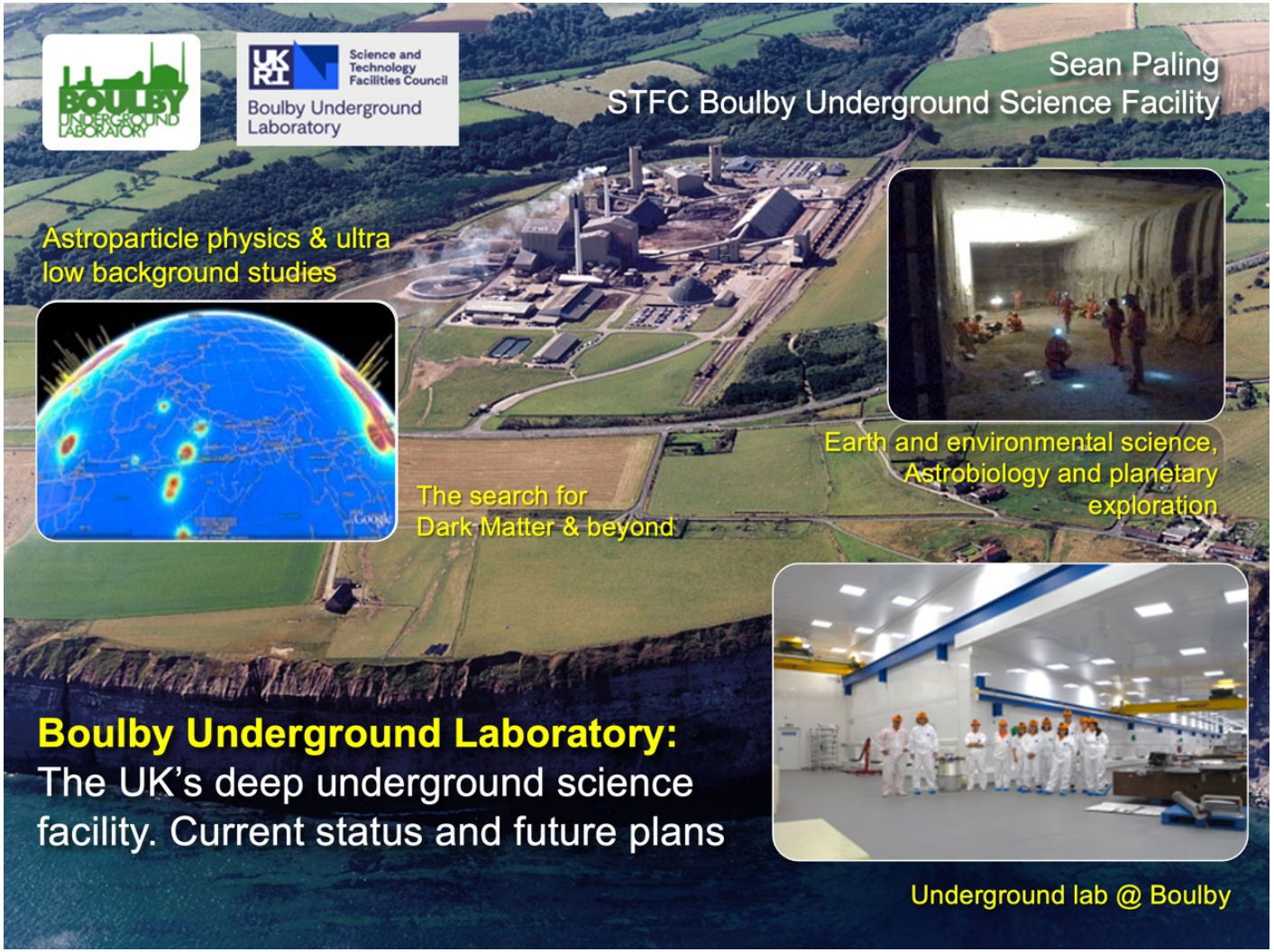
Science and Technology Facilities Council

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

Sean Paling
Boulby Underground Laboratory, UK



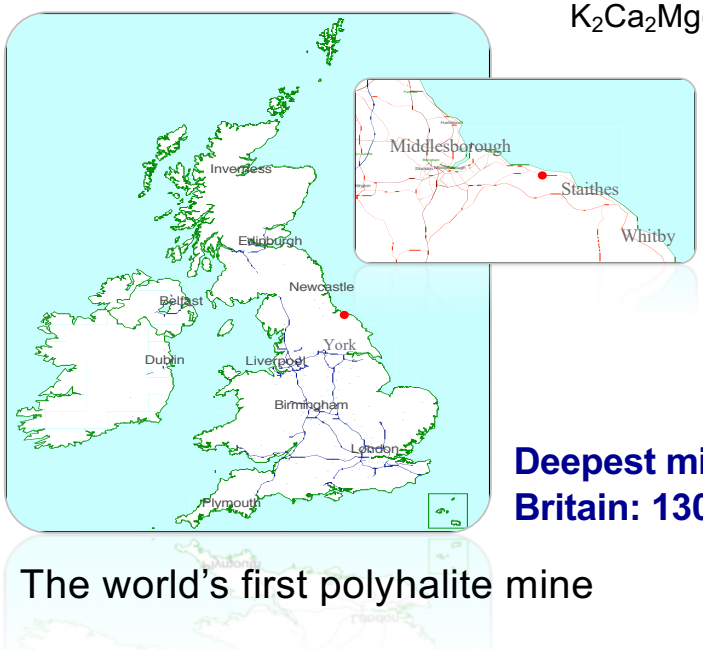
Sean Paling. Boulby Underground Lab. 2024

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.



Deepest mine in Britain: 1300km

The world's first polyhalite mine

Polyhalite: $K_2Ca_2Mg(SO_4)$

Ships worldwide for agricultural fertiliser

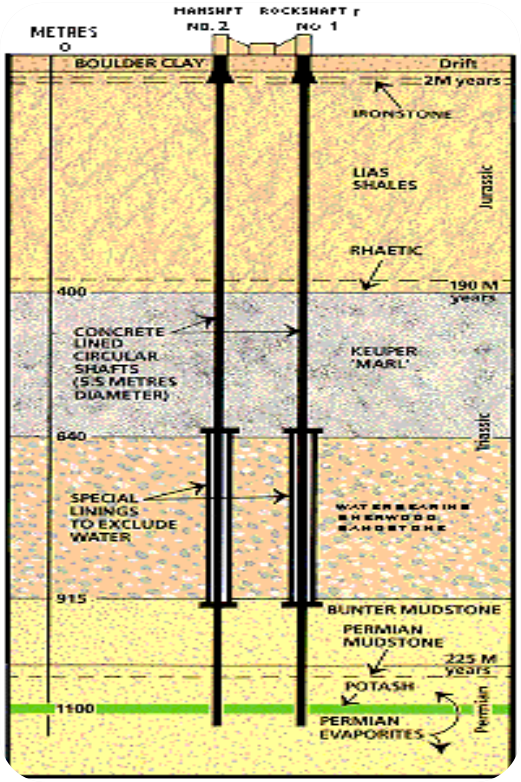
12 miles North of Whitby, N. Yorks

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.



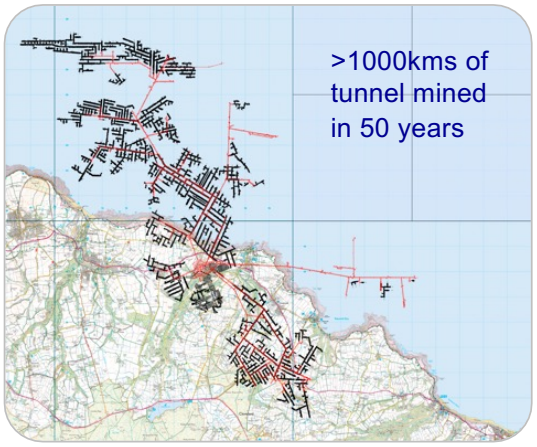
Boulby Geology

Polyhalite

Potash

Rock-Salt

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



Typical Boulby Salt Roadway

Zechstein Sea

Mine Shafts

Current Lab (2017)

ICL Fertilizers

UKRI Science and Technology Facilities Council

Boulby Underground Laboratory

Science and Technology Facilities Council
Boulby Underground Laboratory

Boulby Underground Laboratory

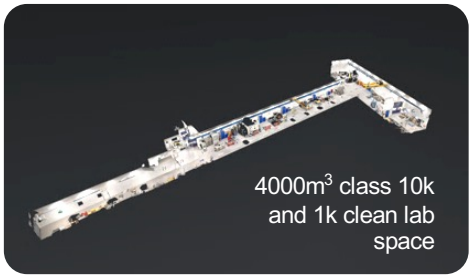
The UK's deep underground science facility operating in a working potash and salt mine.

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

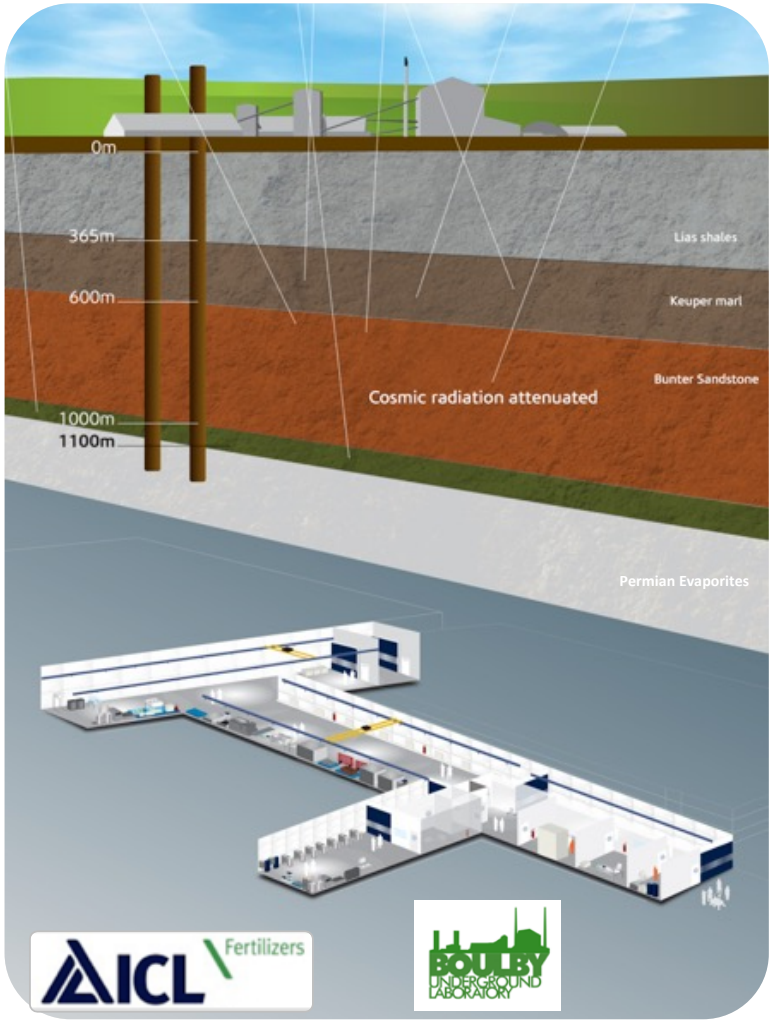
Outside Experimentation Area (OEA)

A QUIET place in the Universe



Lab entrance

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




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.

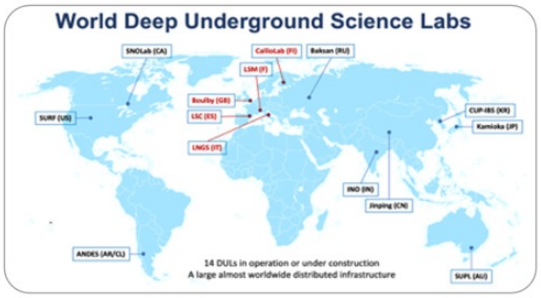
Boulby Underground Laboratory (UK)

Science and Technology Facilities Council
Boulby Underground Laboratory

Boulby Facility Details…

Science and Technology Facilities Council
Boulby Underground Laboratory

- 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.

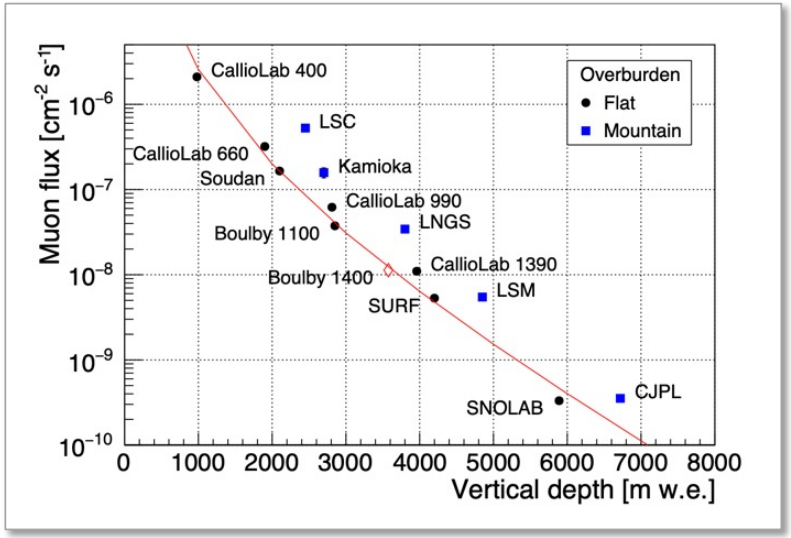


How does Boulby Compare?
- Low Radon levels (3 Bq/m³)
- Diverse science programme.
- Science and Industry partnership

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

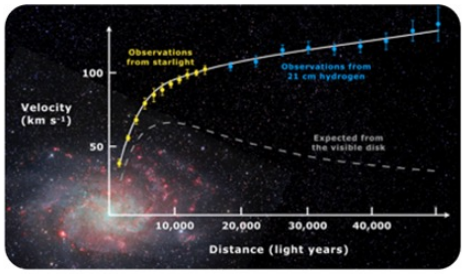
Particle physics and ultra-low background studies

Science and Technology Facilities Council
Boulby Underground Laboratory

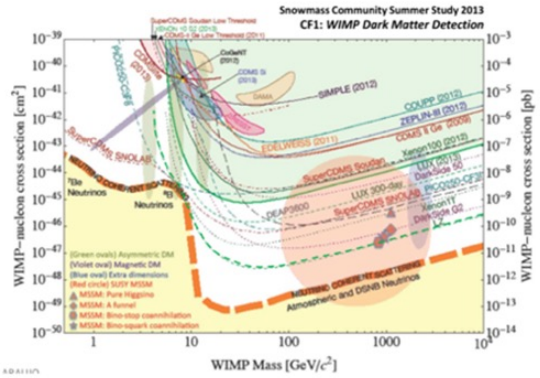
Boulby Dark Matter Studies…

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



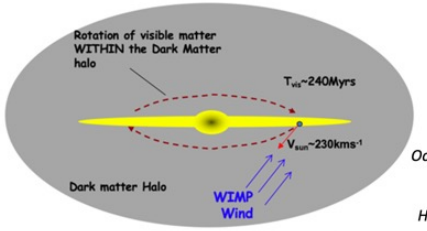
World DM particle search limits and future projections

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

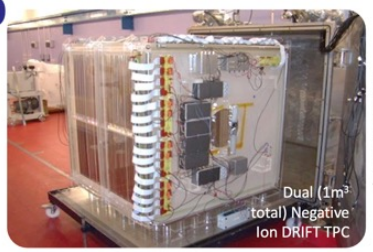
ZEPLIN-III @ Boulby

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**).

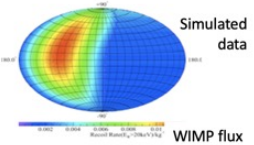


Our movement within the Dark Matter Halo



Directional detection

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

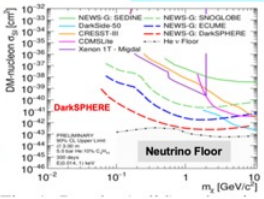


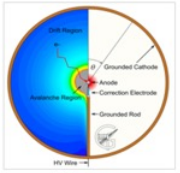
NEWS-G

Spherical Proportional Counter (SPC) studies @ Boulby

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

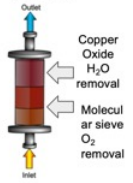
Al-S30 R&D Detector





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

Purpose-made gas filter



11-anode sensor

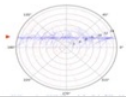
Direction of R&D at Boulby

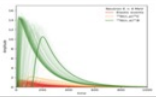
- Instrumentation development for NEWS-G at SNOLAB
  - Multi-anode sensor
  - Gas filtration
  - Rate effect studies
- Neutron spectroscopy (N_2)
  - Neutron BG surveys
  - Industrial applications
- **Towards scaled-up detector at Boulby, 3m diam. 5 Bar He-CH_4H_{10}: DarkSPHERE**

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)

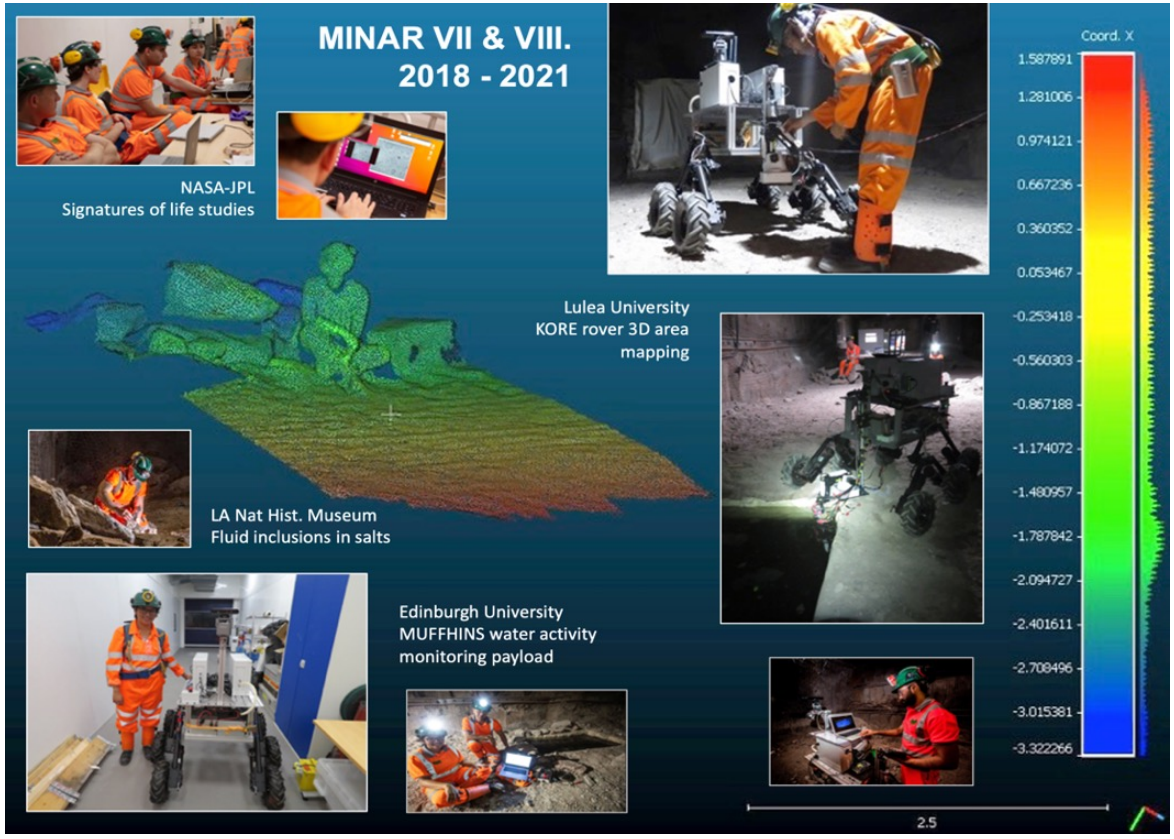
- ULB Germanium (8)
- XIA: Surface alphas (2)
- Radon Emanation *
- ICPMS *

* Commissioning

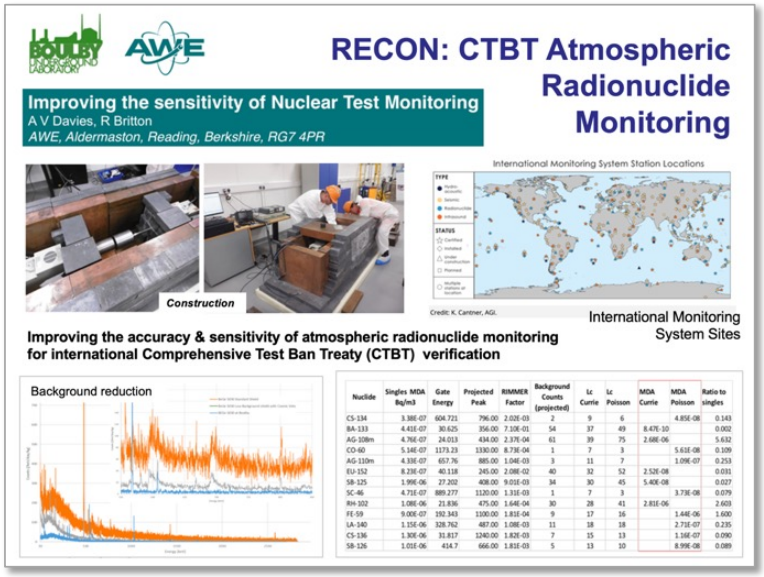
Multidisciplinary Science

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

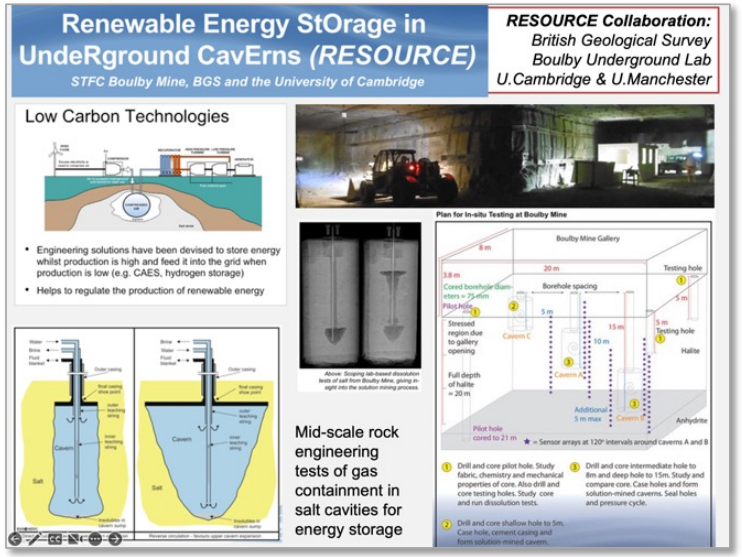
***MINAR**:*
Astrobiology and planetary exploration technology development



***RECON**:*
Atmospheric monitoring for nuclear security



***RESOURCE**:*
Compressed gas energy storage R&D



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

(Not comprehensive)

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 Underground Science:

→ **UKRI's Future Underground Dark Matter Experiments Fund - 2024**

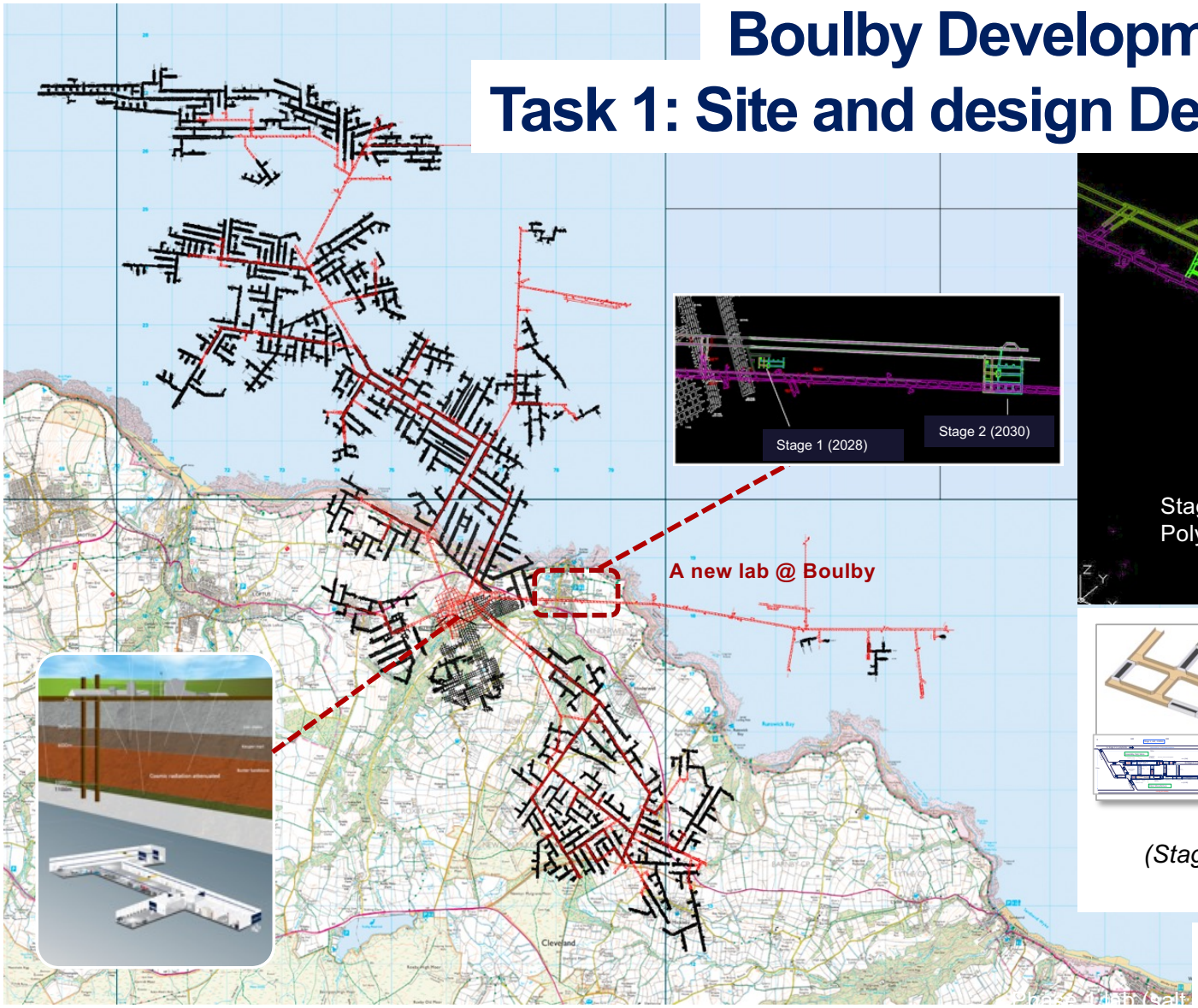
Medium-to long term: Prepare to build a **major new deep underground science facility** in the UK **to host next-generation world-leading science projects coming 2030+**

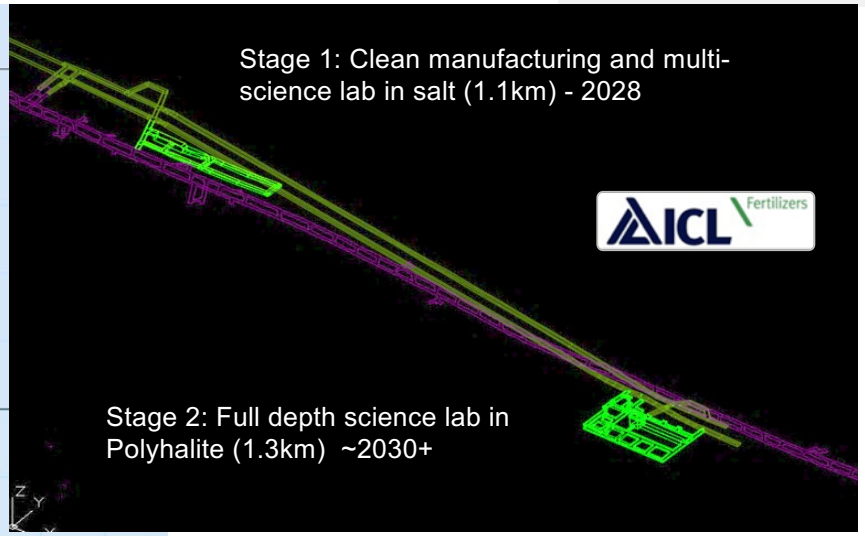
→ **Boulby Development Project:**

Plans & preparations for a major new multi-disciplinary Deep Underground Science Facility in the UK

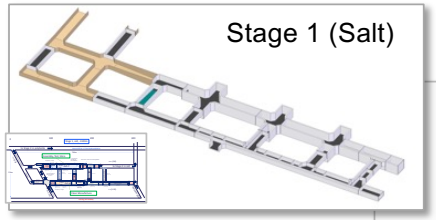
Boulby Development Project
Task 1: Site and design Development.

Science and Technology Facilities Council
Boulby Underground Laboratory

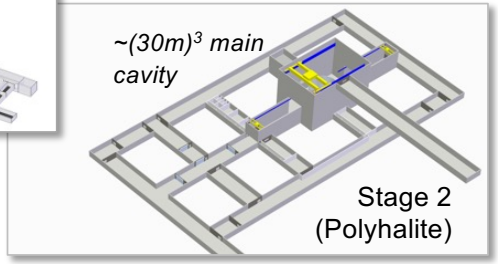




DRAFT: 2-stage Designs



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

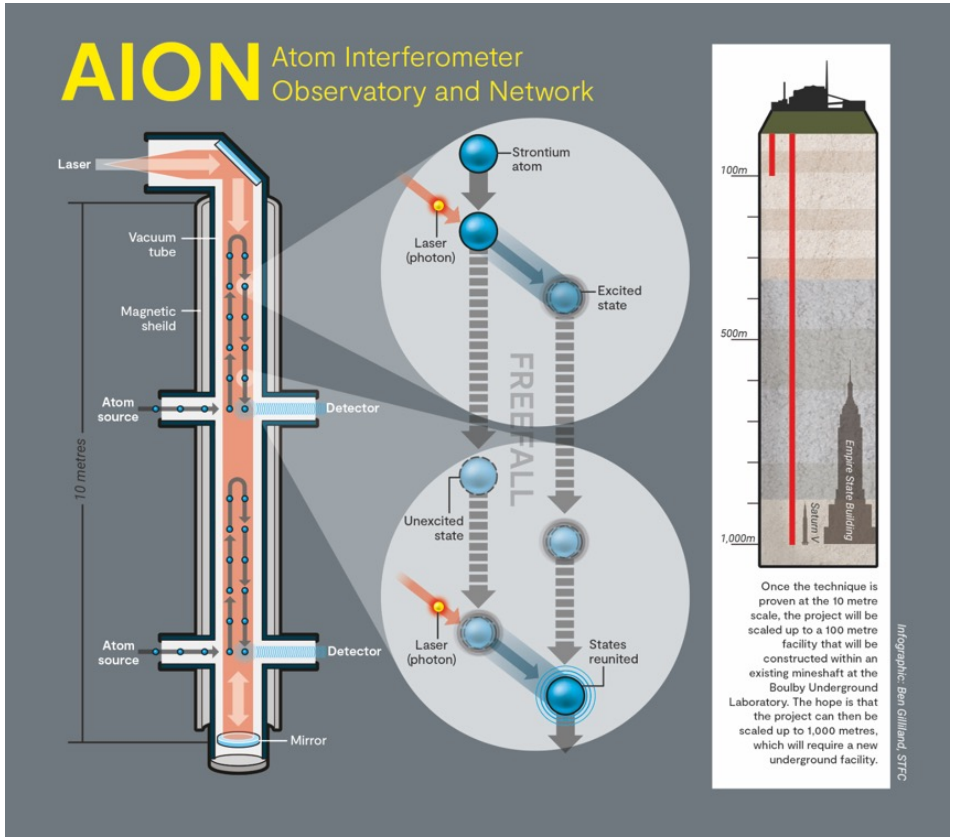


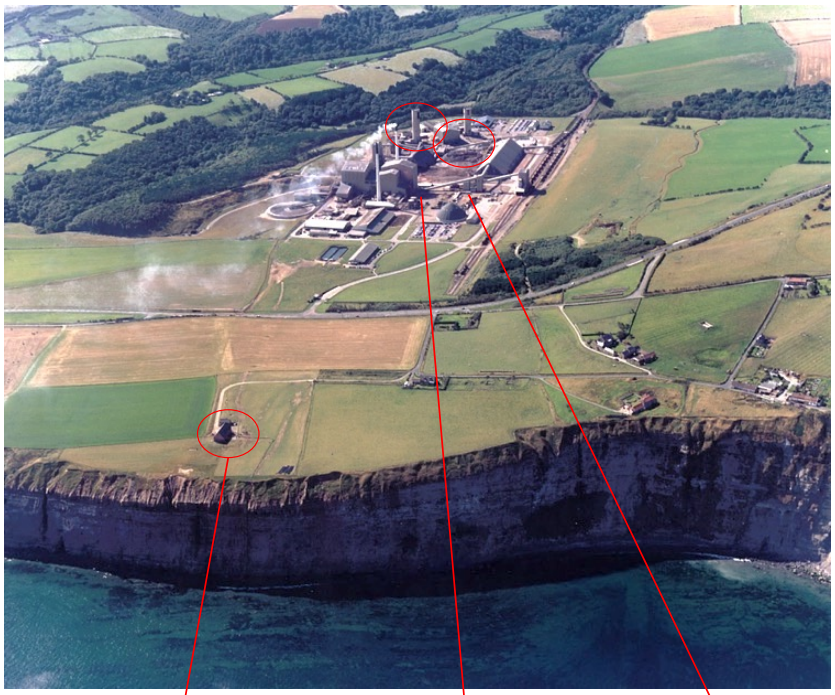
Excavations for stage 1 of expansion currently expected to begin mid-2024.

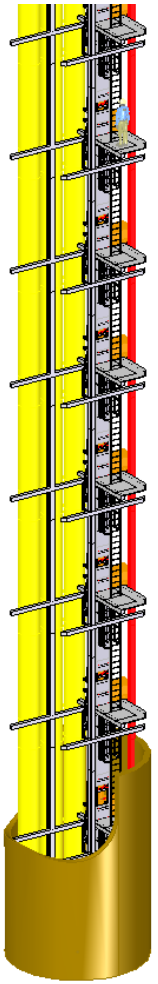
Prospects for Atomic Interferometry at Boulby…

Science and Technology Facilities Council
Boulby Underground Laboratory

ALONGSIDE new underground laboratories to be excavated, there is 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.







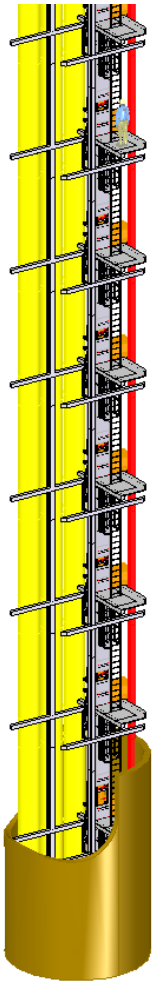
Prospects for Atomic Interferometry at Boulby…

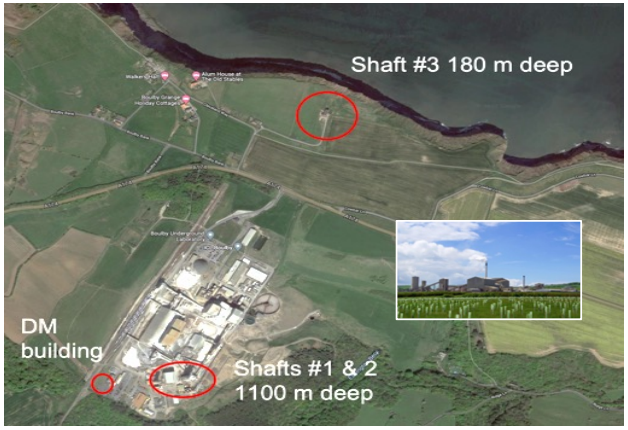
Science and Technology Facilities Council
Boulby Underground Laboratory

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

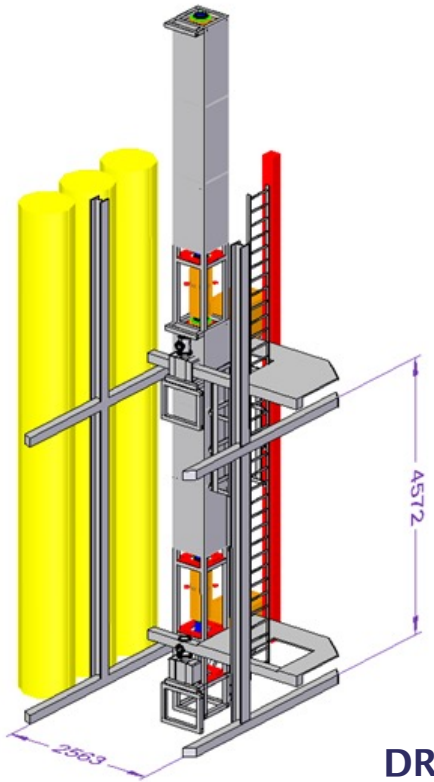


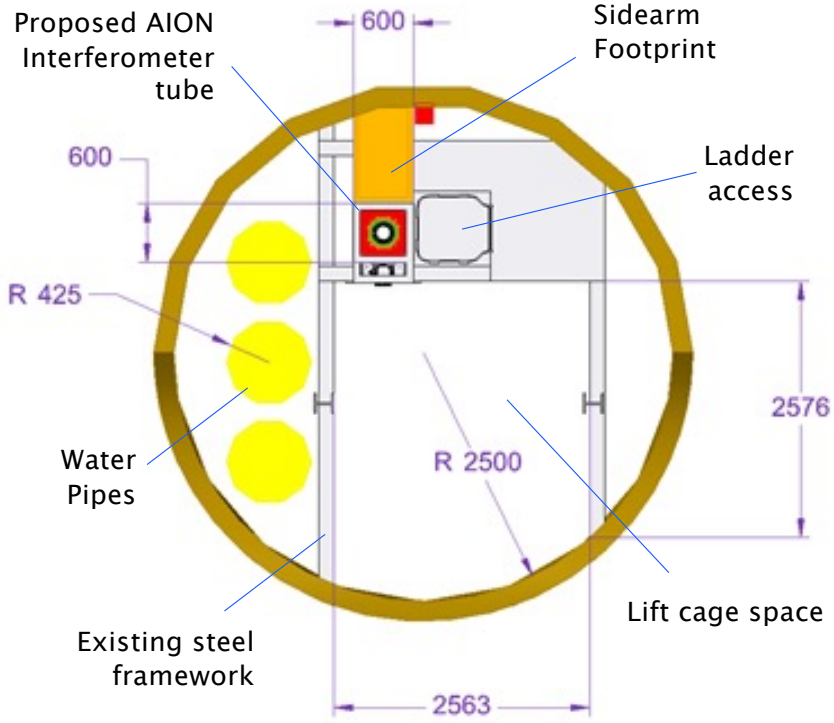


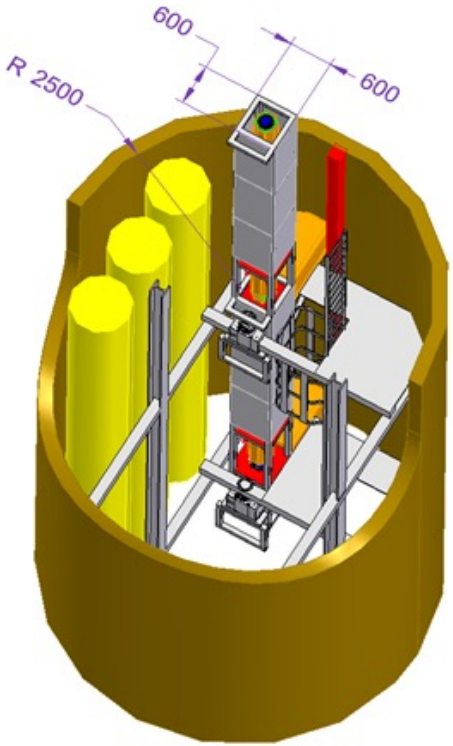
Prospects for Atomic Interferometry at Boulby…

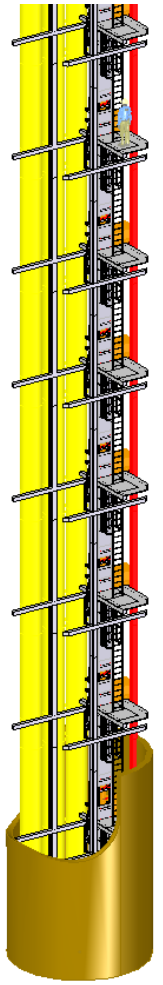
Science and Technology Facilities Council
Boulby Underground Laboratory

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

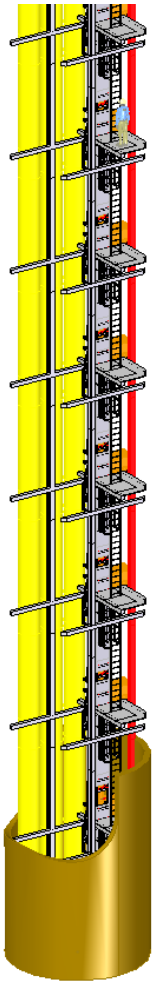
AION

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

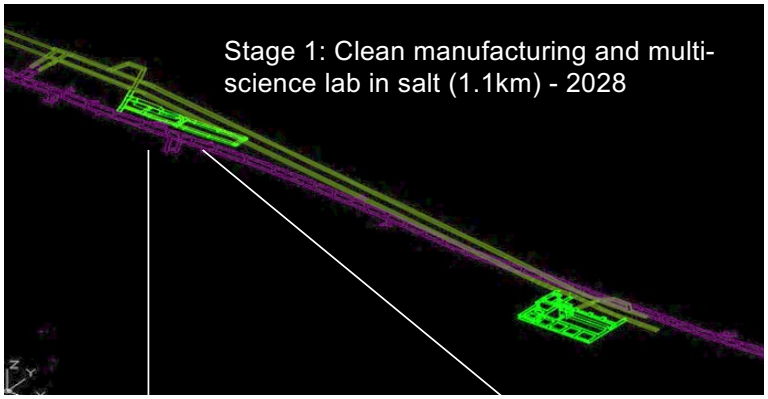
Next-level site evaluation & preparation studies underway (Mar 24)
Mitchell, Kettlety et al.

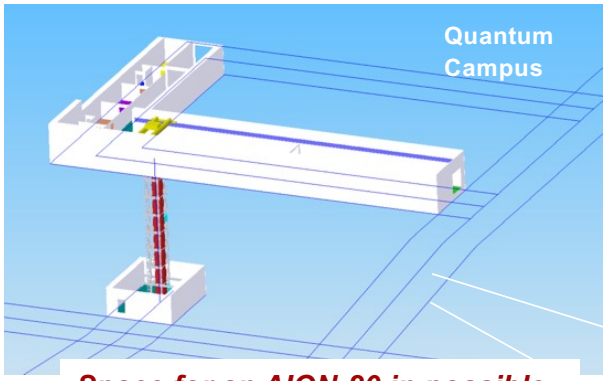
AION



New: Potential for Atomic Interferometry in new (Stage 1) Underground Lab.

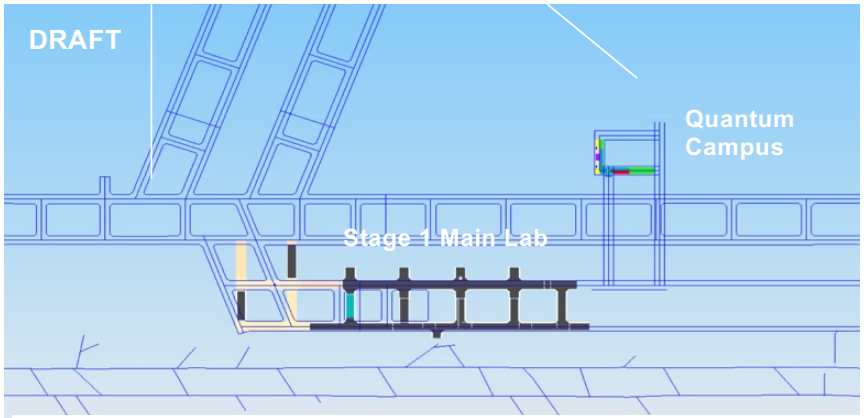
Science and Technology Facilities Council
Boulby Underground Laboratory



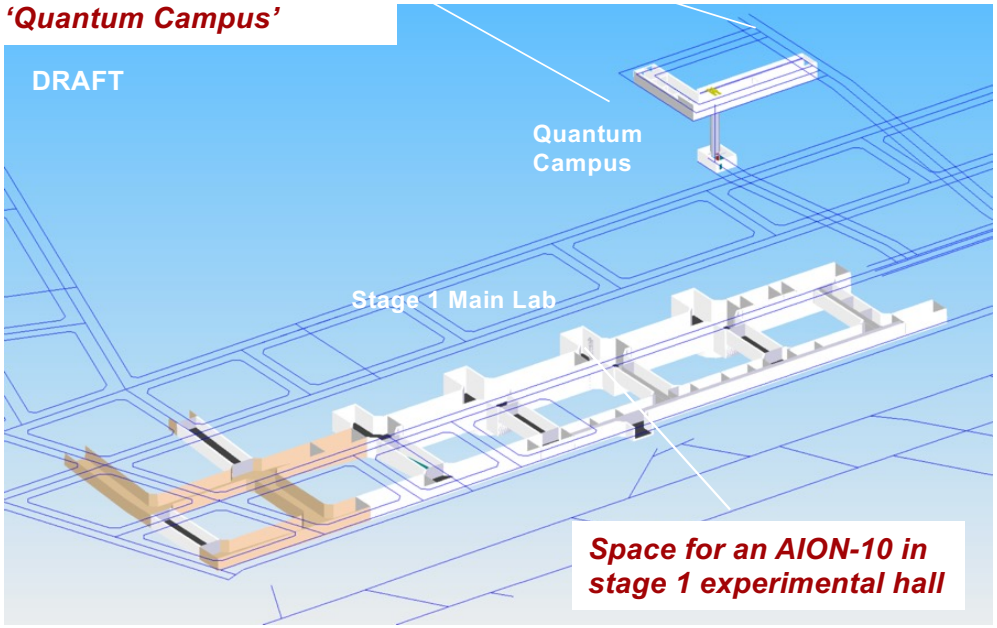


Space for an AION-20 in possible stage 1 'Quantum Campus'

Opportunity for an AION-10 or AION-20 system to be operated in the new stage 1 underground facility 'Quantum Campus'.



Barnaby Matthews 2024



Space for an AION-10 in stage 1 experimental hall

Towards a world-leading low background Quantum Technology facility for fundamental science, seismic monitoring and more

Stage 1 excavations to begin mid-2024. Outfitting completed ~2028

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

Sean Paling. Boulby Underground Lab. 2024

Summary…

Science and Technology Facilities Council
Boulby Underground Laboratory

Boulby Underground Lab status

- The UK's deep underground science facility
- A rich and varied current science programme in astroparticle physics and low background science, Earth and environmental science, astrobiology and planetary exploration studies.

Future plans:

- UKRI/STFC are now looking to maximally exploit the current facilities at Boulby, in addition we are working toward a major expansion of facilities to enable the UK to host major international next-generation science projects from 2028+
- **STFC is keen to consider proposals for siting future Atomic Interferometry studies of varying sizes in Boulby shafts, or in the new Boulby Underground Laboratory**