WP3: XLZD Cryostat

Pawel Majewski and Joe O’Dell
(STFC/Rutherford Appleton Laboratory)

4 July 2023, Imperial College London

Key elements of this work package:

1. Design (site dependent) in collaboration with KIT (Germany) and NIKHEF (Netherlands)
2. Material selection and procurement
3. Fabrication (site dependent)
4. Testing and cleaning
5. Transportation and assembly in the experimental hall (site dependent)

Top level requirements :

1. Design and material compliance with pressure vessel code
2. Cryostat material compliance with XLZD radioactivity budget from background simulations to achieve required sensitivity
3. Inner vessel - compact geometry to minimize use of passive xenon
4. Outer vessel - simple geometry for efficient coverage of the outer detector
5. Inner and outer vessel geometry facilitating staging of the TPC and increasing amount of LXe in the detector

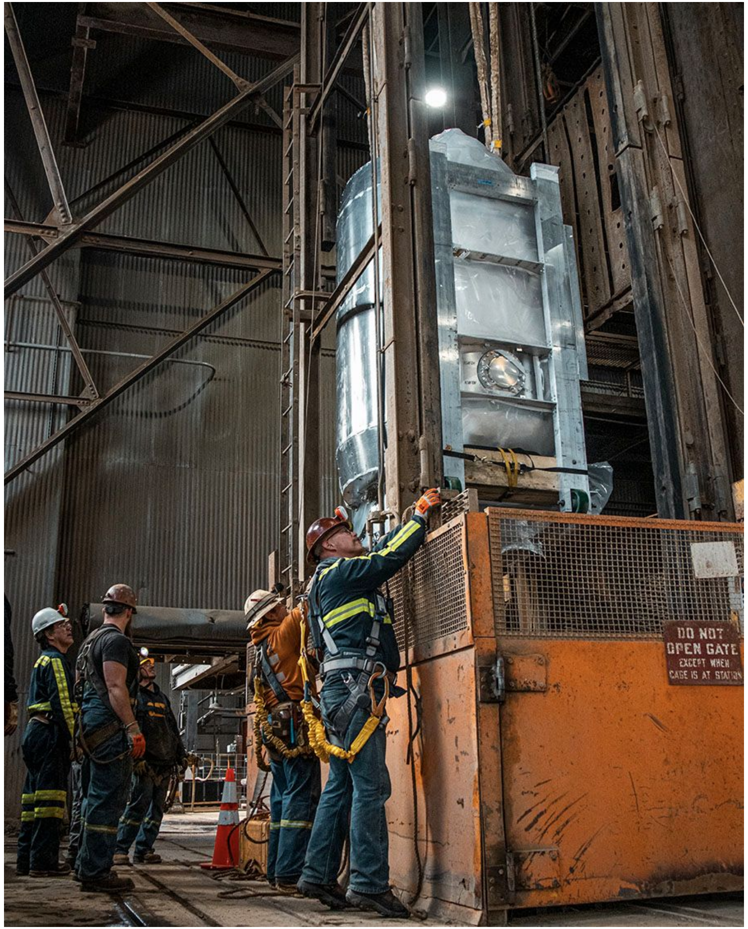
In case of vertical transportation and with a limited cross-section of the shaft :

- Inner and outer vessel to be segmented into minimum number of elements to minimise complexity of fabrication u/g.
- Required mechanical tolerances should fit to achievable precision available in the fabrication processes u/g.

Top level requirements :

In case of vertical transportation and with a limited cross-section of the shaft :

- Inner and outer vessel to be segmented into a minimum number of elements to minimise complexity of fabrication u/g.
- Required mechanical tolerances should fit to achievable precision available in the fabrication processes u/g.



LZ cryostat inner vessel in the shaft ready for transportation u/g.

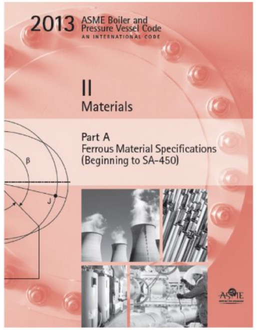
For LZ cryostat deployed in the US:

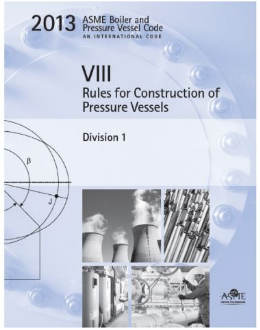
1. ASME BPVC II (a,d) and
   ASME BPVC VIII div 1

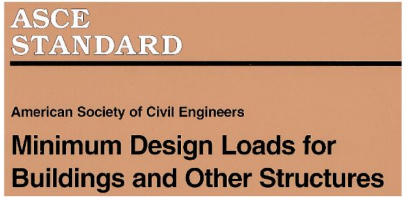
- material Ti	Product form SB265
- shell wall	UG-27/28
- dished ends and heads	UG-32/33
- ICV conical section	UG-28.1/33
- ports and local reinforcement	UG-36/37
- flanges	M. App 2

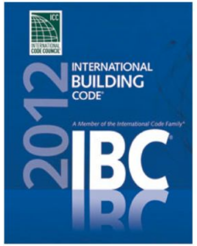
2. ASCE 7 for seismic conditions

3. 2012 International Building Code



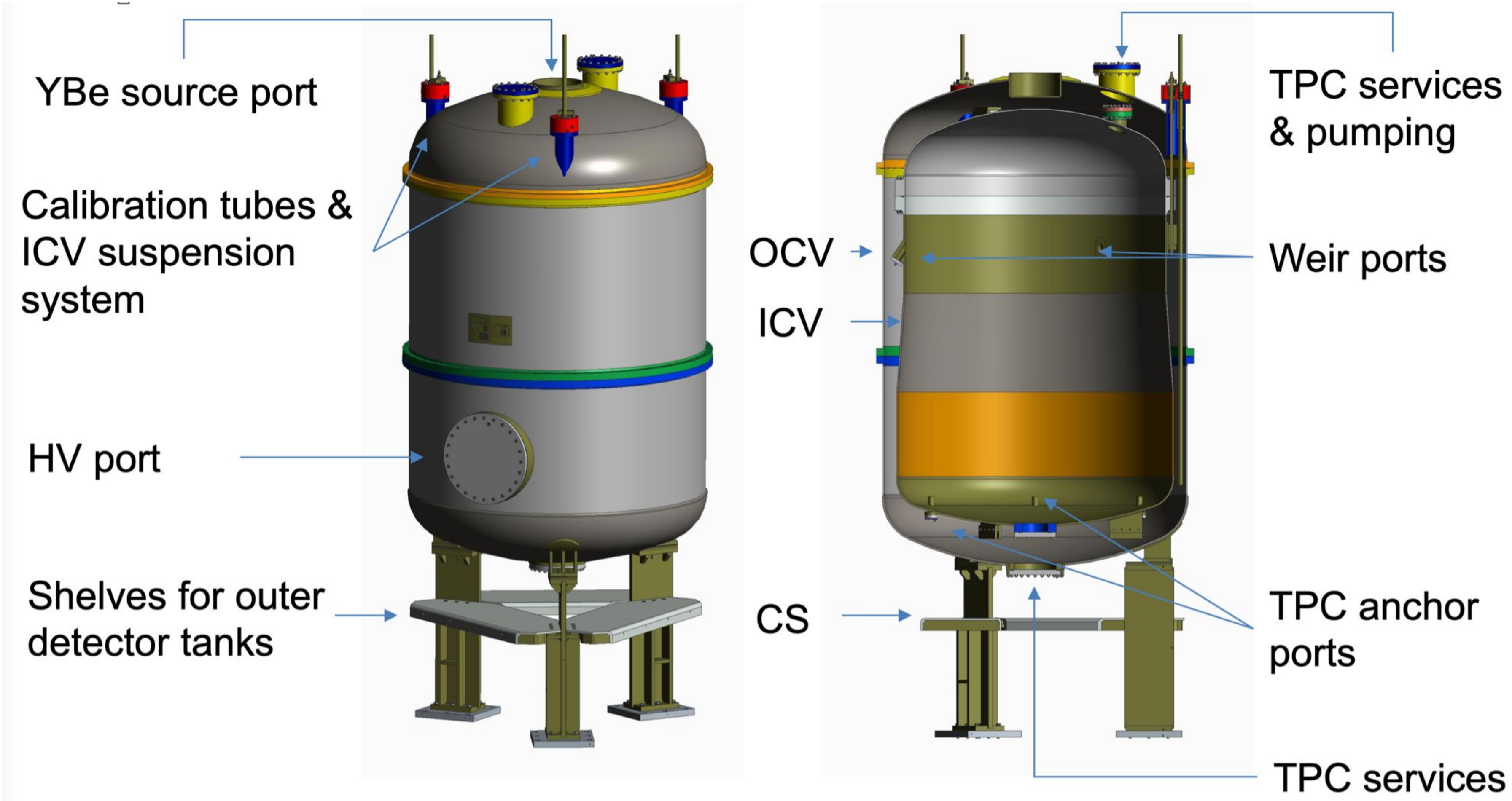






PD 5500

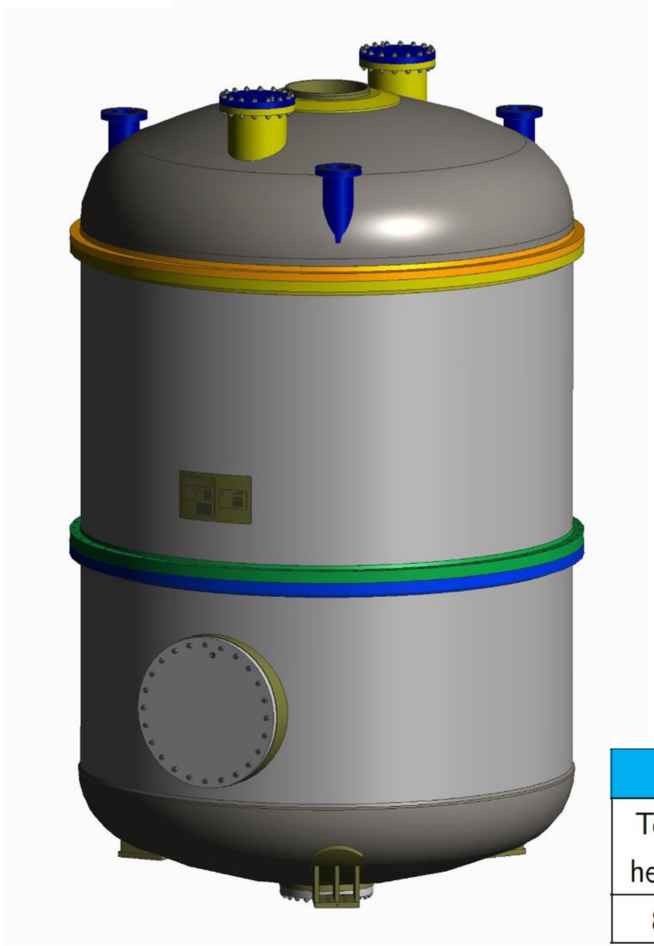
UK standard for pressure vessels



General View **ICV and OCV cross section**

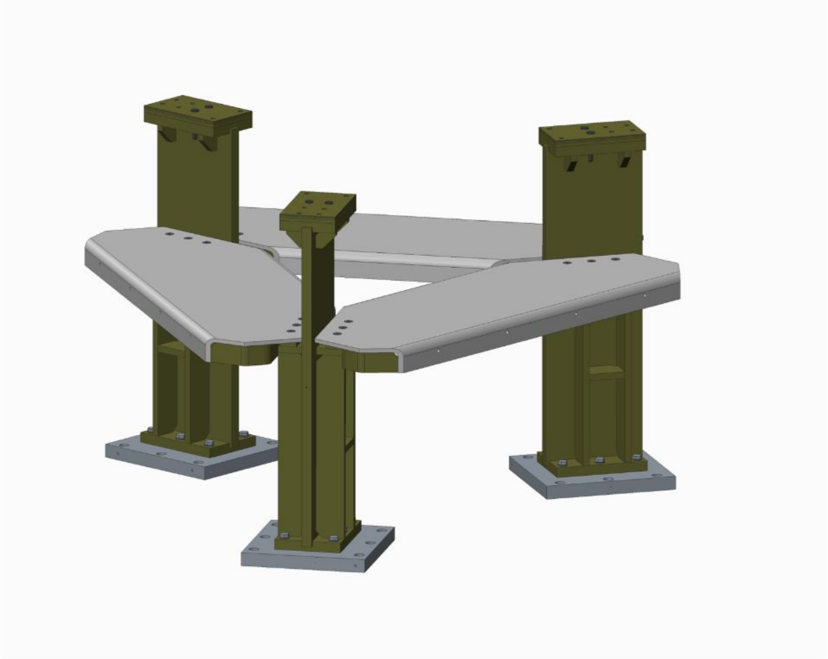
Inner Vessel					
Top head	Upper wall	Conical section	Lower wall	Dished end	Total mass
7	9	9	9	11	950

- Holds 10000 kg of liquid xenon and TPC
- Two segments : top head and lower part
- Suspended from OCV top head
- Ports :
  - 2 x top head (cabling + pumping)
  - 3 x weir ports
  - 1 x high voltage
  - 6 x TPC ports
  - 1 x central dished end (cabling)
- Thermosyphon fins : 6 (wall) + 4 (dished end)
- 3 x tie rod attachments
- 2 x top head lifting points
- 5 x seismic limiters



- Holds Inner Cryostat Vessel
- Three segments : top head, middle and lower part
- Supported by the cryostat base
- Ports:
  - 2 x top head (cabling + pumping)
  - 3 x tie rod ports
  - 1 x YBe source closed port
  - 1 x HV port
  - 1 x central dished end (cabling, fluid)
- Top head flange + YBe source port reinforcement to support OD top acrylic vessels

Outer Vessel			
Top head	Side wall	Dished end	Total mass
8	7	14	1115



- Supports LZ cryostat (full load of 14000 kg)
- System with 3 flat legs (30 mm thick) to maximize OD tanks coverage
- Height and level adjustable with shims
- 3 shelves to support OD tanks
- Seismic conditions included in the design
- Mounting plates at the bottom for assembly with water tank base

Material search campaign

- 21 samples of Ti and 22 of stainless steel screened
- Selected : Timet heat number HN3469 Ti slab melt in Morgantown in Pennsylvania
- Three 5T slabs were made available to the project

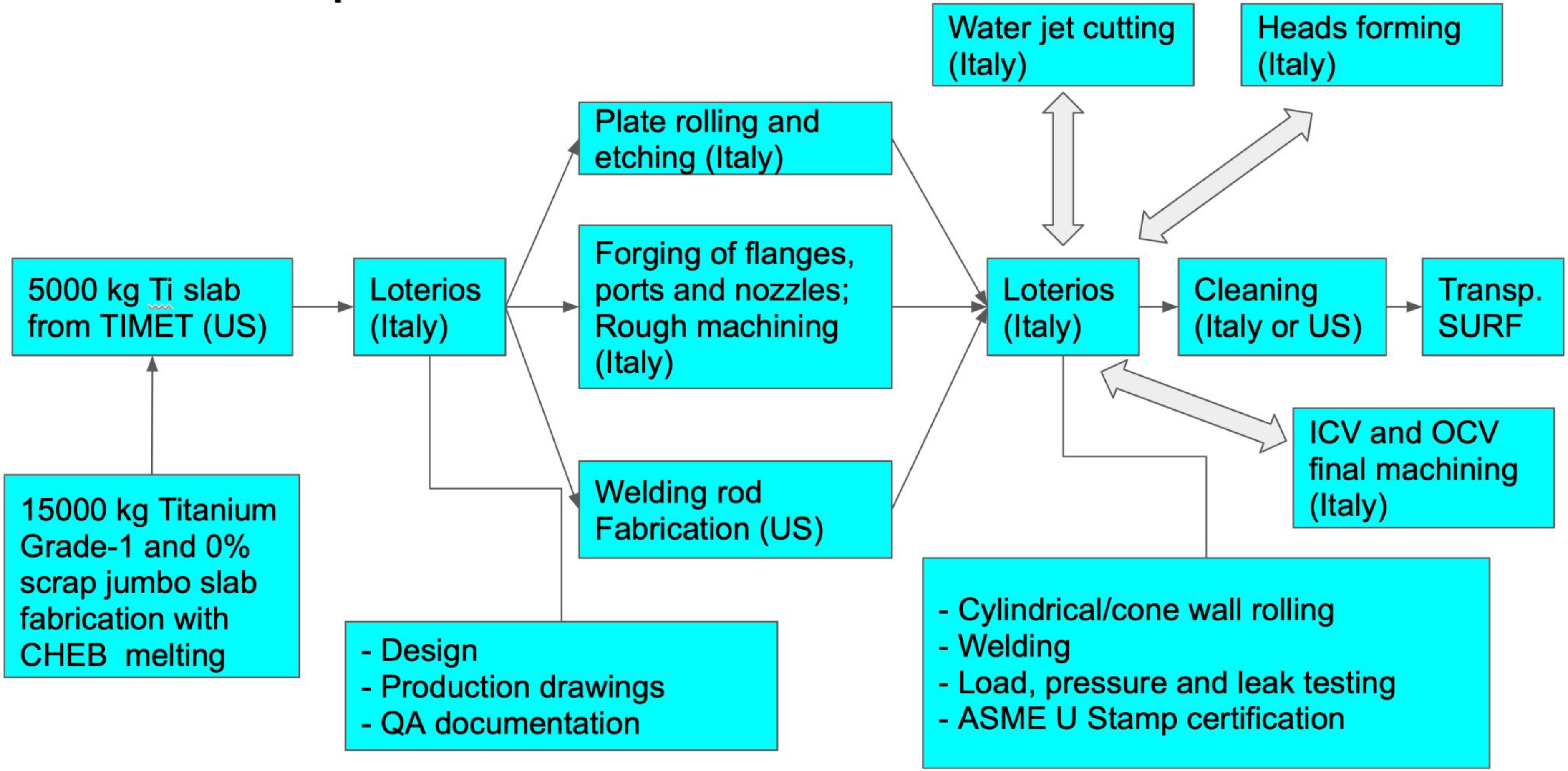
Identification of Radiopure Titanium for the LZ Dark Matter Experiment and Future Rare Event Searches

D.S. Akerib,[1,2] C.W. Akerlof,[3] D. Yu. Akimov,[4] S.K. Alsum,[5] H.M. Araújo,[6] I.J. Arnquist,[a] M. Arthurs,[3] X. Bai,[7] A.J. Bailey,[6,b] J. Balajthy,[8] S. Balashov,[9] M.J. Barry,[10] J. Belle,[11,c] P. Beltrame,[12] T. Benson,[5] E.P. Bernard,[13,14] A. Bernstein,[15] T.P. Biesiadzinski,[1,2] K.E. Boast,[16] A. Bolozdynya,[4] B. Boxer,[17,9] R. Bramante,[1,2] P. Brás,[18] J.H. Buckley,[19] V.V. Bugaev,[19] R. Bunker,[7,d] S. Burdin,[17] J.K. Busenitz,[20] C. Carels,[16] D.L. Carlsmith,[5] B. Carlson,[21] M.C. Carmona-Benitez,[22] C. Chan,[23] J.J. Cherwinka,[5] A.A. Chiller,[24] C. Chiller,[24] A. Cottle,[11] R. Coughlen,[7] W.W. Craddock,[1] A. Currie,[6,e] C.E. Dahl,[25,11] T.J.R. Davison,[12] A. Dobi,[10,f] J.E.Y. Dobson,[26] E. Druszkiewicz,[27] T.K. Edberg,[8] W.R. Edwards,[10] W.T. Emmet,[10] C.H. Faham,[10,g] S. Fiorucci,[10] T. Fruth,[16] R.J. Gaitskell,[23] N.J. Gantos,[10] V.M. Gehman,[10,h] R.M. Gerhard,[28] C. Ghag,[26] M.G.D. Gilchriese,[10] B. Gomber,[5] C.R. Hall,[8] S. Hans,[29] K. Hanzel,[10] S.J. Haselschwardt,[30] S.A. Hertel,[31] S. Hillbrand,[28] C. Hjemfelt,[7] M.D. Hoff,[10] B. Holbrook,[28] E. Holtom,[9] E.W. Hoppe,[a] J.Y-K. Hor,[20] M. Horn,[21] D.Q. Huang,[23] T.W. Hurteau,[14] C.M. Ignarra,[1,2] R.G. Jacobsen,[13] W. Ji,[1,2] A. Kaboth,[9,i] K. Kamdin,[10,13] K. Kazkaz,[15] D. Khaitan,[27] A. Khazov,[9] A.V. Khromov,[4] A.M. Konovalov,[4] E.V. Korolkova,[32] M. Koyuncu,[27] H. Kraus,[16] H.J. Krebs,[1] V.A. Kudryavtsev,[32] A.V. Kumpan,[4] S. Kyre,[30] C. Lee,[1,2,j] H.S. Lee,[33] J. Lee,[33] D.S. Leonard,[33] R. Leonard,[7] K.T. Lesko,[10]

Name	^{238}U (mBq/kg)		^{232}Th (mBq/kg)		^{60}Co	^{40}K
	early	late	early	late	(mBq/kg)	(mBq/kg)
NIRONIT (1)	7.3	0.35	1.1	4.0	14.5	0.53
NIRONIT (2)	1.2	0.27	0.12	0.49	1.6	<0.4
NIRONIT (3)	<1	0.54	0.49	1.1	1.7	<0.59
NIRONIT (4)	1.4	0.5	0.5	0.32	2.6	<0.5
NIRONIT (5)	1.1	0.38	0.81	0.73	5.6	<0.46
NIRONIT (6)	0.5	1.9	1.7	1.5	4.5	<0.5
NIRONIT (7)	-	1.1	-	4.1	8.2	<3.0
NIRONIT (8)	-	<0.6	-	<0.8	7.4	<3
NIRONIT (9)	-	<0.6	-	<0.9	6.5	<3
NIRONIT (10)	-	4	-	2.2	26	<4
NIRONIT (11)	-	<0.6	-	4.8	32	<2
NIRONIT (12)	-	<0.8	-	2.1	32	5
NIRONIT (13)	-	<1.4	-	<1.5	335	<4
GERDA D6	<5		<0.4		-	<0.002
published [5]	<0.6		<1.4		16.8 ± 2.4	<1.8
GERDA G1	<5		<0.4		-	<0.003
published [5]	<1.3		<2.6		45.5 ± 2.1	<2.8
GERDA G2	<5		<0.4		-	<0.003
published [5]	<0.86		<0.24		14.0 ± 0.1	< 0.93
NEXT 10 mm	7.46		<0.24		-	<0.63
published [24]	<21		<0.59		2.8 ± 0.2	<0.96
NEXT 15 mm	12.4		<0.24		-	<0.63
published [24]	<25		<0.69		4.4 ± 0.3	<1.0
NEXT 50 mm	12.4		<0.24		-	<0.63
published [24]	67 ± 22		2.1 ± 0.4		4.2 ± 0.3	<2.5

Name	Type	^{238}U (mBq/kg)			^{232}Th (mBq/kg)		^{40}K
		early	late	^{210}Pb	early	late	(mBq/kg)
Supra Alloy Sheet (1)	ASTM Grade 1 Sheet	32	4.2	-	3.3	2.8	<1.9
Supra Alloy Sheet (2)	ASTM Grade 2 Sheet	110	<2	-	200	180	25
TIMET Sponge (1)	Sponge	25	<2	250	<4.1	<4.1	<12
TIMET Sponge (2)	Sponge	<25	<2	6200	<4.1	<2.4	<15
TIMET Sponge (3)	Sponge	<25	<2	<62	<5.3	<1.6	<12
TIMET Sponge (4)	Sponge	74	<2	120	<4.1	<1.6	<12
TIMET Sponge (5)	Sponge	<12	<2	740	<4.1	<1.6	<12
TIMET Sponge (6)	Sponge	74	<4	2500	<5.3	14	<19
TIMET Sponge (7)	Sponge	37	25	2500	12	5.7	<12
TIMET Sheet (1)	ASTM Grade 1 Sheet	11	<0.62	-	<0.8	<0.6	<2.5
TIMET Sheet (2)	ASTM Grade 1 Sheet	5	3.3	-	2.8	0.8	<1.5
TIMET Sheet (3)	ASTM Grade 1 Sheet	8.5	0.37	-	0.45	0.61	<0.5
TIMET Sheet (4)	ASTM Grade 1 Sheet	8.0	<0.12	-	<0.12	<0.1	<0.6
TIMET HN3469-T	ASTM Grade 1 Slab	<1.6	<0.09	-	0.28	0.23	<0.5
TIMET HN3469-M	ASTM Grade 1 Slab	2.8	<0.10	-	<0.20	0.25	<0.7
PTG Sheet (1)	ASTM Grade 1 Sheet	47	2.8	-	2.0	2.8	<1.9
PTG Sheet (2)	ASTM Grade 2 Sheet	<9.9	3.7	-	<0.81	2.4	<2.2
Bolts	Bolts	1300	<6.2	-	160	160	<37
Nuts/Washers	Nuts/Washers	520	<8.6	-	<12	81	<62
Honeywell Sheet	ASTM Grade 1 Sheet	3.7	4.7	-	1.5	1.6	<1.5
VSMPO Disc (10% scrap)	ASTM Grade 1 Metal	62	<6.2	-	<4.1	<4.1	<31
VSMPO Sponge	ASTM Grade 1 Sponge	17	12	-	<4.1	<4.1	<6.2

Fabrication process



Material - Titanium CP-1 (grade 1) from Timet

Machining

Assembly at Loterios

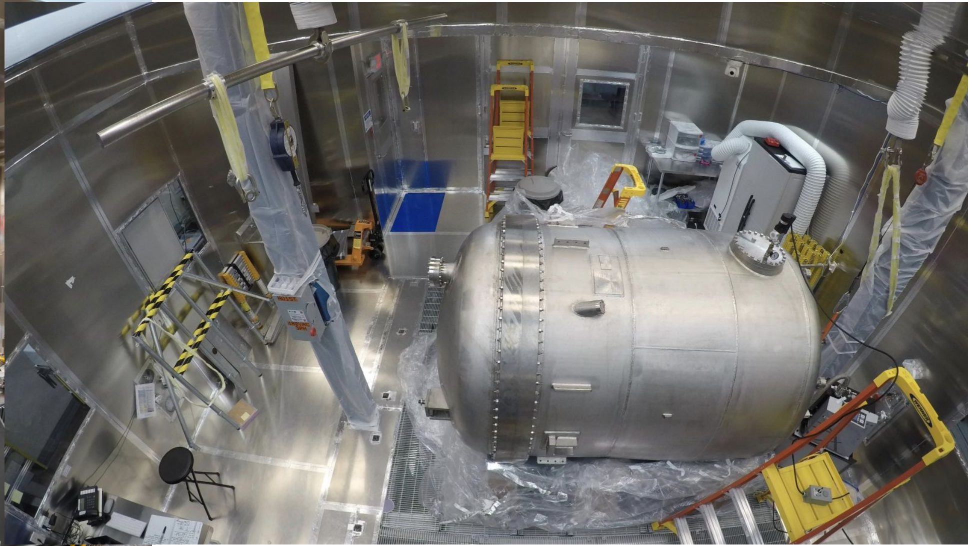
Cryostat metrology as built

Final cleaning at AstroPak (CA)

Titanium etching and
water jet cleaning at AstroPak (US)

Cryostat vessels at SURF in the SAL

From a single slab to a beautiful engineering and manufacturing marvel.



XLZD Cryostat@Boulby

- We designed the LZ cryostat and together with our colleagues from KIT and NIKHEF who designed the Darwin cryostat we are well prepared for the next step.
- We have successfully selected the best radio-pure material to date and we know low radioactivity material suppliers worldwide.
- In collaboration with TWI and Nuclear AMRC we can reach best UK vessel manufacturers to help us in our XLZD endeavor deep in the Yorkshire salt.