SABRE General Meeting

4-5-6 October 2017, LNGS (L'Aquila)

SABRE Australia Vessel Design

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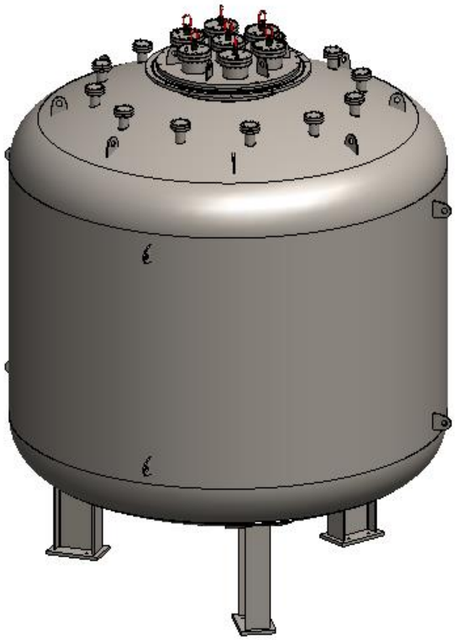
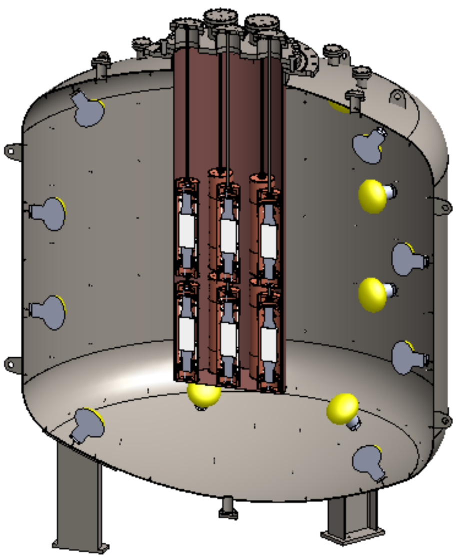
0. Introduction – status

- **Design** of the VV for SABRE Australia **finalized** in August 2017;
- Design **submitted for tender** – discussion of the contract ongoin with 2 AU companies;
- ***Tasweld* welding material tested** for radioactivity (U,Th) and proven to be OK;

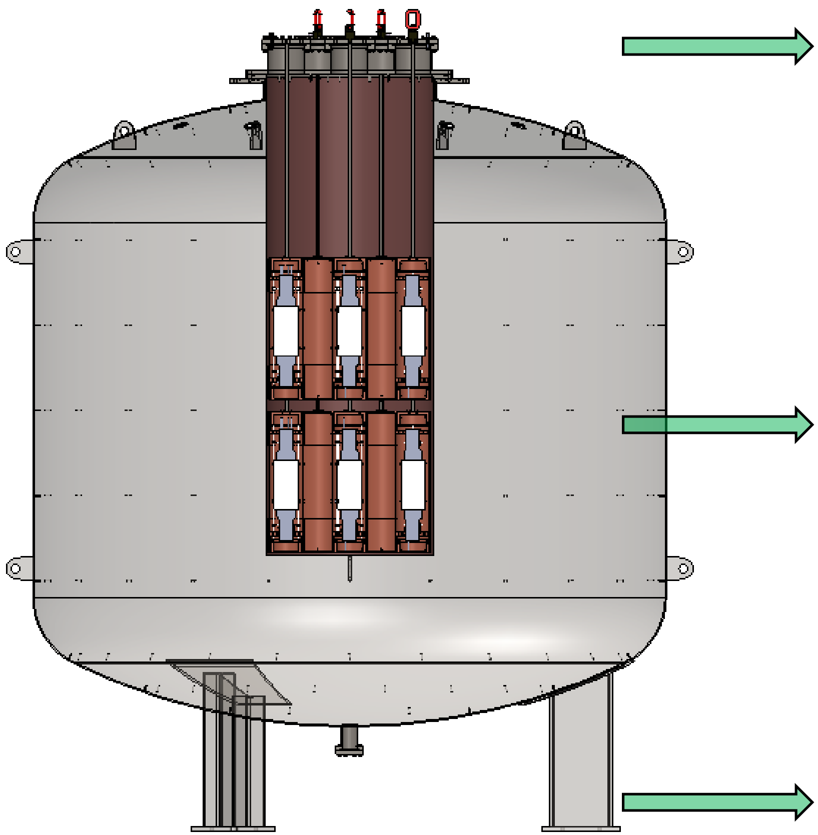
→ Once final design is available: **testing of steel samples** from **Nironit** and tender.





1. General design aspects

- **How does the vessel look like?**



Flanges – N1 nozzle

Vertical access

System tightness

Connection/support of enclosures

Glovebox, Cu tube and CF nozzles connection

Central vessel body:

Liquid containment

PMTs+reflector installation

CF nozzles; lugs

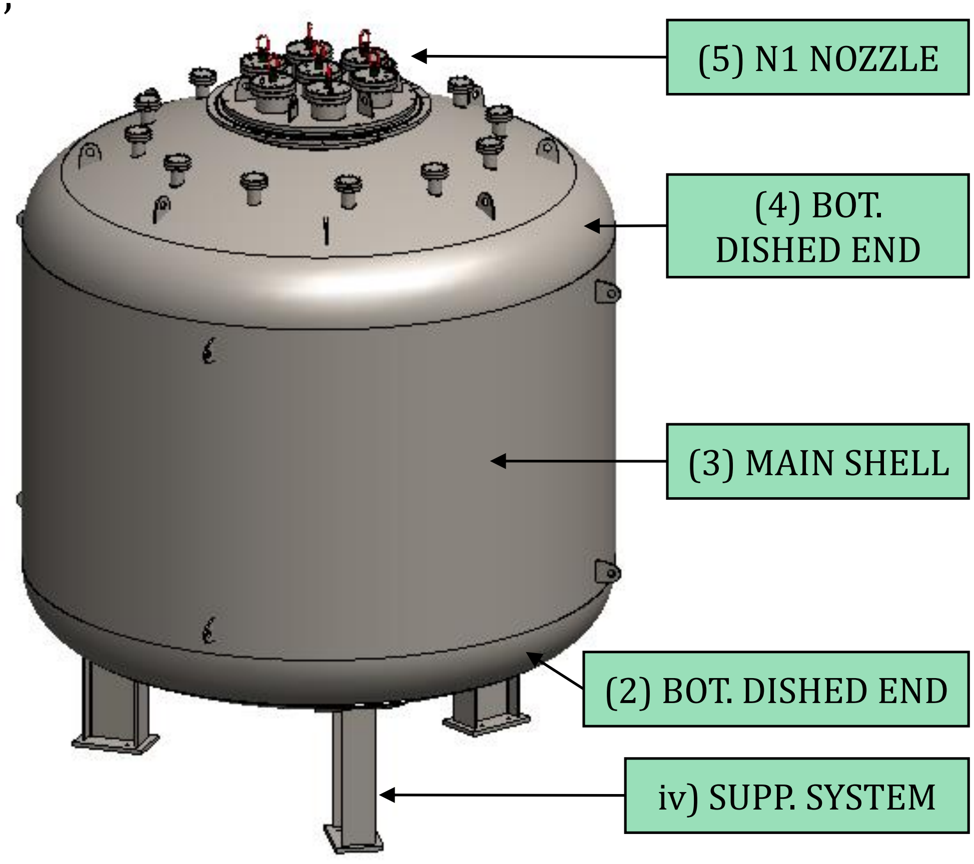
Columns:

Structural support

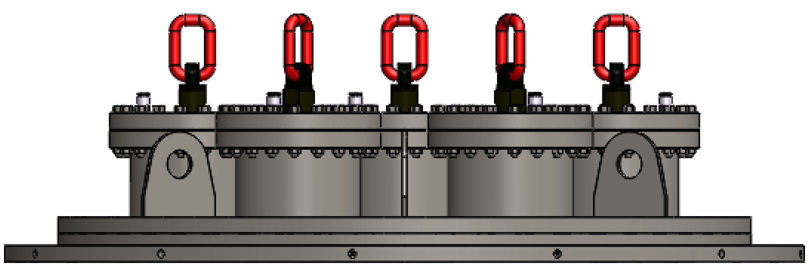
1. General design aspects

- **Main vessel parts:**

- Support system (I-shaped columns) (1);
- Bottom toroshperical dished end (2);
- Main cylindrical shell (3);
- Top torospherical dished end (4);
- N1 nozzle – 3-flanges system (5).



- **N1 nozzle detail:**



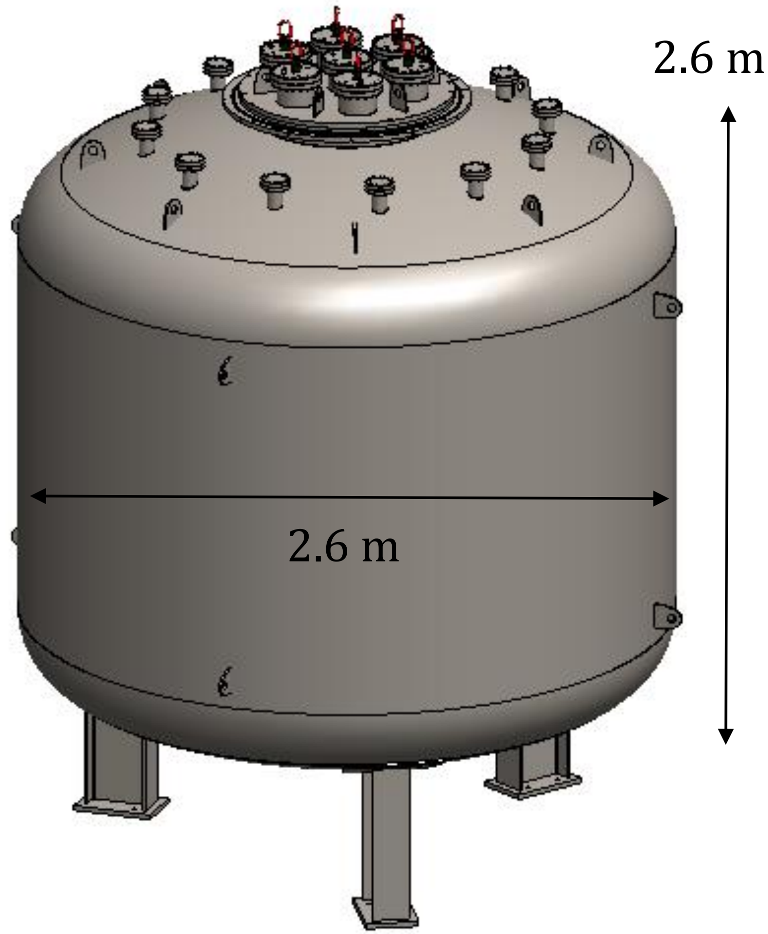
1. General design aspects

- **New design approach** for SABRE Australia vessel:

- Outer dimensions: ~ **2x p.o.p.** ones;
- **Double torospherical** dished **end**;
- Vessel **laying vertically** onto 3 columns;
- Top flange («N1» nozzle): similar to p.o.p. one,

7 CF nozzles in total;

- **PMTs immersed** in liquid scintillator;
- Vessel designed as per **AS1210.**



1. General design aspects

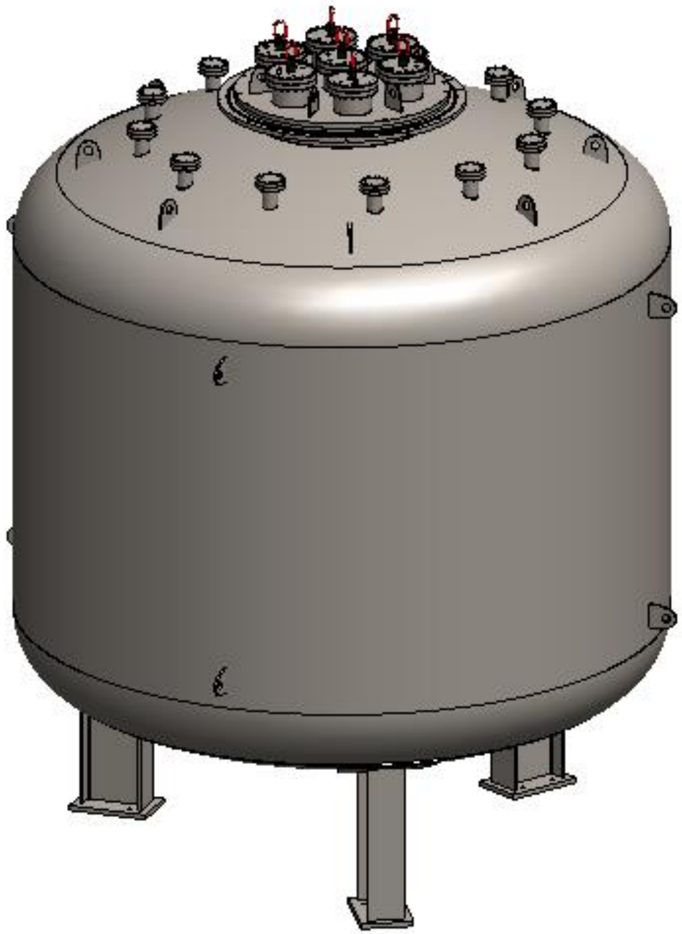
- Vessel designed to **improve mechanics** and fullfil physics constrains;
- Main advantages:

- **Axisymmetric layered detector** from inner detector to outer shielding;

- Possibility to **optimize space handling** - empty space between vessel/shielding minimized;

- **Flexibility** of the design **to both dry/wet** conditions;

- **Improved mechanical behaviour** of the tank.



2. Specific design aspects

- Design criteria: **main shell and torospherical ends thickness (6 mm)**

According to AS1210 the following criteria were taken into account:

1) Stress limitation: t = f(p,D);

2) Nominal thickness **of pressure parts;**

3) Transp./storage **of hazardous materials:**

«The recommended minimum thickness of any pressure parts in case of hazardous or lethal contents is twice as the above values»

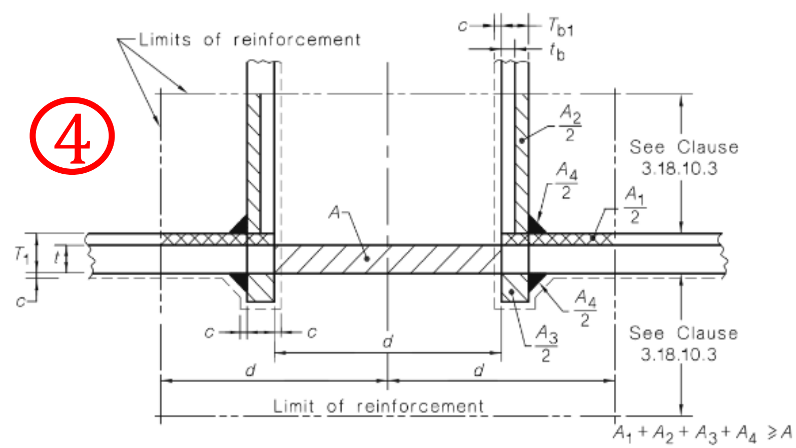
4) Reinforcement of vessel openings;

②

MINIMUM NOMINAL THICKNESS OF ANY PRESSURE PART

Vessels constructed of metal	Outside diameter of vessel part (D_o) mm	Minimum nominal thickness for type of manufacture (see Notes 1 and 2): Forged; metal and submerged-arc welded mm	Brazed; GTAW welded; GMAW welded and heat exchanger tubes mm	Cast mm
All except as noted below (see Note 3)	≤225	2.0	$0.10\sqrt{D_o}$	4
	>225 ≤1000	2.3	1.5	8
	>1000	2.4	2.4	10

④



Cylindrical shell ① Torospherical end

$$t = \frac{PD}{2f\eta - P} = \frac{PD_m}{2f\eta} = \frac{PD_o}{2f\eta + P}$$

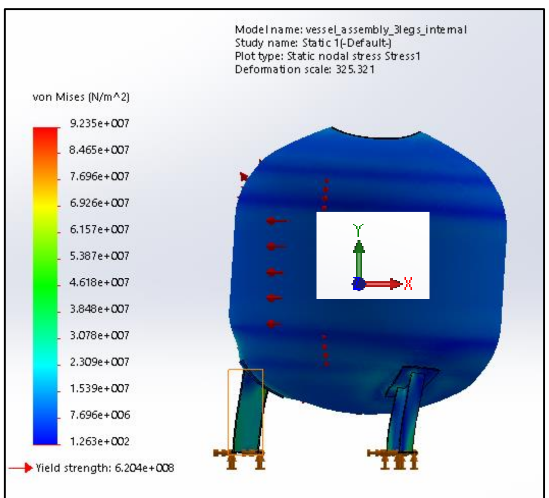
$$t = \frac{PRM}{2f\eta - 0.5P}$$

2. Specific design aspects

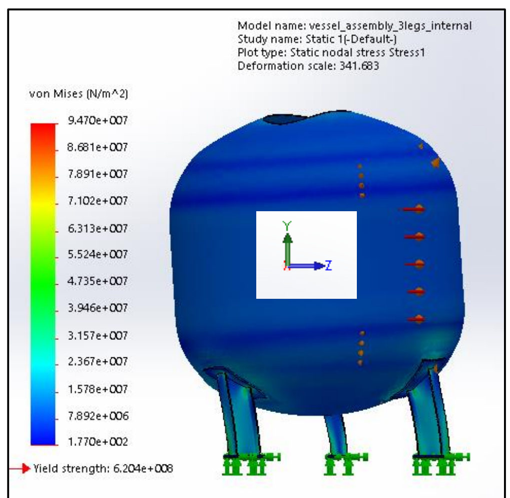
- Design criteria: **support columns (I-shape)**

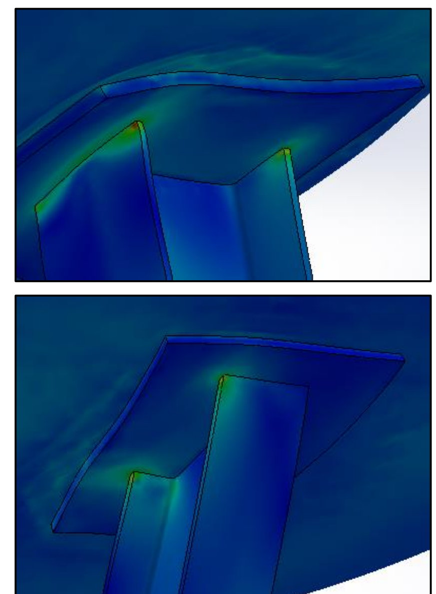
- Performed considering **i) analytical models ii) numerical simulations;**
- **3-legs system** was chosen for ease of top flange levelling (compared with 4-legs solution);
- **I-beam shape** was chosen for better mechanical behavior: vertical+horizontal loads; buckling;*
- Thickness of different parts calculated analitically and **verified numerically.**

Force along + x



Force along + z





Local behaviour

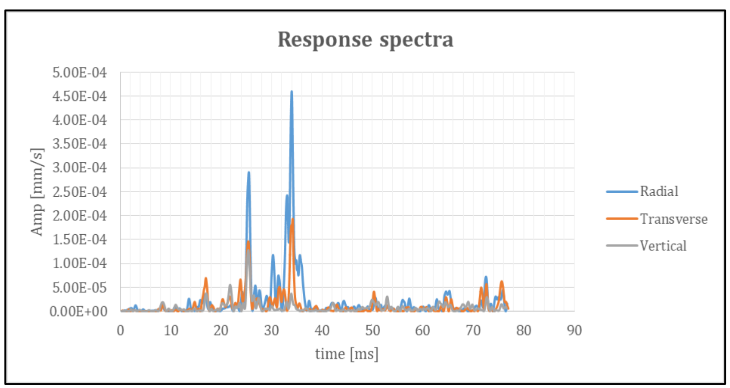
2. Specific design aspects

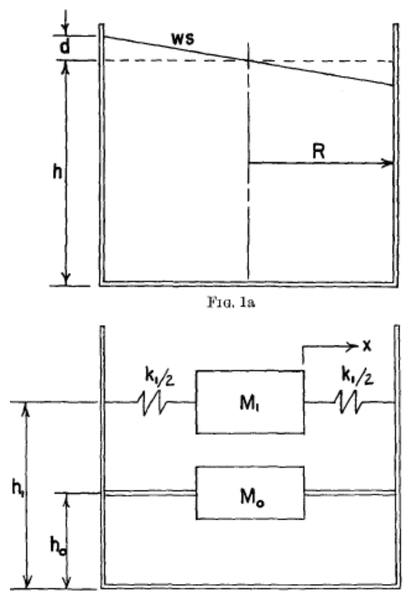
- Design criteria: **support columns (I-shape)**

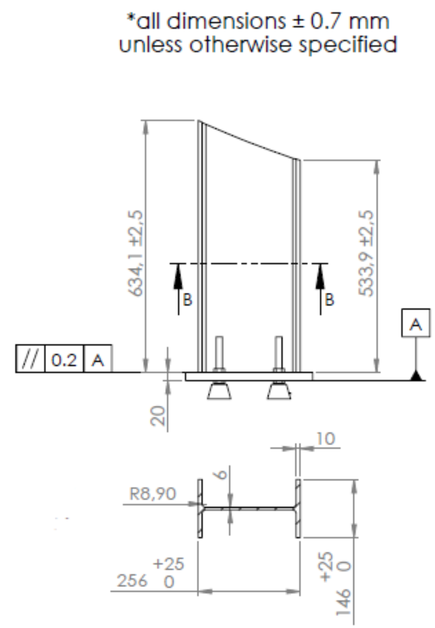
- Analysis of horizontal actions: study of typical **mine blast waveforms;**

- Acceleration peaks defined for i) longitudinal waves; ii) transverse waves; peaks combined by means of **SRSS directional combination - Final peak = 0.26 g;**

- Horizontal actions implemented by means of **equivalent inertia forces** in filled tank condition (~ 10 t of LAB) – analytical model by **G.W. Housner** - along +/- X and Z .







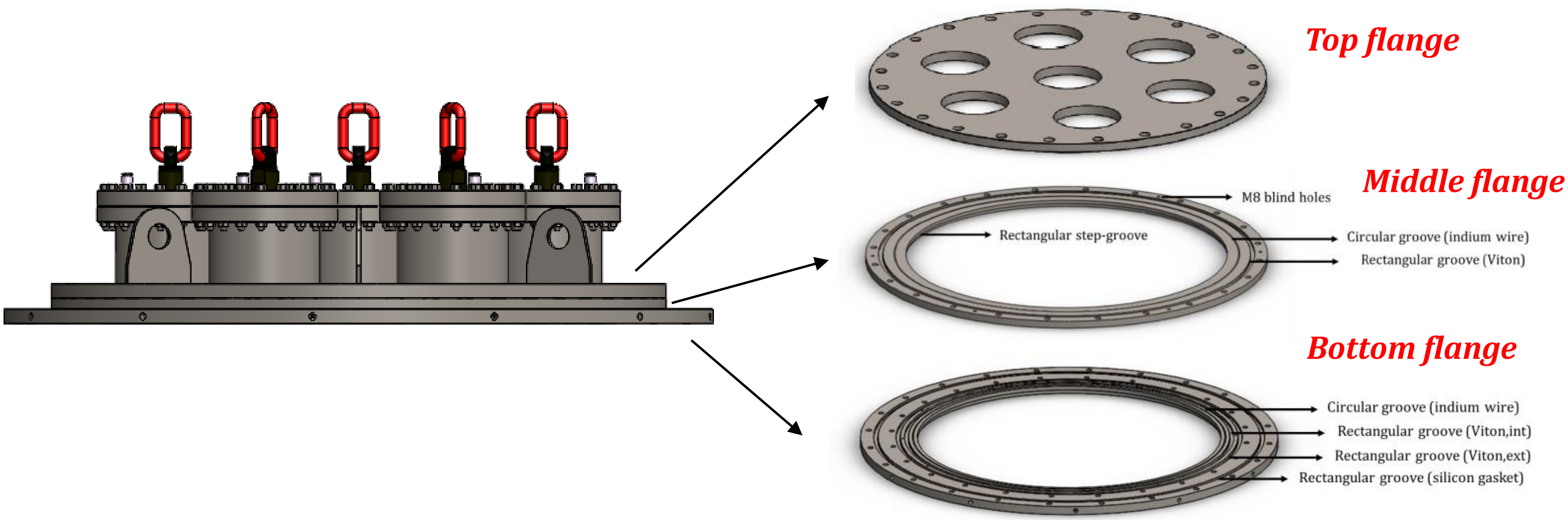
2. Specific design aspects

- Design criteria: **N1 nozzle – 3-flanges system: «bottom», «middle» and «top» flange**

- *Mechanical requirements:* mechanical **resistance and robustness** as per AS1210 and other applicable standards;

- *Physics requirements:* **helium-tight system** (leak rate < 10^{-6} ml bar/s);

- *Operational requirements:* compatibility with both **dry-wet conditions** – removable middle flange; ease of access; ease of connection with glovebox.



2. Specific design aspects

- Design criteria: **«bottom» flange**

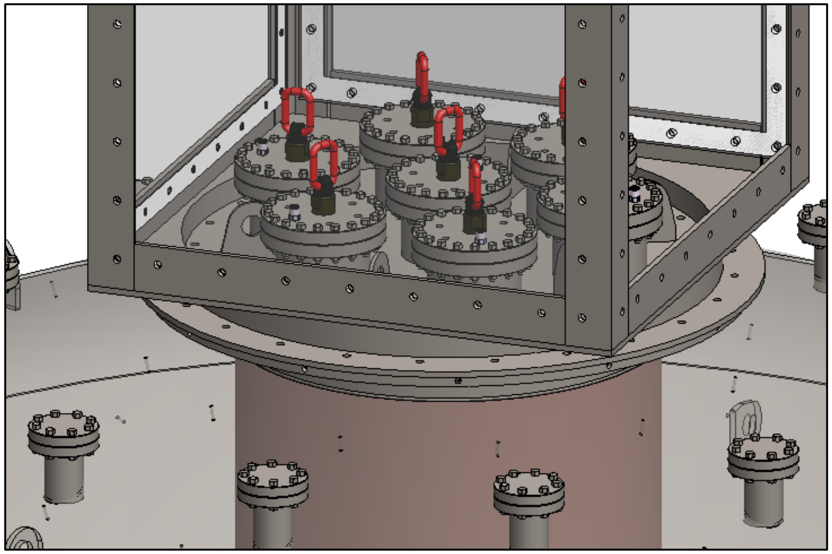
- **Inner part:** rectangular grooves – **double Viton gasket + N2 purge line; back-up** semi-circular groove for **indium**

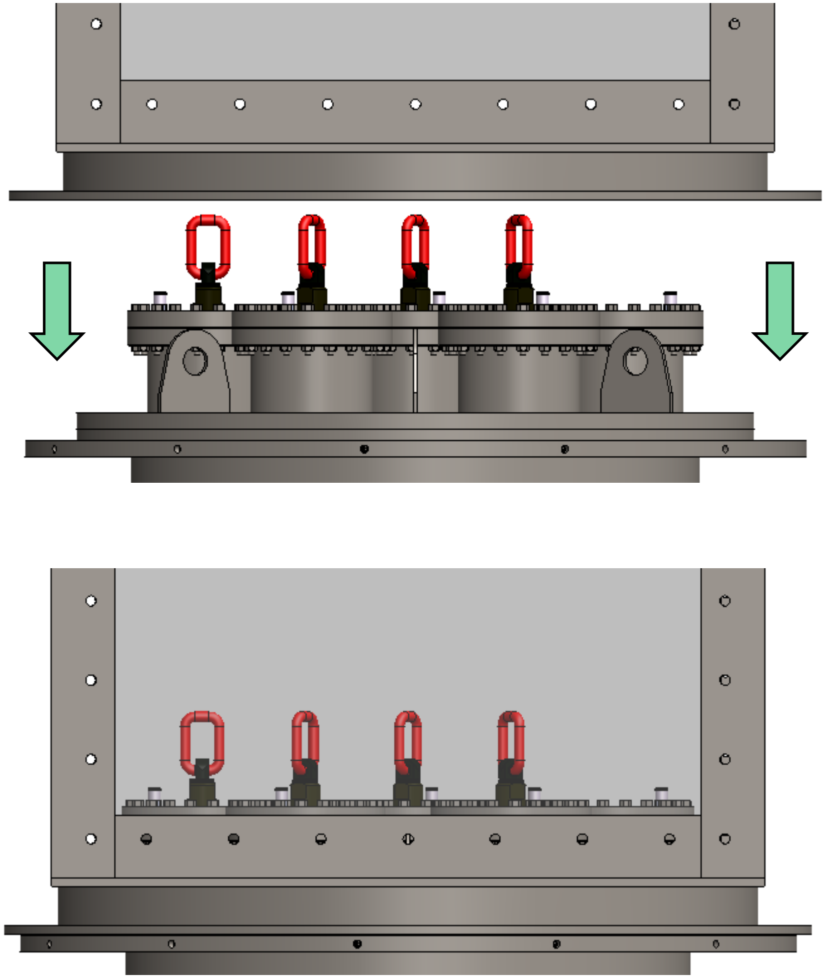
- **Outer part:** rectangular groove – **Silicon gasket for glove-box** mounting

2. Specific design aspects

- Design criteria: **«bottom» flange**

- **Connection with the glove box**

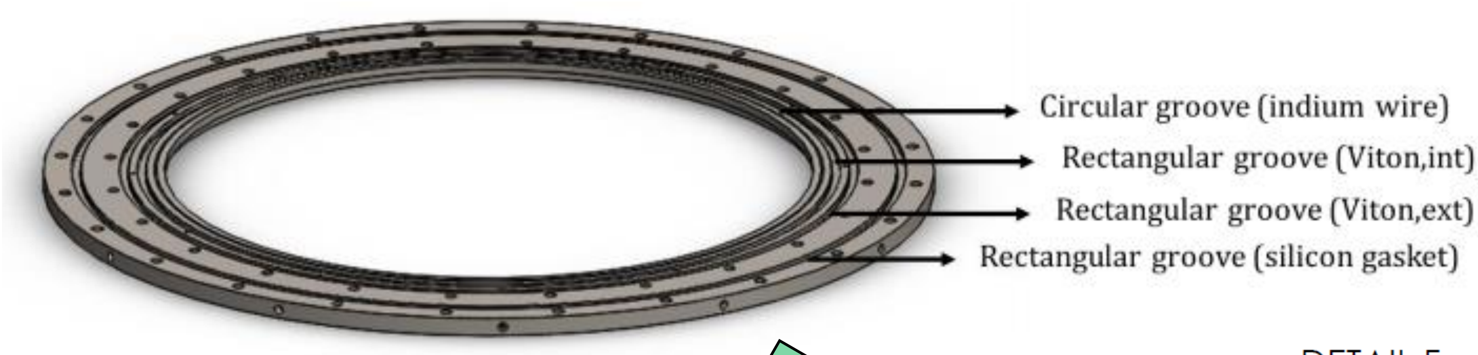


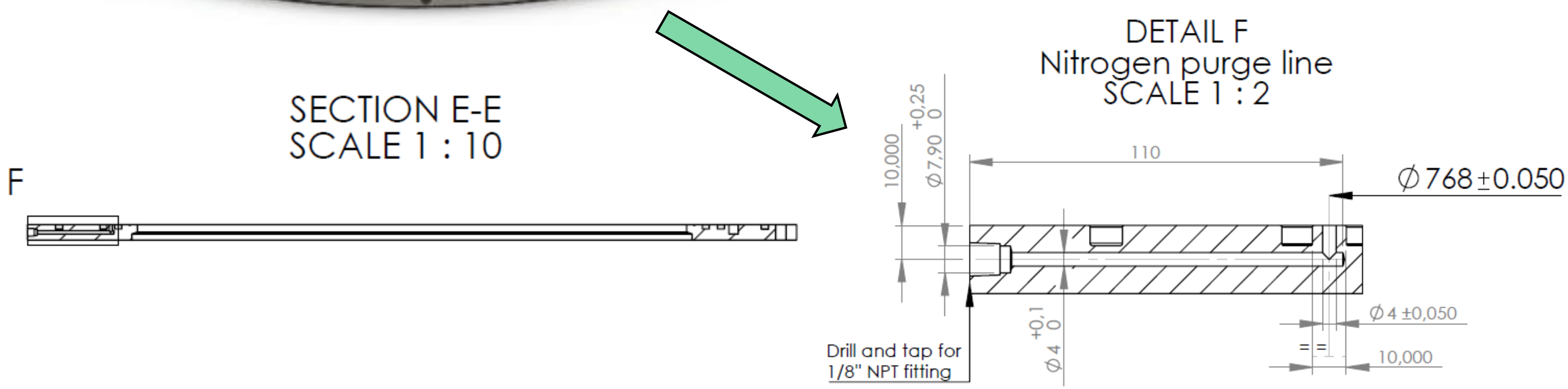


2. Specific design aspects

- Design criteria: **«bottom» flange**

- **N2 line** to purge the space in between the two Viton grooves

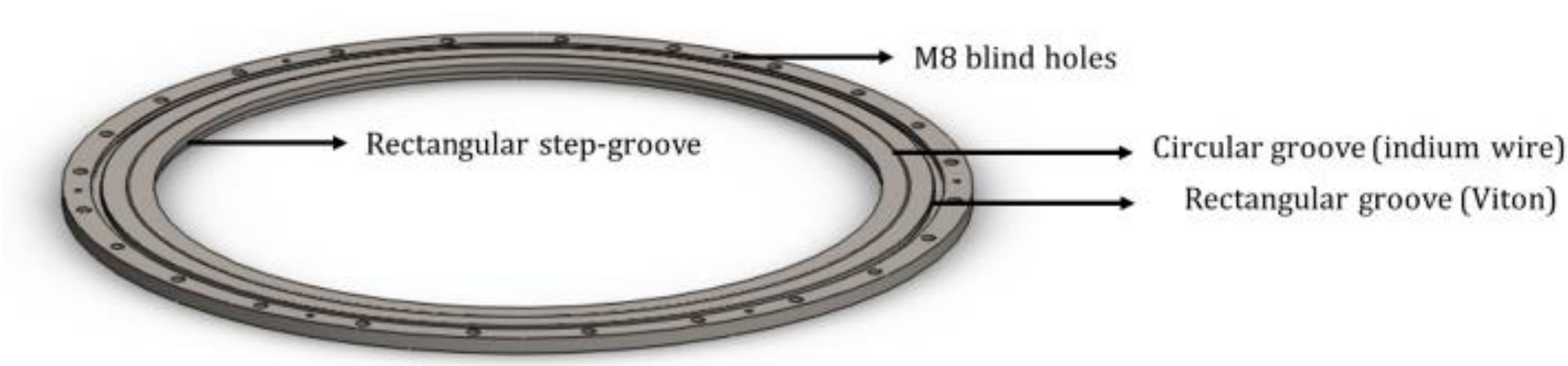




2. Specific design aspects

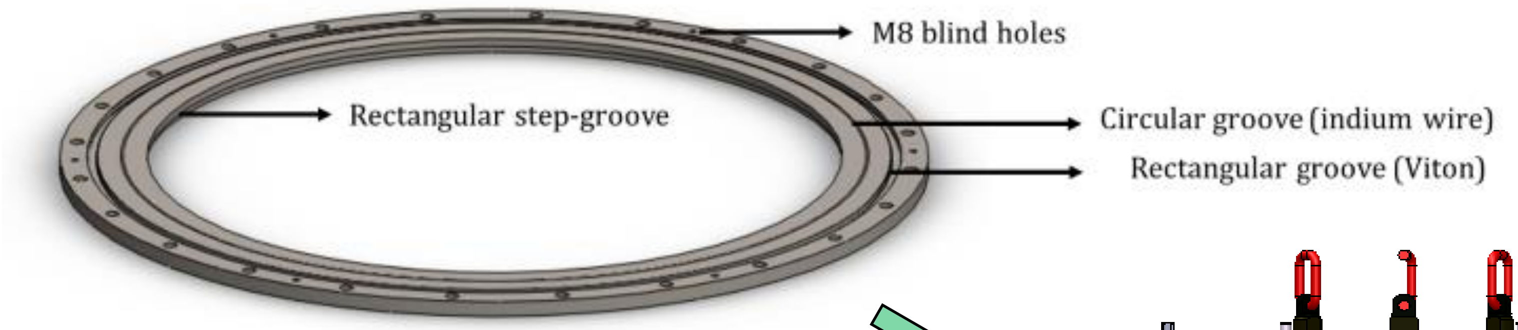
- Design criteria: **«middle» flange**

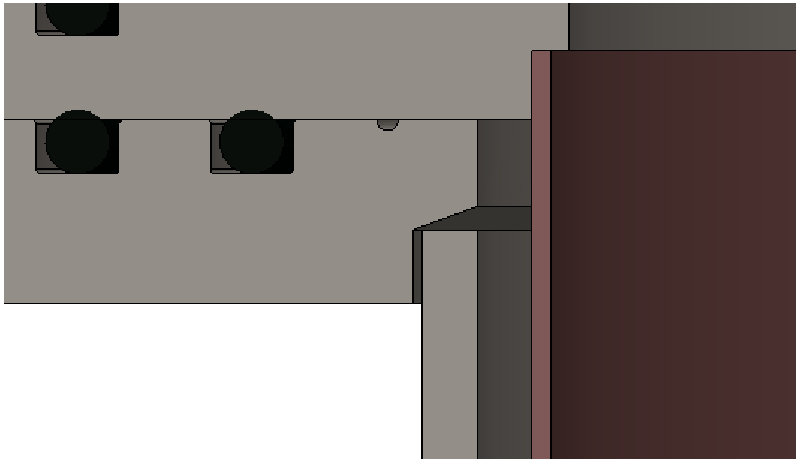
- Rectangular grooves for **Viton gasket;**
- **Step-groove** for Cu tube brazing;
- **Blind holes** for lifting the system;

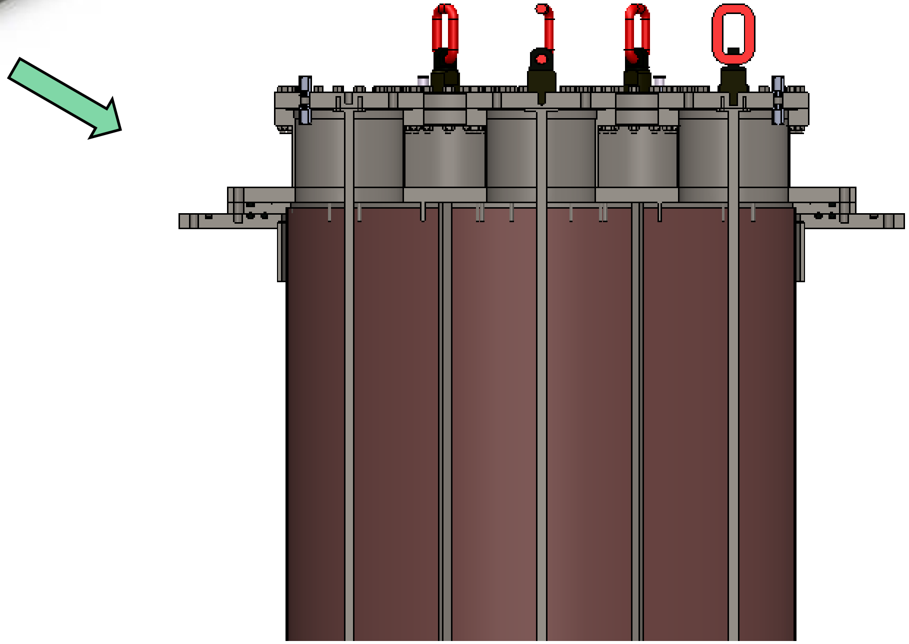


2. Specific design aspects

- Design criteria: **«middle» flange**

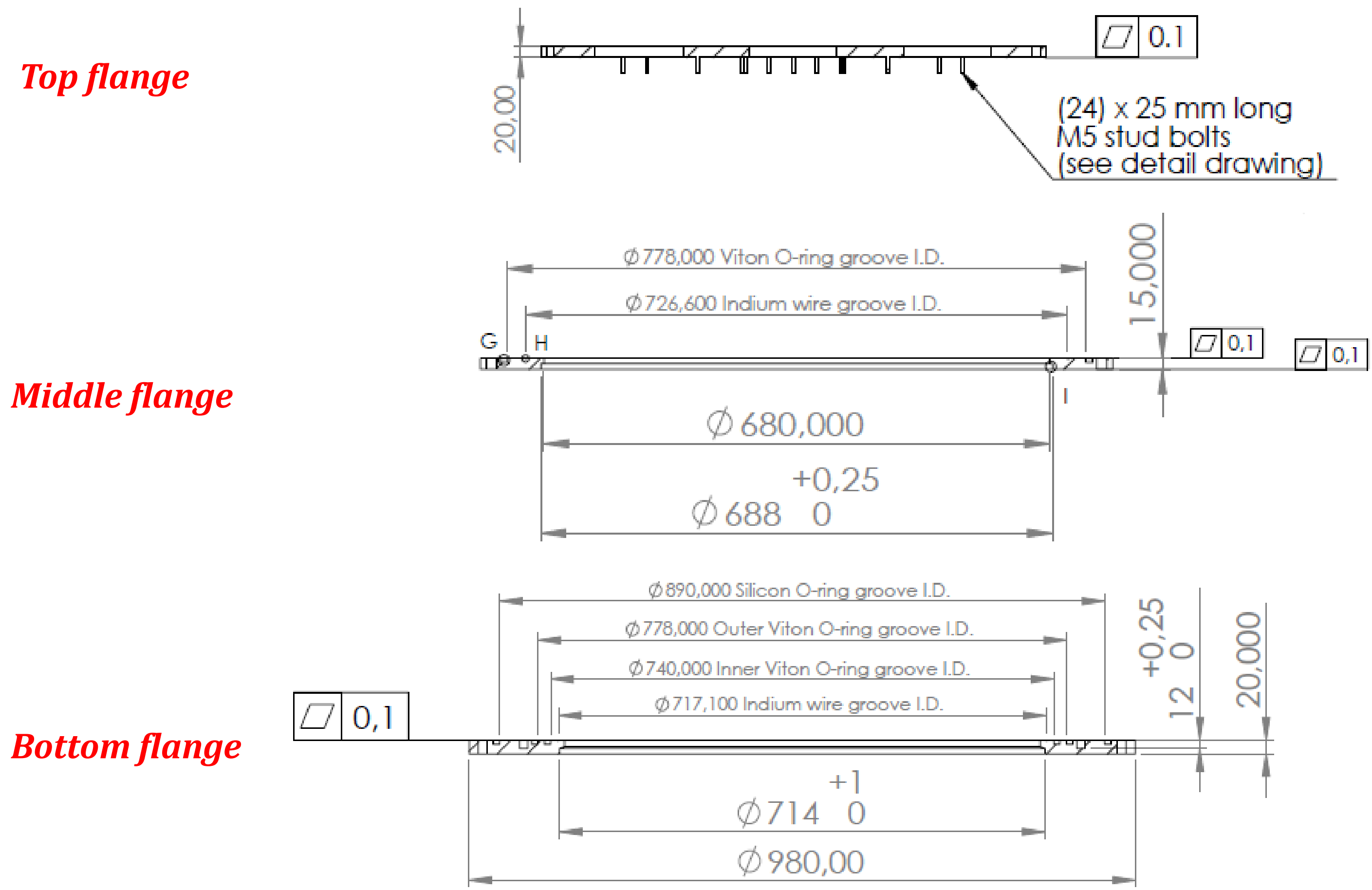






2. Specific design aspects

- Design criteria: **N1 nozzle – 3-flanges system**



2. Specific design aspects

- Mechanical verifications – stress limits and flange stifness (AS1210):

Parameter	Description	Value	Unit
A	Outer flange diameter	1050	[mm]
B	Inner flange diameter	700	[mm]
C	Bolt diameter	820	[mm]
G	Gasket diameter	739	[mm]
hg	Distance BC and gasket	40.5	[mm]
g1	Thickness of flange at hub end	6	[mm]
hT	Moment arm for HT	47.3125	[mm]
hD	Moment arm for HD	57	[mm]
hG	Moment arm for HG	15.5	[mm]
Pd,tot	Total design pressure	0.060	[mPa]
H	Total hydrostatic pressure force	25722.3	[N]
HT	Difference	2643.3	[N]
HD	Hydrostatic end force inside flange	23079.0	[N]
W	Flange design bolt-force	29094.0	[N]
HG	Gasket force	3371.7	[N]
MT	Moment associated to HT	125061.1	[Nmm]
MD	Moment associated to HD	1315503.0	[Nmm]
MG	Moment associated to HG	144140.2	[Nmm]
M0	Total design moment	1584704.2	[Nmm]

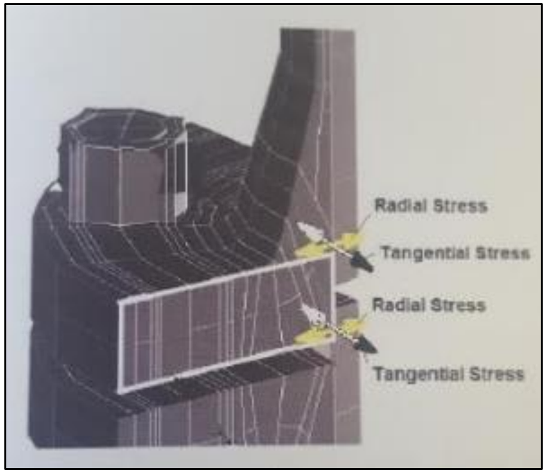
Flange stress calculations			
Mtl	Flange material	SS 304L	[-]
SH	Longitudinal hub stress	57.45	[N/mm2]
SR	Radial flange stress	7.10	[N/mm2]
ST	Tangential flange stress	9.62	[N/mm2]
SF	Design strength at design temp	136	[N/mm2]
SN	Design strength - nozzle neck	136	[N/mm2]

Flange stress factors and parameters			
K	Outside/inside diam ratio	1.500	[-]
T	Factor=f(K)	1.711	[-]
h0	Factor=sqrt(B*g0)	64.8	[-]
g0	Thickess of hub at small end	6	[mm]
h	Hub length	20	[mm]
h/h0	Ratio	0.31	[-]
g1/g0	Ratio	1.00	[-]
F	Factor=f(h,h0,g1,g0)	0.90892	[-]
e	Factor=F/h0, integral flanges	0.014	[-]
V	Factor=f(h,h0,g1,g0)	0.550103	[-]
U	Factor=f(K)	5.452	[-]
d	Factor=f(U,V,h0,g0)	23121.20816	[-]
t	Flange thickness	20	[mm]
L	Factor=f(t,e,T,d)	1.095	[-]
f	Hub stress correction factor	1	[-]
Y	Factor=f(K)	4.961	[-]
Z	Factor=f(K)	2.600	[-]

Stress verifications					
Number	Condition	Limit	Value	Logic	% on limit
1	SH < 1.5 SF	204	57.5	OK	28.2
2	SH < 2.5 SN	340	57.5	OK	16.9
3	SR < SF	136	7.1	OK	5.2
4	ST < SF	136	9.6	OK	7.1
5	(SH+SR)/2 < SF	136	32.3	OK	23.7
6	(SH + ST)/2 < SF	136	33.5	OK	24.7
Flange rigidity verification - for DN > 600 mm					
Number	Condition	Limit	Value	Logic	
7	174 M0*V/(L*E*g0^2*h0) < 1	1	0.288	OK	28.8

Long. hub stress

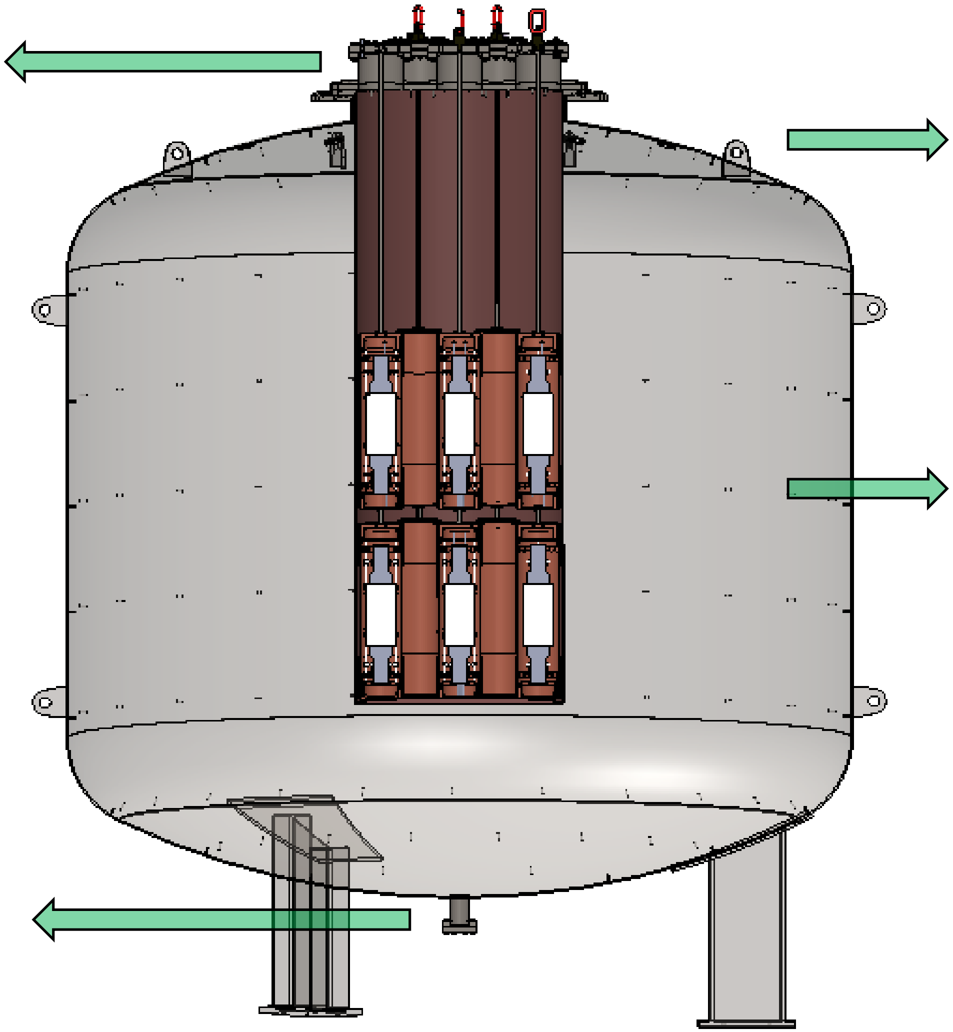
Tangential/radial stress



3. Additional features

N°(7) CF150 nozzles to be welded onto the top flange for crystals+enclosures insertion;

N°(13) CF63 nozzles for: HV, readout, N2 fluxing, possible calibration sources, tank filling; drainage



N°(22) lifting lugs distributed uniformely on: outer shell, top TDE, top flange;

~ **N°(200) M5 stud bolts** for reflector foil + PMTs installation.

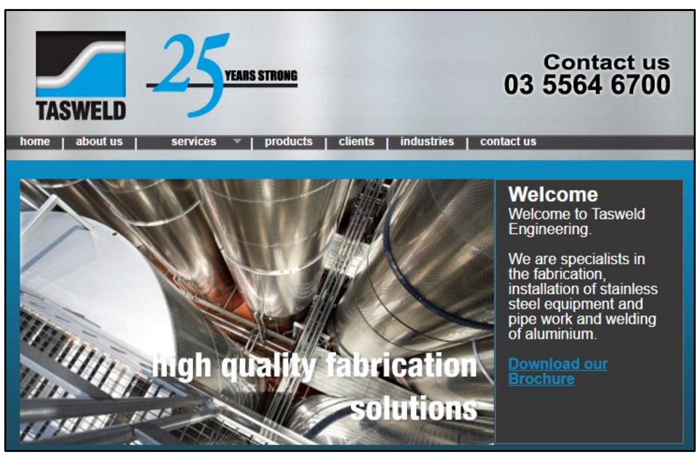
4. Documentation

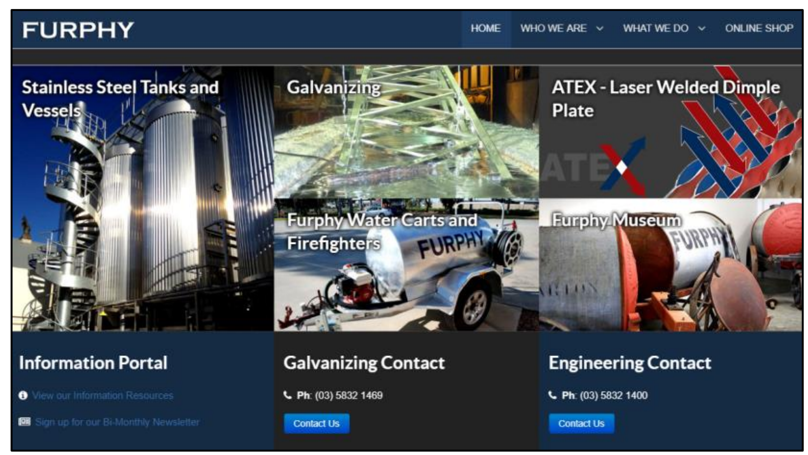
- Manufacturing specs document has been forwarded to two Australian manufacturers: ***Tasweld Engineering*** and ***Furphy Engineering***, inclusive of:

1) General and detailed description; 2) responsibilities (engineering, manufacturing, spare and shipment, quality and tests, design/construction codes, documentation); 3) technical and design specs; 4) procedure requirements; 5) mechanical tolerances.

- Latest version almost identical to the one circulated in late August – only few minor corrections. **It will be circulated soon;**

- All additional technical features/details can be found on these documents.





THANK YOU

Back-up slides- Additional features

- The following additional components are part of the manufacturing request:

- **N°(12) CF63 nozzles** to be welded on the top TDE for: HV, readout, N2 fluxing, possible calibration sources, tank filling;

- **N°(7) CF150 nozzles** to be welded onto the top flange for crystals+enclosures insertion;

- **N°(22) lifting lugs** distributed uniformely on: outer shell, top TDE, top flange;

- **~ N°(200) M5 stud bolts** for reflector foil + PMTs installation.

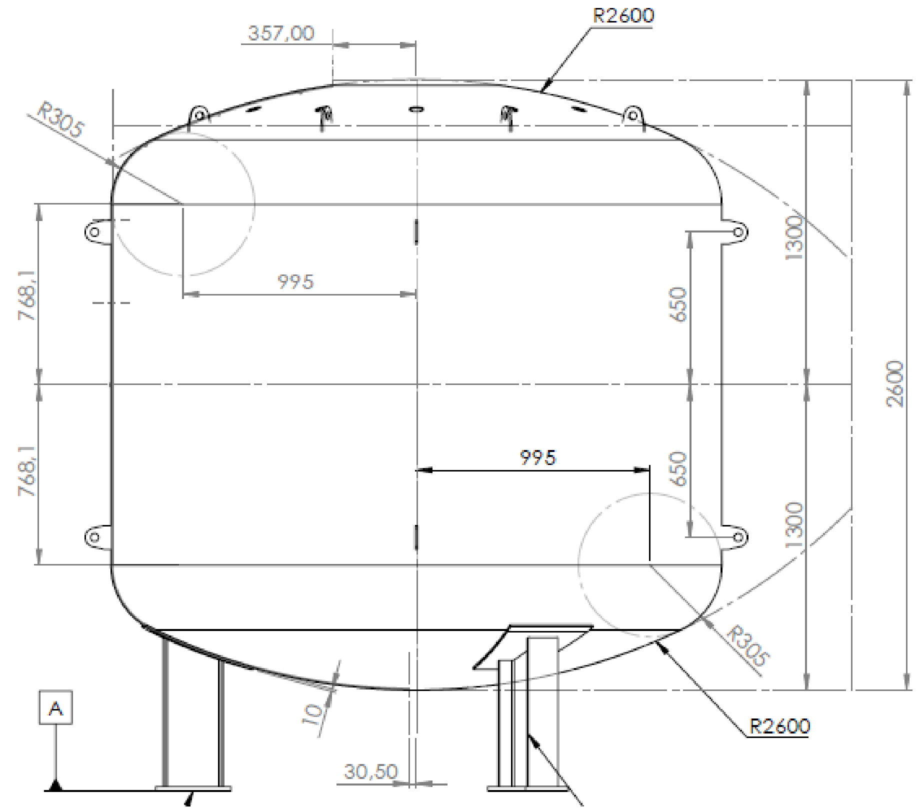
- All the lifting lugs shall verified accounting of *all possible failure modes,*

- Load test + 100% NDT shall be performed on the lifting lugs.

Back-up slide: General design aspects

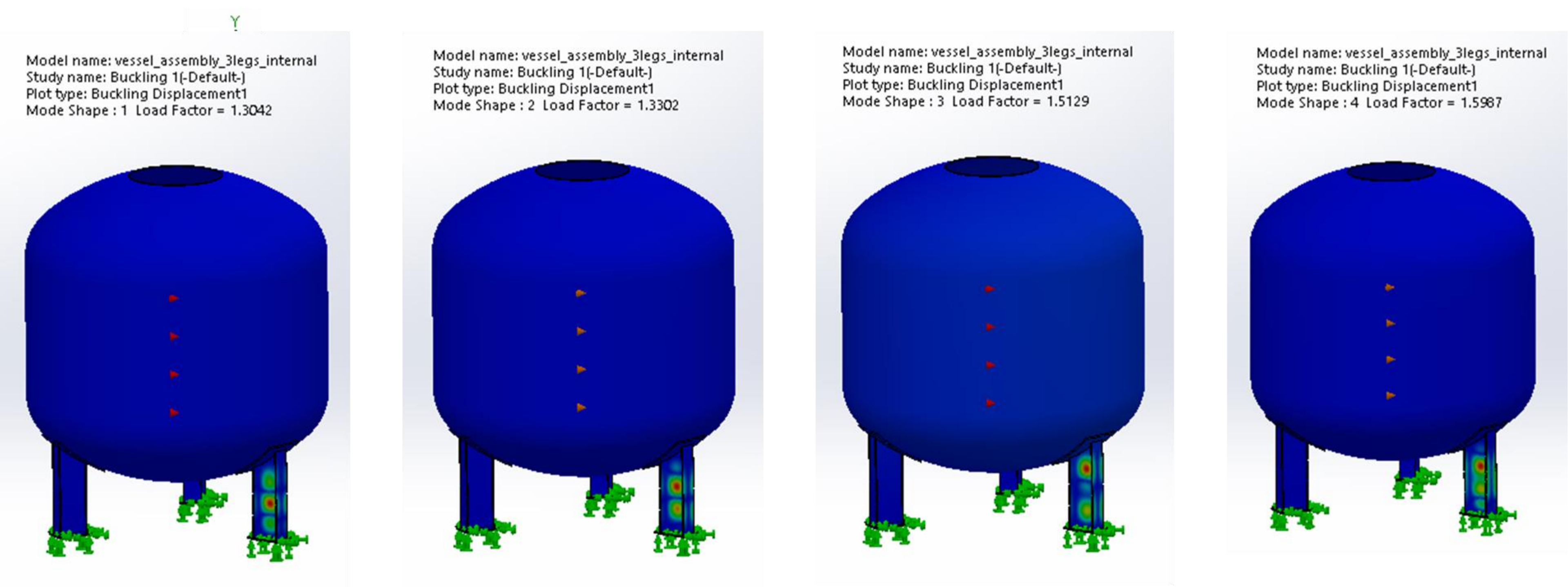
- **New design approach** for SABRE Australia vessel:

- Outer dimensions: ~ **2x p.o.p.** ones;
- **Double torospherical** dished **end**;
- Vessel **laying vertically** onto 3 columns;
- Top flange («N1» nozzle): similar to p.o.p. one, 7 CF nozzles in total;
- **PMTs immersed** in liquid scintillator;
- Vessel designed as per **AS1210.**



Back-up slide: Buckling analyses

- Performed with vertical load only (pv=1 Mpa) and vertical+horizontal (pv=1 Mpa, ph=0.2 Mpa) ~ 20 x design pressure;
- No buckling; all buckling modes have load factors > 1 and are local on column webs;



Back-up slide: Load tests for lugs

The following design principles shall also be followed in the design/manufacturing/welding of the lifting lugs:

- Lifting lugs shall be uniformly distributed: on the VV cylindrical shell; on the VV torospherical top end; on the top (blind) flange of the N1N.

- Load testing of the lifting lugs shall be performed in accordance with specifications from sec. 2 of this document.

Lifting lugs are to be designed with a minimum load factor relative to the SLW:

$$L_{f,min} = 2$$

Load testing shall be carried out according to the following test load:

$$T_{load,min} = 1.25\ SLW$$

Back-up slide: BF specs – from documentation

a) *Internal groove*

This semi-circular groove shall be cut using a ball-end mill for a back-up indium wire (in case of unexpected leaks on the Viton seal). The suggested diameter for the indium wire is 2.4 mm. The suggested groove geometry is as follows:

- Groove diameter = indium wire diameter;
- Groove depth = indium wire radius.

It shall be FE's responsibility to ensure that the groove design, including wire diameter, is compatible with:

1) The required tightness of the seal;
2) The indium wire spread under the flange compression*.

**The compressed indium wire shall never spread over the internal edge of the flange (manhole, internal side), neither over the edge of the Viton groove (external side).*

b) *Middle grooves – Viton O-rings*

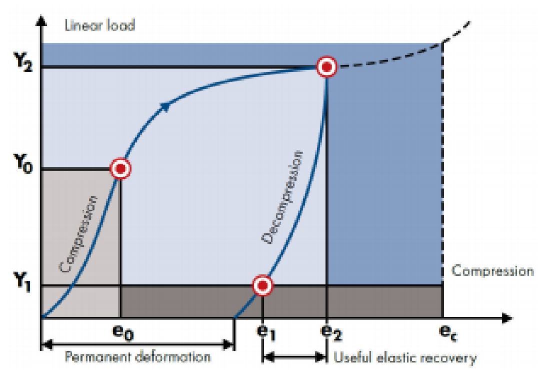
These grooves shall be cut for two concentric Viton O-rings, having a nitrogen purge line in between. UoM suggests a cross section diameter of 7.00 mm for the two gaskets.

FE shall discuss directly with the Viton O-rings producer in order to procure the best quality seals for this application and to ensure that the final design of the flange/groove is compatible with the target sealing level and the optimal functionality of the O-rings.

Back-up slide: Helicoflex solution

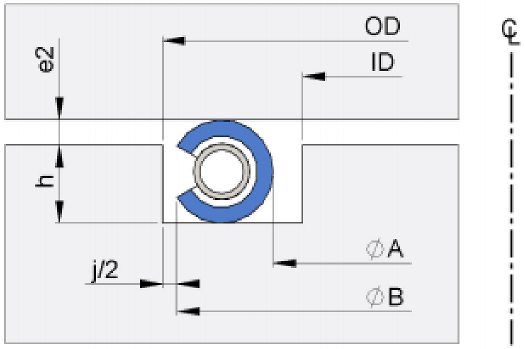
Seal Data

Seal style	HN200
Cross section [mm]	4.00
Average seal diameter (DJ) [mm]	747.50
Seal ID (A) [mm]	743.50
Seal OD (B) [mm]	751.50
Sealing material	SS304L
Coating	None
Inner material	SS304L
Spring material	Nimonic 90
Leak tightness	Helium
Compression load (Y2) [N/mm]	590 $^{\pm 10\%}$



Groove Data

Groove ID [mm]	741.80 ^{max}
Groove OD [mm]	752.00 $^{+0/+0.20}$
Groove depth (h) [mm]	3.40 $^{+/-0.050}$
Compression value (e2) [mm]	0.60
Diametrical clearance (j) [mm]	0.50
Roughness obtained as per Technetics' specification	Ra0.8 - Ra1.6
Minimum hardness [HV]	
Minimum seating load (Fj) [N]	1524073.0



Back-up slide: Helicoflex solution

Loads calculation

Minimum seating load (Fj)	Fj = π.DJ.Y2max	1524073 N	1524073 N
Hydrostatic end thrust	Ff = π.DJ².P / 4	20187 N	24136 N
Min. working load	Fm = π.DJ.Ym	375734 N	375734 N
Min. load @20°C	Fs = Ff + Fm	395921 N	399871 N
Min. load @ working temp.	Fs* = Fs x E / ET	395921 N	399871 N
Min. load to apply on the seal	**Fb1 = k.max{Fs*,Fj}**	**1524073 N**	**1524073 N**

Fb1 is the minimum load to be applied on the assembly in order to reach the target leak rate.

Min. load for metal-to-metal contact	**Fb2**	**1544260 N**	**1548210 N**

Fb2 = k.max{Fs*,Fj} with Fs=Ff+Fj => Fb2 = k.(Ff+Fj).E/ET
The tightening load Fb2 ensure the metal-to-metal contact (flange to flange) in operating condition. If allowed by the assembly, this is the recommended tightening load.

The load above is not the only parameter to take into account to design the assembly.
For instance, the calculations do not take into account any other external load (e.g. Moment on the assembly).
--- In doubt, feel free to reach our engineering department. ---

Stresses and torques

		Operating (Fb1)	Operating (Fb2)	Proof test (Fb1)
Tensile stress	σ0 = Fb/(nb.Sr)	138 [MPa] !	140 [MPa] ✗	138 [MPa] !
Min. torque value [μ=0.15]	C0 = (Fb/nb)[0.16p+μ(0.583d2+Dm/2)]	338.5 [N.m]	343.0 [N.m]	338.5 [N.m]
Min. torque value [μ=0.20]	C0 = (Fb/nb)[0.16p+μ(0.583d2+Dm/2)]	441.2 [N.m]	447.1 [N.m]	441.2 [N.m]
Min. torque value [μ=0.25]	C0 = (Fb/nb)[0.16p+μ(0.583d2+Dm/2)]	544.0 [N.m]	551.2 [N.m]	544.0 [N.m]

The friction coefficient depends on the bolting, the lubrication and if there is washers. This is a critical parameter and must be double-checked. Also, the friction depends on the diameter of the bolts.
For information, 0.15 = bolts in really good condition, lubricated, with washers ; 0.20 = bolts in good condition with washers 0.25 = bolts in fairly good condition with washers ; 0.3 = bolts with an elevated friction coefficient.

Assembly according to Technetics Group specification FT921-15 or FT921-45 for vacuum application.

Your specific application should not be processed without being studied and estimated. While the utmost care has been used in compiling this software, we assume no responsibility for errors. Specifications subject to change without notice.
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