Passive, continuous monitoring of carbon dioxide geostorage using muon tomography

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International Advanced School on Muon Spectroscopy
Rutherford Appleton Laboratory, UK, August 2019

Durham University | The University Of Sheffield. | NASA | Boulby Underground Laboratory | University of Bath

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UK Policy on Carbon Capture

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Policy

Reducing the UK's greenhouse gas emissions by 80% by 2050

Organisations: Department of Energy & Climate Change, + 4 others
Page history: Updated 6 March 2014, see all updates
Topics: Climate change, + 2 others
Ministers: The Rt Hon Gregory Barker MP and The Rt Hon Edward Davey MP

Policy | Detail | Latest

Contents
- Issue
- Actions
- Background
- Bills and legislation
- Who we're working with
- Case studies

Issue

The 2008 Climate Change Act established the world's first legally binding climate change target. We aim to reduce the UK's greenhouse gas emissions by at least 80% (from the 1990 baseline) by 2050.

We are trying to achieve this reduction through action at home and abroad. Moving to a more energy efficient, low-carbon economy will help us meet this target. It will also help the UK become less reliant on imported fossil fuels and less exposed to higher energy prices in the future.

- One aspect of this is capturing and storing CO_2 ….

Carbon Capture and Storage

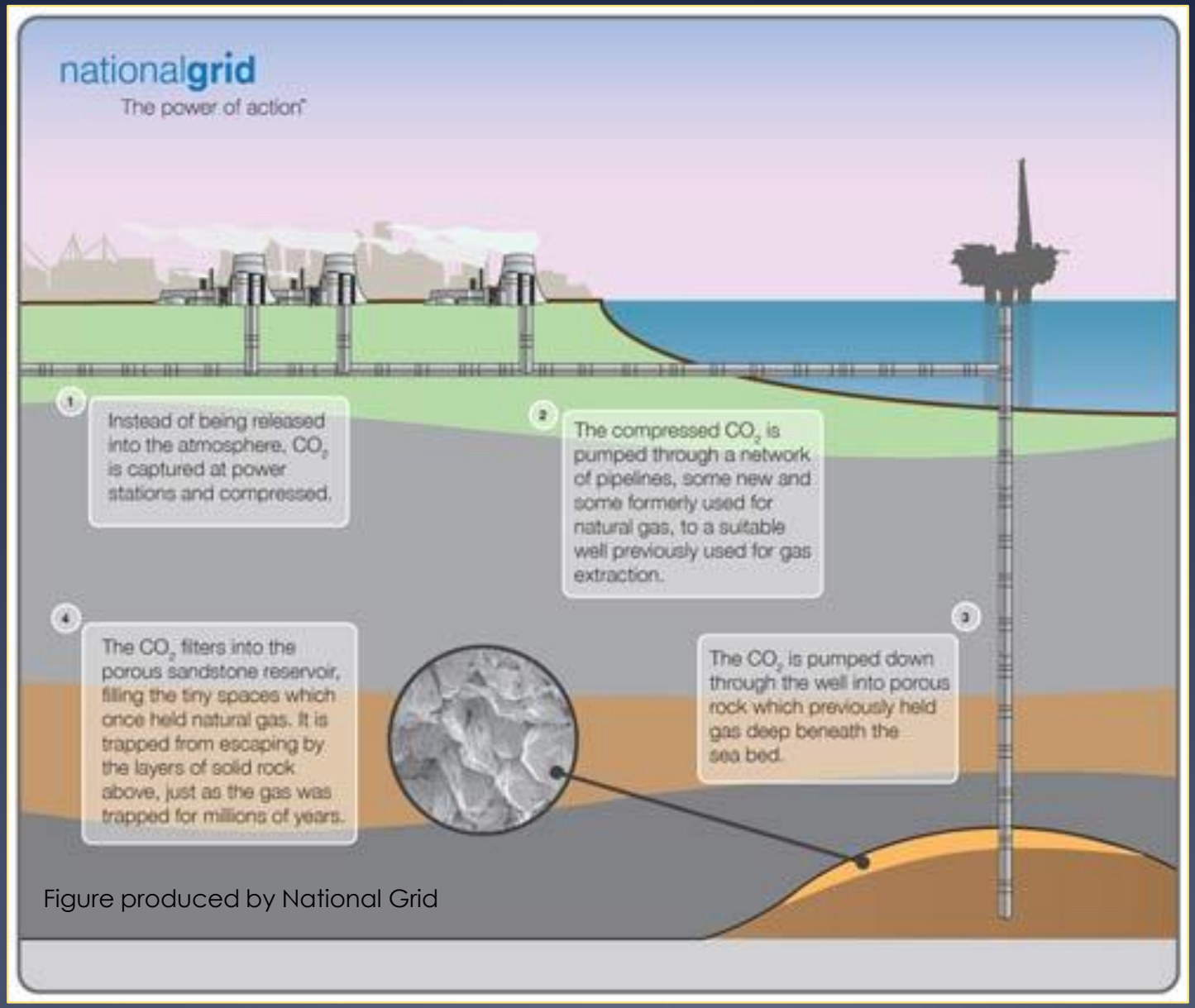


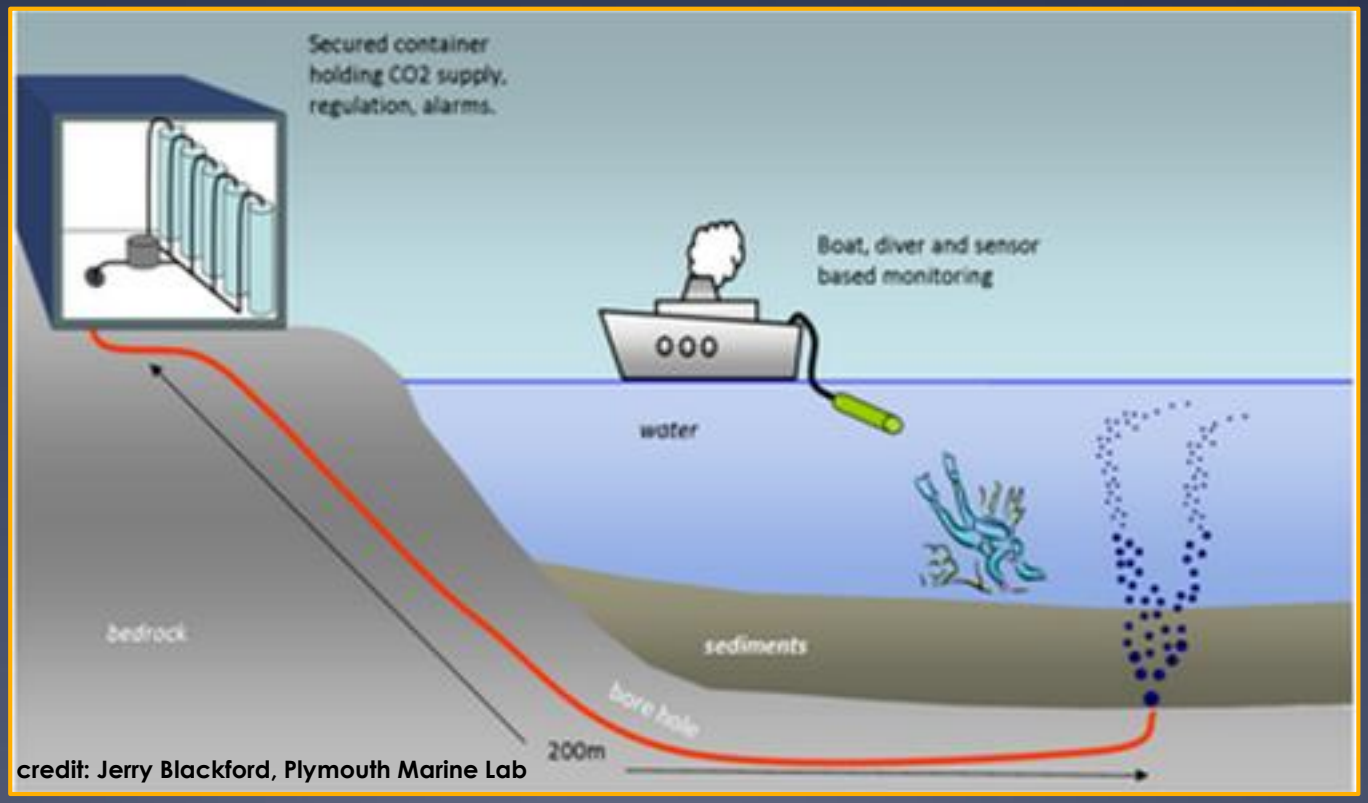
Figure produced by National Grid

Potential CO_2 storage sites

- The UK is fortunate and has access to any hundreds of potential CO_2 storage sites including >400 oil and gas fields and ~50 large saline aquifers

CO_2 storage monitoring

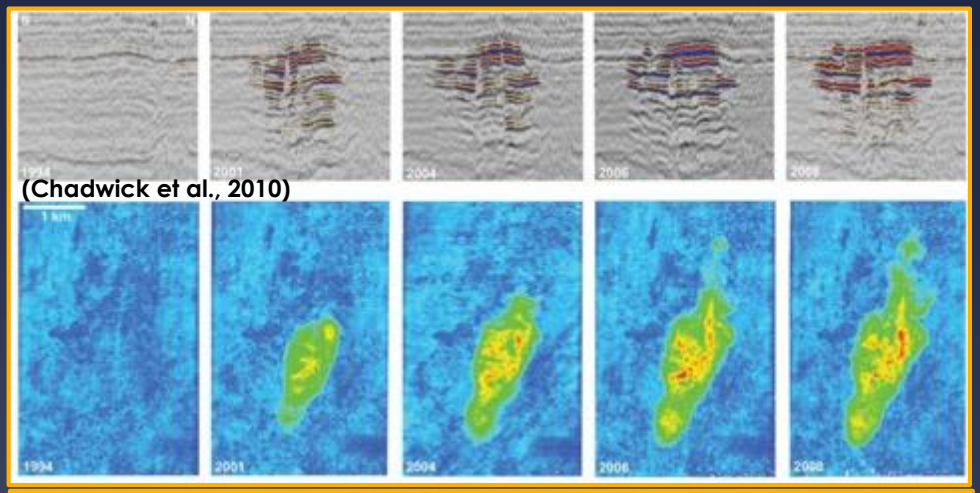
- Successful capture and storage isn't the end of the problem
- EU legislation is likely to require less than 1% leakage per 1000 years
- Monitoring will be required
- Costs of monitoring will need to factored in

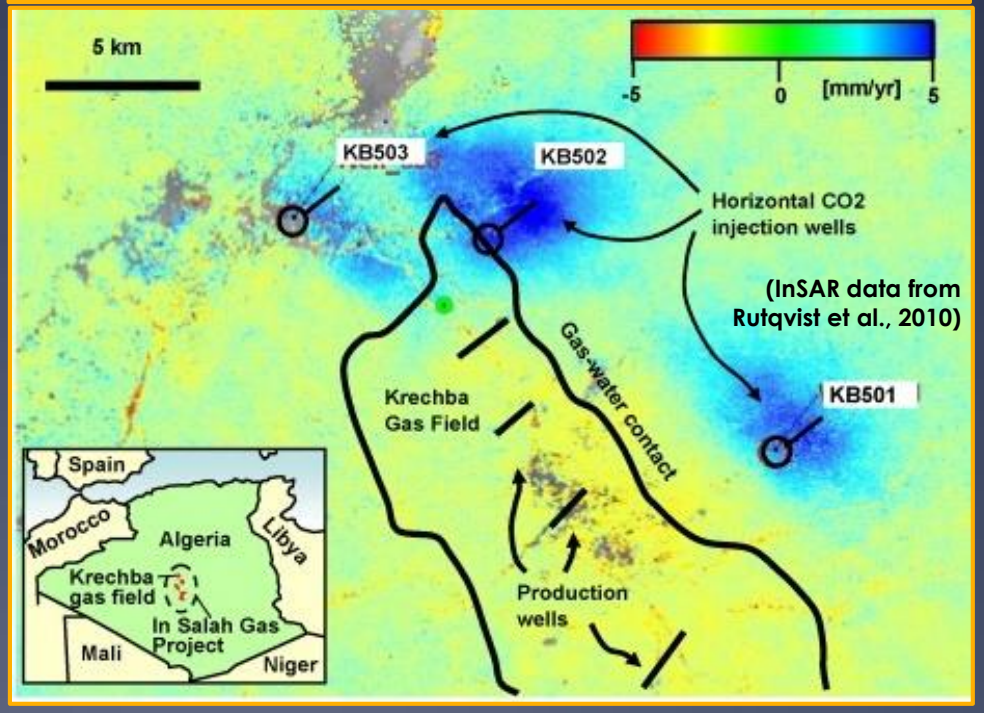


credit: Jerry Blackford, Plymouth Marine Lab

Monitoring Technologies

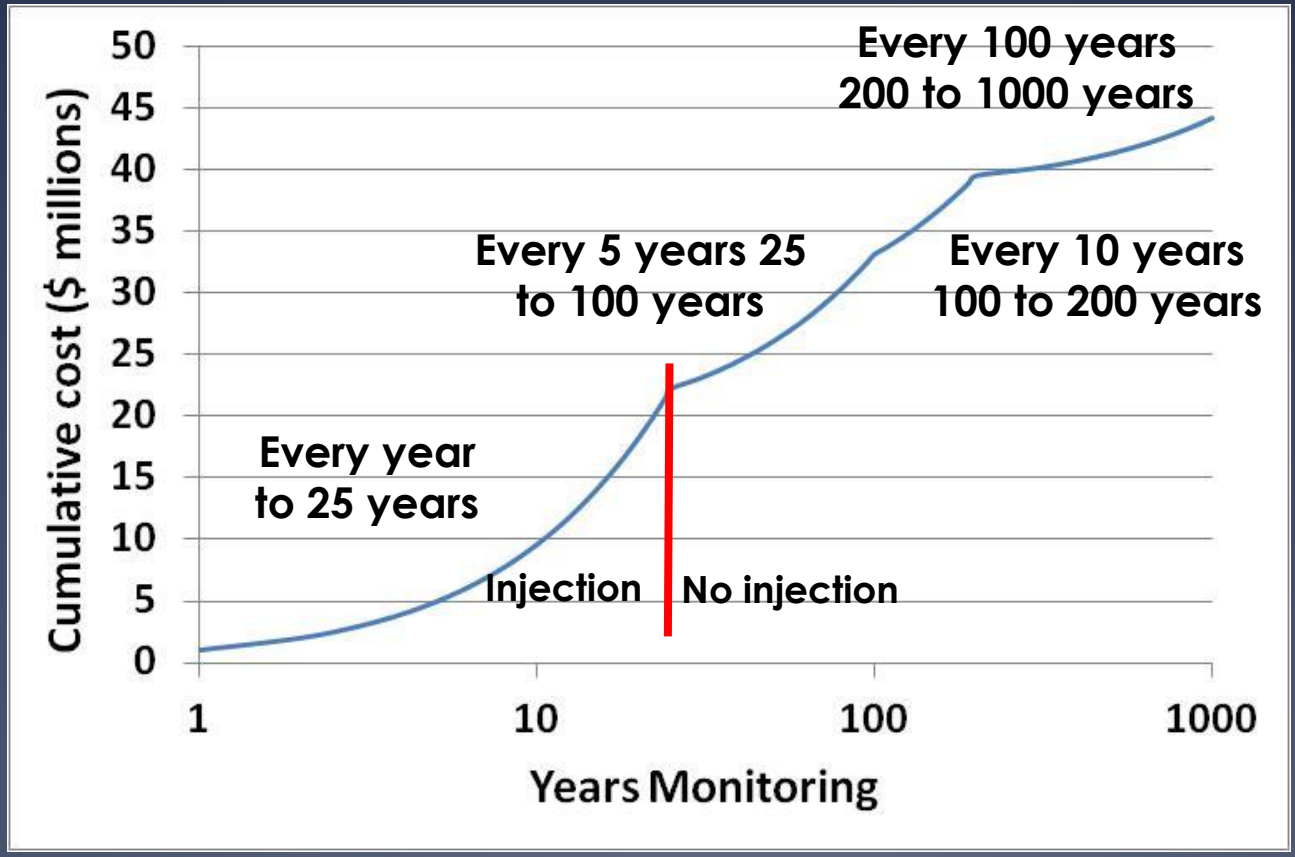
- **Marine**
  - 4d seismic
  - Electromagnetic surveys
- **Land**
  - 4d seismic
  - Insar
  - CO_2 seep detection





4-D Seismic detection costs

- Assumes £1M per "shot" (some estimates as high as £5M)
- Costs for 1 storage site – up to 150 may be developed
- (No inflation!)



CCS monitoring

- 4d seismic surveys are not the optimal tool for CCS monitoring, in particular they
  - are episodic – what happens between surveys
  - do not measure CO_2 density directly (measures acoustic contrast, *f*)
- An ideal monitoring methodology would be
  - inexpensive
  - continuous
  - passive
  - directly sensitive to CO_2 density
  - last for hundreds of years

Are there alternative technologies that can address some of these issues?

Muon Flux Simulations

- Initial studies (2010) indicates that by instrumenting 1000 m^2 and taking data for 1 year then 0.4% mean volume density variations (7% pore volume) can be measured at 1km depth

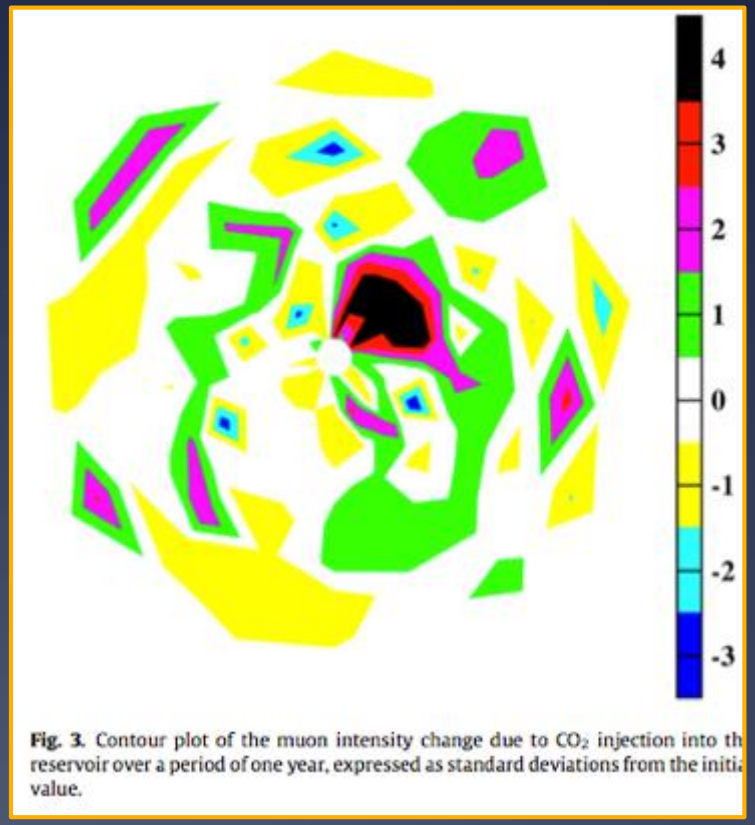


Fig. 3. Contour plot of the muon intensity change due to CO_2 injection into th reservoir over a period of one year, expressed as standard deviations from the initi value.

Monitoring subsurface CO2 emplacement and security of storage using muon tomography V.A. Kudryavtsev et al.,

International Journal of Greenhouse Gas Control 11 (2012) 21–24

Muon Tomography for CCS Monitoring

- Muon tomography offers a monitoring tool that is:
  - Continuous – some methods are episodic, what happens between measurements?
  - Passive
  - Directly sensitive to CO_2 density – some methods do not measure CO_2 density directly
  - Capable of delivering useful data for many years
  - cost effective
- but there are challenges …
  - Need to instrument below/around the volume of interest
  - Restricted borehole geometry not well-suited to particle physics instrumentation
  - Elevated temperatures
  - Need to instrument large areas cheaply

CCS consortium

- Awarded a ~£1.5M grant from DECC and Premier Oil
- Other funding from STFC, University of Sheffield

Work Package Structure

WP1: Muon detector design and construction

WP4: Muon trajectory methods

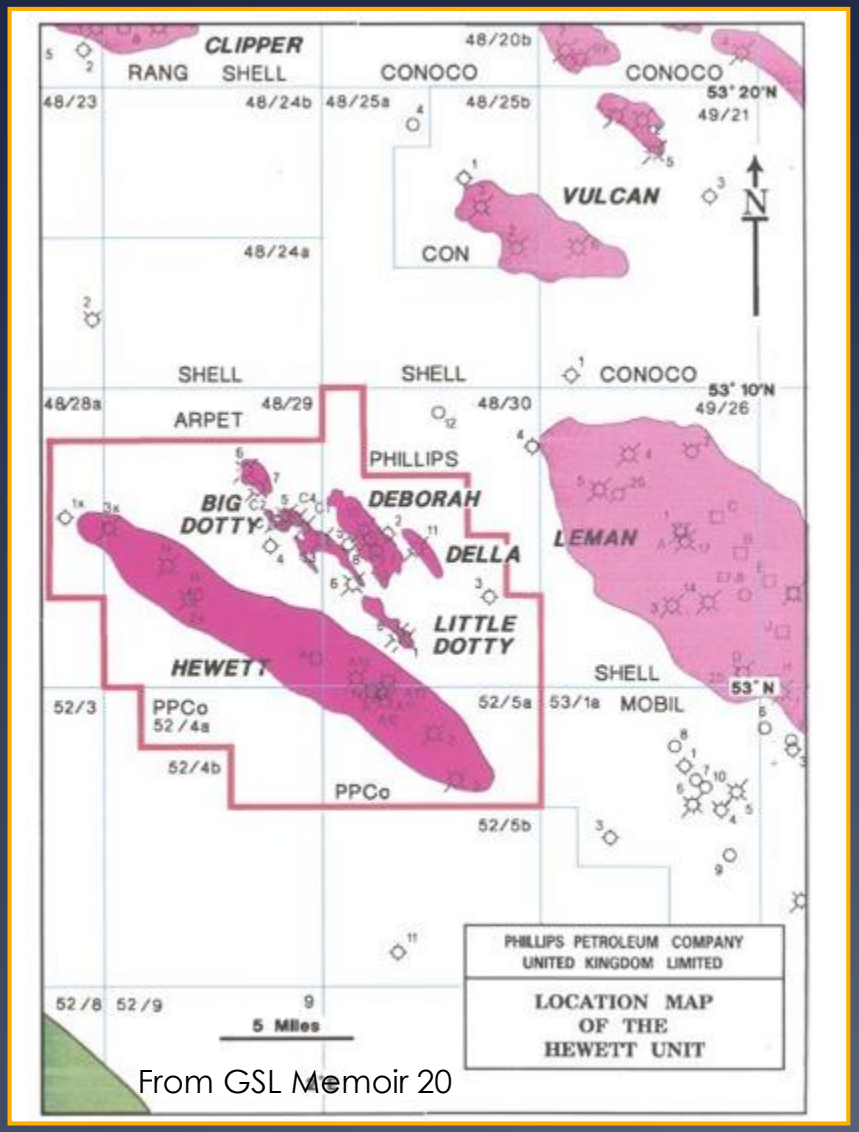
WP2: Physical and chemical models of CO_2 repositories

WP5/6: Detector tests and borehole deployment

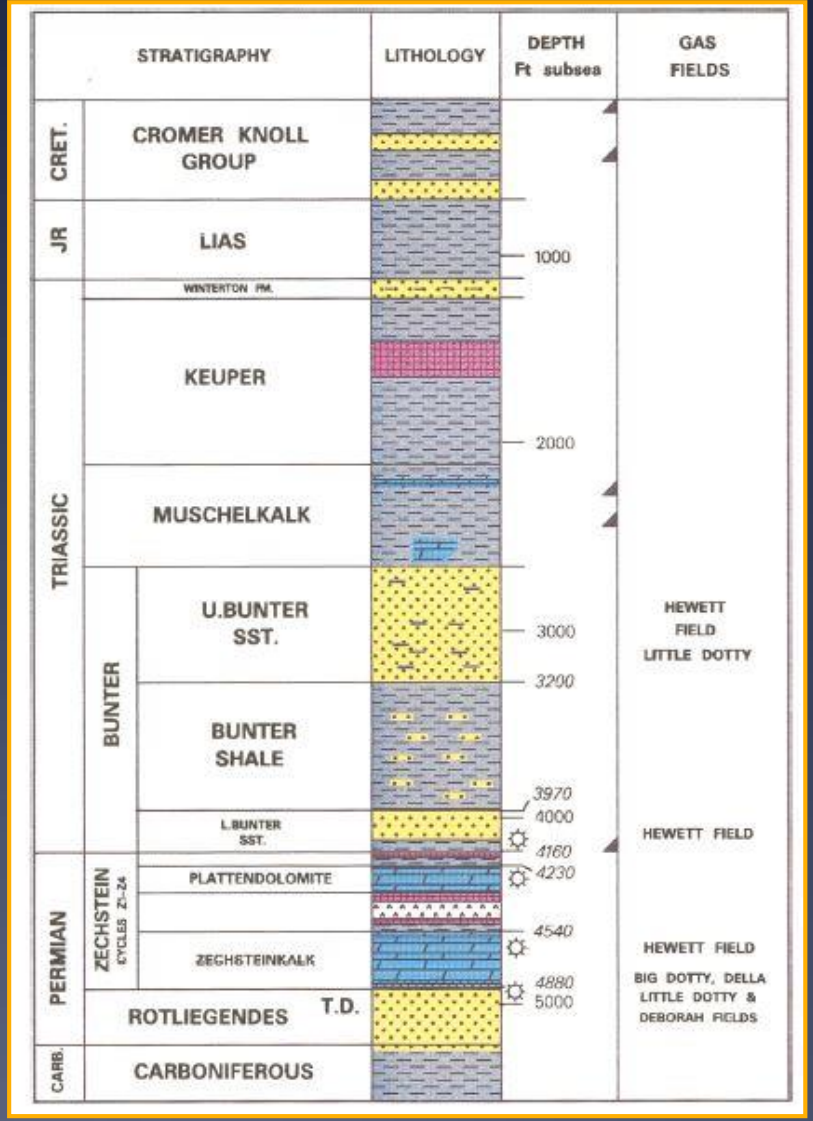
WP3: Muon transport and detection modelling

WP7: Adoption and commercialistion

Geological Modelling



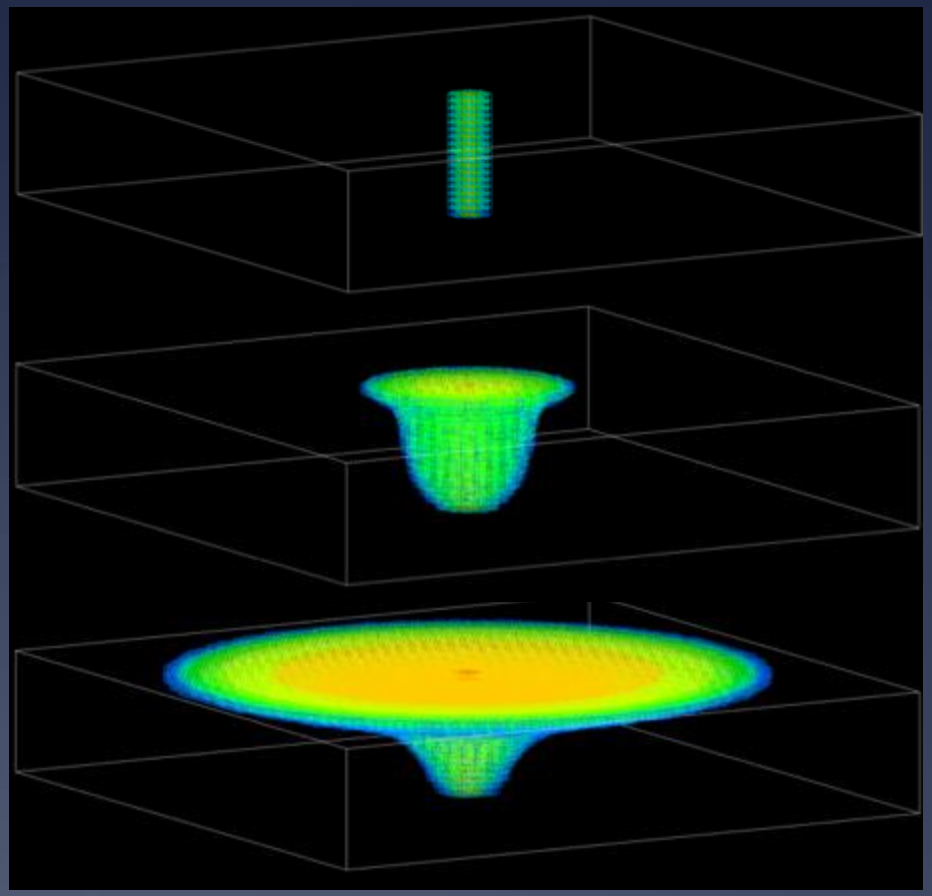
From GSL Memoir 20



- Hewett field – a candidate CO_2 storage site

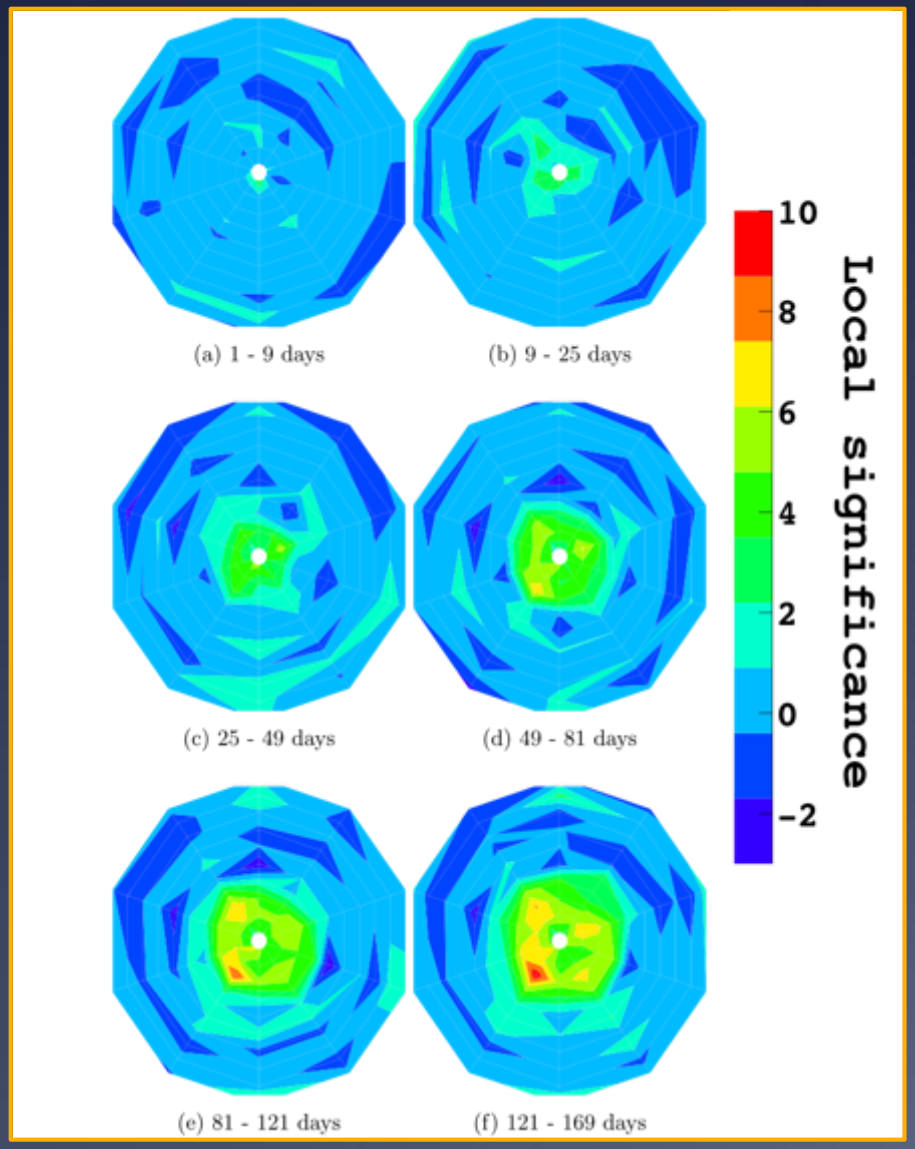
CO_2 plume evolution

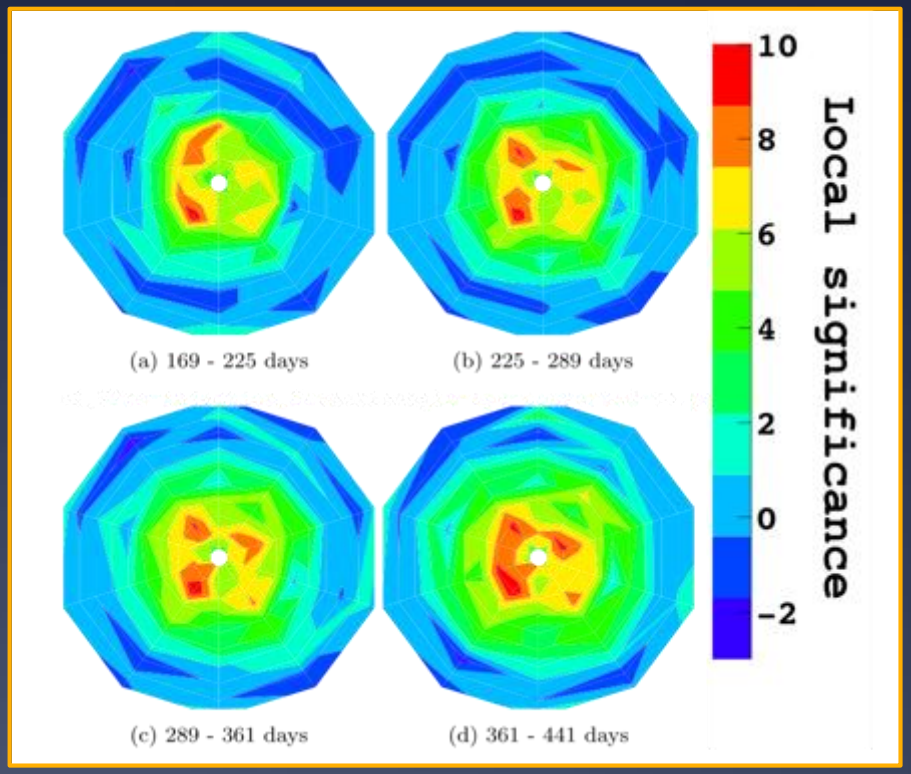
- Also of interest is whether the muon tomography method could be used to monitor the injection of the CO_2 as the "plume" evolves
- Following plots are based on realistic values of 20kg.s^{-1} injection of CO_2 and injection into a reservoir layer that is 170m in thickness at 1km in depth



- Use a full-blown numerical model based on fluid mechanics which considers the continuity of multiple fluid phases in a porous medium

CO_2 plume evolution

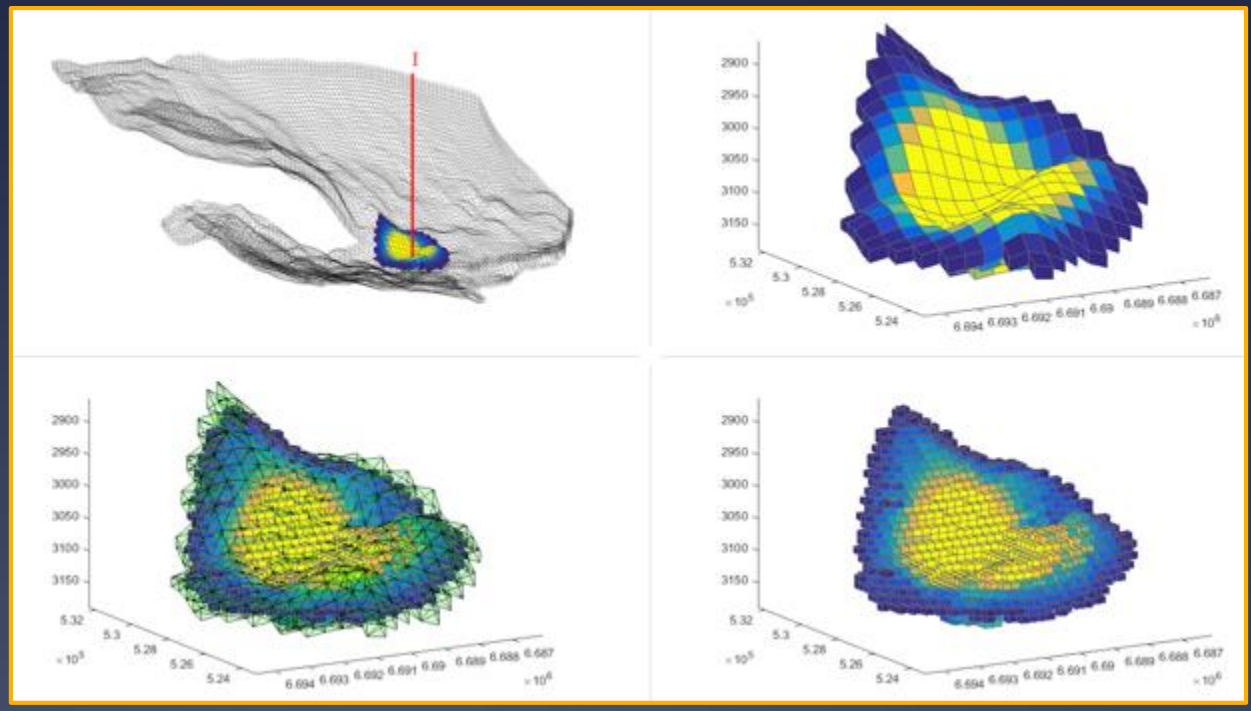




- In this configuration after 25 days of injection a 3.9 ∫ variation in the muon flux is seen. More realistic assumption would be 3 ∫ in ~9-12 months.

Refining the models

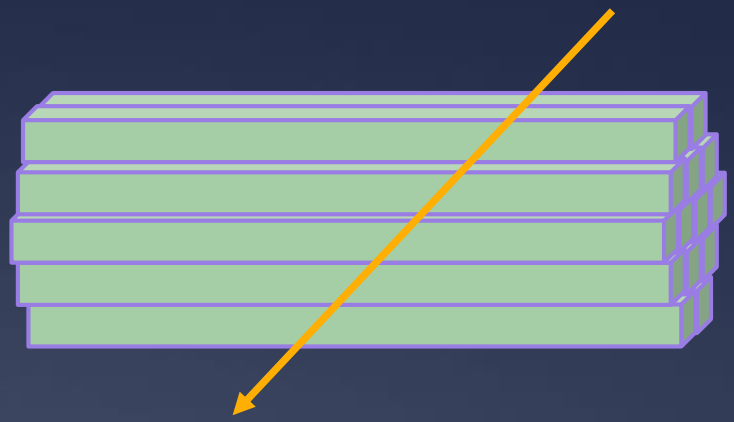
- More recently we have developed a more refined model for the plume evolution
- Enables complicated topography and injection sites to be accurately modelled



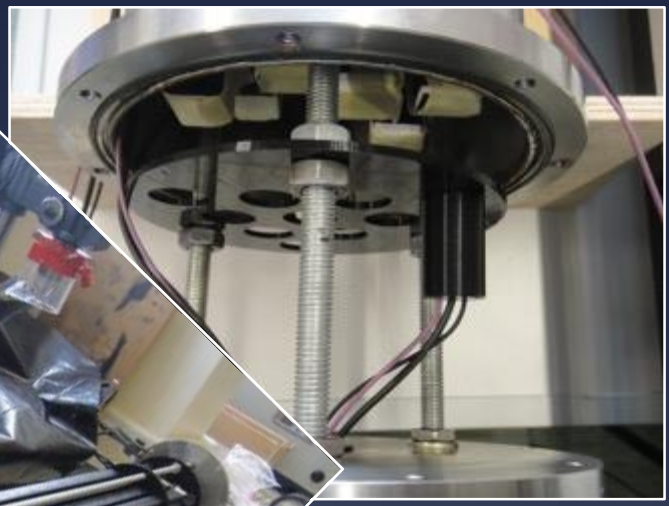
- Plots show Johansen field (Norway) at a point in time while undergoing injection.
- Voxels represent complex moving regions thereby enabling the simulation and reconstruction of muon transport through a migrating CO_2 plume.

A prototype "Borehole Detector"

- Part of the project was to develop a low TRL prototype/demonstrator borehole detector
- Significant constraints in terms of geometry, location, environment conditions
- Use solid plastic scintillator as the principle detection medium
- NB, for the prototype no DAQ on board - external



Borehole Detector Prototype



Boulby Underground Science Lab

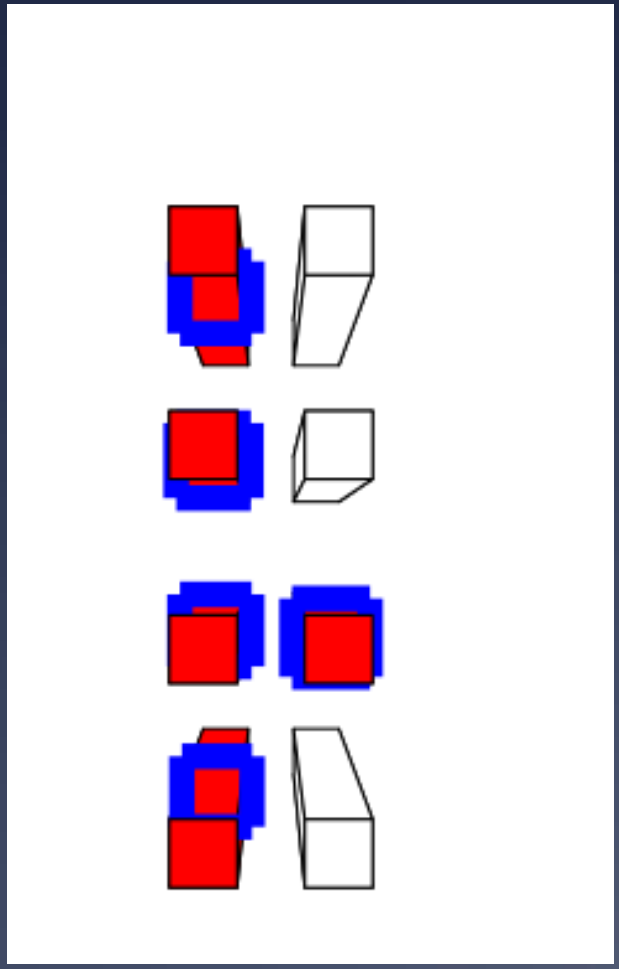
- STFC-operated Boulby Science Lab is situated ~1.5km underground
- Proved to be an invaluable testing ground for the CCS project
- The mine also has disused tunnels running out under the North Sea

Borehole Detector Installation at Boulby

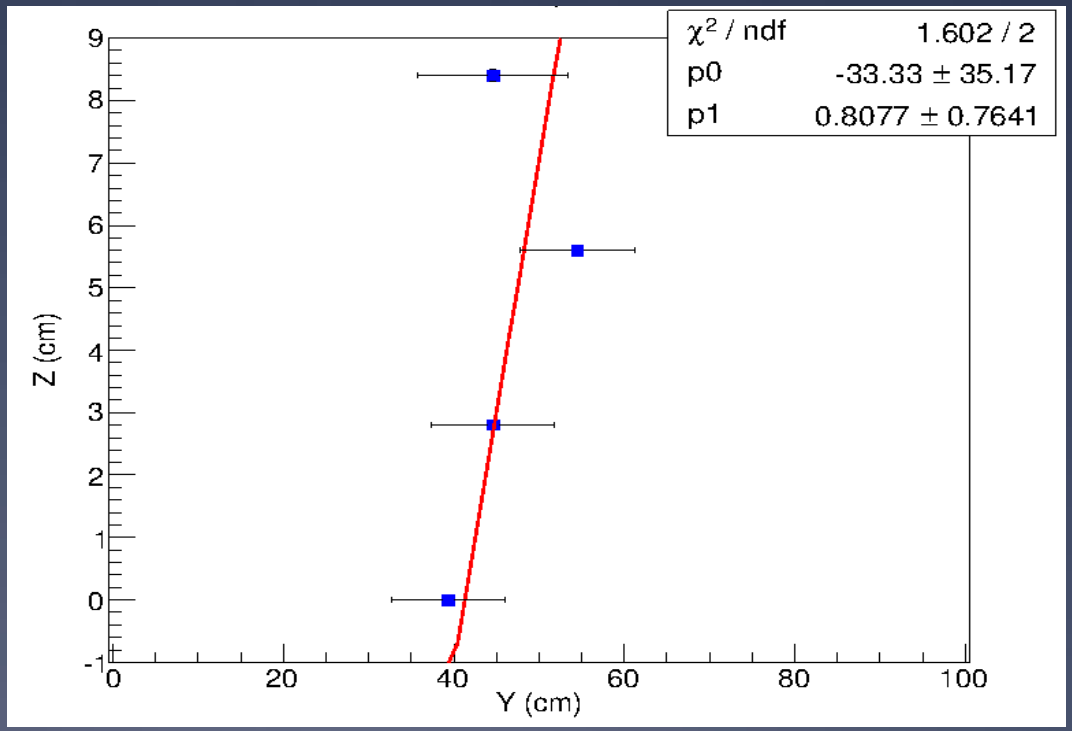
- In summer 2014 a mock "borehole" was drilled into a rock side wall at the Boulby mine to give the team experience of working in such environments
- Subsequently a prototype borehole detector was deployed in that area

- After a period of commissioning muon events were successfully recorded at this location

Borehole detector events



- Based on an 8 bar borehole detector
- Trigger requires >100mV signals to be recorded on PMTs at both ends of the bar and >2 bars hit



Ministerial Visit to CCS work at Boulby

- The Rt Hon Michael Fallon MP, Energy Minister at the time, visited the Boulby underground site in June 2014
- Accompanied by members of the CCS office at DECC

DECC
@DECCgovuk

Follow

Energy Minister Michael Fallon visits Boulby Potash Mine today to see how innovative CO2 monitoring technology can help reduce costs of #CCS

Conclusions

- The joint DECC/Premier Oil grant was a great success, a large amount of work was completed in assessing the possibility of using muon tomography in the monitoring of stored CO_2 including:
  - assessing the sensitivity of the technique with detailed simulations involving
    - wireframe geological models
    - accurate muon transport (MUSIC software - Kudryavtsev)
    - analysis of the CO_2 plume evolution
  - development and successful deployment of a prototype borehole detector in a mock borehole in the Boulby Underground Science Lab

Epilogue 1

- The original intention of the grant was that methods and instrumentation was to be developed to low TRL and then there was a requirement to engage with industry (in this case oil instrumentation companies) for further funding
- We did engage with companies such as Schlumberger and Baker-Hughes - 2 of the "big 3" global oil instrumentation companies. There were useful conversations and definite interest
- However we then suffered a "double whammy"
  - Government closes DECC (BIS —> BEIS)
  - Oil price hits an all-time low -10,000 redundancies

Epilogue 2 – don't give up

- January 2018 – met with rail industry infrastructure integrity testing company
- August 2019 – reengaged with energy industry, renewed interest