



Science and
Technology
Facilities Council

Boulby Underground Laboratory: Status and Future plans for UK Deep **Multidisciplinary** Science

Sean Paling
Boulby Underground Laboratory
Science and Technology Facilities Council

UKRI Science and Technology Facilities Council
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

Boulby Underground Laboratory:
The UK's deep underground science facility. Status, plans and opportunities for growth

Underground lab @ Boulby

Boulby Underground Laboratory (UK)



Boulby Underground Laboratory



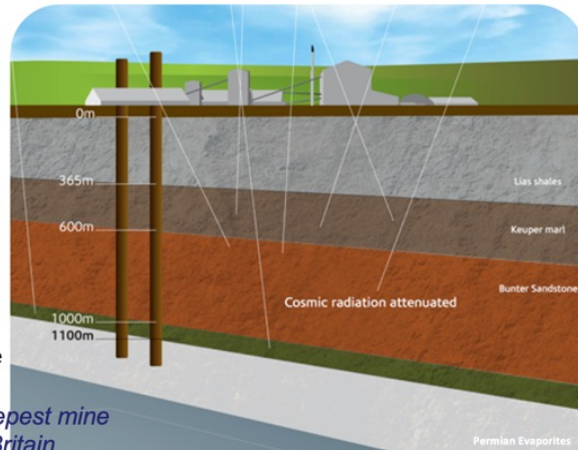
The UK's deep underground science facility operating in a working polyhalite & salt mine.

1.1km depth (2805 mwe). With low background surrounding rock-salt

Operated by the UK's Science & Technology Facilities Council (STFC) in partnership with the mine operators ICL



Polyhalite



Deepest mine in Britain

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



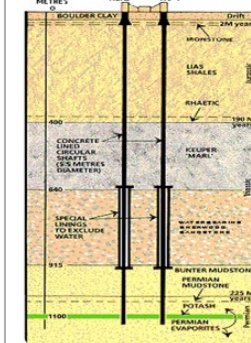
A QUIET place in the Universe



Whitby, North Yorkshire

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.



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

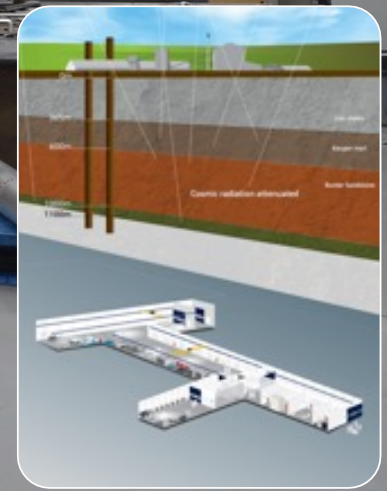
Supported access to surrounding geology & UG environs. Power, wifi/internet.

3000m³ Outside Experimentation Area

Surface support and staging building

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.

BUGS Material screening



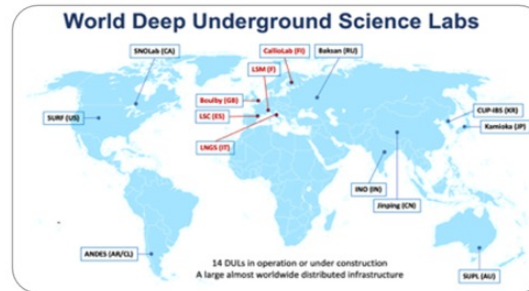
Boulby Underground Laboratory (UK)



Boulby Facility Details...

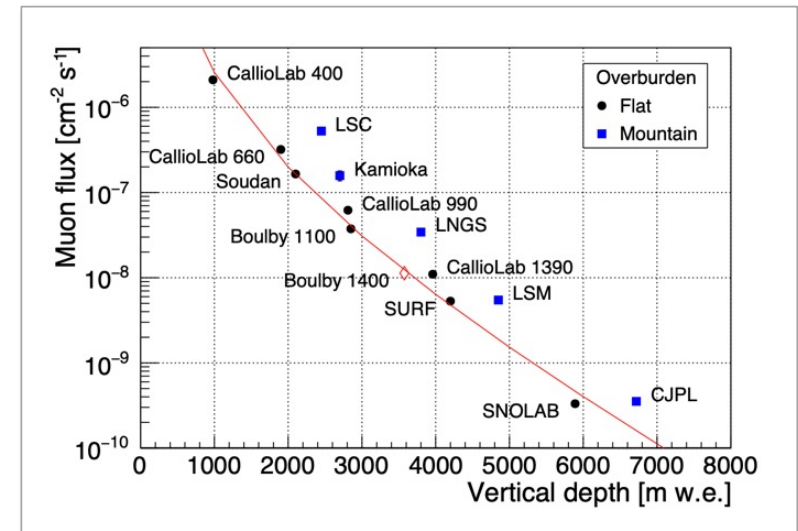


- The UK's deep underground science facility. One of 5 in Europe, <15 in the world.
- Supports work of >10 collaborative projects (astrophysics to climate, geology, environment etc), >40 institutions, >170 scientists & students.
- Facility funded and operated by the Science & Technology Facilities Council (STFC).
- Operations, H&S & science programme managed by 17 (+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



Science Programme Status & Plans.

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

Boulby Science Now & Future

Particle physics and ultra-low background studies

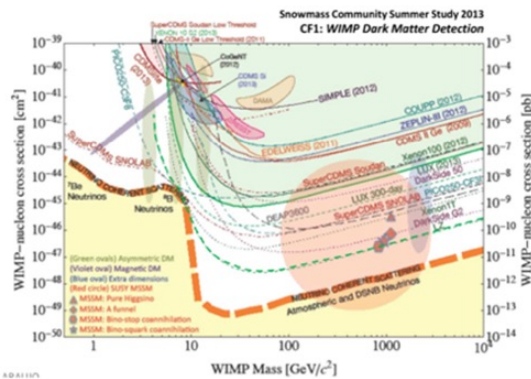
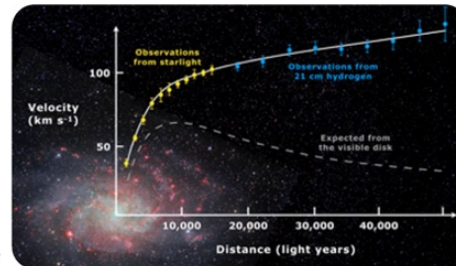


Boulby Dark Matter Studies...

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



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

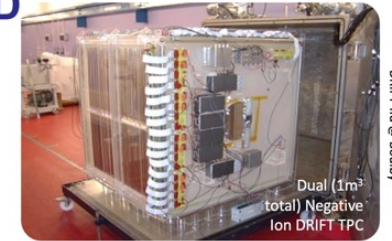
World DM particle search limits and future projections



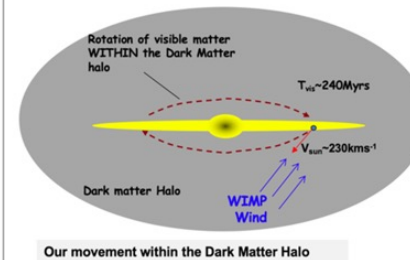
ZEPLIN-III @ Boulby

DRIFT/CYGNUS: Directional Dark Matter Detection R&D

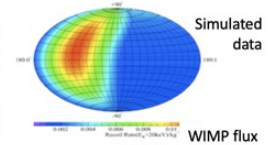
STATUS: Programme operating at Boulby since 2001. Performance & scale-up R&D. Plans for further R&D & expansion / collaboration (CYGNUS).



DRIFT-III @ Boulby



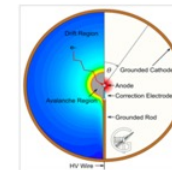
Occidental College, New Mexico, Colorado State, Hawaii, Wellesley, Sheffield, Edinburgh, Boulby



NEWS-G

Spherical Proportional Counter (SPC) studies @ Boulby

k. Nikolopoulos, I. Katsioulas, P. Knights, T. Need, R. Ward
University of Birmingham
And wider NEWS-G Collab.

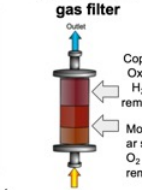


SPC concept: Variable target Low E_{min} , Low mass sensitivity

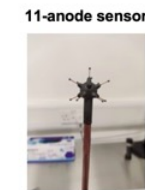
Simulation study of neutron interactions in the S30 at Boulby



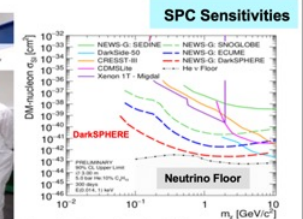
AI-S30 R&D Detector



Purpose-made gas filter

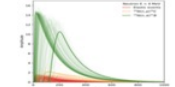


11-anode sensor



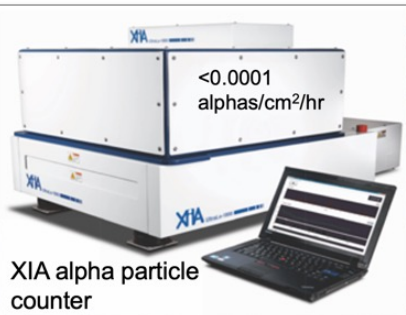
Direction of R&D at Boulby

- Instrumentation development for NEWS-G at SNOLAB
 - Multi-anode sensor
 - Gas filtration
 - Rate effect studies
- Neutron spectroscopy (N_2)
 - Neutron BG surveys
 - Industrial applications
- Towards scaled-up detector at Boulby, 3m diam. 5 Bar $He-CH_4-H_2O$: **DarkSPHERE**



Boulby Science Now & Future

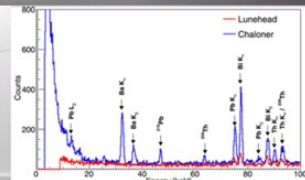
Particle physics and ultra-low background studies



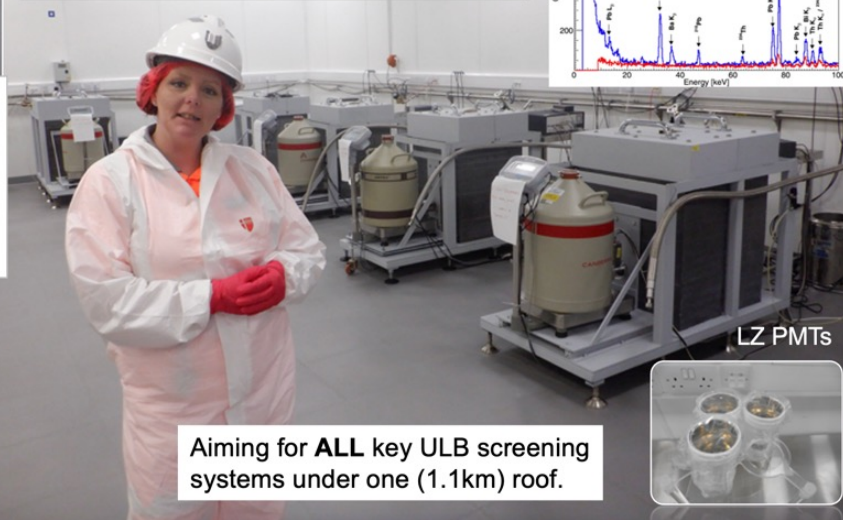
XIA alpha particle counter



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



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 *
- ICPMS * * Commissioning

Multidisciplinary Science

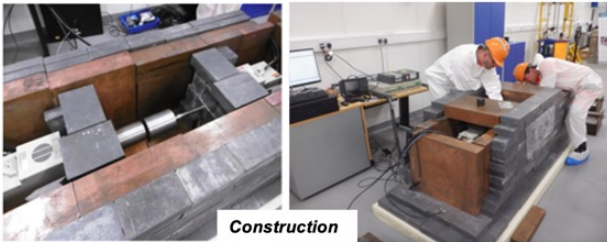
Applied low background particle physics, Earth and Environmental science, Astrobiology & Planetary Exploration Technology Development.



RECON: CTBT Atmospheric Radionuclide Monitoring

Improving the sensitivity of Nuclear Test Monitoring

A V Davies, R Britton
AWE, Aldermaston, Reading, Berkshire, RG7 4PR



Construction

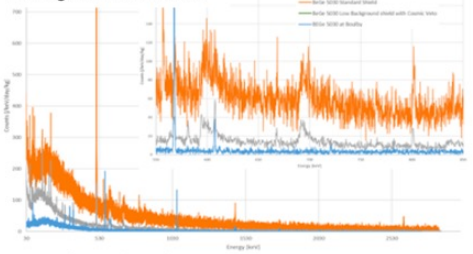


Credit: K. Cantner, AGI.

International Monitoring System Sites

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

Background reduction



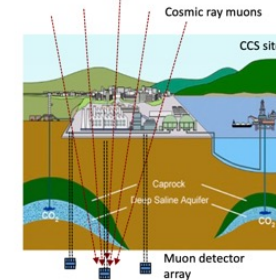
Nuclide	Singles MDA Bq/m ³	Gate Energy	Projected Peak	RIMMER Factor	Background Counts (projected)	Lc Currie	Lc Poisson	MDA Currie	MDA Poisson	Ratio to singles
CS-134	3.38E-07	604.721	796.00	2.02E-03	2	9	6	4.85E-08	0.143	
BA-133	4.41E-07	30.625	356.00	7.10E-01	54	37	49	8.47E-10	0.002	
AG-108m	4.76E-07	24.013	434.00	2.37E-04	61	39	75	2.68E-06	5.632	
CO-60	5.14E-07	1173.23	1330.00	8.73E-04	1	7	3	5.61E-08	0.109	
AG-110m	4.33E-07	657.76	885.00	1.04E-03	3	11	7	1.09E-07	0.253	
EU-152	8.23E-07	40.118	245.00	2.08E-02	40	32	52	2.52E-08	0.031	
SB-125	1.99E-06	27.202	408.00	9.01E-03	34	30	45	5.40E-08	0.027	
SC-46	4.71E-07	889.277	1120.00	1.31E-03	1	7	3	3.73E-08	0.079	
RH-102	1.08E-06	21.836	475.00	1.64E-04	30	28	41	2.81E-06	2.603	
FE-59	9.00E-07	192.343	1100.00	1.81E-04	9	17	16	1.44E-06	1.600	
LA-140	1.15E-06	328.762	487.00	1.08E-03	11	18	18	2.71E-07	0.235	
CS-136	1.30E-06	31.817	1240.00	1.82E-03	7	15	13	1.16E-07	0.090	
SB-126	1.01E-06	414.7	666.00	1.81E-03	5	13	10	8.99E-08	0.089	

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

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)

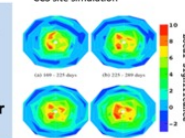


Muon-tides detector development



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)



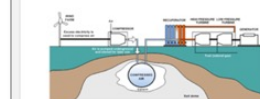
CCS site simulation

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

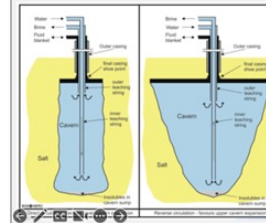
RESOURCE: Compressed gas energy storage R&D

Renewable Energy StORage in UndeRground CavErns (RESOURCE)

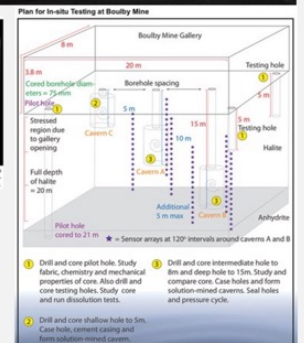
Low Carbon Technologies



- 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



RESOURCE Collaboration: British Geological Survey Boulby Underground Lab U.Cambridge & U.Manchester

RECON: Radionuclide monitoring for nuclear security

Multidisciplinary Science

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

MINAR:

Astrobiology and planetary exploration technology development

MINAR VII & VIII. 2018 - 2021

NASA-JPL Signatures of life studies

Lulea University KORE rover 3D area mapping

LA Nat Hist. Museum Fluid inclusions in salts

Edinburgh University MUFFHINS water activity monitoring payload

Coord. X

1.587891
1.281006
0.974121
0.667236
0.360352
0.053467
-0.253418
-0.560303
-0.867188
-1.174072
-1.480957
-1.787842
-2.094727
-2.401611
-2.708496
-3.015381
-3.322266

2.5

Astrobiology & Planetary Exploration

BISAL
Boulby International Subsurface Astrobiology Lab

MINAR - Habit: Sampling life in Boulby Brine

MINAR - XRF: Subsurface Astrobiology Laboratory

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

Life in Boulby salt

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

Led by Edinburgh, UKCA

MINAR - Pancam: Mining & extraplanetary exploration instrumentation development

MINAR - MARE: Mars Analogue Research

Boulby and Instrumentation for Earth and Space Exploration

sean.paling@stfc.ac.uk



Boulby 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
		Muon Tomog – CCS & undersea Geoimaging R&D	A
Earth & Environmental		RESOURCE – Energy store R&D	A
		Seismology/AION R&D	A
		BISAL – Biology/Astrobiology	A
Astrobiology & Planetary Exploration		MINAR – Planetary Exploration Tech development	A
		Misc. Other. SELLR, C14, Adrok, BIO-SPHERE...	A/P
		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/I
BUTTON-30 – Nuclear security R&D	A
RECON+ - Nuclear Security R&D	A/I
DarkSPHERE – DM Search	I
DATUM – Neutrino Tech R&D	I
SoLAr, SOLAIRE – DM/Neutrino R&D	I
AION-100 & 1000 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. Quantum Computing Tech R&D	-
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 (DarkSideLM+)
- Gas (DarkSPHERE+)

Neutrinos:

- BUTTON-100+
- DATUM (LEGEND Support),
- SoLAr / SOLAIRE+

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

- Ge, XIA, RnEm, ICPMS, Cleanliness & Engineering R&D

Misc Other:

- AION-100
- AION 1000
- Nuclear Security Gamma spec
- Quantum Computing Tech R&D & Operation

Target projects for a major new UK underground facility / campus

Earth & Environmental Science:

- Sustainable Energy R&D
- 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
- Robotics and AI
- Mining and industry application development.

Outreach and Education:

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

UK Underground Science Facilities. Now and the Future...

What Boulby Is:

- An internationally-important centre for pure & applied multi-disciplinary science.
- A local (North East) and national asset for science, technology and outreach/education.
- A successful and proud example of science and industry partnership
- A UKRI/UK facility with potential, opportunity and support for wide-ranging growth.

UKRI Strategic Objectives



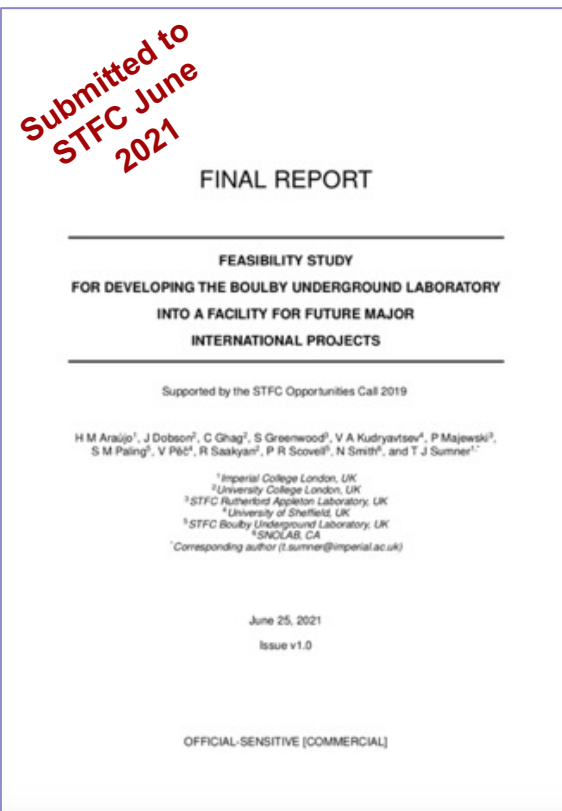
STFC/Boulby now looking to: *continue to develop the UK underground science facilities to further enable truly internationally-important astro-particle physics and pure and applied multi-disciplinary science.*

Short term: Maximally exploit the **current Boulby facility** to host world class Astro-particle Physics & Low Background Science, Earth & Environmental Science, Astrobiology & Planetary Exploration Studies

Medium-to long term: Prepare to build a **major new deep underground science facility in the UK to host next-generation world-leading science projects coming 2030+**

**Boulby Development Project:
Plans & preparations for a major new multi-disciplinary Deep Underground Science Facility in the UK**

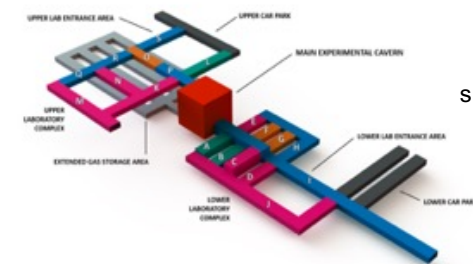
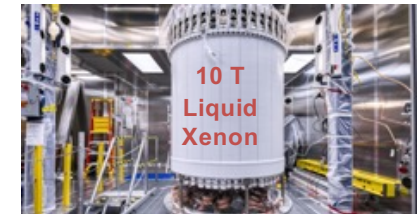
Boulby Feasibility Study (**Boulby-FS**)



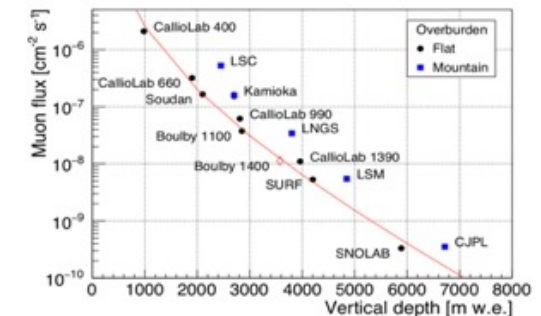
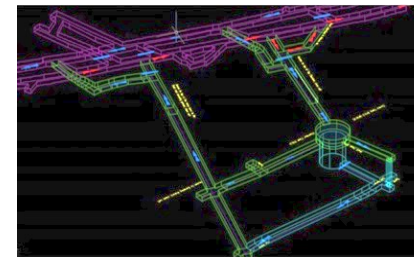
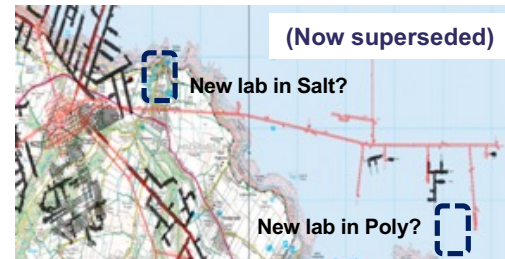
Boulby-FS (2020-21) Overview:

- Community-led study of motivation, context and practicalities of creating a major new deep underground science facility in UK
- Infrastructure specifications for potential projects (Dark Matter, Neutrinos & more).
- Conceptual designs for excavations and outfitting laboratories in 1.1km (Salt) and 1.4km (Polyhalite) layers
- Staffing and surface facility needs.
- Detailed costs and schedules.

LZ @ SURF.
Next generation in the UK?



New lab specifications & designs



Government 'fit': Levelling Up, Strength in Places, Build Back Better, UK Science Superpower...

Results: It IS feasible, well motivated and timely.
Outfitted facility: £100-200m (Inc contingency, VAT)

Summary: Boulby Development Project (BDP)...

“Towards a major new underground science facility in the North East, with the potential to host a major international science infrastructure, such as a next generation dark matter experiment.”



A new world-leading UK underground science facility hosting next-generation science 2030+

- Searches for Dark Matter (inc. XLZD)
- Neutrino studies
- Quantum Sensors, Quantum Computing
- Pure & applied low background particle physics
- Earth and Environmental Sciences
- Astrobiology & planetary exploration.
- Outreach, Education and more...

Government ‘fit’: *Levelling Up, Strength in Places, UK Science Superpower...*

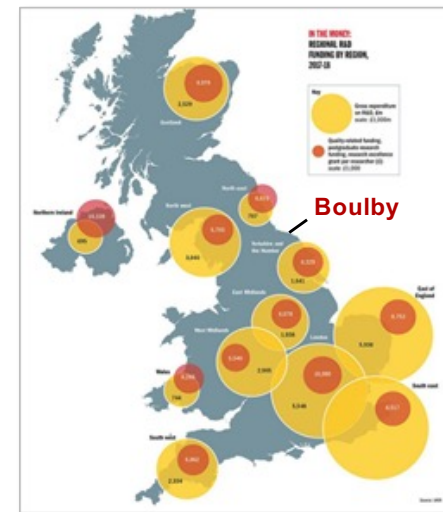
Boulby Development Project (BDP)
3-year Preliminary IF-funded study

Led by STFC/UKRI & UK science community

~£3M from 2022-2025

- Location & site design
- Science Prog Development
- Business case development
- Stakeholder Liaison

Regional
R&D
Spending
2017-18



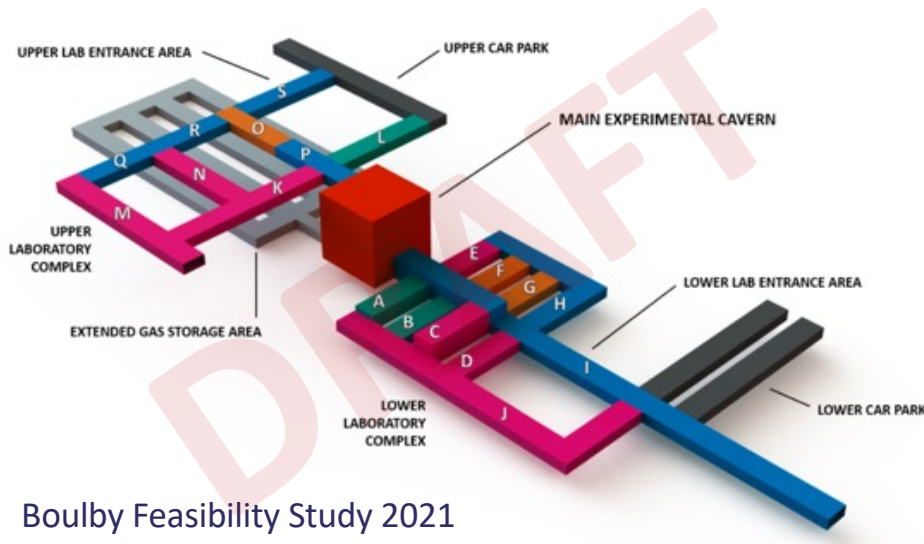
A new UK facility will bring:

- HIGH-impact, world-leading science
- LARGE multi-national collaborations
- BIG fundamental science questions
- MAJOR local & national investment, employment, impact and visibility

Task 1: Site and Facility Development



a) Next-level review of new lab design required.
Meeting needs of all possible experiments



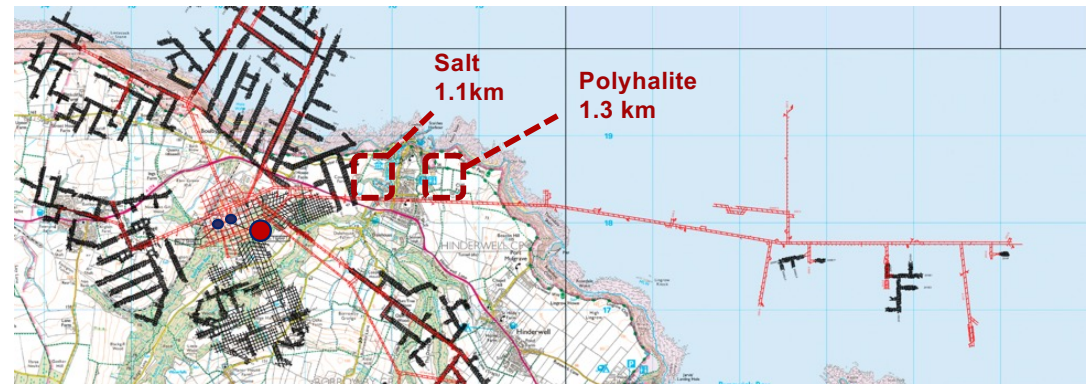
Boulby Feasibility Study 2021

Figure 6: Underground cavern design at 1,400m showing the usage of each facility space. The main experimental cavern is a 25 m cube, which provides the scale. Most outfitted areas are based on standard drift excavations (8 m width and 3.8 m height). Laboratory spaces are colour-coded: magenta is ISO 7 and teal is ISO 6; orange areas are soundproof. Labels correspond to Table 5 – A: clean manufacture facility; B: precision cleaning facility; C: test/staging facility; D: clean workshop; E: radon reduction plant; F: control room; G: messroom/restrooms; H: storeroom; I: main entrance / loading bay & gowning area; J: noble gas storage; K: water treatment plant; L: scintillator plant; M: radioassay facility; N: electronics room; O: messroom/restrooms; P: upper entrance & gowning area; Q: workshop; R: storeroom/LN store; S: upper entrance / loading bay.

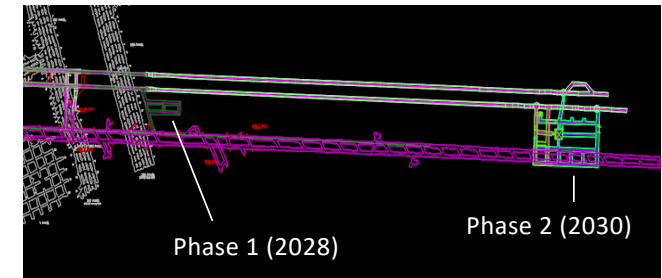
>30,000m³ experiment and support space. High spec construction assembly and operation facilities

b) Next level site and excavation design development.

Available sites @ Boulby Mine



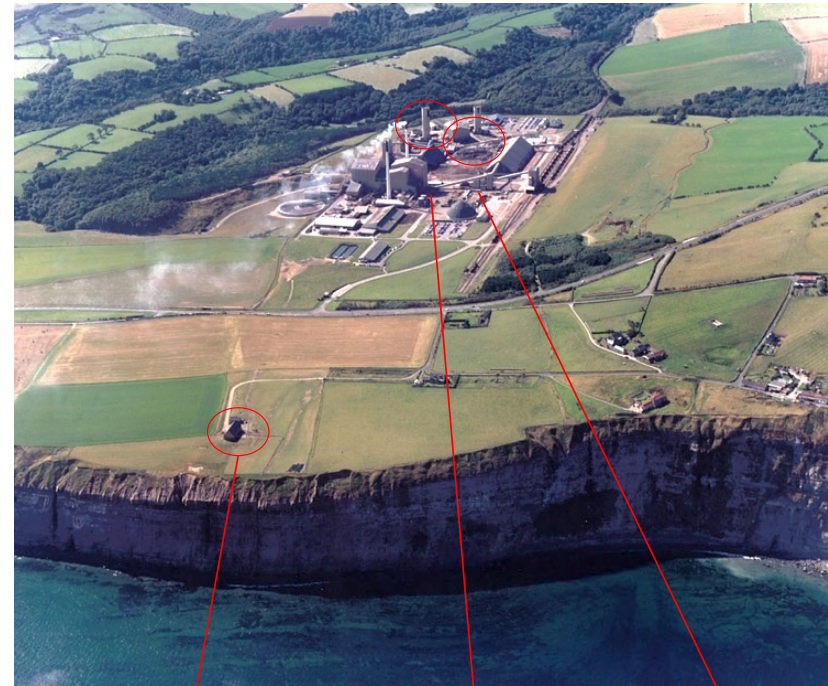
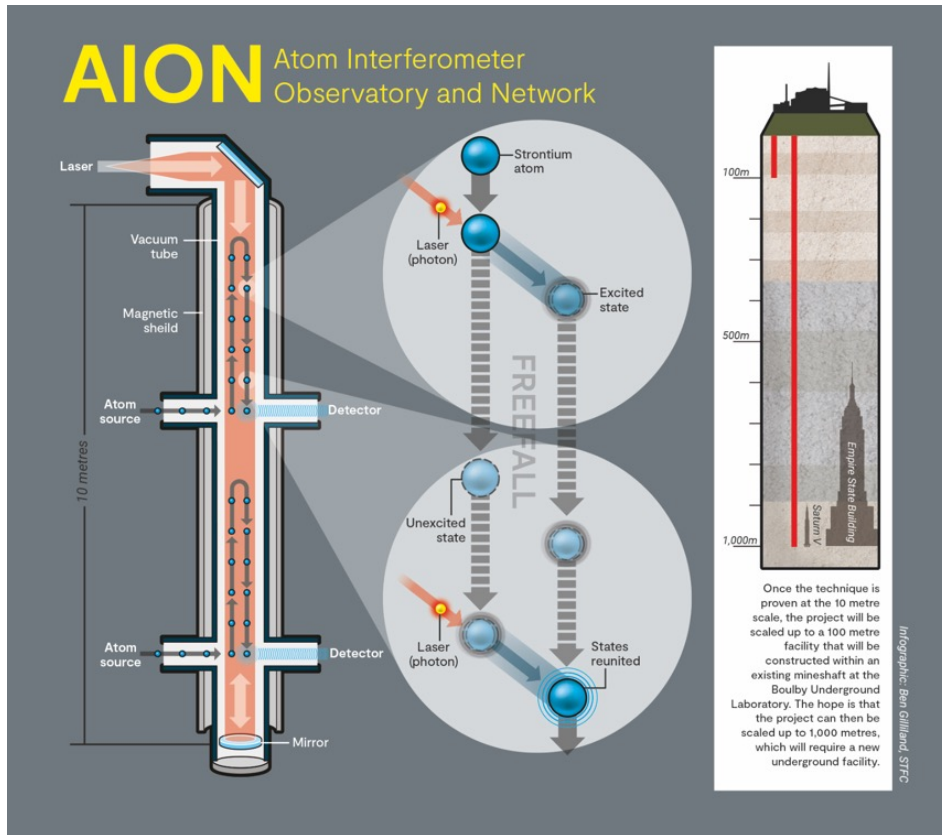
Option for 2-phase design in salt (1.1km) and Polyhalite (1.3km). Construction, assembly & experimental space in both phases



c) Next level excavation and facility build plans to be developed...

Prospects for Atomic Interferometry at Boulby...

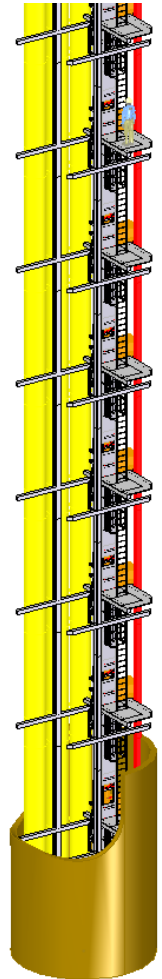
ALONGSIDE new underground laboratories to be excavated, there is strong user interest and STFC support for hosting atomic interferometry projects (**AION 100 & 1000**) in existing or new commercial shafts at or near Boulby Lab in NE England.



Shaft 3
Tailings Shaft
180m

Shaft 1
Rock Shaft
1.1km

Shaft 2
Personnel
1.1km

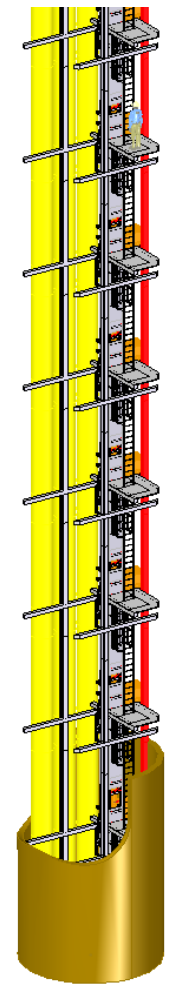
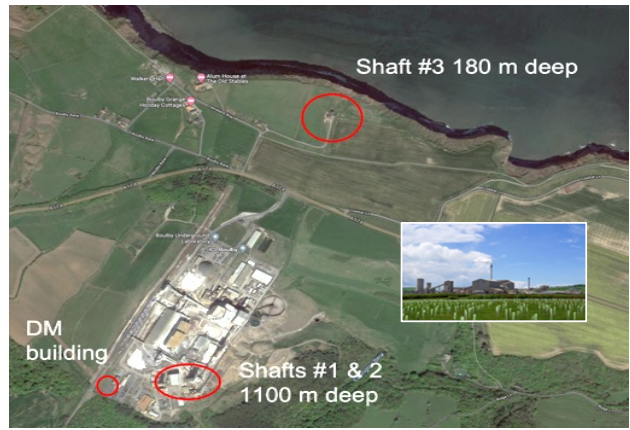


Prospects for Atomic Interferometry at Boulby...

Boulby SHAFT 3: Tailings shaft. Possible location for **AION-100** @ Boulby

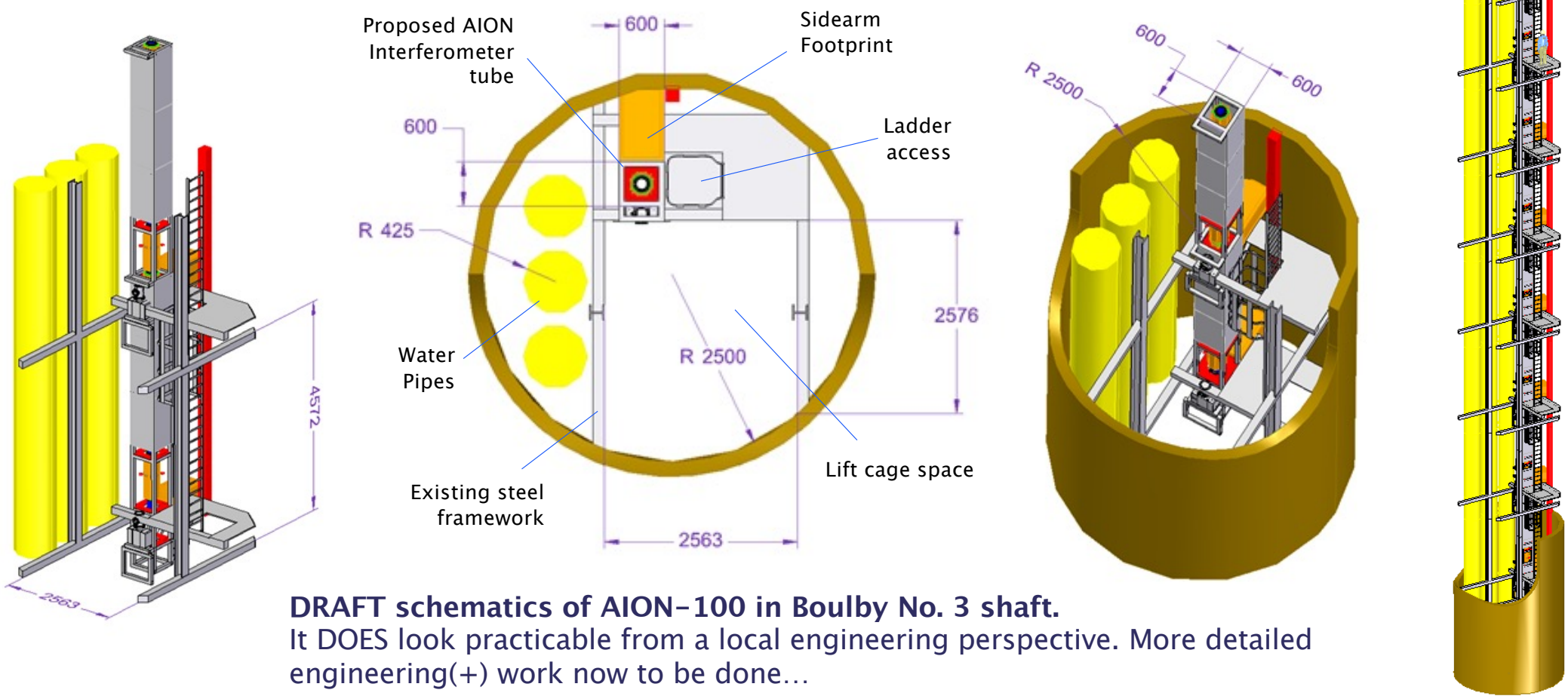
Tailings (no. 3) shaft specs:

- 180m vertical shaft
- ~50m from coastal cliffs.
- 5m diameter shaft with 3T capacity crane.
- Personnel Cage (used few times/day), water & ventilation pipes, access stairs/ladders



Prospects for Atomic Interferometry at Boulby...

Boulby SHAFT 3: Tailings shaft. Possible location for **AION-100** @ Boulby



DRAFT schematics of AION-100 in Boulby No. 3 shaft. It DOES look practicable from a local engineering perspective. More detailed engineering(+) work now to be done...

Prospects for Atomic Interferometry at Boulby...

Boulby SHAFT 3: Tailings shaft. Possible location for **AION-100** @ Boulby

Infrastructure requirements

Lab infrastructure requirements

- 100m² clean-room ISO-6 Assembly & Installation Surface Laboratory, standard power and utilities requirements. 2 x 2.5T crane needed. Direct access route to shaft. ✓
- 100m² Operational Surface Laboratory, separate space for electronics. This can be the same space as above, repurposed. ✓
- Adjacent office space for ~ 5 staff, with toilet/kitchenette facilities. ✓

Shaft requirements

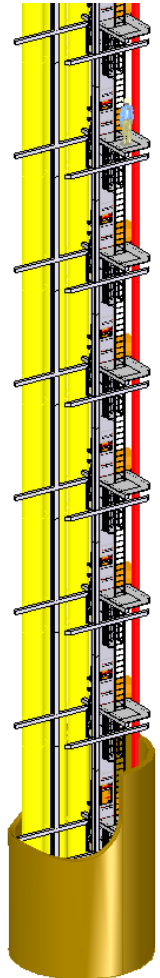
- 5m diameter is bare minimum (Initial evaluations)
- 2.5T crane cover
- Vertically moveable platform coupled ✓
- Interferometry services
- Magnetic/thermal/seismic stability ?
- Safety structures, egress routes



Site assessment work plan

- **Magnetic surveillance**
 - Design of magnetometry surveillance set-up, sensors, scanning structures, fixations to area.
 - Design of prototype shielding environment/structure incl magnetometry
 - On-site presence of PDD/Eng to conduct “raw” magnetometry measurements, analysis
- **Seismic surveillance**
 - Ambient seismic noise and atmospheric infrasound
 - In collaboration with Oxford Geology/NERC (?)
 - Need on-site tech support, AI specific analysis
- **Thermal surveillance**
 - Design of thermometry mapping of area
 - Thermometry analysis
- Mechanical/operational integration
 - installation and assembly design specifics
 - Operational access
 - Provision of lab facilities in a mine shaft environment
 - Integrate in design phases (preliminary/critical/final) AION-100
- Building infrastructure
 - Construction and assembly surface lab coupled to shaft
 - Control and Operations lab on surface

Next-level site evaluation & preparation studies in planning phase (July 23)
Buchmuller, Coleman, Mitchell, Newbold et al.



Boulby Underground Laboratory: Status, plans and opportunities for growth.

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)

Sean Paling
STFC Boulby Underground Laboratory

Sean Paling. Boulby Underground Lab. 2023

Summary...



Boulby Underground Lab status

- The UK's deep underground science facility
- Medium scale and depth. A strong history in Dark Matter search technology development
- A rich and varied current science programme in astroparticle physics and misc. pure and applied low background science, Earth and environmental science, astrobiology and planetary exploration studies.

Future plans:

- A number of new **multi-disciplinary** studies are expressing interest in Boulby. We are now looking to facilitate these projects with the current and expanded facilities.
- In addition, with strong national support we are now working toward a major expansion of facilities to enable the UK to host major international next-generation Dark Matter and neutrino studies from 2030+