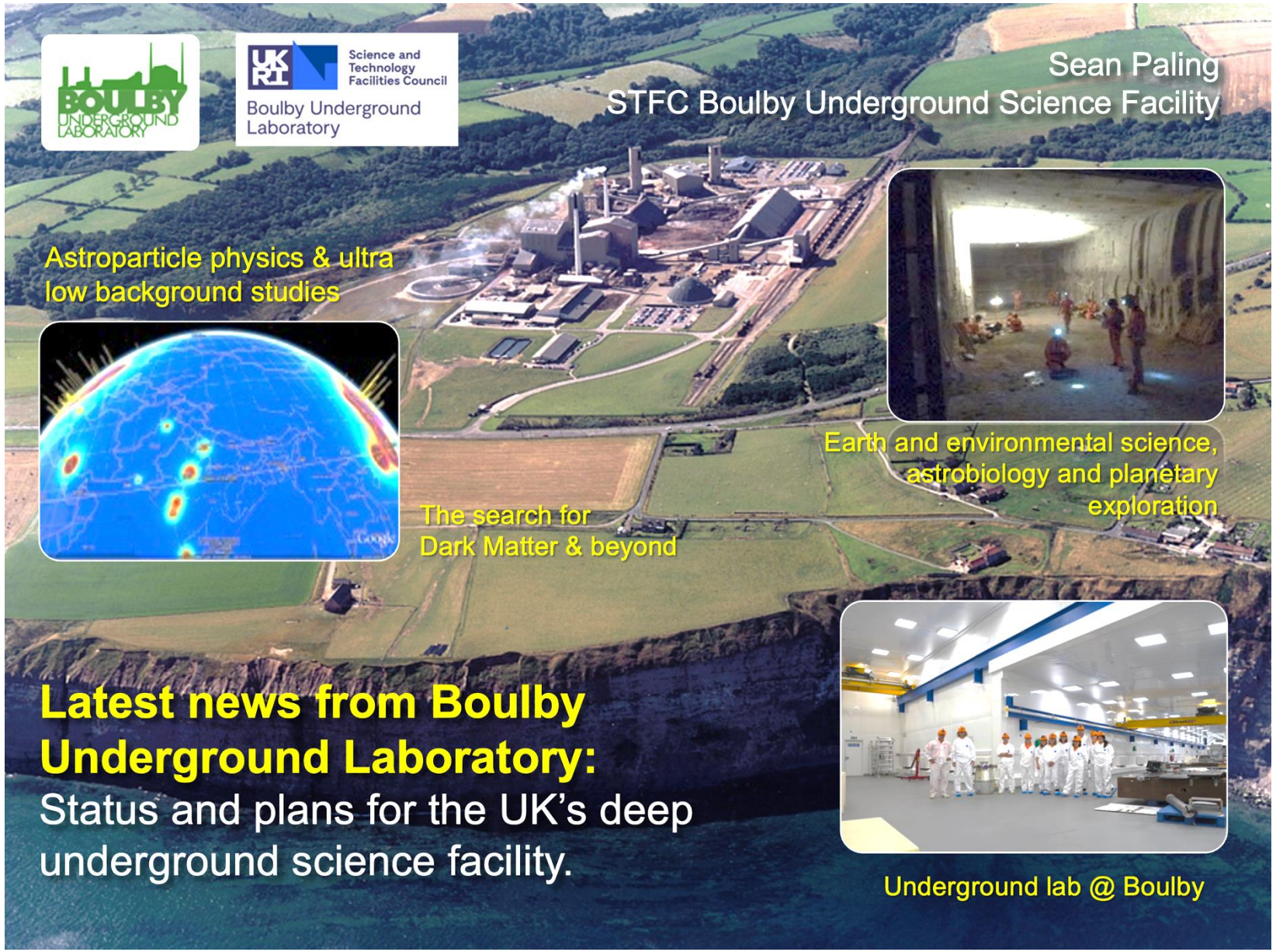
Latest news from Boulby Underground Laboratory:

Status and future plans for the UK's deep underground science facility

Sean Paling
STFC Boulby Underground Laboratory

Science and Technology Facilities Council
Boulby Underground Laboratory



April 2025

Boulby Mine

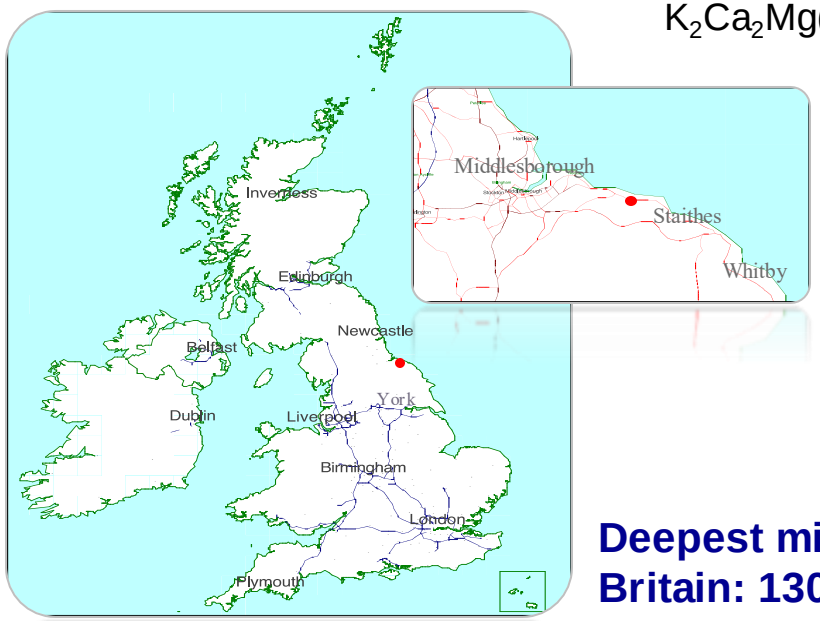
A working polyhalite and rock-salt mine on the North East coast of England.

Owned by Israel Chemicals Ltd. (ICL-UK). Locally operated as Cleveland Potash Ltd.

Major local employer: ~500 direct staff and 2000 indirect employment.

Polyhalite: $K_2Ca_2Mg(SO_4)$

Ships worldwide for agricultural fertiliser



Deepest mine in Britain: 1300km

The world's first polyhalite mine

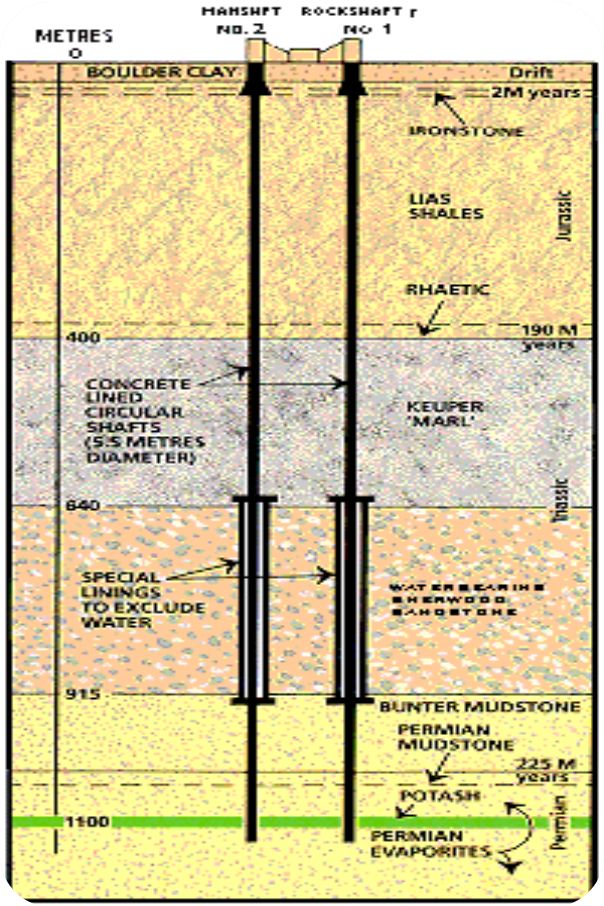
12 miles North of Whitby, N. Yorks

View from Staithes

Boulby Geology & Mining

Excavations are in Salt (NaCl), Potash (KCl) and Polyhalite ($K_2Ca_2Mg(SO_4)$). Permian evaporite layers left over from the Zechstein Sea (250m.yrs past).

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



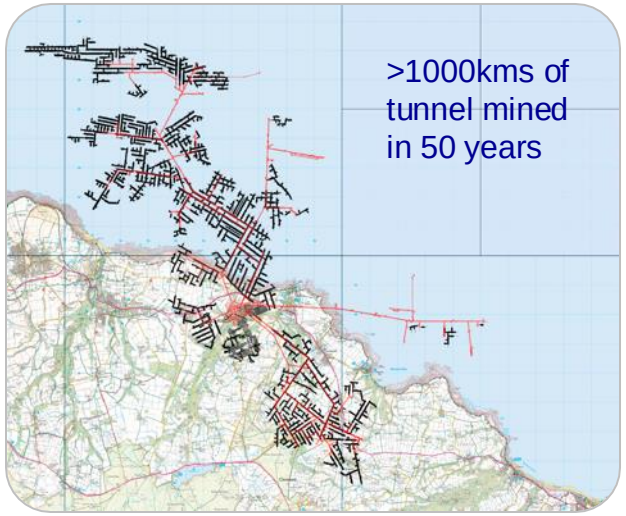
Boulby Geology

Polyhalite

Potash

Rock-Salt

Low activity salt
U ~67 ppb,
Th ~125 ppb



Typical Boulby Salt Roadway

Zechstein Sea

ICL Fertilizers

UKRI Science and Technology Facilities Council

Boulby Underground Laboratory

Science and Technology Facilities Council

Boulby Underground Laboratory

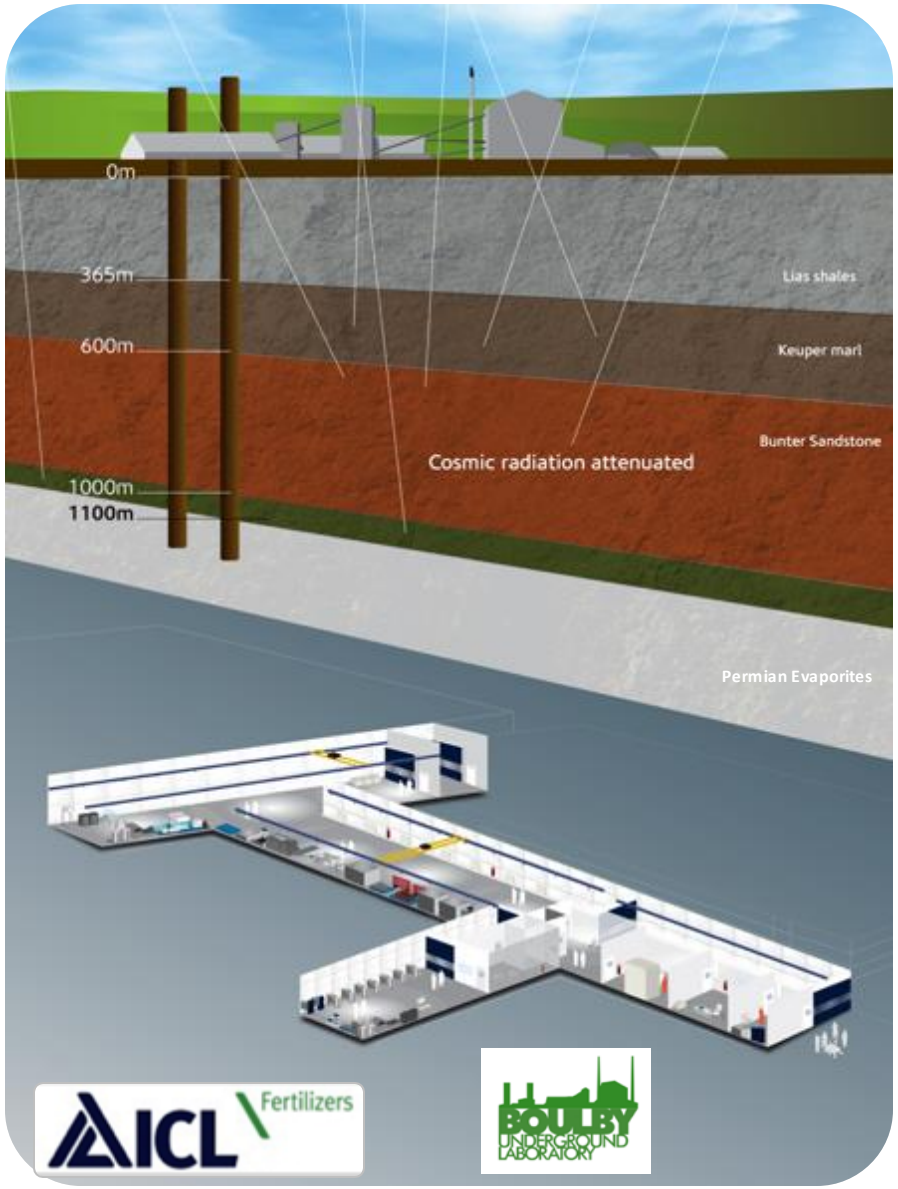
Boulby Underground Laboratory

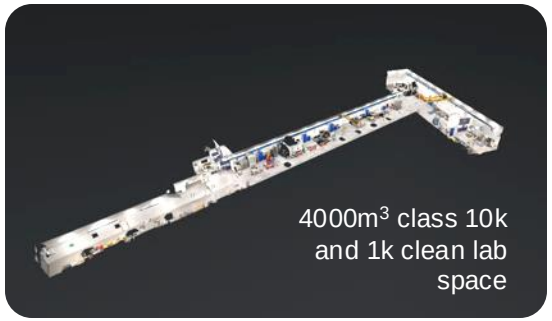
The UK's deep underground science facility operating in a working potash and salt mine.

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-UK

Outside Experimentation Area (OEA)





Lab entrance

Factor ~10^6 reduction in cosmic ray flux vs. surface

A QUIET place in the Universe

Surface support and staging building

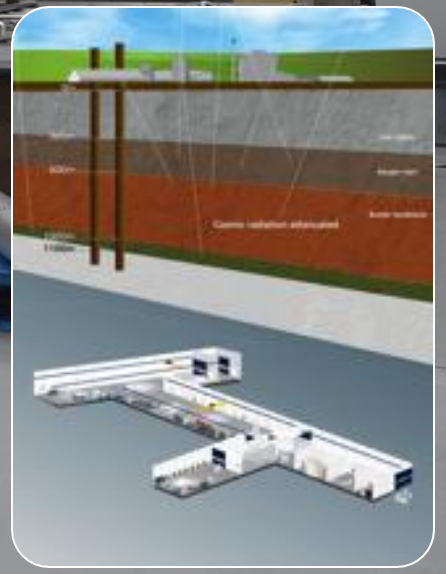
Office space, chemistry & clean prep lab, storage and staging space, IT room, conference room,

Supported access to surrounding geology & UG environs. Power, wifi/internet.

3000m^3 Outside Experimentation Area

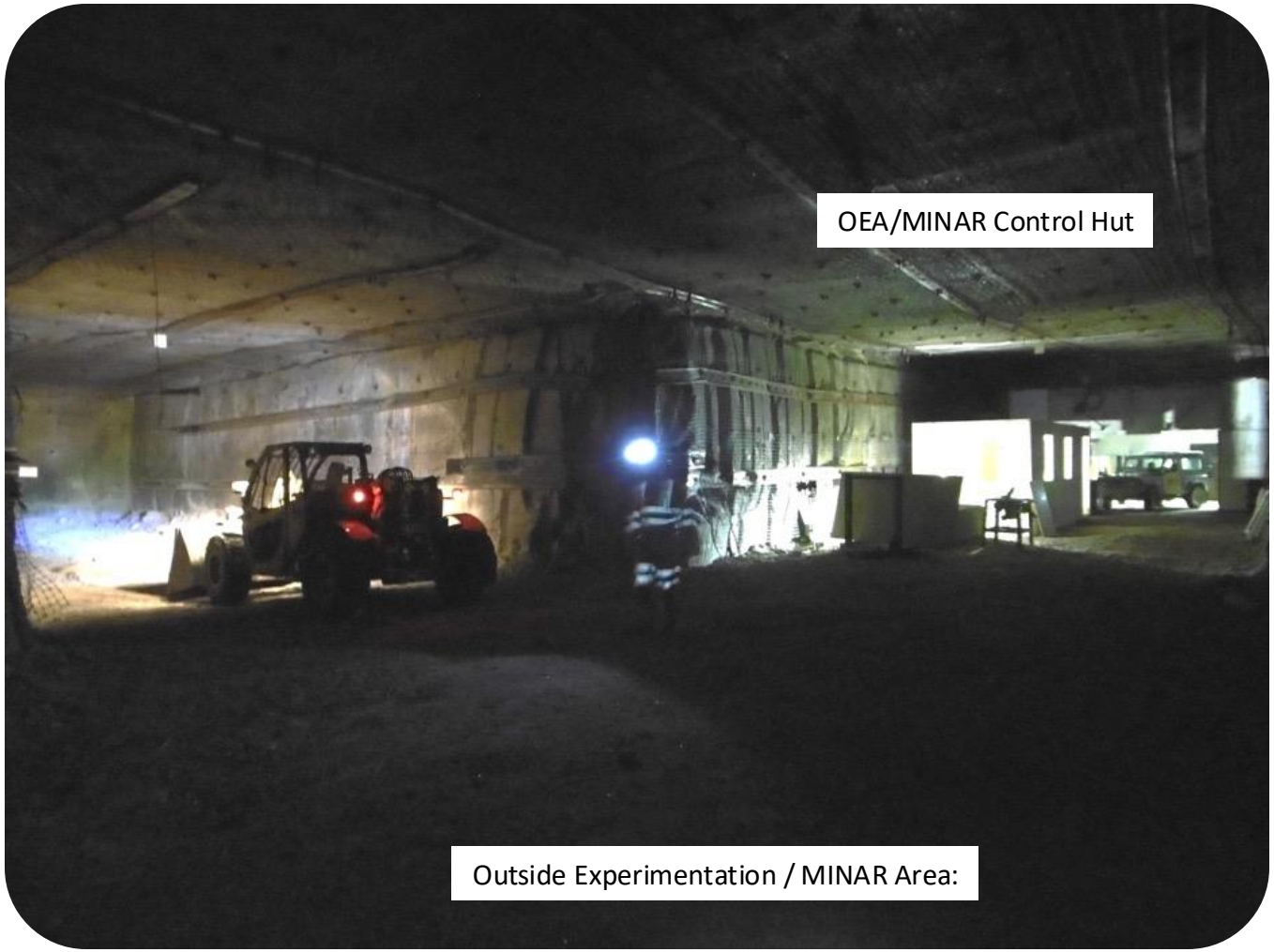
BUGS Material screening

Boulby Underground Lab Facilities 2023: >4000m^3 class 1k & 10k (ISO 6 & 7) clean room lab space. 10Gb Internet. AC, air filtration, 5T & 10T lifting, LN generation, fume hood & clean prep space. 3000m^3 Outside Experimentation Area (OEA) with power & internet. Supported access to wider mine environs.



Outside Experimentation Area (OEA)

Lighting, 240/110V power, Internet / WIFI. Ventilation, doors, MINAR Base Station Hut



'Outside Science'
Geology & Geophysics
Astrobiology, MINAR, Mars Analogue space

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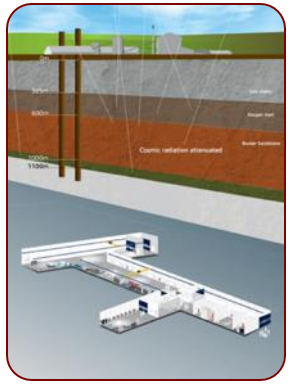
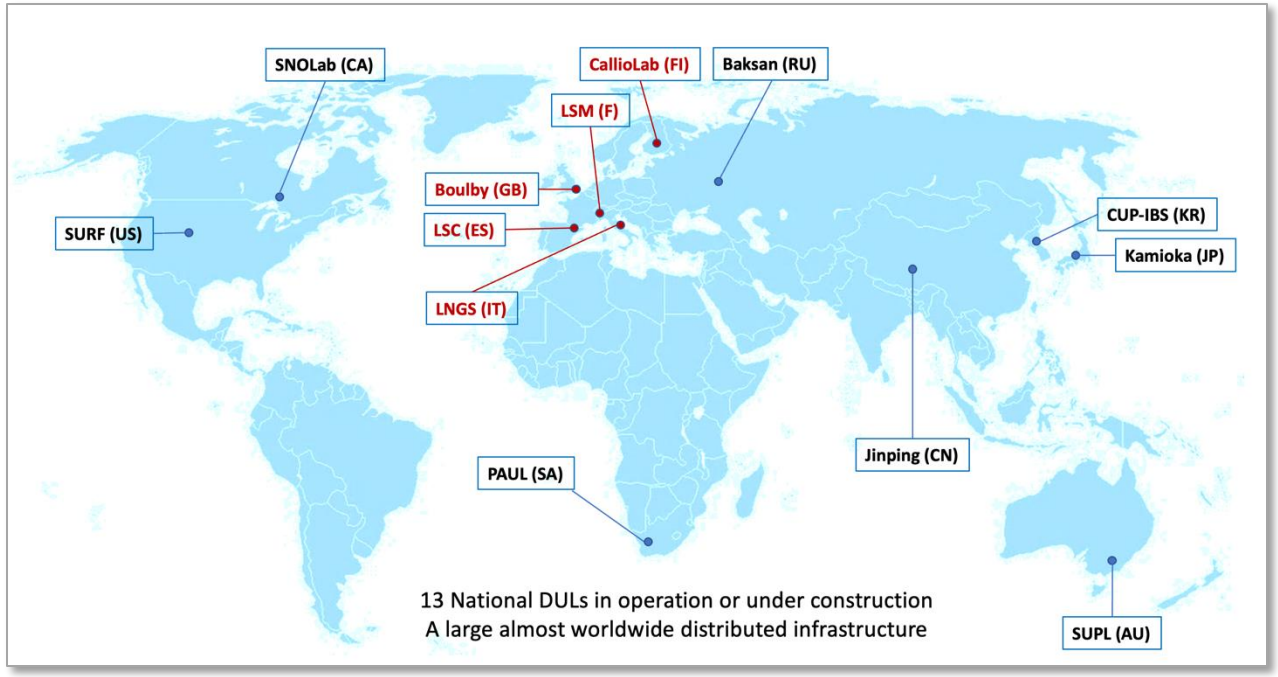
World deep underground laboratories…

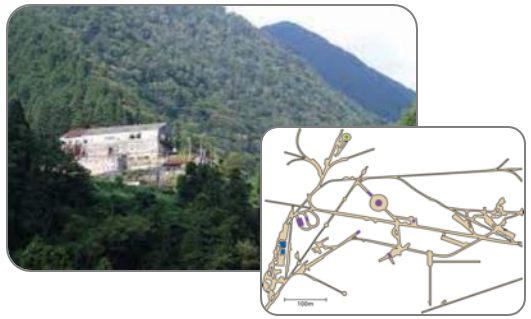


Boulby Underground Laboratory (UK)
Working Mine, 2850 mwe
Current vol: 7,200m^3
ZEPLIN+ (past), BUGS, News-G, RECON, BUTTON & more…

SNOLAB (Canada)
Active Mine, 5890 mwe
Current vol: 30,000m^3
SNO+, SuperCDMS, Deep3600, PICO, Next Gen 0vBB (to come?)

World Underground Labs





Kamioka (Japan)
Active Mine, 2700 mwe
Current vol: 150,000m^3
Super-K, XMAS, Kamland-Zen +. Hyper-K (nearby, to come)

SURF Laboratory (USA)
Disused Mine, 4200 mwe
Current vol: 7,100m^3
LZ, MJD, DUNE (to come)

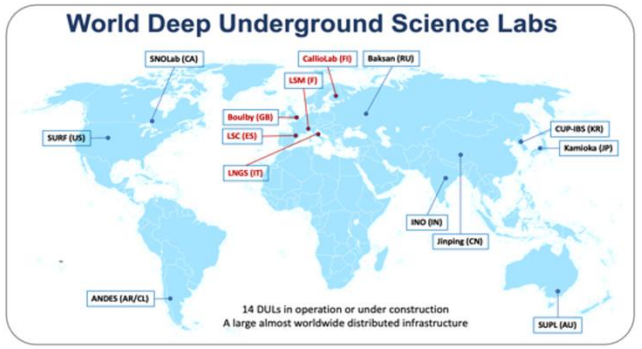
Gran Sasso National Laboratory
LNGS (Italy)
Under mountain, 3800 mwe
Current vol: 180,000m^3
Borexino, Xenon, DarkSide +

Boulby Underground Laboratory (UK)

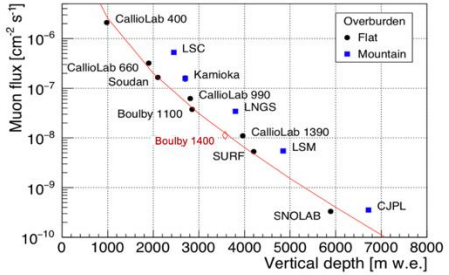
Science and Technology Facilities Council
Boulby Underground Laboratory

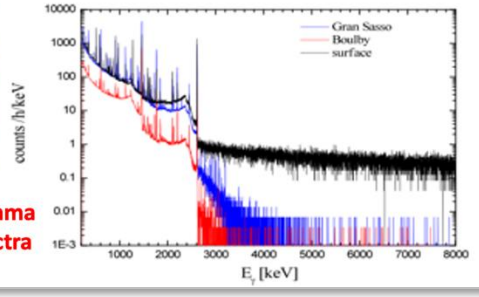
Boulby Facility Details…

- The UK's deep underground science facility. One of 5 in Europe, <15 in the world.
- Supports work of >10 collaborative projects (astrophysics to climate, geology, environment etc), >60 institutions, >250 scientists & students.
- Facility funded and operated by the Science & Technology Facilities Council (STFC).
- Operations, H&S & science programme managed by 23 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

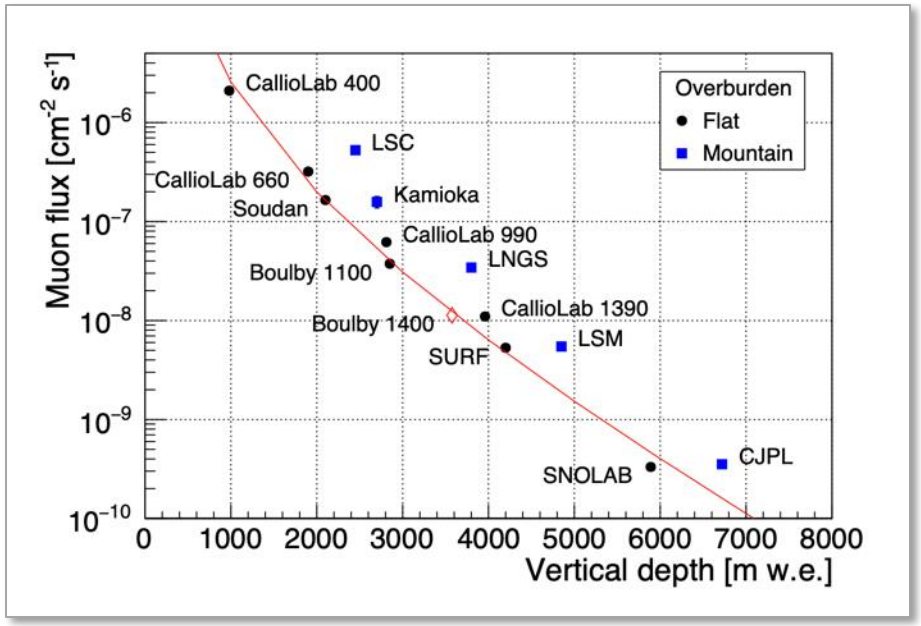




Gamma Spectra

Science and Technology Facilities Council

ICL Fertilizers



Science and Technology Facilities Council
Boulby Underground Laboratory

Science Programme Status & Plans.

- Astroparticle & Low Background Science
- Earth & Environmental Science
- Astrobiology & Planetary Exploration Studies
- Outreach & Education

Find out more:
@BoulbyLab
www.stfc.ac.uk/boulby

Boulby Underground Laboratory 2023

Science and Technology Facilities Council

Boulby Underground Laboratory

Working alongside Mining @ Boulby

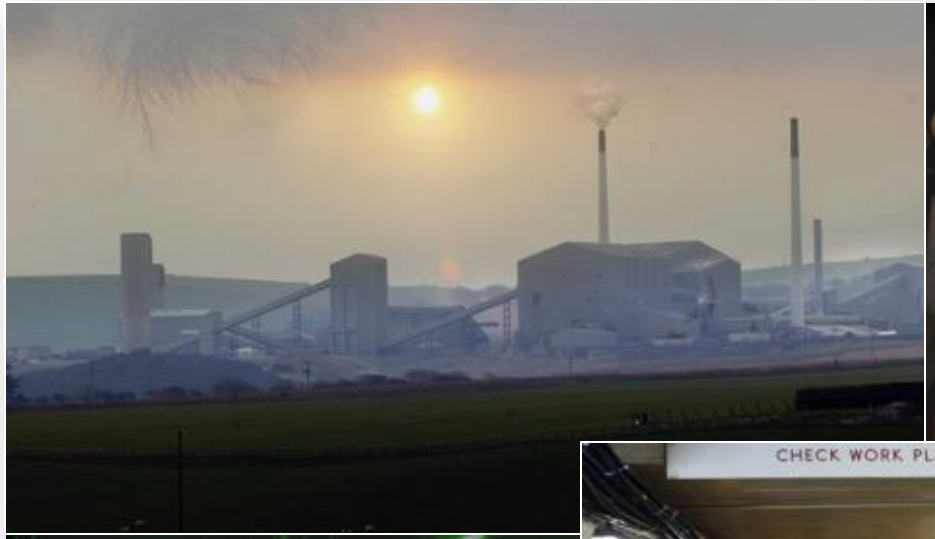
STFC-Boulby Lab responsibility:

Run and maintain the lab
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

ICL



Science and Technology Facilities Council

Boulby Underground Laboratory

Science Programme Status and Plans.

- Astroparticle & Low Background Science
- Earth & Environmental Science
- Astrobiology & Planetary Exploration Studies
- Quantum Sensors and Computing (new)
- Outreach & Education

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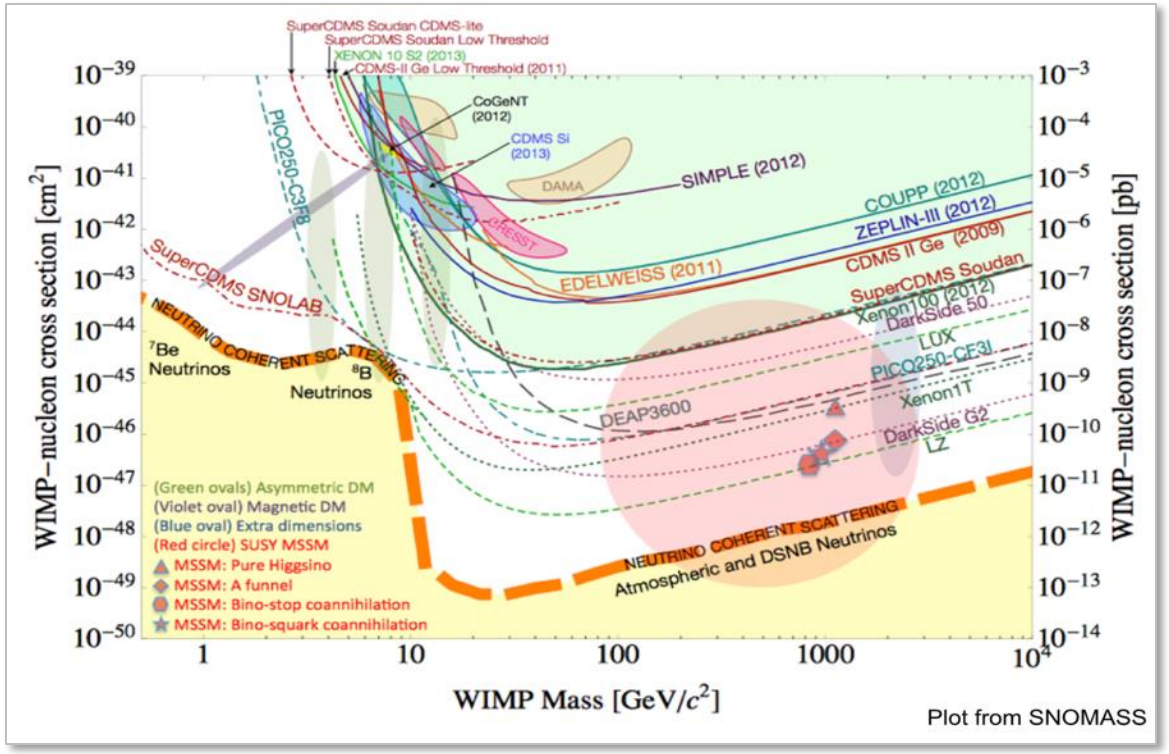
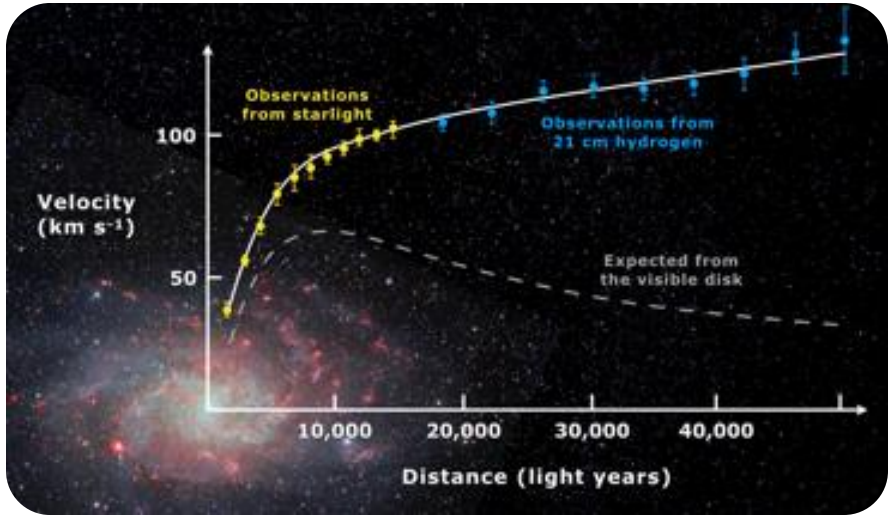
Boulby Dark Matter Studies…

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

Boulby now hosts CYGNUS directional DM programme, NEWS-G / Dark-Sphere R&D and providing ULB material screening for other studies, inc **LUX-ZEPLIN (LZ)**





Galactic rotation curves

World DM particle search limits and future projections

ZEPLIN-II & III: *The world's first 2-phase Xenon dark matter detectors (Finished 2011)*

ZEPLIN-III @ Boulby

Spherical Proportional Counters (SPC) at Boulby

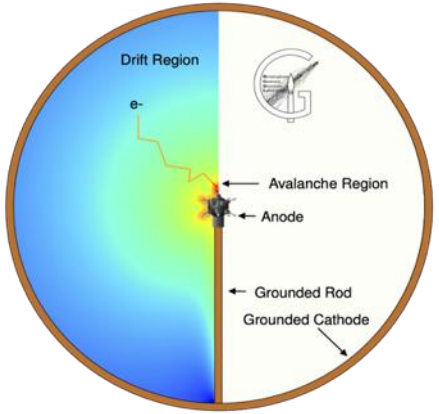
NEWS-G DarkSPHERE

K. Nikolopoulos, P. Knights, L. Millins, G. Rogers, D. Spathara, P. Walters
University of Birmingham
and international NEWS-G Collaboration

UNIVERSITY OF BIRMINGHAM

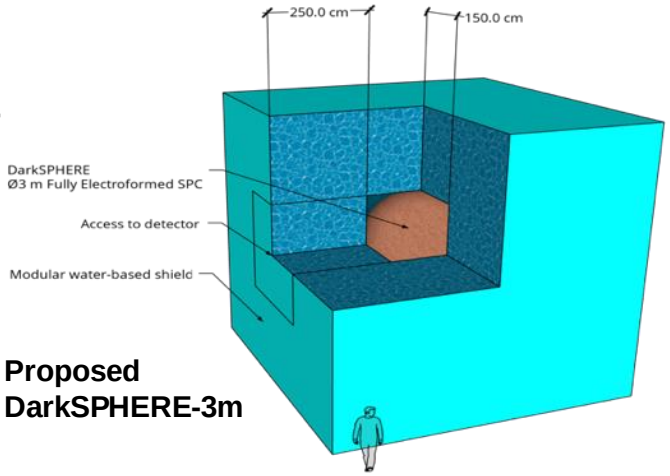
NEWS-G Activities at Boulby

- Instrumentation developments
  - Multi-anode sensor
  - Gas filtration
  - Rate effect studies
- Neutron spectroscopy (with N_2 gas)
  - Neutron background surveys
  - Industrial applications
- High-purity copper electroformation
- **Towards scaled-up, electroformed, detector at Boulby, 3m diam. 5 bar He:CH_4H_{10} *DarkSPHERE***



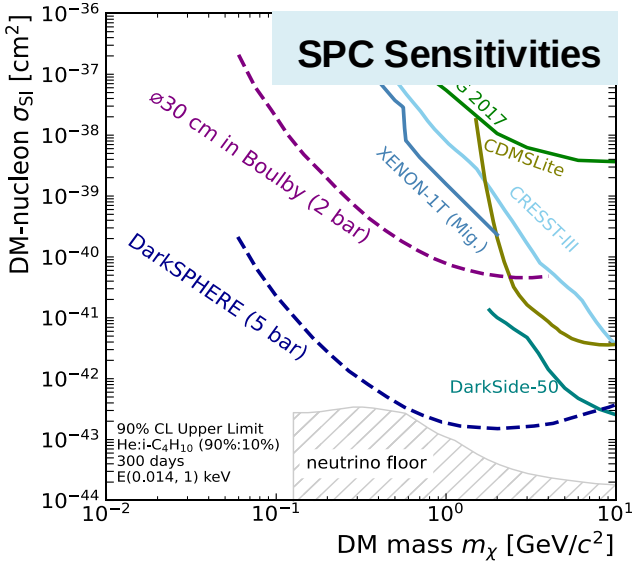
SPC concept: Variable target
Low E_{th}, Low mass sensitivity

11-anode sensor

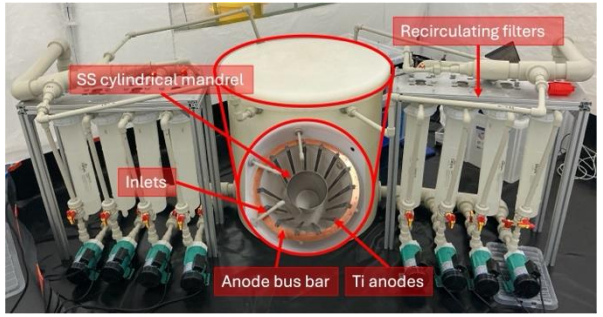


Proposed DarkSPHERE-3m

See at IOP:
Dimitra Spathara - Talk
Giovanni Rogers - Poster
Peter Walters - Poster



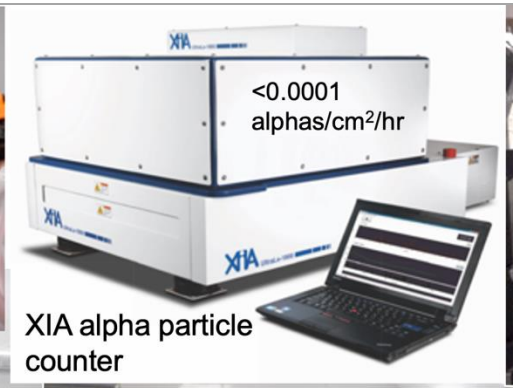
Al-S30 R&D Detector



Copper electroforming at Boulby

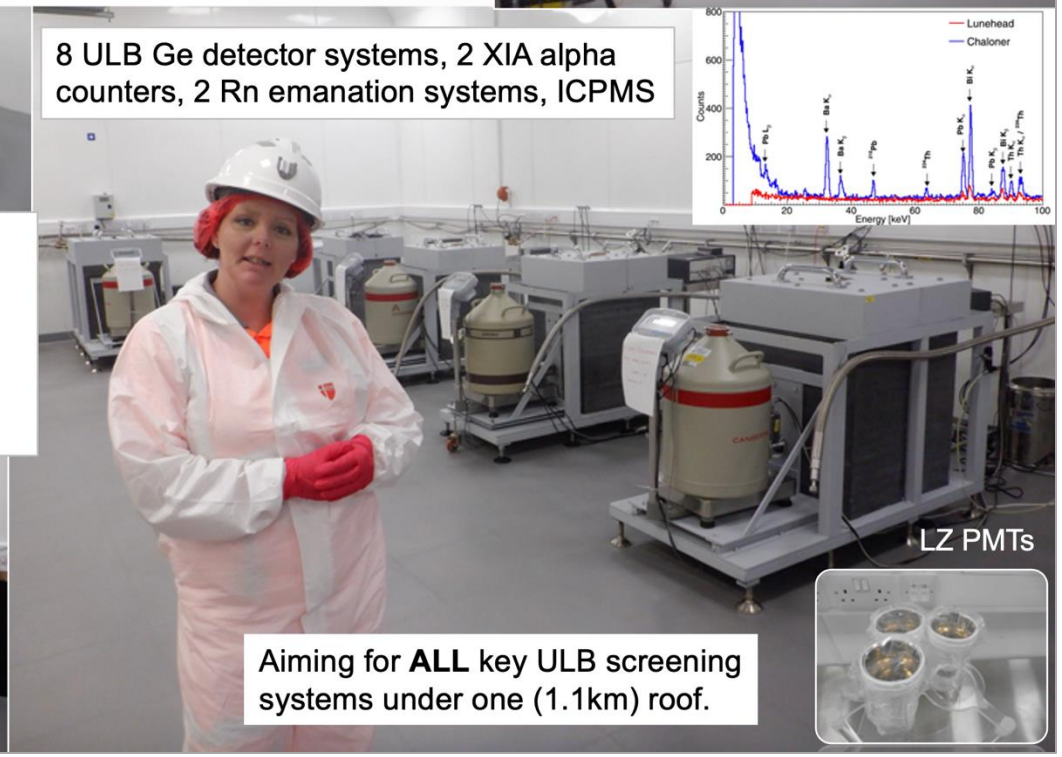
Science and Technology Facilities Council
Boulby Underground Laboratory

Ultra Low Background Material Screening @ Boulby (BUGS)



8 ULB Ge detector systems, 2 XIA alpha counters, 2 Rn emanation systems, ICPMS

BUGS (Boulby UnderGround Screeening). World-class material screening for current and future ULB experiments. Towards PPT sensitivity for G3 DM and Neutrino experiments



Aiming for **ALL** key ULB screening systems under one (1.1km) roof.

BUGS (UG): A range of HPGe detectors and *alpha particle detectors* for intrinsic and surface radioactivity measurements.

ICP-MS (Surface): Newly installed system for trace element analysis and isotopic ratio measurements.

BUGS Facility: (Boulby Under-Ground Screening)

- ULB Germanium (8)
- XIA: Surface alphas (2)
- Radon Emanation (2)
- ICPMS-QQQ * All now in operation

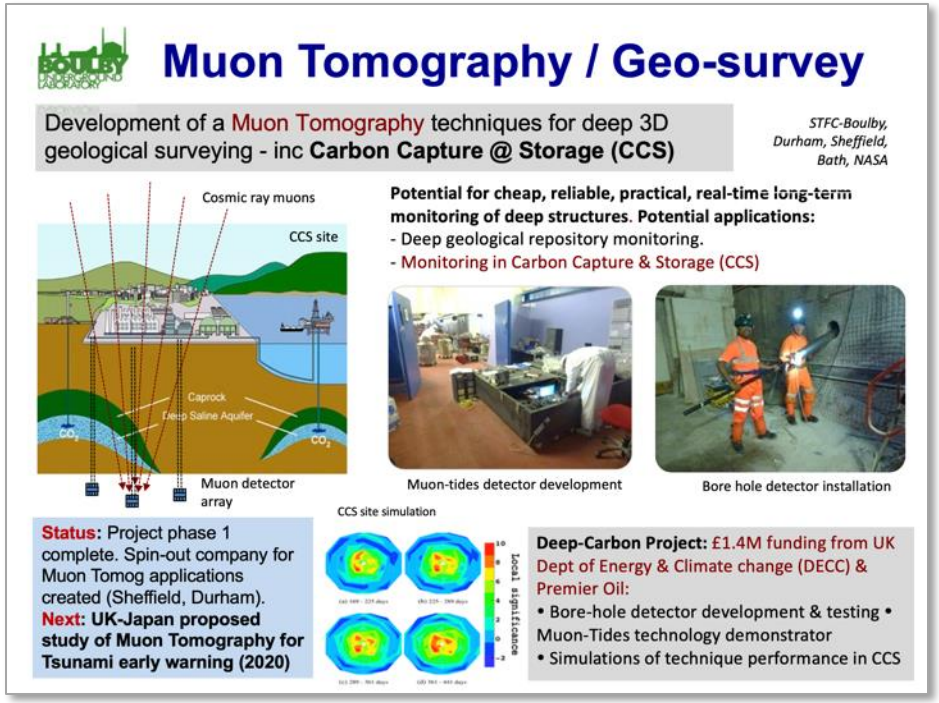
At this conference…

Alice Hamer – Talk Mon pm
Sid Ahmed Maouloud – Talk Tues pm
Sophie Carroll – Poster Mon pm

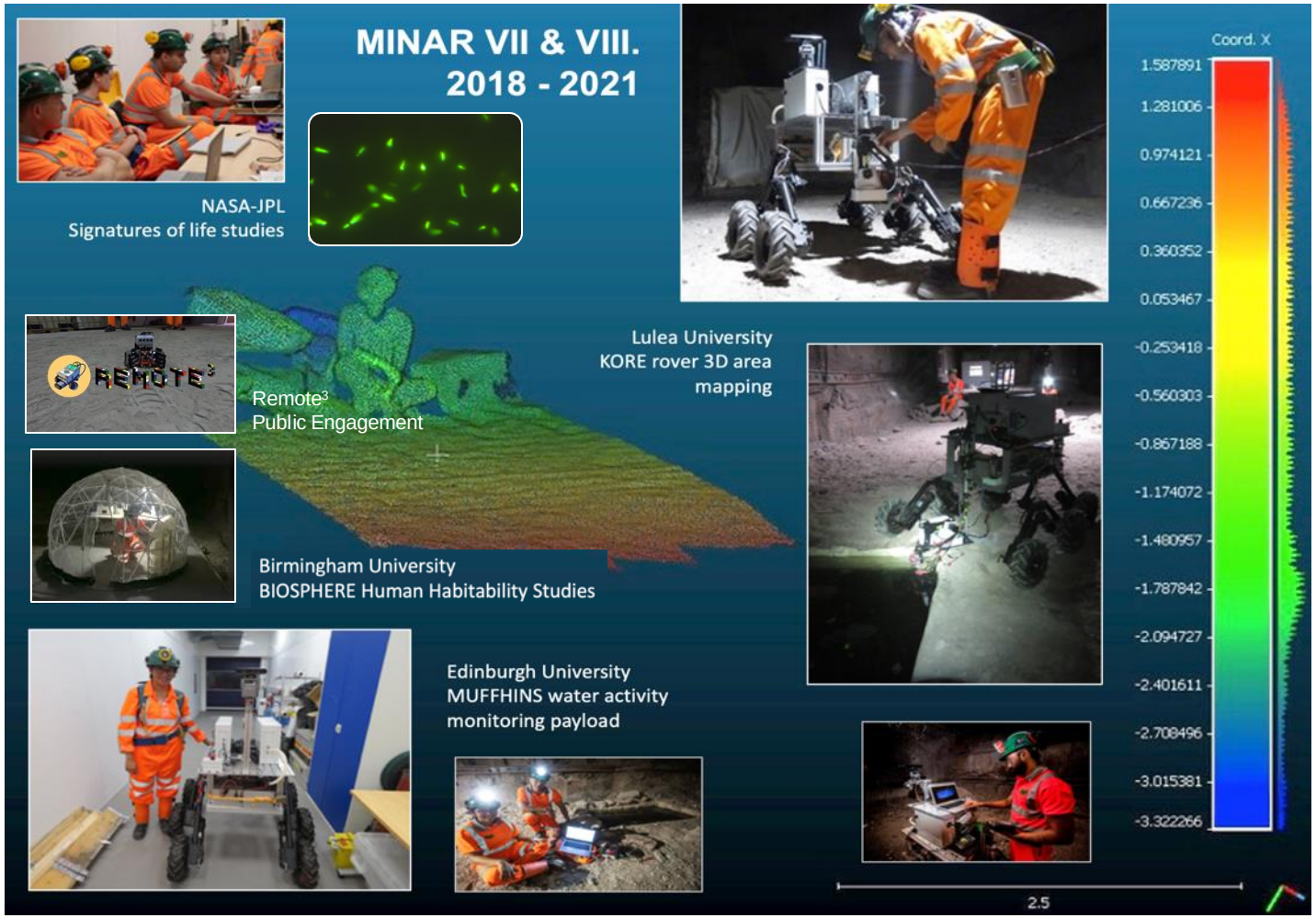
Multidisciplinary Science

Applied low background particle physics, Earth and Environmental science, Astrobiology & Planetary Exploration Technology Development.

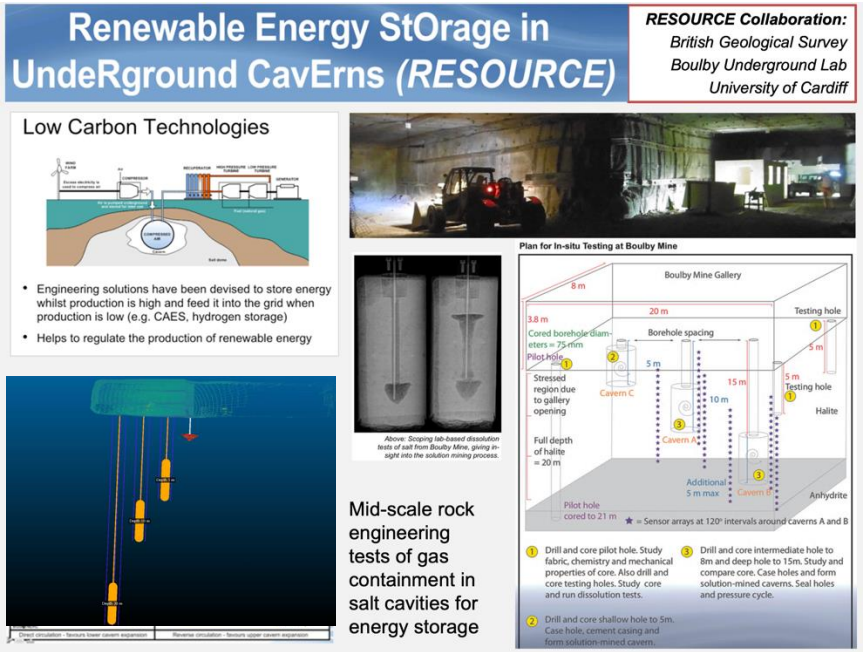
Deep CARBON: Muon Tomog R&D for CCS & more



MINAR: Astrobiology and planetary exploration technology development



RESOURCE: Compressed gas energy storage R&D

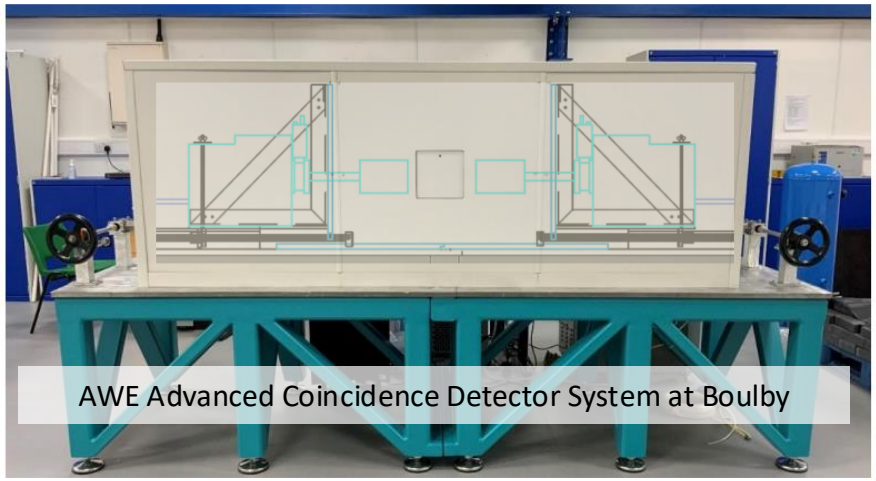


Project RECON – CTBT Verification.

Enhancing the capability to monitor for signs of nuclear testing

Science and Technology Facilities Council

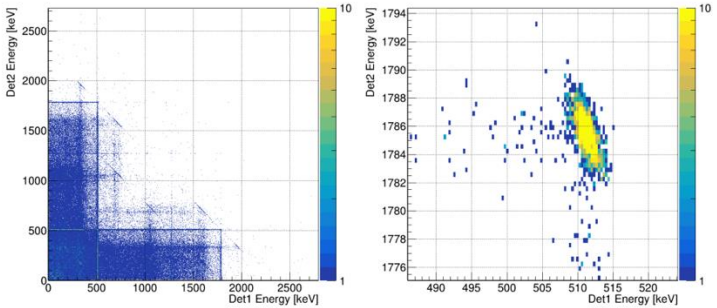
AWE NUCLEAR SECURITY TECHNOLOGIES

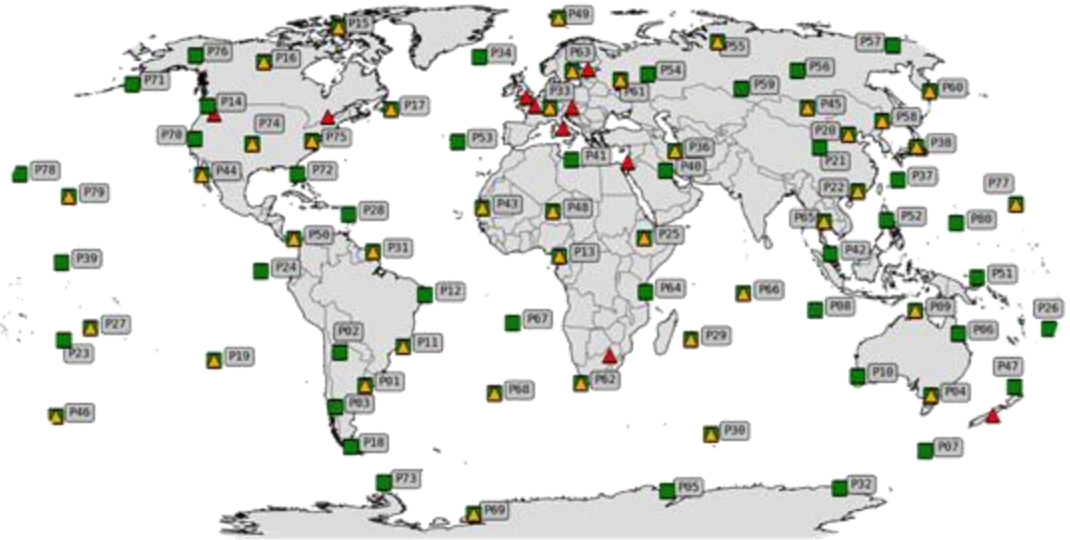


AWE Advanced Coincidence Detector System at Boulby

AWE Chief Scientist Visit to Boulby (2025)

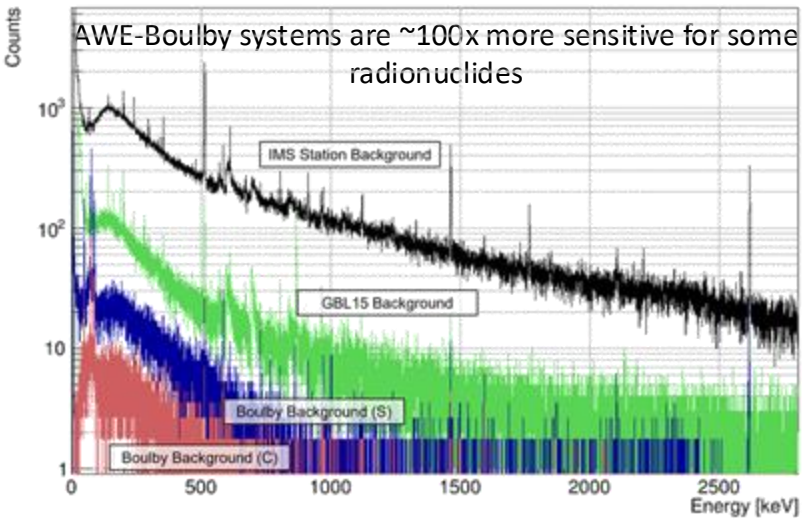
AWE and STFC Boulby have recently established a collaboration framework





The International Monitoring System (IMS) Radionuclide Network

AWE have been collaborating with STFC Boulby for ~ 8 years to develop an advanced coincidence detector system capable of improving measurement sensitivity for radionuclide samples used for verification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT).



Figures from Goodwin *et al.*, (2025) In draft

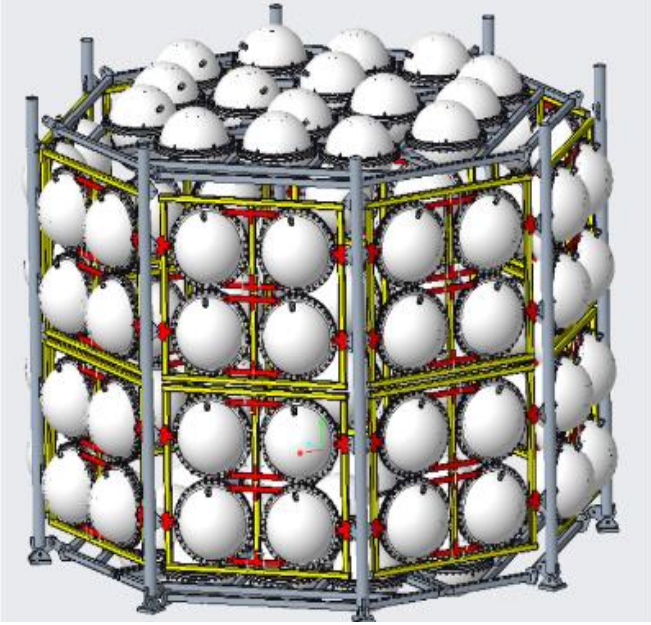
BUTTON: a technology testbed for future (anti)neutrino detection

World antineutrino flux levels

~50 members across 16 institutions in the UK and U.S.

Lawrence Livermore National Laboratory
AWE
BERKELEY LAB
Brookhaven National Laboratory
THE UNIVERSITY of EDINBURGH
Science and Technology Facilities Council
Boulby Underground Laboratory
UNIVERSITY OF MICHIGAN
University of Sheffield
UF UNIVERSITY of FLORIDA
UNIVERSITY OF LIVERPOOL
Pacific Northwest NATIONAL LABORATORY
University of Glasgow
Penn UNIVERSITY of PENNSYLVANIA
THE UNIVERSITY OF WARWICK

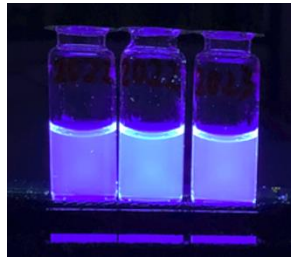
Funded in the UK by STFC from the UKRI Fund for International Collaboration & the MoD, & in the U.S. by NNSA (National Nuclear Security Administration).



A US-UK proof of concept project for a non-proliferation implementation

BUTTON-30 is a proof of concept for a future 1-kT detector providing 100-tonne fiducial volume

Part of a worldwide effort to develop WbLS detector technology. Other experiments include EOS at LBNL and the Brookhaven 30-ton at BNL.

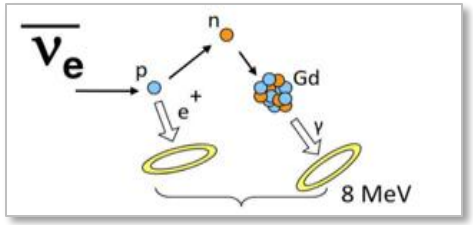


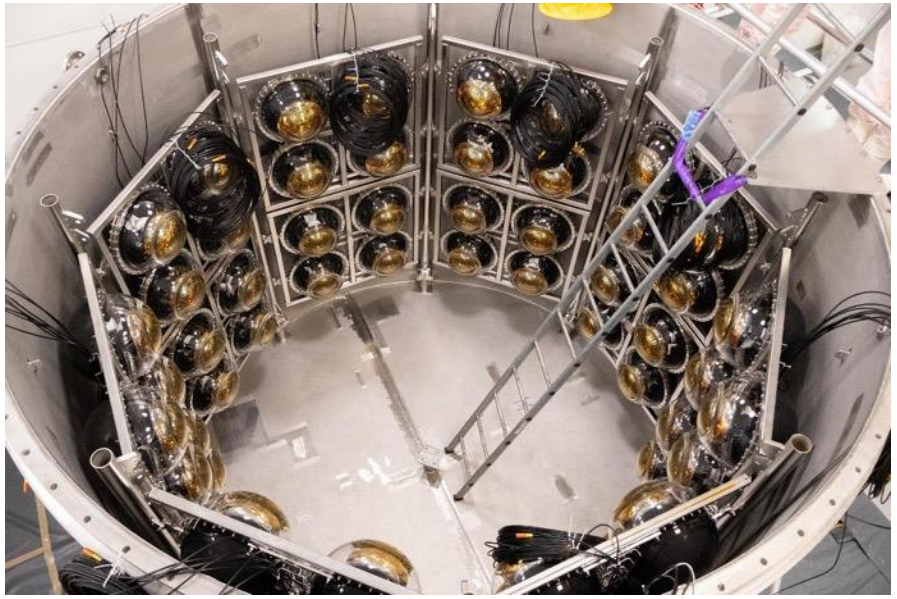
Water Based Liquid Scintillator (WbLS)

Boulby provides uniquely suited experimental space in ultra-low background Environment.

30T Liquid Filled (Gd+H_20, Water Based Liquid Scintillator (WBLS) and Gd-WbLS) prototype detector.

Anti-neutrino discrimination with Gd-H_20

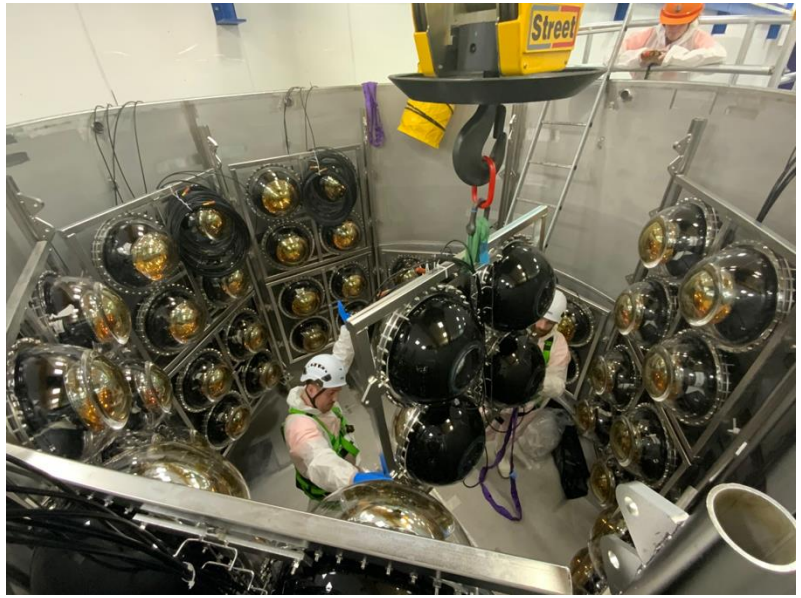


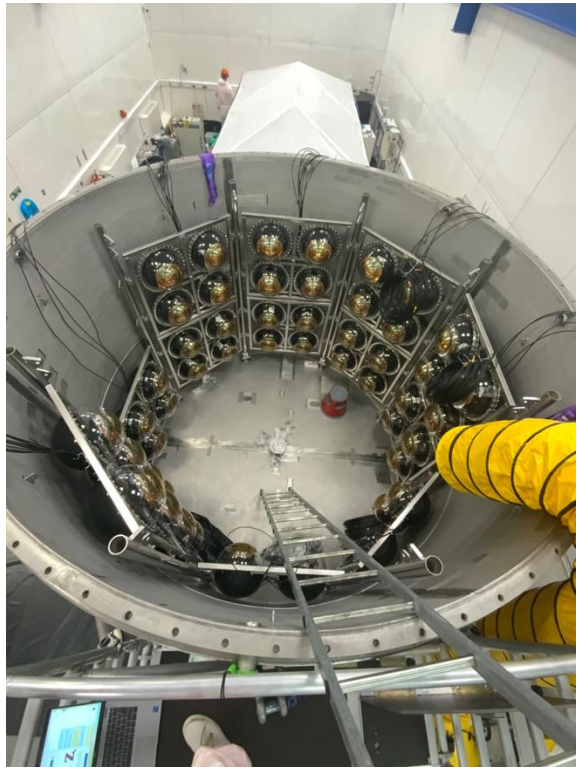


Button @ Boulby Feb 25

BUTTON Installation – Jan 25

See (at this conf)…
Adam Tarrant – Talk and Poster
James Gooding - Talk





Boulby Science Activities Now and Potential Future

Now

	Current Projects	Status
Particle Physics & Low Background	CYGNUS - DM R&D	E/P
	News-G - DM R&D	A
	BUGS: Ge, XIA, RnEm - Material Screening	A
	RECON - Nuclear Security R&D	A
	BUTTON – Nuclear security R&D	A
Earth & Environmental	Muon Tomog – CCS & undersea Geoimaging R&D	A
	RESOURCE – Energy store R&D	A
	Seismology/AION R&D	A
Astrobiology & Planetary Exploration	BISAL – Biology/Astrobiology	A
	MINAR – Planetary Exploration Tech development	A
	Misc. Other. SELLR, C14, BIO-SPHERE…	A/I
	Outreach/ Education - Misc events, progs, Remote3…	A

Status: A = Active, P = Paused, E = End,
I = Interest confirmed

2023-2030

Medium Term (Current Lab + mods)	Status
BUGS: Ge, XIA, RnEm, ICPMS - Material Screening	A
BUTTON-30 – Nuclear security R&D	A
RECON+ - Nuclear Security R&D	A/I
DarkSPHERE, SDMS, SOLAIRE, UltraDark, MechQSDM – DM Search	I
DATUM – Neutrino Tech R&D	I
SoLAr – Neutrino R&D	I
Seismology Array – Geosurvey R&D	I
RESOURCE+ – Energy store R&D	A/I
Muon Tomog – CCS & undersea Geoimaging R&D	A/I
BISAL+ – Biology/Astrobiology	A/I
MINAR+ – Planetary Exploration Tech development	A/I
Misc. Other. AION R&D – Atomic Interferometry Quantum Computing Tech R&D?	A I
Outreach/ Education: General Public, Schools +	A

2030-2040+

Long Term (Current lab plus major new lab)

Particle Physics and Low Background Science:

Dark Matter: Major Next Gen Experiments:

- Xenon (XLZD)
- Argon (SOLAIRE+)
- Gas (DarkSPHERE+)
- ULT technologies for DM
- Quantum Technologies for DM

Target projects for **a major new UK underground facility** / campus

Neutrinos:

- BUTTON-100+
- DATUM (LEGEND Support),
- SoLAR +….

Mat screening & LB Techniques: A world's best facility:

- Ge, XIA, RnEm, ICPMS, Cleanliness & Engineering R&D
- RECON+ - Nuclear Security Gamma spec

Earth & Environmental Science:

- Sustainable Energy R&D (Gas Storage, Geotherm, CCS)
- Local/Global Seismology Observatory
- Geological Repositories R&D
- Misc geology / Geophysics R&D

Astrobiology & Planetary Exploration:

- Extremophile R&D
- Astrobiology / life beyond Earth R&D
- Human habitation R&D
- Planetary exploration technology development
- Mining and industry application development.

Quantum Sensors and Computing:

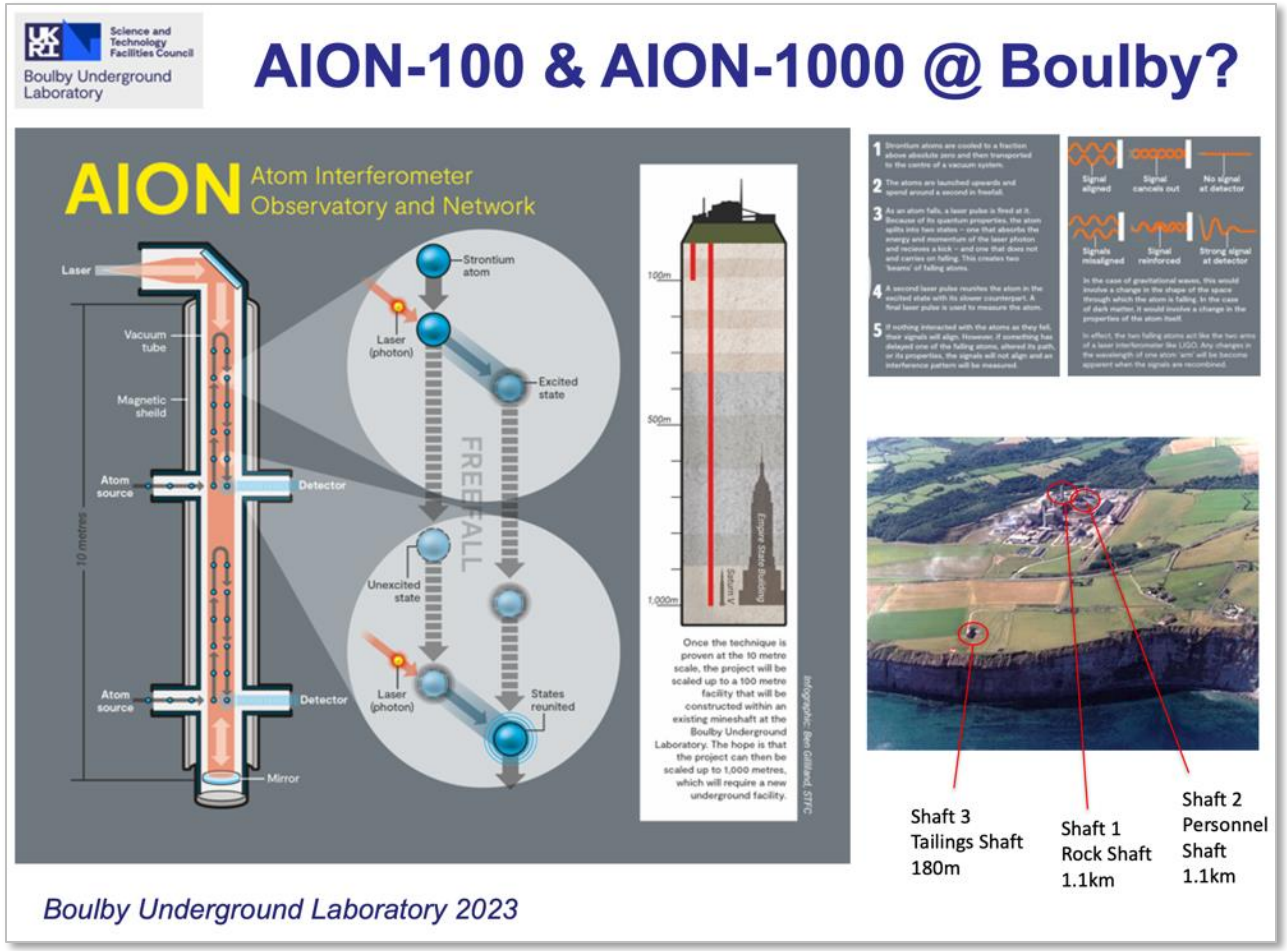
- AION-20/100/100 – Atomic Interferometry
- Quantum Sensor and Computing Technology R&D

Outreach and Education:

- A National Centre for Science and technology outreach and education.

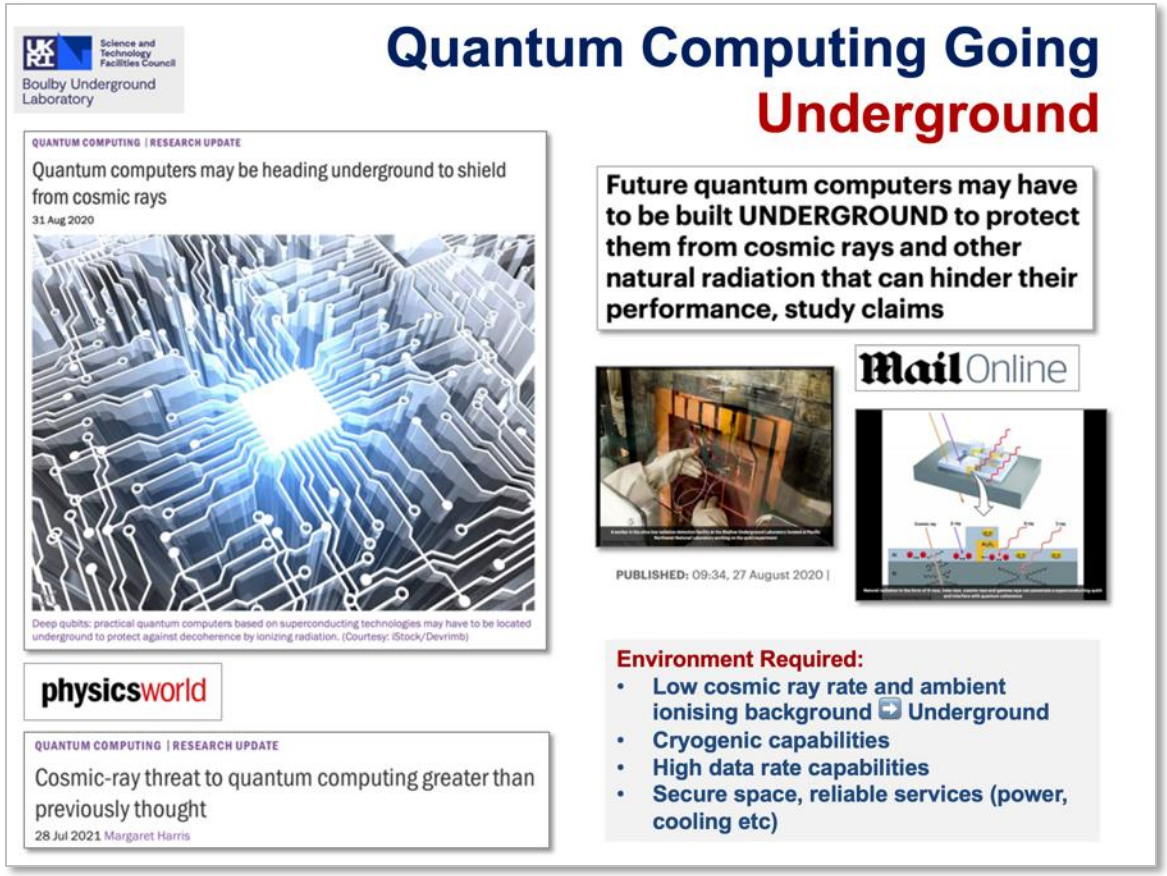
Science and Technology Facilities Council
Boulby Underground Laboratory

Future facilities & science @ Boulby?



AION-100 & 100: Atomic interformetry for GW and light DM studies

Quantum Sensors and Quantum Computing



Quantum Computing in Ultralow background environment

Boulby Future Earth and Environmental Science

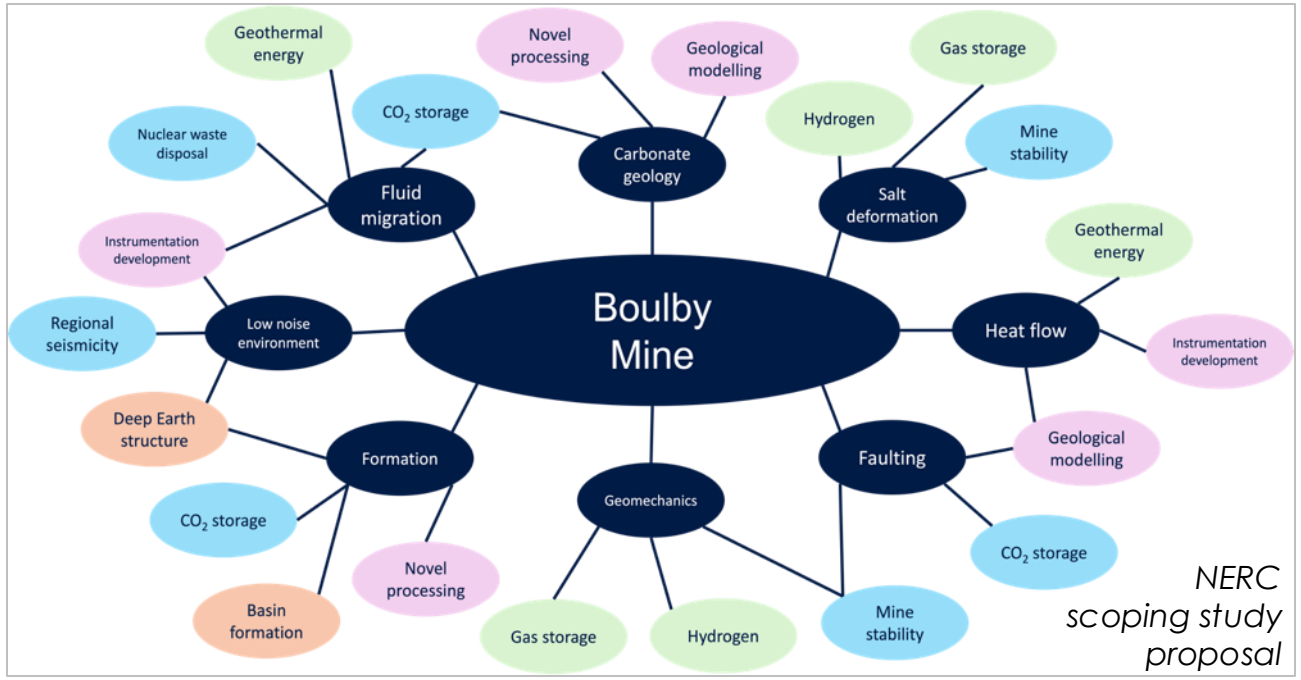
Developing program of Earth science research at Boulby by a consortium of UK universities and industry.

Earth science at Boulby workshop August 2024

Sustainable energy. Seismology. Geological repositories.

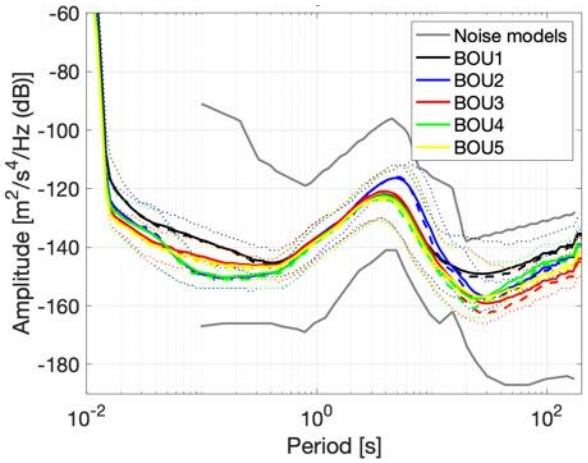
Workshop of 17 universities and 4 companies has led to a proposal of an integrated program of Earth science research, currently being considered by NERC.

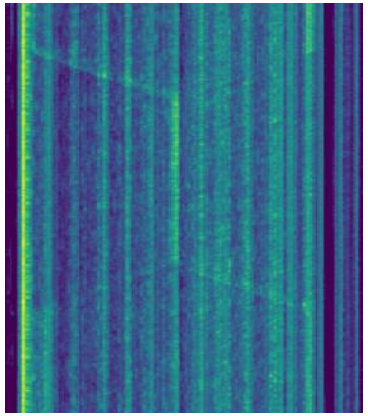
Research themes of the Boulby programme



NERC scoping study proposal

SENSE: Pilots studies and towards a major national seismic observatory.





Seismometers and fibre optic acoustic sensors deployed to baseline vibration levels for AION experiment and North Sea regional earthquake monitoring.

Next Generation Xe Dark Matter(+) Detector (XLZD)

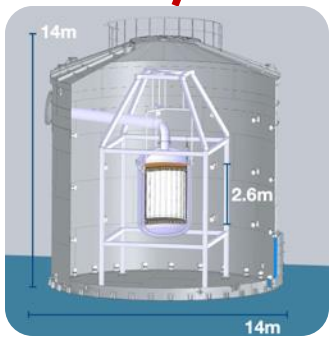
Lux-ZEPLIN (LZ). SURF, S. Dakota, USA

LZ: 10T 2-phase Drk Matter detector operating in SURF lab, USA. Early 2-phase Xe technology developed in the UK. STFC/UK investment continues.

Xenon-nT
LNGS, Italy

XLZD
2021 merging of LZ, Xenon and DARWIN teams

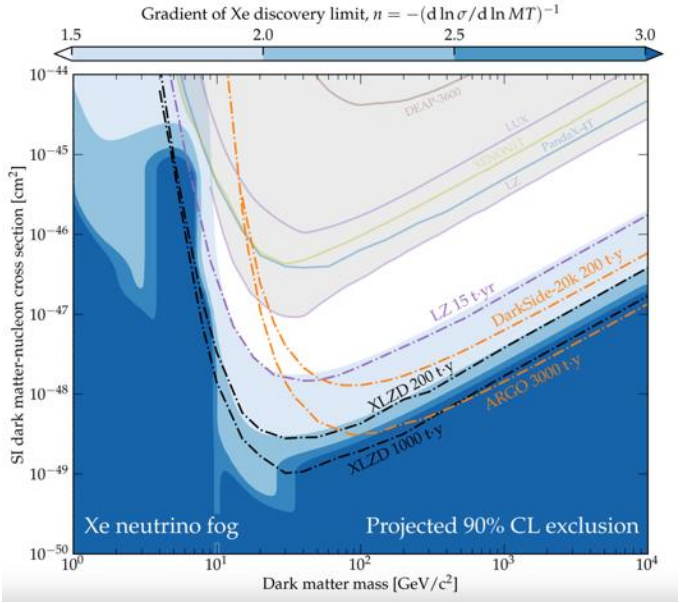
DARWIN
(Proposed)



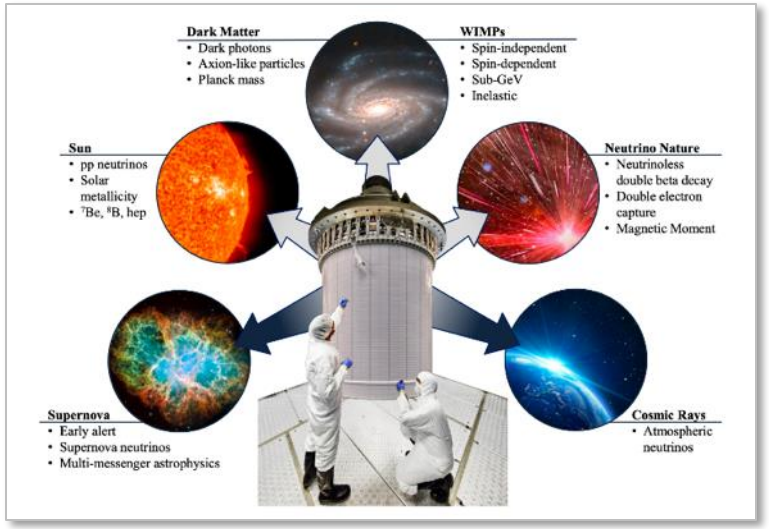
XLZD
50-100T LXe
Operation 2032+
Site evaluation underway

Could XLZD be constructed and operated at Boulby 2030+?

Projected sensitivity (Akerib P5 town hall mtg 2023)



Next generation **world's best** Dark Matter (+) detector. **Expected 2030+**



Next (Current) Steps: Boulby Development Project (BDP)

BDP Project Goal:

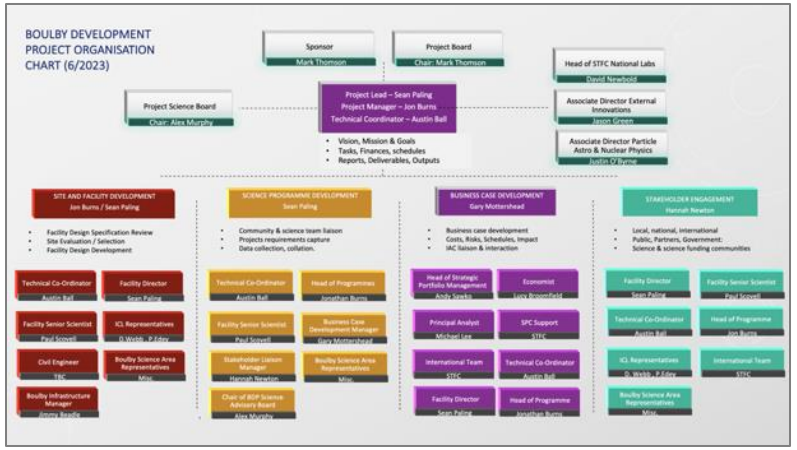
Next level planning and preparing for a…
"… **greatly expanded underground science facility in the North East, with potential to host a major international science infrastructure, such as a next generation dark matter experiment.**" (STFC strategic delivery plan (2022-2025)

UKRI Preliminary Infrastructure Funding £2.84M, 3 year project (2022/3-2024/5).

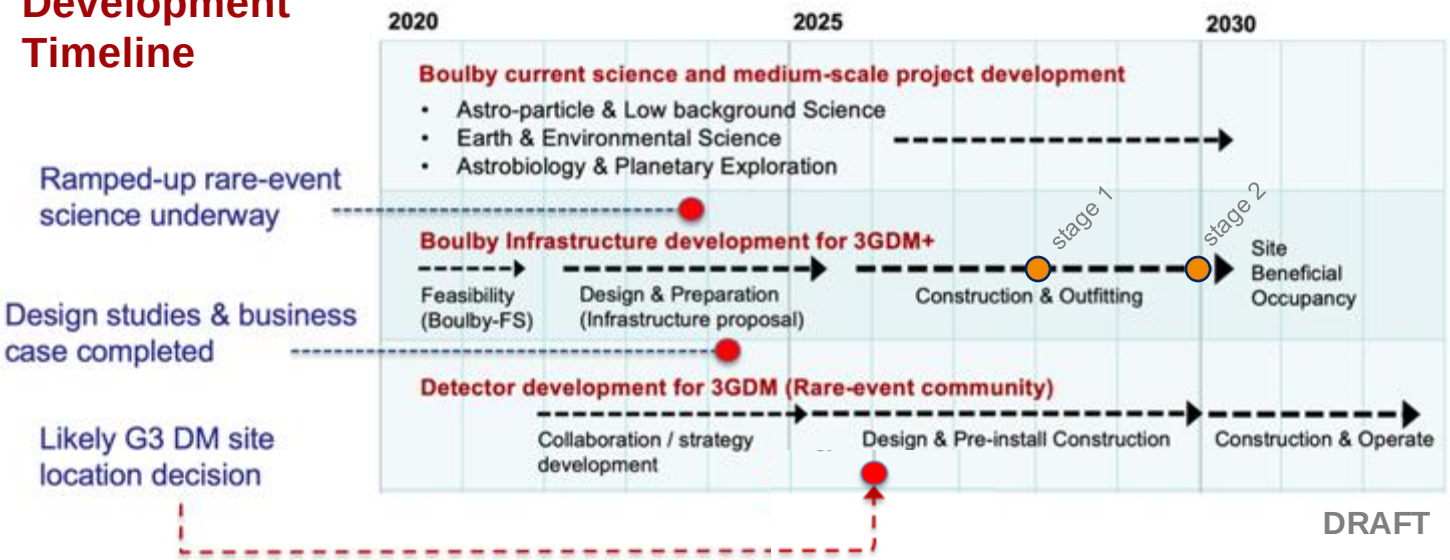
Tasks / Deliverables:

1) Facility design development (for sites at various depths and locations)
2) Science programme development
3) Business case(s), economic impact studies, risks → **Submission to Gov.**
4) Stakeholder engagement: Local, National & International:
   - Public & Partners
   - Government
   - Science communities & funders

Boulby Development Project Organisation



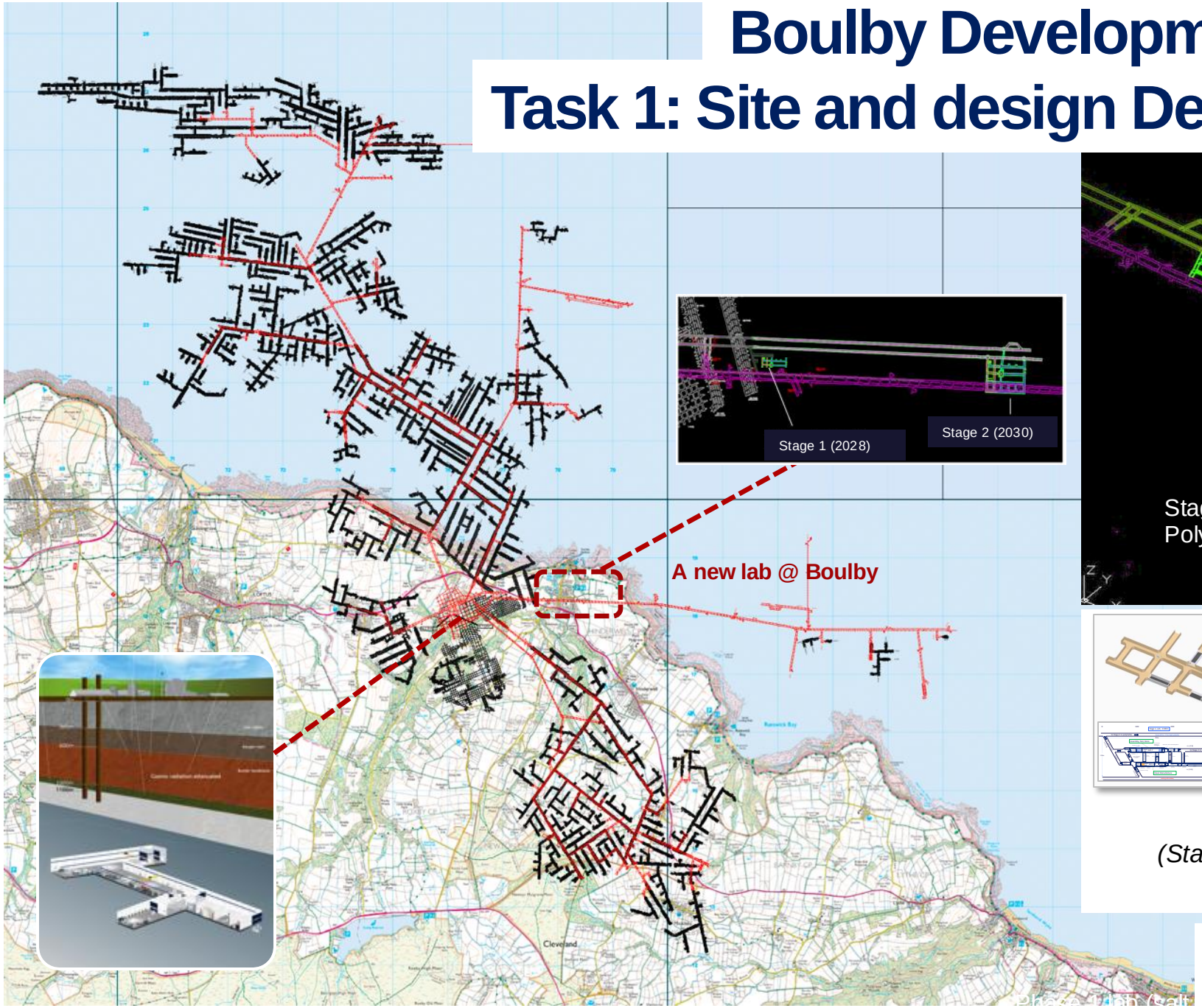
Boulby Development Timeline

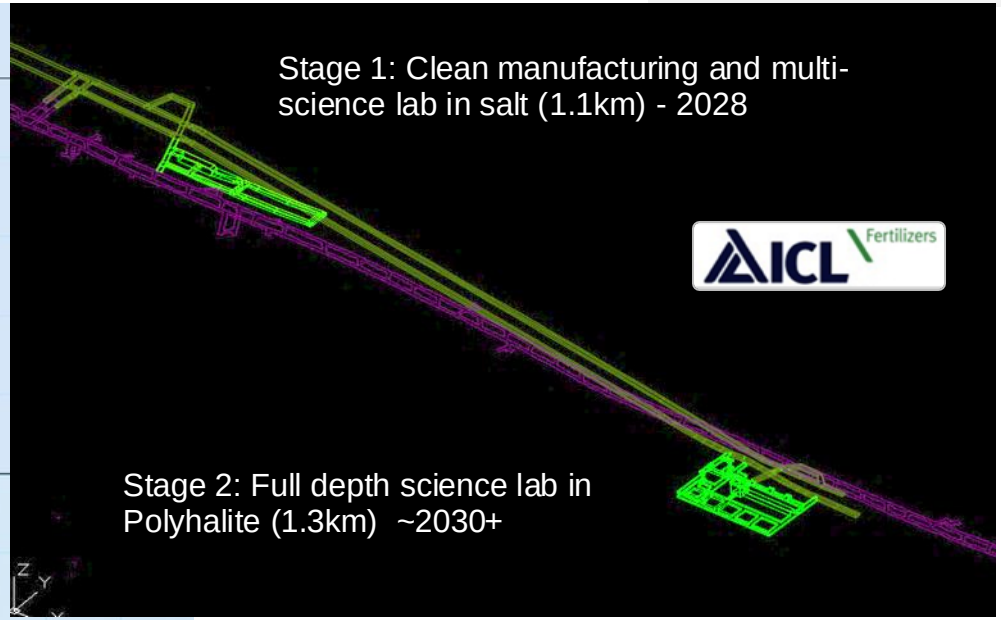


DRAFT

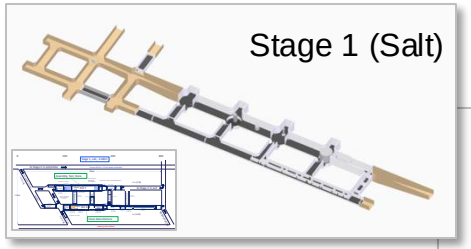
Boulby Development Project
Task 1: Site and design Development.

Science and Technology Facilities Council
Boulby Underground Laboratory

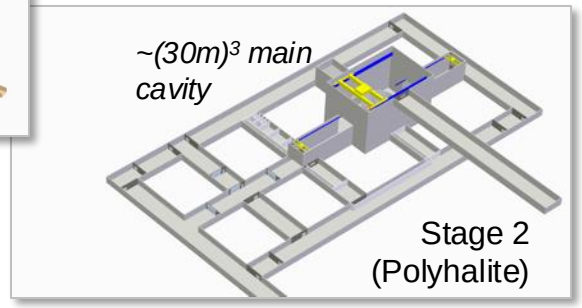




DRAFT: 2-stage Designs



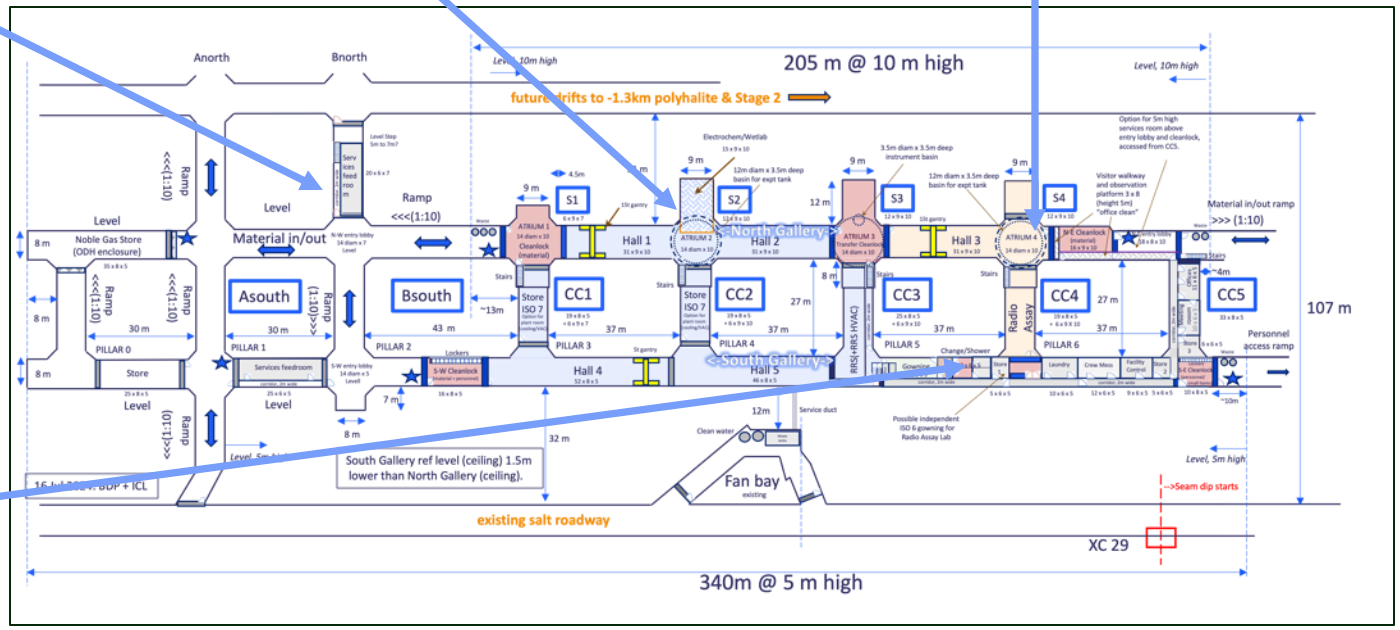
Total volume
(Stage 1 + stage 2)
~120,000m^3



Excavations for stage 1 of expansion currently expected to begin mid-2024.

Boulby Development Project:
Stage 1 Excavation

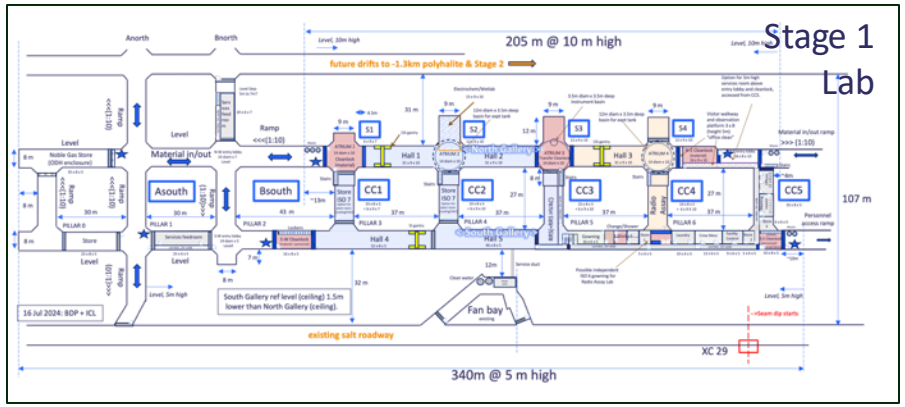
Progress
August 2024

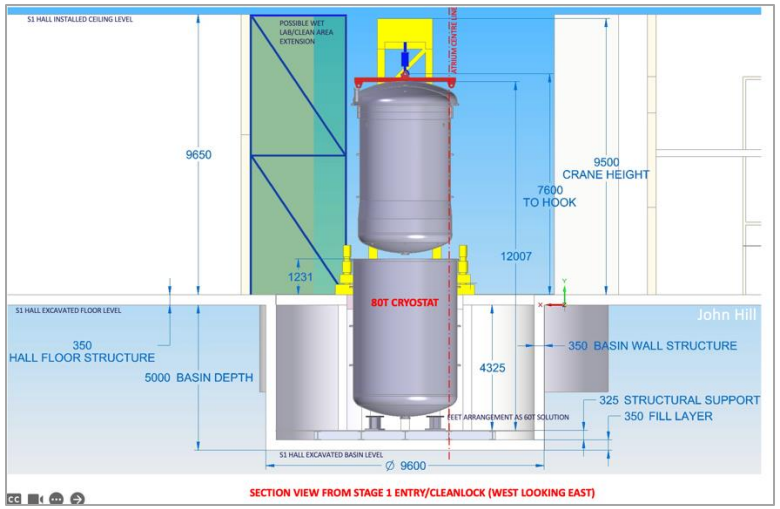


Stage 1 Functional Design

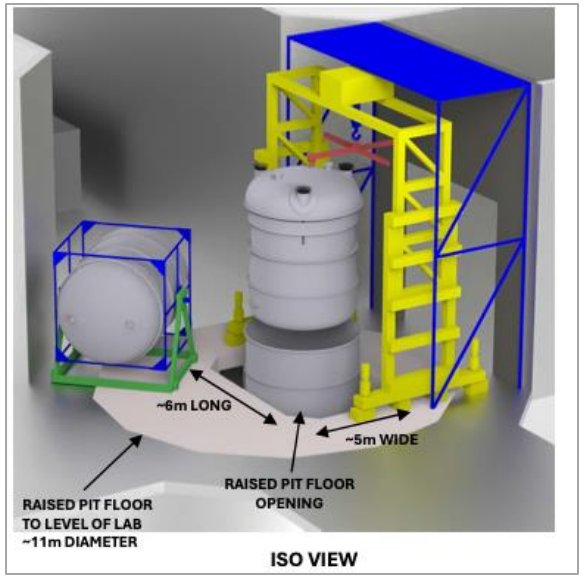
Excavation well underway. Completion mid 2025 (Outfitting ~2028)

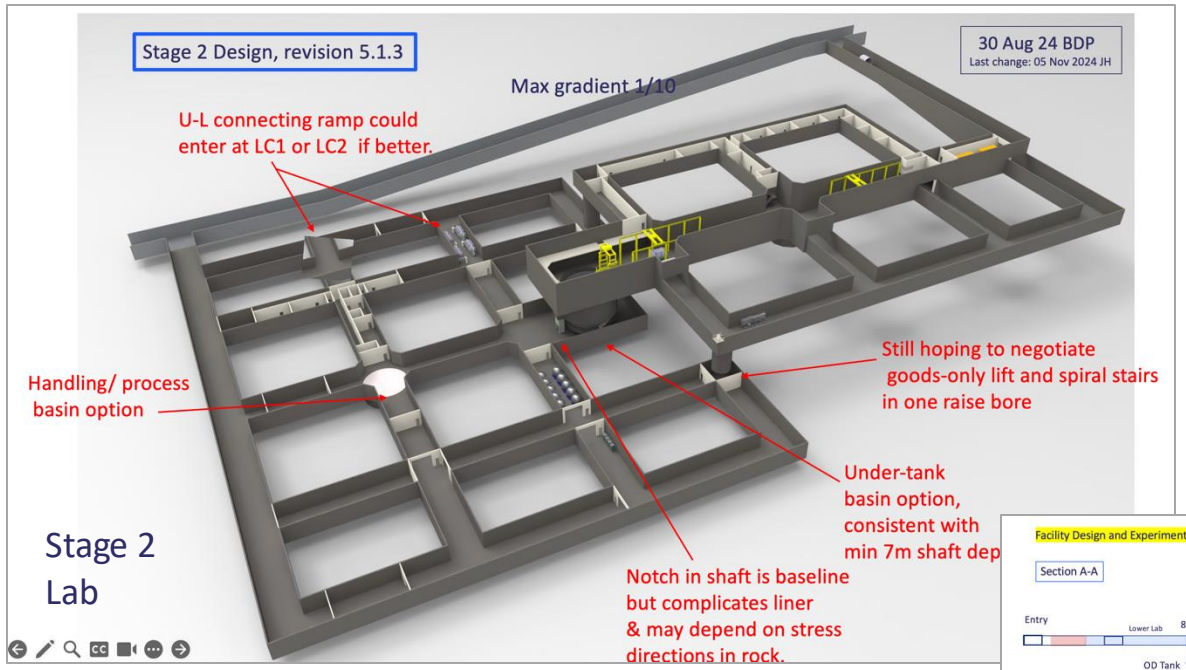
New Lab(s) Design



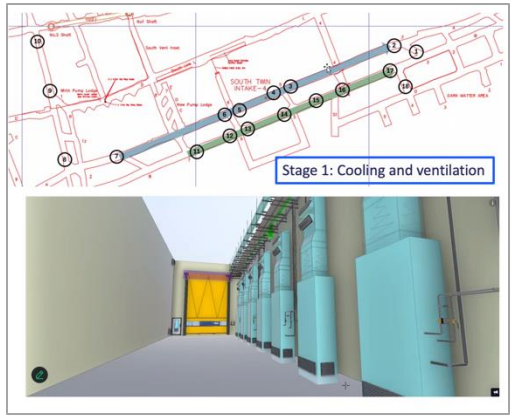


Stage 1 XLZD Pre-Construction



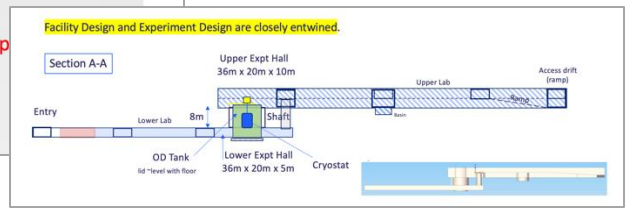


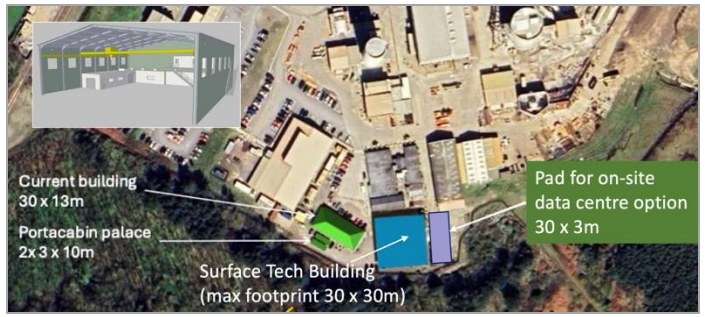
XLZD in Stage 2



Stage 1 Ventilation

Stage 1 Lining Options





Surface Building option

Latest news from Boulby Underground Laboratory:

Status & plans for the UK's Deep Underground Science Facility.

Summary…

Science and Technology Facilities Council
Boulby Underground Laboratory

Boulby Underground Lab Status:

- The UK's deep underground science facility
- Medium scale & depth. A strong history in Dark Matter search technology development
- A rich & varied science programme in pure & applied low background science, Earth & environmental science, astrobiology & planetary exploration, quantum sensors & computing.

Future plans:

- We are now looking to significantly expand & improve facilities at Boulby to accommodate future projects across all science themes, inc. a major rare event study (XLZD)
- Stage 1 (of a two-stage) facility expansion – now underway.
- **Come and visit us!**

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