



Science and Technology Facilities Council

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

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Boulby Underground Laboratory, UK

**UKRI** Science and Technology Facilities Council

**UKRI** Science and Technology Facilities Council  
Boulby Underground Laboratory

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STFC Boulby Underground Science Facility

Astroparticle physics & ultra low background studies

The search for Dark Matter & beyond

Earth and environmental science, Astrobiology and planetary exploration

**Boulby Underground Laboratory:**  
The UK's deep underground science facility. Current status and future plans

Underground lab @ Boulby



# 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.



Polyhalite:  
 $K_2Ca_2Mg(SO_4)$



Ships worldwide for agricultural fertiliser



**Deepest mine in Britain: 1300km**

The world's first polyhalite mine



12 miles North of Whitby, N. Yorks



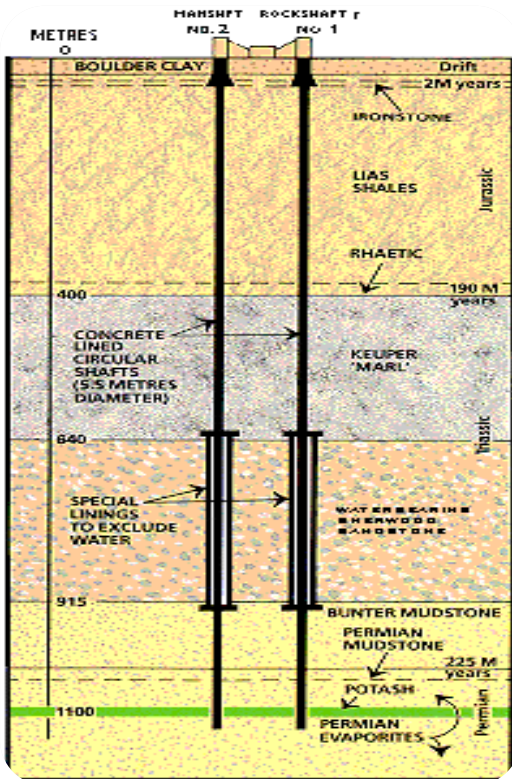
View from Staithes



# 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



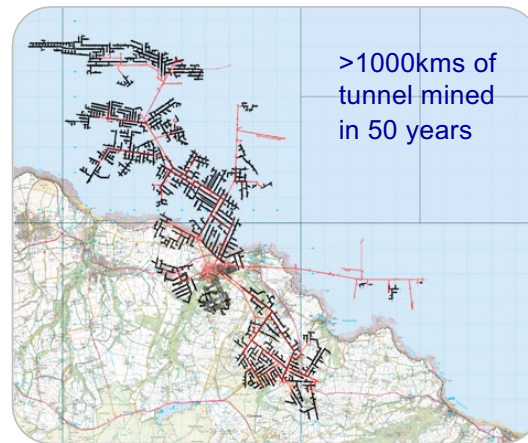
Potash



Rock-Salt



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



Typical Boulby Salt Roadway



Zechstein Sea



# Boulby Underground Laboratory

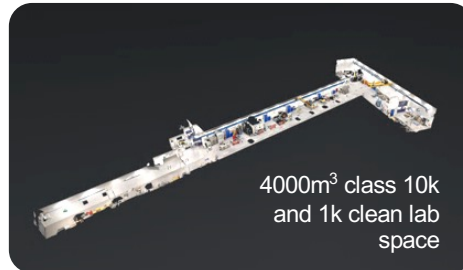
The UK's deep underground science facility operating in a working potash and salt mine.

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)

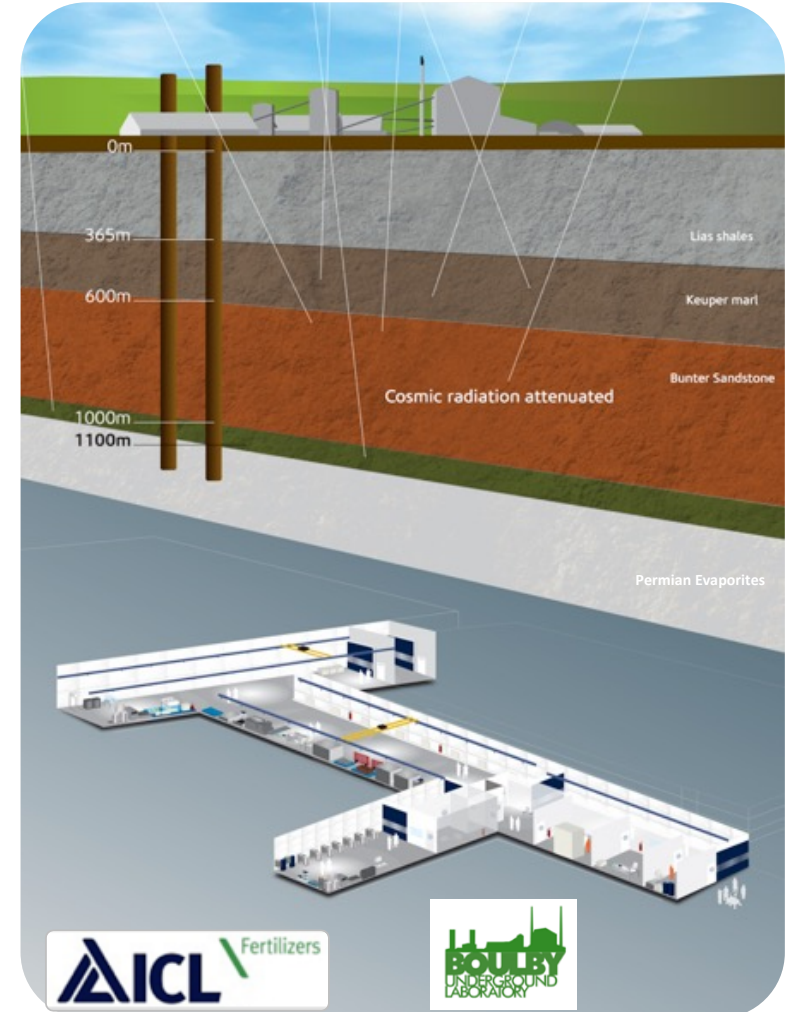


4000m<sup>3</sup> class 10k and 1k clean lab space



Lab entrance

*Factor ~10<sup>6</sup> reduction in cosmic ray flux vs. surface*



A **QUIET** place in the Universe



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

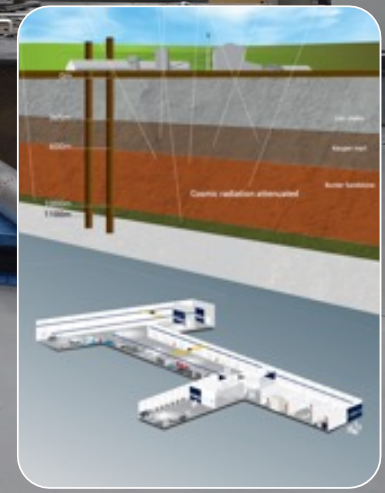
Supported access to surrounding geology & UG environs. Power, wifi/internet.

3000m<sup>3</sup> Outside Experimentation Area

Surface support and staging building

**Boulby Underground Lab Facilities 2023:** >4000m<sup>3</sup> 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. 3000m<sup>3</sup> Outside Experimentation Area (OEA) with power & internet. Supported access to wider mine environs.

BUGS Material screening



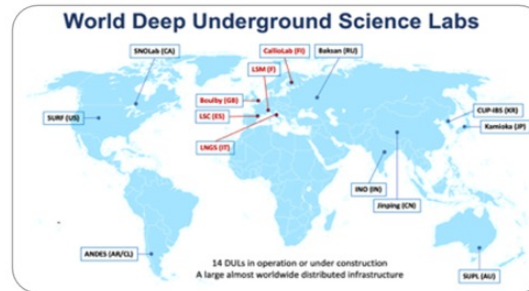
# Boulby Underground Laboratory (UK)



## Boulby Facility Details...

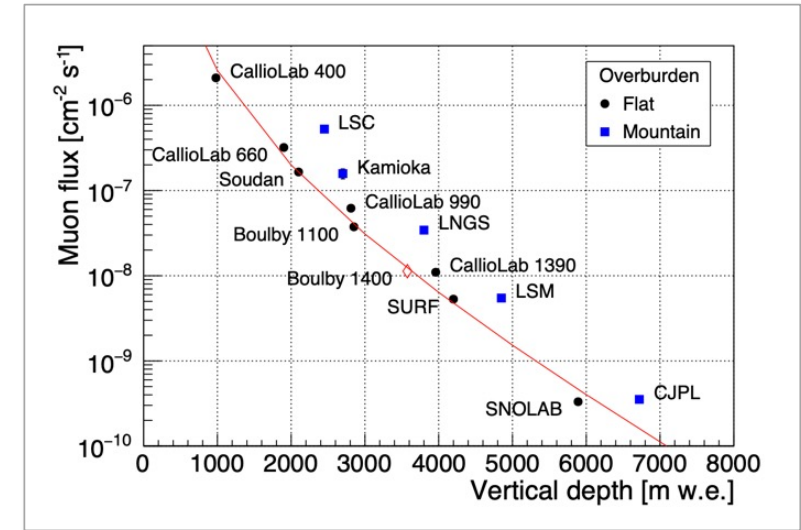


- The UK's deep underground science facility. One of 5 in Europe, <15 in the world.
- Supports work of >10 collaborative projects (astrophysics to climate, geology, environment etc), >40 institutions, >170 scientists & students.
- Facility funded and operated by the Science & Technology Facilities Council (STFC).
- Operations, H&S & science programme managed by 17 (+2) onsite staff and supported by Rutherford Appleton Lab (PPD).
- Mine operators ICL-UK provide wide-ranging operational & high level support.



### How does Boulby Compare?

- Low Radon levels (3 Bq/m<sup>3</sup>)
- Diverse science programme.
- Science and Industry partnership



## Science Programme Status & Plans.

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



# Boulby Science Now & Future

Particle physics and ultra-low background studies

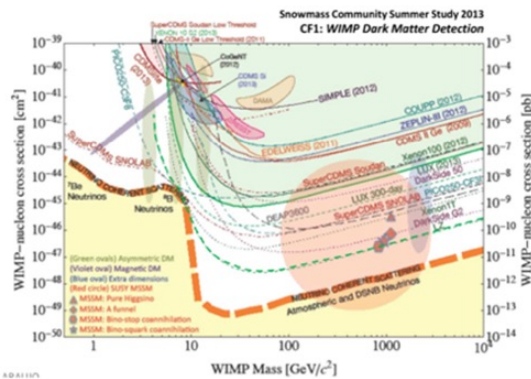
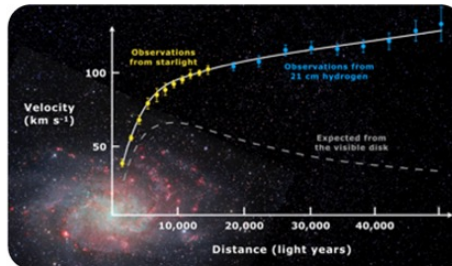


## Boulby Dark Matter Studies...

Boulby has hosted **Dark Matter search** studies for over two decades. Including the **NAIAD**, **DRIFT** & **ZEPLIN** experiment programmes.

Boulby now hosts **CYGNUS** directional DM programme, **NEWS-G**/Dark-Sphere R&D and providing ULB material screening for other studies, inc **LUX-ZEPLIN (LZ)**

Galactic rotation curves



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

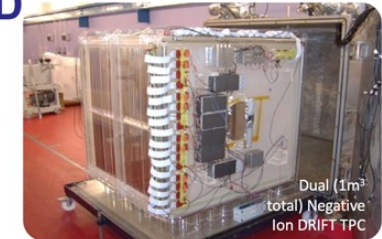
World DM particle search limits and future projections



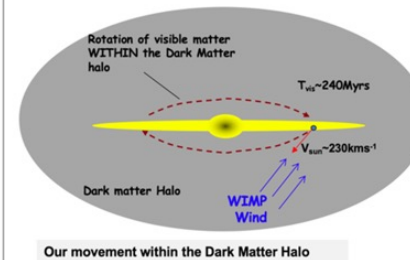
ZEPLIN-III @ Boulby

## DRIFT/CYGNUS: Directional Dark Matter Detection R&D

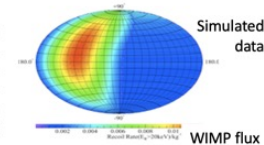
**STATUS:** Programme operating at Boulby since 2001. Performance & scale-up R&D. Plans for further R&D & expansion / collaboration (CYGNUS).



DRIFT-III @ Boulby



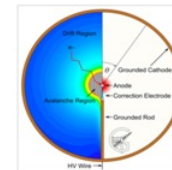
Occidental College, New Mexico, Colorado State, Hawaii, Wellesley, Sheffield, Edinburgh, Boulby



## NEWS-G

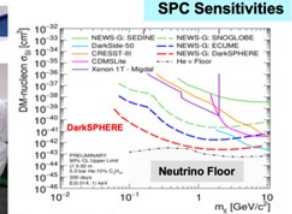
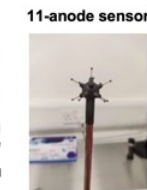
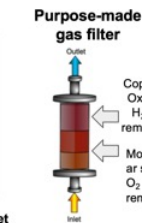
Spherical Proportional Counter (SPC) studies @ Boulby

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



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

Simulation study of neutron interactions in the S30 at Boulby

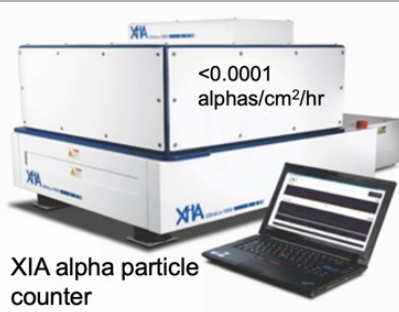


- Direction of R&D at Boulby**
- Instrumentation development for NEWS-G at SNOLAB
    - Multi-anode sensor
    - Gas filtration
    - Rate effect studies
  - Neutron spectroscopy ( $N_2$ )
    - Neutron BG surveys
    - Industrial applications
  - Towards scaled-up detector at Boulby, 3m diam, 5 Bar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



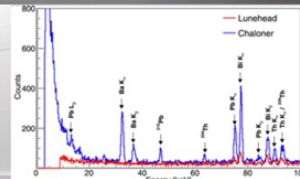
# Boulby Science Now & Future

Particle physics and ultra-low background studies

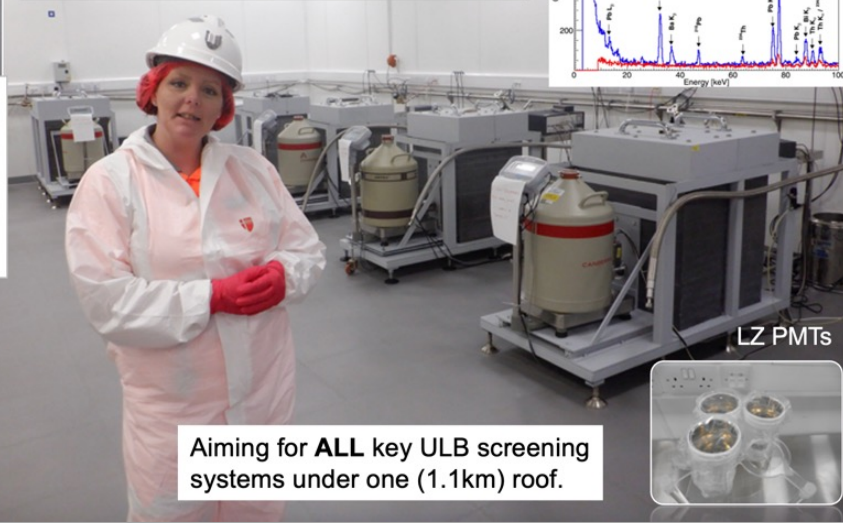


XIA alpha particle counter

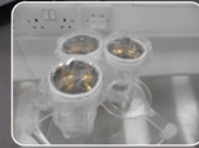
8 ULB Ge detector systems, 2 XIA alpha counters, Rn emanation, ICPMS to come



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



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



**BUGS (UG):** A range of HPGe detectors and *alpha* particle detectors for intrinsic and surface radioactivity measurements.



**ICP-MS (Surface):** Newly installed system for trace element analysis and isotopic ratio measurements.

## BUGS Facility: (Boulby Under-Ground Screening)

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



# Multidisciplinary Science

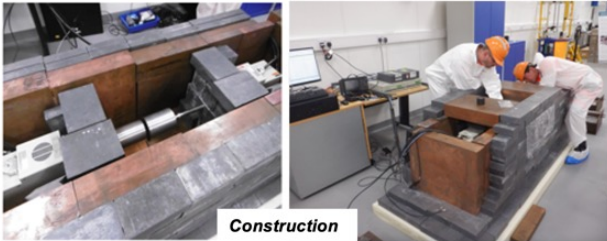
Applied low background particle physics, Earth and Environmental science, Astrobiology & Planetary Exploration Technology Development.



## RECON: CTBT Atmospheric Radionuclide Monitoring

### Improving the sensitivity of Nuclear Test Monitoring

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



Construction

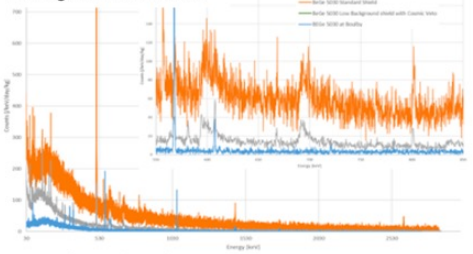


Credit: K. Cantner, AGI.

International Monitoring System Sites

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

### Background reduction



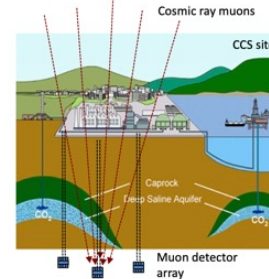
Nuclide	Singles MDA Bq/m <sup>3</sup>	Gate Energy	Projected Peak	RIMMER Factor	Background Counts (projected)	Lc Currie	Lc Poisson	MDA Currie	MDA Poisson	Ratio to singles
CS-134	3.38E-07	604.721	796.00	2.02E-03	2	9	6	4.85E-08		0.143
BA-133	4.41E-07	30.625	356.00	7.10E-01	54	37	49	8.47E-10		0.002
AG-108m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

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

## Muon Tomography / Geo-survey

Development of a Muon Tomography techniques for deep 3D geological surveying - inc Carbon Capture @ Storage (CCS)

STFC-Boulby, Durham, Sheffield, Bath, NASA



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

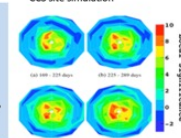


Muon-tides detector development



Bore hole detector installation

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



CCS site simulation

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

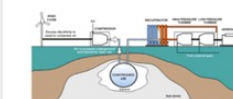
RESOURCE: Compressed gas energy storage R&D

## Renewable Energy StORage in UndeRground CavErs (RESOURCE)

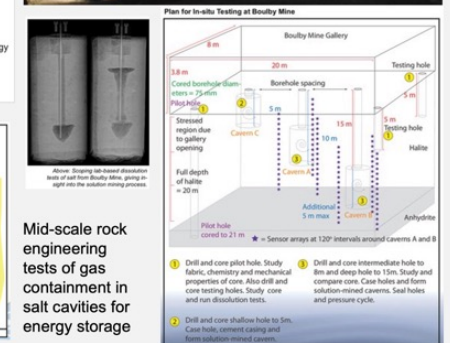
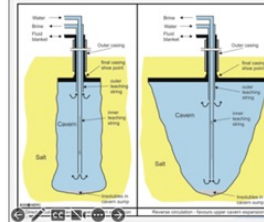
STFC Boulby Mine, BGS and the University of Cambridge

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

**MINAR VII & VIII. 2018 - 2021**

NASA-JPL Signatures of life studies

Lulea University KORE rover 3D area mapping

LA Nat Hist. Museum Fluid inclusions in salts

Edinburgh University MUFFHINS water activity monitoring payload

Coord. X

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

2.5

**Astrobiology & Planetary Exploration**

**BISAL**  
Boulby International Subsurface Astrobiology Lab

MINAR - Habit: Sampling life in Boulby Brine

MINAR - XRF: Subsurface Astrobiology Laboratory

Life in Boulby salt

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

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

Led by Edinburgh, UKCA

MINAR - Clupe: Mining & extraplanetary exploration instrumentation development

MINAR - Pancam: Boulby and Instrumentation for Earth and Space Exploration

sean.paling@stfc.ac.uk





# Boulby Activities Now and Potential Future

		Now	
		Current Projects	Status
Particle Physics & Low Background		CYGNUS - DM R&D	E/P
		News-G - DM R&D	A
		BUGS: Ge, XIA, RnEm - Material Screening	A
		RECON - Nuclear Security R&D	A
		BUTTON – Nuclear security R&D	A
		Muon Tomog – CCS & undersea Geoimaging R&D	A
Earth & Environmental		RESOURCE – Energy store R&D	A
		Seismology/AION R&D	A
		BISAL – Biology/Astrobiology	A
Astrobiology & Planetary Exploration		MINAR – Planetary Exploration Tech development	A
		Misc. Other. SELLR, C14, Adrok, BIO-SPHERE...	A/P
		Outreach/ Education - Misc events, progs, Remote3...	A

Status: A = Active, P = Paused, E = End, I = Interest confirmed

## 2023-2030

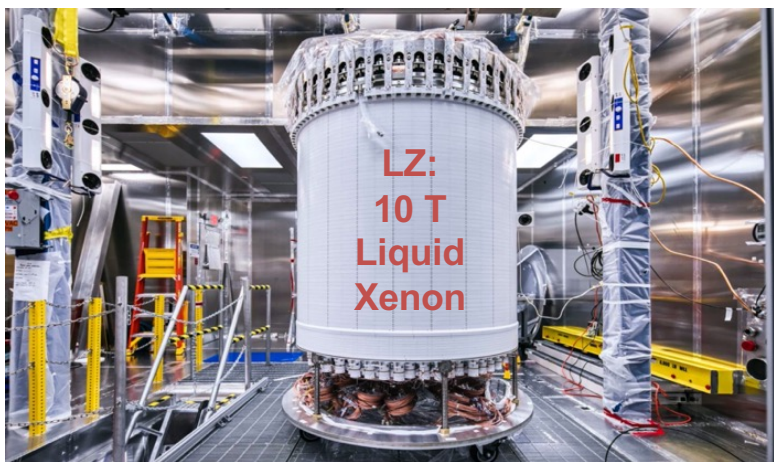
Medium Term (Current Lab + mods)	Status
BUGS: Ge, XIA, RnEm, ICPMS - Material Screening	A/I
BUTTON-30 – Nuclear security R&D	A
RECON+ - Nuclear Security R&D	A/I
DarkSPHERE – DM Search	I
DATUM – Neutrino Tech R&D	I
SoLAr, SOLAIRE – DM/Neutrino R&D	I
AION-100 & 1000 R&D	I
Seismology Array – Geosurvey R&D	I
RESOURCE+ – Energy store R&D	A/I
Muon Tomog – CCS & undersea Geoimaging R&D	A/I
BISAL+ – Biology/Astrobiology	A/I
MINAR+ – Planetary Exploration Tech development	A/I
Misc. Other. Quantum Computing Tech R&D	-
Outreach/ Education: General Public, Schools +	A

Long Term (Current lab plus major new lab)
<p><b>Particle Physics and Low Background Science:</b></p> <p>Dark Matter: Major Next Gen Experiments:</p> <ul style="list-style-type: none"> <li>Xenon (XLZD)</li> <li>Argon (DarkSideLM+)</li> <li>Gas (DarkSPHERE+)</li> </ul> <p>Neutrinos:</p> <ul style="list-style-type: none"> <li>BUTTON-100+</li> <li>DATUM (LEGEND Support),</li> <li>SoLAr / SOLAIRE+</li> </ul> <p>Mat screening &amp; LB Techniques: A world's best facility:</p> <ul style="list-style-type: none"> <li>Ge, XIA, RnEm, ICPMS, Cleanliness &amp; Engineering R&amp;D</li> </ul> <p>Misc Other:</p> <ul style="list-style-type: none"> <li>AION-100</li> <li>AION 1000</li> <li>Nuclear Security Gamma spec</li> <li>Quantum Computing Tech R&amp;D &amp; Operation</li> </ul>
<p><b>Earth &amp; Environmental Science:</b></p> <ul style="list-style-type: none"> <li>Sustainable Energy R&amp;D</li> <li>Seismology Observatory</li> <li>Geological Repositories R&amp;D</li> <li>Misc geology / Geophysics R&amp;D</li> </ul>
<p><b>Astrobiology &amp; Planetary Exploration:</b></p> <ul style="list-style-type: none"> <li>Extremophile R&amp;D</li> <li>Astrobiology / life beyond Earth R&amp;D</li> <li>Human habitation R&amp;D</li> <li>Planetary exploration technology development</li> <li>Robotics and AI</li> <li>Mining and industry application development.</li> </ul>
<p><b>Outreach and Education:</b></p> <ul style="list-style-type: none"> <li>A National Centre for Science and technology outreach and education.</li> </ul>

Target projects for a major new UK underground facility / campus

# Next Generation Xe-based Dark Matter Detector (**XLZD**)

Lux-ZEPLIN (LZ). SURF, S. Dakota, USA



LZ: 10T 2-phase Dark Matter detector operating in SURF lab, USA. Early 2-phase Xe technology developed in the UK. STFC/UK investment continues.



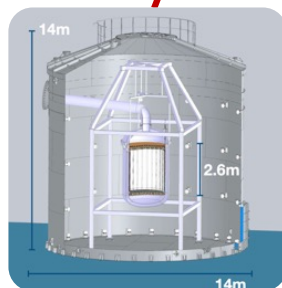
Xenon-nT  
LNGS, Italy

**XLZD**  
2021 merging  
of LZ, Xenon  
and DARWIN  
teams



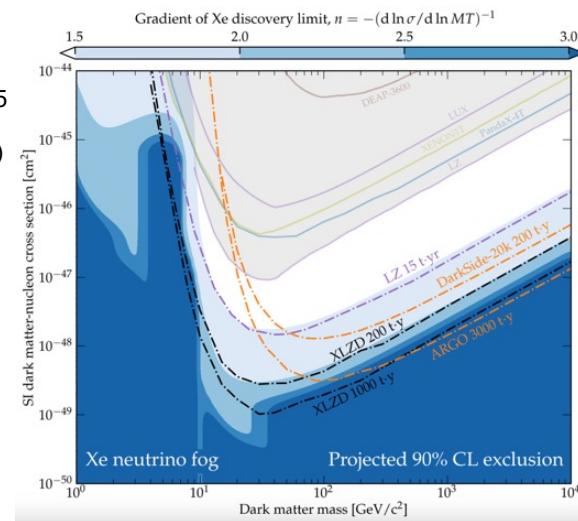
DARWIN  
(Proposed)

**XLZD**  
50-100T LXe  
Operation 2032+  
Site evaluation  
underway 2023-5

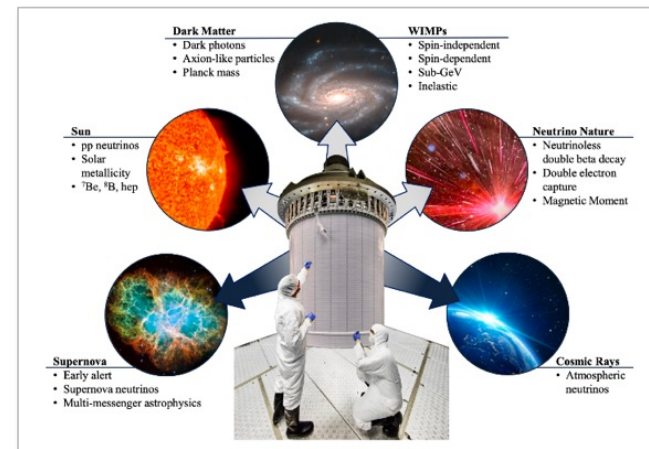


Could XLZD be  
constructed and  
operated at  
Boulby 2030+?

Projected  
sensitivity  
(Akerib P5  
town hall  
mtg 2023)



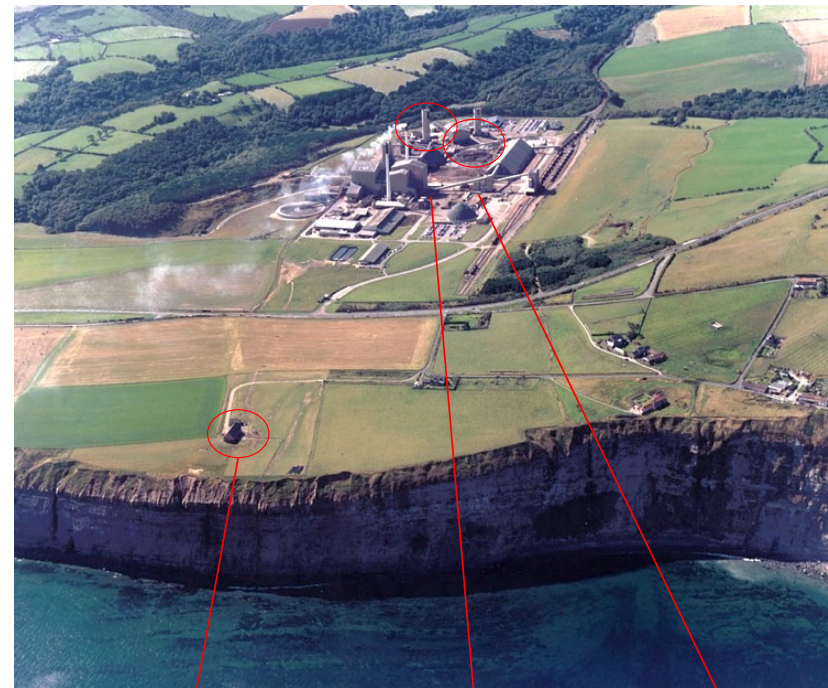
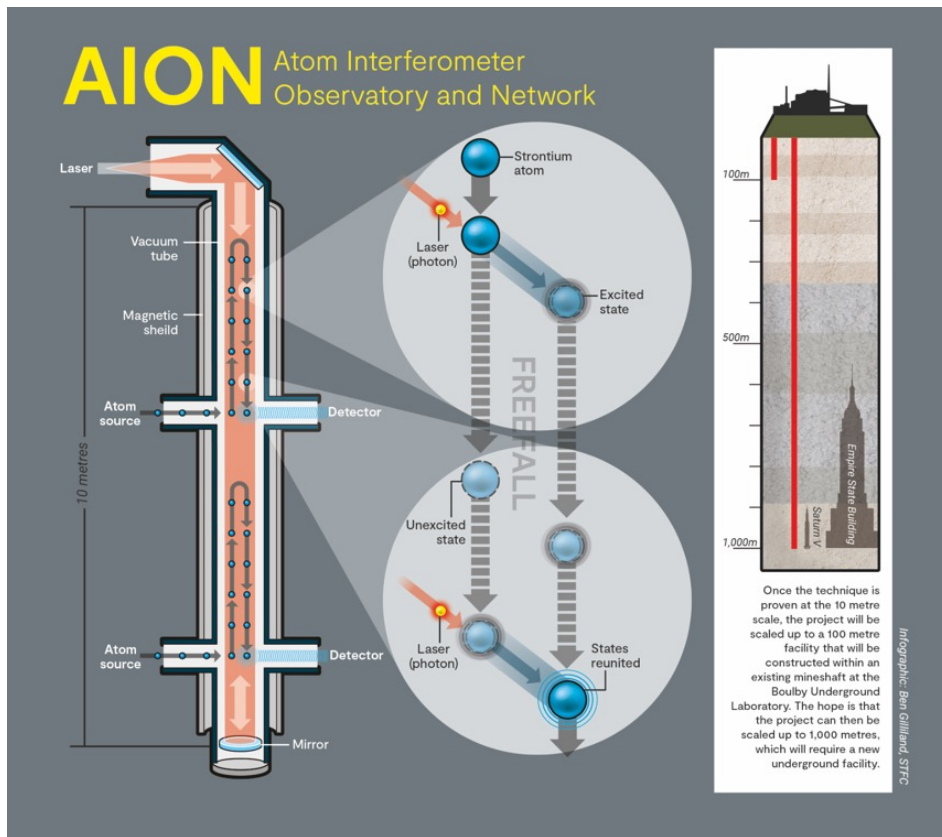
Next generation **world's best** Dark Matter (+) detector. **Expected 2030+**





# Prospects for Atomic Interferometry at Boulby...

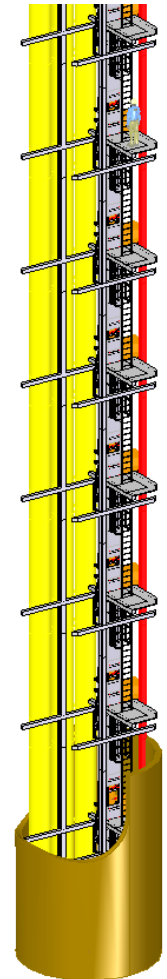
**ALONGSIDE** new underground laboratories to be excavated, there is strong user interest and STFC support for hosting atomic interferometry projects (**AION 100 & 1000**) in existing or new commercial shafts at or near Boulby Lab in NE England.



Shaft 3  
Tailings Shaft  
180m

Shaft 1  
Rock Shaft  
1.1km

Shaft 2  
Personnel  
1.1km



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

## What Boulby Is:

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

### UKRI Strategic Objectives



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

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

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

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

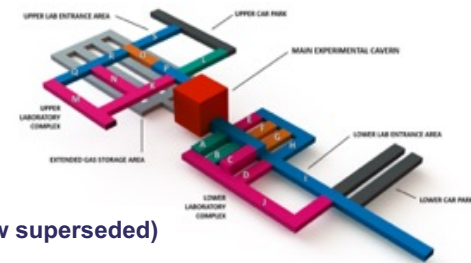


# Boulby Expansion Feasibility Study (Boulby-FS)

## Boulby-FS (2020-21) Overview:

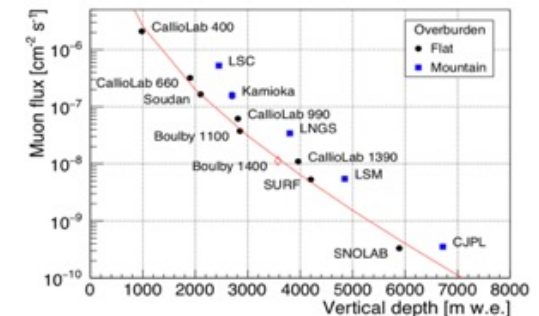
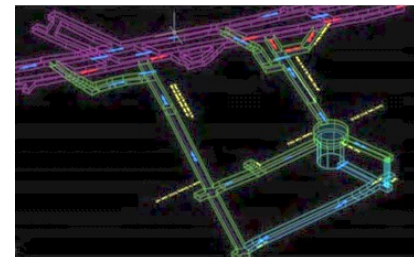
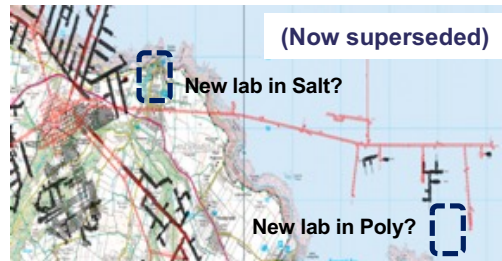
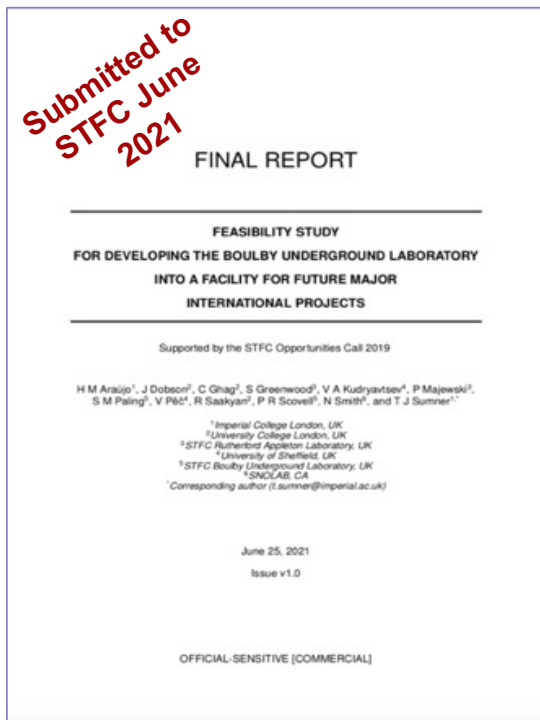
- Community-led study of motivation and practicalities of creating a major new deep underground science facility in UK
- Infrastructure specifications for potential projects (Dark Matter, Neutrinos & more).
- Conceptual designs for excavations and outfitting laboratories in 1.1km (Salt) and 1.4km (Polyhalite)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

LZ @ SURF.  
Next generation in the UK?



New lab specifications & designs

(Now superseded)



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

**Results: It IS feasible, well motivated and timely.**  
Outfitted facility: ~£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).

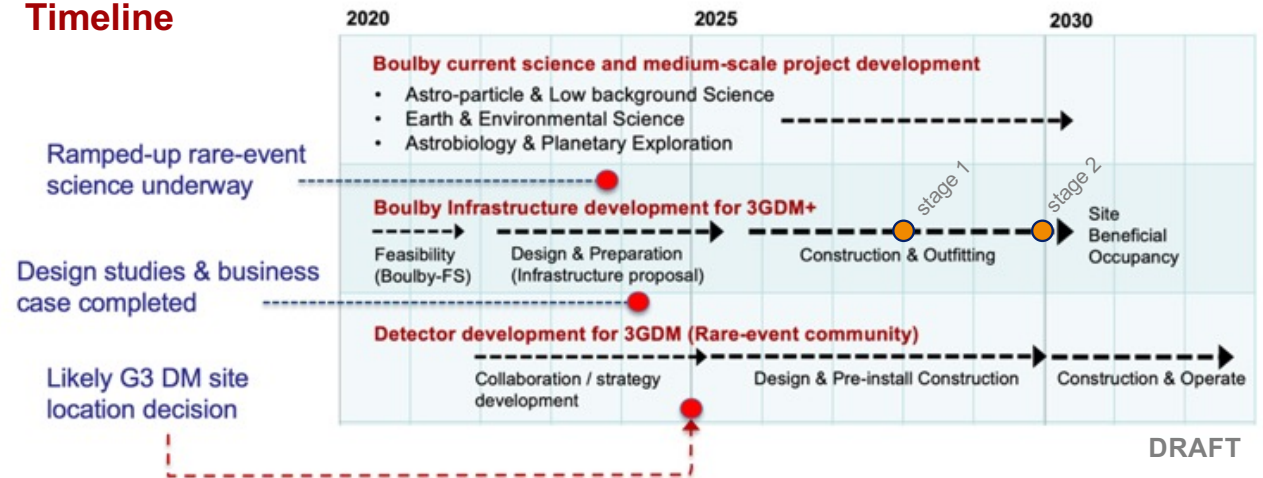
### Tasks / Deliverables:

- 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 Timeline

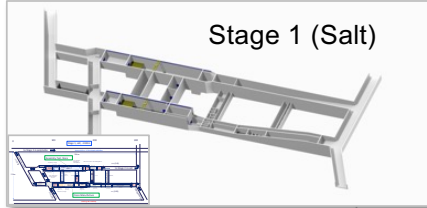
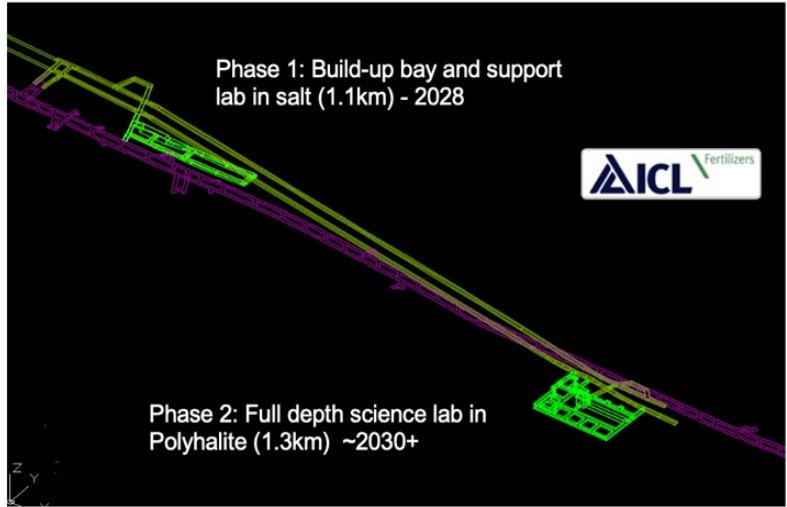
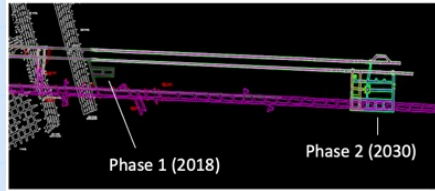
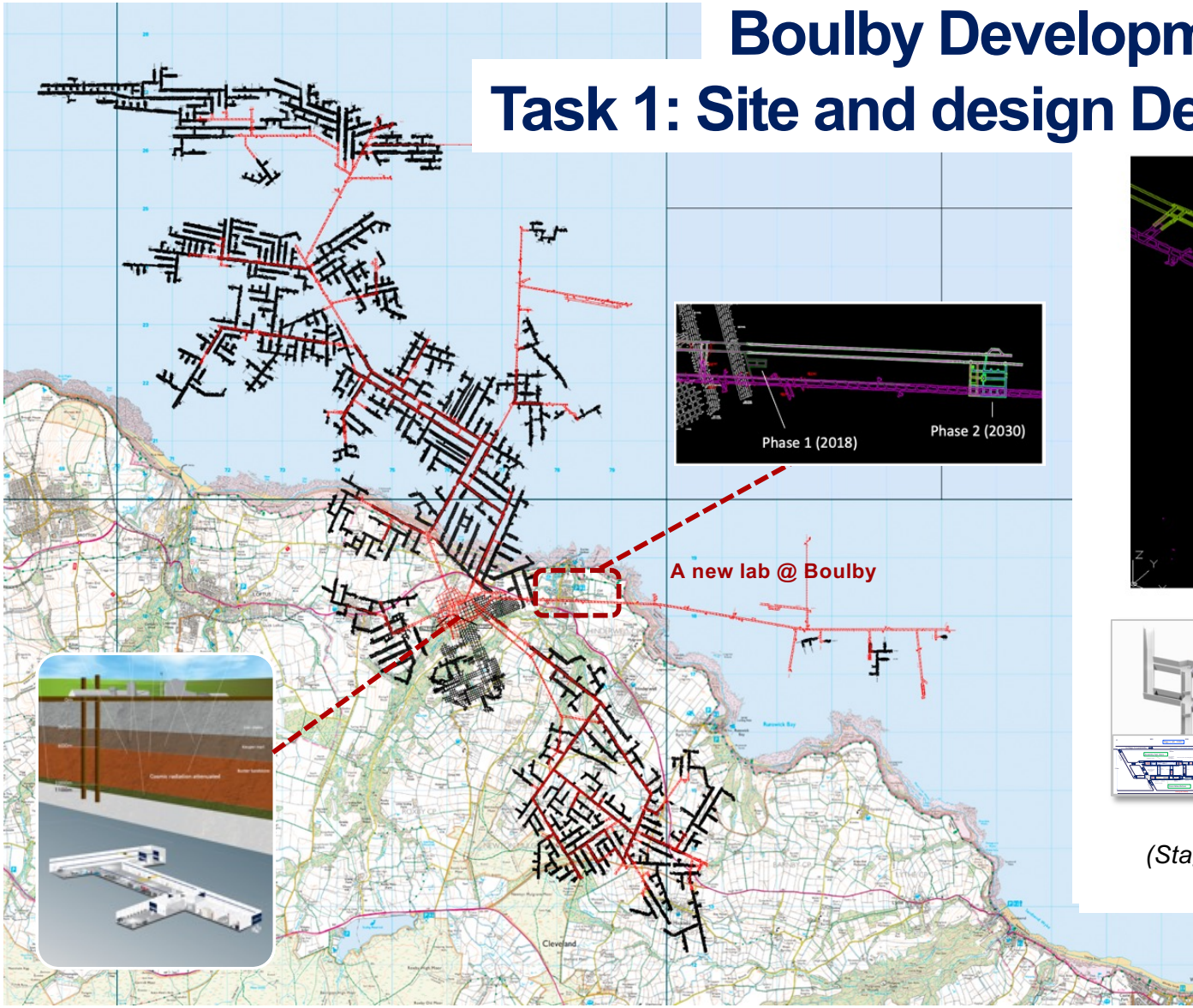
Boulby Development Project Infrastructure Bid: 2022-2025





# Boulby Development Project

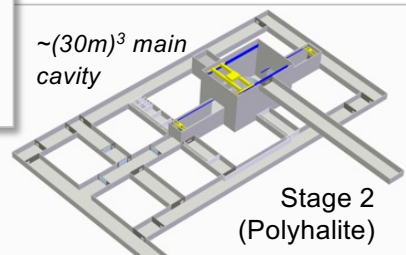
## Task 1: Site and design Development.



Stage 1 (Salt)

Total volume (Stage 1 + stage 2) ~120,000m<sup>3</sup>

*DRAFT: 2-stage Designs*



~(30m)<sup>3</sup> main cavity

Stage 2 (Polyhalite)

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

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

## Summary...

### Boulby Underground Lab status

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

### Future plans:

- A number of new 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+**



**Thank You....**

UKRI Science and Technology Facilities Council  
Boulby Underground Laboratory

UKRI COO Team Visit  
November 2022

REMOTE

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