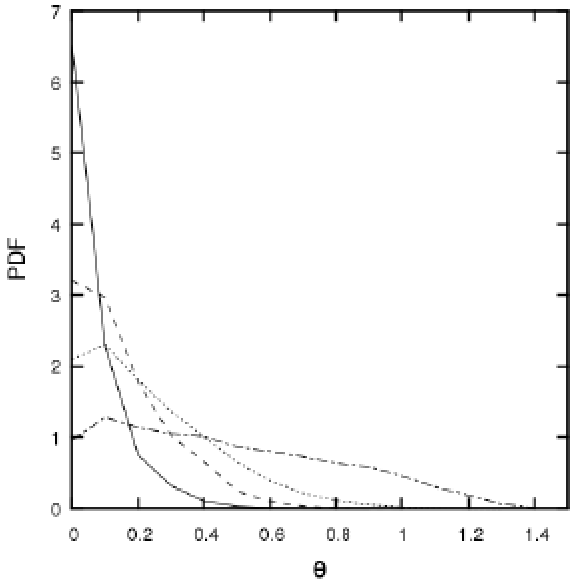
St = 92

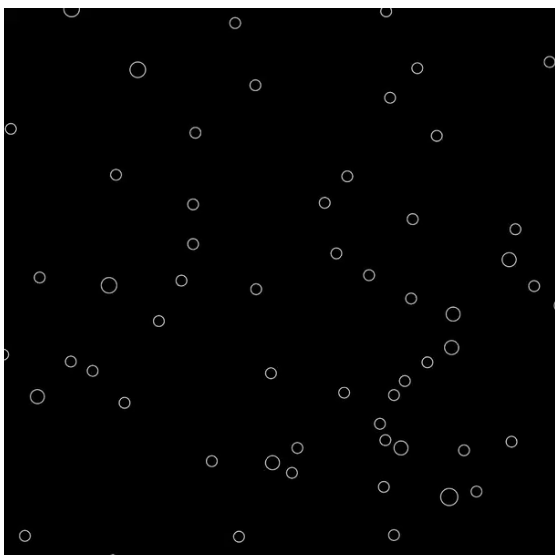


Turbulence modulation, collisions and agglomeration

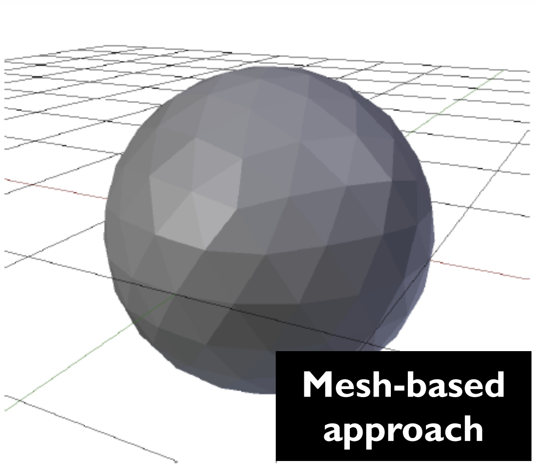
- Particles at high density ratio attenuate the turbulence field.
- Particles at high density ratio collide with greater angles, especially near the wall.
- Particles at low Stokes number undergo agglomeration in regions of high concentration



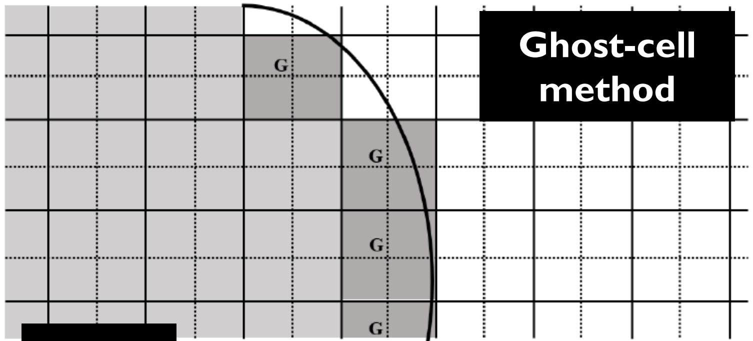




Immersed boundary method for simulation of binary particle interaction



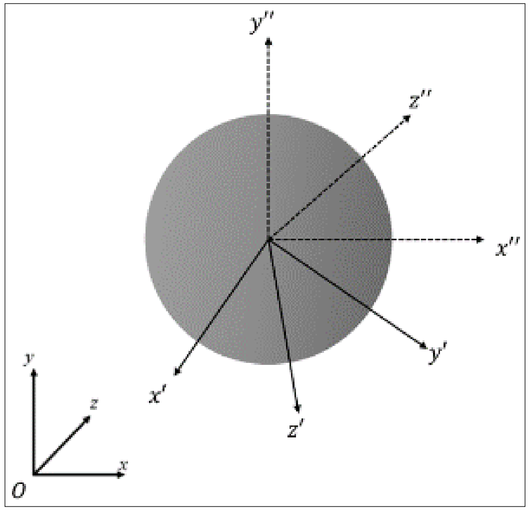
Mesh-based approach



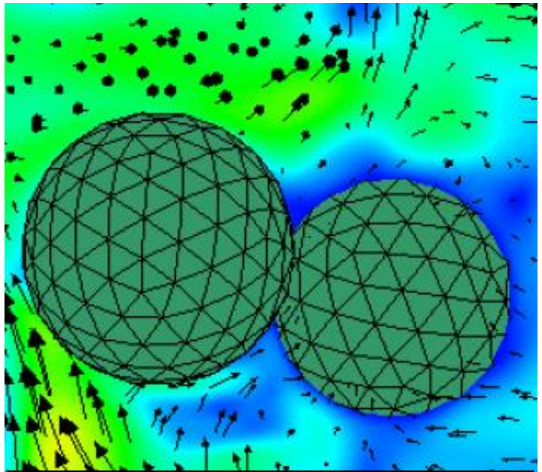
Ghost-cell method

Forces

$$F_j = \sum_{f=1}^{N_f} \left(\underbrace{-P^f \delta_{ij}}_{\text{Pressure}} + \underbrace{\tau_{ij}^f}_{\text{Viscous}} \right) n_j^f \, dS^f$$



Particle rotation



Particle-fluid interaction

DLVO

$$f_{kl}^{VDV} = \frac{-Ar_P}{12H_{kl}^2},$$

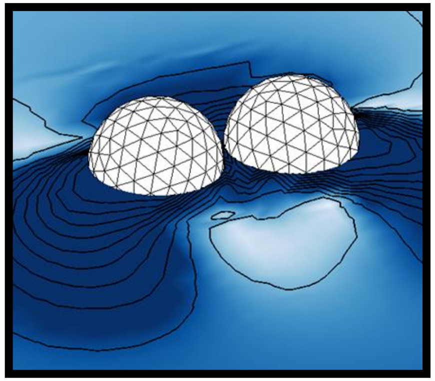
Attractive van der Waals

$$f_{kl}^{EDL} = \frac{64\pi r_P n k_B T_F \Theta^2 e^{-\kappa H_{kl}}}{\kappa}.$$

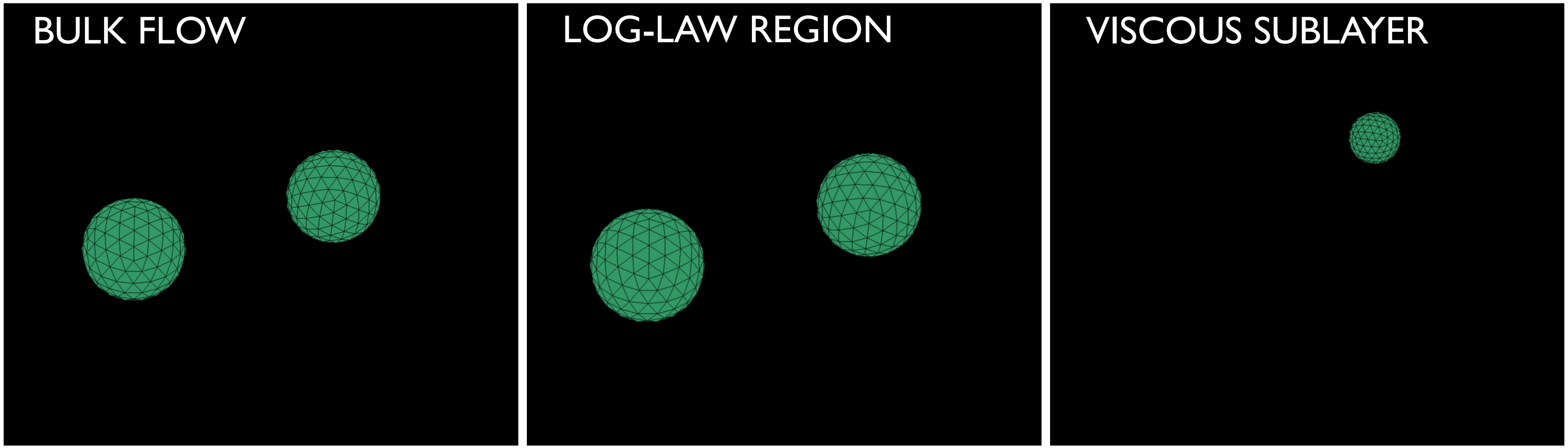
Repulsive electric double layer

Immersed boundary method for simulation of binary particle interaction

- DLVO properties match those of calcite in water. A simulant for nuclear waste material.
- Particles released with velocities matching pre-collision data from LPT.
- Snapshots of interactions animated below.

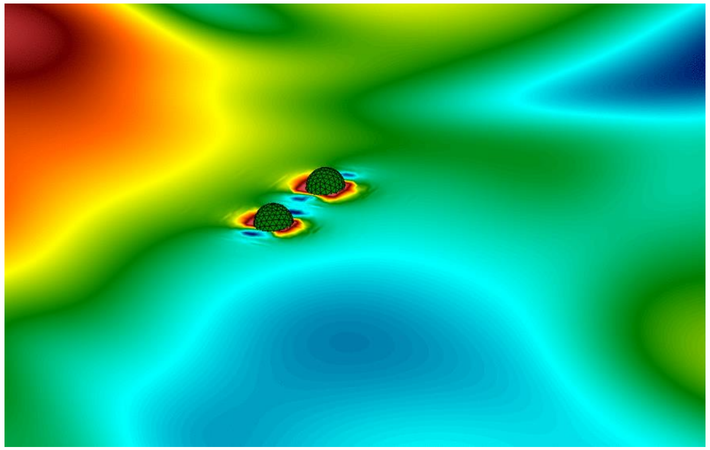


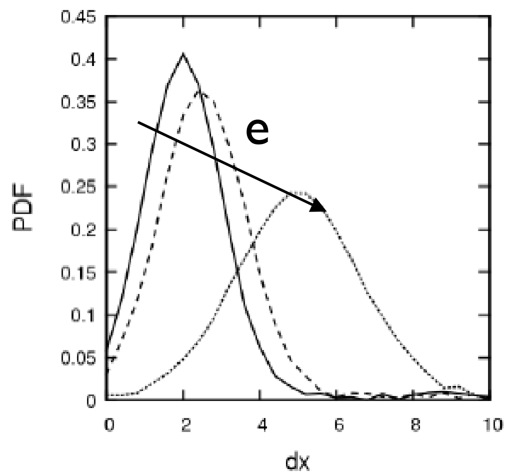
INCREASING Re_λ



Behavioural modification techniques using IBM

- DNS-IBM simulations aimed to probe deeper into the fundamental dynamics (physical and chemical) associated with particle-particle agglomeration on a level not studied before.
- Four regions of homogeneous isotropic turbulence within which pairs of particles were injected with collision properties similar to those present in channel flow.
- Sensitivity studies on Hamaker constant, **coefficient of restitution** and electric double layer potential.





Mean particle displacement PDF sampled over ensemble of 40 collision events.

Project direction

- Investigate other controllable parameters using the IBM such as ionic strength and temperature.
- Implement model for addition of polymer additives or flocculation agents to control aggregation and interaction properties of the particle-laden flow.
- Investigate interaction of non-spherical particles using IBM and LPT.
- Extend LPT simulations to application-based geometries such as ducts and pipes.
- Investigate deposition in wall-bounded flows.
- More complex geometries such as pipes with bends or beds.
- Polydispersed flows with particle size distributions commonly found in slurry flows.

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Thank you

Lee Mortimer
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Ongoing development of heavy ion irradiation experiments on glassy waste forms

Laura Leay, The University of Manchester's Dalton Cumbrian Facility

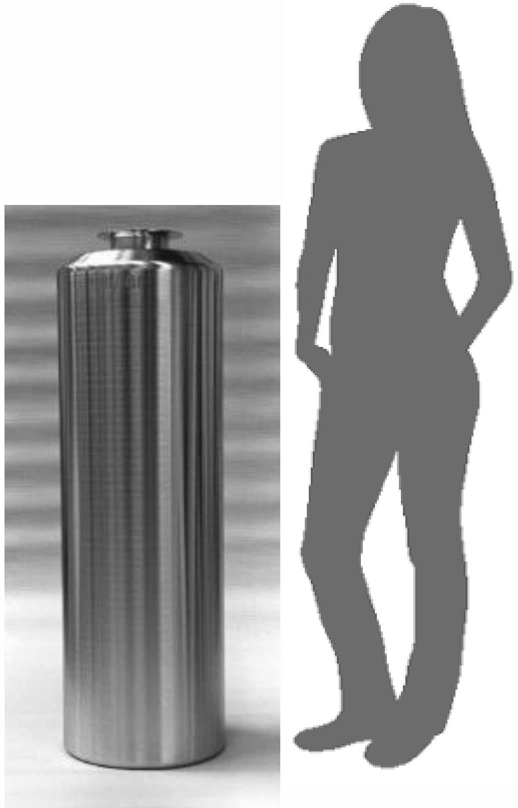
2019 Annual Meeting

3rd April 2019
Bath

Energy
For a Low Carbon Future

Background

- Vitrification is the UK's preferred method for immobilising High Level Waste
    - Original development in 1980's
    - More recent development of a new glass formulation



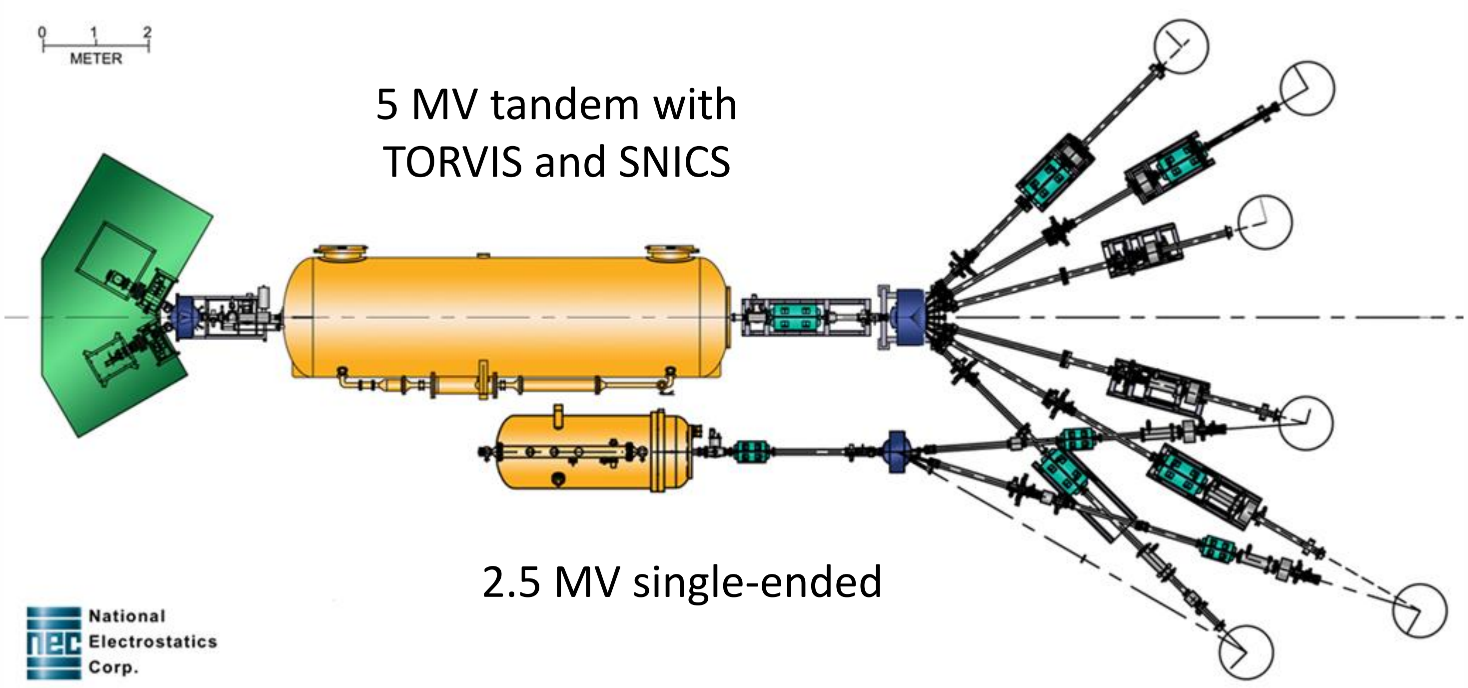
Current status

- Ongoing work:
  - Developing a fundamental understanding of heavy ion irradiation of glass

- Forthcoming work:
  - How does the degree of crystallinity in a glass-ceramic affect radiation tolerance?

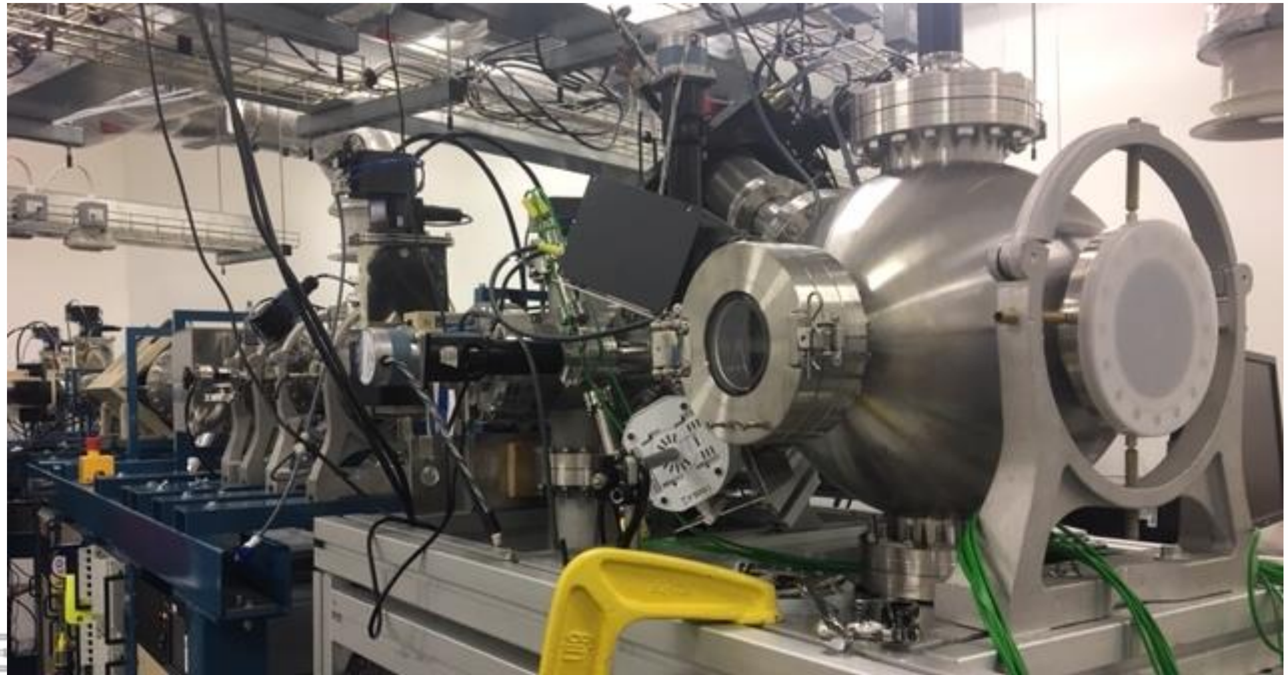
Experimental set-up

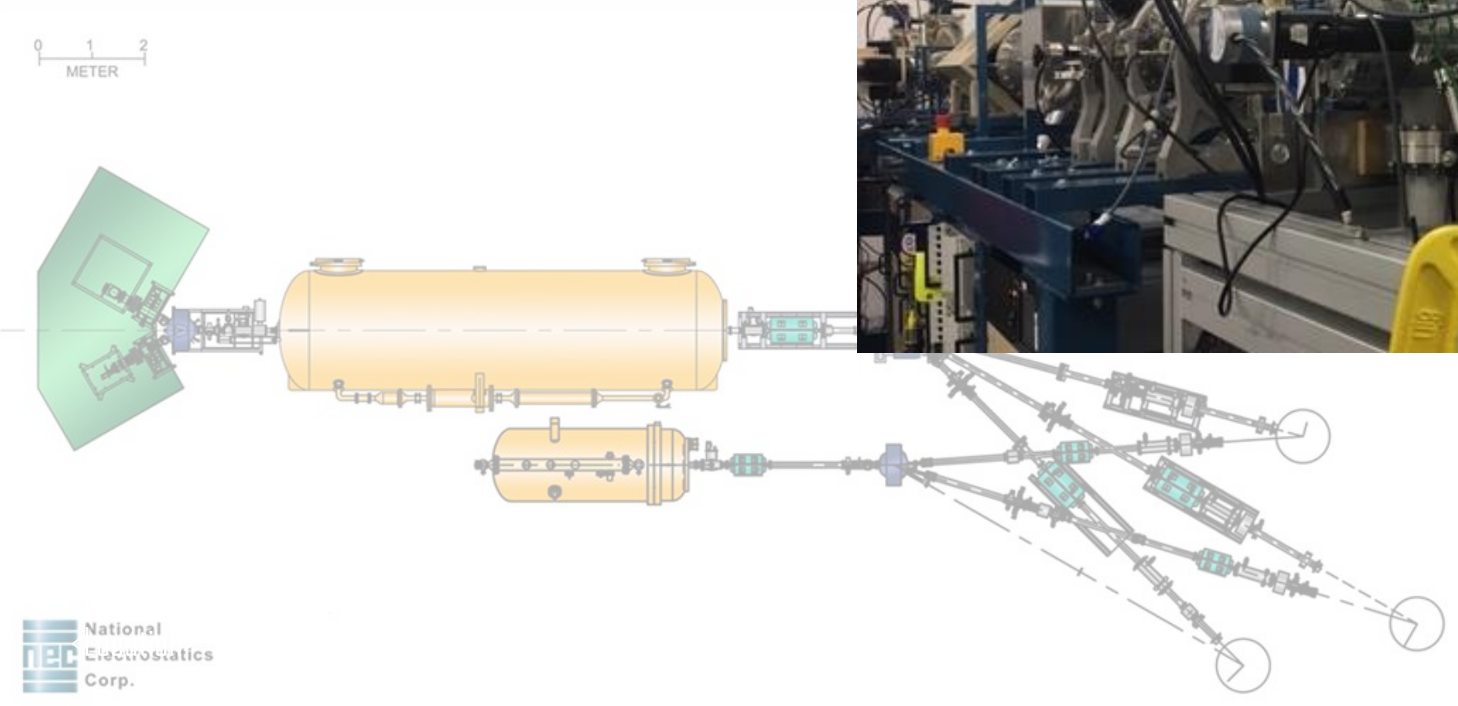
- Heavy ion irradiation



Experimental set-up

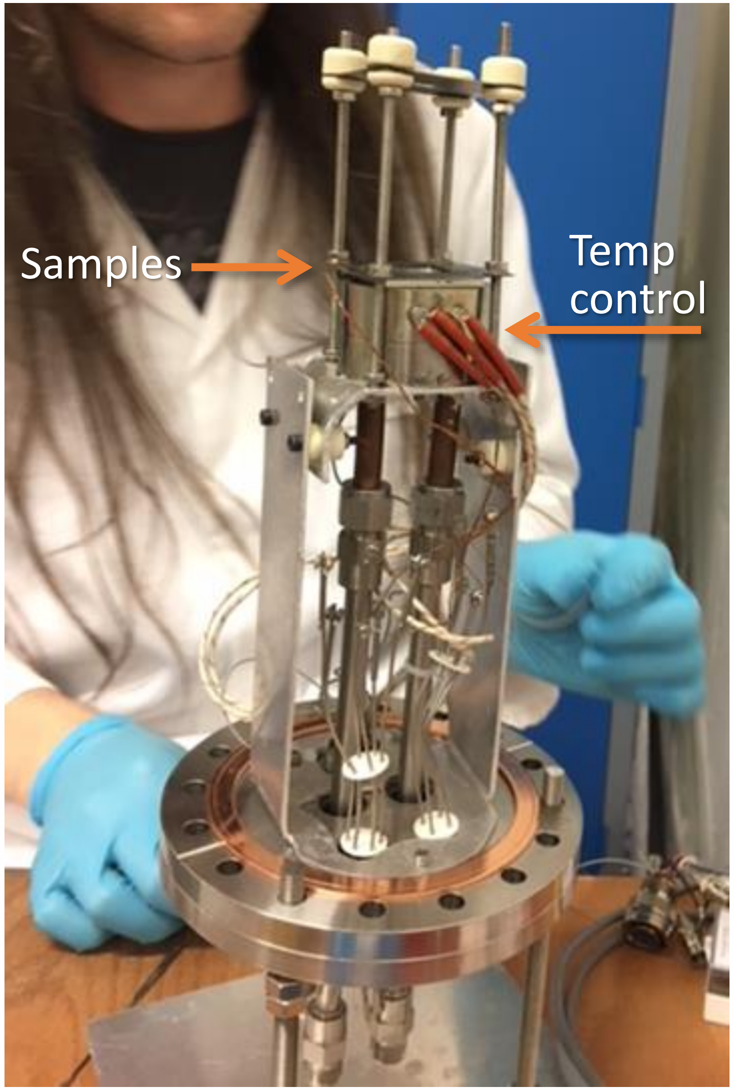
- Heavy ion irradiation





Experimental set-up

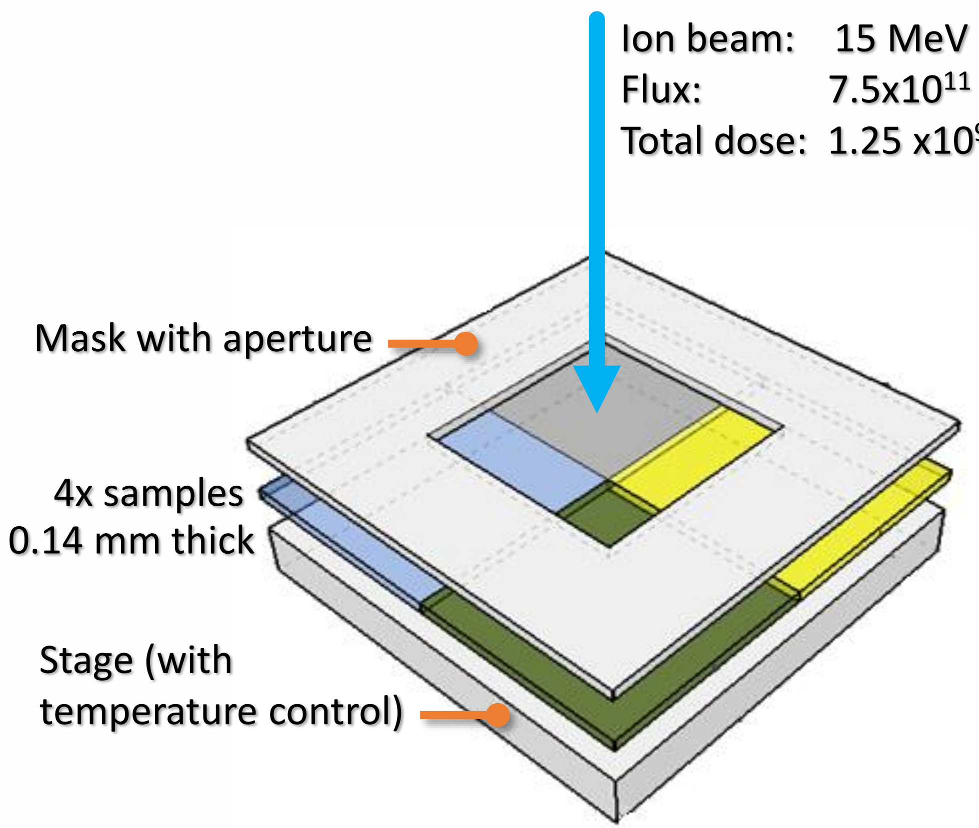
- Heavy ion irradiation

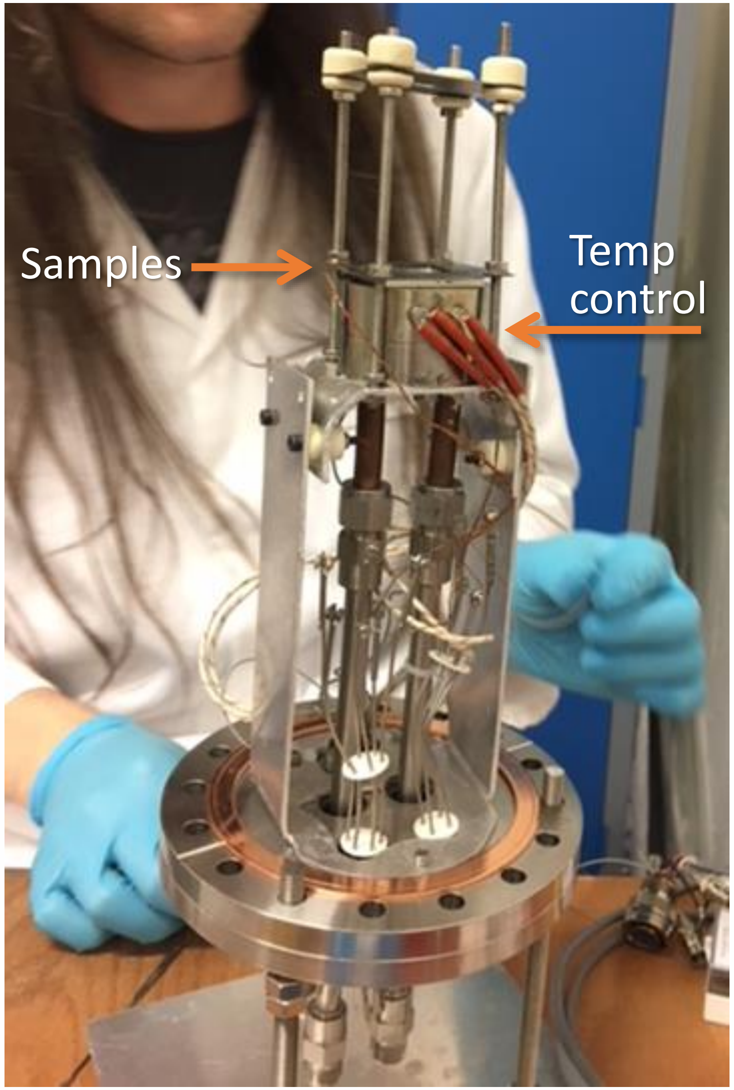


Experimental set-up

- Heavy ion irradiation

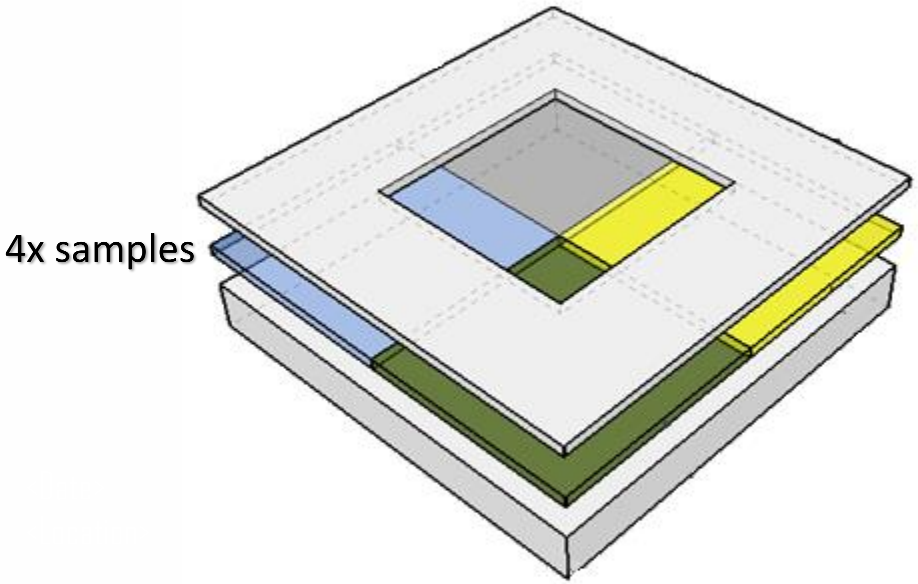
Ion beam: 15 MeV Ni
Flux: 7.5×10^{11} ions/cm^2/sec
Total dose: 1.25×10^9 Gy per sample

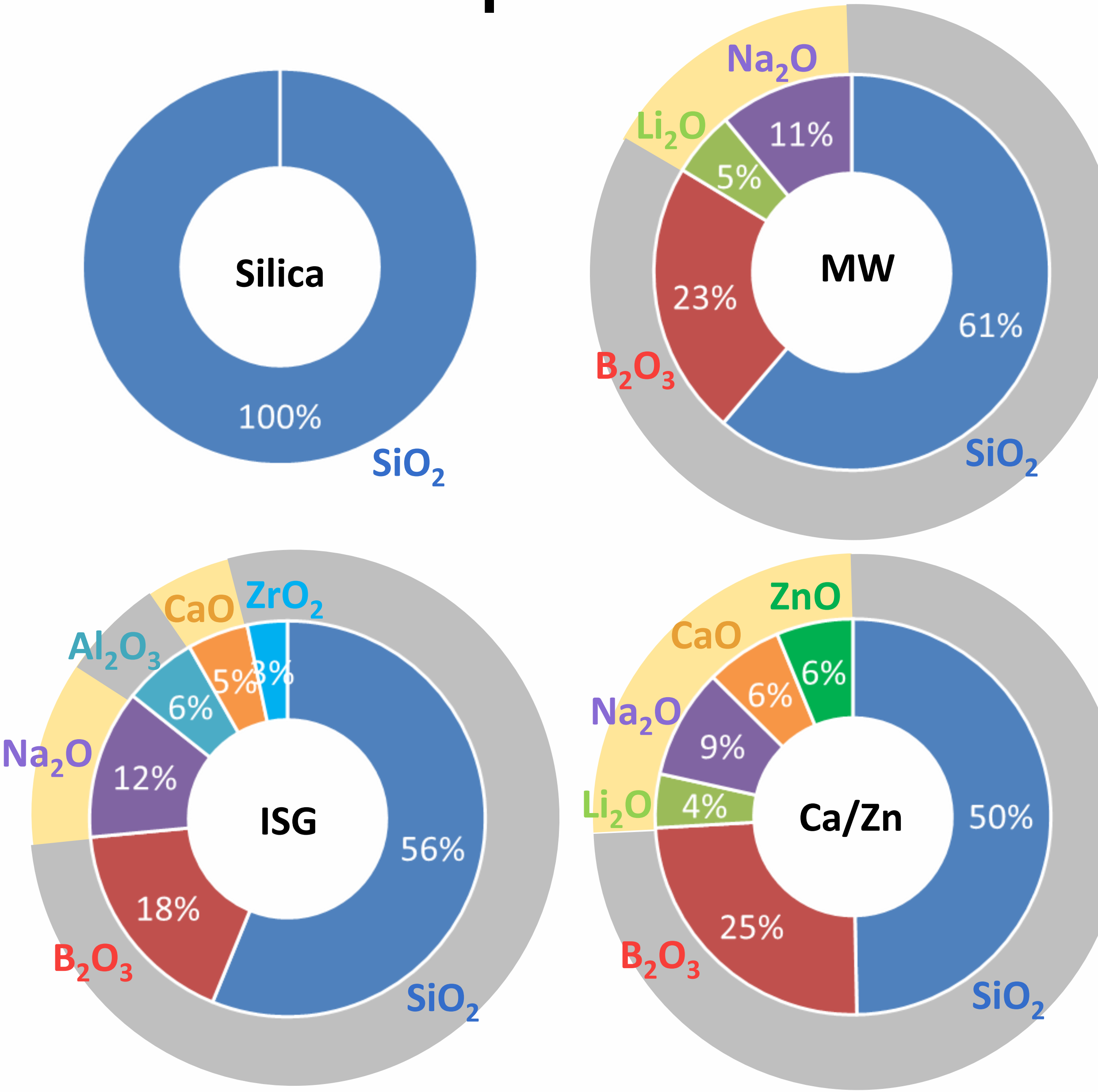




Experimental set-up

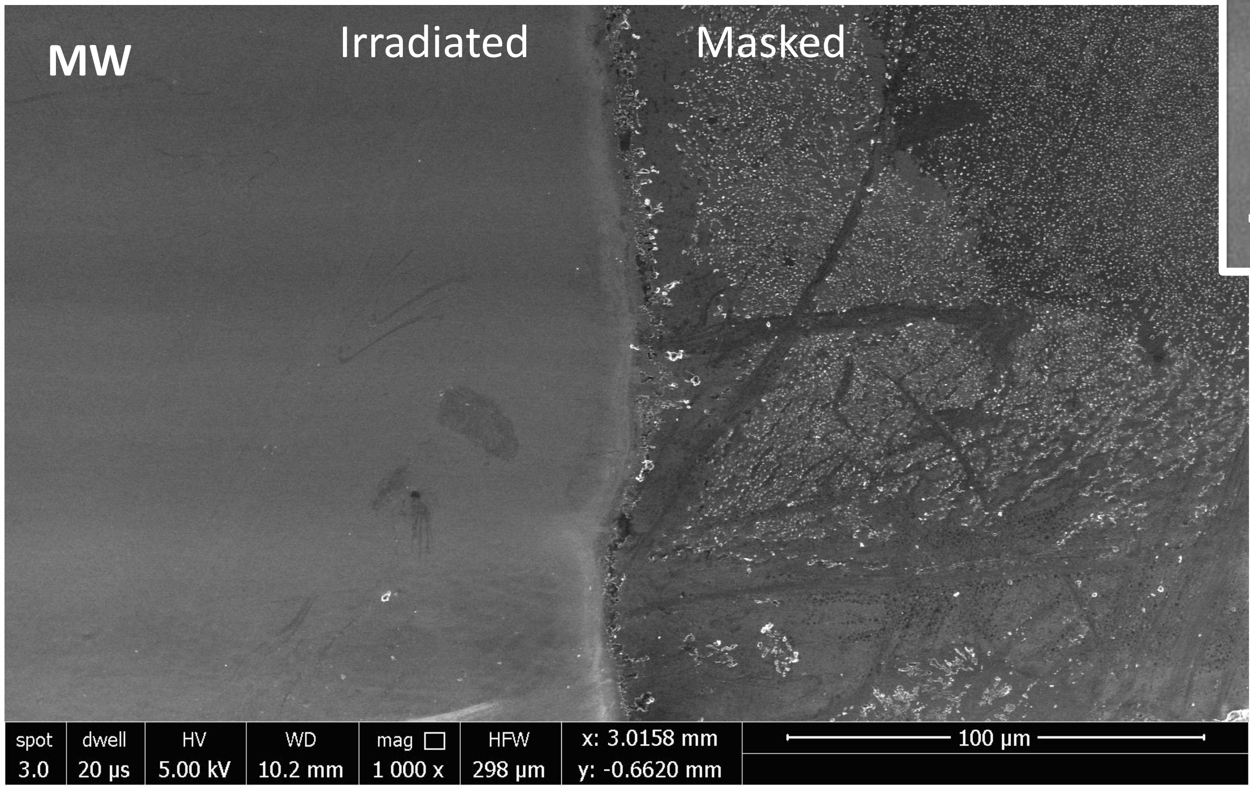
- Heavy ion irradiation

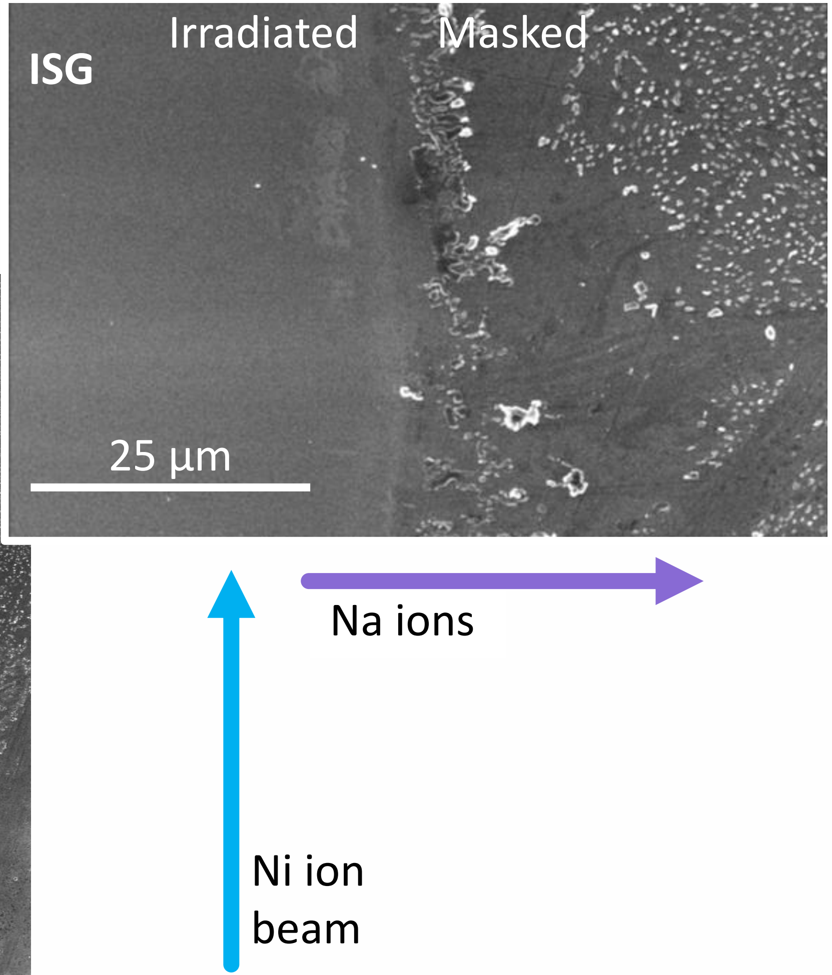




Results so far

- Scanning electron microscopy
  with energy dispersive x-ray spectroscopy (EDX)





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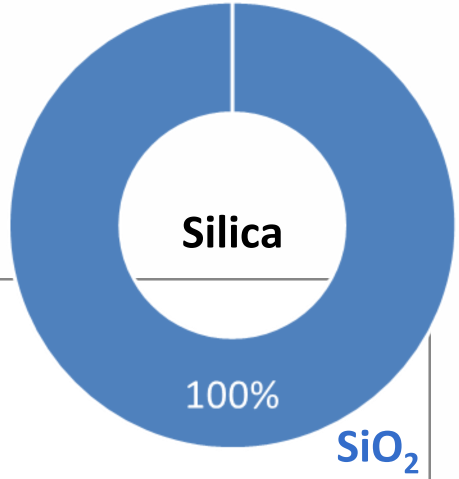
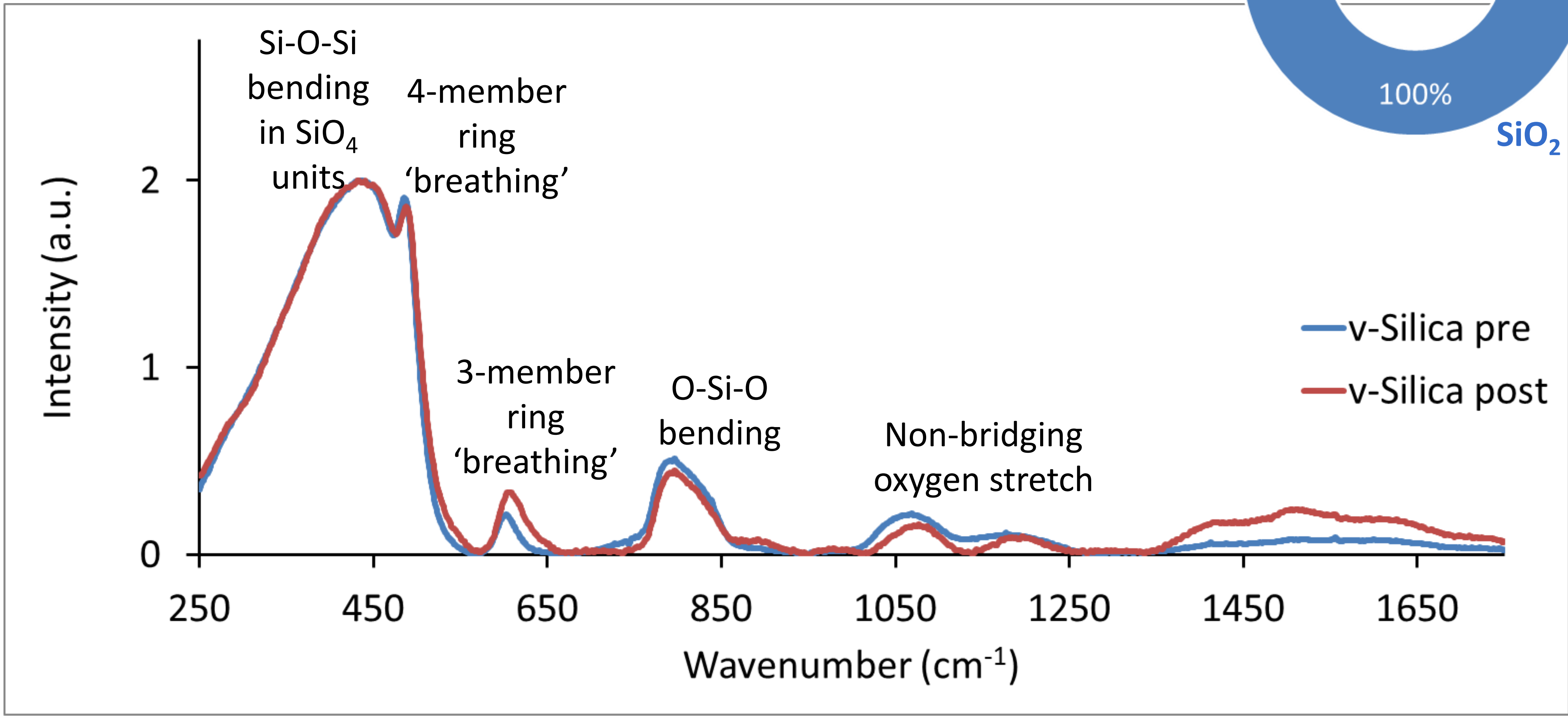
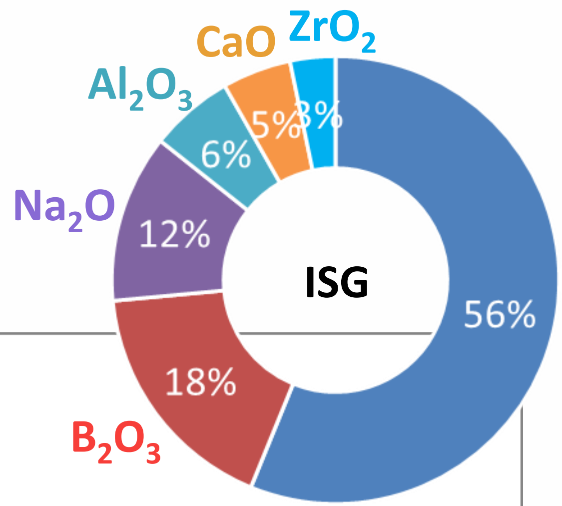
Results so far



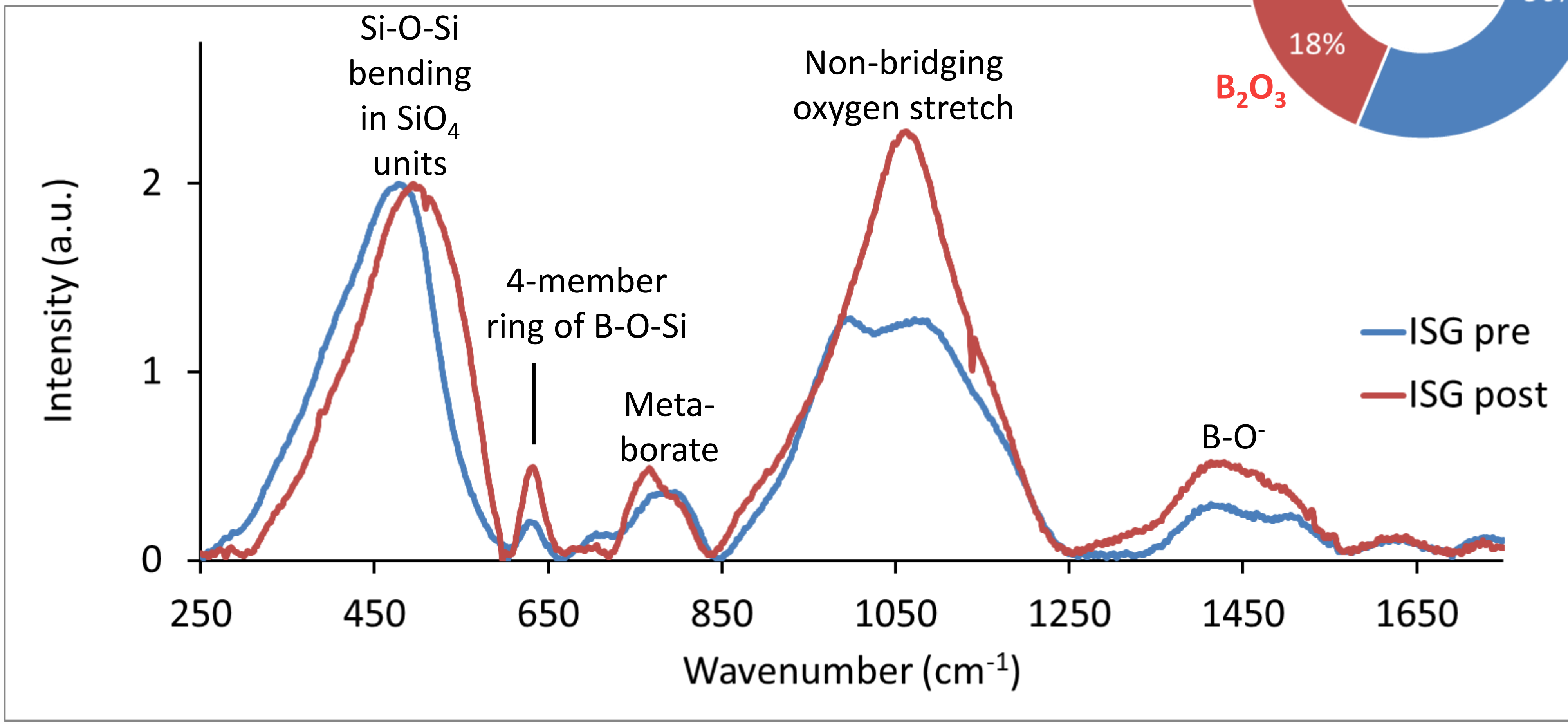
- Raman spectroscopy



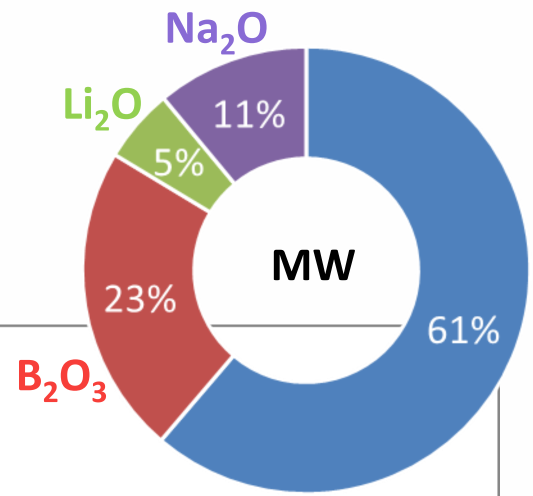
Results so far



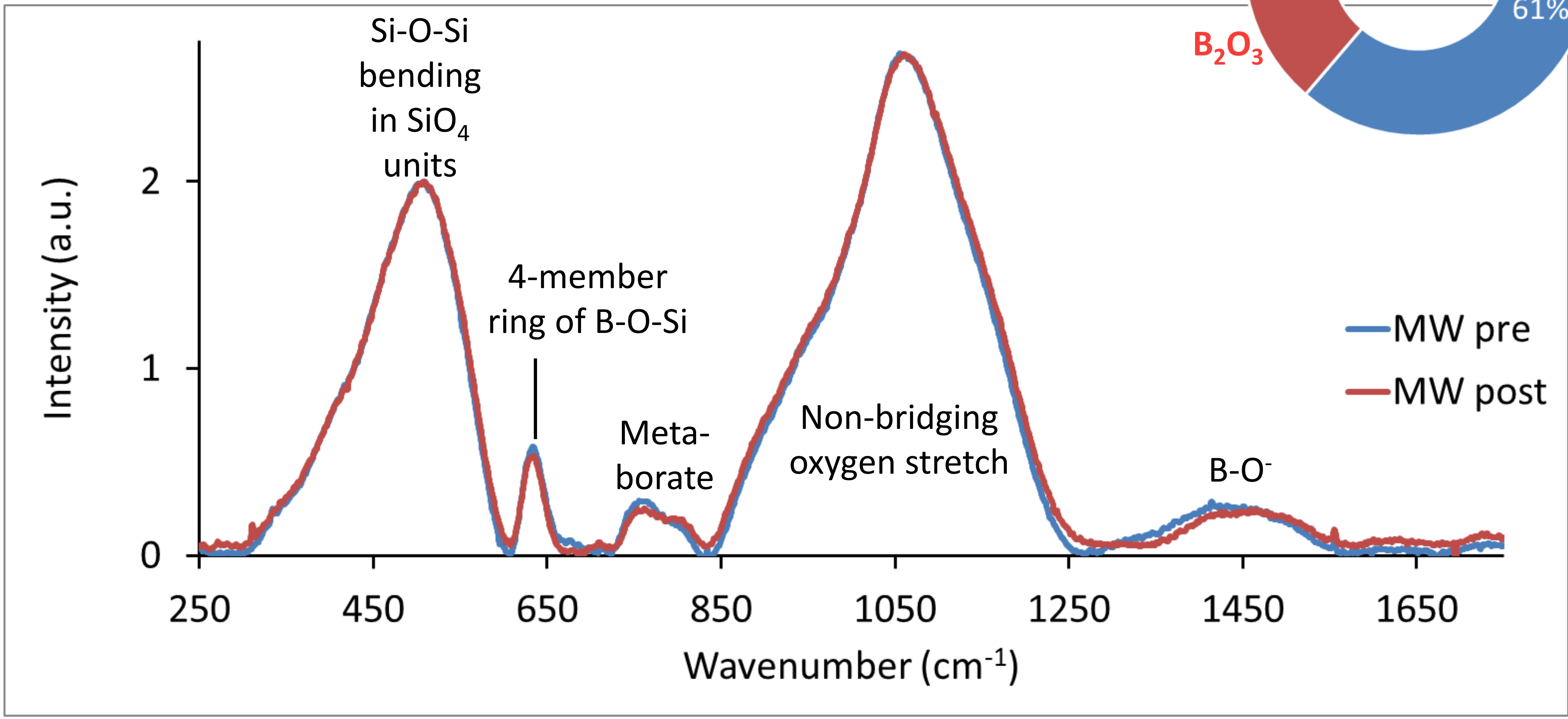
- Raman spectroscopy



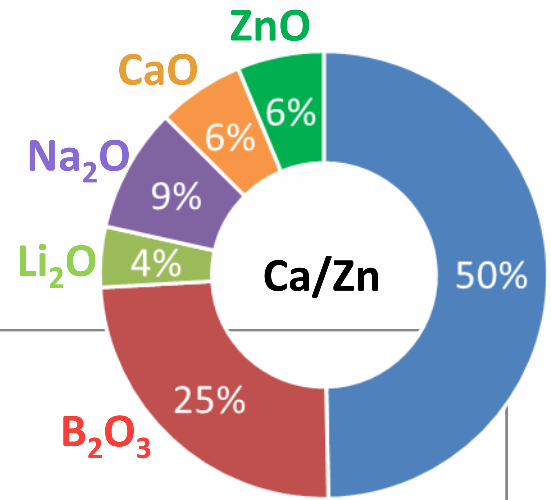
Results so far



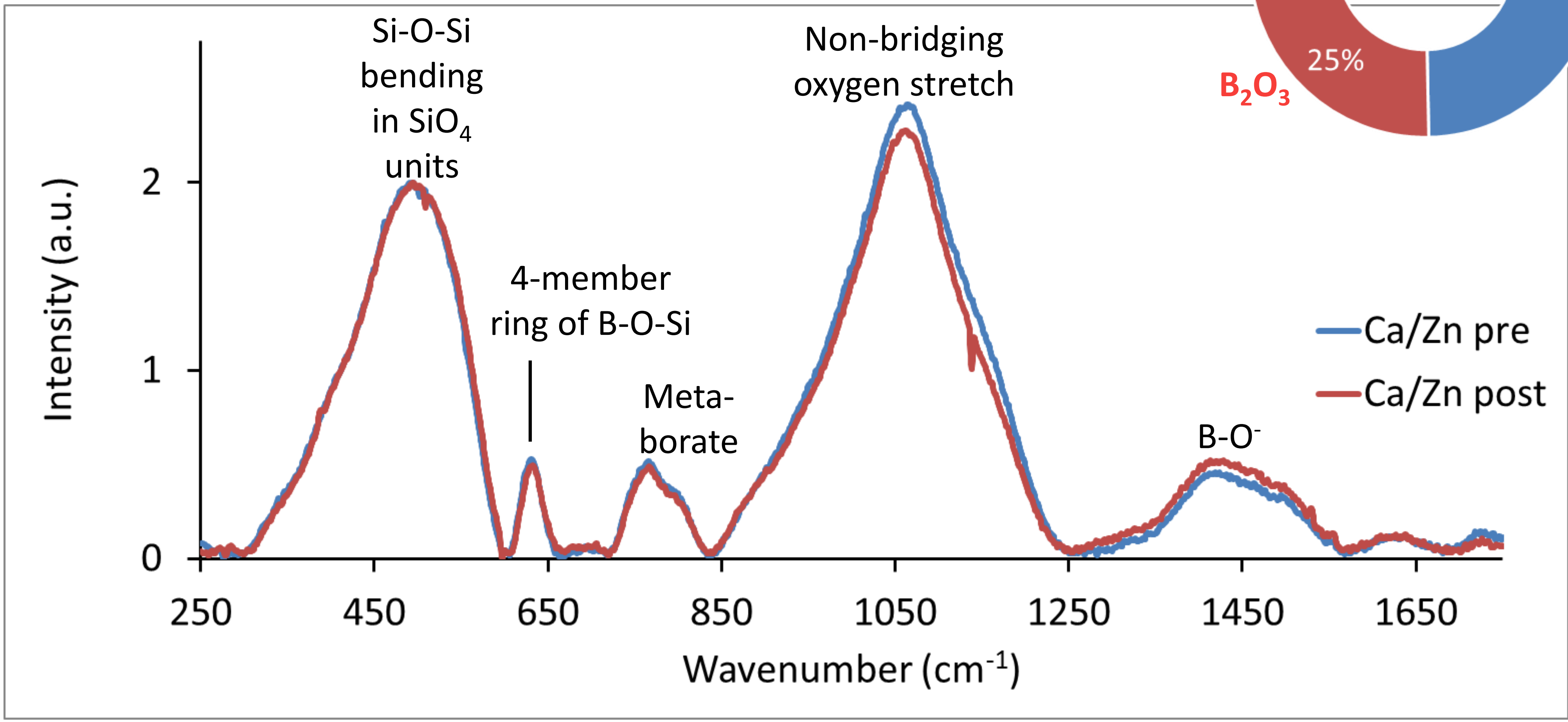
- Raman spectroscopy



Results so far

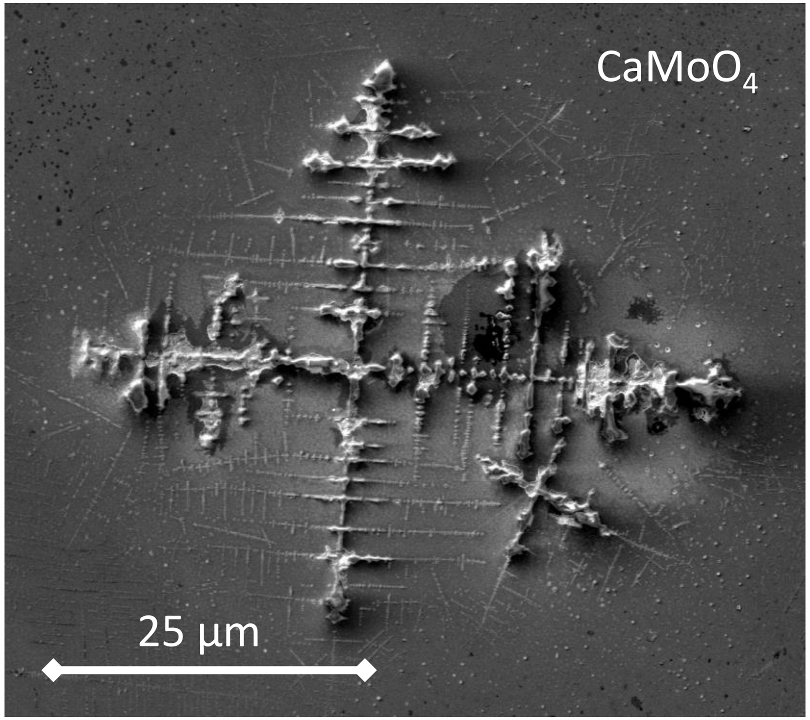


- Raman spectroscopy



Forthcoming work

- How does the degree of crystallinity in a glass-ceramic affect radiation tolerance?



Stage 1: Glass-ceramic production
- Time-temperature transformation diagrams

Stage 2: Ion irradiation
- Building on our developing protocol

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Thank you

Laura.leay@manchecster.ac.uk

Ultrasonic backscatter for characterising nuclear slurries and suspensions: Perspectives and future work

Dr Tim Hunter

School of Chemical & Process Engineering, University of Leeds

https://engineering.leeds.ac.uk/staff/473/Dr_Timothy_Hunter

PhD Position Vacant

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TRANSCEND: Transformative Science and Engineering for Nuclear Decommissioning

Funded PhD project: UK and EU

Value: A full standard studentship consists of academic fees (£4,327 in Session 2019/20), together with a maintenance grant (£15,009 in Session 2019/20) paid at standard Research Council rates.

Number of awards: 3

Deadline: 29/06/2019

Supervisors: Dr Timothy Hunter, Professor Michael Fairweather and Professor Bruce Hanson. Contact Dr Timothy Hunter to discuss this project further informally.

https://engineering.leeds.ac.uk/research-opportunity/2878/transcend:-transformative-science-and-engineering-for-nuclear-decommissioning

Acknowledgements

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Leeds Researchers

Dr Jaiyana Bux, **Alastair Tonge (DISTINCTIVE)**, **Dr Hugh Rice (DIAMOND)**, Dr David Cowell, Prof Steven Freear, Prof Jeff Peakall, Prof Mike Fairweather

Collaborators

Martyn Barnes (Sellafield), Geoff Randall (Sellafield)
Jonathan Dodds (NNL)

Funders:

EPSRC Engineering and Physical Sciences Research Council

Innovate UK Technology Strategy Board

Sellafield Ltd

NDA Nuclear Decommissioning Authority

Motivation – *in situ*/ online characterisation

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- ***In situ*** **monitoring of sludges and slurries to optimise of processing, transport and separation & aid modelling.**

Started on DIAMOND then DISTINCTIVE now TRANSCEND

First Generation Magnox Storage Pond - Sellafield

Water Treatment Thickener

Advanced acoustic backscatter array [1]

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•Ultrasound Array Research Platform (UARP)

- High resolution concentration & interfaces from backscatter echo strength.
- Up to **sixteen** 1.5 – 2.5 MHz transducer heads aid depth penetration.

Specification	UARP
Maximum Output Voltage	5 Level ± 100V, ± 50V, GNS
Transmit Frequency	0.5 MHz to 15 MHz
Number of channels	16 per module (Max: 256)
Raw data transfer to computer	PCI Express Gen 3 (Max : 64Gbps)
Analog Digital Converter	AFE5807 (Max 80MSPS)
Mechanical aspects	Communications via PCIe Dedicated Clock and Synchronisation signals.

a

Full Scale In situ monitoring

Measurement principle [2,3]

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$$V_{\mathrm{rms}} = \frac{k_s k_t}{\psi r} M_W^{\frac{1}{2}} e^{-2r(\alpha_w + \alpha_s)}$$

$$K_s = \frac{f}{\sqrt{\rho_s a_s}},$$

f = Dimensionless scattering factor

$$\alpha = \alpha_w + \frac{3\chi M}{4 a_s \rho_s}.$$

χ = Dimensionless attenuation factor

k_s	**particle species backscatter co-efficient**
k_t	transducer constant
ψ	near field correction factor
r	distance from transducer face
M_W	**mass concentration**
a_s	**Particle radius**
α_w	attenuation of water
α_s	**attenuation of suspended particles**

Most applications to date: Focus on concentration

Normalised scattering relationship [3]

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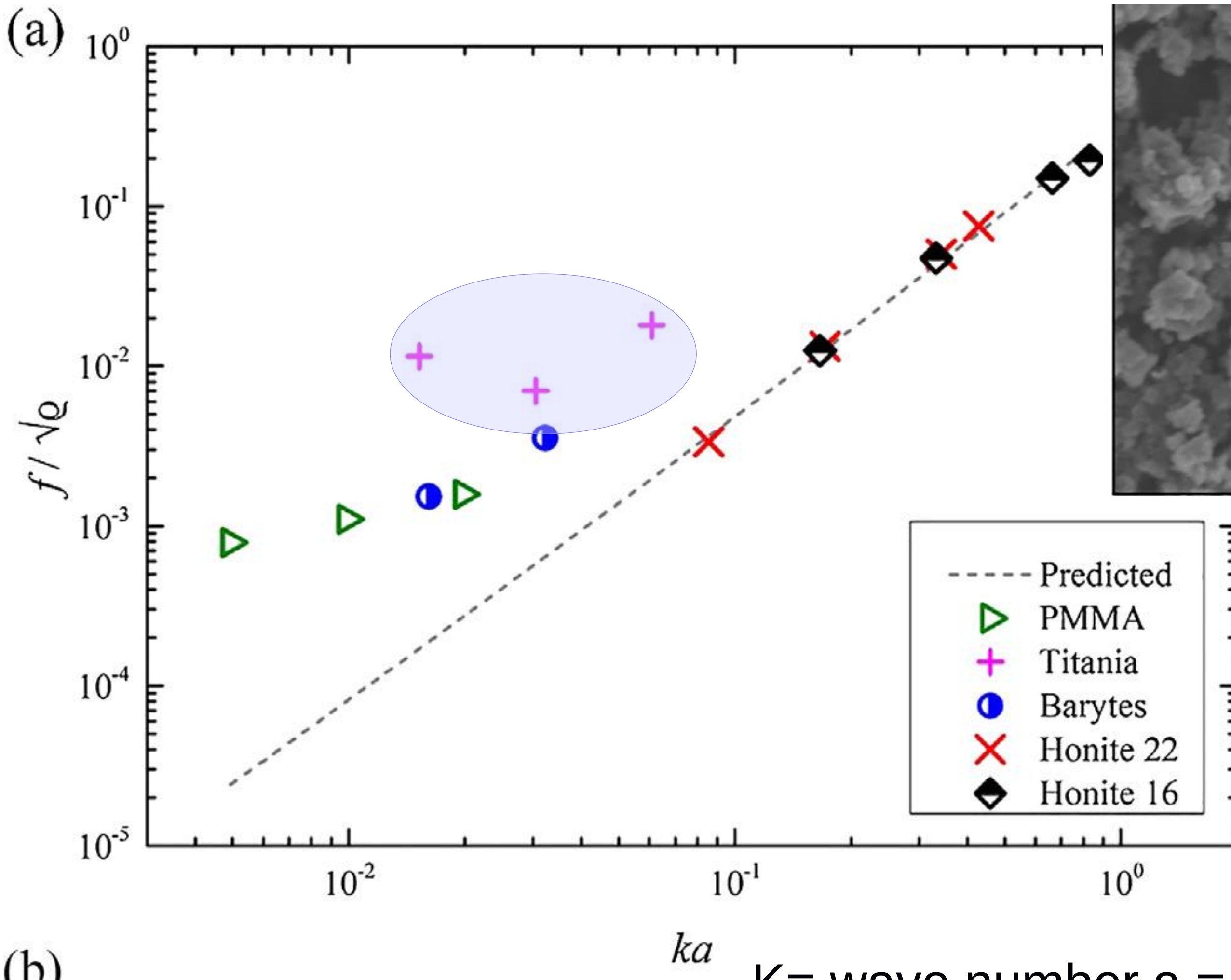

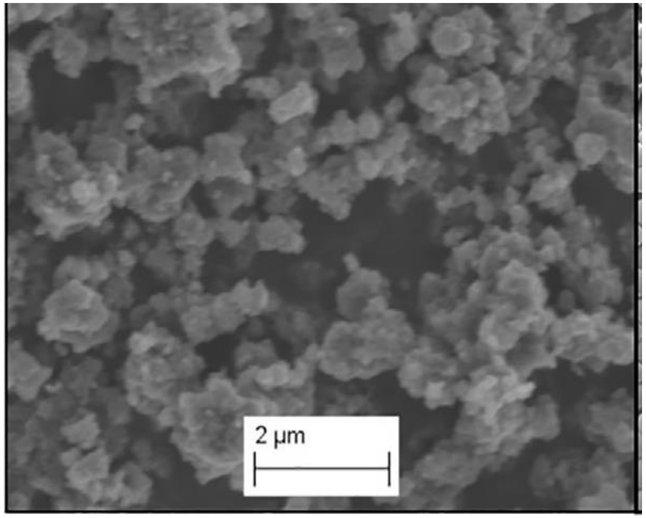

K= wave number a = particle radius

Batch separation of complex waste suspensions [4]

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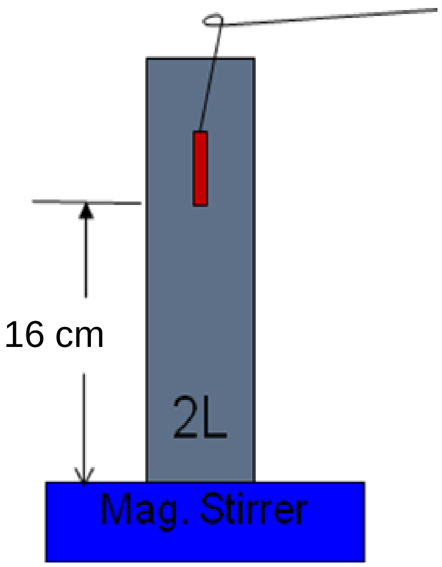

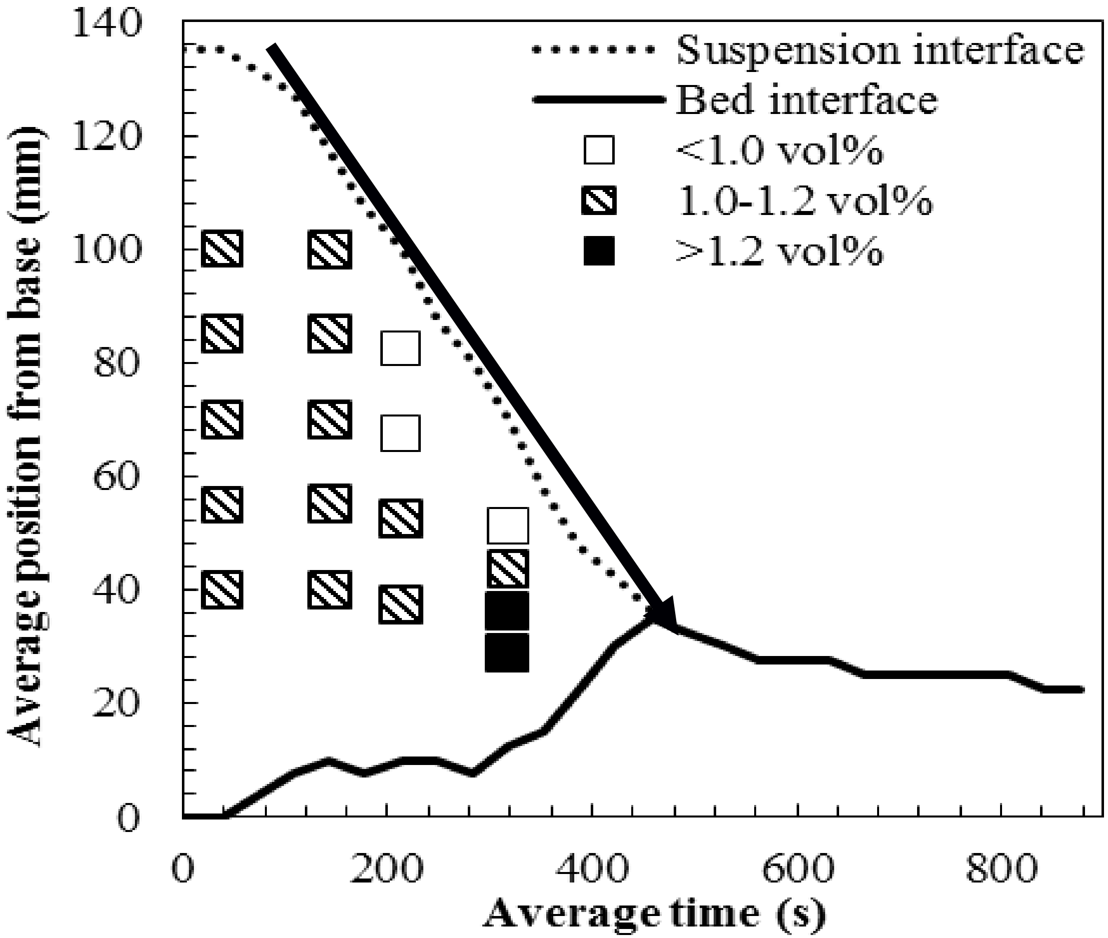

Settling of TiO_2 suspension

Analysis of HASTs jet mixing (FTR) [5]

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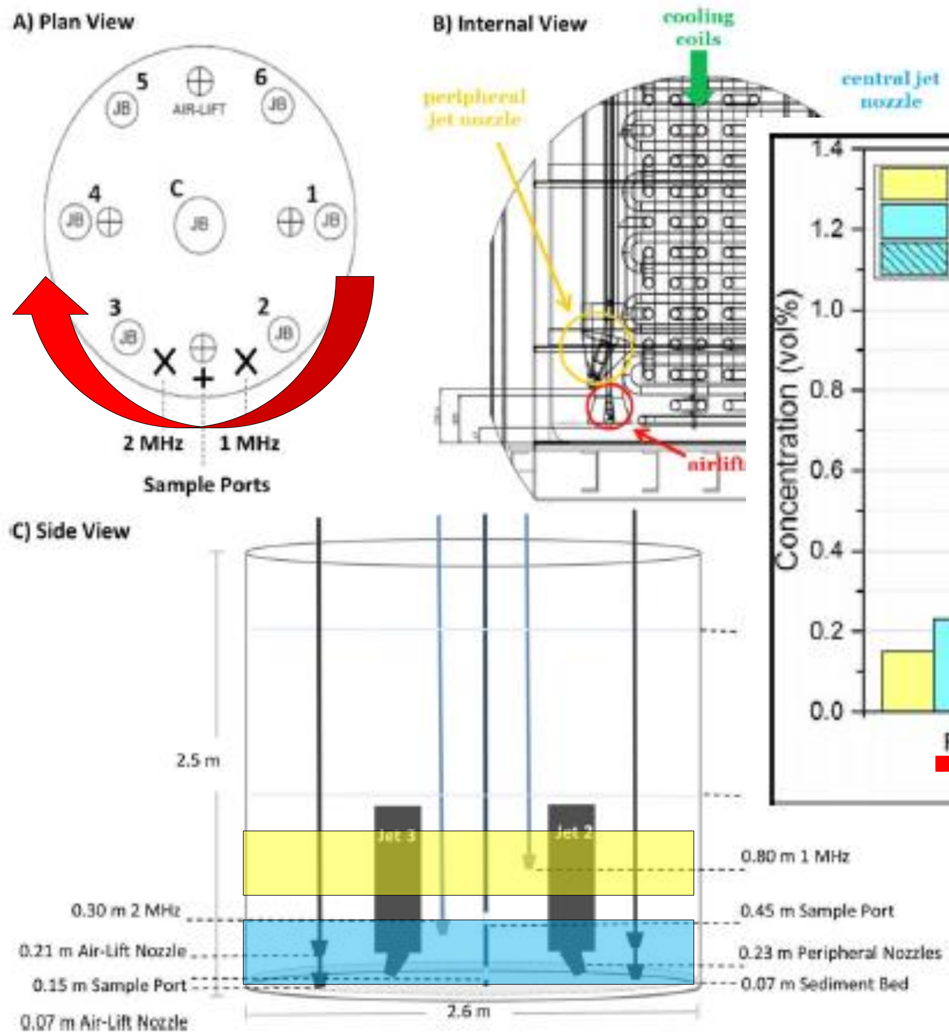

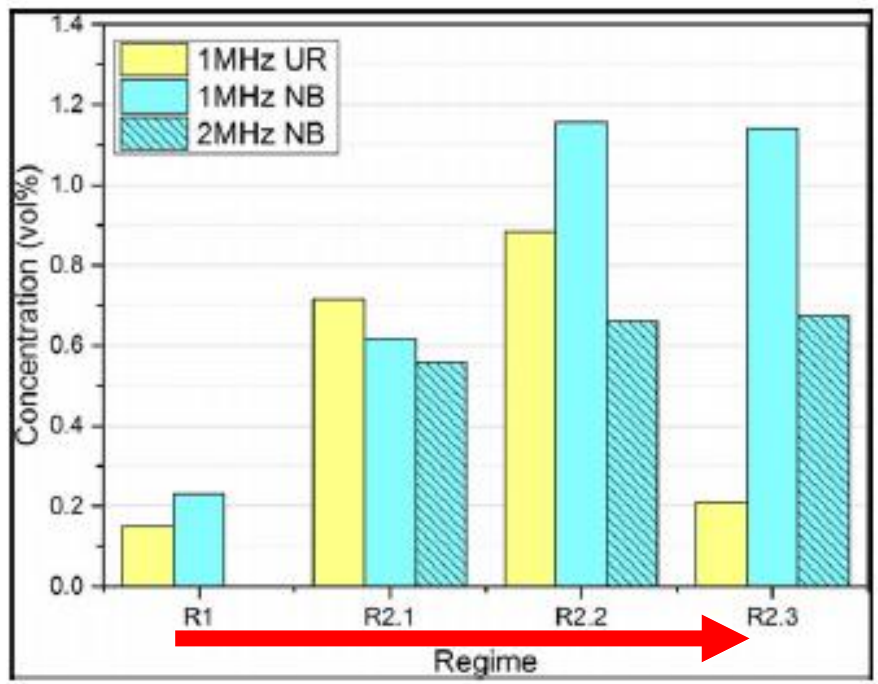

In situ Acoustics Trials – Sellafield Pile Fuel Storage Pond (1/3 scale)

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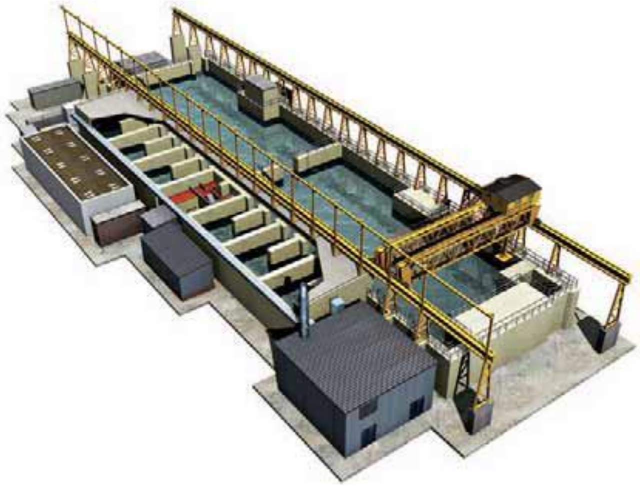

- Spent fuel from the first Windscale pile reactors has been stored in the PFSP for > 50 years.
- Corrosion of the waste material and additional organic mater has resulted in a significant build up of sludge.
- A horizontal clarifier (‘corral’) 15 m long has been inserted to consolidate sludge pumped off pond floor
- A 1/3 scale 9 m^3 clarifier used for non-active trials of acoustic array

Large-scale clarifier trials (1/3 scale Sellafield Pond corral)

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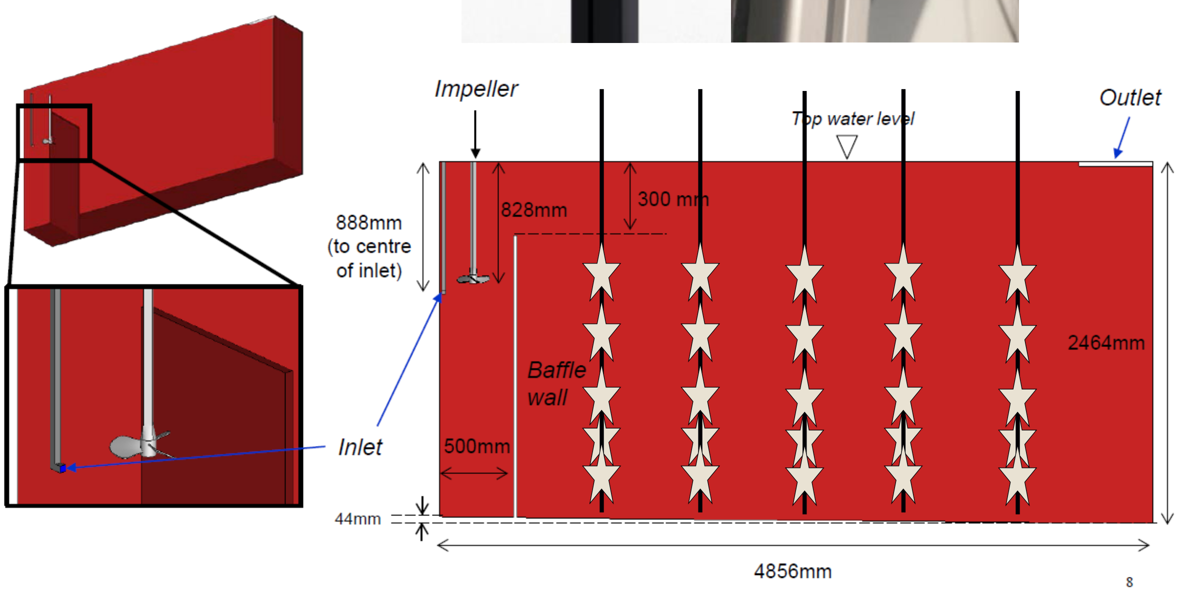
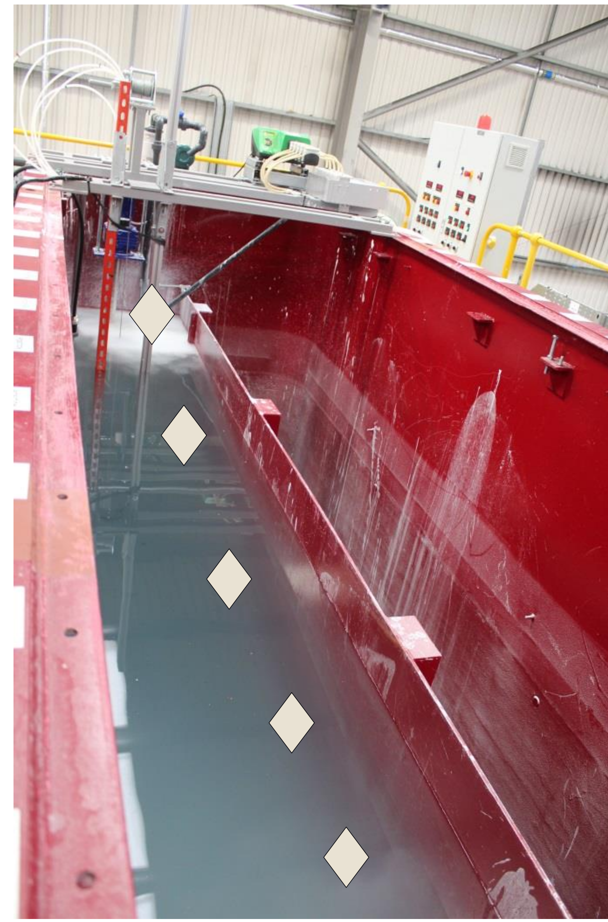
- Flocculated calcite with 10 ppm anionic polyelectrolyte





Correlation: Integrated ABS Power [6]

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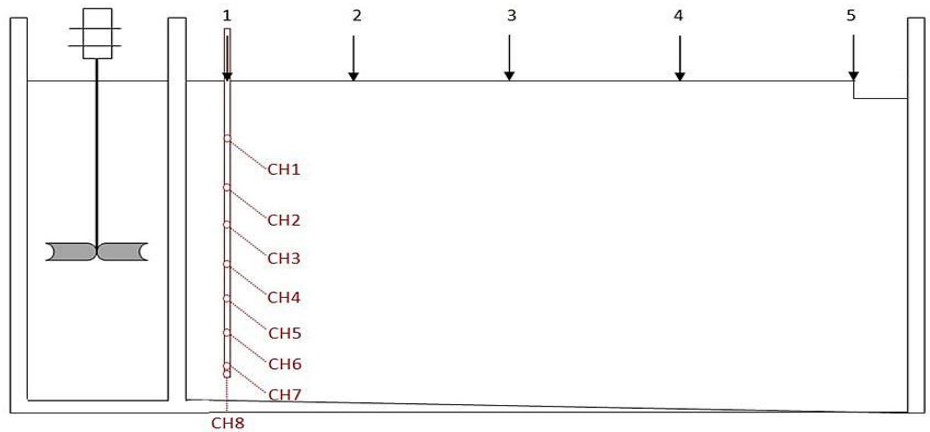

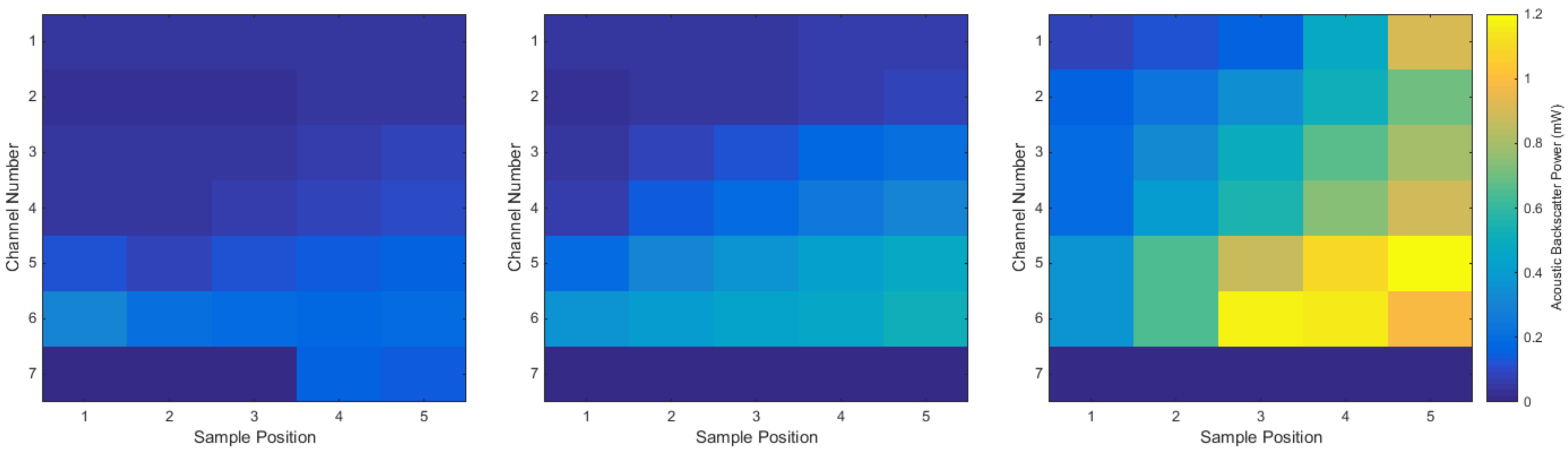

Sample T+130 | Sample T+180 | Sample T+230

Sample vs Integrated ABS Power

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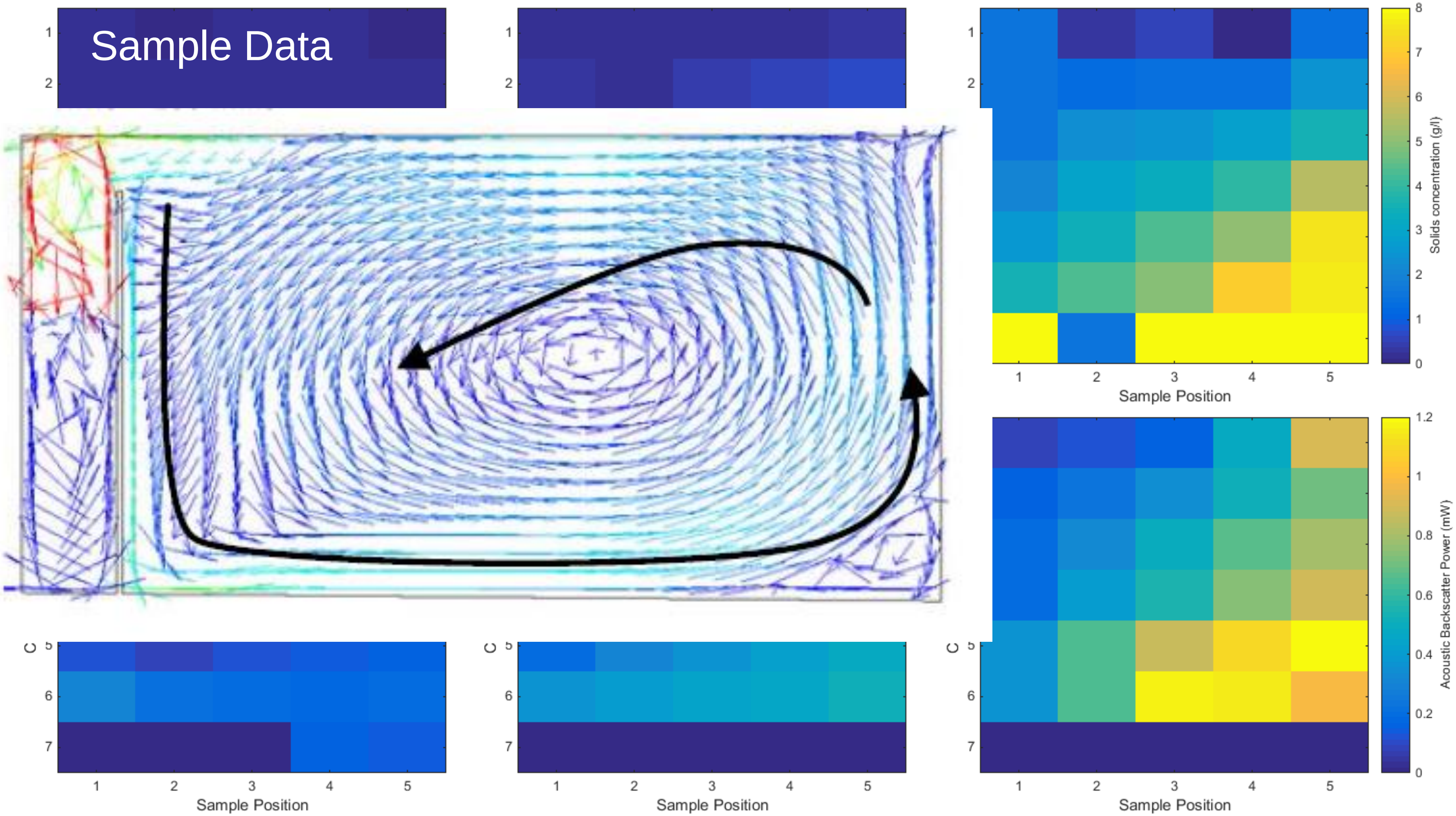

Sample T+130 Sample T+180 Sample T+230

Acoustic monitoring of multiphase pipe flow – Concentration profiling [7]

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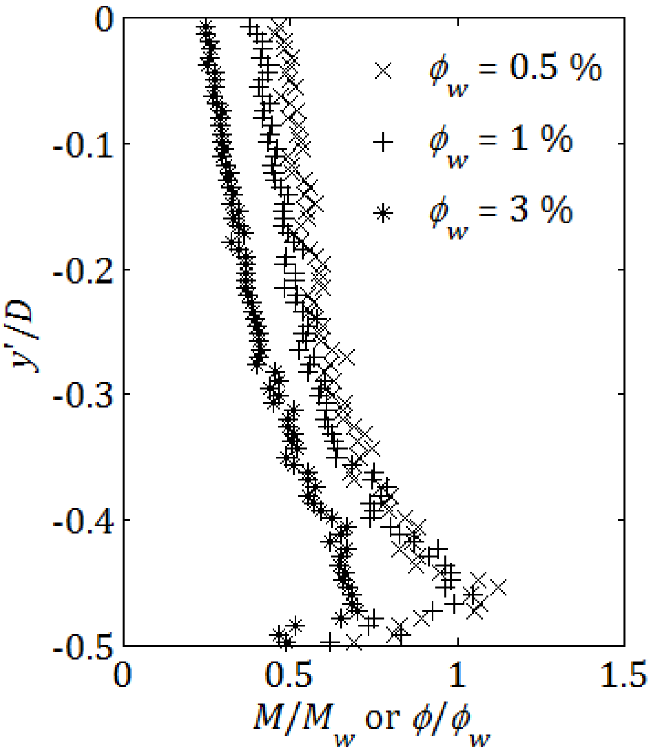
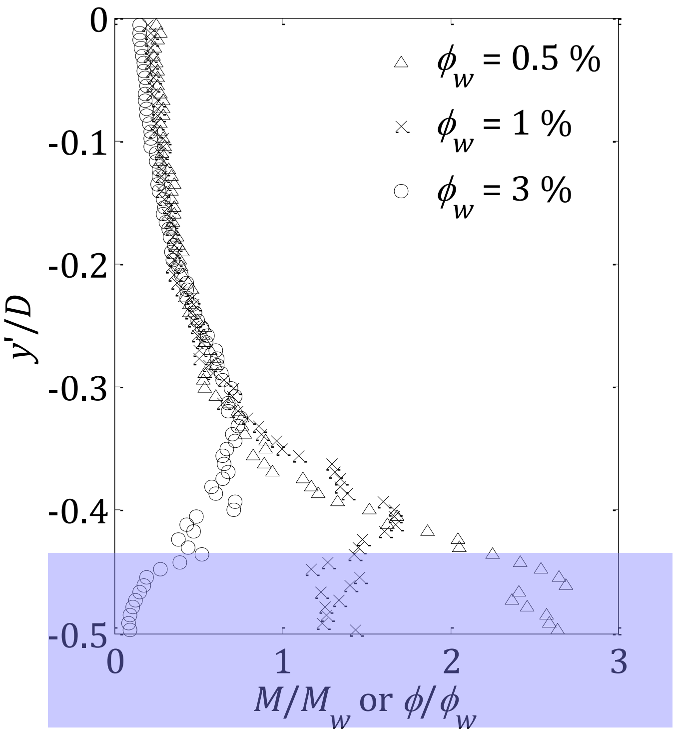
Large glass, Re ≈ 50,000



Large glass, Re ≈ 26,000



Moving bed

Future Work: TRANSCEND

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- Focus on pipe-flow systems– utilising non-intrusive transducer arrangements
- Key research on extending work on concentration profiling to more robustly include simultaneous *in situ* particle/aggregate size
  - Will use ‘realistic’ highly aggregated waste simulants
- Understand influence of aggregation state/polydisperity on acoustic backscatter/attenuation constants
- Utilize machine learning to aid size/concentration correlations to acoustic response using training data

References

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[1] D.M.J. Cowell et al., IEEE IUS **2015** 10.1109/ULTSYM.2015.0165

[2] H.P. Rice et al., *J. Acoust. Soc. Am*. **2014**, 136, 156-169

[3] J. Bux et al. *Appl. Acoust.,* **2019, 146** , 9-22

[4] J. Bux et al. *Powder Technol.,* **2015,** 284, 530-540

[5] J. Bux et al. *AIChE Journal* **2017,** 63, 2618-2629

[6] T.N. Hunter et al IEEE IUS 2016 10.1109/ULTSYM.2016.7728870

[7] H.P. Rice et al. *Chem. Eng. Sci*. **2015**, 126 745-758

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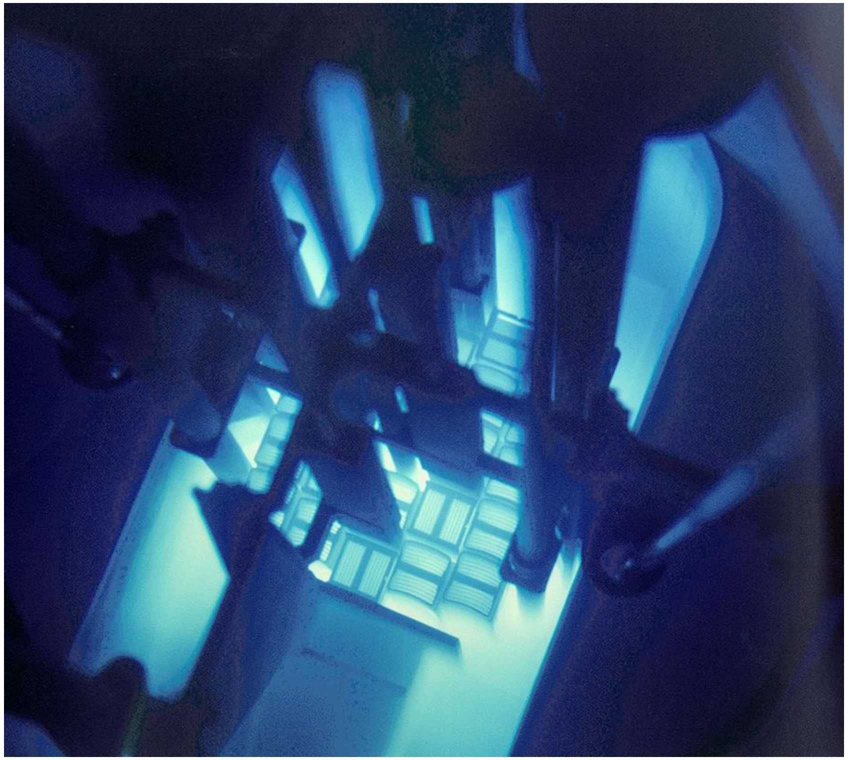
From Fission to Final Site Clearance – Decommissioning of the CONSORT Reactor



Presentation to the First Annual Meeting of the TRANSCEND Consortium – 3rd April 2019

Trevor Chambers, Head of Reactor Centre, Imperial College London

Alternate Title

**The secret diary of
the CONSORT reactor
aged 53 $^3/_4$**

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So what am I going to be talking about?

Decommissioning of the Imperial College CONSORT reactor

Progress and challenges to date

What is left to do

Challenges with what is left to do

Where your research may help similar decommissioning projects in the future

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But before I start!

Does anyone know the sum for the latest NDA total decommissioning cost estimate?

But before I start!

Does anyone know the sum for the latest NDA total decommissioning cost estimate?

£234 Billion!!

But before I start!

Does anyone know the sum for the latest NDA total decommissioning cost estimate?

£234 Billion!!

We'll come back to that later

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CONSORT - 1961 to 2012 - A Brief History

In 1961 UK Government announced programme to provide three low power reactors to be available to universities

Consort Reactor designed jointly by Mechanical Engineering Department of IC and GEC Ltd – commenced in 1962

Consort commenced operation in April 1965

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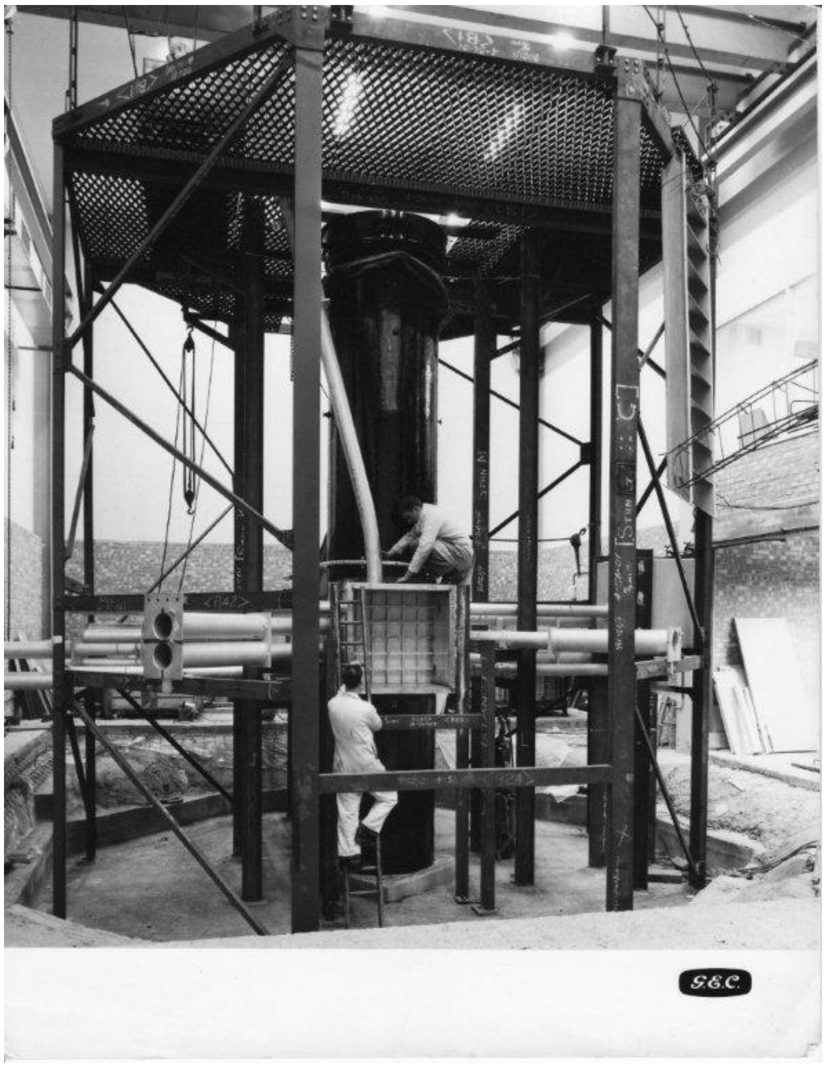
London

1961 to 2012 - A Brief History

Office building containing radiochemistry labs adjoining reactor hall completed in 1971

Used for over 40 years for research and teaching in reactor physics, reactor engineering, neutron physics, radiochemistry, activation analysis and radioisotope production

Construction Phase 1963-1965 (1)



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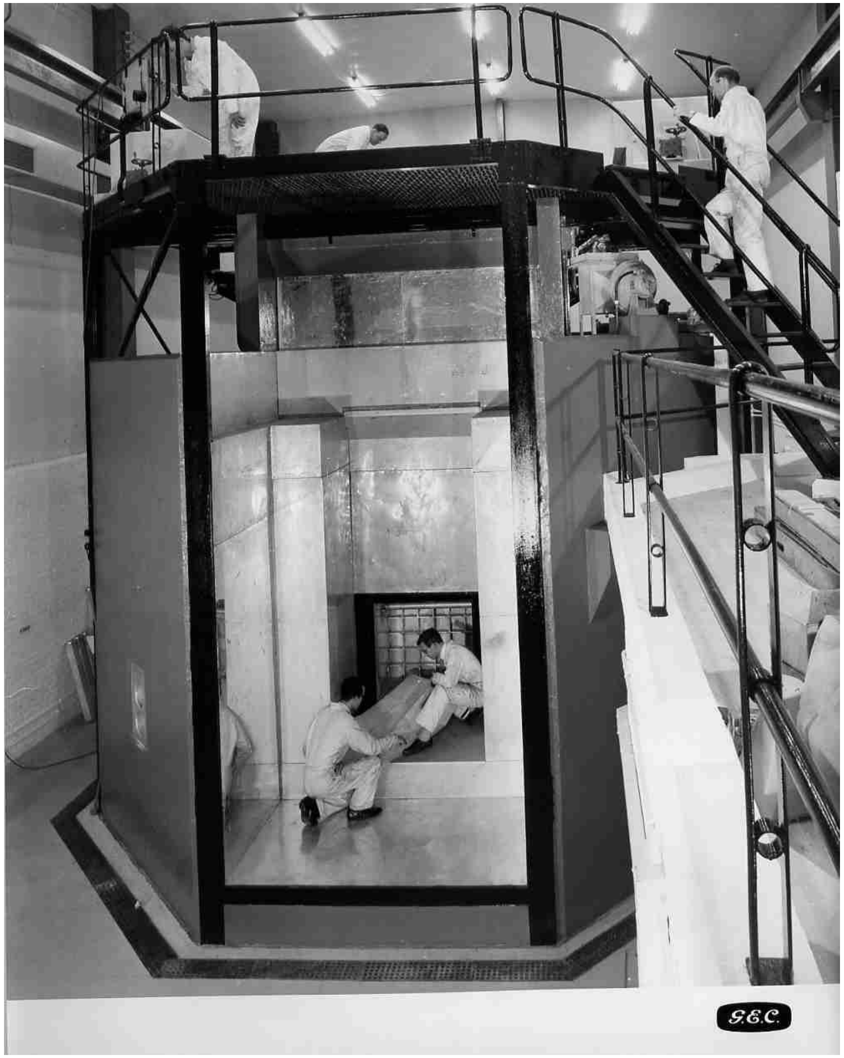
Construction Phase 1963-1965 (2)

Tank shield doors in place

Completion of the vessel

Official Opening June 1965



PLATFORM PARTY 22/06/65 (L to R)
Sir Harold Melville
Sir Douglas Logan (Principal University of London)
Lord Sherfield (Chairman)
Sir Thomas Creed (Vice Chancellor)
Sir Patrick Linstead (Rector)
Sir Owen Saunders (Pro Rector)
Professor Richards

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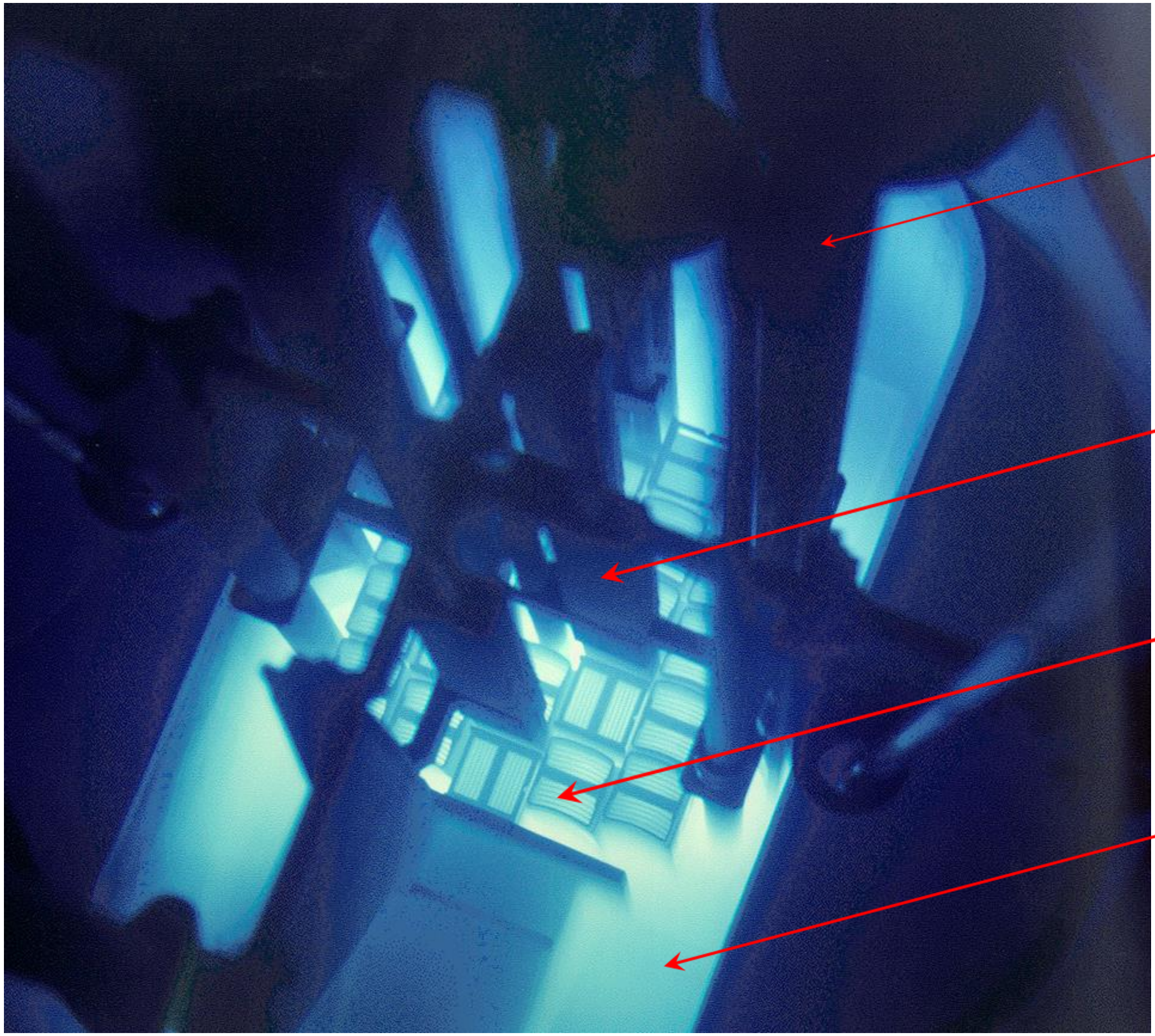
1965 - 2012

1965 – 2012 CONSORT Core



Irradiation Tube
(8 in total)

Control Rod
(4 in total)

Fuel Assemblies
(24 off U/Al alloy)

Light Water
(moderator)

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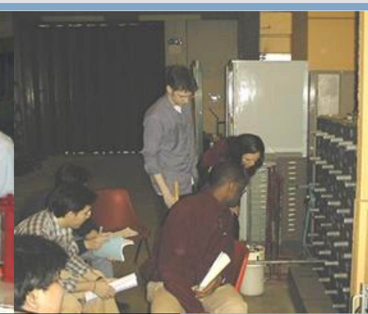
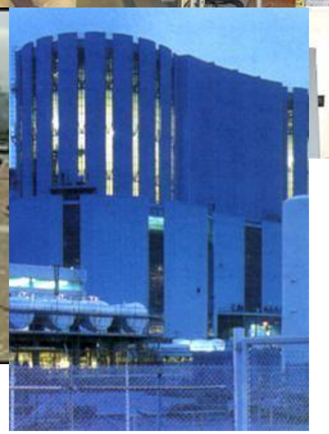
1965 – 2012 Applications

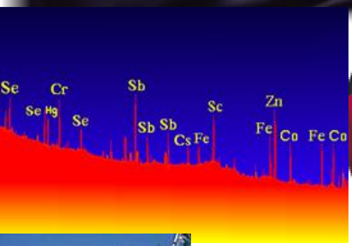




Teaching
& Training

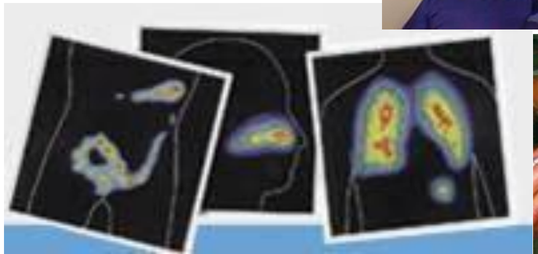




Calibration facilities
for neutron detectors




Isotopes & sources


Trace element analysis for environmental
and waste management

Decommissioning

Reactor Shutdown 19 December 2012

Key Decommissioning Phases:

- Defuel
- Start-up Source Removal
- Control Rod Removal
- Core Structural Component Dismantling and Removal
- Bio-shield Dismantling and Removal
- Soft strip
- Demolition
- Land Remediation
- De-Licence

Decommissioning - The First Step - Defuel

For commercial power reactors this is usually part of normal operations

For CONSORT this represented a significant change from normal practise, since re-fuelling was not a standard operation

Defuel posed a number of specific challenges

Typical Fuel element (Mk 3 16 Plate)

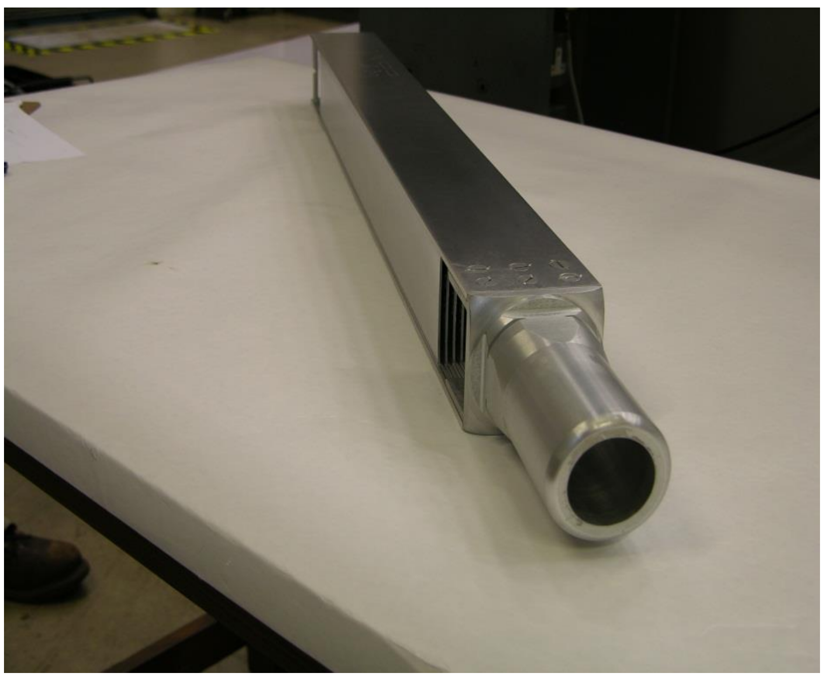
Approximately 915mm long

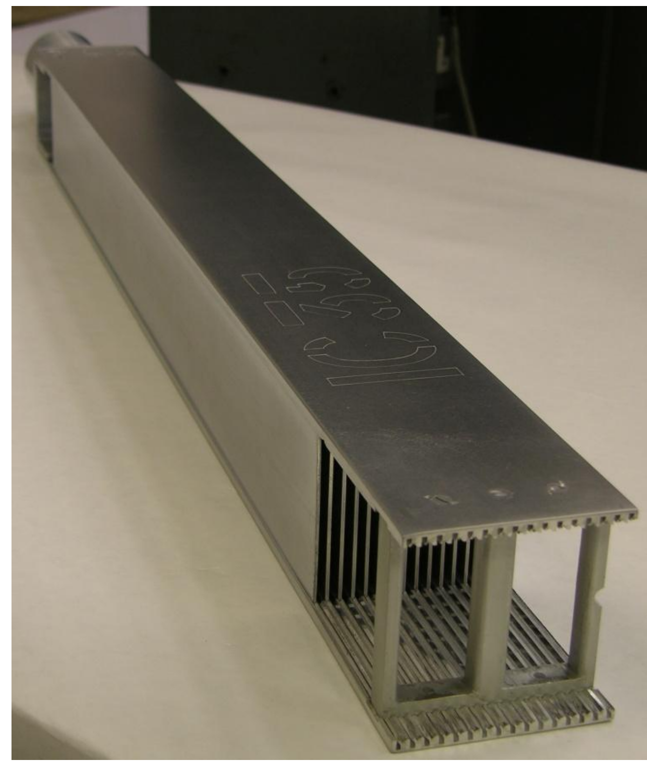
Approximately 75mm square

Aluminium cladding

Aluminium/Uranium matrix

Estimated maximum dose rate 75 mSv/h at 1m





Defuel Challenges – Reactor Hall Crane

Non-nuclear lift crane

5 Ton SWL

Low lift height above reactor top – approximately 1.7m

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Defuel Challenges – No Defuel Equipment!

Unirradiated fuel had gone in by hand…

But it was definitely coming out remotely!

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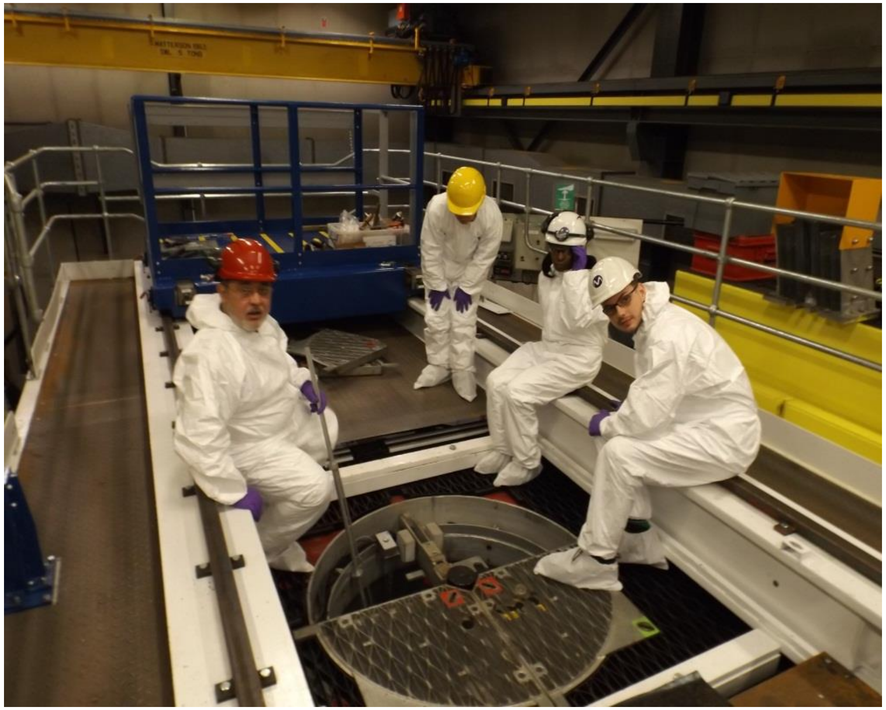
Defuel Challenges – Need for Shielded Fuel Transfer

No fuel flask available to withdraw fuel at ICRC

No shielded transfer facilities installed



Defuel Challenges – Selecting a suitable Transport Cask

Preference to transfer all fuel elements in one shipment

- More efficient
- Fewer security implications

Power reactor fuel flask unsuitable due to size and weight

Very limited number of suitable flasks available, particularly in UK

Defuel Challenges – Limited Loading Bay Arrangement

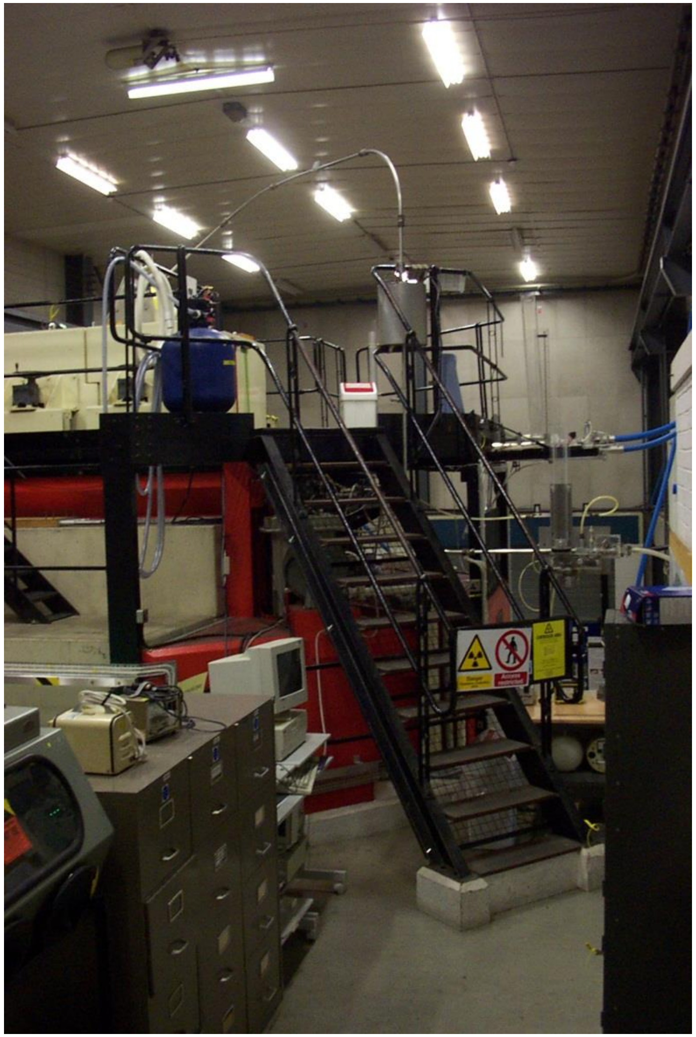
Low headroom

5 Ton non nuclear lift crane

Asbestos cladding surround

Defuel Challenges – Low Ceiling Headroom

Approximately only 2.3m headroom above reactor top



Defuel Challenges – Safety Case

The existing safety case covered operation of the CONSORT reactor

Defueling was not covered by the existing safety case

A new safety case was required to be produced and approved by the regulator

Early considerations for solutions to challenges – How to transport the fuel?

Trawl of certified flasks available in the UK revealed no obvious suitable transport flask for ICRC fuel

Areva MTR fuel transport cask

- Modern standards stainless steel/lead transport cask
- Top loading but without gamma gate
- Would enable transport of all fuel in one shipment
- Could be received by Sellafield

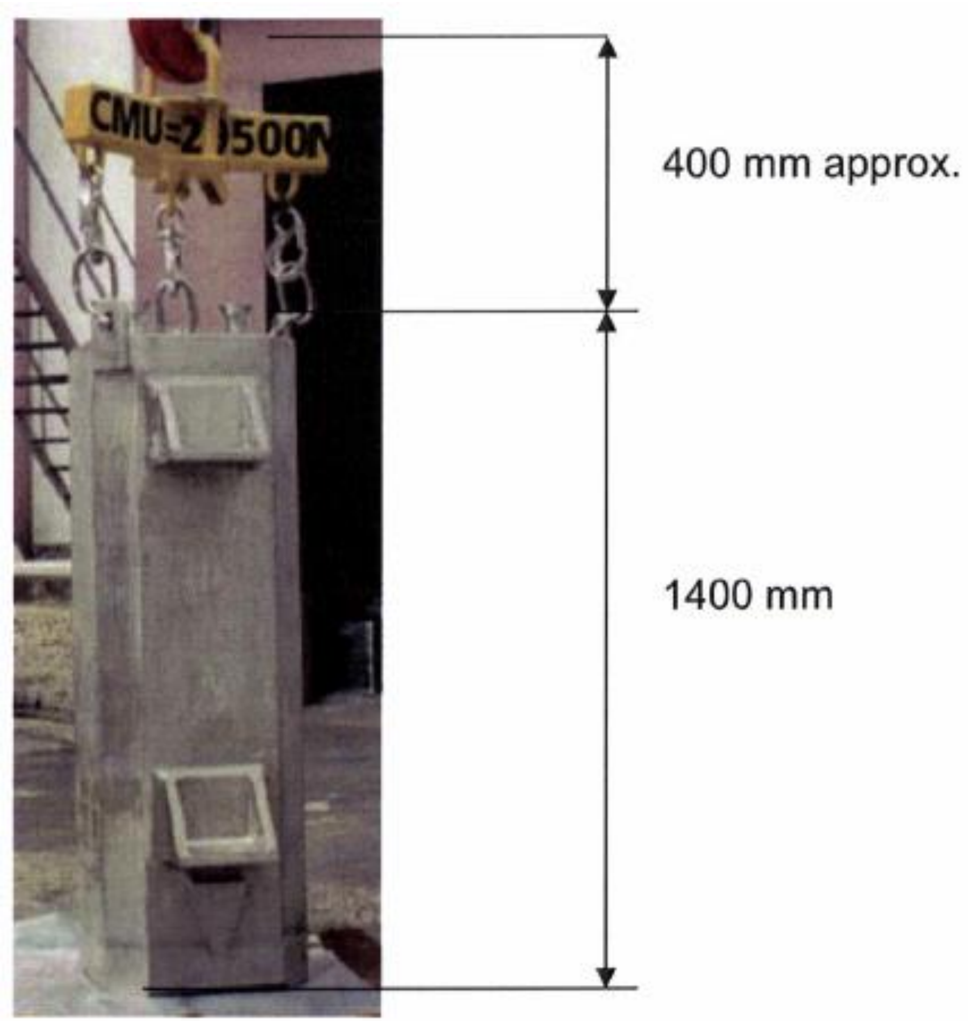
Drawbacks!

- Requirement to devise shielded loading into cask
- Not approved for ICRC fuel
- No approval certificate for use on UK roads

Early considerations for solutions to challenges – How to transport fuel from core to transport cask?

Areva transfer flask

- Bottom loading gamma gated flask
- Enables shielded transfer from core to flask utilizing core water moderator and gamma gate as shielding
- Cavity size is suitable for CONSORT fuel
- Flask shielding is adequate for CONSORT fuel



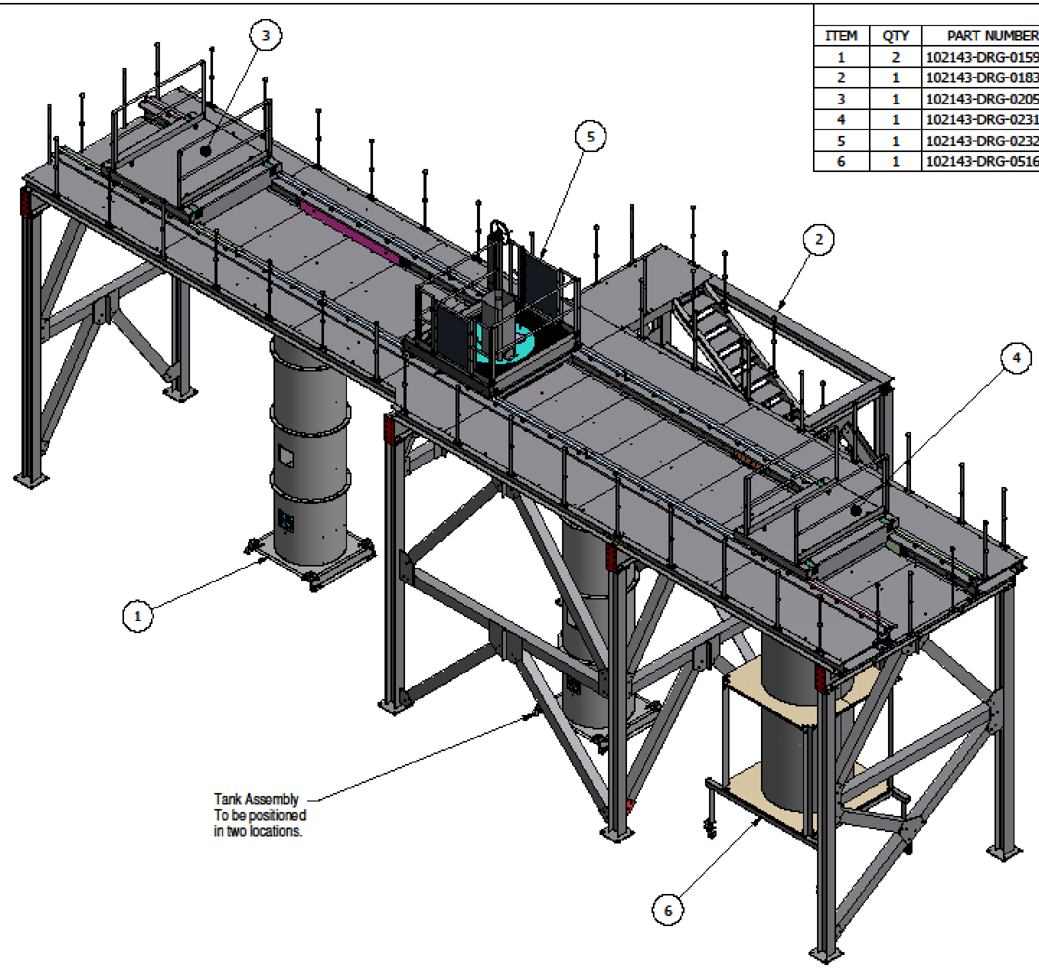
Early considerations for solutions to challenges – How to ensure shielded transfer of fuel into transport flask?

Areva Top Hat

- Enables shielded transfer from flask to transport cask using water filled top hat bolted/sealed to flask

Flaskway and Trolley Assembly

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	102143-DRG-0159	Tank Assembly
2	1	102143-DRG-0183	Support Structure GA
3	1	102143-DRG-0205	Sliding Cover Assembly (Large)
4	1	102143-DRG-0231	Sliding Cover Assembly (Small)
5	1	102143-DRG-0232	Bogey Assembly
6	1	102143-DRG-0516	Cask Assembly



NOTES:

Defuel Stakeholders

Successful defueling required coordination between a range of different stakeholders

- ONR Safety (Safety Case endorsement and permissioning)
- ONR Security (site security during defuel, transport security for consignment by road)
- ONR Safeguards (Safeguards and Euratom)
- ONR (RMT) Transport Container licence for use in UK
- Environment Agency (permissioning)
- Civil Nuclear Constabulary (site security and transport security)
- INS (Transport of the fuel to Sellafield, safety and security Plans)
- Sellafield Site Ltd (Receipt and storage of fuel at Sellafield)
- Department of Energy and Climate Change (DECC)

Coordination between Stakeholders was facilitated by setting up two groups

- CONSORT Decommissioning Regulatory Interface Forum – chaired by ICRC Head of Rector Centre
- DECC Working Group – chaired by senior civil servants directly reporting to ministers

August 2012 - Careful that's a Listed Building! (Dummy Run of Flask Vehicle and Crane)

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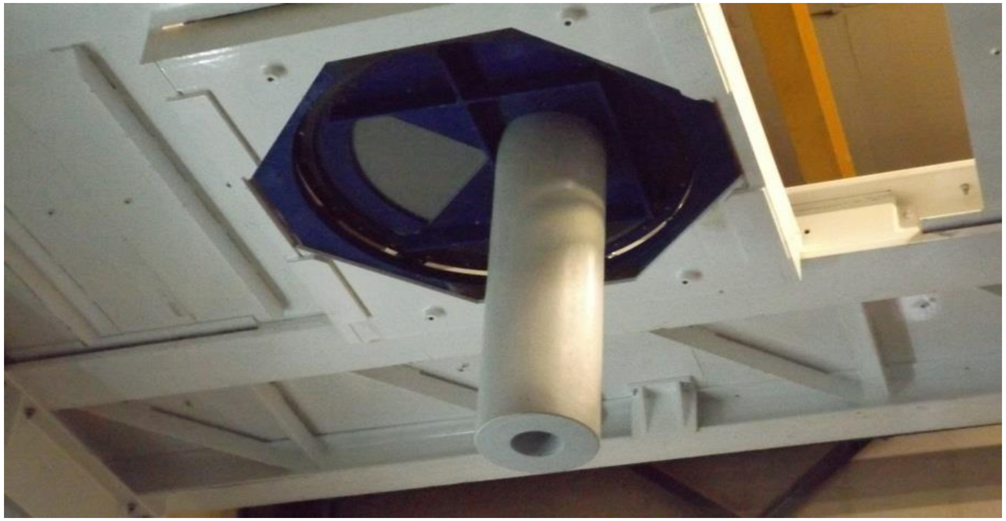
August to November 2013 - Installation of Flaskway

August to November 2013 - Installation of Flaskway



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Additional Defuel Equipment – Fuel Grab

A fuel grab and posting rods were required to operate remotely through the Areva transfer flask

These were designed and manufactured by a local engineering company, Woodley Engineering

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January 2014 - Cask Receipt and Installation

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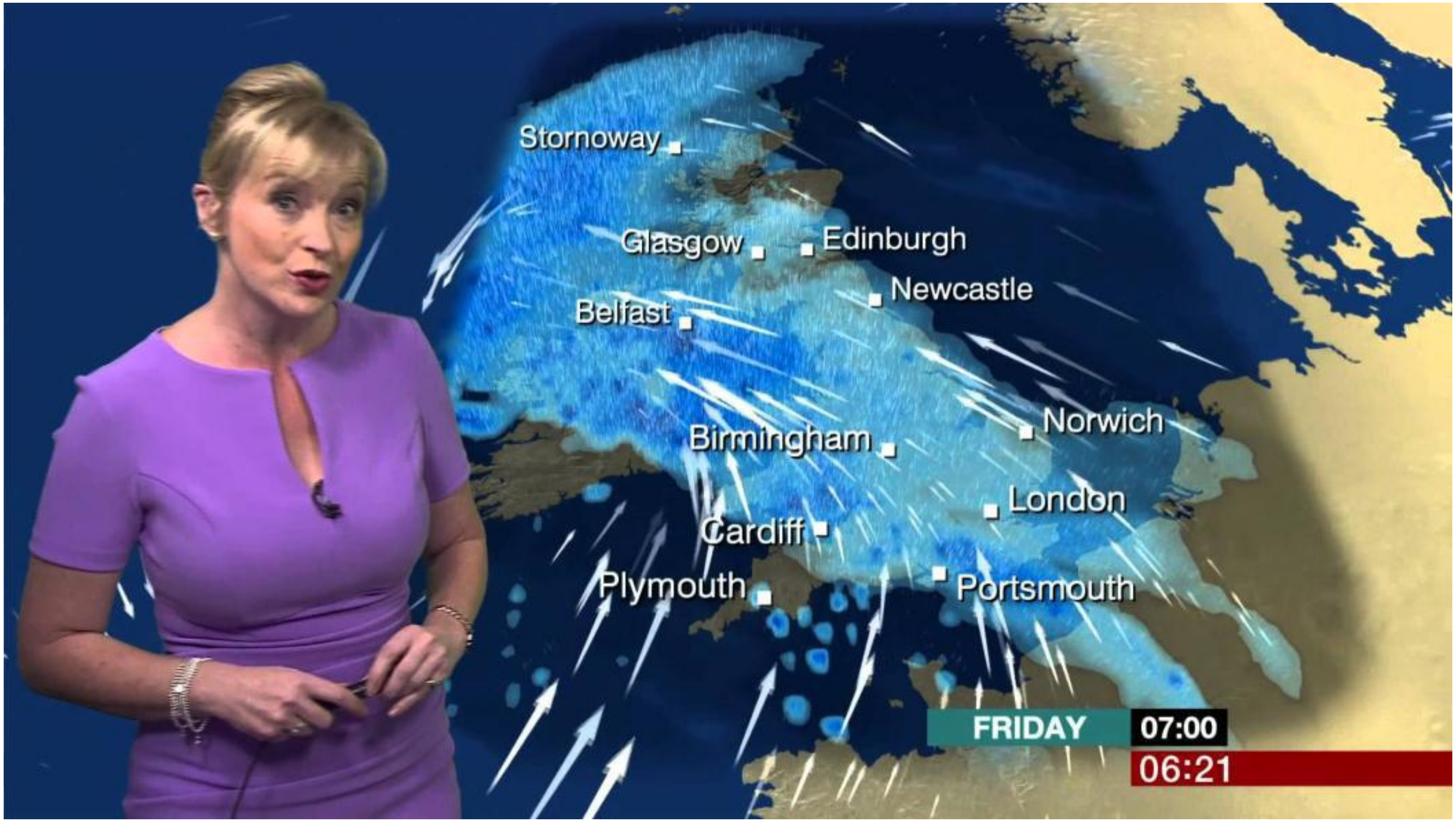
January 2014 - Cask Receipt and Installation

February 2014 - Cask Top Hat and Shielding Assembly

February 2014 - Just when we thought it was going well!!



February/March 2014 – It rained a bit near Ascot!!

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April 2014 – Major Electrical Power Failure at ICRC – Rain probable culprit

Incoming cable to Reactor Centre from main campus short circuits

Also damage to one internal cable found

Urgent repairs carried out

Standby generator used for emergency support

All works completed in record time

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May 2014 - Staff Training/Inactive Commissioning

Plant commissioned by ICRC team following draft Operating Instructions

All operations staff provided with classroom training covering all aspects from the safety case, radiation protection and emergency arrangements

Written test used to certify staff understanding of arrangements

All staff trained by dummy runs to ensure staff familiar with all equipment operation

Staff training files completed

Full dummy run of defuel carried out from dummy reactor tank to transport cask

Inactive Commissioning Phase completed

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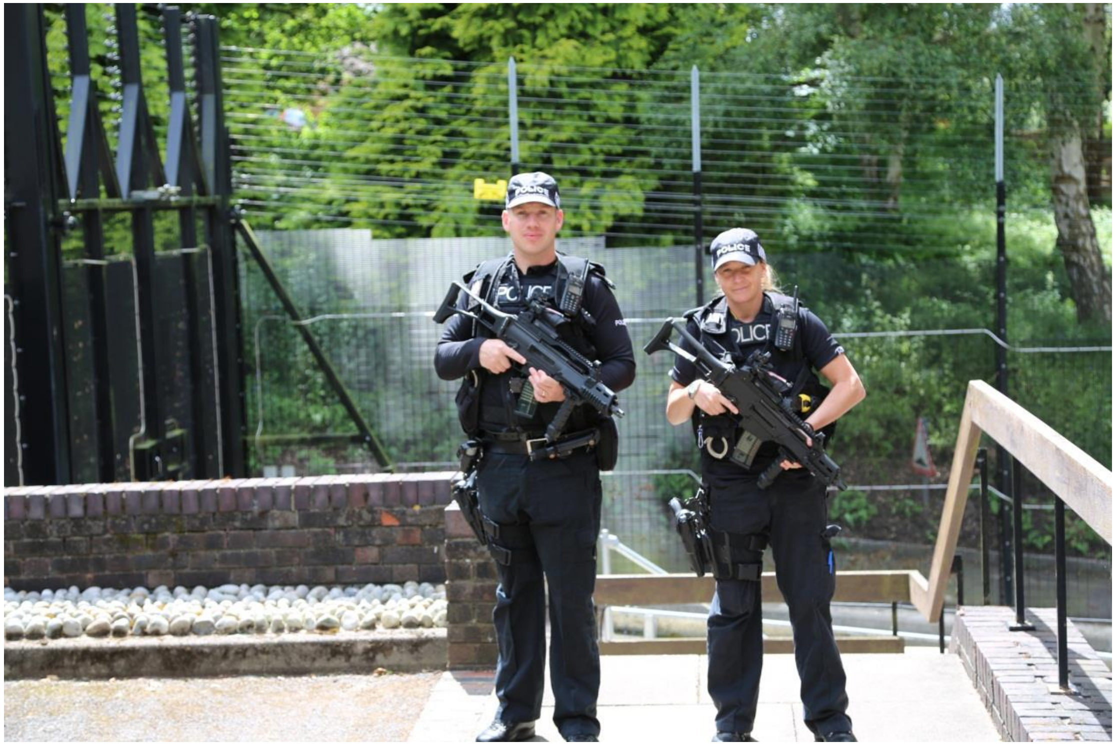
May to July 2014 - Security Arrangements

Civil Nuclear Constabulary (CNC) Officers provided 24/7 armed security during the period of defuel

Special facilities provided by ICRC to support CNC operations



12 June 2014 - At last – Defuel!!

Defuel carried out two elements per day

Two shift system used where possible to spread the load for small team

Each team comprised:

- Defuel Supervisor (DAP)
- Fuel Handling Tool Operator (SQEP)
- Flask Operator (SQEP)
- Control desk operator (SQEP) – to monitor all Control Room alarms during defuel

Late June 2014 - Oh No Not Again! – This time a Heat Wave

Weather forecast: UK sees hottest day of the year

It was hot work up on the flaskway!

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Attaching Fuel handling Tool to Balance Arm

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Connecting FHT to Fuel Element

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FHT raising Fuel element and transferring to Posting Position

Aligning Transfer Flask/Trolley over Core

Lowering Grab through flask to connect to Fuel Element

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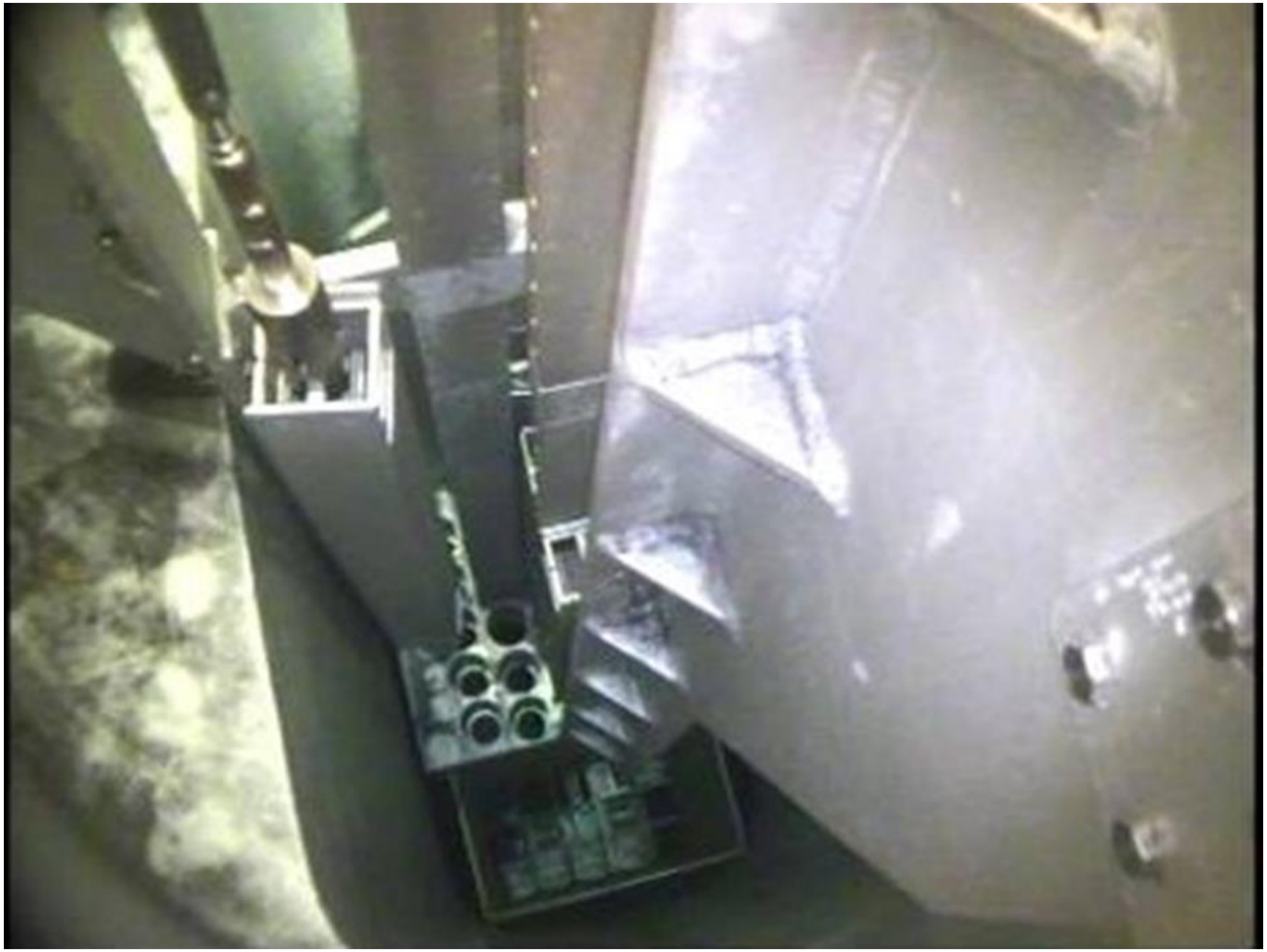
Fuel Element being raised from Core to Transfer Flask



Fuel Element being raised from Core to Transfer Flask

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Rotating Flask to align with Unloading Position in Cask

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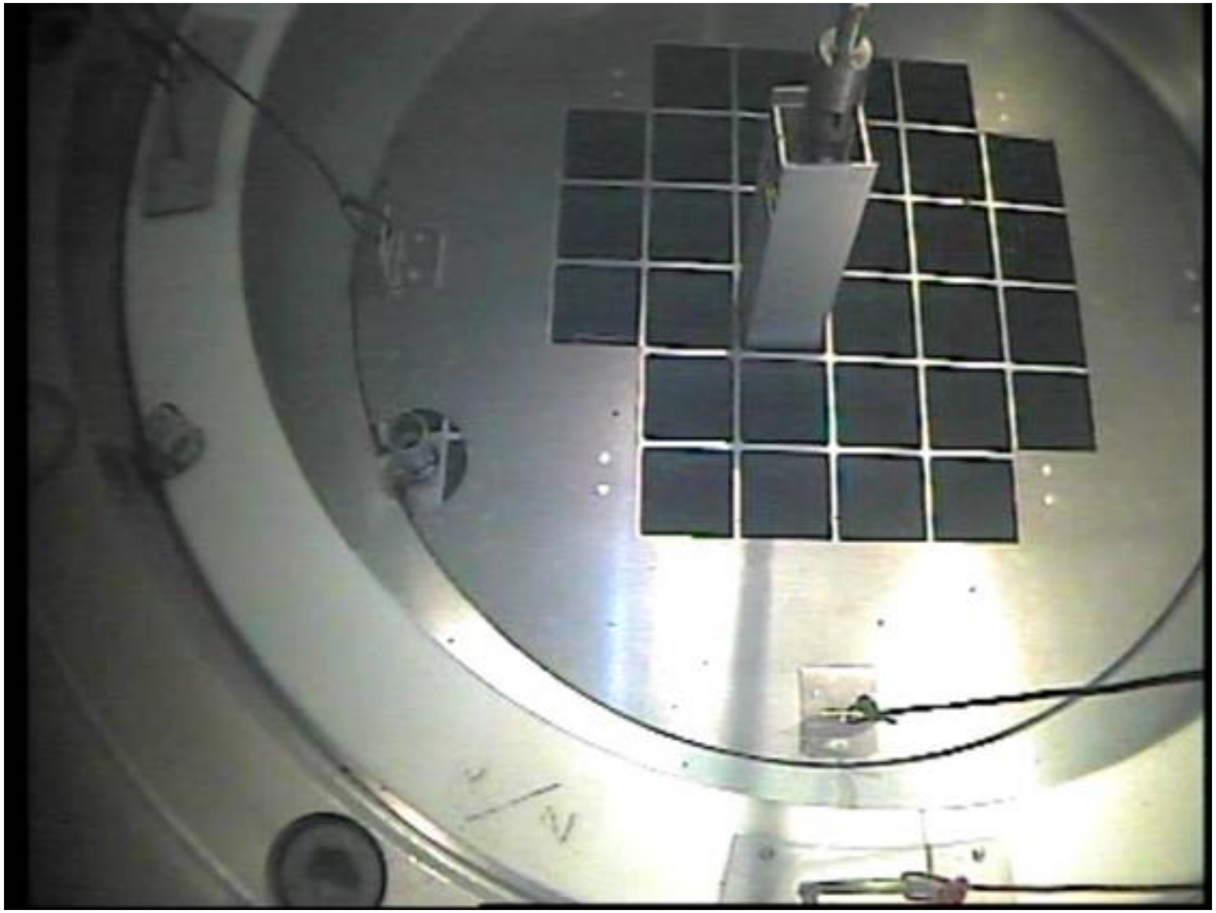
Lowering Fuel Element from Transfer Flask to Transport Cask

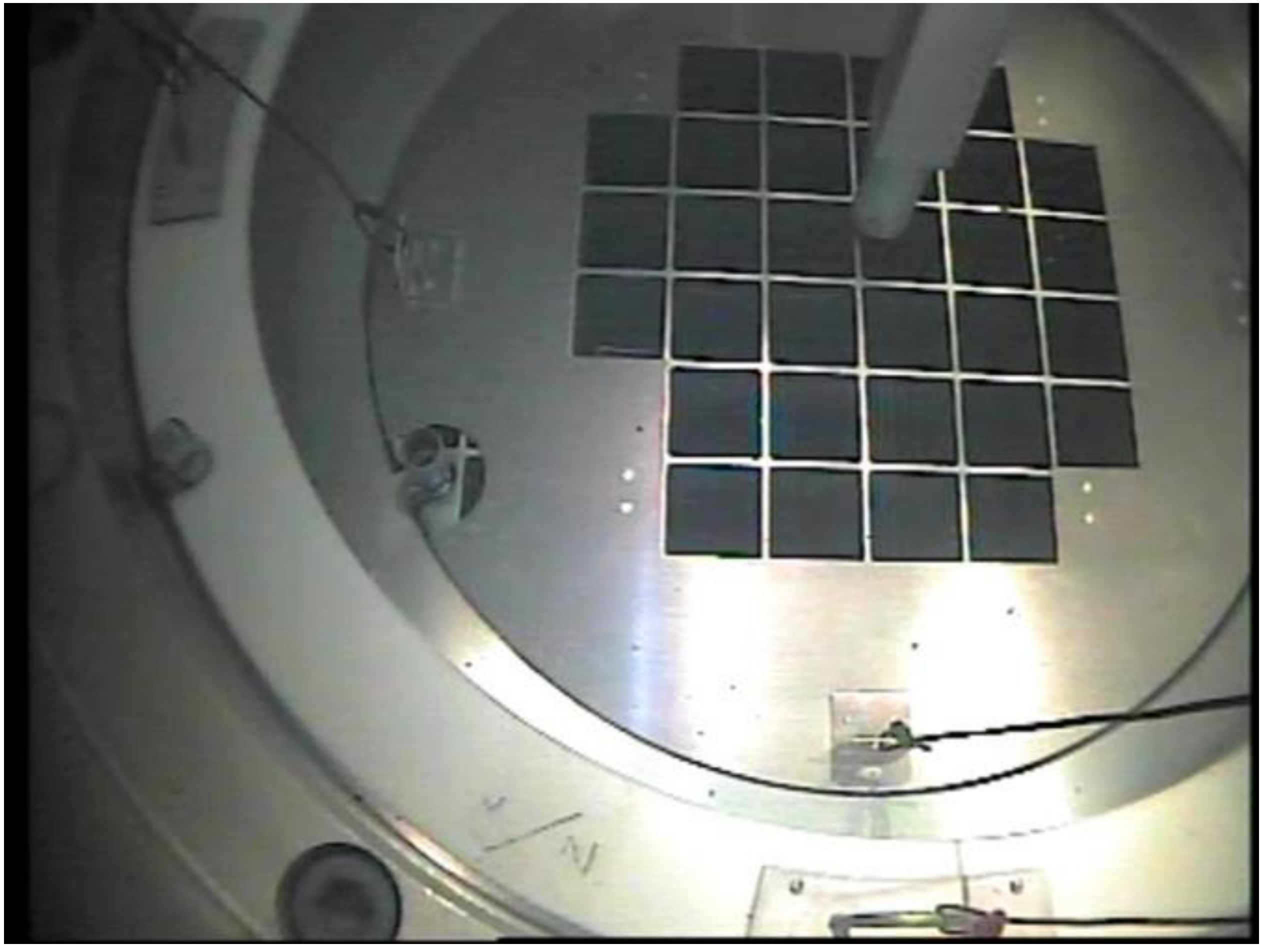
Recording Fuel element Identification Number

Lowering Fuel Element from Transfer Flask into Cask Loading Position



Transferring Fuel Element from Unloading Position to Transport Position in Cask using FHT

Transferring Fuel Element from Unloading Position to Transport Position in Cask



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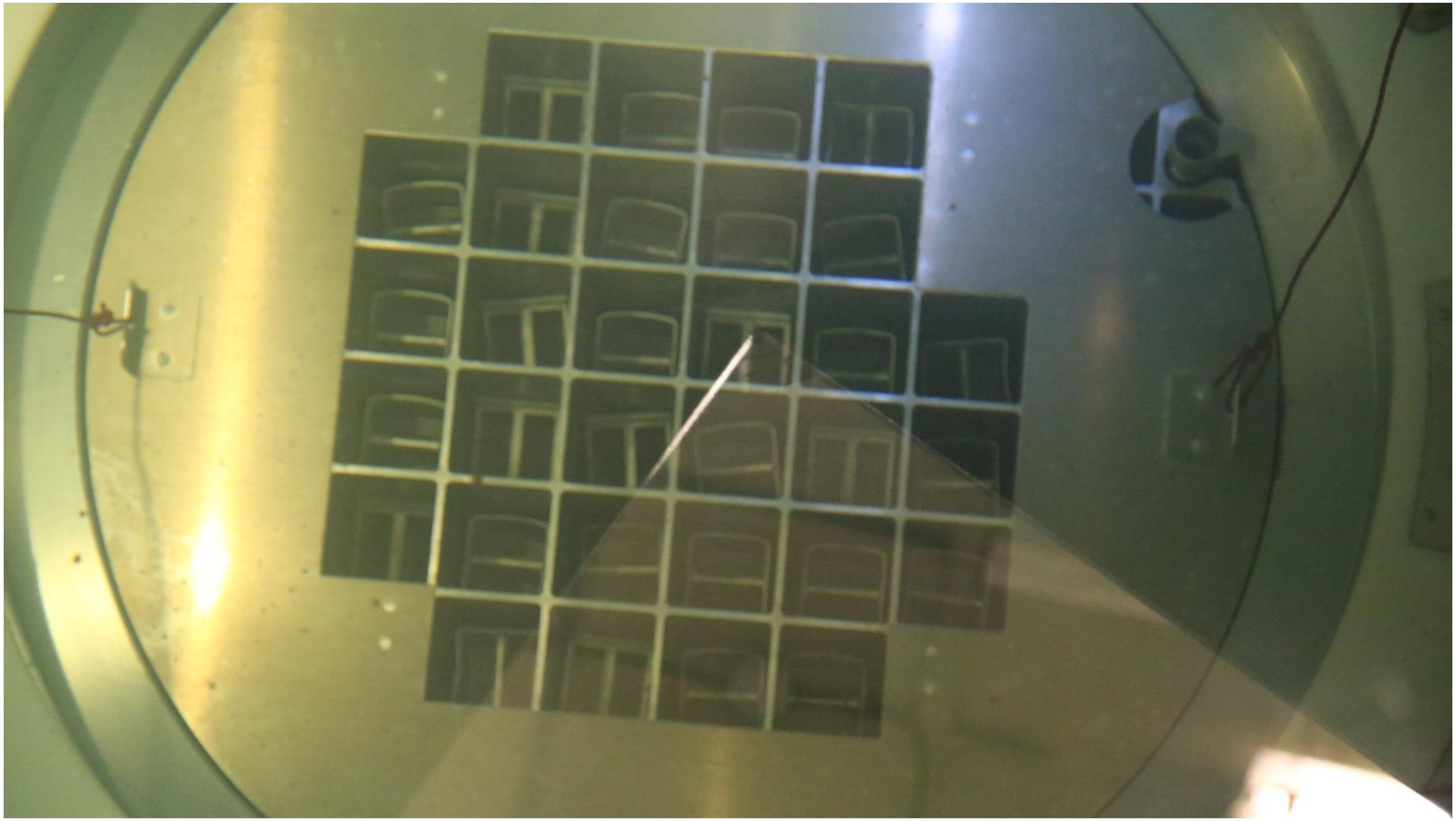
2 July 2014 - Cask Loaded



Raising cask Lid for Refitting to Cask

Lowering Cask Lid through Water Filled Cask Top Hat onto Cask

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17 July 2014 - Loading Transport cask onto Road Vehicle

Operator Doses

Design Dose Restraint Target of < 1mSv per operator

EPD’s set at 100 μSv/h alarm rate and 100 μSv accrued dose

Highest total dose to any operator 20 μSv!!

Design, training and practise paid off

So ultimately what were the key Challenges encountered with Defuel?

Electrical Failure

Delays with supply of equipment

CNC on a university campus

Timescales driven by unavailability of High Security Vehicle

Need for security clampdown over operations and transport dates

Small team

Hot weather

Lessons Learnt

Perceived very low/highly unlikely risks can bite – Electrical failure

Ageing team – enthusiasm doesn’t entirely compensate for years!

Good regulator interaction – Regulatory Interface Forum helped enormously

Dummy runs invaluable to provide confidence for team and regulators

Core Support Structure

Required dismantling in shielded cell to remotely disassemble ILW from LLW

ILW will be placed in shielded flask and transported to Sellafield

LLW transferred to LLWR

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Ground Floor Shielded Cell for Dismantling Core Support Structure

Shielded cell constructed from existing concrete blocks

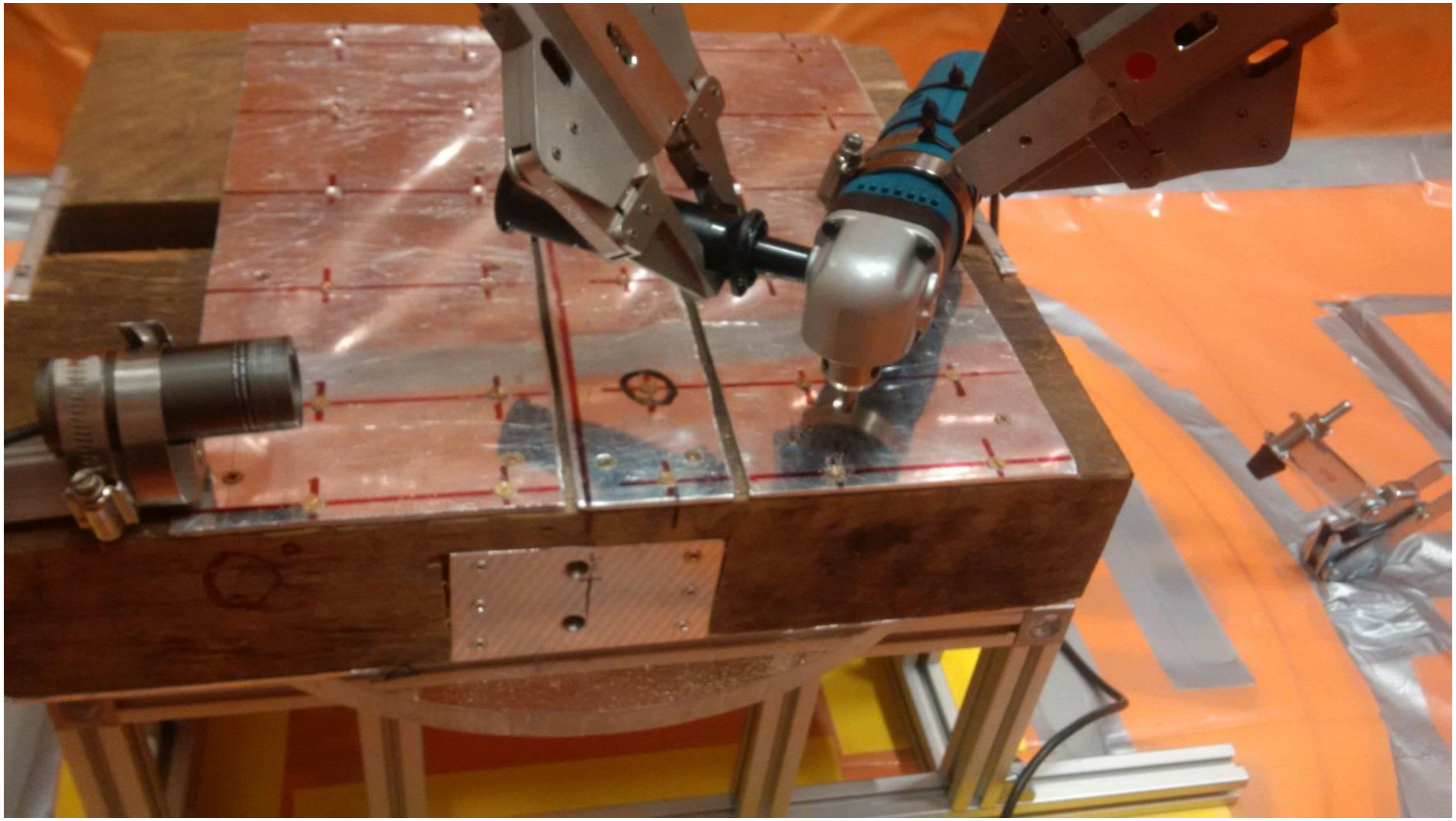
Heavy Duty master-slave-manipulators fitted over cell wall on framework

In cell viewing provided by a series of cameras

Main Viewing Screen

Dummy Core Support Structure in Cell

Practising Dismantling Techniques



Progress since last meeting – Core Support Structure Removal

Core Support Structure successfully removed from reactor tank on 20th April and lowered into shielded cell

Doserates around 50% lower than estimated

Dismantling commenced 24th April

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Operators Dismantling CSS

Remote Cropping Operations

Virtual Reality Research

Potential use for VR in nuclear industry:

- Assist design of ergonomically efficient control systems
- Assist design of shielded facilities
- Training for reactor/plant operation
- Explore clean up options following emergencies
- Training for maintenance of plant
- Assessment of dose uptake

VR has been used within the nuclear industry on a very limited basis

Cost, complexity and timescales perceived to be an issue

Imperial VR PhD research intended to investigate simple, cost effective VR solutions

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VR Shielded Cell Simulator

A low cost simulator was constructed to mimic the core structure shielded dismantling cell

Aim to replicate the functionality of the real-world hardware

Used to explore the use of simulation for training operators prior to carrying out active work

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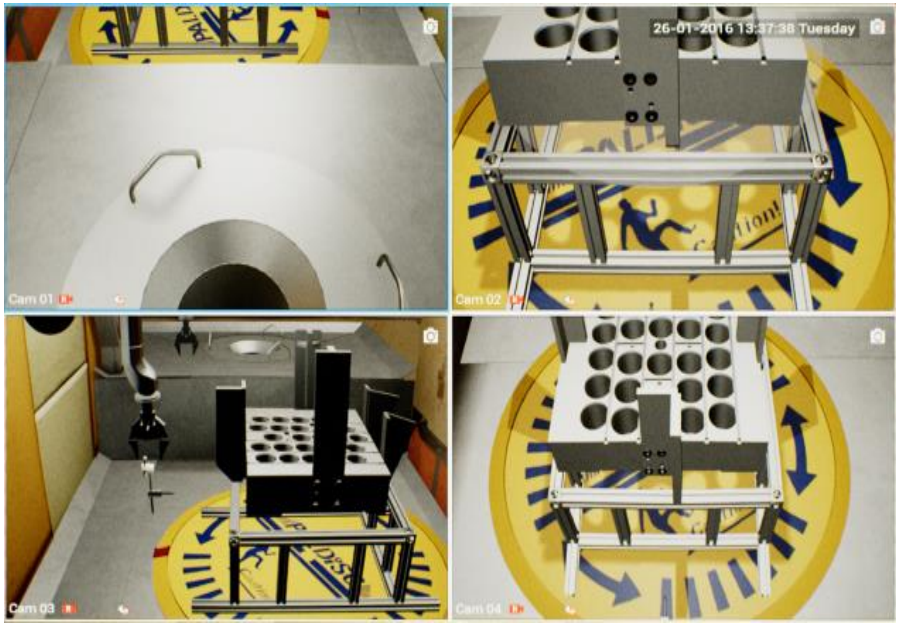
Shielded Cell Simulator – Screenshot

The MSM simulator software was developed using the Unreal Engine (UE4)

The software allows a user to interact with a virtual representation of the shielded cell

User can progress through the process of dismantling the reactor core assembly



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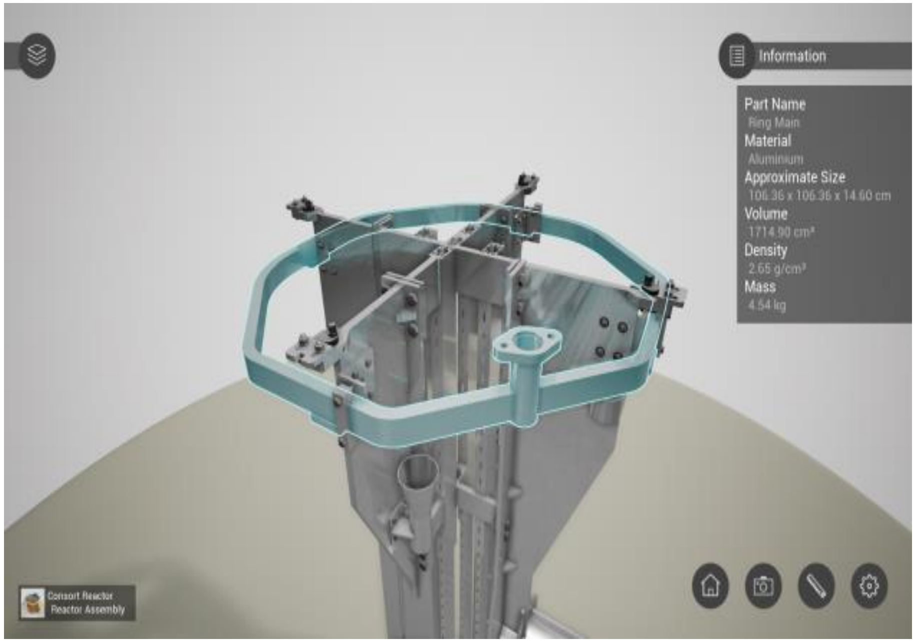
One Early Success

It was identified that with the core assembly stood vertically the MSMs would foul on the ring-main

It would not be possible to dismantle the core assembly

Ring-main would have to be removed before moving the assembly into the shielded cell

This discovery saved significant time, cost and potential dose



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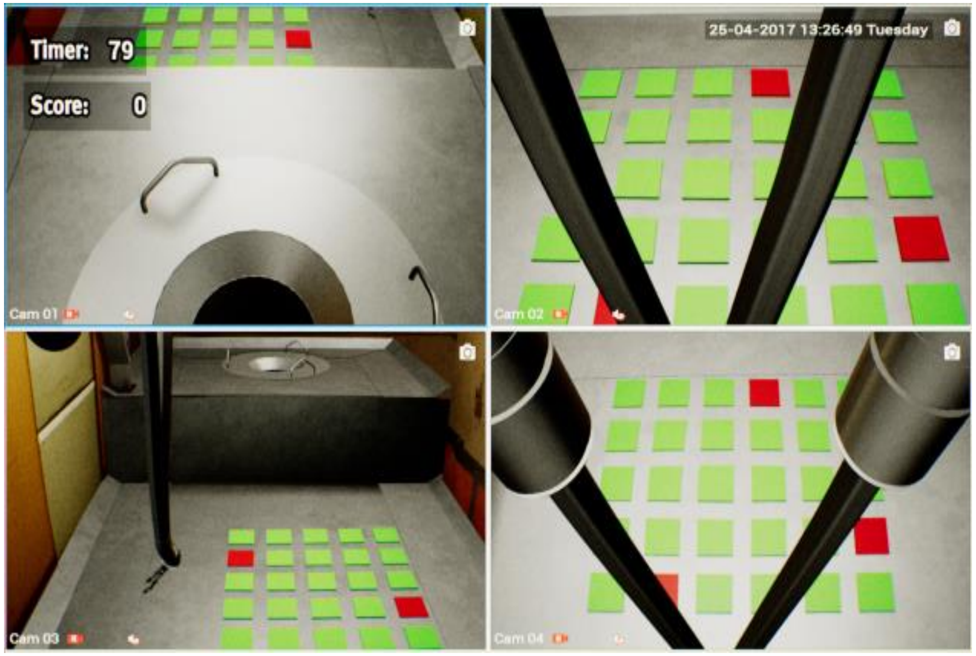
Enhancement of Training

A series of mini games were created, designed to develop MSM skills



The games aim to develop the following set of competencies:

- Spatial Awareness
- Manual Dexterity
- Depth Perception
- Object Manipulation
- Confidence with MSMs
- Interpreting CCTV Images
- Process Familiarisation
- Inverse/Offset Control

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HTC Vive

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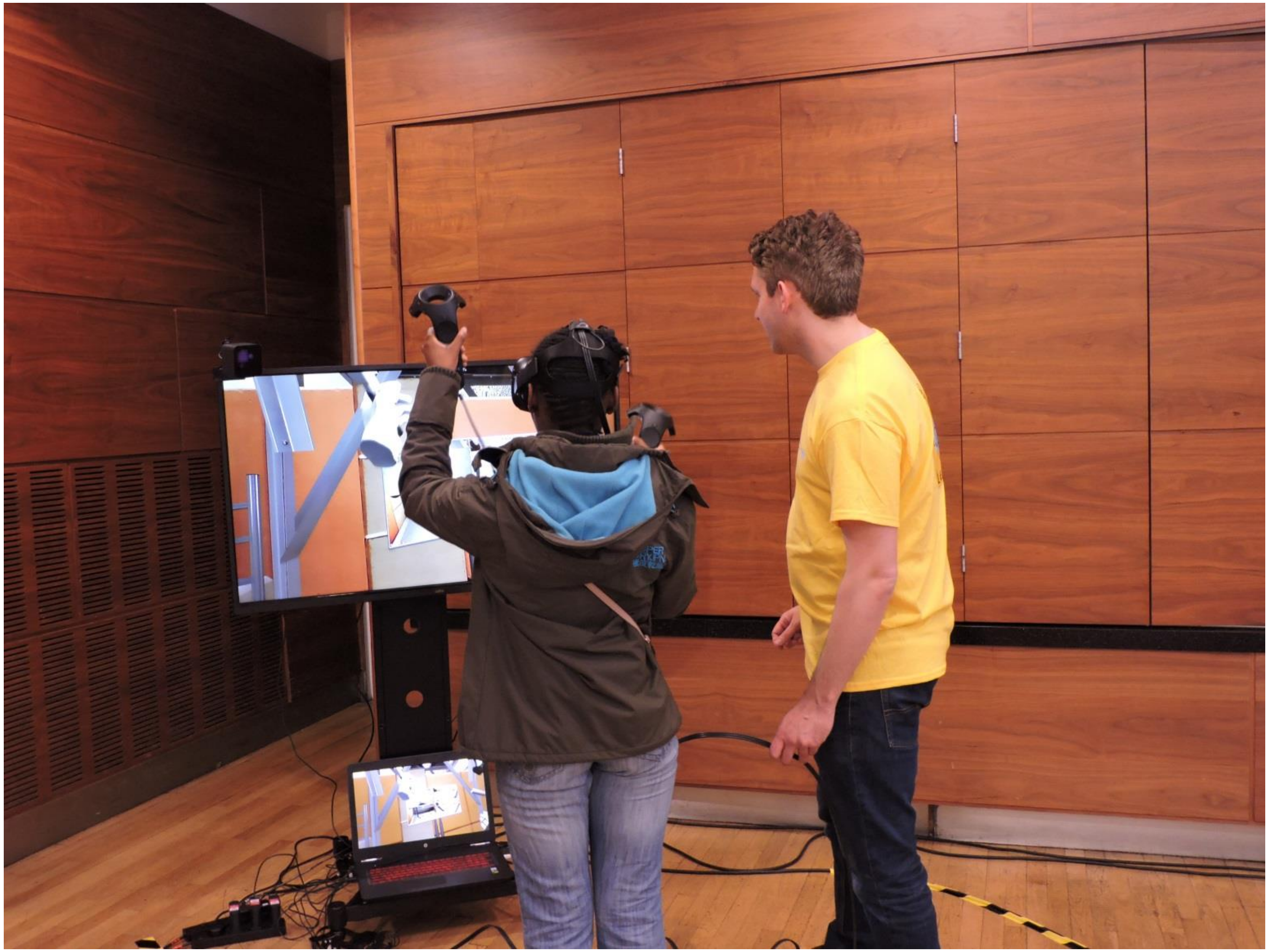
Imperial Festival 2017

Imperial College London

Imperial Festival 2017



Imperial Festival 2017

DSCN2082.MOV

DSCN2084.MOV

So what happens next?

Bio-shield dismantling using diamond wire cutting

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London

So what happens next?

Asbestos strip out followed by demolition

Standard demolition techniques will be employed

Need to consider impact on campus regarding noise etc

Remediate land

De-license Site

Challenges for Land Remediation

Potential ground contamination from underground storage pits

Potential for base slab contamination

Potential for contamination under base slab

Potential for contaminated drainage system

Almost certain buried asbestos waste

Potentially poor records of where underground services lie

Poor records of historic liquid wastes

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Proposed Way Forward

Entire area will be monitored using ScanPlot

Utilizes lab quality Gamma Spectroscopy

This will focus areas for intensive soil sampling

Proposed Way Forward

Soil samples will be taken and analysed off-site

Soil removal will be driven by sample analysis results

Some delay will be experienced due to analysis timescales

Final soil samples will be taken to demonstrate to the regulators that the point of ‘No danger’ has been reached

Imperial College London

So where do you come in?

Conventional sampling techniques have the potential to:

- Miss significant contamination ie Heterogeneity vs. sample data density
- Can be expensive to implement
- Can result in large waste volumes that require to be transported for disposal and challenge existing disposal routes
- Dependent upon laboratory sample analysis
- Uses significant resources
- Open to regulatory challenge re completeness of data

So where do you come in?

Innovative technology to address identified remediation issues and challenges must:

- Have low detection limits
- Perform isotope-specific assay
- Be rugged
- Be reliable in all weather conditions
- Flexible for different terrains
- Be cost effective
- Satisfy all regulatory requirements

One Final Plea

One Final Plea

Please remember the KISS principle!

One Final Plea

Please remember the KISS principle!

KEEP IT SIMPLE STUPID

Imperial College London

One Final Plea

Please remember the KISS principle!

KEEP IT SIMPLE STUPID

However innovative the monitoring method please keep the technology as simple as possible to ensure minimum failure modes

Your Challenge

And so back to that NDA total decommissioning cost budget

Your Challenge

And so back to that NDA total decommissioning cost budget

£234 Billion

Your Challenge

And so back to that NDA total decommissioning cost budget

£234 Billion

To reduce this cost technological innovation will be critical

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Your Challenge

And so back to that NDA total decommissioning cost budget

£234 Billion

To reduce this cost technological innovation will be critical

Good luck!!

Any questions?

TRANSCEND Annual Meeting 2019

Theme 2: Site Decommissioning, Deconstruction and Remediation

Rebecca J Lunn, Dept. of Civil and Environmental Engineering, University of Strathclyde

Luc J Vandeperre, Dept. of Materials, Imperial College London

Theme 2: Technical Challenges

Decommissioning nuclear sites

- waste retrieval,
- decontamination & deconstruction,
- Care and maintenance/final end-state
  - containment and/or remediation of the remaining structure and surrounding land.

Key challenges

- **limiting radiation exposure** for the workforce,
- **restricting the spread** of radionuclides during deconstruction and 'care and maintenance' phases
  - in groundwater, surface water & airborne particulates,
- **minimising the volume** of contaminated waste for disposal.

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Research Aims

To develop **new technologies for monitoring, remediation and containment**

that serve to **minimise the volume** of radioactively contaminated **waste for disposal**,

for application **prior to**, **during** and **after** retrieval, deconstruction and decontamination operations.

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Work Packages Overview

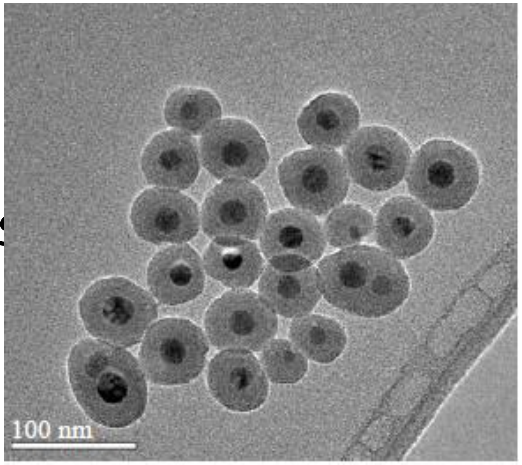
WP2.1 Colloidal-Silica Grout

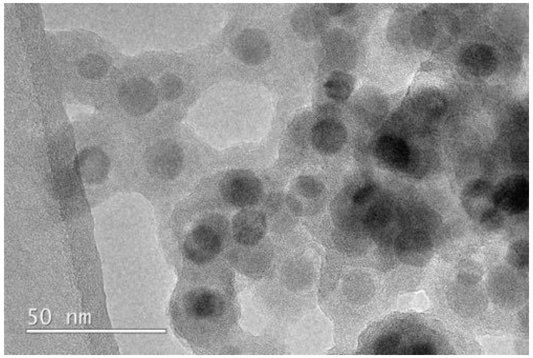
Grouts which gel and solidify. Can be injected under small pressure in low permeability materials and generate e.g. hydraulic barrier

M. Pedrotti, C. Wong, G. El Mountassir, R.J. Lunn, Tunnelling and Underground Space Technology, 70, 2017, 105-113
Pedrotti M., C. Wong, G. El Mountassir, R.J. Lunn (2018). Engineering Geology, 243: 84-100
Pedrotti, M., Wong, C., El Mountassir, G., Renshaw J. C., & Lunn, R (2018 – revision) - Desiccation behaviour of colloidal silica grouted sand: A new material for the creation and report of near surface hydraulic barriers. Engineering Geology

Main research focus TRANSCEND:

- **treatment of surface soils to inhibit air- and water-born radionuclide migration**





TEM in collaboration with E.Cali, Imperial

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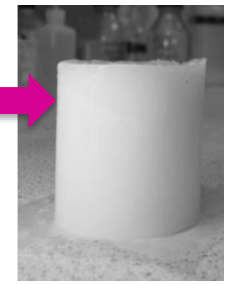
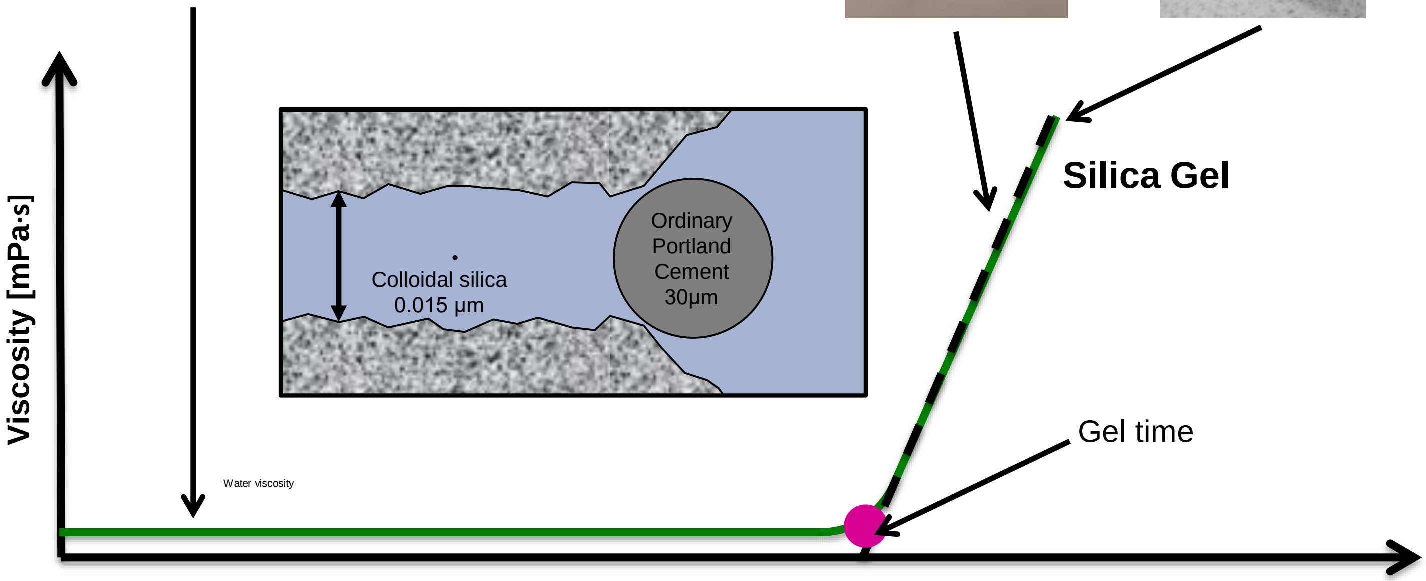
Soil stabilisation and barrier formation

Colloidal Silica

+ Accelerator (Salt solution) =



Injectable ground barriers



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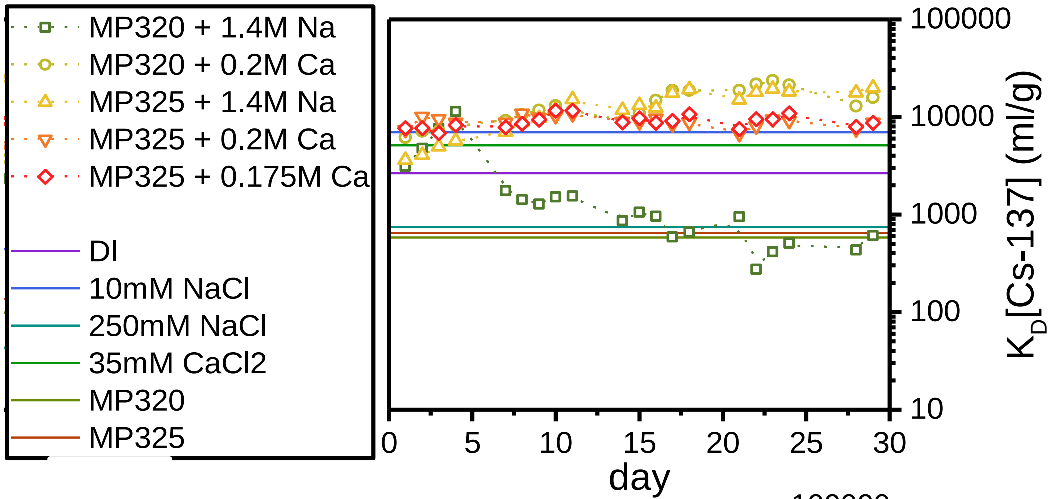
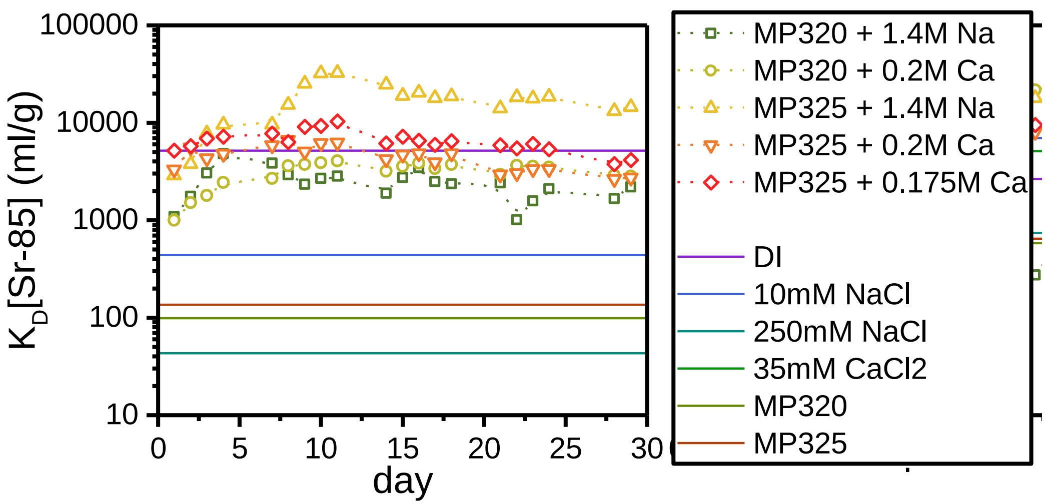
Increased sorption capacity in grouted soils



- ➢ **Increased sorption capacity**

- ➢ **No mobilisation of existing Cs or Sr in the environment**



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Work Packages Overview

Specific Objectives

1. Soil stabilization
2. Inhibition of airborne particulates and surface and groundwater transport
3. In-situ vitrification
4. Increased sorption capacity – provide chemical as well as hydraulic barrier
5. Combine with Electro-kinetics

1 PDRA

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Contact : Becky Lunn, University of Strathclyde

Work Packages Overview

WP2.2 Electrokinetic Ground Remediation:
Electrokinetic (EK) techniques use low voltage DC current to control migration of, remove or degrade contaminants in soils.

EK test cells at laboratory and intermediate(m)-scales

- remove, focus or degrade contaminants
- direct subsurface water, chemical and colloid flow

Numerical models of EK processes

- to inform full-scale on-site application by nuclear site holders

Work Packages Overview

Specific objectives:

- adapt low-energy ex-situ electrokinetic remediation and volume minimisation techniques already proven on AWE legacy wastes to other UK nuclear legacy wastes and sites;
- develop in-situ **low-energy electrokinetic fencing** (for groundwater) **and remediation** (for soils and sediments), to limit the spread of active contaminants, and minimise soil volumes for subsequent treatment; and
- combine EK with colloidal silica grouting to minimise soil contamination for in-situ vitrification.

1 PDRA + 1 PhD at Southampton

Contact : Andrew Cundy, University of Southampton

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Work Packages Overview

WP2.3 Non-Invasive Monitoring of Soil Contamination, Structural Degradation, Assessment and Repair.

- Muon scattering tomography for the detection of chloride corrosion in structural reinforcement

  1 PhD @University of Strathclyde, UoS

  Contact : Marcus Perry, University of Strathclyde

- Tools for improved identification of ground contamination associated with contaminated in-ground infrastructure that may remain at the site end state

  1 PhD @Lancaster University, NDA

  Contact : Malcolm Joyce, Lancaster University

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Work Packages Overview

WP2.3 Non-Invasive Monitoring of Soil Contamination, Structural Degradation, Assessment and Repair.

- In-situ bio-remediation of damaged concrete structures
  1 PhD @ University of Strathclyde, Cavendish Nuclear

Contact : Becky Lunn, University of Strathclyde

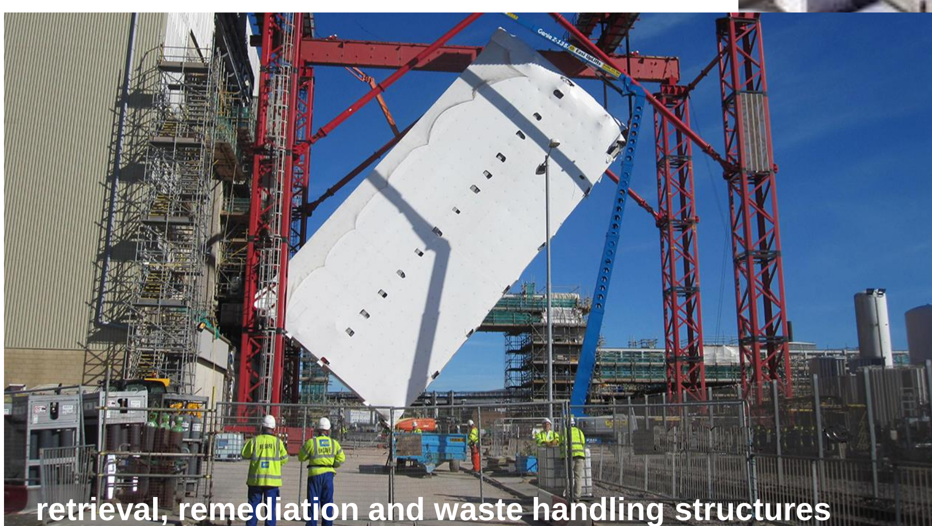
- Develop algorithms to determine gamma dose rates based on restricted information
  1 PhD @University of Surrey, Sellafield

Contact : David Read, University of Strathclyde

The scale of the decommissioning problem?


Legacy sites

New build power


retrieval, remediation and waste handling structures

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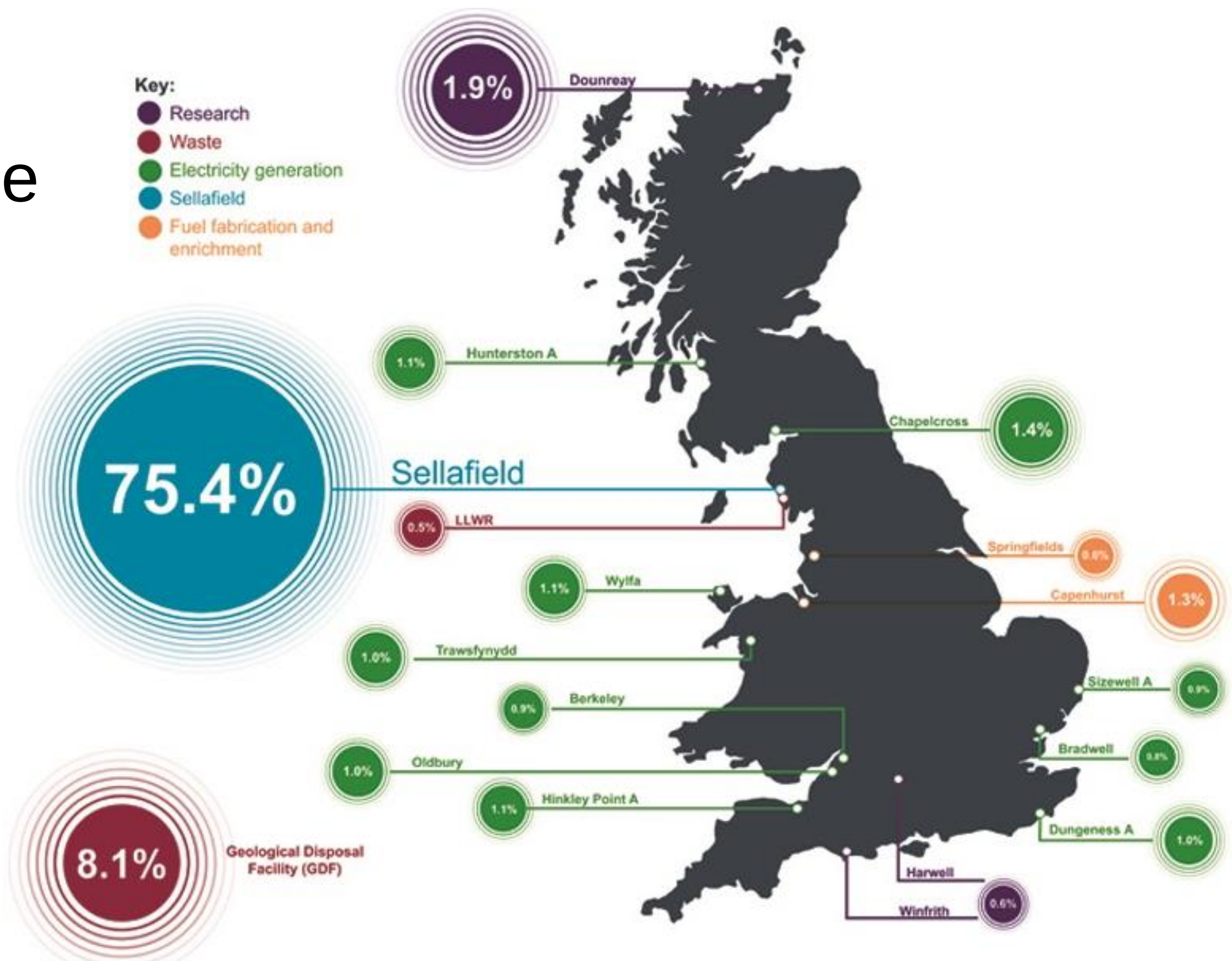
Legacy sites: Decommissioning and deconstruction

Current NDA estimate of the discounted cost is **£234 billion**

New build?



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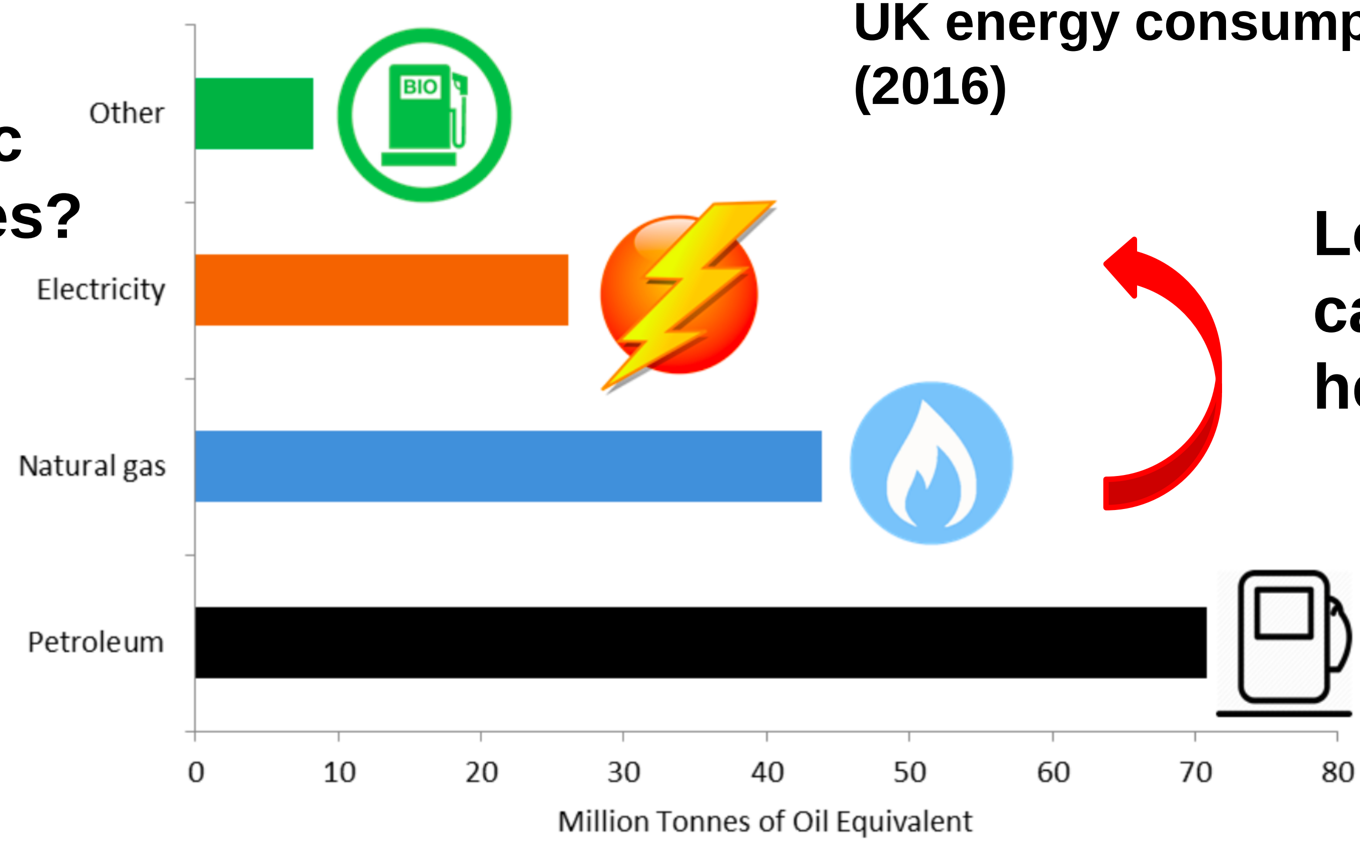
Demand

Electric vehicles?



UK energy consumption (2016)

Low-carbon heating?

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UK Nuclear New Build Programme

- Planning up to **19GW of new nuclear power capacity**
- Nuclear power is needed to meet global carbon targets
- First new reactors expected to be operational in the mid-2020s

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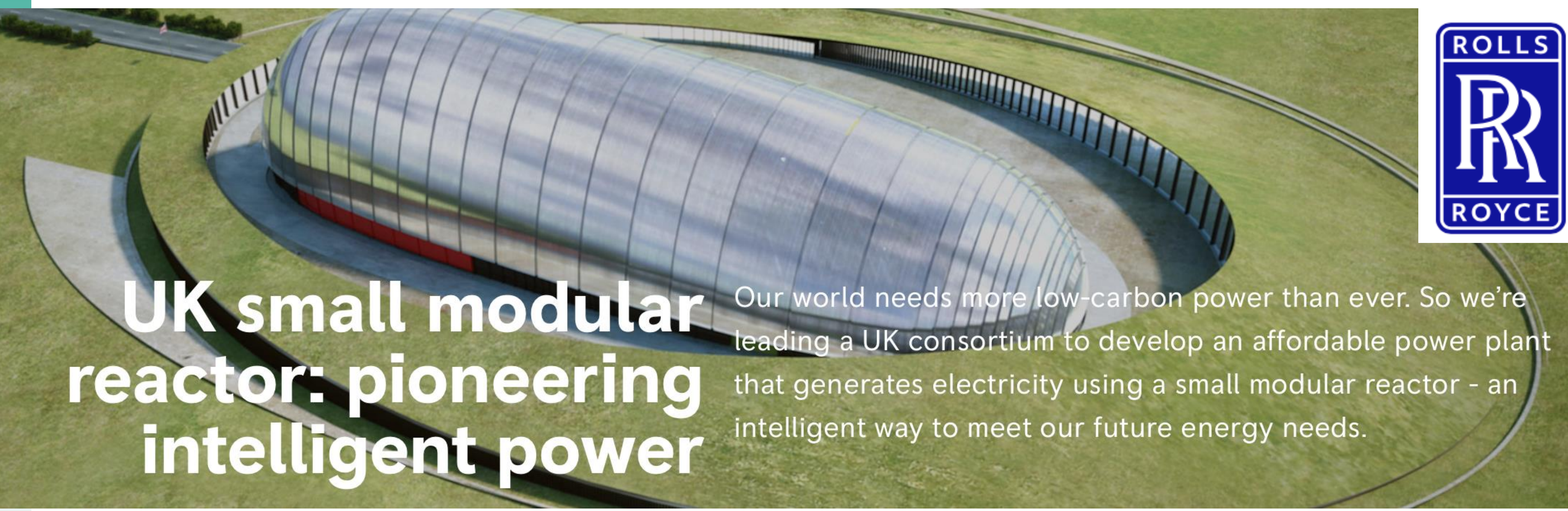
UK SMR Programme

8 organisations invited to participate in the Advanced Modular Reactor Feasibility and Development Project



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UK Geological Disposal Programme

20 December 2018 — News story

Government launches new policy to deal with radioactive waste

RWM begins the search for a site to locate a Geological Disposal Facility

BUT: Numerous examples of failure in GDF programmes

- largely on public acceptability

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The good, the bad

SCIENTIFIC AMERICAN.

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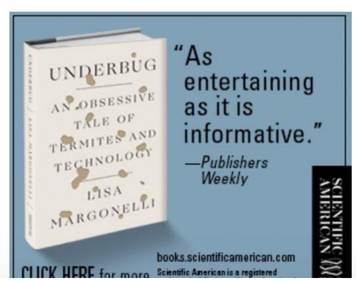
SUSTAINABILITY

How Nuclear Power Can Stop Global Warming

Nuclear power is one of the few technologies that can quickly combat climate change, experts argue

By David Biello on December 12, 2013



Flowers Report (1976):

there should be no further commitment to nuclear energy unless it could be demonstrated that long-lived highly active radioactive wastes could be contained for the indefinite future

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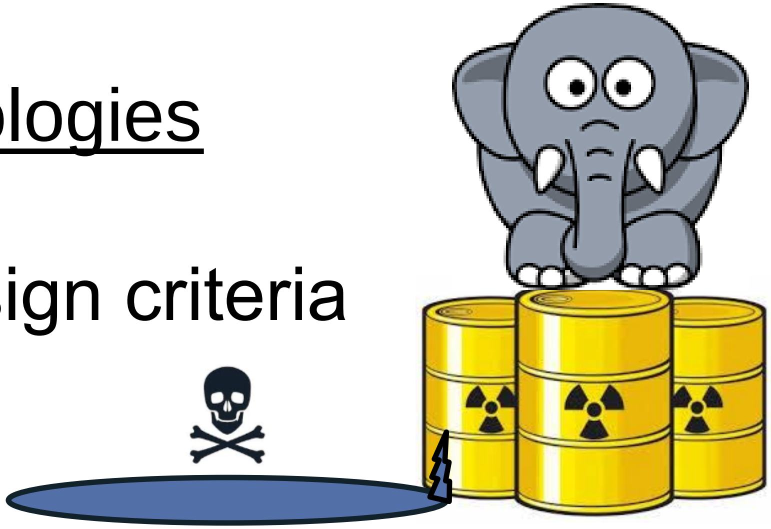
… and the ugly

How might we ensure that next generation nuclear goes ahead without resulting in a similar decommissioning and disposal legacy?

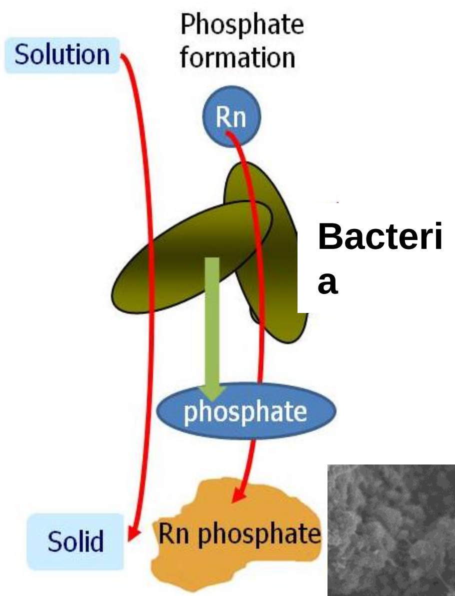
<u>Opportunity for Theme 2 technologies</u>

- Make disposability and ‘decommissionability’ key design criteria

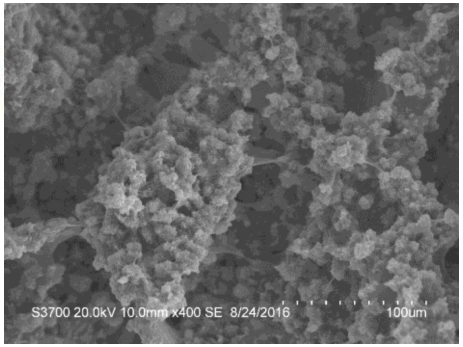


Waste reduction – new build and decommissioning plant

Decommissionable Concrete



Hydroxyapatite precipitated by *Pseudomonas* biofilms on the surface of OPC

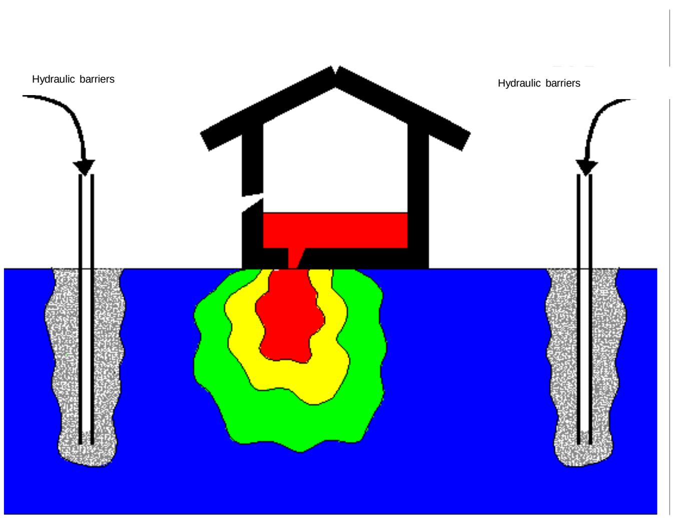


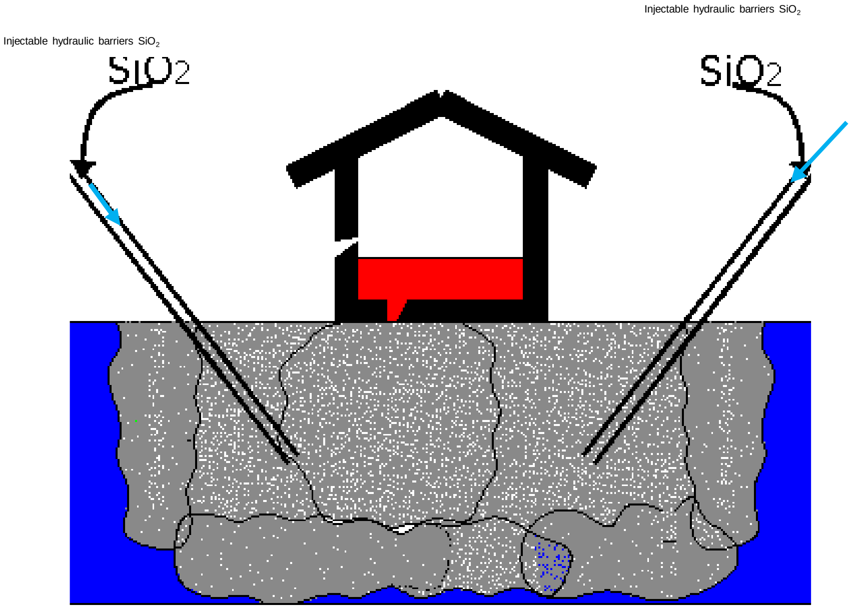
EPSRC Prosperity Partnership (**£4.2M**: £2.1M EPSRC, £2.1M industry)

- Pre-treatment of concrete surface
- Microbial precipitation of apatite layer
  - high adsorption capacity and low permeability to trap radionuclides
  - Readily-removable from the remaining structure

Risk reduction

Pre-treat the ground during the construction phase to inhibit future migration





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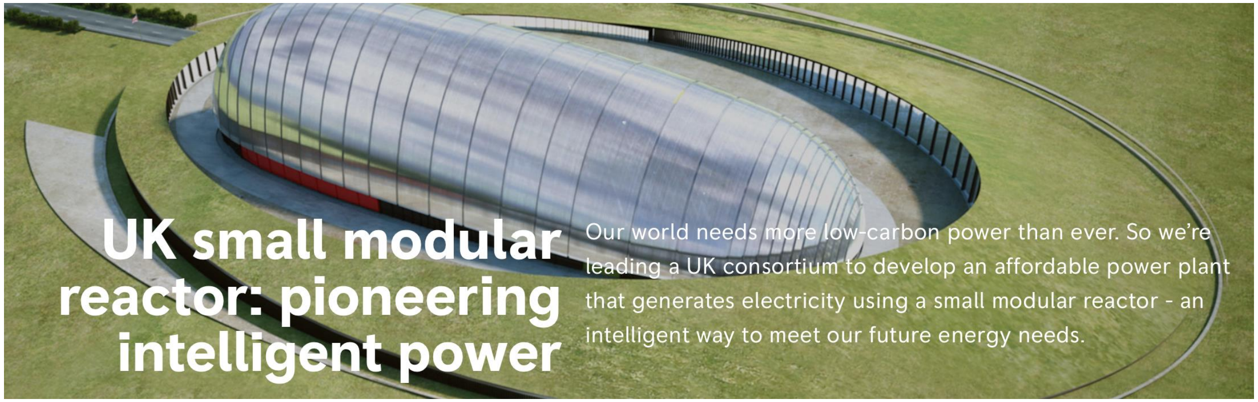
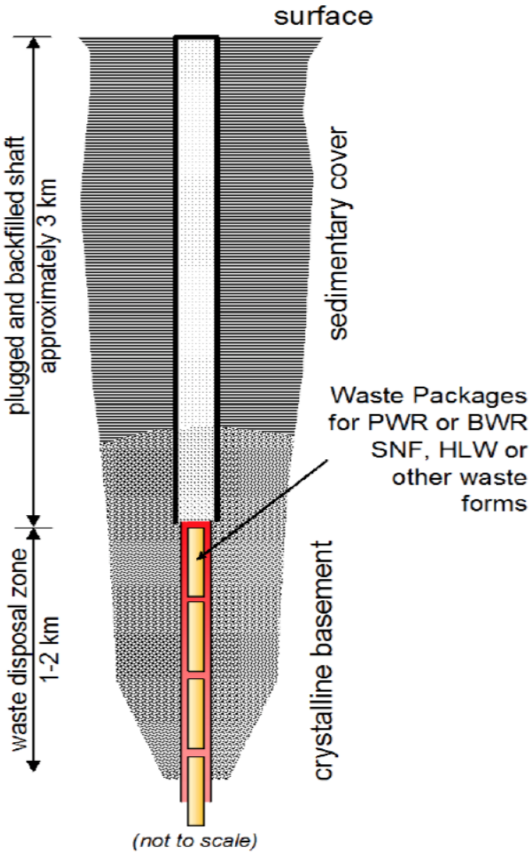
Design for Disposability



Could we design for easy borehole disposal and remove our reliance on GDF development?



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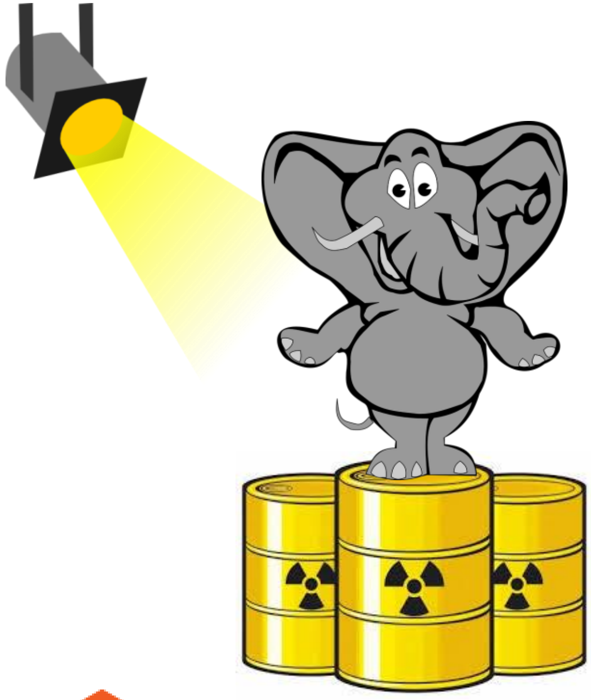
Design for Easy Decommissioning and Disposal

- In-built electrodes to enable movement of radionuclides using electro-kinetics?
- EK fencing?
- In-built monitoring tools and strategies (including the surrounding ground and structures)
- Pre-constructed ground barriers
- Develop readily decommissionable materials in modular form

Wide applicability of Theme 2 technologies

Decommissionability and disposability of the plant should be constraints in all new build design – including waste handling plant

- Avoid leaving a similar waste legacy
- Decreased risk of legal challenge
- Increased public confidence



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Theme 2 Summary – job done!

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Transformative Science and Engineering for Nuclear Decommissioning

Inhibiting Radionuclide Migration during Deconstruction and Decommissioning using Colloidal Silica Grout: THE INJECTION PROCESS

Matteo Pedrotti,

Christopher Wong, Dr. Pieter Bots, Dr. Gráinne El Mountassir, Prof. Rebecca Lunn

University of Strathclyde

TRANSCEND Annual Meeting 2019

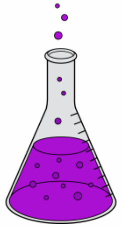
April 3rd 2019
Bath, UK

Energy
For a Low Carbon Future

Colloidal silica grout

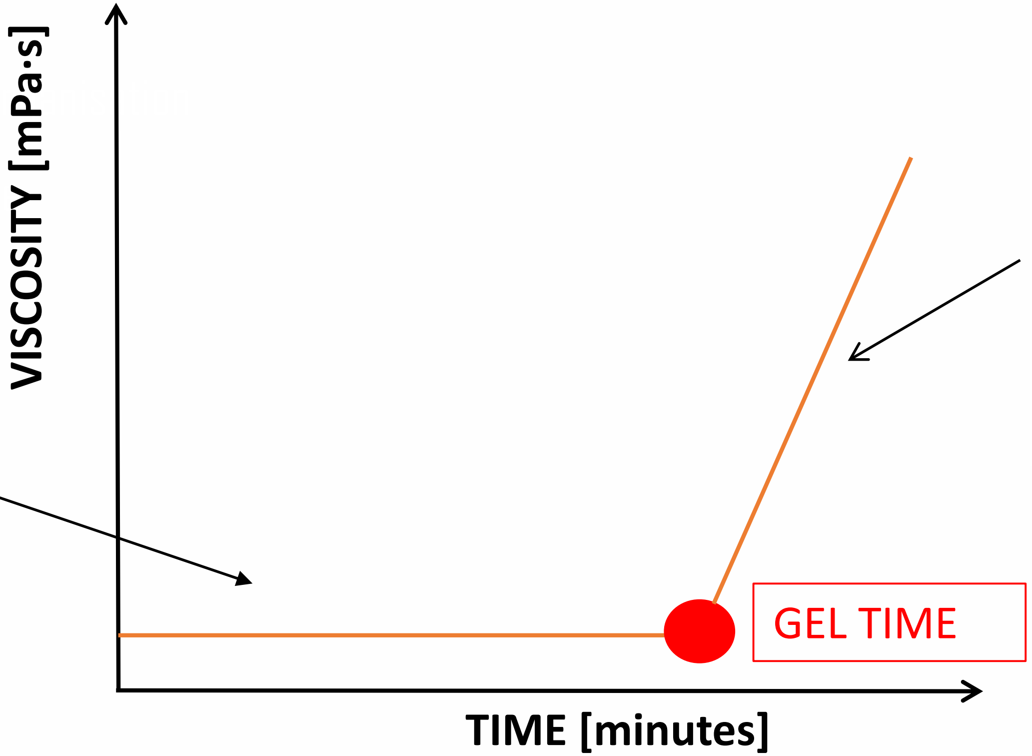
COLLOIDAL SILICA GROUT

mixing



ACCELERATOR

COLLOIDAL SILICA



GEL

COLLOIDAL SILICA GROUT

DISPERSE

GELLING

GEL

COLLOIDAL SILICA GROUT

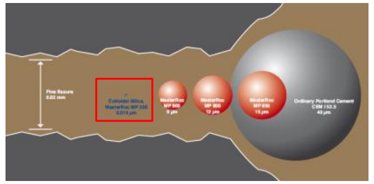
LOW INITIAL VISCOSITY

Initial viscosity ~ 5mPa·s

CONTROLLABLE GEL TIME

Gel time can vary from minutes to days

ABILITY TO PERMEATE FINE-GRAINED LAYER THANKS TO SMALL PARTICLE SIZE



Particle size from tens to hundreds of nanometres

NO VOLUME CHANGES UPON GELLING

NON-TOXIC

Common addictive in food production

LOW HYDRAULIC CONDUCTIVITY AFTER GELLING

K=1E-10 m/s

Conductivity of the gel alone 1E-10 - 1E-11 m/s
Bulk hydraulic conductivity dependent on achieving good penetration of the pores.

COLLOIDAL SILICA GROUT

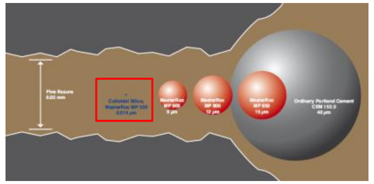
LOW INITIAL VISCOSITY

Initial viscosity ~ 5mPa·s

CONTROLLABLE GEL TIME

Gel time can vary from minutes to days

ABILITY TO PERMEATE FINE-GRAINED LAYER THANKS TO SMALL PARTICLE SIZE



Particle size from tens to hundreds of nanometres

NO VOLUME CHANGES UPON GELLING

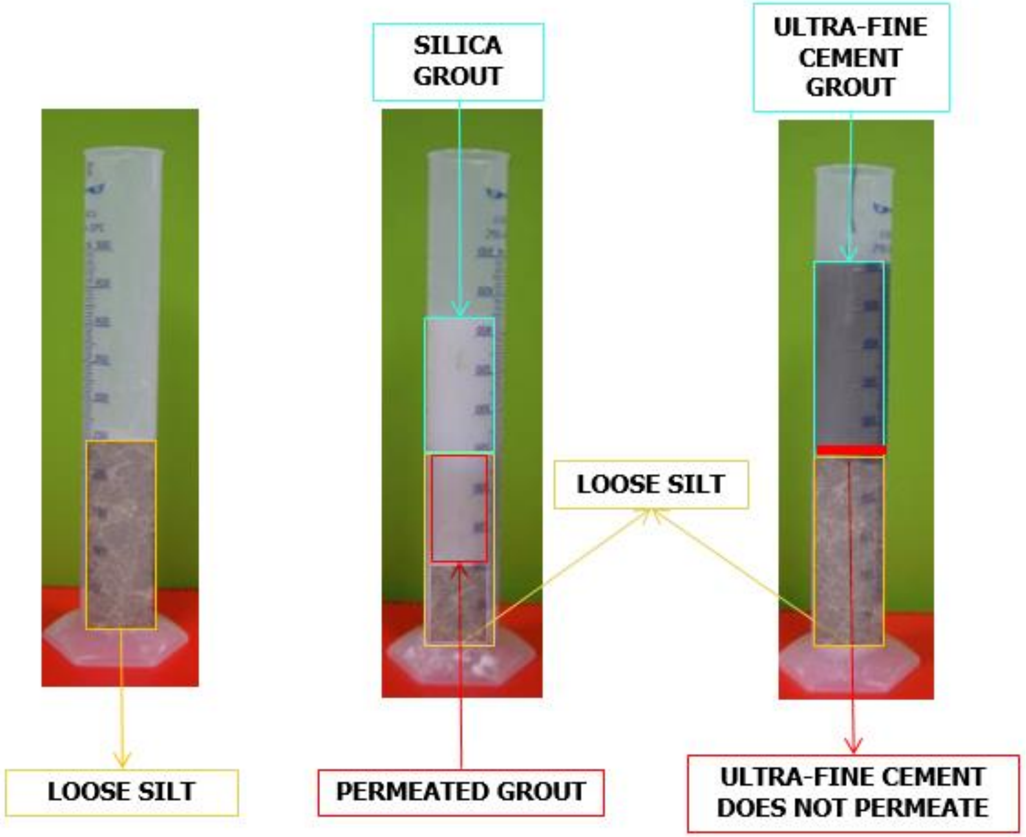
NON-TOXIC

Common addictive in food production

LOW HYDRAULIC CONDUCTIVITY AFTER GELLING

K=1E-9 m/s

Conductivity of the gel alone 1E-10 - 1E-11 m/s
Bulk hydraulic conductivity dependent on achieving good penetration of the pores.



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COLLOIDAL SILICA GROUT

LOW INITIAL VISCOSITY

Initial viscosity ~ 5mPa·s

CONTROLLABLE GEL TIME

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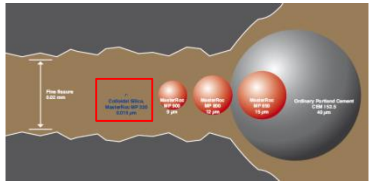
ABILITY TO PERMEATE FINE-GRAINED LAYER THANKS TO SMALL PARTICLE SIZE



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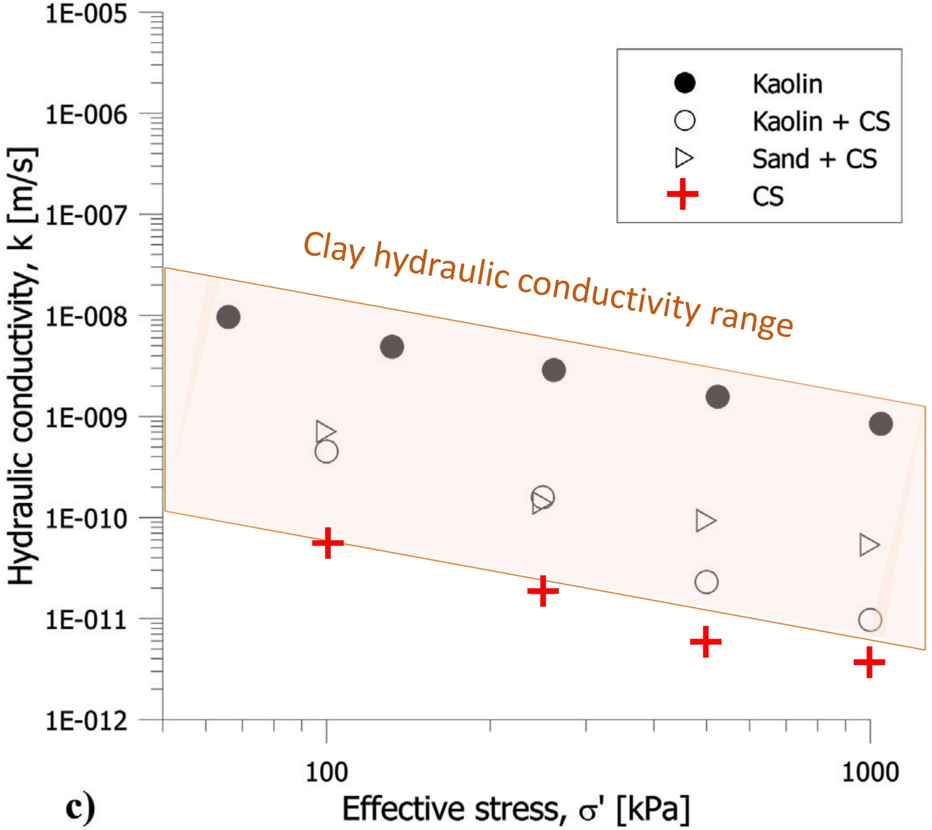
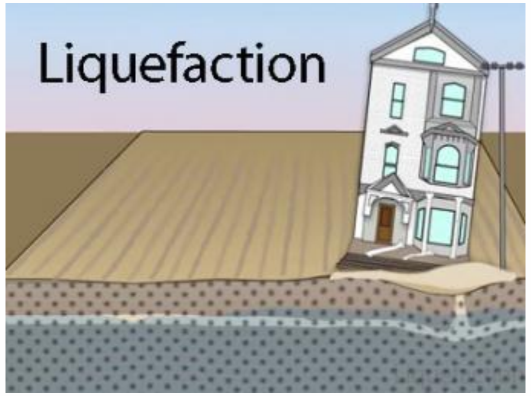
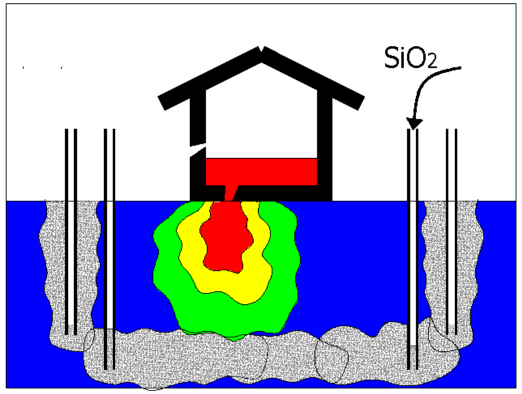


c)

COLLOIDAL SILICA APPLICATIONS



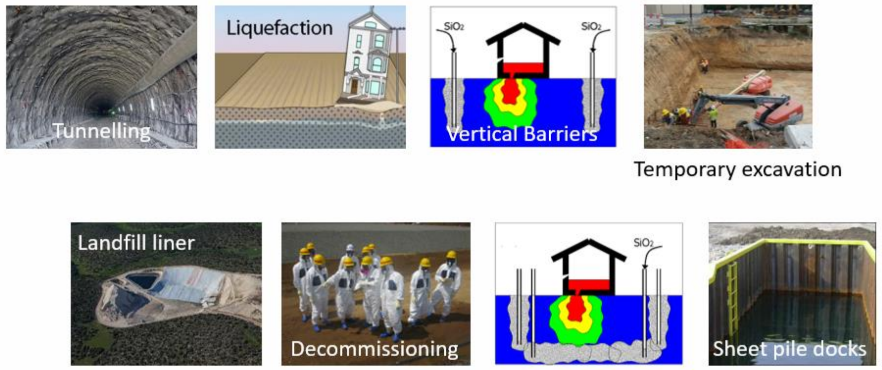
Temporary excavation consolidation



Horizontal Barriers

COLLOIDAL SILICA INJECTION

COLLOIDAL SILICA APPLICATIONS

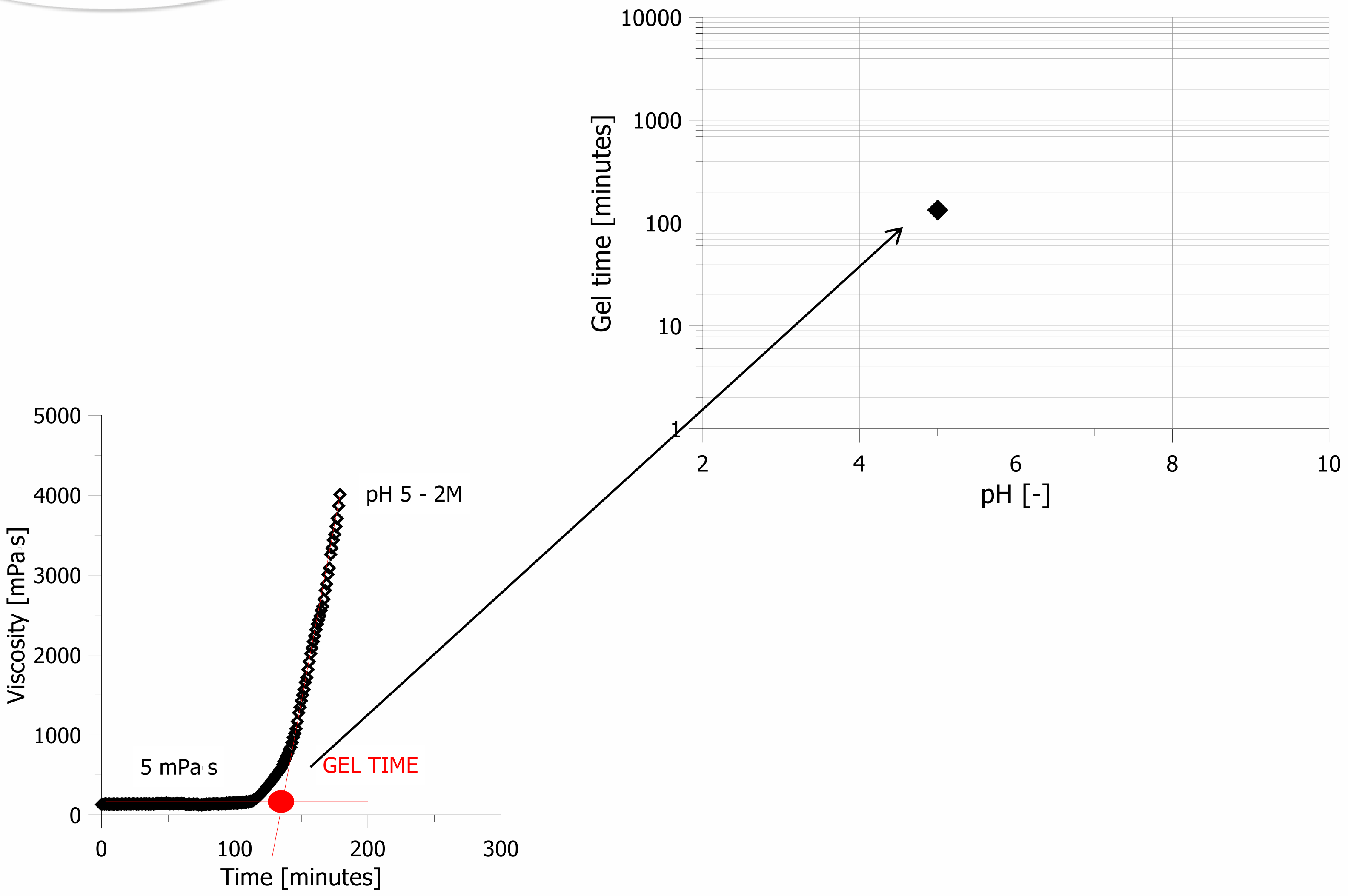


ABILITY OF DESIGNING AND PREDICTING
THE INJECTION PROCESS

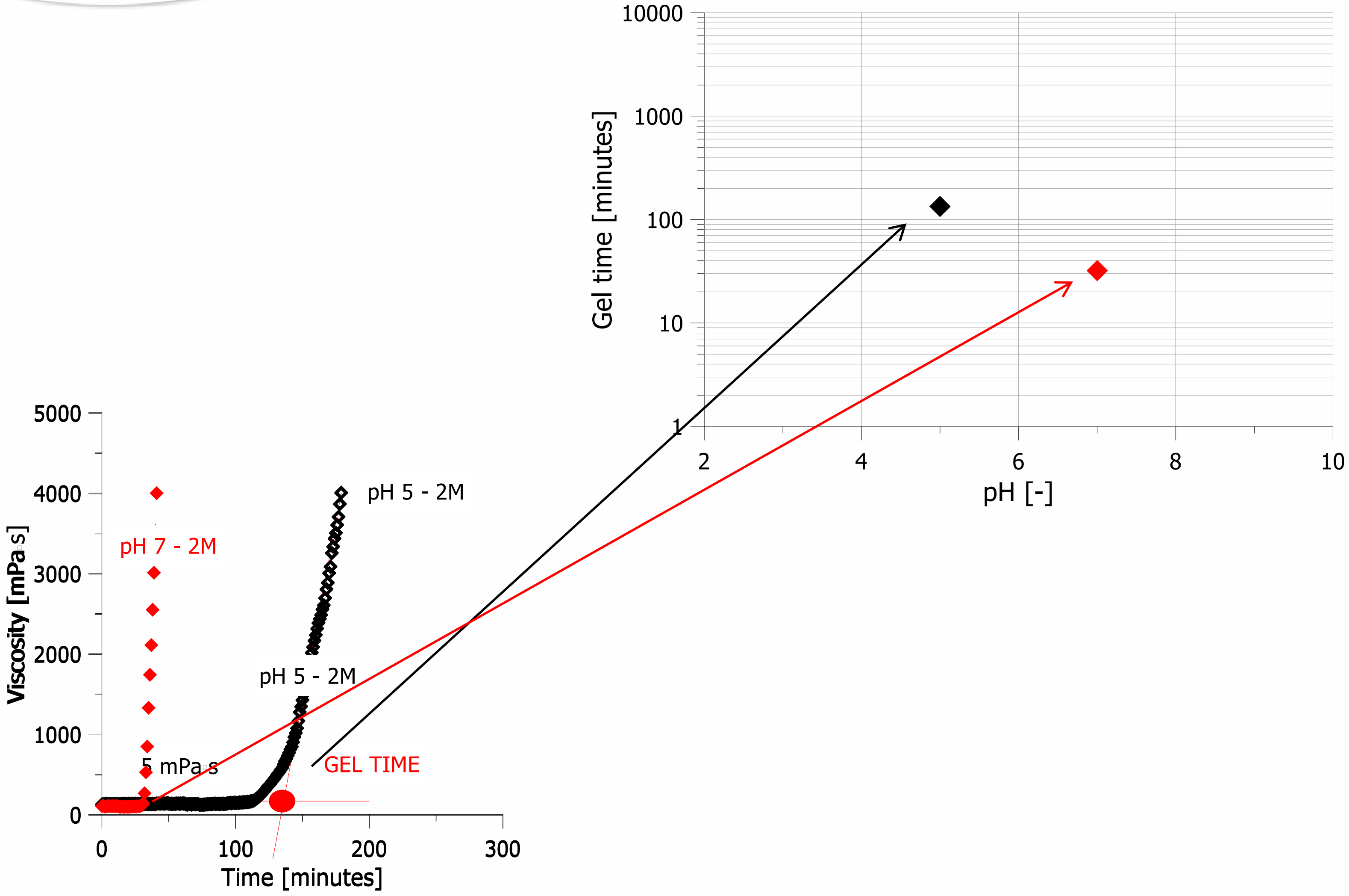
1. Colloidal silica injectability with different **types of ground**
2. Control colloidal silica gel time against different **environmental factors**
3. Predict evolution of colloidal silica **viscosity over time**
4. Modelling colloidal silica **flow** during injection
5. **Monitoring** and evaluating the grouting process

Gel time

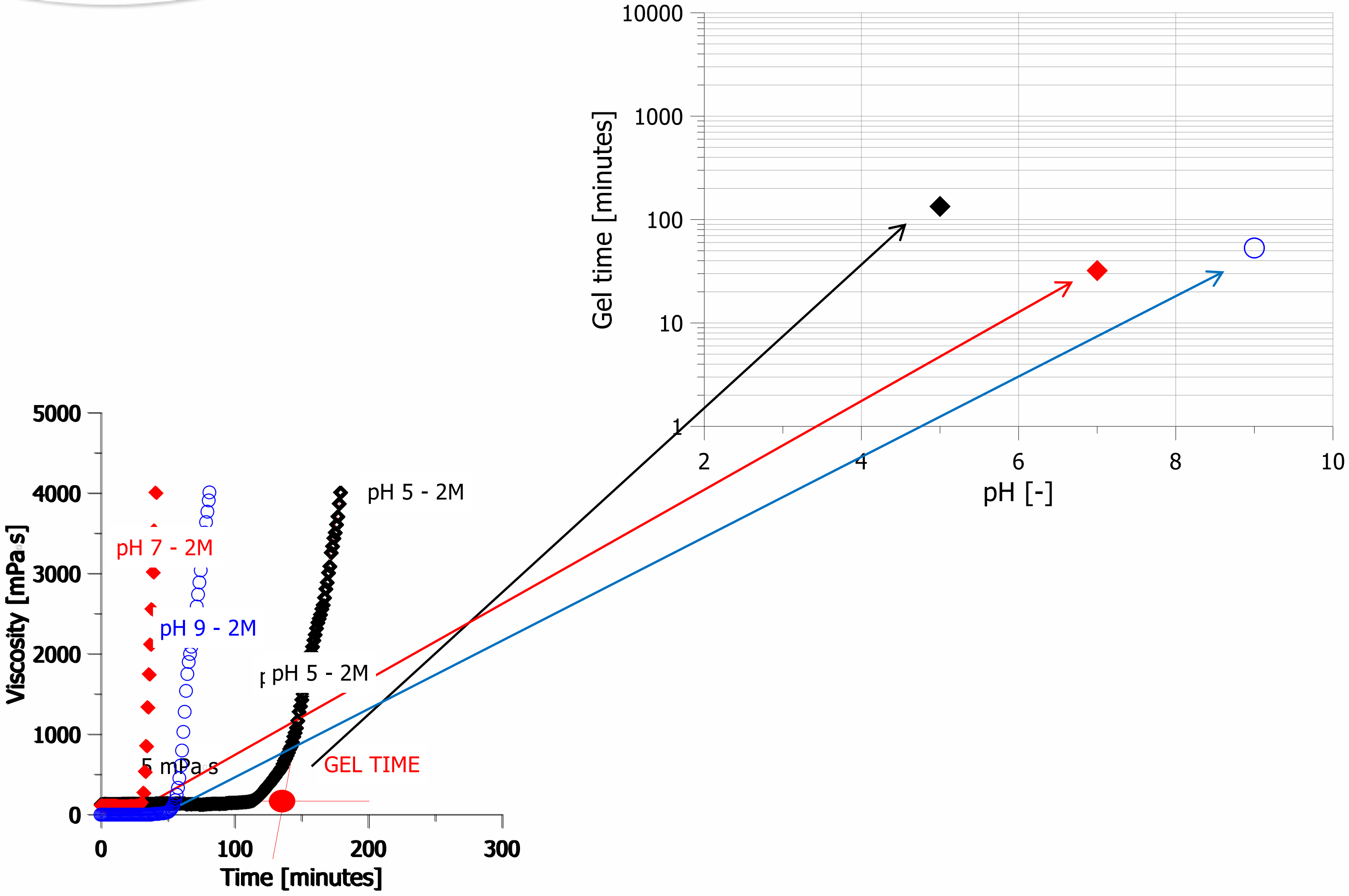
COLLOIDAL SILICA GEL TIME



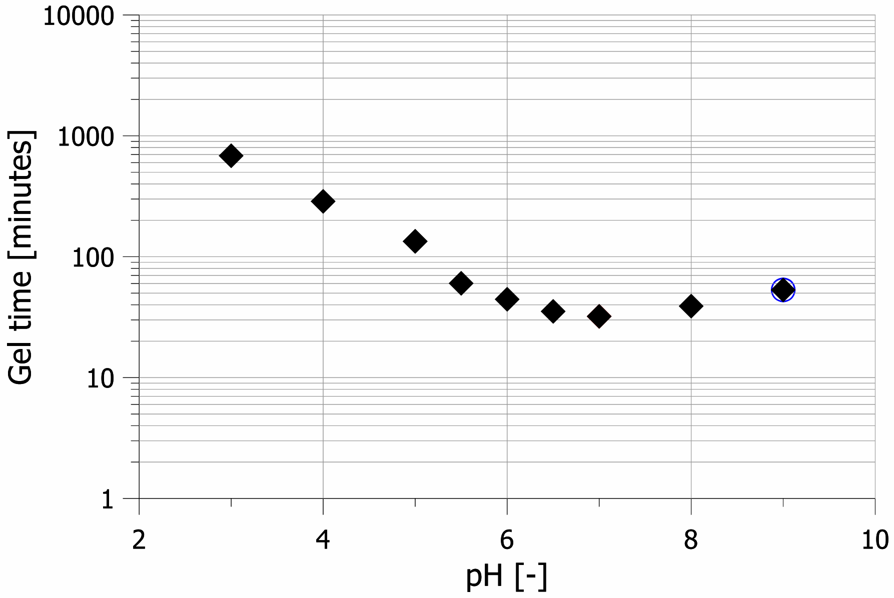
COLLOIDAL SILICA GEL TIME

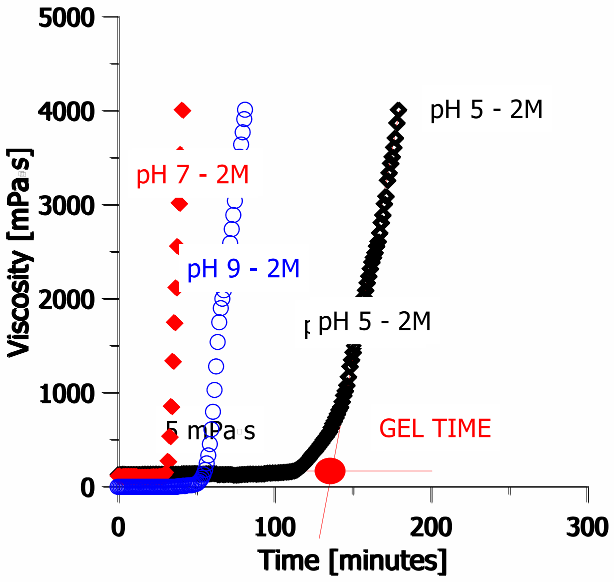


COLLOIDAL SILICA GEL TIME

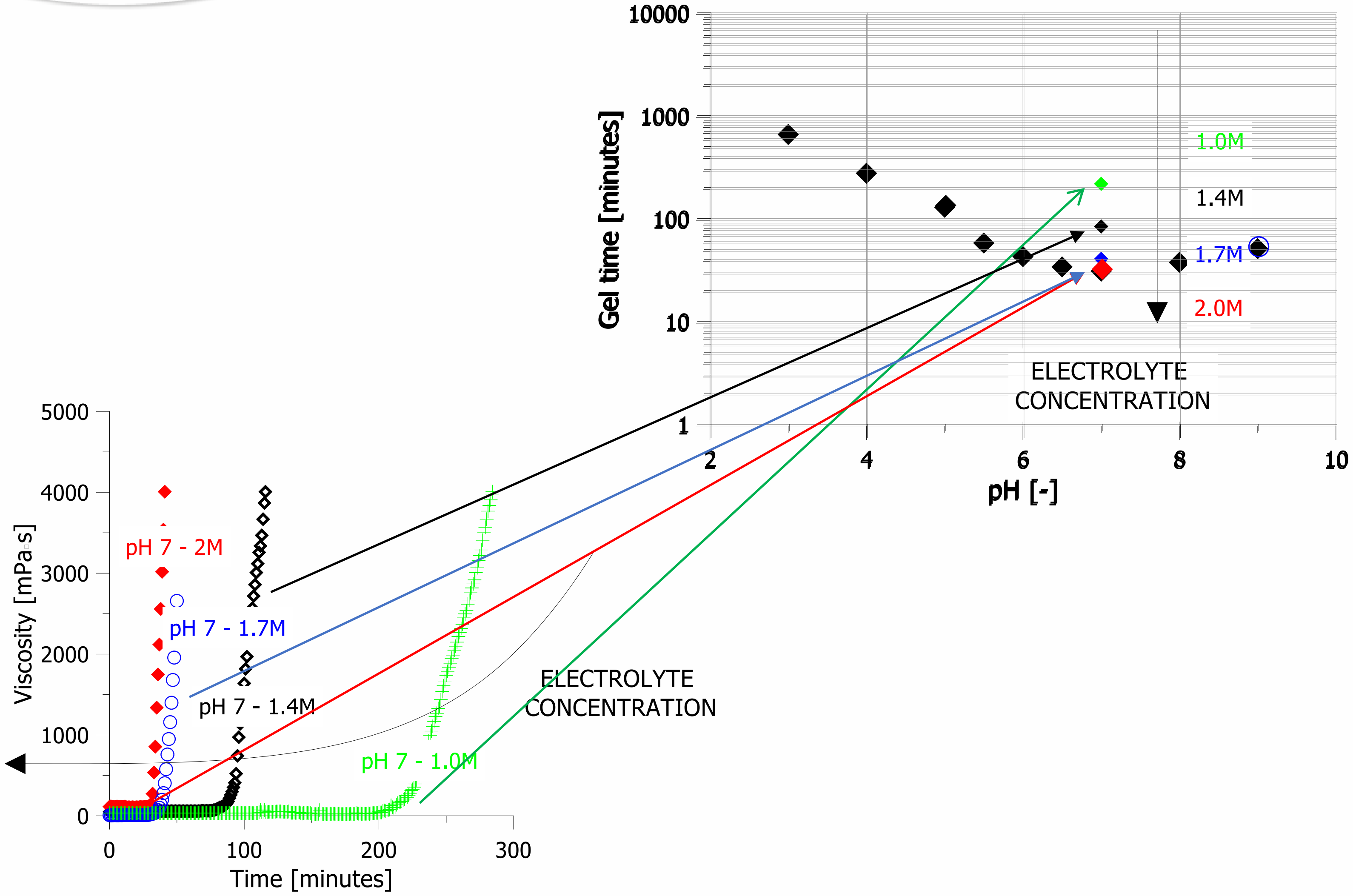


COLLOIDAL SILICA GEL TIME





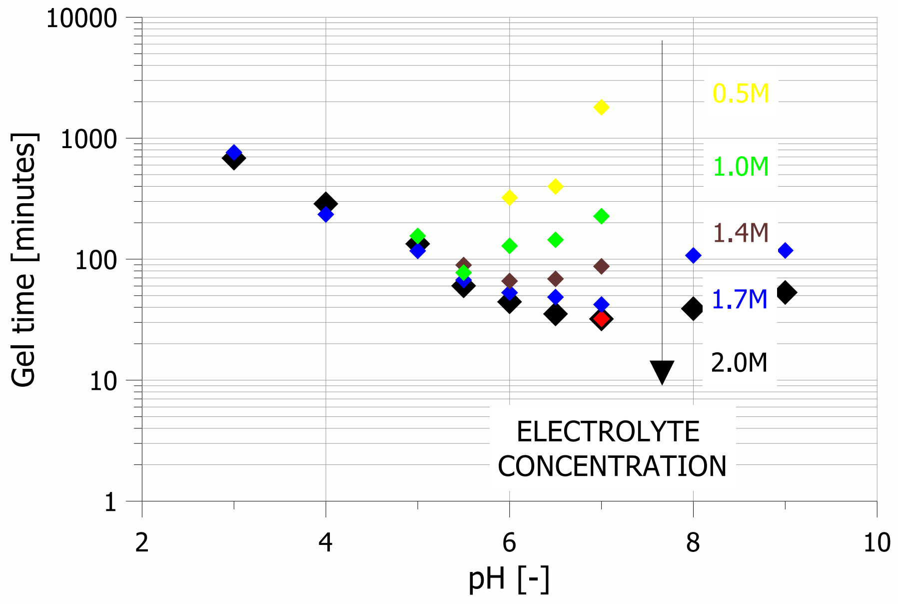
COLLOIDAL SILICA GEL TIME

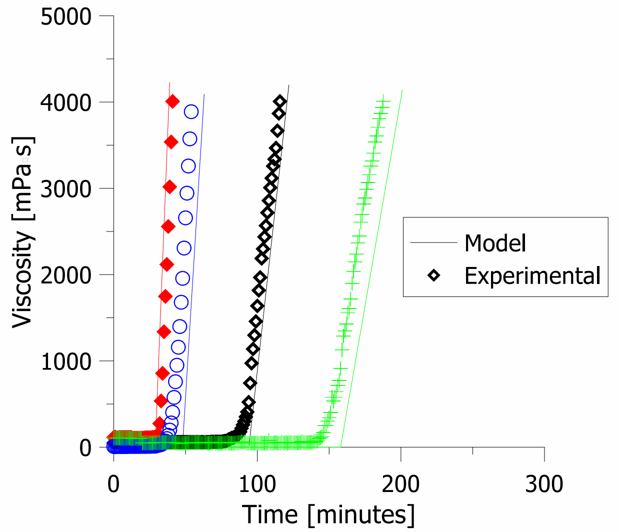


COLLOIDAL SILICA GEL TIME

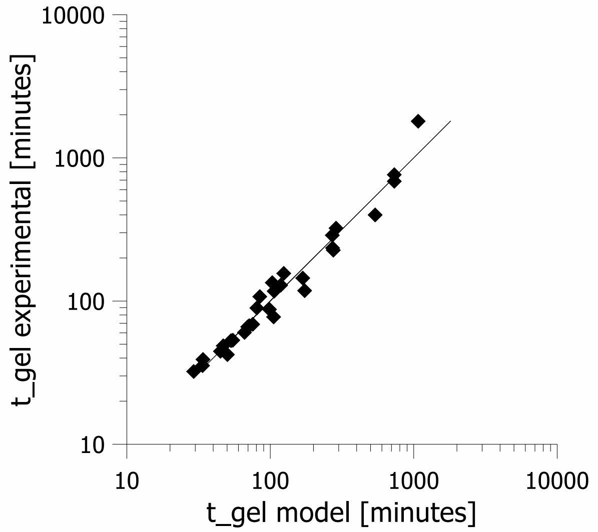
Gel time dependent on:

- pH
- Silica concentration
- Temperature
- Accelerator concentration
- Accelerator valency





Pedrotti et al. (2017) *Tunnelling and Underground Space Technology 70:105-1134*



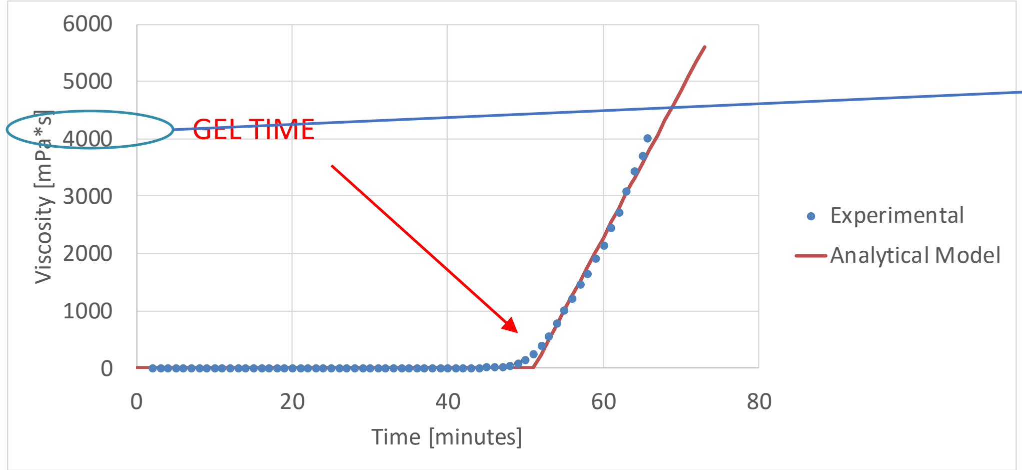
Standard deviation of less than 20 minutes over a maximum experimental gel time of 1809 minutes

Viscosity evolution

COLLOIDAL SILICA VISCOSITY

DARCY'S LAW

$$\text{FLOW}\ [\tfrac{1}{s}] \rightarrow \frac{1}{VISCOSITY\ [mPa{\cdot}s]}$$



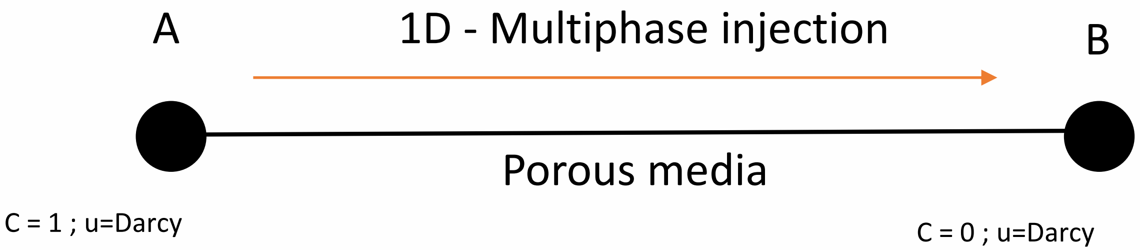
4000 times bigger than initial viscosity

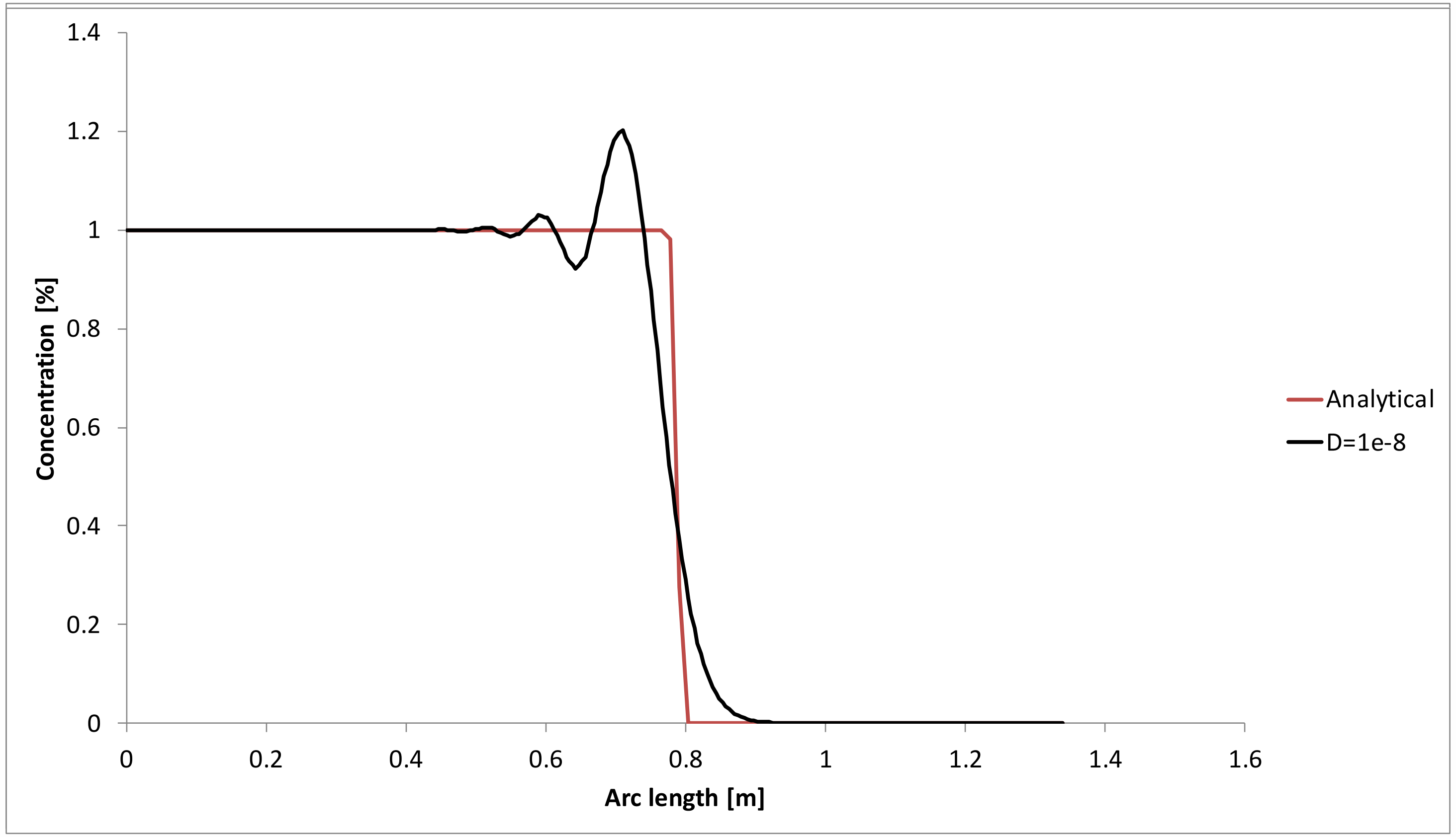
Viscosity becomes 100 times bigger than initial viscosity before the gel time.
This means that before the gel time is reached silica grout flow is already a hundred times smaller.

We are looking at the problem at the wrong scale

Numerical Model Instability

NUMERICAL MODEL INSTABILITY

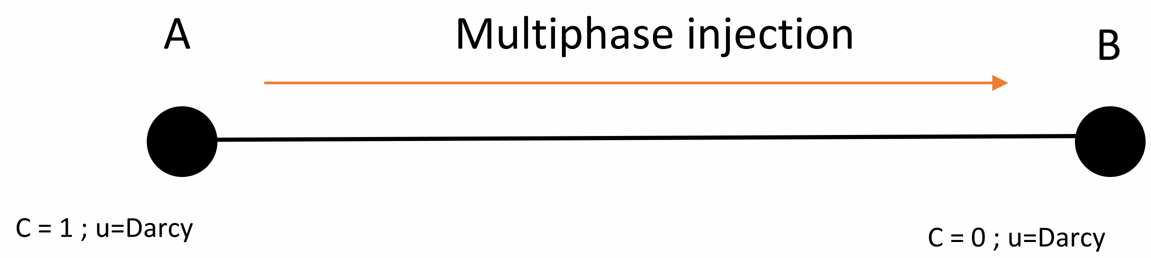


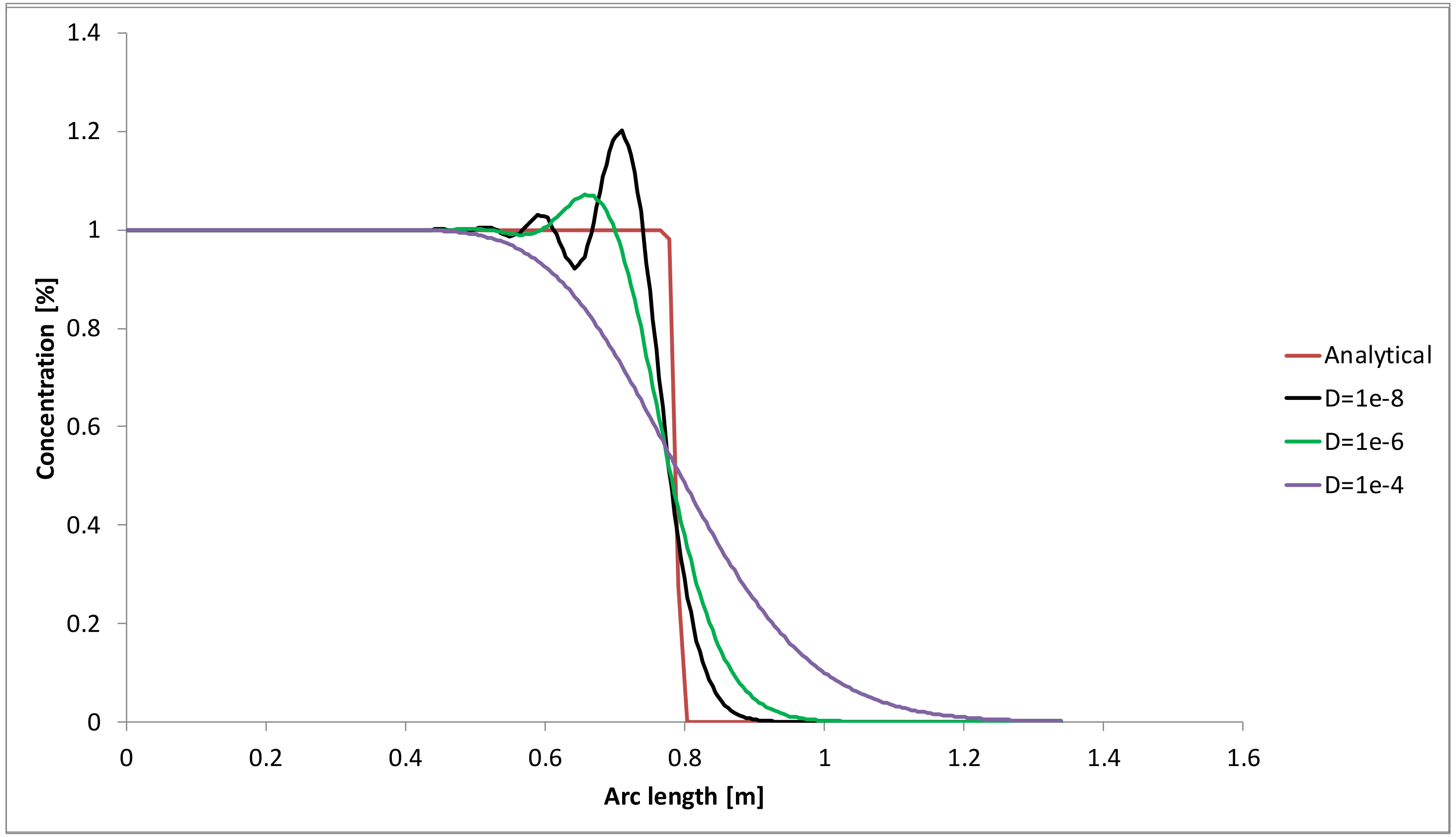


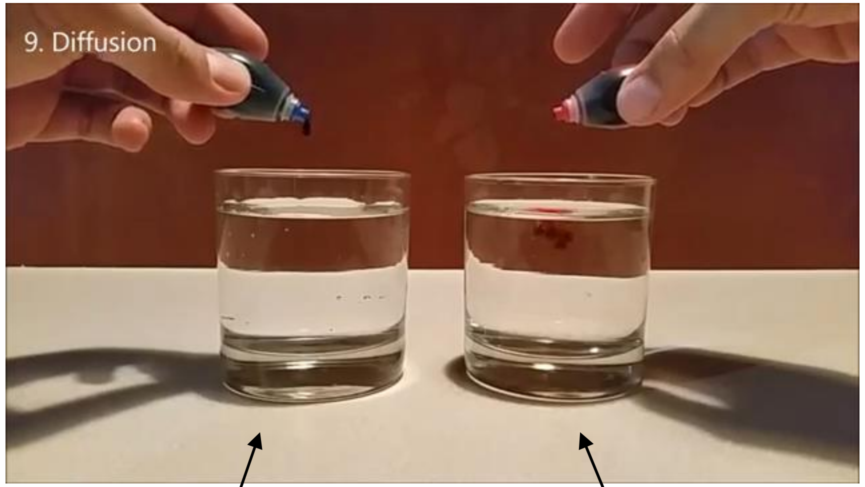
Numerical modelling of multiphase injection is a very unstable problem. Major sources of instability are:

- Time dependent viscosity
- Time dependent density
- Low ratio between diffusion and advection

NUMERICAL MODEL DIFFUSION





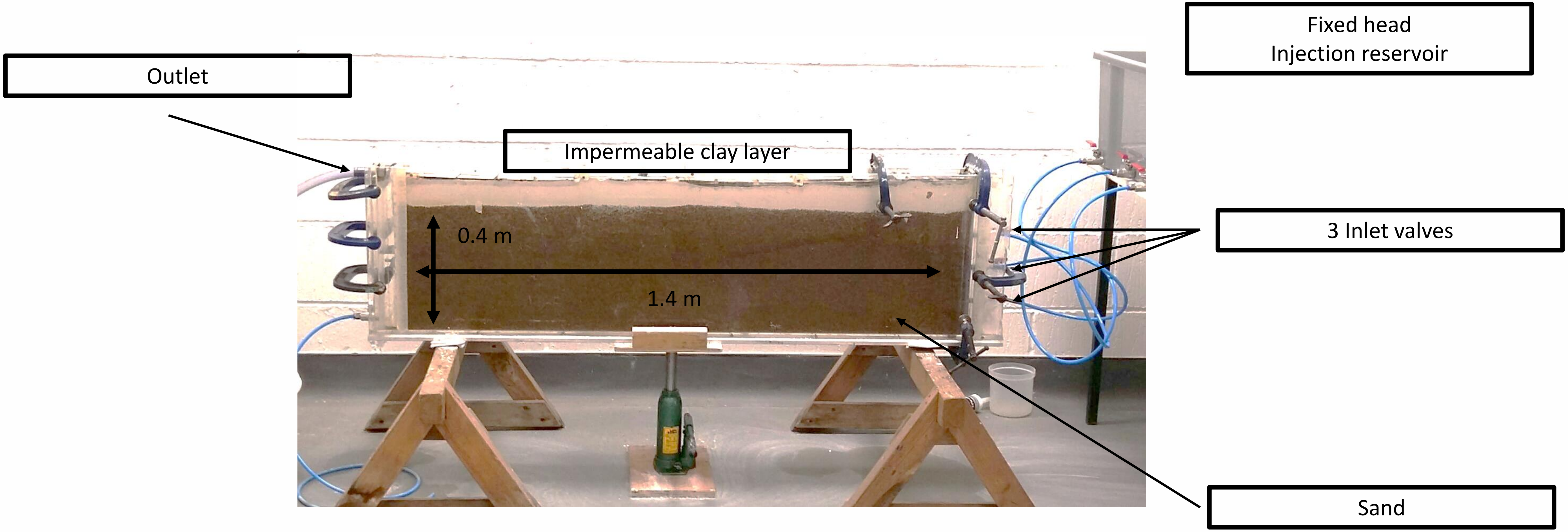


Colloidal silica-like behaviour

Behaviour implemented in the model

Laboratory tank injection

Laboratory tank injection

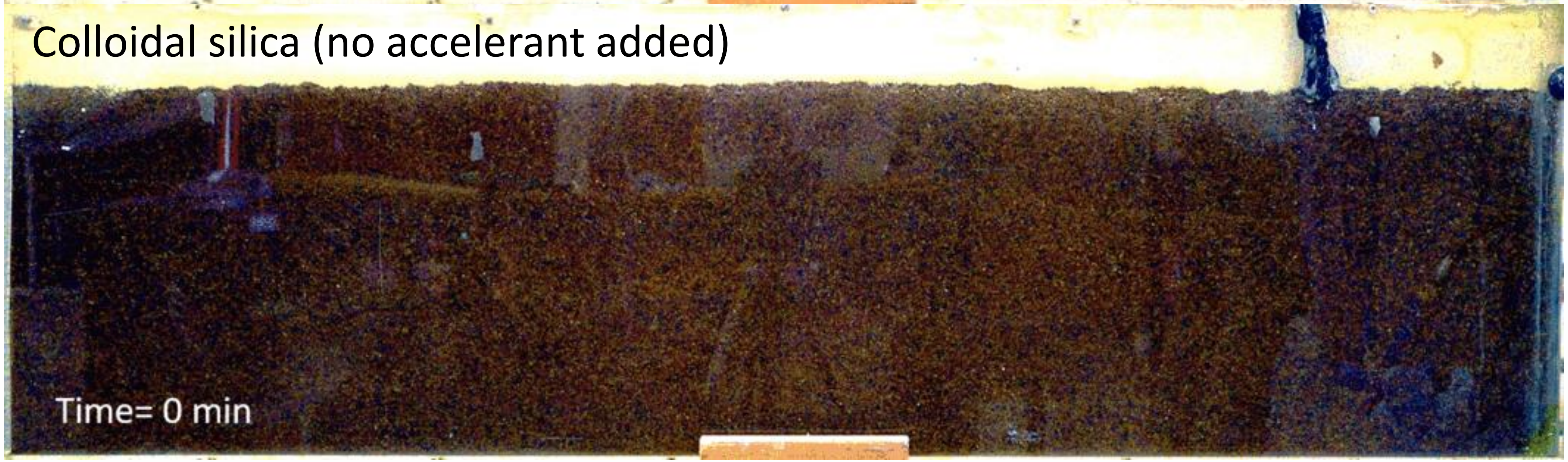


Laboratory tank injection

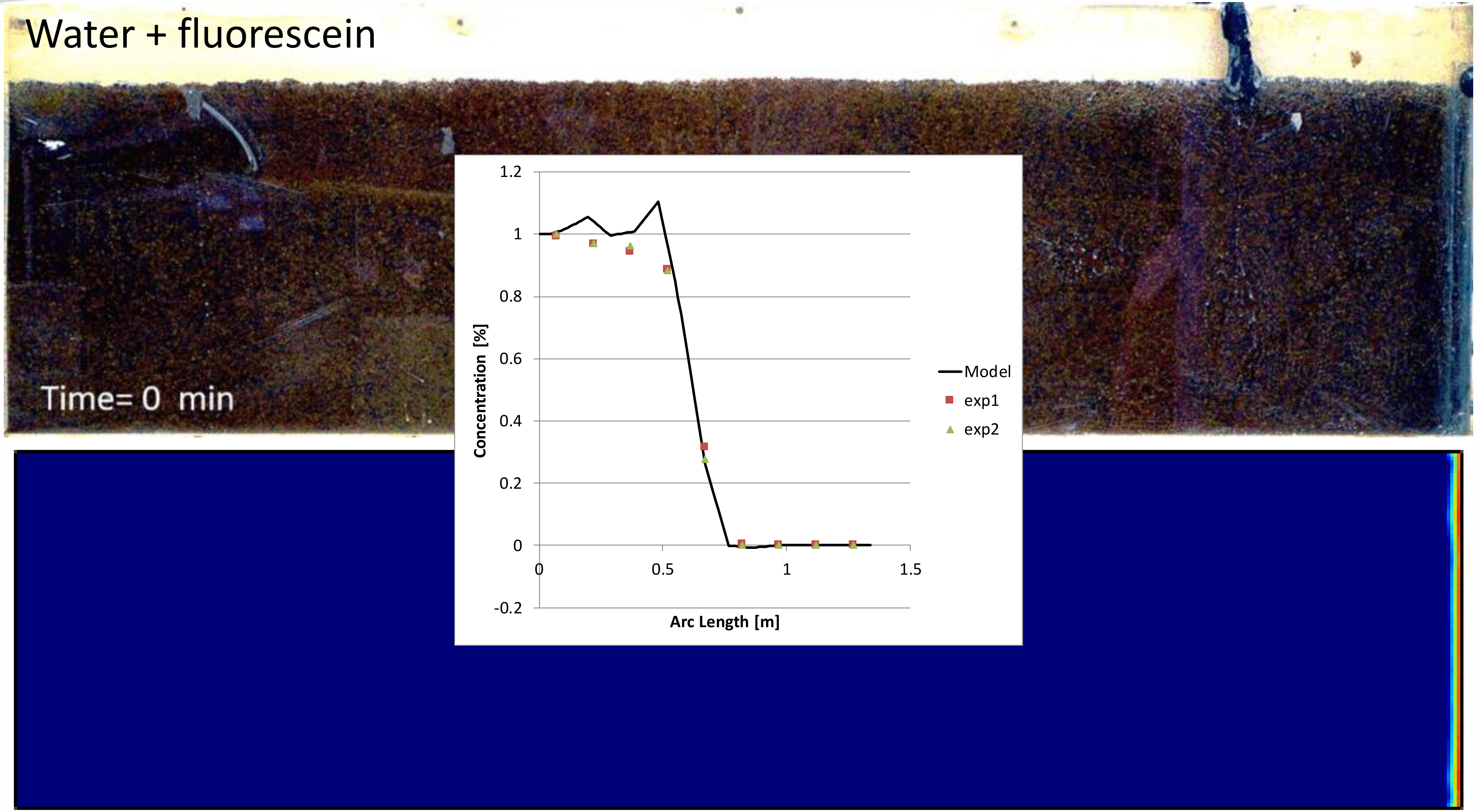
Sampling points to measure the electric conductivity

From the electric conductivity it is possible to calculate the silica concentration

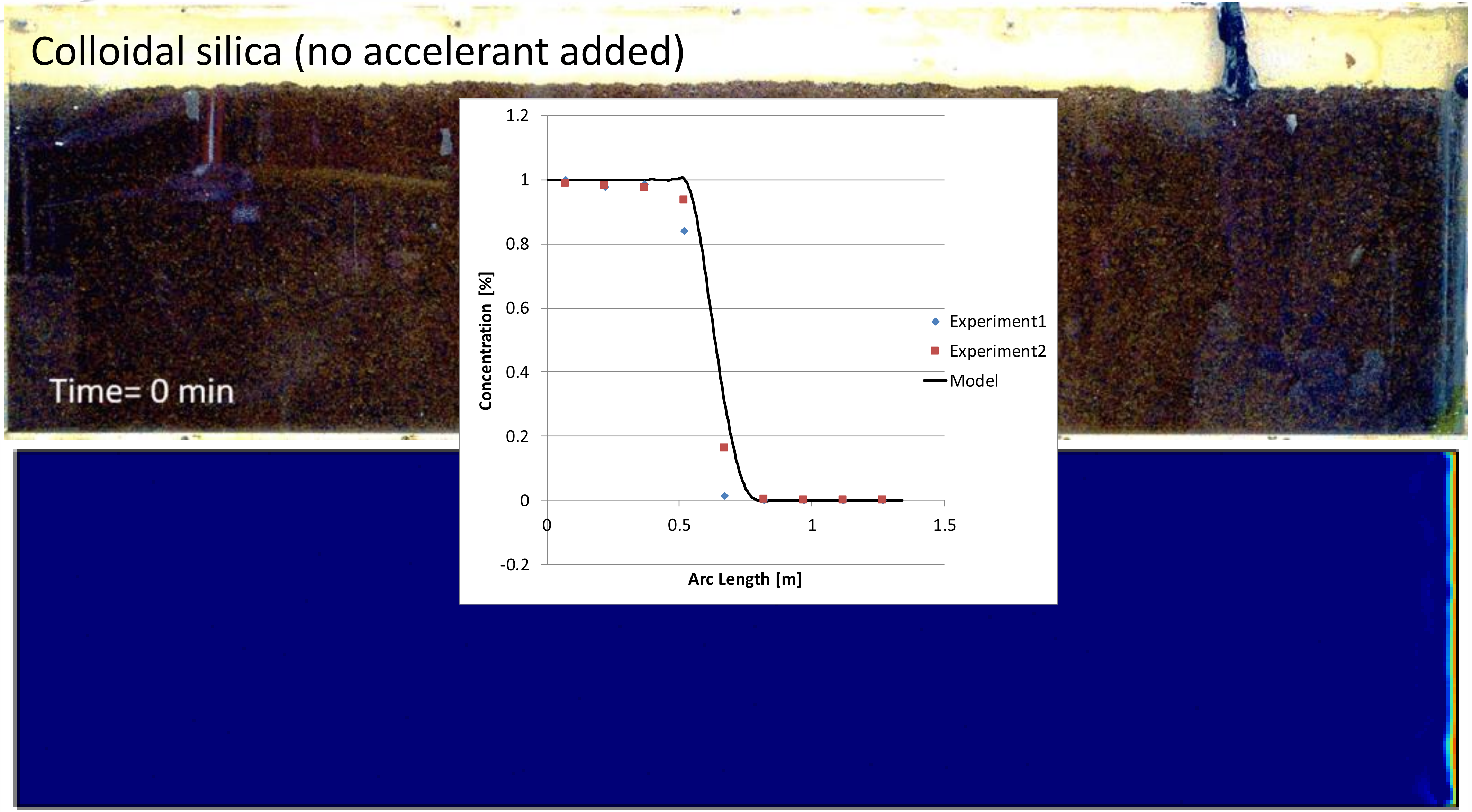
Laboratory tank injection



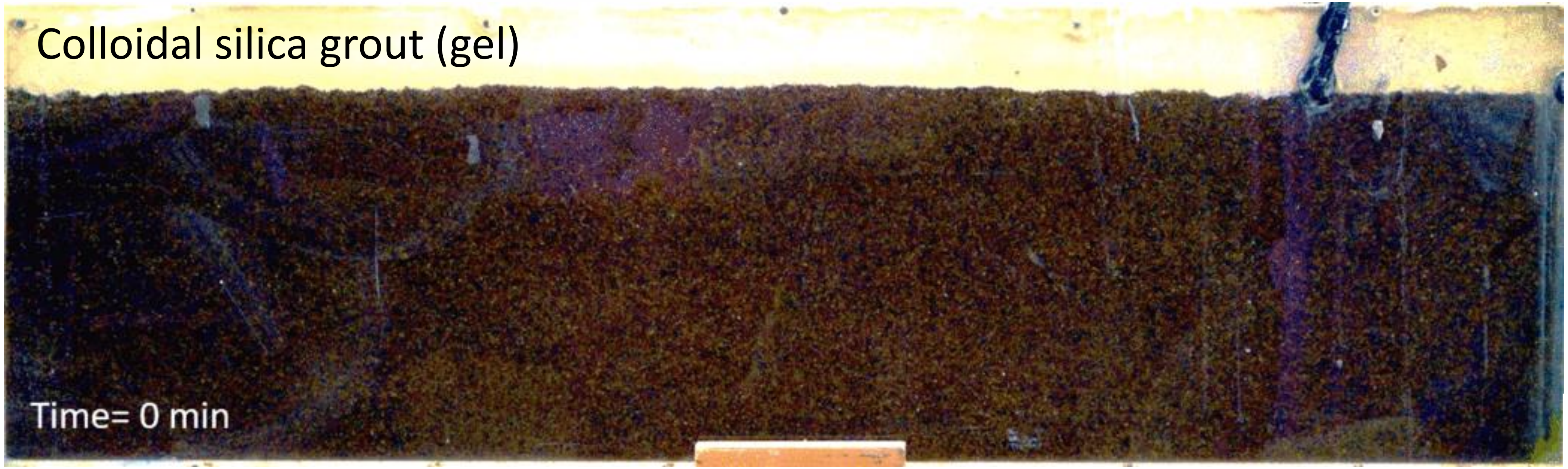
Laboratory tank injection



Laboratory tank injection

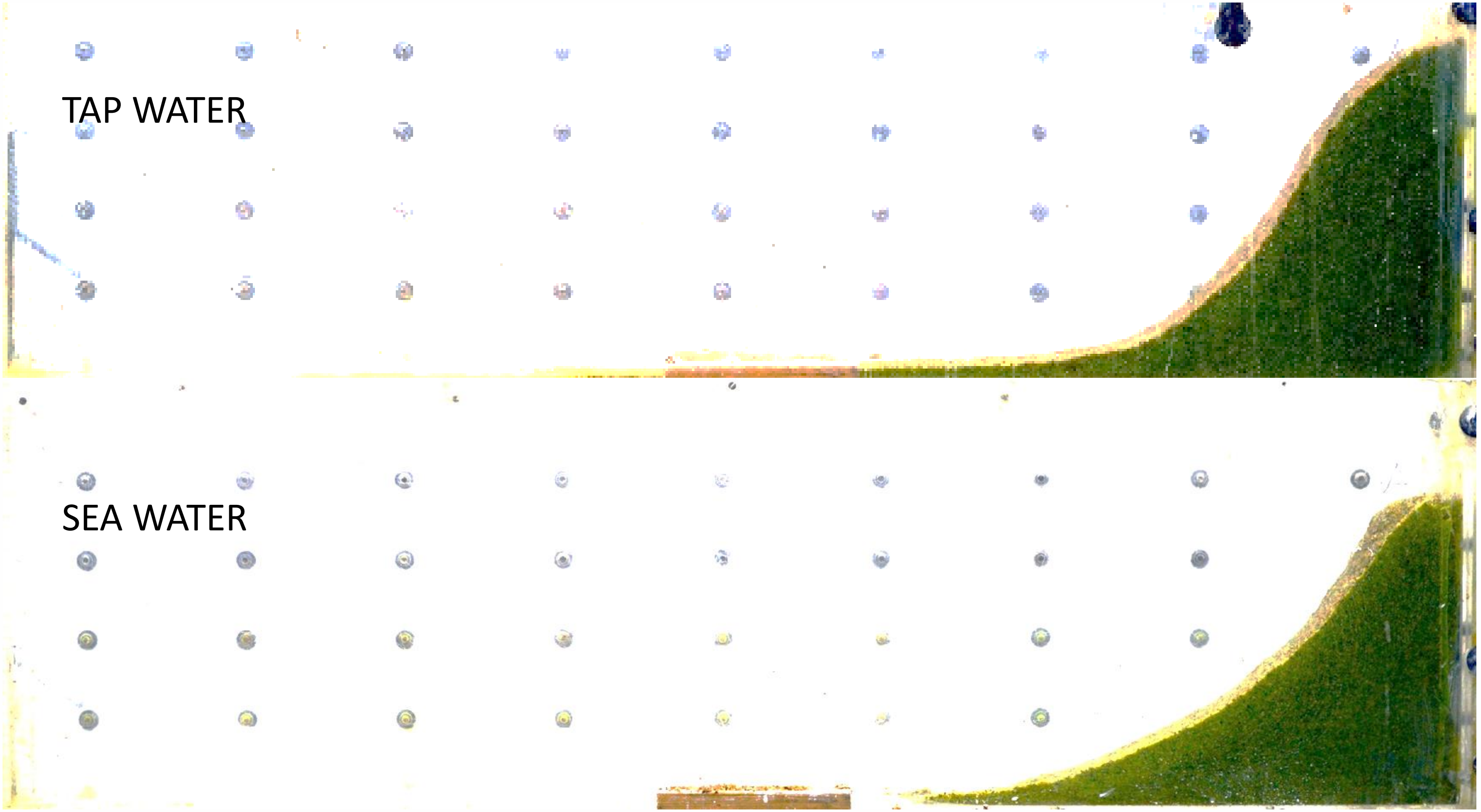


Laboratory tank injection



Laboratory tank injection

Laboratory tank injection

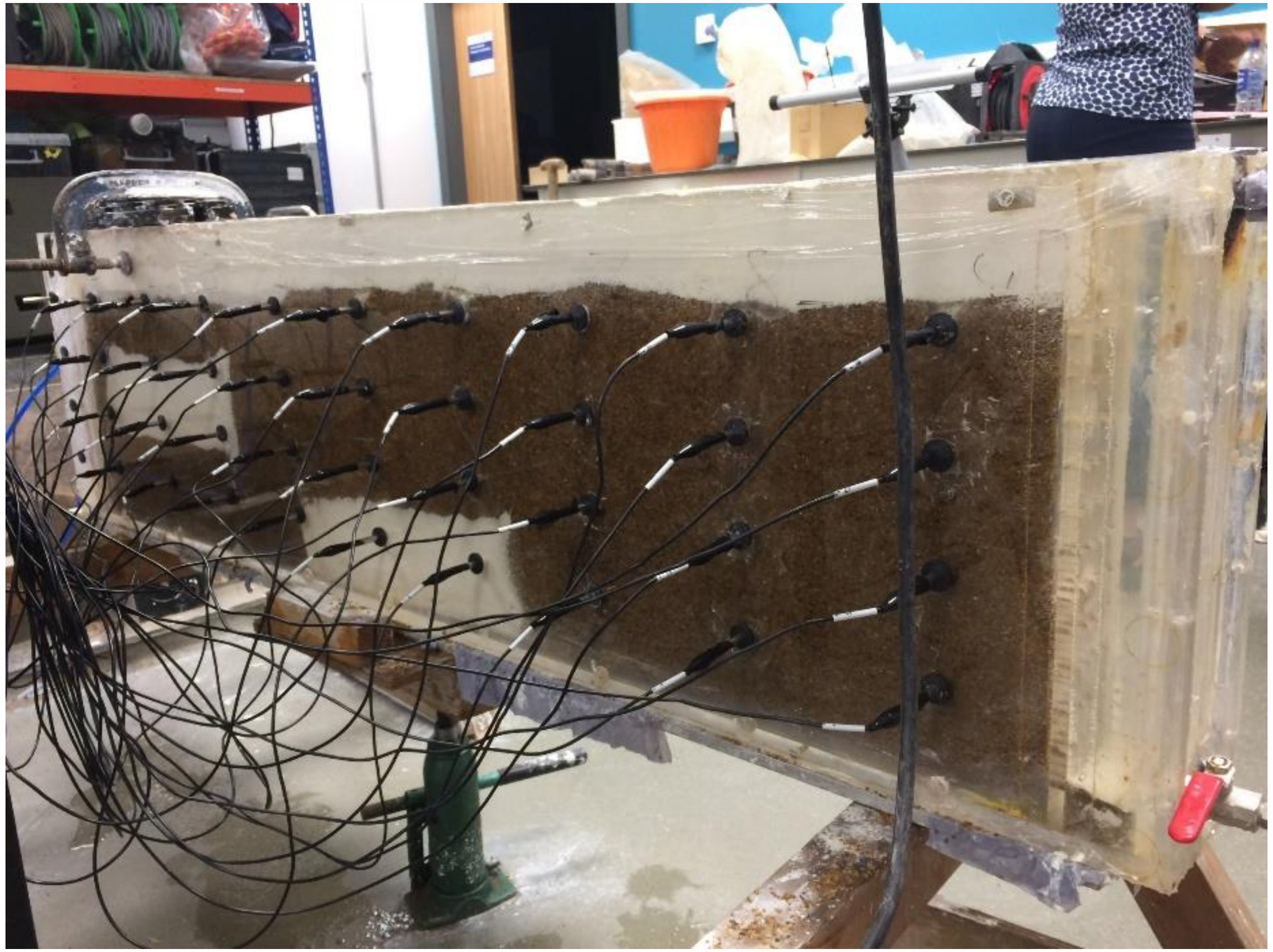


The accelerator was tailored to have the same gelling time.
For the sea water scenario, a designed combination of sea water and a KCl solution was used to create the accelerator.

Injection Monitoring

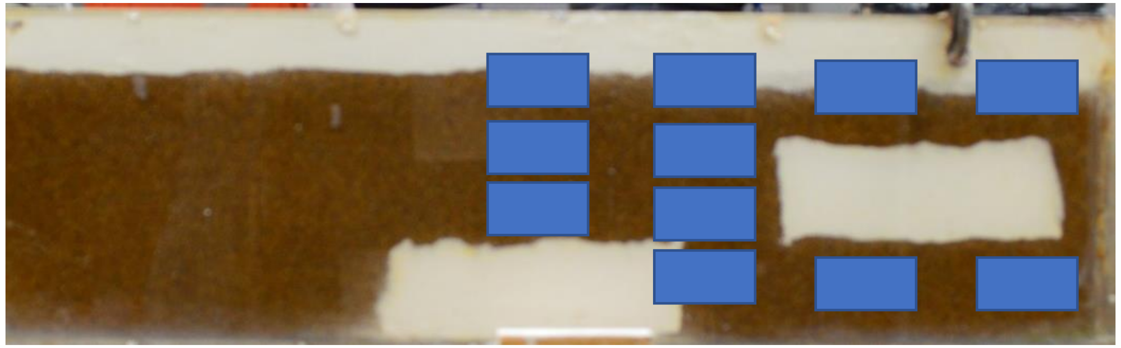
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

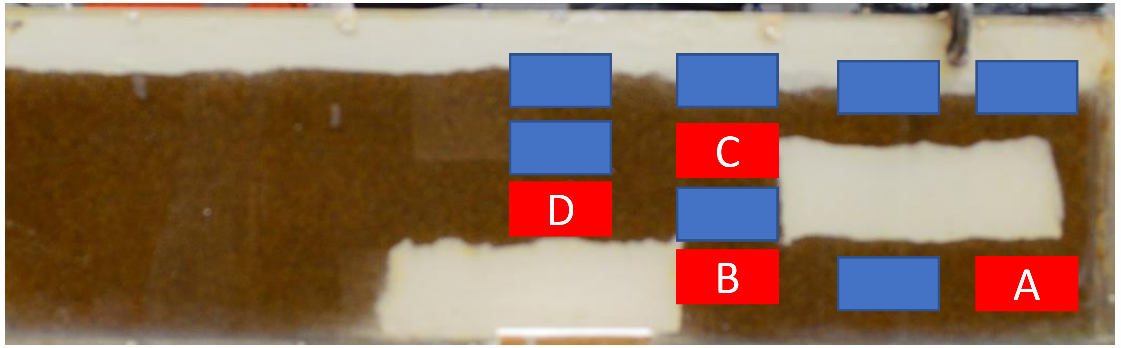
Injection Monitoring

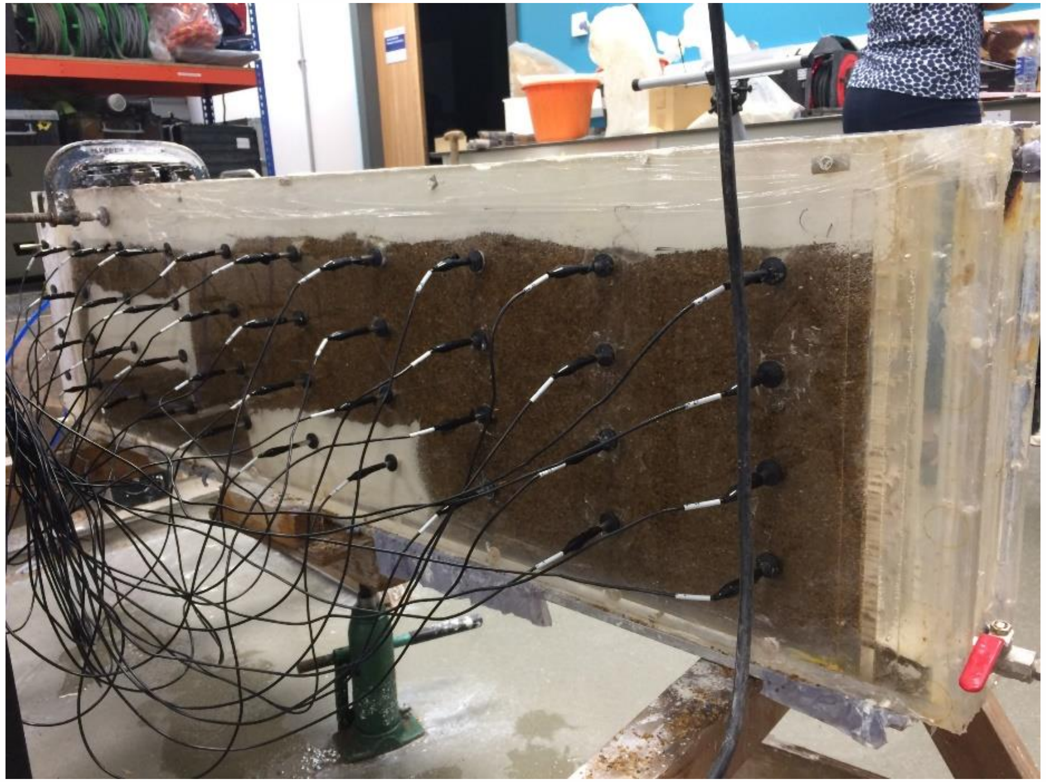


Injection Monitoring

Injection Monitoring

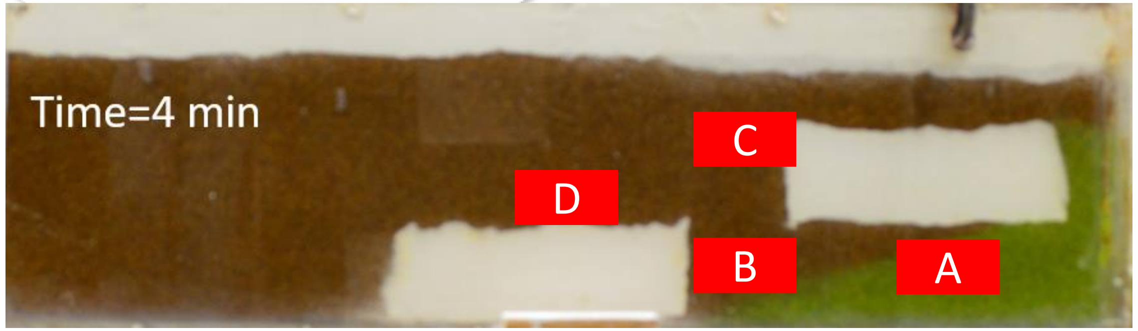


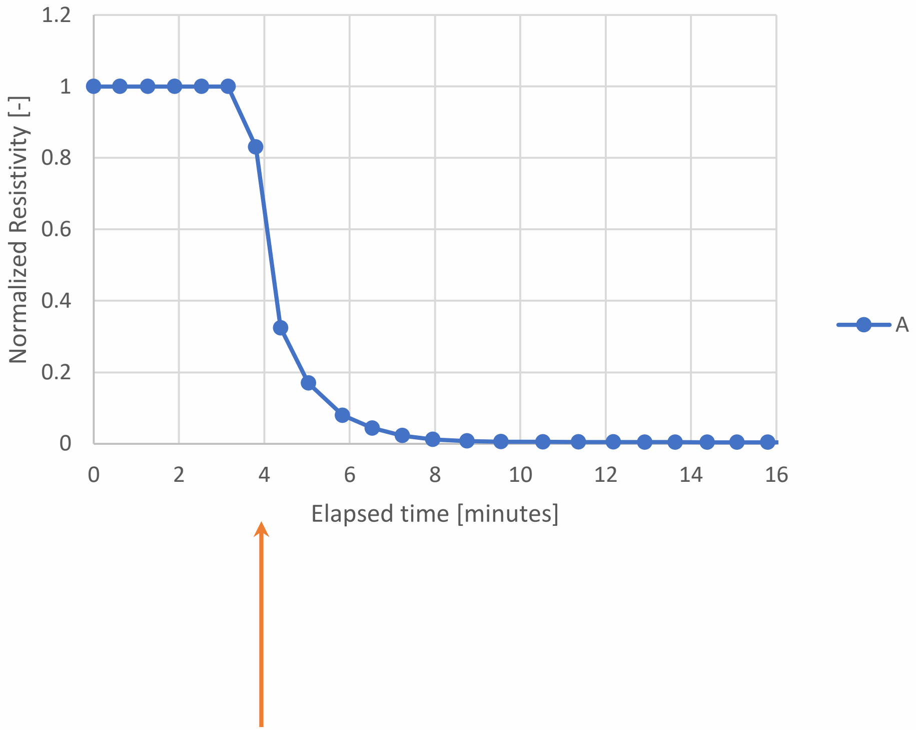




Control volumes in order to live monitoring the colloidal silica grout injection

Injection Monitoring





Conclusions

Conclusions

ABILITY OF DESIGNING AND PREDICTING
THE INJECTION PROCESS

1. Colloidal silica injectability with different **types of ground**
2. Control colloidal silica gel time against different **environmental factors**
3. Predict evolution of colloidal silica **viscosity over time**
4. Modelling colloidal silica **flow** during injection
5. **Monitoring** and evaluating the grouting process

Thank you

matteo.pedrotti@strath.ac.uk

Transformative Science and Engineering for Nuclear Decommissioning

Calcite Biomineralisation for the Repair of Damaged Concrete

Ronald Turner, University of Strathclyde

Site Decommissioning & Remediation

3rd April 2019
Bath, England

Summary

- What is Calcite Biomineralisation
- How Calcite Biomineralisation is relevant to concrete repair
- Experimental Work So Far – Proofs of concept/Lab-Scale Testing
- Potential Future Work under TRANSCEND – Field Application Methods

What is Calcite Biomineralisation?

- The generation of calcium carbonate (calcite) from urea and calcium precursors

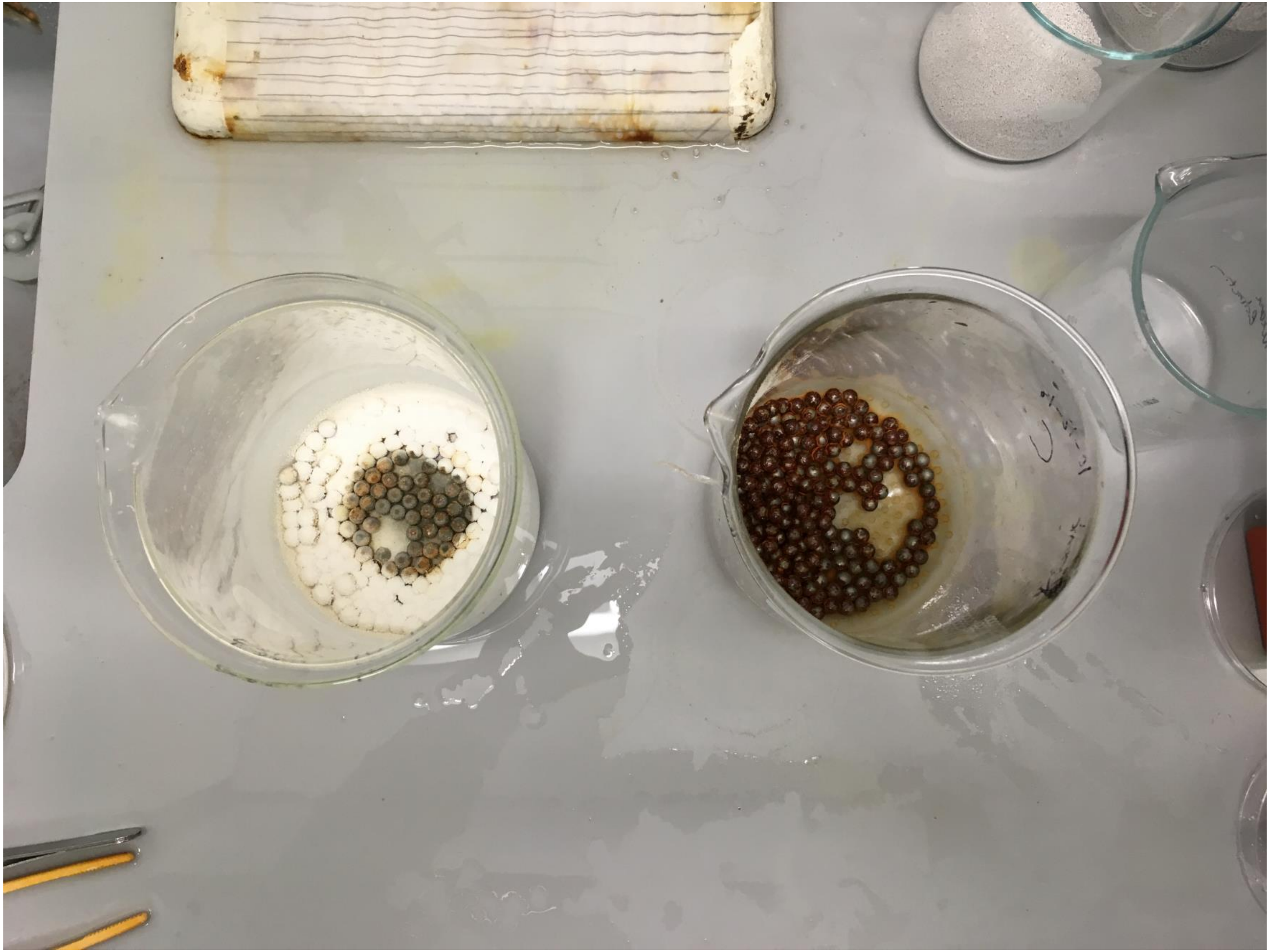
- Mediated by the enzyme urease, synthesised by the bacterium *Sporosarcina pasteurii*

$$CO(NH_2)_2 + 2H_2O \xrightarrow[\text{urease enzyme}]{} 2NH_4^+ + CO_3^{2-} \quad (1)$$

$$Ca^{2+} + cell \rightarrow cell - Ca^{2+} \quad (2)$$

$$cell - Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \downarrow \quad (3)$$

Reaction diagram from Minto, J. M. et al. 'Microbial mortar'-restoration of degraded marble structures with microbially induced carbonate precipitation. Constr. Build. Mater. 180, 44–54 (2018).



- Calcite generated after a single bacterial treatment cycle (8 hours)

Bacterial Calcite for Concrete Repair

- Concrete is a mixture of (un)hydrated calcium silicates, calcium hydroxide, and calcium carbonate (+ aggregate and iron rebar). Used in many nuclear infrastructure applications, both structural and non-structural.

Bacterial Calcite for Concrete Repair

- Calcium carbonate - a component of concrete - can be generated by bacterial action

- To date, research has been focused on cosmetic/semi-structural repairs, and ‘self-healing’ new-builds

Crack sealing

The effectiveness of the MICP crack healing properties are displayed in Figures 3 and 4.

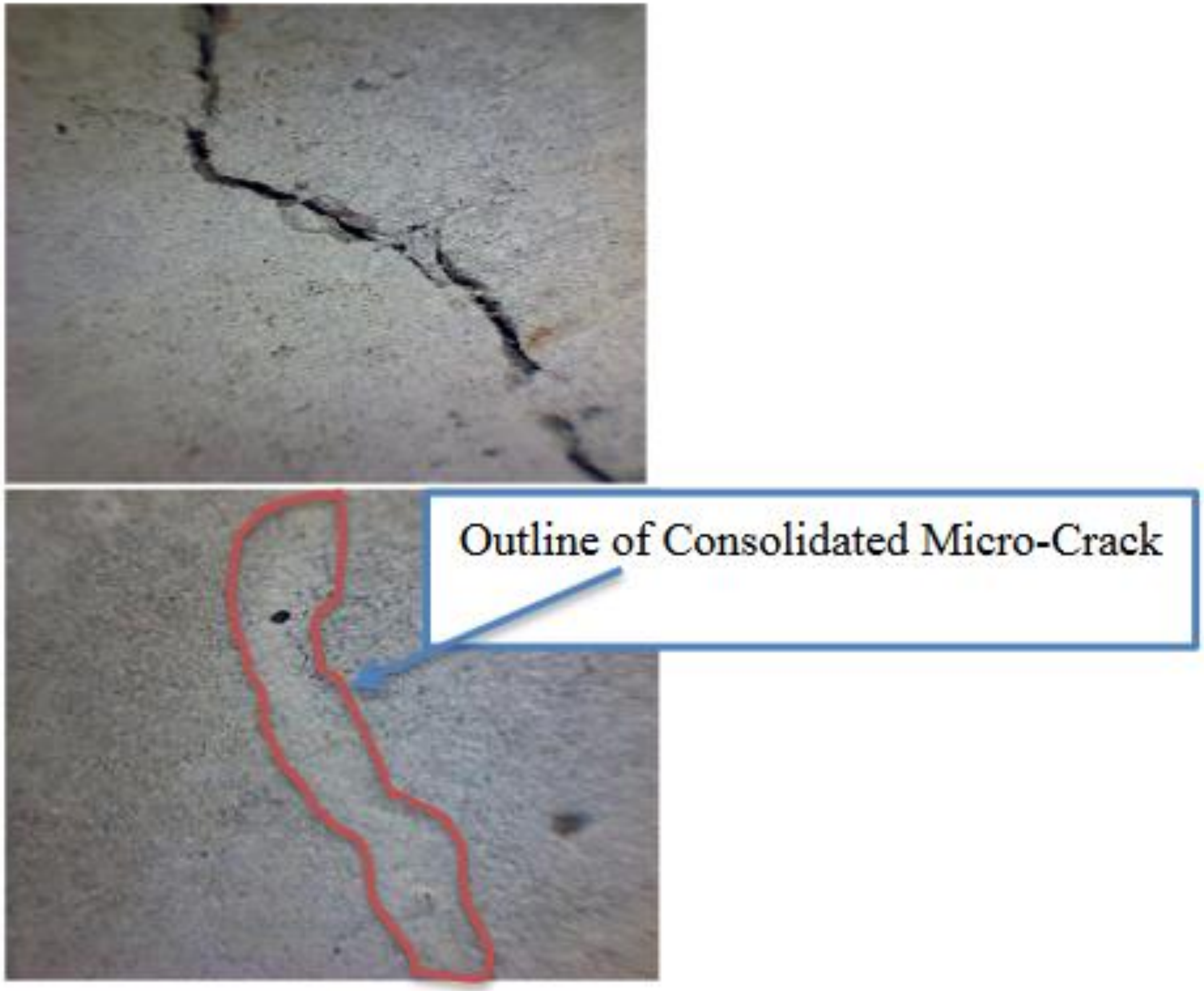


Figure 3. Above cracked fibre beam and below MICP sealing the crack

Figure from Richardson, Coventry, and Pasley. "Bacterial Crack Sealing and Surface Finish Application to Concrete", 2016, SCMT4

What hasn’t been studied?

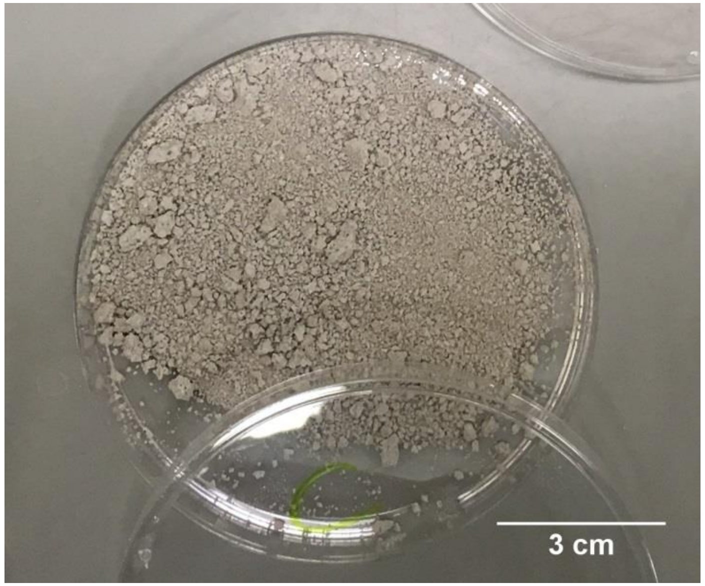
- Repair/cementation of heavily damaged concretes

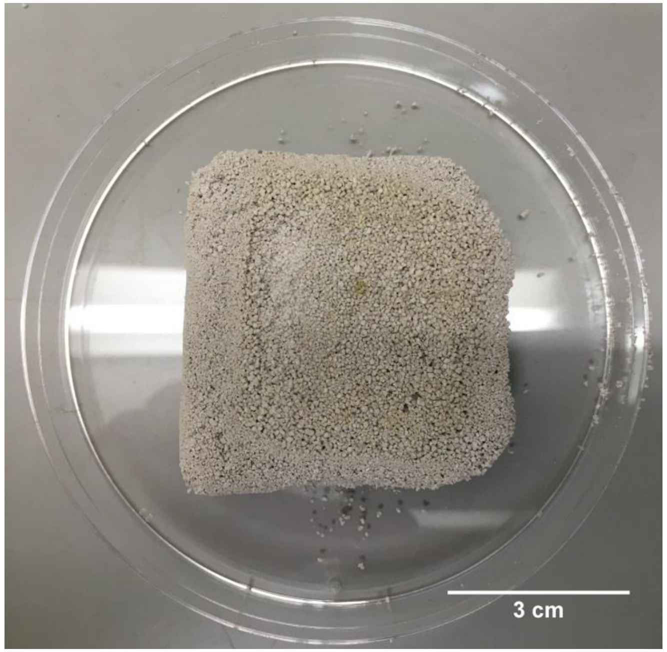
- Permeability/pore structure changes in these materials

- Field-scale application of calcite biomineralisation concrete treatment protocols to nuclear infrastructure

Repair/Cementation of (damaged) concretes

- Analogue 'damaged' system: Crushed Concrete





- Results look promising, bacterially treated crushed concrete demonstrated reduced permeability to water and clear consolidation/cementation

Repair/Cementation of (damaged) concretes

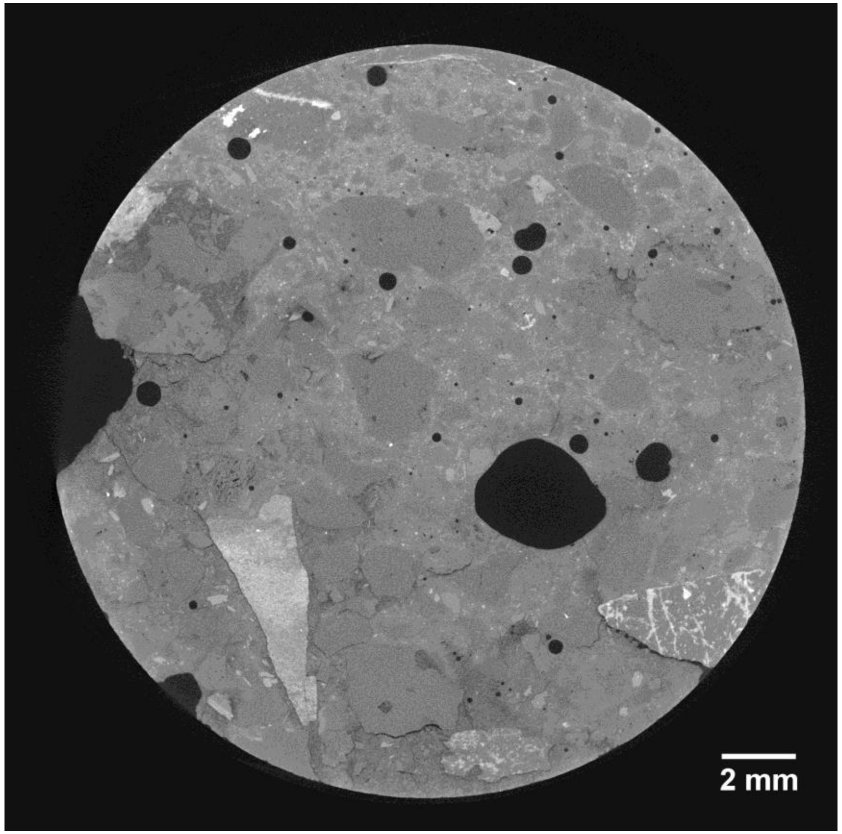
- ‘Damaged’ Concrete cores from Devonport dry dock

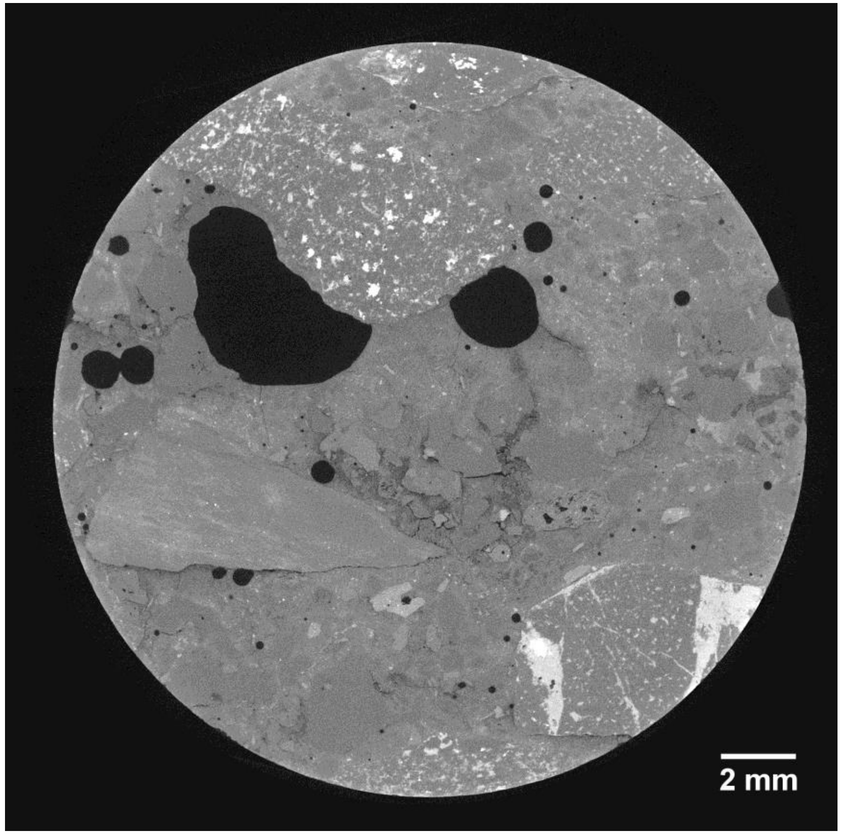
Before Treatment

After Treatment

Permeability and Pore Structure Changes

- Very little study to date of biomineralisation in concrete pore structures, for example using X-CT





Summary – Experimental Results so far

- Calcite biomineralisation process can consolidate/cement individual concrete particles, at particle sizes ranging from 425 – 6000μm

- Calcite deposition is apparent on intact concrete as well, but need to investigate penetration depths/pore structure filling ability

Applications to TRANSCEND

- Application of described methods to damaged concrete in-situ (PhD studentship planned in this area)

- Biomineralisation capacities under radiological challenge, another significant knowledge gap here

Summary/Conclusions

- A method has been developed which can generate large amounts of calcite onto concrete at the lab scale
  - Further work will quantify the properties of this repair method in terms of penetration depth, and permeability/porosity changes
  - Would be interesting to investigate this calcite mineralisation process under radiological challenge

- Application of this methodology to field-scale repairs of concrete nuclear infrastructure via TRANSCEND-funded PhD studentship

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Thank you

Dr Ronald J Turner
Research Associate
Department of Civil & Environmental Engineering
University of Strathclyde
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Realising the potential - electrokinetics and decommissioning

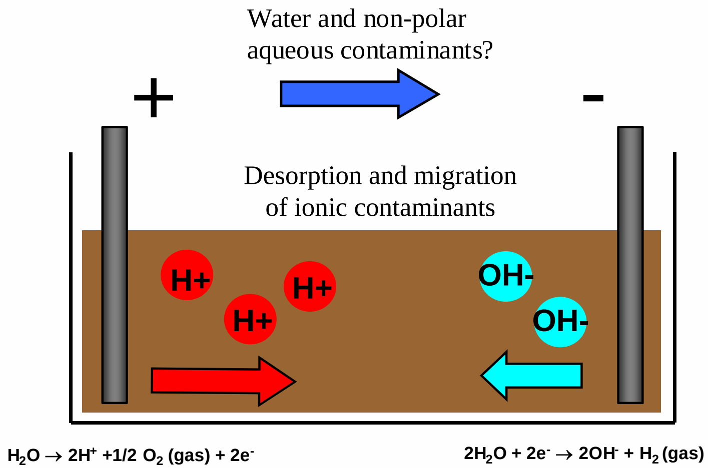
Professor Andy Cundy, GAU Radioanalytical, University of Southampton

TRANSCEND Annual meeting, session 2

3/4/19
Apex City of Bath Hotel

Plan:

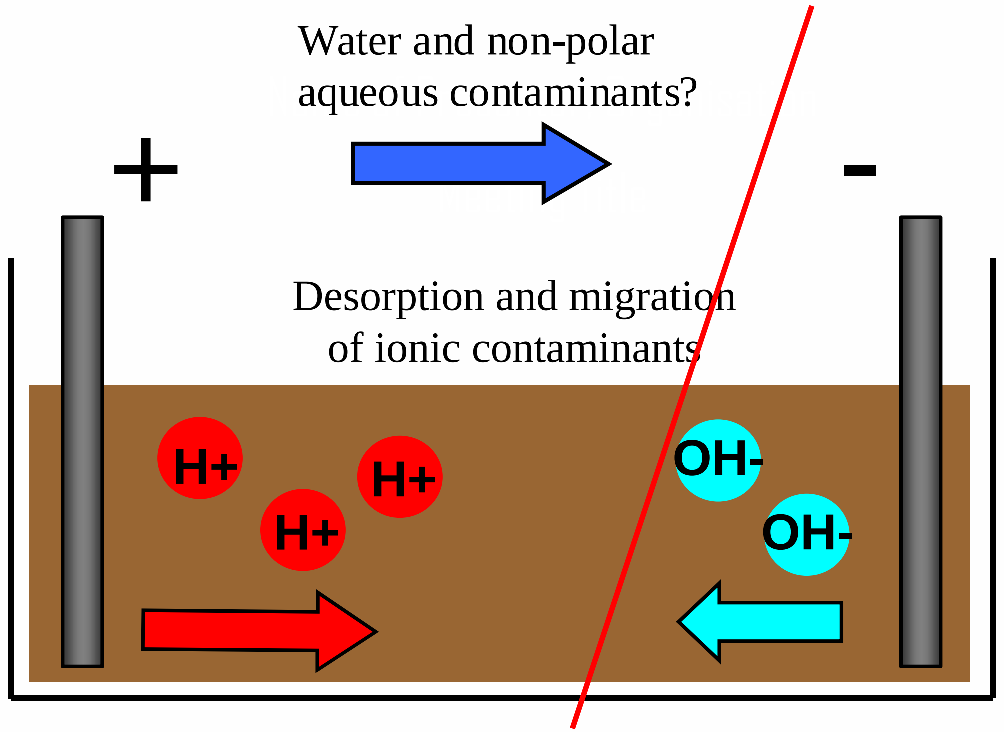
1. Background to electrokinetic remediation
2. Previous intermediate and field-scale work
3. The TRANSCEND work content
4. Combined approaches, and towards field-scale application



Background to electrokinetic remediation

Electrokinetic remediation: technology that has received considerable historical (and current) interest as a potential *in-situ* remediation technique for clay-rich soils.

In its most basic form: apply electrical current between electrodes that have been implanted in the ground on each side of a contaminated soil mass…..



$H_2O \rightarrow 2H^+ + 1/2\ O_2\ (gas) + 2e^-$

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

Background to electrokinetic remediation

Despite a variety of promising results, at present there is no standardised universal electrokinetic soil/sediment remediation approach.

Many of the current electrokinetic technologies: technically complex and energy intensive, and geared towards the removal of 90% or more of specific contaminants, under very specific field or laboratory-based conditions. Widespread practical usefulness?

However, in the real environment a robust, low-energy contaminant reduction / containment technique may be more appropriate and realistic.

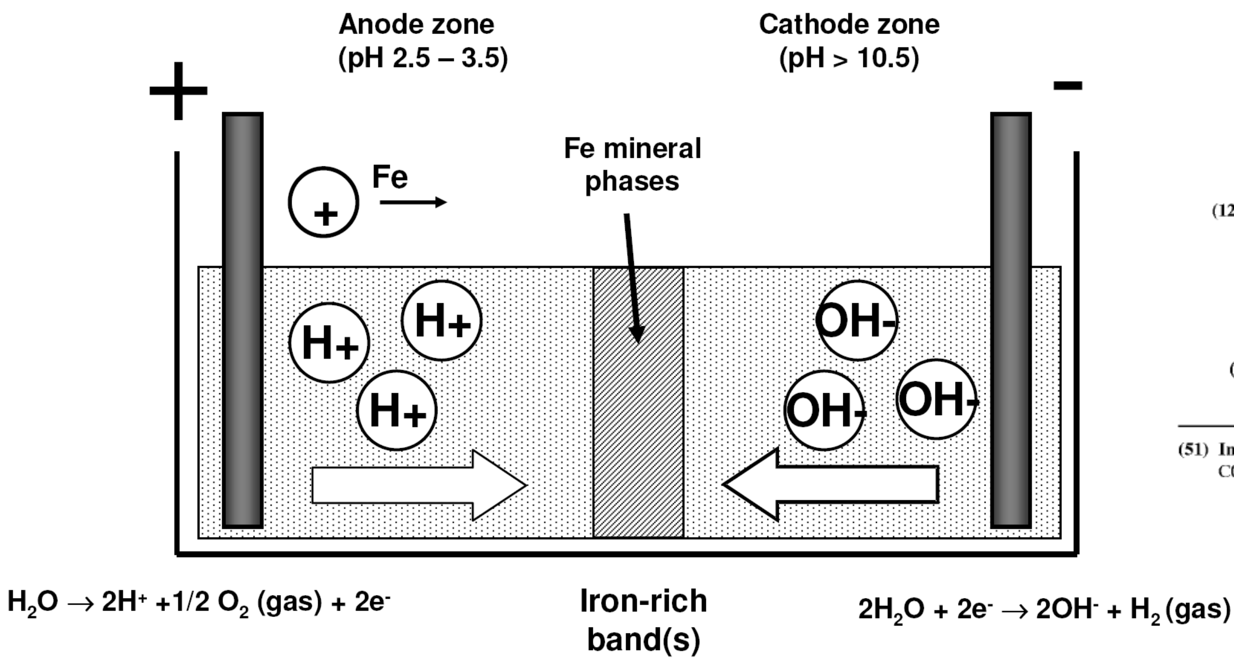
Can we simulate natural geological reactions to produce a low-cost, robust alternative electrokinetic technique ?

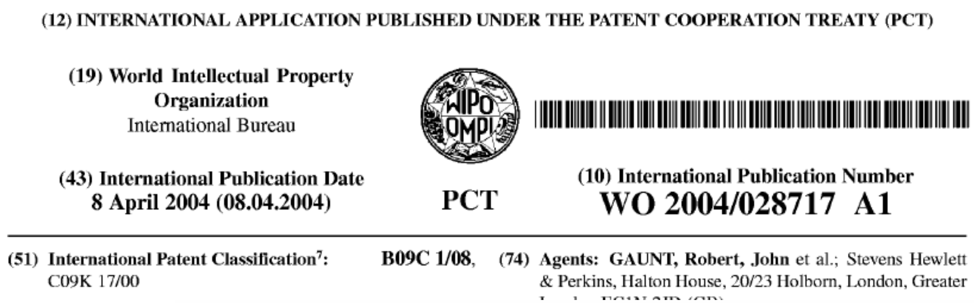
FIRS (Ferric Iron Remediation and Stabilisation)

Using low voltages and copying natural iron mineralisation processes, FIRS:

Acid (or alkali) washes soils and concentrates contaminants onto an iron band, which can then be dug-out (waste minimisation)

Dumps dissolves iron into an area of soil, which can then reduce and trap elements such as Cr and Tc, or precipitate and strengthen the soil (inc soil engineering approaches)




(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
8 April 2004 (08.04.2004)

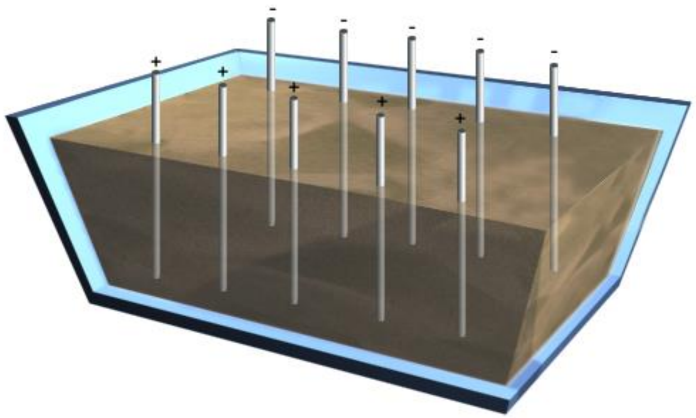
PCT

(10) International Publication Number
WO 2004/028717 A1

(51) International Patent Classification[7]: B09C 1/08, C09K 17/00

(74) Agents: GAUNT, Robert, John et al.; Stevens Hewlett & Perkins, Halton House, 20/23 Holborn, London, Greater

Previous intermediate and field-scale work



Remediation of Cr-contaminated soils

Five tonne composite soil sample was transported to the Churngold Remediation Ltd laboratory in Avonmouth from a contaminated site in the north of Britain, and treated in a bespoke treatment cell (BTC) converted from an industrial skip (with water recirculation and neutralisation system).

Soil pH 10.6, Cr(tot) = 4700mg/kg, Cr(VI) = 710mg/kg

Pore fluids: Cr(tot) 290mg/l, Cr(VI) 280mg/l

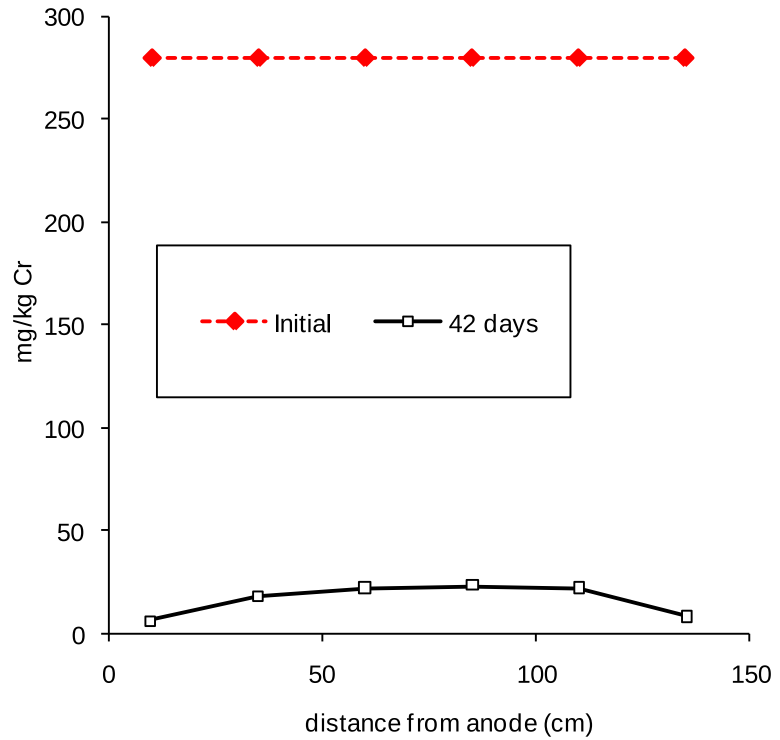
42 day treatment time, at 55 volts (0.36V/cm).

Chemical analysis from UKAS and MCERTS accredited laboratory

Hopkinson et al (2009) CL:AIRE RB9, Claire.co.uk

Remediation of Cr-contaminated soils

Apparent migration of Cr species from cathodic to anodic zone, followed by reduction of Cr^{6+} and trapping via Fe/Cr hydroxide formation.



Chromium leachate profile at onset (initial), and termination (after 42 days), of the pilot trial

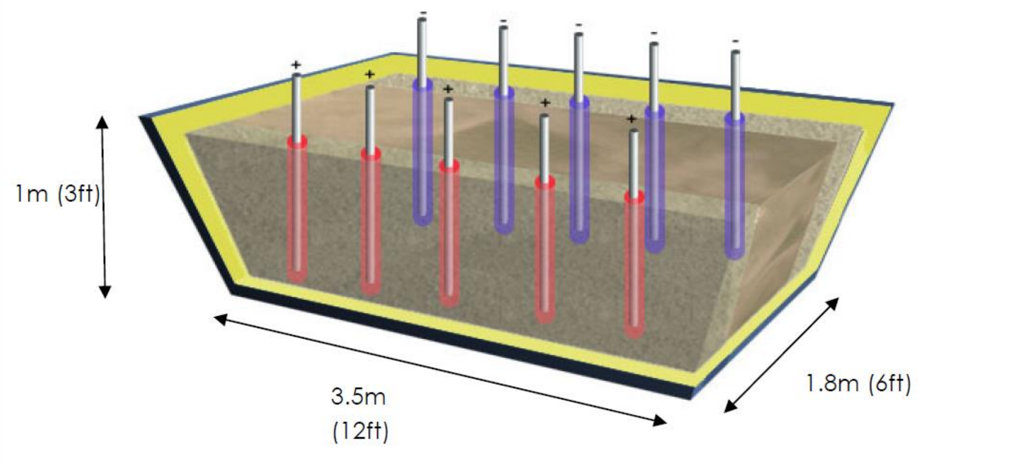
Leachability of chromium in the BTC was reduced by an average of ~94%, providing a strong indication that the trial was successful, and that the highly mobile Cr(VI) was substantially reduced to Cr(III).

Remediation of Pu-contaminated soils

Soils labelled with historical Pu contamination (held on site in containment units) treated in adapted containment cell, on the AWE Aldermaston nuclear site.

Using 48V (rechargeable) battery array power source, over 4 months

Field implementation followed rigorous lab testing and design process via KTP funded by NERC and AWE – design to on-site deployment in < 2 years



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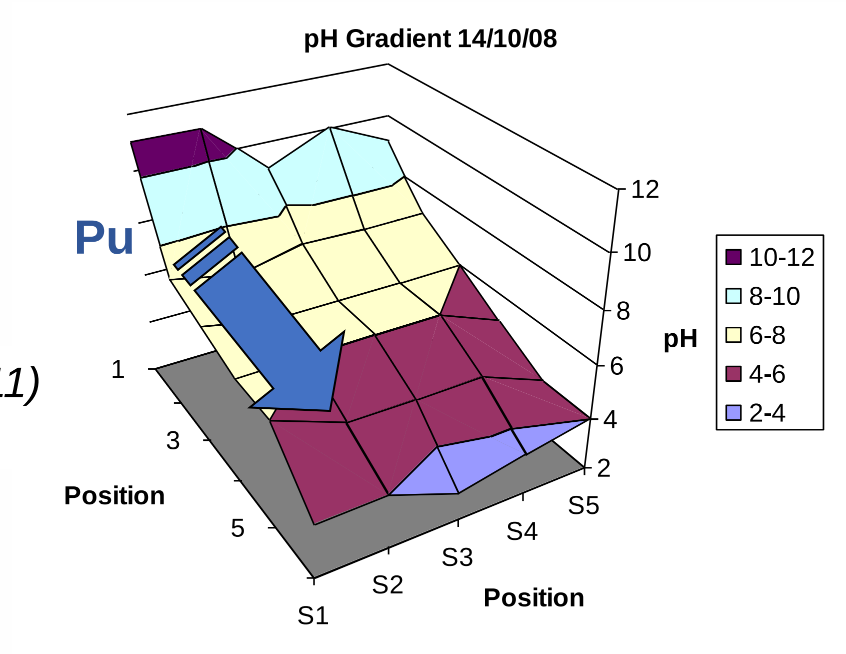
Remediation of Pu-contaminated soils

Field trial results indicate clear mobilisation / removal of Pu (and U) by FIRS: remediation of Pu to below UK free-release level (i.e. classed as non-radioactive) – waste minimization approach

Agnew et al (2011)
Jnl. Haz Mat



Successful partnership – winner of “Best partnership Funded by the NERC” at the national KTP awards 2011

Also trialled on Sellafield site materials in independent tests

The TRANSCEND work content

Specific objectives are:

(1) To adapt low-energy ex-situ electrokinetic remediation and waste volume minimisation techniques already proven on AWE legacy wastes (Agnew et al, 2011) to other UK nuclear legacy wastes and sites.

(2) To develop in-situ low-energy electrokinetic *fencing* (for groundwater) and *remediation* (for soils and sediments), to limit the spread of active contaminants, and minimize soil volumes for subsequent treatment.

(3) To combine EK with colloidal silica grouting to minimise soil contamination for in-situ vitrification.

1 PhD student and 1 PDRA, plus 3 current Msci/MSc students (fencing and remediation in bench-scale systems)

The TRANSCEND work content

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1 PhD student and 1 PDRA, plus 3 current Msci/MSc students (fencing and remediation in bench-scale systems)

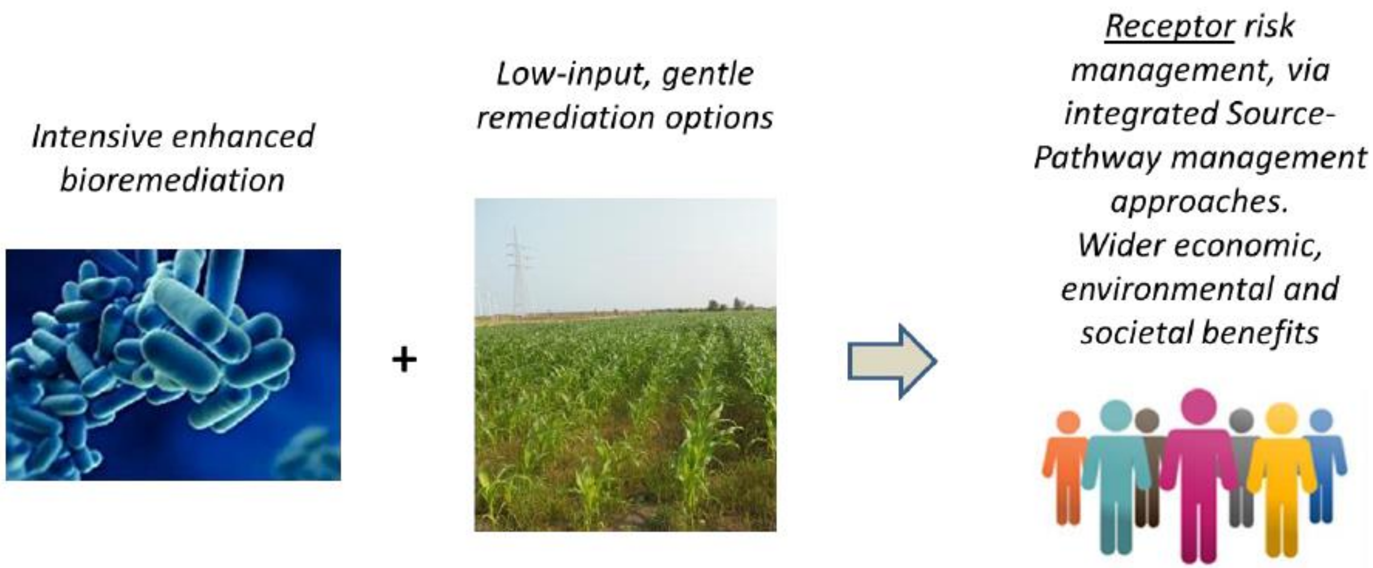
Combined approaches, and towards field-scale application

Combined approaches with colloids and nanoparticles (via electrophoresis), for land and wastes treatment, and in-situ vitrification

University of Strathclyde Glasgow

PHOTON WATER

Creation of active sub-surface treatment / containment zones (treatment zone and residuals containment)



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Acknowledgements:
EPSRC funding under TRANSCEND (EP/S01019X/1)
L. Hopkinson (University of Brighton, co-inventor of FIRS technique).

UNIVERSITY OF Southampton School of Ocean and Earth Science

GAU Radioanalytical Laboratories

A.Cundy@soton.ac.uk

Thank you

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Predicting Gamma Dose Rates based on Limited Information

University of Surrey

C. Shenton-Taylor, P. Sellin, D. Read

April/2019

Energy

For a Low Carbon Future

Predicting Gamma Dose Rates based on Limited Information | PhD to commence July/ Oct 2019

Develop a robust methodology to predict gamma dose rates in contaminated underground structures based on limited direct information

Provide a decision-making tool that can:

1. ***Identify*** what is in the pipe
2. ***Quantify*** the pipe contents
3. ***Calculate*** dose rates

Recommend choice of algorithm, detector, methodology.

TRL 6 | Technology model or prototype demonstration in a relevant environment.

http://www.dorsetlife.co.uk/2009/11/how-the-mighty-atom-came-to-dorset/

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Predicting Gamma Dose Rates based on Limited Information

UNIVERSITY OF SURREY

Environmental evaluation

Development experimental facility

In-field gamma measurements

Modelling capability

Enhanced data analysis

Recommended Methodology

- Focus, representative discharge pipes at Winfrith
- Assess types / levels of contamination
- Ascertain supporting infrastructure for diagnostic measurements

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Predicting Gamma Dose Rates based on Limited Information

UNIVERSITY OF SURREY

Environmental evaluation

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Predicting Gamma Dose Rates based on Limited Information

UNIVERSITY OF SURREY

Environmental evaluation

Develop experimental facility

In-field gamma measurements

Modelling capability

Enhanced data analysis

Recommended Methodology

- Existing soil tank for preliminary measurements
- Create enhanced soil tank for representative depth of contaminated pipe
- Ability to control environment (soil moisture, density, introduced sealed contaminant pipe).

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Transformative Science and Engineering for Nuclear Decommissioning

Predicting Gamma Dose Rates based on Limited Information

UNIVERSITY OF SURREY

Environmental evaluation

Develop experimental facility

In-field gamma measurements

Modelling capability

Enhanced data analysis

Recommended Methodology

Selection of detector and diagnostic methods considering:

Radiation based – gamma detection

- Surface based measurements – ***gamma spectroscopy***
- Soil / gas sampling diagnostics Efficiency and resolution requirements
- Sensitivity to key isotopes and likely encountered activities
- Networked detectors and remote detector control

Environmental based

- Moisture sensors

Laboratory representative campaigns – TRL 4

In-field measurement campaigns, Winfrith – TRL 6

Transformative Science and Engineering for Nuclear Decommissioning

Predicting Gamma Dose Rates based on Limited Information

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Develop experimental facility

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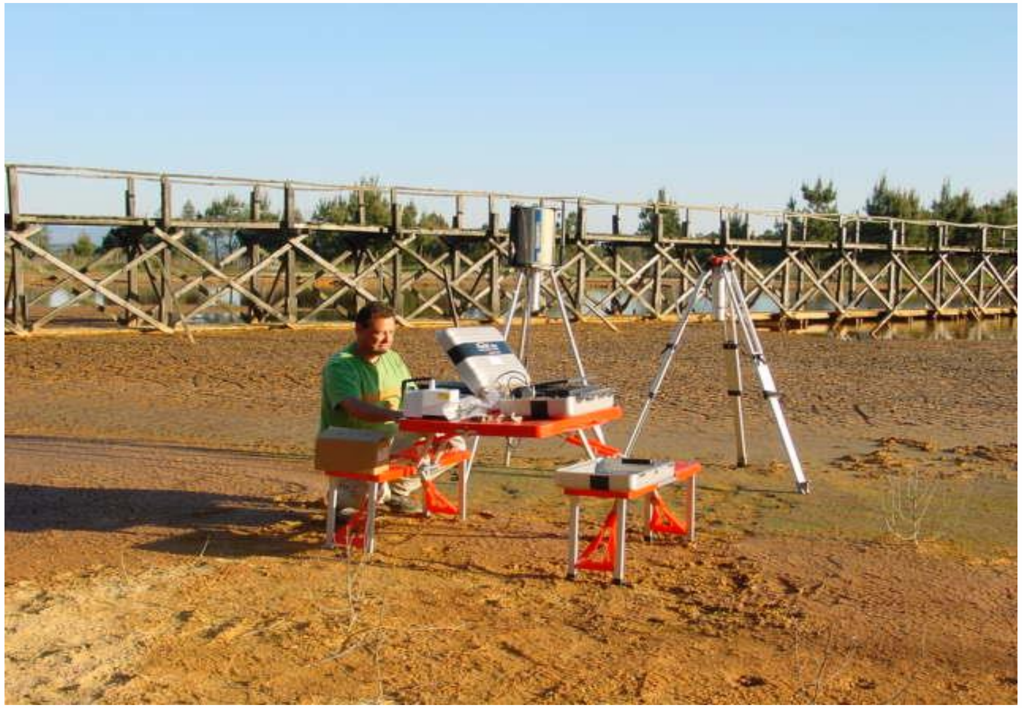
Recommended Methodology



Laboratory representative campaigns – TRL 4

In-field measurement campaigns, Winfrith – TRL 6

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Predicting Gamma Dose Rates based on Limited Information

UNIVERSITY OF SURREY

Environmental evaluation

Develop experimental facility

In-field gamma measurements

Modelling capability

Enhanced data analysis

Recommended Methodology

Modelling capability, consider:

- Contamination
- Location/dispersion
- Decay profile of contaminants
- Decay profile of pipe
- Impact of environmental soil conditions

Geant4 to model radiation transport, utilise Surrey HPD cluster. Model attenuation of photons.

GEANT4

A SIMULATION TOOLKIT

Predicting Gamma Dose Rates based on Limited Information

Environmental evaluation

Develop experimental facility

In-field gamma measurements

Modelling capability

Enhanced data analysis

Recommended Methodology

Routine analysis

- Comparison of experimental data to modelled capability
- Use of models to inform/enhance data analysis
- Correction for soil attenuation, concrete, other underground features

Enhanced analysis and mathematical techniques, may include

- ***Fuzzy logic***; combine quantitative and qualitative datasets
- ***Wavelet analysis***; for location of concealed spectral features (peaks) within sparse data
- ***Parley method***; consensus across sparse distributed network of sensors
- ***Receiver Operator Characteristic (ROC) curves***; confidence and uncertainty
- ***Frequentist and/or Bayesian methods*** for predictive gamma dose rates
- ***Optimised sensor location***

Predicting Gamma Dose Rates based on Limited Information

Environmental evaluation

Develop experimental facility

In-field gamma measurements

Modelling capability

Enhanced data analysis

Recommended Methodology

Provide a decision-making tool that can:

1. ***Identify*** what is in the pipe
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Thank you

c.shenton-taylor@surrey.ac.uk