

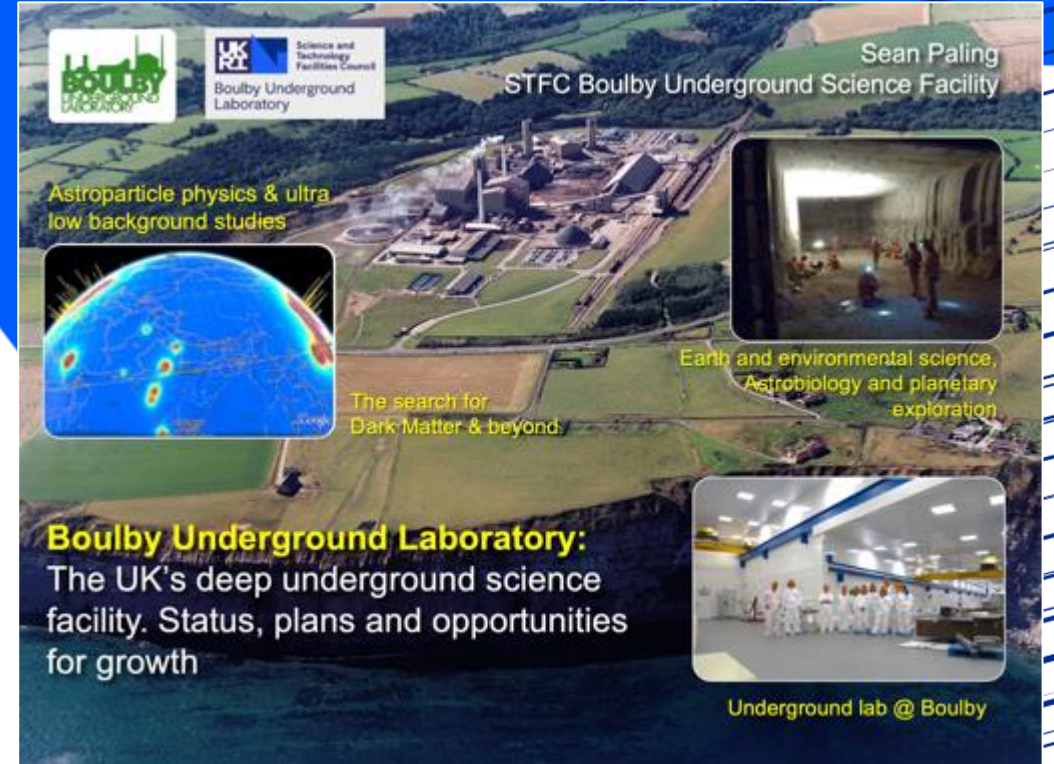


Science and
Technology
Facilities Council

Boulby Development Project Overview

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

Sean Paling
Jonathan Burns
Science and Technology Facilities Council



Boulby Underground Laboratory (UK)



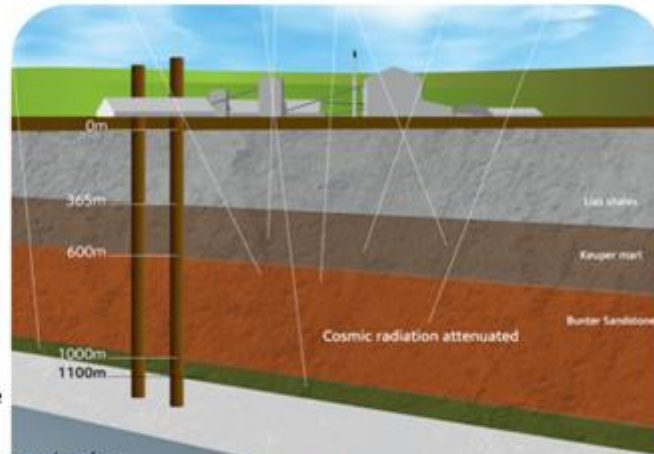
Boulby Underground Laboratory

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 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 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



Boulby Underground Laboratory (UK)



Boulby Facility Details...

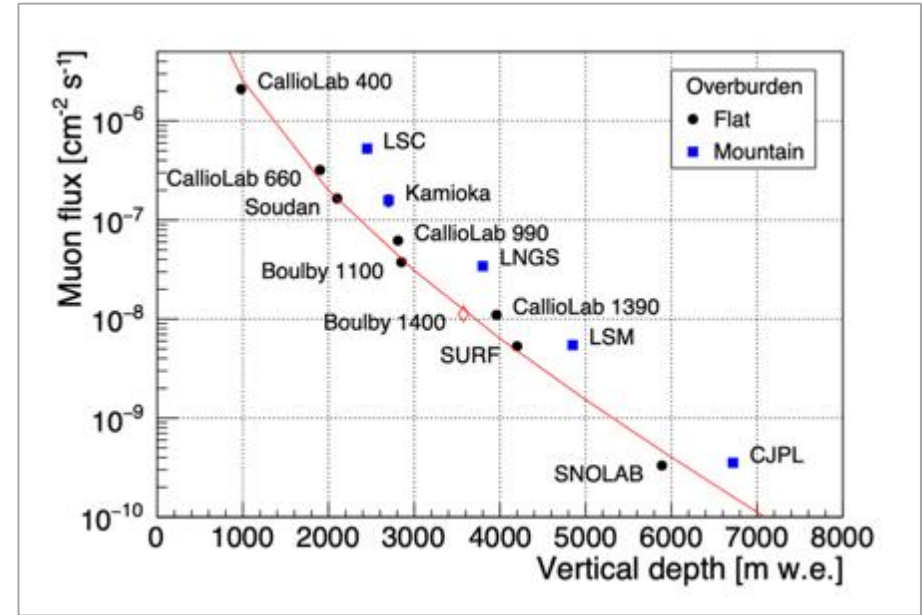


- The UK's deep underground science facility. One of 5 in Europe, <15 in the world.
- Supports work of >10 collaborative projects (astrophysics to climate, geology, environment etc), >40 institutions, >170 scientists & students.
- Facility funded and operated by the Science & Technology Facilities Council (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



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

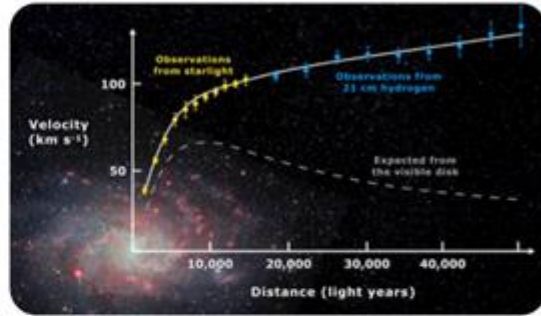


Boulby Dark Matter Studies...

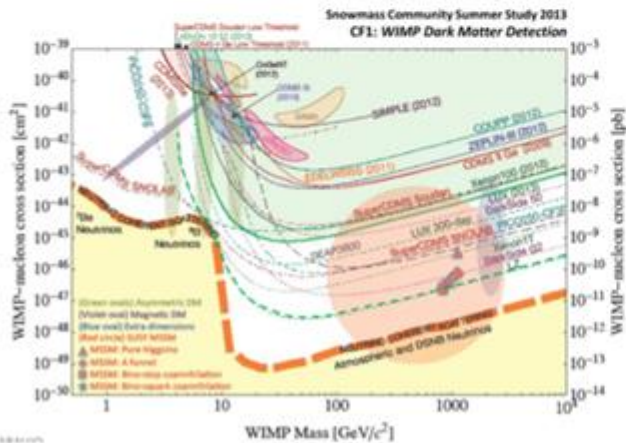


Boulby has hosted **Dark Matter search** studies for over two decades. Including the **NAIAD**, **DRIFT** & **ZEPLIN** experiment programmes.

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

XIA alpha particle counter
 <0.0001 alphas/cm²/hr

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 PULB experiments. Towards PPT sensitivity for G3 DM and Neutrino experiments

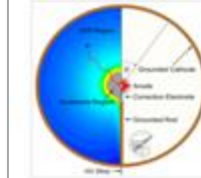
Aiming for **ALL** key ULB screening systems under one (1.1km) roof.

LZ PMTs

NEWS-G

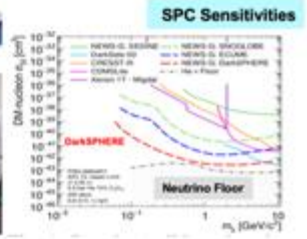
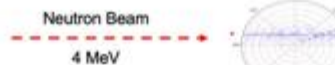
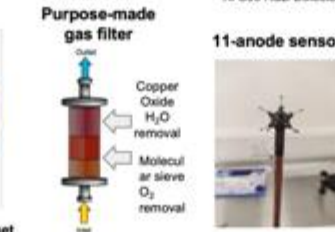
Spherical Proportional Counter (SPC) studies @ Boulby

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



- Direction of R&D at Boulby**
- Instrumentation development for NEWS-G at SNOLAB
 - Multi-anode sensor
 - Gas filtration
 - Rate effect studies
 - Neutron spectroscopy (N₂)
 - Neutron BG surveys
 - Industrial applications
 - Towards scaled-up detector at Boulby, 3m diam. 5 Bar He-CH₄H₂: **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

Coord. X

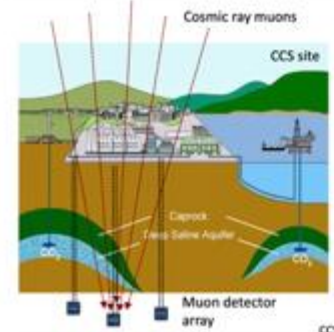
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-0.560303
-0.867188
-1.174072
-1.480957
-1.787942
-2.094727
-2.401611
-2.708496
-3.015381
-3.322266

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,
Both, 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)

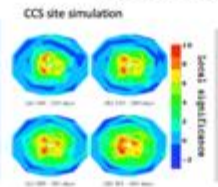


Muon-tides detector development



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)



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 Activities Now and Potential Future

2030-2040+

		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	P
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)

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

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.

Target projects for a major new UK underground facility / campus

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 Feasibility Study (Boulby-FS)

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 Ghag², S Greenwood³, V A Kudryavtsev⁴, P Majewski⁵, S M Paling⁶, V Pab⁷, R Saakyan⁸, P R Scovell⁹, N Smith¹⁰, and T J Sumner^{11*}

¹Imperial College London, UK

²University College London, UK

³STFC Rutherford Appleton Laboratory, UK

⁴University of Sheffield, UK

⁵STFC Boulby Underground Laboratory, UK

⁶SNOLAB, CA

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

June 25, 2021

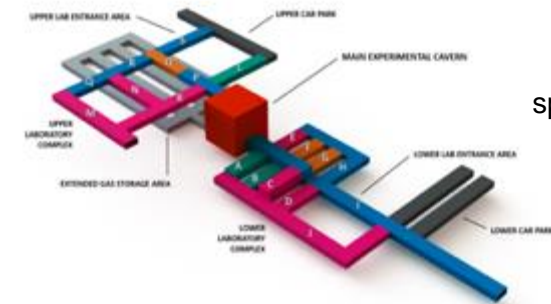
Issue v1.0

OFFICIAL-SENSITIVE [COMMERCIAL]

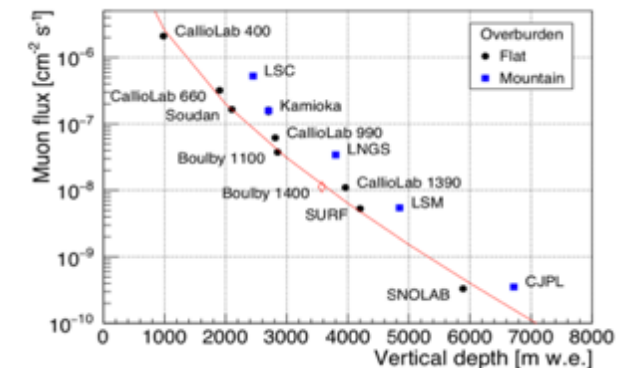
Boulby-FS (2020-21) Overview:

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

LZ @ SURF.
Next generation in the UK?



New lab specifications & designs

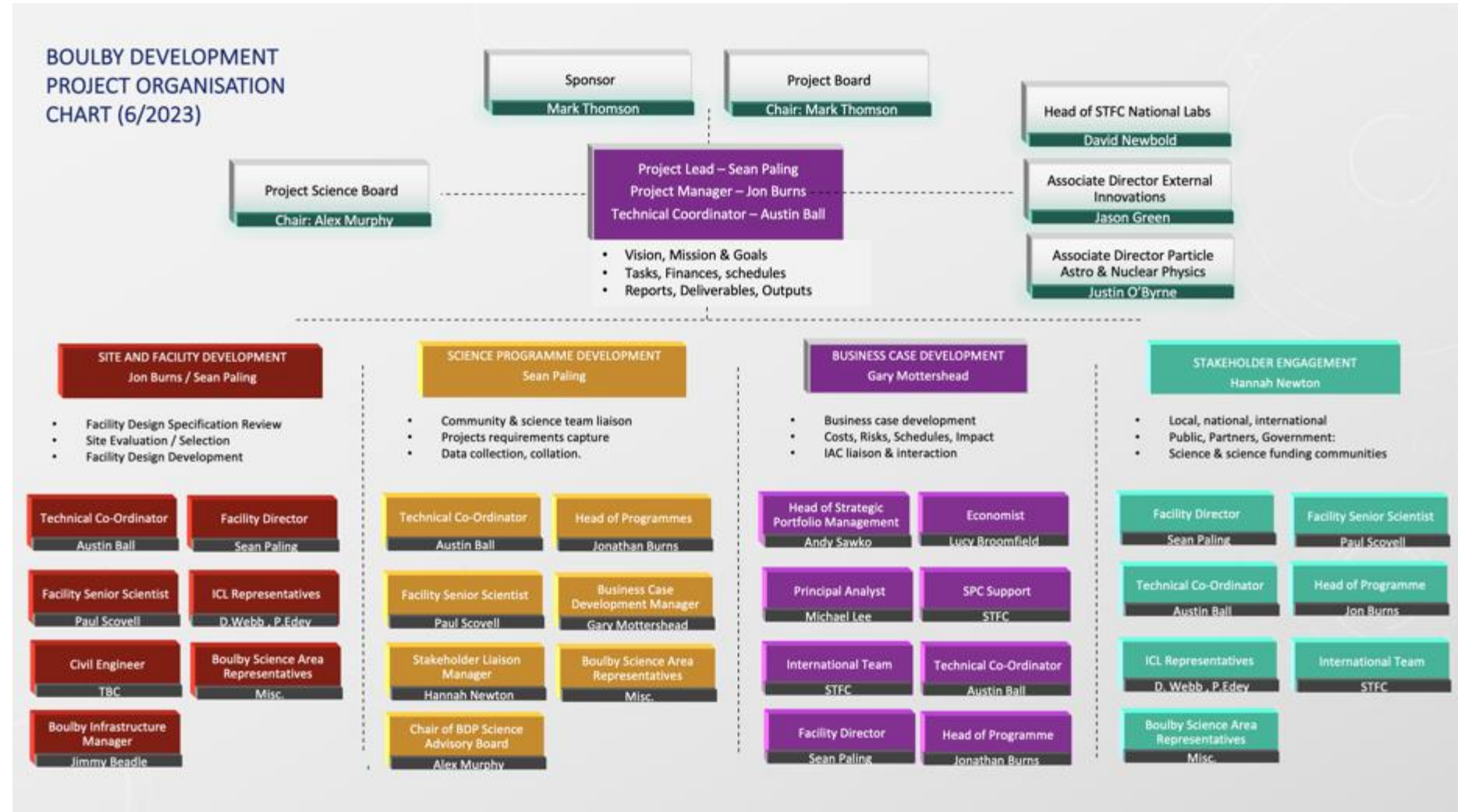


Government 'fit': Levelling Up, Strength in Places, Build Back Better, UK Science Superpower...

Results: It IS feasible, well motivated and timely.
Outfitted facility: £100-200m (Inc contingency, VAT)

Boulby Development Project (BDP)

Project Governance & Organisation:



Boulby Development Project (BDP)

Project Sponsor: Mark Thomson

Project Board: Mark Thomson (Chair)
Paul Monks
Peter Knight
Andrea Casson
Nigel Smith
Alex Murphy

BDP Science Advisory Board Alex Murphy (Chair)

Project Advisors:

STFC PPD Director Dave Newbold

STFC Associate Director - External Innovations Jason Green

STFC Associate Director - Particle Astro & Nuclear Justin O'Byrne

BDP Project Team:

Principle Investigator Sean Paling

Programme Manager Jon Burns

Technical Coordinator Austin Ball

Stakeholder Manager Hannah Newton

Business Case Development Gary Mottershead

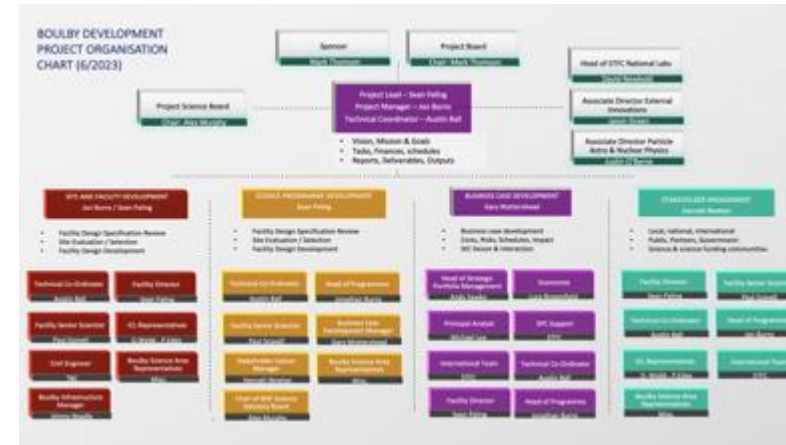
STFC Strategy Support Andrzej Sawko

Business Case Development Support Lucy Broomfield

STFC Finance Sion Evans

STFC Estates Stuart Buxton

Programmes Support Matt Chisholm



Project Governance & Organisation:



STFC Boulby Lab Team

Director	Sean Paling
Senior Scientist	Paul Scovell
Facility Manager	Emma Meehan
ES&H Manager	Tony Murphy
Dep Facility Manager Ops	Louise Yeoman
Dep Facility Manager Infrastructure	Jimmy Beadle
Science Support	Chris Toth
Science Support	Ed Banks
Director / Facility PA	Sue Armstrong
Facility Support	Maria Wood
Facility Support	George Currie

ICL Boulby Team

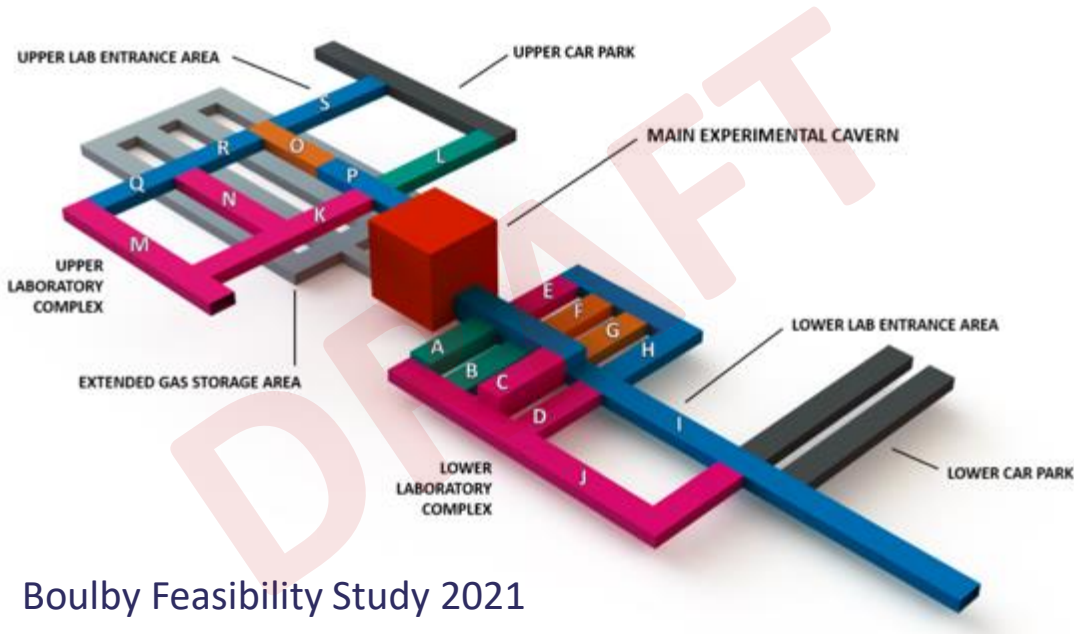
Future facility design & logistics	Duncan Webb
Future facility design & logistics	Pete Edey



Task 1: Site and Facility Development



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



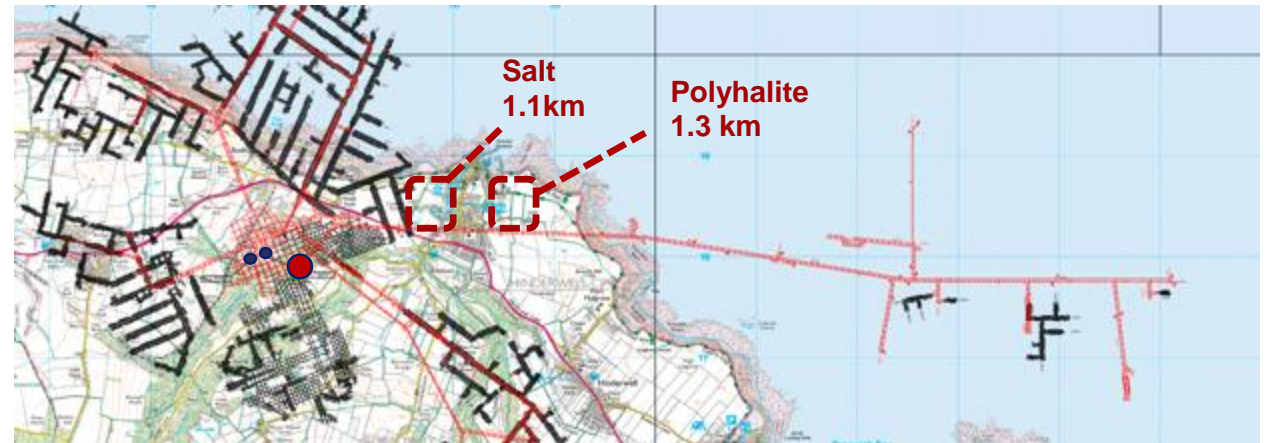
Boulby Feasibility Study 2021

Figure 6: Underground cavern design at 1,400m showing the usage of each facility space. The main experimental cavern is a 25 m cube, which provides the scale. Most outfitted areas are based on standard drift excavations (8 m width and 3.8 m height). Laboratory spaces are colour-coded: magenta is ISO 7 and teal is ISO 6; orange areas are soundproof. Labels correspond to Table 5 – A: clean manufacture facility; B: precision cleaning facility; C: test/staging facility; D: clean workshop; E: radon reduction plant; F: control room; G: messroom/restrooms; H: storeroom; I: main entrance / loading bay & gowning area; J: noble gas storage; K: water treatment plant; L: scintillator plant; M: radioassay facility; N: electronics room; O: messroom/restrooms; P: upper entrance & gowning area; Q: workshop; R: storeroom/LN store; S: upper entrance / loading bay.

Science community input/support needed...

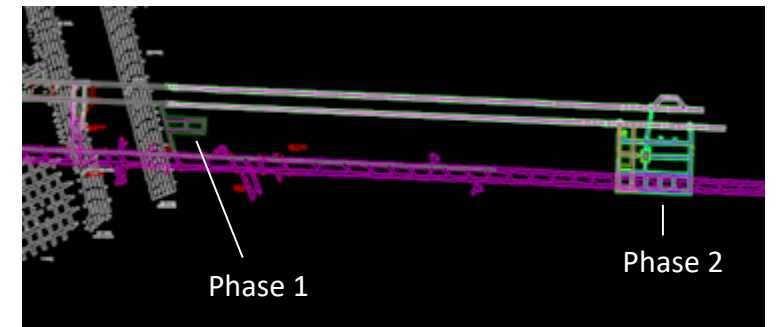
b) Preferred site(s) to be selected – Salt &/or Polyhalite

Possible sites @ Boulby Mine



Possible low lab sites in salt (1.1km) and/or Polyhalite (1.3km).

Deeper site preferred for OvBB capability



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

Your Input Needed... Towards XLZD @ Boulby

a) Facility Design Requirements: We need to know XLZD facility space requirements for us to work into a next stage facility design:

- Experimental Science Space: main experiment hall – 25x25x25?
- Support caverns: Clean build up bay, Xe capture, LS and H₂O treatment plants, control rooms, IT/data rooms, storage, offices etc.
- Environmental conditions: Cleanliness, temperature, humidity, Rn, vibration.

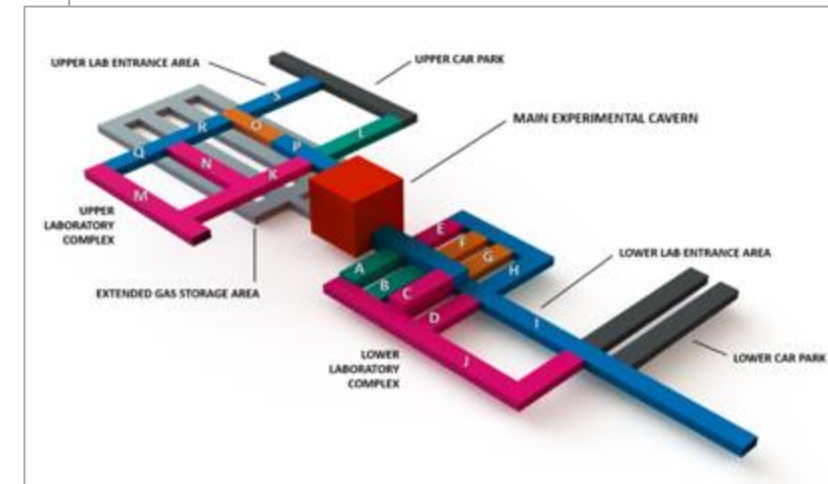
b) Facility Support Services Requirements: We need to know facility support services requirements:

- Power requirements (maximum and stability)
- IT/ Internet
- Lifting, water, compressed air, cleaning, ventilation, disposal etc/

c) Governance, Management & Science Support: Work with us on:

- Facility governance & management details/requirements
- Local resource support (onsite support, project management etc)
- Schedules and logistics. What do you need and when?

We need to continue to talk about...



Boulby Underground Laboratory



Science and
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Facilities Council

Boulby Development

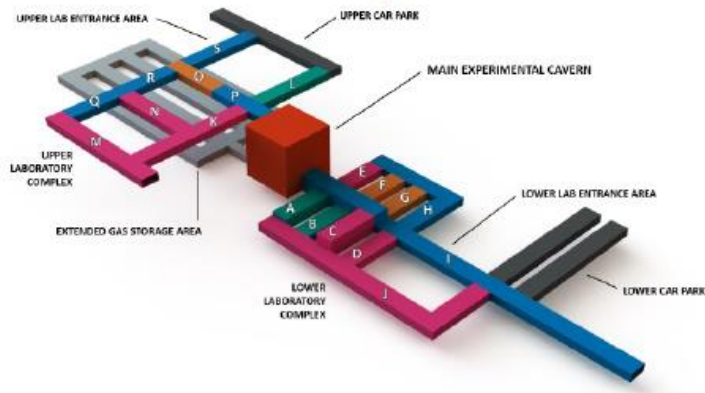
Boulby Underground Laboratory Development Plan

4th July 2023

Jonathan Burns, Sean Paling
Head of Boulby Development Programme
Director Boulby Underground Laboratory
jonathan.burns@stfc.ukri.org
sean.paling@stfc.ac.uk

Overall Programme Aim

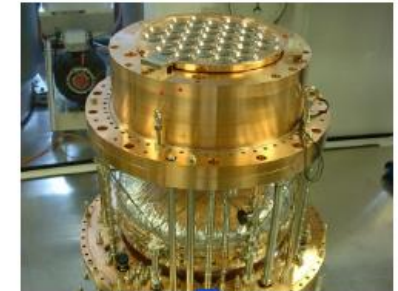
Underground Facility



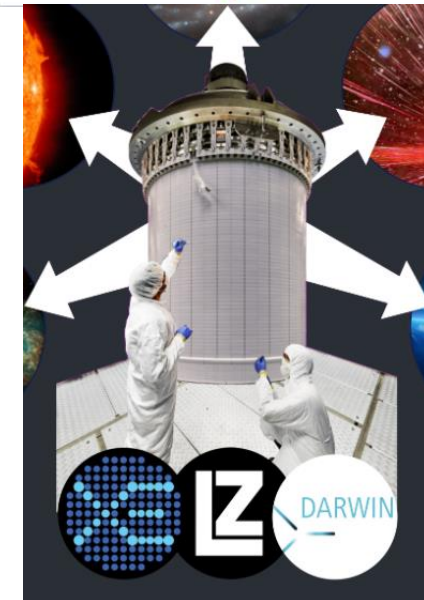
Surface Facility



Experiment



Zeppelin III



Strategic Delivery Plan

STFC's new Strategic Delivery Plan was published, alongside other Council Delivery Plans, on 2nd September 2022

- Sets out STFC's exciting plans for the next three-year spending period
- **Many new activities and investments across all STFC areas**
- Explains the role STFC will play in delivering UKRI's wider mission/vision
- Structured around the six objectives of the UKRI Strategy
- <https://www.ukri.org/publications/stfc-strategic-delivery-plan/>



Our ambitious plan: Ideas and Places

Major investment and activity across STFC, examples include

- **An increase of £19 million** over the next three years for STFC-supported frontier research programmes
- **Enhancing UK scientific links globally**, initially targeting new scientific collaborations with India, Japan and the US. Initially this will include funding the Hyper-Kamiokande neutrino experiment in Japan and the US Simons Observatory (located in Chile)
- **Delivery of a portfolio of infrastructure projects** to provide the capability to enable the UK's thriving research and innovation communities to address the most pressing industrial and societal challenges:
 - Major investments in all our large multi-disciplinary facilities
 - Funding to develop plans for Boulby area

STFC's Strategic Delivery Plan

“Complete the design study 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's Strategic Delivery Plan

- Now exploring the feasibility of a new facility in the UK
 - Boulby is acknowledged as a technically suitable site for the facility
 - UK's international reputation in the field makes this a credible prospect but the need to work with international partners is clear
- The benefits
 - Would underwrite the UK's 'scientific superpower' aspirations. We strongly support international fundamental physics – but have no facilities in the UK
 - Scale makes this a driver for the high-tech economy in North-East England
 - Of course – supporting science
- The challenges
 - Requires a significant and rapid scale-up of facilities
 - Buy-in needed from many parties in HMG, in the region, and in community
 - Significant engineering and logistic challenges in delivering the project
 - Needs to deliver in the long term (decades) – flexible design needed
 - Requires a **new** strategic capital investment by government

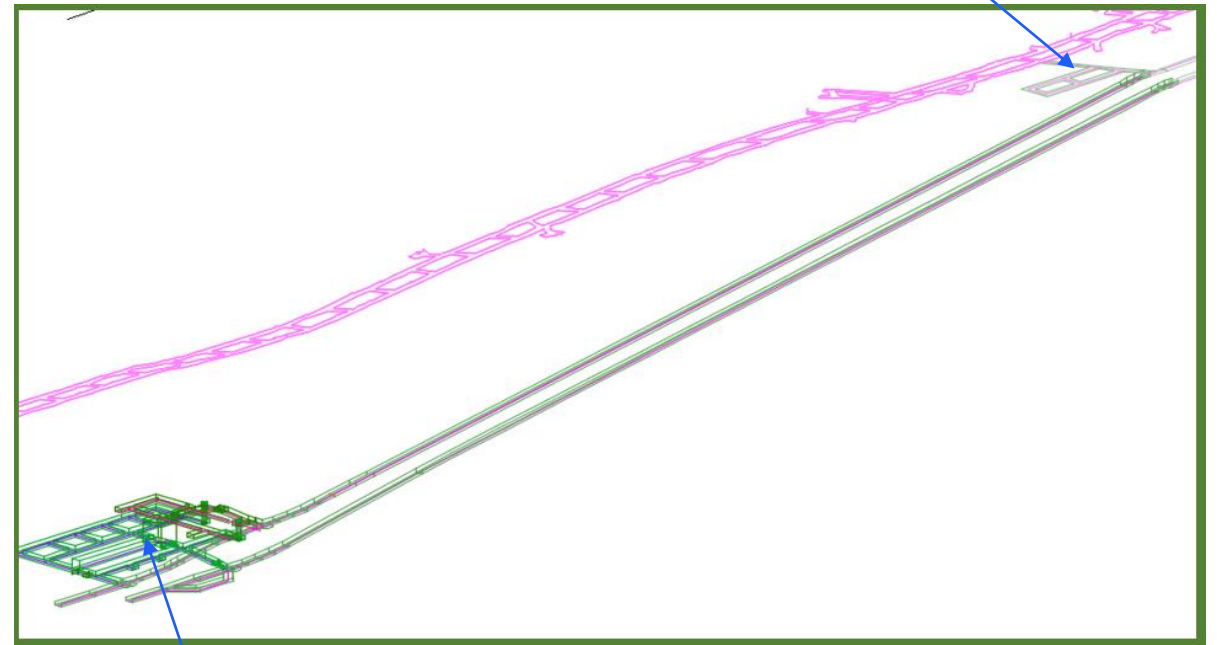
Site and Facility Design and Planning - Boulby

- ICL Boulby are currently considering polyhalite mining as part of their future mining activity
- Two build sites have been identified at Boulby at -1.1km and -1.3km in salt and polyhalite layers respectively. Both sites could host the XLZD experiment but a depth of -1.3km may be required for part of the physics programme and is considered to be the optimum depth for Boulby to be competitive as an XLZD host site
- Commercial activity at Boulby indicates that the salt site will be available for new laboratory construction from 2024 onwards. Note design studies at this site were completed as part of the AIT project
- Boulby Development Programme aims to complete all design work in the 2022-2025 period and start work on the main laboratory in 2025.

Site and Facility Design and Planning - Boulby

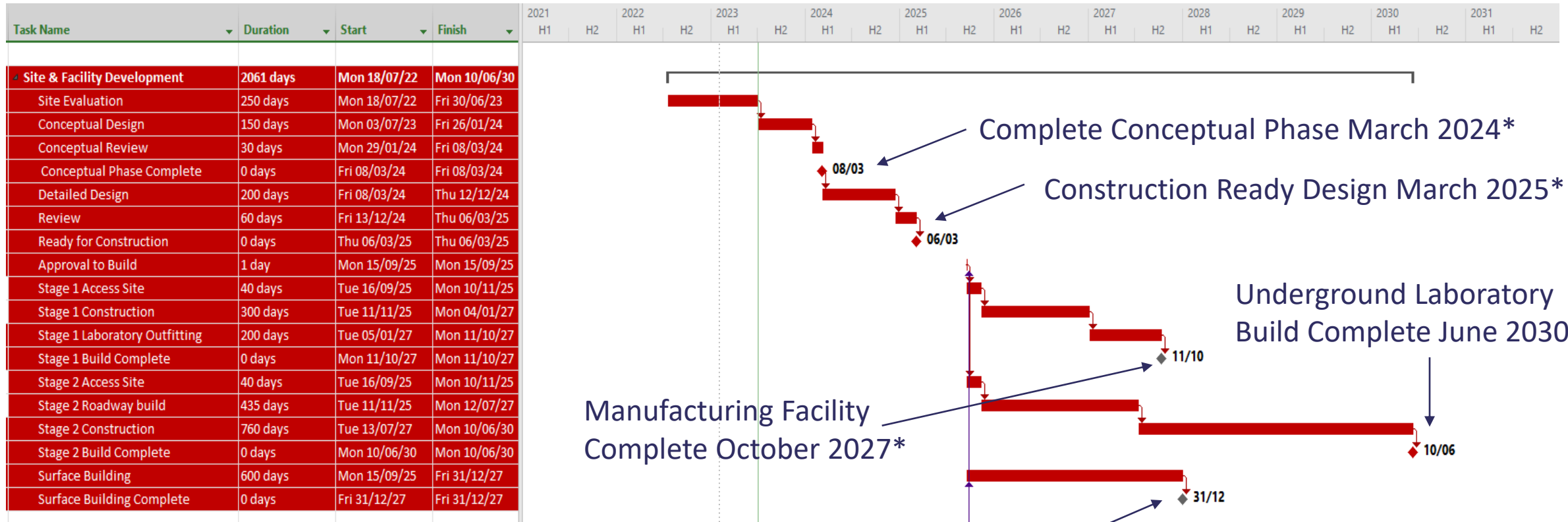
- XLZD experiment aim to have access to underground laboratory site by 2030
- BDP Team are exploring the option to split the new build into 2 phases
 - Stage 1 – New manufacturing site by 2028
 - Stage 2 – New underground laboratory by 2030
- Preliminary estimate for build time
 - Stage 1 - ~100wks to completion
 - Stage 2 - ~296wks to completion (including roadways)

Stage 1 Manufacturing site



Stage 2 Laboratory

Site and Facility Design and Planning - Boulby 2025/26 Build Start



Site and Facility Design and Planning – Laboratory Build Complete Status



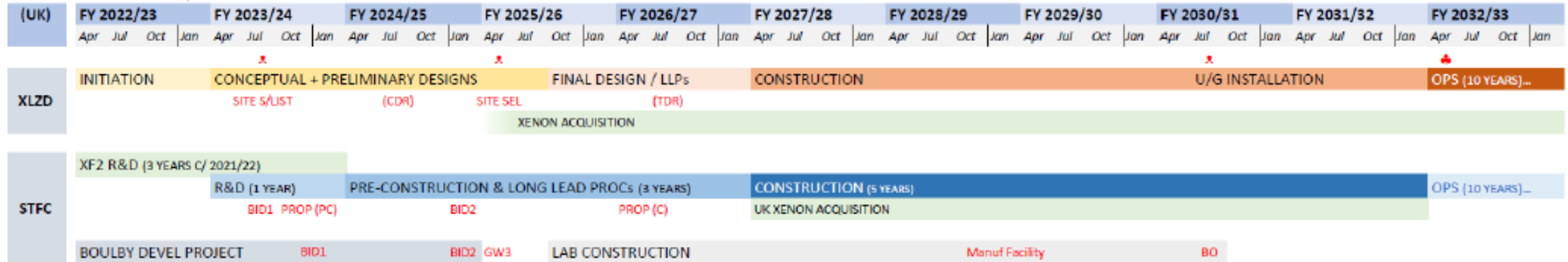
BEST PRACTICE - FLUSH LIGHT FITTINGS AND INTEGRATED SERVICES



BEST PRACTICE - FLUSH DOORS AND WINDOWS/VISION PANELS

Build complete status includes outfitting of the spaces, clean room barriers, roller doors, power and welfare facilities .

XLZD Experiment



- A key milestone is site selection in 2025, associated with inter-agency agreements and IF investments decisions for both Boulby and XLZD construction: achieving investment decisions in 2025 is essential for a deployment at Boulby to remain competitive – Statement from XLZD SOI
- Boulby Development Programme schedule meets the timescale put forward by XLZD team

Boulby Infrastructure Advisory Scheme

- The aim of the scheme is to fund teams or individuals to support the development of the requirements for a new UK laboratory facility. Ensuring a broad range of underground science can be fully accommodated and supported in the facility.
- Applicants needed to demonstrate that any project idea was aimed at supporting the working the development of a new underground laboratory.
- Panel review has been completed and final written feedback is being prepared.
- Successful applicants will be notified in the next ~2 weeks

Summary

- The new laboratory construction project is planned to be completed by **2030** with a new manufacturing facility by **2028** with major construction started in **2025/26**.
- XLZD could be hosted in the UK within the timescales proposed by the XLZD consortium.
- STFC supportive of the Boulby Development and XLZD@Boulby

Key Programme Contacts

- Grahame Blair, Executive Director Programme Directorate
- Jenny Hiscock, Acting Associate Director Particle Astrophysics and Nuclear Physics
- Jamie Parkin, Head of Nuclear Physics and Particle Astrophysics
- Sarah Verth, Associate Director for Particle Physics
- Karen Clifford, Head of Particle Physics
- Jonathan Burns, Head of Programme Boulby Development
- Jason Green, Associate Director Cross Cutting and International Programmes
- Other key people are Mel Kidd, Jane Long, Lindsay Clarke, Nicole Ashman, Doranne Fernandes, and Jess Atkinson