

Boulby Underground Laboratory: Plans for Development of Facilities and Science...

UKRI Science and Technology Facilities Council
Boulby Underground Laboratory

STFC Boulby Underground Science Facility

Sean Paling

Astroparticle physics & ultra low background studies

The search for Dark Matter & beyond

Earth and environmental science, Astrobiology and planetary exploration

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

Underground lab @ Boulby

Sean Paling
STFC Boulby Underground Laboratory

DMUK Imperial College 22nd Sept 2022

UKRI Science and Technology Facilities Council
Boulby Underground Laboratory

Boulby Underground Laboratory (UK)

UKRI Science and Technology Facilities Council
Boulby Underground Laboratory

Surface support and staging building

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

3000m³ Outside Experimentation Area

BUGS+ Material screening

Boulby Underground Lab Facilities 2020:
 >4000m³ class 1k & 10k clean room lab space
 100Mb Internet AC, Air filtration, 5T & 10T lifting, LN generation, fume hood & clean prep
 3000m³ Outside Expt. Area. Power & internet

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

Factor ~10⁶ 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 Geology

Potash KCl
Rock-Salt NaCl
Polyhalite K₂Ca₂Mg(SO₄)₆·2H₂O

Zechstein Sea

Boulby Underground Laboratory (UK)



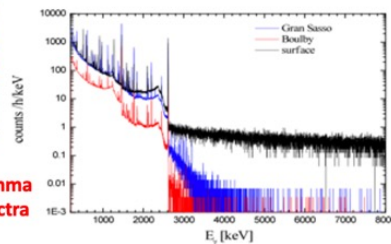
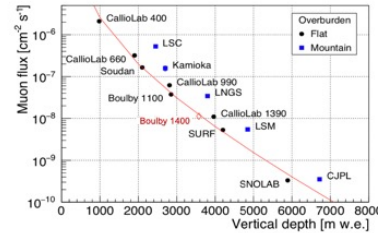
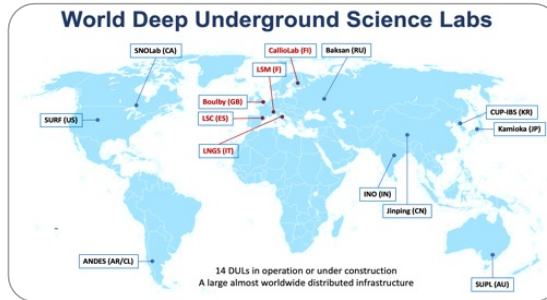
Boulby Facility Details...



- 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



Gamma Spectra

Underground Science @ Boulby Mine

- DRIFT/CYGNUS: Directional Dark Matter
- Spherical Proportional Counters (NEWS-G) R&D
- BUGS: Ultra-low background material screening (for LUX-ZEPLIN and Super-K-Gd and more)
- AWE(Ge): Atmospheric gamma spectroscopy
- RESOURCE: Salt cavity energy storage study
- BISAL: Geo-microbiology / Astrobiology studies
- MINAR: Space Exploration Tech. Development
- Misc. Low Background & Geoscience...
- Etc... (More to come).



ULB screening of LZ PMTs



Life in Boulby salt...

Astrobiology & planetary exploration

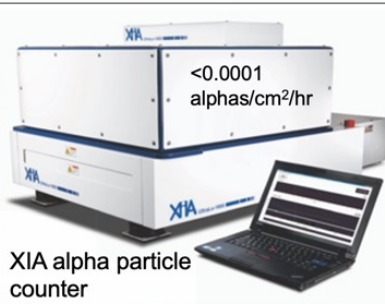
A busy & growing multi-disciplinary science programme: Astrophysics and Low Background science, Earth and Environmental Science, Astrobiology and Planetary Exploration.



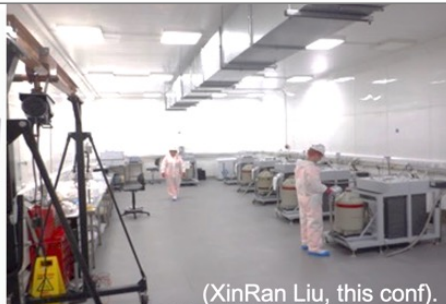
Boulby Science Now & Future

Particle physics and ultra-low background studies

BUGS



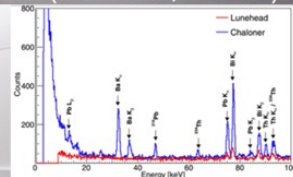
XIA alpha particle counter



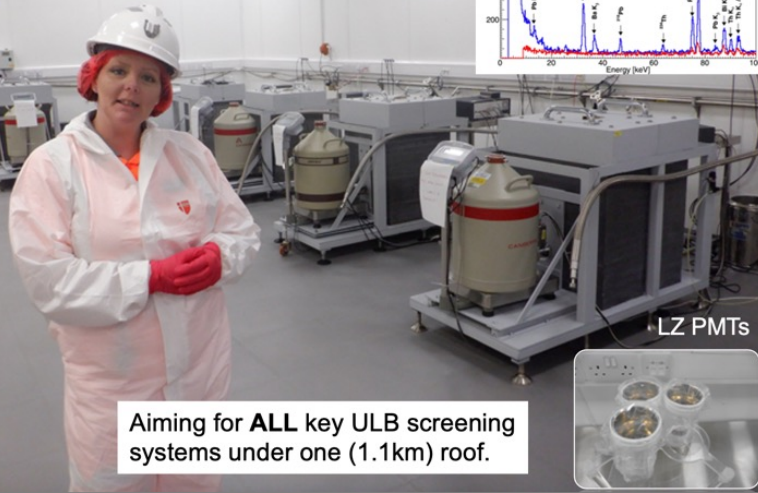
(XinRan Liu, this conf.)



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.

LZ PMTs

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

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.

Purpose-made gas filter

- Copper Oxide
- H₂O removal
- Molecular sieve O₂ removal

11-anode sensor

SPC Sensitivities

Direction of R&D at Boulby


- Instrumentation development alongside NEWS-G at SNOLAB
 - Multi-anode sensor
 - Gas mixtures & filtration
- Working towards scaled-up detector at Boulby, 3m diam. **DarkSPHERE**
- Establishing **Electro-forming Capability** at Boulby for Dark SPHERE and beyond
(I. Katsioulas, This conf.)

Simulation study of neutron interactions in the S30 at Boulby

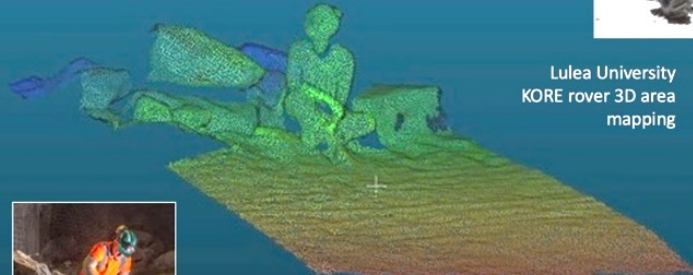
Neutron Beam 4 MeV

Multi-disciplinary Science


Earth and environmental studies, low background and/or underground particle physics, Astrobiology & Planetary exploration.




NASA-JPL
Signatures of life studies




Lulea University
KORE rover 3D area mapping

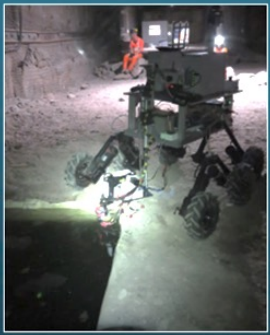



LA Nat Hist. Museum
Fluid inclusions in salts

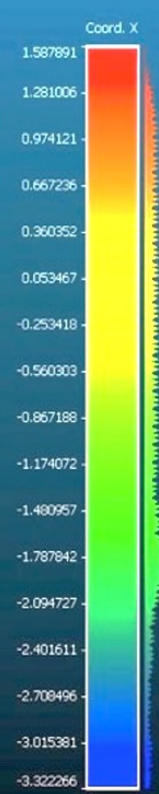


Edinburgh University
MUFFHINS water activity monitoring payload










2.5



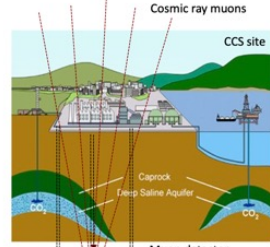
Muon Tomography / Geo-survey

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)



Cosmic ray muons
CCS site
Caprock
Deep Saline Aquifer
CO₂
Muons detector array

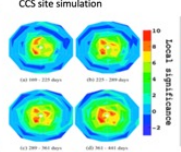


Muon-tides detector development



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

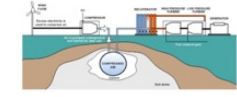
Deep-Carbon Project: £1.4M funding from UK Dept of Energy & Climate change (DECC) & Premier Oil:

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

Renewable Energy StORage in UndeRground CavErns (RESOURCE)


STFC Boulby Mine, BGS and the University of Cambridge

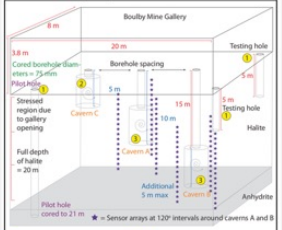
Low Carbon Technologies



- 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

NERC Grant Proposal 2020
British Geological Survey
Boulby Underground Lab
U. Cambridge & U. Manchester





Plan for In-situ Testing at Boulby Mine

Boulby Mine Gallery

3.8 m Cored borehole (diam 35-45mm) (Pilot hole)

20 m Borehole spacing

5 m Stressed region due to gallery opening

15 m Additional 5 m max cavern

5 m Testing hole

5 m Testing hole

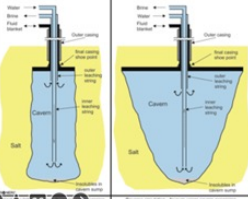
10 m Hallie

Full depth of hallie = 20 m

Pilot hole cored to 21 m

• Sensor arrays at 120° intervals around Caverns A and B

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



Boulby Future Science...

1) Exploitation of CURRENT Boulby Underground Lab facilities

- Use and expansion of BUGs -> Best in World (Ge, XIA, Rn Emanation, ICPMS...)
- Continue development of current projects:
 - Astro-particle & low background science
 - Earth and Environmental Science
 - Astrobiology and Planetary exploration
- New medium-scale projects for current facility.

2) Development of NEW facilities and science for Boulby (Boulby Development Project)

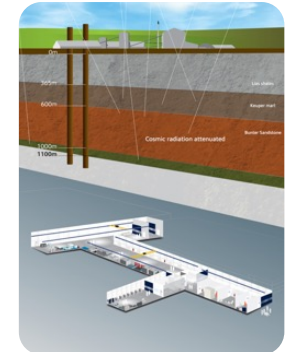
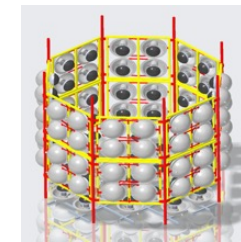
- Towards a new major international science facility capable of hosting major next-generation rare event projects (Dark Matter 0vBB and more).


Strong STFC support for exploiting and developing its national scientific asset

BUGS Development



BUTTON 30T neutrino technology testbed.






Science and Technology Facilities Council
Boulby Underground Laboratory


Next Generation Rare Event Studies @ Boulby

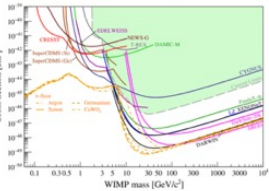
Towards EXPANDING Boulby to host MAJOR international Dark Matter, neutrino & fundamental science projects from 2030+



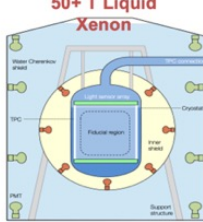
10 T Liquid Xenon

LZ, SURF, USA

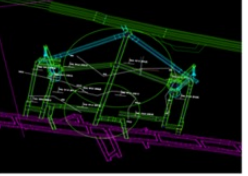




WIMP mass [GeV/c²]



50+ T Liquid Xenon



Next generation DM and/or 0vBB at Boulby?

E.g. LZ / XENON / DARWIN / G3

Boulby-FS study: Infrastructure design, feasibility & costing studies for next generation Dark Matter and/or 0vBB detectors. Study undertaken 2020-2021

Expansion bringing to the UK:

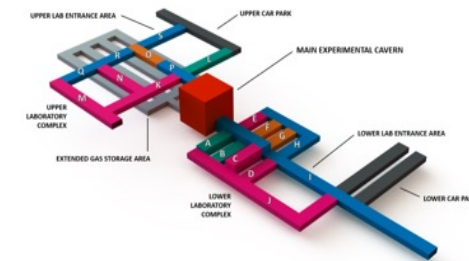
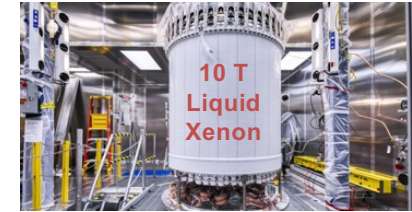
- HIGH-impact, world-leading science
- BIG fundamental science questions
- LARGE multi-national collaborations
- MAJOR local & national investment, impact and visibility

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

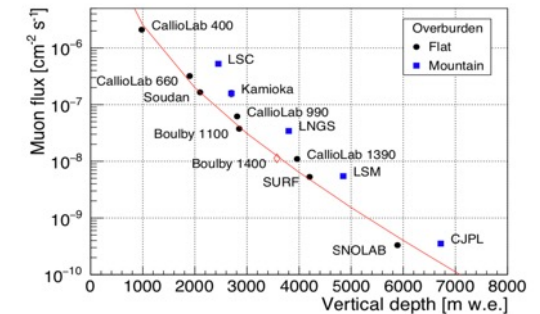
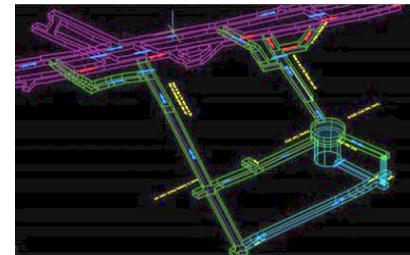
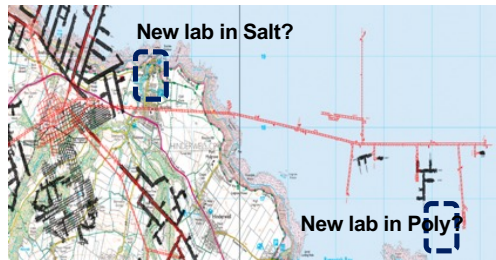
Boulby-FS Overview:

- Context and need for a major new deep underground science facility in UK: DM, 0vBB and more..
- Infrastructure specifications for potential projects (LXe & LAr DM, Ge 0vBB & more).
- Conceptual designs for excavations and outfitted labs – 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



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 Araujo¹, J Dobson², C Ghag², S Greenwood², V A Kudryavtsev⁴, P Majewski³, S M Paling⁵, V Péc⁶, R Saakyan⁷, P R Scovell⁸, N Smith⁹, and T J Sumner^{1,2*}

¹Imperial College London, UK
²University College London, UK
³STFC Rutherford Appleton Laboratory, UK
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⁵STFC Boulby Underground Laboratory, UK
⁶SNOLAB, CA
⁷Corresponding author (t.sumner@imperial.ac.uk)

June 25, 2021
Issue v1.0

OFFICIAL-SENSITIVE [COMMERCIAL]

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

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

Boulby Development Project (BDP)

BDP Project Goal:

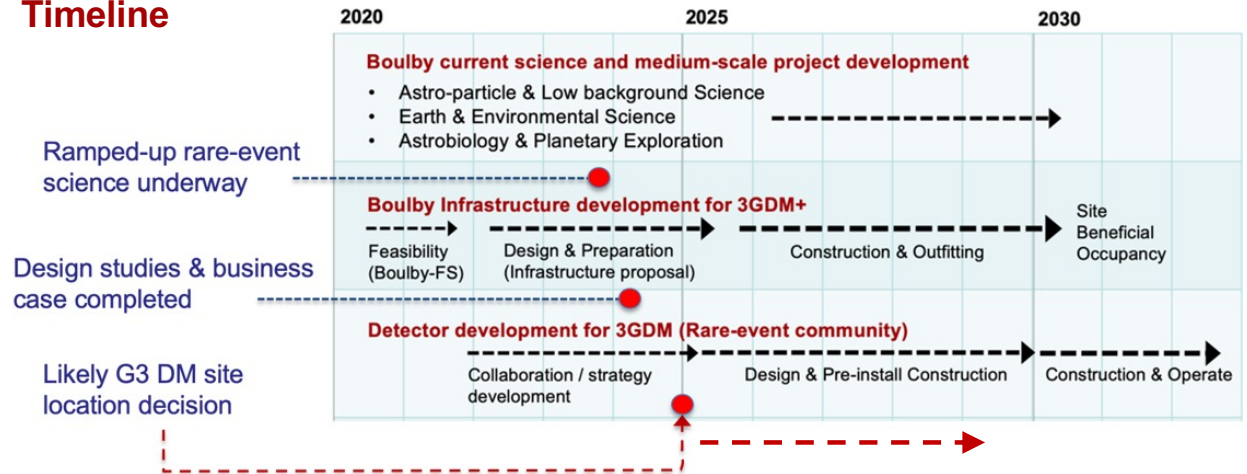
Next level planning and preparing for a...
“... greatly expanded underground science facility in the North East, with the potential to host a major international science infrastructure, such as a next generation dark matter experiment.” (STFC strategic delivery plan (2022-2025))

UKRI Prelim Infrastructure Funding £2.84M, 3 year project (2022/3-2024/5).

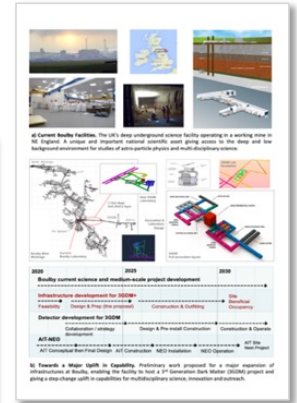
Tasks / Deliverables:

- 1) Facility design development (for sites at 1.1km &/or 1.4km)
- 2) Business case(s), economic impact studies, risks → **Submission to BEIS**
- 3) Stakeholder engagement: Local, National & International:
 - Public & Partners
 - Government
 - Science communities & funders

Boulby Development Timeline



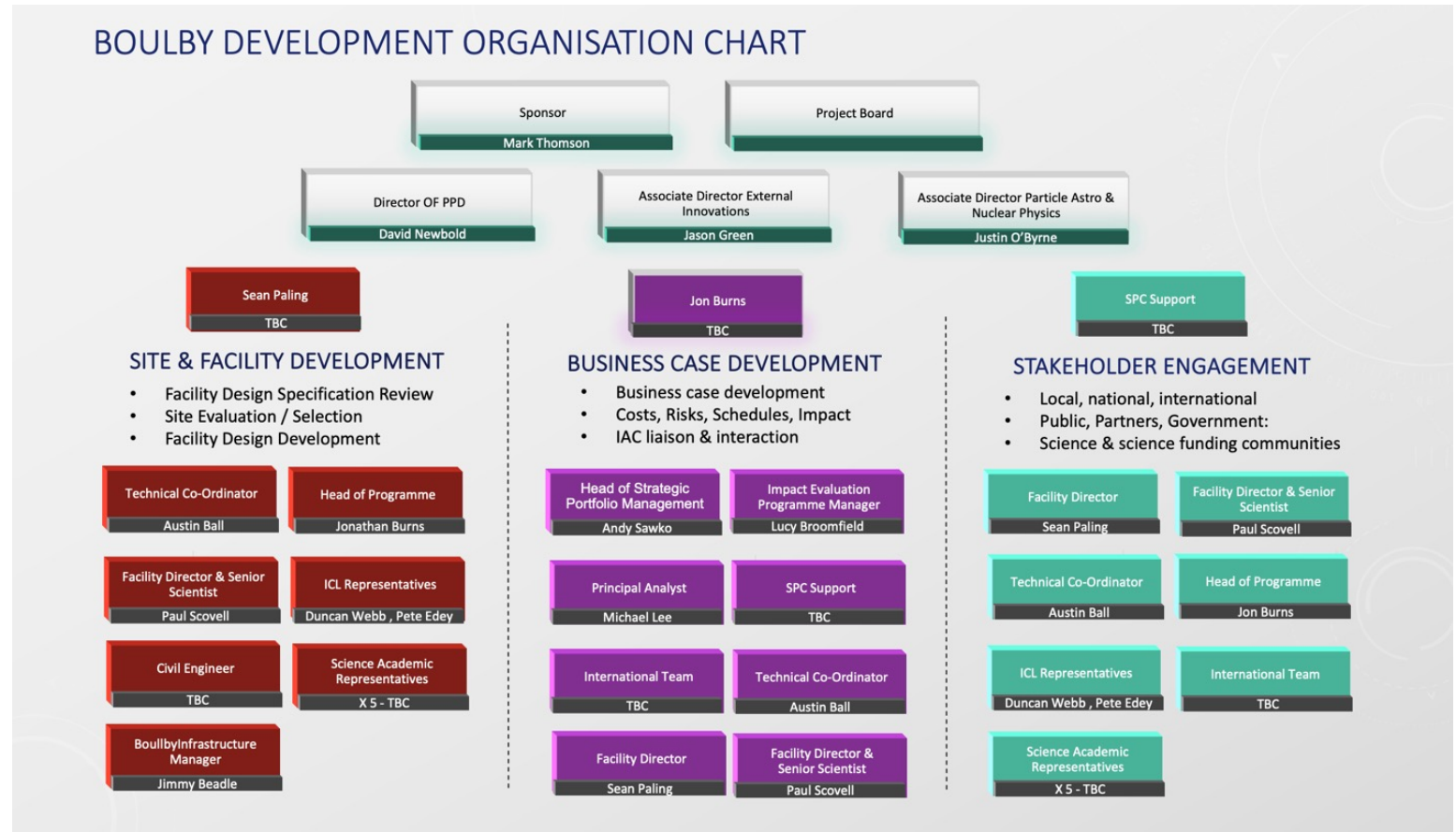
Preliminary details and descriptions	
Name of project (and acronym if short)	Boulby Underground Laboratory - Dark Matter and Beyond
Type of infrastructure project	Significant change to existing capability to support ongoing, low-level activity or to create new facilities
Subsidiary Capability/Service(s)	[] None [] Basic [] Special [] Advanced [] Core [] High [] Large multifunctional facility (CITE envisaged)
Principal Investigator	Prof. James Lewing (JCU) contact: James.Lewing@jcu.ac.uk
UKRI Contact	Email: james.lewing@ukri.ac.uk
Phase(s)	Phase 1: Design & Preparation (2022-2025)
Long description of the preliminary activity	UKRI will present evidence for the next five years...
Short description of the preliminary activity	UKRI will present evidence for the next five years...



Boulby Development Infrastructure Bid

Boulby Development Project (BDP)

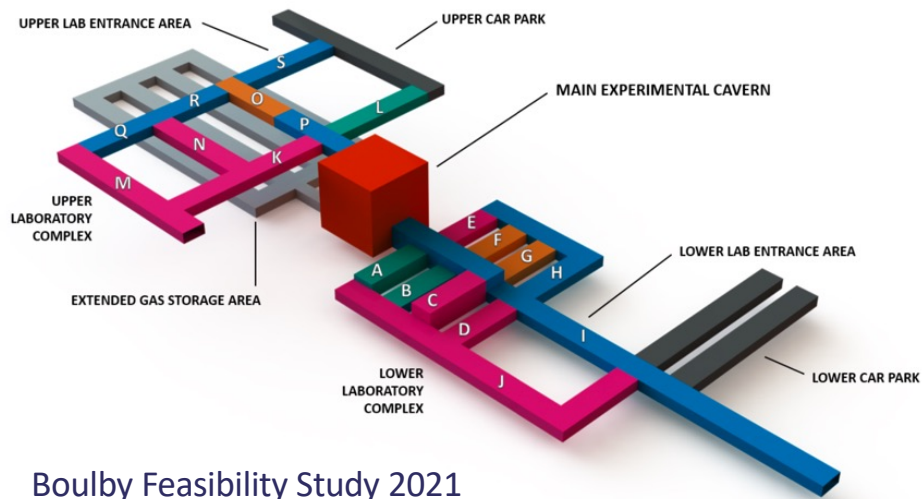
Project Governance & Organisation:



Boulby Underground Laboratory

Task 1: Site and Facility Development

1) Next-Level review of new lab design required.
Meeting needs of all possible experiments



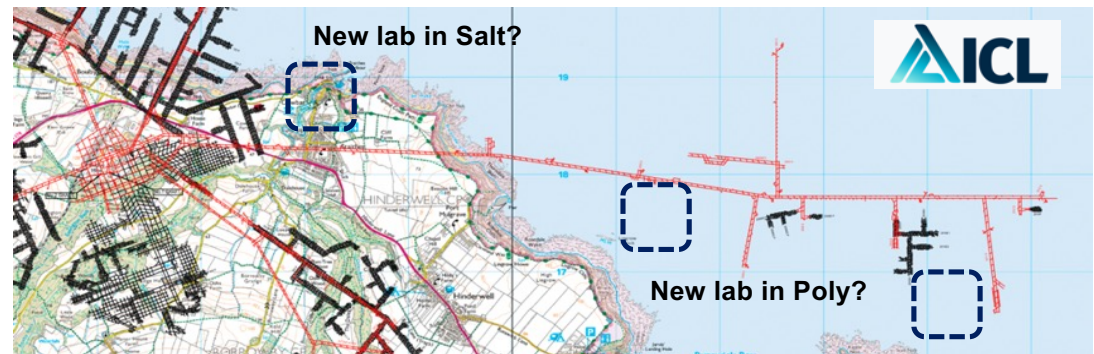
Boulby Feasibility Study 2021

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 ISO7 and teal is ISO6; 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.

Science community input/support needed...

2) Preferred site(s) to be selected – Salt or Polyhalite

Possible sites @ Boulby Mine



Site options in salt (1.1km) or Polyhalite (1.3 or 1.4km). Deeper site favoured for 0vBB studies & to better compete with LNGS & SURF



3) Next Level excavation and facility build plans to be developed...

Task 2: Business Case Development

Timescales for Development of BDP Business Cases:

Scientific, societal & economic impact, schedule, costs, risks:

- Strategic Business Case - Dec/22
- Outline Business Case - 23/24
- Full Business Case - ...

Timescales for next IF bid submissions:

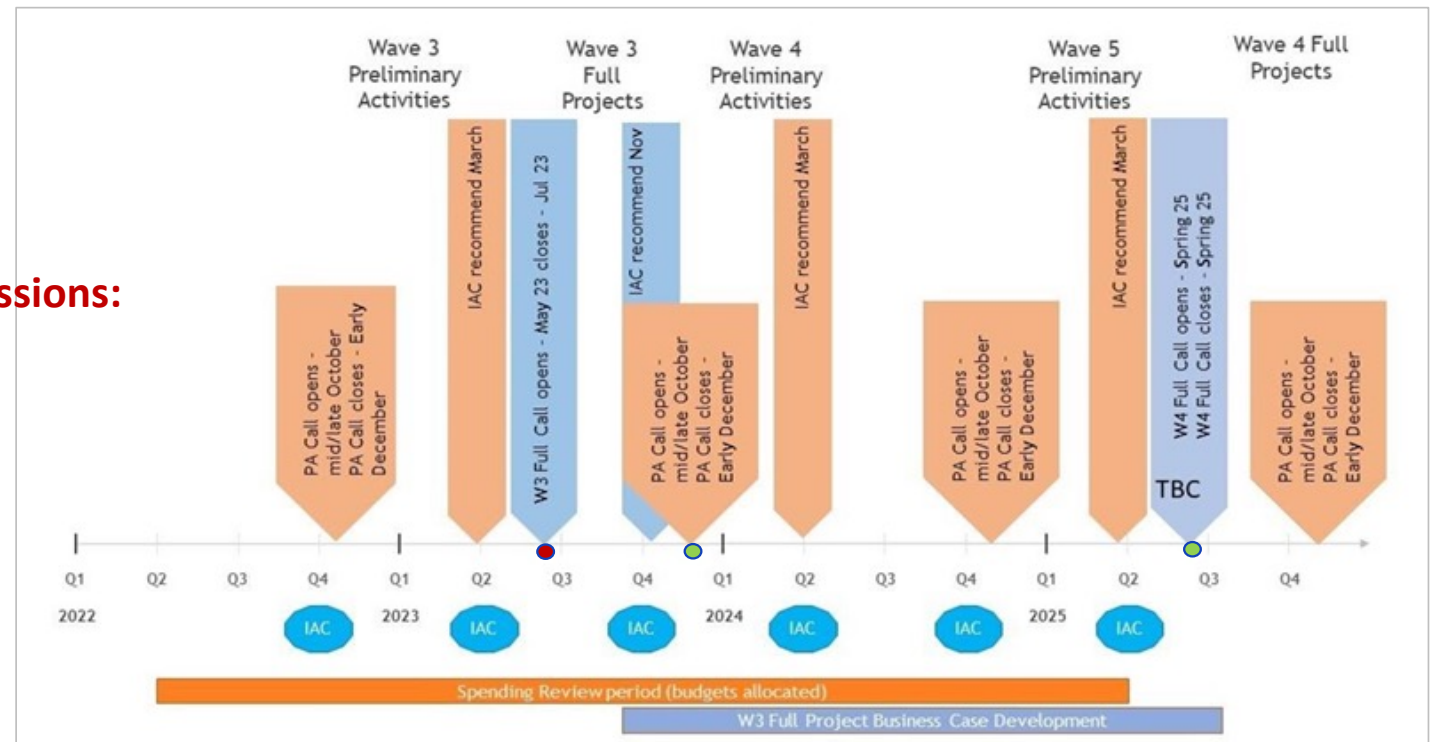
Option 1:

- Full IF Bid (Design & Build) - Q3/23
- Money received - Q3/25
- Lab complete – 2030/1

Option 2:

- Prelim IF Bid (Design) – Q4/23
- Full IF Bid (Build) - Q3/25
- Money received - Q3/27
- Lab complete – 2032/3

Infrastructure Fund Submission Schedule



Science community input / support needed...

Task 3: Stakeholder Engagement

Public:

Local & National: Plans and benefits to region and country. Media, social media

Partners:

- UKRI / Innovate-UK -> Exec and Board
- Mine hosts -> Boulby mine

Government:

Local: Support from regional leaders. Inc

- MPs: Simon Clarke (Levelling up)
- Teeside Mayor: Ben Houchen

National: Support from national leaders:

- BEIS: Minister, CSA (Paul Monks)
- Gov: Science Minister, MPs & more.
- Etc...

International:

- UK/international relations & partnerships

Science Communities:

National: Getting science communities behind initiative and planning for use. Town halls, conferences etc.

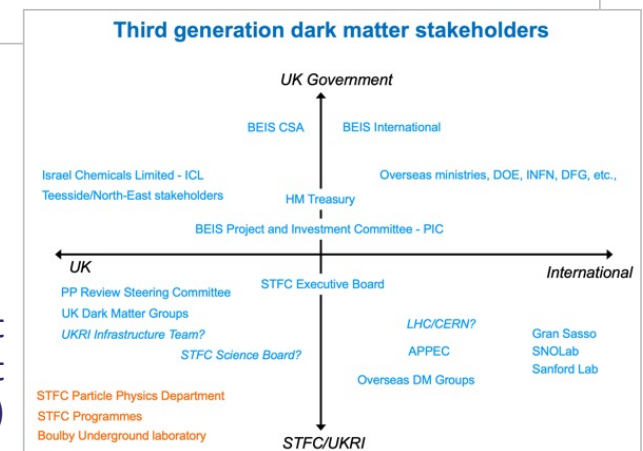
- Particle / Astro-particle Physics
- Multidisciplinary science area

International:

- Specific science project teams: Promoting use of new facility: Xe/Ar/etc DM, 0vBB, Quantum, Multidisciplinary Science.
- International science funding bodies. Partnerships, trading.

Science community input / support needed...

Stakeholder engagement plan under development (SPC support TBD)



Get Involved: Science Community Involvement & Support...

Proposals welcomed ANY TIME for projects @ Boulby Laboratory:

- **Current facility:** Use of BUGS material screening facilities or space in main laboratory.
- **New / Future Facility:** Expected spaces of ~25x25x25m to be available. Clean and ultra-low background environment. Science, technical and engineering support facilities,

Upcoming Boulby Development Project Grants:

Proposed funding amount up to **£150,000 pa** (for up to 2 years)

Opening date **25th October** (TBC)

Closing date **13th December** (TBC)

Notification **Feb 2023** (TBC)

Funding to support the development of new innovative projects in a proposed new underground facility in the vicinity of Boulby

Underground Laboratory managed by STFC.

Mandate:

- *Input to new facility design requirements*
- *Development of science project(s) plans, designs, costings etc*
- *Advocacy and support in stakeholder engagement*

Expecting 4 or 5 positions covering fields of:

- Dark Matter Search (Xe, Ar, others)
- 0vBB studies
- Quantum & Low background technologies
- Multi-disciplinary studies

**APPLICATIONS
WELCOMED
SOON.**



Boulby Underground
Laboratory