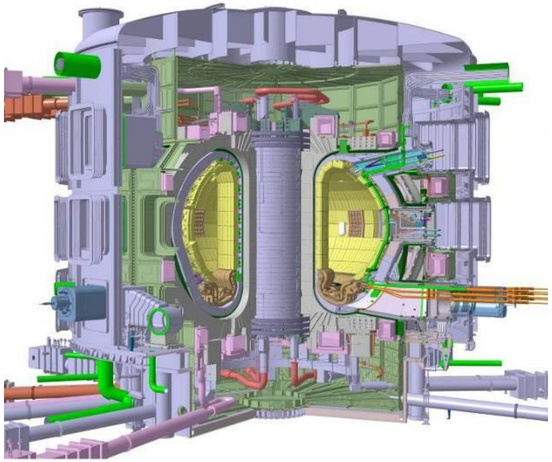
Progrès dans la Conception et la Construction du Système de Vide ITER



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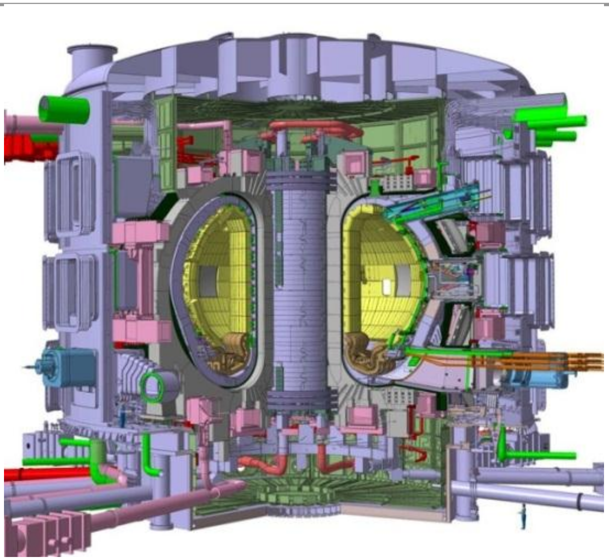
Summary



- ITER the Objective
- An introduction to the machine.
- Progress with the civil work
- 2 Large vessels
- Pumping
- The Roughing system
- Neutral beam pumping
- Torus pumps (if time)

Acknowledgements

ITER EU Vacuum Team (F4E) - Stamos Papastergiou, Aurelien Rousseau, Francina Canadell Navarro

ITER US Vacuum Team (US IPO) Graeme Murdoch, Michael Hechler, Will Kirkland, Owen Wes, Peter Lukens, Juras Ray, Francis Ruppel, Larry Baylor, Steve Meitner Robert Duckworth

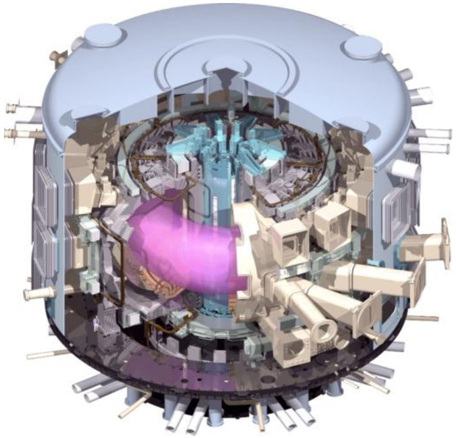
ITER IO Vacuum Alexander Antipenkov, Jean Louis Bersier, Bastien Boussier, Florin-Lucian Chitu, Matthias Dremel, Silvio Giors, Shaun Hughes, Eamonn Quinn, Graeme Vine, Gilles Wolfers, Nick Woods, Liam Worth.

+ **Contractors, Experts, and Manufactures**

ITER- The Objective

- **To construct and operate as an international collaboration between 7 parties:-**

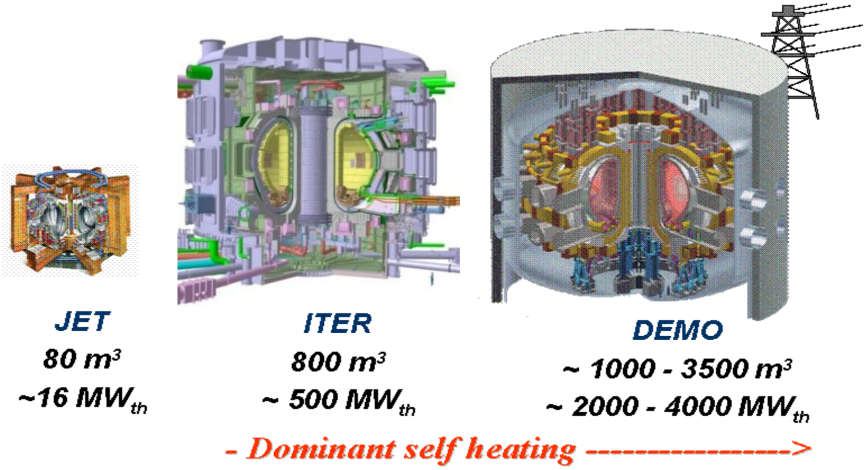
EU- China – Japan –USA –
Russia – India – Korea
Representing ½ world population.



- **The principal goal: Q>10**

to produce significant fusion power
input power 50 MW
output power 500 MW

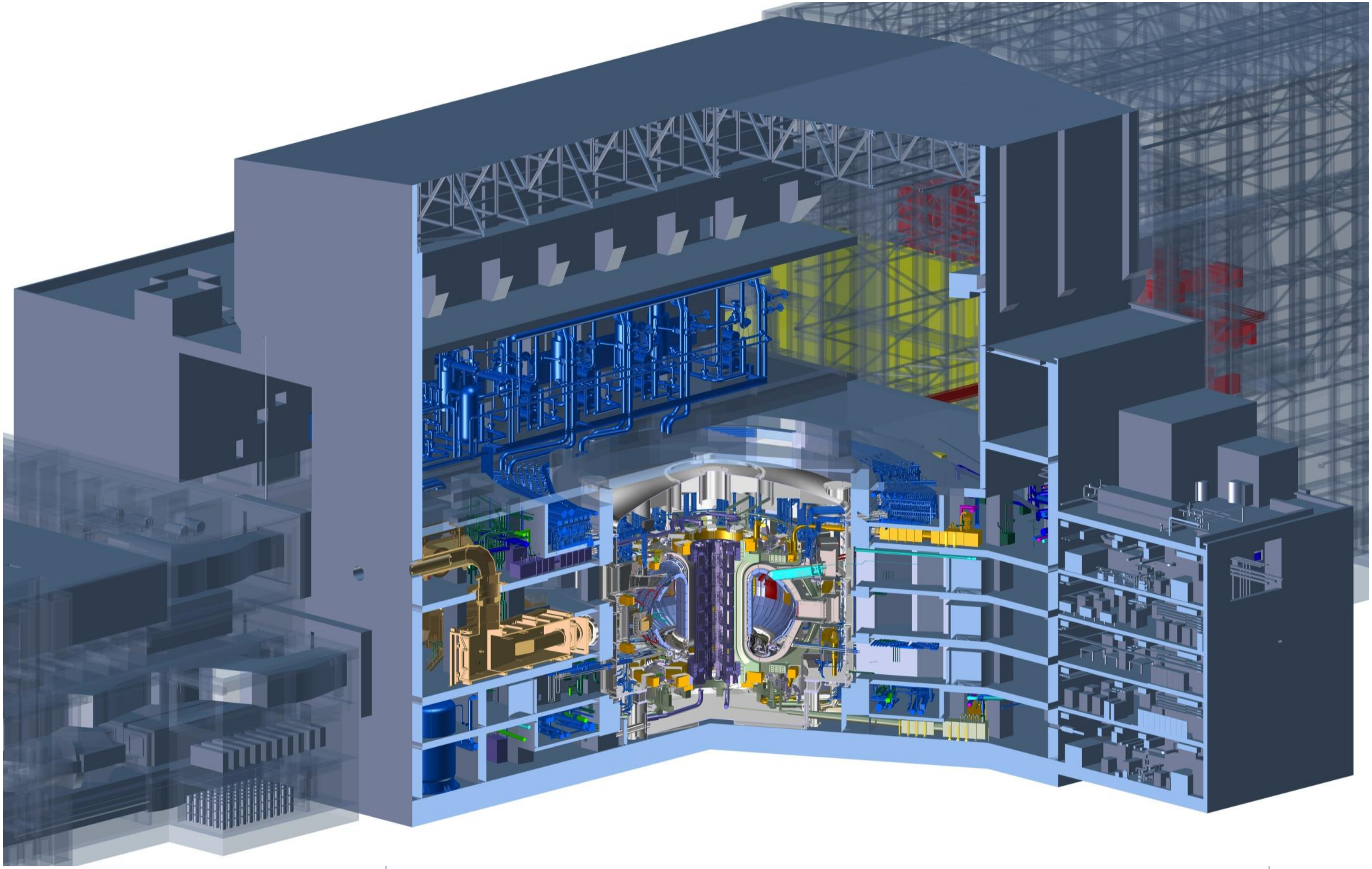
To demonstrate the integration of technologies and safety features for a fusion reactor.



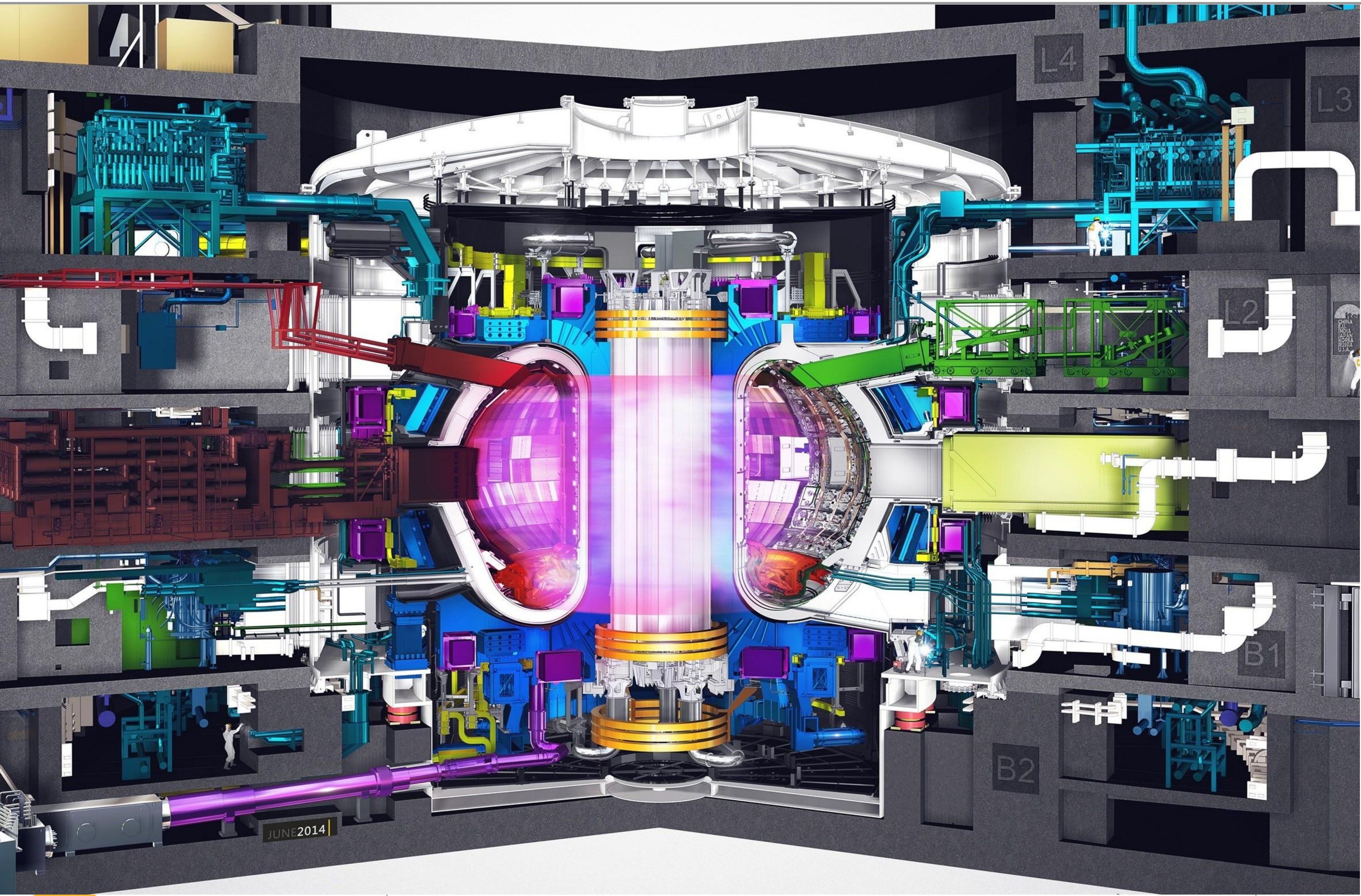
•To construct within the agreed costs:

•4.8 B Euro, 90% In-kind supply (estimate – real cost to party may differ)
•1.58 B Euro, ITER staff, R&D, Materials and Services
•0.75 B Euro, Assembly, ITER purchased Infrastructure, Testing

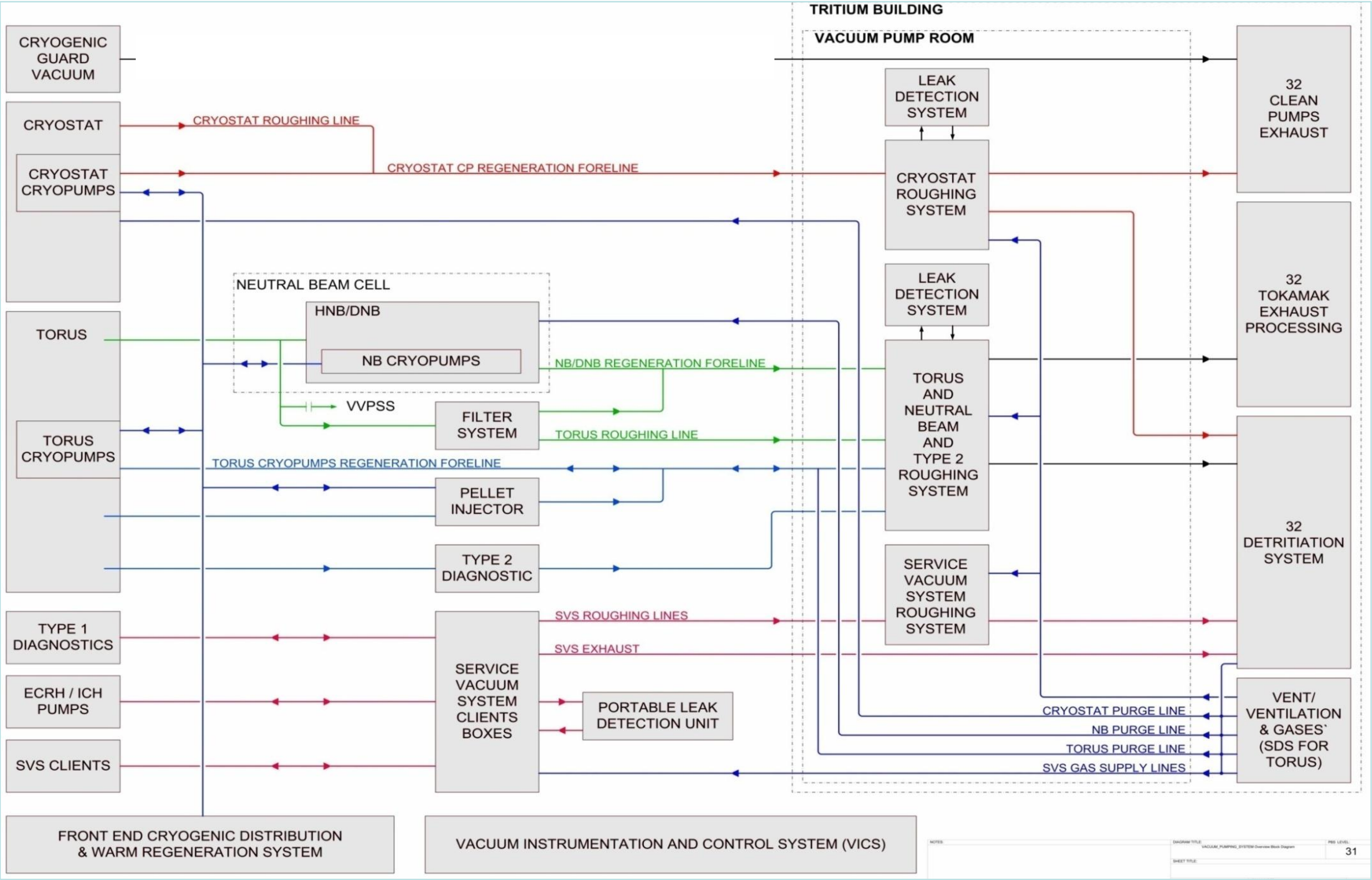
ITER THE TOKAMAK COMPLEX



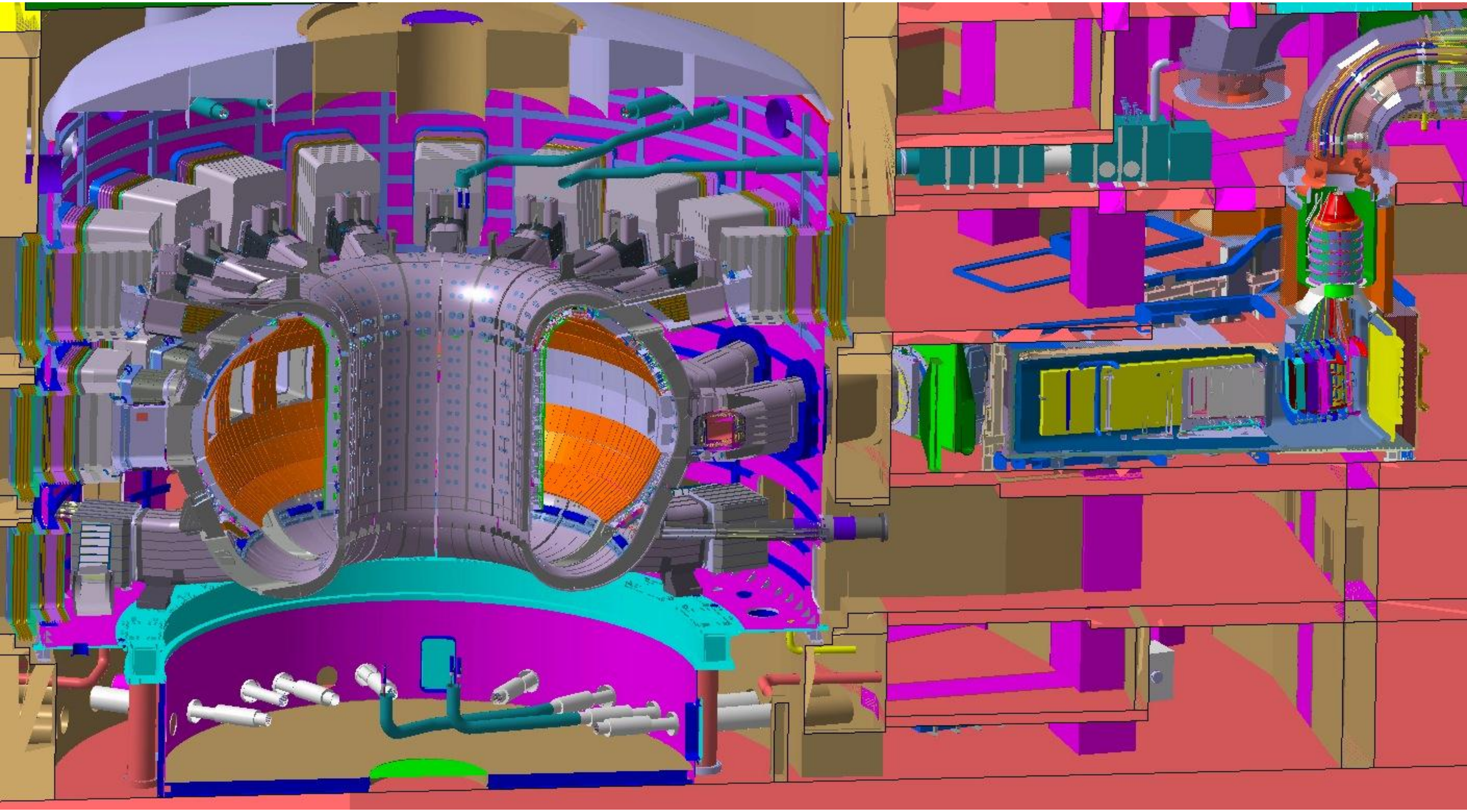
The ITER Machine



Vacuum System Overview block Diagram



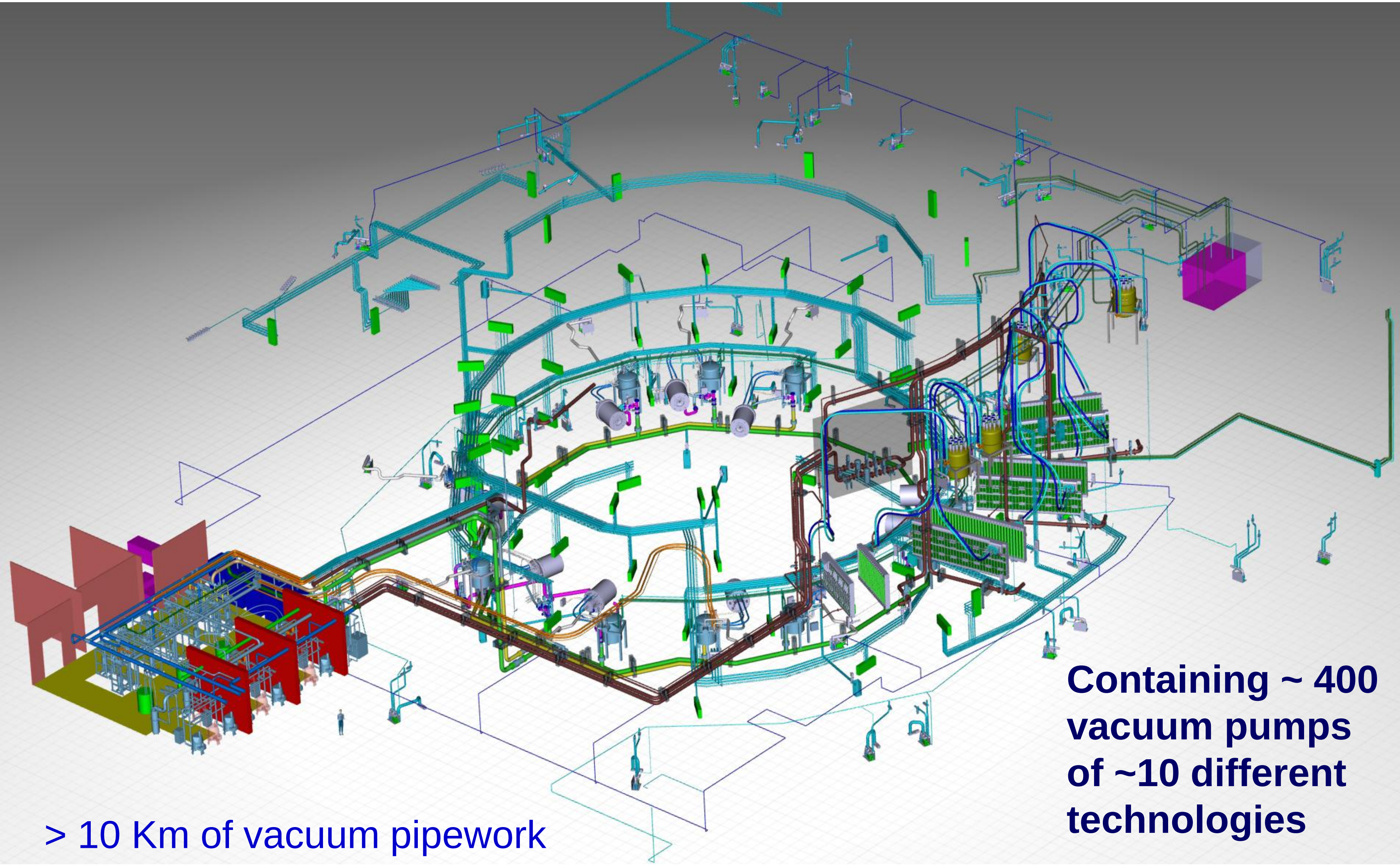
One of The largest Complex Vacuum System



Cryostat vacuum(<10^{-4} Pa) 8500 m^3
Torus vacuum(~10^{-6} Pa) 1330 m^3
Neutral Beam vacuums(~10^{-7} Pa) 860 m^3 (for 4)

Cryogenic Guard Vacuum
Service Vacuum System (Inc diagnostics)
ICRH and ECRH Vacuums

The vacuum pumping systems



Containing ~ 400 vacuum pumps of ~10 different technologies

> 10 Km of vacuum pipework

Challenges in the Construction

- Much of the technology required for ITER is first of a kind in terms of scale or required performance, requiring additional:- prototyping, dummy manufacture, pre-production manufacture.
- Design work has been performed over a long duration (since 1998 and before) by diverse means and with varying levels of maturity and with varying levels of consideration to manufacturing and assembly.
- Due to the size of many components new facilities need to be built before components can be built.
- ITER is a nuclear facilities (INB) under the French order of 7th February 2012 and hence has to demonstrate a fully qualified design and manufacturing process where relevant for safety.
- ITER is a highly compact machine requiring exceptional attention to integration and interfacing between systems and components supplied by different parties.
- The 7 ITER parties have a common goal in the demonstration of fusion but different constrains on budgets and schedule, as well as differing skills, experience and working practices.

The schedule to complete ITER is primarily determined by the construction time for the vacuum vessel and then the civil construction.

Civil Construction Started 2008

Site leveling

The flat Platform ready for Excavation in 2010

Poloidal Field Coil Winding Building May 2011

Tokamak and Hot cell Pit Excavation May 2011

Tokamak Complex seismic support structure March 2013

Mass of the future Tokamak Complex: 360 000 tons (including the 23,000-ton ITER Tokamak)

Height of the future Tokamak Building: 73 metres (approximately 60 metres above ground)

Dimensions of the Seismic Pit: 90 x 130 metres

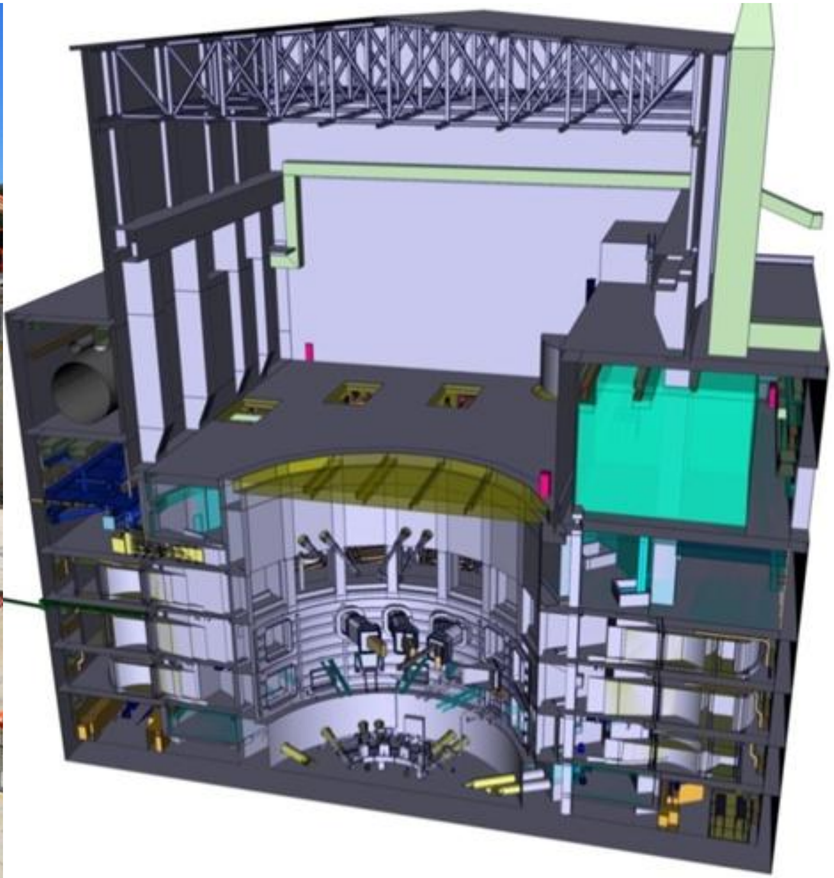
Number of Seismic pads supporting the Tokamak Complex: 493

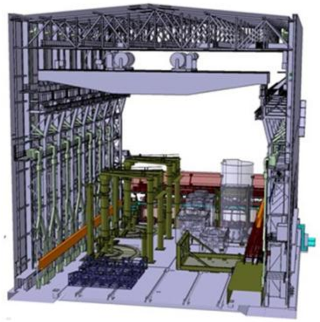
Tokamak Complex ready to form basement slab July 2013

Cryostat assembly building, main assembly building behind Aug 2013

June 2014 – Working on the Basement Slab (B2) completion

27 August 2014 – Basement Slab (B2) (~14, 000m3 concrete)





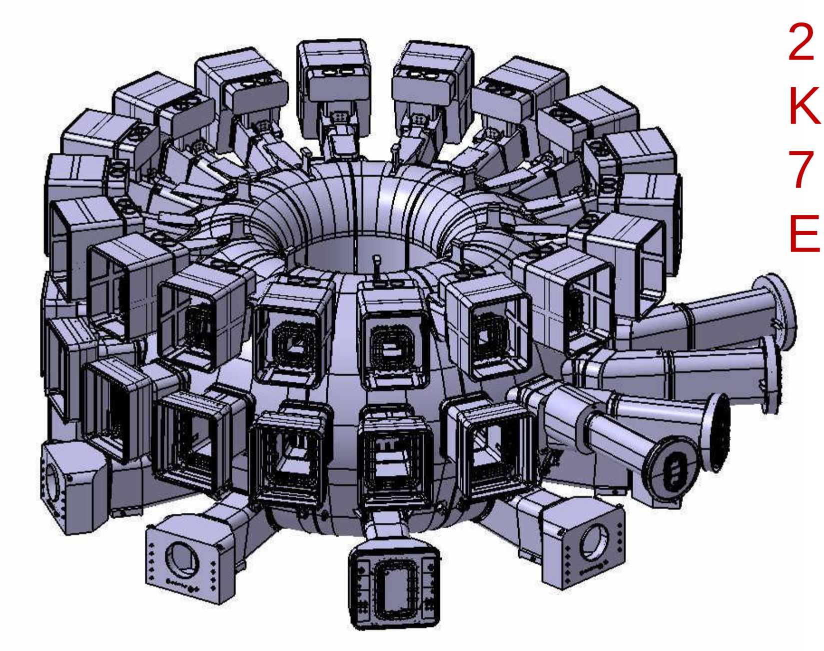
Steel frame 60*100*60ht m Assembly building also now started.

Walls of tokamak complex now started 80*110*60^{ht} m (-16m underground, 350,000tons)

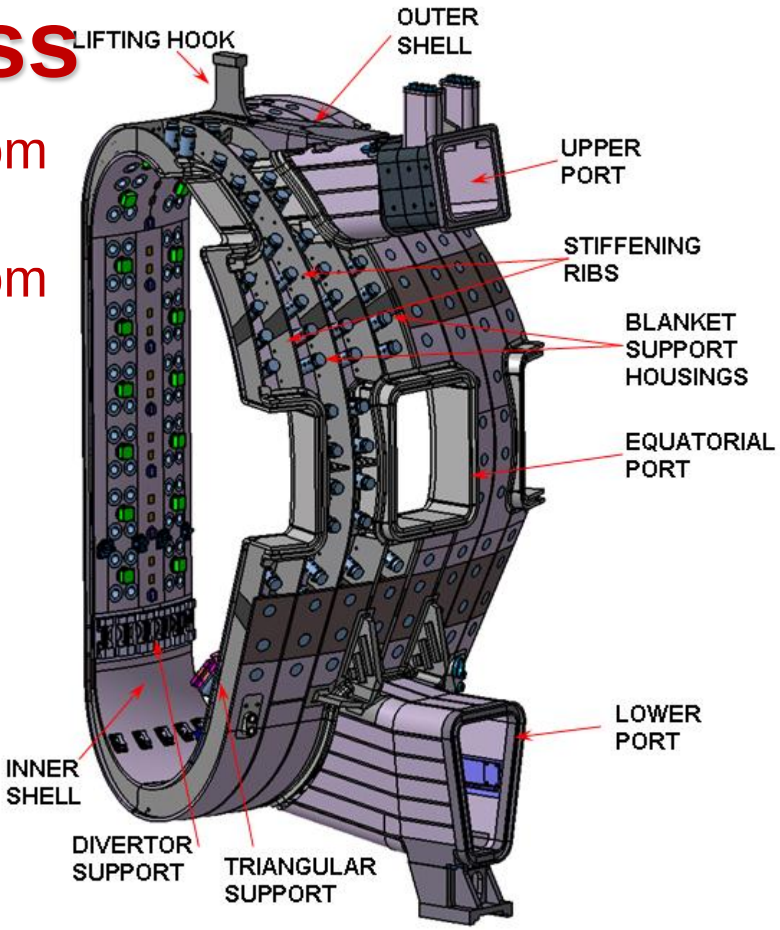
The Site as expected by 2017/8

18 Buildings, 180 Hectares

Vacuum Vessel Progress



2 Sectors from Korea
7 Sectors from EU



VV & In-vessel components
mass: ~8000 t
19.4 m diameter
11.3 m tall

Eiffel Tower
mass: ~7300 t
324 m tall

9 X 40° sector (~600 t each)
Double-wall structure
Shielding and cooling water between shells (304 SS + 1 - 2 % boron, SS 430 ferromagnetic)
40° sector fabrication at factory (~600 t)
34 Port (upper equatorial and divertor)

Progress with the ITER Vacuum Vessel

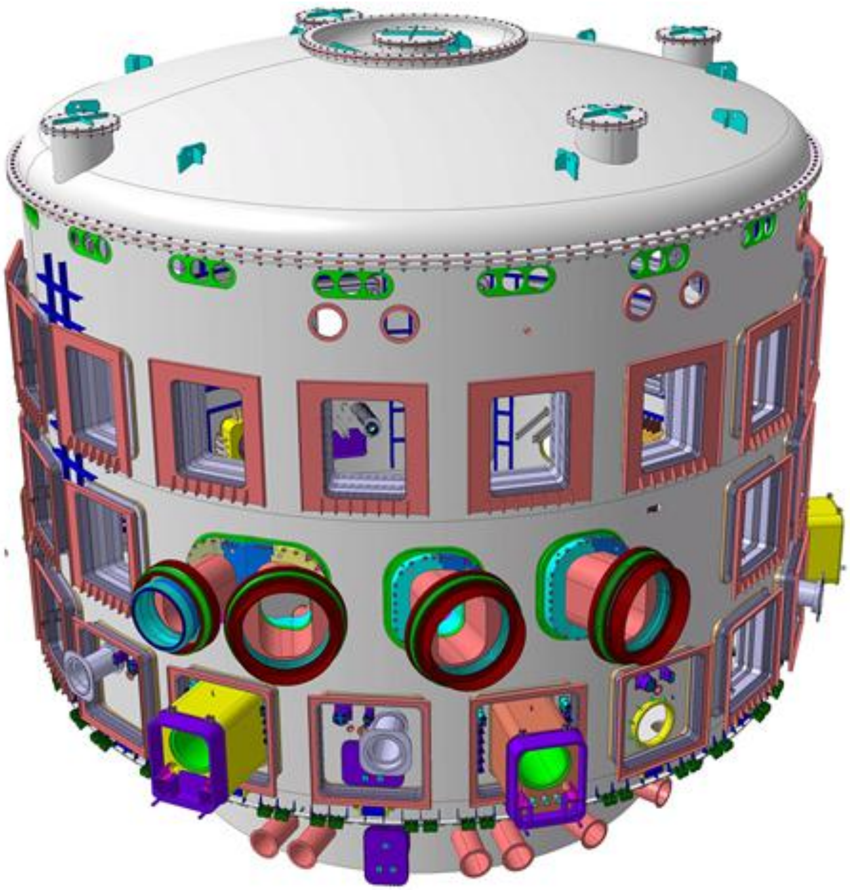
Manufacture of first sector of vacuum vessel started in Korea Feb 2012 expected delivery in 2018

Weld examination using ITER qualified liquid dye penetrant

EU Segment mock-up, manufacturing due to start on first EU last sector predicted January 2021

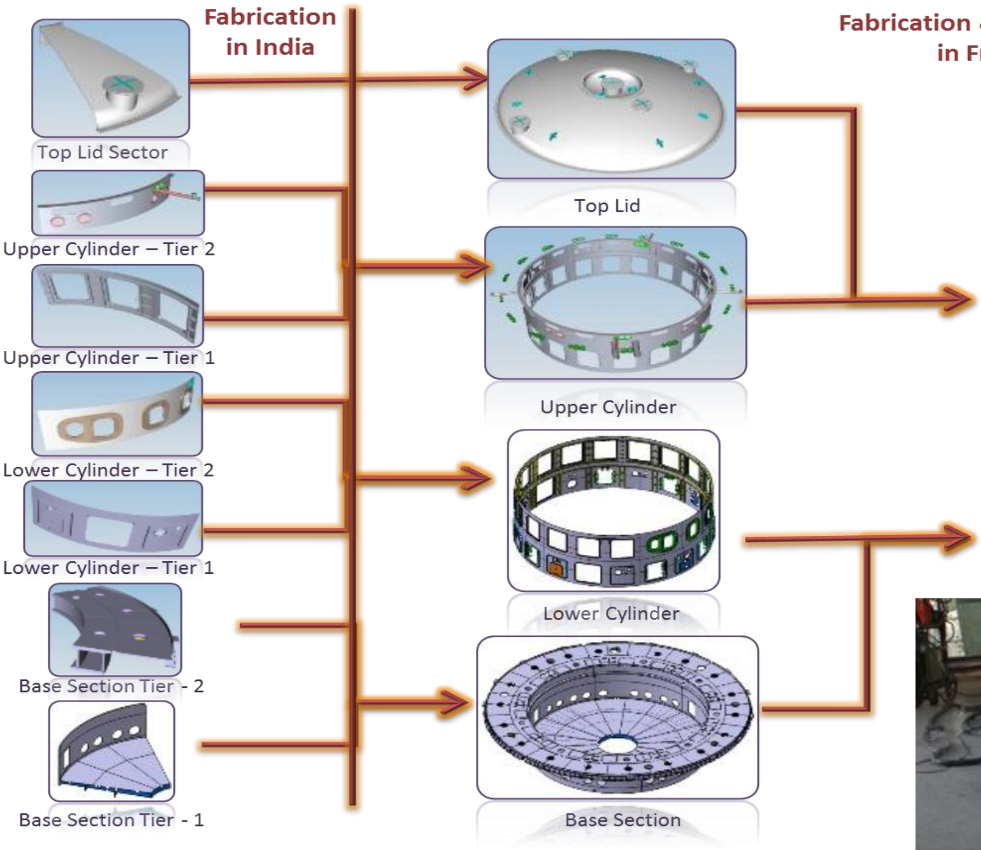
Upper part of KO segment (2014)

Progress with ITER Cryostat



Cryostat Outside Diameter (max)	29 m
Cryostat Height	29.25 m
Wall Thickness	40mm-180mm
Number of Sections	4
Main cylinder Shell Thickness	50 & 60 mm
Structure & Material of Construction single wall with reinforced Rib	Dual mark 304L/304
Design base Pressure	1×10^{-4} Pa
Cryostat pumping system	Two Cryo-sorption pumps cooled by supercritical helium
Required Leak Rate of completed Cryostat (including inside components)	$\leq 1\times10^{-4}$ Pam^{-3}/s
- Cryostat Surface Area	~3400 m^2
- Interior Free Volume	~8500 m^3
- Interior Total Volume	~16000 m^3
- Base Section	1250 ton
- Total mass	~3500 ton

Progress with the ITER cryostat.



Site Workshop assembly Sept 2015 to 2020

Mock up of part of base ring Aug 2013

Manufacturing in India started October 2013

Site workshop ready for assembly Nov 14

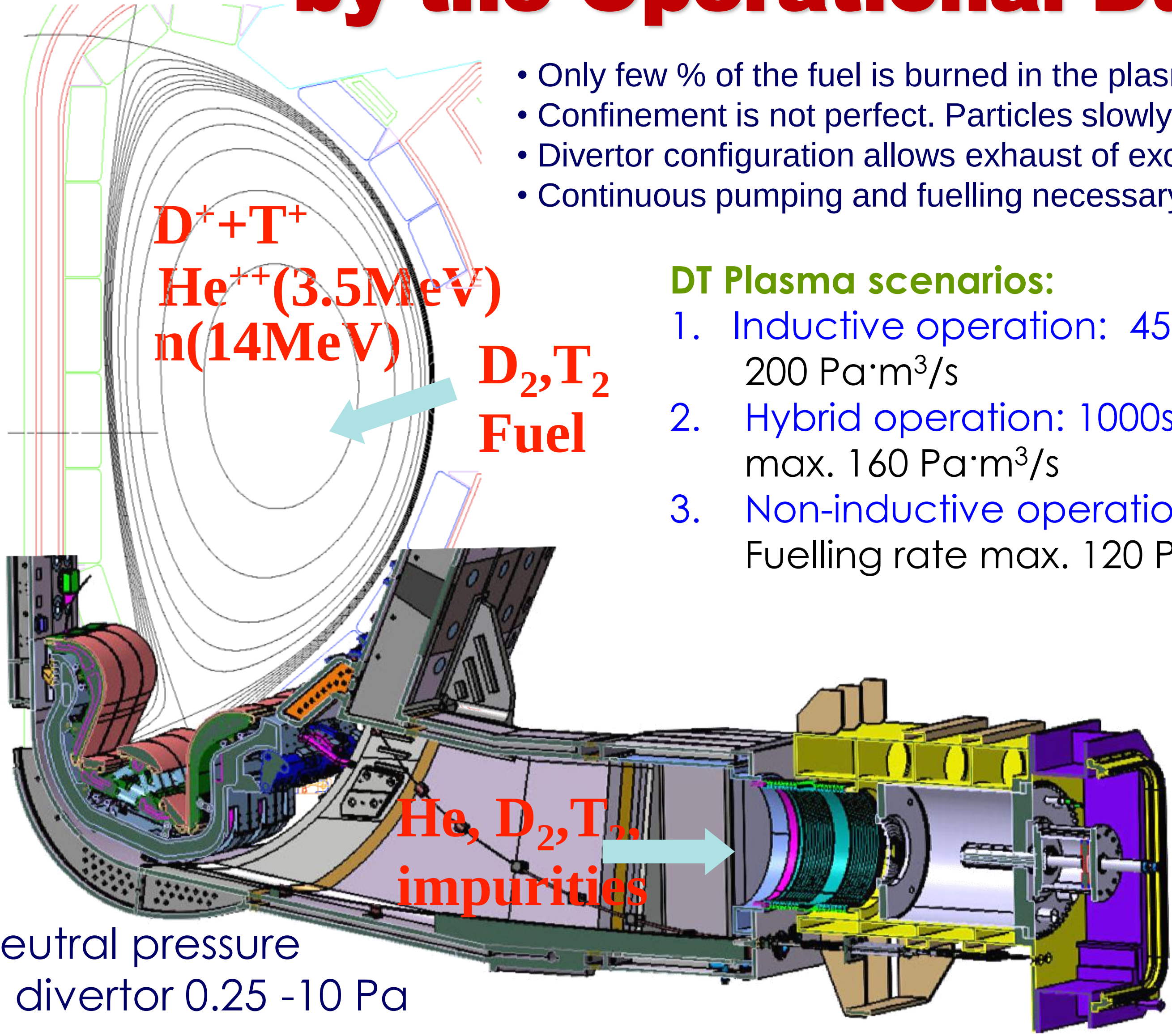
Ref . Anil K Bhardwaj

ITER-India, Institute for Plasma Research, Gandhinagar, India

Cryostat assembly building ready Nov 2014

Design of the Tokamak Pumps is driven by the Operational Duties

- Only few % of the fuel is burned in the plasma and turn into He ashes.
- Confinement is not perfect. Particles slowly migrates to plasma edges.
- Divertor configuration allows exhaust of excess fuel, ashes and impurities.
- Continuous pumping and fuelling necessary for correct machine operation



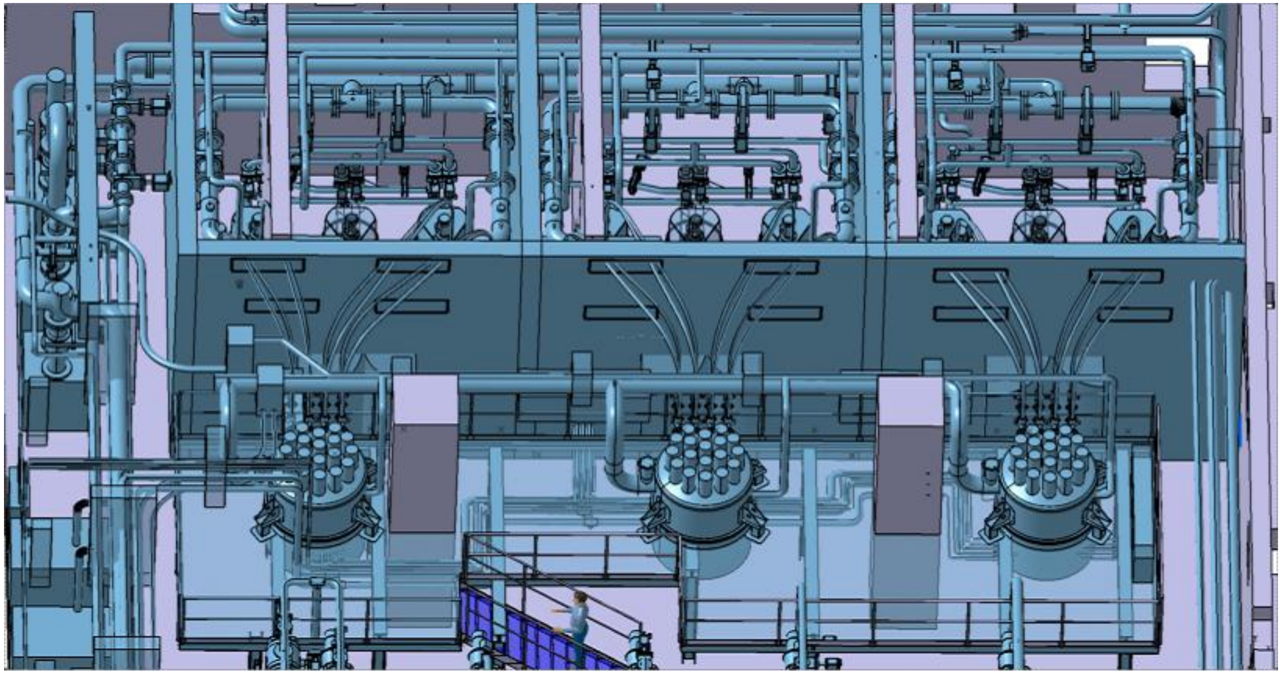
DT Plasma scenarios:

1. Inductive operation: 450s pulse Fuelling rate: 200 Pa·m³/s
2. Hybrid operation: 1000s pulse Fuelling rate max. 160 Pa·m³/s
3. Non-inductive operation: 3000s Fuelling rate max. 120 Pa·m³/s

6 isolatable fast regenerative cryo-sorptions pumps are used in flexible configurations to control hydrogen inventories and provide necessary pumping.

Neutral pressure in divertor 0.25 -10 Pa

ITER Roughing Pumping System



Post Fukushima nuclear plant accident there is higher sensitivity to detonation of hydrogen inventories.

Inventories in roughing room divided in to 4 cells

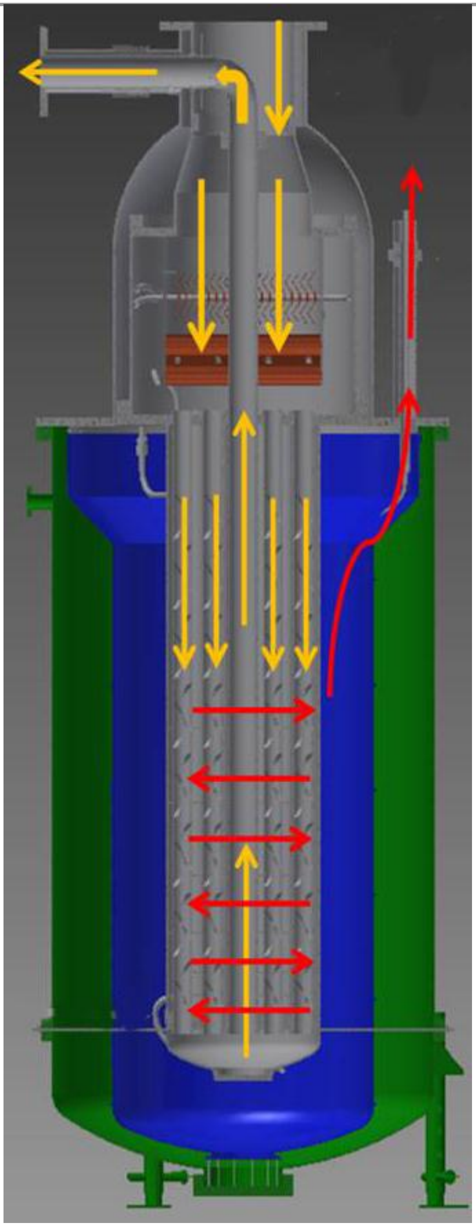
Core of roughing system 3 pumping bays for fusion exhaust gas pumping and a number of mechanical pumping sets for large volume roughing.

6 Cryogenic Viscous flow Compressor (CVC) are used for the hydrogen isotope pumping with regenerations of the CVC using either a tritium compatible, piston pumps or scroll pumps.

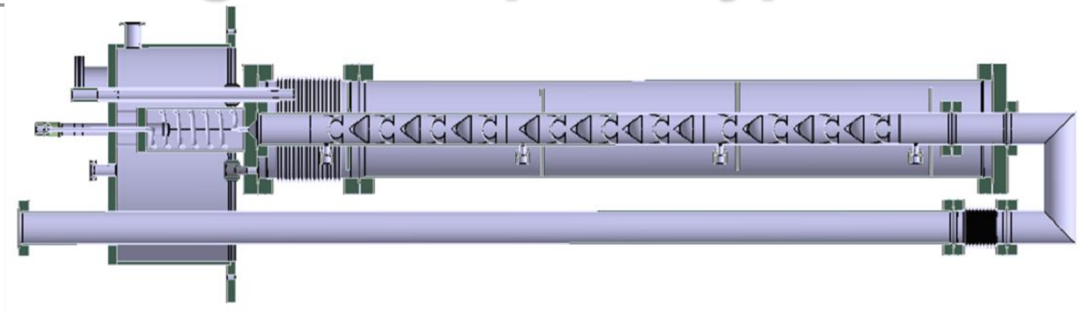
Large volume roughing and low other gas with no or low levels of tritium are to be pumps by special roots/ screw pump combinations.

Development of CVC

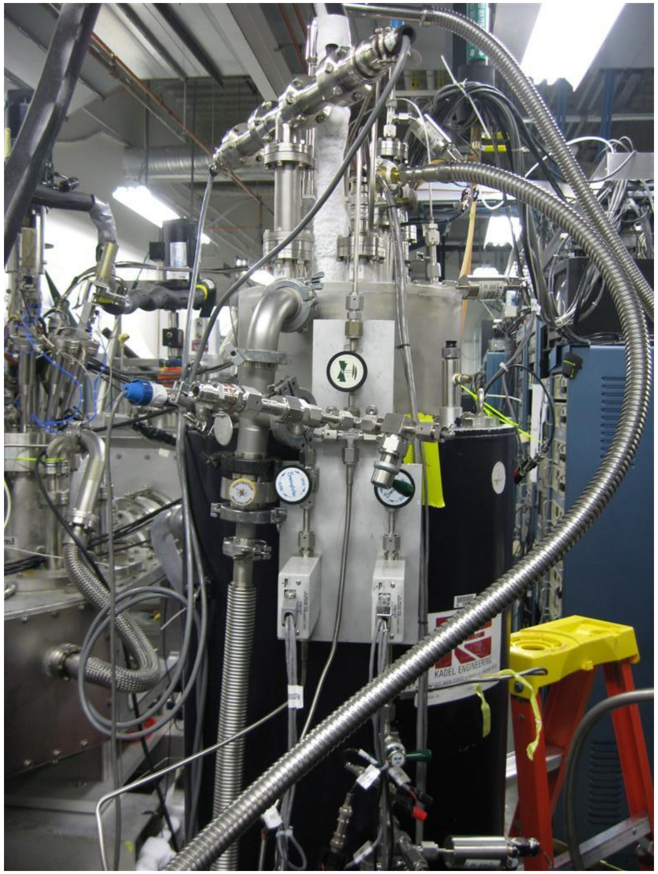
- During plasma operations, to pump the mixture of gasses originating from the regenerations of torus and neutral beam cryo-pumps, the roughing system will utilize 6 cryogenic viscous flow compressors (CVC).
- The principle of the CVC is that it will cryogenically condense hydrogen isotope mixtures, while providing first stage compression of helium ash originating from the fusion process.
- Each CVC is designed for throughputs of 200 Pam^3/s and consists of a tube heat exchanger housed in a cryostat of diameter ~1 m and height 2.5 m.
- Inventory is limited to 50 moles of hydrogen isotope and 70 g tritium per cell.
- The very novel nature of this pump requires a full size prototype, which has been manufactured and will go through a test campaign.

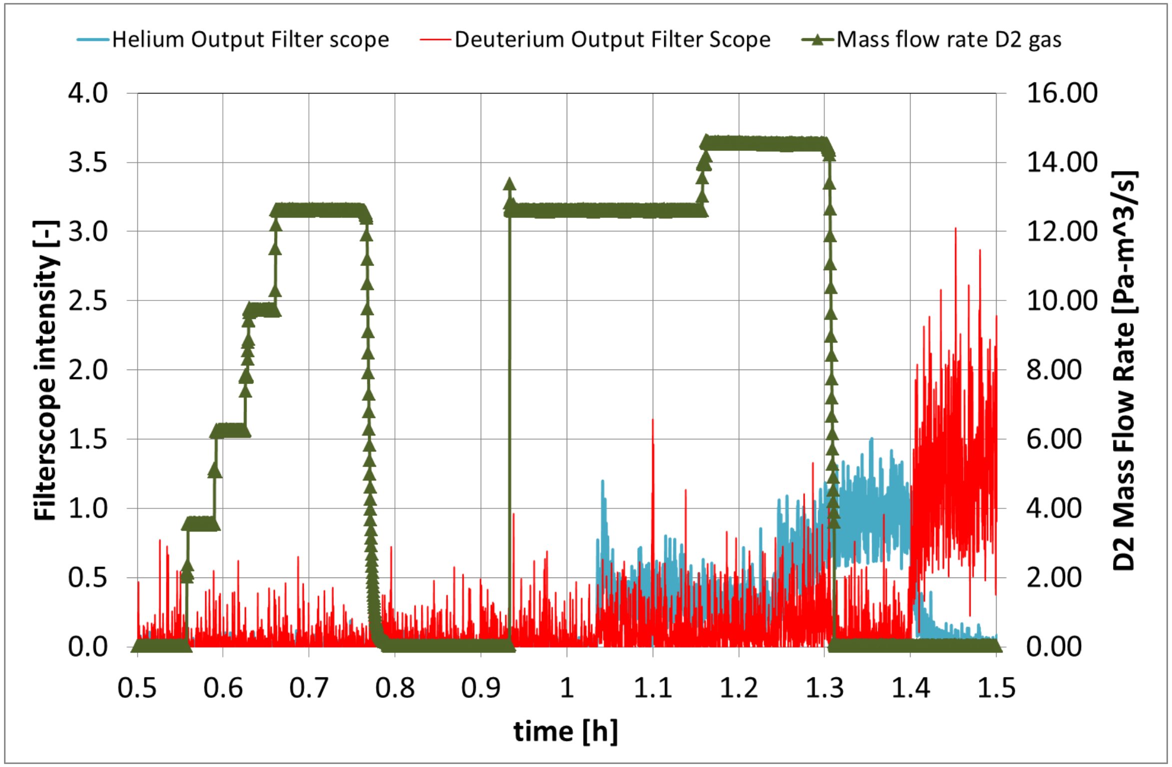


Single tube prototype tests of CVC (Oak Ridge)



Demonstration with deuterium helium mixture of effective cryogenic pumping of deuterium and mechanical pumping of helium. Helium flow increased from 0.07, 0.21, 0.32 Pa-m3/s.

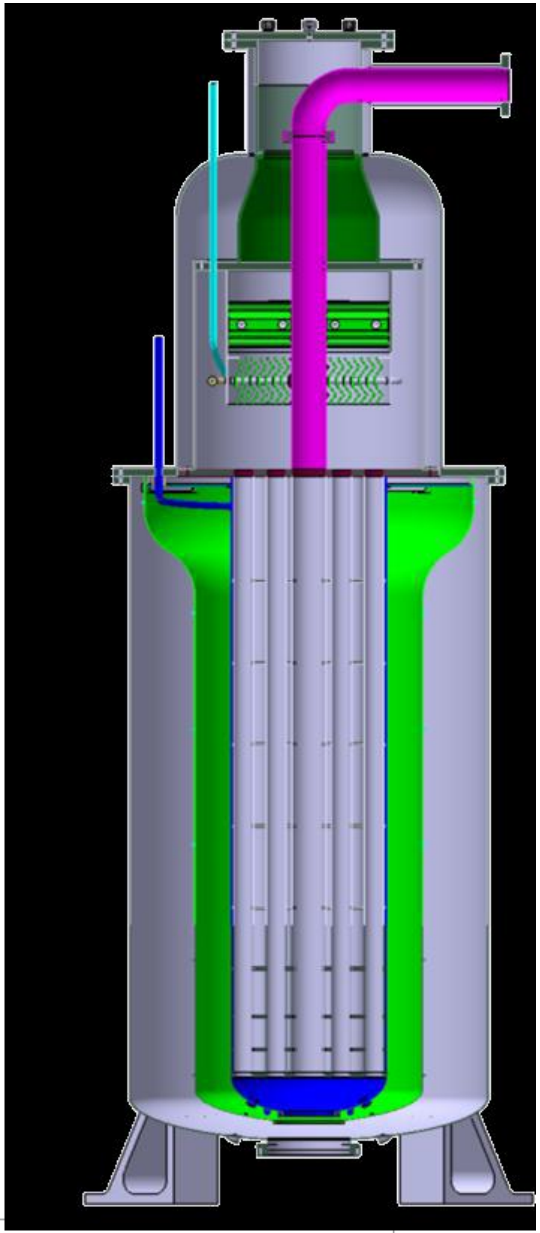


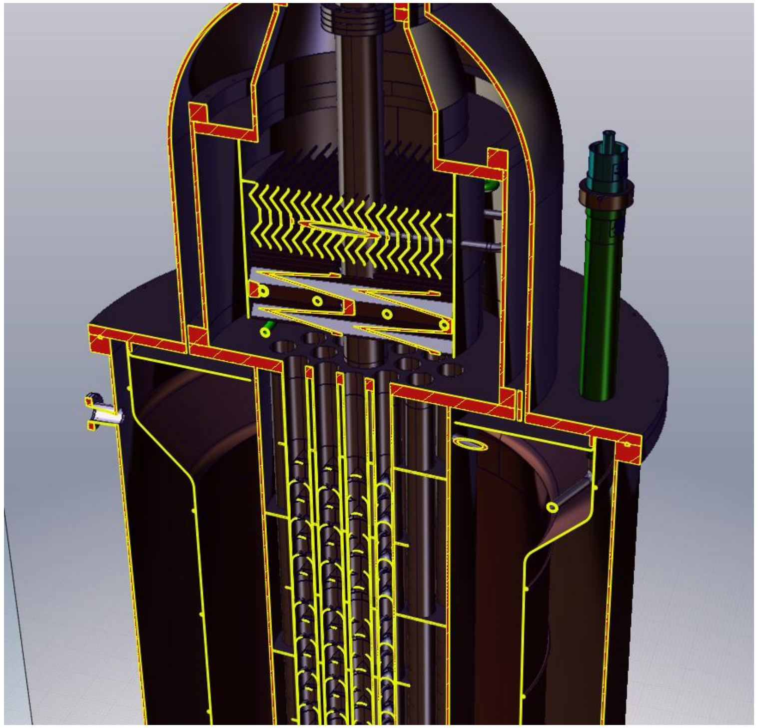


Full size CVC Prototype Design

Design made to ASME 8
Heat exchanger 24 flow and 1 return

Overall outer Diameter	1.041 m
Overall Height	2.655 m
Inlet flange Diameter	0.250 m
Inner volume	0.480 m^3

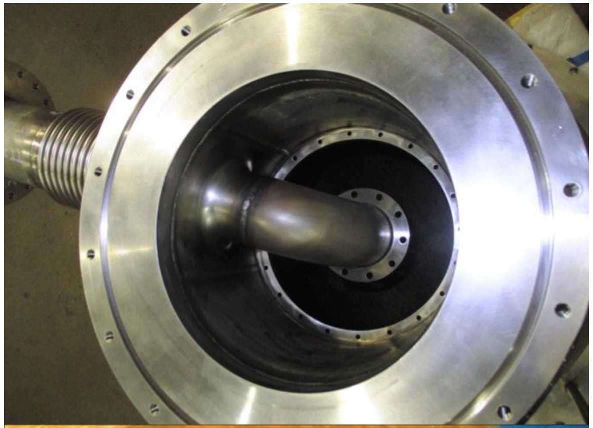




The flow tubes have segmented and brazed static mixer (Kinecs, Inc)

Manufacturing of full scale Prototype CVC (Major Tools inc)

CVC manufacturing Completion and cold Leak tests



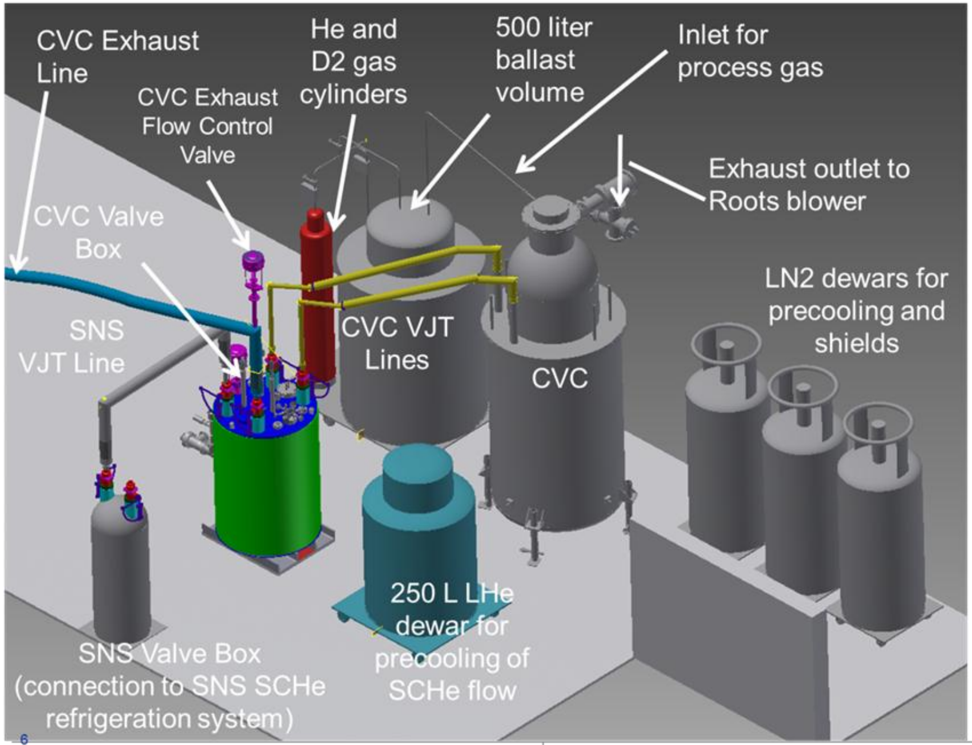
Top
Pumping
port

80K
Thermal
shield.

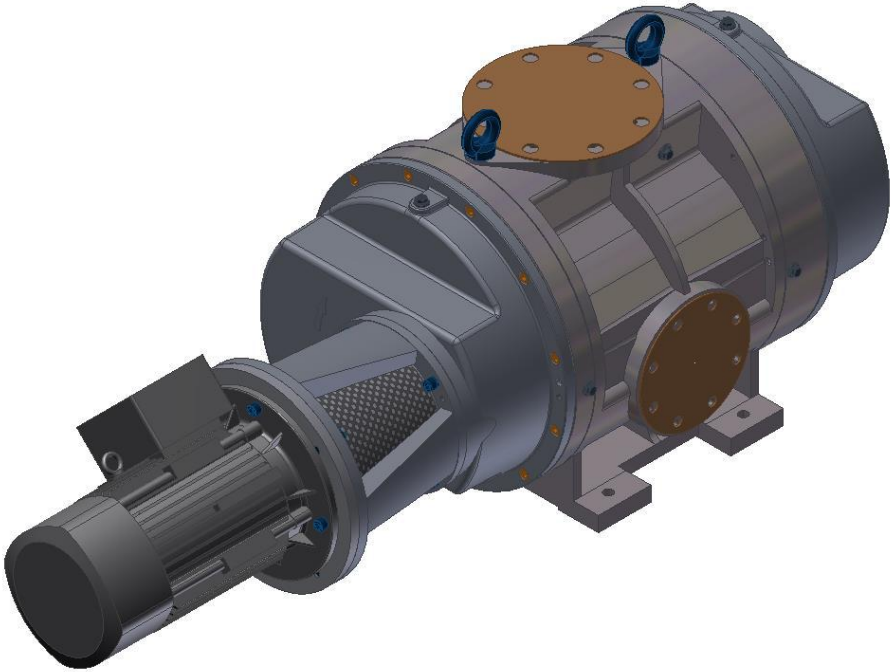
Cold Leak
tests
Sept 2014

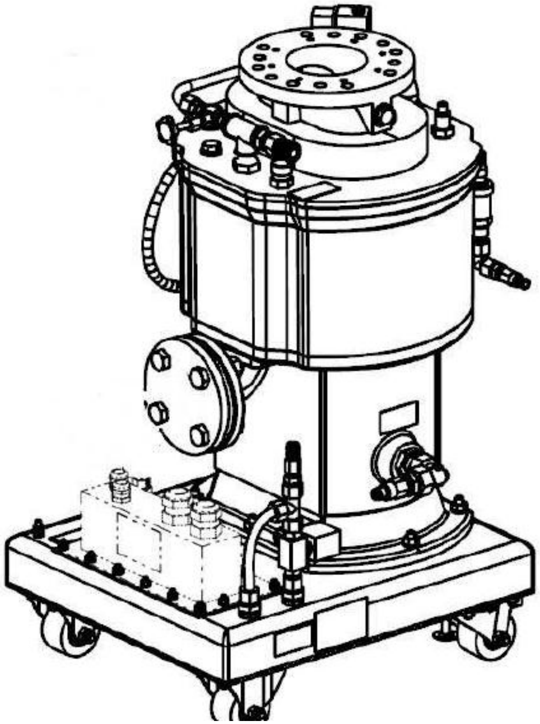
CVC prototype Test Campaign in Preparation

CVC prototype will be tested using an ITER like super critical He supply at SNS, Oak ridge using deuterium and helium mixtures.



Roots - Screw pumping train.



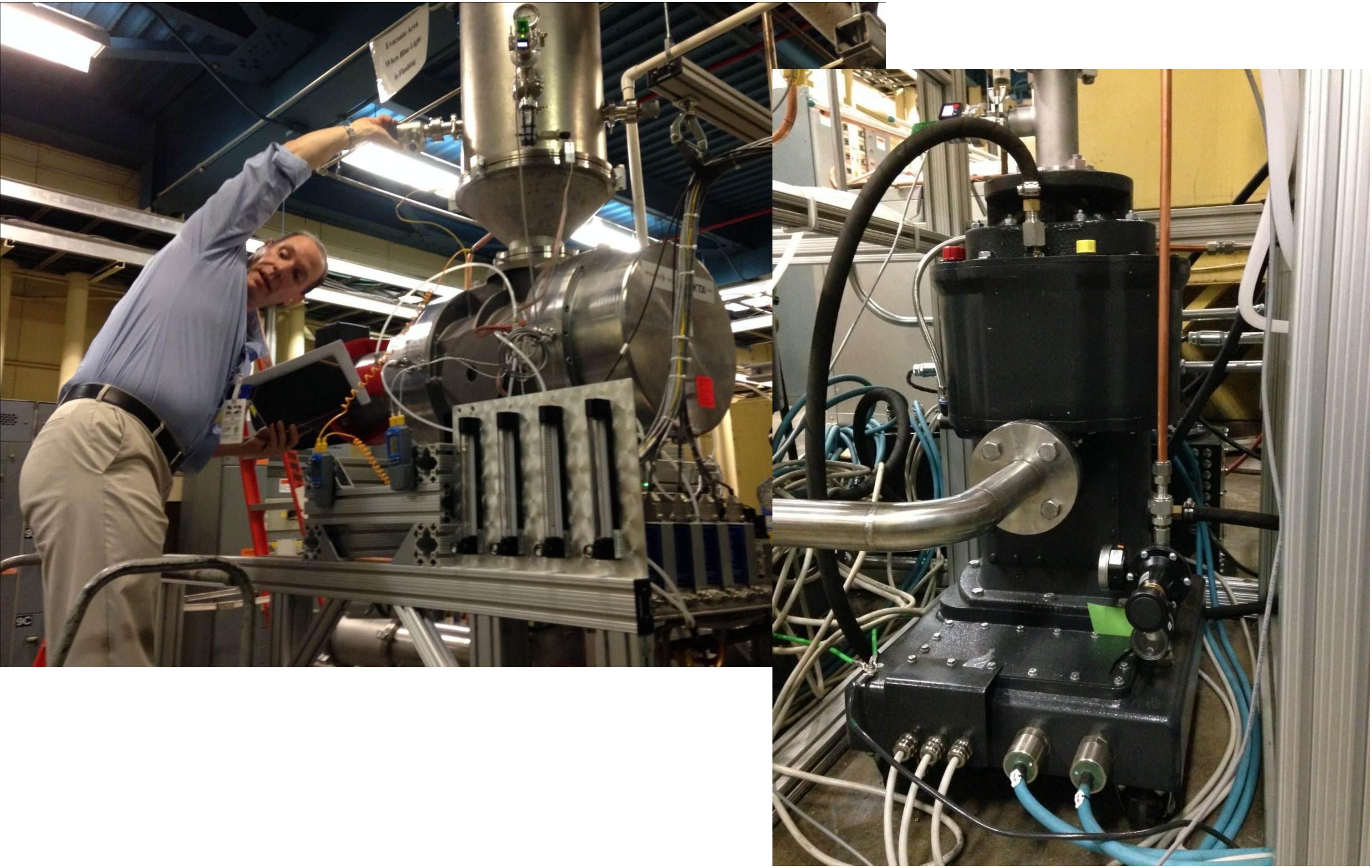


Stainless steel metal sealed roots blower with canned motor and glide ring seals to oil reservoir under validation. Pfeiffer Vacuum, Okta 1500 GM.

Oil free screw pump with EPDM fully sealed enclosure under . validation testing. Special Sterling SihiDry V250

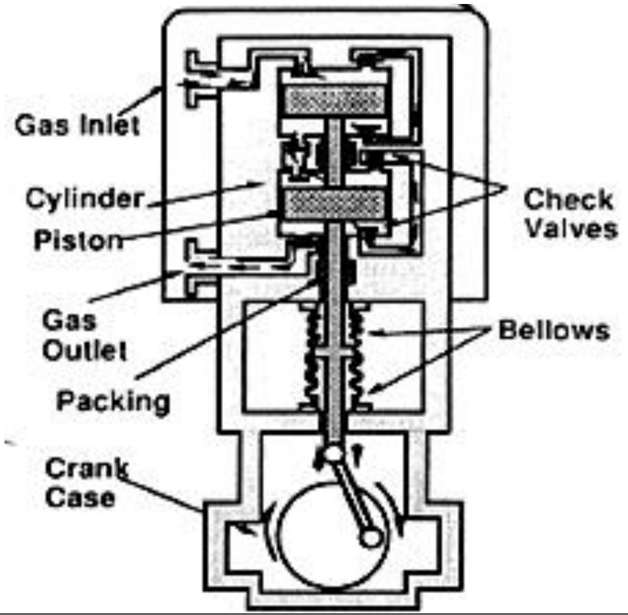
Pumping train validation in US in Nov 2014

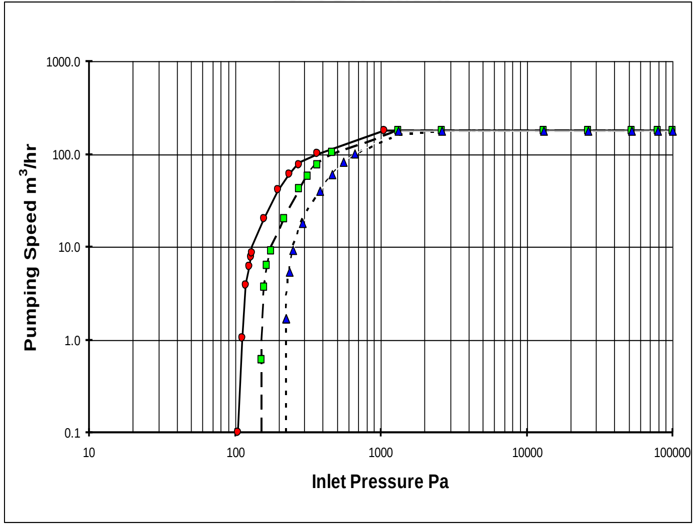
Pumping train validation in US in Nov 2014



New Tritium Compatible Piston Pump

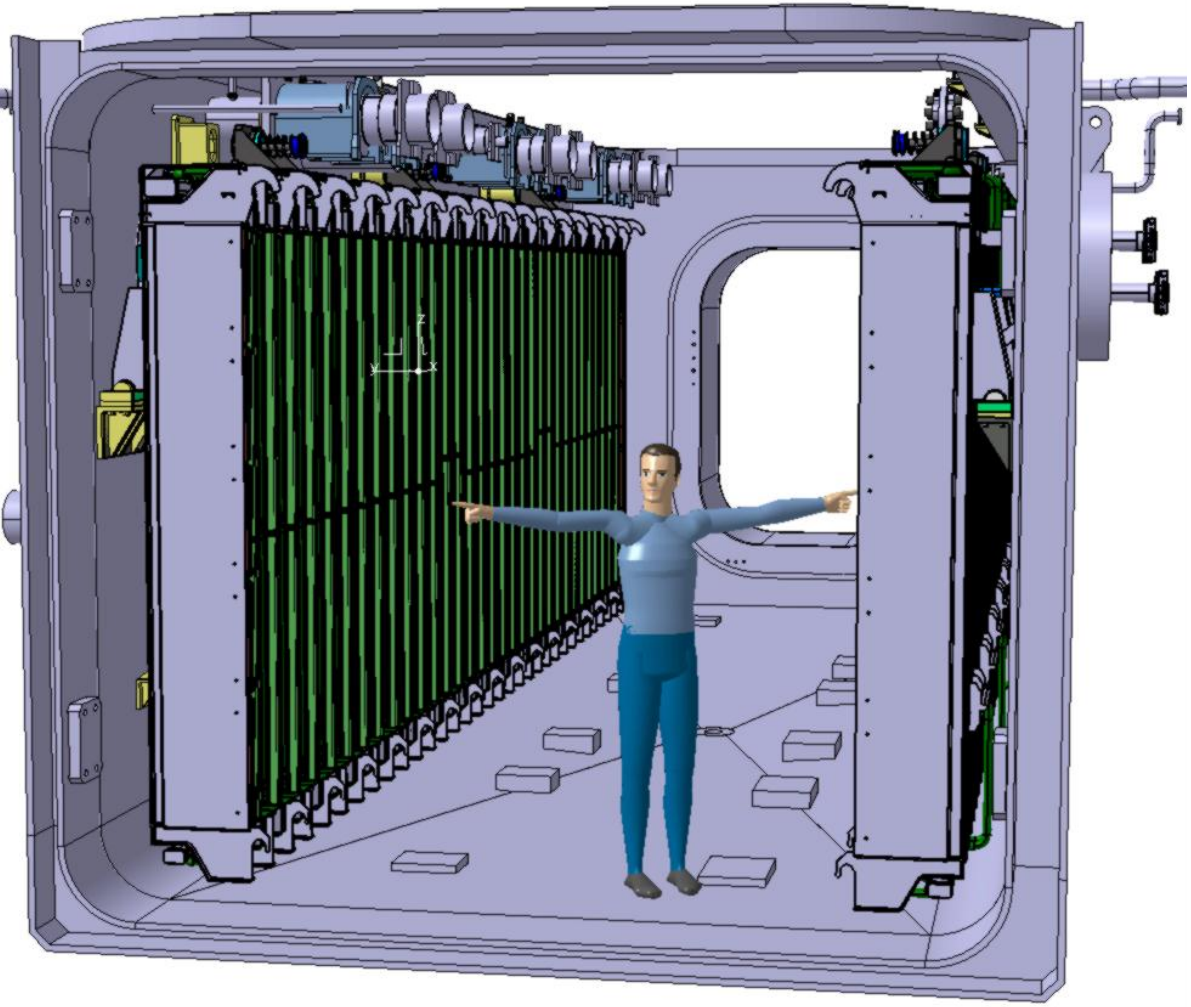
Mikuni (Toyo) 180m^3/h piston pump





Pump adapted to give factor 10 reduction in ultimate pressure.
Now being life tested at US ITER

ITER Neutral Beam Cryo-pumps



The ITER neutral beam systems (up to 4 off) are to each be pumped by a pair of open structure panel style cryo-sorption pumps with a length of 8 m, and height of 2.8 m.

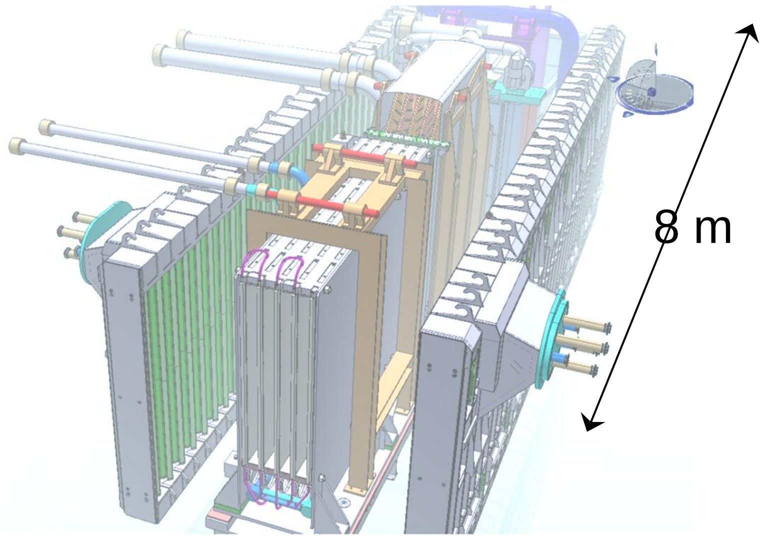
They should achieve a pumping speed of 4500 m3/s for hydrogen.

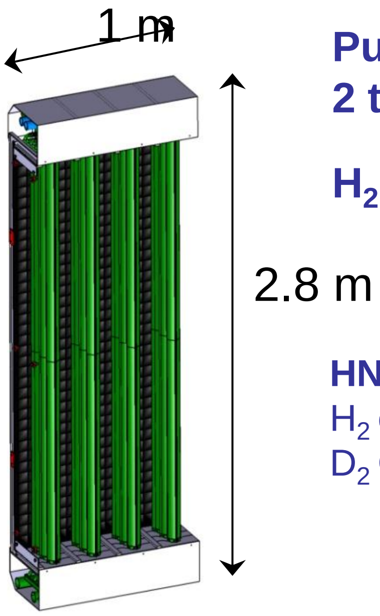
A robust stainless steal boundary is necessary for the cryogenic circuits to provide a confinement barrier between tritium and cryogenic helium.

The cryogenic assemblies (4.5K) see very high heat loads during the injection of the high energetic neutral beam of deuterium or hydrogen into the plasma.

Regeneration temperatures are up to 400K.

Neutral beam cryopumps



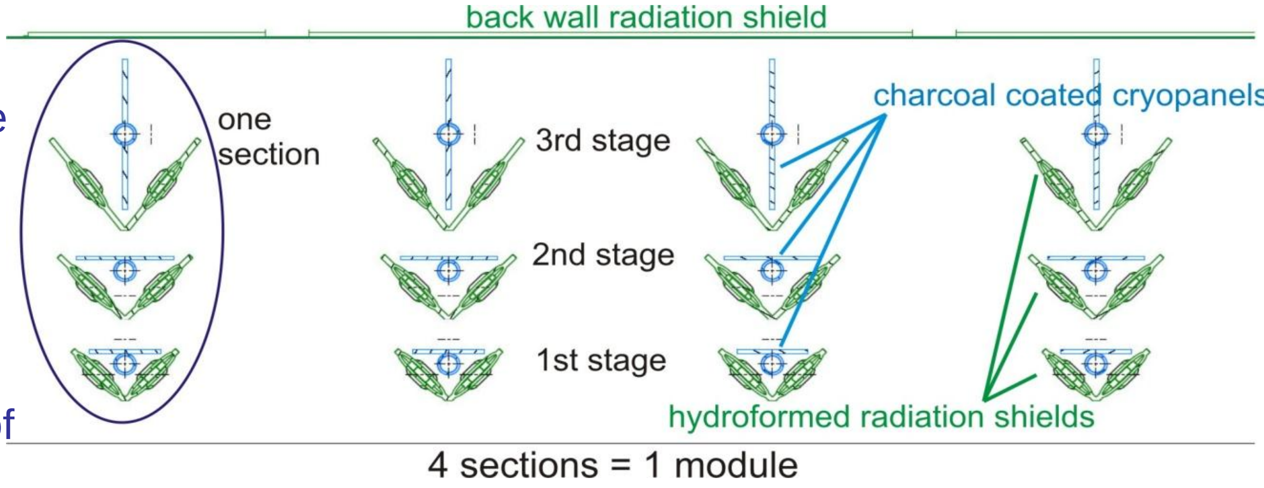


Pumping surface:
2 times 8m * 2.3m = 36.8 m^2

H_2 pumping speed: 4700 m^3/s

HNB Gas Flow:-
H_2 operation (870KeV) 48 Pam^3/S
D_2 Operation (1MeV) 23 Pam^3/S

Blue: 4.5 K surfaces, Green: 80K shielding



Originally designed based on SS hydro-formed panels. (like torus pump)

Found that thermal performance of SS fins was inadequate to maintain cryogenic temperature for sufficient pumping.

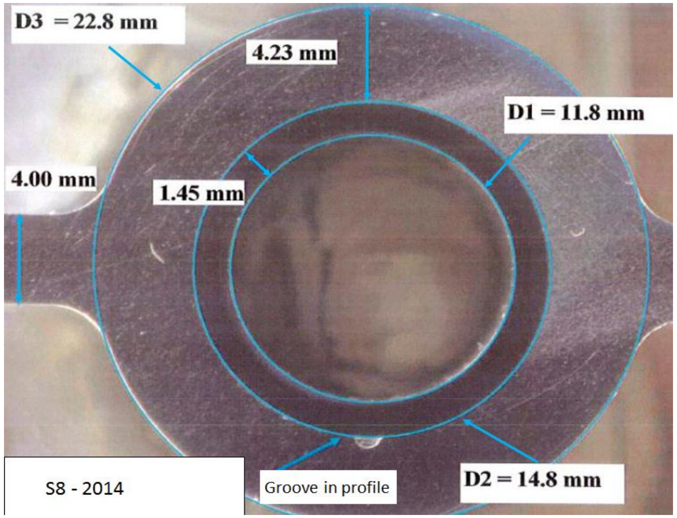
Manufacturability of design became questionable, in terms of tolerances and time scales

Development of new Manufacturing method for Cryo-panels

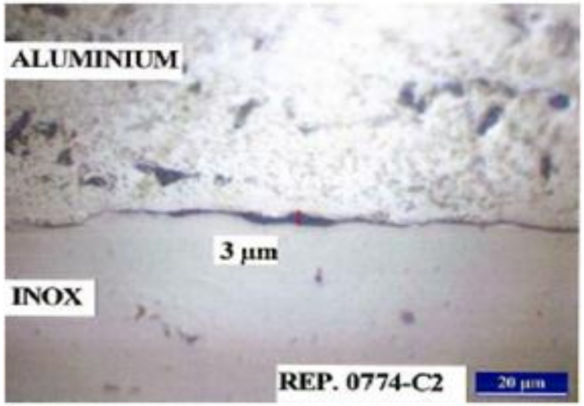
Aim was to find a method to combined structural and weld-ability properties of Stainless and the thermal conductivity of Aluminum at low temperature by a process which could be productionised.

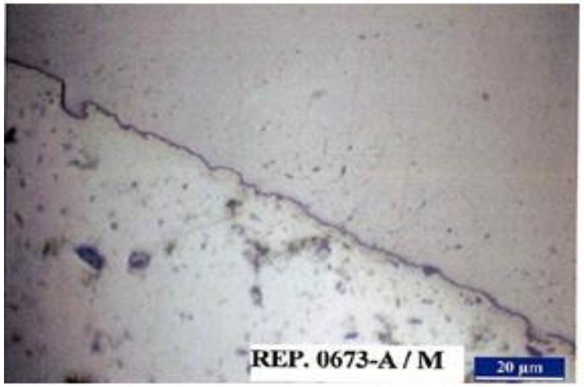
Co-extrusion of aluminum panels with stainless tube was tried but was not successful

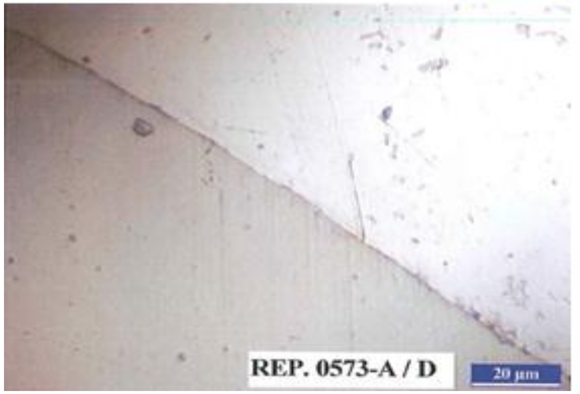
A method was found of hydraulic expansion of stainless tube into aluminum profile.



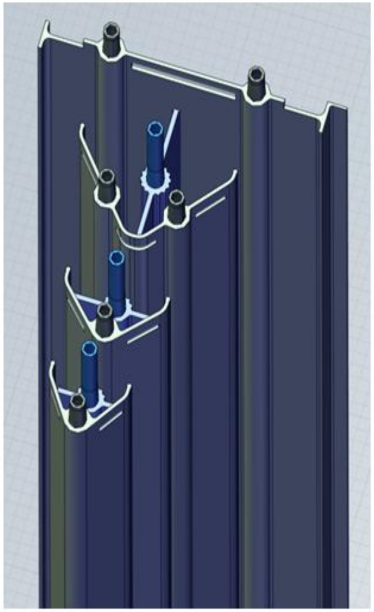
By taking the stainless into plastic deformation and keeping the aluminum in elastically deformed a bond is produced which stays in excellent thermal contact over the 4.5 to 400K temperature range, despite the different materials thermal expansion coefficients.

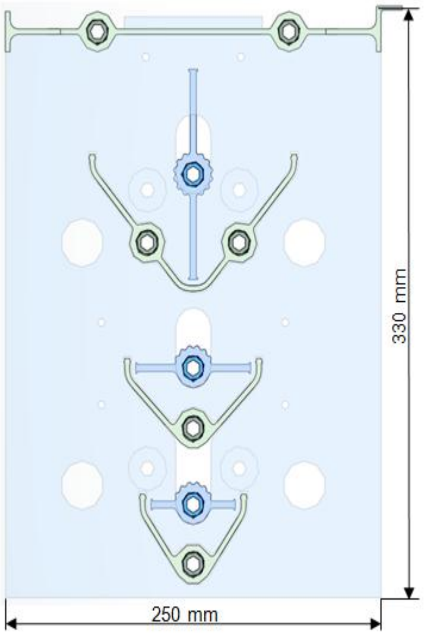




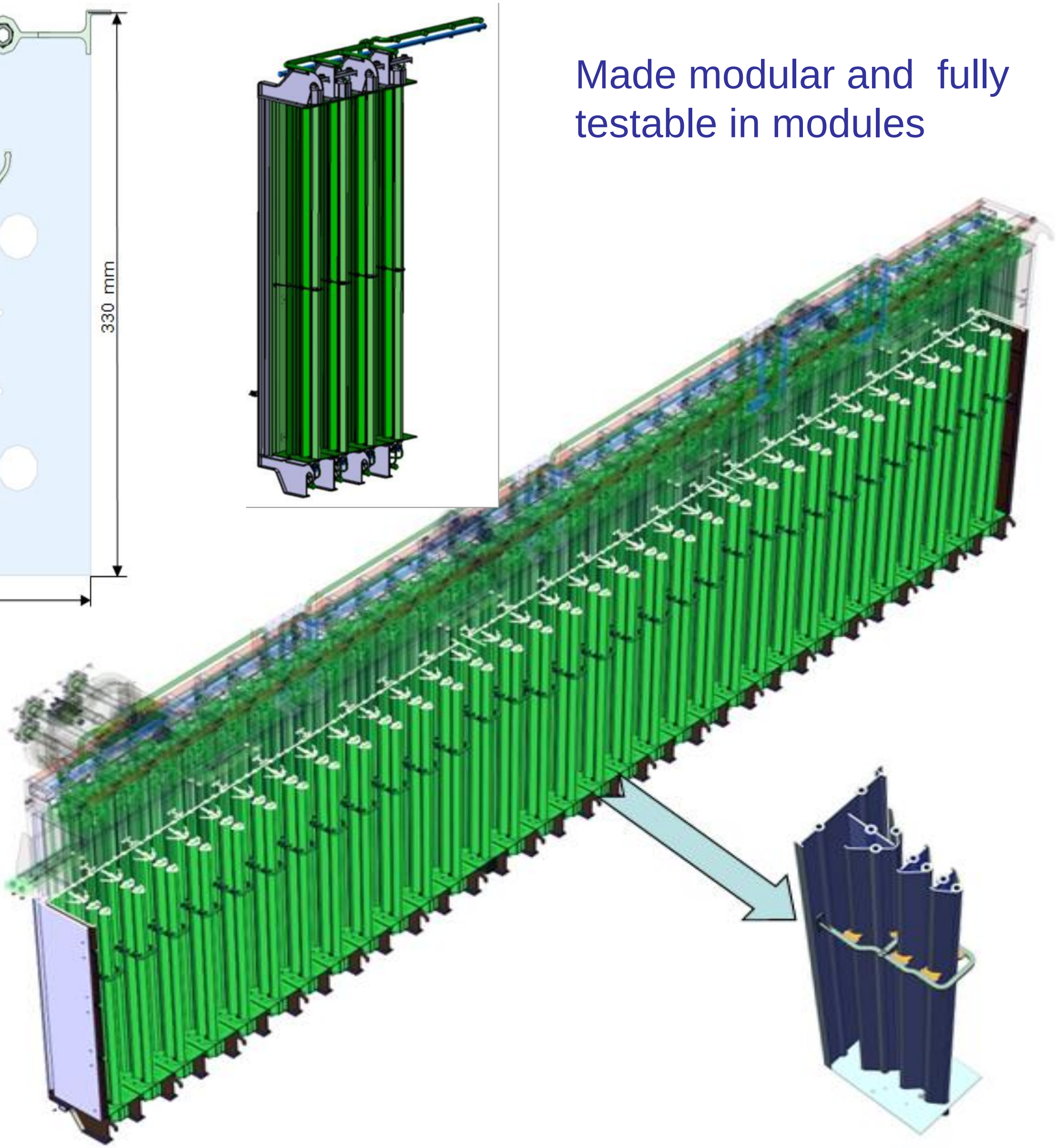


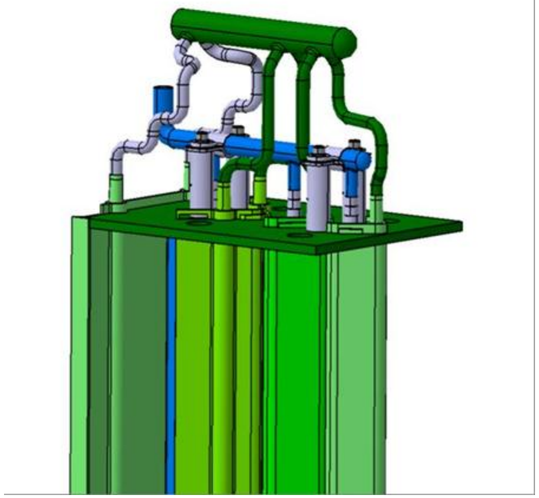
New manufacturing method has led to improved design





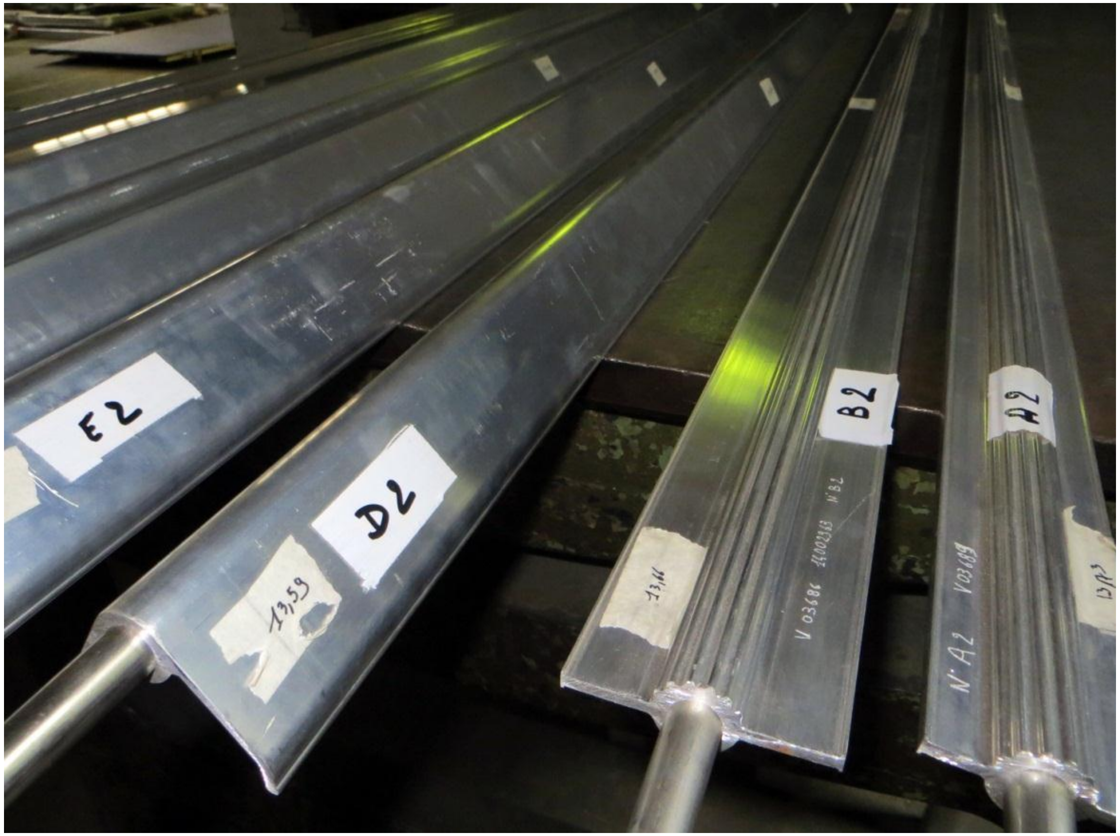
Made modular and fully testable in modules





Checking the manufacturing

All profiles manufactured and thermal cycled to confirm thermal contact and to check for bending due to residual stresses.



Pipe in SS EN1.4306 profiles in aluminium 6082-T5

Expansion rig for 2.3m profiles at 200 M Pa

Design Ready to Procure First Pump

First pumps to be procured is for the Neutral Beam test facility in Padua, Italy.

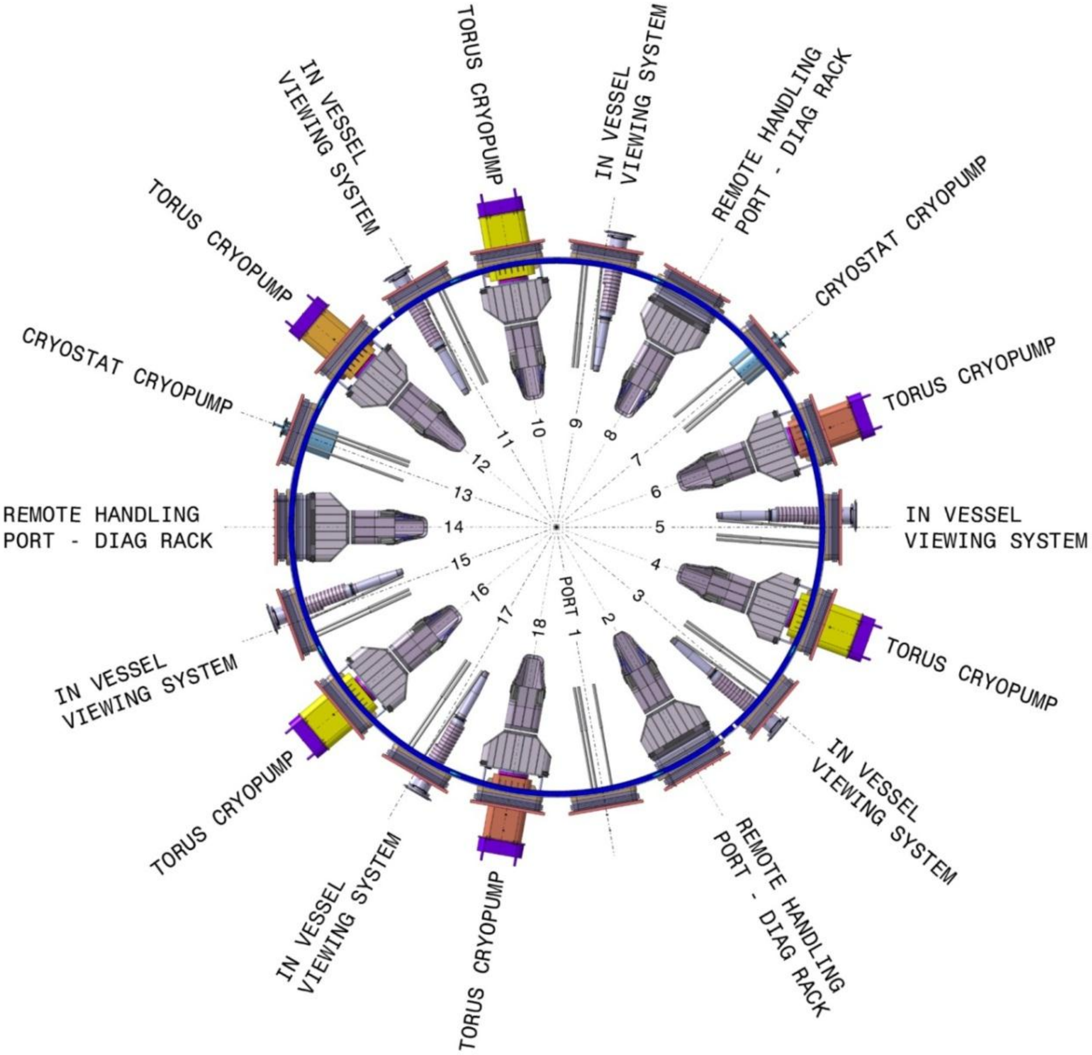
Strategy is to procure using “build-to-print” design through EU DA using three contracts :-

1. Main contractor for welding, support frames assembly, frames, assembly modular cold tests.
2. Contractor for preparation of cryo-panel and thermal shields including stainless/aluminum expansion.
3. Contractor for activated charcoal coatings.

Design ready but production method for charcoal coatings still needs development.

Procurement will start in 2015 for with pump delivery by 2018

Configuration of torus and cryostat cryo-pumps

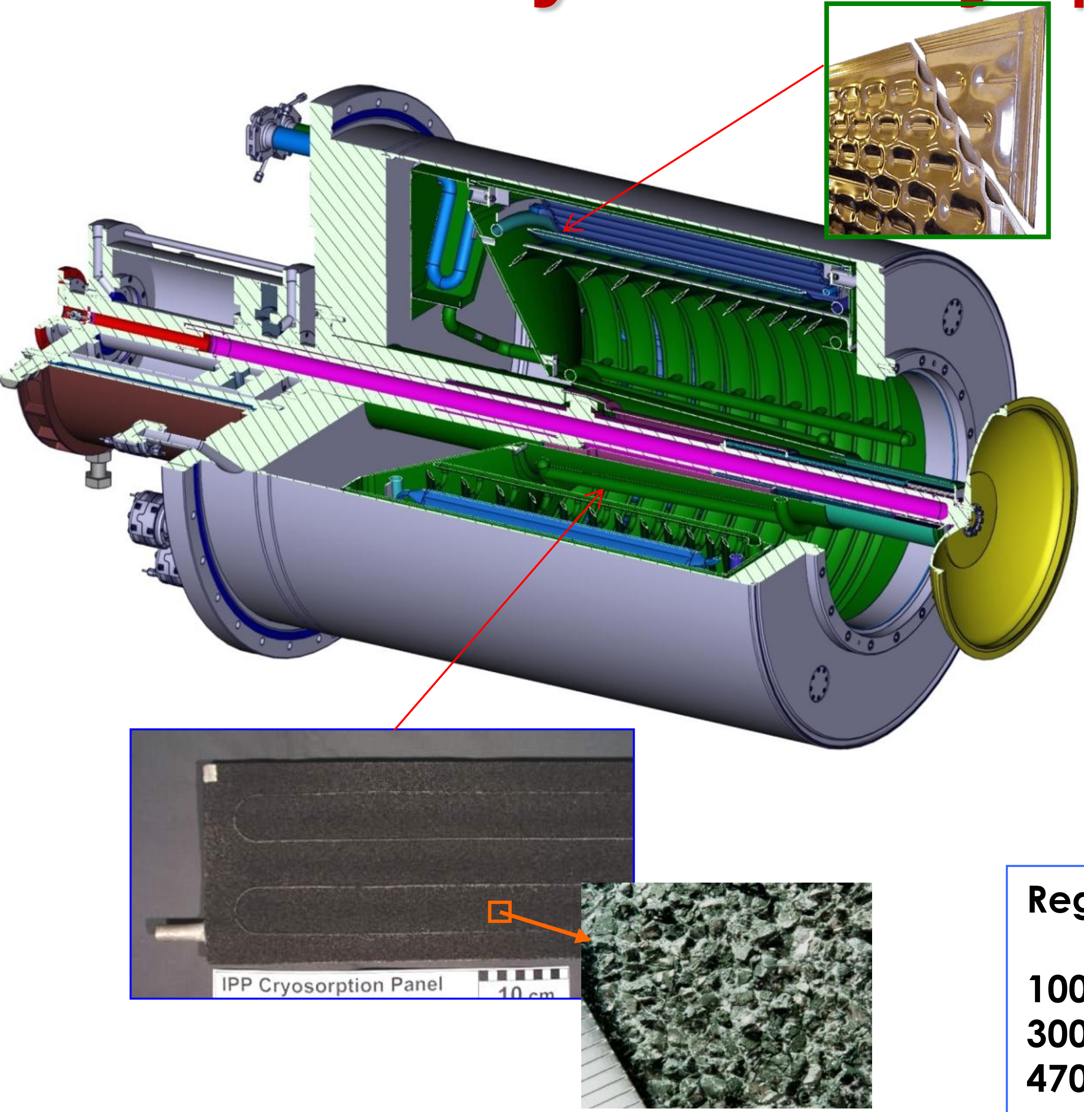


The ITER vacuum vessel and cryostat are to be pumped by a total of 8 cylindrical cryo-sorption pumps with integral 800 mm all metal vacuum valves.

The “build-to-print” design of these pumps has been optimised and finalised and the first pump is being manufactured.

6 torus cryo-pumps   2 Cryostat cryo-pumps

Design configuration of torus and cryostat cryopump



Main inlet valve for flow control and separation of the pump from the torus for regeneration

Thermal radiation shields:
Cooled to about 85 K by forced flow cooling of helium gas at 1.8 MPa

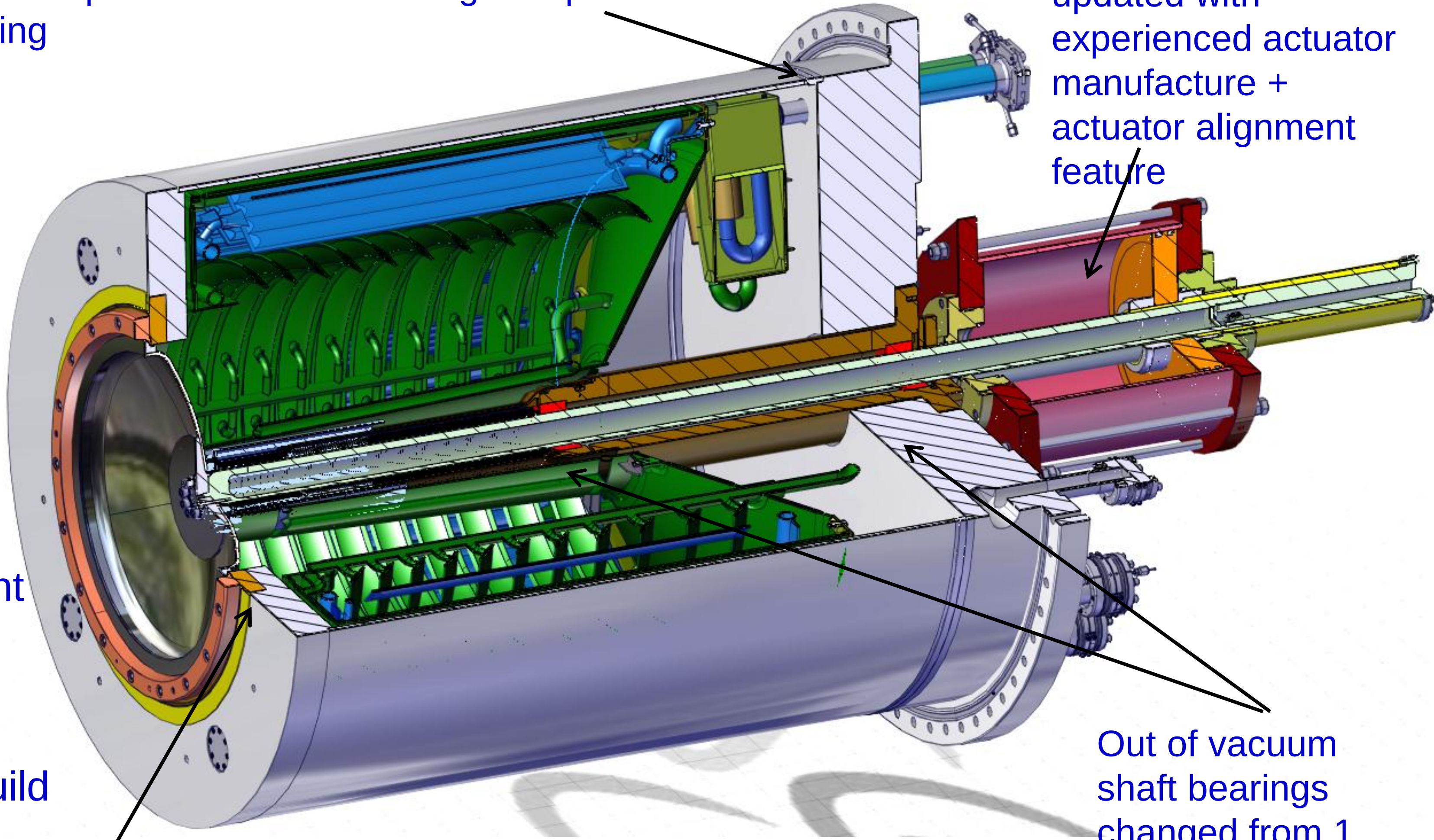
4 K pumping circuit made of charcoal coated panels by forced flow cooling with ScHe at 0.4 MPa

Pumping by charcoal:
Efficiently Helium at T< 5 K
Efficiently all hydrogen isotopes at T < 10 K

Regeneration:

100K to release He, Ne and Hydrogen isotopes
300K to release Ar, O2, N2, CO, CH4, CO2
470K to release higher hydrocarbons

Main Design updates in manufacturing 2013/14



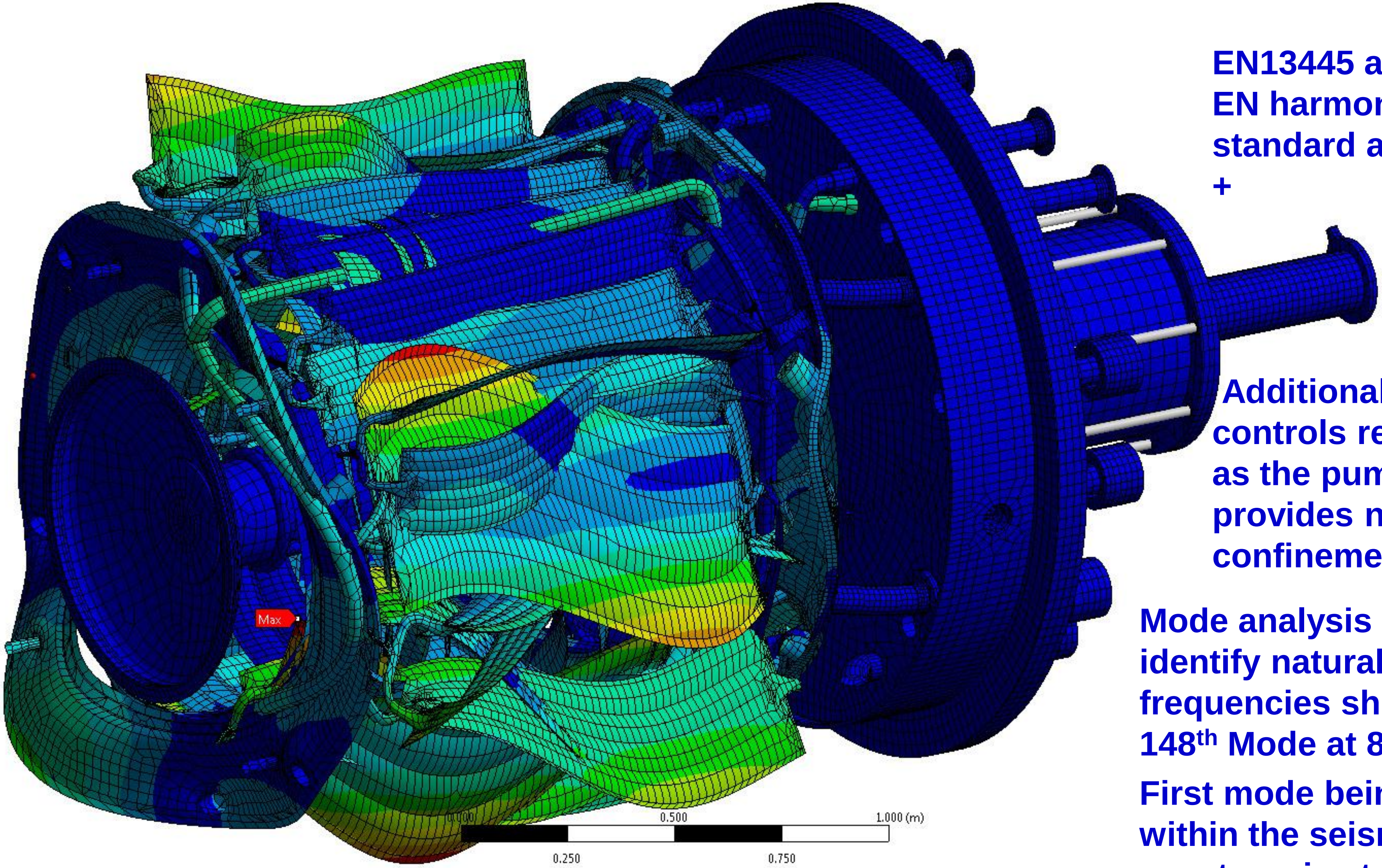
Features developed for E-Beam welding Pump plug to casing

Pneumatic actuator updated with experienced actuator manufacture + actuator alignment feature

Seal face arrangement updated to allow final alignment following build up of all manufacturing tolerances

Out of vacuum shaft bearings changed from 1 to 2 fix alignment

Cryo-pump Design is Validated for all possible loading conditions by structural analysis.



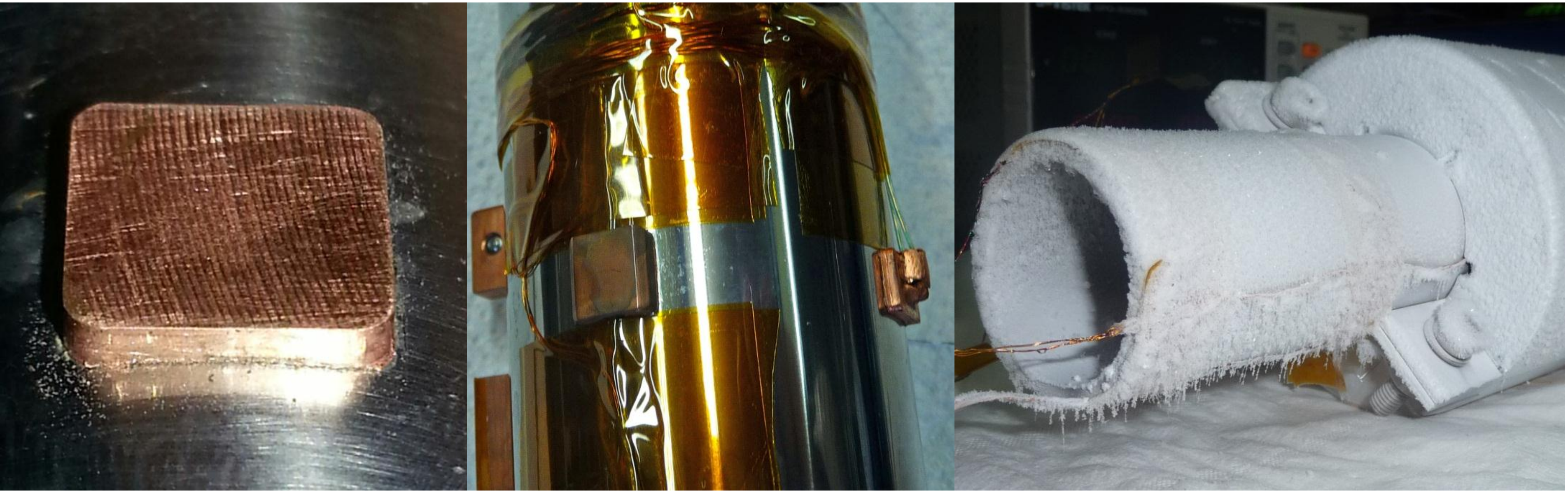
EN13445 and the EN harmonized standard are used +

Additional controls required as the pump provides nuclear confinement

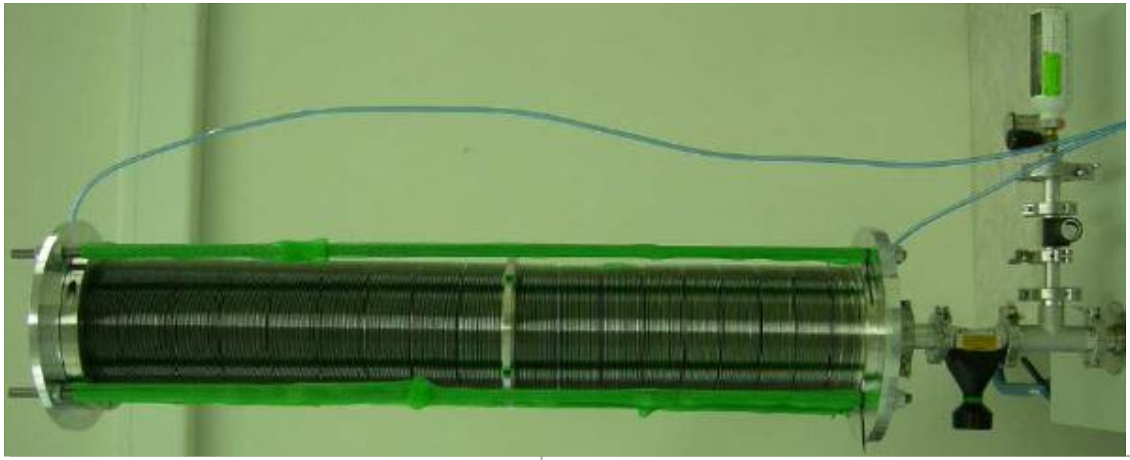
Mode analysis to identify natural frequencies showing 148th Mode at 82.Hz.

First mode being within the seismic spectrum is at 15.2Hz.

Progress with Manufacturing Pre Production Cryopump

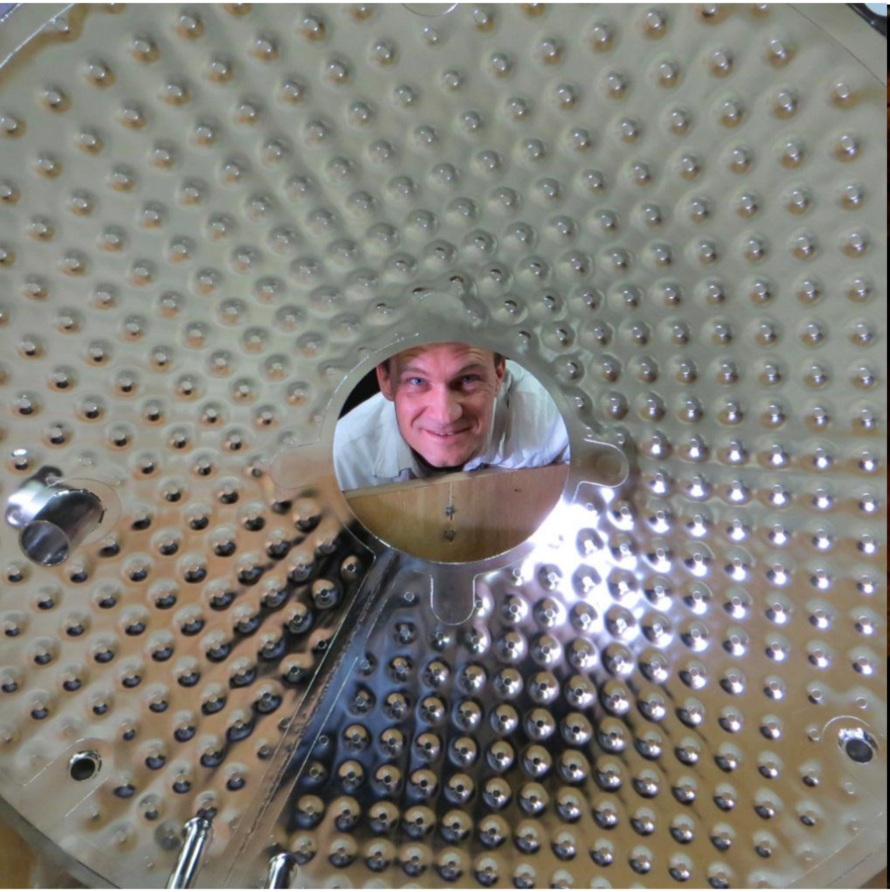


Temperature sensor (4- 470K) bonding by coper deposition onto helium pipe assemblies developed and validated for both thin film resistance temperature sensors (Cernox™) and Carbon-Ceramic Resistor (TVO) – Assemblies manufactured and delivered. (CECOM)



Double shaft bellows successfully manufactured and validated for 80,000 operations cycles 500mm stroke. Bellows assemblies manufactured and delivered (COMVAT)

Hydro-formed cryogenic panels and thermal shields



Electro-polished rear radiation shield.

All hydro-formed cryogenic panel manufactured and delivered either for charcoal coatings or for assembly. (SDMS – Ziemex)

Hydro-formed thermal shield undergoing 80K thermal cycle.

4.5 K Cryopanel after 130 bar burst test

Charcoal coating of 32 + spares cryo-panels

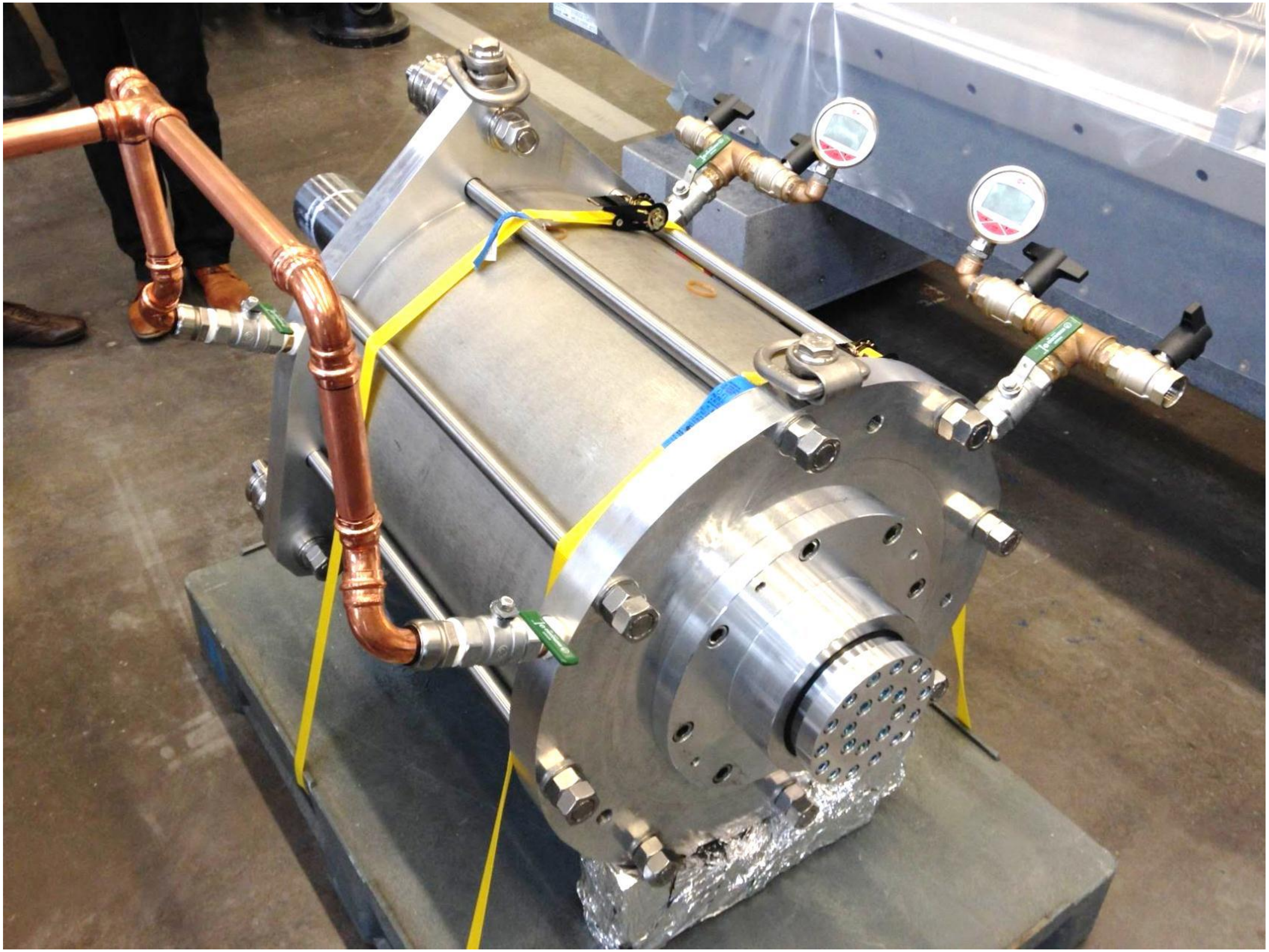
Cold shock testing

Packing

Panel coated with required density of 450 g/m^2 by spraying of ceramic glue and charcoal.

Panels all coated delivered to main assembly contractor (KIT)

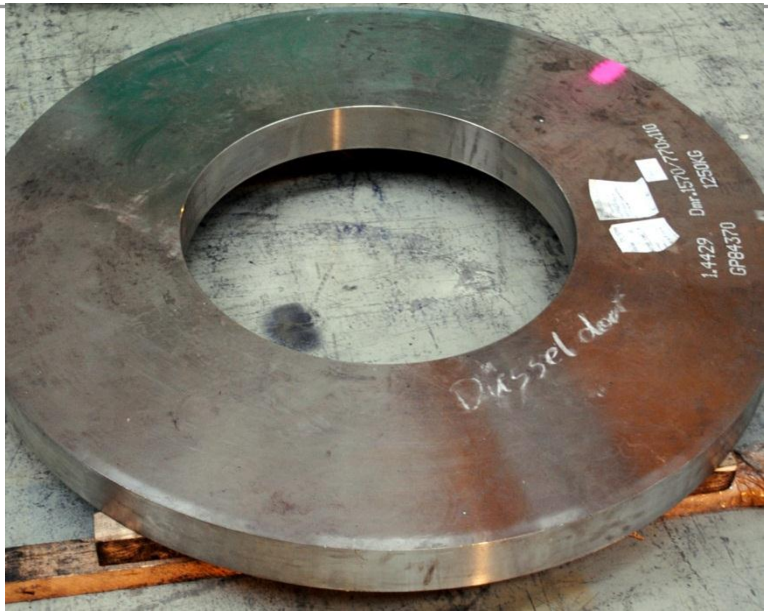
Valve actuator (8 bar pneumatic)



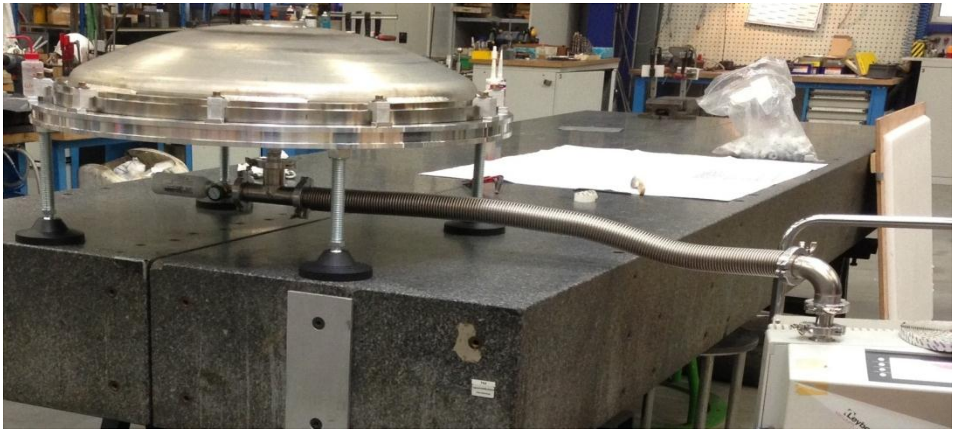
Actuator detailed designed, manufactured and tested. Provides 12.5 ton sealing force to valve. Full stroke (480mm) <10 sec with protection damping. Requires only 12mbar delta P to move unloaded. (Research Instruments – Konstantin)

Main machining Progress

2 m diameter EN 1.4307 (304L) stainless steel billet for machining cryopump flange.



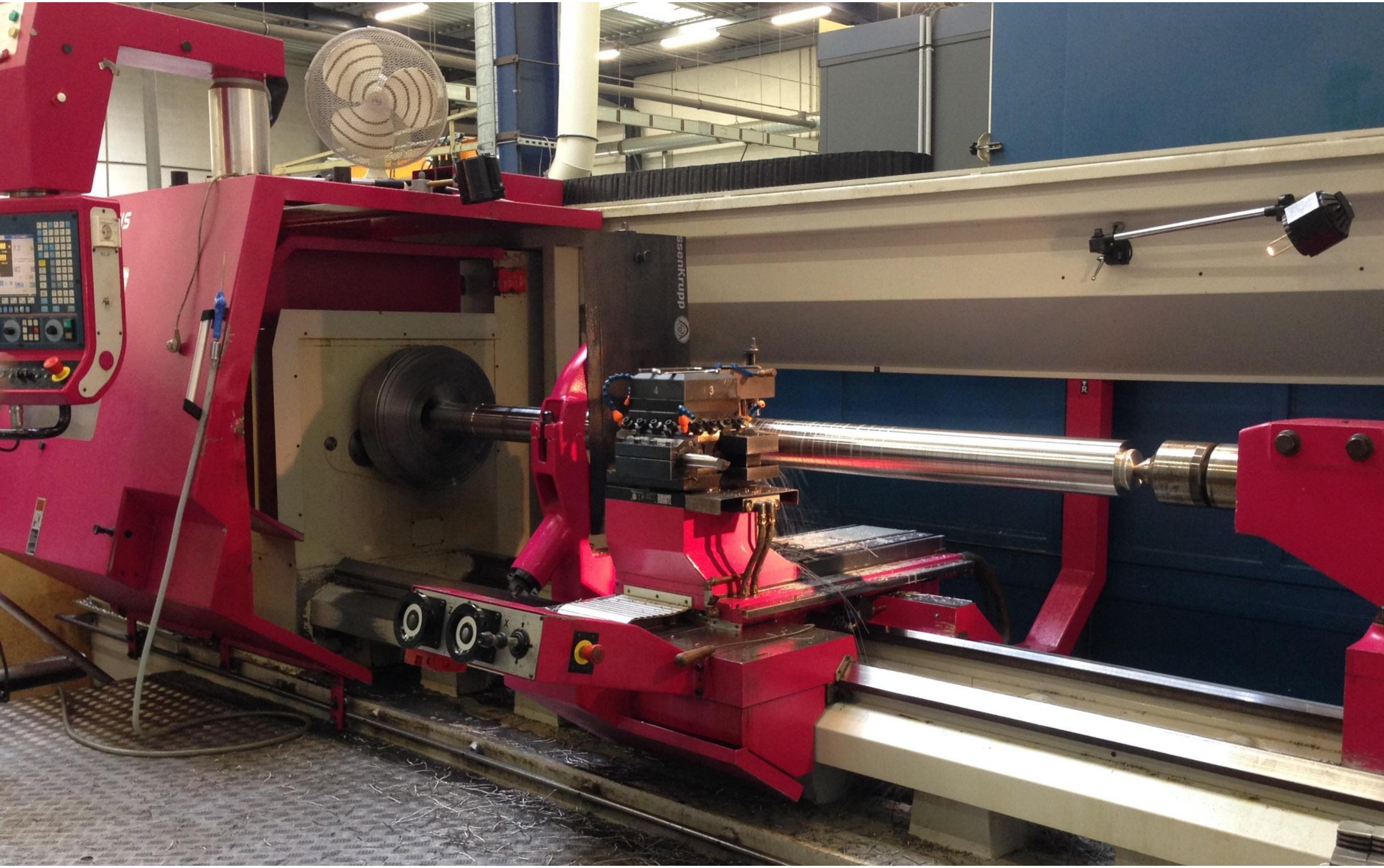
Front flange billet EN 1.4429 (S31653) low activation SS.



Leak test of Valve head (800mm) machining prototype in 1.407 stainless.

All quality documentations / certification in place ready for start of main machining. (Research Instruments – Alsyom -Seiv)

First machining of valve shaft (Research Instruments – Alsyom -Seiv)



Conclusion

1. ITER is progressing well to build one of the most complex large vacuum system in the world.
2. The task is more complex and taking long than originally perceived but manufacturing has started and is progressing.
3. Construction of the main vacuum components will intensify over the next ~5 years.

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