Deep Science at Boulby Underground Laboratory:
Subterranean studies at the UK’s deep underground science facility
A WATer CHerenkov Monitor of ANtineutrinos

**AIT-NEO (WATCHMAN)**

**HARTLEPOOL REACTORS**

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

**WATCHMAN detector at the Boulby mine**

Funding: US (>$70M), UK (~£10M) confirmed in 2017 & 2018 respectively

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

- 3500 tons of gadolinium doped water
- 3000 photomultiplier tubes
- Signal: ~11 events/month/core
- Background: ~20 events/month
Deep Science @ Boulby Underground Laboratory…

1) About Boulby Mine and Boulby Underground Lab

2) Boulby Science Overview:
   - Astroparticle Physics & Low Background Science
   - Earth & Environmental Science
   - Astrobiology & Planetary Exploration Studies

3) The future: inc. AIT-NEO (WATCHMAN)
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

A QUIET place in the Universe

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

Map of the Dark Matter research areas

1990’s
Stub 2
Stub 2a,3

'H’ Area

JIF Area
2000
2003

2003 - 2015

JIF Area

Genuine garden shed

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

Surface support and staging building

Boulby Underground Lab Facilities 2020:
>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
Large Experimental Cavern (LEC)

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

Old lab collapsed to create ‘outside experimentation area’

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

‘Outside Experimentation / MINAR Area: OEA/MINAR Control Hut

‘Outside Science’: Geology / Geophysics studies. Astrobiology, MINAR, Mars Analogue space
Underground Science @ Boulby Mine

- DRIFT/CYGNUS: Directional Dark Matter
- Spherical Proportional Counters (NEWS-G) R&D
- BUGS: Ultra-low background material screening (for LUX-ZEPLIN and Super-K-Gd and more)
- AWE(Ge): Atmospheric gamma spectroscopy
- RESOURCE: Salt cavity energy storage study
- BISAL: Geo-microbiology / Astrobiology studies
- MINAR: Space Exploration Tech. Development
- Misc. Low Background & Geoscience…
- Etc... (More to come).

A busy & growing multi-disciplinary science programme:
Astrophysics and Low Background science, Earth and Environmental Science, Astrobiology and Planetary Exploration.
Boulby Facility Details...

• The UK’s deep underground science facility. One of 4 in EU. >10 in the world.

• Supports work of 10 collaborative projects (astrophysics to climate, geology, environment etc), >40 institutions, >170 scientists and students.

• Facility funded and operated by the Science & Technology Facilities Council (STFC).

• Operations, H&S & science programme managed by 8 (+2) onsite staff and supported by Rutherford Appleton Lab (PPD).

• Mine operators ICL-UK provide wide-ranging operational & high level support.

How does Boulby Compare?
• Low Radon levels (3 Bq/m³)
• Diverse science programme.
• Science and Industry partnership

Gamma Spectra
Working alongside mining at Boulby...

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

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

- Astroparticle Physics & Low Background Science
- Earth & Environmental Science
- Astrobiology & Planetary Exploration Studies
- The Future: inc. AIT-NEO (WATCHMAN)
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: The world’s first 2-phase Xenon dark matter detector (Finished 2011)**

Current limits & future projections

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Dark Matter Studies @ Boulby.

**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).

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

Directional DM detection – providing the most powerful direct detection signature
Spherical Proportional Counters in Boulby

k. Nikolopoulos
I. Katsioulas
P. Knights
T. Need
R. Ward
University of Birmingham

Al-S30 R&D Detector

Simulation study of neutron interactions in the S30 at Boulby

Purpose-made gas filter
- Copper Oxide
- H₂O removal
- Molecular sieve O₂ removal

11-anode sensor

Neutron Beam
- 4 MeV

NEWS-G sensitivity

Neutron Beam

Neutron Beam

Direction of R&D at Boulby
- Instrumentation development for NEWS-G at SNOLAB
  - Multi-anode sensor
  - Gas filtration
  - Rate effect studies
- Neutron spectroscopy N₂-based
  - Neutron BG measurements for rare event searches
  - Industrial applications
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)

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

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 Super-K-Gd

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

Now material Screening for Gd upgrade to Super-K / T2K
LZ and SK-Gd sample testing underway. XIA surface alpha screening system commissioned.

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

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

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

**Low Background Science, Earth & Environment Science, Astrobiology & Planetary Exploration**...

**MINAR**: Space Technology Development

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

Plus Misc. Geology & Geoscience (& more to come)...
Development of a Muon Tomography techniques for deep 3D geological surveying - inc Carbon Capture @ Storage (CCS)

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)

**Status:** Project phase 1 complete. Spin-out company for Muon Tomog applications created (Sheffield, Durham).

**Next:** UK-Japan proposed study of Muon Tomography for Tsunami early warning (2020)

**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
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 rock engineering tests of gas containment in salt cavities for energy storage
Astrobiology & Planetary Exploration

Sampling life in Boulby Brine

Subsurface Astrobiology Laboratory

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

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

Boulby and Instrumentation for Earth and Space Exploration

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MINAR V. 9th to 20th 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 VI. 10th-20th 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.
- Expanding **Astrobiology, MINAR & wider Robotics**
- **RESOURCE study (NERC)**: Salt cavity test facility for studies of compressed gas energy storage?
- Misc Others… Inc. supporting **NEWS-G, DAMIC, AION…**
- ‘**BOULBY-FS**’: STFC funded feasibility study for Boulby hosting next generation Dark Matter, Neutrino and Neutrino-less Double beta decay studies...
- **AIT-NEO (WATCHMAN)**: 6kT Water-based neutrino detector for nuclear non-proliferation purposes & more...

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

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Advanced Instrumentation Testbed

WATer CHerenkov Monitoring of Anti-Neutrinos

US-UK project to demonstrate & develop particle physics detector technology for nuclear security & fundamental science

Funding: US (>70M), UK (~10M) confirmed in 2017 & 2018 respectively

Global reactor antineutrino fluxes
AIT-NEO (WATCHMAN)

A WATer CHerenkov Monitor of ANtineutrinos

Design, excavation, installation & operation 2019 to 2026(+)

HARTLEPOOL REACTORS

- 2 cores
- 1570 MWt per core
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World antineutrino flux levels

WATCHMAN detector at the Boulby mine

A 6kT Gd-loaded water detector looking at anti-neutrinos from Hartlepool nuclear reactor

Vertices within 50cm

$\Delta T \sim 30\mu s$  
8 MeV
AIT-NEO (WATCHMAN)
Technology & Science

1) Reactor Monitoring for Nuclear Non-proliferation

A prototype detector for proof-of-principle and R&D for remote monitoring of distant nuclear reactors.

2) Technology Development & Fundamental Science

A world-class research detector for technology development and fundamental neutrino science R&D.

Supernovae Neutrinos: Studies of exploding stars (immediate capability)

Geo-neutrinos: Studies of the Earth’s centre (possible with later AIT phases)

A world-class pure & applied neutrino science project

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August 2019
New excavation required...

Design, excavation, installation & operation 2019 to 2026(+)

Existing STFC-Boulby Deep underground science facility

Main cavity and ancillary tunnels. Concept. design

100+ Collaborators from 20+ US/UK research institutes
From Above

Spade (Heliminer etc) planned to first hit rock 2022

Design, excavation, installation & operation 2019 to 2026(+)

From Side
Thank You….

Please Contact us…

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