



Sean Paling  
STFC Boulby Underground Science Facility

Dark Matter search & ultra low background studies



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

**Deep Science at Boulby Underground Laboratory:**

Multidisciplinary deep science: From astrophysics to geology, climate the environment, life on Earth and beyond.



Underground lab @ Boulby



# Boulby Underground Laboratory

The UK's deep underground science facility operating in a working polyhalite & 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

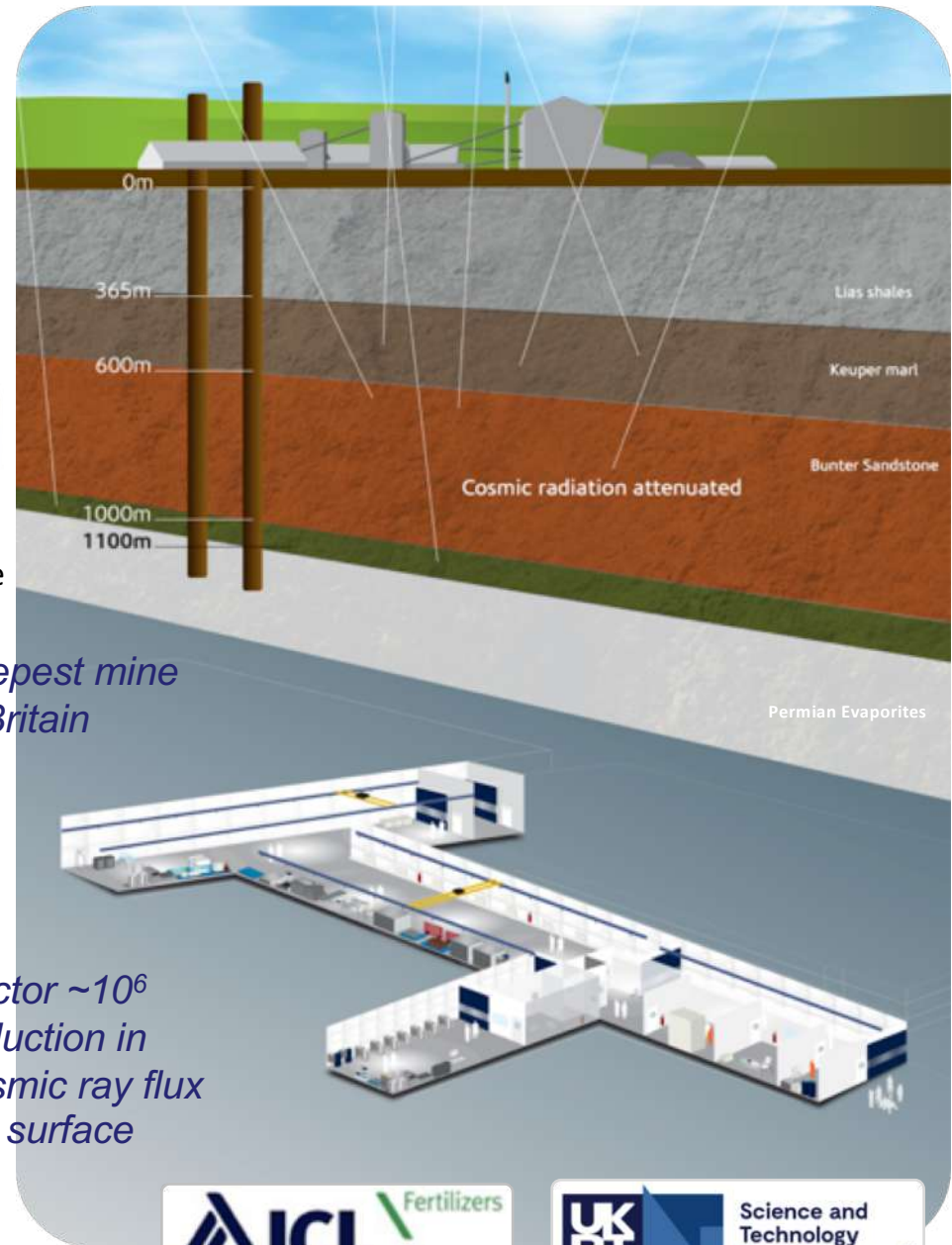


Polyhalite



*Deepest mine in Britain*

*Factor  $\sim 10^6$  reduction in cosmic ray flux vs. surface*



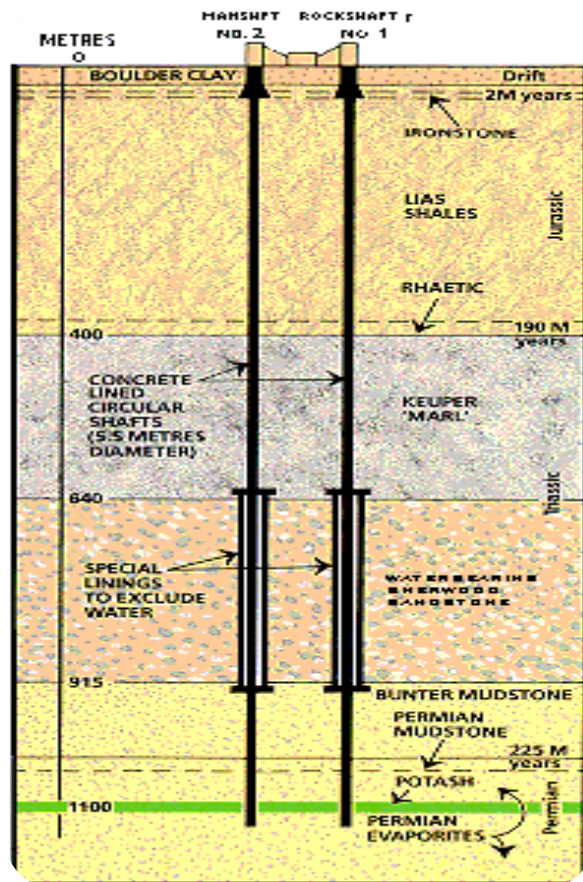
A **QUIET** place in the Universe





# Boulby Geology & Mining

Major local employer. Open since 1968.  
 Originally mining potash (KCl) for fertiliser.  
 Now first and only producers of polyhalite  
 Excavations are in Salt (NaCl) & Potash (KCl) Permian evaporite layers left over from the Zechstein Sea.



Boulby Geology

Potash



KCl

Rock-Salt



NaCl

Polyhalite



$K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$



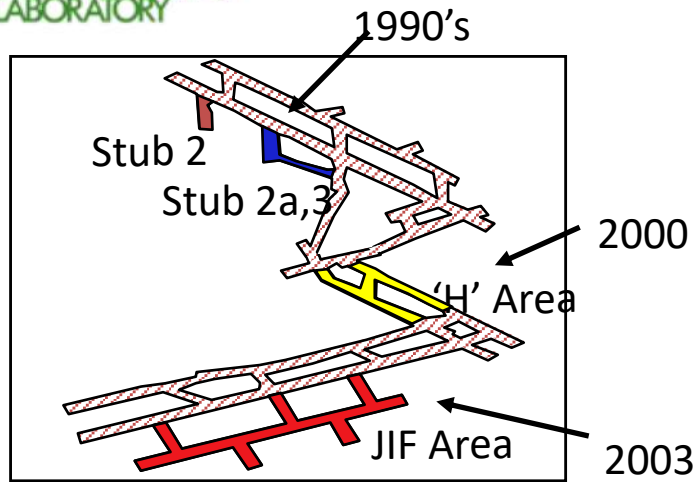
Typical Boulby Salt Roadway



Zechstein Sea

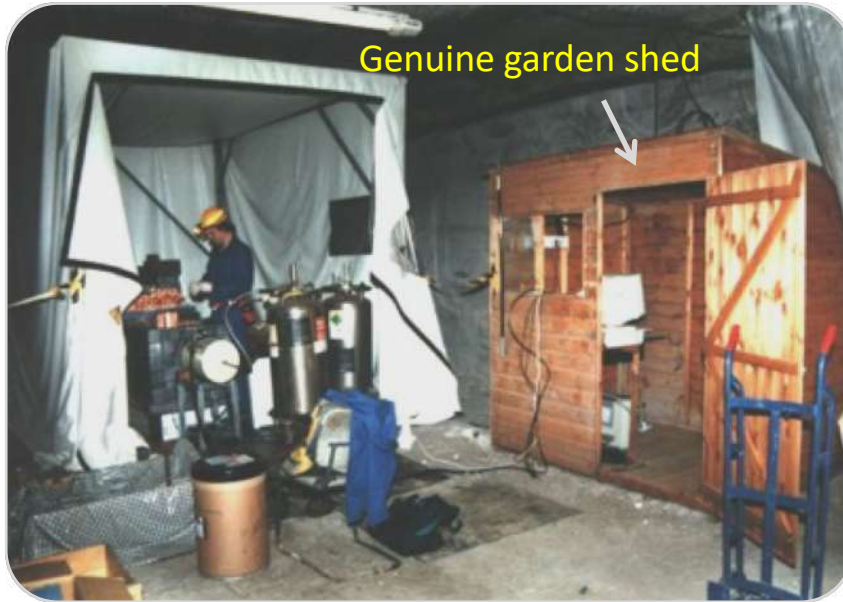


# Boulby Infrastructure Evolution



Map of the Dark Matter research areas

JIF Area  
2003-2015





Surface support and staging building

Office space, chemistry & clean prep lab, storage and staging space, IT room, conference room,

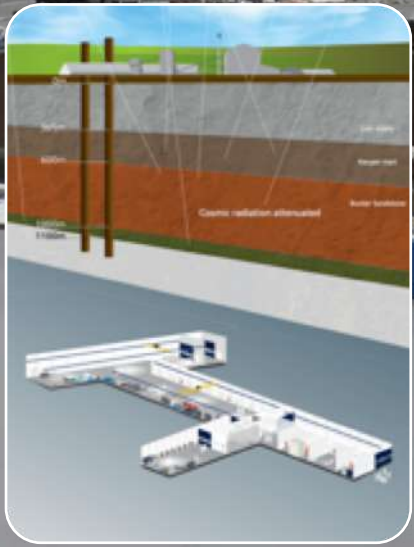


3000m³ Outside Experimentation Area



BUGS+ Material screening

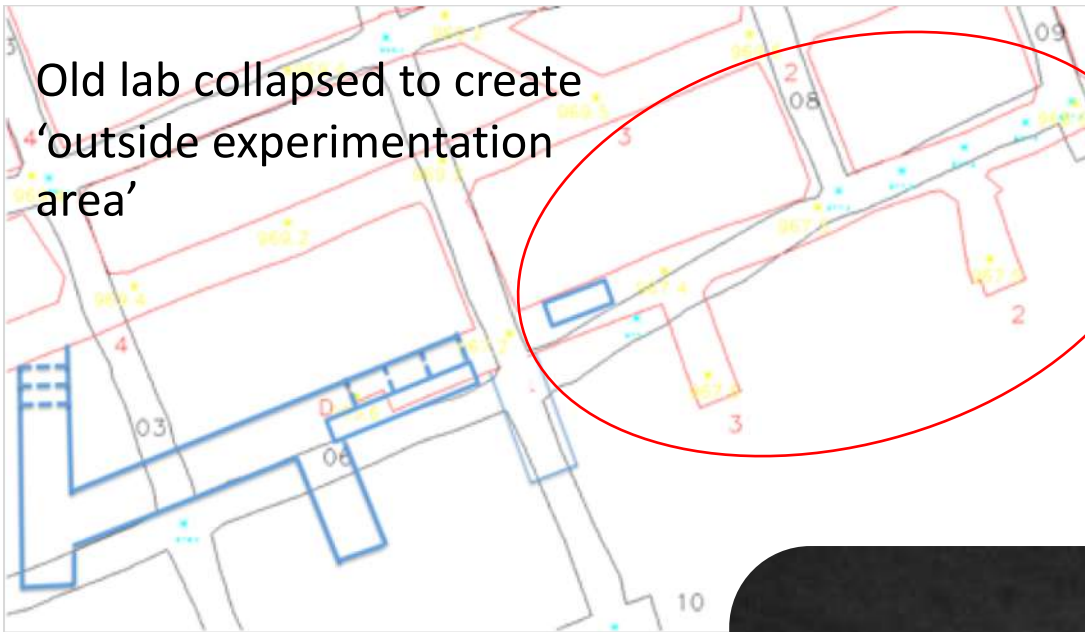
**Boulby Underground Lab Facilities 2019:**  
>4000m³ class 1k & 10k clean room lab space  
100Mb Internet AC, Air filtration, 5T & 10T lifting, LN generation, fume hood & clean prep  
3000m³ Outside Expt. Area. Power & internet





# Outside Expt Area (OEA)

Old lab collapsed to create 'outside experimentation area'



Work yet to do: Install lighting, 240/110V power, Internet. Ventilation, doors, MINAR Hut



'Outside Science': Geology / Geophysics studies. Astrobiology, MINAR, Mars Analogue space



OEA/MINAR Control Hut

Outside Experimentation / MINAR Area:

# Underground Science @ Boulby Mine

- DRIFT/CYGNUS: Directional Dark Matter
- BUGs: Ultra-low background material screening (for LUX-ZEPLIN and Super-K-Gd and more)
- ERSaB: Environmental gamma spectroscopy
- NPL-C14: ULB C14 half-life measurement
- RESOURCE: Salt cavity energy storage study
- BISAL: Geomicrobiology / Astrobiology studies
- MINAR: Space Exploration Tech. Development
- Misc. Geology / Geoscience
- Etc... (More to come).



ULB screening of LZ PMTs



Astrobiology & planetary exploration



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





# Boulby Facility Details...

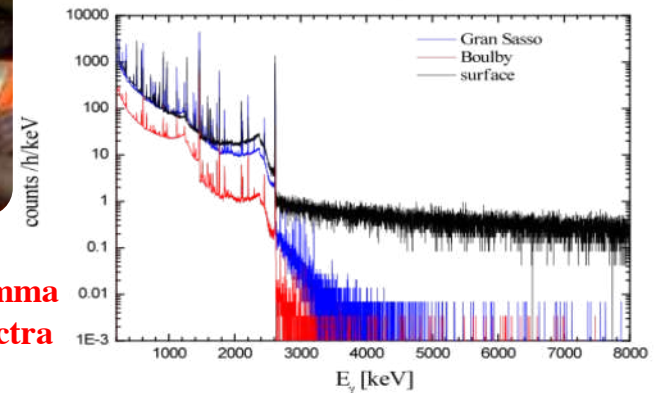
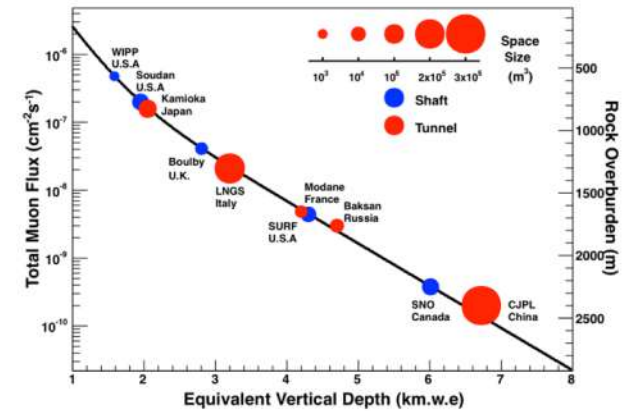
- The UK's deep underground science facility. One of 4 in EU. ~10 in the world.
- Supports work of 9 collaborative projects (astrophysics to climate, geology, environment etc), 40 institutions, > 150 scientists and students.
- Facility funded and operated by the Science and Technology Facilities Council (STFC).



- Operations, H&S & science programme managed by 7(+2) onsite staff and supported by Rutherford Appleton Lab (PPD).
- Work in partnership with Boulby Mine operators ICL-UK

**How does Boulby Compare?**

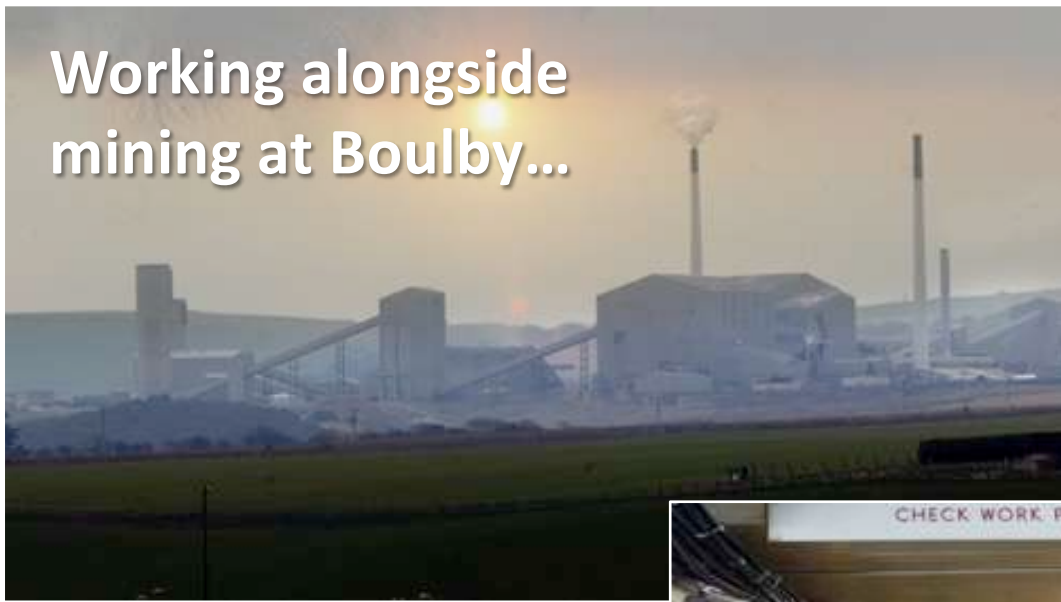
- Lowest Radon levels (3 Bq/m<sup>3</sup>)
- Diverse science programme.
- Science and Industry partnership



**Gamma Spectra**



# Working alongside mining at Boulby...



STFC-Boulby Lab responsibility:  
Facilitate / Support Science  
Health & Safety  
Operations Impact  
Outreach & Media

CPL/ICL support us:  
Keep the mine operating and safe  
Emergency H&S  
Materials transportation  
High level support



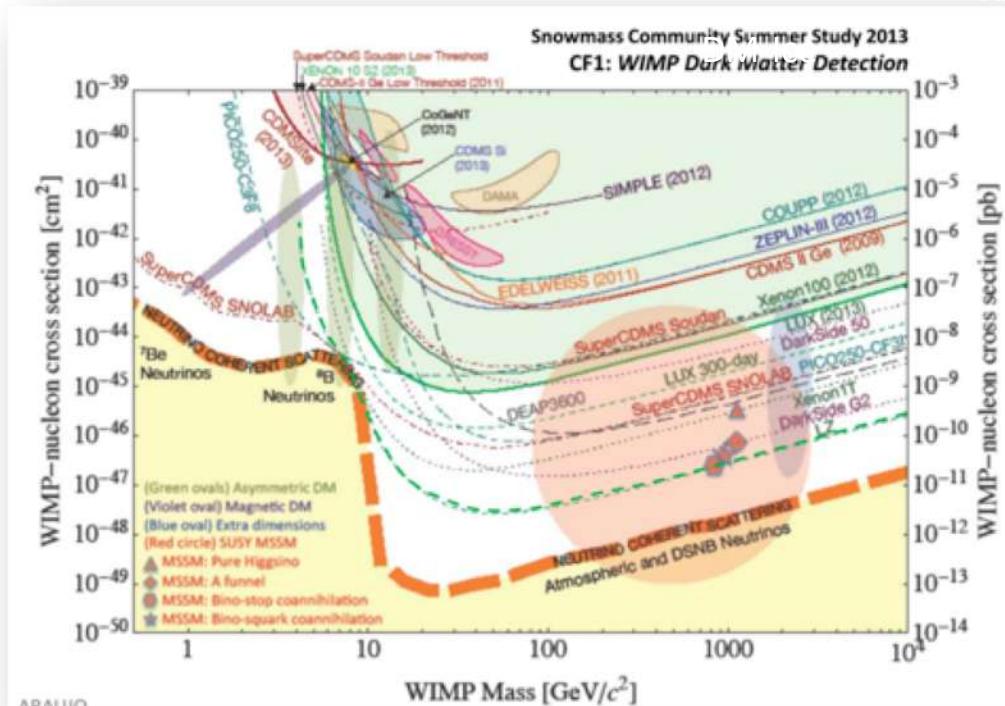
# Boulby Dark Matter Studies

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 CYGNUS & providing ULB material screening for other studies, inc **LUX-ZEPLIN (LZ)**



ZEPLIN-III @ Boulby



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



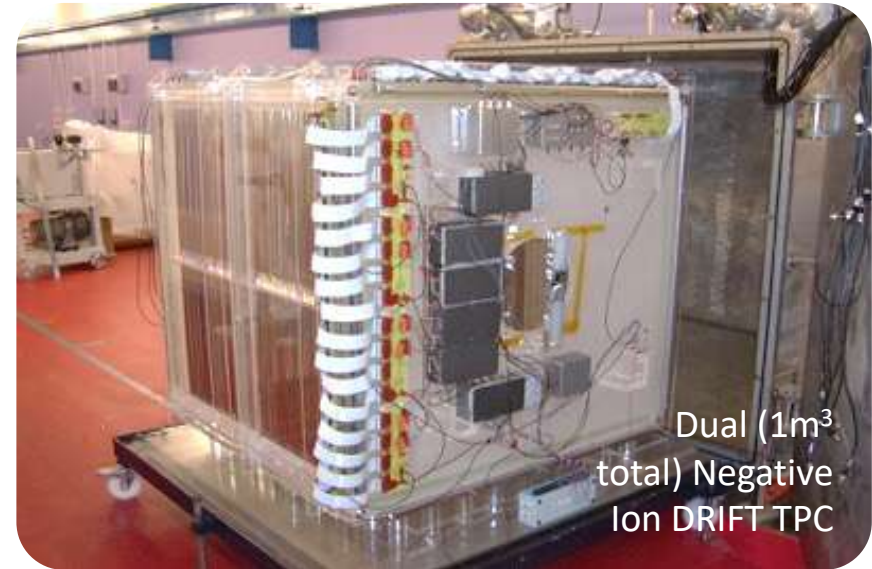
Current limits & future projections



# DRIFT/CYGNUS Programme..

## DRIFT/CYGNUS: R&D for DIRECTIONAL Dark Matter detection.

**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**).

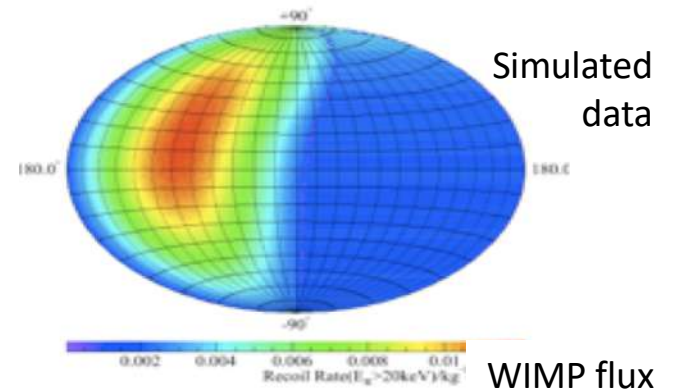


DRIFT-II-d @ Boulby

Dual (1m<sup>3</sup> total) Negative Ion DRIFT TPC

Directional detection

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



CYGNUS ThGEM development

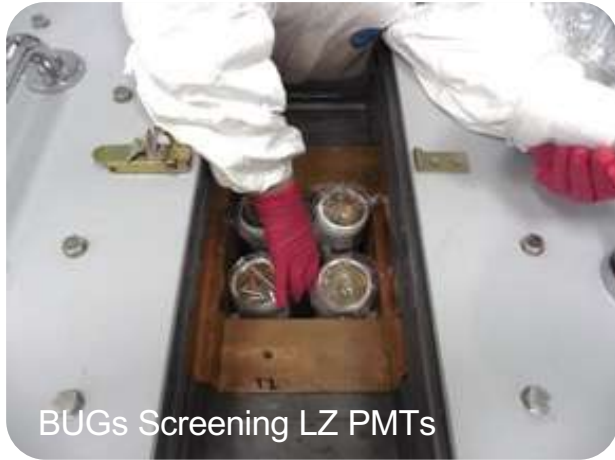
**DRIFTII-d limit setting & collaborative R&D exploring issues & technologies for scale up - CYGNUS**

**Directional DM detection – providing the most powerful direct detection signature**



# BUGS (+) Material Screening

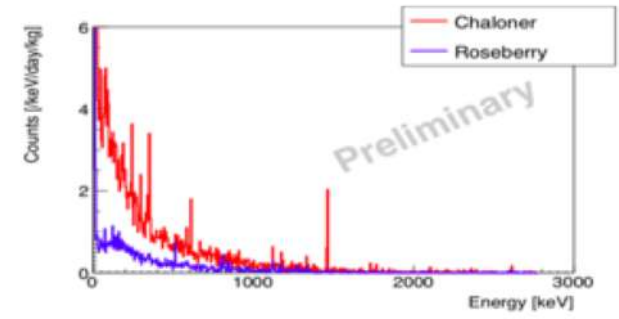
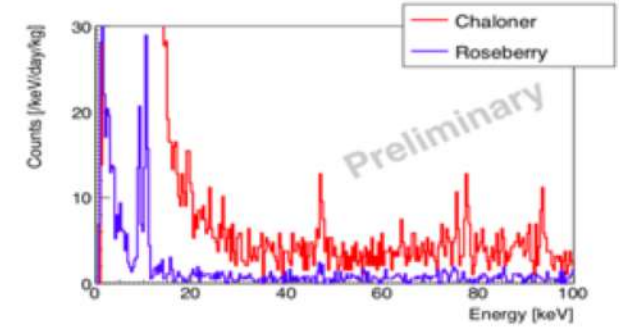
Growing suite ('BUGS': Boulby Underground Germanium Suite) of Ultra-Low-Background (ULB) germanium detector systems to support Dark Matter & misc 'rare-event' studies...



BUGs Screening LZ PMTs

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

- Our Current Detectors;**
- Ortec 1.8 kg (72%) p-type (ULB)
  - Canberra 2.0 kg (112%) & 3.2 kg (171%) p-types (S-ULB)
  - 2x Canberra BEGe detectors (5030 ULB, 6530 S-ULB)
  - Canberra SAGe Well-type (S-ULB)

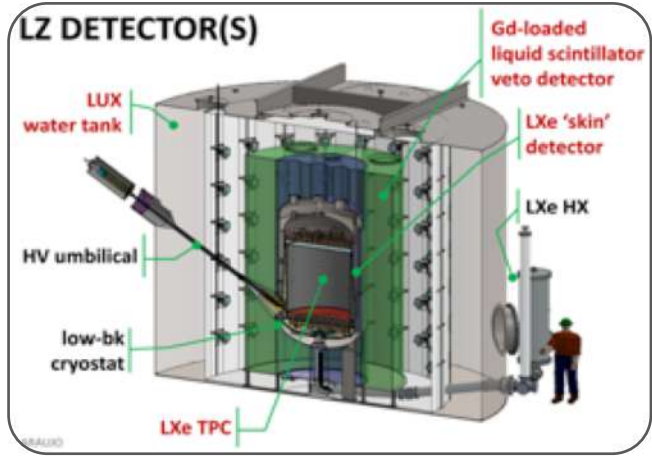


ULB counting studies supporting UK DM (**LZ**) and neutrino communities.

Now **EXPANDING** ULB counting capabilities. Inc. **XIA surface alpha counting**

In collaboration with UCL, DMUK, Sheffield & others.

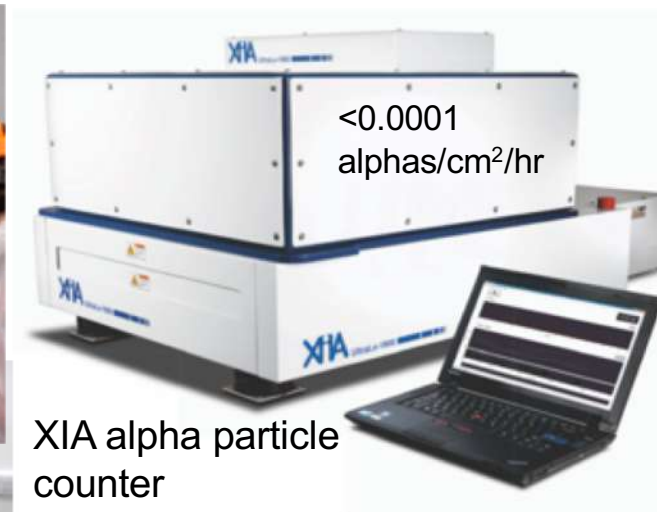
Boulby undertaking major role in material selection for **LUX-ZEPLIN** and **SK-Gd/T2K**



**LUX-ZEPLIN**



BUGS ULB Germanium Suite



XIA alpha particle counter



**BUGS capabilities expanding** to support current and future ULB experiments. Working towards PPT sensitivity for G3 DM and Neutrino Expts.



LZ PMTs



LZ sample testing underway. New XIA surface alpha detection system now commissioned.



# Boulby Multi-Disciplinary Studies



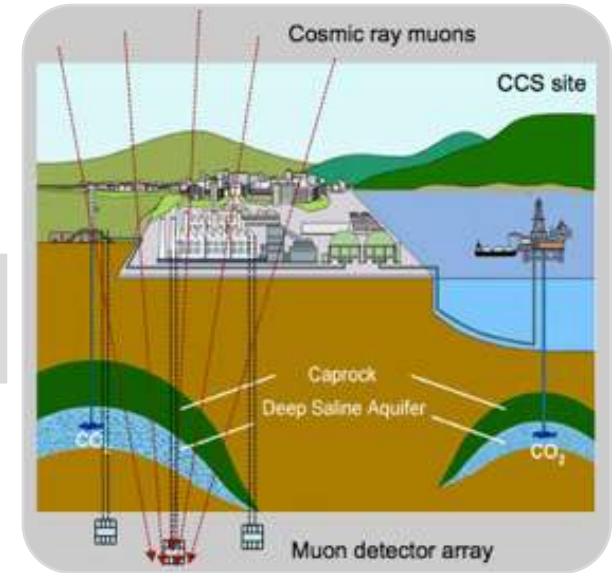
**ERSaB:** Gamma spectroscopy & low background counting environmental radioactivity studies

*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 geology, geophysics, the environment, life on Earth & beyond...**



**MINAR:** Space Technology Development

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

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



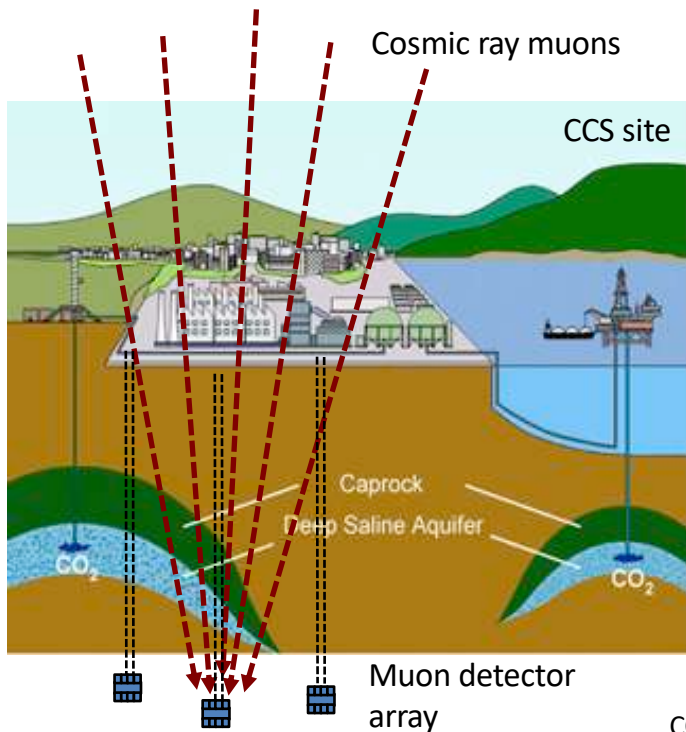
**BISAL:** Astrobiology / Geo-microbiology. Studies of life in salt, life on Earth & beyond



# 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)**



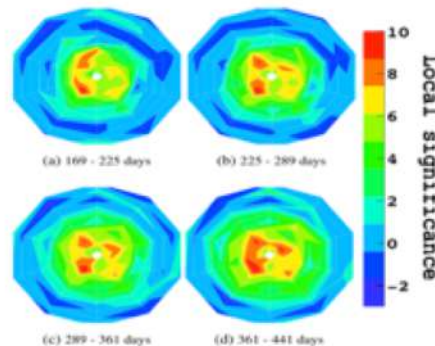
Muon-tides detector development



Bore hole detector installation

**Status: Project largely on hold. Continuation funds needed. Muon Tides continues – funded by STFC. Progress is slow but steady. Remote site needs to be re-assessed.**

CCS site simulation



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

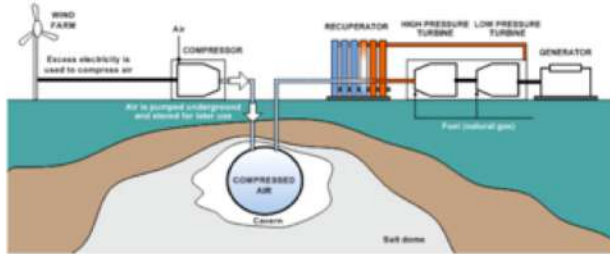
- Bore-hole detector development & testing
- Muon-Tides technology demonstrator
- Simulations of technique performance in CCS

# Renewable Energy StOrage in UndergrounD CavErns (RESOURCE)

STFC Boulby Mine, BGS and the University of Cambridge

**NERC Project Proposal**  
British Geological Survey  
Boulby Underground Lab  
University of Cambridge

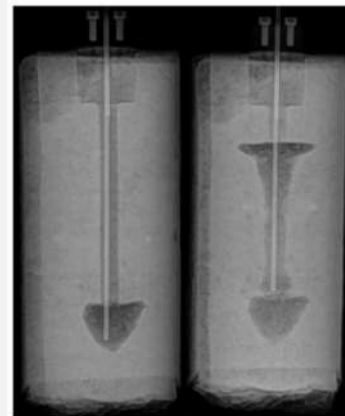
## Low Carbon Technologies



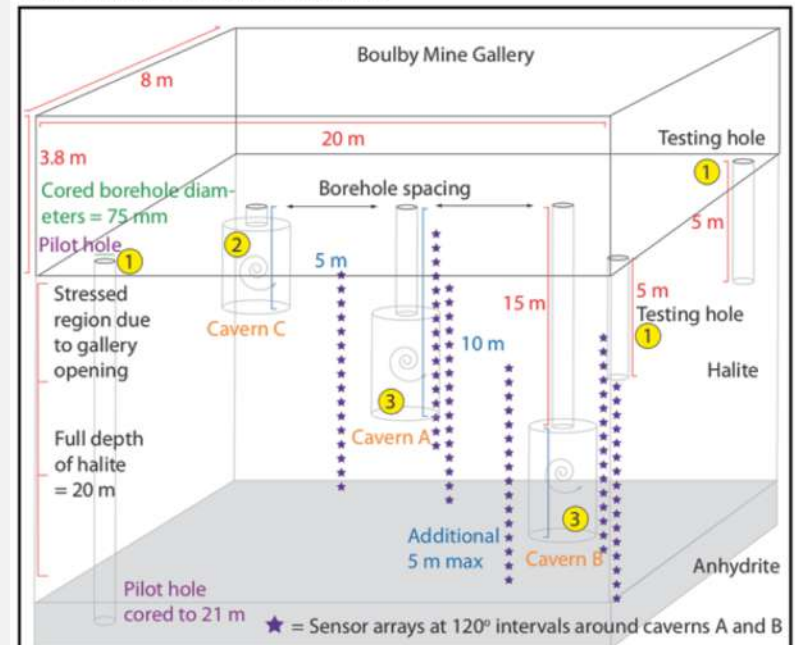
- Engineering solutions have been devised to store energy whilst production is high and feed it into the grid when production is low (e.g. CAES, hydrogen storage)
- Helps to regulate the production of renewable energy



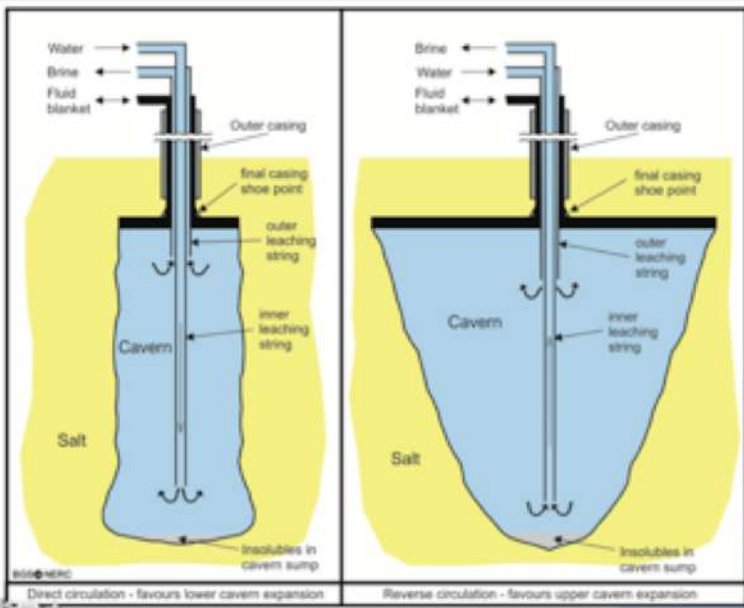
Plan for In-situ Testing at Boulby Mine



Above: Scoping lab-based dissolution tests of salt from Boulby Mine, giving insight into the solution mining process.



- 1 Drill and core pilot hole. Study fabric, chemistry and mechanical properties of core. Also drill and core testing holes. Study core and run dissolution tests.
- 2 Drill and core shallow hole to 5m. Case hole, cement casing and form solution-mined cavern.
- 3 Drill and core intermediate hole to 8m and deep hole to 15m. Study and compare core. Case holes and form solution-mined caverns. Seal holes and pressure cycle.



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



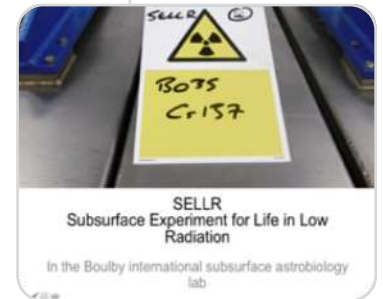
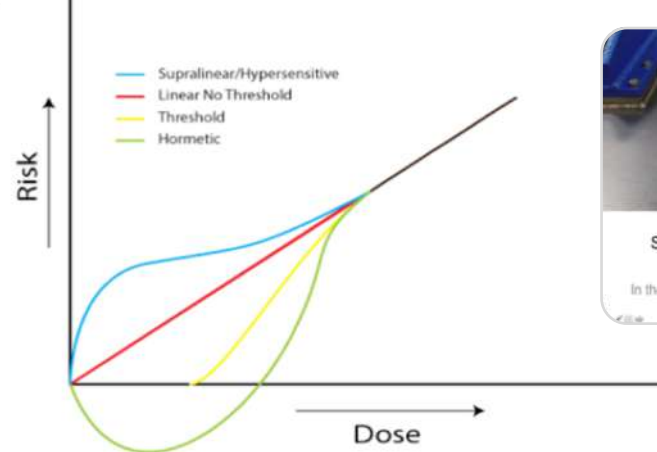


# SELLR: Life in Low Background



SELLR - Life in low background

## Radiation dose versus risk of damage to organism



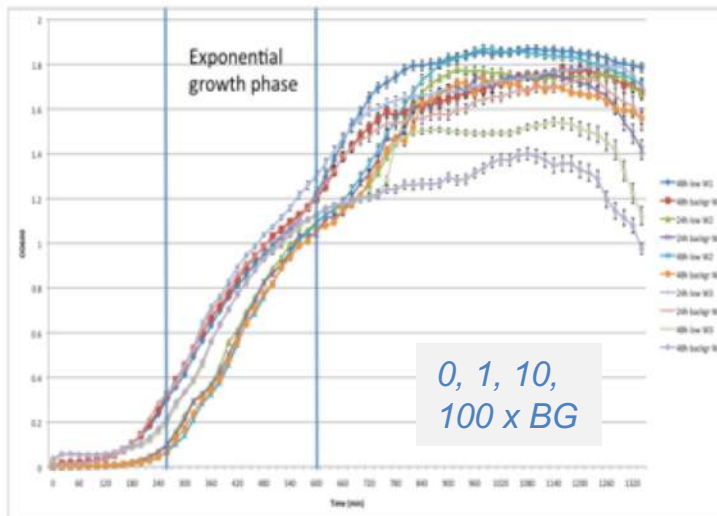
*E. Coli*  
*B. subtilis*

UK CENTRE FOR ASTROBIOLOGY

## Summary of results

- Various microbes grown in a low-radiation environment show no difference in their linear exponential growth phase in comparison with that of microbes grown in a surface, 'background' dose.
- Similarly, the microbes grown at a higher dose (10 x and 100 x 'background' radiation) display no apparent effect on their linear exponential growth phase.
- Microbes grown in low vs. 'background' radiation show no difference in viability after being exposed to a short burst of UVC irradiation (stress).

Weeks 1-3  
24 & 48h low vs. background



Status: First 2 data sessions complete.



# Astrobiology & Mars Analogue



Sampling life in Boulby Brine



MINAR - XRF  
Subsurface Astrobiology Laboratory



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



Life in Boulby salt

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

Led by Edinburgh, UKCA



MINAR - Clupi



MINAR - Pancam

Mining & extraplanetary exploration instrumentation development

Boulby and Instrumentation for Earth and Space Exploration





# MINAR V. 9<sup>th</sup> to 20<sup>th</sup> October 2017

## MINAR 5

### Overall objectives:

- To test instruments and methods for the subsurface exploration of the Moon and Mars.
- To develop new educational material.

MINAR – Pac Man, HABIT & many more

### Main accomplishments:

- Testing of life detection equipment and planetary exploration instruments from: NASA JPL, NASA Ames, University of Leicester, Space-X Institution, University of Newcastle, University of Edinburgh, Luleå University of Technology.
- Development of education materials on planetary exploration at primary and secondary school level.
- Training of ESA Astronaut, Matthias Maurer.
- Life links from Boulby with up to 38,000 views.
- Live link with Kalam Centre, India



MINAR - SPLIT



MINAR - Pancam

**Live from Mars!**

Join our live feed from 1 km underground in Boulby mine, UK - an extreme, Mars like environment where scientists are preparing for the exploration of space!

- > See planetary scientists at work
- > Explore an underground astrobology laboratory
- > Learn about preparations for planetary exploration

Monday 9th October 10-11 am BST  
in collaboration with the Kalam Centre, India  
Wednesday 11th October 10-11 am and 3-4 pm BST  
Live with ESA astronaut Matthias Maurer

Like: [www.facebook.com/UKCentreforAstrobiology/](https://www.facebook.com/UKCentreforAstrobiology/) for live feed  
Send your Mars exploration questions in advance to [Runderground@ukastro.org](mailto:Runderground@ukastro.org)

**Boulby Underground Laboratory** shared UK Centre for Astrobiology's live video.

Published by Emma Meehan [?] · 17 October · 🌐

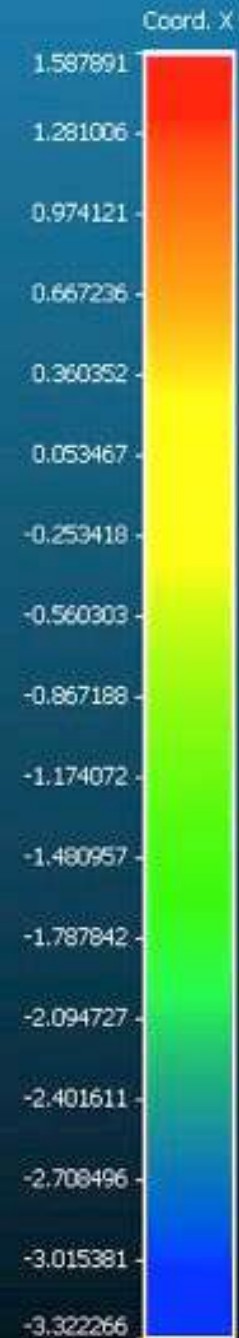
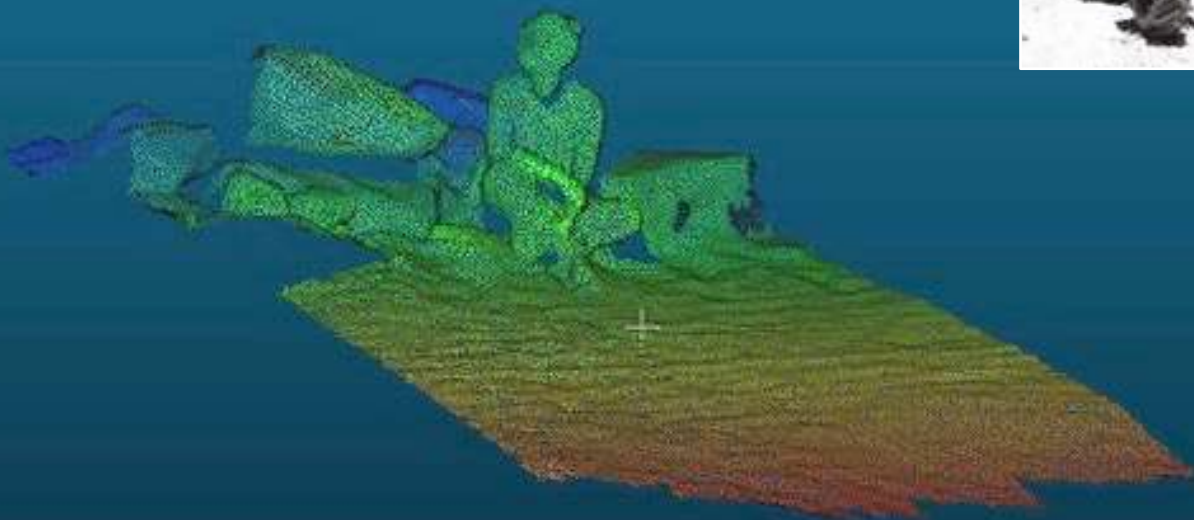
14,955 Views

UK Centre for Astrobiology was live.



# MINAR VI. 10<sup>th</sup>-20<sup>th</sup> September 2018

Lulea University  
KORE rover 3D area mapping



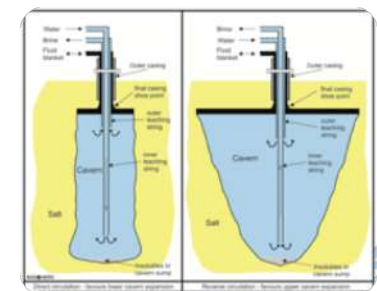
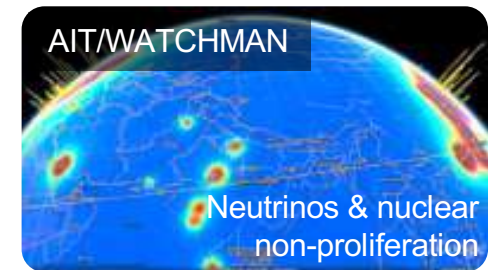
Edinburgh University  
MUFFHINS water activity  
monitoring payload



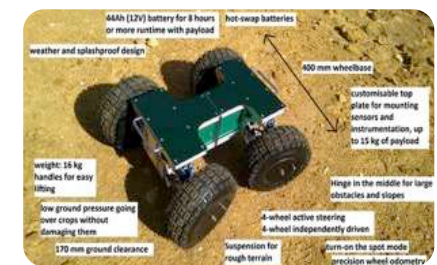
# Future Science...

Continue current studies, PLUS...

- **BUGS:** Expanding ULB material screening and environmental gamma spectroscopy. SK-Gd, Hyper-K, DUNE & more
- Expanding **Astrobiology**, **MINAR** & wider **Robotics**
- **RESOURCE** study (NERC): Salt cavity test facility for studies of compressed gas energy storage?
- **AIT/WATCHMAN:** 6 kT Gd-doped water neutrino detector for nuclear non-proliferation purposes (and more)?
- **Next generation Dark Matter, Neutrino and Neutrino-less Double beta decay studies...** e.g. SuperNEMO, CYGNUS, etc...



RESOURCE: Salt cavity energy storage



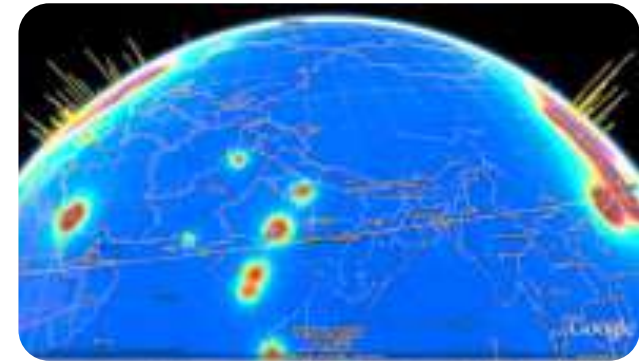
Robotics

Continue / increase hosting **core STFC science projects** & wider **multidisciplinary studies** addressing RCUK (UKRI) priority themes



# AIT-WATCHMAN

World  
antineutrino  
flux levels



## A WATER Cherenkov Monitor of ANtineutrinos

Design,  
excavation,  
installation &  
operation 2019  
to 2024(+)

### HARTLEPOOL REACTORS

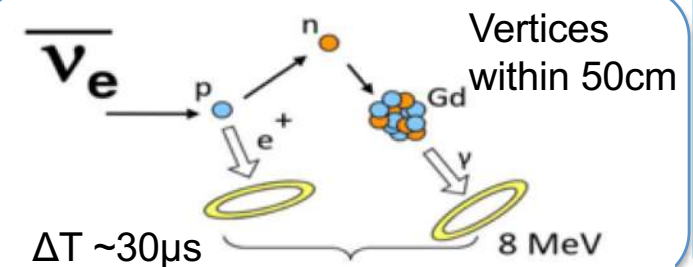
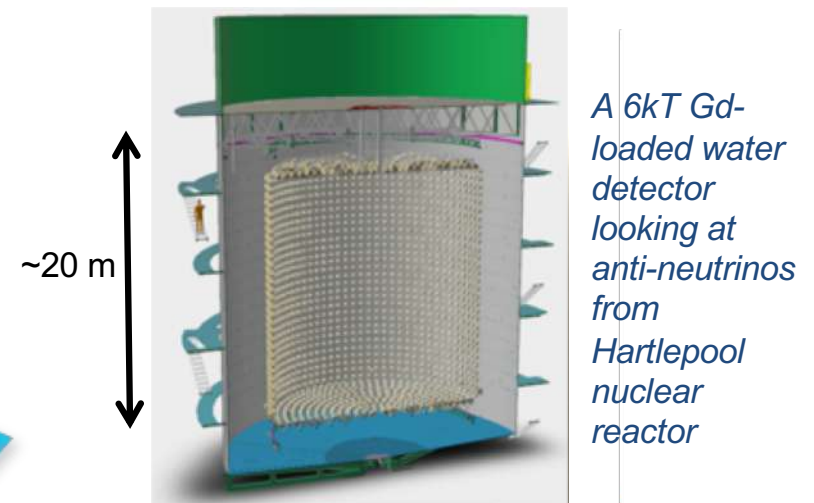


- 2 cores
- 1570 MWt per core
- 25 km standoff



Funding: US (>\$50M), UK (~£10M)  
confirmed in 2017 & 2018 respectively

### WATCHMAN detector at the Boulby mine

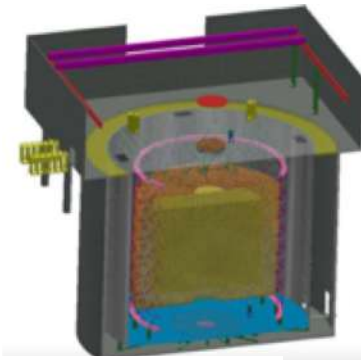


**NEW** 6kT prototype detector: R&D for anti-neutrino monitoring of nuclear reactors for global nuclear non-proliferation purposes & more

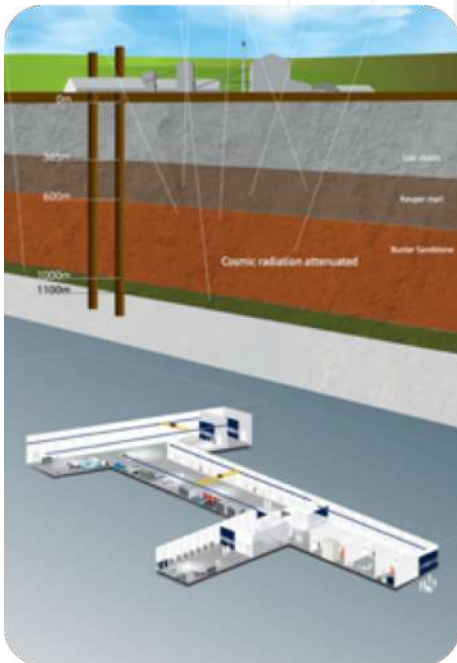
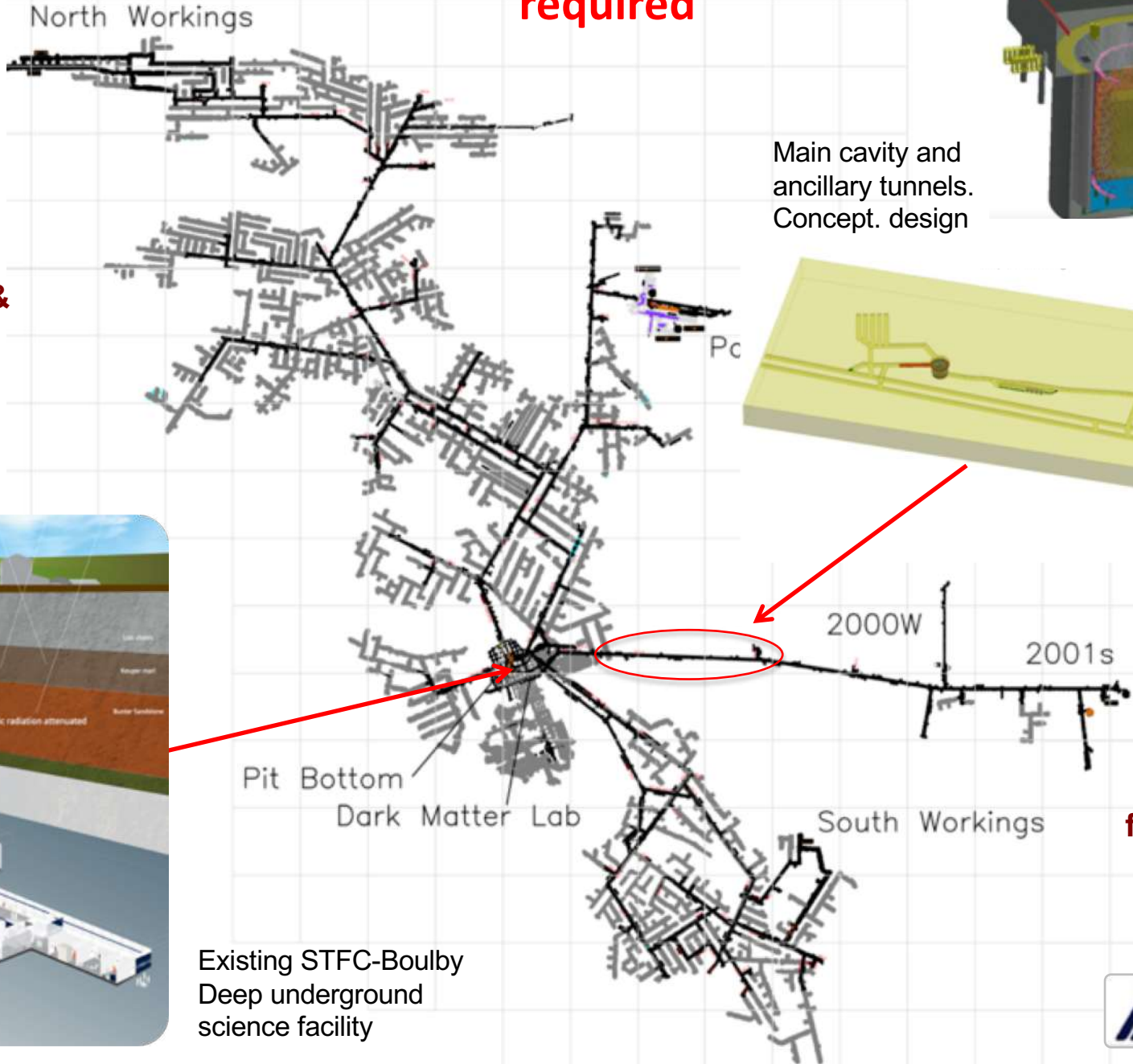
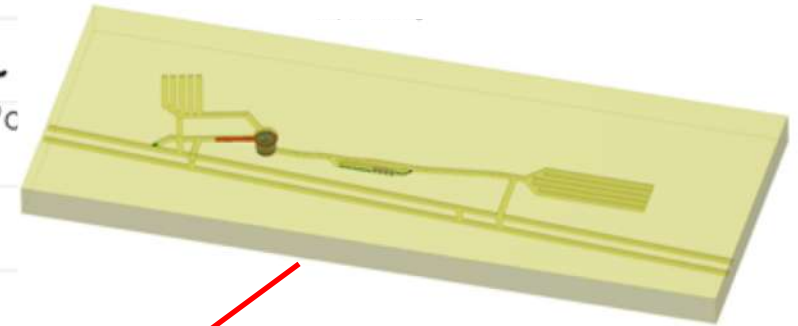


# New excavation required

Design, excavation, installation & operation 2019 to 2024(+)



Main cavity and ancillary tunnels. Concept. design



Existing STFC-Boulby Deep underground science facility

100+ Collaborators from 20+ US/UK research institutes





# Thank You....



Coming Soon:  
MINAR VIII – Mar 2<sup>nd</sup>-11<sup>th</sup> 2020  
MINAR IX (+ DULIA-BIO-3) - 2021



Sean Paling  
STFC Boulby Underground Laboratory

Please Contact us...

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