

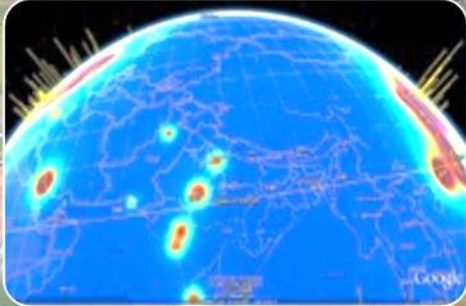
Deep Science at Boulby Underground Laboratory:

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

Sean Paling
STFC Boulby Underground Laboratory

  Sean Paling
STFC Boulby Underground Science Facility

Astroparticle physics & ultra low background studies

 The search for Dark Matter & beyond

Earth and environmental science, astrobiology and planetary exploration

  Underground lab @ Boulby

Latest news from Boulby Underground Laboratory:
Status and plans for the UK's deep underground science facility.

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



UKRI Science and
Technology
Facilities Council
Boulby Underground
Laboratory



12 miles North of Whitby, N. Yorks

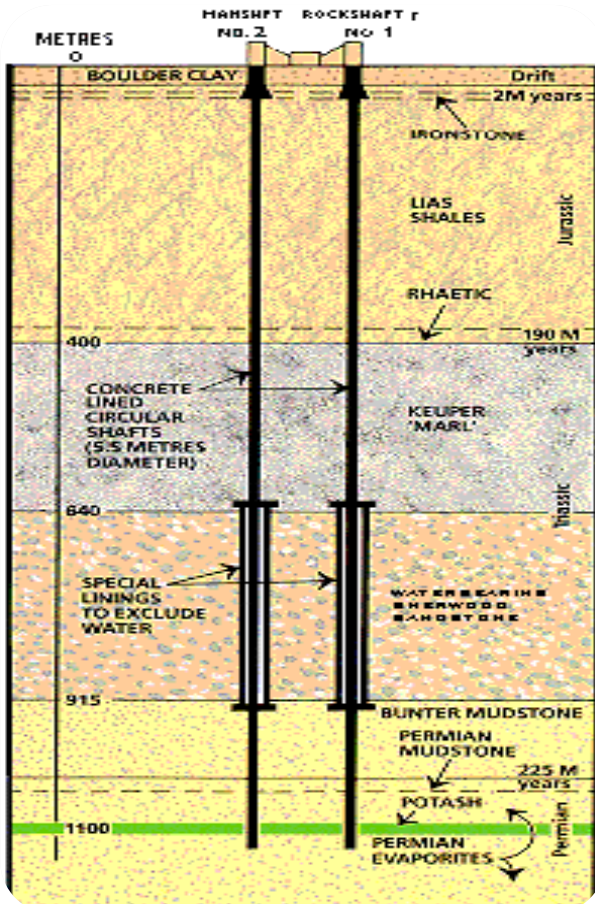


View from Staithes

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.



Polyhalite



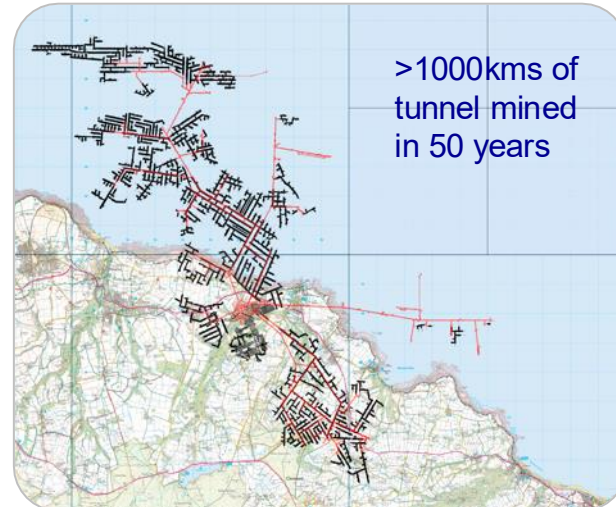
Potash



Rock-Salt



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



Boulby Geology



Typical Boulby Salt Roadway



Zechstein Sea



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)

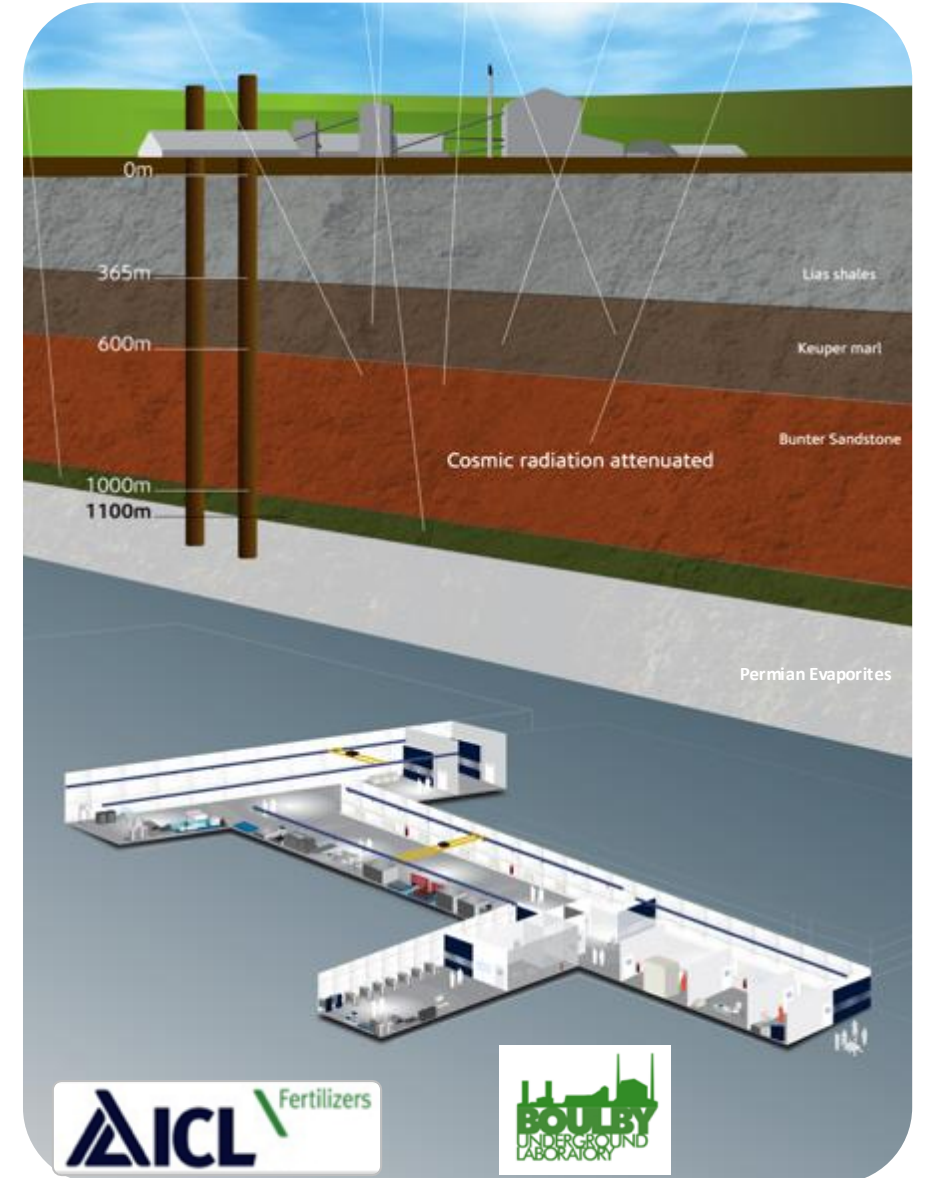


4000m³ class 10k and 1k clean lab space



Lab entrance

Factor ~10⁶ 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.

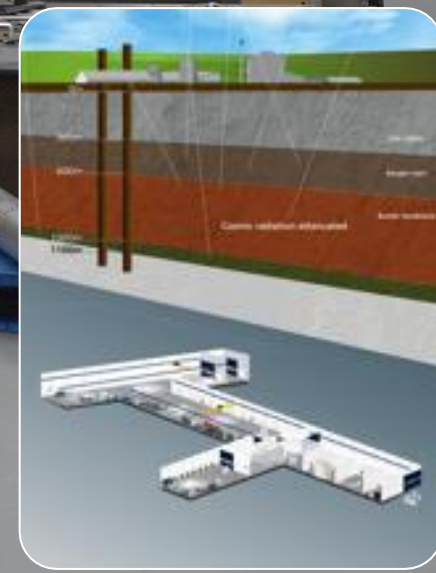


3000m³ Outside Experimentation Area



BUGS Material screening

Boulby Underground Lab Facilities 2026: >4000m³ 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. 3000m³ Outside Experimentation Area (OEA) with power & internet. Supported access to wider mine environs.



World deep underground laboratories...



SNOLAB (Canada)
Active Mine, 5890 mwe
Current vol: 30,000m³
SNO+, SuperCDMS, Deep3600,
PICO, Next Gen 0vBB (to come?)

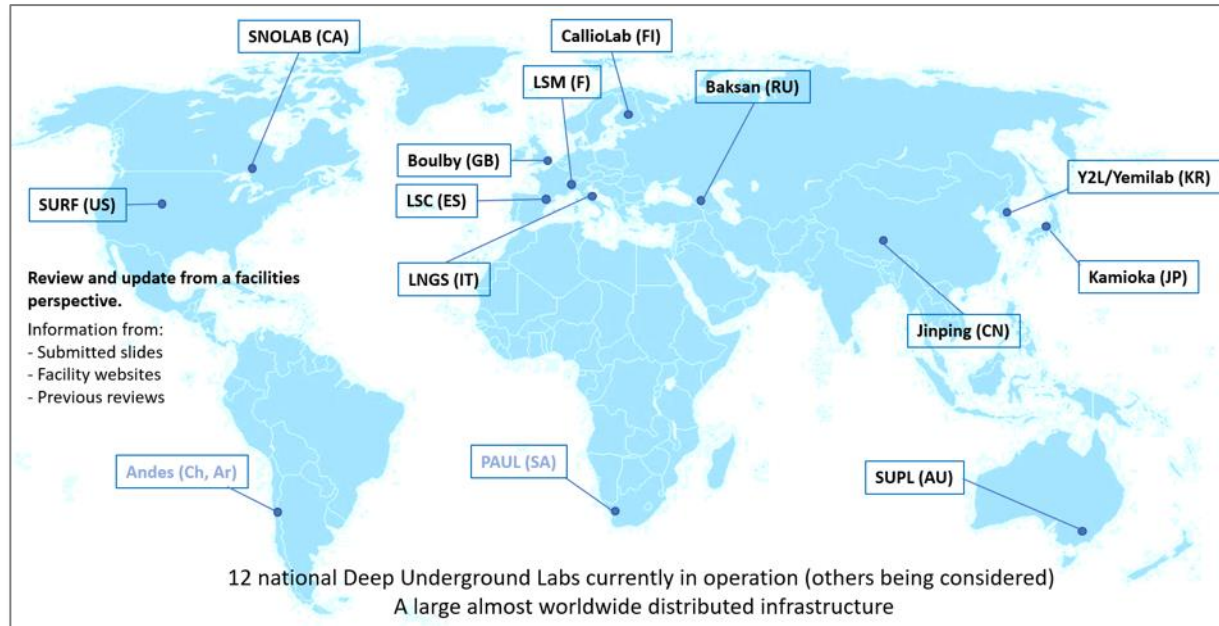


SURF Laboratory (USA)
Disused Mine, 4200 mwe
Current vol: 7,100m³
LZ, MJD, DUNE (to come)



Boulby Underground Laboratory (UK)
Working Mine, 2850 mwe
Current vol: 7,200m³
ZEPLIN+ (past), BUGS, News-G,
RECON, BUTTON & more...

World Underground Labs



CJPL Jinping (China)
Hydro power plant, >6000 mwe
Current vol: 330,000m³
Panda-X, CDEX, JUNA,
GeoDEX, JNE and more to come



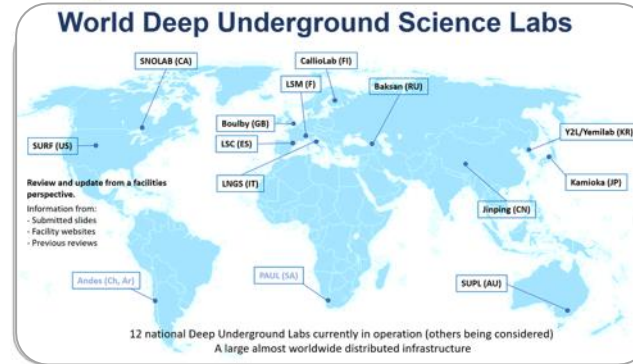
Gran Sasso National Laboratory
LNGS (Italy)
Under mountain, 3800 mwe
Current vol: 180,000m³
Borexino, Xenon, DarkSide +

Boulby Underground Laboratory (UK)

Boulby Facility Details...

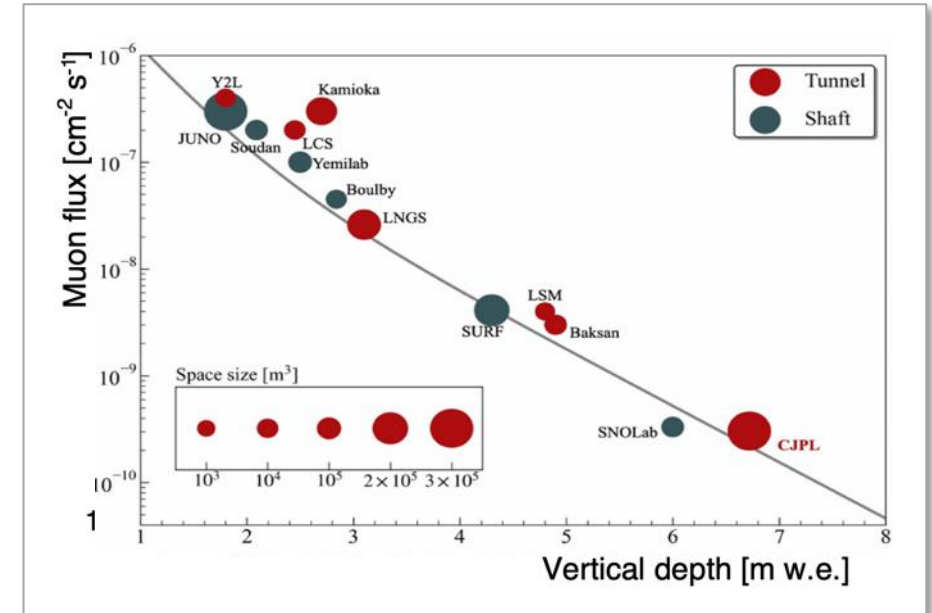


- The UK's deep underground science facility. One of 5 in Europe, <15 in the world.
- Supports work of >10 collaborative projects (astrophysics to climate, geology, environment etc), >60 institutions, >250 scientists & students.
- Facility funded and operated by the Science & Technology Facilities Council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



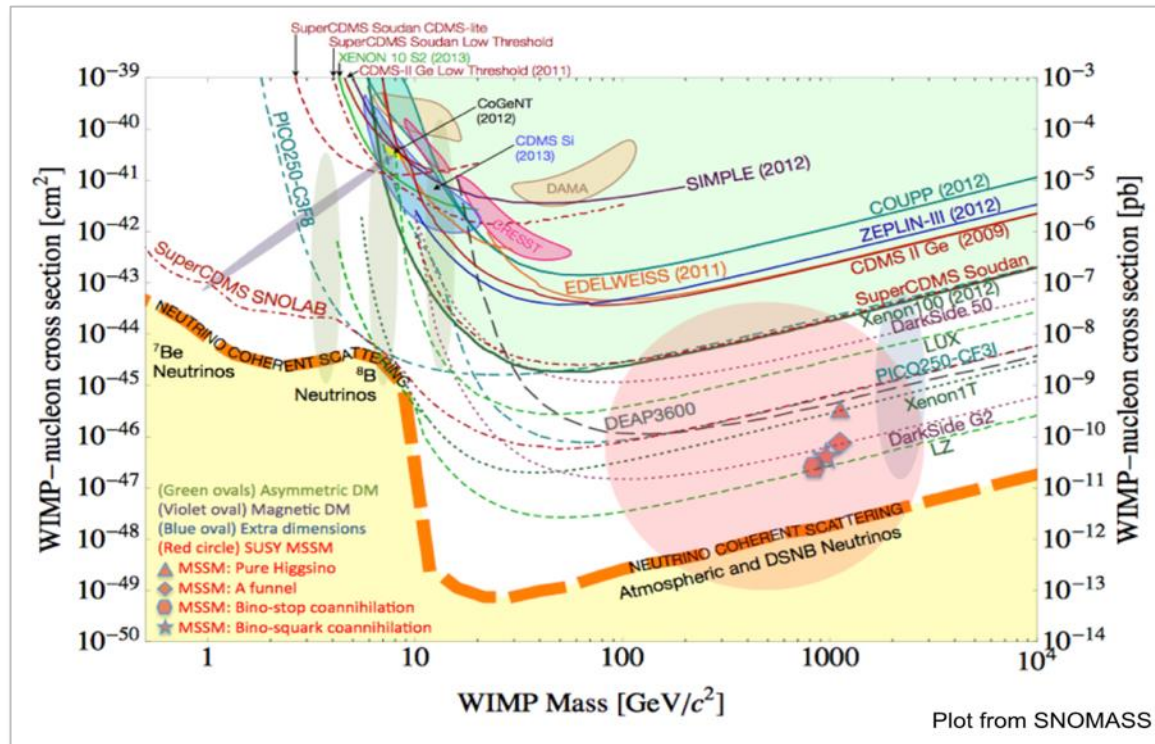
Science Programme Status and Plans.

- Low background Particle and Nuclear Physics
- Earth & Environmental Science
- Astrobiology & Planetary Exploration Studies
- Quantum Sensors and Computing (new)
- Outreach & Education

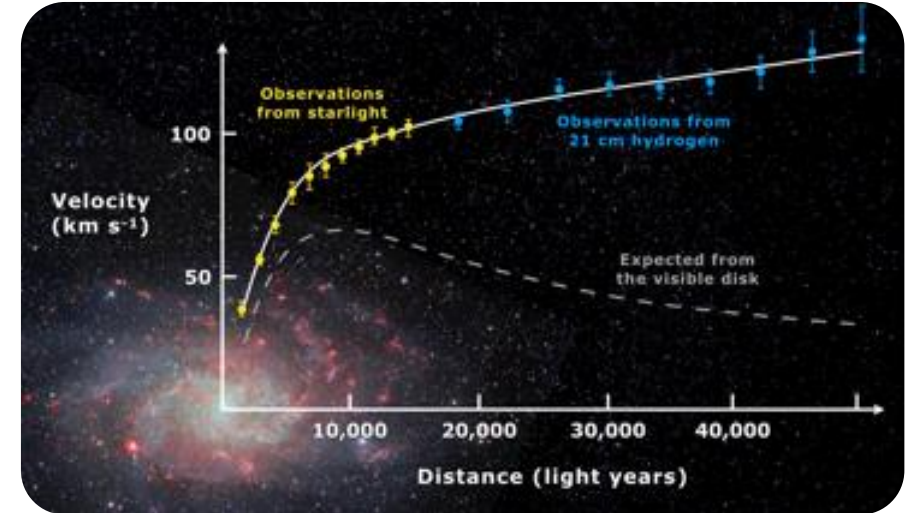
Boulby Dark Matter Studies...

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

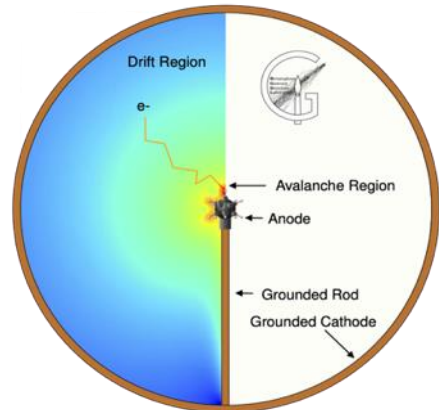
DarkSPHERE

K. Nikolopoulos, P. Knights, L. Millins,
G. Rogers, D. Spathara, P. Walters
University of Birmingham
and international NEWS-G
Collaboration (France, Canada,
Greece, USA)



NEWS-G Activities at Boulby

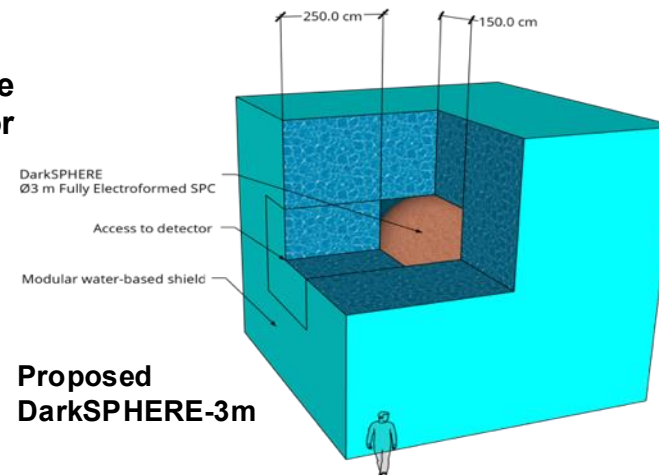
- Instrumentation developments
 - Multi-anode sensor
 - Gas filtration
 - Rate effect studies
- Neutron spectroscopy (with N₂ gas)
 - Neutron background surveys
 - Industrial applications
- High-purity copper electroformation
- **Towards scaled-up, electroformed, detector at Boulby, 3m diam. 5 bar**
He:CH₄H₁₀ **DarkSPHERE**



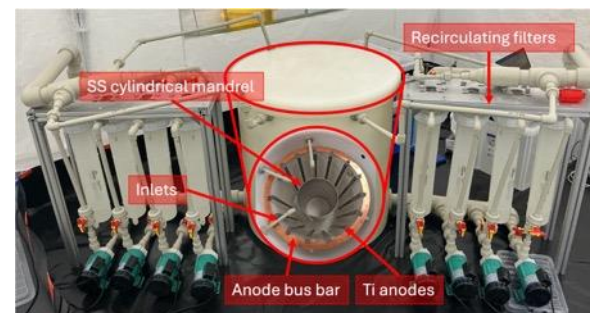
SPC concept: Variable target
Low E_{th}, Low mass sensitivity



11-anode
sensor



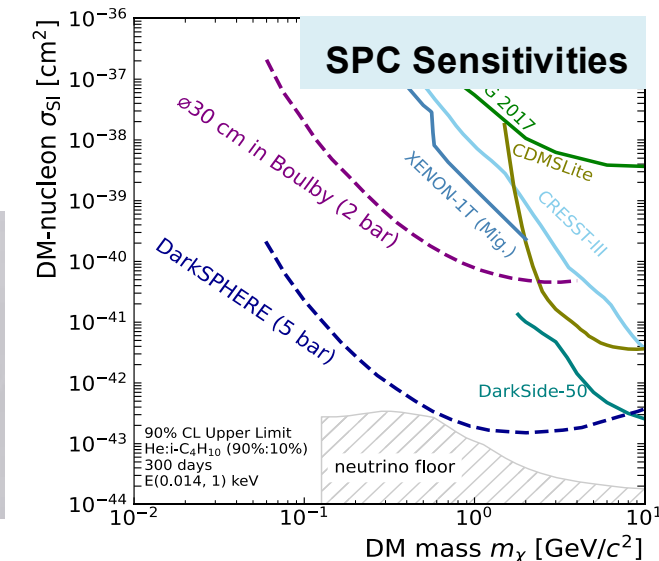
AI-S30 R&D Detector



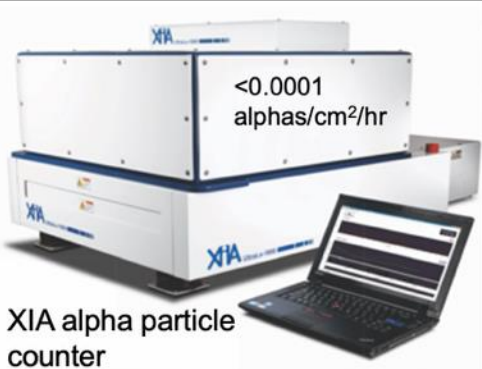
Copper electroforming at Boulby



Selected as top in STFC's Medium
Scale Dark Matter Fund bid (2025)



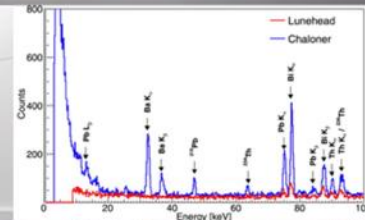
Ultra Low Background Material Screening @ Boulby (**BUGS**)



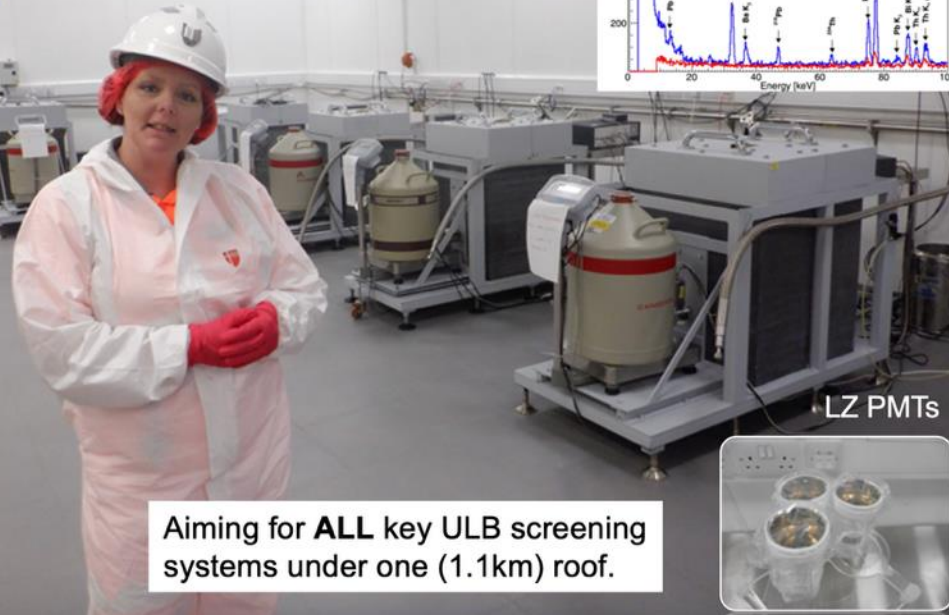
XIA alpha particle counter



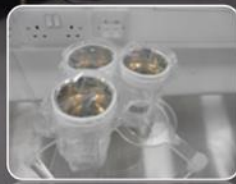
8 ULB Ge detector systems, 2 XIA alpha counters, 2 Rn emanation systems, ICPMS



BUGS (Boulby UnderGround Screening). 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

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

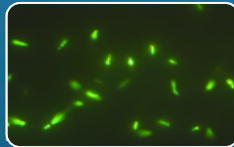
MINAR:

Astrobiology and planetary exploration technology development

MINAR Programme 2018 - present



NASA-JPL
Signatures of life studies



Remote³
Public Engagement



Birmingham University
BIOSPHERE Human Habitability Studies



Edinburgh University
MUFFHINS water activity
monitoring payload



Lulea University
KORE rover 3D area
mapping



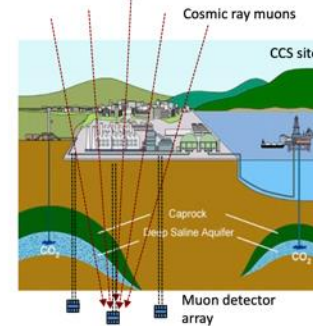
2.5



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)



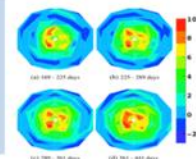
Muon-tides detector development



Bore hole detector installation

Status: Project 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)

CCS site simulation



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

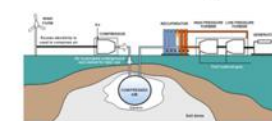
- Bore-hole detector development & testing
- Muon-Tides technology demonstrator
- Simulations of technique performance in CCS

RESOURCE:
Compressed
gas energy
storage R&D

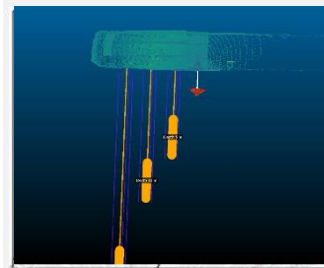
Renewable Energy StOrage in UndeRground CavErns (RESOURCE)

RESOURCE Collaboration:
British Geological Survey
Boulby Underground Lab
University of Cardiff

Low Carbon Technologies

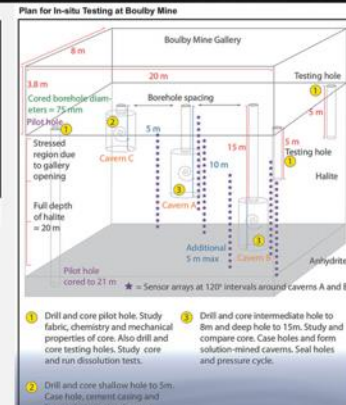


- Engineering solutions have been devised to store energy whilst production is high and feed it into the grid when production is low (e.g. CAES, hydrogen storage)
- Helps to regulate the production of renewable energy



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

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

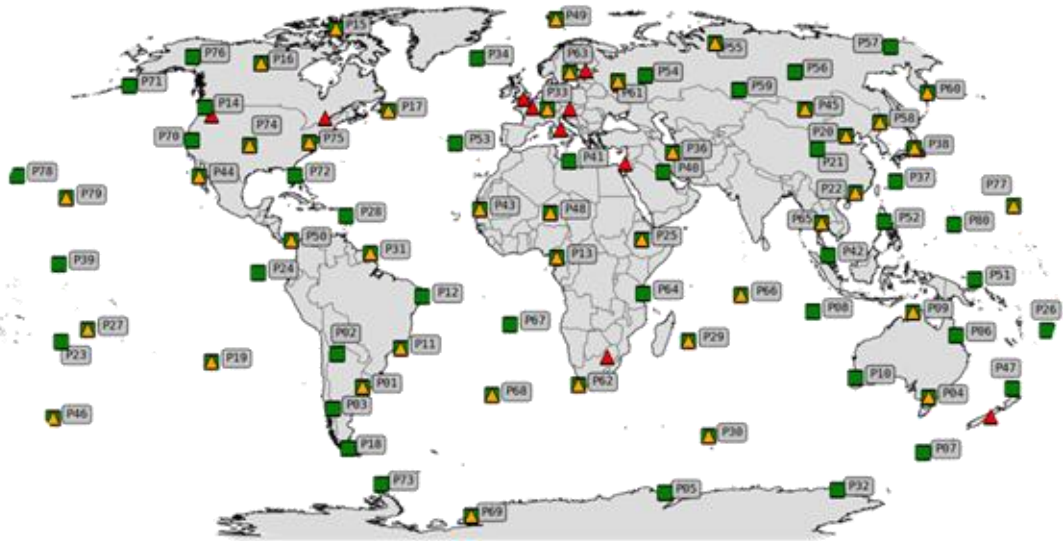
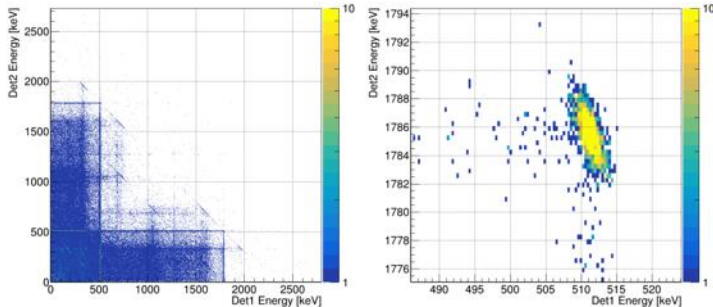


Project **RECON** – CTBT Verification.

Enhancing the capability to monitor for signs of nuclear testing

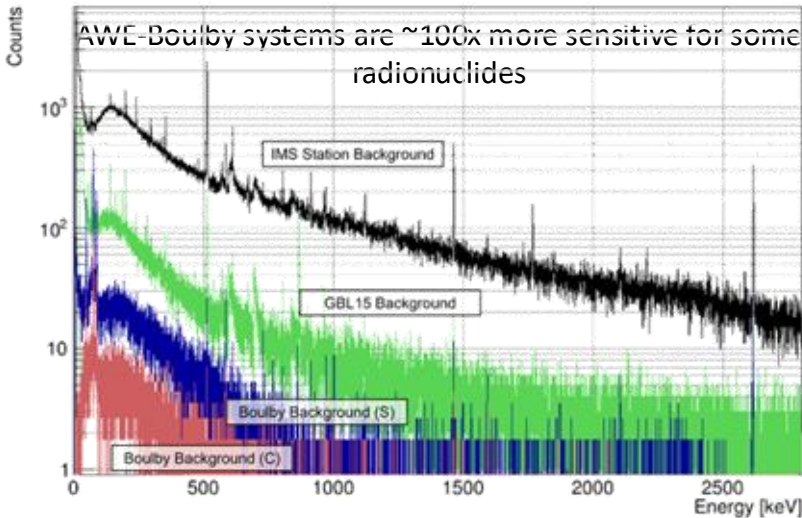


AWE and STFC Boulby have recently established a collaboration framework



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

US-UK technology development and proof of concept for nuclear non-proliferation

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.



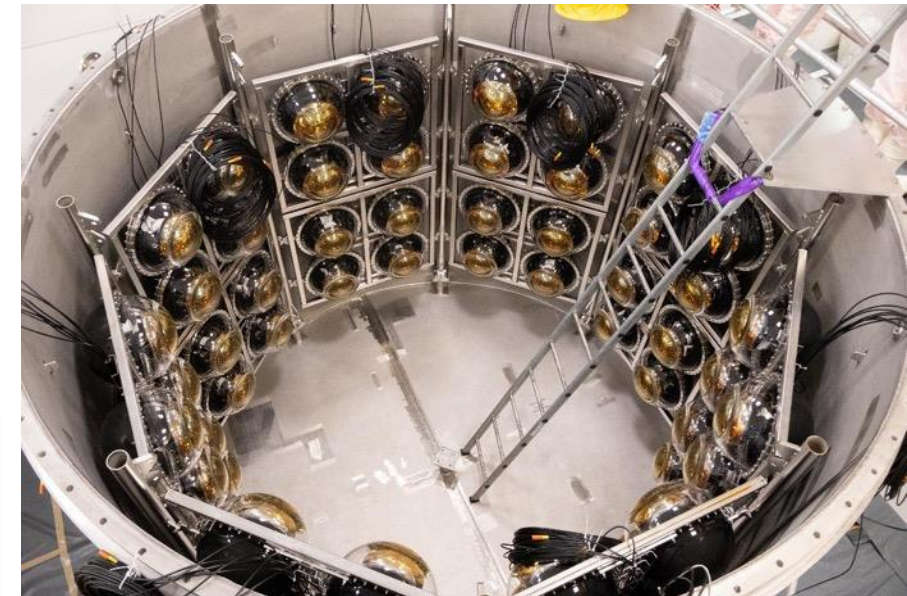
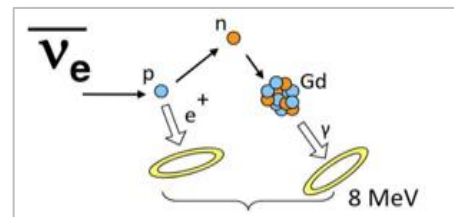
Jan 2025.
BUTTON-30 now assembled and preparing for liquid fill

30T Liquid Filled (Gd+H₂O, Water Based Liquid Scintillator (WbLS) and Gd-WbLS) prototype detector.



Water Based Liquid Scintillator (WbLS)

Anti-neutrino discrimination with Gd-H₂O



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

(To be updated)

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

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

Boulby Future Earth and Environmental Science

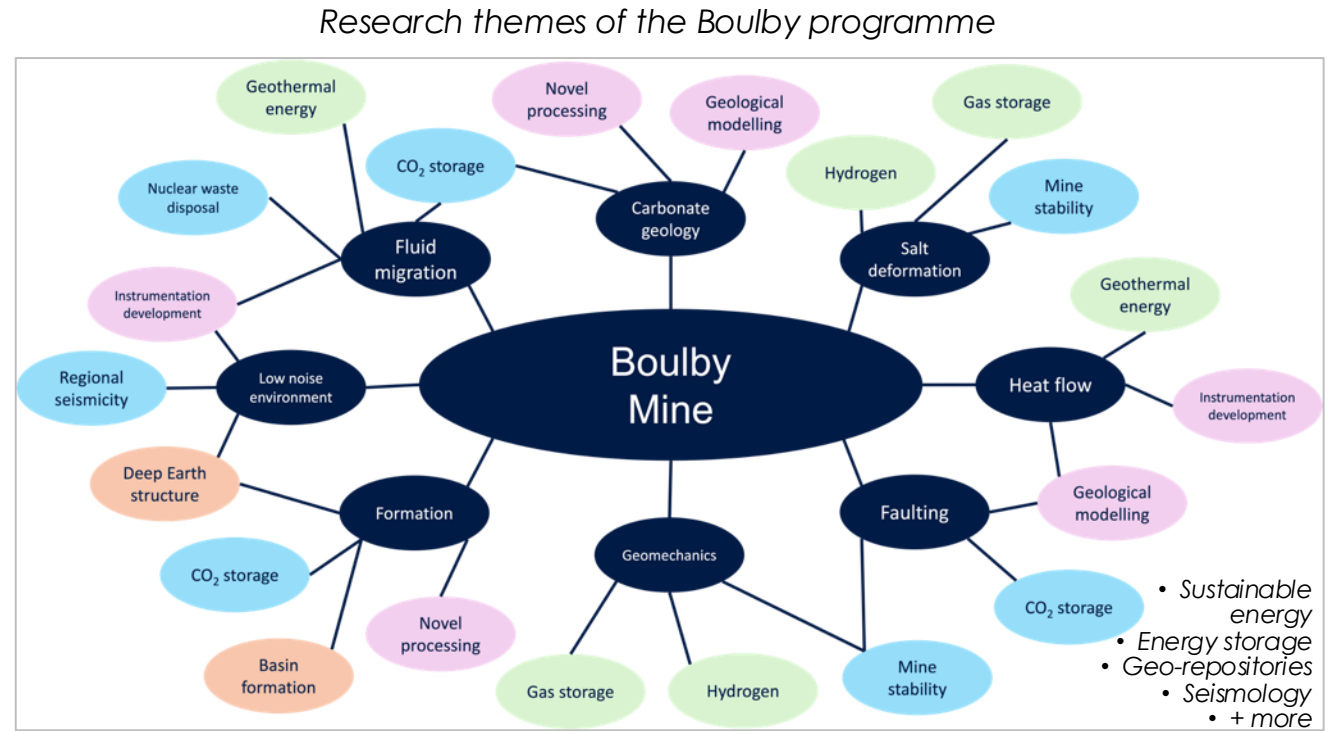
Developing program of Earth science research at Boulby by a consortium of UK universities and industry.

Earth science at Boulby workshop August 2024

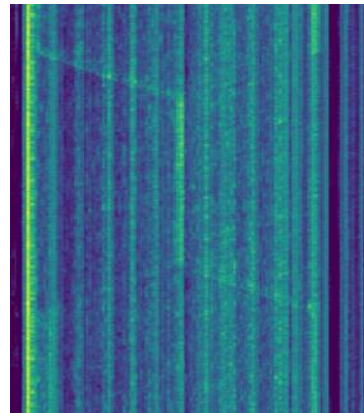
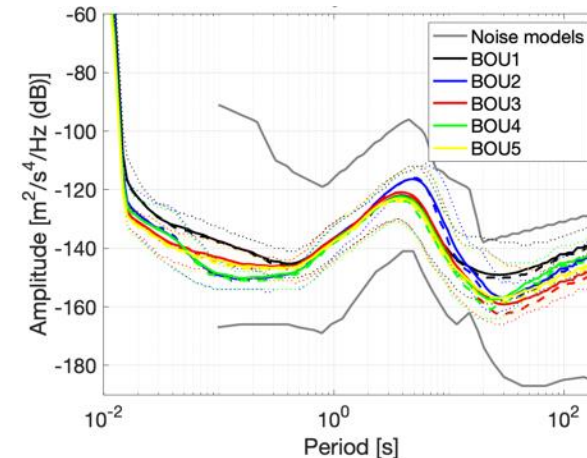


Workshop of 17 universities and 4 companies has led to a proposal of an integrated program of Earth science research, currently being considered by NERC.

NERC
scoping
study
proposal

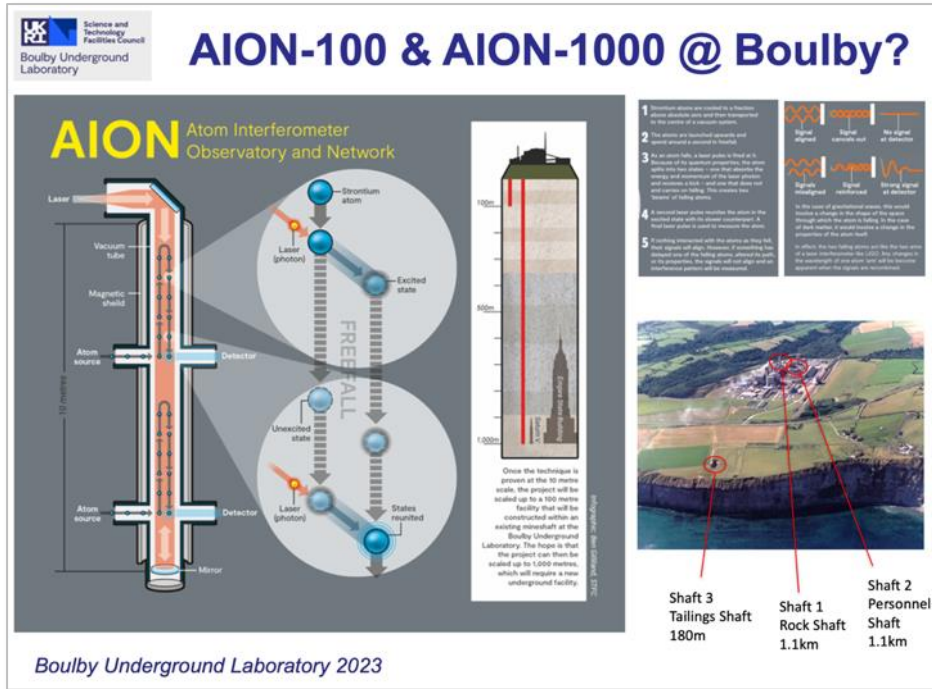


Developing a community coordinated programme of Earth Science @ Boulby



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

Quantum Sensors and Computing @ Boulby...

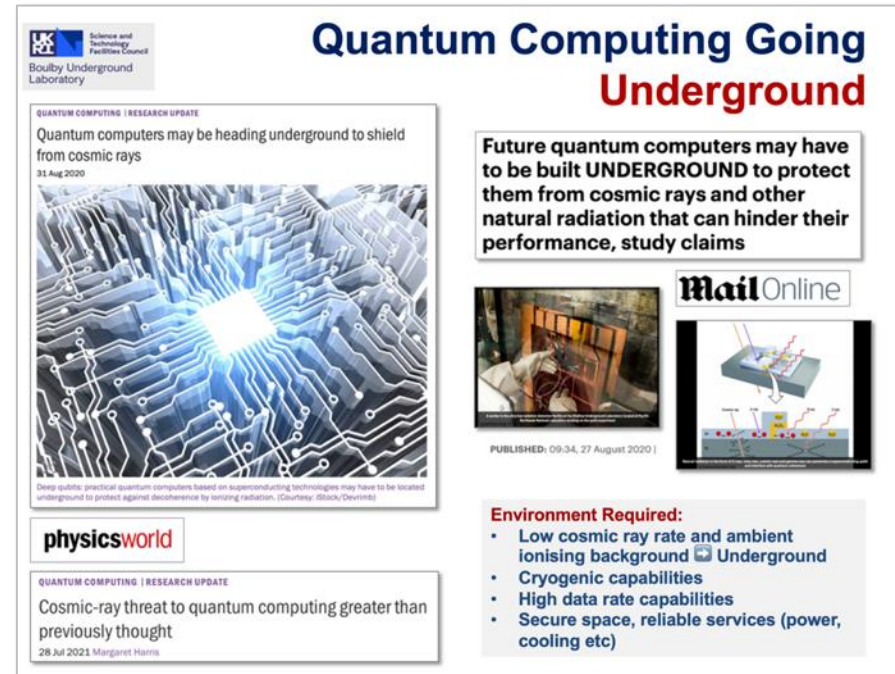


AION-20, 100 & 1000: Atomic interferometry for GW and light DM studies

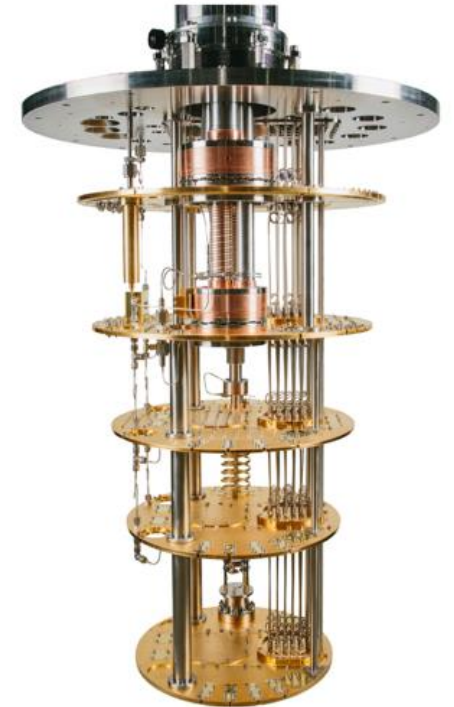
A growing Quantum @ Boulby community:

- Planning future quantum sensors and computing R&D and operation
- Helping to specify technical infrastructure needs for a future hosting facility
- Community meetings held Sept 24, October 25
- **Durham laser cold atom project (QuASAR) being installed @ Boulby (3/26).**

Quantum Computing in Ultralow background environment?



Coming to Boulby v.soon!
Oxford Instruments
Proteox MX Dilution Fridge



In collaboration with **National Quantum Computing Centre (NQCC)**.
Will be available for use by wider community.

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.



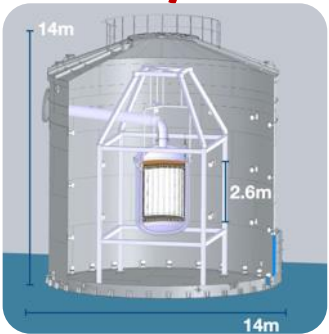
Xenon-nT
LNGS, Italy

XLZD
2021 merging
of LZ, Xenon
and DARWIN
teams



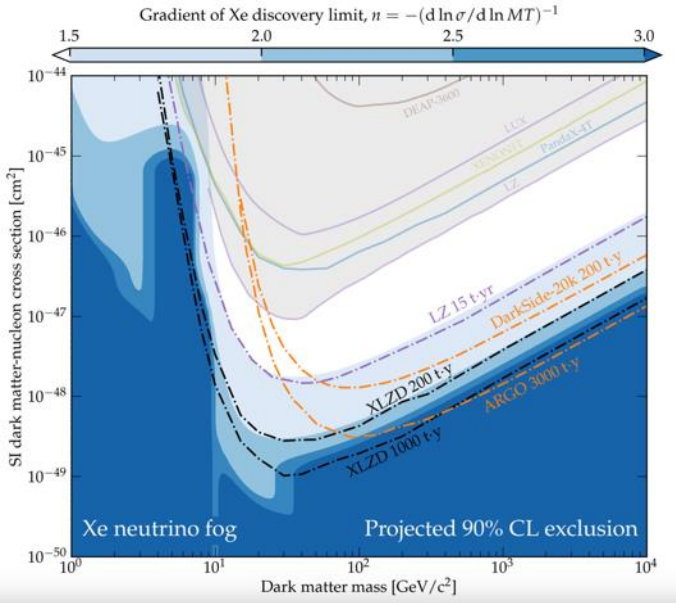
DARWIN
(Proposed)

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

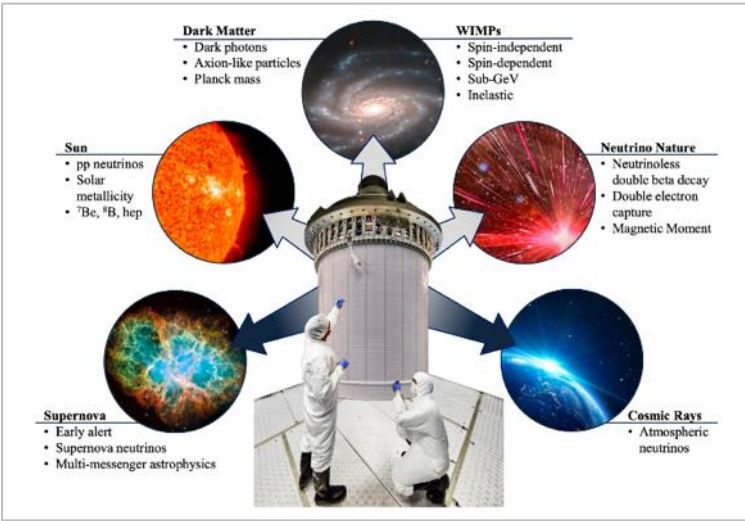


**Could XLZD be
constructed
and operated at
Boulby 2030+?**

Projected
sensitivity
(Akerib P5
town hall
mtg 2023)

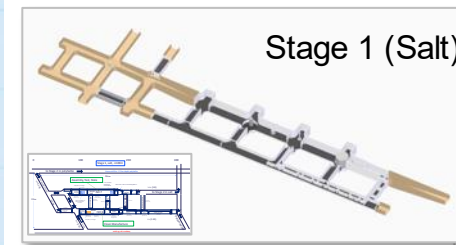
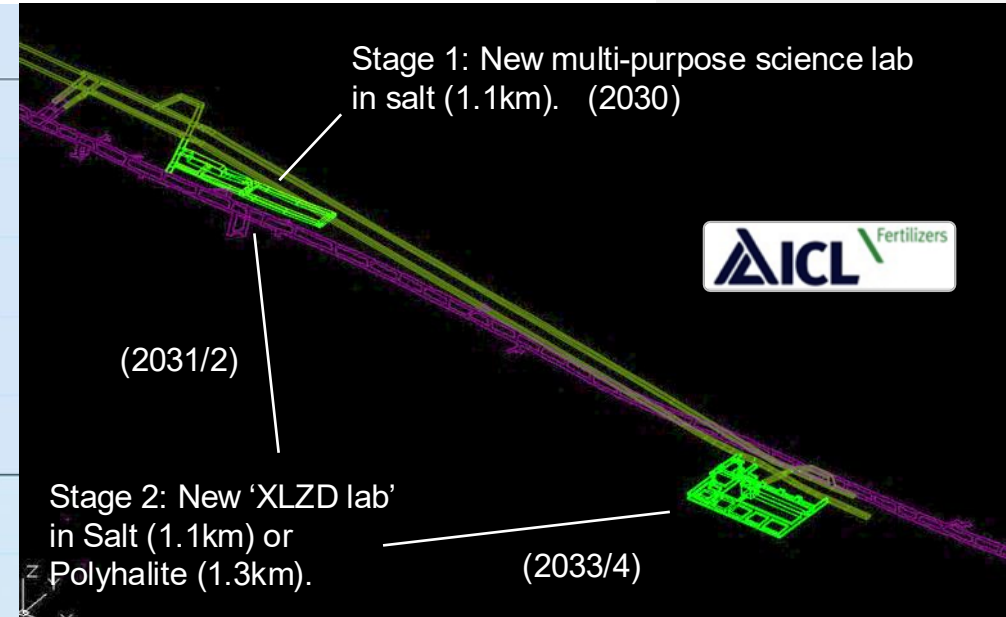
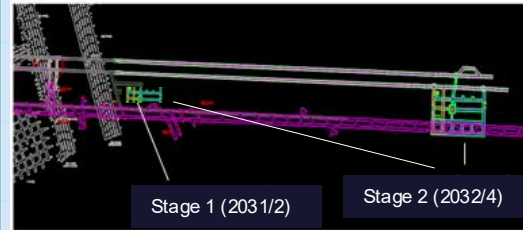
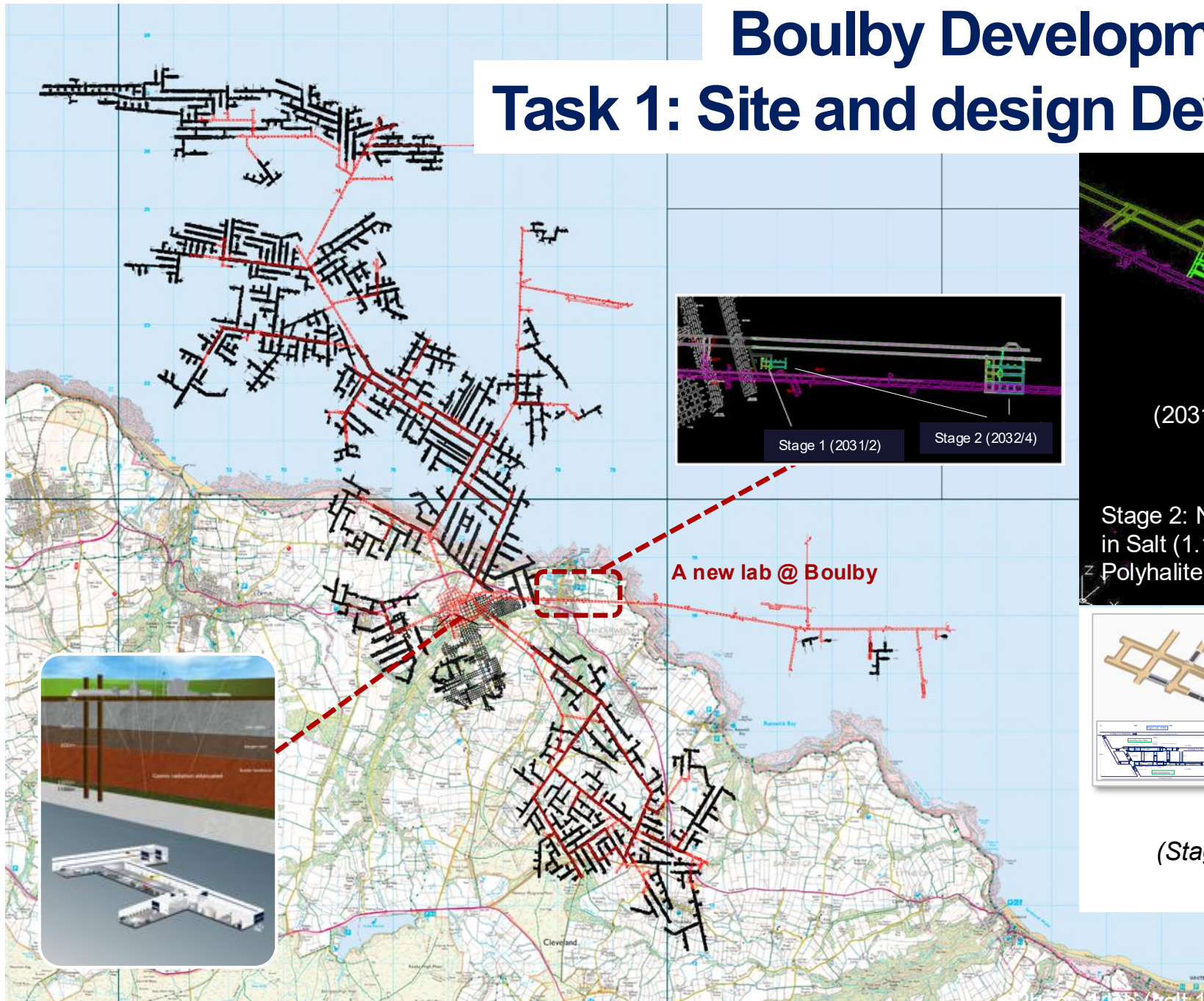


Next generation **world's best** Dark
Matter (+) detector. **Expected 2030+**

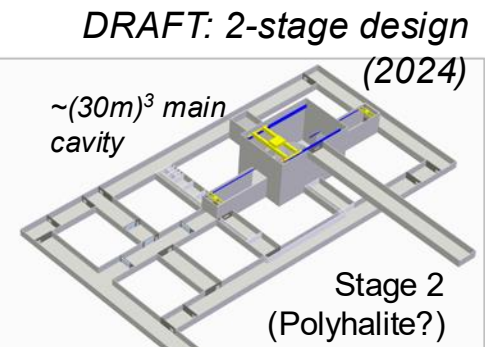


Boulby Development Project

Task 1: Site and design Development.



Total volume
(Stage 1 + stage 2)
~120,000m³



Excavations for stage 1 of expansion by ICL-UK began in mid-2024.

Stage 1: A new world-class multi-disciplinary deep underground science facility.

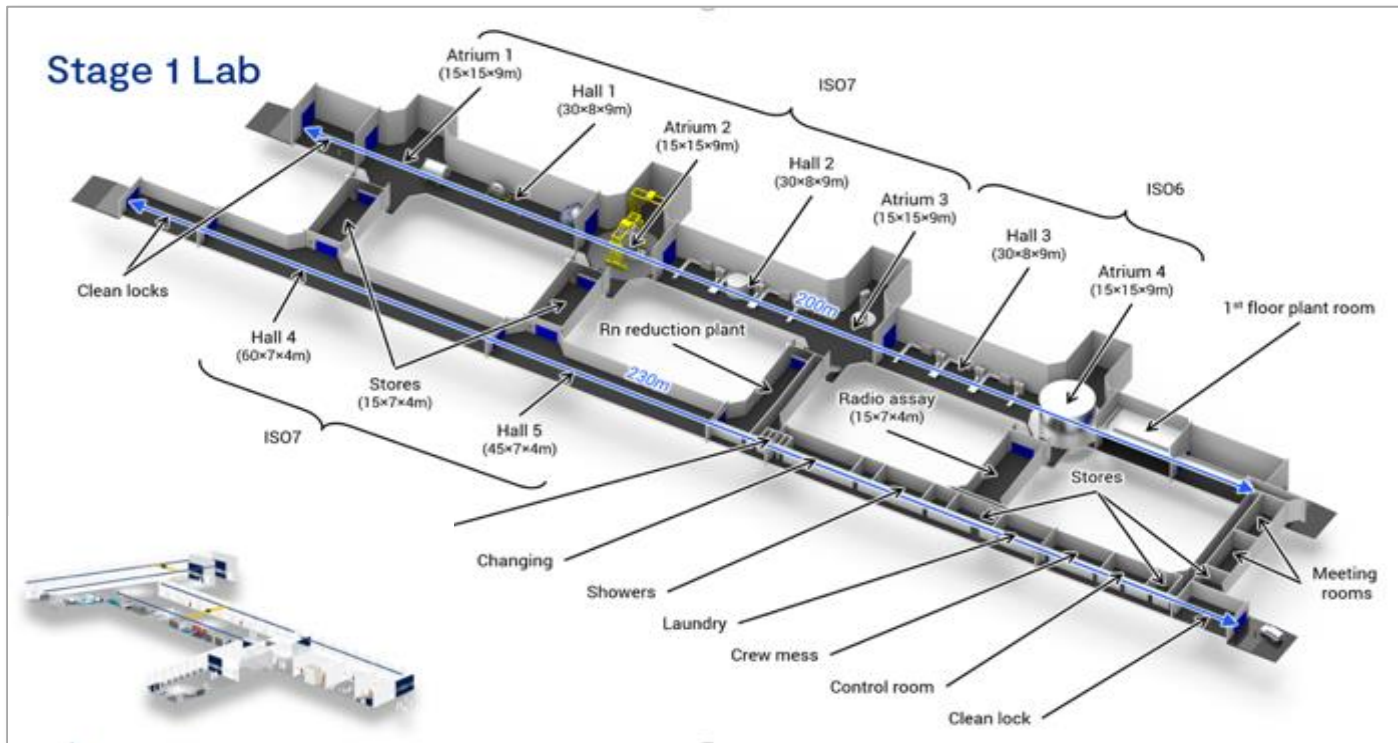


Image Credit: A Ball, J Elmer, C Kinahan, J Hill et al.

EXCAVATION NOW COMPLETE (Oct 2025).
Planning for laboratory outfitting now underway



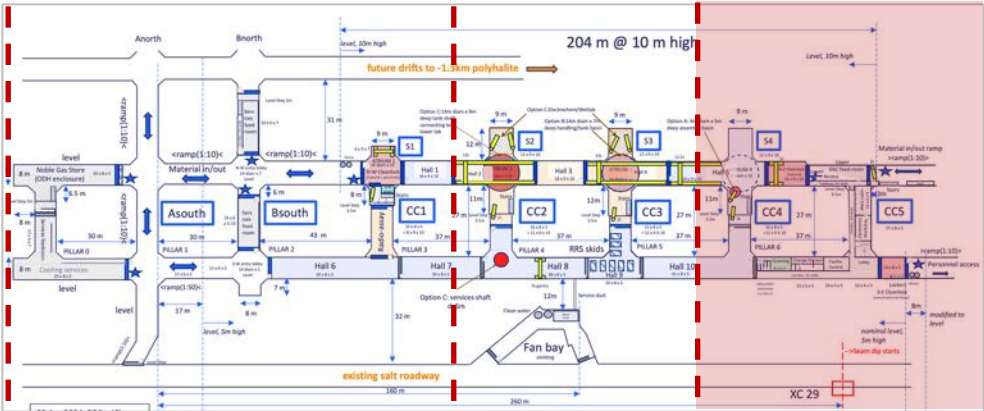
Stage 1 Outfitting

A new, world-class multidisciplinary science facility, complementing and succeeding the current Boulby laboratory

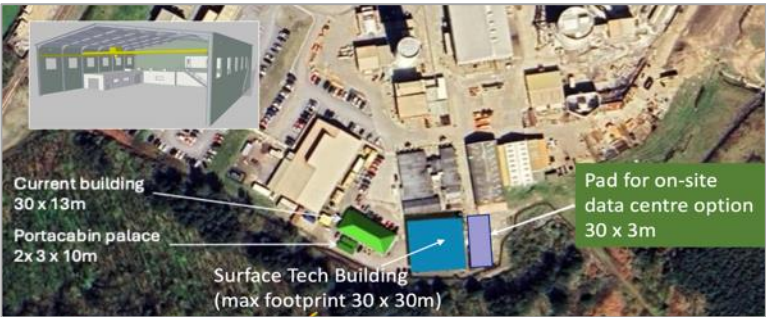


Stage 1 Lining Options

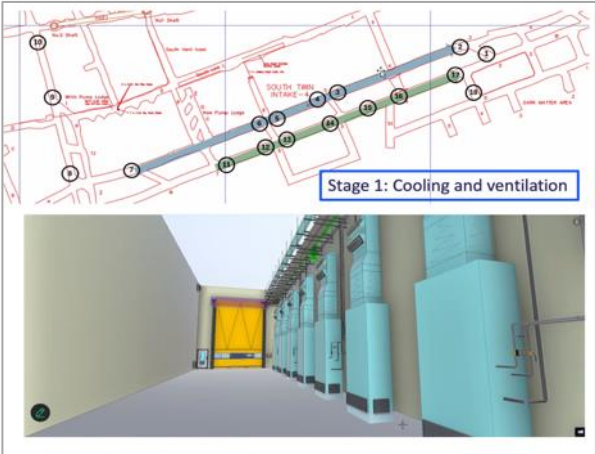
Possibility for single shot or staged outfitting



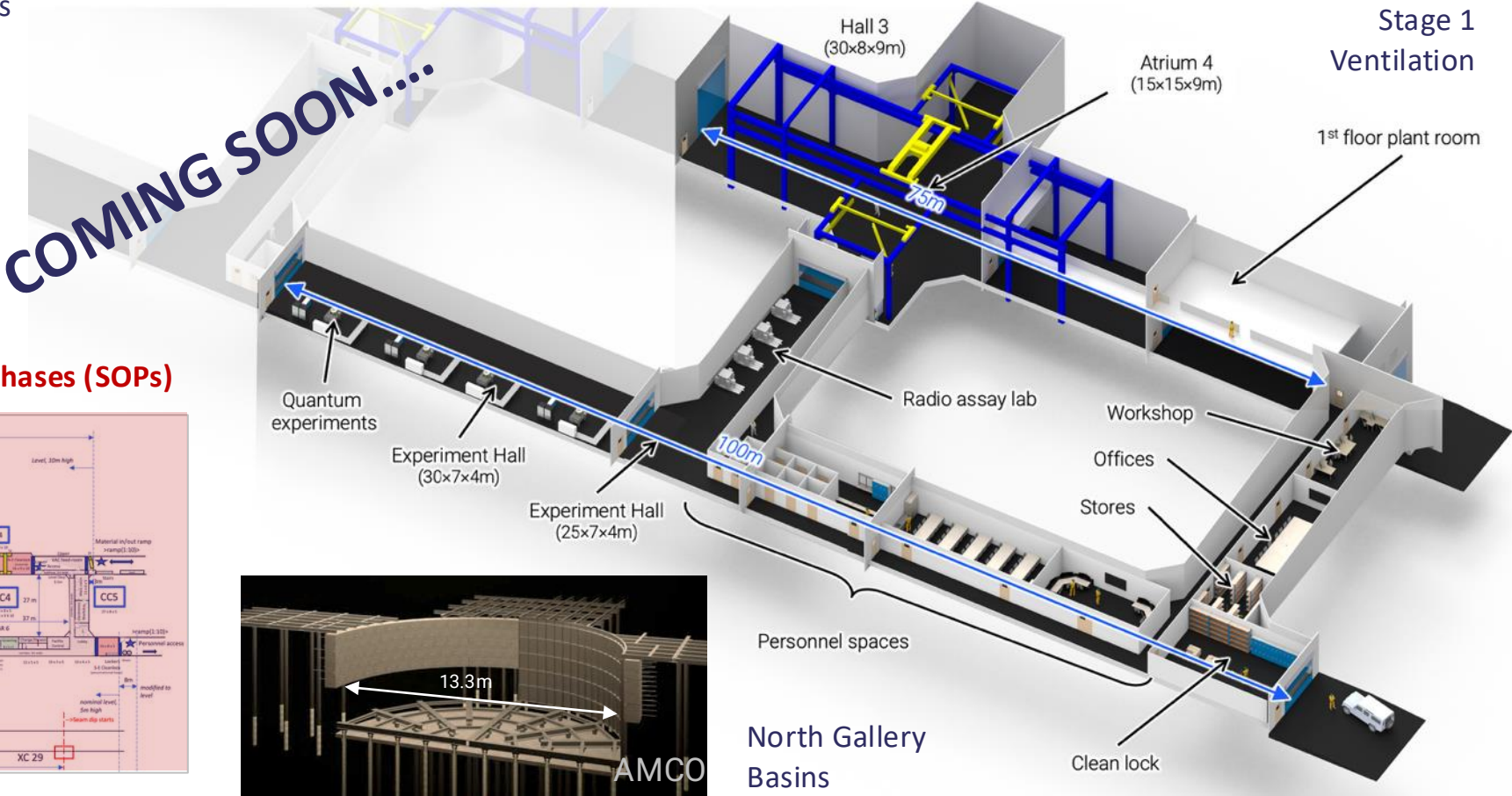
SOP3 SOP2 SOP1



Surface Building Development



Stage 1 Ventilation



Deep Science at Boulby Underground Laboratory: Status & plans for the UK's Deep Underground Science Facility.

Boulby Underground Lab – in a nutshell:

- The UK's deep underground science facility. A prominent one - of just a dozen in the world.
- A strong history in Dark Matter technology development. Now a rich, varied and impactful science programme in [pure & applied low background particle and nuclear physics](#), Earth & environmental science, astrobiology & planetary exploration, [quantum sensors & computing](#).

Boulby Underground Lab – impact and importance:

- Provides [national capability](#) for: a wide range of research fields of importance to national science priorities, industry and defence.
- Boulby capabilities and activities strongly align to:
 - All of the [UKRI's missions](#): Increasing Knowledge, Improving Lives, Driving Growth.
 - Three of the five [Government's Priority Missions](#): Kick-start economic growth, Make Britain a clean energy superpower, Break down barriers to opportunity.
 - Five of the eight [Government UK Modern Industrial strategy \(IS8\) themes](#): Advanced manufacturing, Clean Growth and Energy, Defence and National Security, Digital & Technologies, Life sciences.
- [Boulby is 'STFC North East'](#). Strongly valued for scientific, economic and cultural impact.

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STFC Prioritisation / Transformation:

- Latest news is - Boulby operations funding to be cut by 40%
- What this really means is
 - The basic operational funds to operate Boulby to support multi-disciplinary science is to be cut by 40%
 - More specifically – asked to seek EXTERNAL funds to support that multi-disciplinary science capability (in line with other STFC multi-disciplinary science facilities).
- Whilst challenging – there is a LOT we can / will do at Boulby to get this external funding:
 - Funds from other Research Councils
 - Funds from existing and new projects
 - Funds from new commercial (and defence) involvement
 - Funds from other buckets 2 & 3.
- Still to hear about our submissions to the STFC prioritisation process regarding Boulby capability to support PPAN science.

Support and use your national deep underground lab. We are still here. Boulby's enabling of UK/international underground science will continue. A BIG future (with XLZD and more) is still very possible and needs support.