

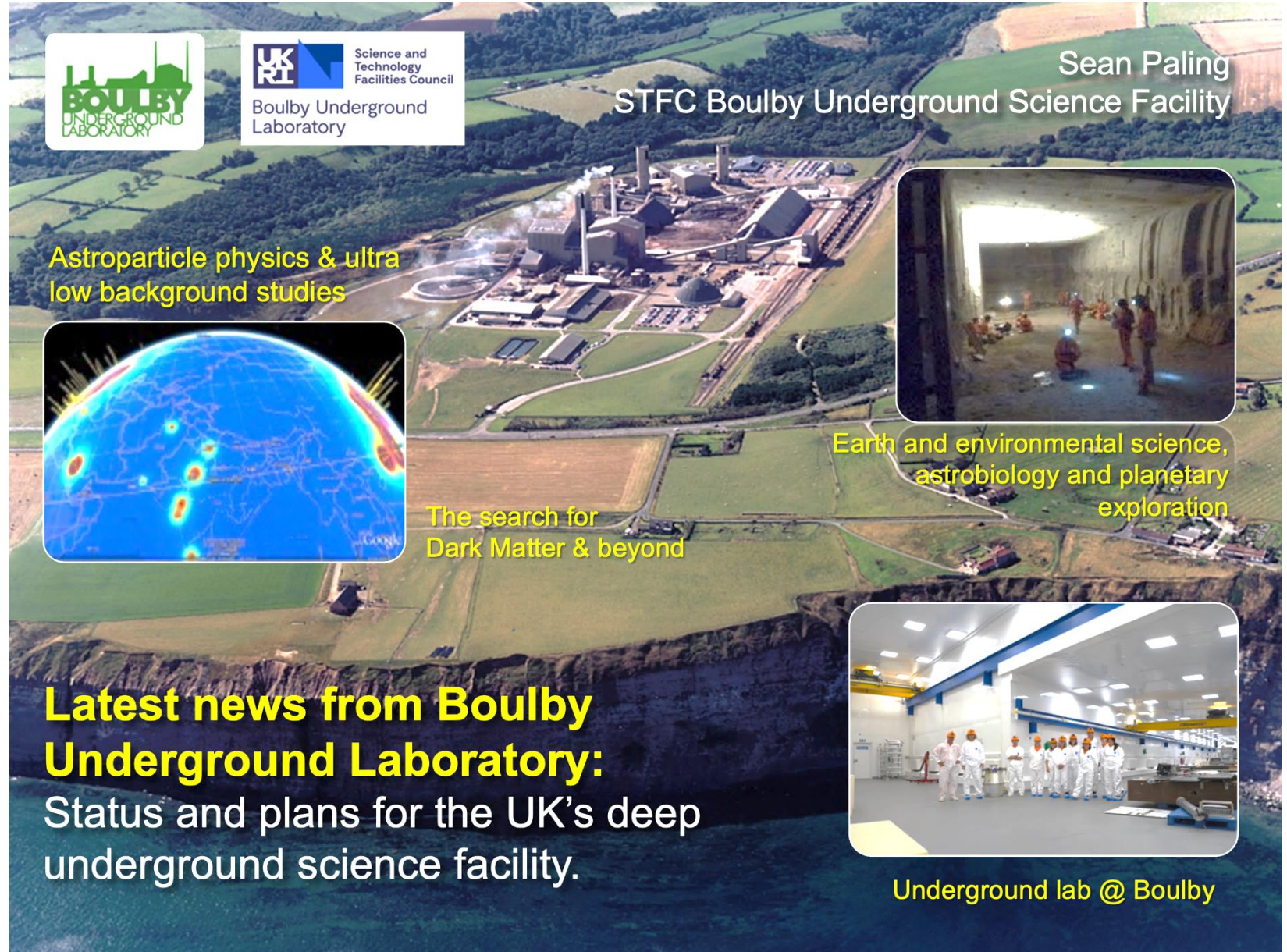
Latest news from Boulby Underground Laboratory:

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

Sean Paling
STFC Boulby Underground Laboratory



Boulby Underground Laboratory



STFC Boulby Underground Science Facility

Sean Paling

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

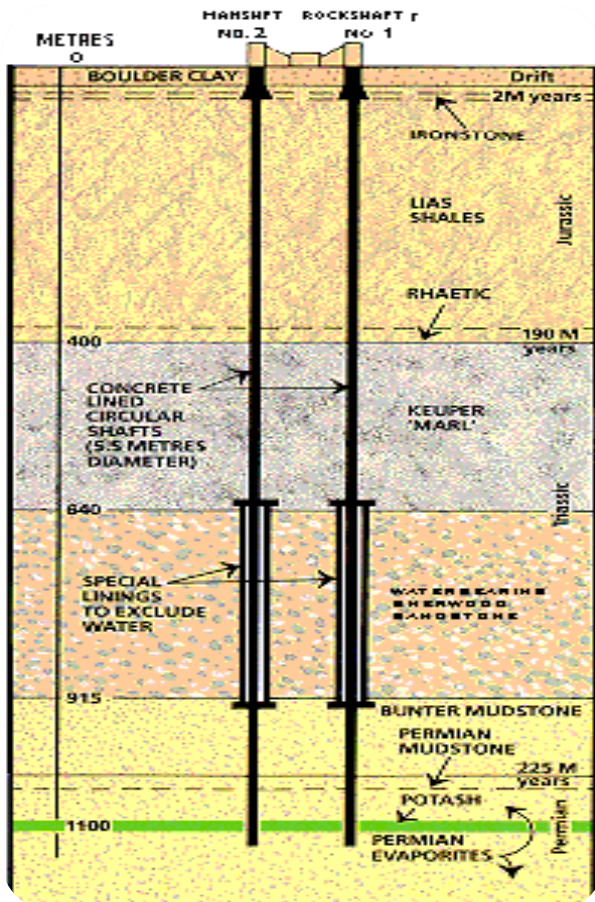


View from Staithes

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



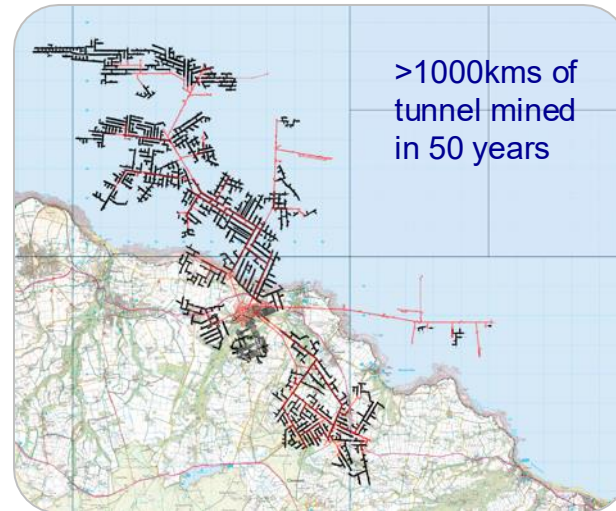
Potash



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)

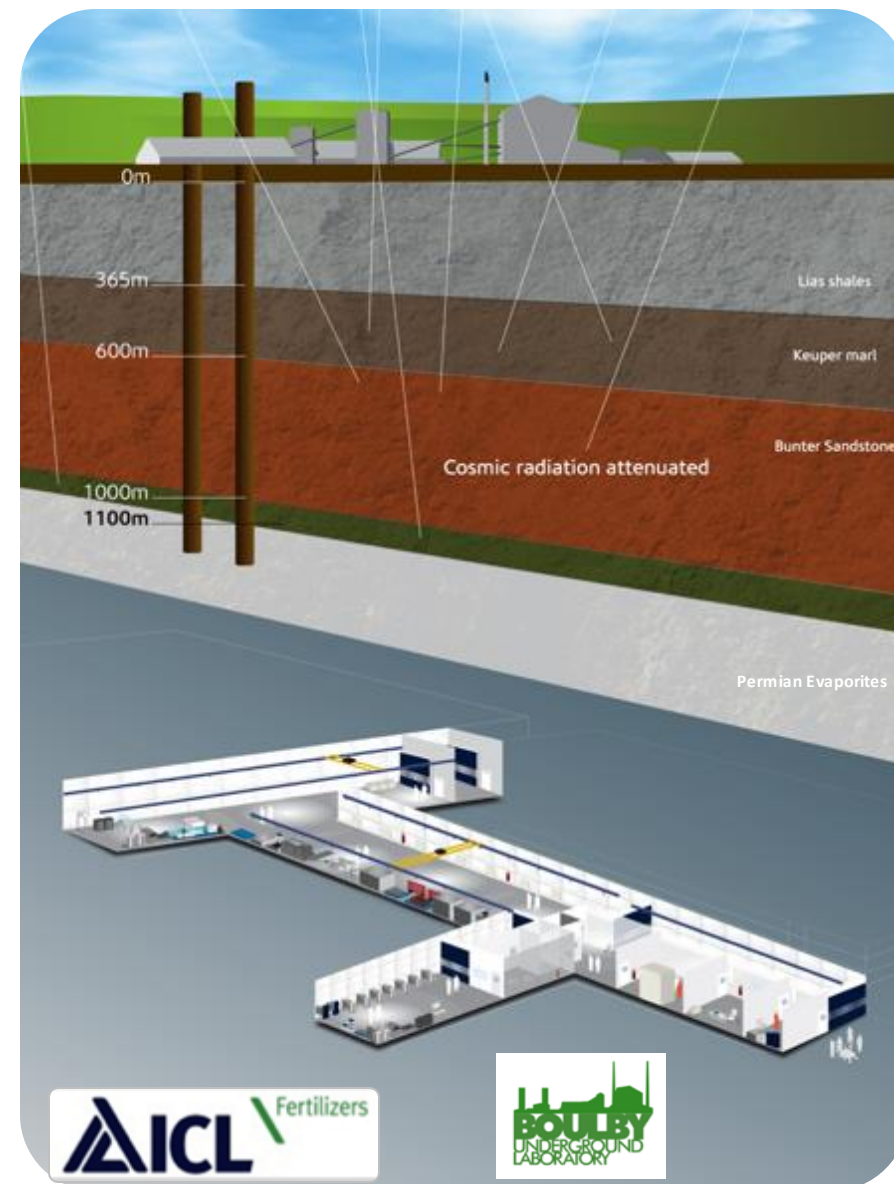


4000m³ class 10k and 1k clean lab space



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.

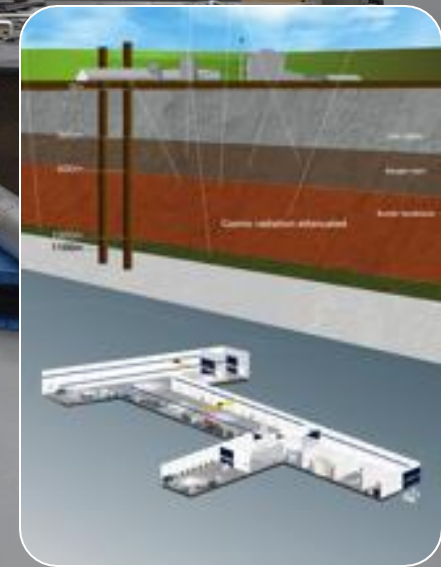


3000m³ Outside Experimentation Area



BUGS Material screening

Boulby Underground Lab Facilities 2023: >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...



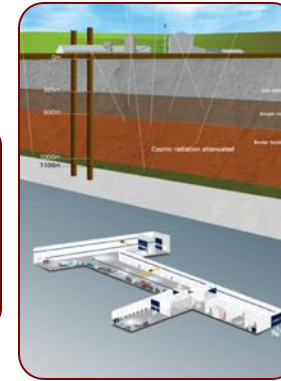
SNOLAB (Canada)

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



SURF Laboratory (USA)

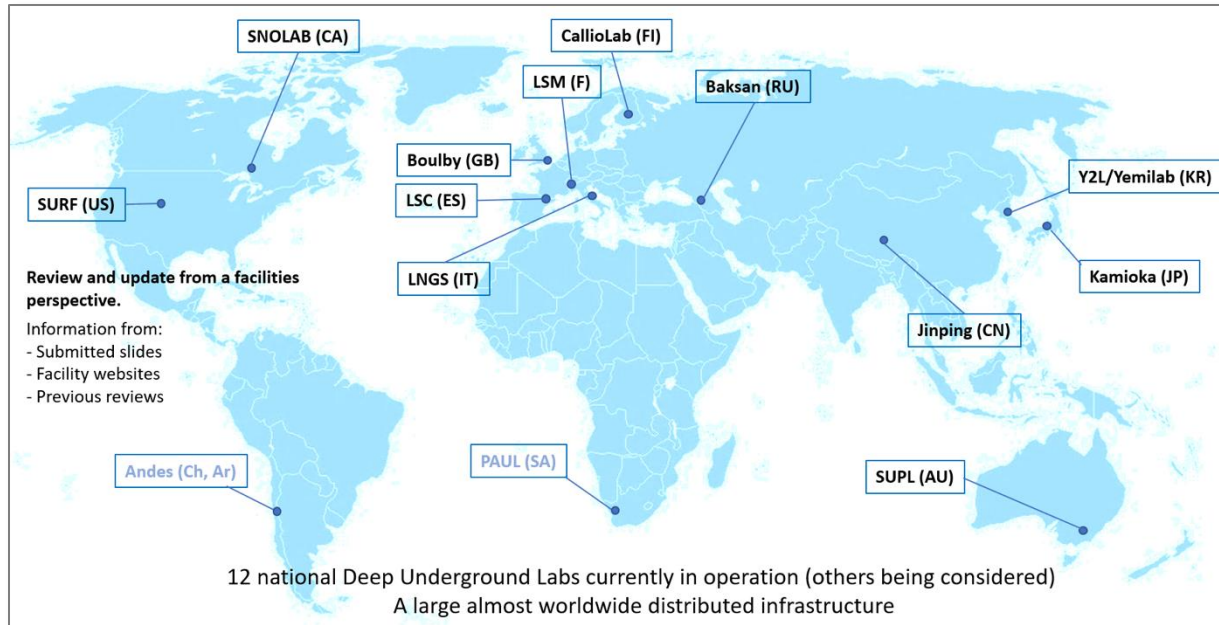
Disused Mine, 4200 mwe
Current vol: 7,100m³
LZ, MJD, DUNE (to come)



Boulby Underground Laboratory (UK)

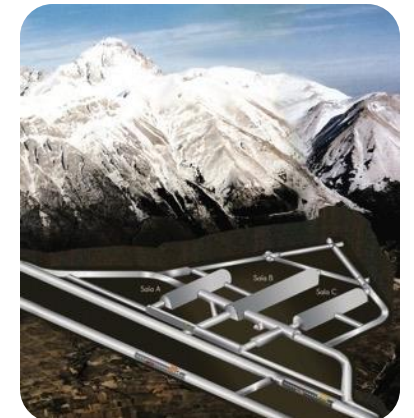
Working Mine, 2850 mwe
Current vol: 7,200m³
ZEPLIN+ (past), BUGS, News-G,
RECON, BUTTON & more...

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 +

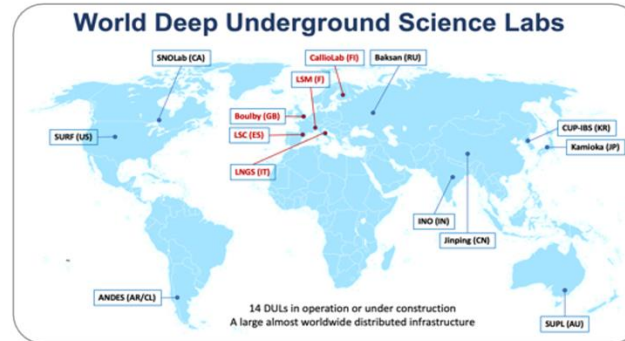
Boulby Underground Laboratory (UK)



Boulby Facility Details...

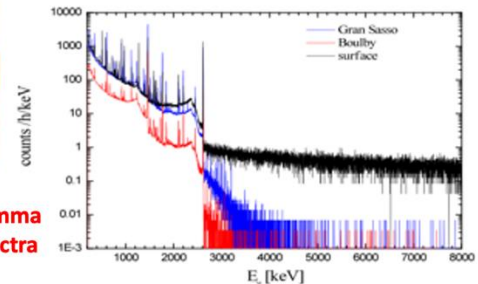
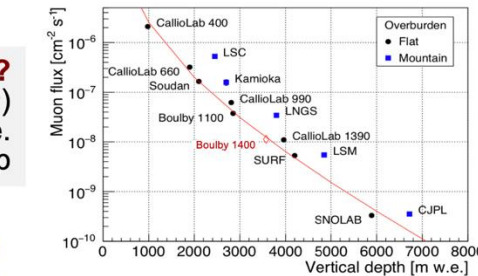


- The UK's deep underground science facility. One of 5 in Europe, <15 in the world.
- Supports work of >10 collaborative projects (astrophysics to climate, geology, environment etc), >60 institutions, >250 scientists & students.
- Facility funded and operated by the Science & Technology Facilities Council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

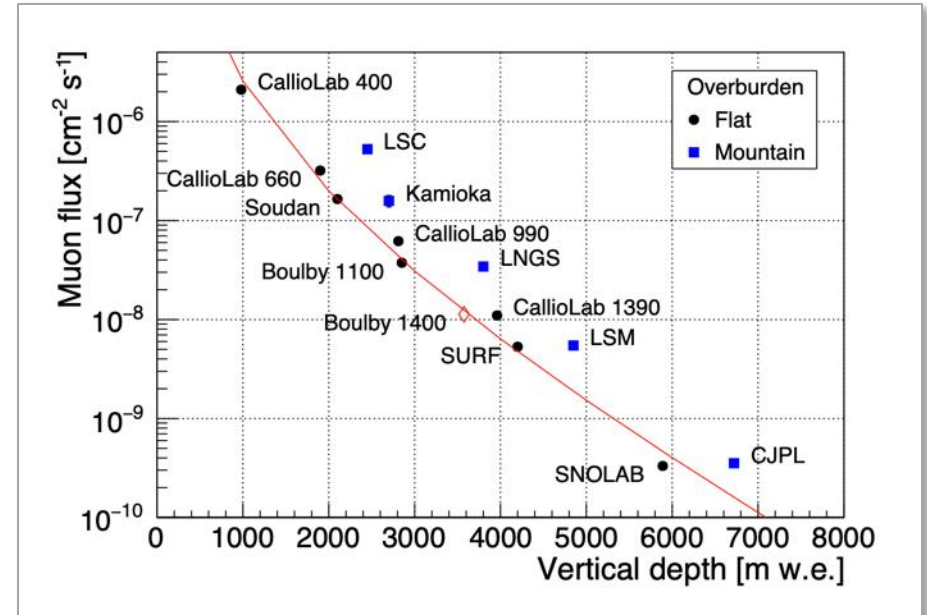


How does Boulby Compare?

- Low Radon levels (3 Bq/m³)
- Diverse science programme.
- Science and Industry partnership



Gamma Spectra



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



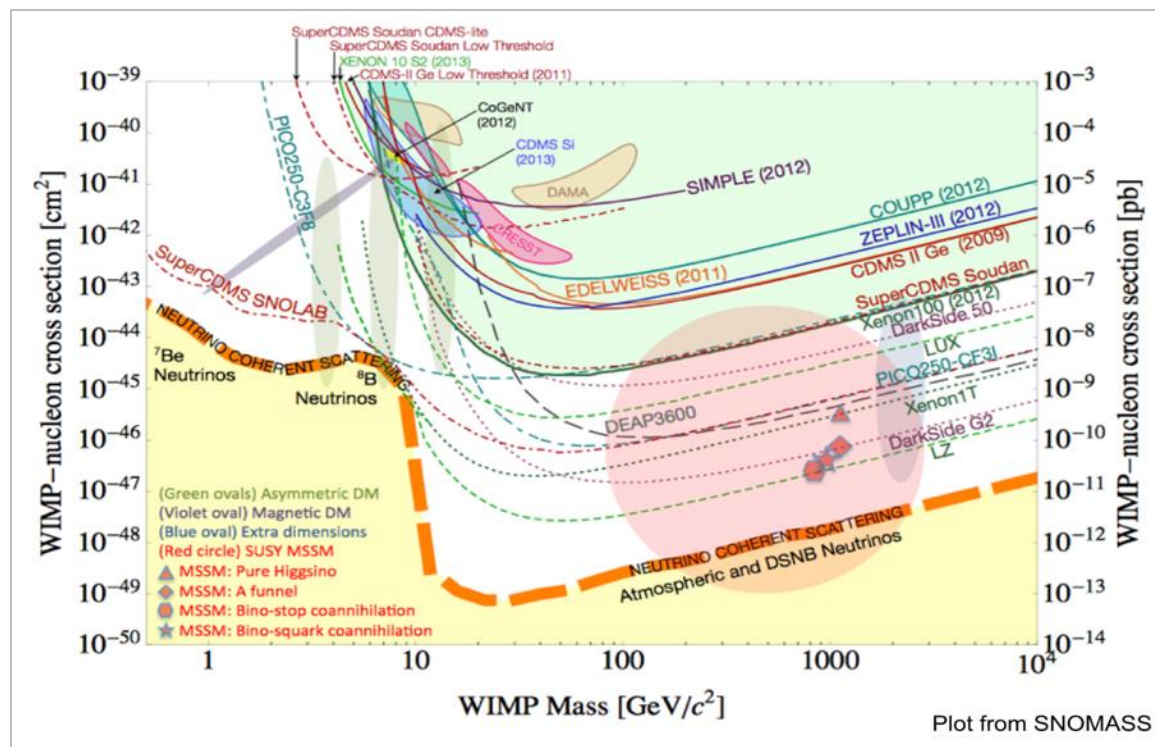
Science Programme Status and Plans.

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

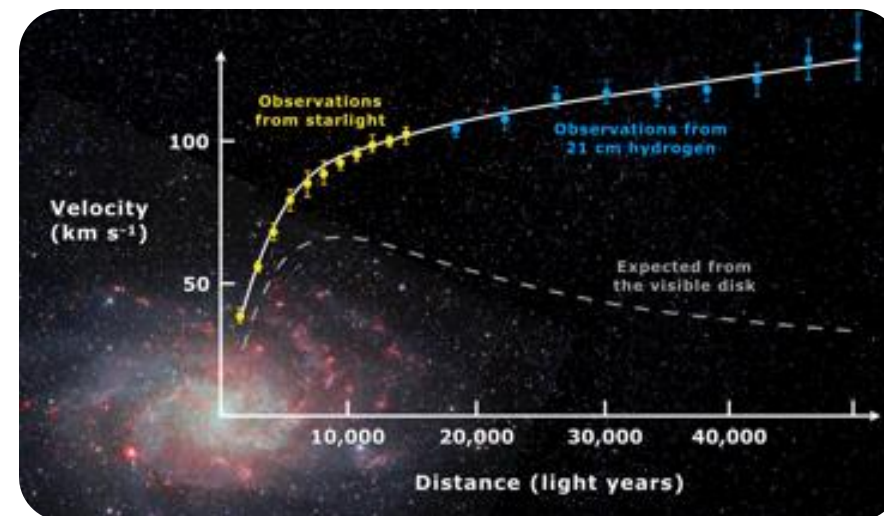
Boulby Dark Matter Studies...

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

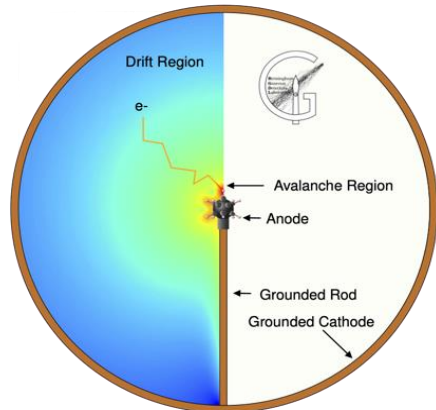
DarkSPHERE

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



NEWS-G Activities at Boulby

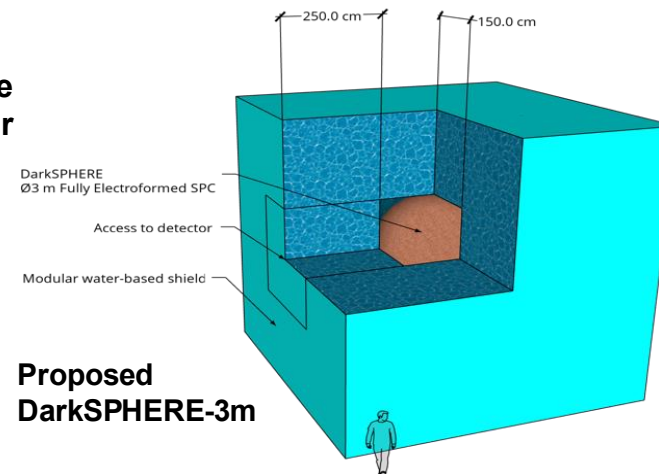
- Instrumentation developments
 - Multi-anode sensor
 - Gas filtration
 - Rate effect studies
- Neutron spectroscopy (with N₂ gas)
 - Neutron background surveys
 - Industrial applications
- High-purity copper electroformation
- **Towards scaled-up, electroformed, detector at Boulby, 3m diam. 5 bar**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



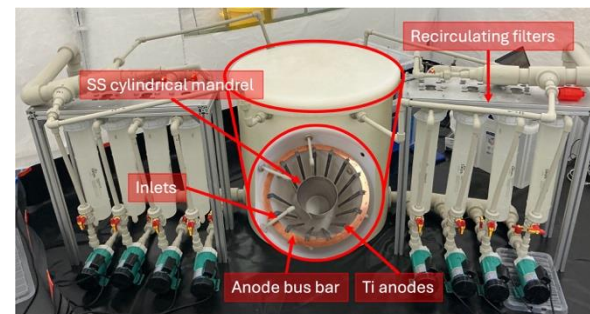
SPC concept: Variable target
Low E_{th}, Low mass sensitivity



11-anode
sensor



AI-S30 R&D Detector

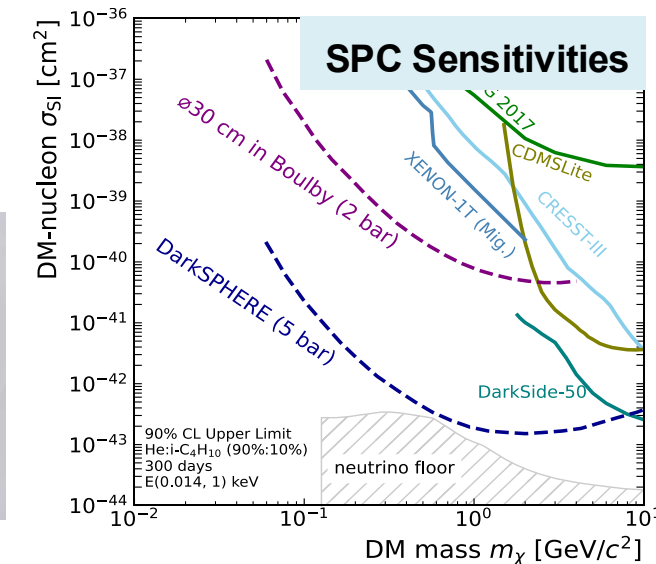


Copper electroforming at Boulby

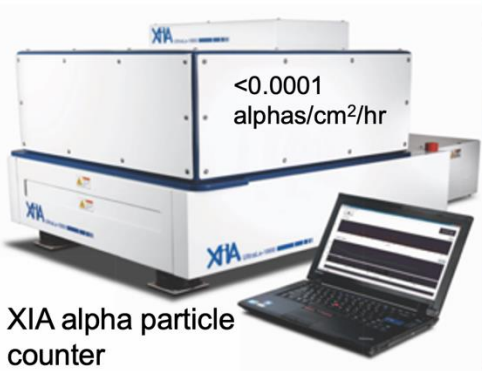


See talks
here by:

Giovanni Rogers
Peter Walters



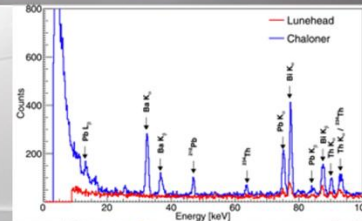
Ultra Low Background Material Screening @ Boulby (**BUGS**)



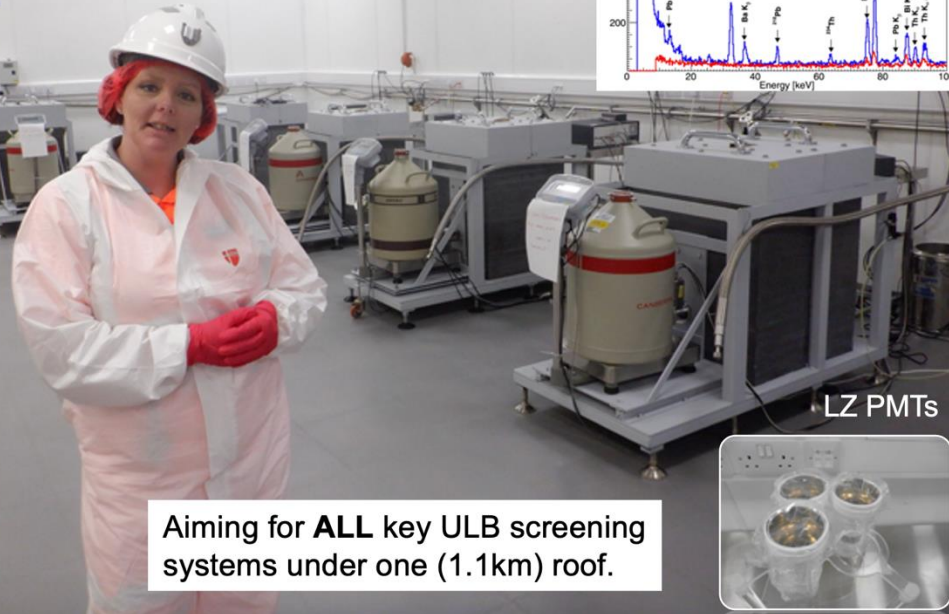
XIA alpha particle counter



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.

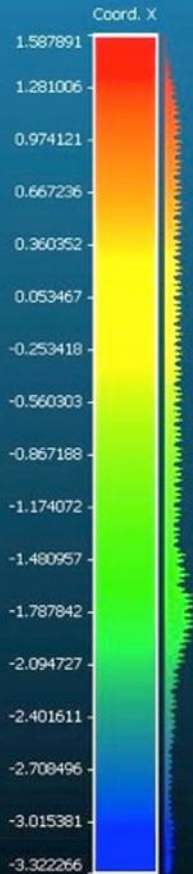
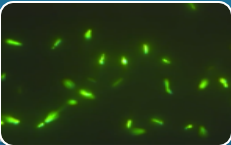
RECON:
Atmospheric
monitoring for
nuclear
security

MINAR:
Astrobiology and planetary exploration technology development



NASA-JPL
Signatures of life studies

MINAR VII & VIII.
2018 - 2021



Remote³
Public Engagement

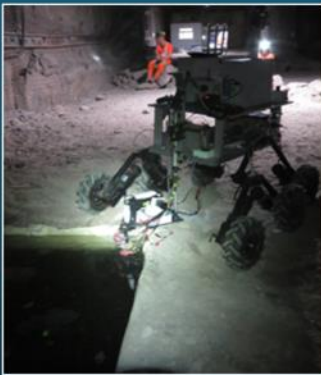
Lulea University
KORE rover 3D area
mapping



Birmingham University
BIOSPHERE Human Habitability Studies



Edinburgh University
MUFFHINS water activity
monitoring payload



RECON: CTBT Atmospheric Radionuclide Monitoring

Improving the sensitivity of Nuclear Test Monitoring
A V Davies, R Britton
AWE, Aldermaston, Reading, Berkshire, RG7 4PR

Construction

International Monitoring System Station Locations

Improving the accuracy & sensitivity of atmospheric radionuclide monitoring for international Comprehensive Test Ban Treaty (CTBT) verification

Nuclide	Single MEA Right	Gate Energy	Projected Peak	Background Factor	Background Counts (Projected)	Isr. Pulse	MEAs	MEAs	Ratio to Single
CS-134	5.96E-07	904.722	796.00	2.05E-01	5	5	6.45E-06	6.45E-06	0.140
SA-132	4.45E-07	30.625	356.00	7.28E-01	54	49	6.45E-06	6.45E-06	0.062
AG-109m	4.76E-07	34.013	414.00	2.37E-01	52	39	2.88E-06	2.88E-06	1.02
CS-136	5.34E-07	1179.03	1330.00	8.79E-01	5	7	5.43E-06	5.43E-06	0.309
AG-102m	4.59E-07	407.76	680.00	1.54E-01	3	11	5.09E-07	5.09E-07	0.055
EU-234	6.32E-07	40.128	280.00	2.88E-01	40	30	2.12E-06	2.12E-06	0.055
SA-132	5.96E-06	27.202	408.00	9.05E-01	34	30	5.40E-06	5.40E-06	0.027
IC-46	4.72E-07	884.277	1220.00	1.33E-01	1	7	3.79E-06	3.79E-06	0.076
SA-132	5.96E-06	21.839	475.00	1.94E-01	30	28	2.82E-06	2.82E-06	0.023
EU-234	5.96E-07	385.340	528.00	1.63E-01	6	27	1.44E-06	1.44E-06	0.040
LA-140	5.09E-06	524.702	407.00	1.59E-01	10	18	2.72E-07	2.72E-07	0.031
CS-136	3.89E-06	31.827	1240.00	1.42E-01	7	22	1.38E-07	1.38E-07	0.090
SA-132	5.02E-06	464.7	686.00	1.83E-01	6	12	6.19E-06	6.19E-06	0.089

RESOURCE:
Compressed
gas energy
storage R&D

Renewable Energy StOrage in UndeRground CavErns (RESOURCE)

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

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

Plan for in-situ Testing at Boulby Mine

Testing hole

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.

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.

Drill and core shallow hole to 5m. Case hole, cement casing and form solution-mined cavern.

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

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

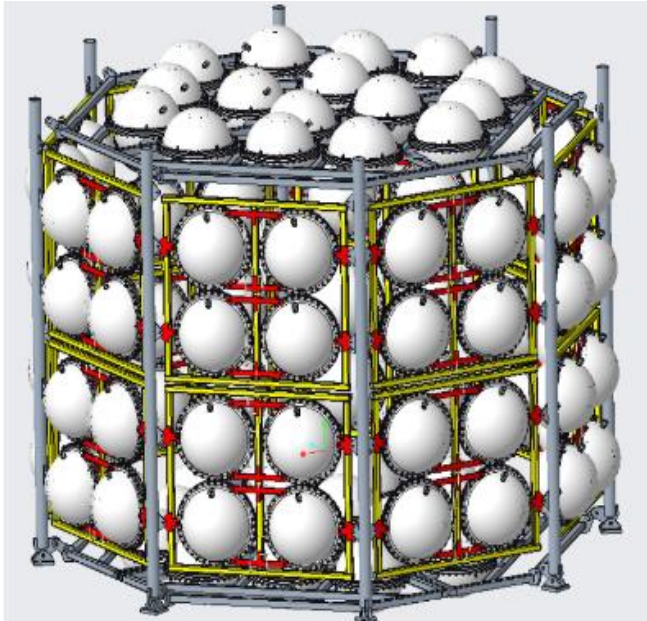


World antineutrino flux levels

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

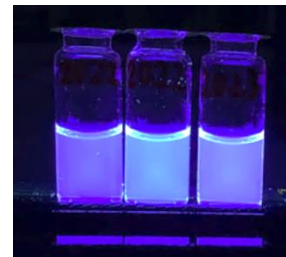
BUTTON-30 is a proof of concept for a future 1-kT detector providing 100-tonne fiducial volume

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



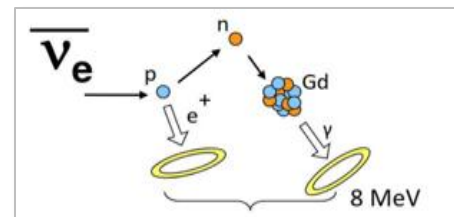
Boulby provides uniquely suited experimental space in ultra-low background Environment.

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

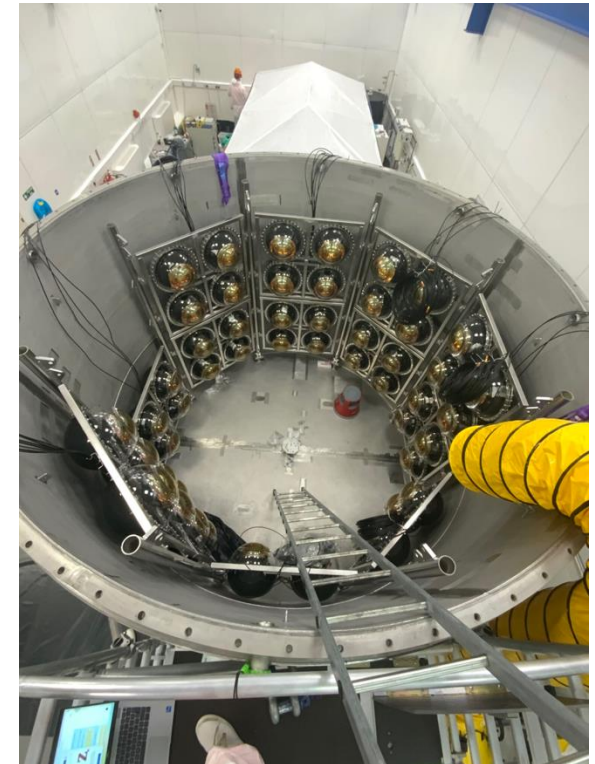
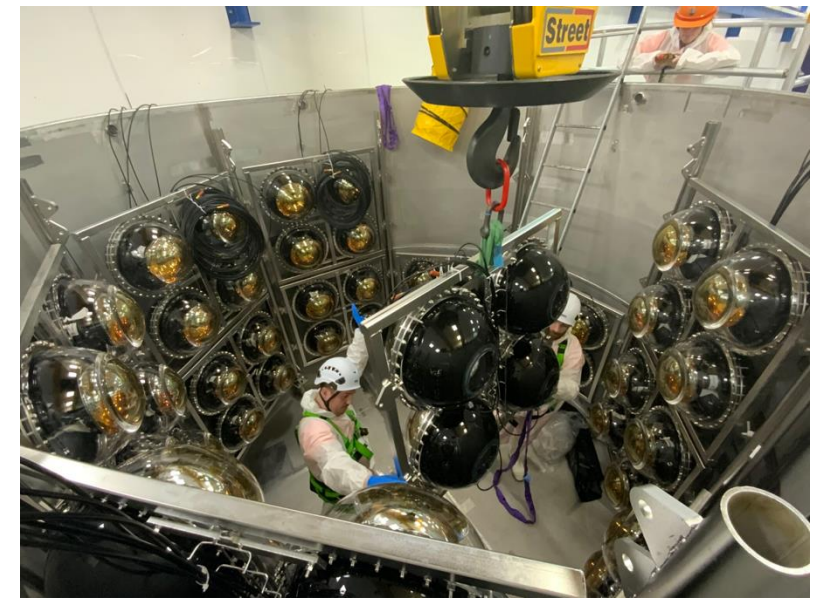


Water Based Liquid Scintillator (WbLS)

Anti-neutrino discrimination with Gd-H₂O



BUTTON Installation: Jan–April 25



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

Long Term (Current lab plus major new lab)	
Particle Physics and Low Background Science:	
Dark Matter: Major Next Gen Experiments:	Target projects for a major new UK underground facility / campus
• 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	
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.	

Future facilities & science @ Boulby?

AION-100 & AION-1000 @ Boulby?

AION Atom Interferometer Observatory and Network

Boulby Underground Laboratory 2023

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

See talks here by: Martin Bauer
Ashlea Kemp

Quantum Computing in Ultralow background environment?

Quantum Computing Going Underground

Quantum computers may be heading underground to shield from cosmic rays

31 Aug 2020

Deep qubits: practical quantum computers based on superconducting technologies may have to be located underground to protect against decoherence by ionising radiation. (Courtesy: Shreyas Devnani)

Environment Required:

- Low cosmic ray rate and ambient ionising background
- Underground
- Cryogenic capabilities
- High data rate capabilities
- Secure space, reliable services (power, cooling etc)

physicsworld

QUANTUM COMPUTING | RESEARCH UPDATE

Cosmic-ray threat to quantum computing greater than previously thought

28 Jul 2021 Margaret Harris

MailOnline

PUBLISHED: 09:34, 27 August 2020 |

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



Quantum Sensors and Quantum Computing

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.



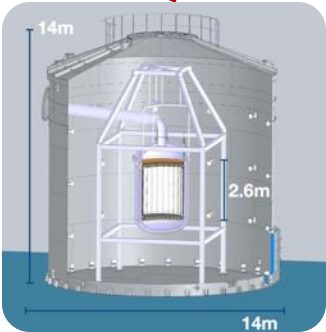
Xenon-nT
LNGS, Italy

XLZD
2021 merging
of LZ, Xenon
and DARWIN
teams



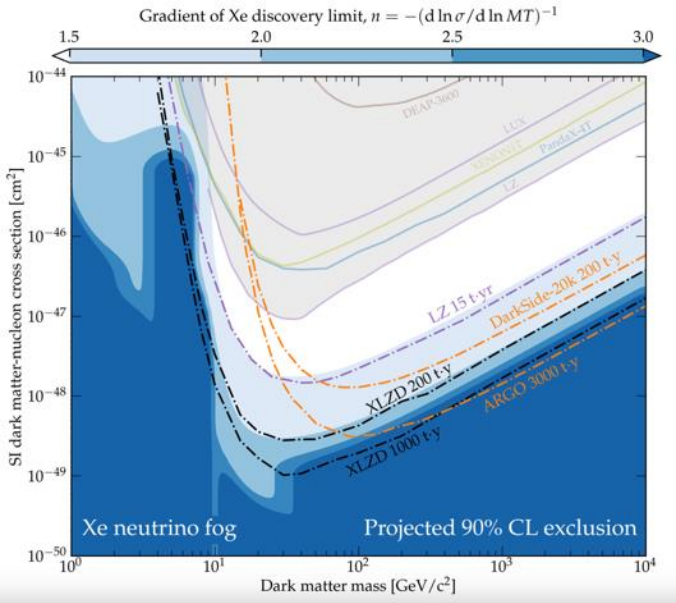
DARWIN
(Proposed)

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

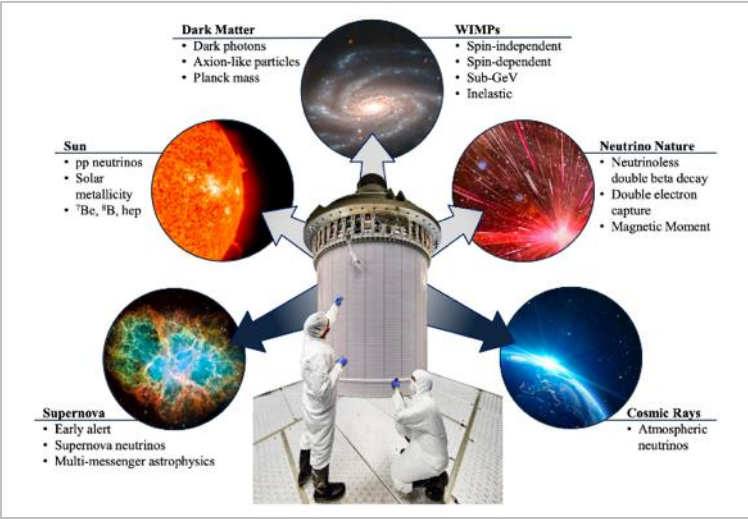


**Could XLZD be
constructed
and operated at
Boulby 2030+?**

Projected
sensitivity
(Akerib P5
town hall
mtg 2023)

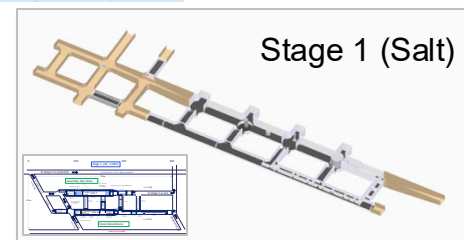
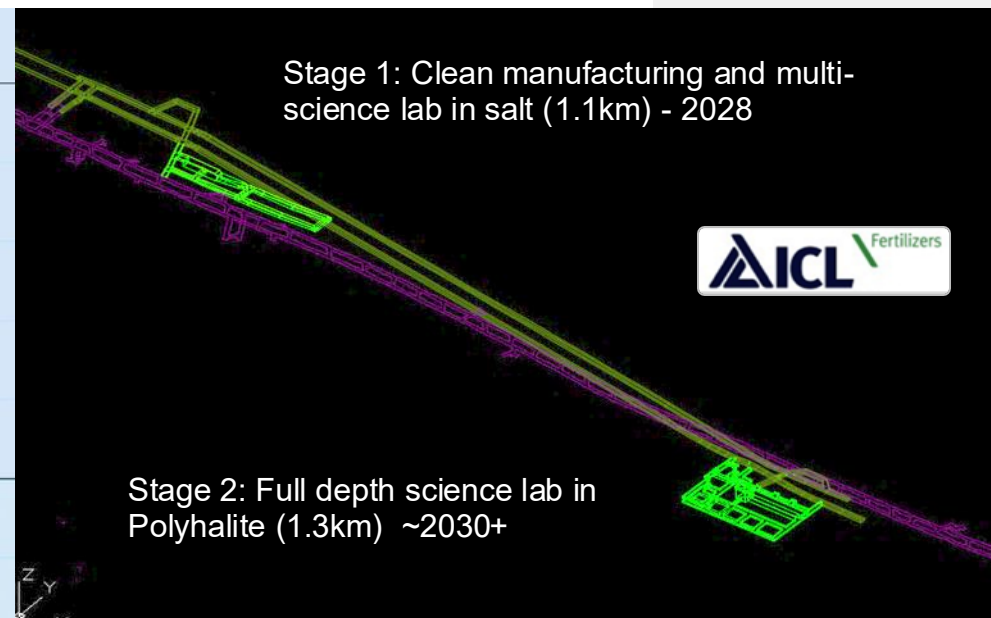
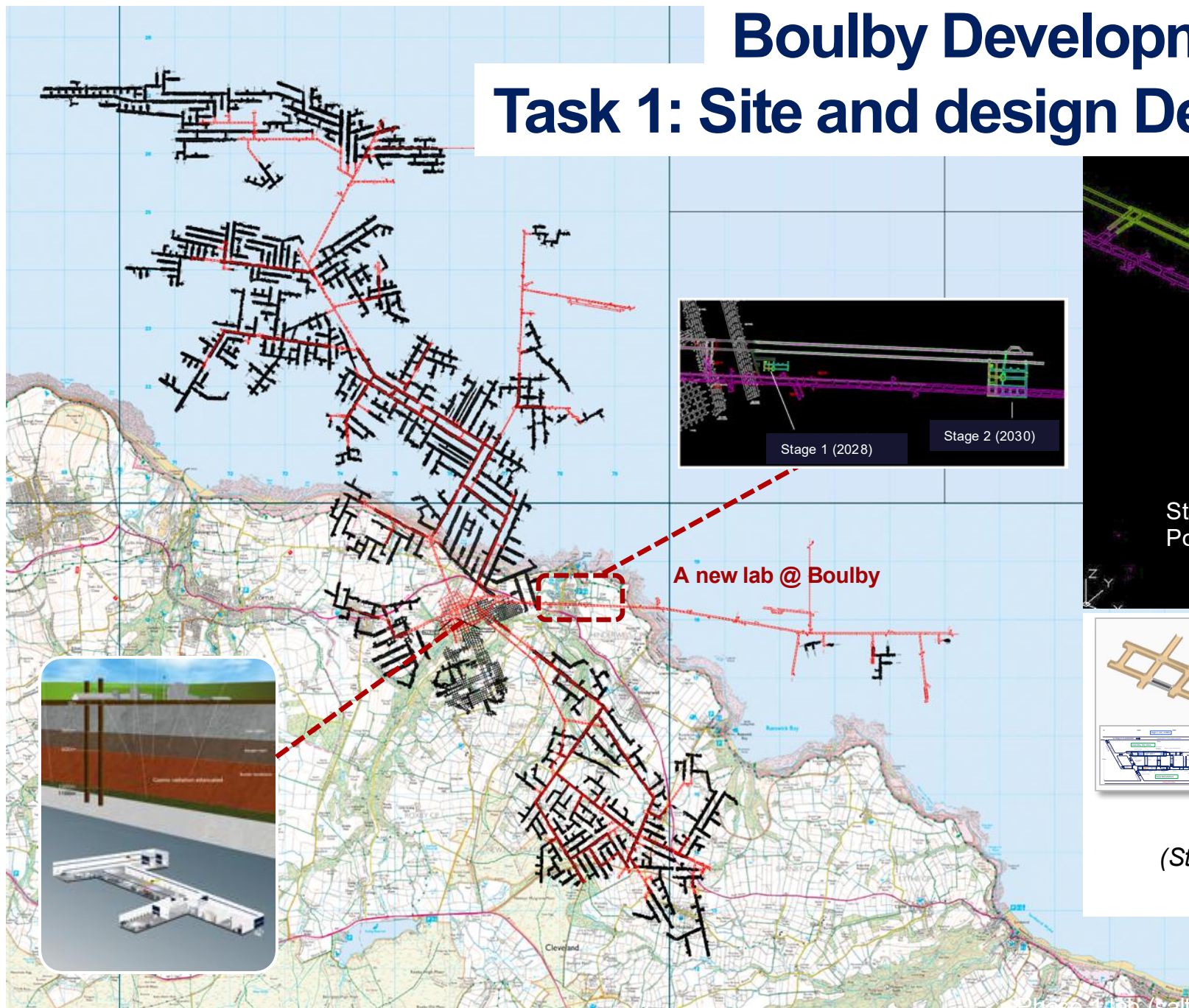


Next generation **world's best** Dark Matter (+) detector. **Expected 2030+**



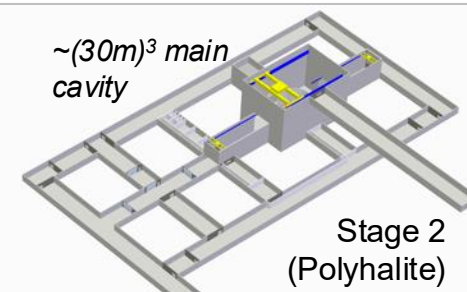
Boulby Development Project

Task 1: Site and design Development.



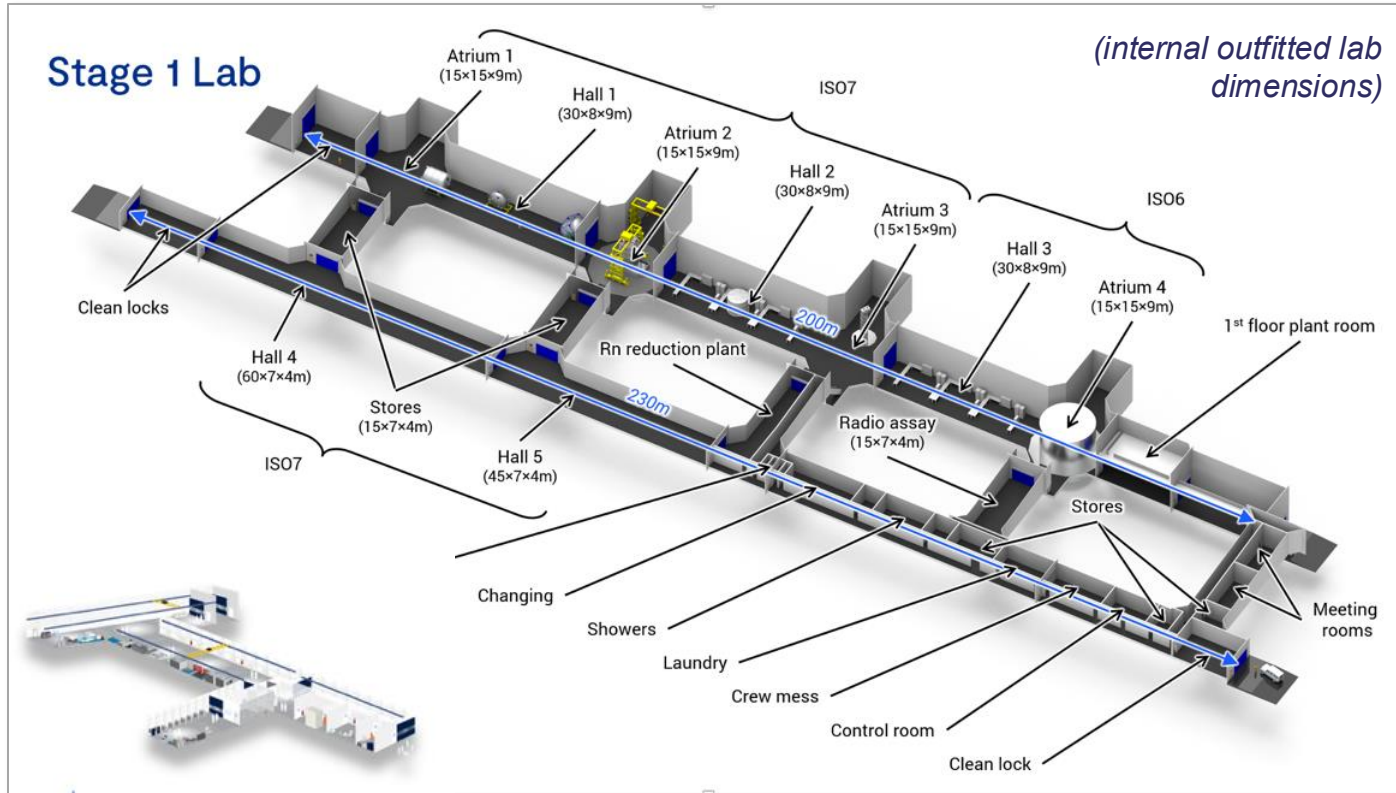
Total volume
(Stage 1 + stage 2)
~120,000m³

DRAFT: 2-stage Designs



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

Stage 1 Excavation:

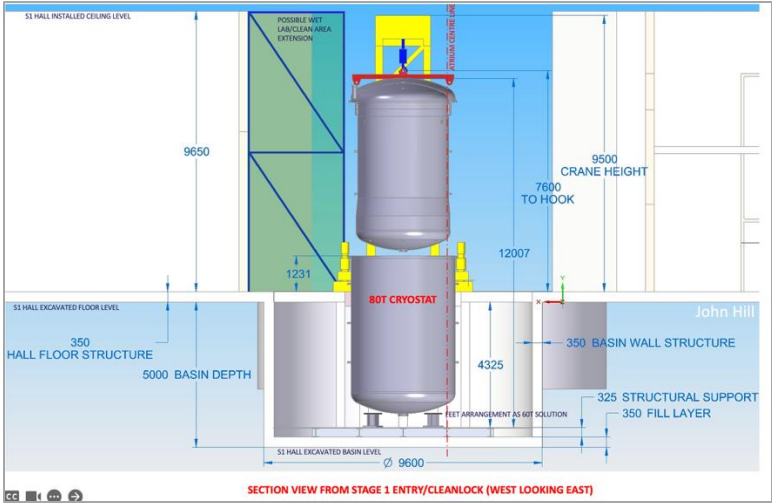
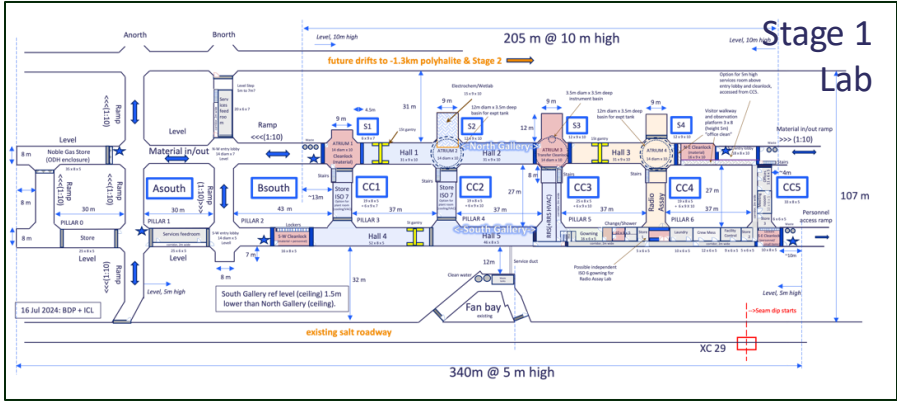


Now complete (Oct 2025) – now awaiting formal independent sign-off.
Planning for outfitting now underway

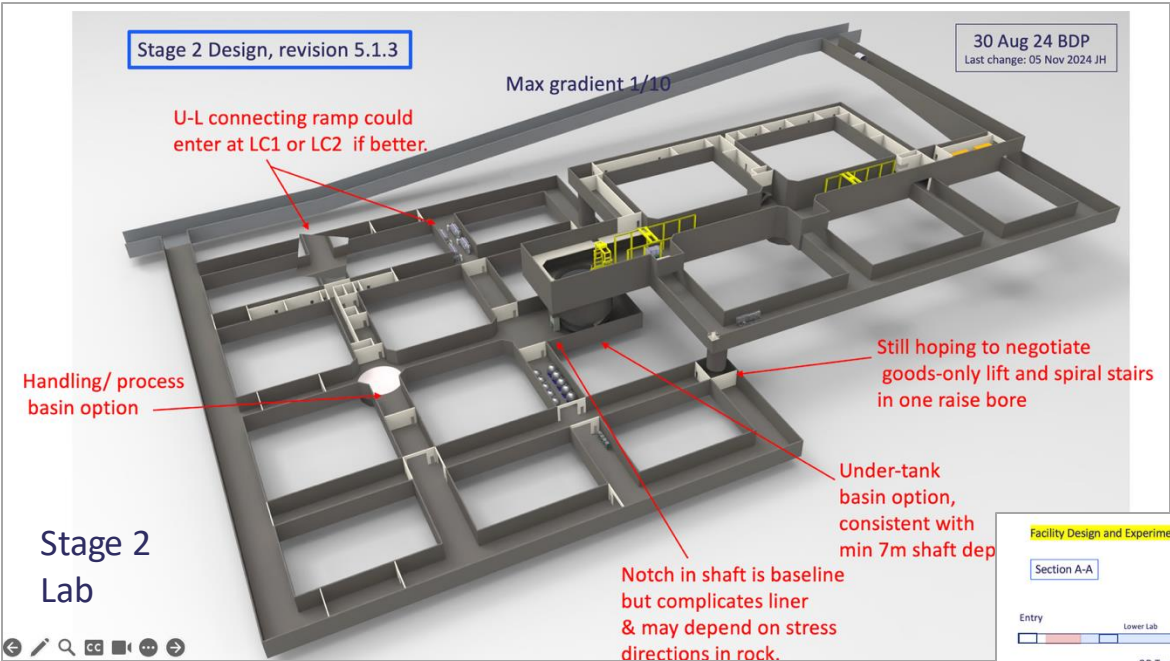
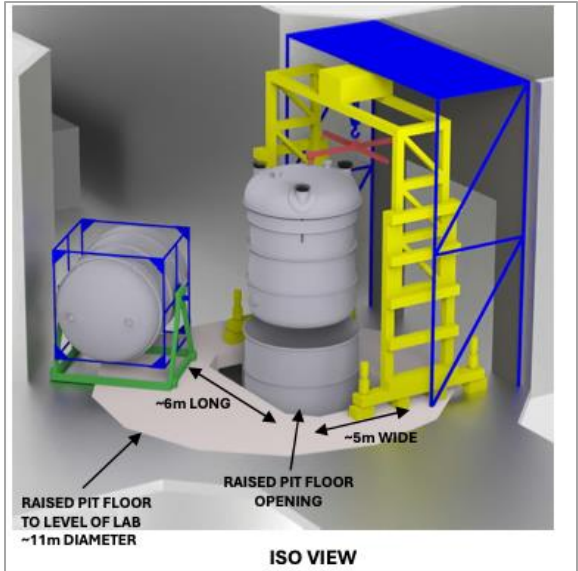


Excavation complete – Oct 25

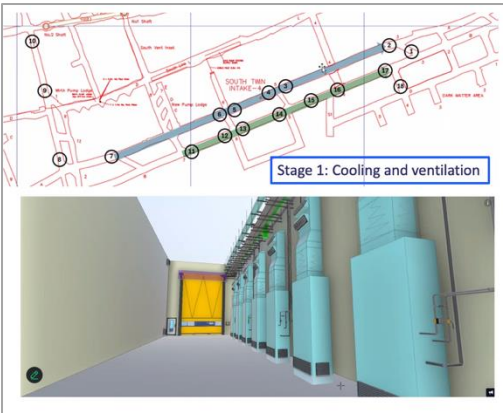
New Lab(s) Design



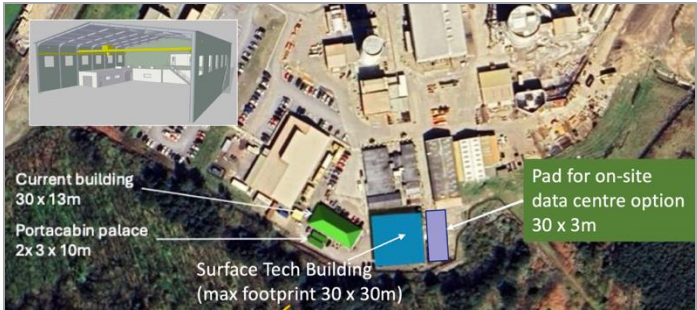
Stage 1 XLZD Pre-Construction



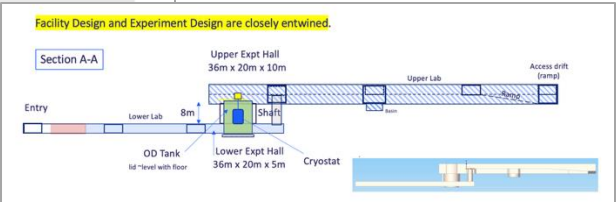
XLZD in Stage 2



Stage 1 Ventilation



Surface Building option



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

Summary...

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!**



Thank You....

Please Contact us...
Email: Boulby@stfc.ac.uk
Web: www.stfc.ac.uk/boulby
Facebook: [Boulby Underground Laboratory](https://www.facebook.com/BoulbyUndergroundLaboratory)
You Tube: [Boulby Underground Laboratory](https://www.youtube.com/BoulbyUndergroundLaboratory)

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