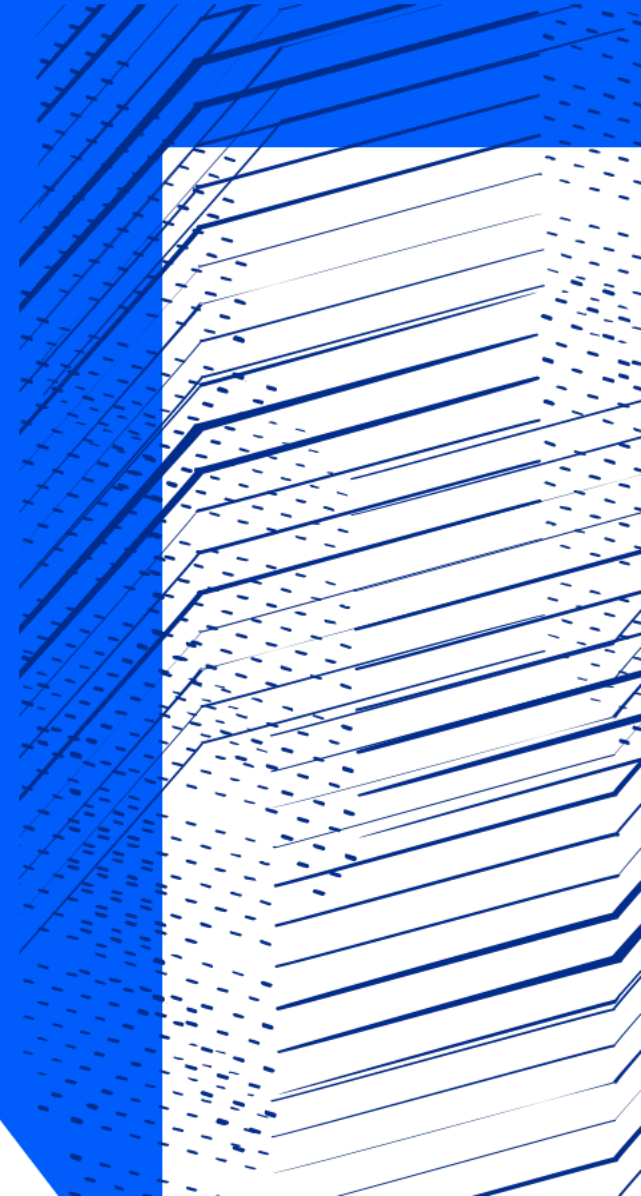




Science and
Technology
Facilities Council

Potential and Opportunity for Atomic Interferometry Projects at Boulby / UK.

Sean Paling
Boulby Underground Laboratory
Science and Technology Facilities Council



Boulby Underground Laboratory (UK)



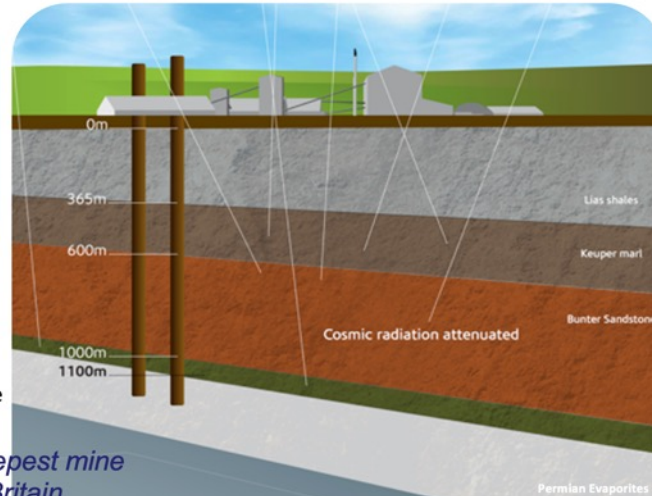
Boulby Underground Laboratory

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

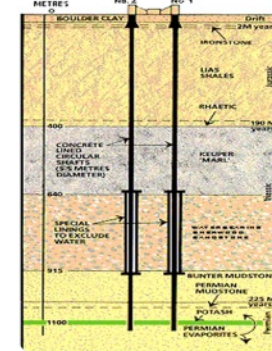


A **QUIET** place in the Universe



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.



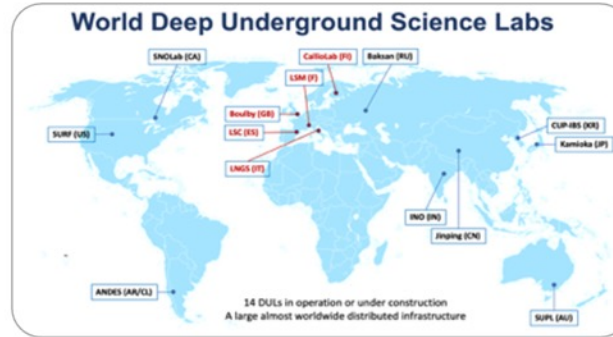
Boulby Underground Laboratory (UK)



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 10 (+2) onsite staff and supported by Rutherford Appleton Lab (PPD).
- Mine operators ICL-UK provide wide-ranging operational & high level support.

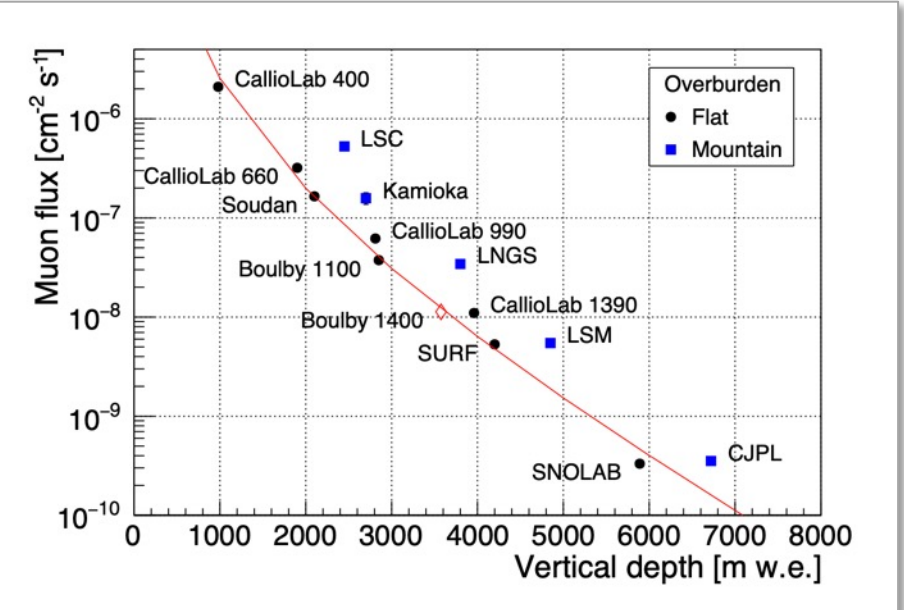


How does Boulby Compare?

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



And more...



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



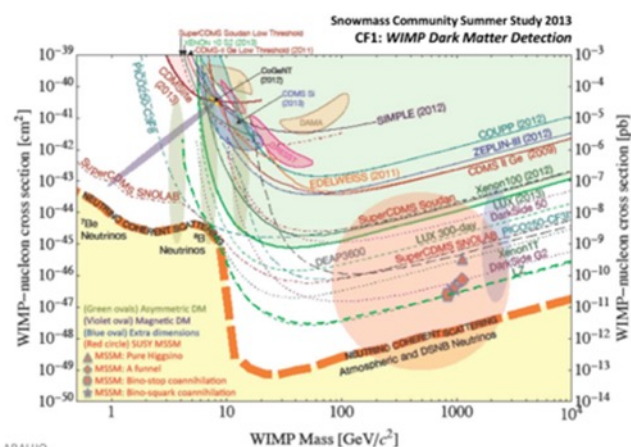
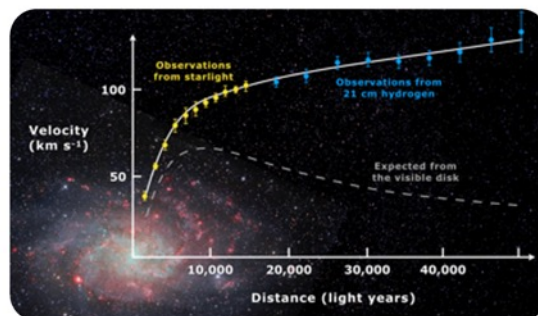
Boulby Dark Matter Studies...



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



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

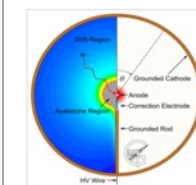
8 ULB Ge detector systems, 2 XIA alpha counters, Rn emanation, ICPMS to come

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

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.



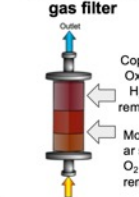
SPC concept: Variable target
Low E_{th} , Low mass sensitivity

Simulation study of
neutron interactions
in the S30 at Boulby



AI-S30 R&D Detector

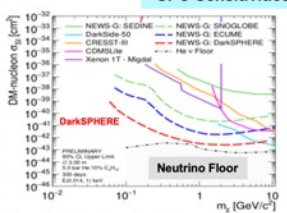
Purpose-made
gas filter



11-anode sensor

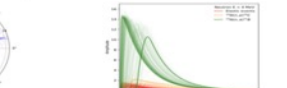
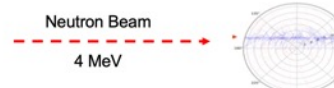


SPC Sensitivities



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**



Multidisciplinary Science

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



NASA-JPL
Signatures of life studies

MINAR VII & VIII.
2018 - 2020



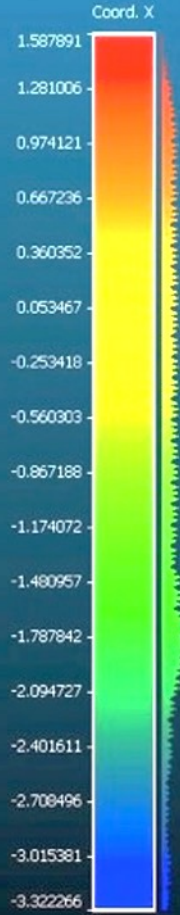
Lulea University
KORE rover 3D area
mapping



LA Nat Hist. Museum
Fluid inclusions in salts



Edinburgh University
MUFFHINS water activity
monitoring payload



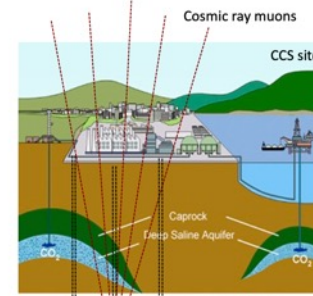
2.5



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)

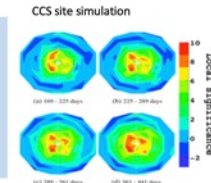


Muon-tides detector development



Bore hole detector installation

Status: Project phase 1 complete. Spin-out company for Muon Tomography 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:

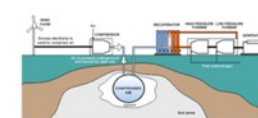
- Bore-hole detector development & testing
- Muon-Tides technology demonstrator
- Simulations of technique performance in CCS

Renewable Energy StOrage in UndergRound CavErns (RESOURCE)

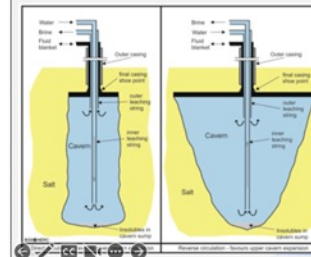
STFC Boulby Mine, BGS and the University of Cambridge

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

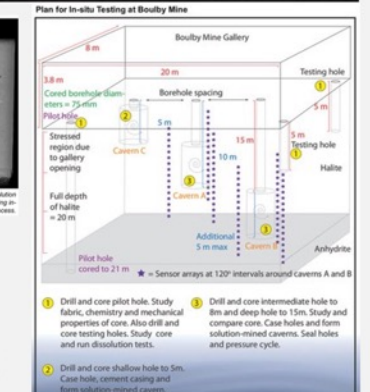
Low Carbon Technologies



- 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



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, 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/P
BUTTON-30 – Nuclear security R&D	A
RECON+ - Nuclear Security R&D	A/P
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)		
<p>Particle Physics and Low Background Science:</p> <p>Dark Matter: Major Next Gen Experiments:</p> <ul style="list-style-type: none">• Xenon (XLZD)• Argon (DarkSideLM+)• Gas (DarkSPHERE+) <p>Neutrinos:</p> <ul style="list-style-type: none">• BUTTON-100+• DATUM (LEGEND Support),• SoLAR / SOLAIRE +.... <p>Mat screening & LB Techniques: A world's best facility:</p> <ul style="list-style-type: none">• Ge, XIA, RnEm, ICPMS, Cleanlines & Engineering R&D <p>Misc Other:</p> <ul style="list-style-type: none">• AION-100• AION 1000• Nuclear Security Gamma spec• Quantum Computing Technology R&D?	<p>Target projects for a major new UK underground facility / campus</p>	
<p>Earth & Environmental Science:</p> <ul style="list-style-type: none">• Sustainable Energy R&D• Seismology Observatory• Geological Repositories R&D• Misc geology / Geophysics R&D		
<p>Astrobiology & Planetary Exploration:</p> <ul style="list-style-type: none">• 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.		
<p>Outreach and Education:</p> <ul style="list-style-type: none">• A National Centre for Science and technology outreach and education.		

Towards a Major New Boulby Facility

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 Araújo¹, J Dobson², C Ghag³, S Greenwood³, V A Kudryavtsev⁴, P Majewski⁵,
S M Paling⁶, V Peči⁷, R Saakyan⁸, P R Scovell⁹, N Smith⁹, and T J Sumner^{1,7}

¹Imperial College London, UK

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⁴University of Sheffield, UK

⁵STFC Boulby Underground Laboratory, UK

⁶SNOLAB, CA

⁷Corresponding author (t.sumner@imperial.ac.uk)

June 25, 2021

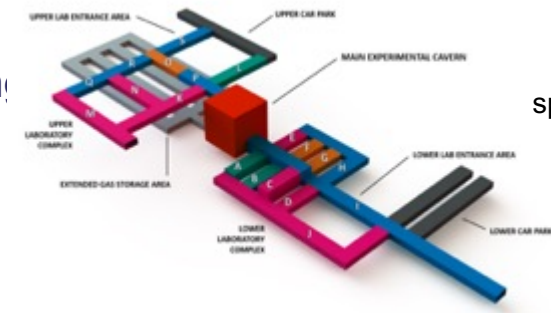
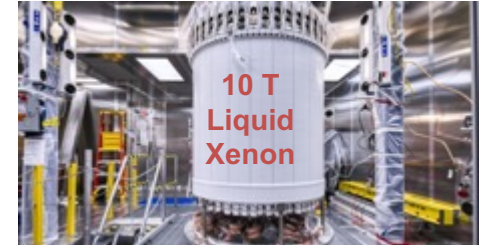
Issue v1.0

OFFICIAL-SENSITIVE [COMMERCIAL]

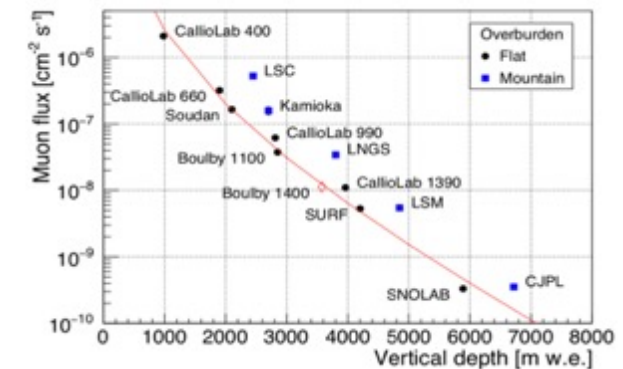
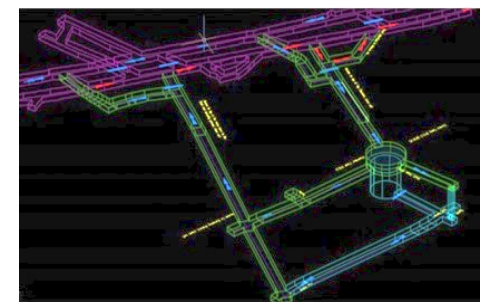
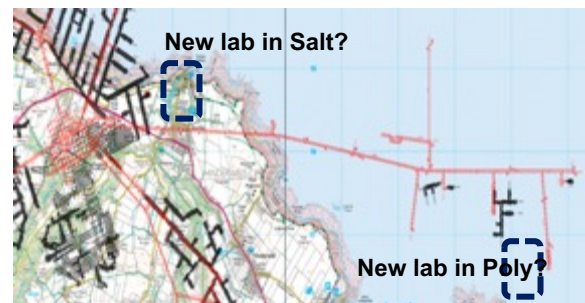
Boulby Feasibility Study (2020-21) Overview:

- 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, VLBAI & 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



Results / Outcomes

- Feasibility and timeliness confirmed
- Development Project (STFC) launched
- Implementation this decade

Next Step: Boulby Development Project (BDP)

BDP Project Goal:

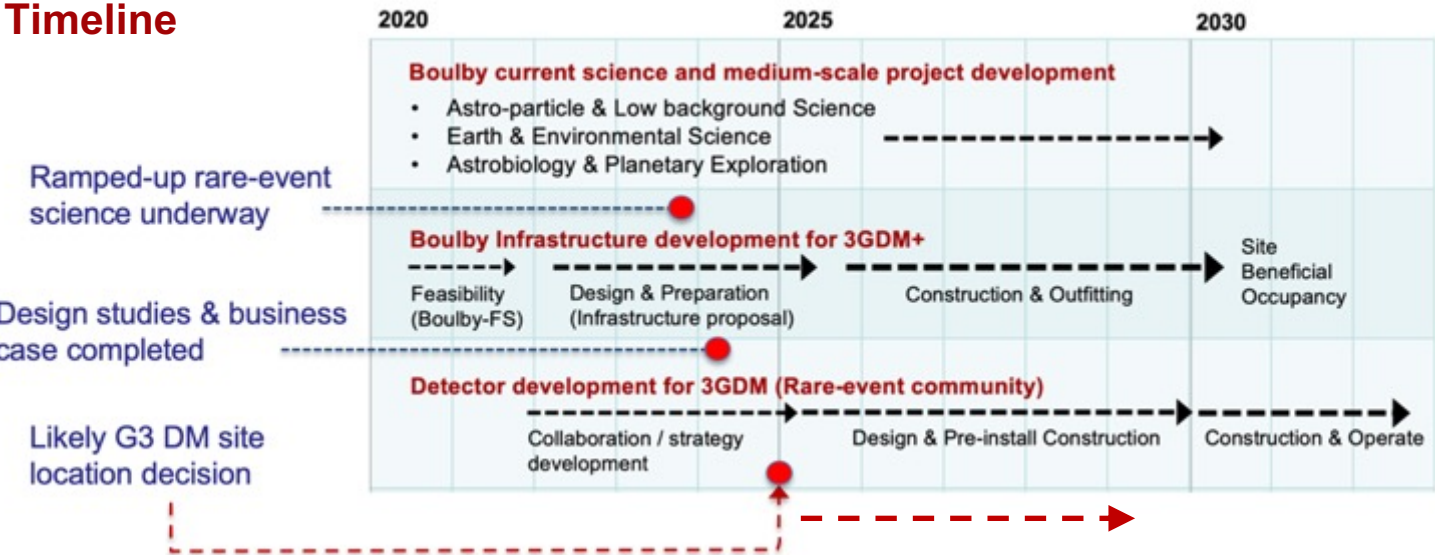
Next level planning and preparing for a...
“... greatly expanded underground science facility in the North East, with the potential to host a major international science infrastructure, such as a next generation dark matter experiment.” (STFC strategic delivery plan (2022-2025))

UKRI Preliminary Infrastructure Funding Granted: 3 year project (2022/3-2024/5).

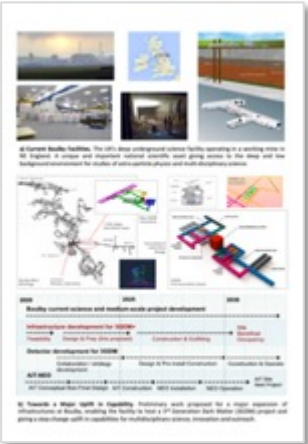
Tasks / Deliverables:

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

Boulby Development Timeline

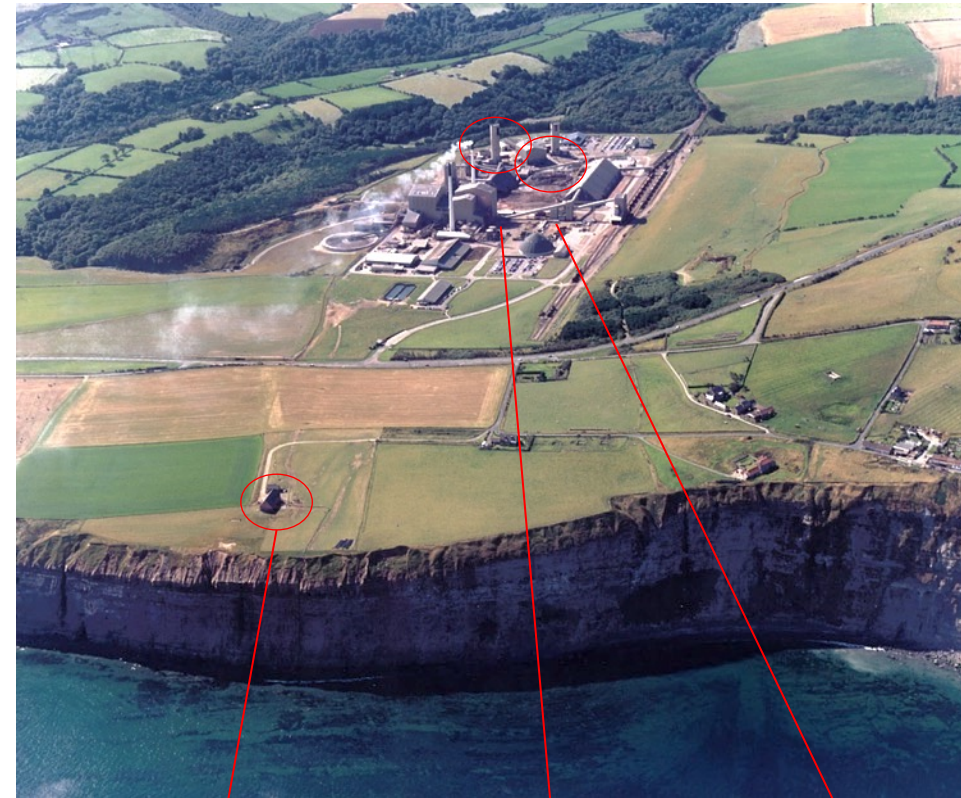
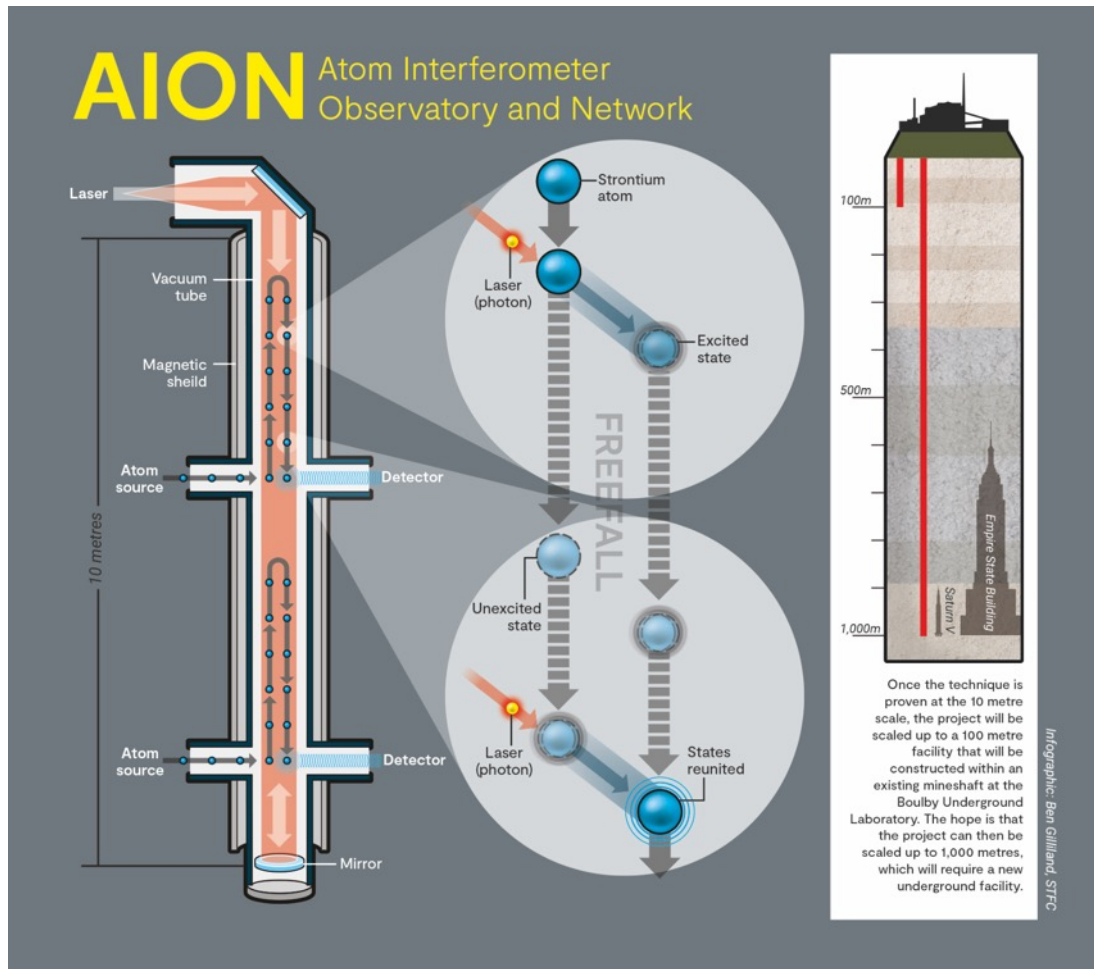


Boulby Development Project Infrastructure Bid: 2022-2025



Prospects for Atomic Interferometry at Boulby...

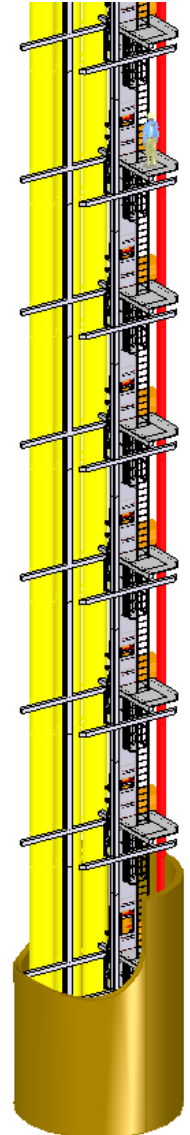
ALONGSIDE new underground laboratories to be excavated, there is strong user interest and STFC support for hosting atomic interferometry projects (**AION 100 & 1000**) in existing or new commercial shafts at or near Boulby Lab in NE England.



Shaft 3
Tailings Shaft
180m

Shaft 1
Rock Shaft
1.1km

Shaft 2
Personnel
1.1km

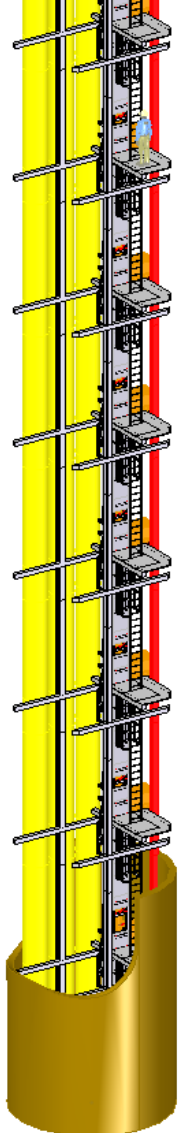
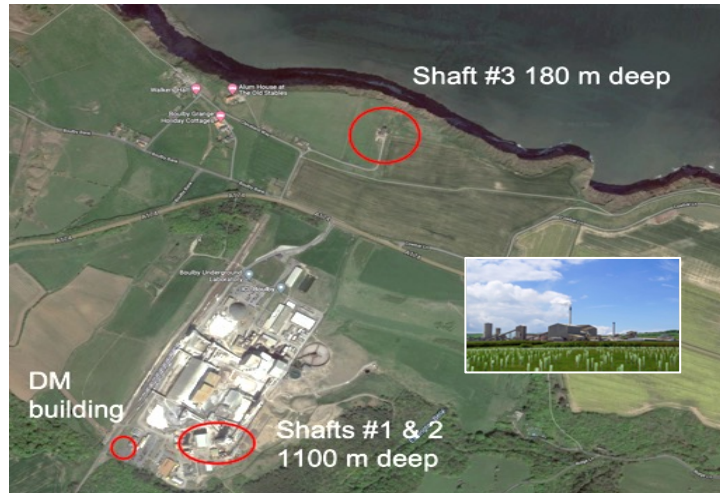


Prospects for Atomic Interferometry at Boulby...

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

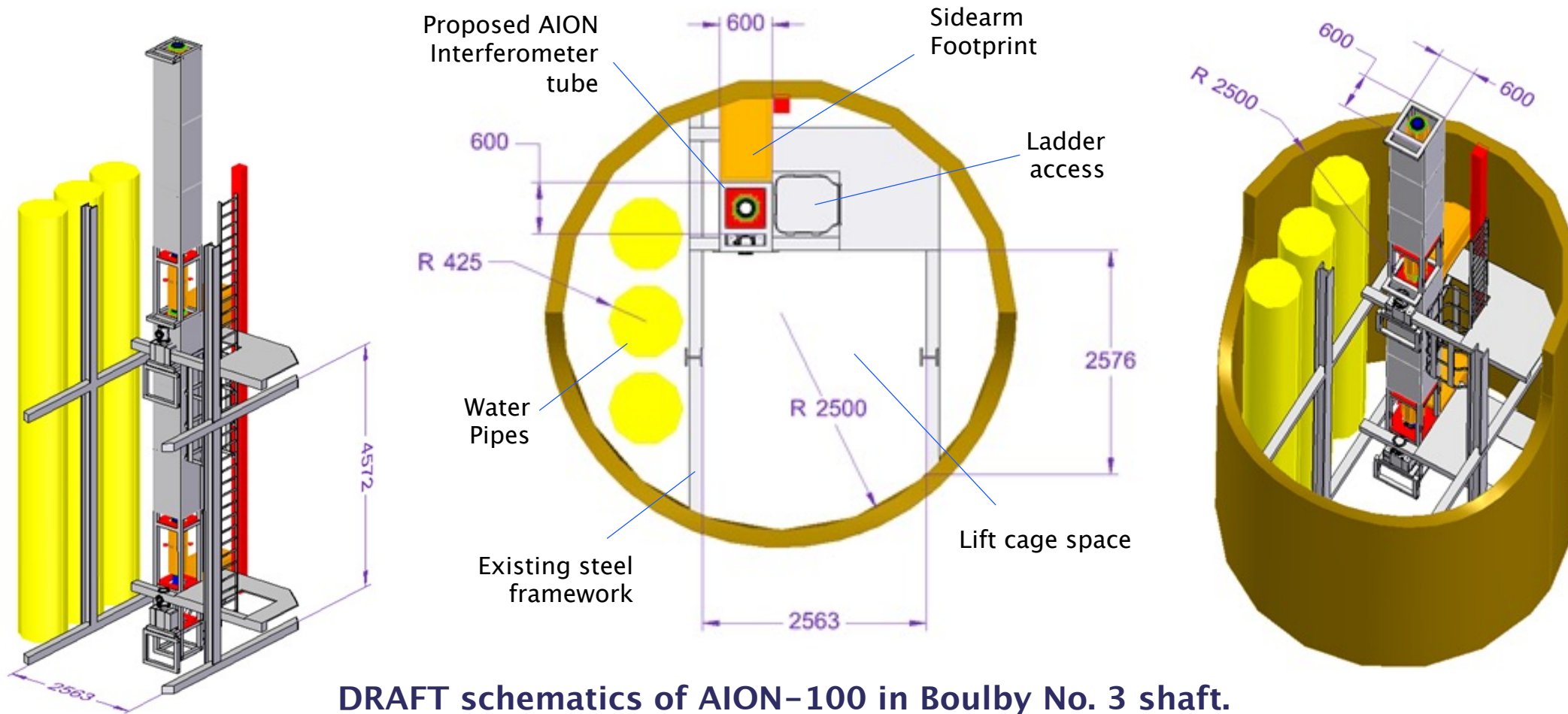
Tailings (no. 3) shaft specs:

- 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



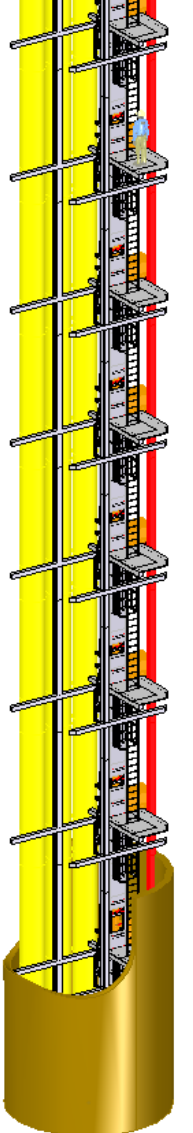
Prospects for Atomic Interferometry at Boulby...

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
 - 2.5T crane cover
 - Vertically moveable platform coupled
 - Interferometry services
 - Magnetic/thermal/seismic stability ?
 - Safety structures, egress routes
- (Initial evaluations)

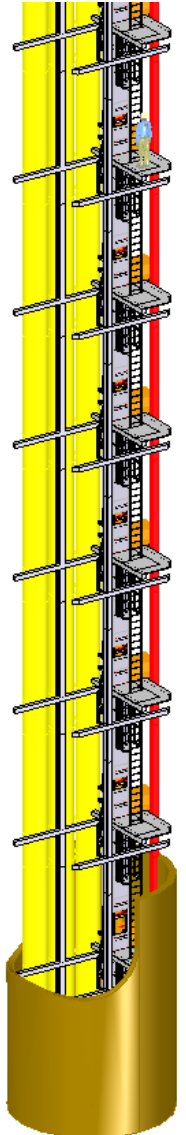
AION

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

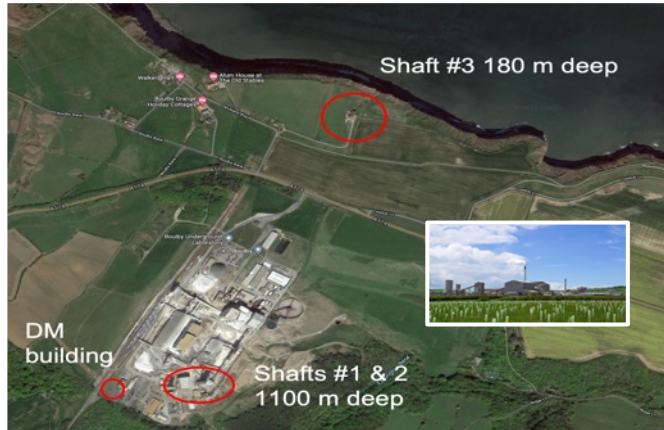
**Next-level
site evaluation &
preparation
studies in
planning phase
(Mar 23)**
*Buchmuller,
Coleman, Mitchell,
Newbold et al.*

AION

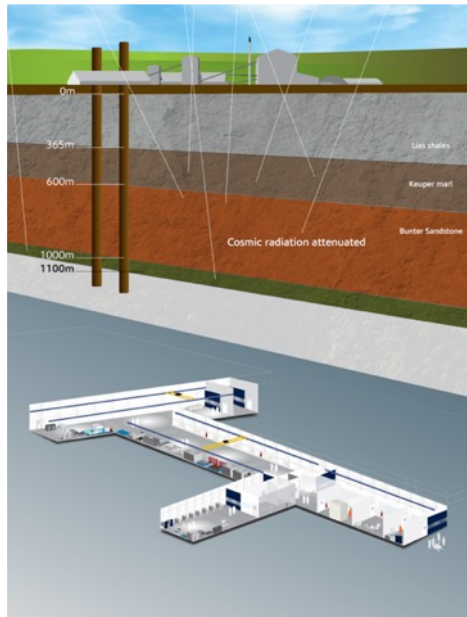


Prospects for Atomic Interferometry at / near Boulby...

Boulby & NE UK region site possibilities / opportunities for **AION-1000**.

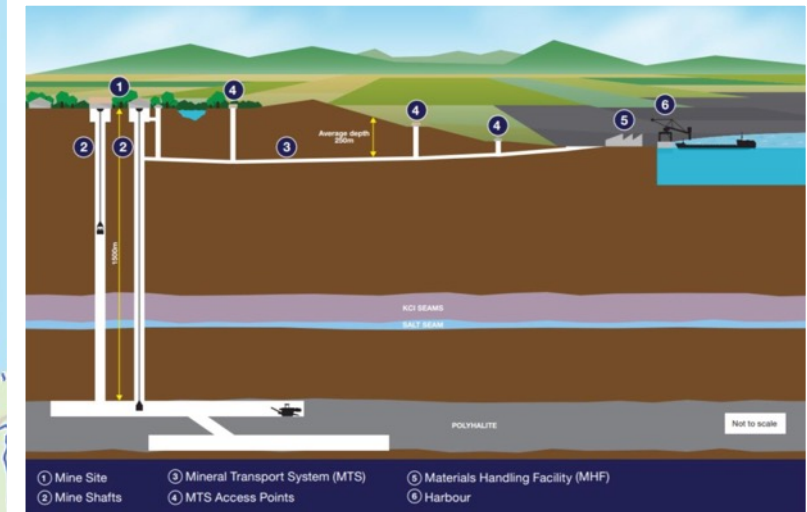
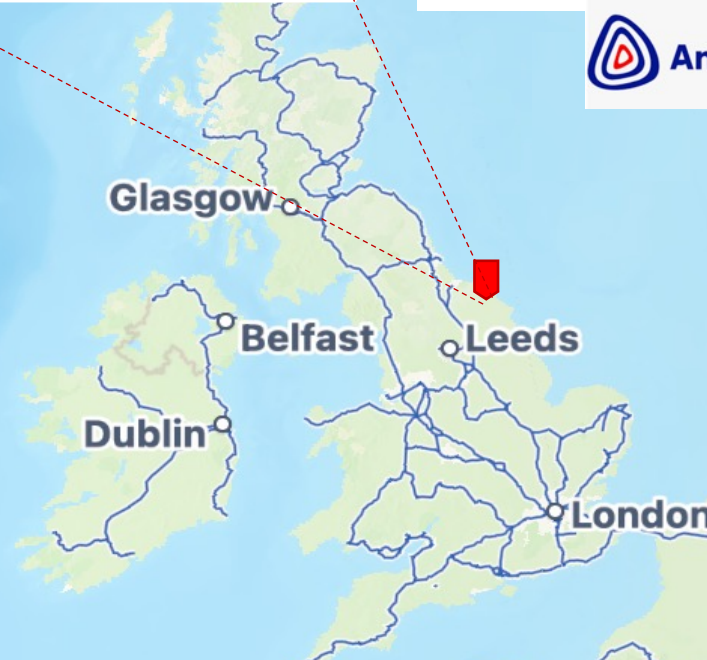


Woodsmith Mine
(Construction – Eta 2030):
2 x 1.5km depth shafts
7m diameter
37km Material Transport System (MTS) tunnel with
misc. >100m access shafts



Boulby Mine (existing):
Shafts 1 & 2
2 x 1.1km depth shafts
5m diameter
Current use:

- Shaft 1: Rock transport
- Shaft 2: Personnel



Discussions re: hosting AION-1000 at both sites underway.
Detailed engineering, logistics & background studies planned

Summary...

- **There is strong UK support for and interest in hosting both AION 100 and AION 1000 in NE England, at or near, Boulby Mine.**
- **Boulby Mine:**
 - Working polyhalite mine. Home of the UK's STFC Boulby Underground Laboratory
 - Very supportive mine hosts
 - 180m shaft 3 'tailings shaft' has potential as site for AION-100. Has depth, support infrastructure and likely free space.
 - Also two 1.1km main shafts at Boulby, with potential for later hosting of AION-1000
 - Early logistics evaluation positive; more detailed engineering, logistics and background studies being launched
- **Woodsmith Mine:**
 - New 1.5km depth polyhalite mine under construction <20km from Boulby
 - Also interested and supportive of AION hosting considerations.
 - Potential opportunities for both AION-100 & AION-1000

Next Steps?

- Detailed engineering, logistics and background studies to be completed over the next 12 months