

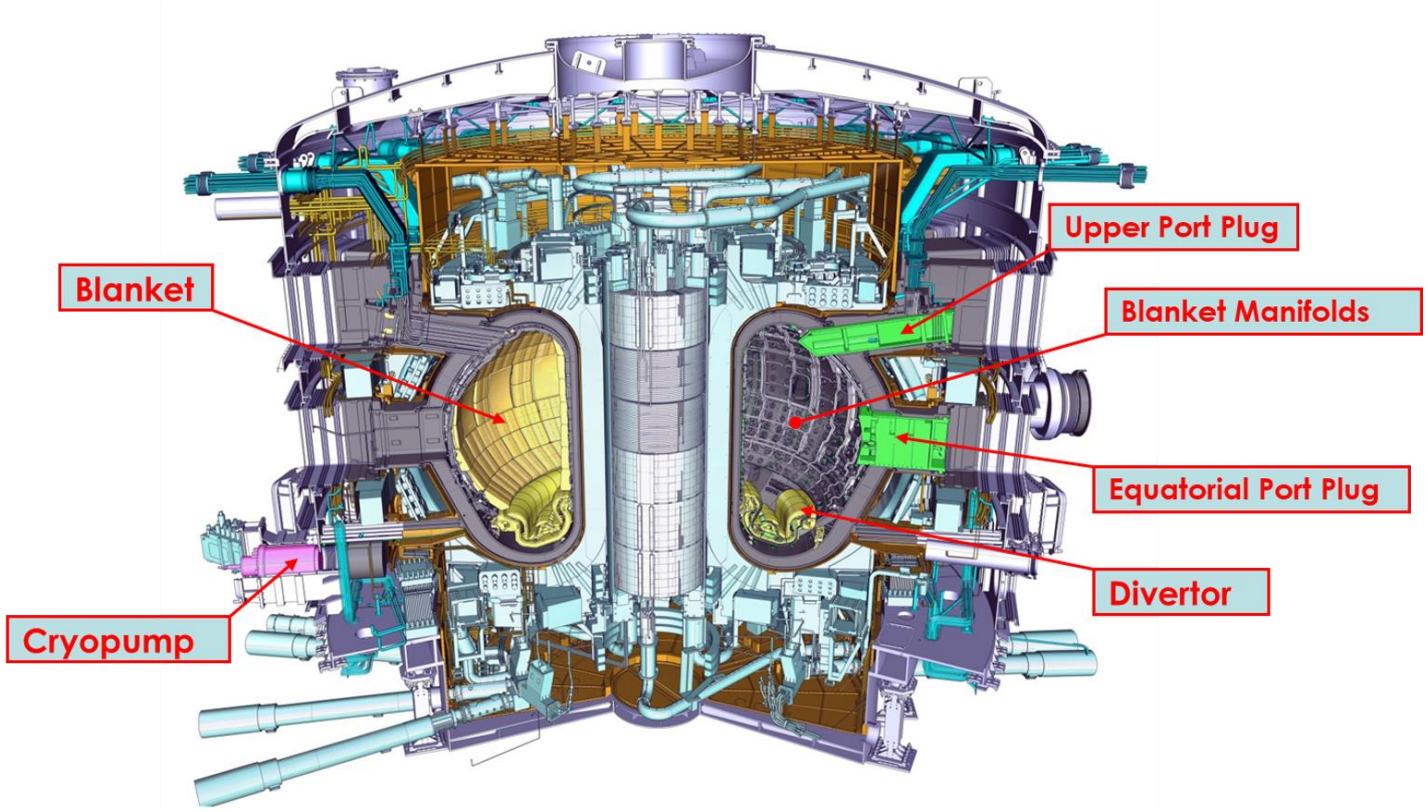
Assessment of inflatable seals concept for the ITER Remote Handling equipment

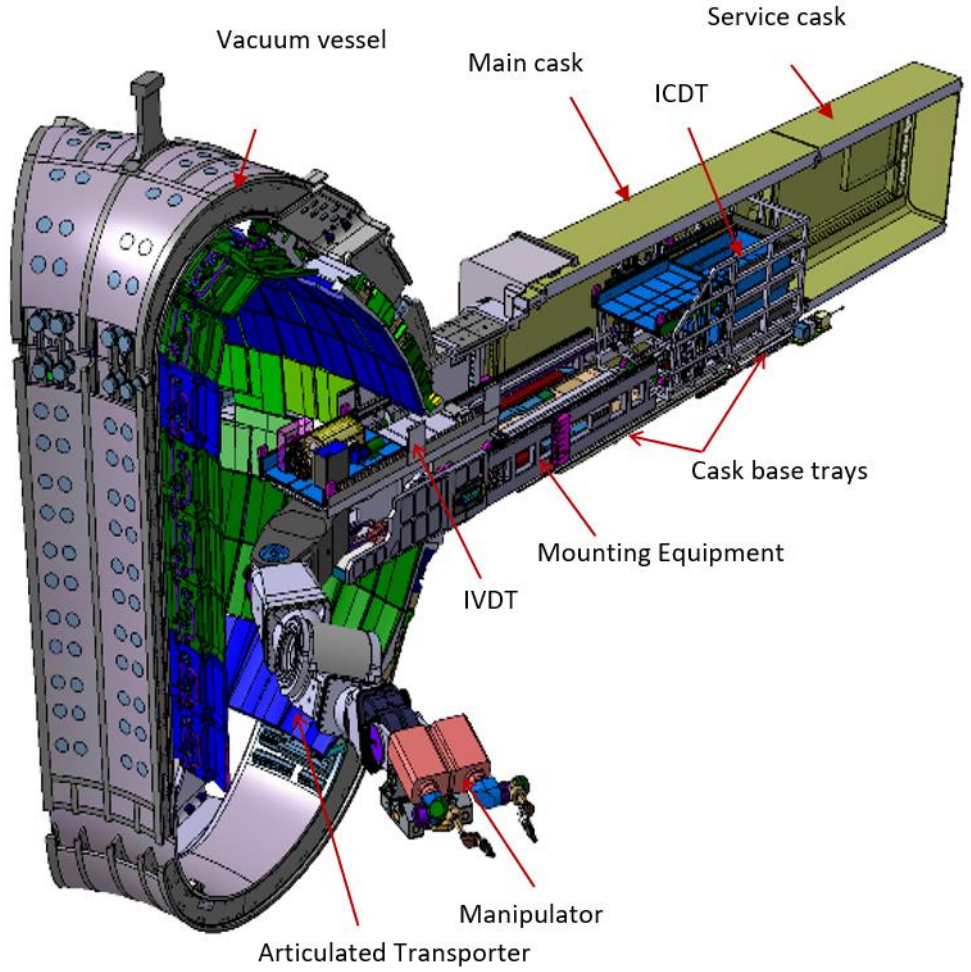
J. Esnoz Larraya, J-P. Martins, M. Battaglia ***ITER ORGANIZATION***
D. Locke, E.Ruiz ***Fusion For Energy***
I. Valiente, D. Lopez, O. Manzano, E. Díez ***Universidad de Alcalá***

iter
china eu india japan korea russia usa

ITER Remote Handling System

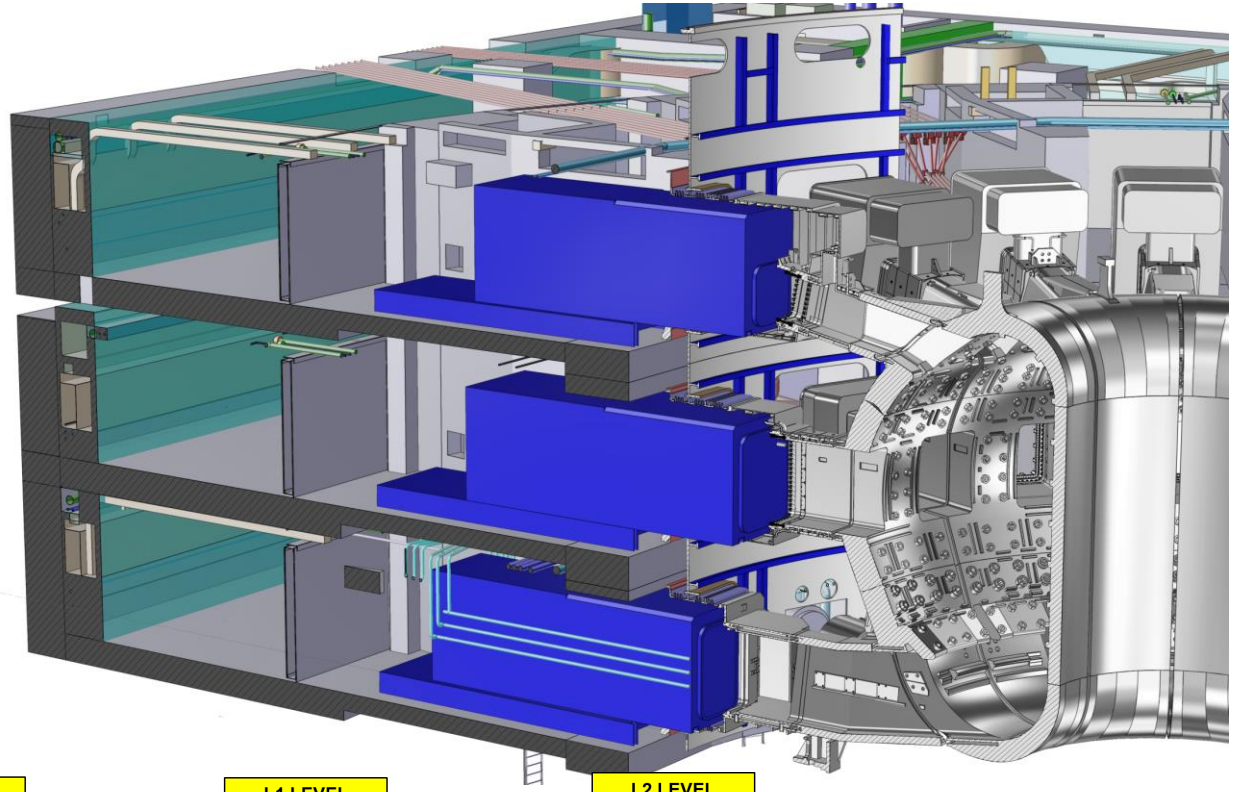
In charge of the future repair, inspection and maintenance of ITER in-vessel components to be carried out remotely due to radiation and contamination.

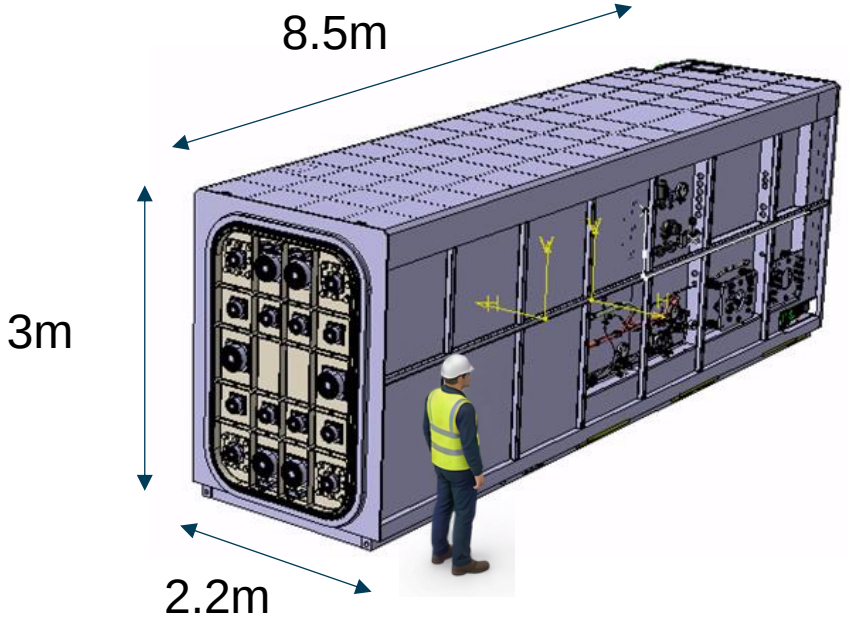


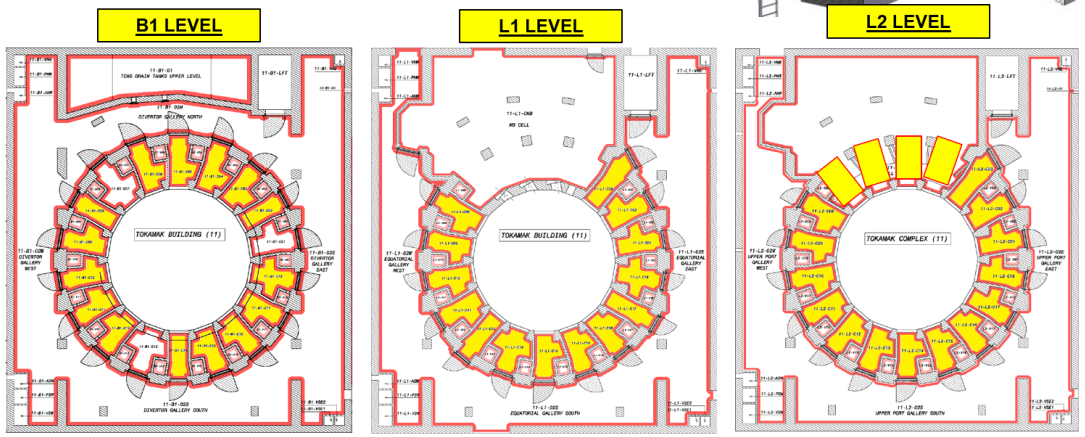


Cask and Plug Remote Handling System (CPRHS)

A cask is a transport container used to deploy Remote Handling robots into the Vacuum Vessel and to safely carry in-vessel components to the Hot Cell facility.







- # 6 - Cryopump
- # 6 - IVVS
- # 3 - Divertor

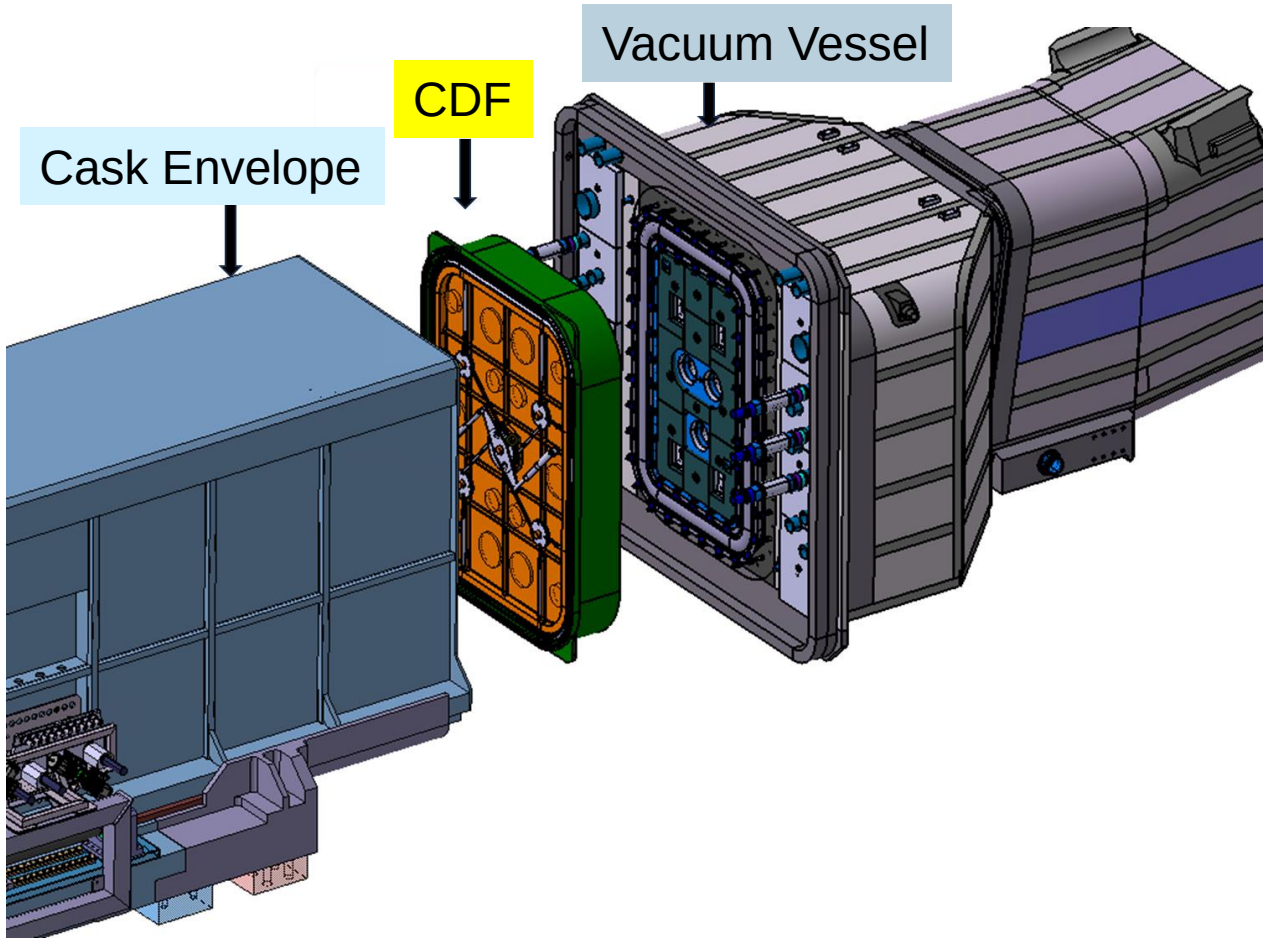
- # 14 - Equatorial

- # 14 - Upper
- # 4 - NB Upper

Cask Docking Flange (CDF)

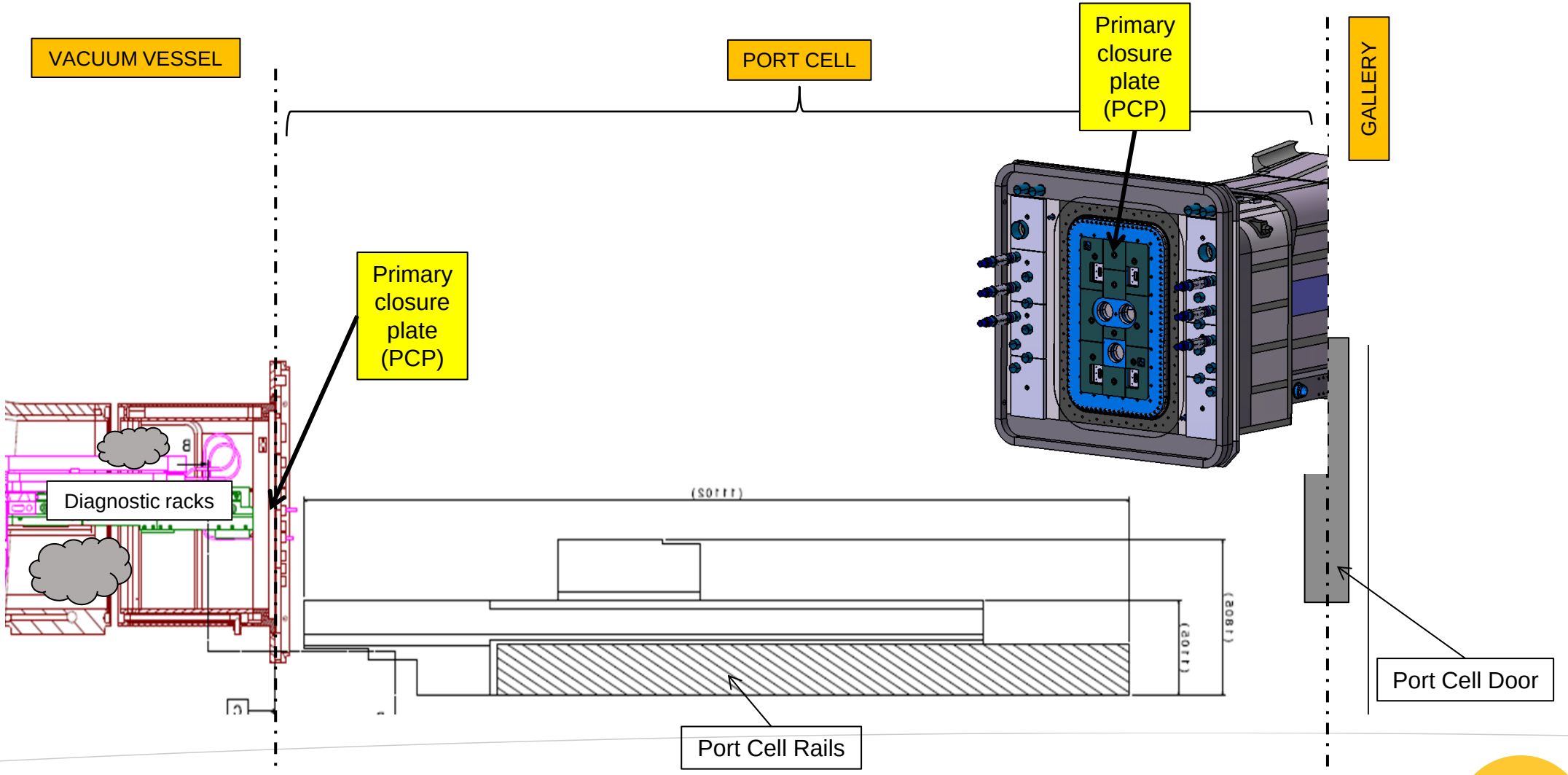
- Provides temporary mechanical coupling between the Vacuum Vessel and the Cask to support remote handling operations and component transfers.

- Provides a leak tight connection, in conjunction with VV dynamic confinement system, to the controlled area boundary.



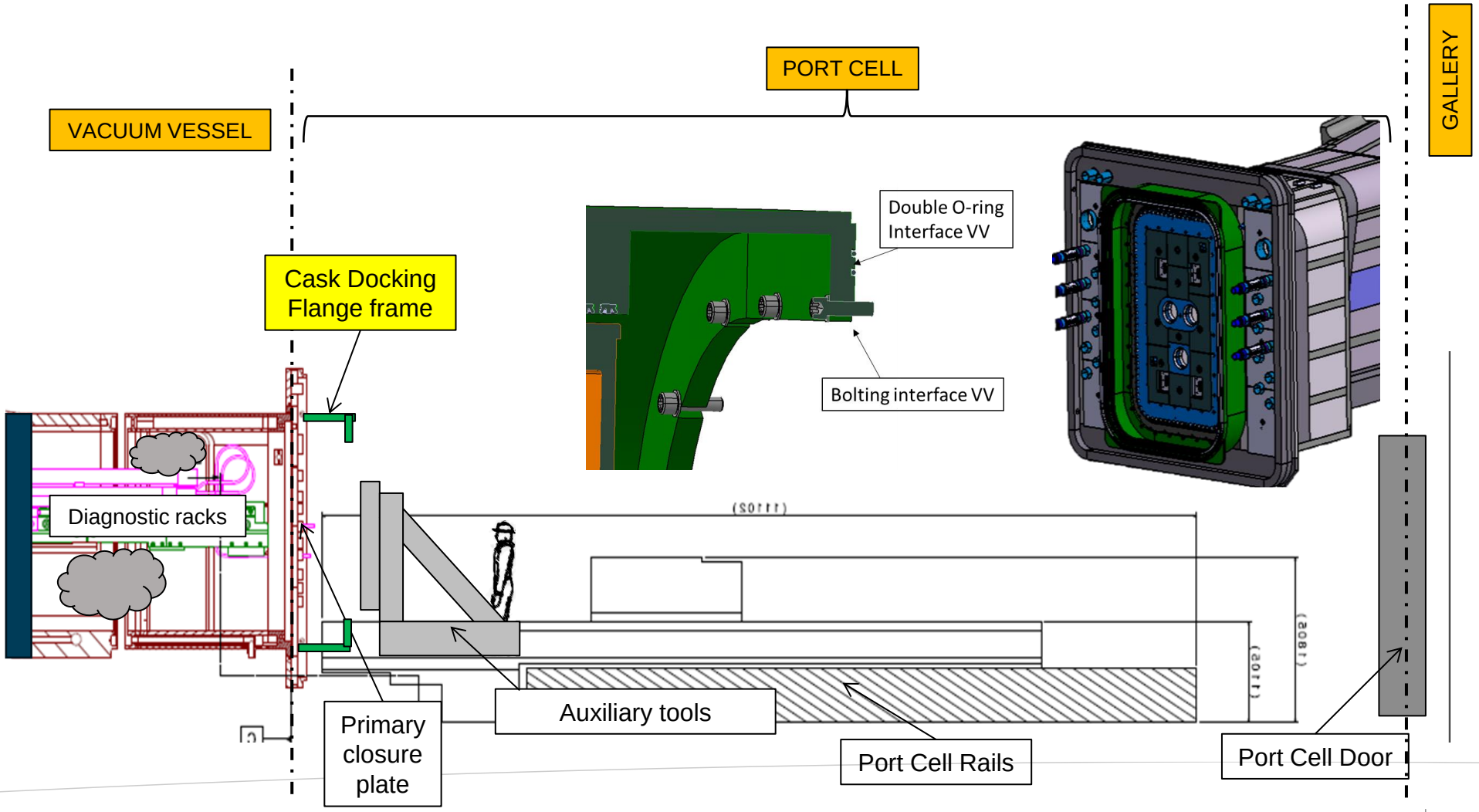
Cask Docking Flange (CDF) operational sequence

Starting Configuration



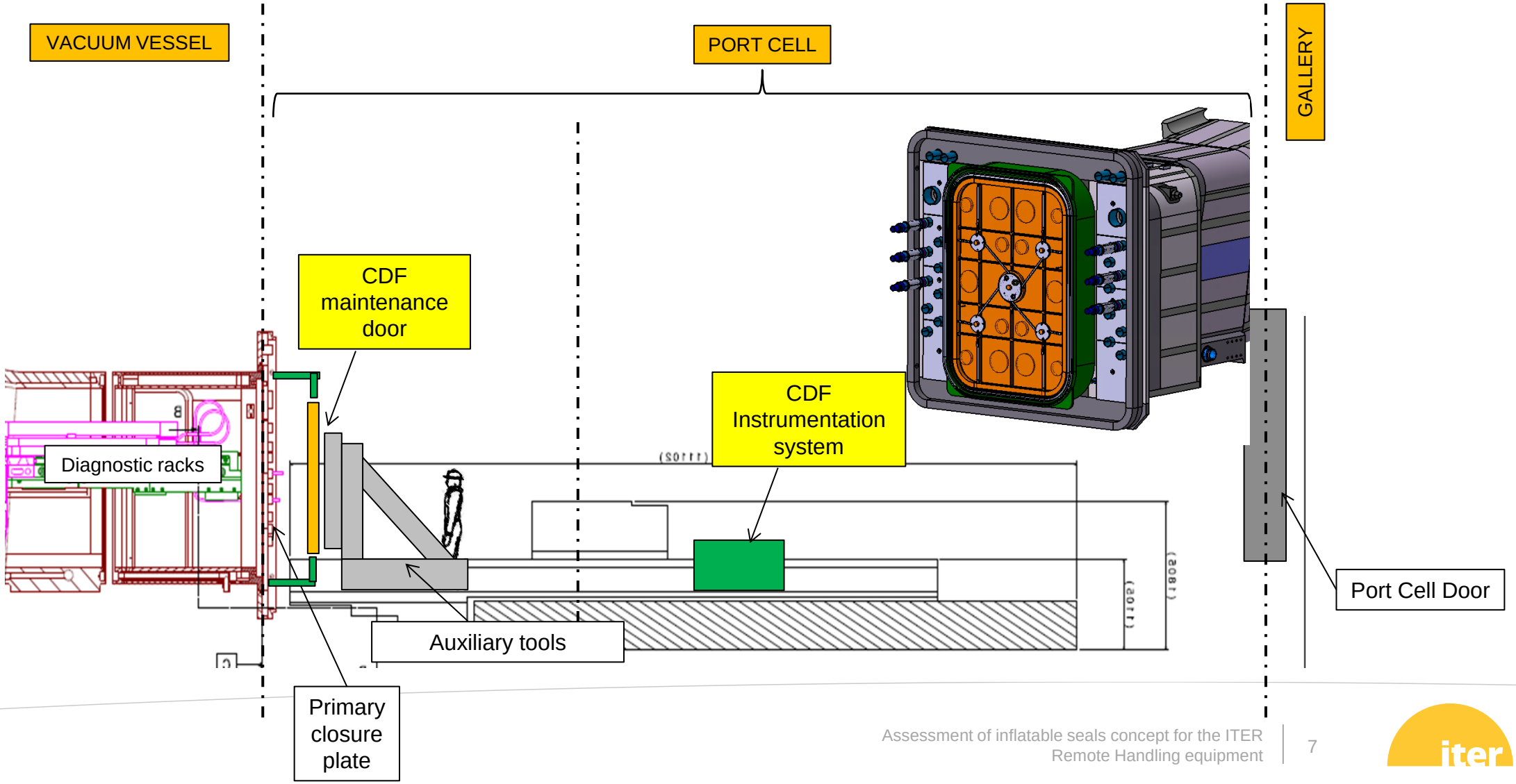
Cask Docking Flange (CDF) operational sequence

CDF frame installation



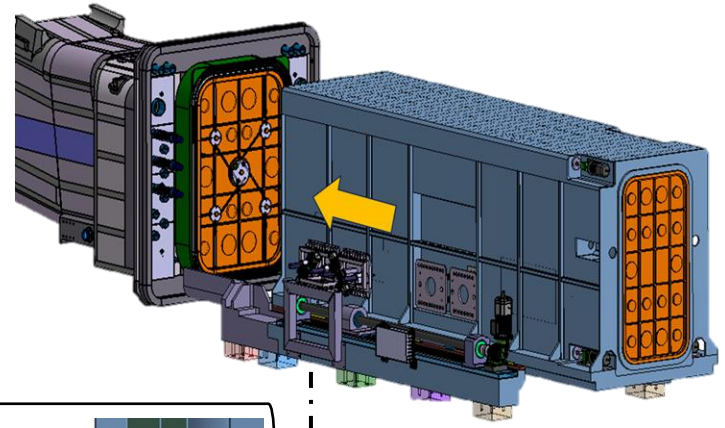
Cask Docking Flange (CDF) operational sequence

CDF door installation



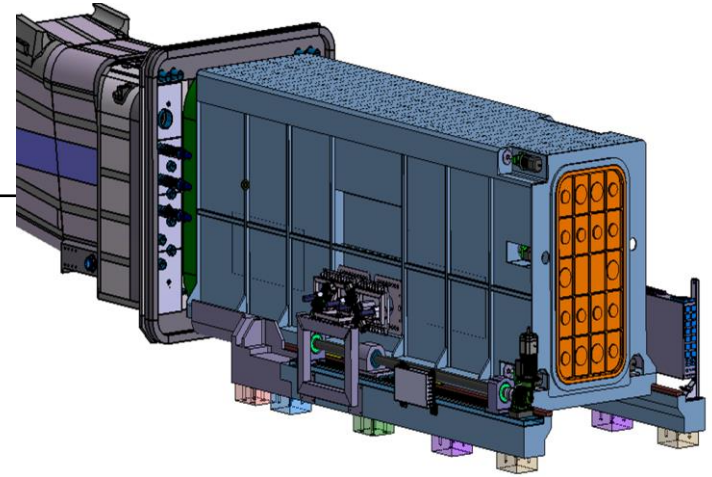
Cask Docking Flange (CDF) operational sequence

Cask Envelop System docking (CES)



Cask Docking Flange (CDF) operational sequence

In-vessel operations

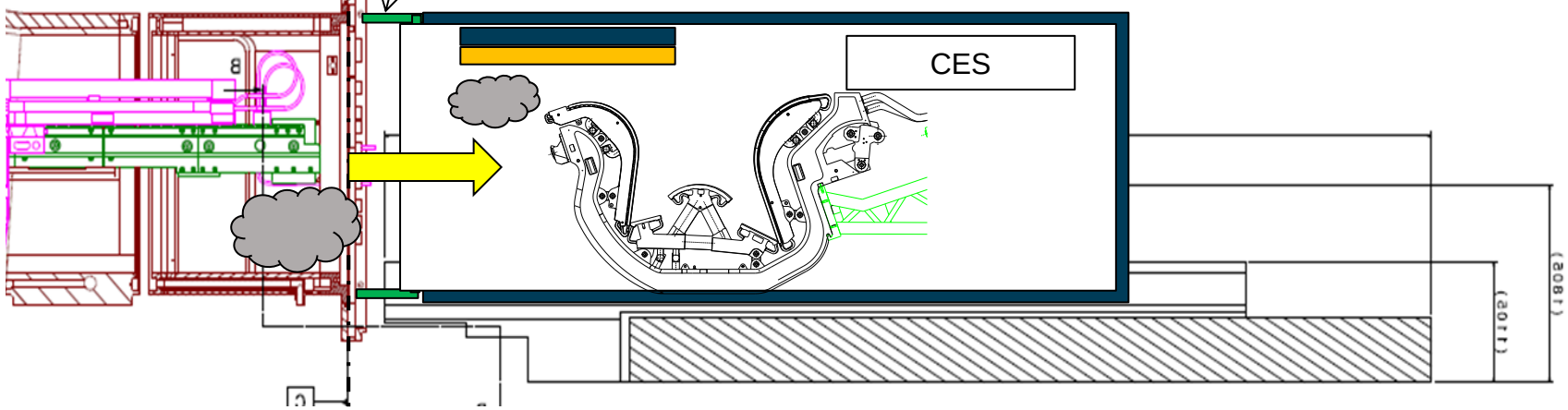


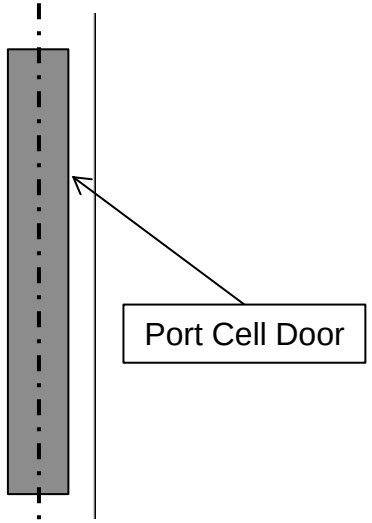
PORT CELL

VACUUM VESSEL

- PCP removal
- Diagnostic rack removal/ Replacement
- Divertor cassettes removal

CDF

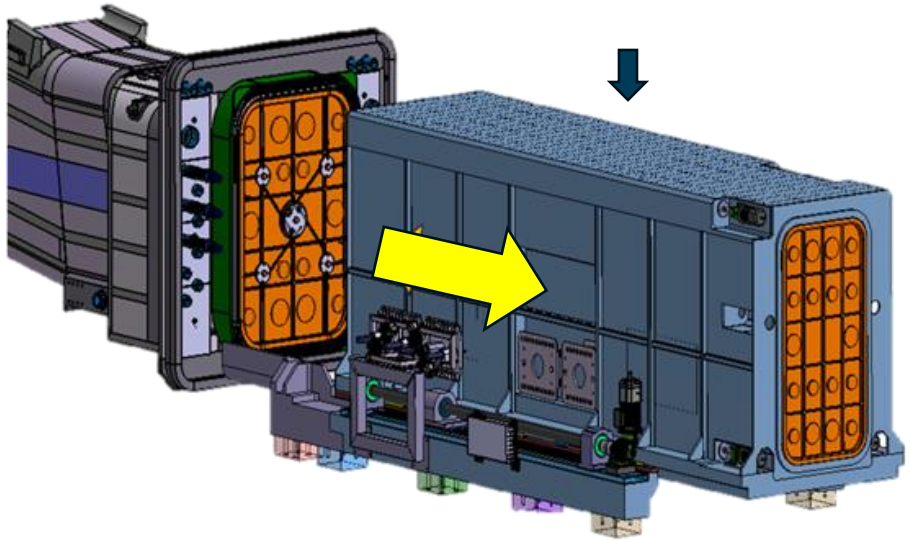


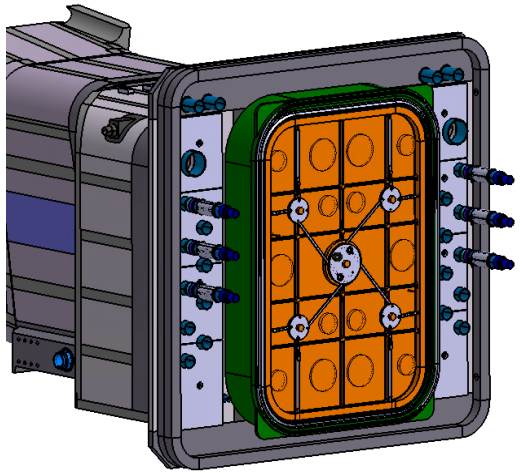


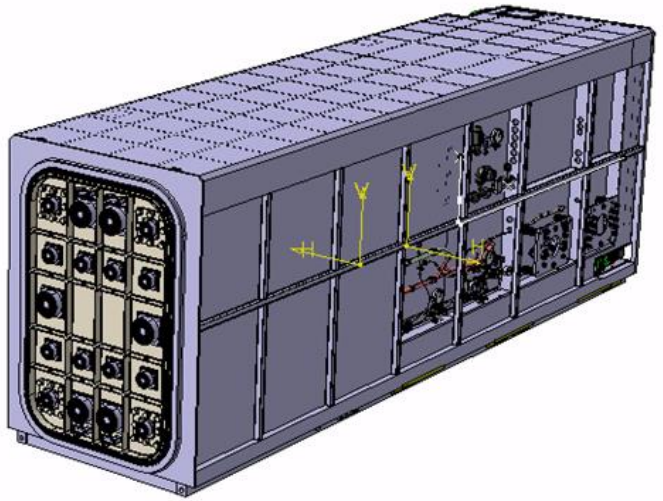
Cask Docking Flange (CDF) operational sequence

CES undock, going to Hot Cell Facility

CES inerted with N_2 -2000Pa







- Primary closure plate removed
- Static confinement of PC performed by CDF

- CES travelling through galleries with In-Vessel components

Experimental Objectives



Can inflatable seals provide reliable confinement under realistic docking misalignments and operational conditions?.

How quickly do we need to recover a failed cask if stuck in the gallery before its internal pressure equalizes ?

Minimum pressure to inflate the seal? Affected by temperature? Affected by misalignment?

Mock-up principles

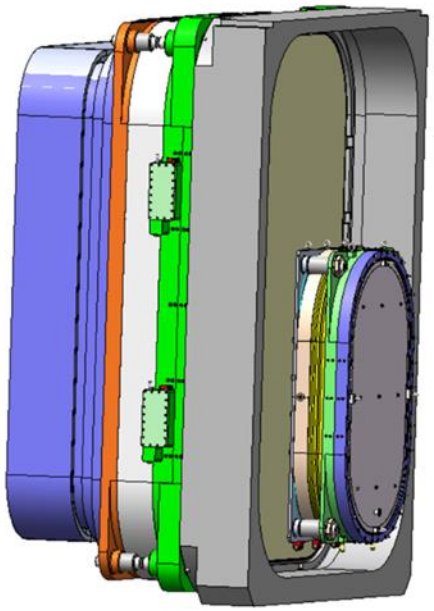
- Mock-up with limited scope → scale version
- Test with different temperatures (RT, 35°C, 50°C)
- Test with a single seal/ double seal
- Test XY misalignment up to 4mm
- Test tilting misalignments up to 0.5 degrees
- Test under different vacuum levels up to -2000Pa

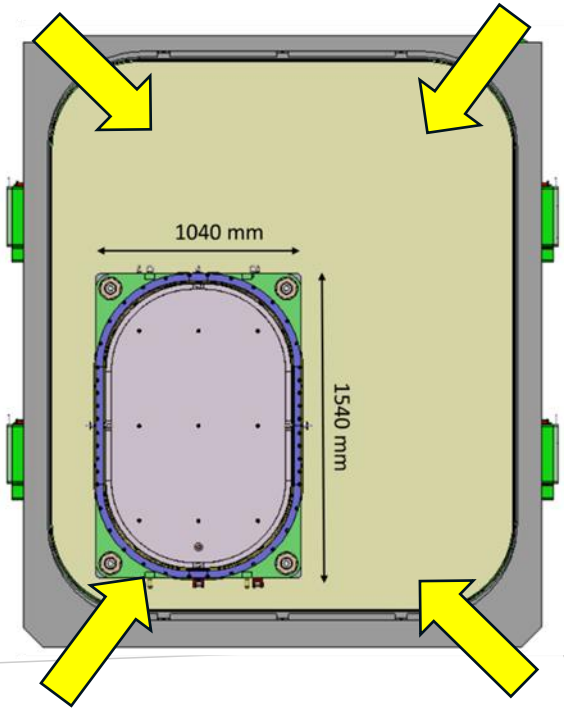
Performance leak tightness measurement by

pressure change method in ISO 10648-2

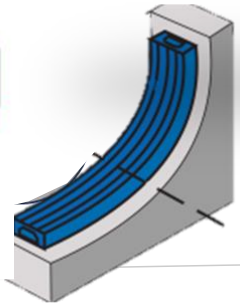
$$Hourly\ Leak\ rate\ T_f\ is\ equal\ to:$$

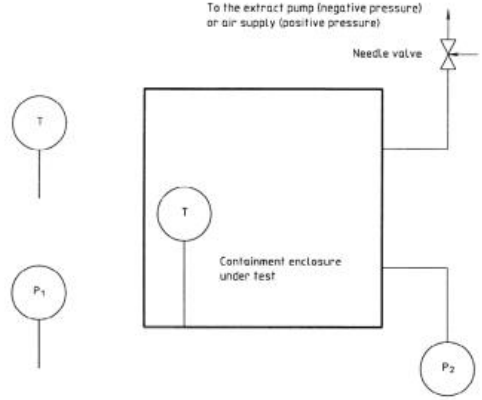
$$T_f = \frac{60}{t} x \left(\frac{P_n T_1}{P_1 T_n} - 1 \right)$$











VALIDITY RANGE according to ISO 10648-2

- Internal temperature variations < 0,3ºC
- Atmospheric pressure variations < 100 Pa
- Internal pressure variation< 30%

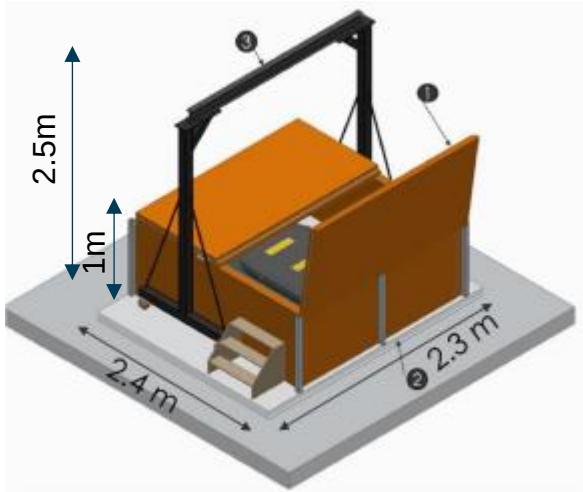
Mock-up Design, Manufacturing and Testing

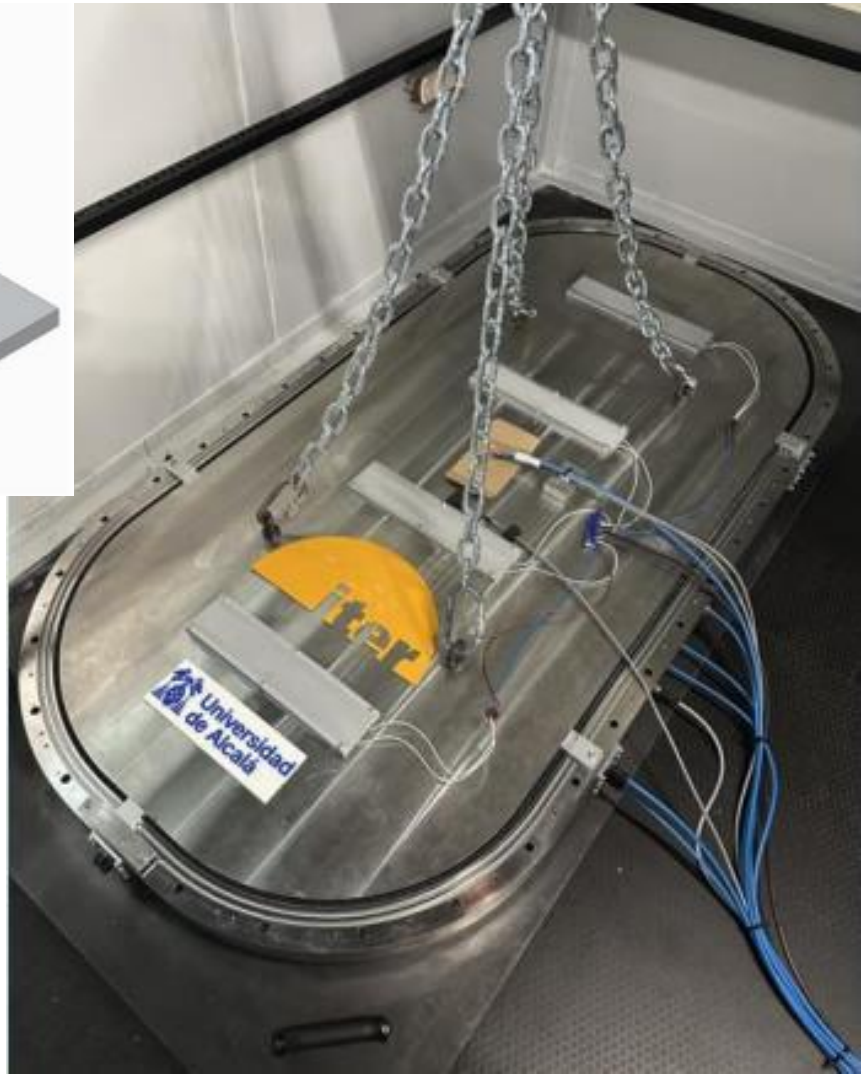
Scaled door +frame (AISI 304)

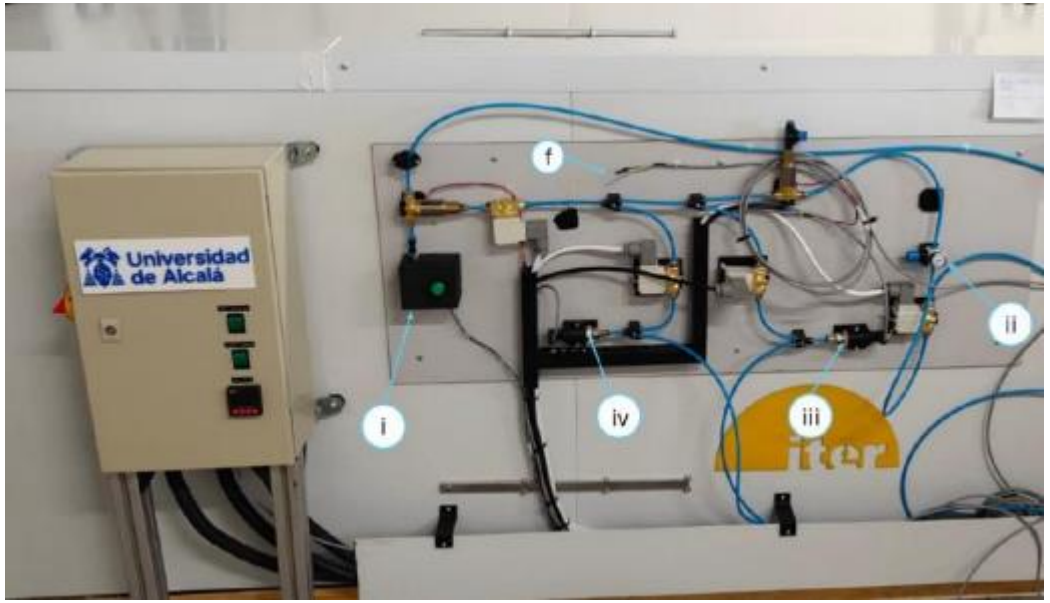
Dedicated Testbench to test up to 50ºC

Leak Survey and Pressure control System (LSPCS)

- Test Accuracy <10Pa
- Temperature accuracy < 0,1ºC
- Vacuum up to -2000Pa *-5000Pa by design





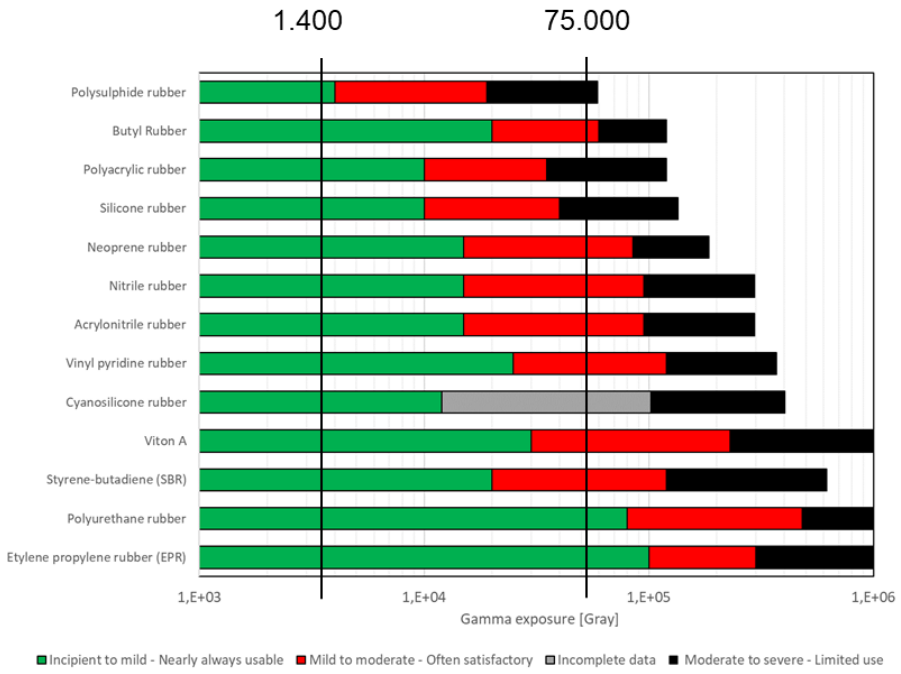


Mechanical, Electrical and Thermal Engineering research group, Universidad de Alcala

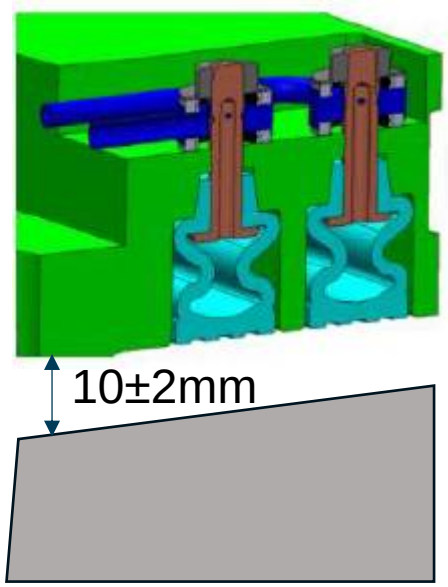
Inflatable seal

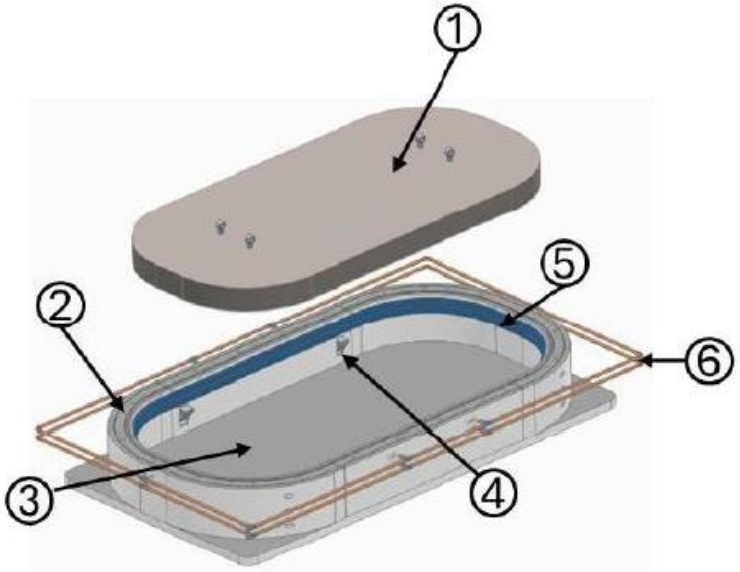
Double seal concept EPDM from **Technetics group**

Elastomer type	ASTM ISO name	Shore range	Operational T° range [°C]	Peak T° [°C]	Properties
Ethylene propylene-diene rubber (ethylene-propylene copolymer)	EPDM,	45-85	-45 to 150	170	• Very good heat behavior • Very good wear resistance • Very good low-temperature performance • Very good radiation resistance • Low permeance

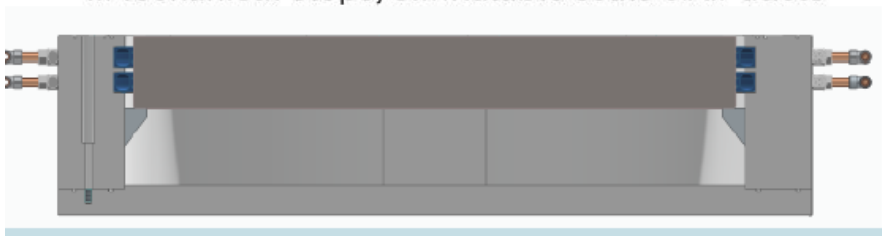


Inflatable seal size 24.5x21

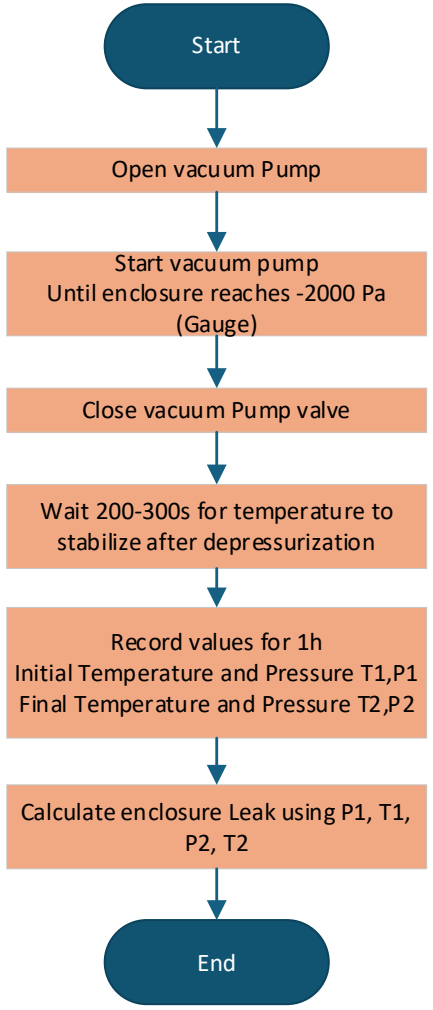


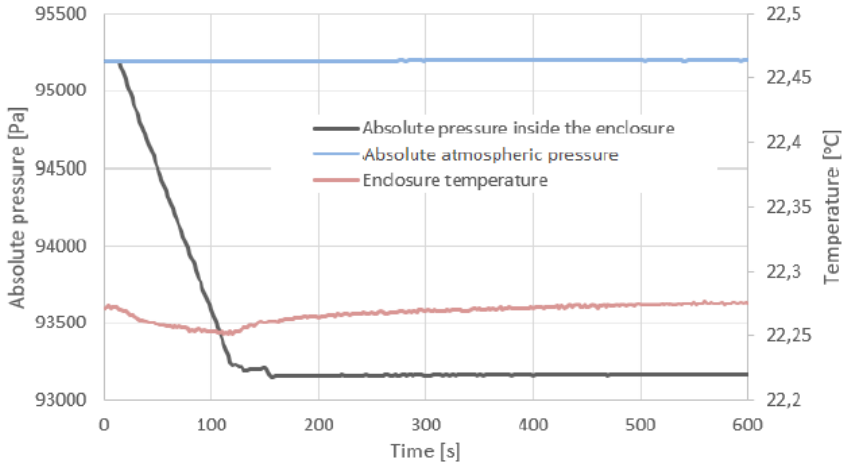


1. Door, 2.Compliant frame, 3.Rear frame/deposit, 4.Mechanical stops, 5.Inflatable seals 6.Air ducts

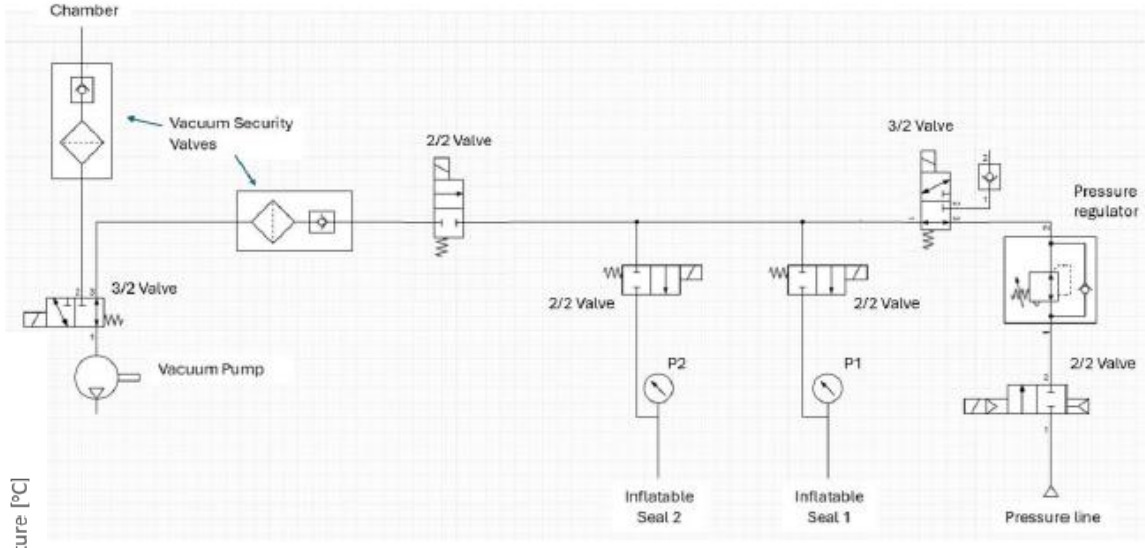


Test Procedure



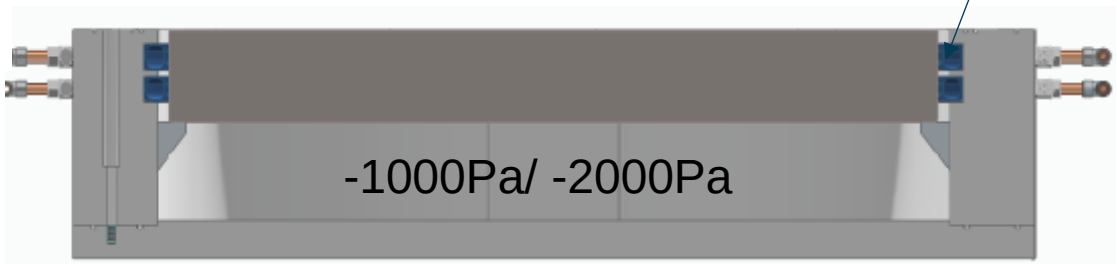


Pneumatic circuit and components

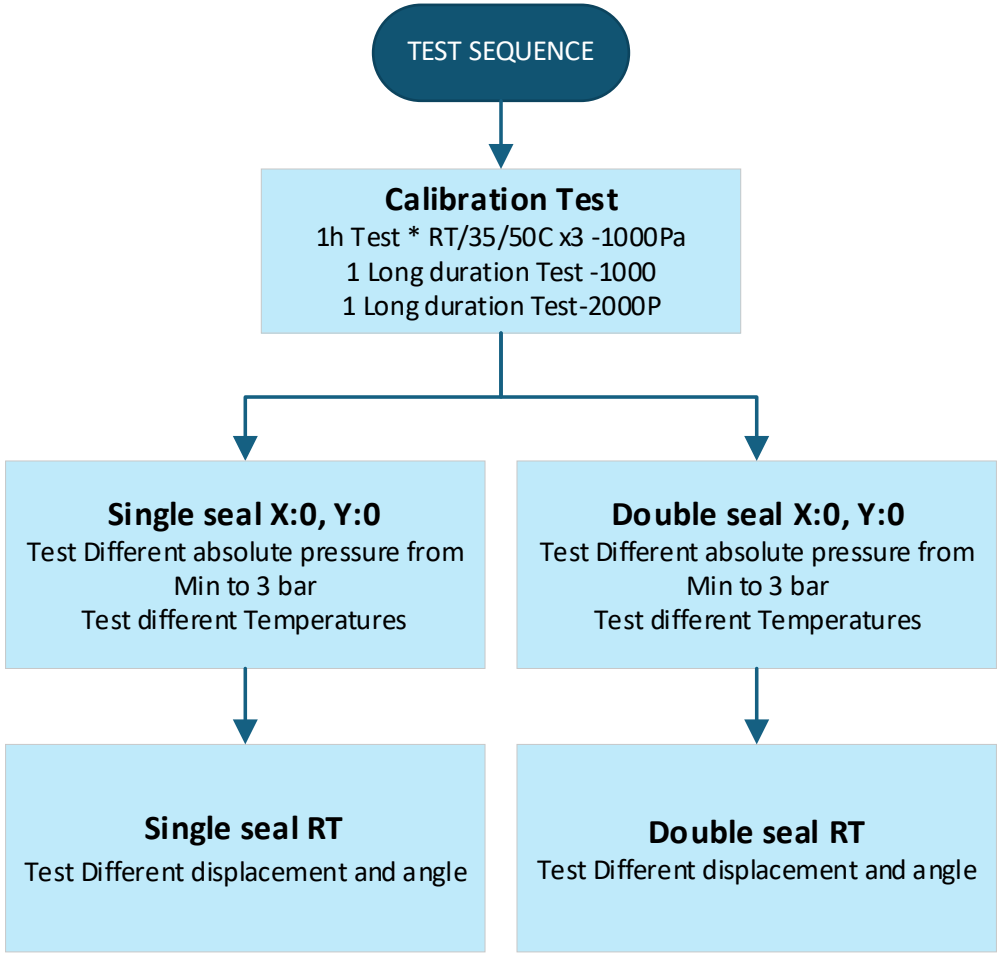


Inflatable seal up to 3bar

Internal absolute Pressure



Test summary



Test ID	Type	Temperature [°C]	Relative Position [mm]	Number of cycles	Seal internal absolute pressure, [bar]	Deposit gauge pressure [Pa]
0	CALIBRATION TESTS (14 tests). Just with Structural Steel frame *0					
0.1	Calibration	RT	N/A	3	N/A	-1000
0.2		RT	N/A	3	N/A	-2000
0.3		35±2	N/A	3	N/A	-1000
0.4		50±2	N/A	3	N/A	-1000
0.5	Calibration Long test*1	RT	N/A	1	N/A	-1000
0.6	Calibration Long test*1	RT	N/A	1	N/A	-2000
0	CALIBRATION TESTS (14 tests). With AISI 304 frame *0					
0.1bis	Calibration	RT	N/A	3	N/A	-1000
0.2bis		RT	N/A	3	N/A	-2000
0.3bis		35±2	N/A	3	N/A	-1000
0.4bis		50±2	N/A	3	N/A	-1000
0.5bis	Calibration Long test*1	RT	N/A	1	N/A	-1000
0.6bis	Calibration Long test*1	RT	N/A	1	N/A	-2000
1	SINGLE SEAL TESTS (21 tests)					
1.1	Single Seal	RT	X=0,Y=0	1*2	min*2	-1000
1.2				3	2	-1000
1.3				3	2.5	-1000
1.4				3	3	-1000
1.5				3		-2000
1.6		RT_long*1		1		
1.7		35±2		3		-1000
1.8		50±2				
1.9		RT_long*1		1		-2000

Test ID	Type	Temperature [°C]	Relative Position [mm]	Number of cycles	Seal internal absolute pressure, [bar]	Deposit gauge pressure [Pa]
2.	DOUBLE SEAL CENTERED TESTS (26 tests)					
2.1	Double Seal Centered	RT	X=0,Y=0	1*2	min*2	-1000
2.2				3	2	-1000
2.3					2.5	-1000
2.4					3	-1000
2.5					2	-2000
2.6					2.5	-2000
2.7					3	-2000
2.8		35±2			3	-1000
2.9		35±2				-2000
2.10		50±2				-1000
2.11		50±2				-2000
2.12		RT_long*1		1	3	-1000
3	DISPLACEMENT TESTS (~~21~~ 19 tests)					
	Type	Temperature [°C]	Relative Position [mm]	Number of cycles	Seal internal abs pressure. [bar]	Deposit gauge pressure [Pa]
~~3.1~~	Double Seal	RT	~~X=1. Y=0~~	3	3	-1000
3.2			X=2. Y=0			
~~3.3~~			~~X=0. Y=1~~			
3.4			X=0. Y=2			
3.5			X=2. Y=2			
~~3.6~~			~~X=Y=2; θx= 0.5, θy = 0~~			
3.7			X=Y=2; θx= θy= 0.5 deg			
3.8			X=4. Y=4	2*3		
3.9	Single seal		X=Y=2; θx= θy= 0.3 deg	3		
3.10			X=Y=2; θx= θy= 0.5 deg			

In total ~100 Tests Performed

In all the test ISO class 1 Leak rate achieved

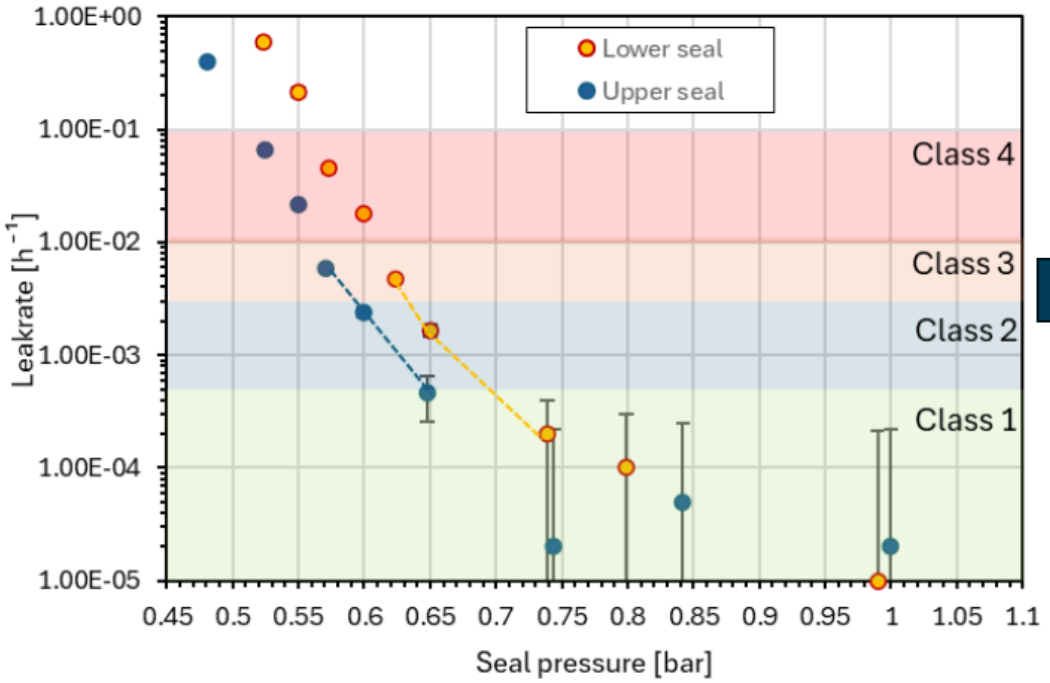
$$T_{f(\boldsymbol{average})} < 2.5x10^{-4}(h^{-1})$$

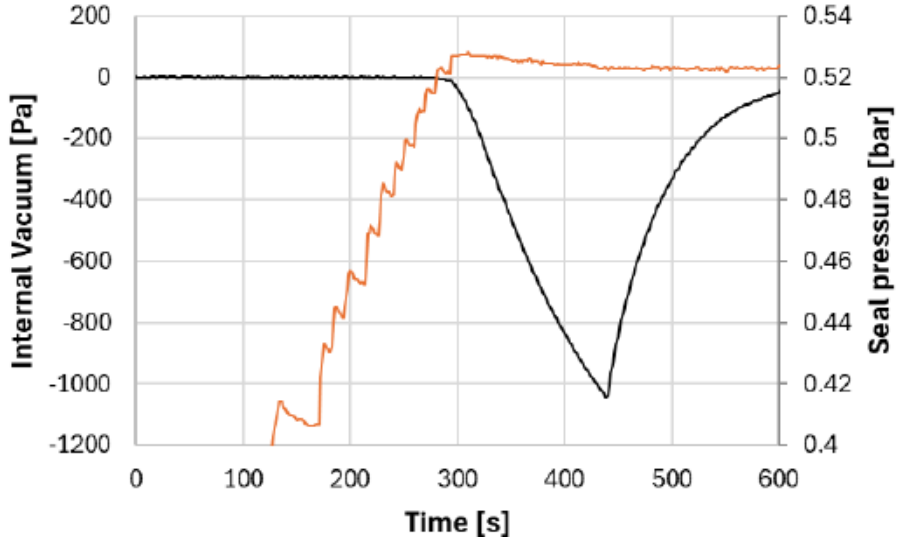
Required Pressure inflation on Seal pressure loss

Minimum sealing pressure at RT, Displacements X:0, Y:0

Pressure in the lower seal is increased in small steps while the vacuum pump is switch on and extracting air from inside the enclosure

Note ≈ Internal vacuum and seal pressure is always referred as the differential pressure.

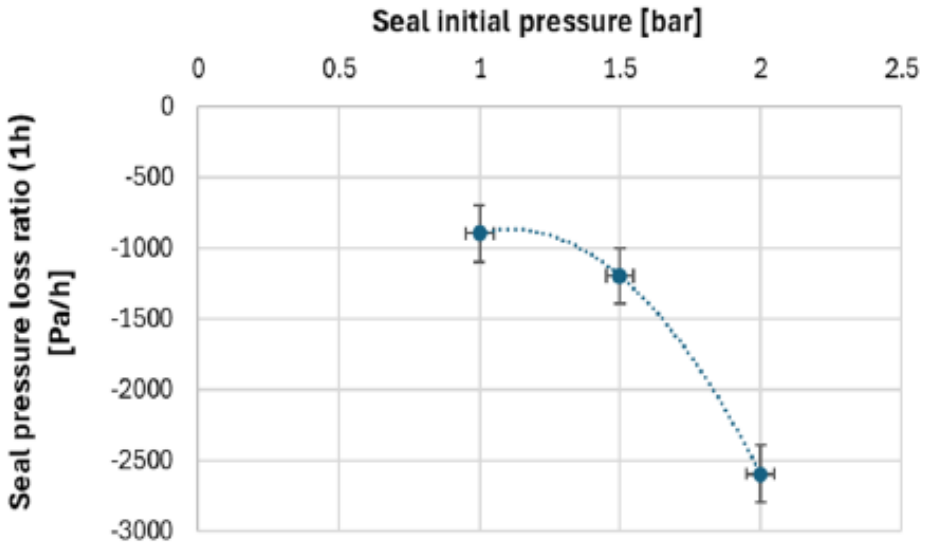




- *Leak rate presents an exponential decay with an increase of inflatable seal pressure.*
- ***Pmin** (**inflation**) to guarantee class 1 ≈ **0.7bar***
- ***Pmin** (deflation) when leak≈ **0.1bar***

Minimum sealing pressure at RT, Displacements X:0, Y:0

Long duration test

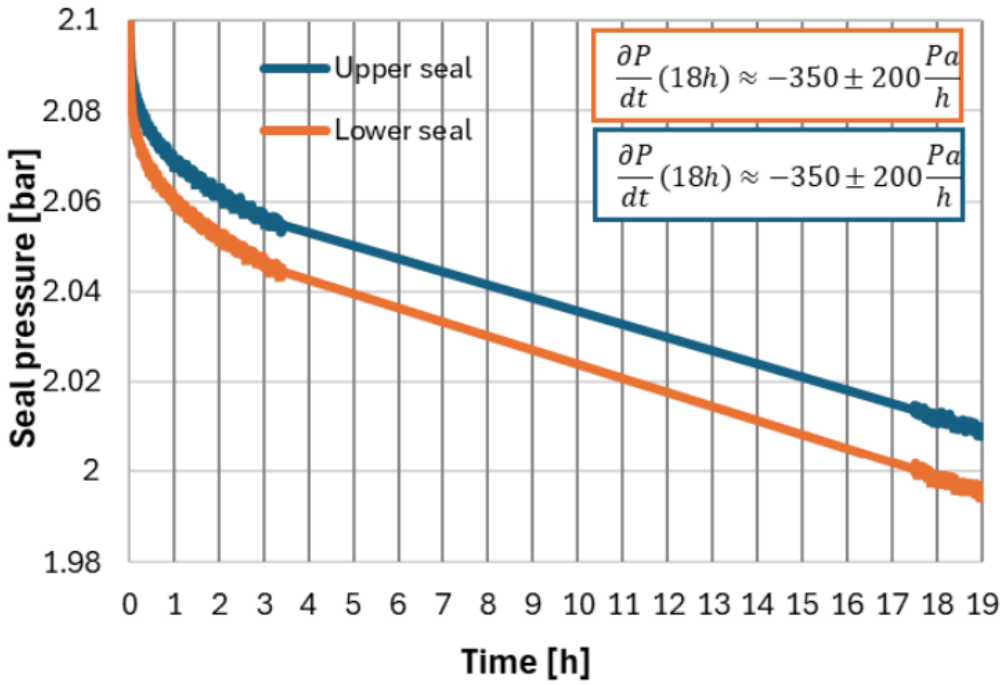


Seal Initial Pressure	Seal Pressure loss ratio
1 bar	900 ± 200 Pa/h
1.5 bar	1200 ± 200 Pa/h
2 bar	2600 ± 200 Pa/h

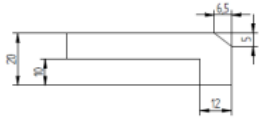
Exponential Delay

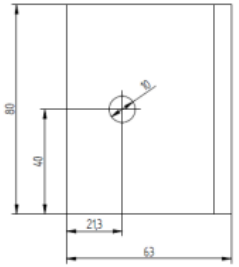
Causes of Pressure loss ratio:

- Initial fast pressure decay during initial stabilization of the seal
- Permeability of air thought the seal walls.
- Leakage in the pneumatic system→ Solenoid leak

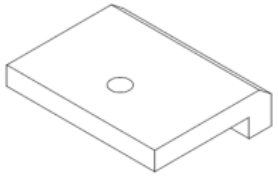


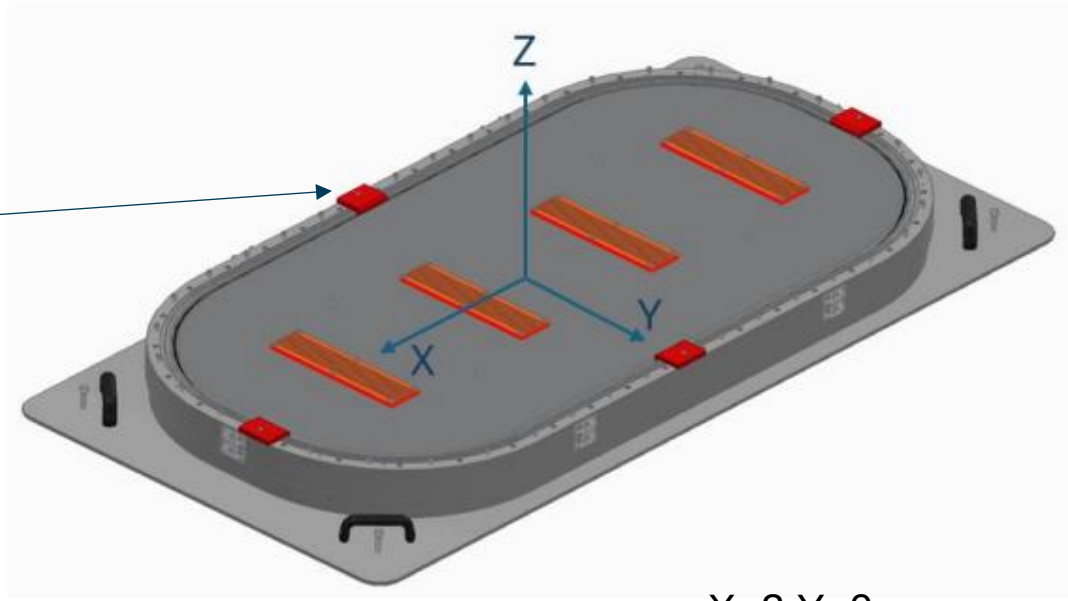
XY misalignments





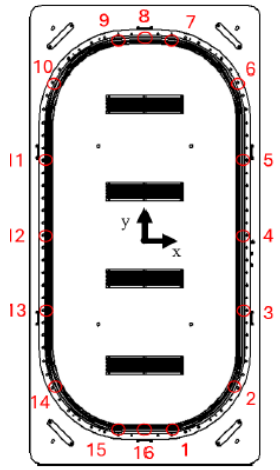
Spacers to position the door







Type	Type Temperature [°C]	Relative Position [mm]	Seal internal Absolute pressure [bar]	Deposit gauge pressure [Pa]
Double seal	RT	X=2,Y=0 X=0,Y=4 X=4,Y=4	Min pressure &2-3	-1000



X=2,Y=0

Point	Measurement [mm]
1	9.52
2	
3	11.71
4	
5	11.75
6	
7	9.8
8	
9	9.29
10	
11	7.58
12	
13	7.73
14	
15	9.25
16	

X=0,Y=4

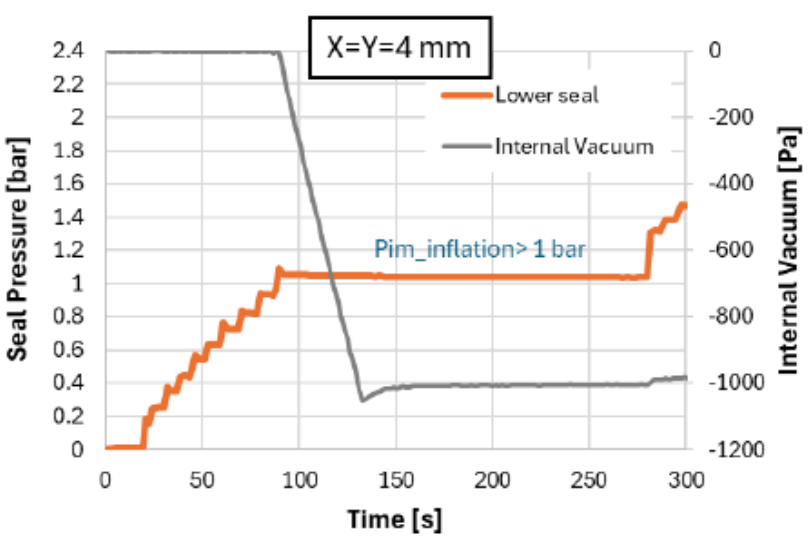
Point	Measurement [mm]
1	7.35
2	
3	9.56
4	
5	9.52
6	
7	11.3
8	
9	11.22
10	
11	9.59
12	
13	9.6
14	
15	7.37
16	

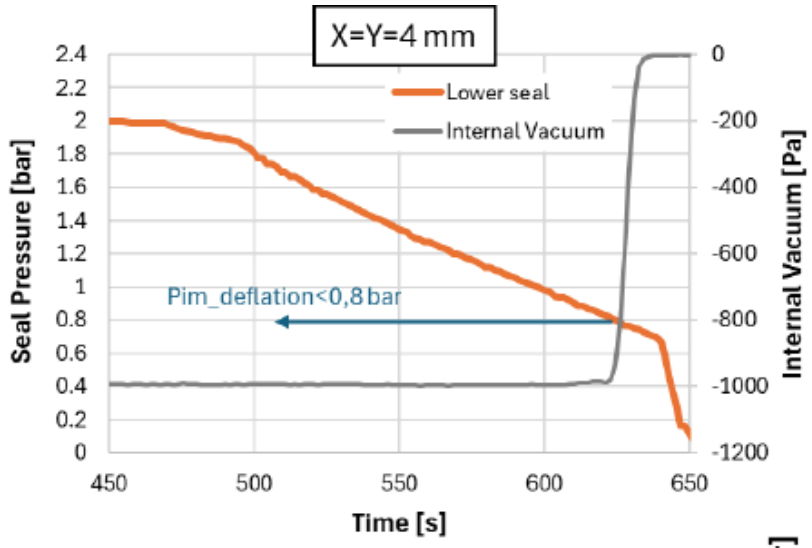
X=4,Y=4

Point	Measurement [mm]
1	5.8
2	11.2
3	13.8
4	13.85
5	13.8
6	15.1
7	14.3
8	13.8
9	13.3
10	7.9
11	5.8
12	5.9
13	5.78
14	4.2
15	4.85
16	5.4

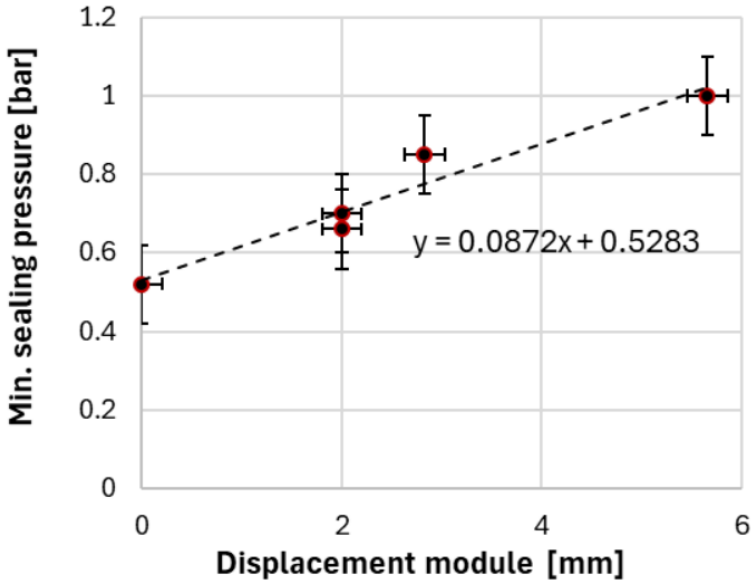
Supplier Inflatable seal expansion **10±2mm** → **Tested 9.5±5mm**

XY misalignments

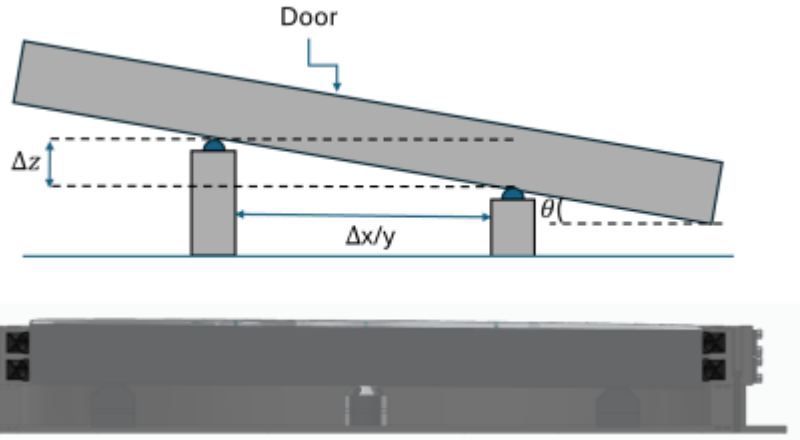




- *Displacement module has a linear influence on the Pmin inflation and Deflaction.*
- ***Pmin*** *(****inflation****) to guarantee class 1 ≈ 1****bar*** ↑
- ***Pmin*** *(deflaction) when leak≈* ***0.8bar*** ↑↑



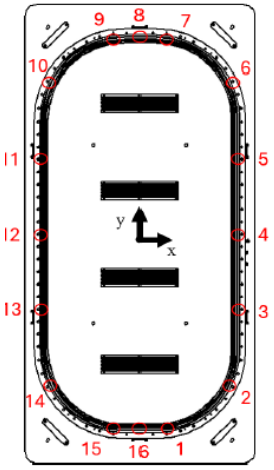
XY misalignment +Tilting







Type	Type Temperature [°C]	Relative Position [mm]	Seal internal Absolute pressure [bar]	Deposit gauge pressure [Pa]
Double seal	RT	X=Y=2, θx=θy= 0.3deg	2 2.5 3	-1000 -2000
		X=Y=2, θx=θy= 0.5deg		
Single seal	RT	X=Y=2, θx=θy= 0.5deg	Min pressure &2-3	-1000



X=2,Y=2 angle 0.3

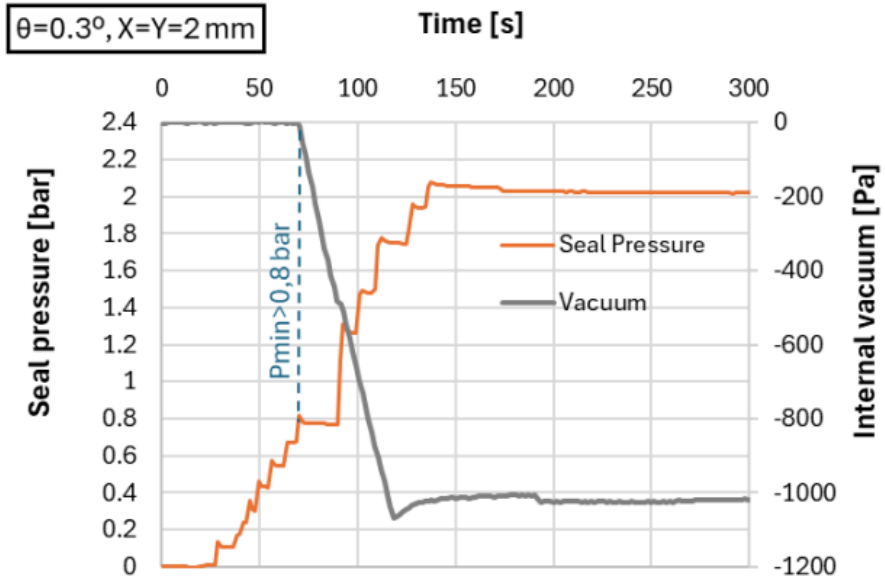
Point	Measurement [mm]
1	7.6
2	
3	11.7
4	
5	12
6	
7	11.8
8	
9	11.8
10	
11	7.6
12	
13	7.7
14	
15	7.3
16	

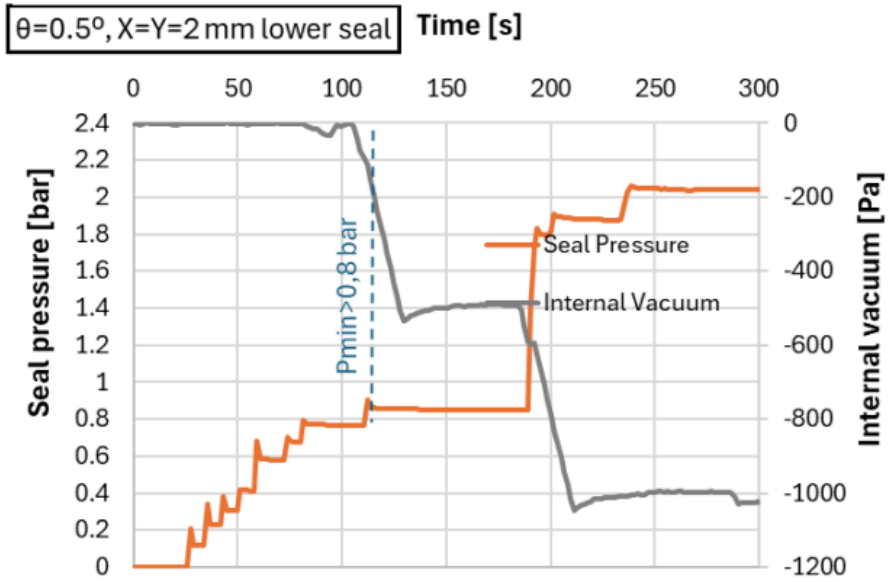
X=2,Y=2 angle 0.5

Point	Measurement [mm]
1	7.9
2	
3	11.5
4	
5	12.1
6	
7	11.7
8	
9	11.5
10	
11	7.4
12	
13	7.8
14	
15	7.7

Supplier Inflatable seal expansion **10±2mm** → **Tested 9.7±2.4mm + angle**

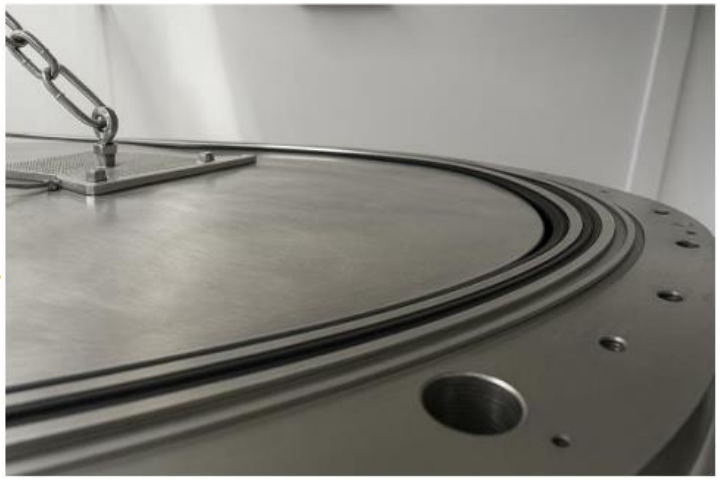
XY misalignment +Tilting

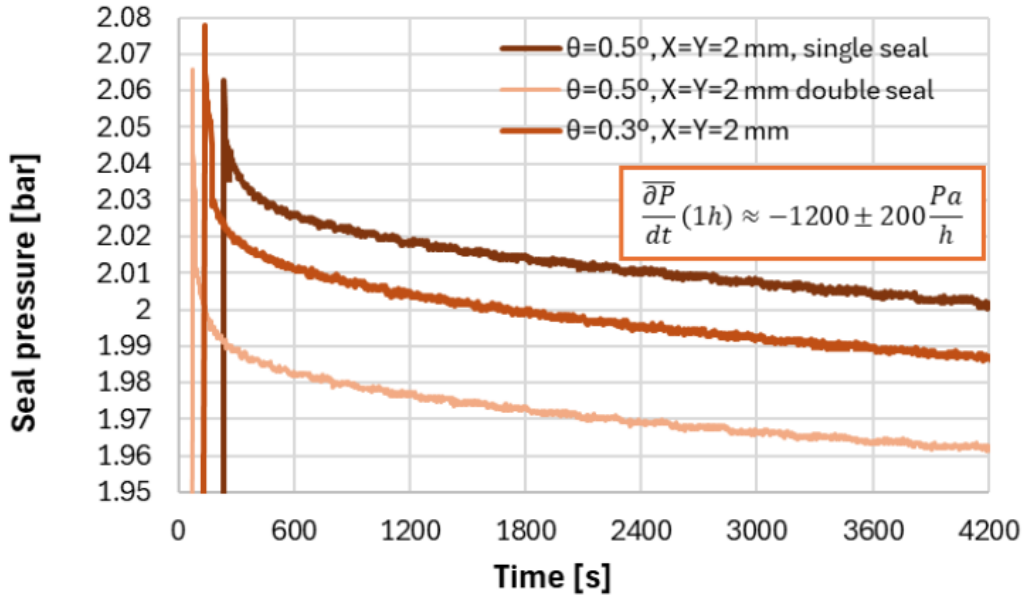




Tilting doesn't have a relevant influence, Min Pressure similar to purely XY misalignment

Pressure loss independent after 1h





Thermal tests

Climatic chamber heating components:

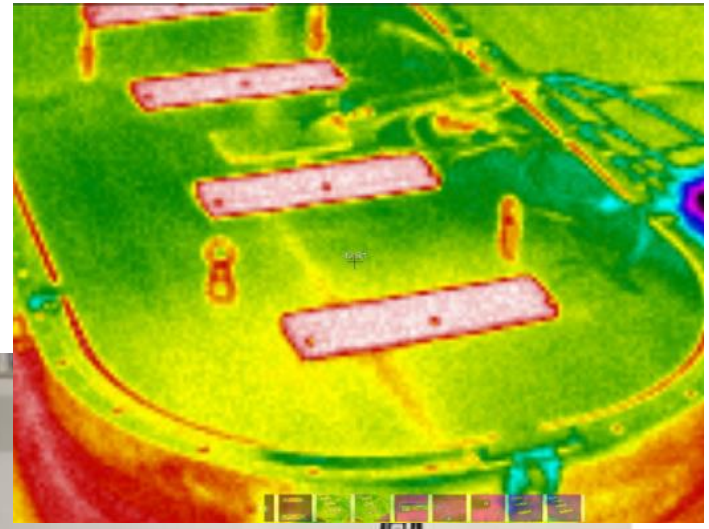
(1) Radiative heater

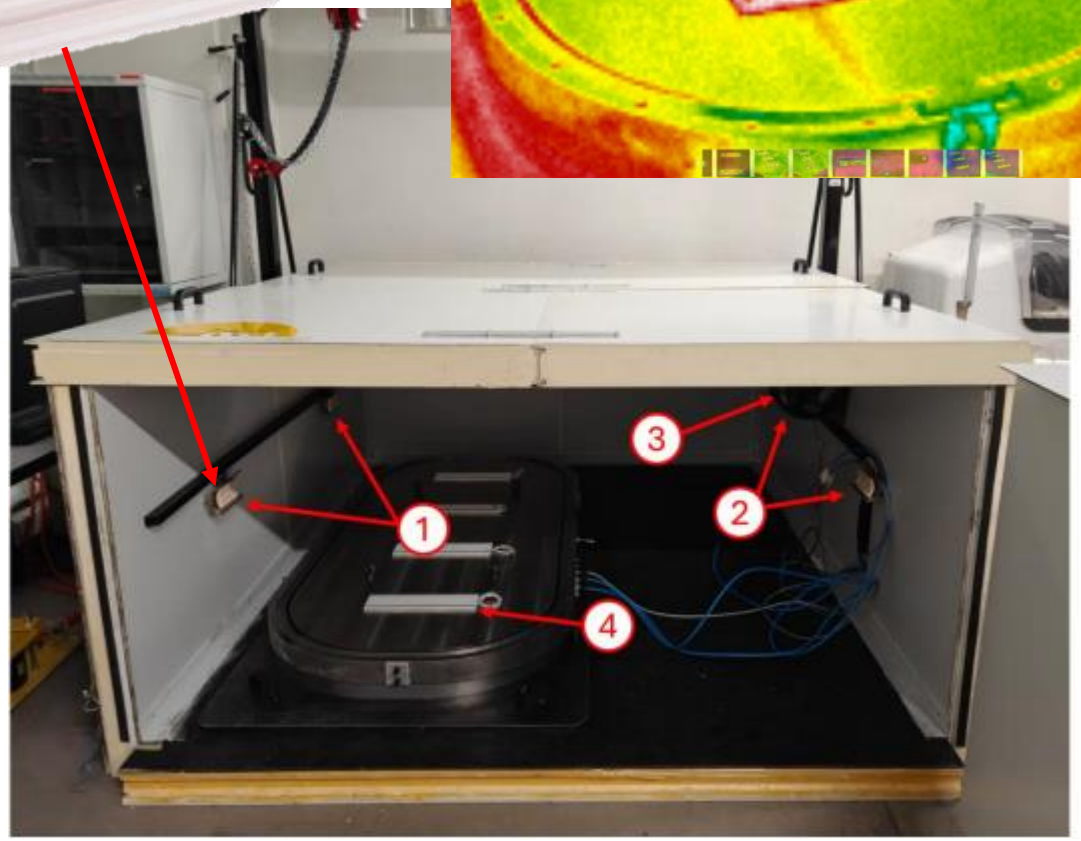
(2) Compensate Heat losses controlled by PID

(3) Small axial fan – to distribute evenly the heat generated

(4) Surface Electrical heaters 500W

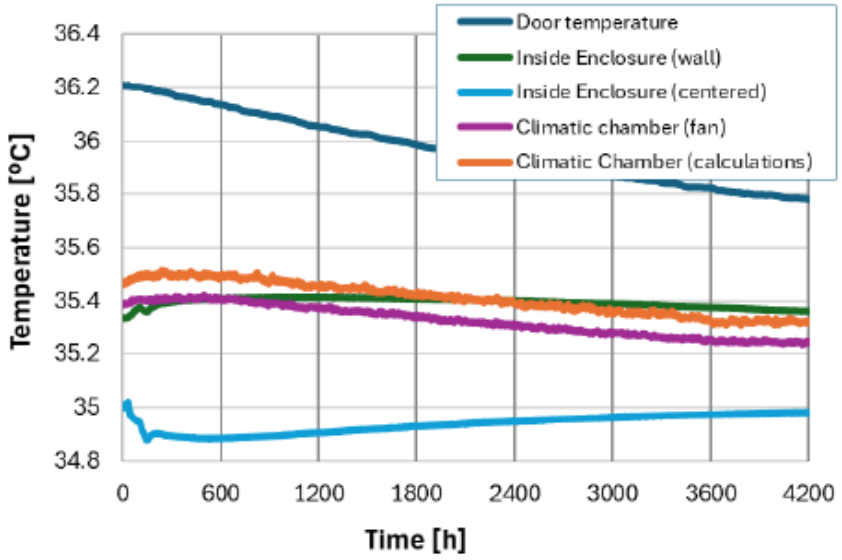


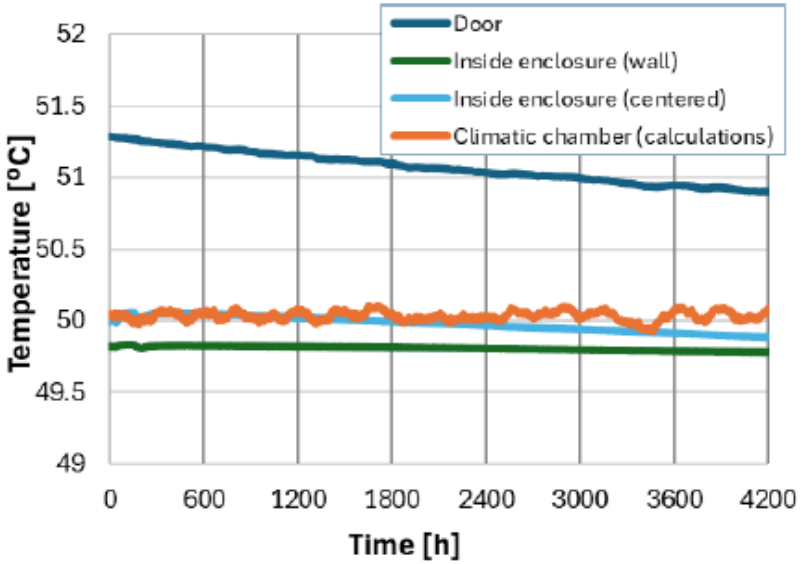




Type	Type Temperature [°C]	Relative Position [mm]	Seal internal Absolute pressure [bar]	Deposit gauge pressure [Pa]
Single seal	RT	X=0,Y=0	3	-1000
	35±2			
	50±2			
	RT_long			
	RT_long			-2000
Double seal	RT	X=0,Y=0	3	-1000/-2000
	35±2			
	50±2			
	RT_long			

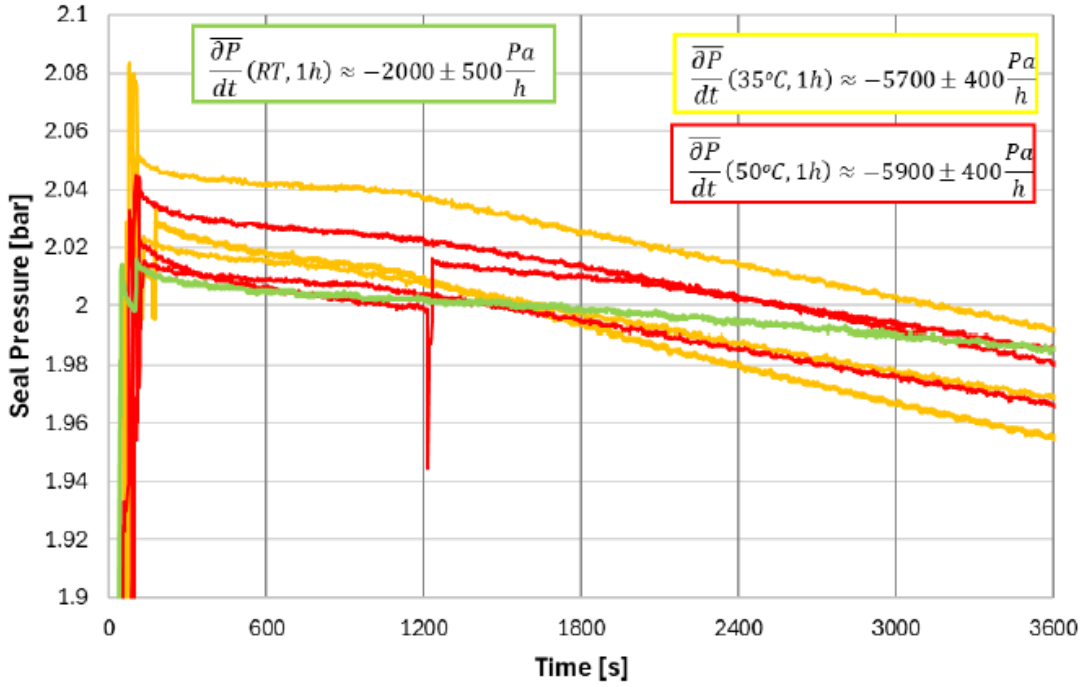
Thermal tests





An increase of temperature increase the pressure loss by up to a factor of 3

Still present some uncertainties due to the short time duration of the tests



Conclusions and Lesson learned

✓ *Inflatable seal performance is always in the range of CLASS 1 sealing according to ISO 10648-2 pressure change method.*

More than 100 Tests performed.

- *Temperature up to 50°C*
- *Misalignments up to X=Y=4*
- *Misalignment + tilting X=Y=2 + angle 0.5 deg*



✓*Class 1 sealing is obtained with just a single seal*

✓*Sealing performance only depends on the seal inflation pressure.*

✓*Minimum sealing pressure depends on in plane misalignments.*

➡ Recommended inflation pressure 2 bar (manometric)

✓*Pressure inside the seals exponentially decay with time.*

➡ Certain variability was found associated to pneumatic system pressure loss

Conclusions and Next steps

$T_{f(\boldsymbol{objective})} = 1x10^{-3}(h^{-1}) - ISO\ 10648 - 2\ \boldsymbol{Class\ 2}$

$T_{f(\boldsymbol{average})} = 2.1x10^{-4}(h^{-1}) - ISO\ 10648 - 2\ \boldsymbol{Class\ 1}$

With only one seal

Supplier Inflatable seal expansion
10±2mm

Tested successfully up to 9.5±5mm

✓ *Additional investigation on*

- *Higher temperatures and longer durations*
- *Different seal material*
- *Potential improvements in the LPSCS (deposit, filter, measuring temperature of seals and interspace…).*



ITER-F4E-UNIVERSIDAD DE ALCALÁ



Mechanical, Electrical and Thermal Engineering research group, Universidad de Alcalá

Thank you!

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D. Locke, E.Ruiz ***Fusion For Energy***
I. Valiente, D. Lopez, O. Manzano, E. Díez ***Universidad de Alcalá***

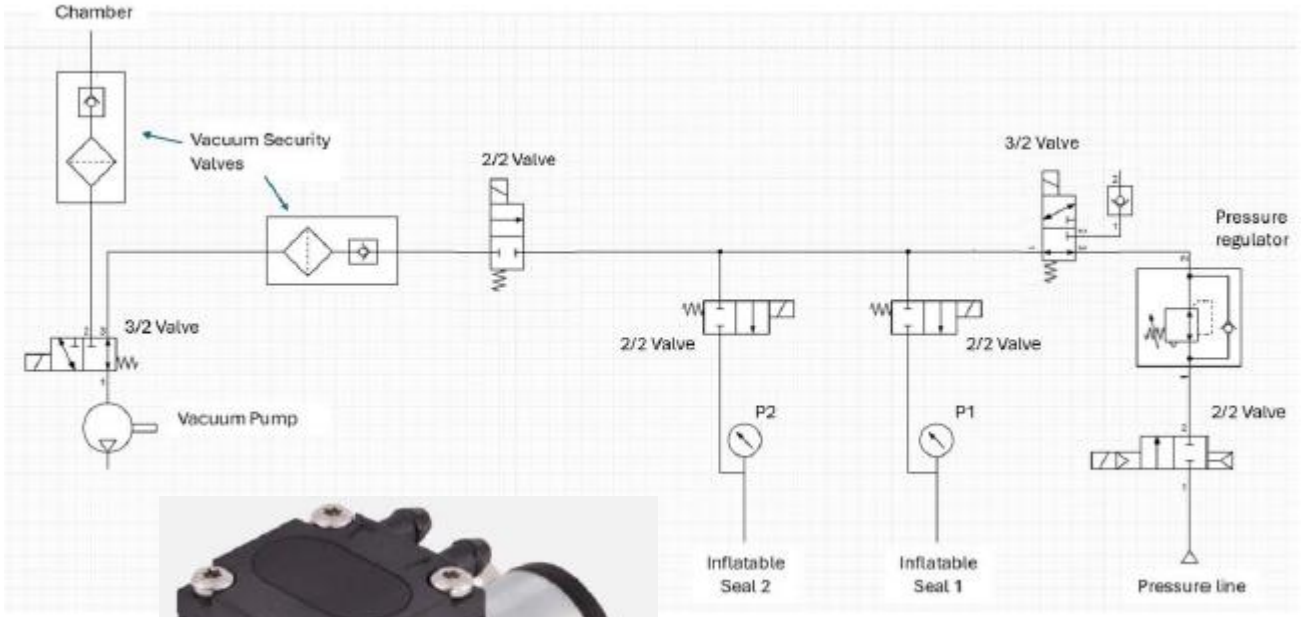
iter

china eu india japan korea russia usa

BACK UP SLIDES

Leak survey & Pressure Control system

Pneumatic circuit and components





ID	ITEM	Reference	Seller	Conector 1	Cnct. 2	Cnct. 3	Units	Comments
1	3/2 Valves (SMC)	VDW350-5G-4-02F-X22-Q	Helium 3	G 1/4 H	G 1/4 H	G 1/4 H	2	1 Pa to 1 MPa
2	2/2 Valves (SMC)	VX224AGA	Helium 3	G 1/4 H	G 1/4 H		4	1 Pa to 1 MPa
3	Pressure regulator	204-0054	RS	6 mm	6 mm		1	0.5 - 8 bar
4	Vacuum Security Valves	204-0032	RS	G 1/4 M	G 1/4 H		2	
5	Tube adapter to G1/4	197-7674	RS	G 1/4 M	6 mm		1	Bag 10 units
6	Absolut Pressure sensors	797-4970	RS	G 1/4 M			2	
7	"T" Quick Connector	916-0918	RS	6 mm	6 mm	6 mm	1	Bag 10 units
8	Pneumatic tube FESTO Polyethylene	126-3103	RS	6 mm			1	50m
9	Vacuum Pump (KNF)	NMP09 KPDCL	Scharlab	4 mm			1	
10	Pneumatic tube SMC Nylon blue	270-4942	RS	4 mm			1	20m
11	Tube adapter 4-6mm	144-2643	RS	6 mm	4 mm		1	Bag 10 units