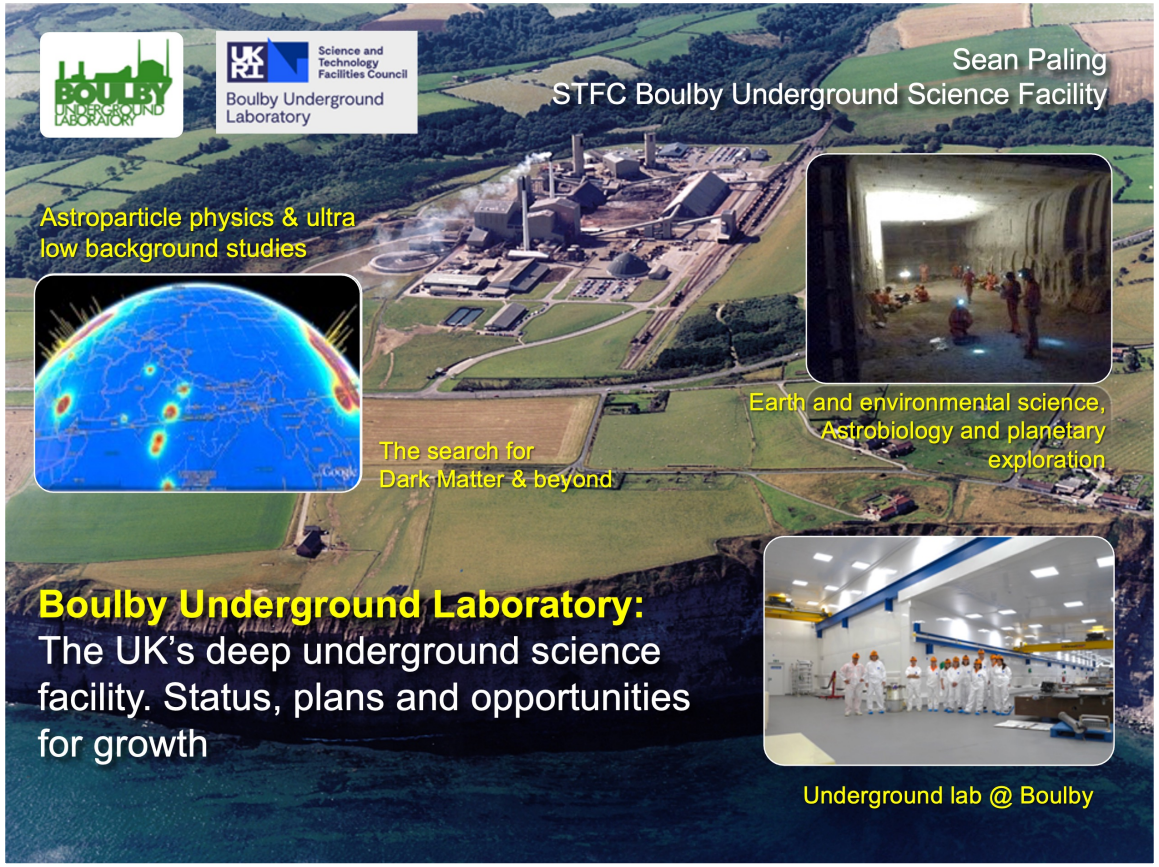
Science and Technology Facilities Council

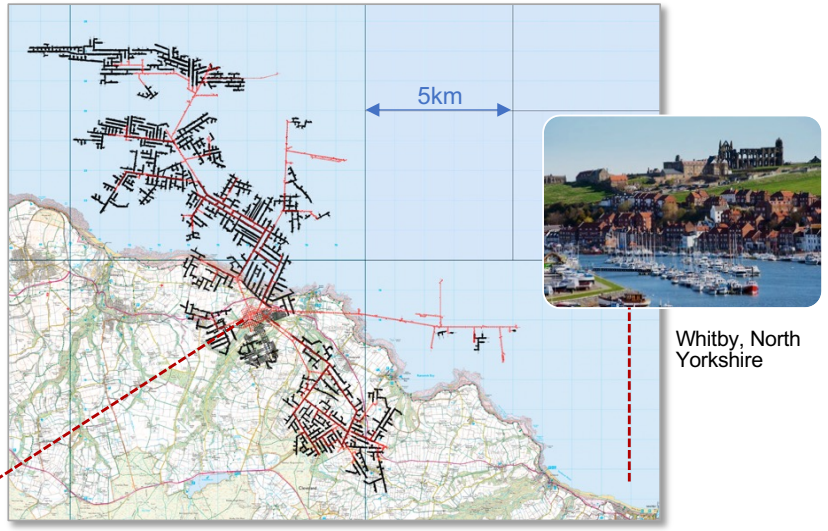
Boulby Underground Laboratory: Status, plans and opportunities for growth.



Sean Paling
Boulby Underground Laboratory
Science and Technology Facilities Council

Boulby Underground Laboratory (UK)

Science and Technology Facilities Council
Boulby Underground Laboratory



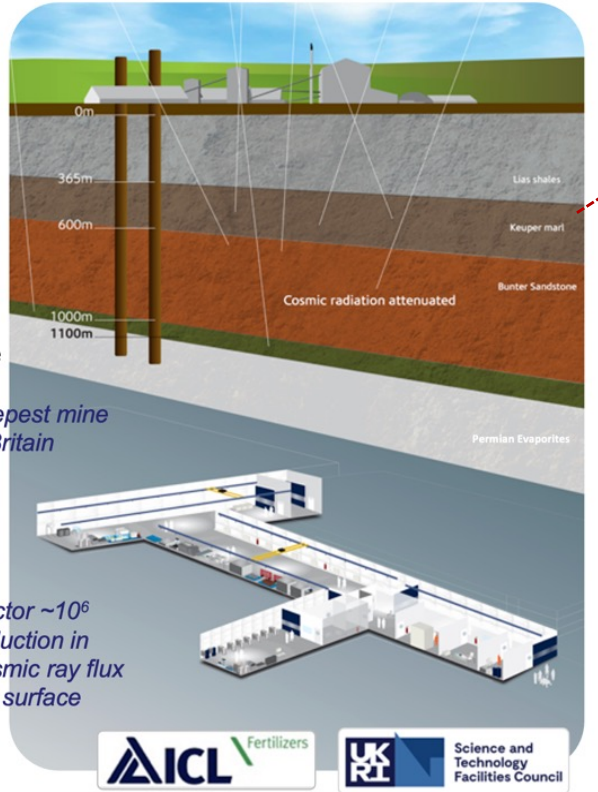
Boulby Underground Laboratory

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

A QUIET place in the Universe

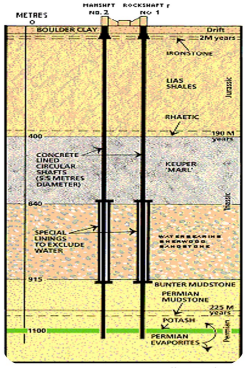
ICL Fertilizers

Science and Technology Facilities Council

Boulby Geology & Mining

Major local employer. Open since 1968. Originally mining potash (KCl) for fertiliser. Now first and only producers of polyhalite

Excavations are in Salt (NaCl) & Potash (KCl) Permian evaporite layers left over from the Zechstein Sea.



Boulby Geology

Potash

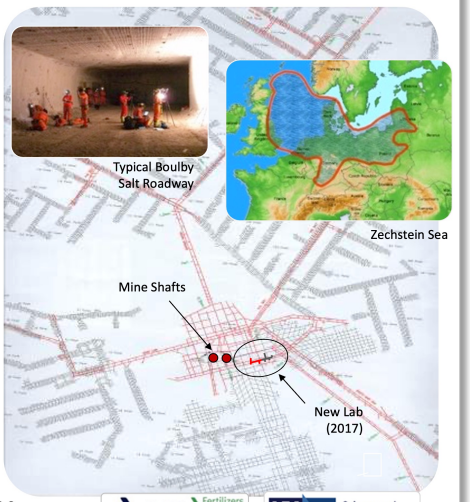
KCl

Rock-Salt

NaCl

Polyhalite

$K_2Ca_2Mg(SO_4)_4{\cdot}2H_2O$



ICL Fertilizers

Science and Technology Facilities Council

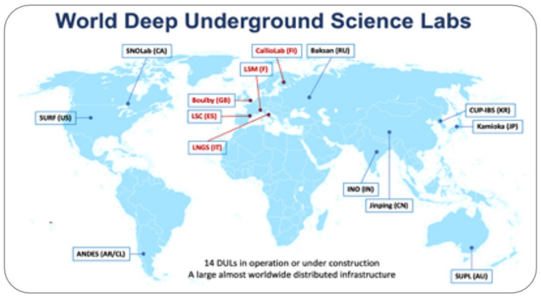

Office space, chemistry & clean prep lab, storage and staging space, IT room, conference room,
Surface support and staging building
Supported access to surrounding geology & UG environs. Power, wifi/internet.
3000m3 Outside Experimentation Area
BUGS Material screening
Boulby Underground Lab Facilities 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.

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), >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.

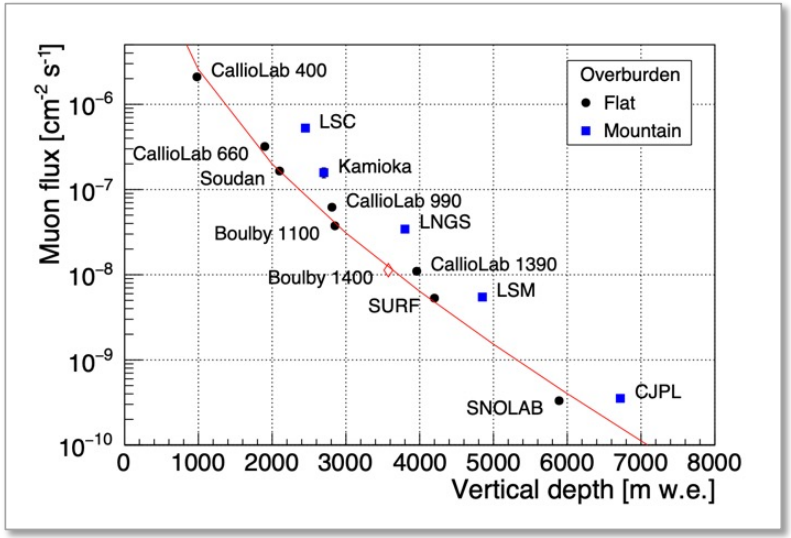


How does Boulby Compare?
- Low Radon levels (3 Bq/m³)
- Diverse science programme.
- Science and Industry partnership

Science and Technology Facilities Council

ICL Fertilizers

Lawrence Livermore National Laboratory · The University Of Sheffield. · Durham University · Department of Energy & Climate Change · AWE · NPL National Physical Laboratory · THE CROWN ESTATE · NASA · THE UNIVERSITY of EDINBURGH · FAIR-SPACE · And more…



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

Boulby Science Now & Future

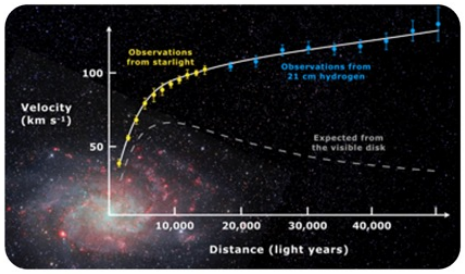
Particle physics and ultra-low background studies

Boulby Dark Matter Studies…

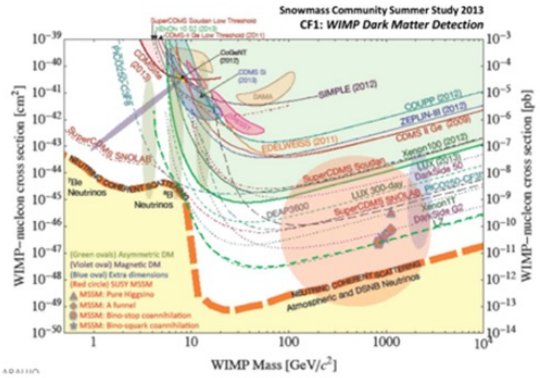
Science and Technology Facilities Council
Boulby Underground Laboratory

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



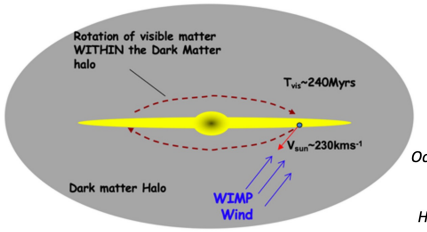
World DM particle search limits and future projections

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

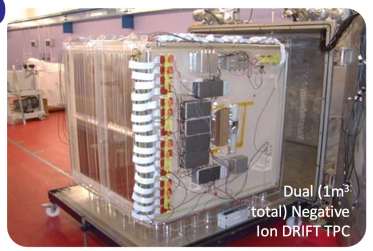
ZEPLIN-III @ Boulby

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**).

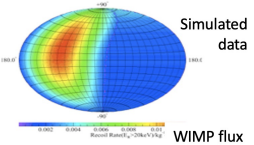


Our movement within the Dark Matter Halo



Directional detection

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

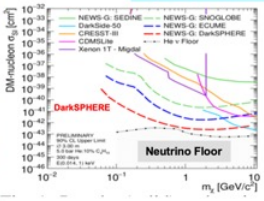


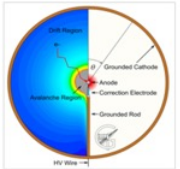
NEWS-G

Spherical Proportional Counter (SPC) studies @ Boulby

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

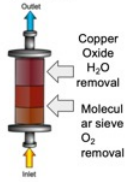
Al-S30 R&D Detector





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

Purpose-made gas filter



11-anode sensor

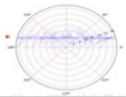
Direction of R&D at Boulby

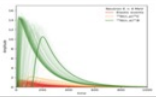
- Instrumentation development for NEWS-G at SNOLAB
  - Multi-anode sensor
  - Gas filtration
  - Rate effect studies
- Neutron spectroscopy (N_2)
  - Neutron BG surveys
  - Industrial applications
- **Towards scaled-up detector at Boulby, 3m diam. 5 Bar He-CH_4H_{10}: DarkSPHERE**

Simulation study of neutron interactions in the S30 at Boulby

Neutron Beam

4 MeV





Boulby Science Now & Future

Particle physics and ultra-low background studies

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

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

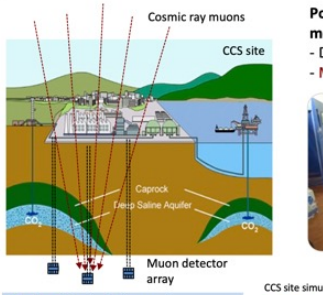
Applied low background particle physics, Earth and Environmental science, Astrobiology & Planetary Exploration Technology Development.

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

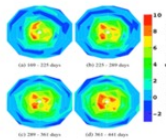


Potential for cheap, reliable, practical, real-time long-term monitoring of deep structures. Potential applications:
- Deep geological repository monitoring.
- Monitoring in Carbon Capture & Storage (CCS)


Muon-tides detector development


Bore hole detector installation

CCS site simulation

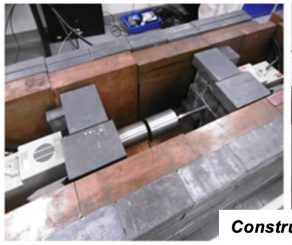
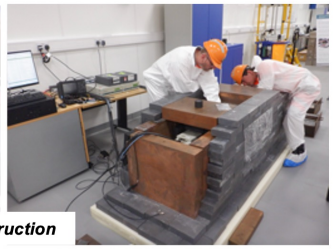


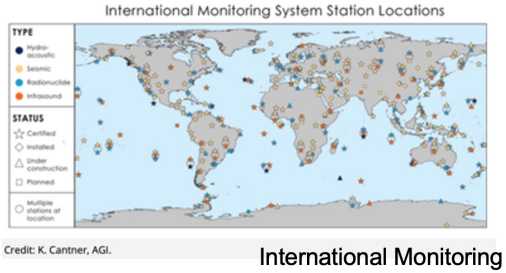
Status: Project phase 1 complete. Spin-out company for Muon Tomog applications created (Sheffield, Durham).
Next: UK-Japan proposed study of Muon Tomography for Tsunami early warning (2020)

Deep-Carbon Project: £1.4M funding from UK Dept of Energy & Climate change (DECC) & Premier Oil:
- Bore-hole detector development & testing
- Muon-Tides technology demonstrator
- Simulations of technique performance in CCS

RECON: CTBT Atmospheric Radionuclide Monitoring

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

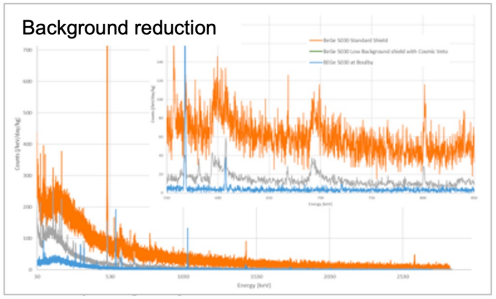


Construction



Credit: K. Cantner, AGI.

International Monitoring System Sites

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



Nuclide	Singles MDA Bq/m3	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-04	5	13	10		8.99E-08	0.089

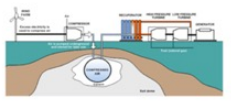
RESOURCE: Compressed gas energy storage R&D

Renewable Energy StOrage in UndeRground CavErns (*RESOURCE*)

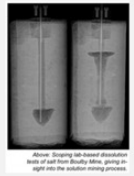
STFC Boulby Mine, BGS and the University of Cambridge

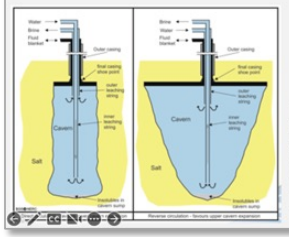
RESOURCE Collaboration:
British Geological Survey
Boulby Underground Lab
U.Cambridge & U.Manchester

Low Carbon Technologies

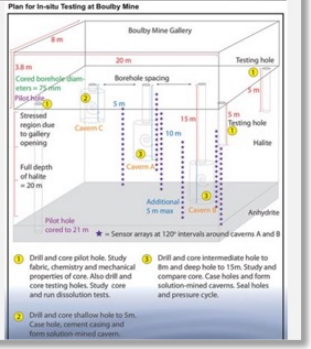


- Engineering solutions have been devised to store energy whilst production is high and feed it into the grid when production is low (e.g. CAES, hydrogen storage)
- Helps to regulate the production of renewable energy





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



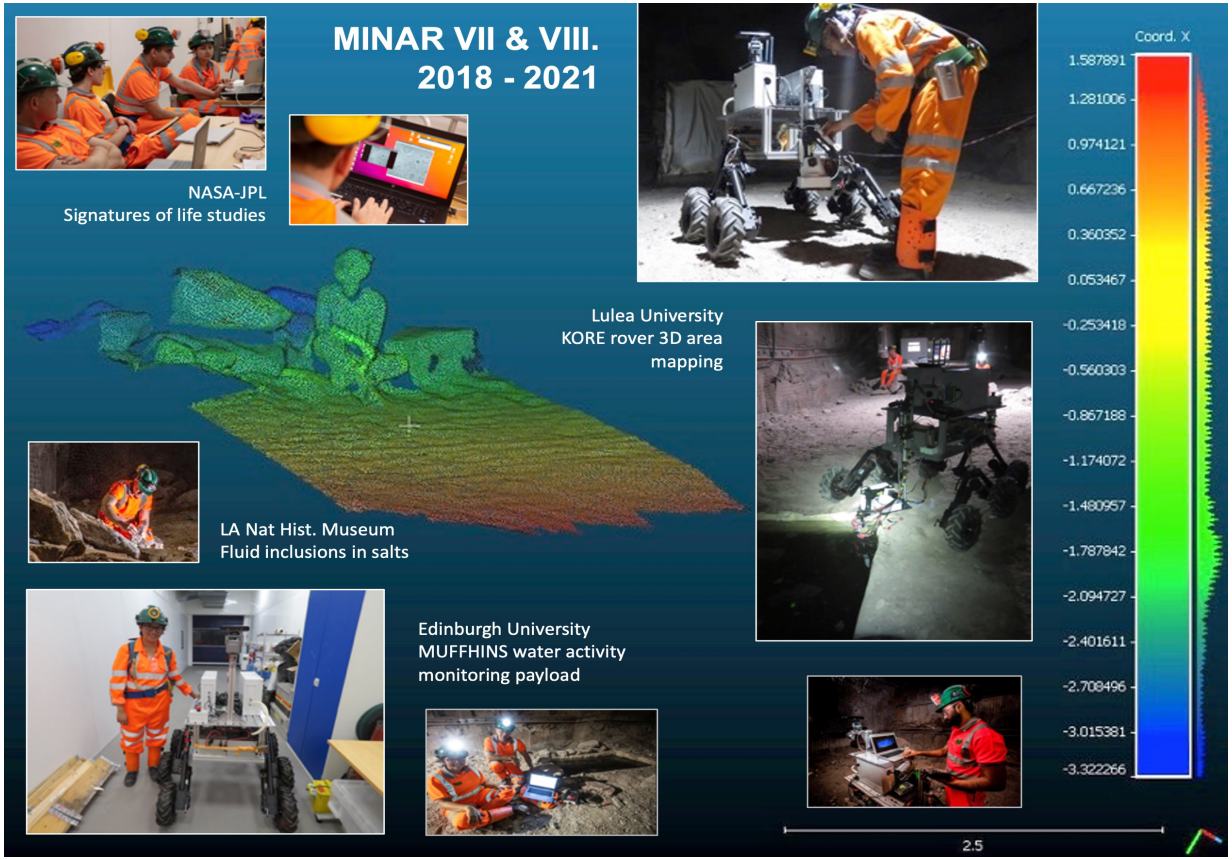
RECON: Radionuclide monitoring for nuclear security

Multidisciplinary Science

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

MINAR:

Astrobiology and planetary exploration technology development



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
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, 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

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 (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.

Science and Technology Facilities Council

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.

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.

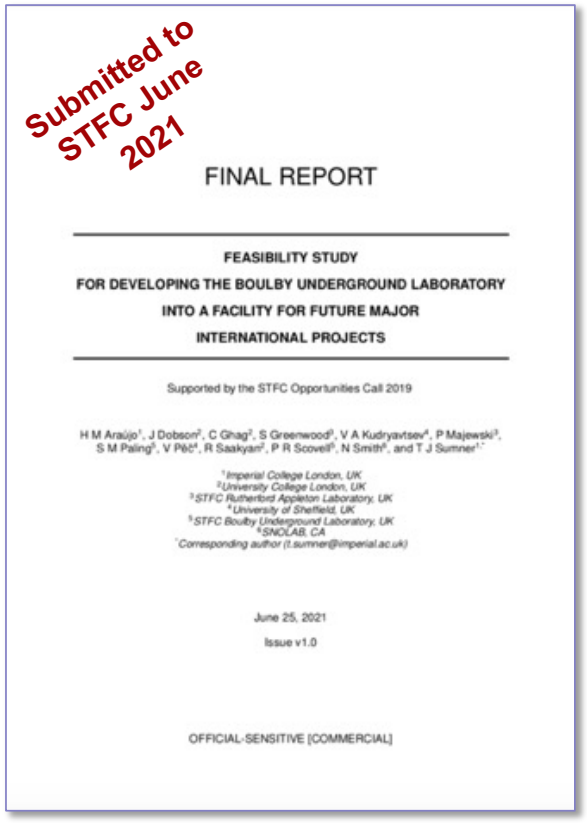
Short term: Maximally exploit the **current Boulby facility** to host world class Astro-particle Physics & Low Background Science, Earth & Environmental Science, Astrobiology & Planetary Exploration Studies

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)

Science and Technology Facilities Council
Boulby Underground Laboratory


Submitted to STFC June 2021

FINAL REPORT

FEASIBILITY STUDY
FOR DEVELOPING THE BOULBY UNDERGROUND LABORATORY
INTO A FACILITY FOR FUTURE MAJOR
INTERNATIONAL PROJECTS

Supported by the STFC Opportunities Call 2019

H M Araújo[1], J Dobson[2], C Ghag[2], S Greenwood[3], V A Kudryavtsev[4], P Majewski[3], S M Paling[3], V Pěč[4], R Saakyan[2], P R Scovell[5], N Smith[6], and T J Sumner[1,*]

[1]Imperial College London, UK
[2]University College London, UK
[3]STFC Rutherford Appleton Laboratory, UK
[4]University of Sheffield, UK
[5]STFC Boulby Underground Laboratory, UK
[6]SNOLAB, CA
[*]Corresponding author (t.sumner@imperial.ac.uk)

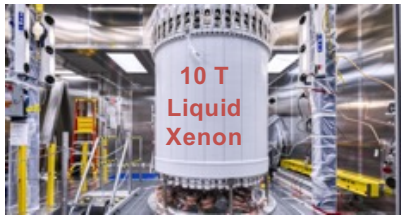
June 25, 2021
Issue v1.0

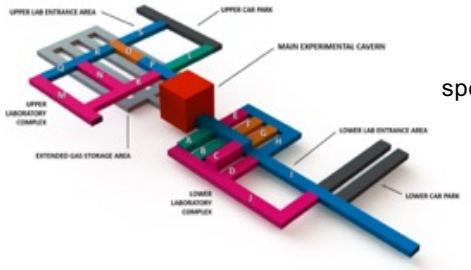
OFFICIAL-SENSITIVE [COMMERCIAL]

Boulby-FS (2020-21) Overview:

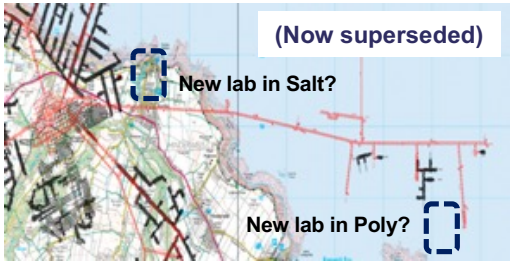
- **Community-led study of motivation, context and practicalities of creating a major new deep underground science facility in UK**
- Infrastructure specifications for potential projects (Dark Matter, Neutrinos & more).
- Conceptual designs for excavations and outfitting laboratories in 1.1km (Salt)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

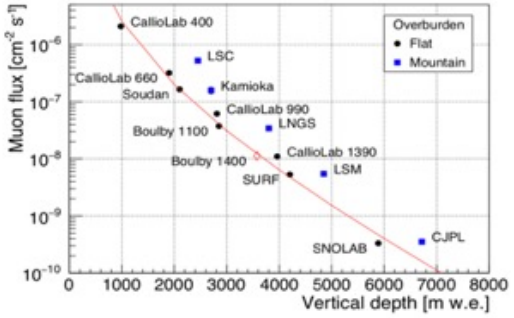
LZ @ SURF. Next generation in the UK?





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)

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

BDP Project Goal:

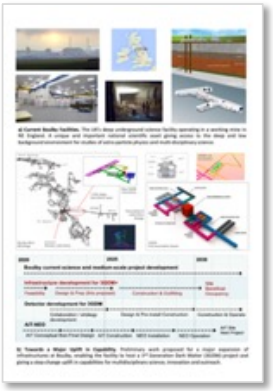
Next level planning and preparing for a…

"… **greatly expanded underground science facility in the North East, with the 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).

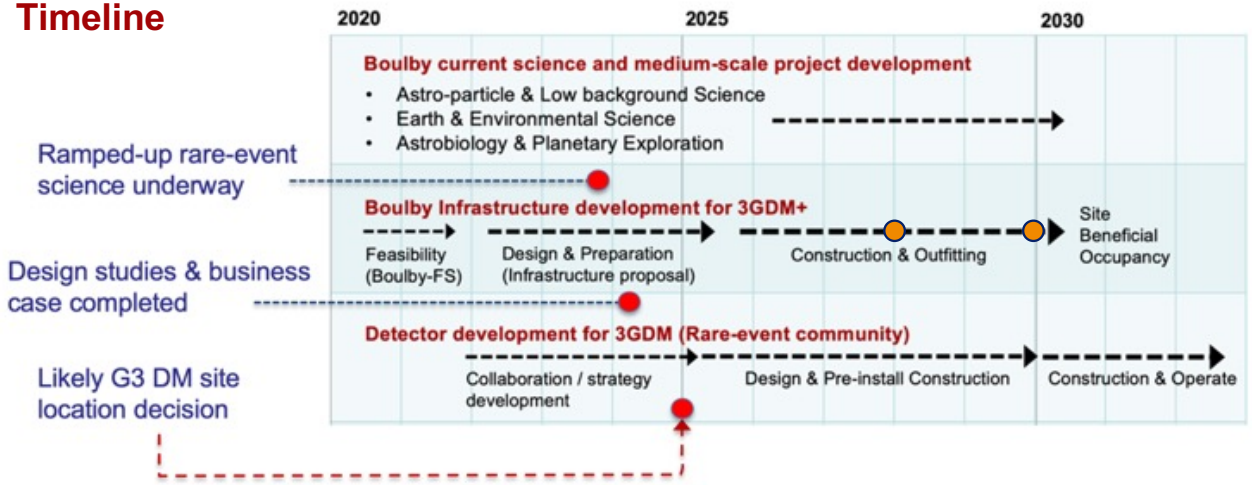
Tasks / Deliverables:

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



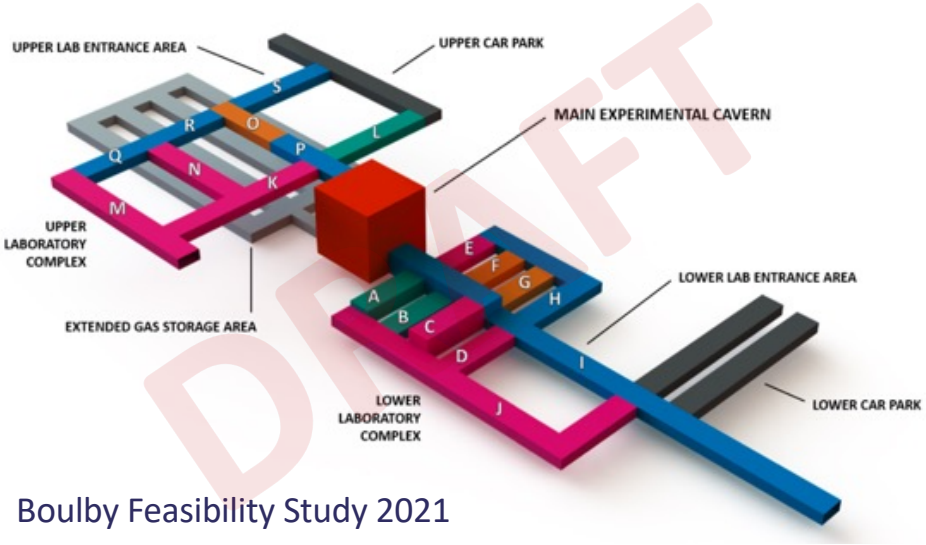
Boulby Development Project Infrastructure Bid: 2022-2025

Boulby Development Timeline



Task 1: Site and Facility Development

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



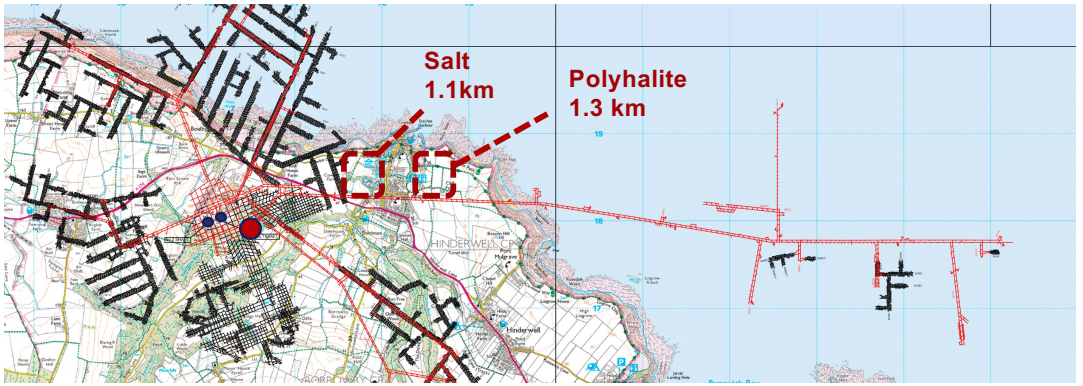
Boulby Feasibility Study 2021

Figure 6: Underground cavern design at 1,400 m 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.

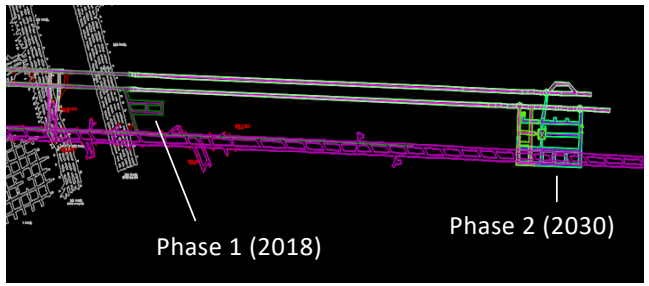
>30,000m^3 experiment and support space. High spec construction assembly and operation facilities

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

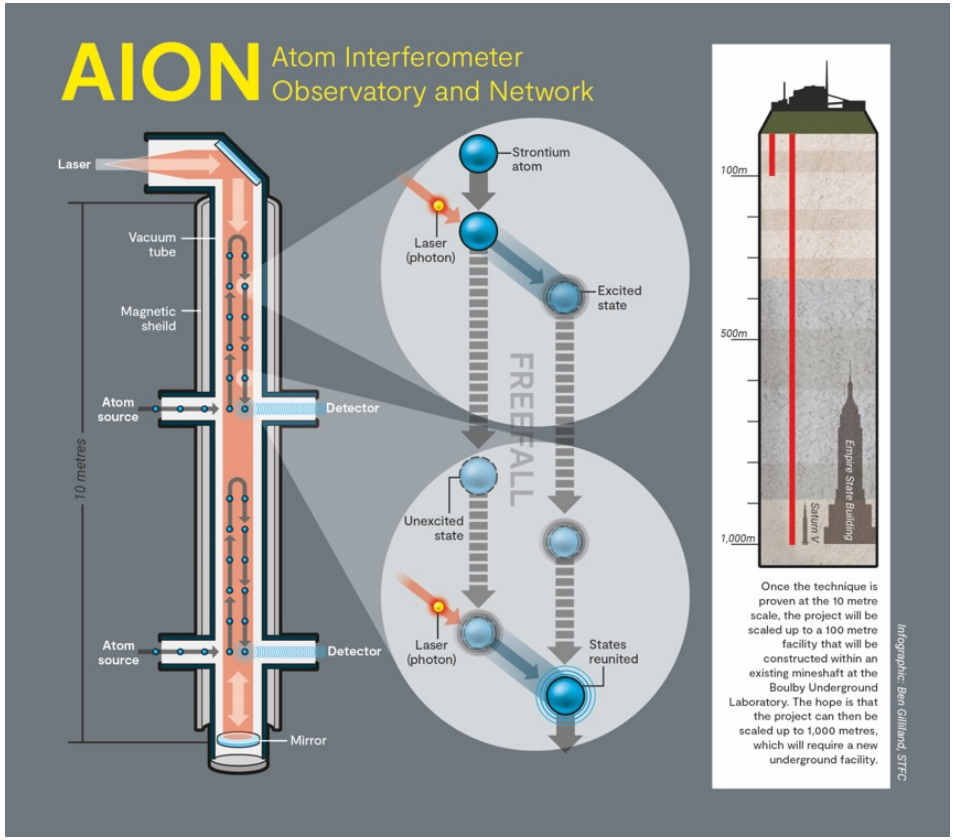


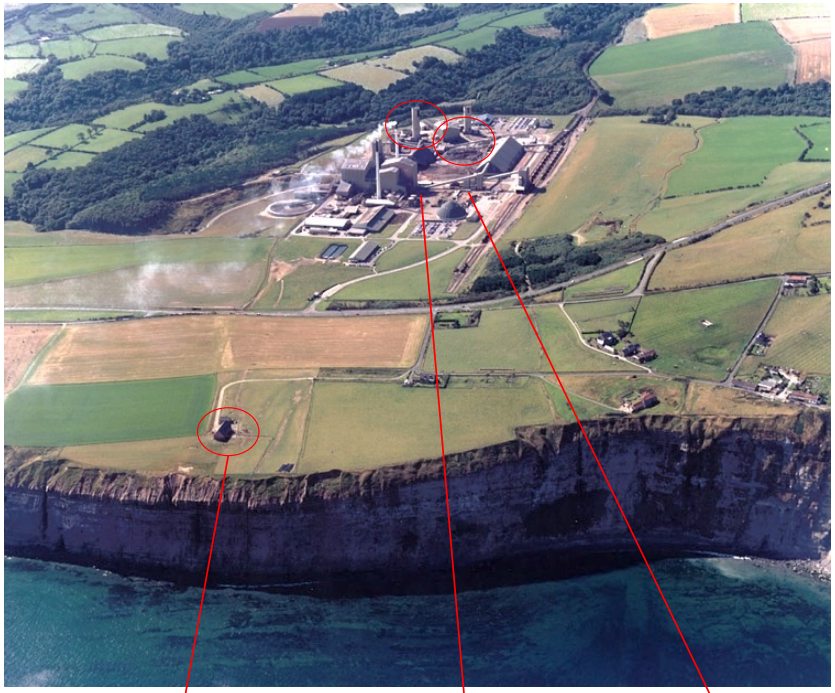
c) Next level excavation and facility build plans to be developed…

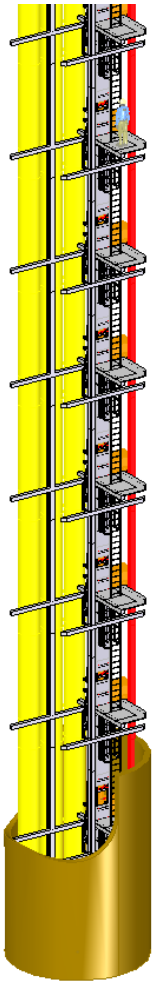
Prospects for Atomic Interferometry at Boulby…

Science and Technology Facilities Council
Boulby Underground Laboratory

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.







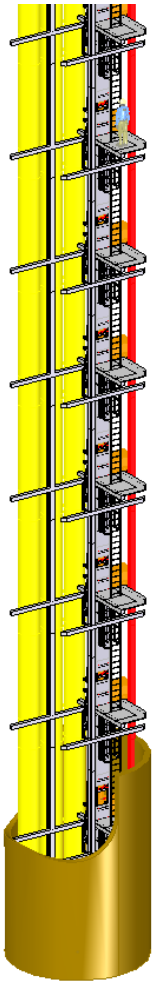
Prospects for Atomic Interferometry at Boulby…

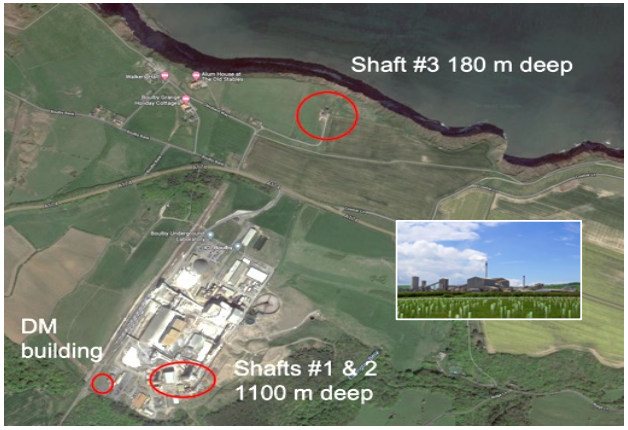
Science and Technology Facilities Council
Boulby Underground Laboratory

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



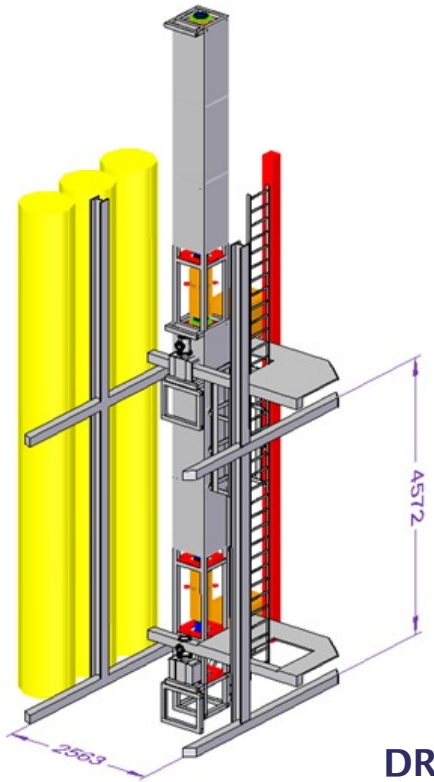


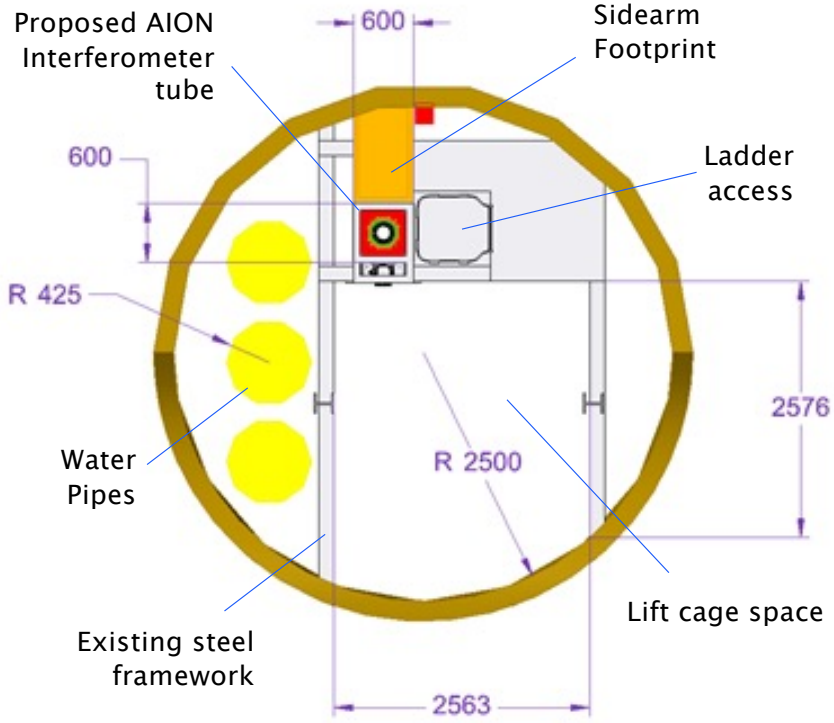
Sean Paling. Boulby Underground Lab. 2023

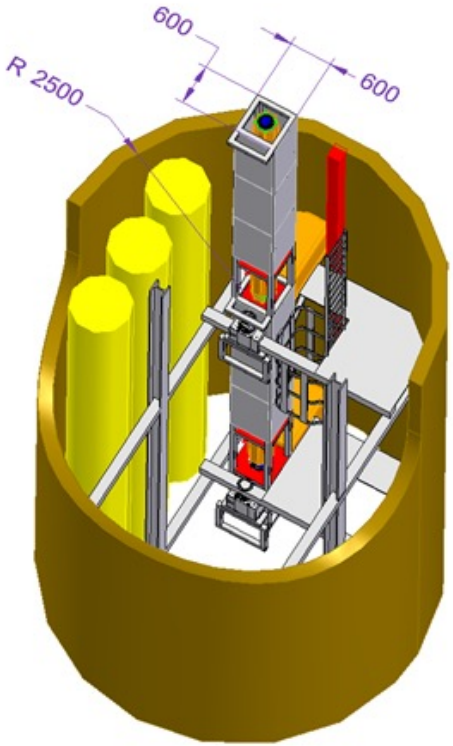
Prospects for Atomic Interferometry at Boulby…

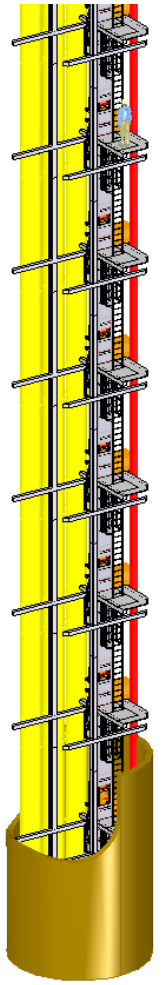
Science and Technology Facilities Council
Boulby Underground Laboratory

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…

Science and Technology Facilities Council
Boulby Underground Laboratory

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

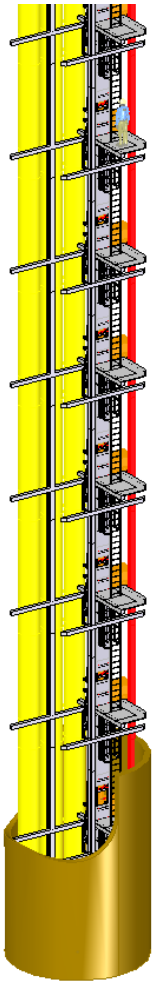
AION

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.

AION



Sean Paling. Boulby Underground Lab. 2023

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

Sean Paling. Boulby Underground Lab. 2023

Summary…

Science and Technology Facilities Council
Boulby Underground Laboratory

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 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+