



Sean Paling  
STFC Boulby Underground Science Facility

Dark Matter Search & ULB  
counting



Multi-disciplinary studies: climate, the  
environment, life on earth & beyond

## Deep Science at Boulby Underground Laboratory:

Current studies & details of new underground  
facilities to support UK & international  
underground science.



New Underground lab @  
Boulby



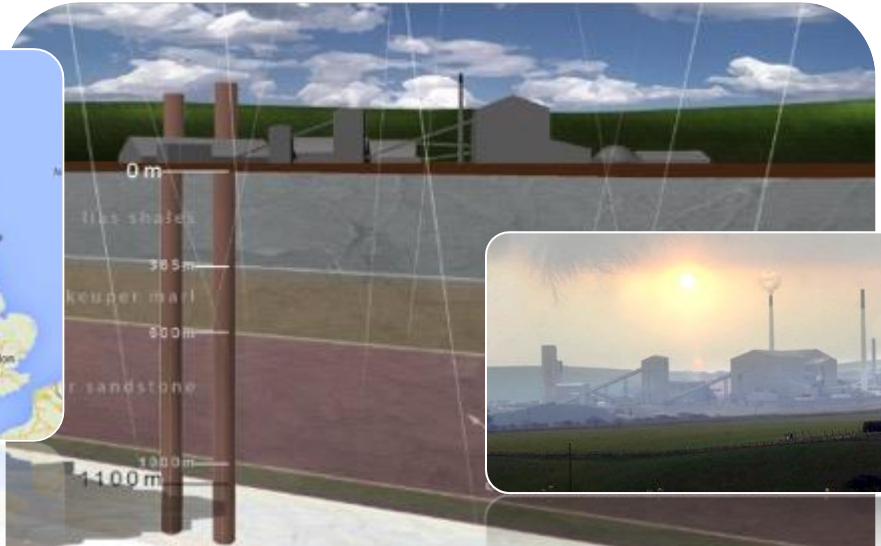


# Boulby Underground Laboratory

The UK's deep underground science facility operating in a working potash and salt mine.

1.1km depth (2805 mwe). With low background surrounding rock-salt

Operated by the UK's Science & Technology Facilities Council (STFC) in partnership with the mine operators ICL



Boulby Palmer lab. >800m<sup>2</sup> floor space.  
Operating since 2001

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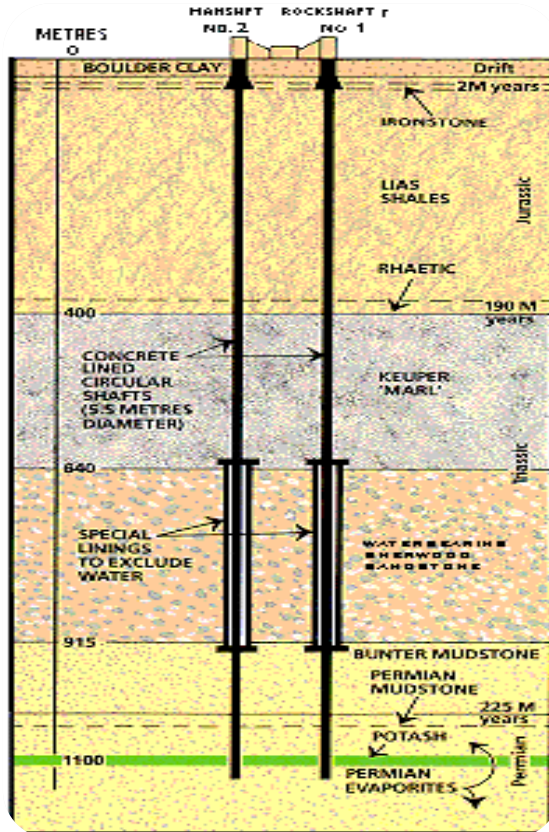
Factor ~1 million reduction in cosmic ray muon flux vs. surface



# Boulby Geology & Mining

Excavations are in Salt (NaCl) & Potash (KCl) Permian evaporite layers left over from the Zechstein Sea.

Over 40 kms of tunnel mined each year (now >1,000kms in total), the long-lived roadways being cut in the lower NaCl layer.



Boulby Geology

U:  $67 \pm 6$  ppb  
Th:  $125 \pm 10$  ppb  
Low  $\gamma$  & n backgrounds  
Low Rn ( $<3$  Bqm<sup>-3</sup>)

Rock-Salt



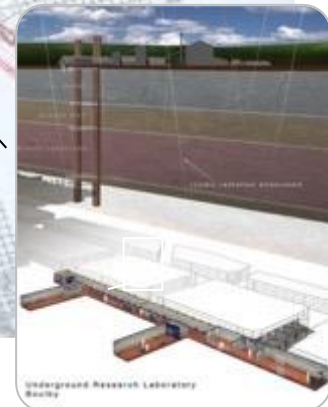
Potash



Typical Boulby Salt Roadway



Boulby Mine



Palmer Lab

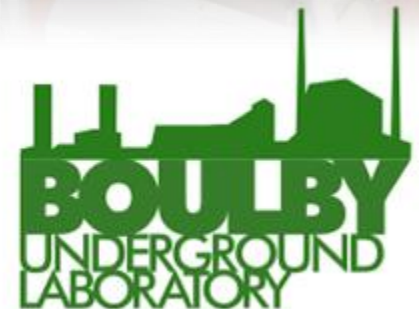


# Underground Science @ Boulby Mine

- DRIFT: Directional Dark Matter Search
- BUGs: Ultra-low background material screening
- Deep Carbon: Muon Tomography for CCS (etc)
- ERSaB: Environmental gamma spectroscopy
- BISAL: Geomicrobiology / Astrobiology studies
- MINAR: Space Exploration Tech. Development
- SELLR: Life in Low background radiation
- Misc. Geology / Geoscience
- Misc. Low-background support projects
- Etc... (More to come).



A growing multi-disciplinary science programme:  
from astrophysics (Dark Matter) to studies of geology,  
climate, the environment, life on Earth and beyond.

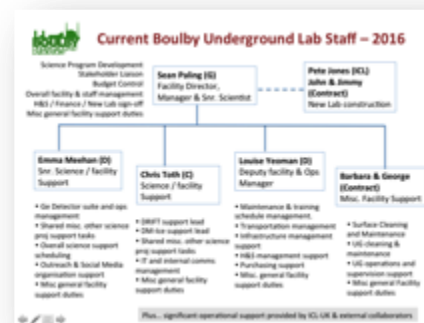


# Boulby Facility Details...

- Supports work of 9 collaborative projects (astrophysics to climate, geology, environment, life etc), 20 institutions, > 70 scientists and students.
- Facility funded and operated by the Science and Technology Facilities Council (STFC) in partnership with CPL/ICL.
- Operations, H&S & science programme managed by 4(+4) onsite staff and supported by Rutherford Appleton Lab (PPD).
- CPL / ICL provide wide-ranging operational & higher level support.



**'A hole in the ground does not make a facility'**



Management



User and science support



Materials transport



Environment monitoring



H&S, medical support

PROJECT RESOURCE SUMMARY (UPDATED)	
Project Name:	ROPLIN III
Contact Person / Institution:	Bonnie Armitage (Imperial College London, RAL)
Brief Description:	A 4kg two phase sonic dark matter detector
Summary of resource requirements from the facility:	
Space requirement, Width/Depth/Height:	3.0m / 10.0m / 3.0m
Crane requirement (type, weight and height):	22T / 10m / 3.0m
Technical power / voltage / phase requirements:	200V single phase 50Hz
Temperature requirements (Installation & Normal operation):	Installation Facility: 10 degree above, target, 400mm/min, 0.1m/s, D&Q, comparing Relocation of local cable from Sub 1 to J1 (300 mm/s) Operations None
Maximum tolerable temperature shock:	5K
Experiment team size underground (Installation / operation):	Installation 4 Operations 4
Cryogenic requirements (LNG):	During installation 100L During emergency recovery 40L

Project tracking, H&S



# World Deep Underground Science Labs

Overview of status & future plans of (some of) the world's underground facilities...



## Europe

- Gran Sasso
- Modane
- Canfranc
- Boulby

## Asia

- Kamioka
- Jinping
- Yangyang
- Ino

## North America

- SNOLAB
- SURF
- Soudan
- WIPP

## Southern Hemisphere

- Andes
- Stawell

Lots going on. Many and varied science projects and laboratories progressing and emerging.

# How does Boulby compare?

- 4 (+5) onsite staff supporting 70 users from 20 UK & international universities and research institutes

## What Makes Boulby Special?

### Requirements for an underground laboratory...

#### Low Backgrounds

- Deep (to shield from cosmic rays)
- Low background rock/lab (and/or adequate shielding)

1.1 km deep (2,850 $\pm$ 20 mwe)  
CR muons attenuated by  $\sim 10^6$   
( $3.79 \pm 0.15$ )  $\times 10^{-8}$  cm $^{-2}$ s $^{-1}$

Salt = low in U/Th (67 $\pm$ 6/125 $\pm$ 10ppb)  
→ Low gamma & neutron backgrounds  
→ Low Radon (<3Bq/m $^3$ )

#### Plenty of Laboratory space

>1000 m $^2$  existing lab space & excellent potential for expansion.

#### Easy access for equipment

Via mine shaft (5m diam. – 2 $\times$ 2 $\times$ 2m cage)  
+ Transport underground

#### Proximity of services / civilisation

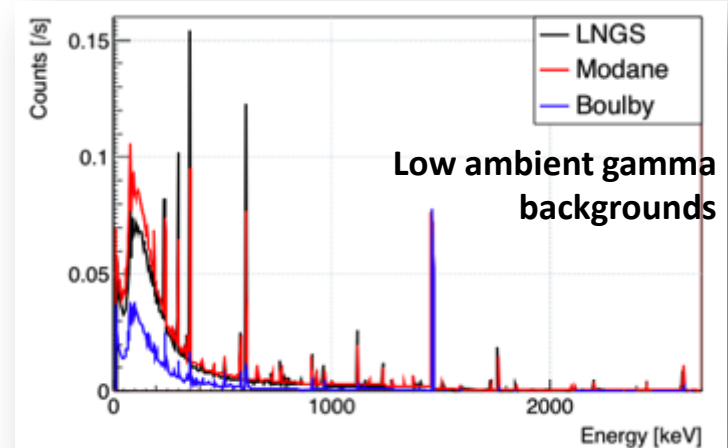
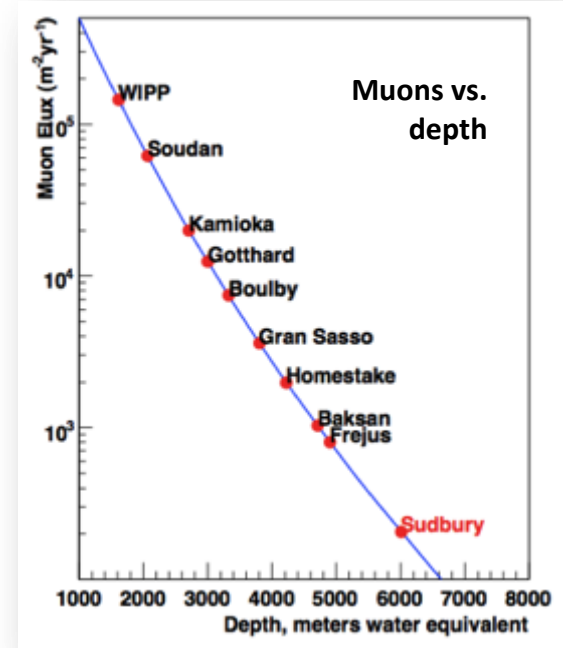
20 min → Whitby, Saltburn  
1 hr → York, Leeds, Middleborough  
< 5 hrs → London, Manchester etc.

#### Good infrastructure + support

- JIF Underground & surface facilities
- Wide-ranging support from mine operators (Cleveland Potash Ltd)

A unique science / industry partnership

- Low ambient gamma backgrounds
- VERY low ambient Radon background: <3 Bq/m $^3$
- Interesting geology, diverse science programme
- Operations well-supported by mine owners ICL







# Current Boulby Underground Lab Staff – 2016

Science Program Development  
Stakeholder Liaison  
Budget Control  
Overall facility & staff management  
H&S / Finance / New Lab sign-off  
Misc general facility support duties

**Sean Paling (G)**  
Facility Director,  
Manager & Snr. Scientist

**Pete Jones**  
**John Toole**  
**Jimmy Beadle**  
New Lab  
construction

**Emma Meehan (D)**  
Snr. Science / facility  
Support

- Ge Detector suite and ops management
- Shared misc. other science proj support tasks
- Overall science support scheduling
- Outreach & Social Media organisation support
- Misc general facility support duties

**Chris Toth (C)**  
Science / facility  
Support

- DRIFT support lead
- DM-Ice support lead
- Shared misc. other science proj support tasks
- IT and internal comms management
- Misc general facility support duties

**Louise Yeoman (D)**  
Deputy facility & Ops  
Manager

- Maintenance & training schedule management.
- Transportation management
- Infrastructure management support
- H&S management support
- Purchasing support
- Misc. general facility support duties

**Barbara & George  
(Contract)**  
Misc. Facility Support

- Surface Cleaning and Maintenance
- UG cleaning & maintenance
- UG operations and supervision support
- Misc general Facility support duties

Plus... significant operational support provided by ICL-UK & external collaborators



# Mining at Boulby...



CPL/ICL support us:  
Keep the mine operating and safe  
Local site admin  
Emergency H&S  
Materials transportation  
Misc. Facility maintenance

# Science @ Boulby...



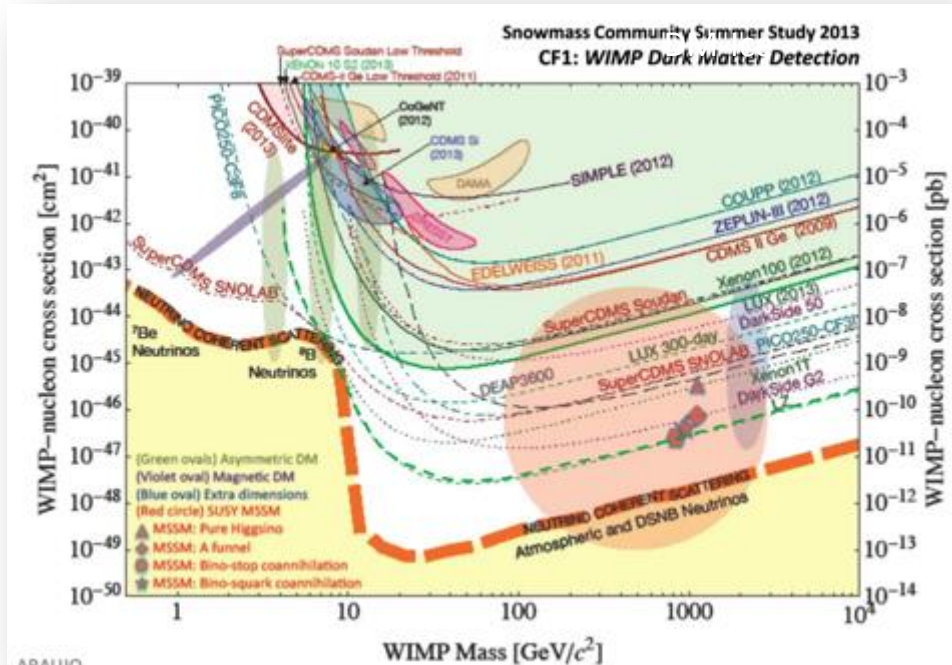
# Boulby Dark Matter Studies

Boulby has hosted Dark Matter search studies for two decades. Including the **NAIAD, DRIFT & ZEPLIN** experiment programmes.

Boulby now hosts DRIFT Directional DM programme, doing R&D for DM-Ice & providing ULB material screening for other studies, inc **LUX-ZEPLIN**



ZEPLIN-III @ Boulby



**ZEPLIN:** The world's first 2-phase Xenon dark matter detector (Finished 2011)

Current limits & future projections

# DRIFT-II (etc) @ Boulby...

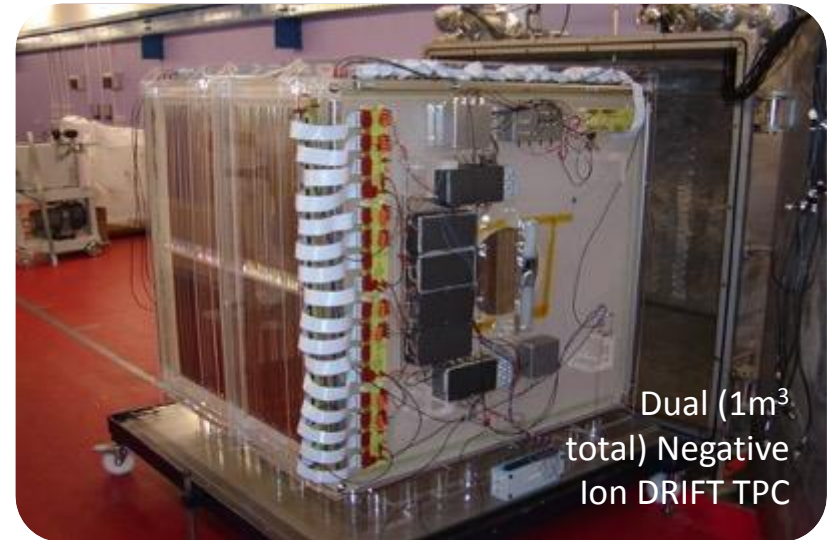
A DIRECTIONAL Dark Matter Detector.

*Occidental College, New Mexico, Colorado State,  
Hawaii, Wellesley, Sheffield, Edinburgh, Boulby*

**STATUS:** Programme operating at Boulby since 2001.  
Currently limit-setting and conducting system  
performance & scale-up R&D. Plans for further R&D &  
expansion / collaboration (**CYGNUS**).

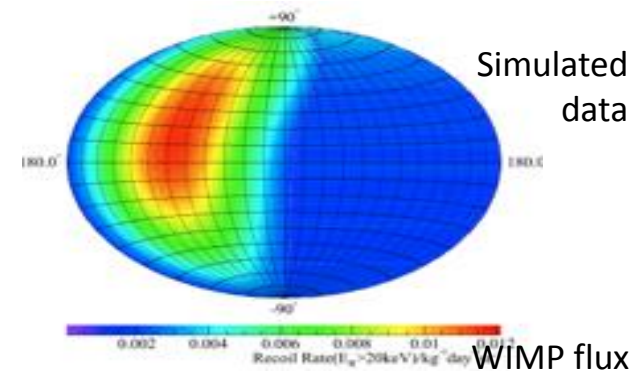


DRIFT IIId and IIe (vessel) now installed in new lab



DRIFT-IIId @ Boulby

Directional detection



Directional DM detection – providing the  
most powerful direct detection signature



# ULB Material Screening

Growing suite ('BUGS') of Ultra-Low-Background germanium detector systems to support Dark Matter & misc 'rare-event' studies.

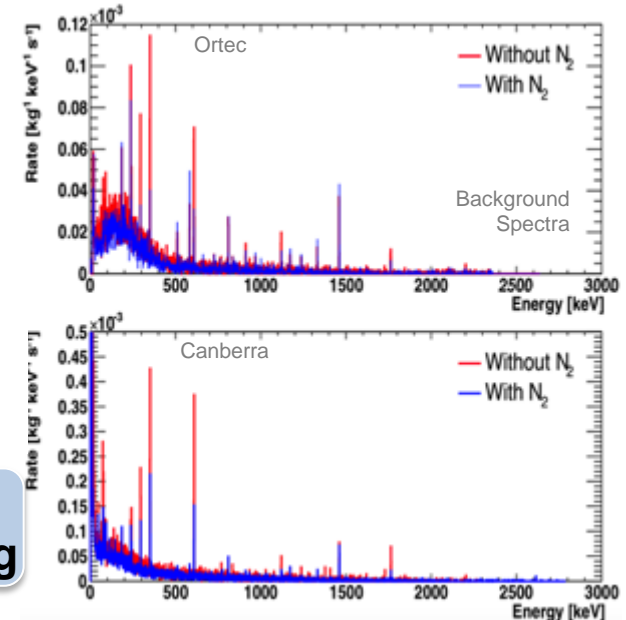


Boulby Underground Germanium Suite (BUGS)



Activity testing steel samples

- Ortec 2kg Coax (90% eff).
- 2 Canberra BEGe detectors
- Canberra SAGE Well-type

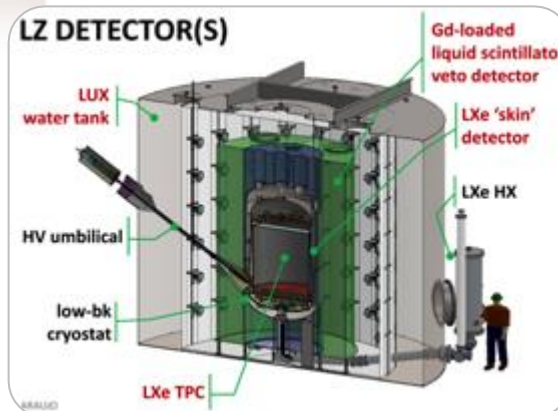


**Sensitivity down to <50ppt  
U/Th per sample, & improving**

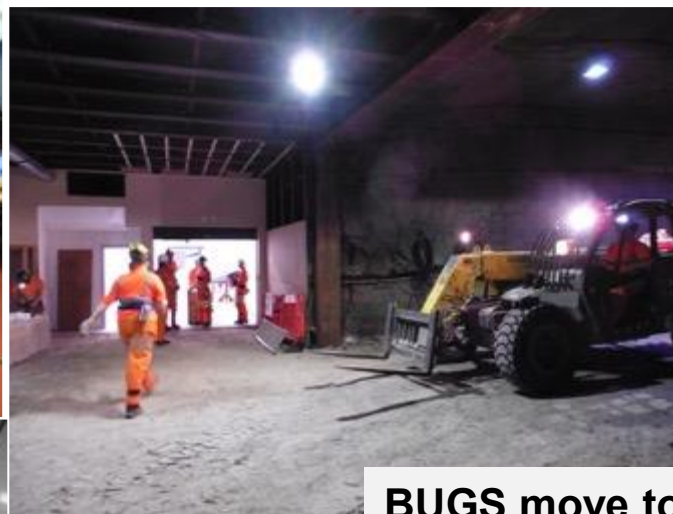
Ultra Low background counting studies supporting UK DM (**LZ**) & 0nuBB communities.

Now **EXPANDING** low BG counting capabilities to meet growing international demand

Working in collaboration with UCL, Oxford, DMUK, STFC-RAL



Boulby undertaking major role (50%) in material selection for **LUX-ZEPLIN**



**BUGS move to new lab complete...** All detectors successfully installed and operating.



**Funding for new detectors secured.** To better support current and future LB experiments (Super-K-Gd & more) & leading towards PPT sensitivity for G3 Dark Matter & 0vBB decay experiments.





# Boulby Multi-Disciplinary Studies



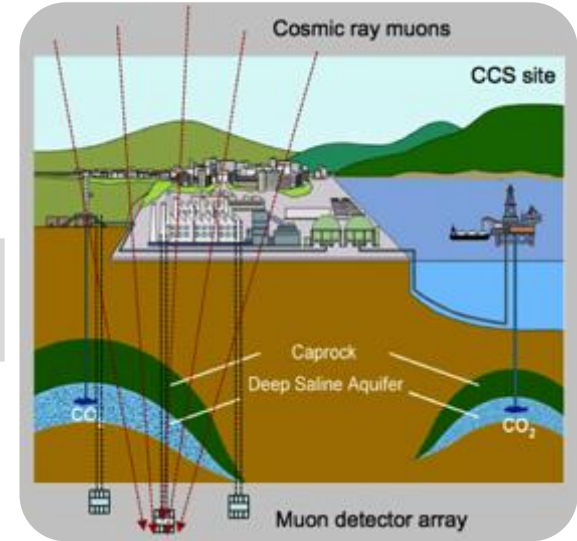
**ERSaB:** Gamma spectroscopy & low background counting environmental radioactivity studies

*Boulby, Scottish Universities Env. Research Ctr (SUERC)*

**DEEP-Carbon:** Muon Tomography for deep geological mapping applications including CCS



*Boulby, Durham, Sheffield, Bath, Premier Oil, CPL.*



**From astrophysics to climate, geology, the environment, life on Earth & beyond...**

**MINAR:** Space Technology Development

*Boulby, Edinburgh, NASA, DLR, CPL etc.*

**Plus** Misc. Geology & Geoscience (& more to come)...

Life in Boulby Salt...



**BISAL:** Astrobiology / Geo-microbiology. Studies of life in salt, life on Earth & beyond



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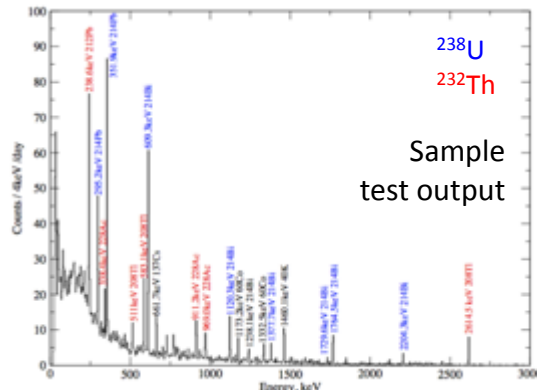
# Low-BG Gamma Spectroscopy

Gamma spectroscopy and low-background counting for **Environment studies** & Beyond

The ultra-low background environment and Ge detectors at Boulby allow existing industrial, environmental and climate-related gamma spectroscopy studies to be extended and improved.

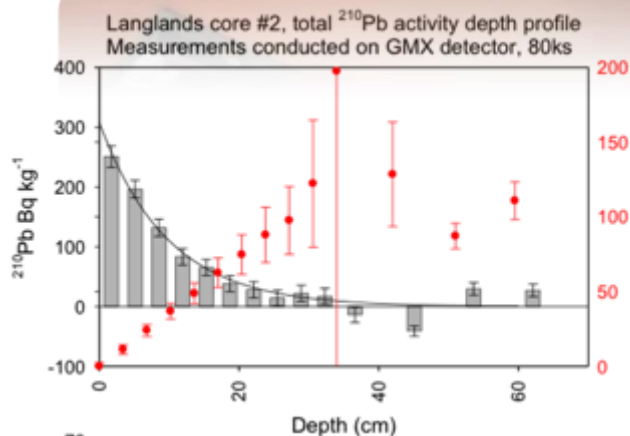


Boulby  
Ultra-low background  
Germanium Suite (BUGS)



## Environmental applications:

- Radioactive tracers for atmospheric & ecosystem processes
- Radio-dating: C-14, Pb-210, Si-32
- Dosimetry in the environment
- Marine radioactivity
- Landscape evolution
- Sedimentology...



Pb-210  
Sediment  
dating



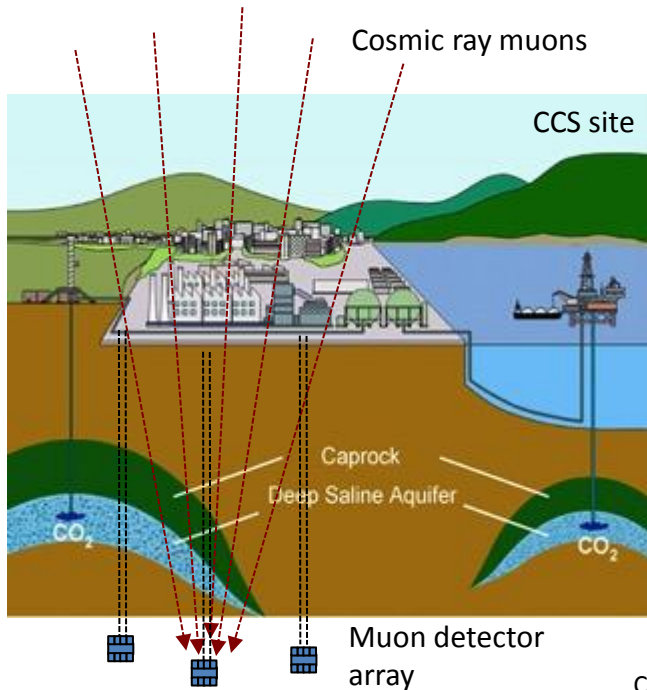
Pb-210 Radio-dating of the 50-250 year timescale is important for understanding RECENT affects of climate change.



# Muon Tomography / Geo-survey

Development of a **Muon Tomography** techniques for deep 3D geological surveying - inc Carbon Capture @ Storage (CCS)

STFC-Boulby,  
Durham, Sheffield,  
Bath, NASA



**Potential for cheap, reliable, practical, real-time long-term monitoring of deep structures. Potential applications:**

- Deep geological repository monitoring.
- **Monitoring in Carbon Capture & Storage (CCS)**

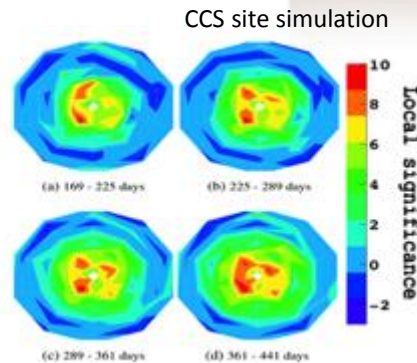


Muon-tides detector development



Bore hole detector installation

**Boulby site and skills**  
uniquely well-suited for  
development and testing:  
appropriate depth and  
geology, ease of access,  
infrastructure & expertise



**Deep-Carbon Project: £1.4M funding from UK Dept of Energy & Climate change (DECC) & Premier Oil:**

- Bore-hole detector development & testing @ Boulby
- Muon-Tides technology demonstrator
- Simulations of technique performance in CCS



# Astrobiology & Mars Analogue



Sampling life in Boulby Brine



Subsurface Astrobiology Laboratory



A base for studies of life in Boulby rock – studies of limits of life on earth and on other planets



**ALSO: An important 'Mars Analogue site'** – with geology & conditions to allow explorations & astrobiology technique & instrumentation development

Led by Edinburgh, UKCA



Mining & extraplanetary exploration instrumentation development

**Boulby and Instrumentation for Earth and Space Exploration**

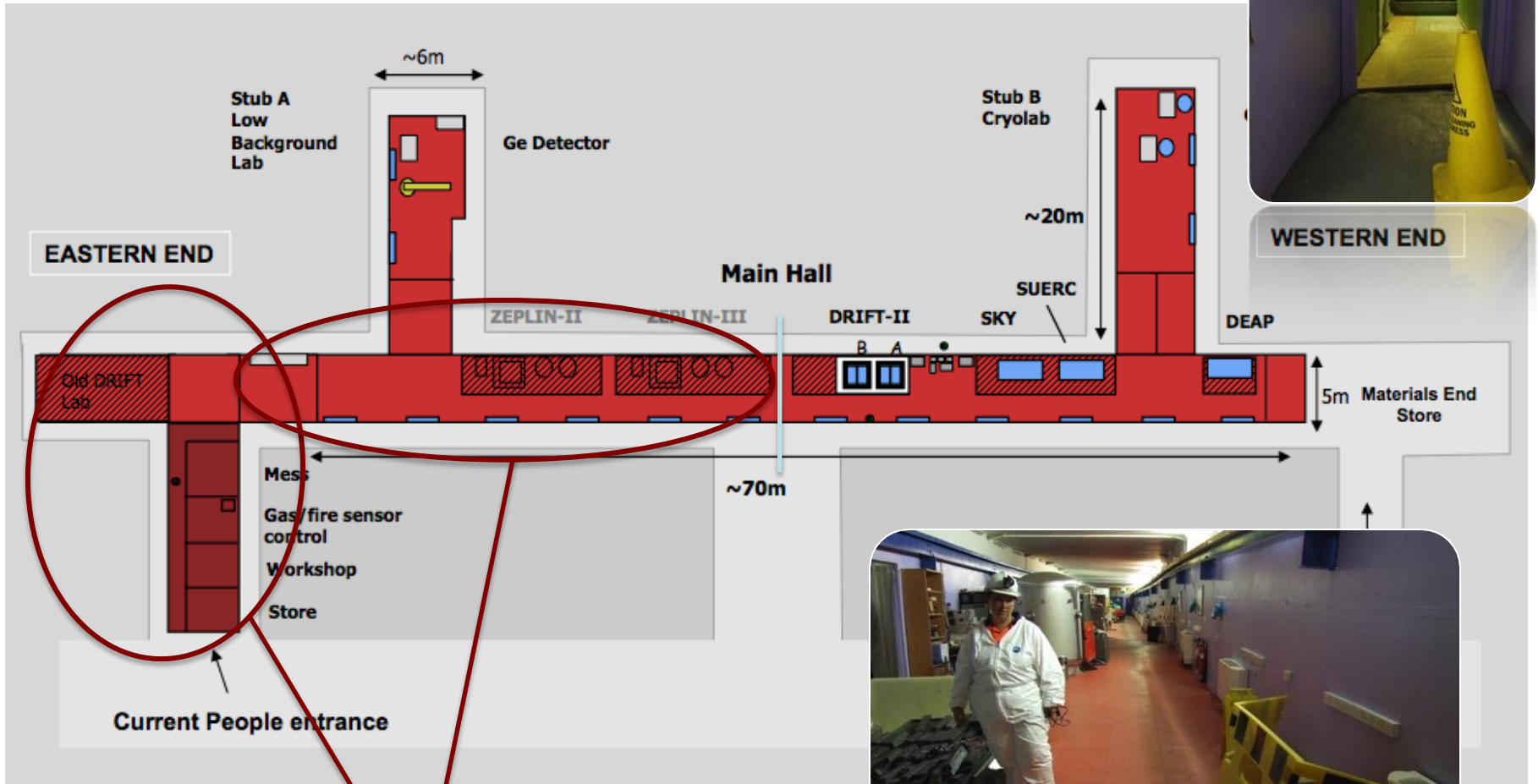


# Bulding a new underground laboratory...



# New underground laboratory plans.

Problems with the old Palmer Lab...



Eastern end: Degradation of lab  
– due to local fault line



# A NEW LABORATORY now being built at Boulby

To replace current facility and host **planned & new projects** for the next decade and more...



**£1.8M from STFC granted in 2014**

Materials Entrance 2

Main hall:  
Internal Lab  
height/width of  
4m/7m

Materials Entrance 1

Mars Analogue  
Area & outside  
testing area

Offices &  
People  
Entrance

Material  
Store

BUGS ULB  
Counting facility

Large Expt. Cave Area:  
Internal lab  
height/width of  
6.5m/7m

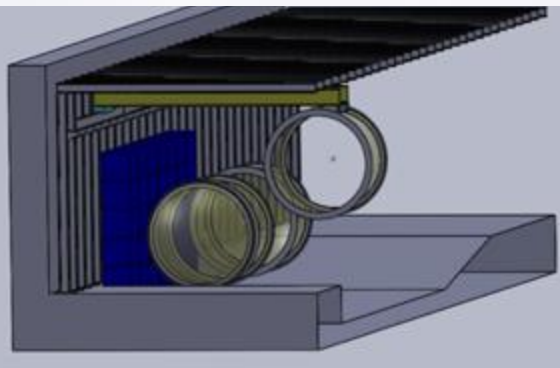
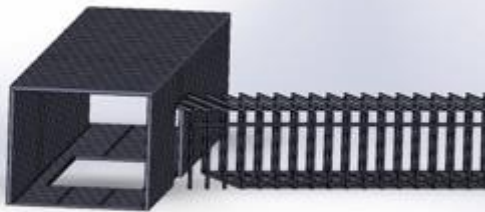
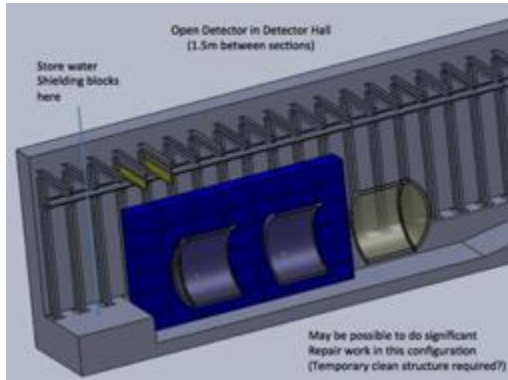


**Expected completion mid-late 2016**

Fully-equipped 4000m<sup>3</sup> lab. Class 10K & 1K clean room throughout. 5-10T lifting capacity.

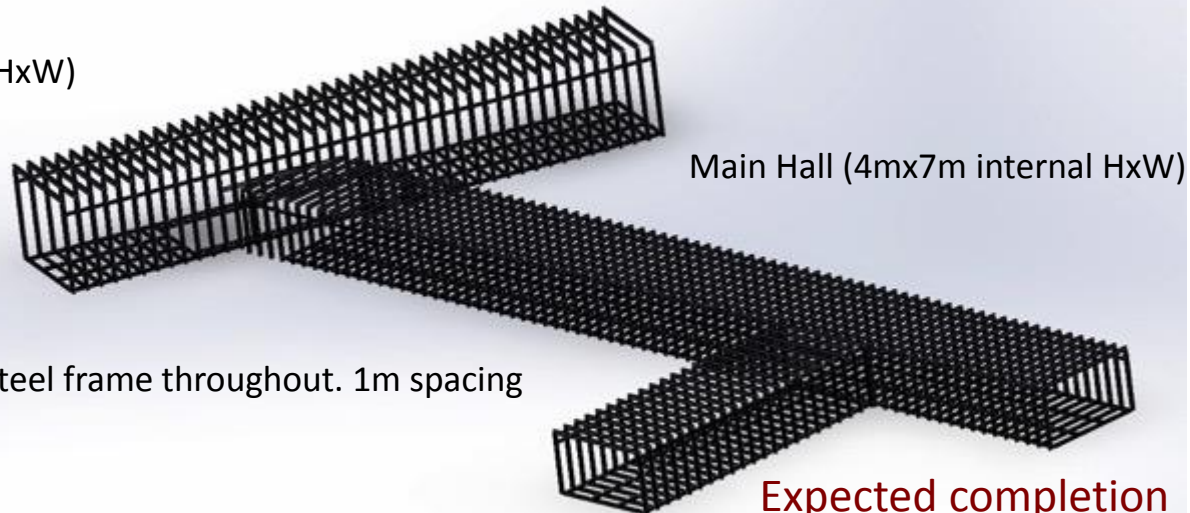
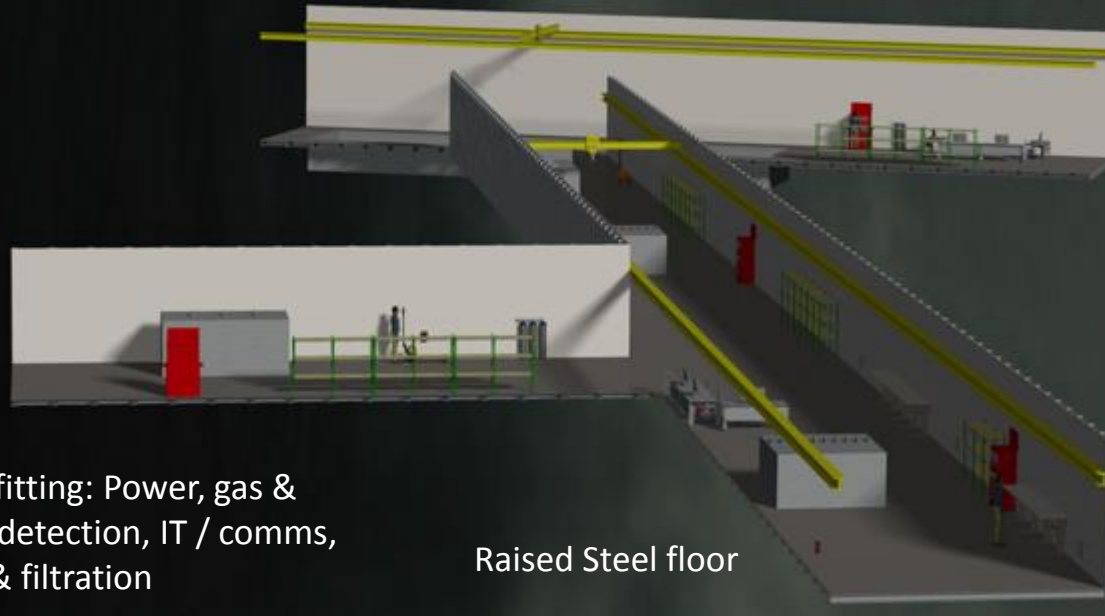


## New Laboratory Details

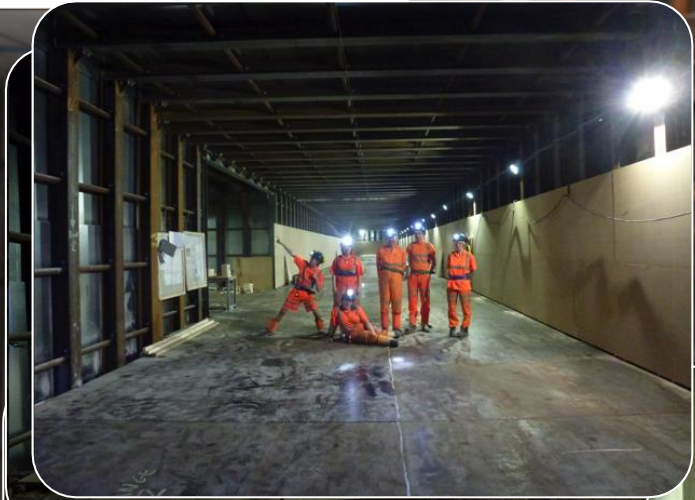


Sean Paling – [sean.paling@stfc.ac.uk](mailto:sean.paling@stfc.ac.uk)

10T and 5T Gantry cranes



Expected completion  
Sept 2016







Main Experimental Hall (7x4x60m)



'BUGS' ULB Germanium Facility

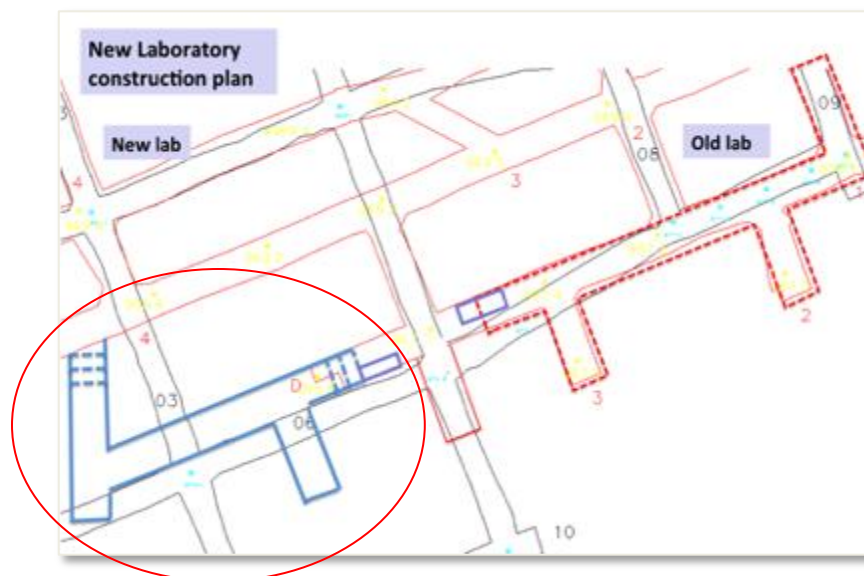


Boulby New Lab  
Construction  
August 2016



Large Experimental Cavern (LEC)  
(7x7x35m)

> **4000m<sup>3</sup>** of well supported **class 1,000** and **class 10,000** clean room experimental space



Air conditioning, HEPA filtration, internet / comms, 5 & 10 Tonne lifting capacity.

Now moving experiments from old lab to new.





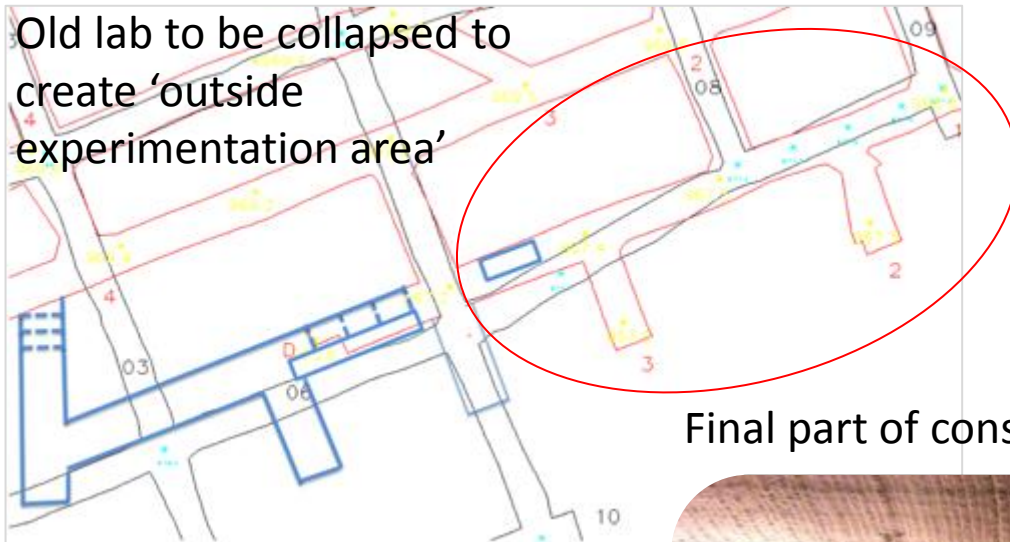
BOULBY  
UNDERGROUND  
LABORATORY



Boulby New  
Underground Lab  
October 2016



Old lab to be collapsed to create 'outside experimentation area'



Science & Technology  
Facilities Council



**Boulby New Lab: Outside  
Experimentation Area**

Final part of construction...



Open salt roadway  
experimental area supported  
and equipped for 'out-of-lab'  
projects





# Upcoming & potential future science projects...

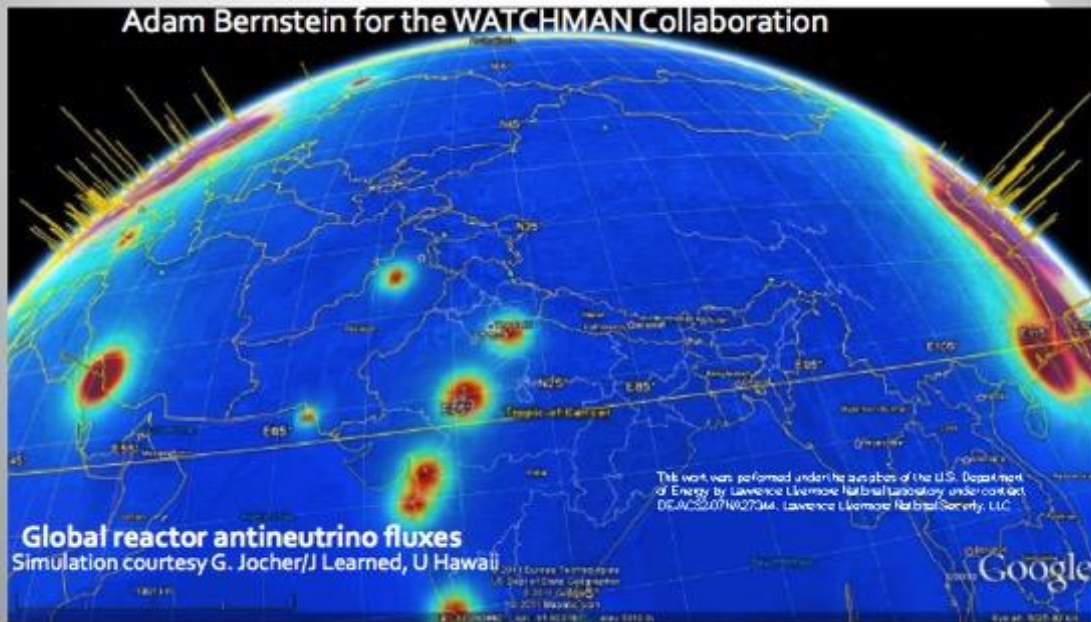
# Future Science?

Continue current  
studies, plus:

- **BUGS:** Expanded ULB material screening and environmental gamma-ray spectroscopy.
- Expanded **Astrobiology**, space exploration and **MINAR** studies
- **ERODES:** Salt cavity engineering test facility for studies of compressed gas energy storage? NERC proposal underway.
- **Watchman:** 1 kT Gd-doped water neutrino detector for nuclear non-proliferation purposes (etc)? Feasibility studies underway
- **CYGNUS:** R&D test-bed and first large scale detector?
- **SuperNEMO** demonstrator modules?
- **SOLID** Neutrino detector categorisation.
- Misc: Hartlepool near detector requests (Solid, DRIFT, Watchman).
- Etc.... (**Watch this space! – more to come**).



# WATCHMAN: A Field Demonstration of Remote Reactor Monitoring



## The Watchman project:

A US (DOE) proposal for a large (MT) Gd-doped water Cerenkov anti-neutrino detector to act as a test nuclear reactor detector for nuclear non-proliferation studies.

A potential MAJOR future UK/US security / non-proliferation research programme with later use for Misc. astrophysics studies.

Site selection underway. Boulby is ideal because:

- Local (20km) >1.5GW nuclear power station @ Hartlepool.
- Proven science support site
- Existing infrastructure

See:

<http://indico.cern.ch/getFile.py/access?contribId=35&resId=1&materialId=slides&confId=199223>

## WATCHMAN is now in its first phase in the United States

- **Overall Project Goal:** demonstrate sensitivity to reactor antineutrinos using a **gadolinium-doped (light) water detector** at 0.1-1 kilometer standoff from a 10-150 MWt US research reactor, or 10-20 kilometers from a 3000 MWt scale US commercial power reactor.



First Phase, 2012-2014:

- identify site
- measure backgrounds
- develop a design envelope for the detector

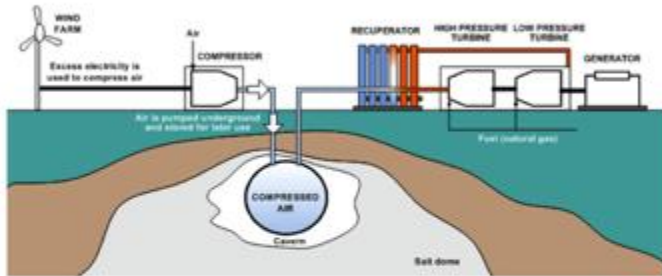
## A deep site: the Boulby mine, 1000 meter depth

- 1000 ton detector target mass
- Power = 1570 MWth (2 cores)

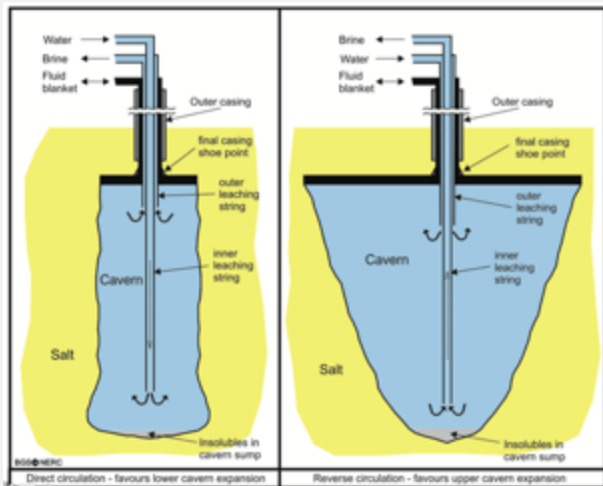


# Experimental Research On Dissolution Evolution in Salts (ERODES)....

## Low Carbon Technologies



- Engineering solutions have been devised to store energy whilst production is high and feed it into the grid when production is low (e.g. CAES, hydrogen storage)
- Helps to regulate the production of renewable energy



Mid-scale  
engineering  
tests of gas  
containment  
in salt cavities  
for energy  
storage

## EPSRC Project Proposal between:

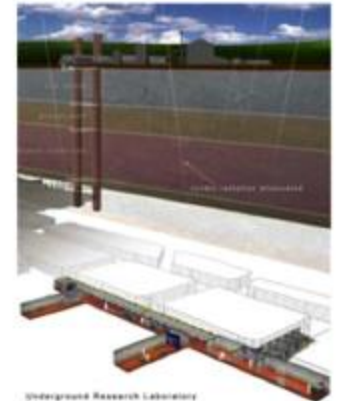
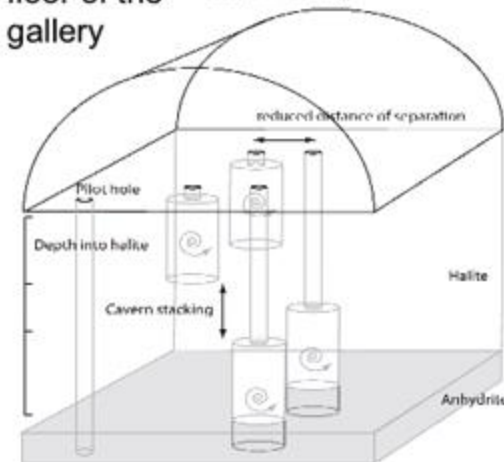
British Geological Survey  
Boulby Underground Laboratory  
University of Cambridge  
University of Manchester

## In-situ test facility @ Boulby



<http://www.bbc.co.uk/news/science-environment-23522734>

Configuration of caverns drilled  
and then solution-mined in the  
floor of the  
gallery



From: <http://www.boulby.stfc.ac.uk/Boulby/>







# Boulby Underground Laboratory

## Review of expressions of interest

### Coming Soon (early 2017)

## Thank You....



**Come and visit / work-with us...**

Email: [Boulby@stfc.ac.uk](mailto:Boulby@stfc.ac.uk)

Web: [www.stfc.ac.uk/boulby](http://www.stfc.ac.uk/boulby)

Facebook: Boulby Underground Laboratory

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