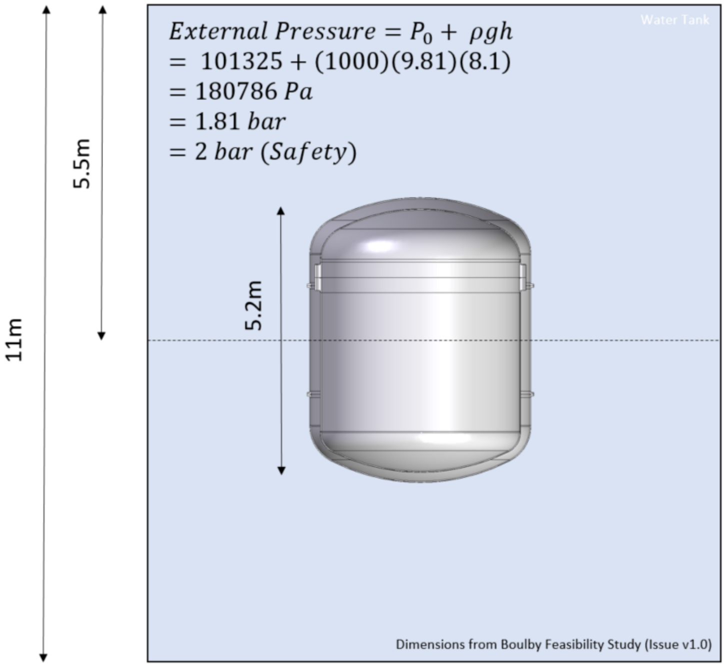
XLZD Cryostat Design

Progress Meeting – 31/07/2023

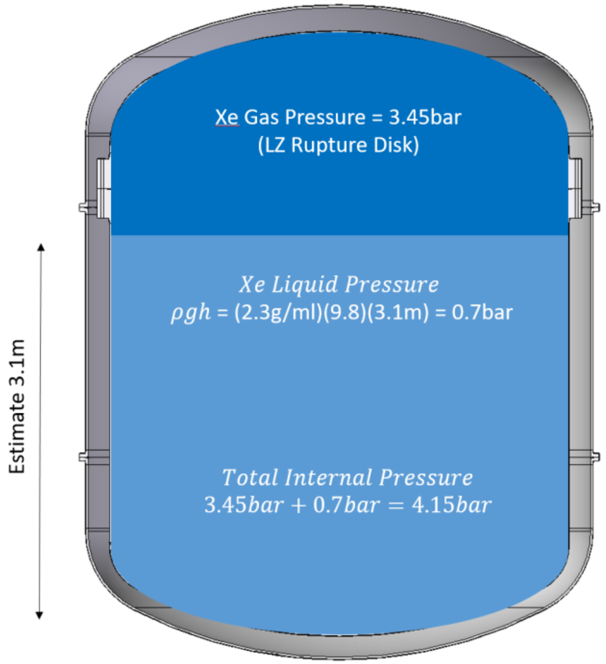
Design Parameters

Case	Vessel	Pressure (bar) Internal	External	Temperature (°C)	Condition
1.1	Inner	4.15	Vacuum	-112 to 37	Operating condition
1.2		Vacuum	1.01	<100	No water in tank + air between OVC/IVC + IVC under vacuum
1.3		Vacuum	2.00	-112 to 37	Water between OVC/IVC + IVC under vacuum
2.1	Outer	Vacuum	2.00	0 to 37	Operating condition
2.2		Vacuum	1.01	<100	No water in tank
2.3		2.00	1.01	0 to 37	Xenon between OVC/IVC + no water in tank

External Case (OCV and ICV):



Internal Case (For ICV only):



Internal Case (For OCV only):

Theoretically doesn't need to support positive pressure, but practically needs some small internal pressure capacity for 2 reasons:

- In a failure event there is some pressure necessary for fluid to get out of the vessel and into the open air.
- It's difficult to find a low value pressure relief device. Such devices are typically not code stamped.

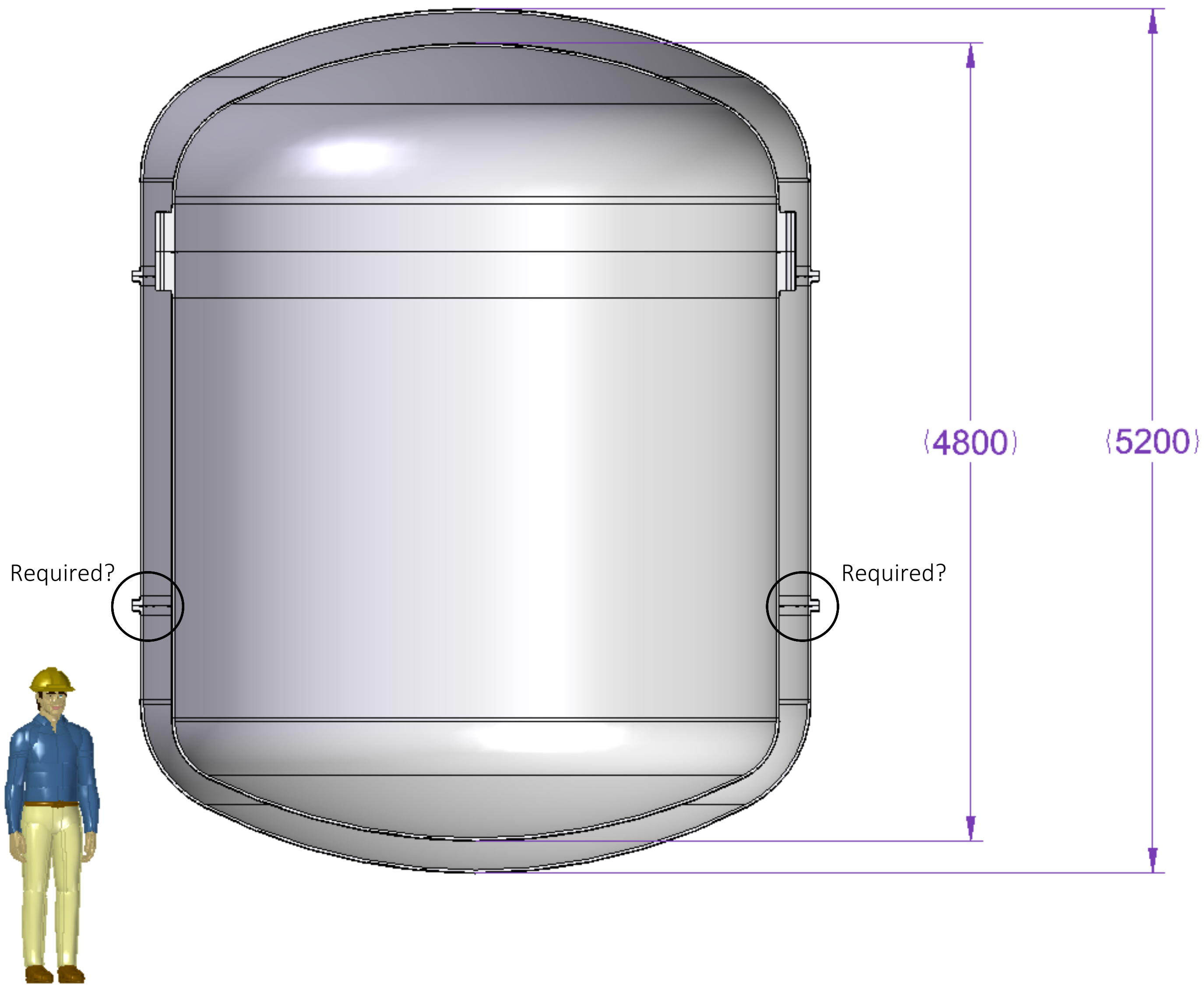
(*Information from J Saba*)

Therefore:

2 bar (assume external pressure case acts internally) – **1.01 bar** (atmospheric pressure externally) = **0.99 bar**

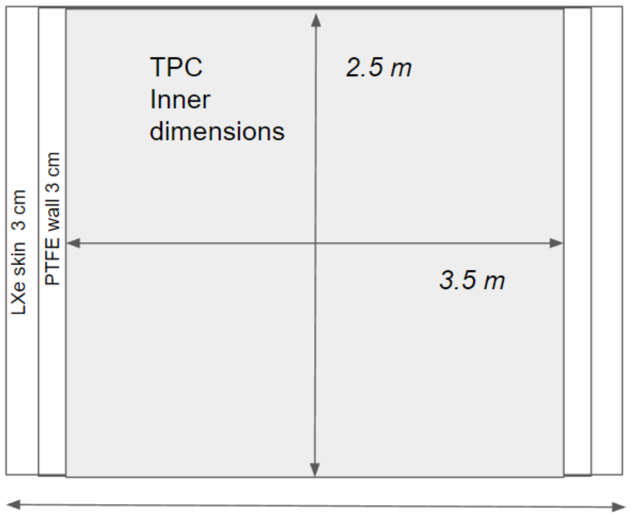
All "best guess" at this stage, but allows me to start doing some preliminary calculations

Estimate Cryostat Dimensions



Component	LZ	G3
2. Cryostat		
Inner Cryostat vessel		
Height (m)	2.6	4.8
Diameter (m)	1.65	3.75
Mass (t)	1.0	2.5–5
Outer Cryostat vessel		
Height (m)	3.0	5.2
Diameter (m)	1.8	4.1
Mass (t)	1.3	4–8
Total cryostat mass (t)	2.3	17.3
4. Water Shield		
Water tank		
Height (m)	5.9	11.0
Diameter (m)	7.6	12.0
Water capacity (t)	270	1,250
Shielding (w.e.)		
Top (m)	1.8	4.0
Bottom (m)	3.0	4.0
Lateral (m)	2.9	4.0

Boulby Feasibility Study (Issue v1.0)



3.5 m + 12 cm = 3.62 m

XLZD Cryostat Model

Materials

Values used

More investigation required

Table Ti.2.3-1 **Design strength values (N/mm²): commercially pure titanium and titanium alloys of material specifications ASTM B265, B338, B348, B363, B381, B861, and B862**

Material grades	A2 Material group	Minimum tensile strength R_m N/mm²	Minimum 0.2% proof stress $R_{p0.2}$ N/mm²	Values of *f* for design temperatures not exceeding °C						
				20	50	100	150	200	250	300
1	51	240	138	80	77	62	49	38	30	25
2	51	345	275	115	112	98	83	72	63	55
2H[a]	51	400	275	133	130	113	96	83	71	58
3	52	450	380	150	146	124	102	85	71	62
7	51	345	275	115	112	98	83	72	63	55
7H[a]	51	400	275	133	130	113	96	83	71	58
9	53	620	485	207	205	197	181	164	148	140
11	51	240	138	80	77	62	49	38	30	25
12	52	485	345	162	159	148	130	116	106	101
16	51	345	275	115	112	98	82	72	62	55
16H[a]	51	400	275	133	130	113	96	83	71	58
17	51	240	138	80	78	62	49	38	30	25
26	51	345	275	115	112	98	82	72	62	55
26H[a]	51	400	275	133	130	113	96	83	71	58
27	51	240	138	80	77	62	49	38	30	25
28	53	620	485	207	205	197	181	164	148	140

[a] Material is identical to the corresponding numeric grade (for example, Grade 2H = Grade 2) except for the higher guaranteed minimum tensile strength, and may always be certified as meeting the requirements of its corresponding numeric grade. In general over 99% of materials in these grades will meet the 400 MPa minimum tensile strength value. A2

Ti.2.2 Materials for low temperature application

The alloys specified in **Ti.2.1.1** are not susceptible to brittle fracture and no special provisions are necessary for their use at temperatures down to at least −100 °C. Tensile and other strength values at room temperature may be used for operational service down to −30 °C.

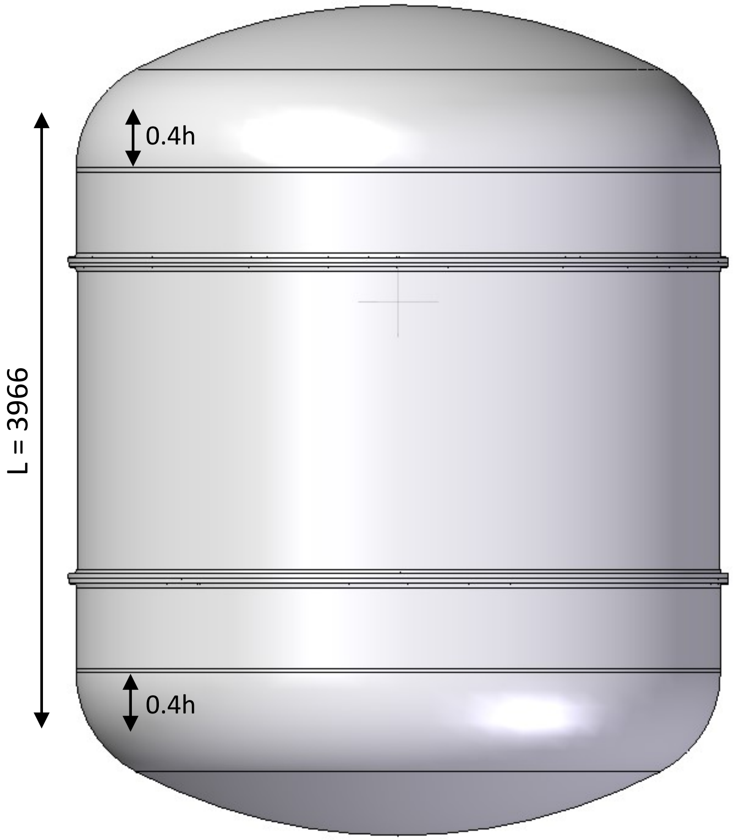
Table Ti.3.6-3 ***E* values for titanium alloys** A2 **(modulus of elasticity)** A2

Temperature °C	*E* N/mm²
0	107 900
20	106 900
50	105 500
100	103 100
150	100 600
200	96 900
250	92 600
300	88 200

s is the factor relating *f* to effective yield point of material; for the purposes of **Ti.3.6**, *s* shall be taken to be 1.1.

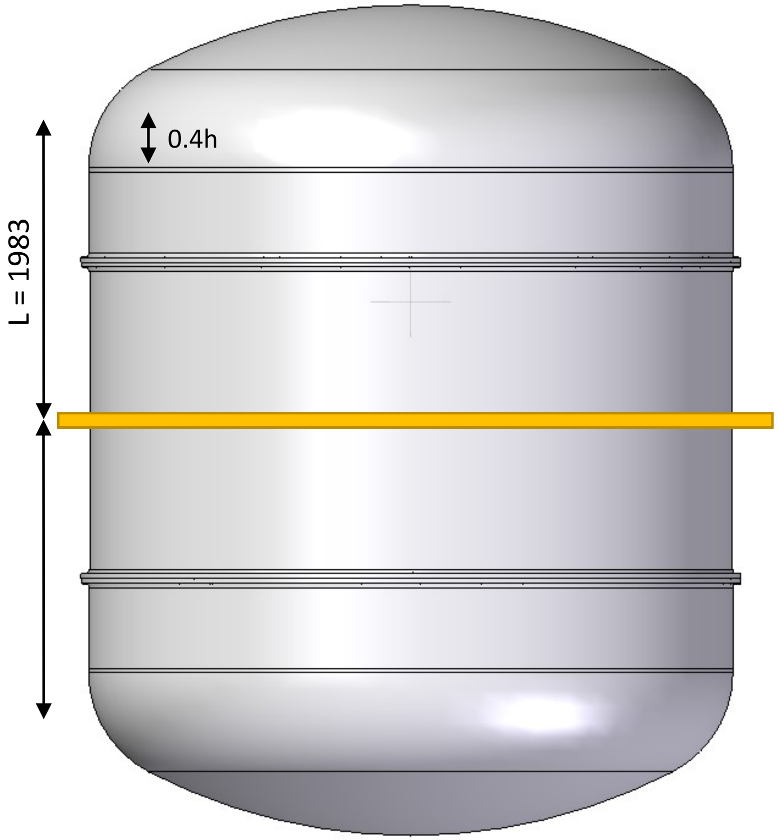
OCV Wall Thickness

With no additional stiffening:



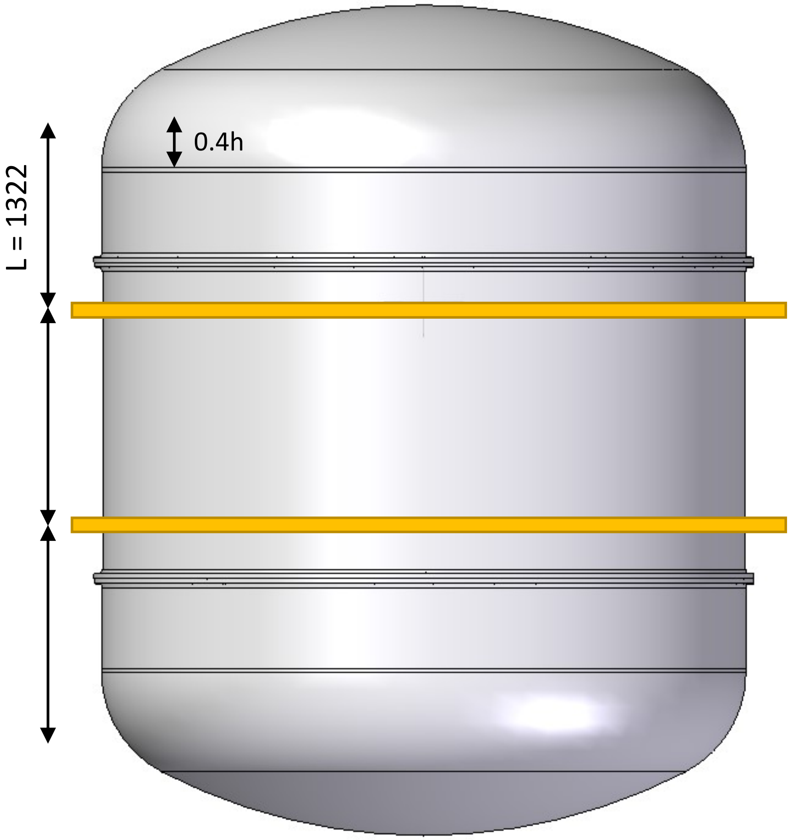
Required cylinder wall thickness: **22mm**
Approximate mass of cylinder: **3996kg**
(Excluding heads and flanges)

With 1 stiffener at the mid-plane:



Required cylinder wall thickness: **17mm**
Approximate mass of cylinder: **3266kg**
(Excluding heads and flanges)

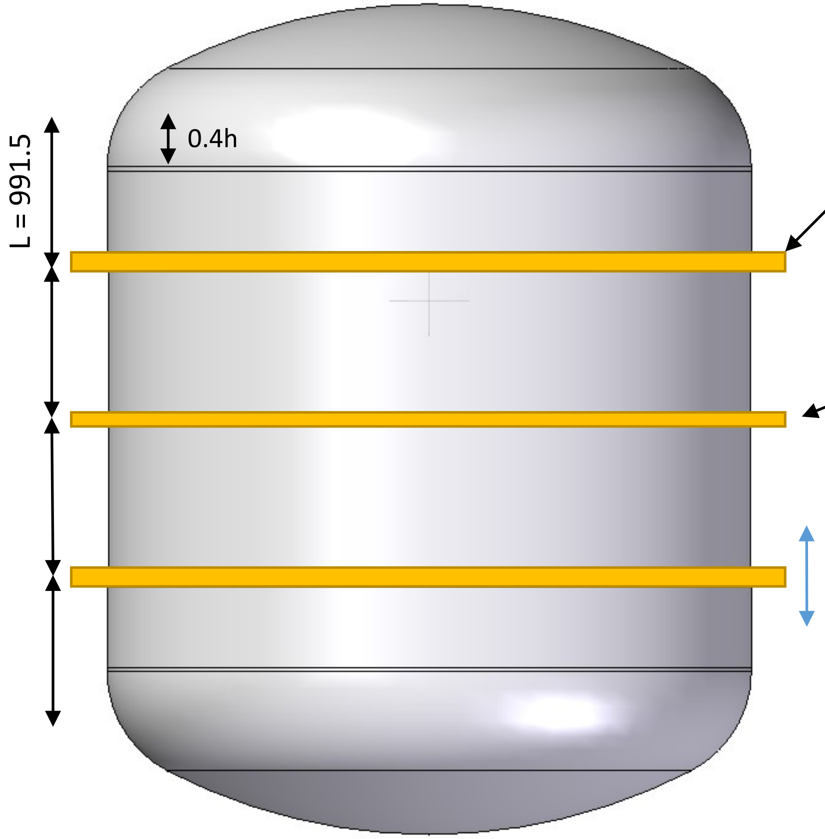
With 2 equally spaced stiffeners:



Required cylinder wall thickness: **14mm**
Approximate mass of cylinder: **2538kg**
(Excluding heads and flanges)

OCV Wall Thickness

With the OCV flanges as stiffeners:



The OCV flanges would need designed such to fulfil the stiffener requirements (PD5500 3.6.2.2 and 3.6.2.3)

(At present, they would fail the requirements)

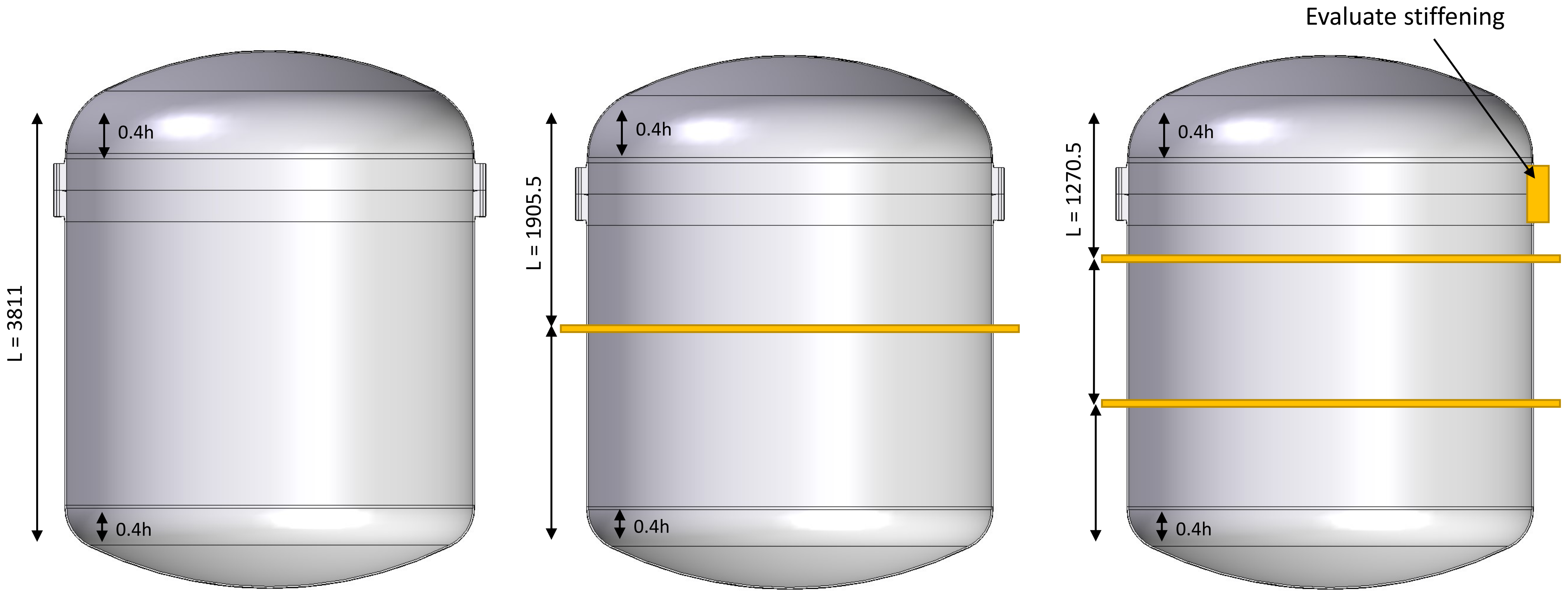
Only one additional "ring" required

Need to better understand the constraints on the OCV flange positions

At present, they're placed such to minimise unsupported length – but in reality there may be other constraints/ requirements regarding their position

Required cylinder wall thickness: **13mm**
Approximate mass of cylinder: **2356kg**
(Excluding heads and flanges)

ICV Wall Thickness



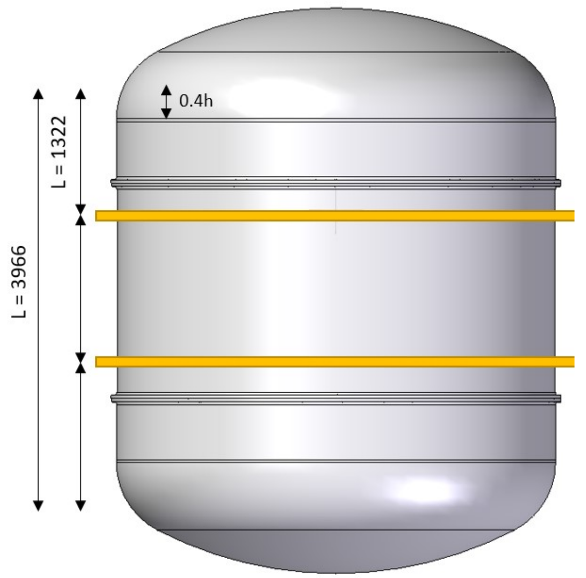
Required cylinder wall thickness: **20mm**
Approximate mass of cylinder: **3283kg**
(Excluding heads and flanges)

Required cylinder wall thickness: **15mm**
Approximate mass of cylinder: **2459kg**
(Excluding heads and flanges)

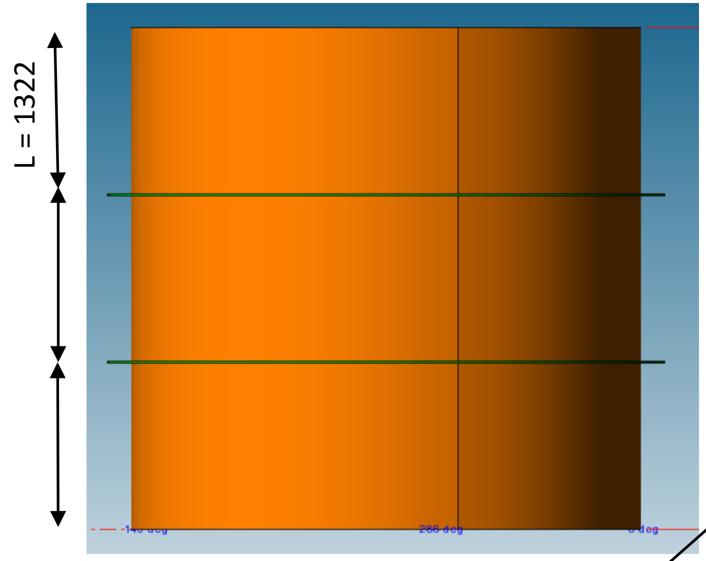
Required cylinder wall thickness: **13mm**
Approximate mass of cylinder: **2130kg**
(Excluding heads and flanges)

Stiffener Work... Ongoing..! (In the first instance to validate that the spreadsheet correctly analyses stiffener dimensions)

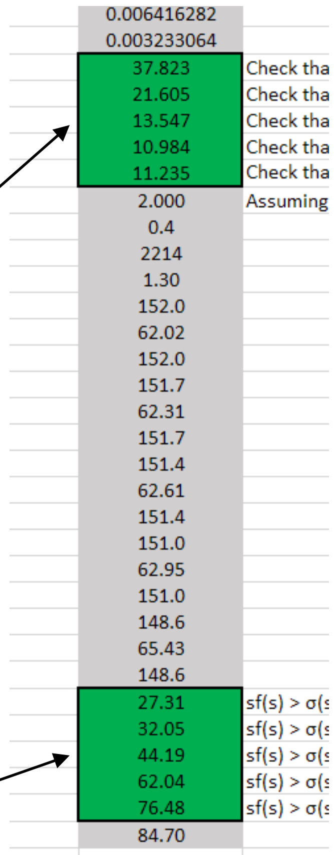
Example CAD model:



Analyse with PVElite model:



Compare with output of hand calculations:



0.006416282	
0.003233064	
37.823	Check tha
21.605	Check tha
13.547	Check tha
10.984	Check tha
11.235	Check tha
2.000	Assuming
0.4	
2214	
1.30	
152.0	
62.02	
152.0	
151.7	
62.31	
151.7	
151.4	
62.61	
151.4	
151.0	
62.95	
151.0	
148.6	
65.43	
148.6	
27.31	sf(s) > σ(s
32.05	sf(s) > σ(s
44.19	sf(s) > σ(s
62.04	sf(s) > σ(s
76.48	sf(s) > σ(s
84.70	

n	Ic mm**4	Pn MPa	Allow(Hot) MPa	Allow(Cold) MPa
2	0.239E+08	38.07	0.36	0.40
3	0.238E+08	21.57	0.36	0.40
4	0.237E+08	13.24	0.36	0.40
5	0.234E+08	10.36	0.36	0.40
6	0.232E+08	10.49	0.36	0.40

Maximum Stress in Stiffener Flange (Sigma) MPa

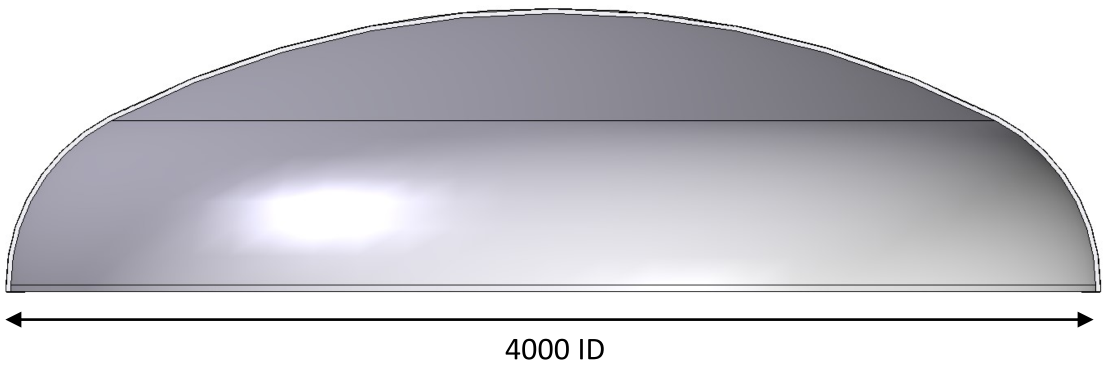
n	--- Hot ---	--- Cold ---	-- Allowed --	Pass/Fail
2	25.173	27.971	84.703	Pass
3	29.411	32.690	84.703	Pass
4	40.580	45.146	84.703	Pass
5	57.919	64.505	84.703	Pass
6	72.577	80.855	84.703	Pass

Stiffening ring dimensions:

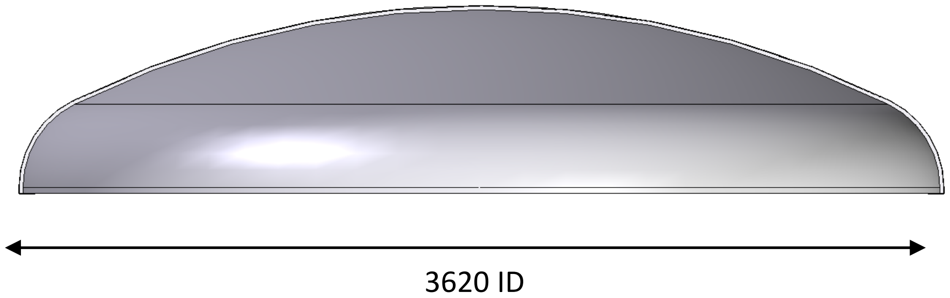
Inside Diameter :	4028	mm
Thickness :	15	mm
Outside Diameter :	4400	mm

(Approx.. not optimised)

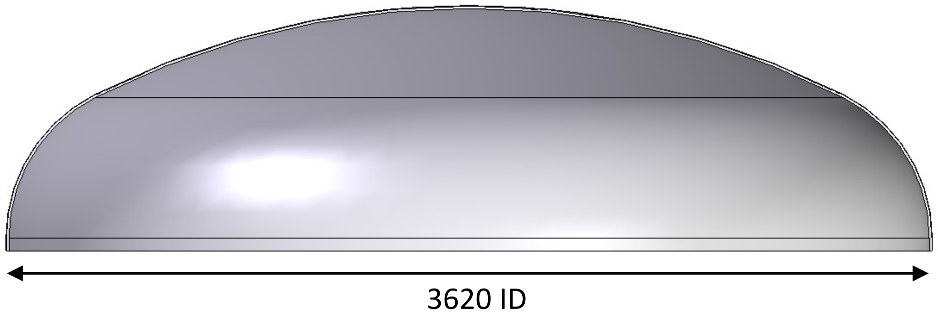
OCV 2:1 Ellipse Head Thickness: 17mm
Mass: 1398kg
Internal Dished Height: 1000mm



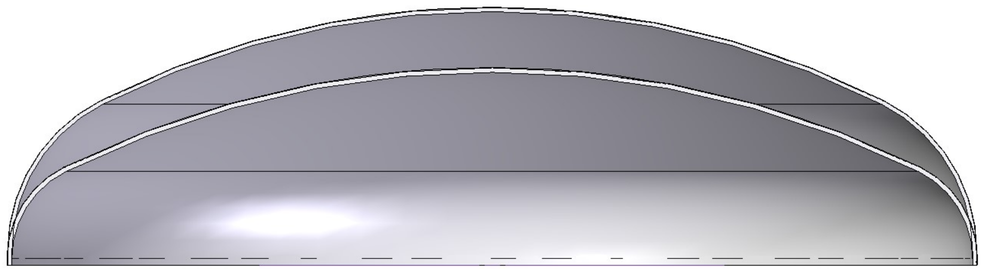
ICV Torispherical Head Thickness: 18mm
Mass: 1098kg
Internal Dished Height: ~701.25mm



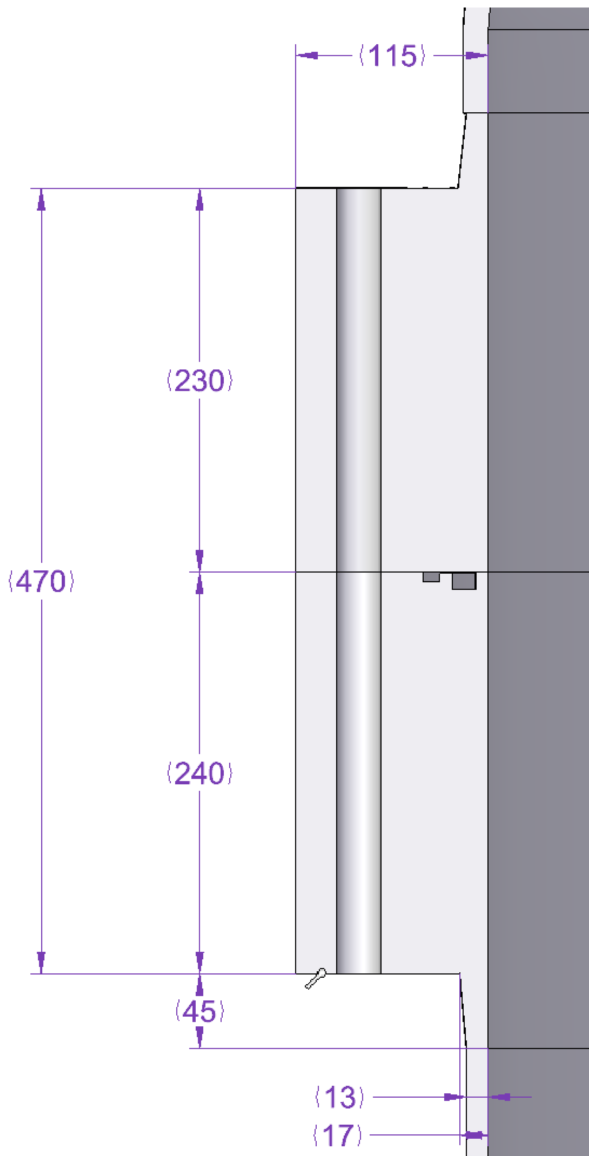
ICV 2:1 Ellipse Head Thickness: 15mm
Mass: 1033kg
Internal Dished Height: 905mm



ICV 2:1 Ellipse Head vs. Torispherical Head



ICV Bolted Flange (Preliminary):



Extracts from "XLZD Cryostat PD5500 Calculations" spreadsheet:

W(m1)_tot	N	Minimum required bolt load for operating conditions	5036162
W(m2)_tot	N	Minimum required bolt load for gasket seating (Sum of sealing two gaskets)	5255841
G_tot	mm	Assumed diameter of gasket load reaction	3649
H_tot	N	Total hydrostatic end force	4454558
A(m1)	mm2	Total cross-sectional area of bolts required for operating conditions	39970
A(m2)	mm2	Total cross-sectional area of bolts required for gasket seating	41713
A(m)	mm2	Total required cross-sectional area of bolts	41713
A(b)	mm2	Actual total cross-sectional area of bolts at the section of least diameter under load	46699
t	mm	Minimum allowable flange thickness, measured at the thinnest section	228
M-BU	Nmm	M(atm) C(F)/B (bolting-up condition)	96935.9
M-OP	Nmm	M(op)C(F)/B (operating condition)	95093.2
SH-OP	MPa	Calculated longitudinal stress in hub (Operating)	68.8
SH-BU	MPa	Calculated longitudinal stress in hub (Bolting-up)	70.2
SR-OP	MPa	Calculated radial stress in flange (Operating)	0.8
SR-BU	MPa	Calculated radial stress in flange (Bolting-up)	0.8
ST-OP	MPa	Calculated tangential stress in flange (Operating)	44.2
ST-BU	MPa	Calculated tangential stress in flange (Bolting-up)	45.0
Avg-OP	MPa	0.5[S(H)+max(S(R);S(T)]	56.5
Avg-BU	MPa	0.5[S(H)+max(S(R);S(T)]	57.6
k		Stress factor for narrow-faced gasketted flanges	1.33
SFA	MPa	Design stress of the flange at atmospheric temperature	77.0
SFO	MPa	Design stress of the flange at design temperature	77.0
SHA	MPa	Design stress of the hub at atmospheric temperature	77.0
SHO	MPa	Design stress of the hub at design temperature	77.0
SFA/k	MPa	Design stress of the flange at atmospheric temperature	57.9
SFO/k	MPa	Design stress of the flange at design temperature	57.9
SHA/k	MPa	Design stress of the hub at atmospheric temperature	57.9
SHO/k	MPa	Design stress of the hub at design temperature	57.9
		Is SH-BU < smaller then 1.5 x SHA or 1.5SFA?	PASS
		Is SH-OP < smaller then 1.5 x SHO or 1.5SFO?	PASS
		Is SR-BU < SFA?	PASS
		Is SR-OP < SFO?	PASS
		Is ST-BU < SFA?	PASS
		Is ST-OP < SFO?	PASS
		0.5[S(H)+max(S(R);S(T)]-BU < SFA	PASS
		0.5[S(H)+max(S(R);S(T)]-OP < SFO	PASS
		Check minimum recommended hub clearance is maintained	60.5
		Check minimum recommended edge clearance is maintained	37.5
		Is A(b) > A(m)?	PASS

Bolt load for operating conditions

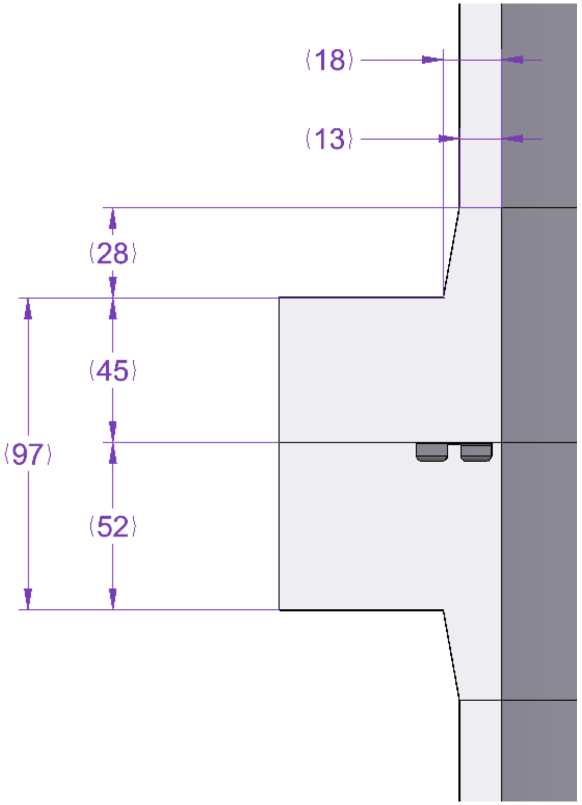
Bolt load for gasket seating

~ 144 M24 bolts (304 SS)

Minimum flange thickness
(i.e. to bottom of O-ring groove)

PD5500 stress limit checks

OCV Bolted Flange (Preliminary):



Extracts from "XLZD Cryostat PD5500 Calculations" spreadsheet:

W(m1)_tot	N	Minimum required bolt load for operating conditions	1272182
W(m2)_tot	N	Minimum required bolt load for gasket seating (Sum of sealing two gaskets)	61891
G_avg	mm	Assumed diameter of gasket load reaction	4039
H_tot	N	Total hydrostatic end force	1267805
A(m1)	mm2	Total cross-sectional area of bolts required for operating conditions	10097
A(m2)	mm2	Total cross-sectional area of bolts required for gasket seating	491.2
A(m)	mm2	Total required cross-sectional area of bolts	10097
A(b)	mm2	Actual total cross-sectional area of bolts at the section of least diameter under load	10951.6
t	mm	Minimum allowable flange thickness, measured at the thinnest section	44
M-BU	Nmm	M(atm) C(F)/B (bolting-up condition)	9033.7
M-OP	Nmm	M(op)C(F)/B (operating condition)	11990.2
SH-OP	MPa	Calculated longitudinal stress in hub (Operating)	86.8
SH-BU	MPa	Calculated longitudinal stress in hub (Bolting-up)	65.4
SR-OP	MPa	Calculated radial stress in flange (Operating)	12.0
SR-BU	MPa	Calculated radial stress in flange (Bolting-up)	9.1
ST-OP	MPa	Calculated tangential stress in flange (Operating)	-3.9
ST-BU	MPa	Calculated tangential stress in flange (Bolting-up)	-2.9
	MPa	0.5[S(H)+max(S(R);S(T)]	49.4
	MPa	0.5[S(H)+max(S(R);S(T)]	37.2
k		Stress factor for narrow-faced gasketted flanges	1.33
SFA	MPa	Design stress of the flange at atmospheric temperature	77.0
SFO	MPa	Design stress of the flange at design temperature	77.0
SHA	MPa	Design stress of the hub at atmospheric temperature	77.0
SHO	MPa	Design stress of the hub at design temperature	77.0
SFA/k	MPa	Design stress of the flange at atmospheric temperature	57.9
SFO/k	MPa	Design stress of the flange at design temperature	57.9
SHA/k	MPa	Design stress of the hub at atmospheric temperature	57.9
SHO/k	MPa	Design stress of the hub at design temperature	57.9
		Is SH-BU < smaller then 1.5 x SHA or 1.5SFA?	PASS
		Is SH-OP < smaller then 1.5 x SHO or 1.5SFO?	PASS
		Is SR-BU) < SFA?	PASS
		Is SR-OP < SFO?	PASS
		Is ST-BU < SFA?	PASS
		Is ST-OP < SFO?	PASS
		0.5[S(H)+max(S(R);S(T)]-BU < SFA	PASS
		0.5[S(H)+max(S(R);S(T)]-OP < SFO	PASS
		Check minimum recommended hub clearance is maintained	28.75
		Check minimum recommended edge clearance is maintained	22.25
		Is A(b) > A(m)?	PASS

Bolt load for operating conditions

Bolt load for gasket seating

~ 76 M16 bolts (304 SS)

Minimum flange thickness
(<u>i.e. to bottom of O-ring groove</u>)

PD5500 stress limit checks

Next Steps:

- Investigate what modifications would be required to the OCV flanges such that they pass the stiffener requirements.
- Gather some information on the constraints/requirements concerning the OCV flange position.
- Update the OCV flange drawings (as this will need fed back to manufacturers).
- Validate the flange calculations in PVElite (started..).
- Further investigate stiffening ring geometry and how to optimise their size.