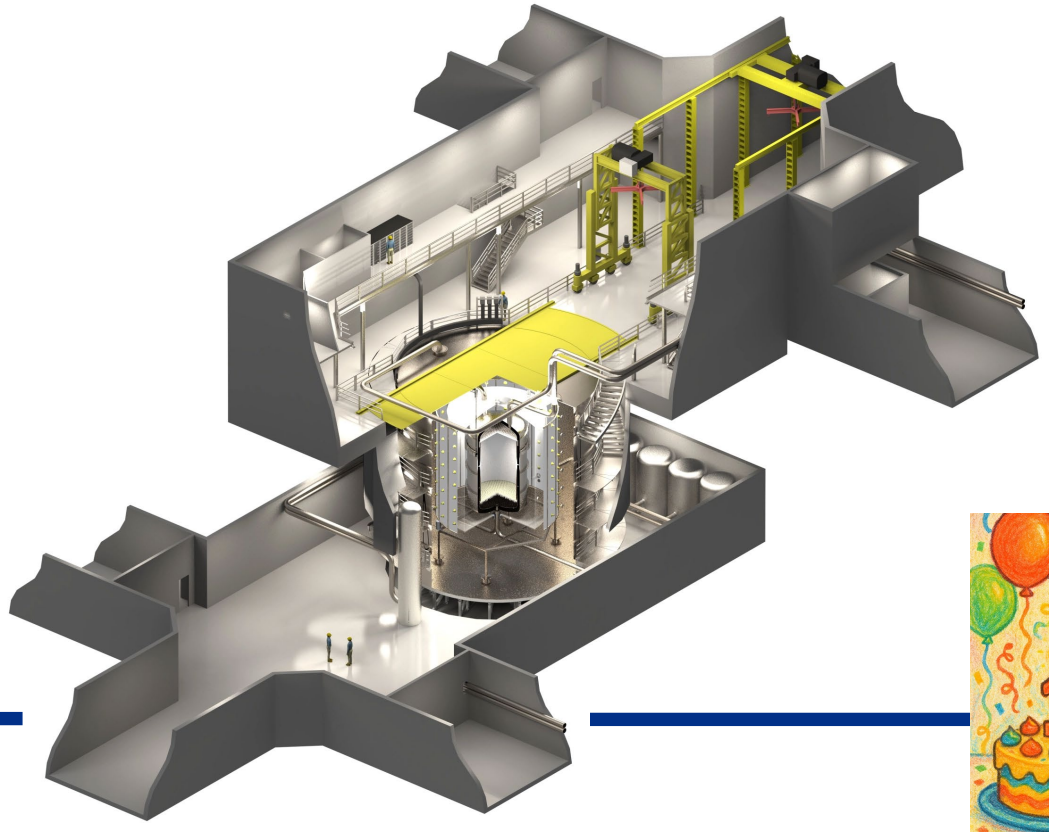
XLZD-UK

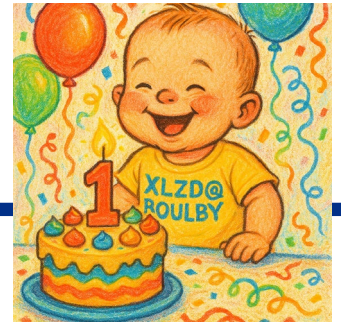
XLZD@BOULBY STATUS

Henrique Araújo (XLZD-UK PI)

Imperial College London &
STFC Rutherford Appleton laboratory

30th June, 2025





XLZD@BOULBY: THE EARLY YEARS

0. Xenon Futures R&D project (2019-25)

- Technical R&D around LXe-TPC technologies: “keeping the band together”

1. Boulby Feasibility Study (2019-21)

- Resonated with the STFC Strategic Delivery Plan 2020-25
- And with the (then) Government strategy (“Levelling up”, …)


FINAL REPORT

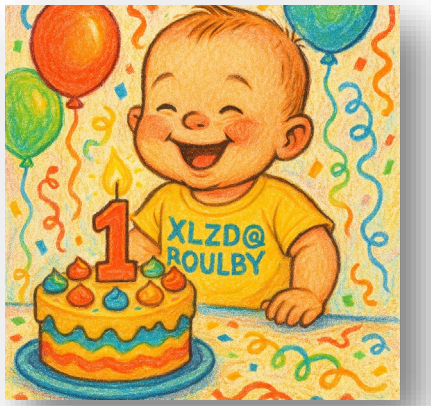
FEASIBILITY STUDY
FOR DEVELOPING THE BOULBY UNDERGROUND LABORATORY
INTO A FACILITY FOR FUTURE MAJOR
INTERNATIONAL PROJECTS

Supported by the STFC Opportunities Call 2019

June 25, 2021
Issue v1.0

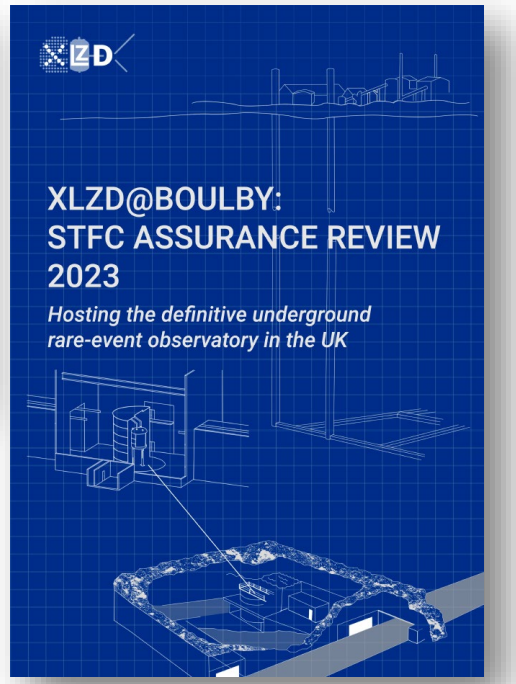
2. Boulby Development Project (2022-25+) (£2.8M+)

- Funded through UKRI Infrastructure Fund (Preliminary Activity)
- Develops facility design – meet Austin Ball and Jon Elmer (STFC)
- Additional funds awarded for **Stage 1 excavations (~£6.5M)**



3. XLZD@Boulby Pre-Construction Project (2024-27) (£8.7M)

- Funded through UKRI Infrastructure Fund (Preliminary Activity), after much review by STFC and its advisory panels
- **Broad objectives**
  - Technical design of UK hardware systems and their interfaces to facility and partner contributions
  - Planning and capacity-building in key areas (e.g. clean manufacture, skills pipeline, sustainability)
  - Working with international partners to build the XLZD collaboration and international project
  - To position the UK to host the experiment at Boulby



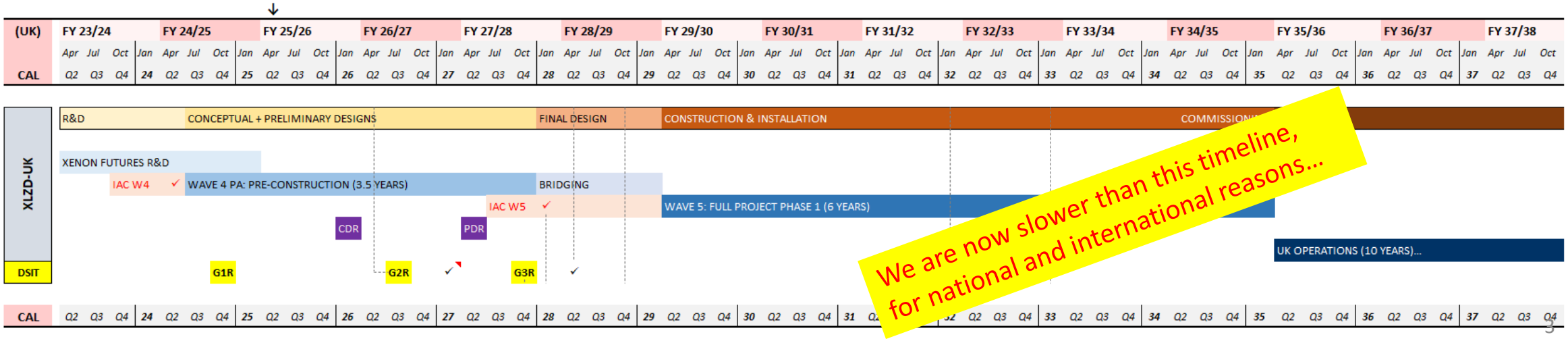
THE PROPOSED PROGRAMME

1. A major new underground facility – prepared by the Boulby Development Project

2. One-third of XLZD project cost – prepared by the XLZD-UK Pre-Construction Project

Combined investment package of ~£500M being discussed with STFC, UKRI, and the UK Government (DSIT)
Business Case started assessment (next slide) – Initial review (Gate 1) was positive, but a long way to go

The message coming from the UK Government is encouraging us to "continue to explore this opportunity"
Comprehensive Spending Review just published, fallout onto DSIT>UKRI>STFC>XLZD@Boulby will filter slowly
Funding Boulby Stage 1 outfitting (BDP) is next priority, even before clarity on "route to funding" for full project



GATE 1 BUSINESS CASE REVIEW (GOVERNMENT LEVEL)

Gate 1 Review
held in November 2024,
positive outcome.
Awaiting final appraisal
by DSIT Investment Committee

Much harder;
expected 2026/27, TBC
good indication of intent to fund

Investment decision;
expected 2027/28, TBC

Link

Box: The business case development framework

Determining the strategic context and undertaking the Strategic Assessment
Step 1: determining the strategic context
Gateway 0: strategic assessment

Stage 1 – Scoping the scheme and preparing the Strategic Outline Case (SOC)
Step 2: making the case for change
Step 3: exploring the preferred way forward
Gateway 1: business justification

Stage 2 – Planning the scheme and preparing the Outline Business Case (OBC)
Step 4: determining potential Value for Money (VfM)
Step 5: preparing for the potential Deal
Step 6: ascertaining affordability and funding requirement
Step 7: planning for successful delivery
Gateway 2: delivery strategy

Stage 3 – Procuring the solution and preparing the Full Business Case (FBC)
Step 8: procuring the VfM solution
Step 9: contracting for the Deal
Step 10: ensuring successful delivery
Gateway 3: investment decision

Implementation and monitoring
Gateway 4: readiness for service

Evaluation and feedback
Gateway 5: operations review and benefits realisation

XLZD@BOULBY PRE-CONSTRUCTION PROJECT

Main goals

i. To develop the **Conceptual Design** of the UK scope, including determination that the selected options meet the needs and production of a cost estimate. This informs the application for funding of the full project, with the ensuing investment decision feeding into the XLZD site selection process.

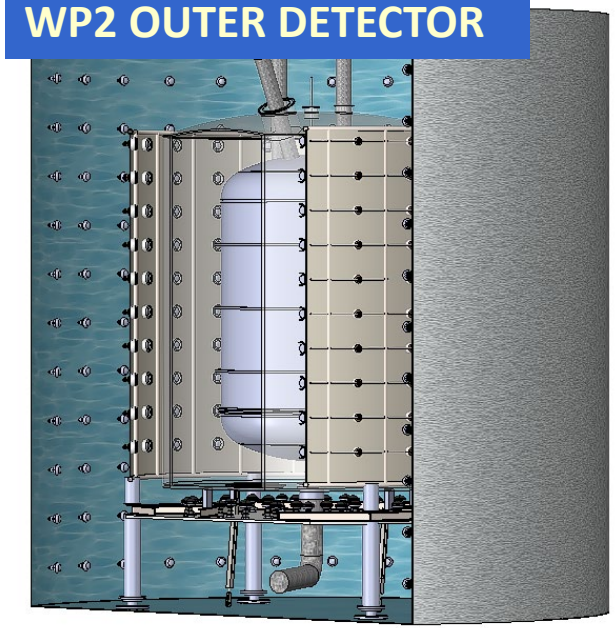
ii. To develop the **Preliminary Design** of the UK scope by 2027, to define the baseline of scope, cost and schedule for the full project, with associated development of a Business Case.

Includes identifying and assessing viable options for each subsystem, selecting the preferred option and progressing that to CD maturity

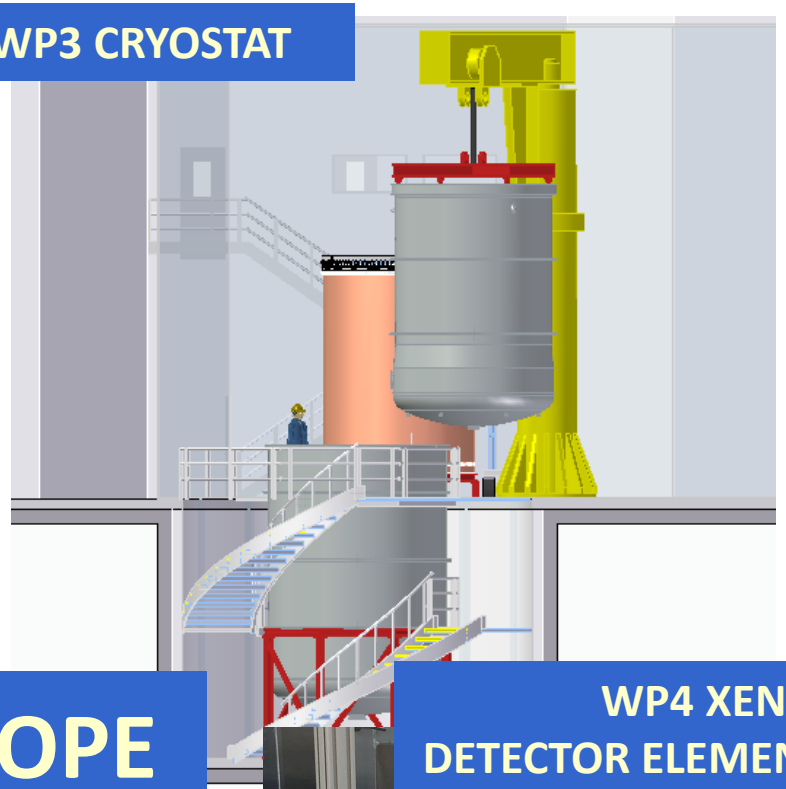
UK CDR planned for next 9 months, but will probably be slower, TBC.
Not for external publication: can seed project-level CDR on longer timescale

WP1 XENON ACQUISITION

WP2 OUTER DETECTOR



WP3 CRYOSTAT

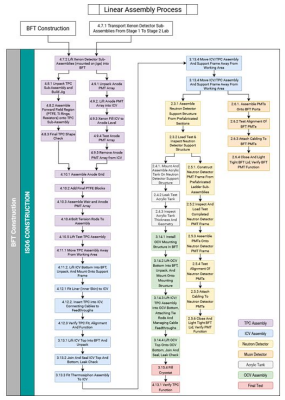


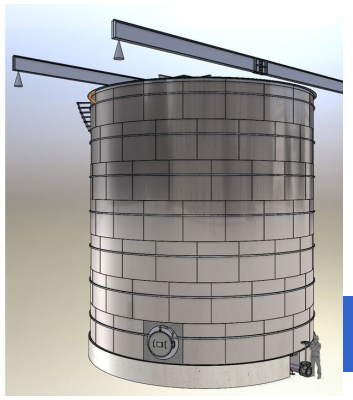
WP8 SUSTAINABILITY

XLZD-UK NOTIONAL SCOPE

WP4 XENON DETECTOR ELEMENTS (FIELDCAGE & SKIN)

WP7 ENGINEERING & SKILLS



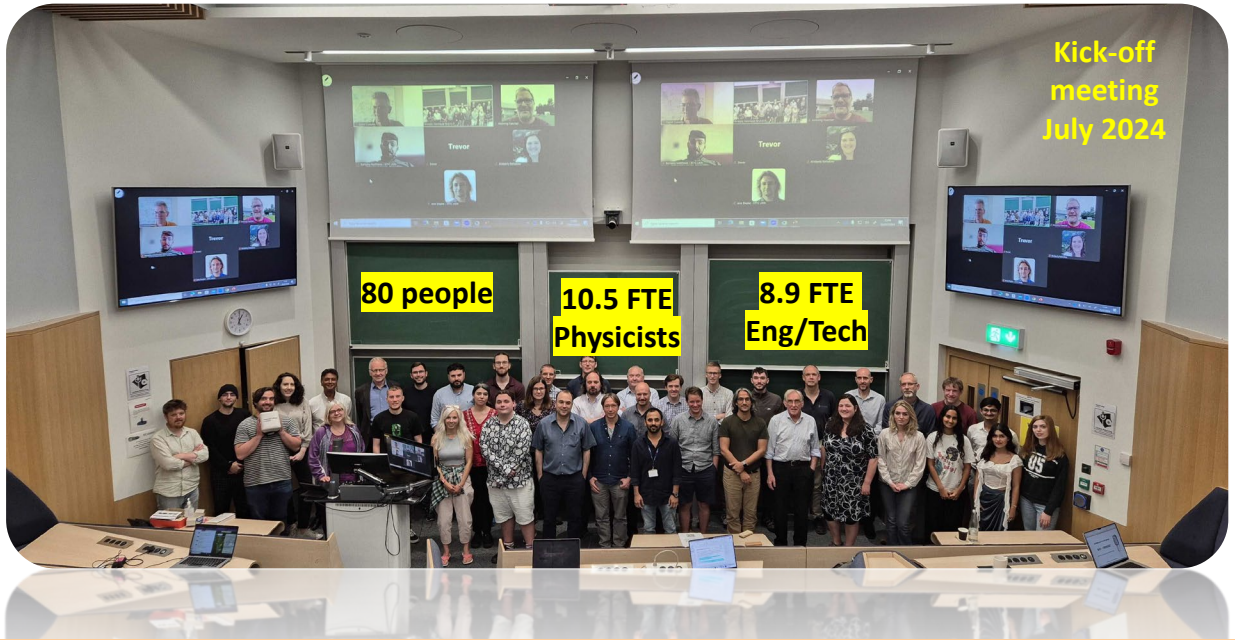


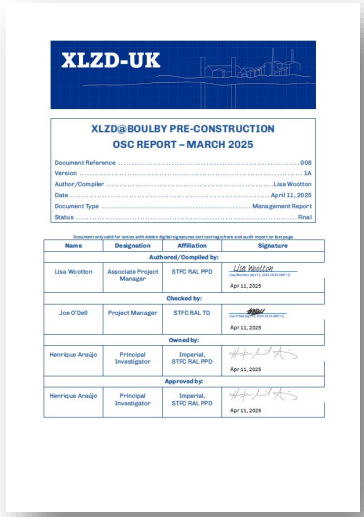
WP6 CLEAN MANUFACTURE

WP5 UK DATA CENTRE & ONSITE COMPUTING

PRE-CONSTRUCTION PROJECT: INITIATION

- Engaged technical teams, developed management systems, connected with industry
- Developed Project Management Plan, approval by “Project Sponsor” is imminent
- First STFC Oversight Committee took place in May, positive feedback




XLZD-UK

XLZD@BOULBY PRE-CONSTRUCTION
OSC REPORT – MARCH 2025

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Version 1A
Author/Compiler ..... Lisa Wootton
Date ..... April 11, 2025
Document Type ..... Management Report
Status ..... Final

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Approved by:			
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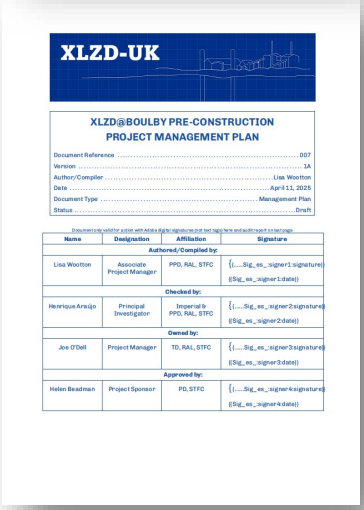
XLZD-UK

XLZD@BOULBY PRE-CONSTRUCTION
PROJECT MANAGEMENT PLAN

Document Reference 007
Version 1A
Author/Compiler ..... Lisa Wootton
Date ..... April 11, 2025
Document Type ..... Management Plan
Status ..... Draft

Name	Designation	Affiliation	Signature
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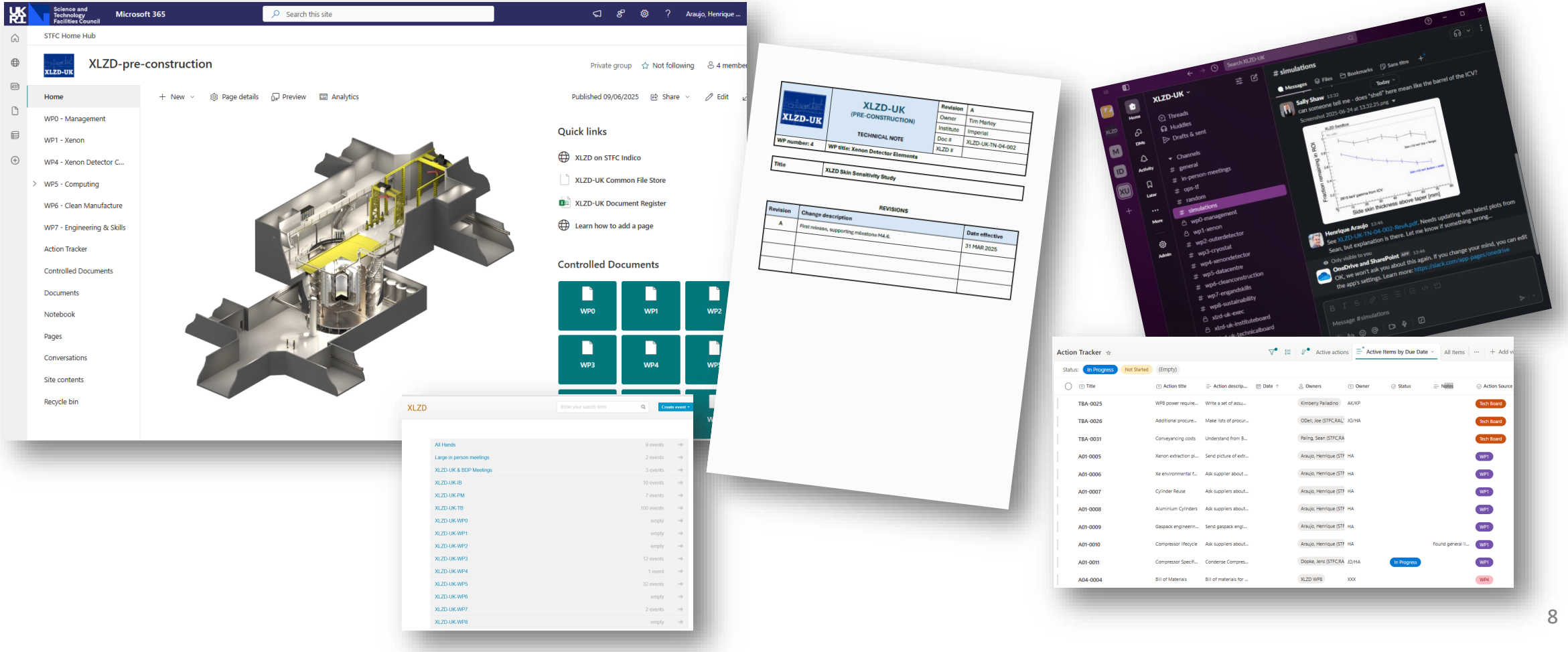
Approved by:			
Helen Beadman	Project Sponsor	PD, STFC	{_:Sig_es_:signer4:signature} {Sig_es_:signer4:date}

14 UK institutes, nearly 80 researchers and engineers (118 Slack users)

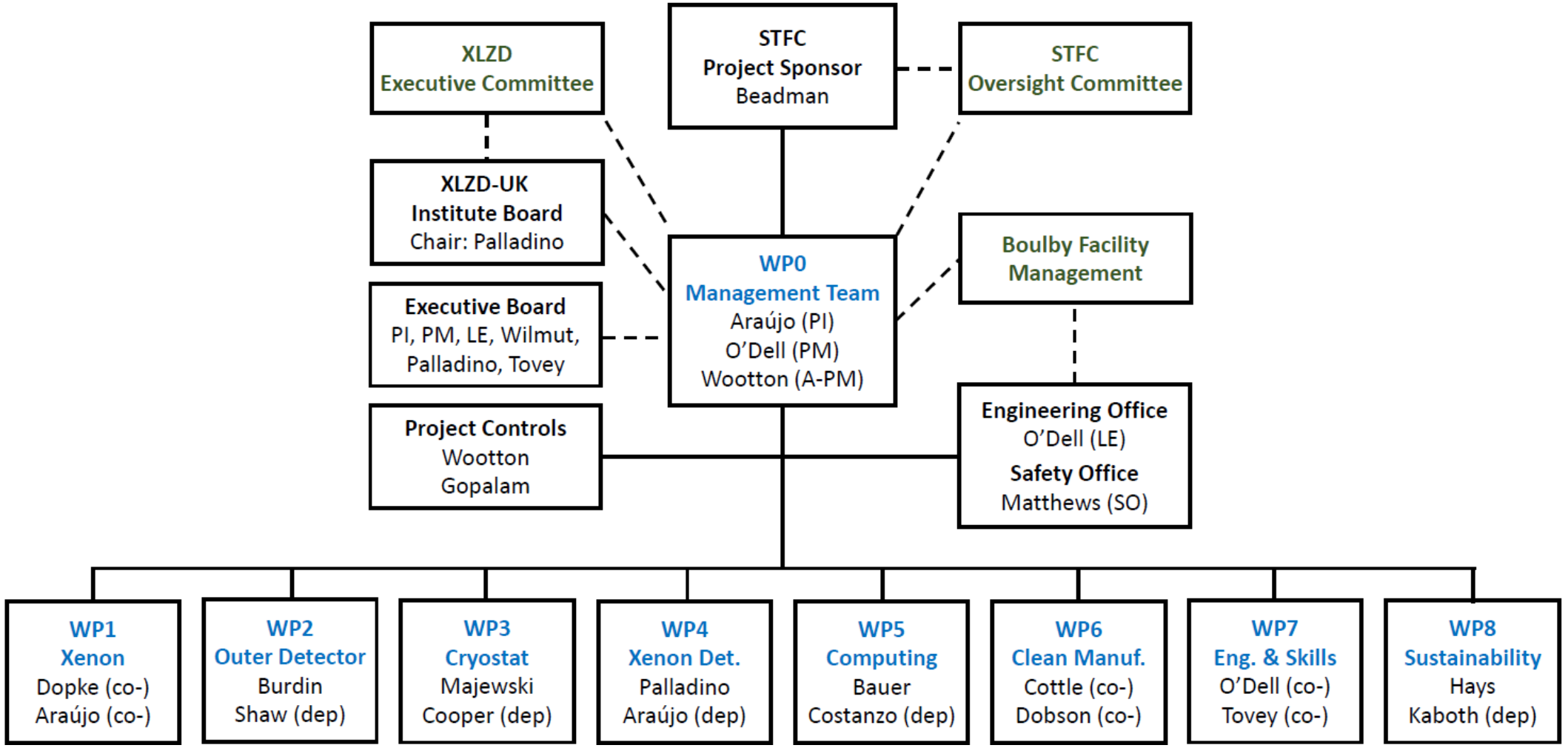
University of Birmingham ◊ University of Bristol ◊ University of Edinburgh ◊ University of Liverpool ◊ Imperial College London ◊ Kings College London ◊ Queen Mary, University of London ◊ Royal Holloway University of London ◊ University College London ◊ University of Oxford ◊ STFC Technology Department ◊ STFC Particle Physics Department ◊ University of Sheffield ◊ University of Sussex

PRE-CONSTRUCTION PROJECT: INITIATION

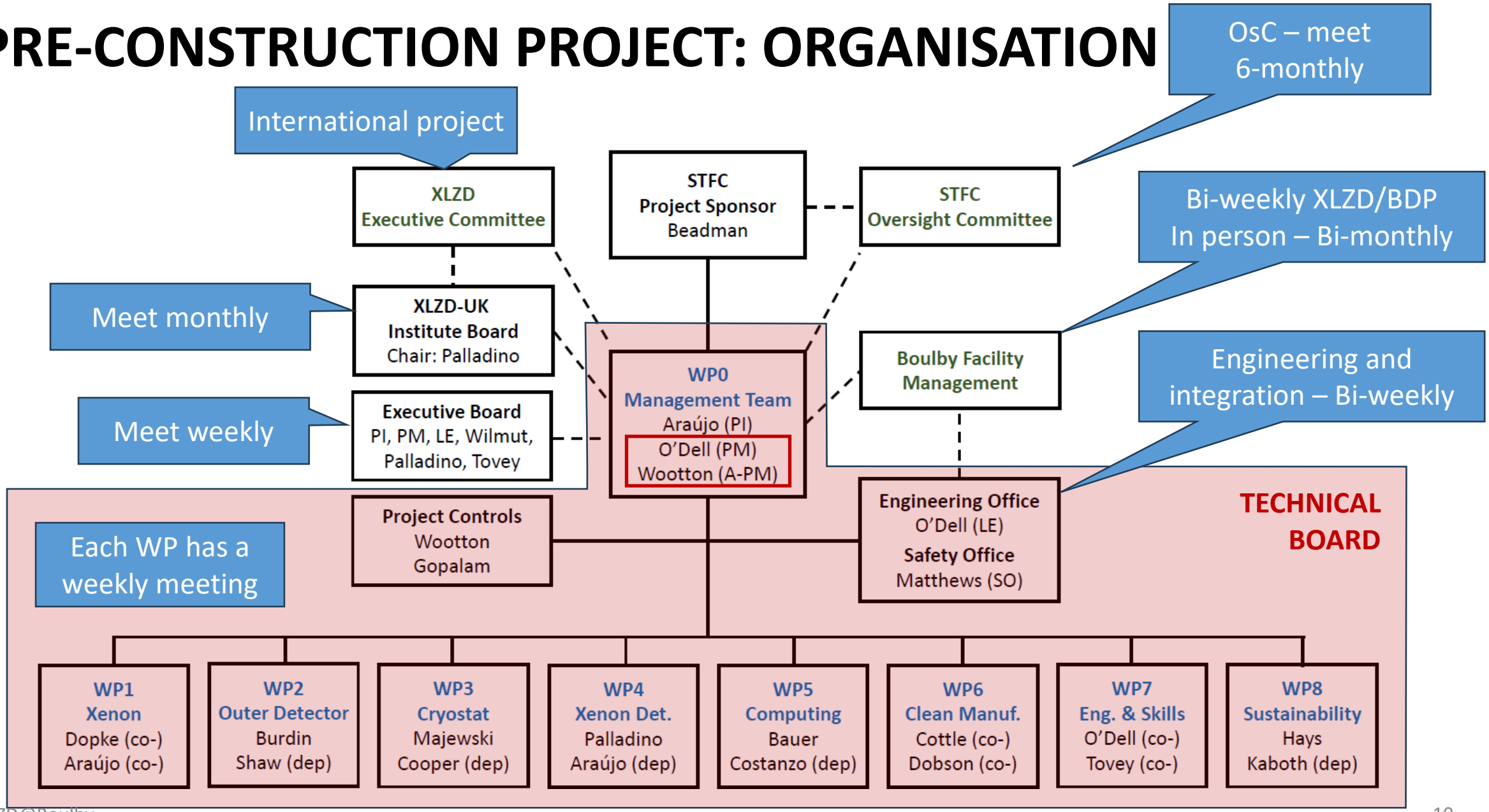
- Information tools developed (project monitoring, SharePoint, Indico, Slack, doc system, action tracker, …)
  - Naturally, we aspire to integrate more closely with international XLZD systems, but we're not there yet…



PRE-CONSTRUCTION PROJECT: ORGANISATION



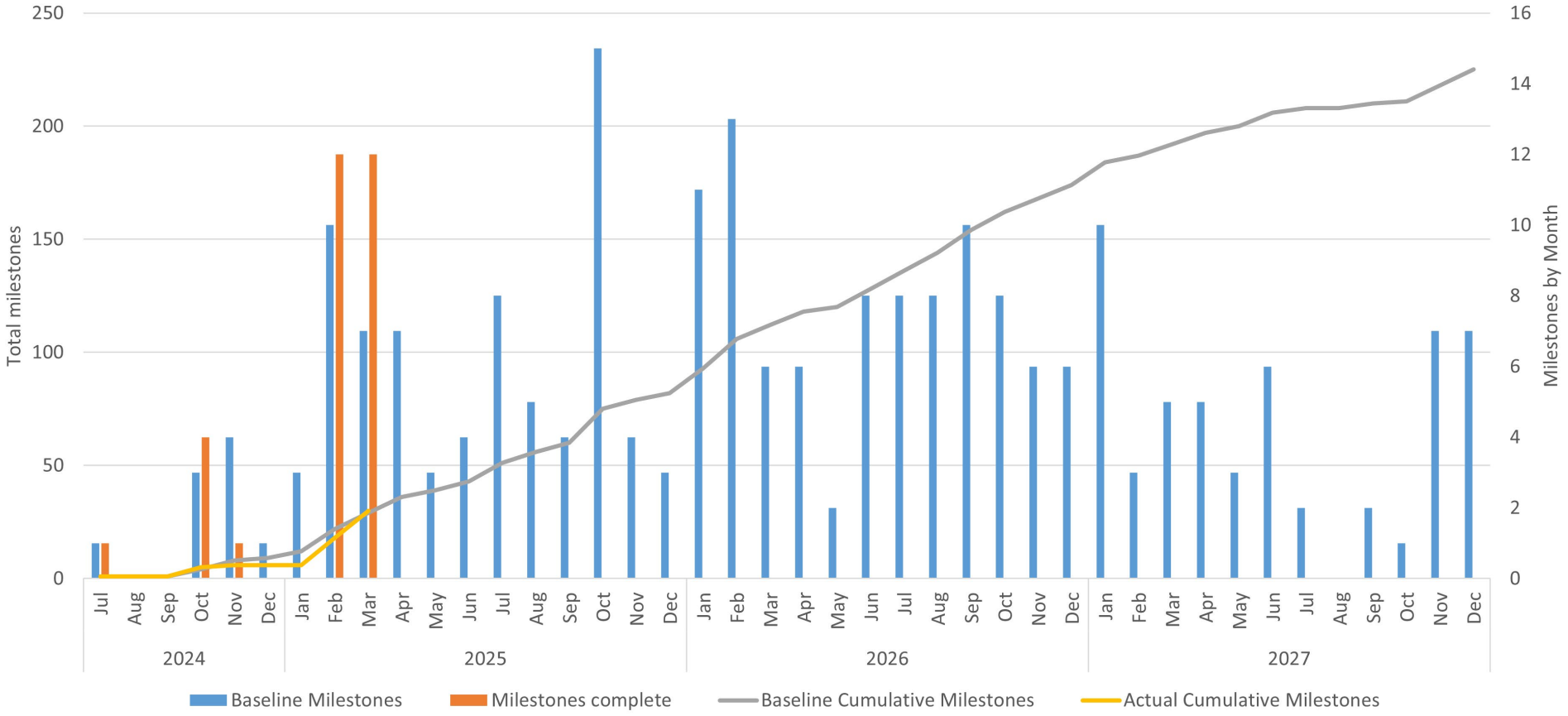
PRE-CONSTRUCTION PROJECT: ORGANISATION

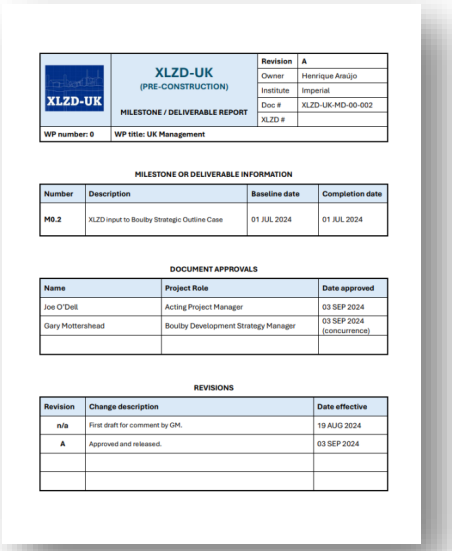


PRE-CONSTRUCTION PROJECT: PERFORMANCE

We are not tracking earned value (and will not) – instead, we monitor by milestone completion

By end March (OsC reporting period): 30 completed out of 33 due; all documented and signed-off





XLZD-UK
(PRE-CONSTRUCTION)
MILESTONE / DELIVERABLE REPORT

Revision	A
Owner	Henrique Araújo
Institute	Imperial
Doc #	XLZD-UK-MD-00-002
XLZD #	

WP number: 0 — WP title: UK Management

MILESTONE OR DELIVERABLE INFORMATION

Number	Description	Baseline date	Completion date
M0.2	XLZD input to Boulby Strategic Outline Case	01 JUL 2024	01 JUL 2024

DOCUMENT APPROVALS

Name	Project Role	Date approved
Joe O'Dell	Acting Project Manager	03 SEP 2024
Gary Mottershead	Boulby Development Strategy Manager	03 SEP 2024 (concurrence)

REVISIONS

Revision	Change description	Date effective
n/a	First draft for comment by GM.	19 AUG 2024
A	Approved and released.	03 SEP 2024

BOULBY DEVELOPMENT

Visit by SLAC team
November 2024

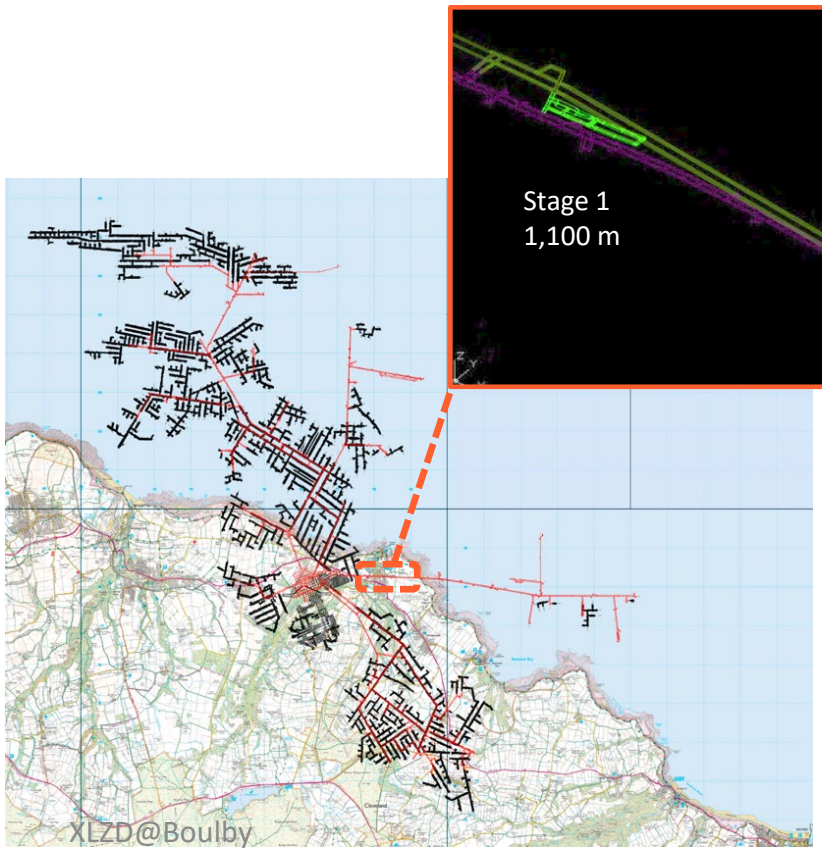
Visit by German PIs
July 2024

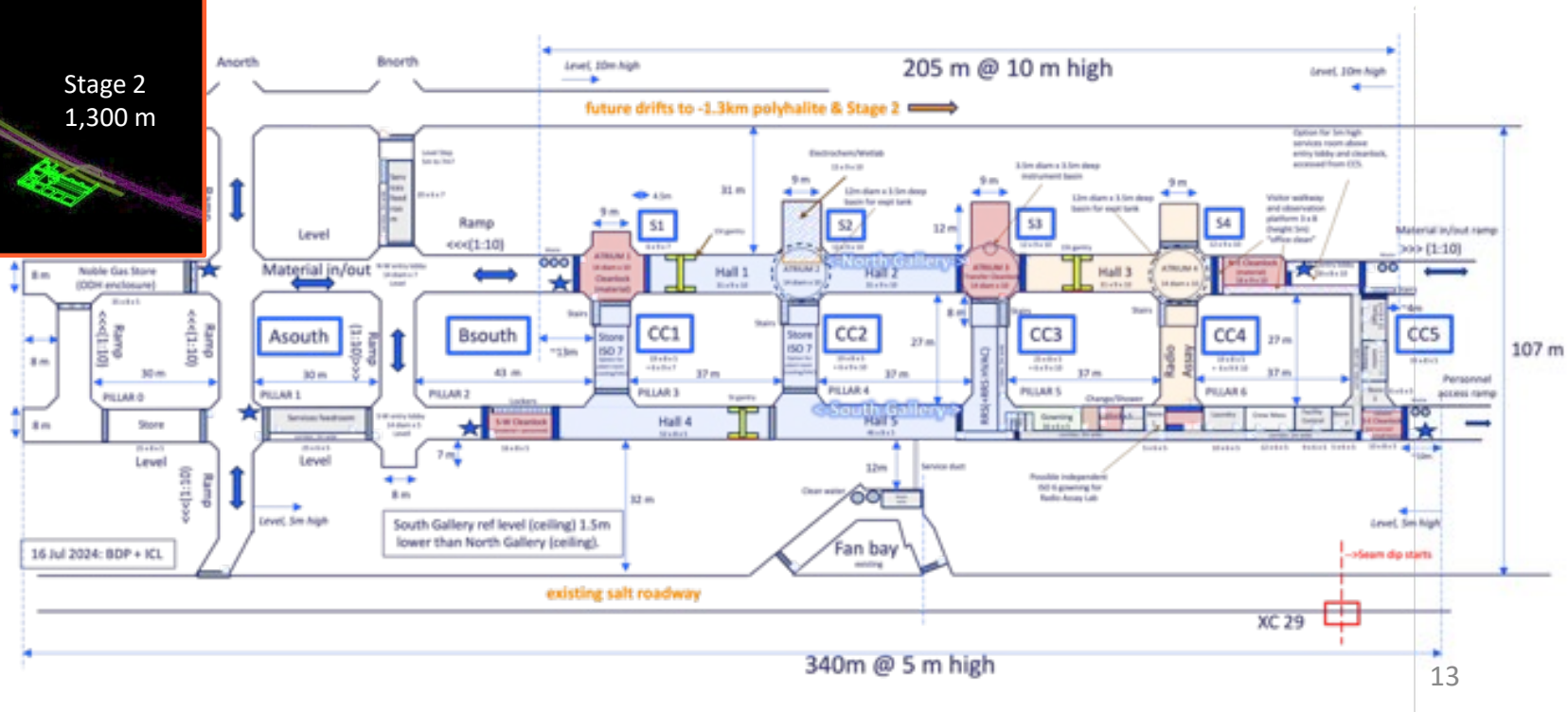
XLZD@Boulby

BOULBY STAGE 1: MANUFACTURING FACILITY

Stage 1 in salt (1,100 m): Clean Manufacturing Facility, beneficial occupancy mid-2029

- Manufacture past-the-bottleneck: radon-reduced cleanrooms, workshop, electrochemistry, radioassay, ...
- A new national facility in its own right, for science beyond XLZD: 45,000 m^3 excavated volume

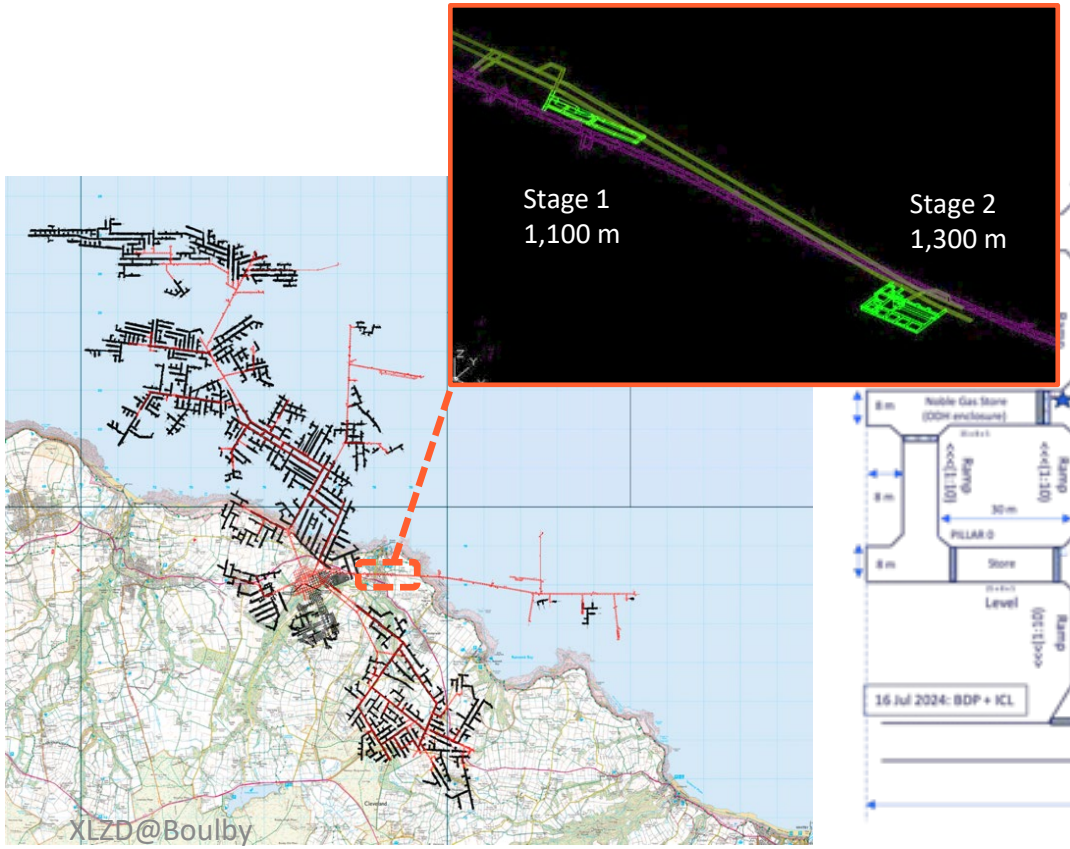




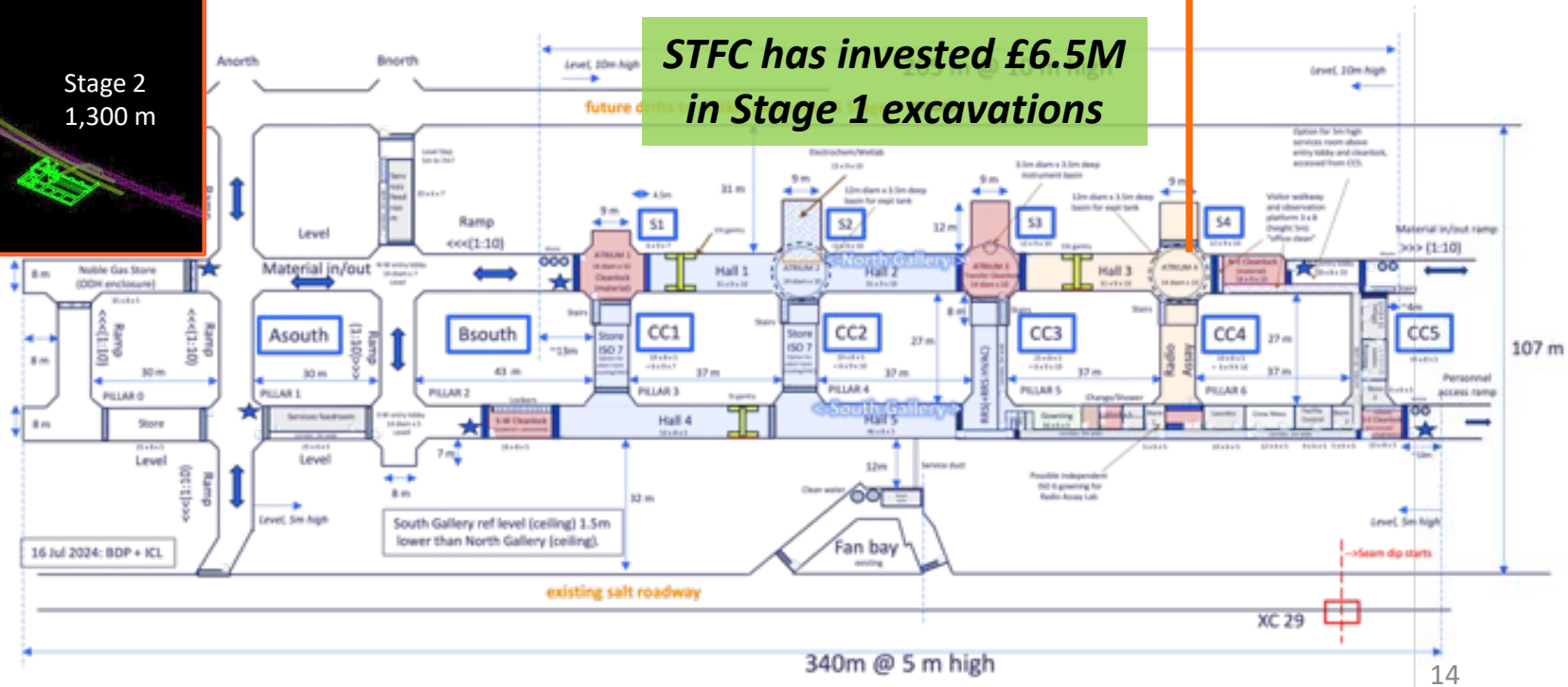
BOULBY STAGE 1: MANUFACTURING

Stage 1 in salt (1,100 m): Clean Manufacturing Facility, beneficial c

- Manufacture past-the-bottleneck: radon-reduced cleanrooms, w
- A new national facility in its own right, for science beyond XLZD: 4



STFC has invested £6.5M in Stage 1 excavations



BOULBY STAGE 1: MANUFACTURING FACILITY

- **Full footprint excavated to initial 4-m height,** for meshing & bolting, “tell tale” creep monitors, array of lifting bolts
- South Gallery now progressing to 8 m wide x 5 m high
- North Gallery now progressing to 9 m wide x 10 m high
- LARGE laboratory, but not large enough for XLZD operation
- Expect completion of excavation contract by Sept 2025


Meshing & bolting


Initial 4 m height

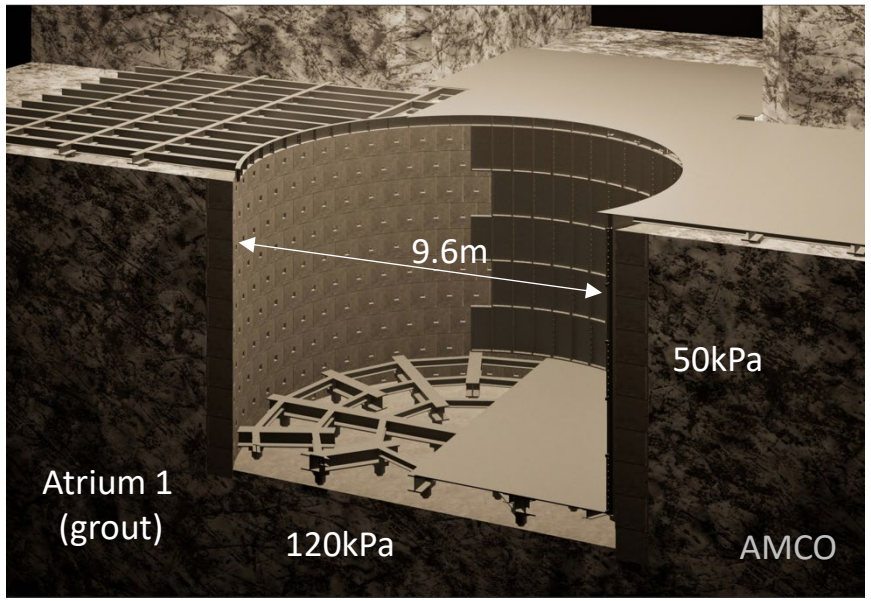

Around 7 m height

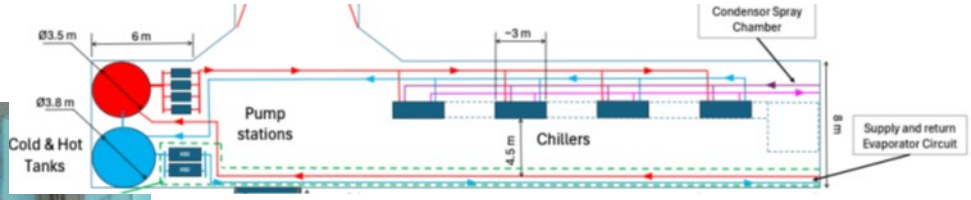
A long gallery….

BOULBY STAGE 1: MANUFACTURING FACILITY

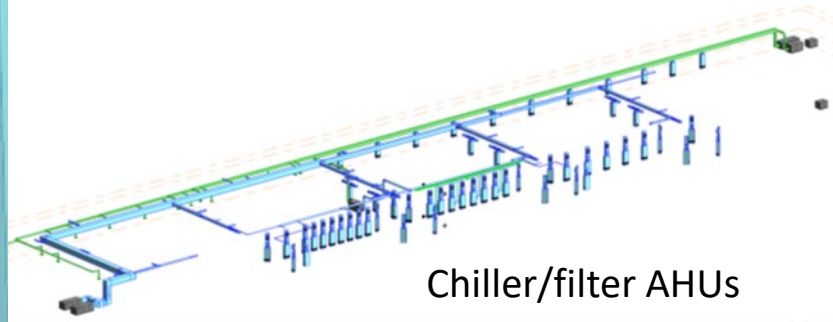
Design solutions mostly understood, some aspects well advanced

- Basin(s) in North Gallery: 10-14 m diameter options being studied, 5 m deep
  - Gives at least 12-m hook-height for assembly and testing of an 80-t cryostat
  - Issues: clay-bands, stability against creep, water-tightness, floor loading; test bores planned
- Lining: membrane solution preferred; easier installation & maintenance; early test in an “outfit pilot zone”
- Progress also on floor design, bulkheads, craneage, cooling & ventilation, heat rejection, power, safety, …





Heat rejection studies

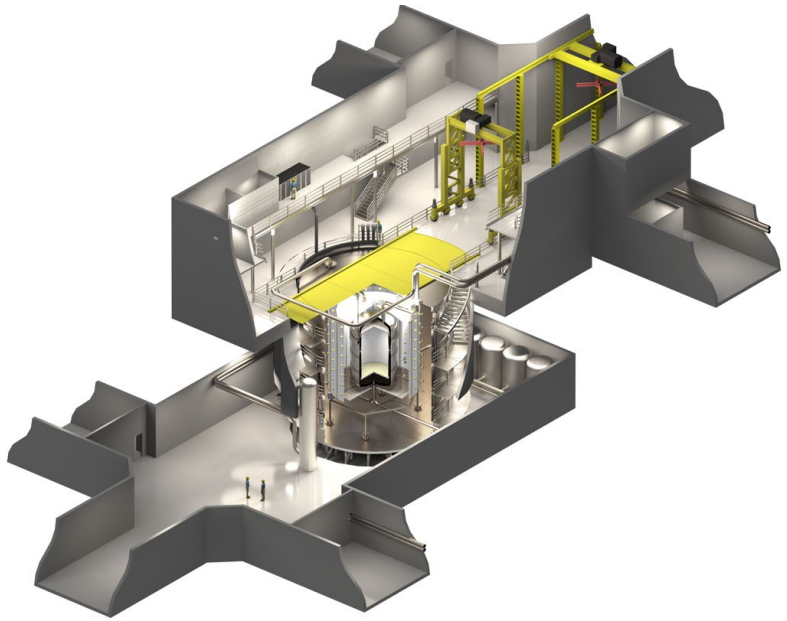


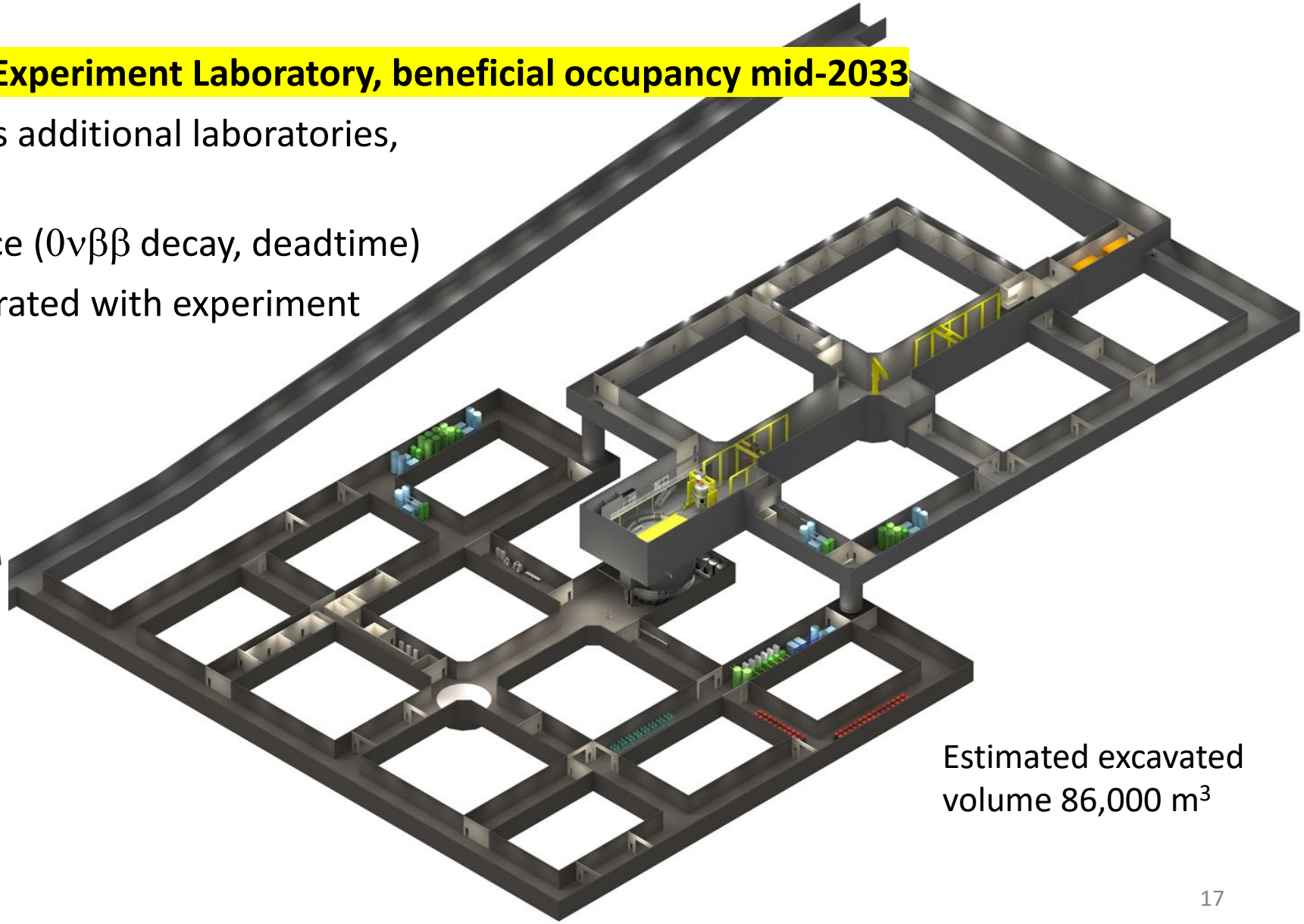
Chiller/filter AHUs

BOULBY STAGE 2: EXPERIMENT LABORATORY

Stage 2 in polyhalite (1,300 m): Experiment Laboratory, beneficial occupancy mid-2033

- Large experimental cavern plus additional laboratories, made to measure for XLZD
- Deeper lab desirable for science ($0\nu\beta\beta$ decay, deadtime)
- Preliminary design being integrated with experiment



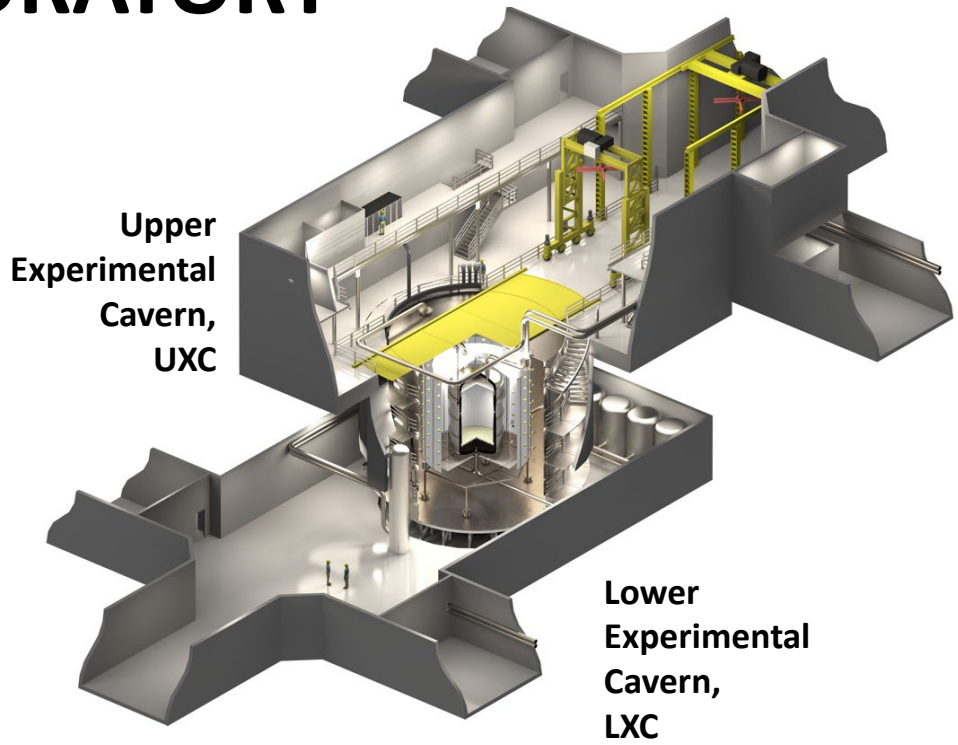


Estimated excavated volume 86,000 m^3

BOULBY STAGE 2: EXPERIMENT LABORATORY

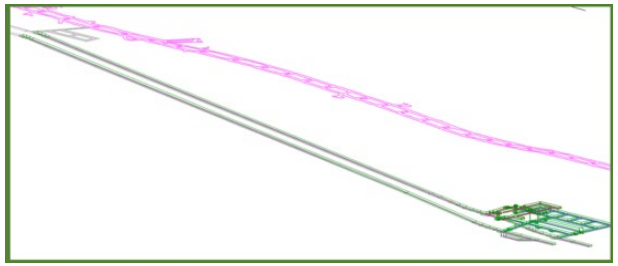
No serious issues yet identified (apart from the obvious…)

- Feasibility of cooling the lab (was main uncertainty):
  risk mitigated by dedicated heat rejection study;
  spray chamber solution seems feasible,
  can reject up to 5 MW from a primary cooling loop

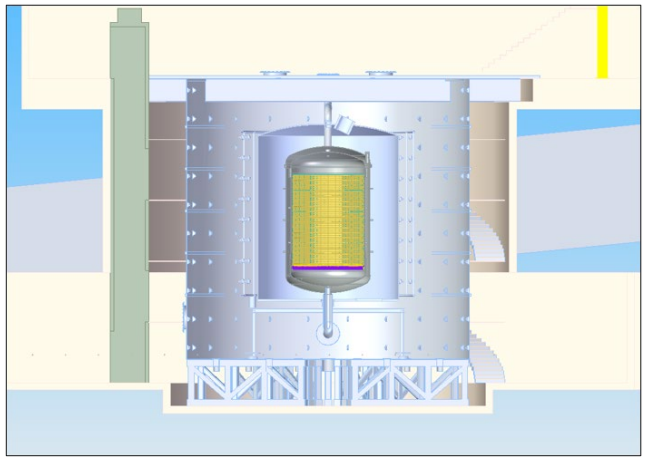


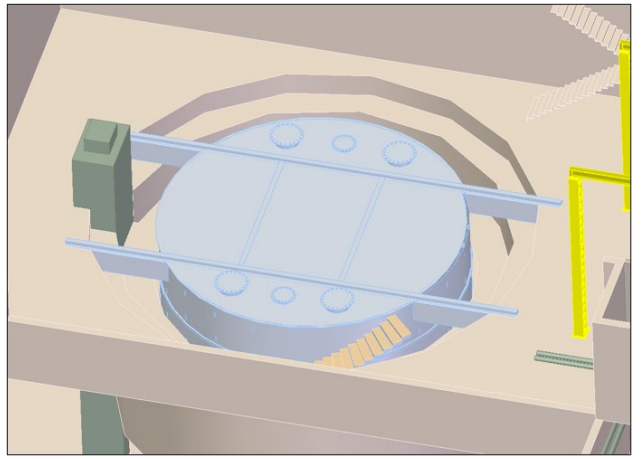
Critical next steps

- Downward drifts to 1,300 m:
  awaiting geology tests and
  mine decision on exploitation zones



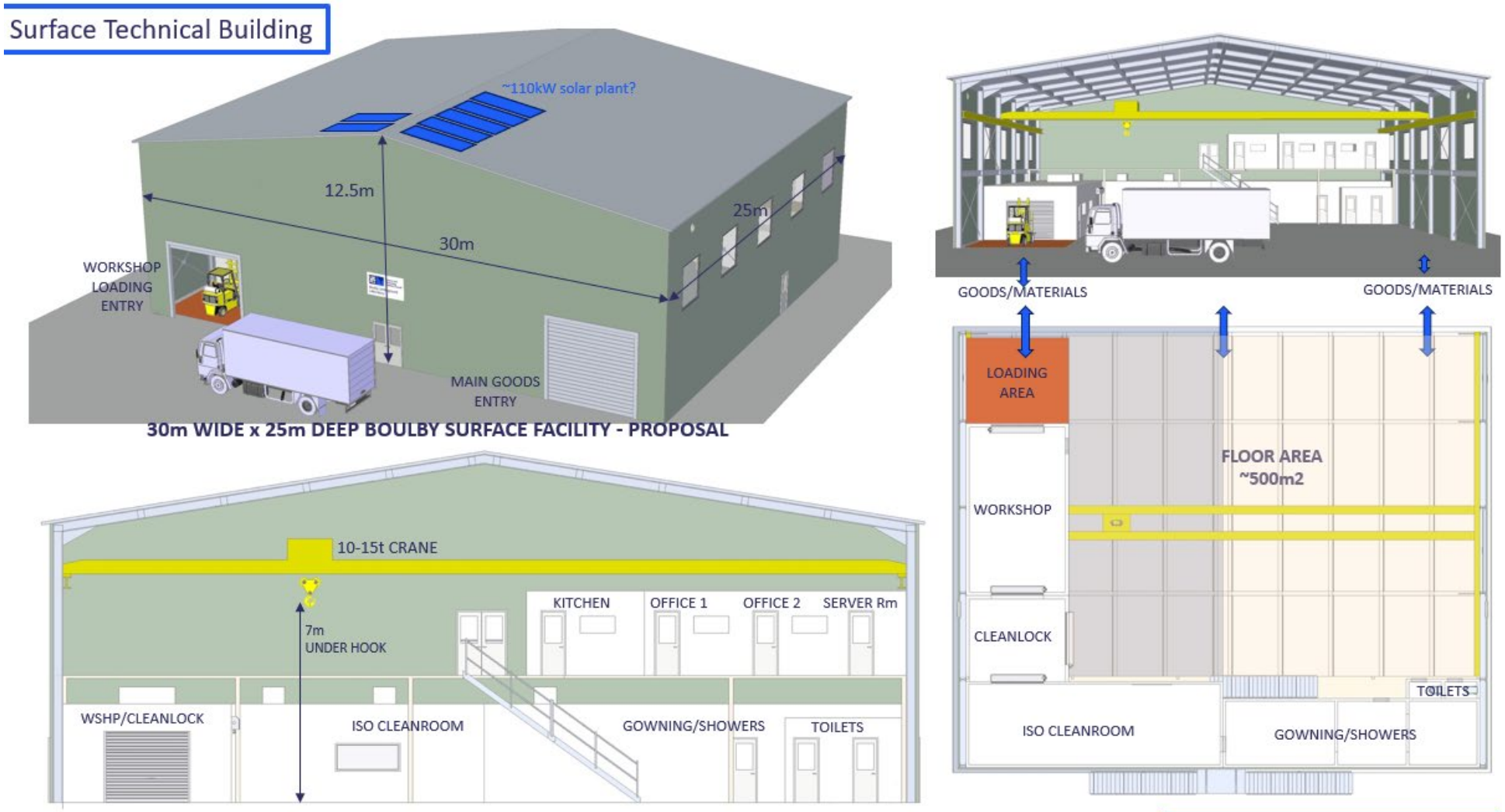
- Shaft design
  (connecting LXC-UXC)
  being integrated with Boulby
  Facility Tank (BFT) and 80-T cryostat.
  Contract for conceptual design study
  should be placed this year





Austin Ball / John Hill / Jon Elmer

SURFACE TECHNICAL BUILDING



Building spec'd to host modular workspaces, but none installed initially

concept AB/John Hill: March 2025

CONCLUSION

- **XLZD@Boulby Pre-Construction Project** making good technical progress
  - In our first year: we spun up the WP teams, defined sensible (preliminary) technical requirements, identified challenges, assessed design options, selected viable options where possible
  - Integration with international partners is now needed
  - Developed a Project Management Plan and are executing on the plan – but "major external factors" can affect the best laid out plans: all we can do is "be ready when the time comes", and that's what we'll keep doing
- **Boulby Development Project** also proceeding at pace
  - Excellent technical team in place and making progress, designing a lab fit for XLZD – talk to Austin & Jon this week!
  - Stage 1 Excavations nearly complete – now seeking funding for Stage 1 Outfitting
  - Interaction with international partners is very desirable

In conclusion: there are strong headwinds everywhere, and we should recognise this; it is clear to us how we navigate these in the UK: continue to work hard, align with the "Place Agenda"…

Take home message, via Thomas Jefferson: "I find that the harder I work, the more luck I seem to have."

additional slides

BOULBY DEPTH

Table 1: Depth, water equivalent overburden and muon flux.

Location	Depth		Muon flux
Kamioka (JP)	1,000 m	2,700 m w.e.	128 /m²/d
Boulby (UK)	1,100 m	2,850 m w.e.	32.3 /m²/d
LNGS (IT)	1,400 m	3,800 m w.e.	29.7 /m²/d
Boulby (UK)	1,300 m	3,330 m w.e.	14.6 /m²/d
SURF (USA)	1,490 m	4,300 m w.e.	4.6 /m²/d
SNOLAB (CA)	2,070 m	5,890 m w.e.	<0.3 /m²/d

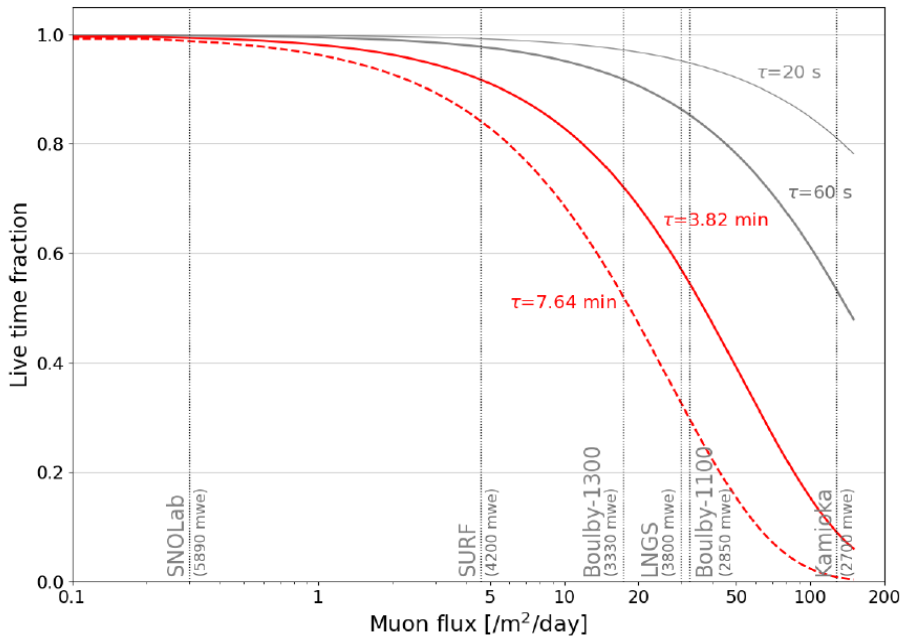


FIGURE 3: Livetime fraction as a function of muon flux (depth) for different dead time values.

Both 1,100 m and 1,300 m locations are acceptable for dark matter searches [2310.16586] – with some uncertainty created by muon-induced deadtime; deeper location is a safer bet for $0\nu\beta\beta$ decay, but not huge difference

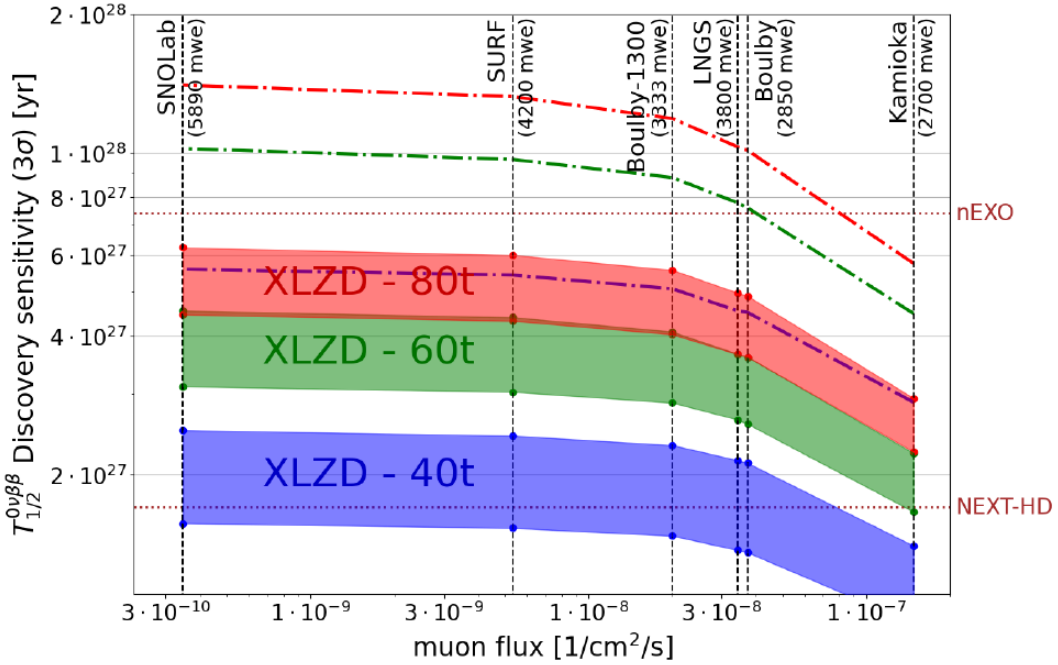


FIGURE 4: 3-sigma discovery sensitivity for 0NBB in Xe-136 at natural abundance in different laboratories after 10 calendar years of exposure, considering a τ = 60 s dead time after each muon crossing the detector and 100% duty cycle. The bands represent the same range of scenarios as Figure 2. The dashed lines indicate the sensitivity for 20% enrichment at 40, 60 and 80 tonnes in the optimistic scenario. Note that the projections shown for nEXO and NEXT-HD do not include a dead time penalty or duty cycle. Adapted from Ref. [2].

XLZD-UK PRE-CONSTRUCTION PROJECT

WP0 Management: Project coordination and reporting, development of Full Project (PI; Project Manager; Scheduler; Controls)

WP1 Xenon Acquisition: Prepare xenon acquisition (inc. advanced procurement), design storage/feed/recovery equipment.

WP2 Outer Detector: Design and prototyping of Gd-WBLS system (∼1 ktonne) with BUTTON, BNL and other international partners, including optical and mechanical designs of inner and outer volumes, design of fluid handling and purification systems and hazard analysis, PMT readout structures, front-end electronics and OD calibration.

WP3 Cryostat: Design of nested pressure vessels made from radiopure material aiming at fabrication underground, including material/supplier identification and plans for manufacture/procurement, test/certification, transportation and installation.

WP4 Xenon Detector Elements: Mechanical, optical and electrostatic designs and prototyping of field-cage and Skin Detector surrounding LXe-TPC meeting the most demanding radioactivity and cleanliness requirements.

WP5 Data Centre & On-Site Computing: design of data pipeline and data centre with international partners; coordination of computing needed for the design phase (simulations, data challenges, data management) and software infrastructure.

WP6 Clean Manufacture: Design and prototyping of radioassay and cleanliness systems and processes, and of the clean manufacture systems and equipment that will compose the Stage 1 Manufacturing Facility at Boulby. Extensive radioassay campaign for selection of critical materials; background simulations.

WP7 Engineering and Skills: Provision of required engineering effort for design coordination (Lead Eng; Integration Eng; Safety Eng; CAD Designer); design of Stage 1 facility specialist outfitting for XLZD; development of apprenticeship scheme.

WP8 Environmental Sustainability: delivery plan for an experiment sustainable in operations; carbon modelling and accounting, development of digital twin, training for green computing and lab operations, design of heat recovery from data centre. Substantial work being led by Boulby Development Project in this area already.

STFC@BOULBY WBS (PRE-CONSTRUCTION)

1.1	Xenon Acquisition (Pre-Construction)	Majewski	Araujo
1.1.0	WP management		
1.1.1	Supplier & consultant interactions		
1.1.2	Procurement plan		
1.1.3	Transportation and storage planning		
1.1.4	Storage pack design		
1.1.5	Feed/recovery system design		
1.1.6	Xenon sampling and assay design		
1.1.7	Xenon sampling prototype		

2.1	Outer Detector (Pre-Construction)	Burdin	Shaw
2.1.0	WP management		
2.1.1	OD mechanical design		
2.1.2	OD fluid process design		
2.1.3	OD optical design		
2.1.4	OD FE electronics design		
2.1.5	OD calibration design		
2.1.6	Muon detector design		
2.1.7	OD photosensor module design		
2.1.8	OD material compatibility		
2.1.9	Radioscreener and prototyping		
2.1.10	Hazard analyses		

3.1	Cryostat (Pre-Construction)	Majewski	Cooper
3.1.0	WP management		
3.1.1	Industry engagement for underground manufacture		
3.1.2	Pressure vessel calculations (code and FEA)		
3.1.3	Local load studies		
3.1.4	Cryostat support design		
3.1.5	Cryostat ancillaries design		
3.1.6	Cryostat connections to water tank		
3.1.7	Thermal design studies		
3.1.8	ICV, OCV and CS interfaces		
3.1.9	Assembly and installation plans		
3.1.10	Cryostat acceptance tests		
3.1.11	Material screening and selection		
3.1.12	Radioactivity budget		
3.1.13	Cleanliness		

4.1	Xenon Detector Elements (Pre-Con)	Palladino	Araujo
4.1.0	WP management		
4.1.1	Fieldcage optical and mechanical design		
4.1.2	Fieldcage electrostatic design		
4.1.3	Fieldcage resistor development		
4.1.4	Fieldcage prototyping & tooling design		
4.1.5	TPC component integration and upgrade planning		
4.1.6	Skin photosensor module design & prototyping		
4.1.7	Skin mechanical, optical and electrostatic designs		
4.1.8	Skin test platform and tooling design		
4.1.9	Xenon Detector component radioassays		
4.1.10	Skin front-end electronics design & prototyping		

5.1	Data Centre & Onsite Comp (Pre-Con)	Bauer	Costanzo
5.1.0	WP management		
5.1.1	Boulby Data Centre design parameters		
5.1.2	UK collaborative infrastructure		
5.1.3	Data transfer demonstration from u/g		
5.1.4	Interaction with Boulby infrastructure		
5.1.5	UK contribution to XLZD Computing		
5.1.6	Integration with XLZD Computing		
5.1.7	UK computing stakeholder engagement		
5.1.8	Sustainable computing planning		
5.1.9	Technical design of UK computing		

6.1	Clean Manufacture (Pre-Construction)	Cottle	Dobson
6.1.0	WP management		
6.1.1	Background simulations and tools		
6.1.2	Full facility design		
6.1.3	Radioassay of key materials		
6.1.4	Cleanliness procedures and QA development		
6.1.5	Electrochemistry development		
6.1.6	Sample preparation and radioassay facility		
6.1.7	Germanium detector development		
6.1.8	Database design and prototyping		
6.1.9	Centre scoping and planning		

7.1	Engineering & Skills (Pre-Construction)	O'Dell	Tovey
7.1.0	WP management		
7.1.1	Draft Delivery Plan: Skills Pipeline		
7.1.2	Understand & document technical challenges of all WPs		
7.1.3	Develop WP system requirements with WP leads		
7.1.4	Develop system requirements into engineering specs		
7.1.5	Develop WP infrasturcuture requirements with WP leads		
7.1.6	Produce and maintain hazard analysis		
7.1.7	Produce integrated Conceptual Design CAD model		
7.1.8	Coordinate technical inputs to CDR		
7.1.9	Generate interface control matrix		
7.1.10	Identify gaps beetween infrastructure provision & reqs		
7.1.11	Address gaps and agree steps with XLZD/Boulby		
7.1.12	Identify engineering skills gaps across all WPs		
7.1.13	Design ecosystem to develop/maintain talent		
7.1.14	Coordinate WP draft assembly plans		
7.1.15	Produce draft integration plans for all sub-systems		
7.1.16	Conduct apprenticeship skills survey		
7.1.17	Develop apprenticeship training syllabus		
7.1.18	Negotiate training contracts with providers		
7.1.19	Produce integrated XLZD Preliminary design CAD model		
7.1.20	Coordinate technical inputs to PDR		
7.1.21	Coordinate baseline assembly plans		
7.1.22	Generate baseline integration plans		
7.1.23	Assist & liaise with international partners		
7.1.24	Coordination of engineering & technical resources		

8.1	Environmental Sustainability (Pre-Con)	Hays	Ghag
8.1.0	WP management		
8.1.1	Engage with other workpackages and scoping work		
8.1.2	Engage with Boulby & ICL-UK on data centre heat recovery		
8.1.3	Engage with Boulby & ICL-UK on green energy		
8.1.4	Heat recovery system conceptual design		
8.1.5	Sustainable Procurement Policy Development		
8.1.6	Outline planning of Sustainable Operations		
8.1.7	Development of carbon model and digital twin		
8.1.8	Development of carbon KPIs		
8.1.9	Definition of training requirements		