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Cryostat Design Studies - XLZD@Boulby Project

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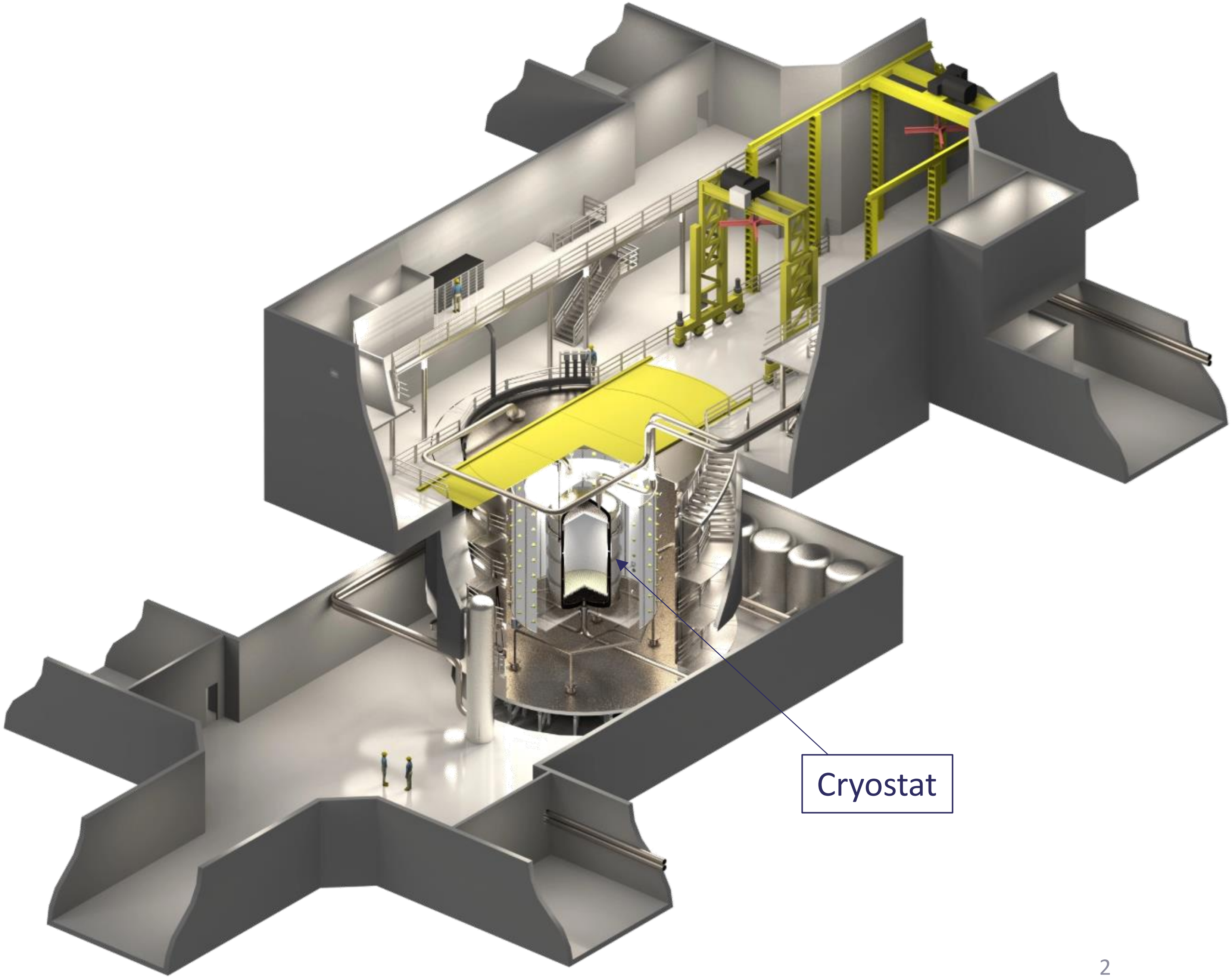

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Cryostat Team

STFC - Rutherford Appleton Laboratory (RAL)

- Harry Byrne (Eng)
- Liam Cooper (Lead Eng)
- Anmol Goyal (Eng)
- Pawel Majewski (Lead*)
- Daniel Wells-Calvo (Eng)
- Dan Wilcox (Eng)

University of Sheffield

- Adam Brown (Physics)
- Jack Fannon (Physics)
- Steven Jones (Industry engagement)
- Paul Kemp-Russell (Welding technologies)
- Dan Tovey (Lead, Industry engagement)

Karlsruhe Institute of Technology (KIT)

- Klaus Müller (Eng)
- Adrian Schwenck (Eng)
- Kathrin Valerius (Lead)

Nikhef

- Auke-Pieter Colijn (Lead*)

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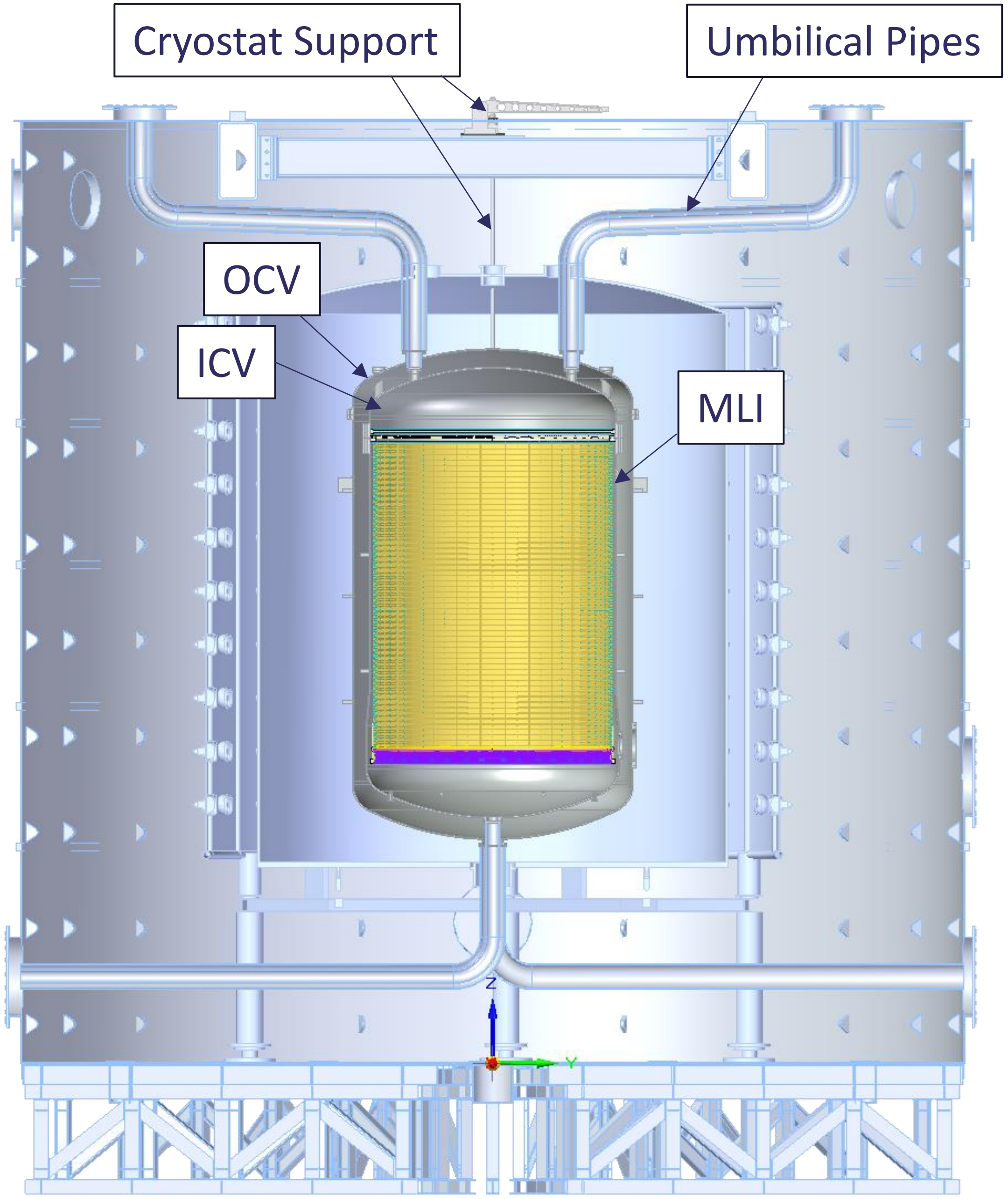
*XLZD Cryostat international convener

Overview

- The cryostat comprises of two vessels, an outer cryostat vessel (OCV) and an inner cryostat vessel (ICV).
- Designed to contain a detector with an 80 T LXe target mass at -100°C.
  - Approximately 100 T of LXe inside of the ICV.
- We propose to build the largest cryostat needed, and not plan for a modular cryostat which increases its size between "early science" and final LXe-TPC stages (single flange pair per vessel).
- Both vessels will be designed and fabricated in accordance with a pressure vessel code.
- We are engaging with cryostat expertise from the LZ and XENONnT experiments.



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Challenges

- Vessels to be **constructed from an ultra radiopure material**.
  - No decision yet on the material.
    - Most work so far assumes CP Gr.1 Ti construction.
    - Calculations also done for a 300-series stainless steel cryostat.
    - We plan to investigate use of ultra-pure nickel.

- At Boulby (or other vertical access labs), the cryostat is too large to be taken underground in one piece and **requires underground manufacture**.
  - To address this technical challenge, we are engaging with industry throughout the design stages.

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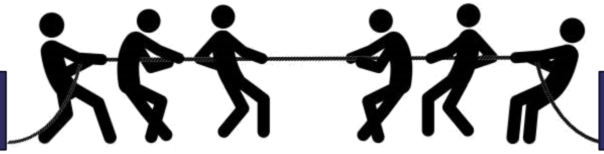
Design - Drivers

Physics



Engineering

Cryostat Design

Physics drivers:

- Construct from ultra radiopure (potentially non-standard) materials.
- Minimise the cryostat wall thicknesses.
- Minimise the vessel masses.
- Minimise the volume of passive LXe.

Engineering drivers:

- Design to pressure vessel codes rules (conservatism!).
- Use standard materials and methods where possible.
- Simplify the manufacture and fabrication methods.
- Use standard vessel geometries where possible.

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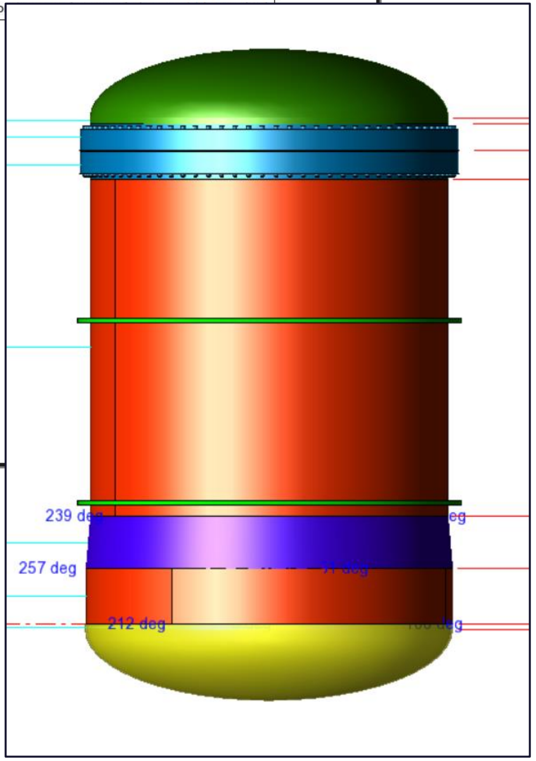
Design - Code Compliance

- The cryostat vessels must be code compliant.
- We use design rules in PD5500 (UK specification) where possible.
    - For aspects not covered by rule, we demonstrate compliance using FEA (to PD5500 Annex A).
- Design procedure:
    - Define requirements & code.
    - Establish design conditions (pressures, temperatures, loads).
    - Material selection.
    - Provisional vessel layout.
    - Design checks (internal pressure calculation, external pressure calculations, load calculations).
    - Design iteration.
- Model in PVElite to check calculations.
- Calculations verified through contracts with industry.



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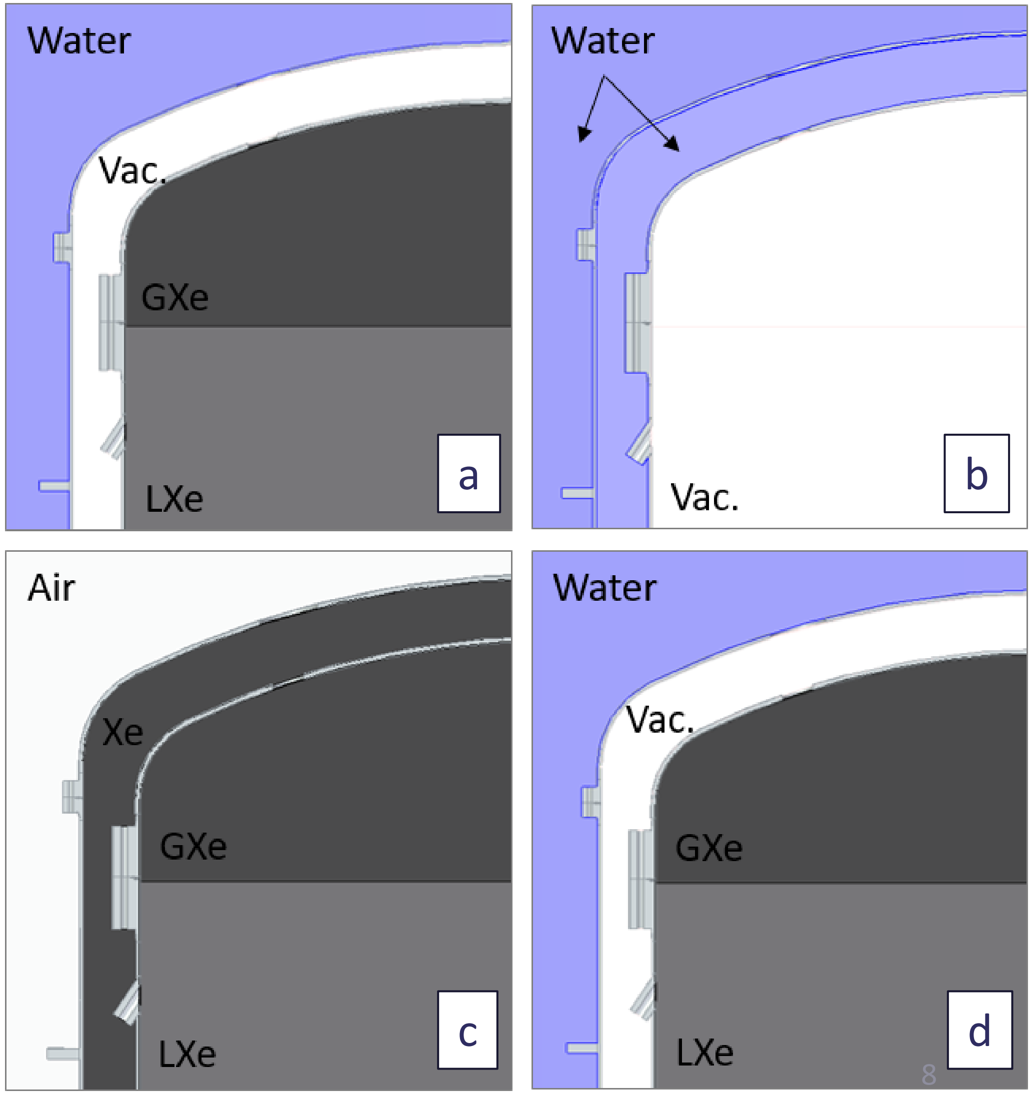
Design - Working Conditions

- Design pressures and temperatures are based off worst case ‘reasonably foreseeable’ conditions.
- ICV:
  - Maximum internal pressure (a):
    Xe inside, vacuum outside.
  - Maximum external pressure (b):
    Water outside, vacuum inside.
- OCV:
  - Maximum internal pressure (c):
    Xe leak inside, tank empty outside.
  - Maximum external pressure (d):
    Water outside, vacuum inside.



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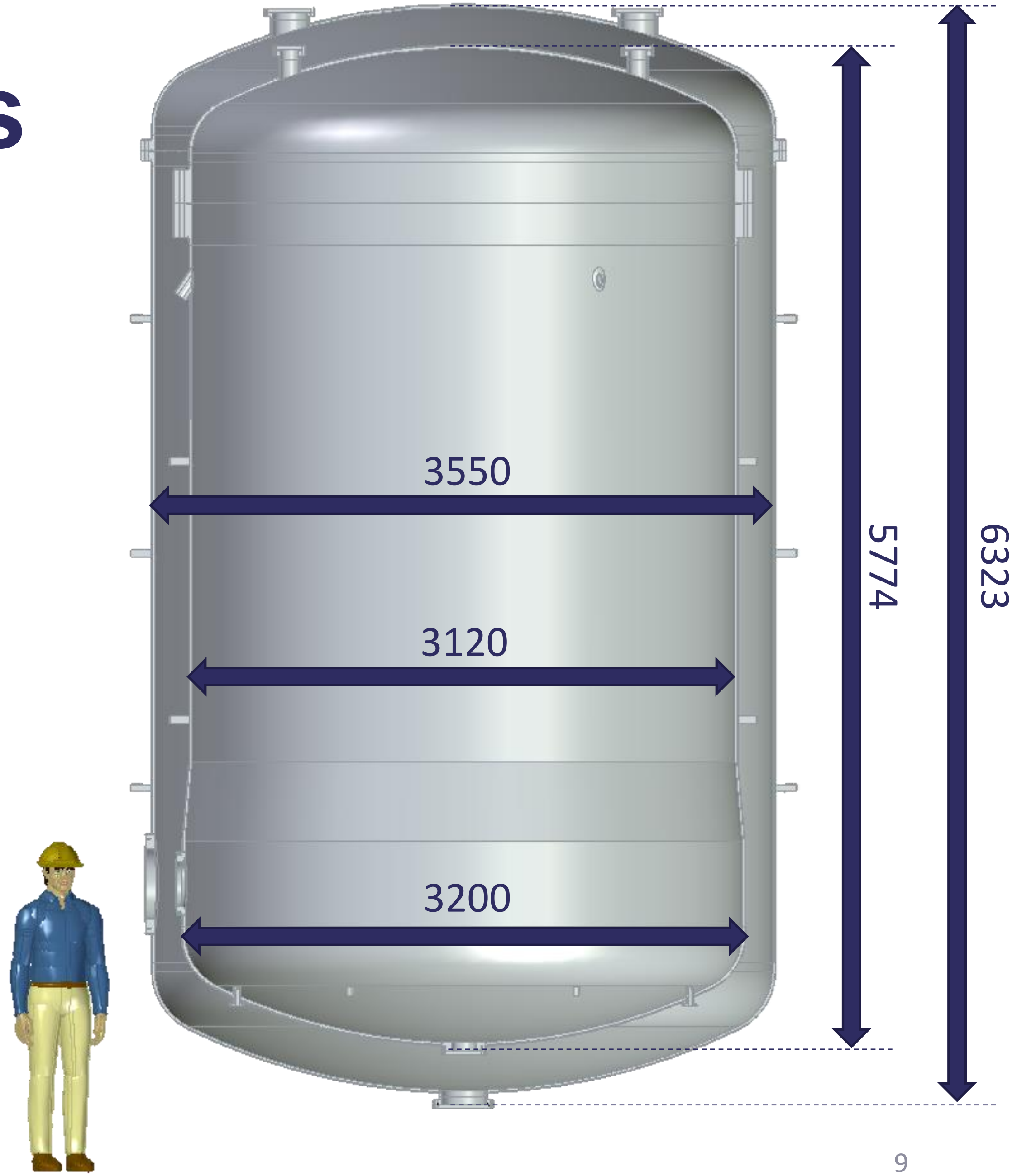
Design - Vessel Sizes

- Inner Vessel
  - Inner diameter: 3120 mm top, 3200 mm bottom.
    - Includes conical segment to save LXe.
  - Height: 5774 mm.
  - Mass: 6.2 T* (if Gr.1 Ti), 7.8 T* (if 304L).

- Outer vessel
  - Inner diameter: 3550 mm.
  - Height: 6323 mm.
  - Mass: 6.1 T* (if Gr.1 Ti), 8.2 T* (if 304L).

*At this stage the calculated masses are based off a design for pressure loading only, and excludes ancillary items (e.g. bolts, seals, lugs), final masses will be higher.



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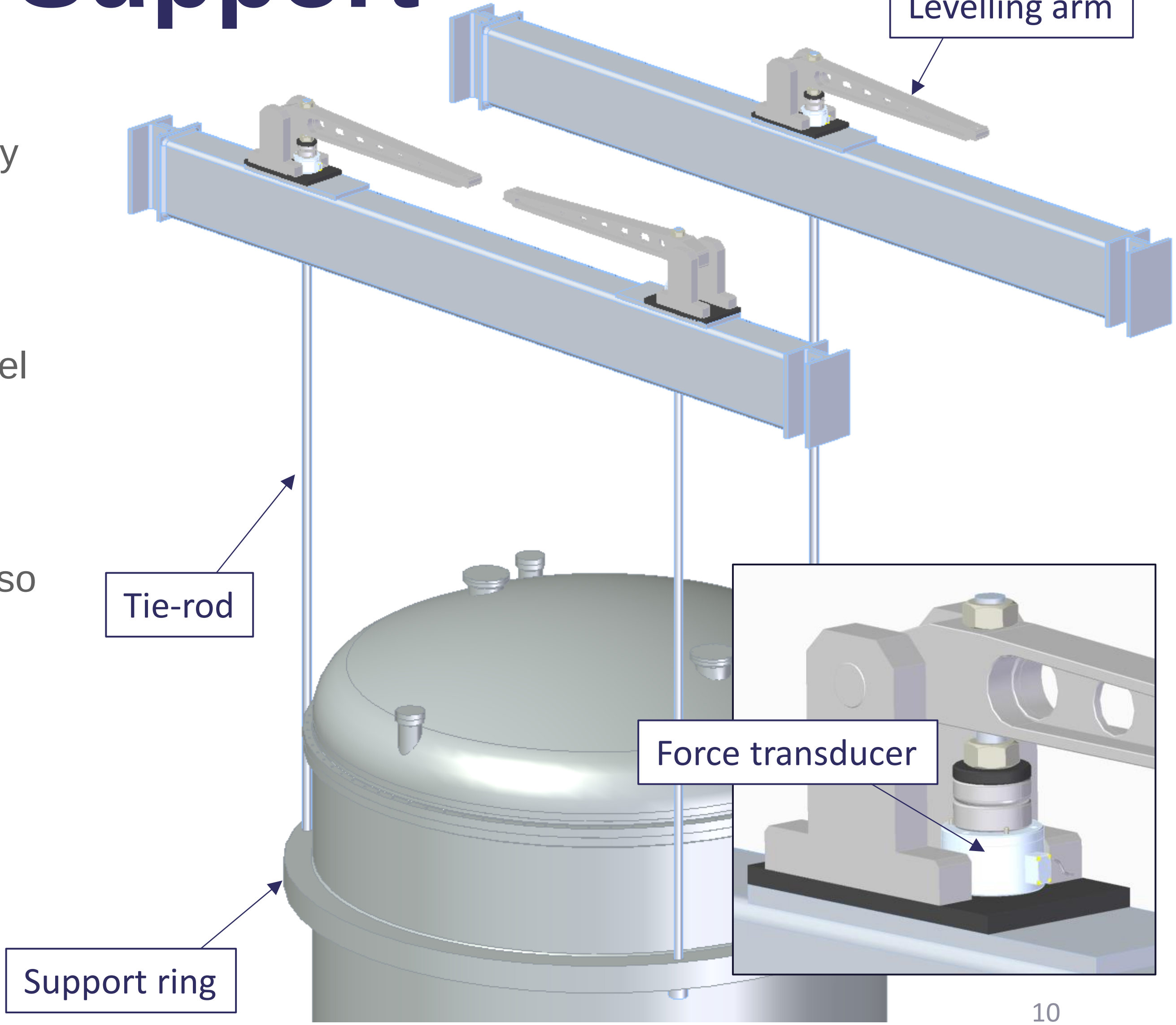
Design - Cryostat Support

- The cryostat support system is being developed by KIT (Adrian Schwenck, Klaus Müller).
- Loading from the liquid xenon is ~10x larger than the LZ or XENONnT vessels (>100 T).
- Suspension from three high-strength stainless steel tie-rods.
- XENONnT style levelling system, with additional integrated load cells to check for uniform loading.
- For the XLZD cryostat, the buoyancy load case also needs to be considered.



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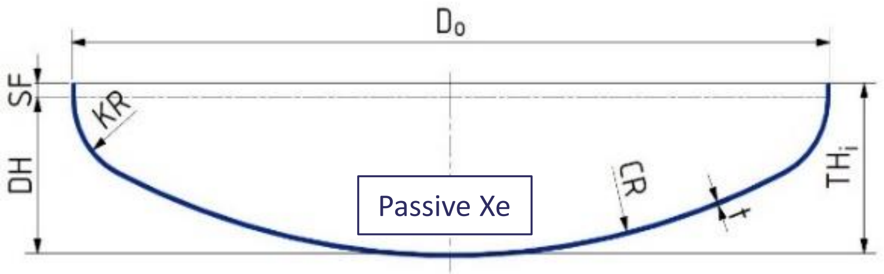
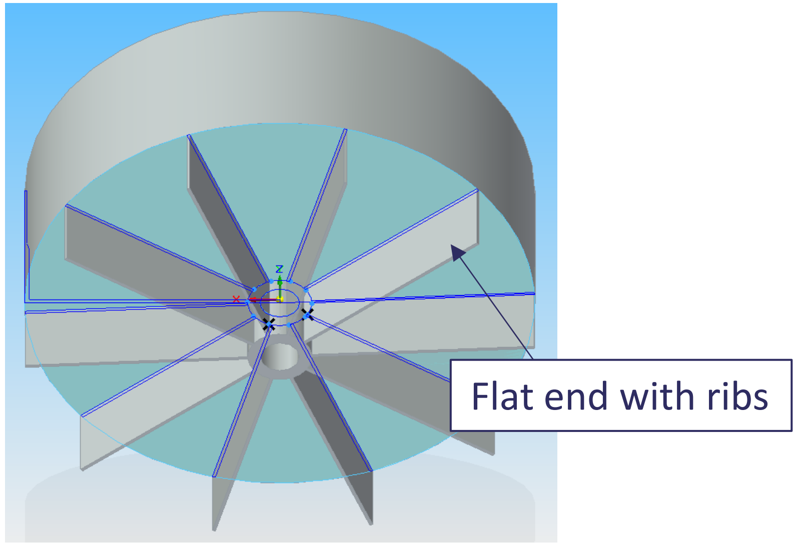
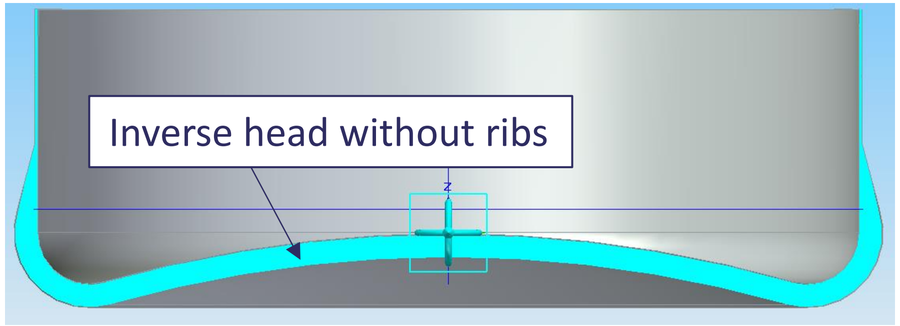
Design - Passive LXe

- Design studies of LXe saving options are being undertaken by Dan Wilcox and Daniel Wells-Calvo (RAL-TD).
- Goals:
  - Minimise passive LXe volume in the ICV.
  - Minimise the ICV head thickness.
    - For outer detector (OD) efficiency.
  - Ensure ICV remains code compliant.
- Exploring options such as:
  - Flat head options (with/ without reinforcement ribs).
  - Inverse head profiles (with/ without reinforcement ribs).
  - LXe displacer materials.
- Also assessing the options in terms of manufacturability, and their effect on interfaces.







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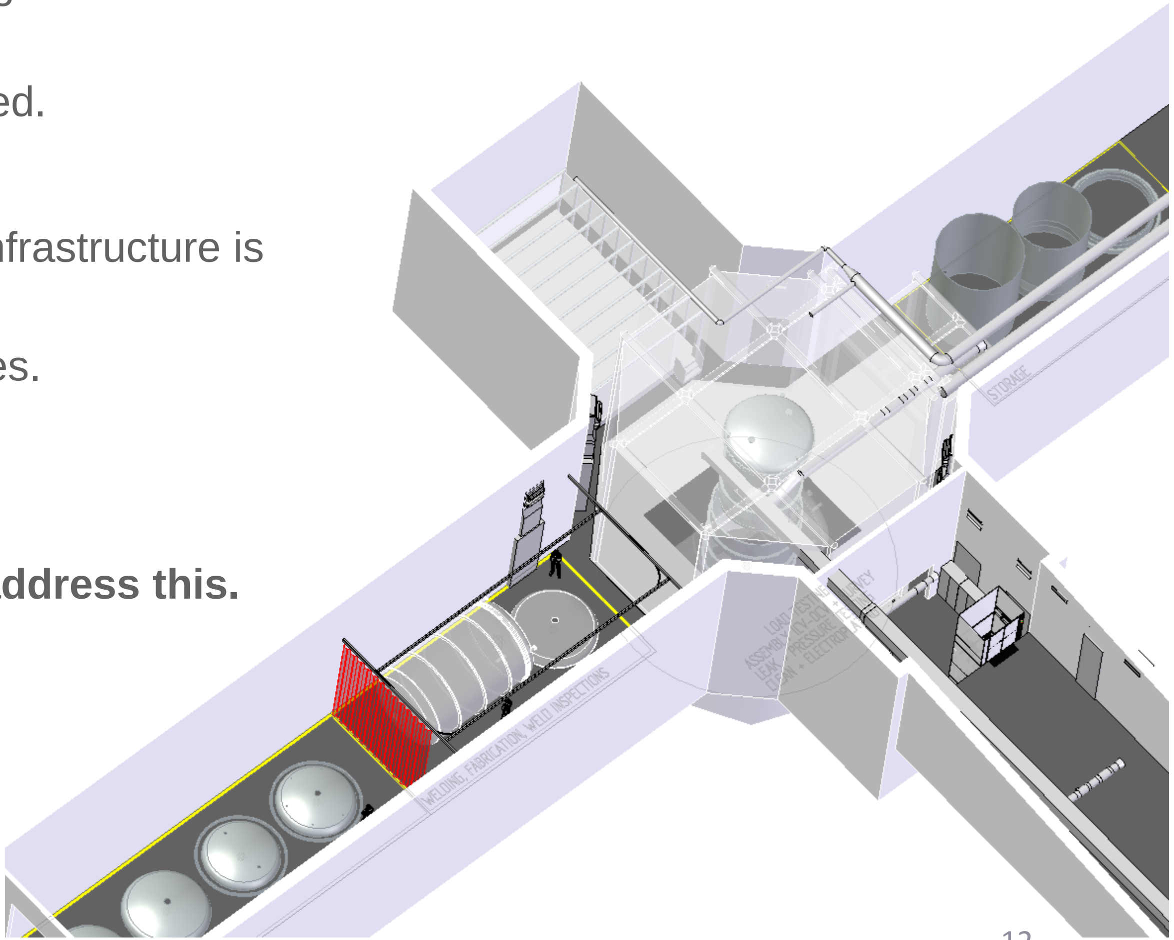
Manufacturing Challenge

- For the vertical access laboratories, the cryostat is too large to be taken underground in one piece. Implications are:
  - Some amount of underground manufacture is required.
  - Underground manufacture is expensive.
  - Specialist equipment is required, and underground infrastructure is needed for the work.
  - Underground manufacture brings technical challenges.
  - Underground manufacture brings more project risks.

- **Early engagement with industry is very important to address this.**



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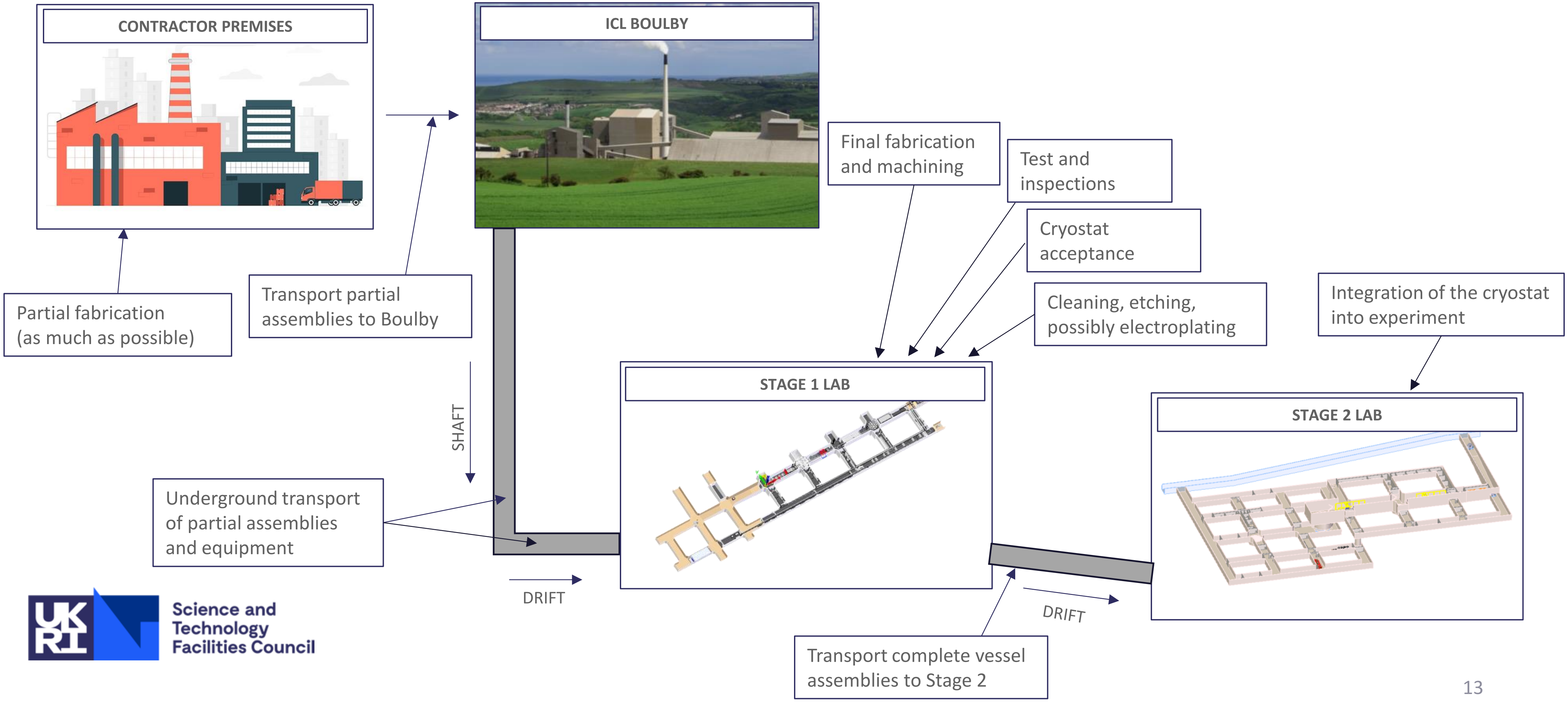
Manufacturing the Cryostat at Boulby



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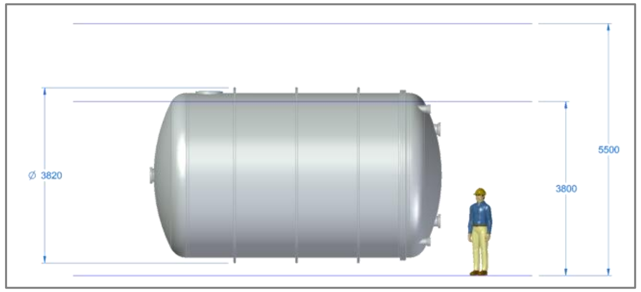
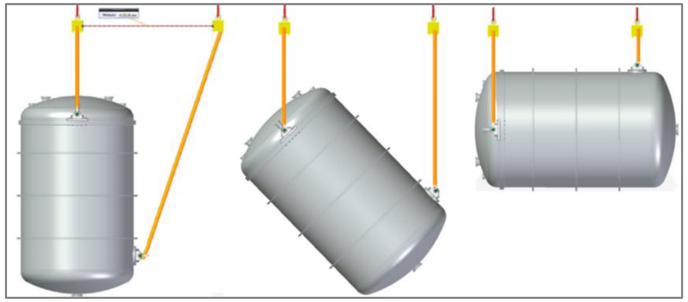
Interfacing with Boulby

Drift heights



Cranage

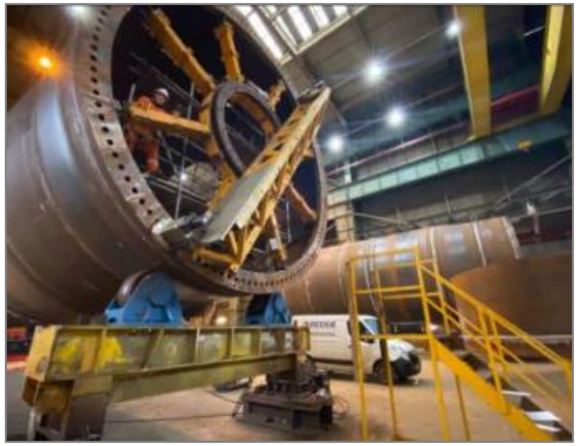


Floor loading

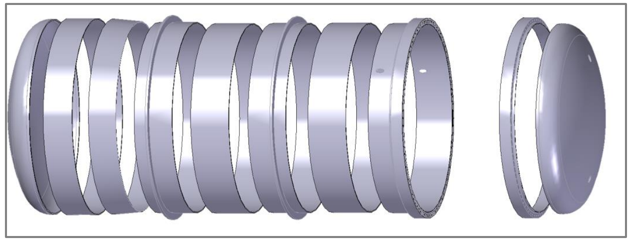
Headroom

Cryostat

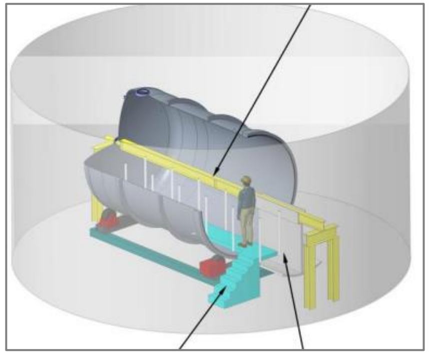
Infrastructure for manufacture



Underground transport envelopes

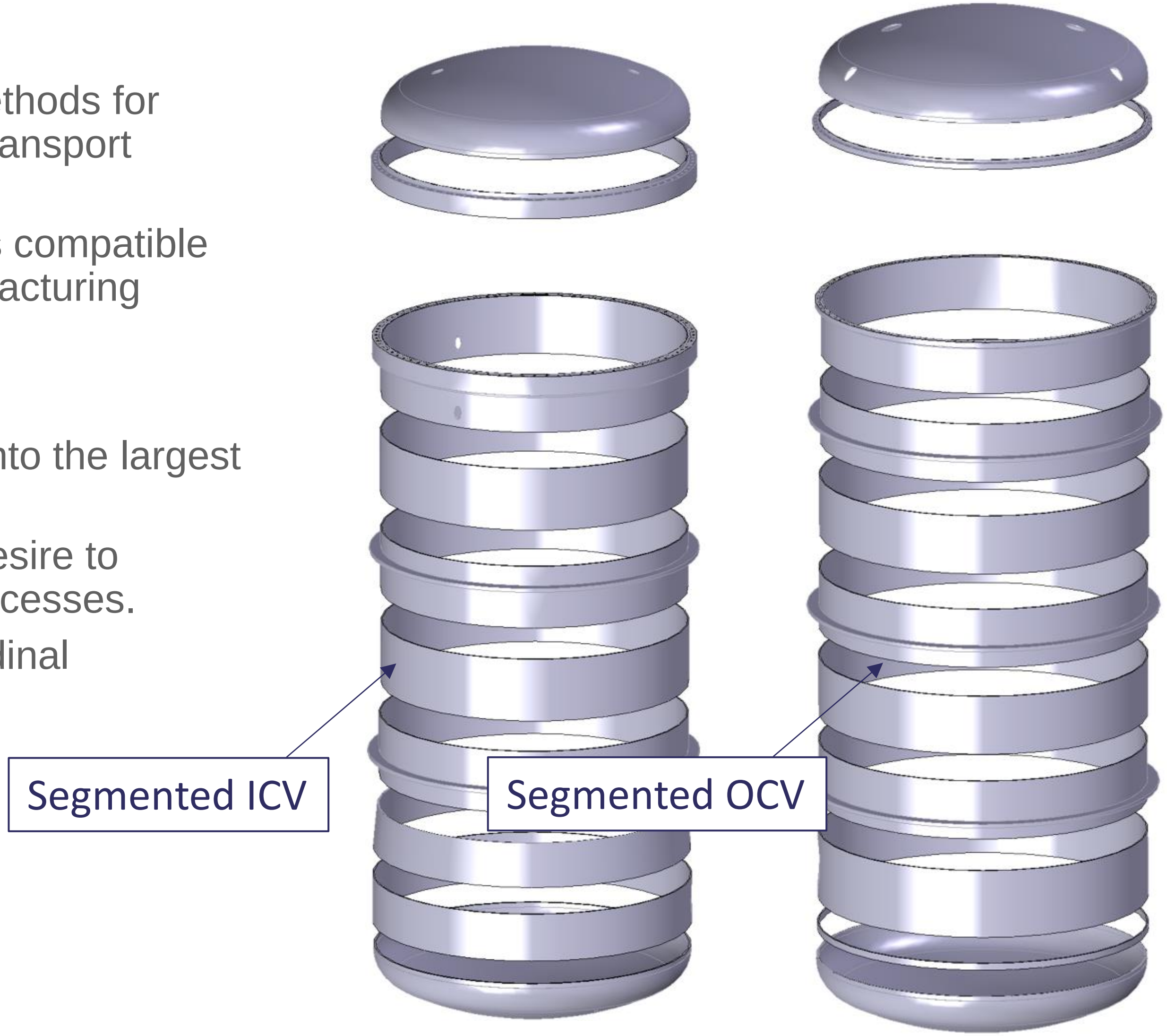


Infrastructure for cleaning and possibly electroplating



Manufacturing Underground

- We are exploring (with industrial input) methods for segmenting the cryostat vessels prior to transport underground.
  - Ensuring the chosen segmentation is compatible with the planned underground manufacturing method.
- The CAD model shows the cryostat split into the largest potential envelope at Boulby.
  - This segmentation is driven by the desire to simplify the underground welding processes.
  - For smaller sized envelopes, longitudinal segmentation may be required.



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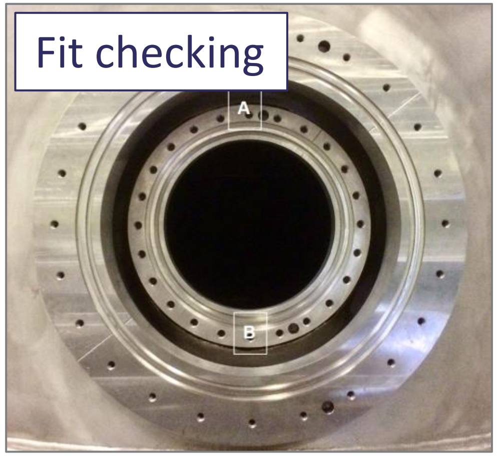
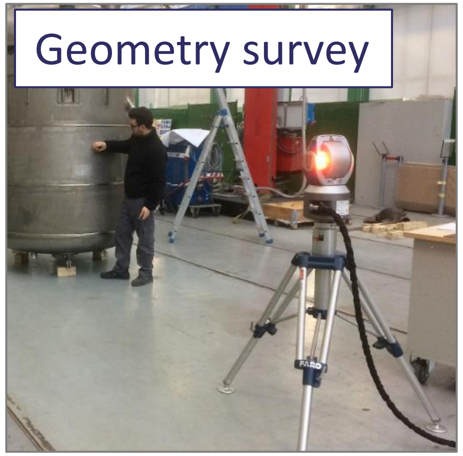
Testing/ Inspections Underground

- In addition to the manufacturing, for code compliance and acceptance tests/ inspections would also need to take place underground:
  - Weld inspections.
  - Geometry surveying.
  - Load testing support and lifting features.
  - Leak testing.
  - Hydraulic pressure testing.
  - ICV – OCV fit checking.

LZ cryostat testing/ inspection examples:





Industrial Engagement

- Industry Open Day for the XLZD@Boulby Cryostat held in December 2024.
  - Over 60 companies (mostly UK based) attended the event.
- Contract with Advanced Manufacturing Research Centre (AMRC):
  - Gateway to UK industry, assessment of manufacturing needs and capabilities.
- Contract with TUV:
  - To ensure vessel code compliance.
- Working with/ towards contracts on:
  - Chemical etching (precision cleaning)
  - Electroplating
  - Fabrication

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Additional Material

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Cryostat Options

- Material
  - Grade 1 titanium, 300-series stainless steel, or nickel.
- Cryostat size
  - Geometry for an 80 T or 60 T LXe TPC.
- TPC attachment
  - Top, bottom, or both.
- Support type
  - Legs or suspended.
- HV delivery location
  - Side or top.
- Service feedthrough location –
  - Top or top and bottom.
- ICV to OCV connection.
- Passive LXe saving.

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Material Searches

- Three options:
  - CP Titanium Grade-1 from TIMET following LZ cryostat.
  - Stainless steel from NIRONIT following XENONnT cryostat.
  - Ultra-pure nickel following announcement from nEXO inner vessel.

- Our aims are to be working closely (directly) with:
  - Fabricator of the raw material.
  - Mills performing raw material hot rolling and forging (procuring sheets and flanges).
  - Mills performing welding wire drawing from the raw material.

- First sample of Ti (EB melt) and Stainless Steel (from NIRONIT) are being screened for radon, U, and Th. Several options for surface treatment are being investigated.

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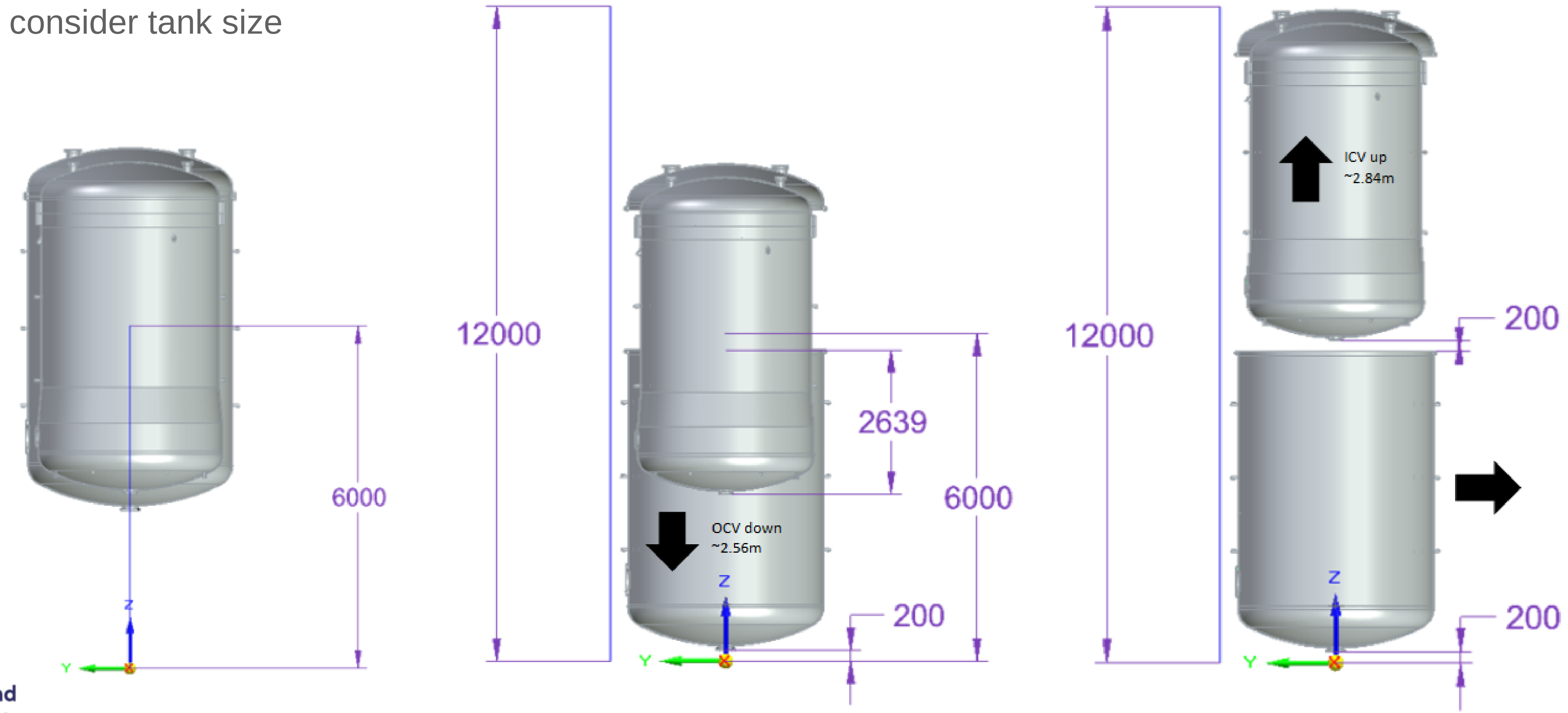
Passive LXe saving options

Concept	Priority	Analysis method
Repeat torispherical head analysis	1	Design by rule, PD5500
Flat head, no ribs	1	Design by rule, PD5500
Inverse dished end, no ribs	2	Design by analysis, PD5500, axisymmetric elastic analysis
Flat head with ribs (radial)	2	Design by rule, EN13445 Part 3 Section 21
Flat head with ribs (square)	3	Design by analysis, PD5500/ASME, 3D analysis, elastic or limit load?
Inverse dished end, with ribs (radial)	3	Design by analysis, PD5500/ASME, 3D analysis, elastic or limit load?
Xenon displacer, Ti shell with He gas	4	Design by analysis, PD5500, axisymmetric elastic analysis
Pressure balanced disk with He gas	5	Design by analysis, PD5500, axisymmetric elastic analysis
Flat head with ribs (other)	6	Design by analysis, PD5500/ASME, 3D analysis, elastic or limit load?
Inverse dished end, with ribs (other)	6	Design by analysis, PD5500/ASME, 3D analysis, elastic or limit load?
Xenon displacer, alternative options	6	Design by analysis, PD5500/ASME, 3D analysis, elastic or limit load?

Removing the Vessel Bottoms

- Important to consider tank size



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