ATLAS Patch panel 01 (PP1)
Engineering aspects and cooling system

INFN-LNF

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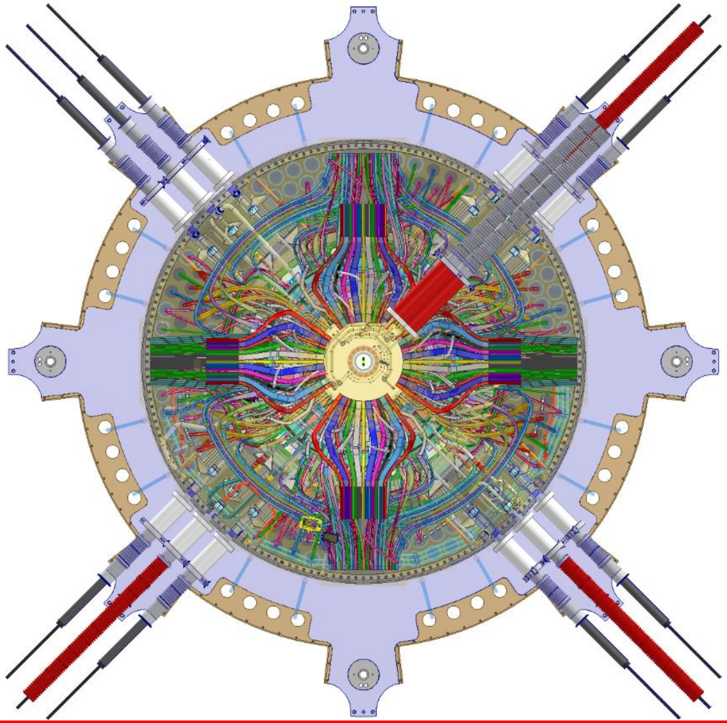
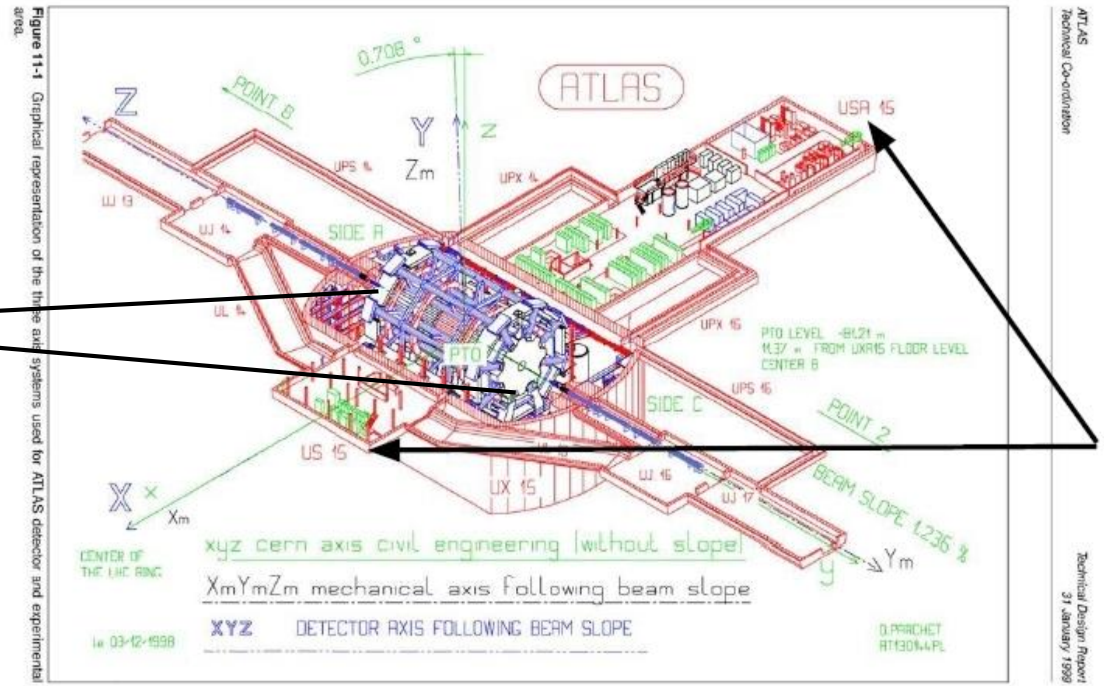
PP1 GLOBAL STRUCTURE

PP1



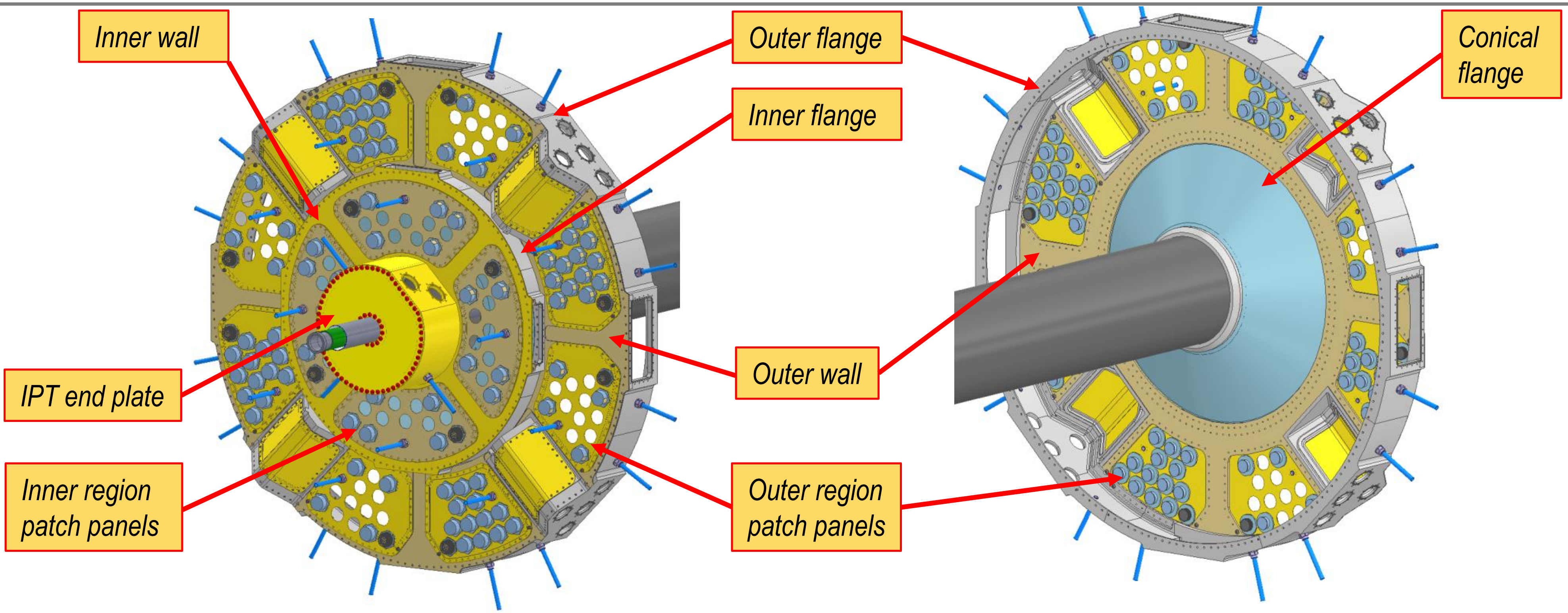


PLANTS

The PP1 panel performs several functions in ATLAS ITK detector, the main ones are:

- Environmental gas sealing and Faraday cage closure of the detector volume.
- Support and housing of the detector services (i.e. High/Low voltage cables and connectors, 14k Data cables, 14 cooling pipe lines)
- Guarantee an internal dew point temperature lower than -60°C.
- Guarantee a maximum internal nitrogen overpressure of 4 mbar.
- Connection between the main plants in the pit and the subdetectors (Endcap, Outer barrel, Inner system).

PP1 GLOBAL STRUCTURE

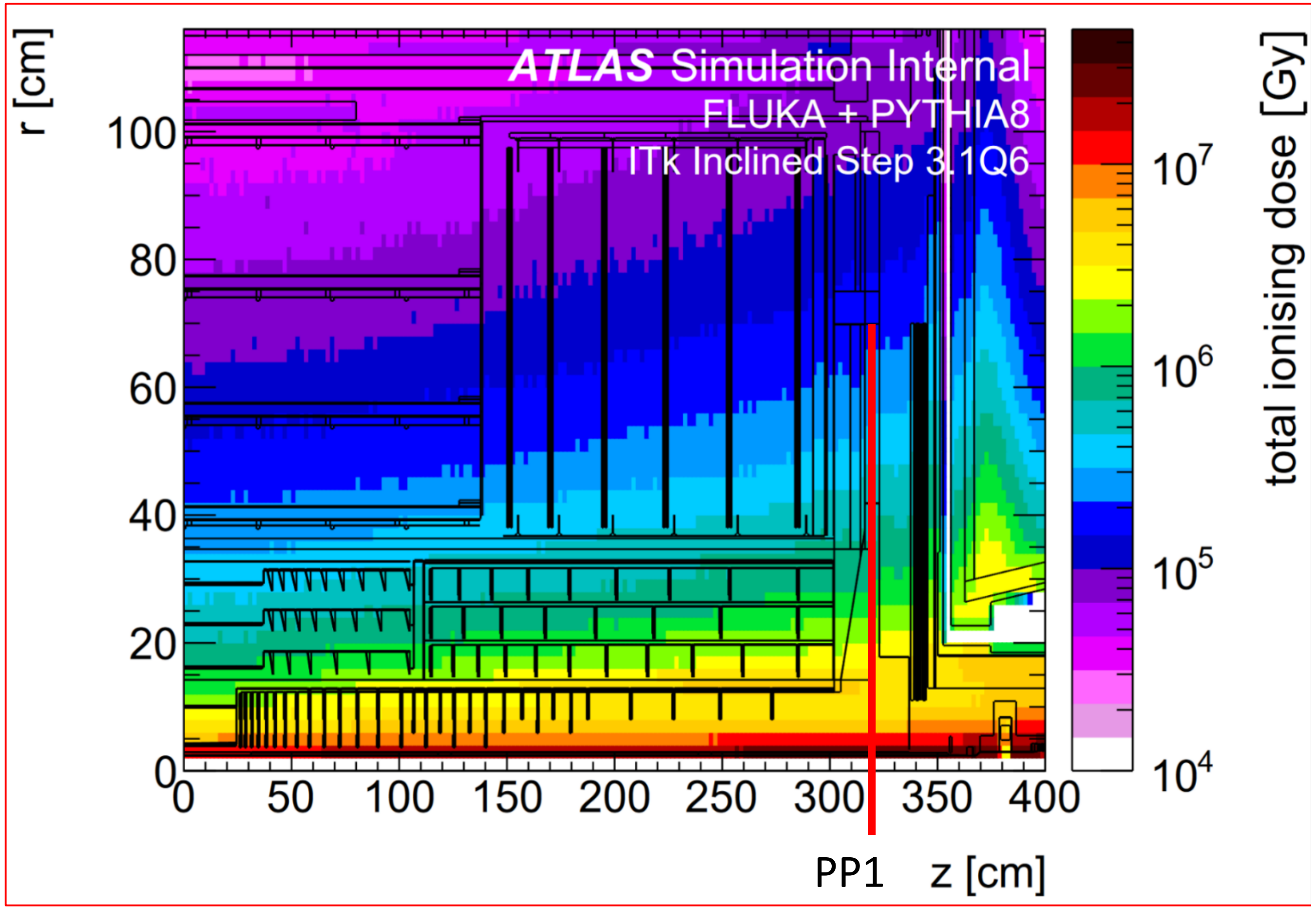


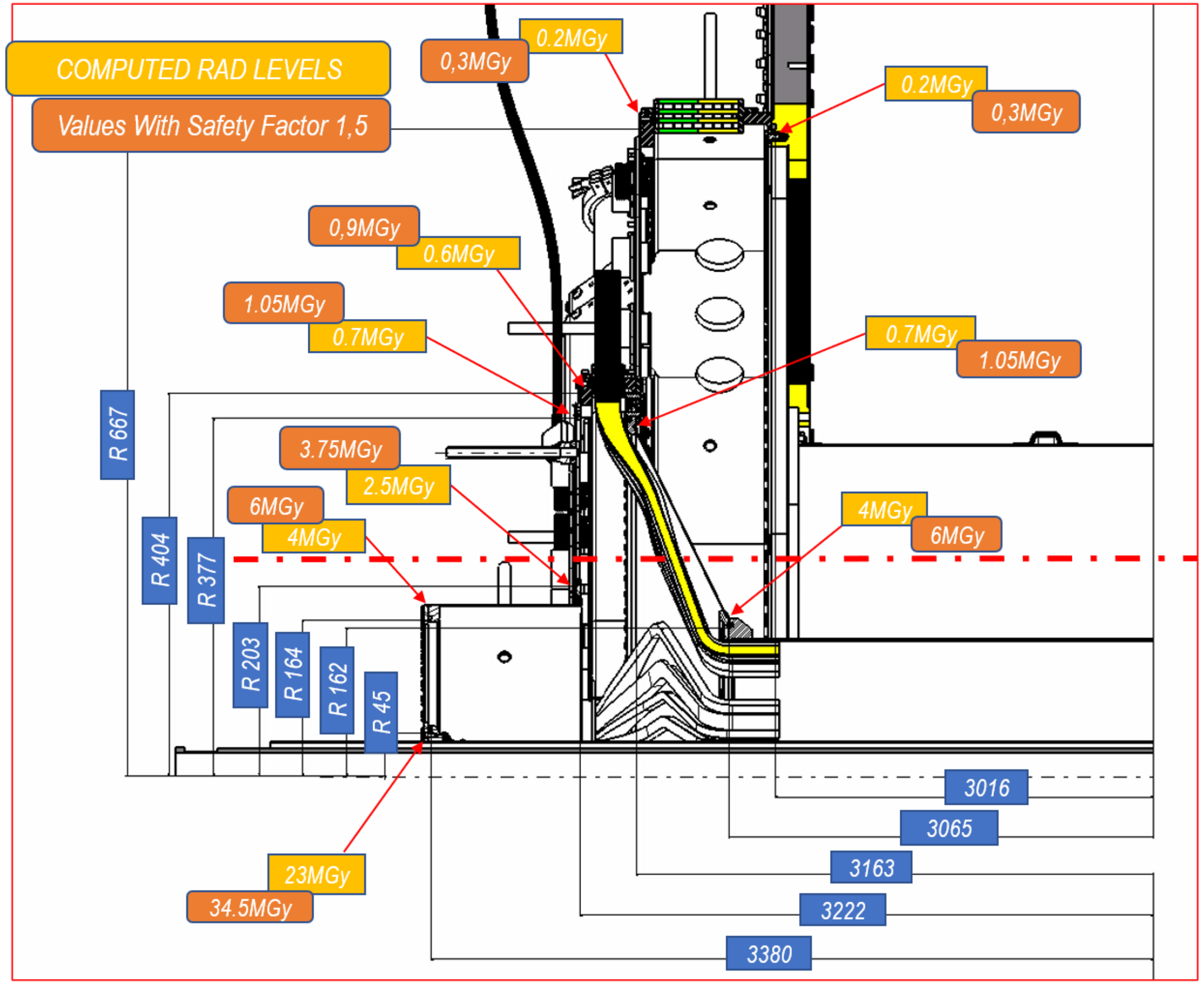
Since the PP1 volume is in a high radiation environment, to reduce the mass budget, we decided to design the parts in Aluminium alloys (EN AW 6082-EN AW5083) made by milling technology.

- The thickness is increased only where there are threaded holes for bolted connections and gasket housings.
- The main parts are reported in the images above.
- The design allows the services integration sequence and test in the different assembly stages.

GAS SEALING-RADIATION LEVEL

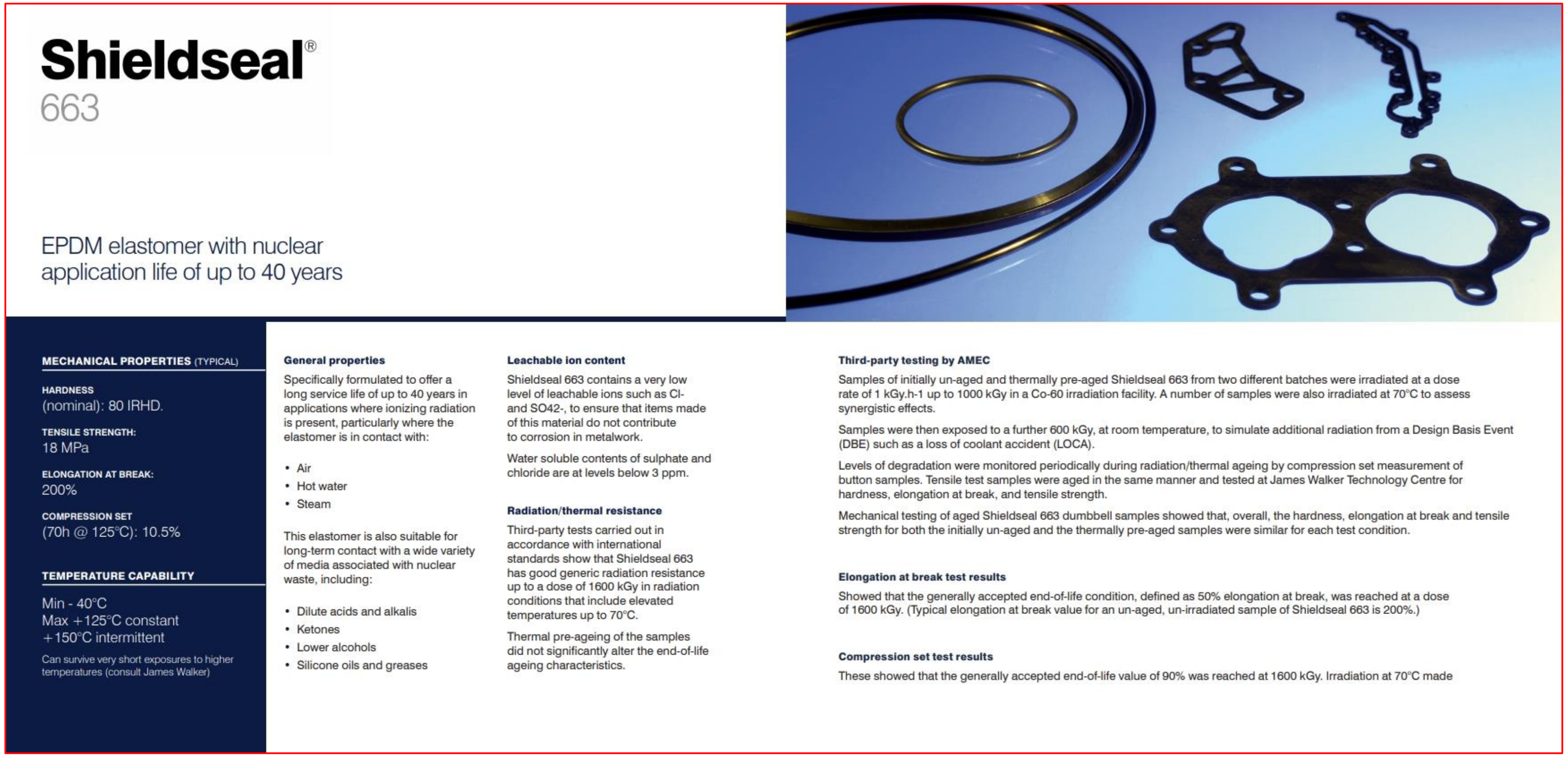
Computed radiation dose
@ 4000 fbarn^-1





The conventional gasket materials are not eligible for gas sealing in the irradiated environment.

SEALING - O-RINGS



Shieldseal®
663

EPDM elastomer with nuclear application life of up to 40 years

MECHANICAL PROPERTIES (TYPICAL)

HARDNESS
(nominal): 80 IRHD.

TENSILE STRENGTH:
18 MPa

ELONGATION AT BREAK:
200%

COMPRESSION SET
(70h @ 125°C): 10.5%

TEMPERATURE CAPABILITY

Min - 40°C
Max +125°C constant
+150°C intermittent

Can survive very short exposures to higher temperatures (consult James Walker)

General properties

Specifically formulated to offer a long service life of up to 40 years in applications where ionizing radiation is present, particularly where the elastomer is in contact with:

- Air
- Hot water
- Steam

This elastomer is also suitable for long-term contact with a wide variety of media associated with nuclear waste, including:

- Dilute acids and alkalis
- Ketones
- Lower alcohols
- Silicone oils and greases

Leachable ion content

Shieldseal 663 contains a very low level of leachable ions such as Cl- and SO42-, to ensure that items made of this material do not contribute to corrosion in metalwork.

Water soluble contents of sulphate and chloride are at levels below 3 ppm.

Radiation/thermal resistance

Third-party tests carried out in accordance with international standards show that Shieldseal 663 has good generic radiation resistance up to a dose of 1600 kGy in radiation conditions that include elevated temperatures up to 70°C.

Thermal pre-ageing of the samples did not significantly alter the end-of-life ageing characteristics.

Third-party testing by AMEC

Samples of initially un-aged and thermally pre-aged Shieldseal 663 from two different batches were irradiated at a dose rate of 1 kGy.h-1 up to 1000 kGy in a Co-60 irradiation facility. A number of samples were also irradiated at 70°C to assess synergistic effects.

Samples were then exposed to a further 600 kGy, at room temperature, to simulate additional radiation from a Design Basis Event (DBE) such as a loss of coolant accident (LOCA).

Levels of degradation were monitored periodically during radiation/thermal ageing by compression set measurement of button samples. Tensile test samples were aged in the same manner and tested at James Walker Technology Centre for hardness, elongation at break, and tensile strength.

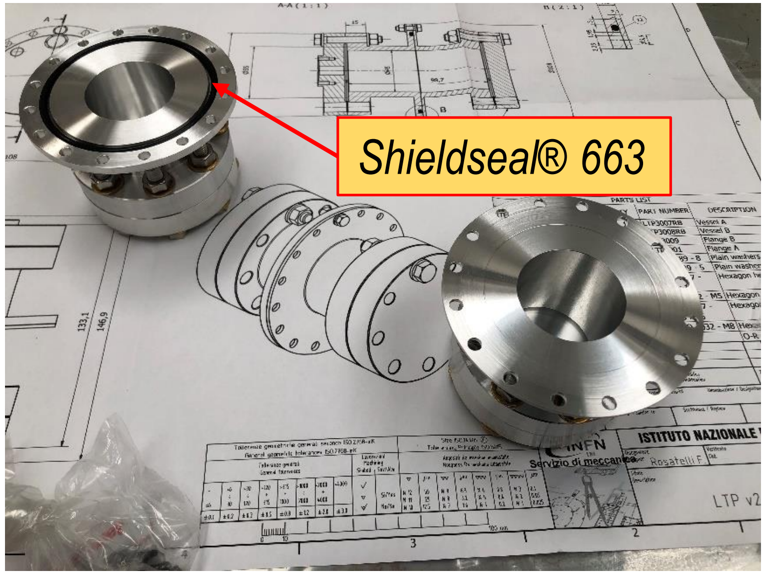
Mechanical testing of aged Shieldseal 663 dumbbell samples showed that, overall, the hardness, elongation at break and tensile strength for both the initially un-aged and the thermally pre-aged samples were similar for each test condition.

Elongation at break test results

Showed that the generally accepted end-of-life condition, defined as 50% elongation at break, was reached at a dose of 1600 kGy. (Typical elongation at break value for an un-aged, un-irradiated sample of Shieldseal 663 is 200%.)

Compression set test results

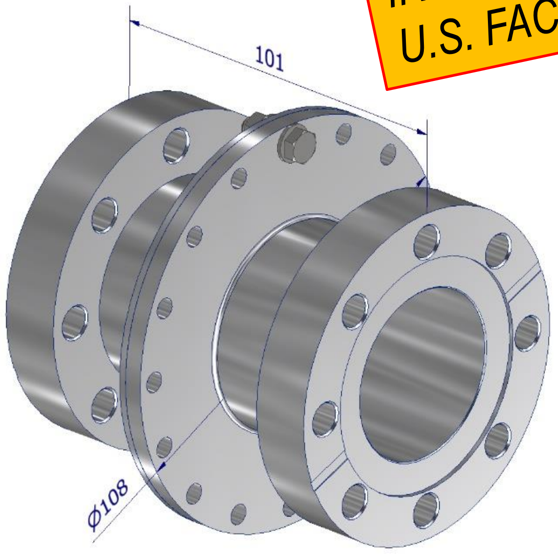
These showed that the generally accepted end-of-life value of 90% was reached at 1600 kGy. Irradiation at 70°C made

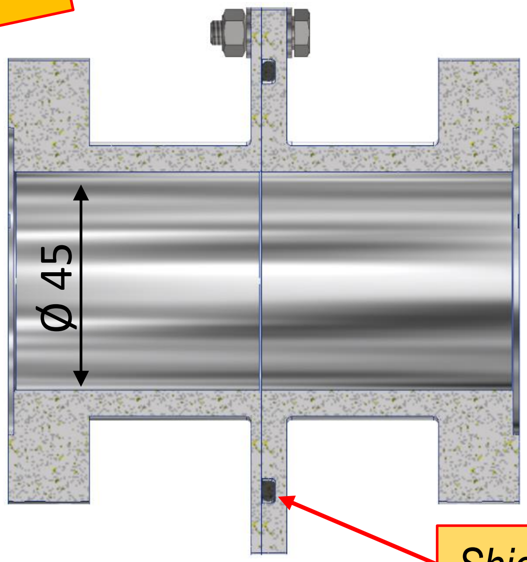


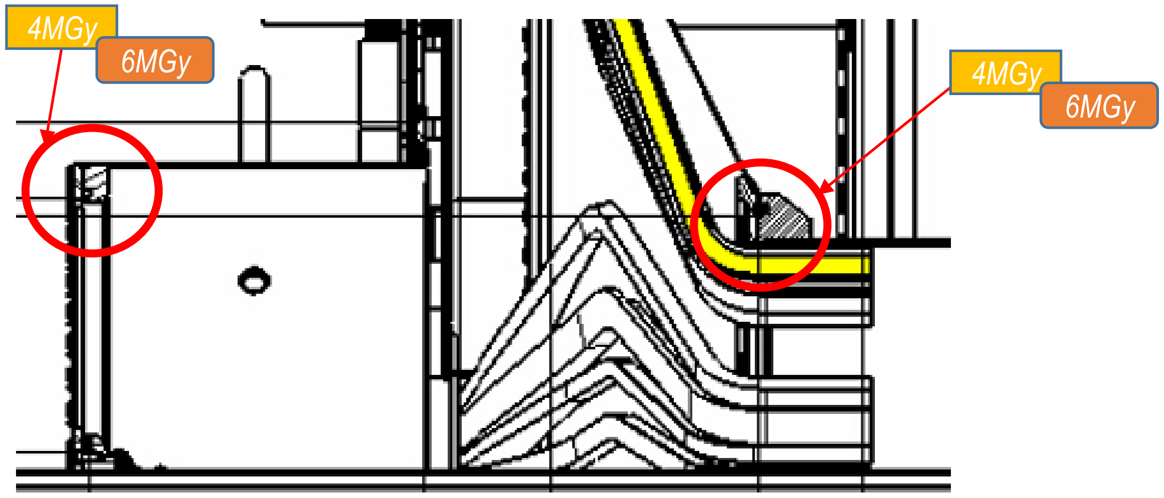
To seal the PP1 environment, the O-Rings material chosen is SHIELDSEAL® 663 (EPDM Family) provided from James Walker and certified up to 1.6 MGy . Used in nuclear plants.
When mounted on dedicated prototypes, we can check the differences in terms of leak performance before and after irradiation.

O-RING QUALIFICATION UP TO 6 MGy

IRRADIATION @ U.S. FACILITY



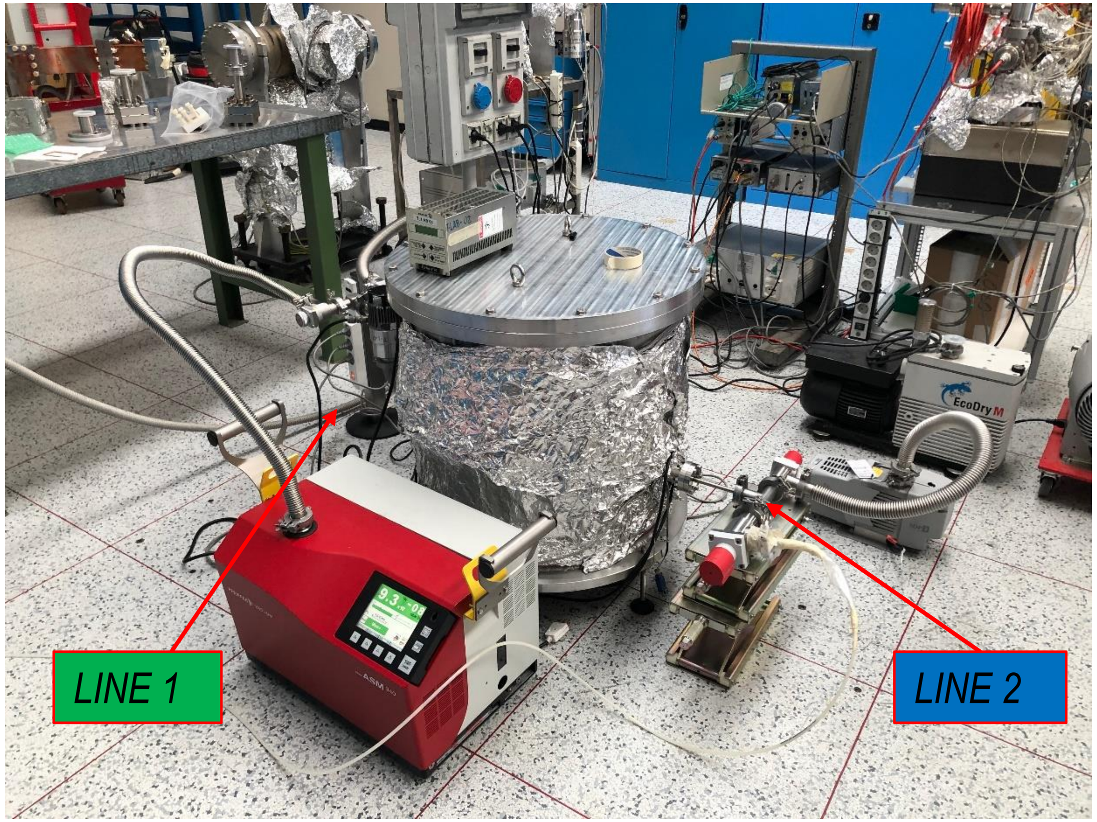


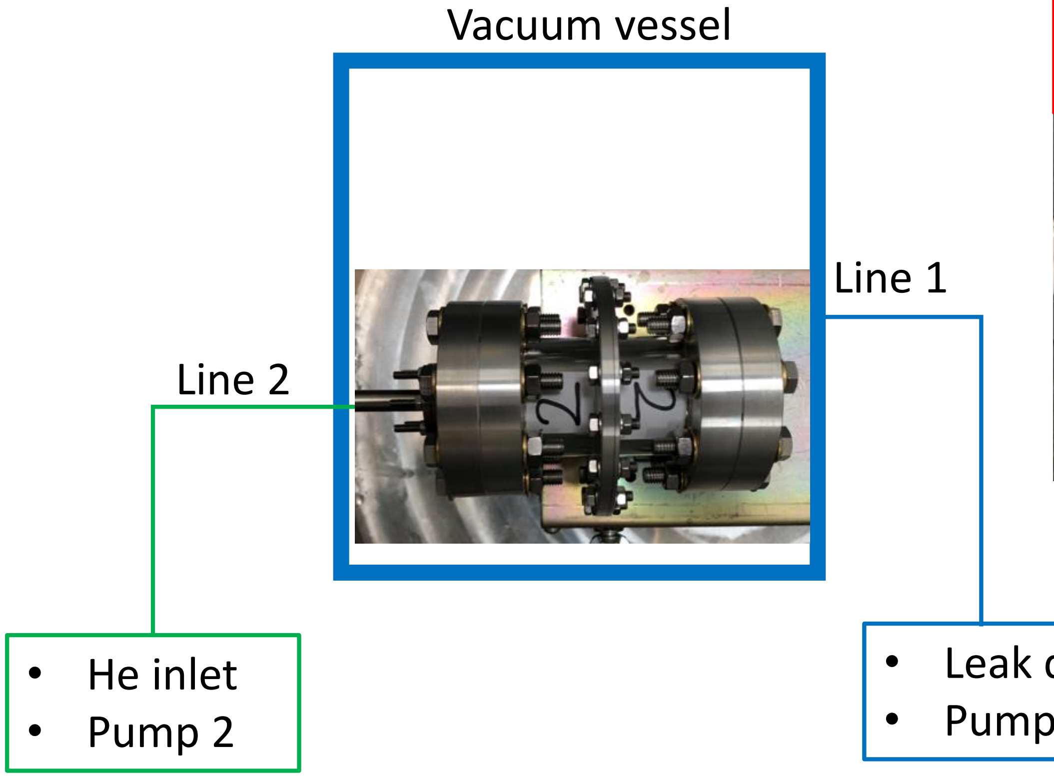


We made three prototypes, to test and qualify a compressed JW O-rings, at three radiation level up to 6 MGy.
O-rings will remain mounted to verify leakage at different operative conditions (rad. dose). O-R groove and thicknesses are equal to PP1 joints. Visual inspection after the test campaign. If the leak test will be passed, we can use the O-ring material to replace the metallic gasket in the PP1/IST interface. The benefits are:

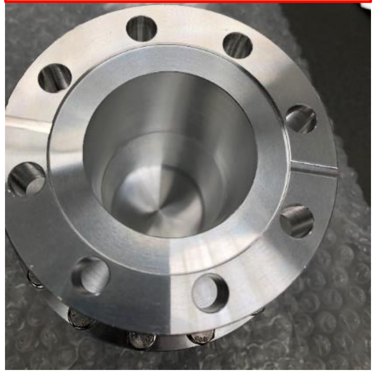
- Simplify the interface integration.
- Using rubber instead of metal gasket.
- Mass budget reduction (project requirement).

LEAK TEST SYSTEM





Visual inspection before and after each test.



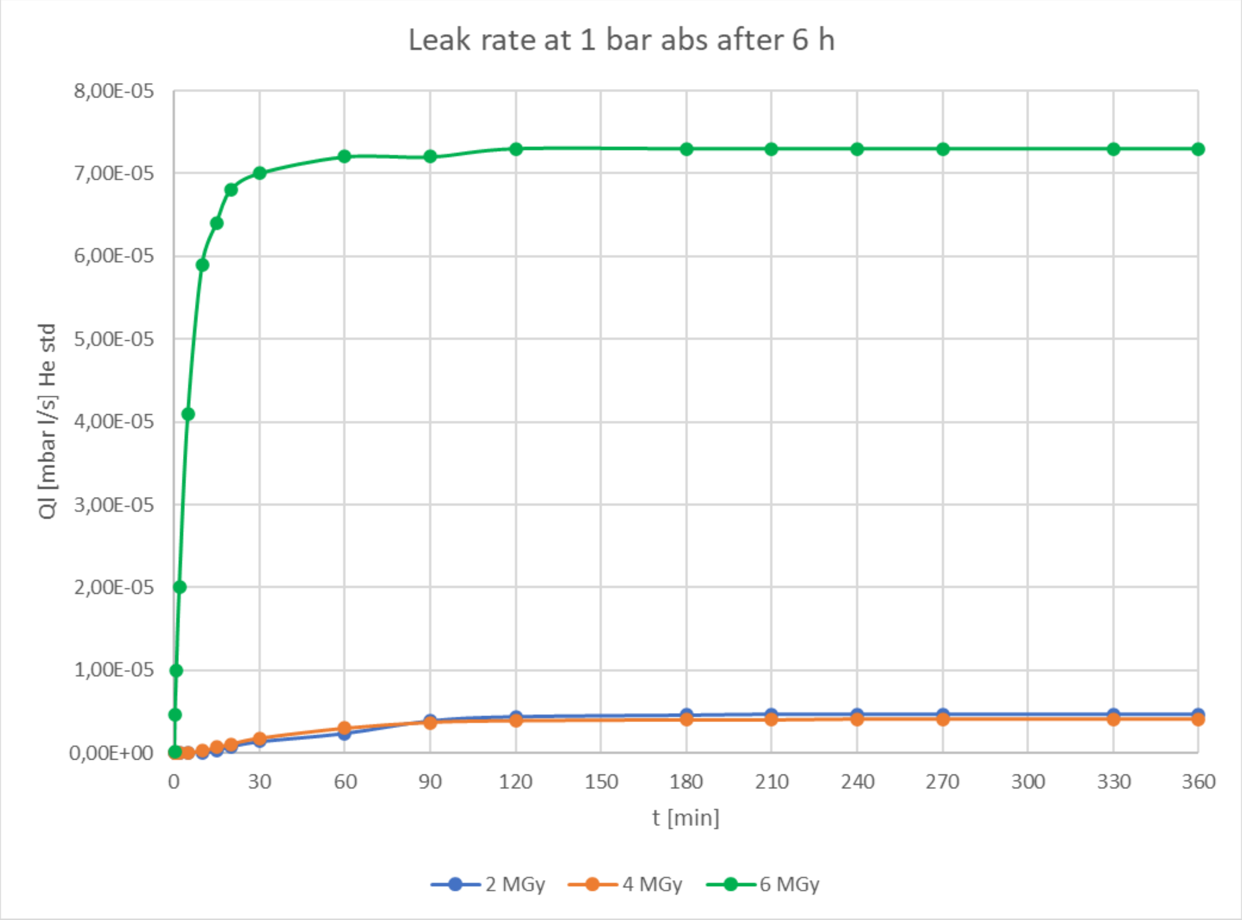
THE LEAK RATE OF O-RINGS WAS MEASURED WITH THE HELIUM DETECTION METHOD:

1. Vacuum on both lines.
2. Flushing Helium at p=1 bar absolute in line 2 (prototype)
3. Read the leak rate in time on vacuum leak detector (line1).

LEAK TEST RESULTS IRR 1

Sample n°	Leak rate [mbar l/s] He std after 6 h	Leak rate [mbar l/s] He std after 24 h
1 irr	4,8E-06	4,8E-06
2 irr	4,1E-06	4,1E-06
3 irr	7,3E-05	7,3E-05

Sample n°	Irradiation1 [MGy]	Irradiation2 [MGy]	Irradiation3 [MGy]
1	2	4	6
2	4	6	-
3	6	-	-



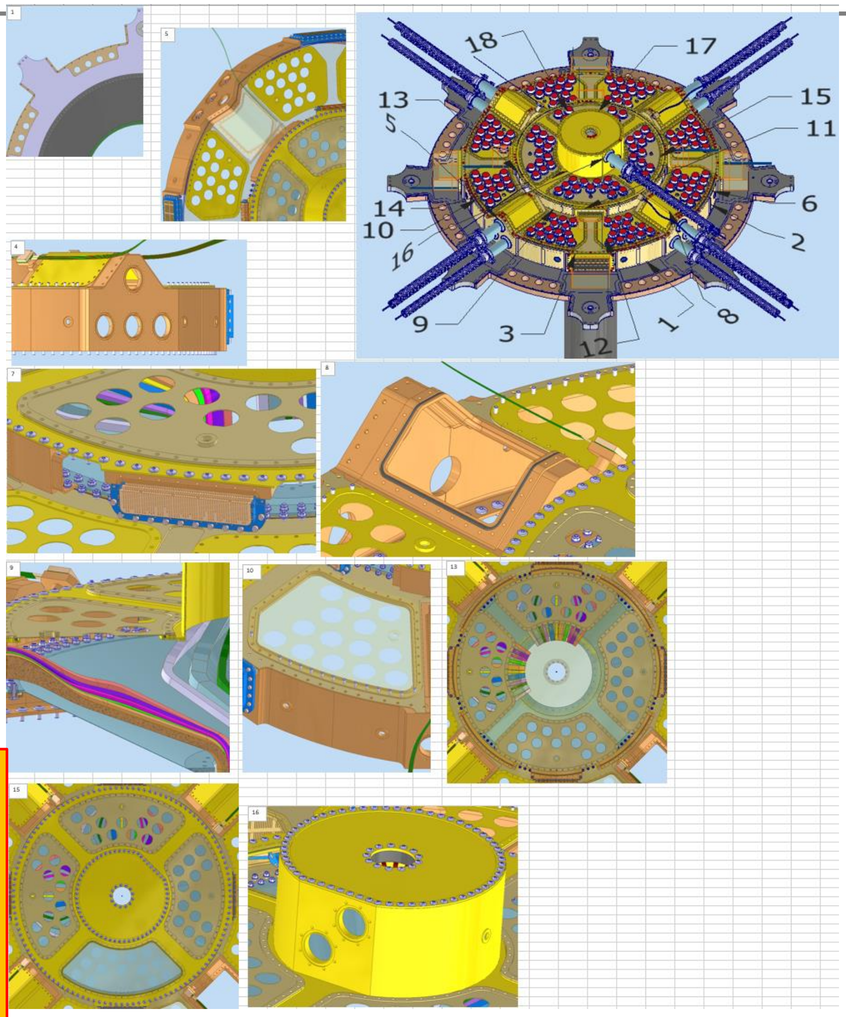
- Send to US facility for radiation step 3 to obtain results on the most critical condition.

LEAK TEST RESULTS- ZERO RADIATION

O-R (Shieldseal 663, d1 3,53; d2 110,7)

Ql	7,30E-05	mbar*l/s	Q	1	m^3/h	
D medio	36,876	cm	Ql Max	312	mbar*l/s He std	1,11 m^3/h
ql	1,98E-06	mbar*l/s cm	Δp	1000	mbar	

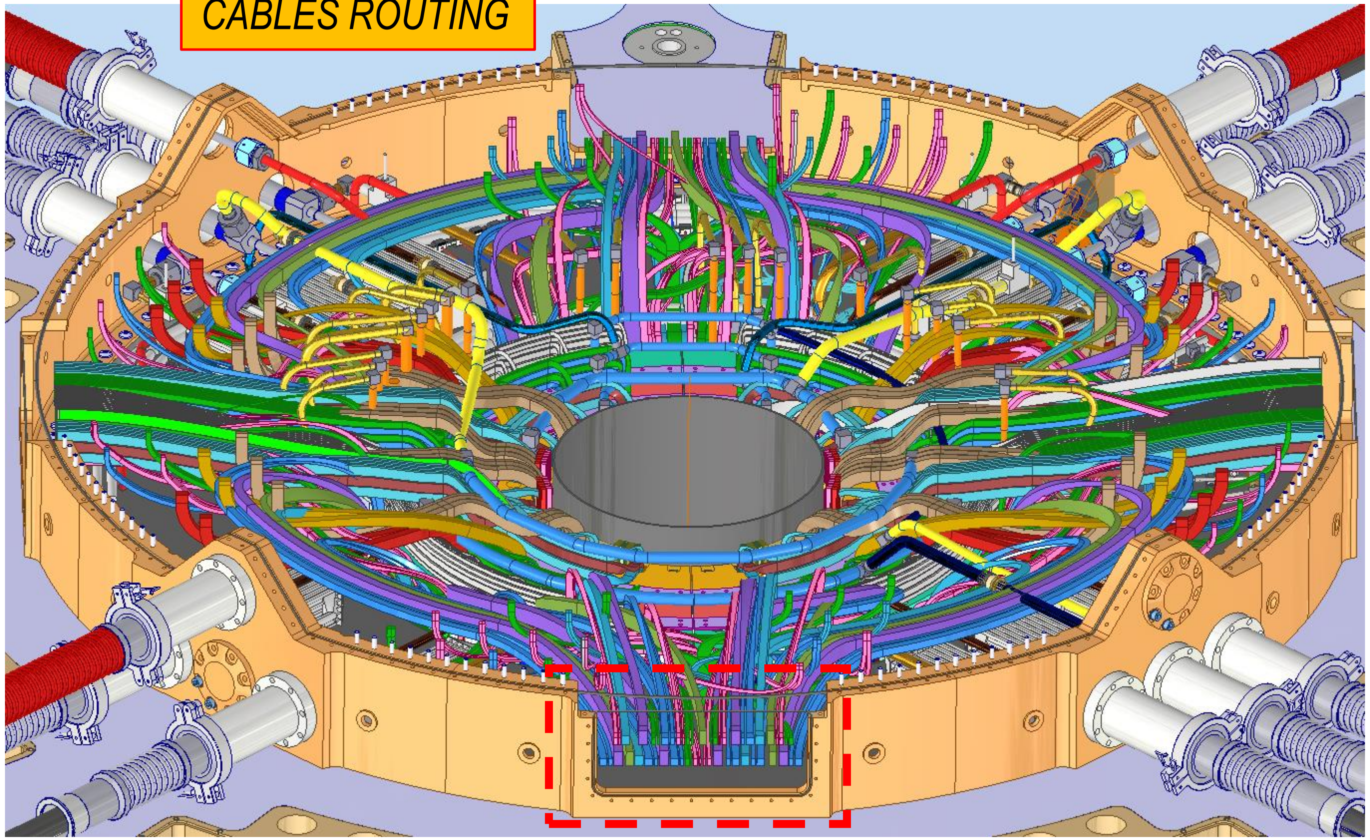
R_{int} [cm]	R_{ext} [cm]	Lm [cm]	D [mm]/C[mm]	Ql [mbar*l/s]	Partial [%]	Region	Element 1	Element 2	Qtà		
						Outer			1		
68,2	68,85	430,5552732	4,1/6,5	8,52E-04	2,73E-04	1	Bulk head	Outer Flange		UPDT da guarnizione piatta a O_R 5 mm perdite hp come sez. 3 mm	
						2	Flange (part)	Flange (part)		Parti saldate o incollate	
		180,6	1,6/2,8	3,58E-04	1,15E-04	3	Outer Flange	Data Cable	4	componenti mancanti	
2,65	3,05	17,90705	2,4/4			4	Flange	Flex line CO2	16	UPDT da step 04.2021_PP1 General Assembly Top	
68,4	68,8	454,3856	2,8/4,8	9,00E-04	2,88E-04	5	Outer Flange	Outer wall	corda	test effettuato con O-r sez 3,53. verificare montaggio	
						Intermediate					
39,15	39,63	247,4946692	2,9/4,8			7	Outer wall	Inner flange			
		77,0468	2,9/4,8	1,53E-04	4,89E-05	8	Cooling housing	Cooling carter	4	UPDT da step 04.2021_PP1 General Assembly Top	
37,2	37,68	235,2424579	2,9/4,8	4,66E-04	1,49E-04	9	Outer wall	Conical_Flange	1	UPDT da step 04.2021_PP1 General Assembly Top	
		93,85	2,9/4,8	1,86E-04	5,95E-05	10	Outer wall	ACT_panel	4	UPDT da step 04.2021_PP1 General Assembly Top	
		97,2		1,92E-04	6,17E-05	11	Flange	Data Cable	4	componenti mancanti	
	2,46	14,76548547		3,27E-03	1,05E-03	12	ACT_Flange	ACT_Connectors	112	dimensione O_R e sede mancante sul glenair	
40,4	40,88	255,3486509	2,8/4,8	5,05E-04	1,62E-04	13	Inner wall	Inner Flange	1	UPDT da step 04.2021_PP1 General Assembly Top	
						Inner					
						14	Flange_base	Flange_Cylinder		RICAVATO DI PEZZO O INCOLLATE (5/03/2020)	
		110,23	2,9/4,8	2,18E-04	6,99E-05	15	Inner wall	ACT_panel	4	UPDT da step 04.2021_PP1 General Assembly Top	
2,65	3,13		2,4/4,8			16	Flange	Flex line CO2	2	IN SVILUPPO (5/03/2020)	
16,2	17,7	108,46		2,15E-04	6,88E-05	17	Inner Flange	End plate		aggiunto	
	2,46	14,76548547		1,52E-03	4,87E-04	18	ACT_Flange	ACT_Connectors	52	dimensione O_R e sede mancante sul glenair	
						End					
	46,2	29		5,74E-05	1,84E-05	19	End plate_bore	Beam Pipe			
						Cone					
37,3	37,6	236,7		4,69E-04	1,50E-04	20	Intermediate Flange	Cone			
15,7	16	101,16		2,00E-04	6,42E-05	21	Cone	IST		aggiunto	
			Ql tot [mbar*l/s]	9,56E-03	3,07E-03	%				→	9,56E-03
			S.F.	4							
			Ql tot sf [mbar*l/s]	3,83E-02	1,23E-02	%				→	0,00E+00



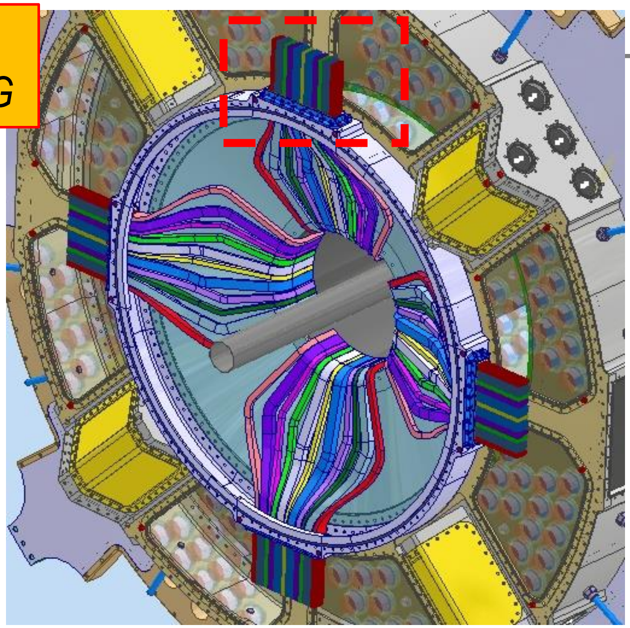
- I use this preliminary results to evaluate the leak rate of all gaskets used in PP1 connections.
- O-ring also in the cooling transfer lines.
- The total leak rate with a Safety Factor 4, is $3{,}8 \times 10^{-2}$ $\mathrm{mbar}\ ^{l}/_{s}$ He std
- The value allowed by specific is 312 $\mathrm{mbar}\ ^{l}/_{s}$ He std. [https://edms.cern.ch/document/2019413/1]
- Data feedthroughs leak is not included. To be tested.

DATA FEEDTHROUGHS

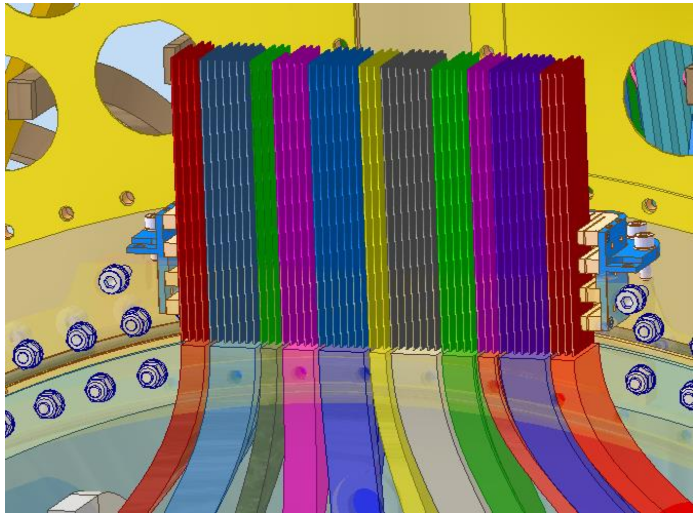
OUTER SYSTEM CABLES ROUTING



INNER SYSTEM CABLES ROUTING



NEW VERSIONS IN DEVELOPMENT

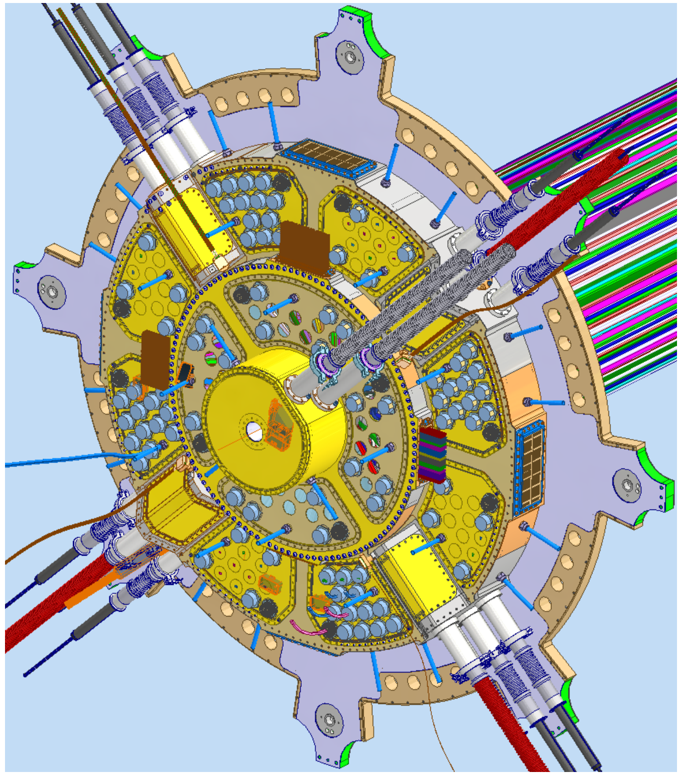


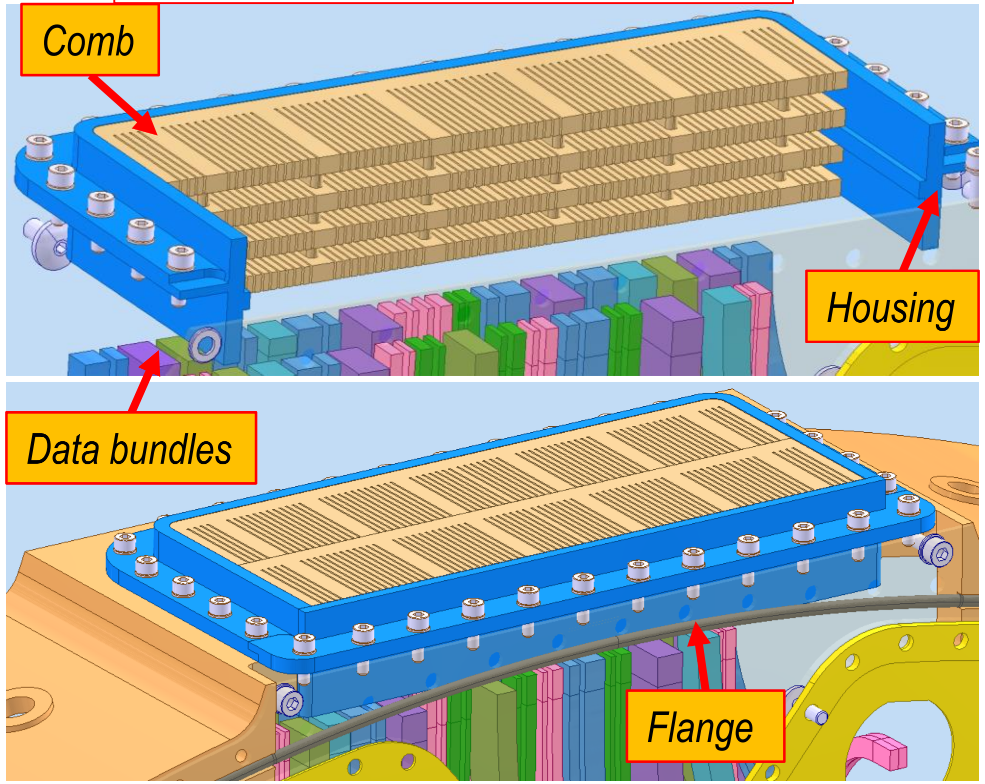
- In the DFT arrived the data bundles from different subsystems that ends in the optoboards.
- The gas sealing must be done also in the feedthroughs.
- Define how to realize filling process and optimize the design.

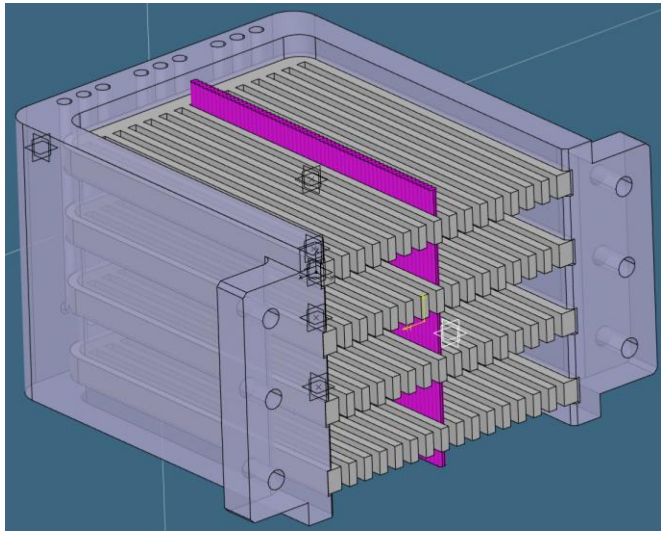
DATA FEEDTHROUGHS PROTOTYPE

Work in progress: under revision

Prototype





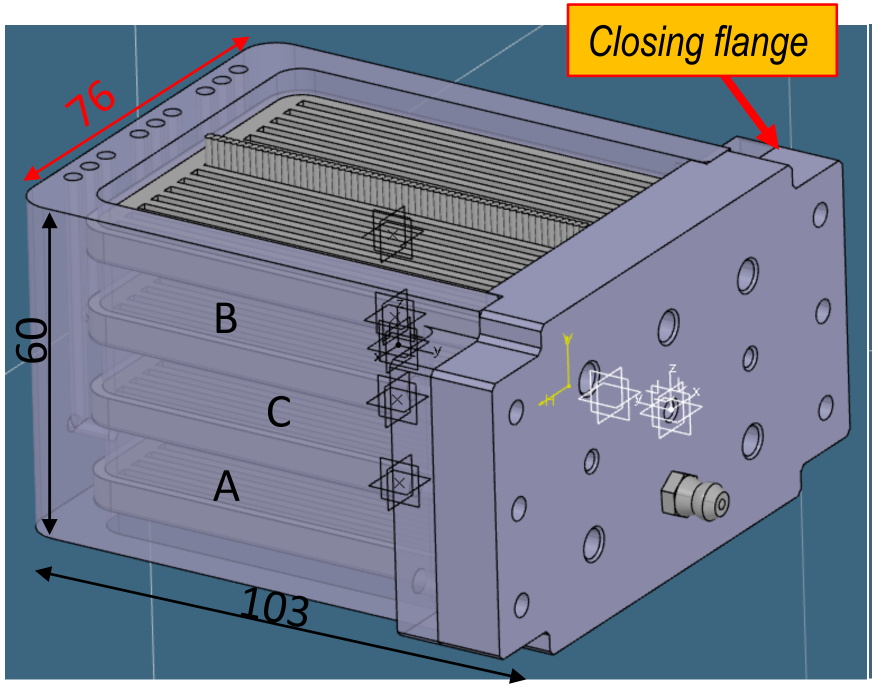


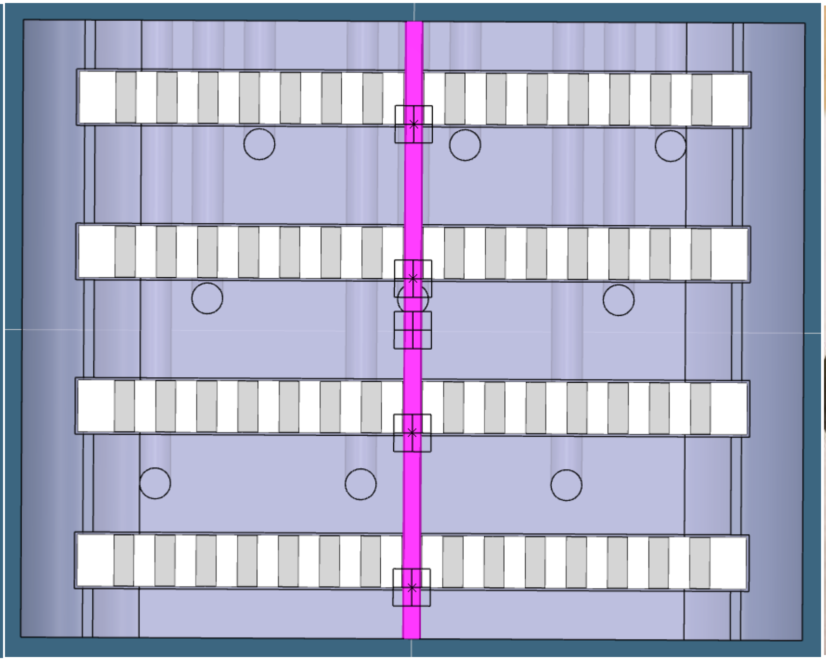
Main features:

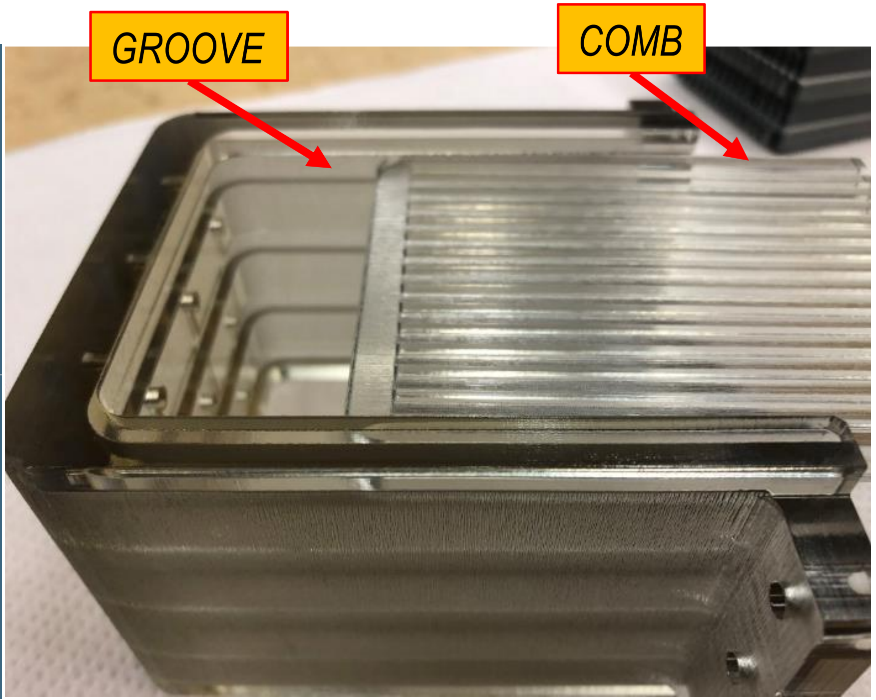
- Combs to store data bundles in position.
- Three chambers to allow the filling of compounds to create the sealing.

Different prototypes to optimize the design and validate the filling process.

PROTOYPE AND FILLING TEST



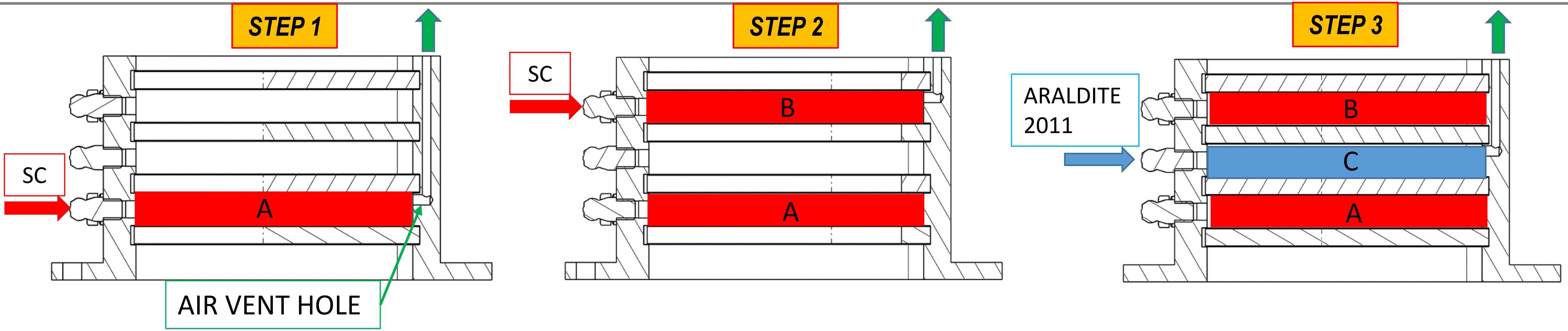




Prototype of Outer Feedthrough was made by Vero Clear (3D printed material):

- 1/3 of the Outer DFT length (red quote). The other two dimensions are the same.
- The combs were made separately to grant dimensional stability (3D printed).
- Grooves allow the correct positioning of combs in the DFT structure.
- Three volumes for compound injection.
- Closing flange with greasing nipples to inject resin inside chambers with greasing gun.

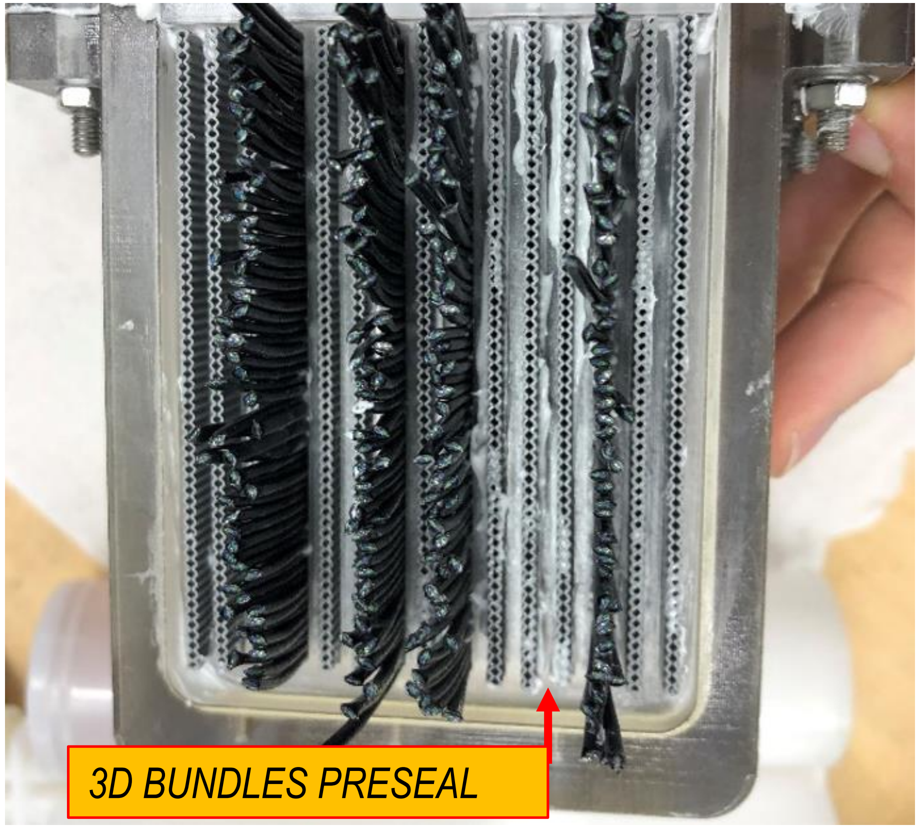
FILLING PROCESS



The filling process follows this step by step procedure:

1. Filling the chamber A with silicon compound (SC). It has high viscosity and low curing time compared to Araldite 2011.This properties are necessary to ensure a containment function.
   The air exits from vent hole, in opposite direction of filling. When the SC leaks out from hole, we proceed to the next injection hole.
2. Filling the chamber B with SC.
3. Now the chamber C is ready for Araldite 2011 injection. It's contained between the two full volumes (A & B) and ensure a tightness in the operative conditions of the detector, due its radiation resistance.

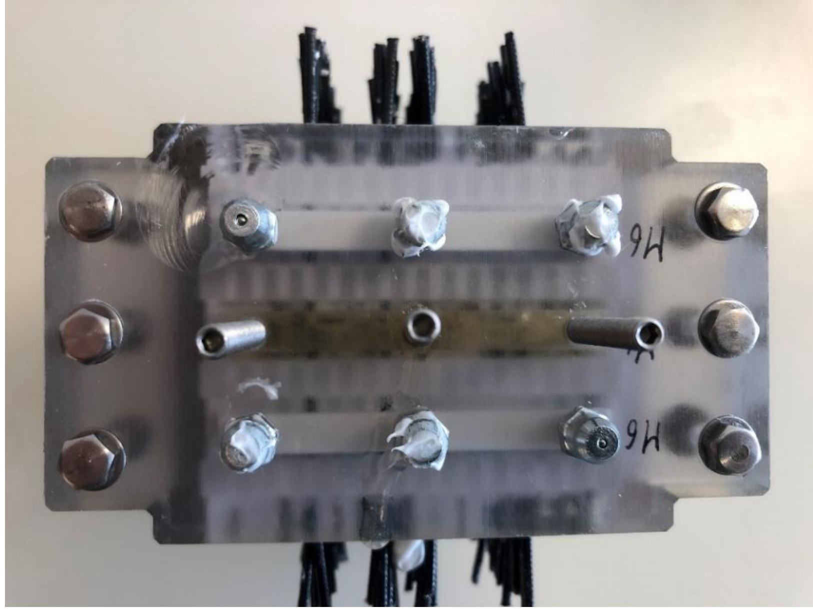
FILLING TEST

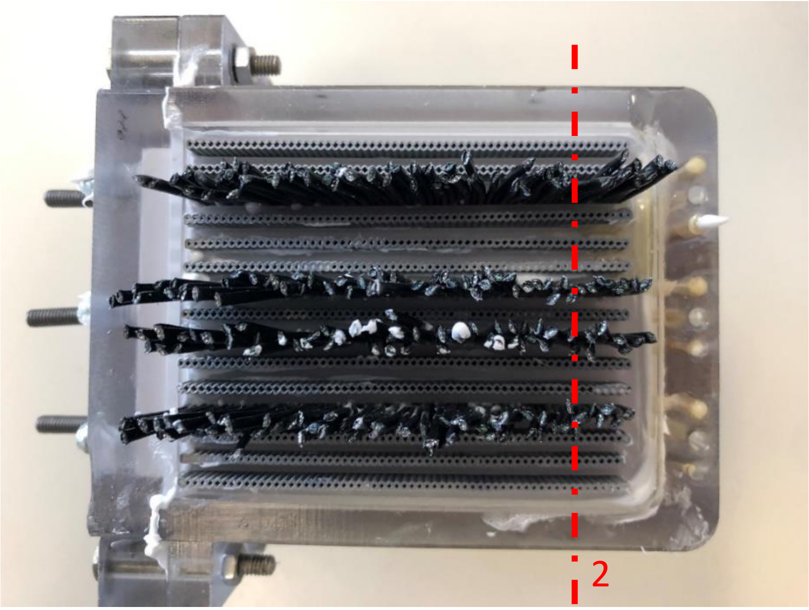


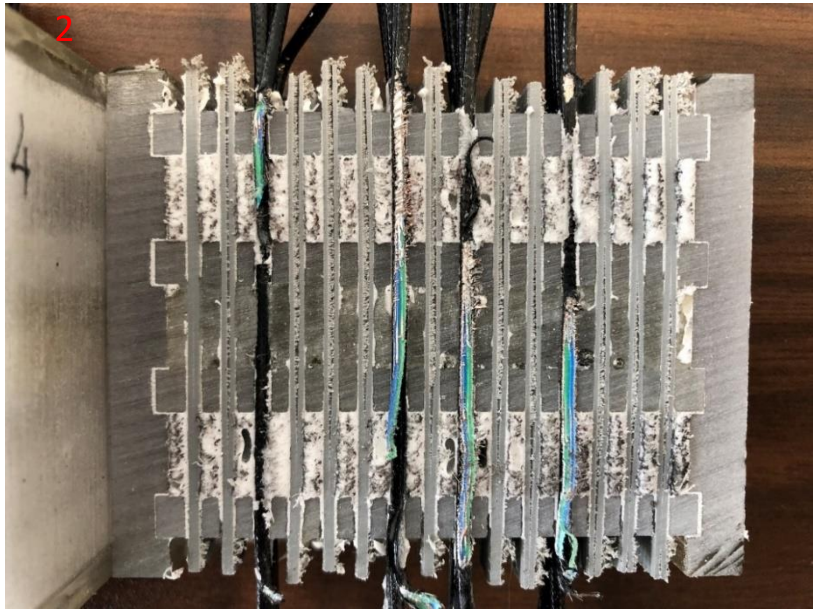
The pre sealing is the most critical aspect:

- Placing combs in position, we presealing them with silicon compound.
- Before placing bundles in position, we pre-seal them with silicon compound.
- Same for the closing flange to avoid spill during the filling operations.

FILLING TEST





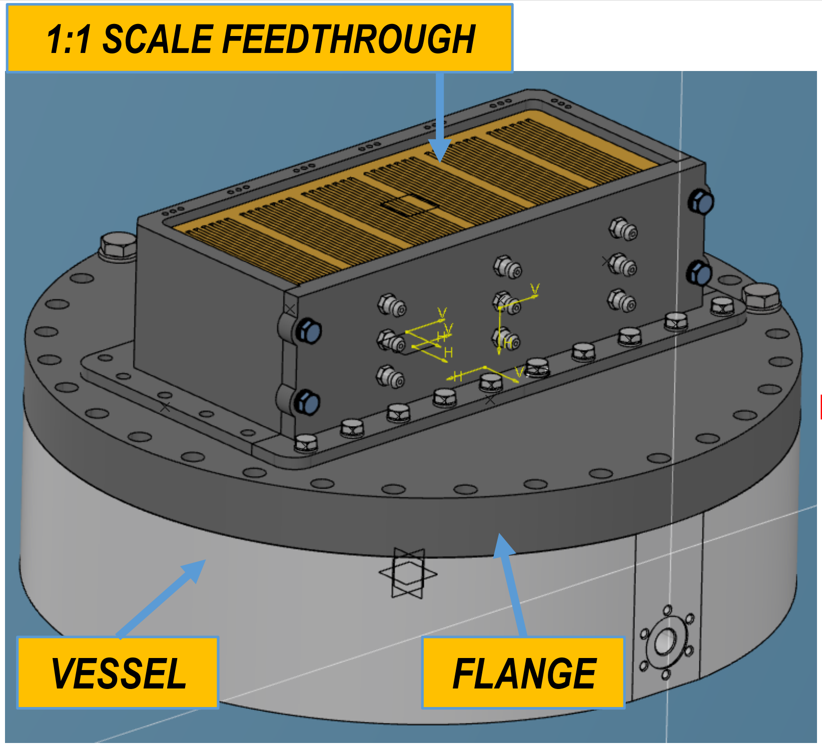


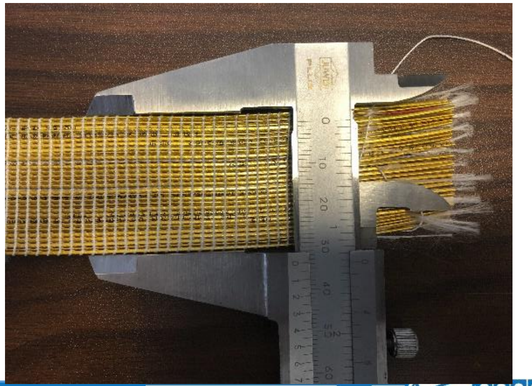
- After 8 hours from the pre seal, we filled the chambers A and B with silicon compound. No leakage were detected.
- After 24 hours we filling the chamber C with Araldite 2011. No leakage were detected in the closing flange.

Results:

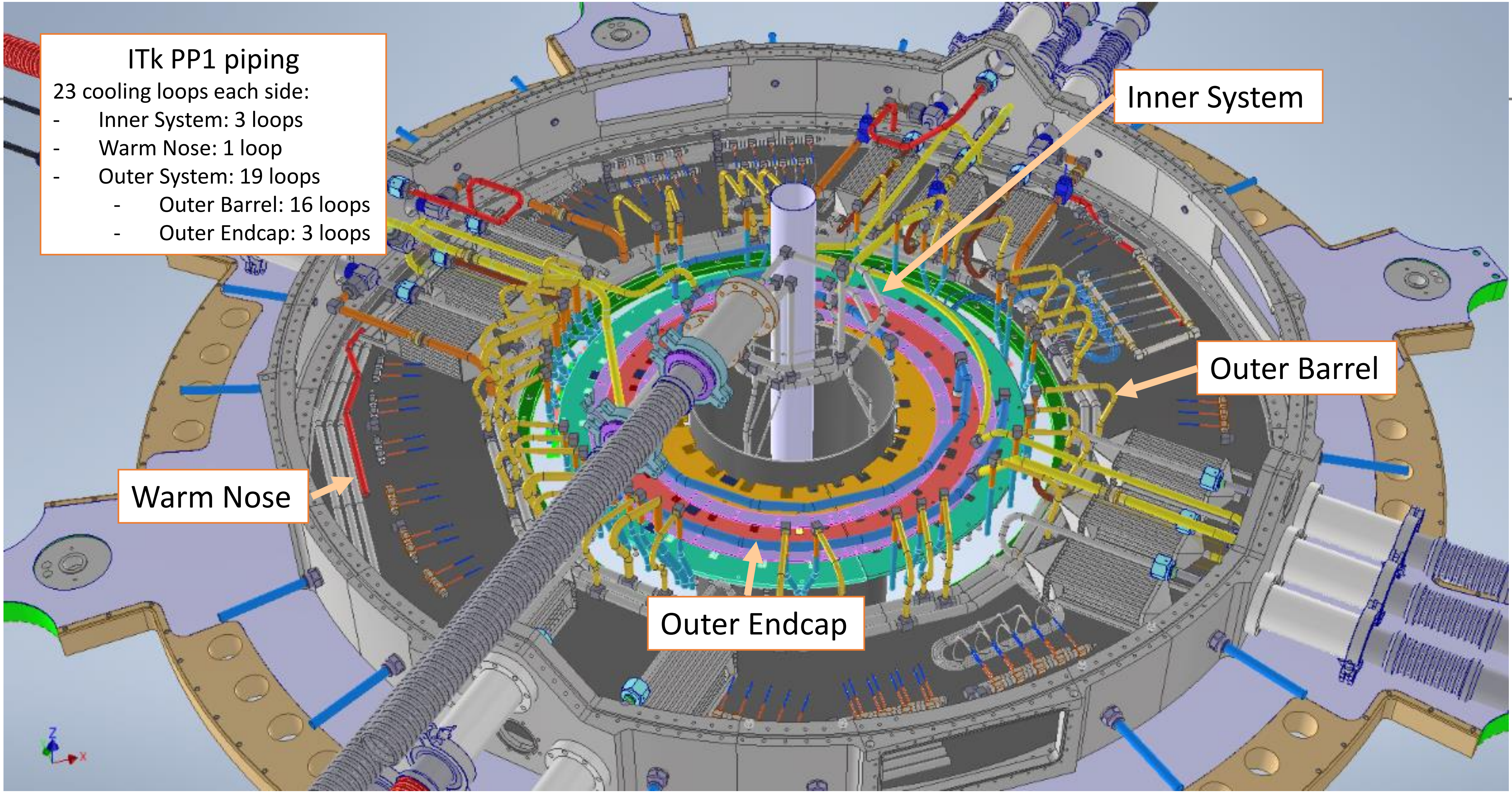
- There is no differences between true twinax and fake parts in terms of leakage.
- Araldite and SC injected with greasing gun, with good results.
- No one of fillers leak out from prototype.
- Sectioned to verify the filling results.
- Preseal avoid resin leak.
- Araldite filled entirely the assigned volume.

OUTER SYSTEM DATA CABLES FEEDTHROUGH TRUE SCALE

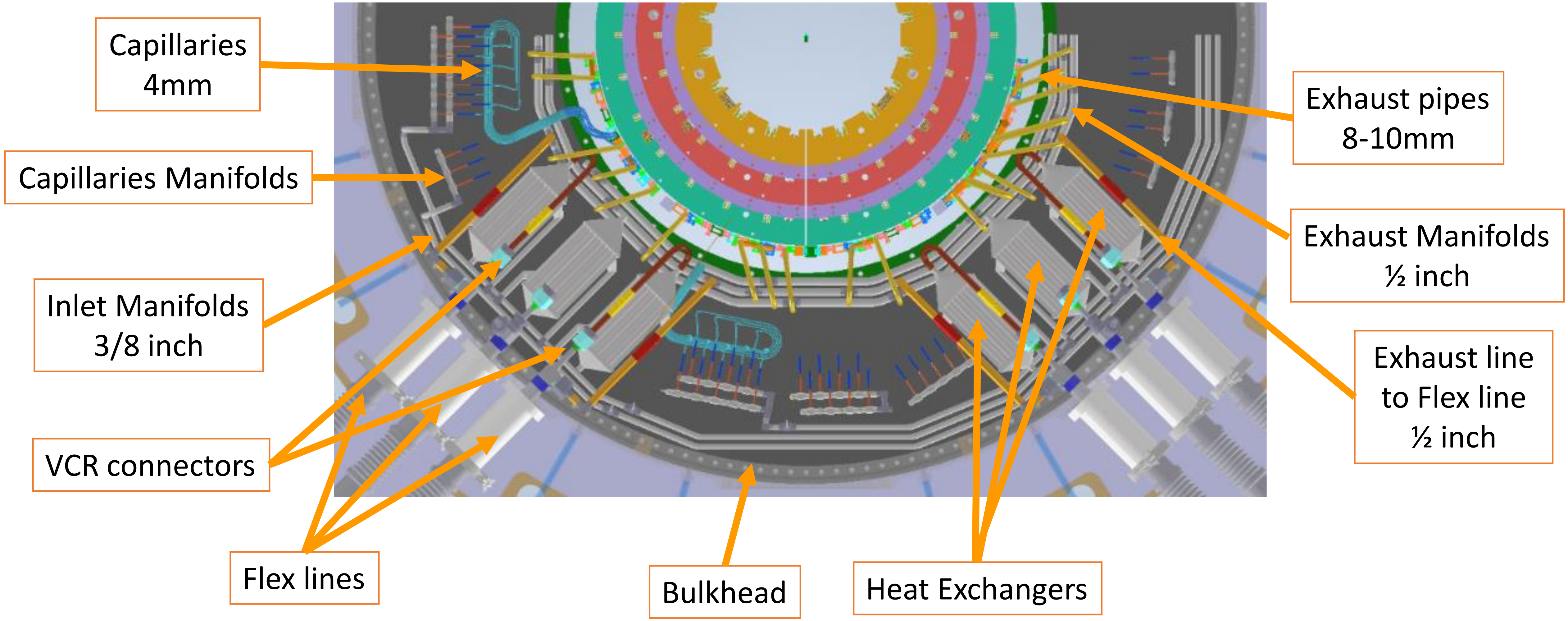




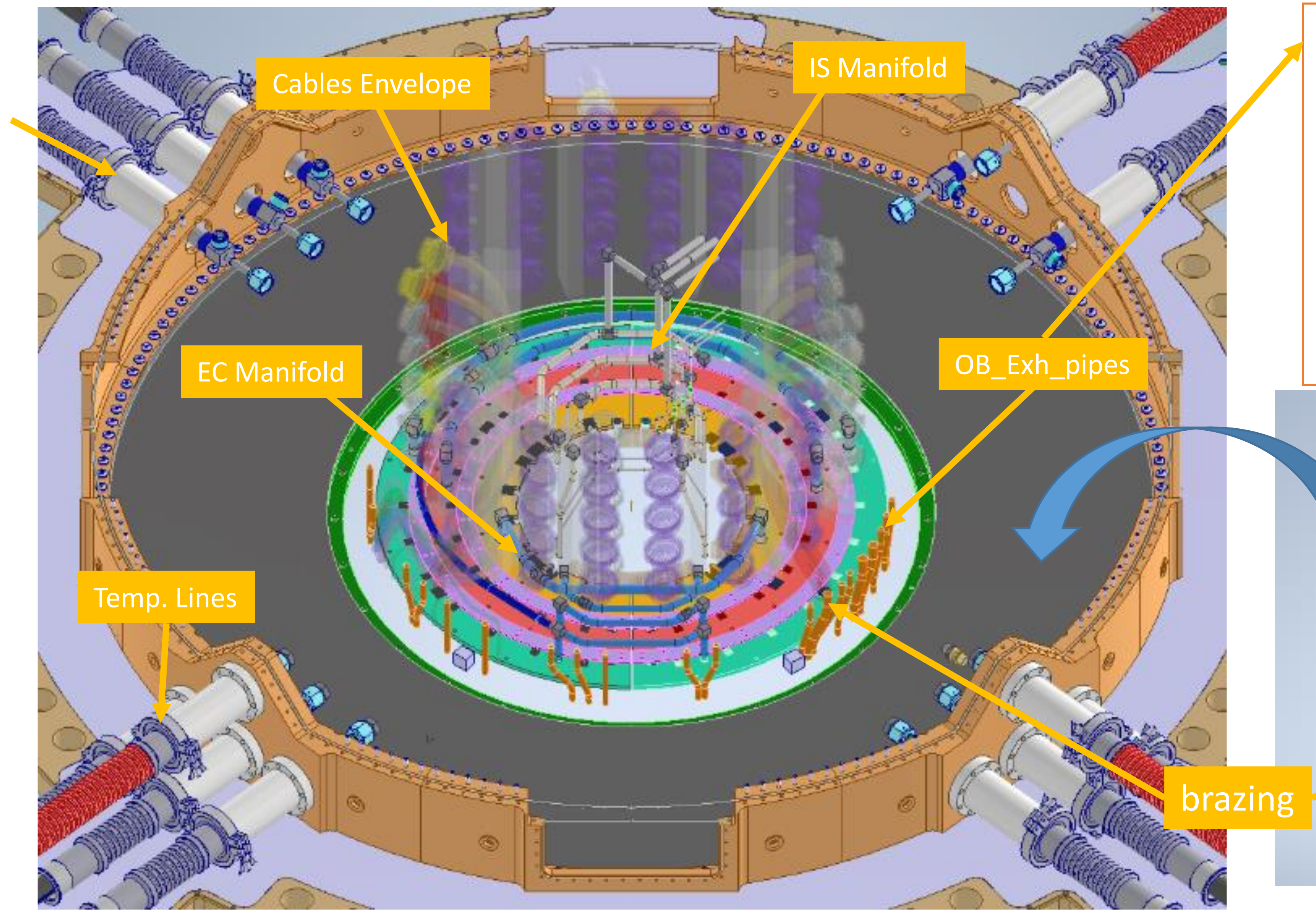
- We use similar design for two 1:1 OS DFT prototypes, to test the resins filling process, in horizontal and vertical position. This, to simulate the integration process in PP1
- Leak test after the filling process.
- Combs will be modified to accommodate the ribbonized twinax bundles (when arrived).


ITk PP1 piping
23 cooling loops each side:
- Inner System: 3 loops
- Warm Nose: 1 loop
- Outer System: 19 loops
- Outer Barrel: 16 loops
- Outer Endcap: 3 loops
Inner System
Outer Barrel
Warm Nose
Outer Endcap

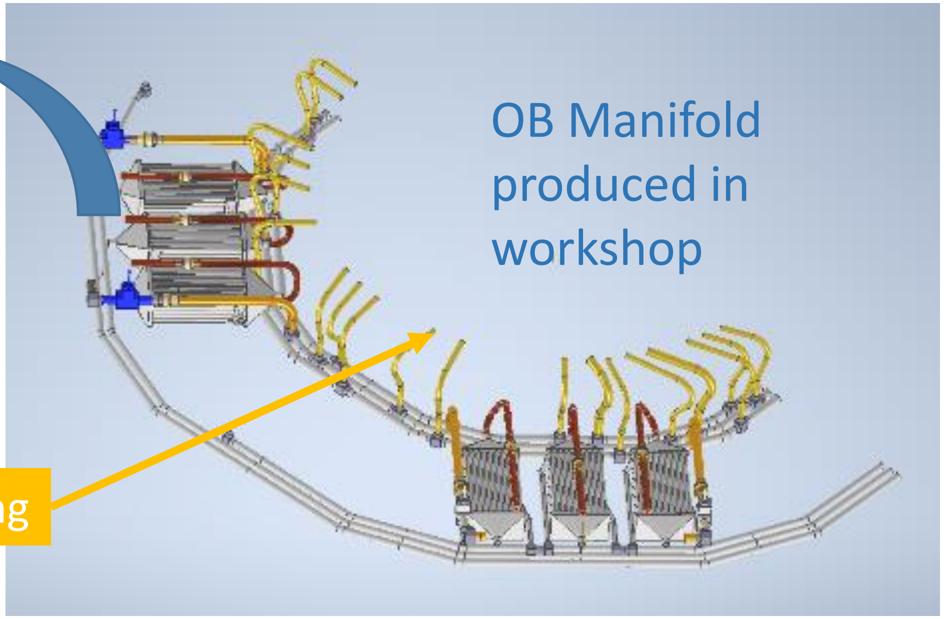
Outer Barrell piping: some details



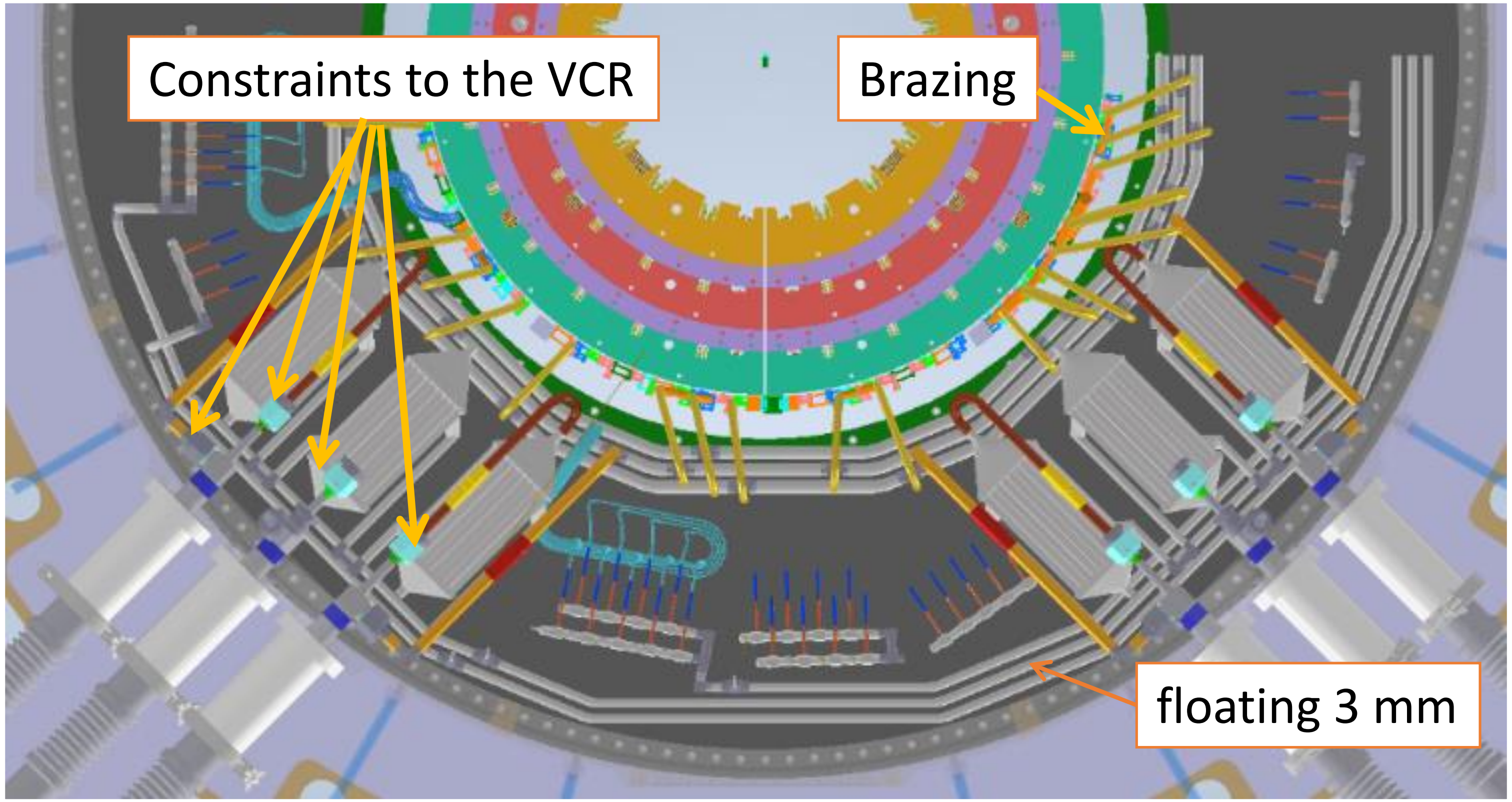
Outer Barrell piping: influence of temperature

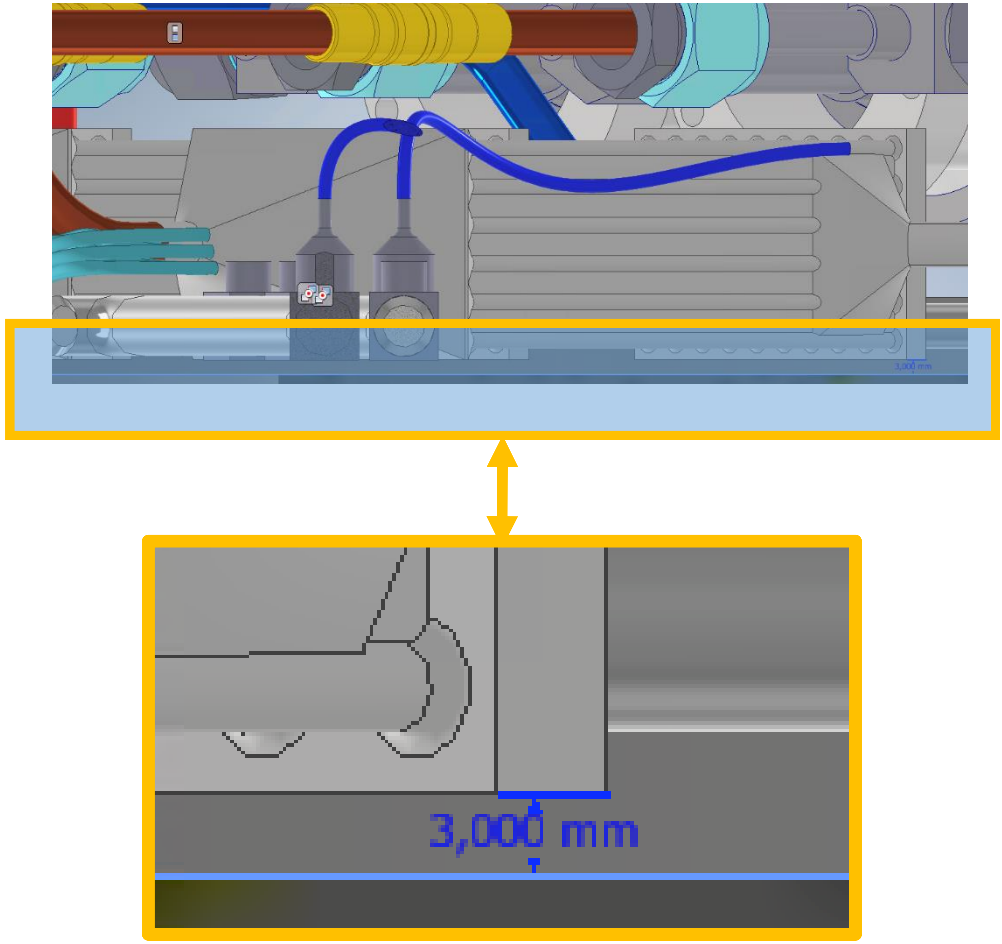


Titanium pipes from Outer Barrel
Length: ~ 2m
Material: Titanium,
External diameter: 8-10mm
Considering CTE: 8.5^-6 (°C^{-1})
Oper. Temp.: -35°C; Worst Case: -55°C
Pipe contraction: ~ 1.5 mm



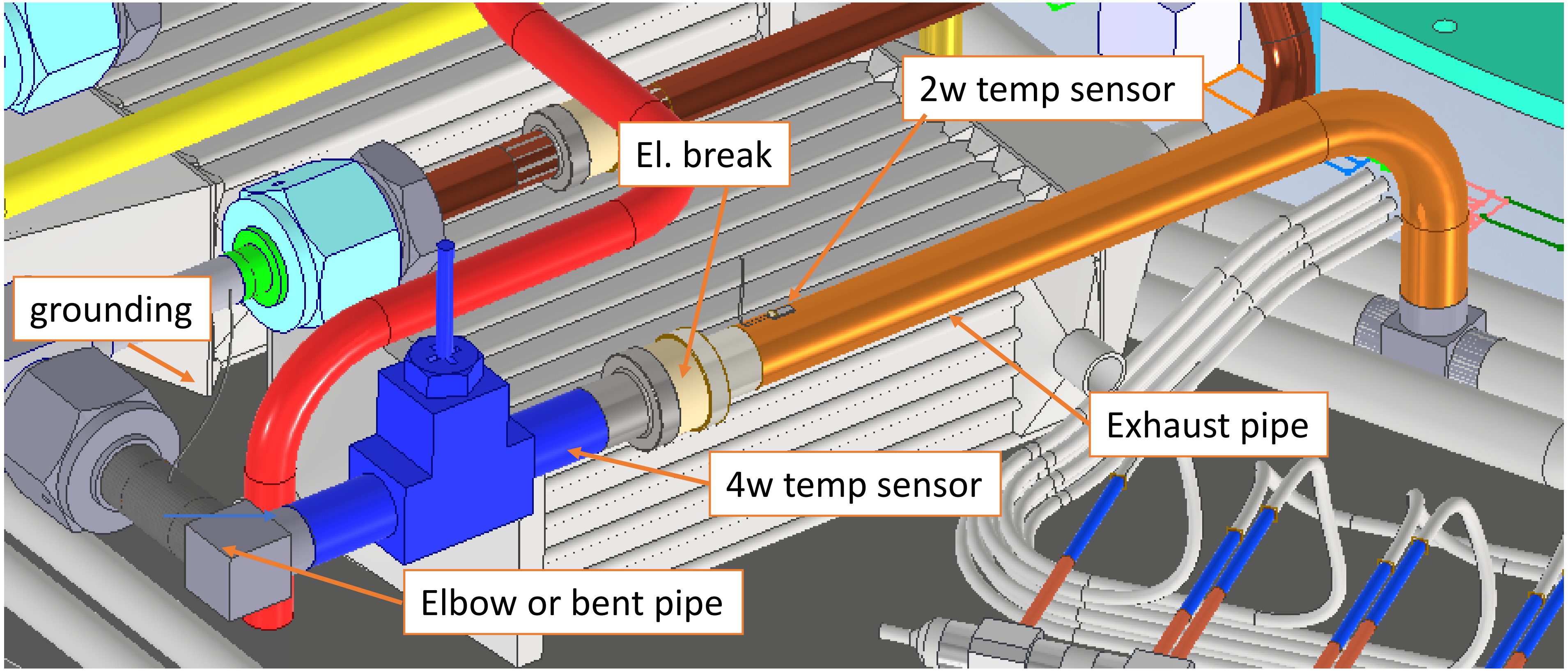
Outer Barrell piping: floating manifolds



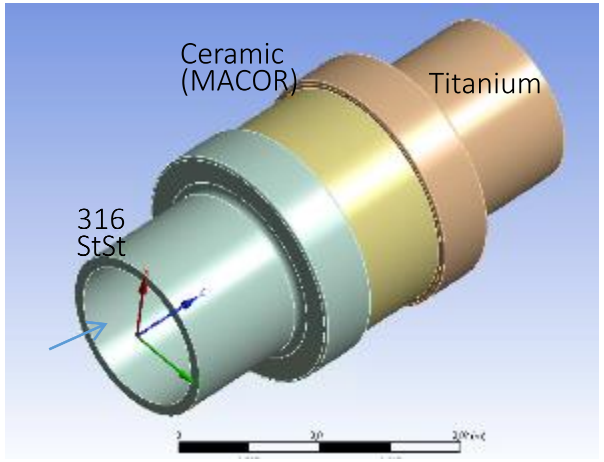


3mm gap between the Outer Barrel Manifolds and the bulkhead is foreseen. The idea is to have the manifolds floating in order to compensate the thermal deformations.

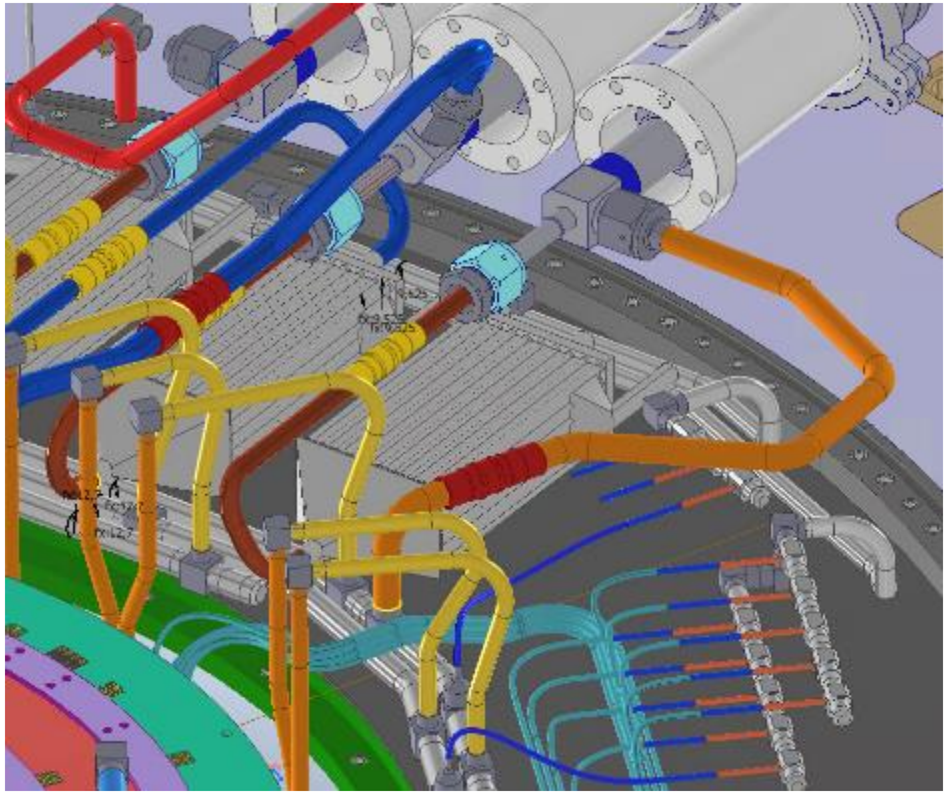
Outer Barrell Components in the exhaust line

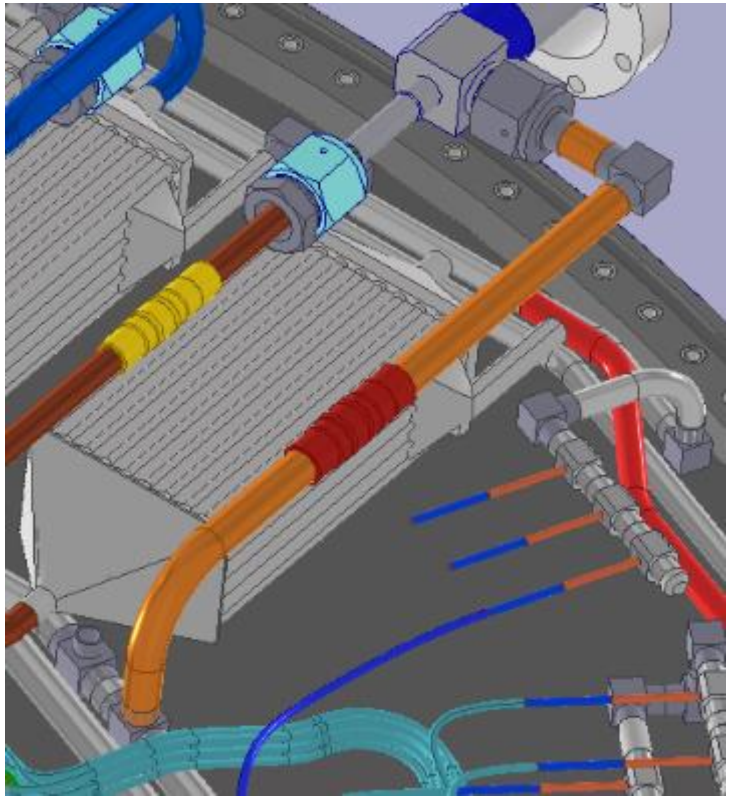


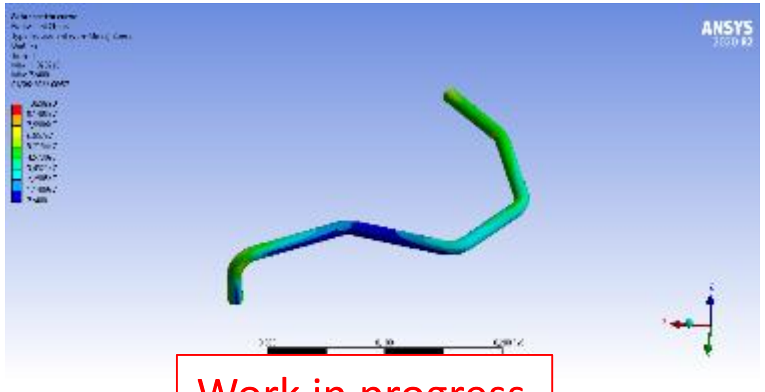
Transition from Stainless Steel to Titanium



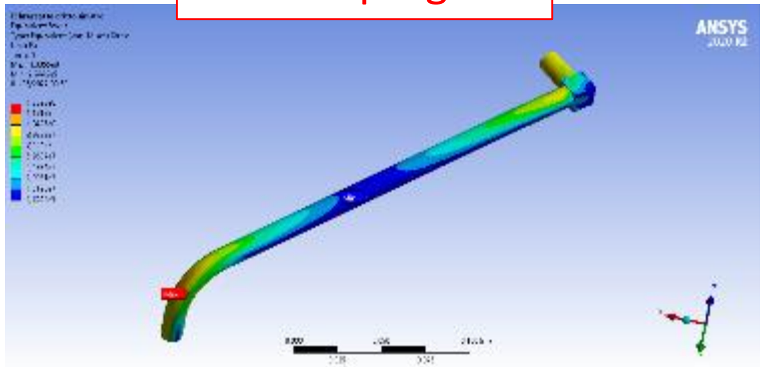
Study of different shapes for the Exhaust connection to the flex lines





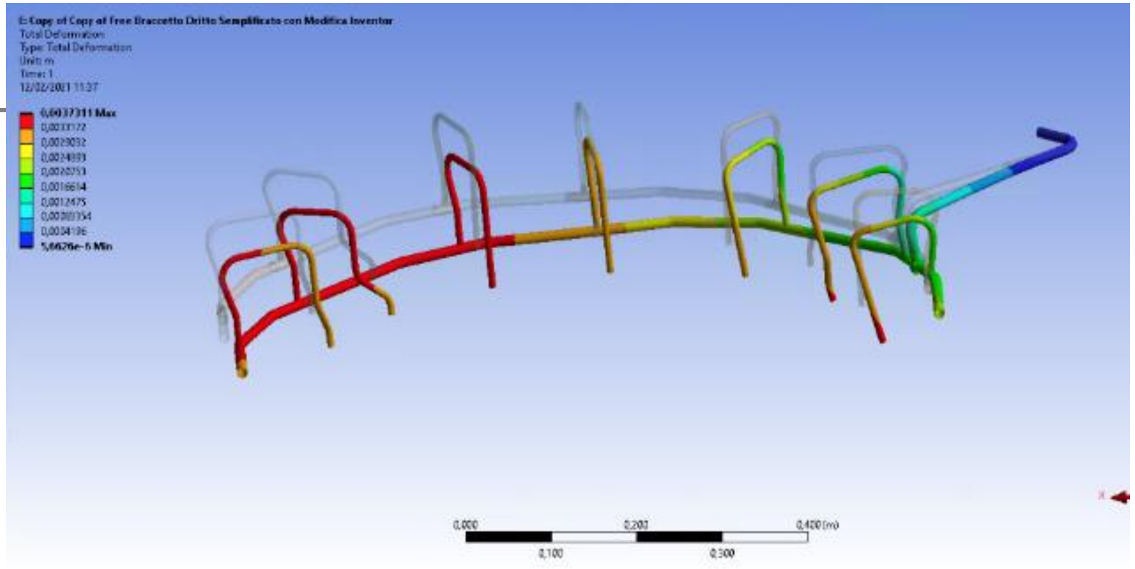


Work in progress

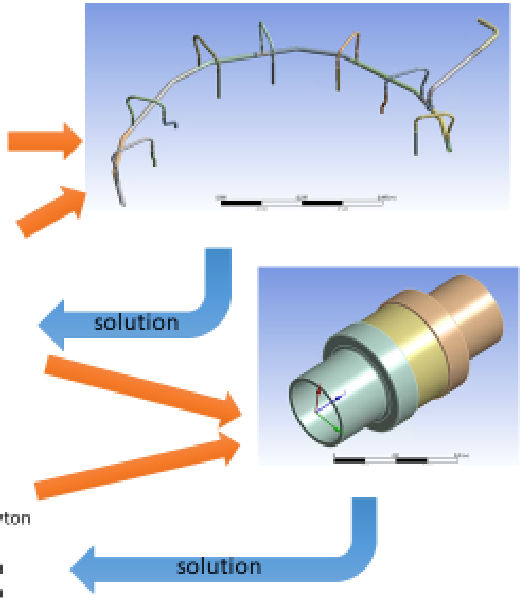


In order to find the best position for the Electric Brake we are considering different shapes, in order to minimize the forces. Model will be more detailed in the following.

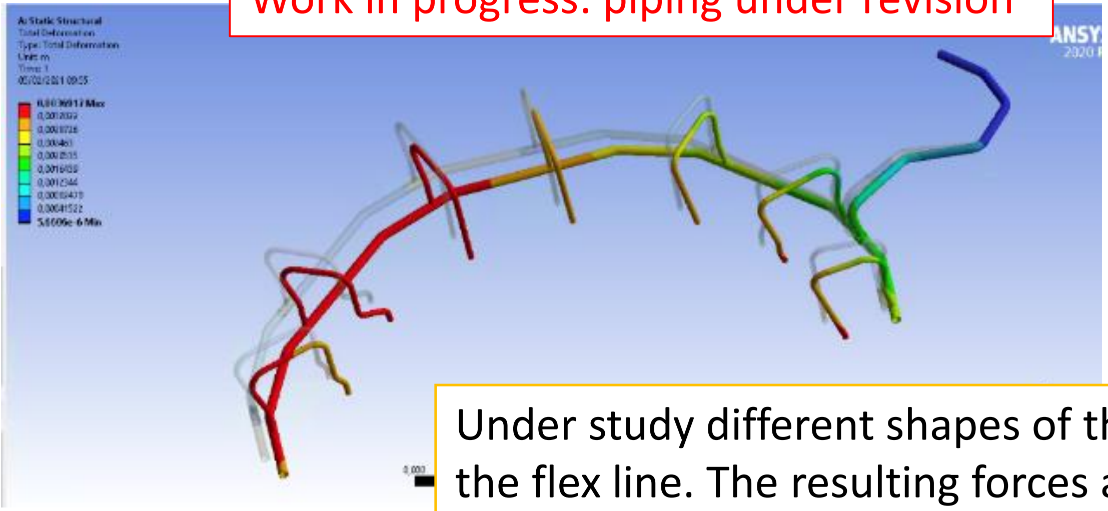
Study of the forces on the ceramic component

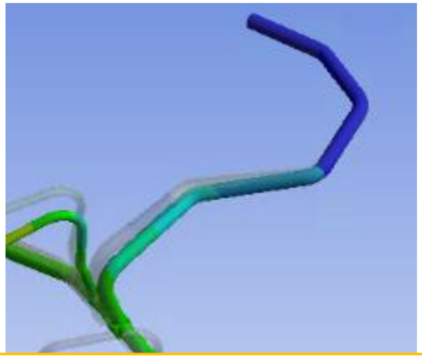


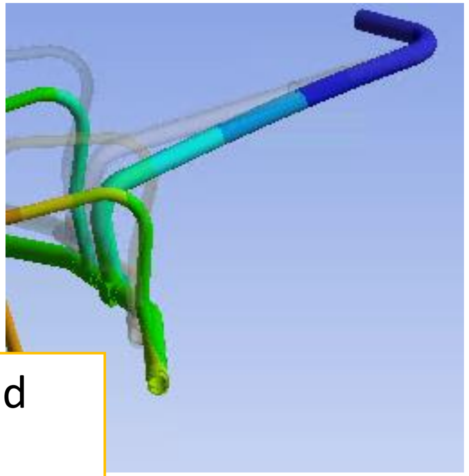
		Config 1	Config 2	
Constraints		Global Coordinates		
	CS_A	fix	fix	
	CS_Bs_X	free	0	
	CS_Bs_Y	free	0	
	CS_Bs_Z	-3	-3	mm
	CS_Bs_rotX	0	0	
	CS_Bs_rotY	0	0	
	CS_Bs_rotZ	0	0	
Loads				
	Th.	-55	-55	°C
Reaction		Local Coordinates		
	FX			N
	FY			N
	FZ			N
	MX			Nm
	MY			Nm
	MZ			Nm
El. Breake add. loads				
	Pressure	160	160	bar
	Th.	-55	-55	°C
	Axial force			Newton
Max Stress				
	El. Brake			MPa
	Ceramic			MPa



Work in progress: piping under revision







Under study different shapes of the pipe connecting the Exh. Manifold and the flex line. The resulting forces are applied to the electric breake, and compare them with allowable load coming from the EB designers.

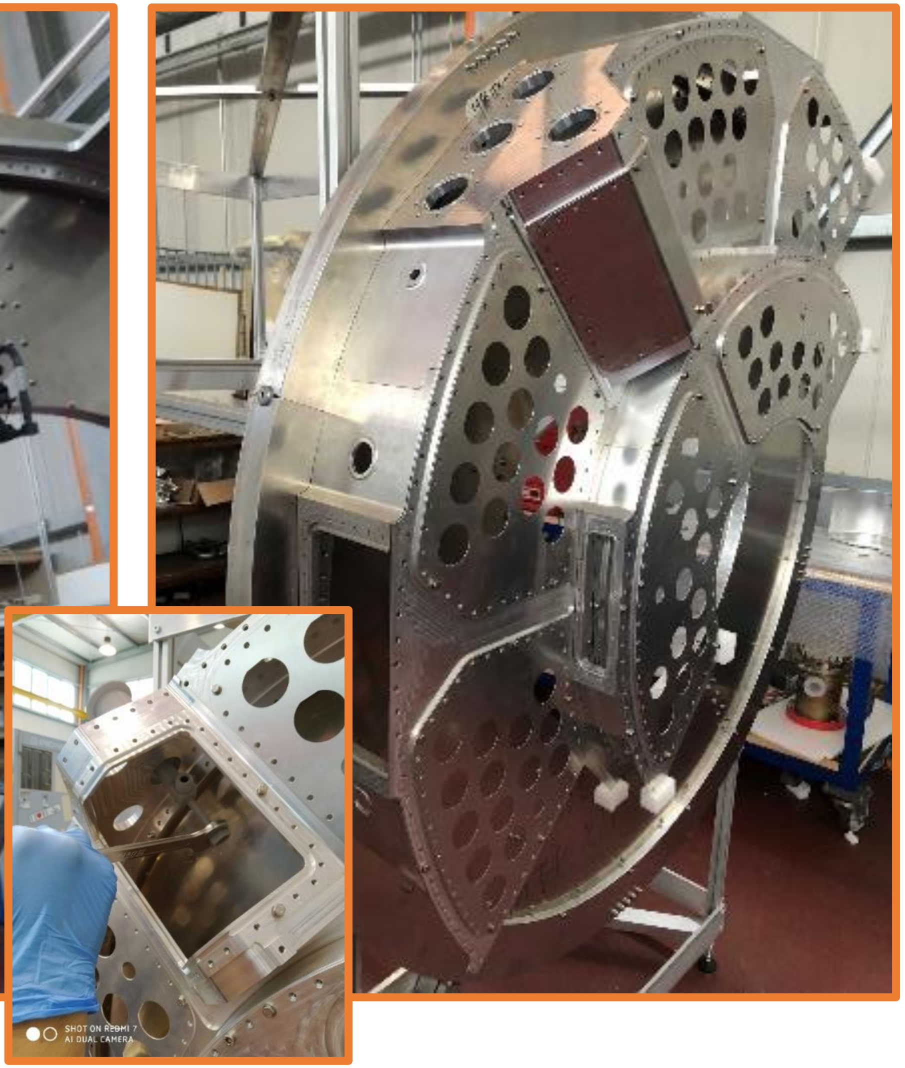
PP1 Mockup

Purpose:

- Simulate assembly procedure
- Rooming for pipes and cables
- Handling with the tools

Material: ASA, ABS

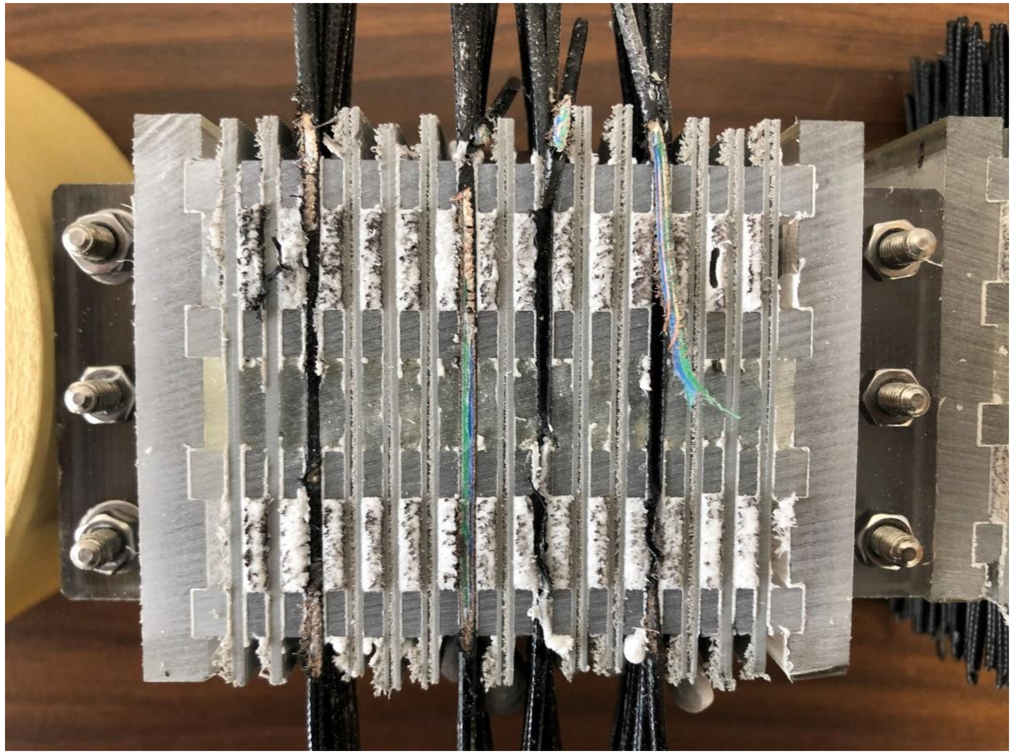
Populate with data cables in the future.



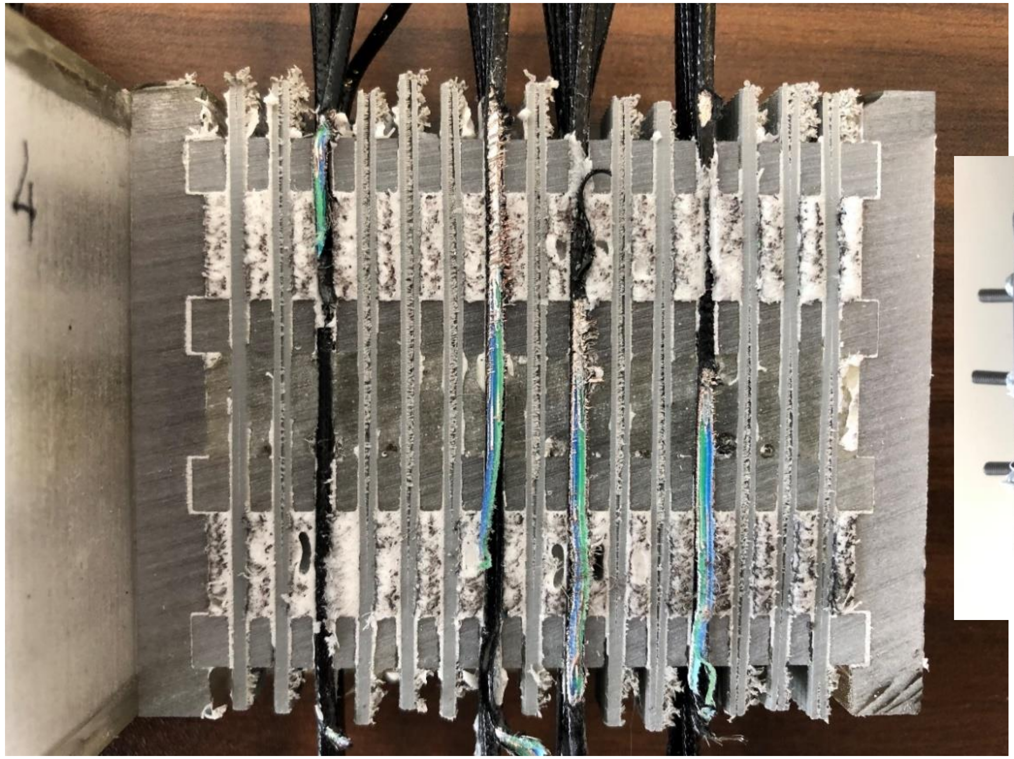
BACKUP SLIDES

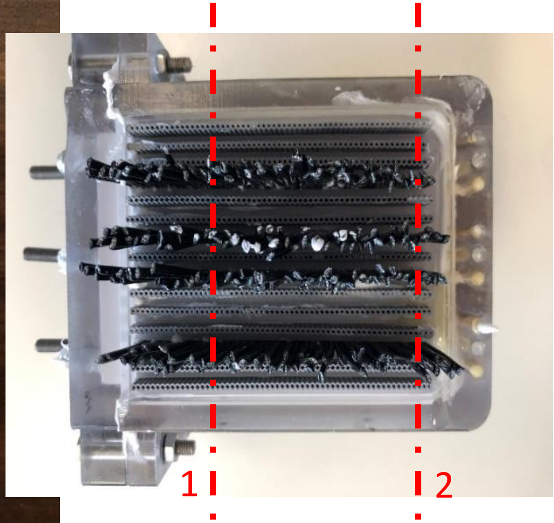
FILLING TEST

1



2





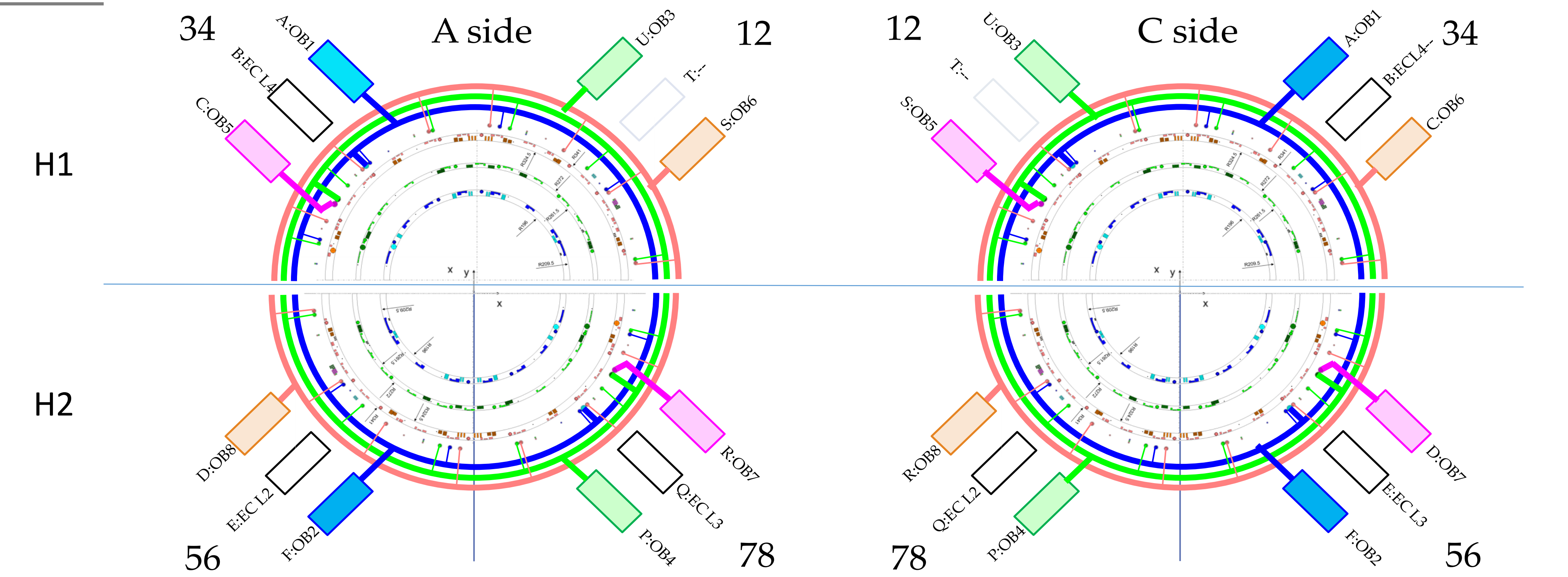
Result of sealing:

- Sectioned to verify the filling results.
- Preseal avoid resin leak.
- Araldite filled entirely the assigned volume.

Update after Diego Input

OS	Layer	Cooling Group /SIDE			Flexline #	#Longerons	# Inclined Half Rings	Power in Cooling Group [kW]* Nominal	High Power Scenario with SF	Plant 4 A side heat load abcdef	pqrstu	Plant 5 C side heatload abcdef	pqrstu
OBH1	OBH1-HL2	1-A	P4	a	P4a	4	6	2,762	3,314	2,762			
		1-C	P5	a	P5a	4	6	2,762	3,314			2,762	
	OBH1-HL3	3-A	P4	u	P4u	5	8	4,097	4,916		4,097		
		3-C	P5	u	P5u	6	8	4,511	5,414				4,511
	OBH1-HL4	5-A	P4	c	P4c	0	9	2,900	3,480	2,900			
		6-A	P4	s	P4s	7	0	2,900	3,480		2,900		
		5-C	P5	s	P5s	0	9	2,900	3,480				2,900
		6-C	P5	c	P5c	7	0	2,900	3,480			2,900	
OBH2	OBH2-HL2	2-A	P4	f	P4f	4	6	2,762	3,314	2,762			
		2-C	P5	f	P5f	4	6	2,762	3,314			2,762	
	OBH2-HL3	4-A	P4	p	P4p	6	8	4,511	5,414		4,511		
		4-C	P5	p	P5p	5	8	4,097	4,916				4,097
	OBH2-HL4	7-A	P4	r	P4r	0	9	2,900	3,480		2,900		
		8-A	P4	d	P4d	7	0	2,900	3,480	2,900			
		7-C	P5	d	P5d	0	9	2,900	3,480			2,900	
		8-C	P5	r	P5r	7	0	2,900	3,480				2,900
EC-HL2	HL2	2-A	P4	e	P4e			4,050	4,861	4,050			
EC-HL3	HL3	3-A	P4	q	P4q			4,050	4,861		4,050		
EC-HL4	HL4	4-A	P4	b	P4b			5,386	6,463	5,386			
EC-HL2	HL2	2-C	P5	q	P5q			4,050	4,861				4,050
EC-HL3	HL3	3-C	P5	e	P5e			4,050	4,861			4,050	
EC-HL4	HL4	4-C	P5	c	P5c			5,386	6,463			5,386	
										20,760	18,458	20,760	18,458
									Total:	39,218		39,218	
									Difference L/R	2,302		2,302	
									Differnce to nomi	1,151		1,151	

Final Configuration Update after meeting with Bart Nov-5th-21



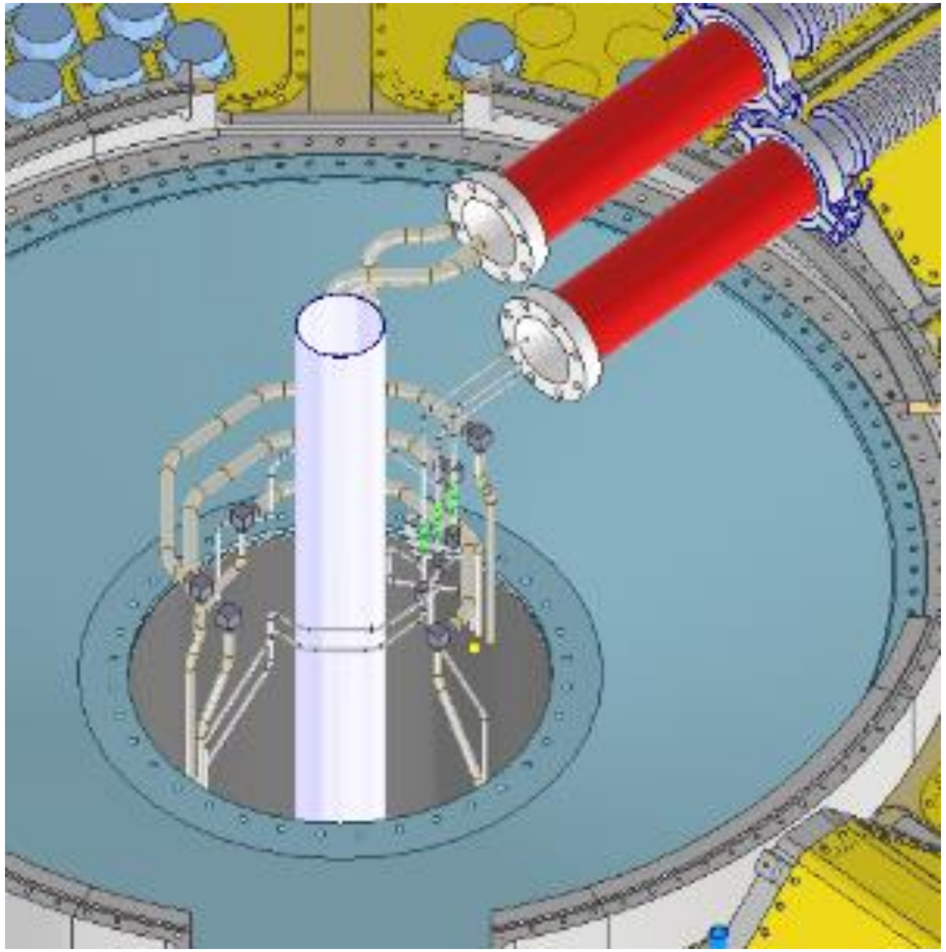
H2	H1
1-A	2-A
3-A	4-A
5-A	7-A
6-A	8-A

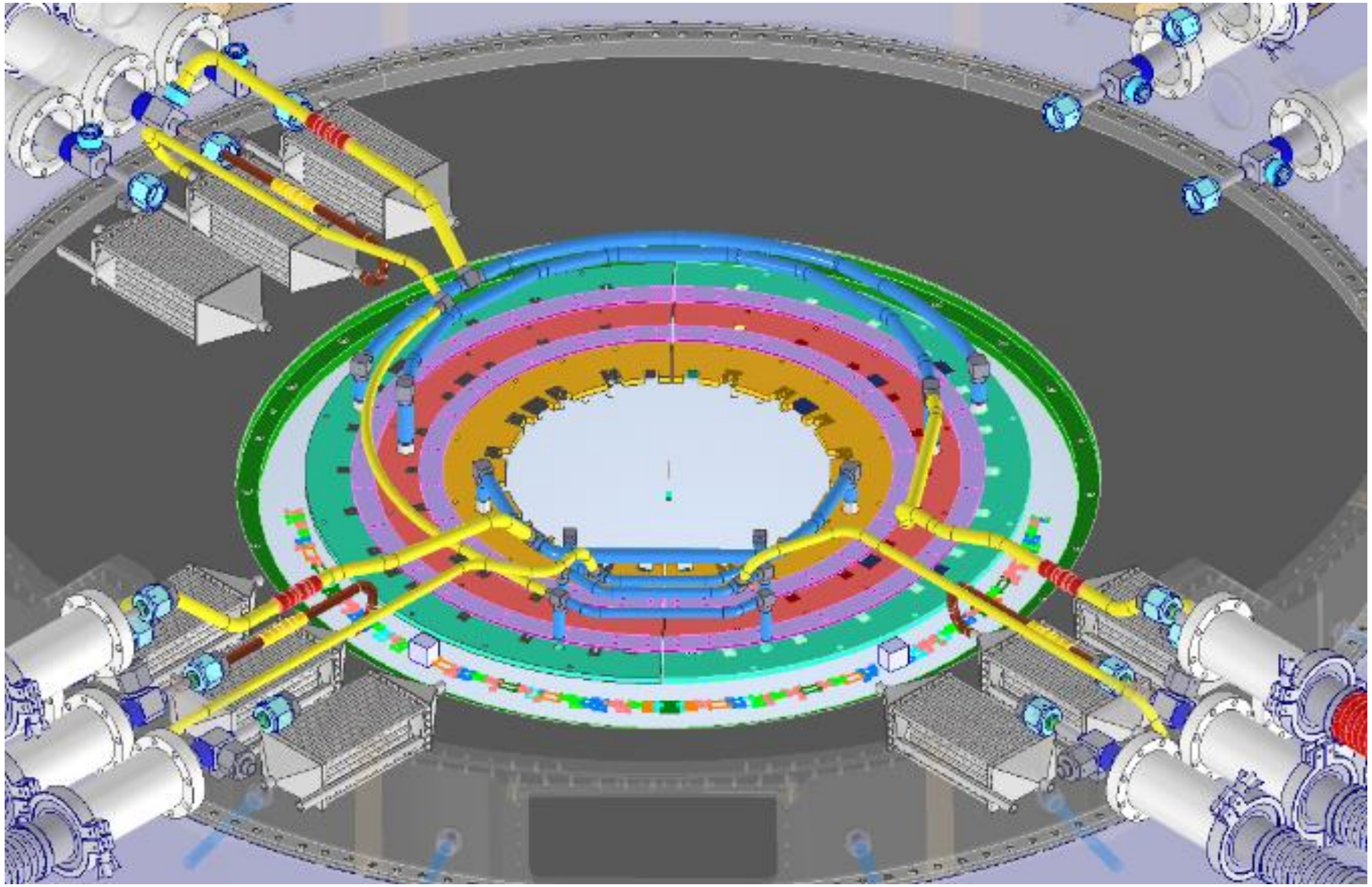
OB H1-H2 CG correspondence

Constraints:
Lines length as short as possible: OB-CG7, OB-CG5, EC-L4
Conditions:
OBH2 should be rotated (π) respect global Z axis to obtain OBH1
OB A-side should be rotated (π) respect global Y axis to obtain C-side
EC should be symmetric respect global XY plane to obtain C-side

- All constraints complied (OB-CG7, OB-CG5, EC-L4)
- OB lines not satisfy the OB conditions:
  - Side AH1: OB-CG1 <-> OB-CG3
  - Side CH1: OB-CG1 <-> OB-CG3
  - Side CH2: OB-CG4 <-> OB-CG2
- EC not symetric for ECL2 and ECL3 side A- side C

Inner System and Endcap Manifolds

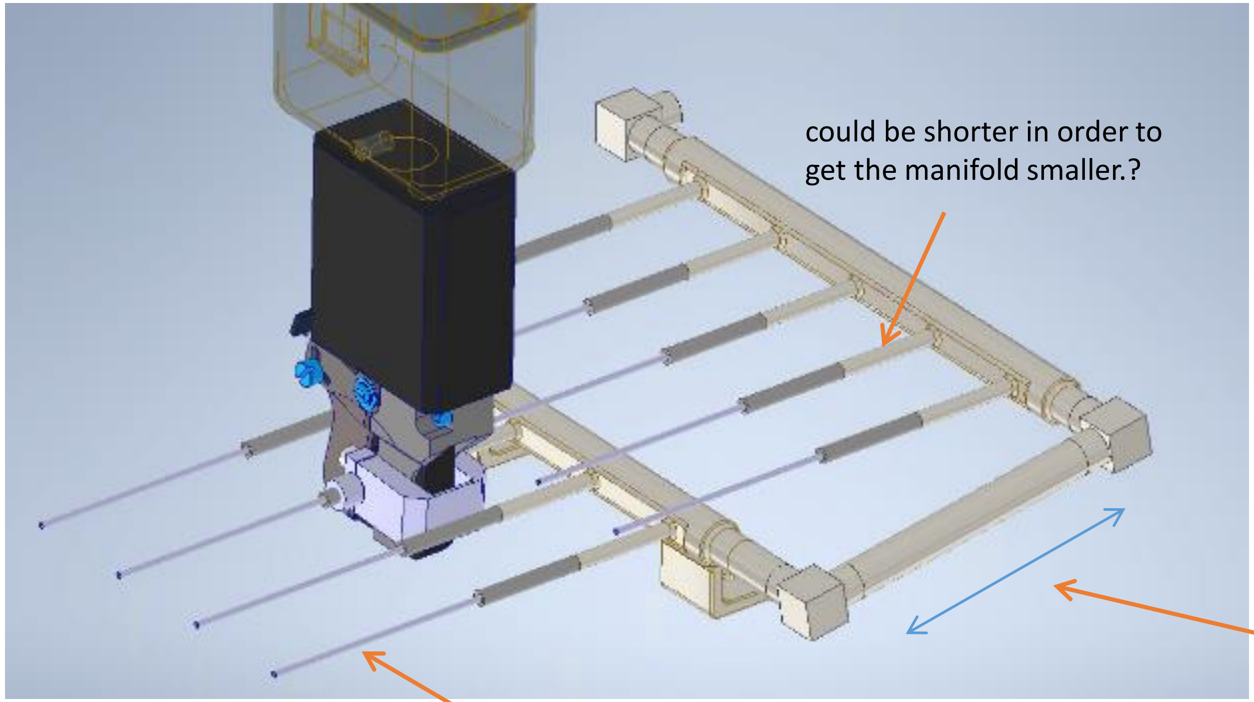




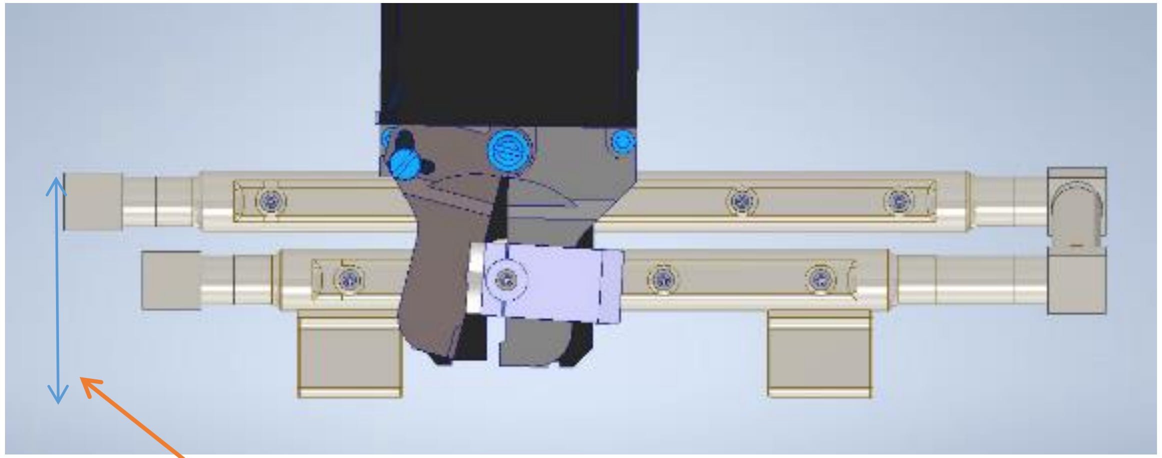
4. welding feasibility

- Questions:
- Do the capillaries have to be workable (for repairing) once installed?
- Can we weld and test half capillaries (the below ones) before and then the others?
- Can we eventually dismount from the BH and repair?
- Can we assembly them after they are tested?

- Vista dall'alto per far capire che lo spazio ci sarebbe

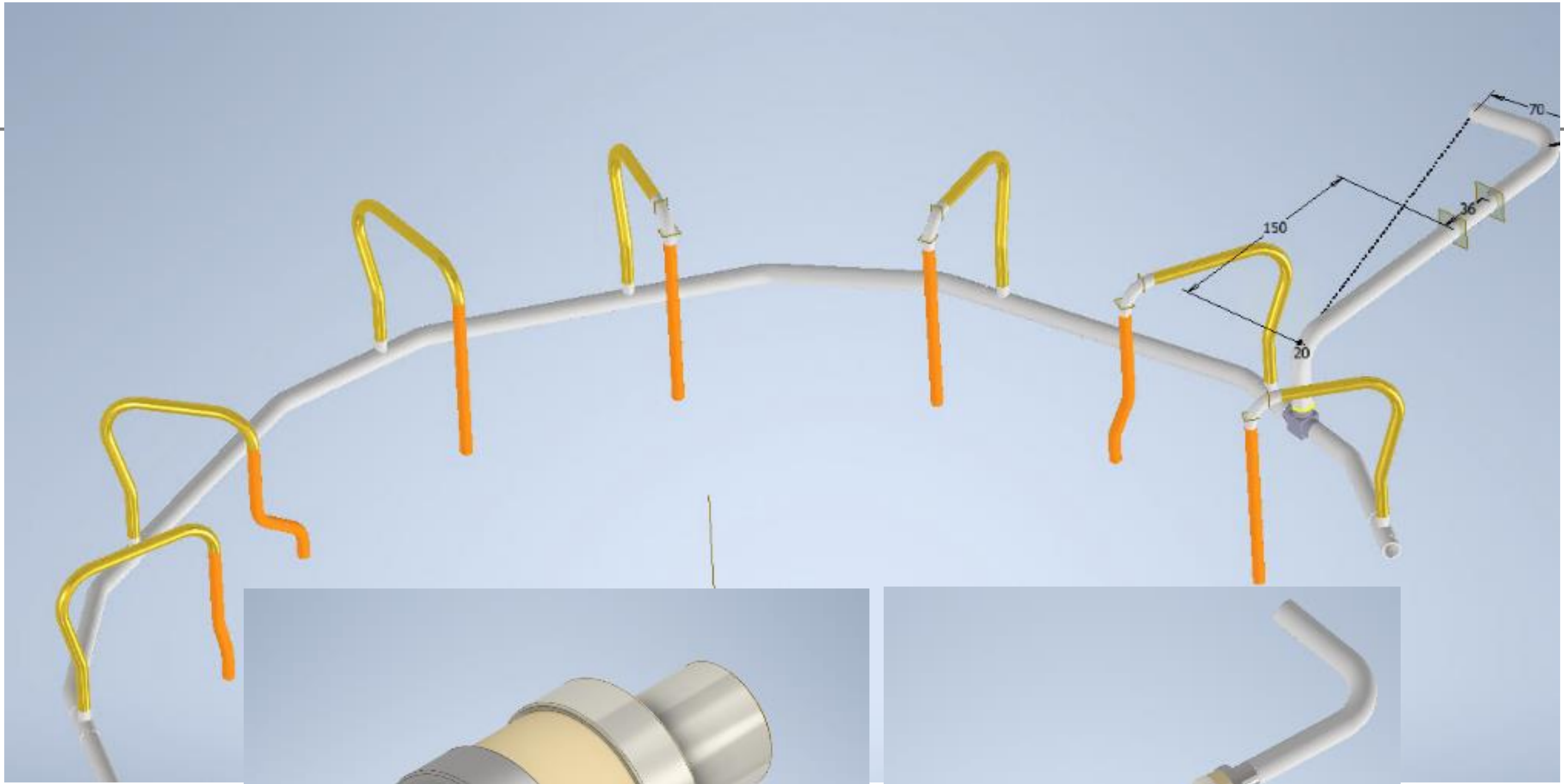


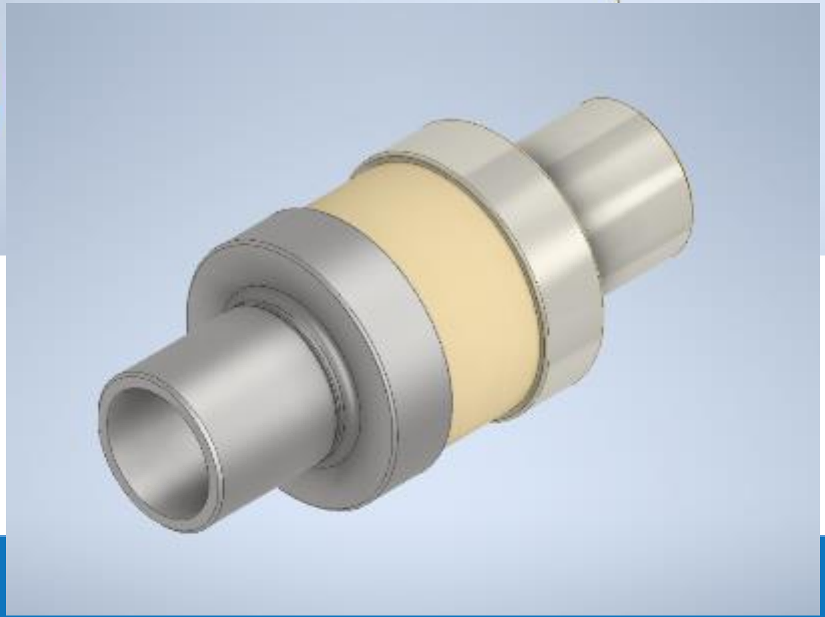
Design_1



wider but shorter in z

Bending radius?


70
36
150
20



Materials

	A	B
1	Temperature (C)	Tensile Yield Strength (Pa)
2	23	3,451E+07
*		

Accuratus MACOR Machinable Glass Ceramic

Physical Properties	Metric	English
Density	2.52 g/cc	0.0910 lb/in³
Porosity	0.00 %	0.00 %

Mechanical Properties	Metric	English
Modulus of Elasticity	66.9 GPa	9700 ksi
Flexural Strength	94.0 MPa	13600 psi
Compressive Strength	345 MPa	50000 psi
Poissons Ratio	0.29	0.29
Fracture Toughness	1.53 MPa-m½	1.39 ksi-in½
Shear Modulus	25.5 GPa	3700 ksi

Electrical Properties	Metric	English
Volume Resistivity	>= 1.00e+14 ohm-cm	>= 1.00e+14 ohm-cm
Dielectric Constant	6.0 @Frequency 1000 Hz	6.0 @Frequency 1000 Hz
Dielectric Strength	40.0 kV/mm	1020 kV/in
Dielectric Loss Index	0.0050 @Frequency 1000 Hz	0.0050 @Frequency 1000 Hz

Thermal Properties	Metric	English
CTE, linear	12.6 µm/m-°C	7.00 µin/in-°F
Specific Heat Capacity	0.790 J/g-°C	0.189 BTU/lb-°F
Thermal Conductivity	1.50 W/m-K	10.4 BTU-in/hr-ft²-°F
Maximum Service Temperature, Air	1000 °C	1830 °F

Descriptive Properties		
Color		White

Titanium Grade 2 Annealed

Physical Properties	Metric	English	Comments
Density	4.51 g/cc	0.163 lb/in³	

Mechanical Properties	Metric	English	Comments
Hardness, Brinell	200	200	
Hardness, Rockwell B	98	98	
Tensile Strength	193 MPa @Temperature 316 °C	28000 psi @Temperature 601 °F	
Tensile Strength, Ultimate	430 MPa	62400 psi	
Tensile Strength, Yield	340 MPa	49300 psi	
Elongation at Break	28 %	28 %	
Rupture Strength	>= 138 MPa @Temperature 316 °C, Time 3.60e+6 sec	>= 20000 psi @Temperature 601 °F, Time 1000 hour	
Tensile Modulus	102 GPa	14800 ksi	
Modulus of Rigidity	38.6 GPa	5600 ksi	
Compressive Yield Strength	340 MPa	49300 psi	
Compressive Modulus	110 GPa	16000 ksi	
Notched Tensile Strength	720 MPa	104000 psi	K_t (stress concentration factor) = 3.0
Ultimate Bearing Strength	930 MPa	135000 psi	e/D = 2
Bearing Yield Strength	660 MPa	95700 psi	e/D = 2
Poissons Ratio	0.34	0.34	
Fatigue Strength	240 MPa @# of Cycles 1.00e+7	34800 psi @# of Cycles 1.00e+7	K_t (stress concentration factor) = 2.7
	280 MPa @# of Cycles 1.00e+7	40600 psi @# of Cycles 1.00e+7	unnotched
Shear Modulus	38.0 GPa	5510 ksi	
Shear Strength	380 MPa	55100 psi	Ultimate shear strength
Charpy Impact	65.0 J	47.9 ft-lb	V-notch
Bend Radius, Minimum	2.5 t @Thickness >=1.80 mm	2.5 t @Thickness >=0.0709 in	

Electrical Properties	Metric	English	Comments

Stainless Steel

AISI 316 Cast Stainless Steel, EN 10088-3

Categories: Metal; Ferrous Metal; Stainless Steel; Cast Stainless Steel; T 300 Series Stainless Steel

Material Notes: Austenitic, hot or cold formed

Key Words: EN 10088-3:1995; X5CrNiMo17-12-2

Vendors: No vendors are listed for this material. Please click here if you are a supplier and would like information on how to add your listing to this

Printer friendly version Download as PDF Download to Excel (requires Excel and Windows)

Export data to your CAD/FEA program

Mechanical Properties	Metric	English
Tensile Strength, Ultimate	500 - 700 MPa	72500 - 102000 psi
Tensile Strength, Yield	>= 200 MPa	>= 29000 psi
Elongation at Break	>= 40 %	>= 40 %

Component Elements Properties	Metric	English
Carbon, C	<= 0.070 %	<= 0.070 %
Chromium, Cr	16.5 - 18.5 %	16.5 - 18.5 %
Iron, Fe	62.86 - 71.5 %	62.86 - 71.5 %
Manganese, Mn	<= 2.0 %	<= 2.0 %
Molybdenum, Mo	2.0 - 2.5 %	2.0 - 2.5 %
Nickel, Ni	10 - 13 %	10 - 13 %
Phosphorus, P	<= 0.040 %	<= 0.040 %
Silicon, Si	<= 1.0 %	<= 1.0 %
Sulfur, S	<= 0.030 %	<= 0.030 %

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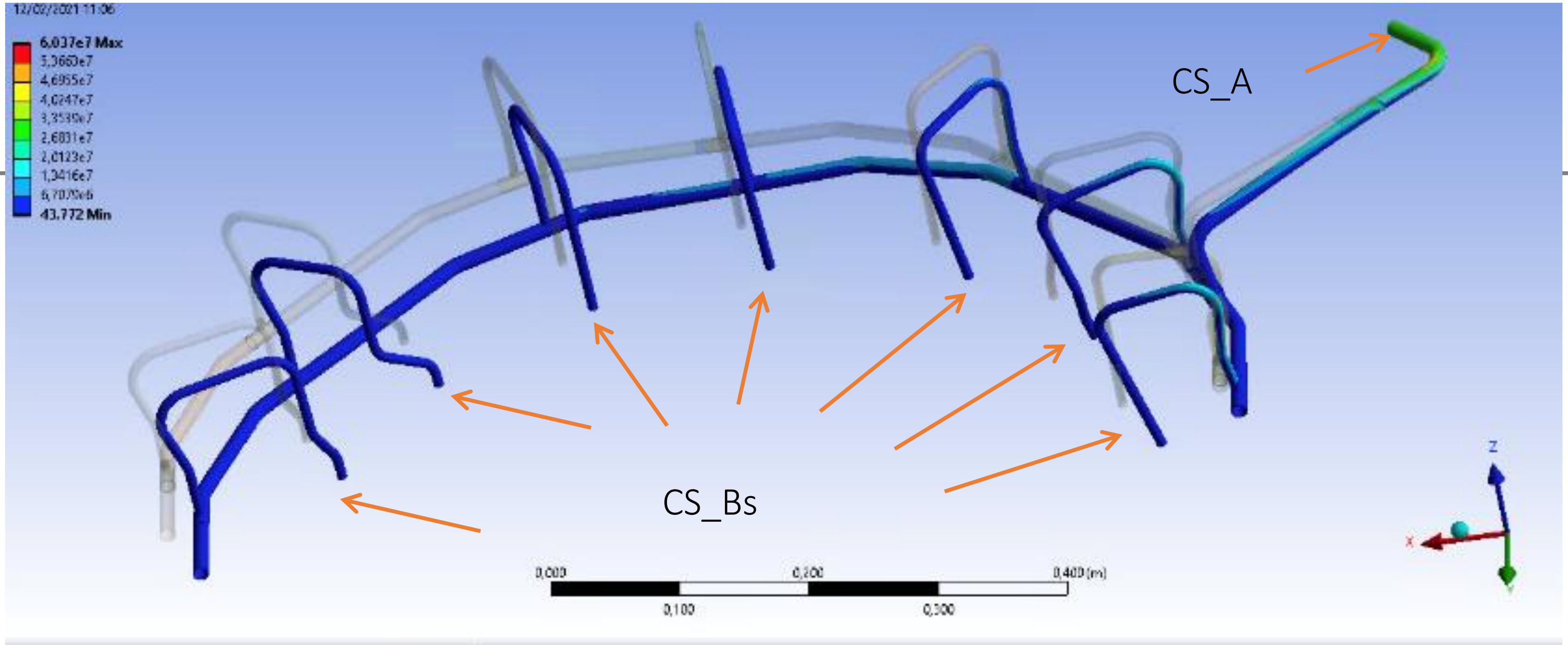
AISI 316 Cast Stainless Steel, ASTM A276 Hot Formed
316 Stainless Steel, annealed sheet
316 Stainless Steel, annealed bar



Config 1	Config 2	Config 3	Config 4
Constraints	Constraints	Constraints	Constraints
CS_A: fix	CS_A: fix	CS_A: fix	CS_A: fix
CS_Bs X, Y: free Z: -3mm rot x, rot y, rot z:0	CS_Bs X, Y: 0 Z: -3mm rot x, rot y, rot z:0	CS_Bs X, Y, Z: 0 rot x, rot y, rot z:0	CS_Bs X, Y: only in phi Z: -3mm rot x, rot y, rot z:0
Loads: Th.:-55°C	Loads: Th.:-55°C	Loads: Th.:-55°C	Loads: Th.:-55°C