Complex Cryogenic lines installation
Features, challenges and status

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OUTLINE

1- Introduction

2- ITER Cryogenic System

3- Cryogenic Complex Cryolines – Design and Features

4 – Installation / Testing strategy

5 – Installation Challenges, Constraints and difficulties

6- Prospective & Conclusion

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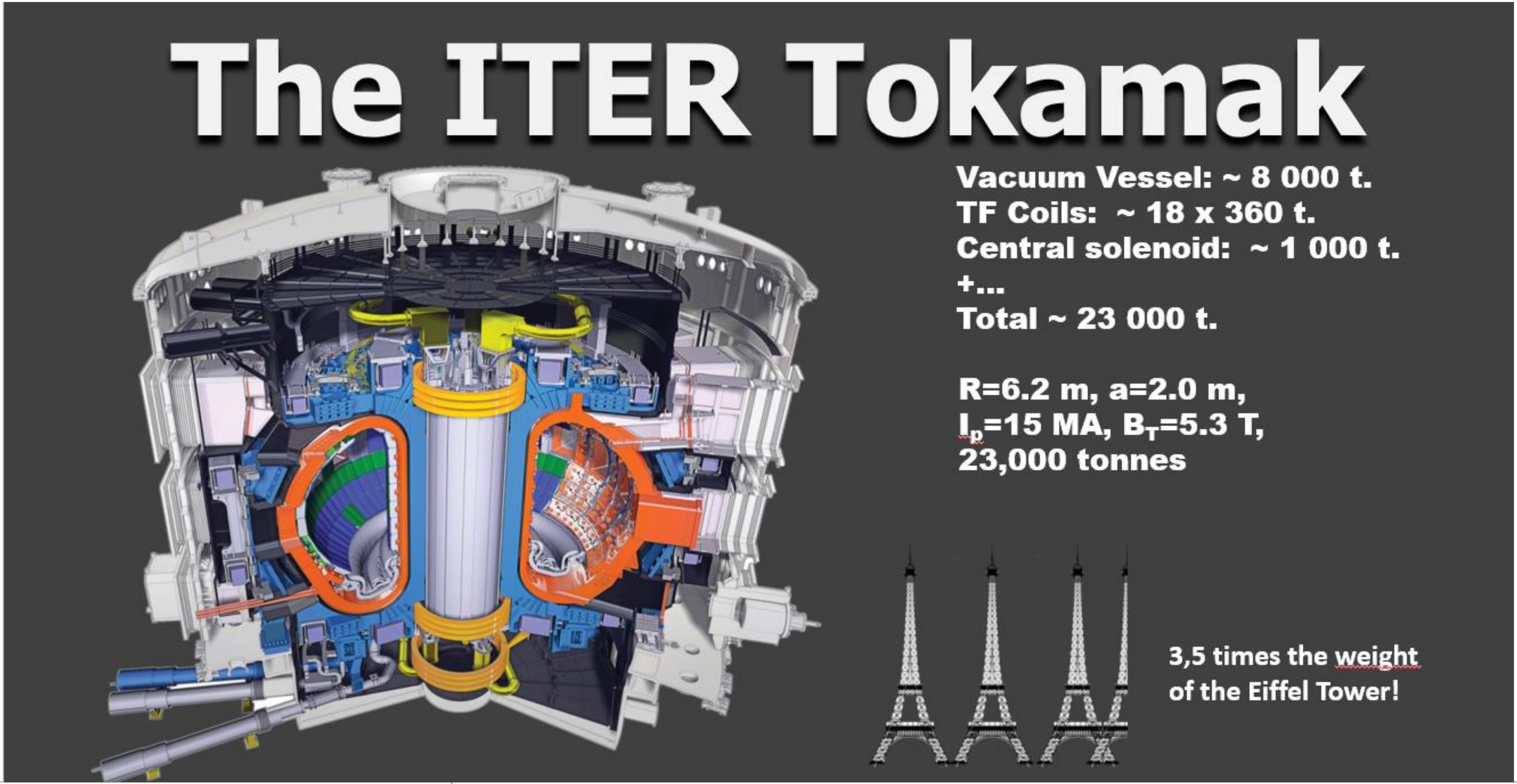
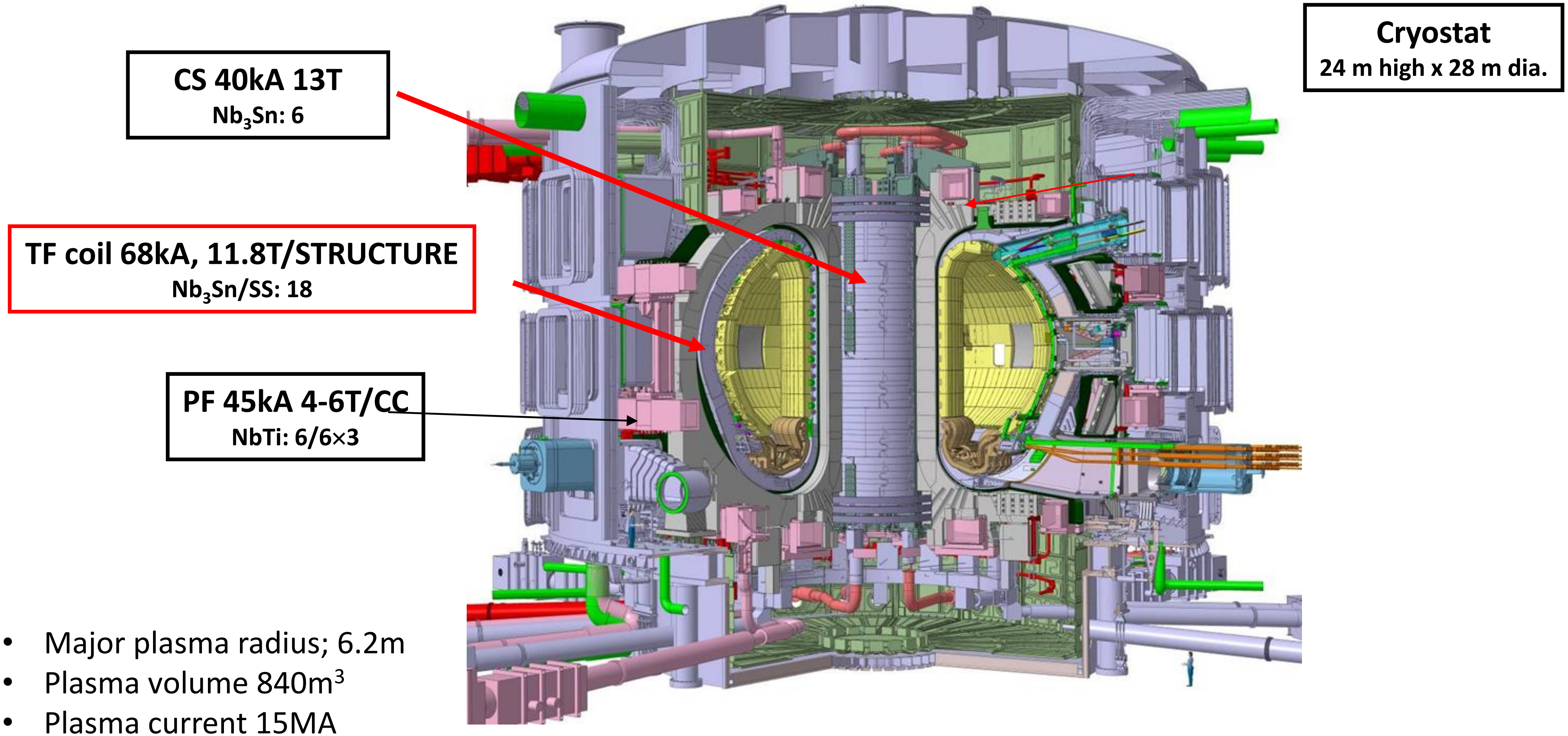
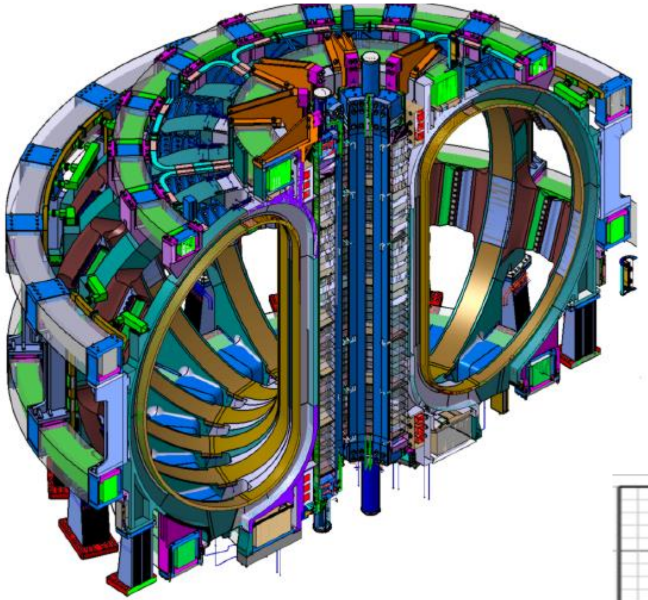
Main Goal : Achieve $Q > 10$ ~500MW thermal energy



TOKAMAK

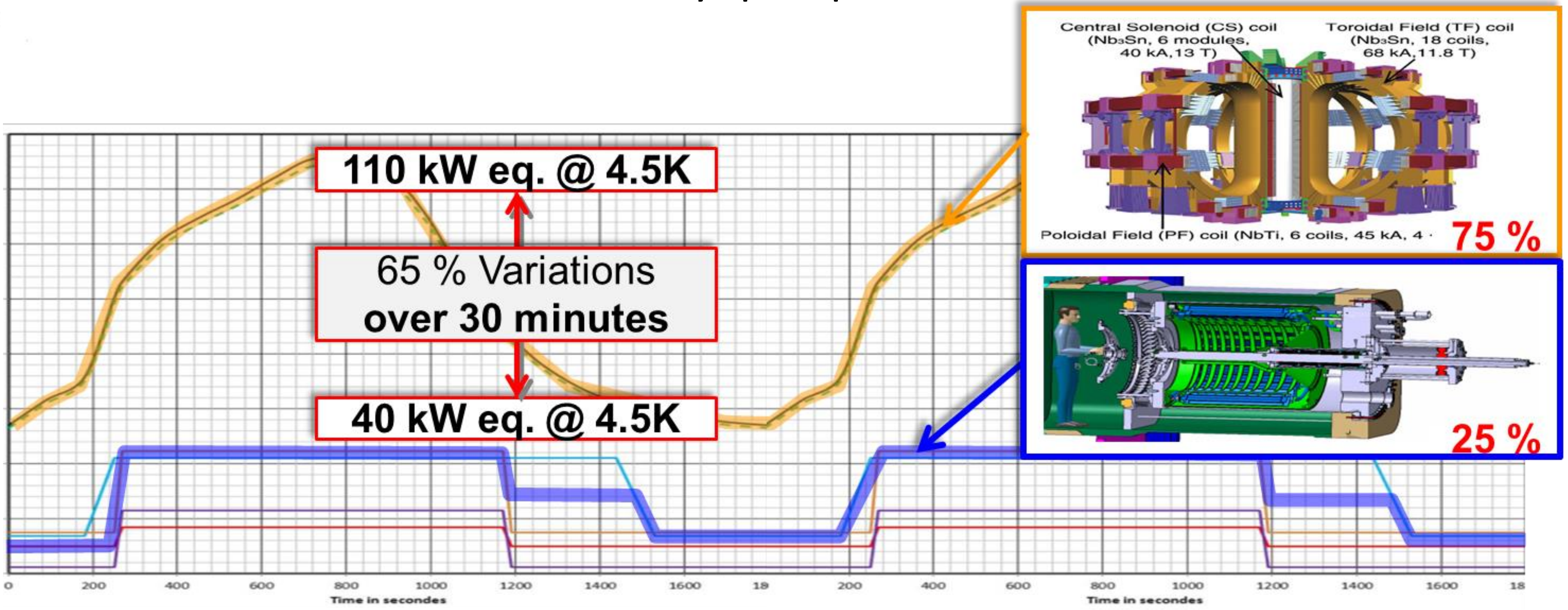


- Major plasma radius; 6.2m
- Plasma volume 840m^3
- Plasma current 15MA
- Fusion power; 500MW



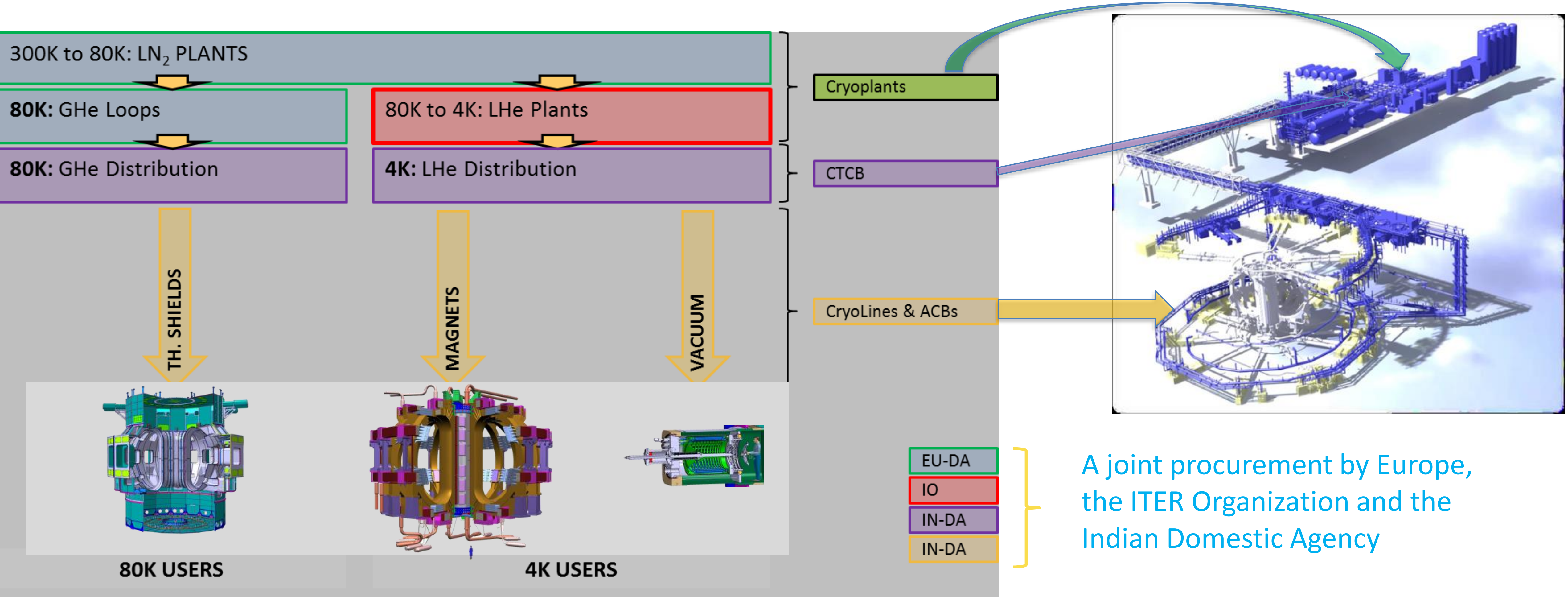
ITER variable heat loads
(overall heat loads)

Due to plasma pulsed operation (plasma initiation, ramp-up, flat top/burn, ramp-down, dwell,) repeated every 1800s :
Important variable heat loads are deposited on the magnet system which is transferred after to the cryogenic system.
Other variable heat loads on cryopumps and current leads.



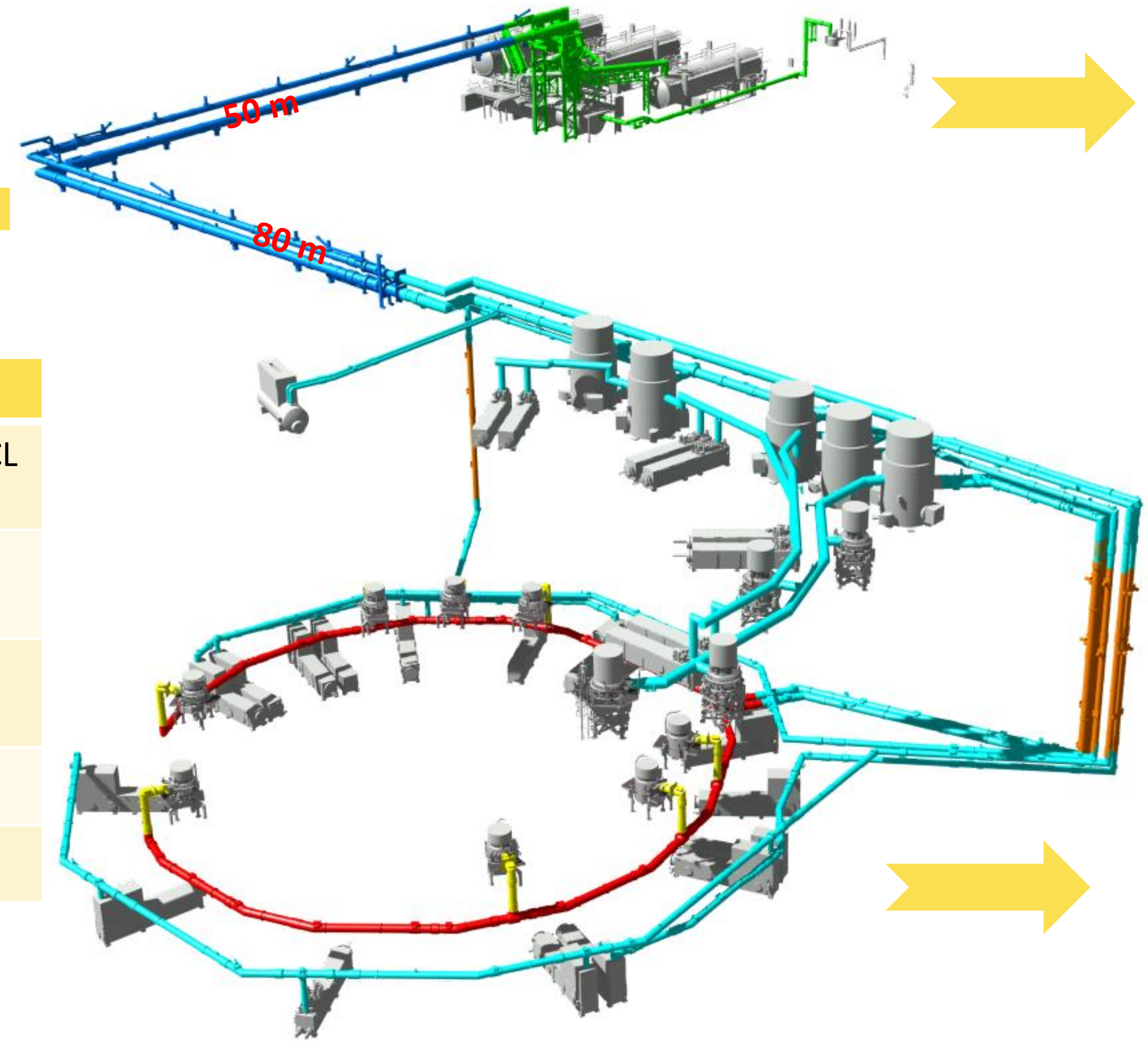
OUTLINE

ITER Cryogenic system



A joint procurement by Europe, the ITER Organization and the Indian Domestic Agency

ITER Cryogenic system



Complex Cryolines in B50s

- 4 Cryolines : 3 CLs CTCB to LHe CBs + 1 CL CTCB to LHe tank CB
- 4 to 7 process pipes in single vacuum jacket
- DN500 to DN700
- 15 spools with L, E and S shapes

Complex Cryolines in Cryo-Bridge

- 2 Cryolines : 1 CL for magnet & 1 CL for CP
- 4 to 5 process pipes in single vacuum jacket
- PP up to DN250 (10”)
  OVJ → DN800 to DN1000
- Total length of 130 m per CL
- 32 spools with L and E shapes

Complex Cryolines in Tokamak

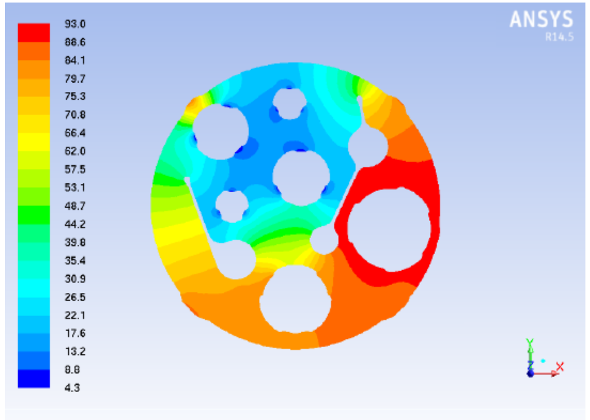
- 2 Cryolines : 1 CL for magnet & 1 CL for CP connected to 5 ACBs + 2 CLs for TSCVB
  10 Cryolines to feed clients (Feeders & CVBs)
- 4 to 6 process pipes in single vacuum jacket
- DN500 to DN1000
- > 150 spools with different shapes

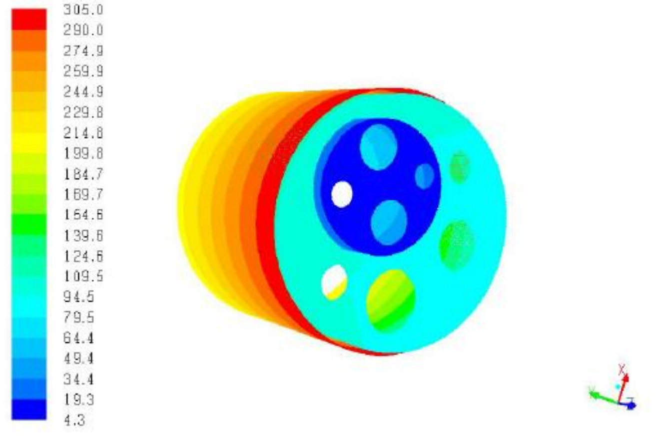
In total ~ 1.5 km of complex Cryolines

OUTLINE

COMPLEX CRYOLINES – Design MAIN FEATURES

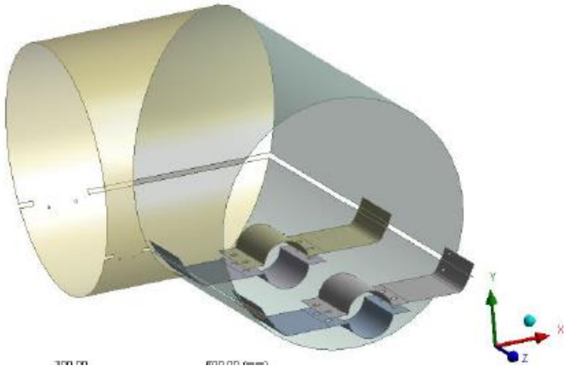
- Roughness of vacuum facing surface < 50 micro meter (except welds)
- Process pipes with different temperature level of 4K, 50K, 80K accommodated together (with MLI) under single vacuum jacket with tight heat load budget due to space constraints
- Designed for Heat load ranges from 1.5 W/m for 4 K lines and 4.5 W/m for 80 K lines (thermo-mechanical optimized design for vacuum barriers and sliding spacers)

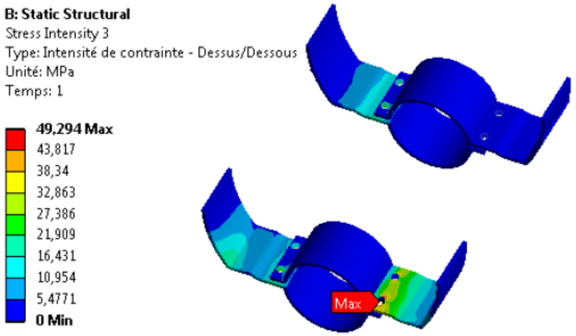


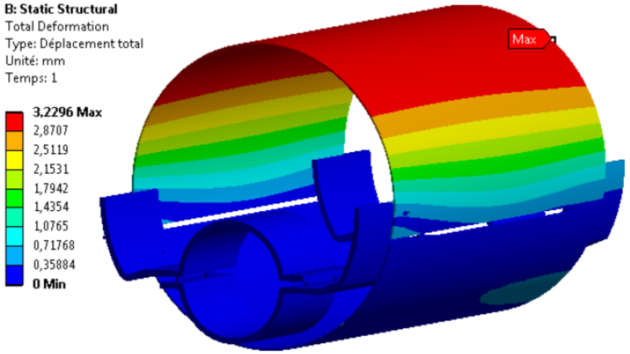


- Aluminum thermal shield design considering thermal and mechanical roles :
  - Thermal role to reach the performance Cryolines system
  - And mechanical role to allow displacement during cold contraction and ensure mechanical resistance during severe events i.e. Seismic

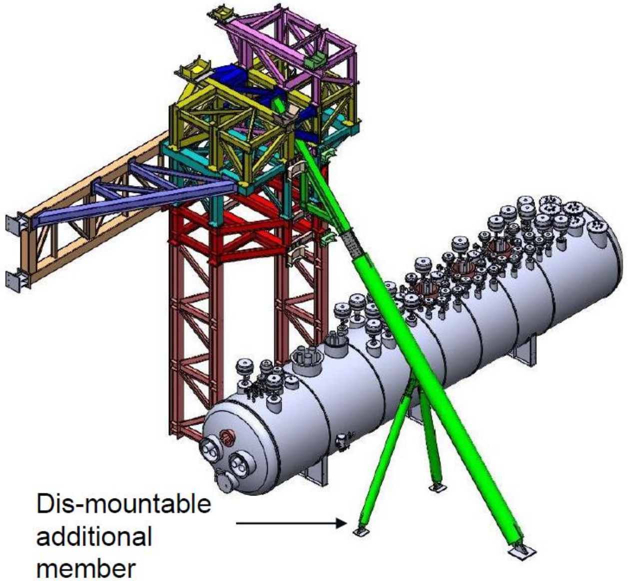
COMPLEX CRYOLINES – Design MAIN FEATURES

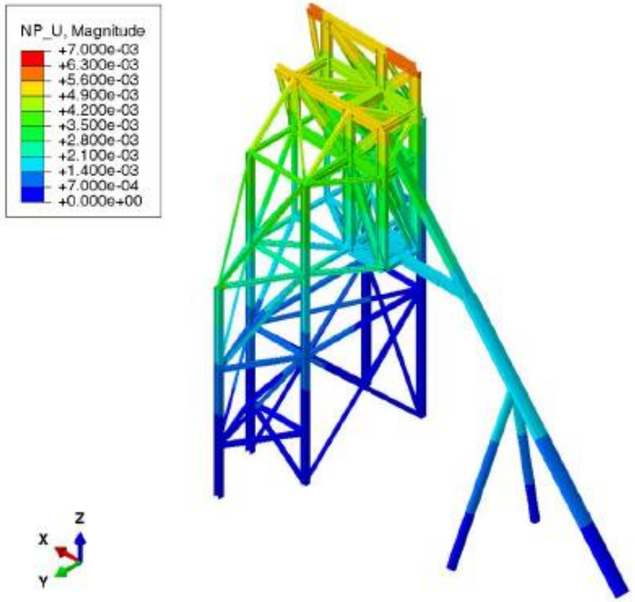






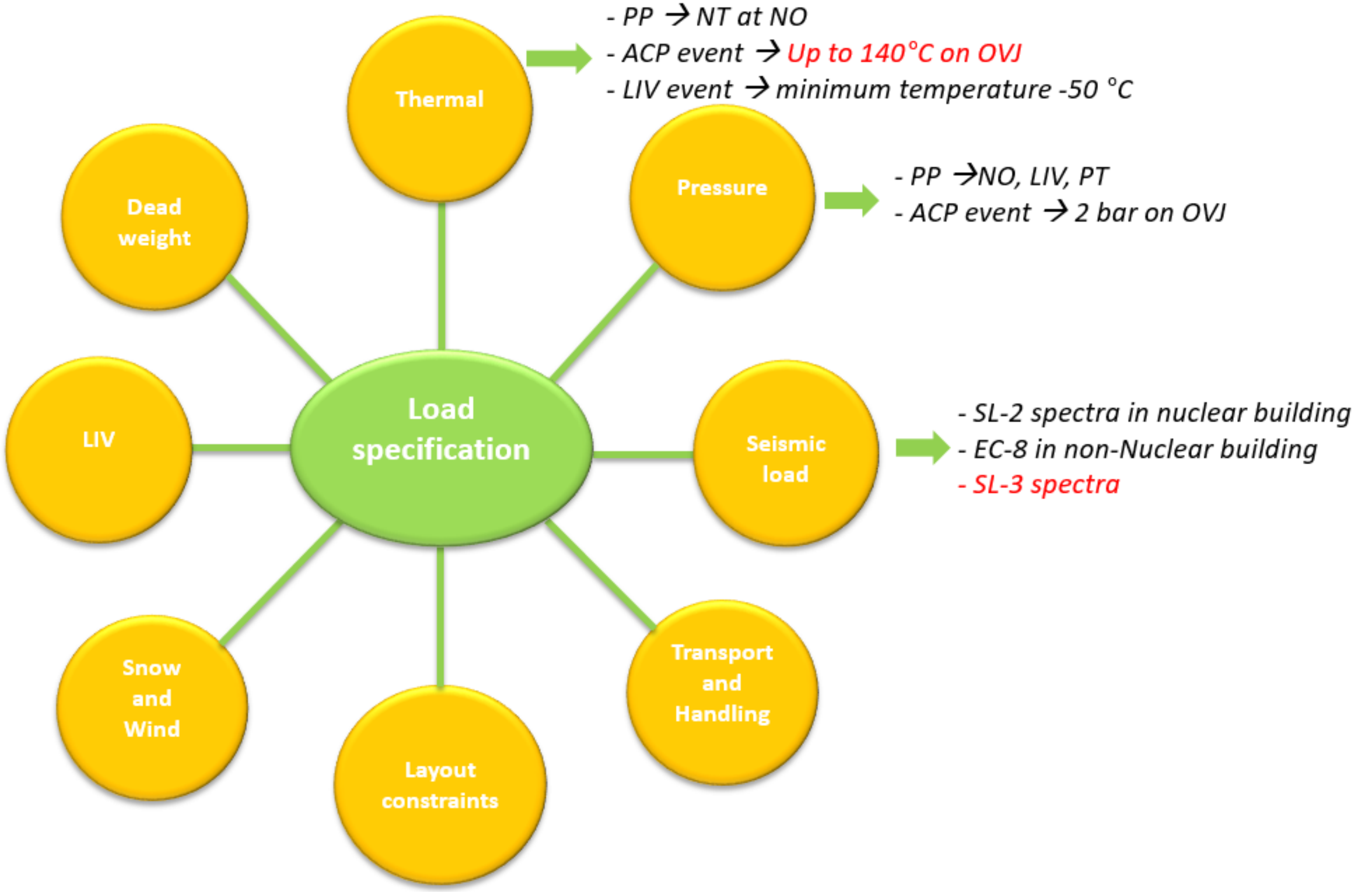
- Complex design of external supports considering, lines routing, very limited space and mechanical loads generated by Cryolines during namely pressure test (End loads due to the presence of bellows) → **Example of iterative calculation to reach the final design**





COMPLEX CRYOLINES – Design MAIN FEATURES

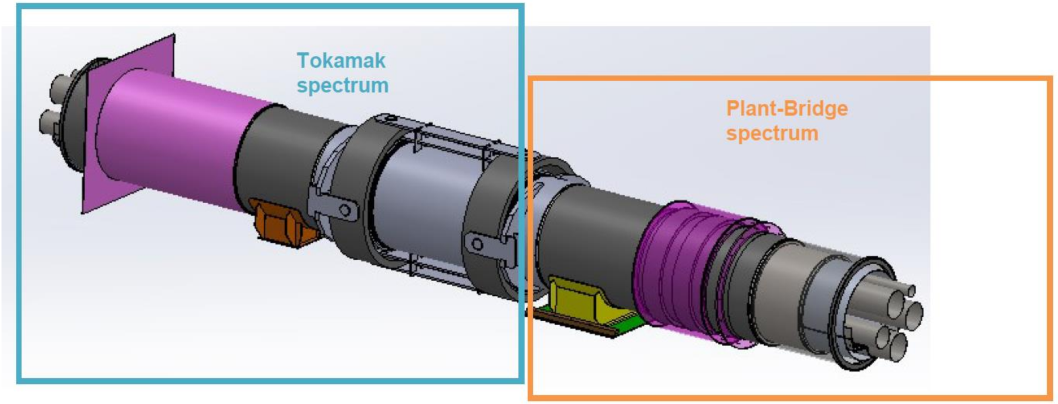
- Designed to sustain very stringent mechanical load cases on the top of construction code requirements



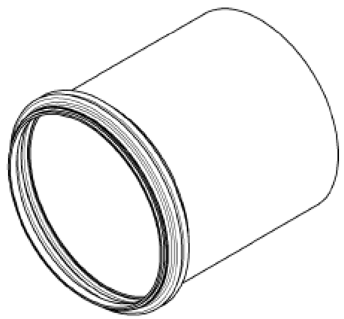
- Designed to meet mechanical requirements (loads and displacements) at the interface with civil works and equipment (Magnet feeders and cold boxes)

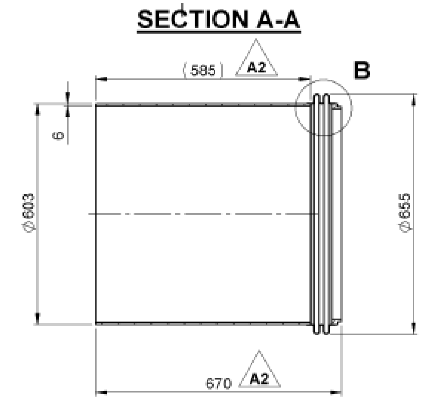
COMPLEX CRYOLINES – Design MAIN FEATURES

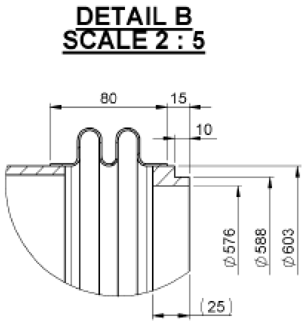
- Designed to decouple displacements between crossed areas by Cryolines in particular between B52/Cyo-Bridge and Cryo-Bridge/Tokamak ***(up to 150 mm per direction)***



- Designed considering safety confinement requirements leading to development of dedicated technical solutions. This is first of kind in cryogenic design systems (iterative integrated calculation has been performed to meet requirements)







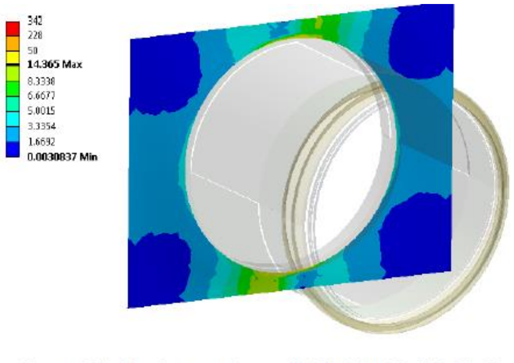


Figure 74: Membrane stress distribution (G+NO+SL-2)

COMPLEX CRYOLINES – Design MAIN FEATURES

- Nearly **200 spools** Complex Cryolines manufactured ranging from **5** to more than **10 m** of length, weight ranging from 1 ton to almost **10 tons** and size from **DN 500** to **DN 1000**

- Some manufacturing requirements more **stringent than** codes and standards (e.g. tungsten inclusion in welds is not allowed)

- Art of integrating many process pipes, internal supports, MLI, bellows/hoses, thermal shield and vacuum jacket in single spool

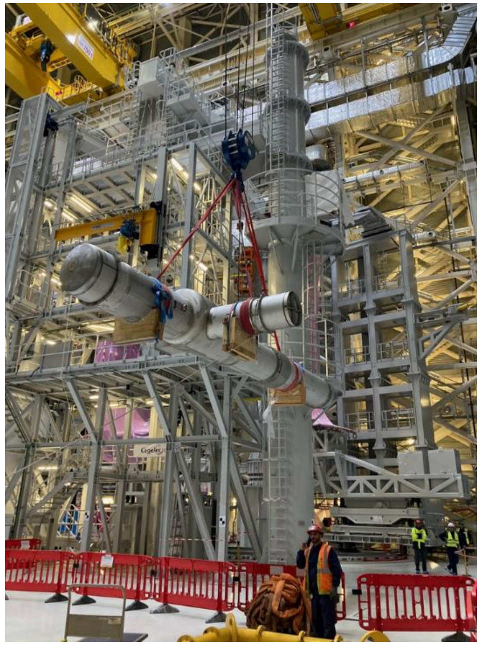
- Specific sequence of a spool assembly..

- High level of level of **cleanliness** (e.g. grinding not allowed), **protection** of insulation during welding, **humidity control** for storage of MLI etc...

COMPLEX CRYOLINES – Design MAIN FEATURES

The shape of segments is derived by the following factors:

- The outcomes of global flexibility analysis in particular the presence of internal (fixed points and vacuum barrier) and external supports
- The feasibility of installation activities :
    - Space available to perform handling, transport and welding
    - Space available for leak testing on interconnections



COMPLEX CRYOLINES – Design MAIN FEATURES

However, some more complex shapes of spools have been resulted in particular the following :

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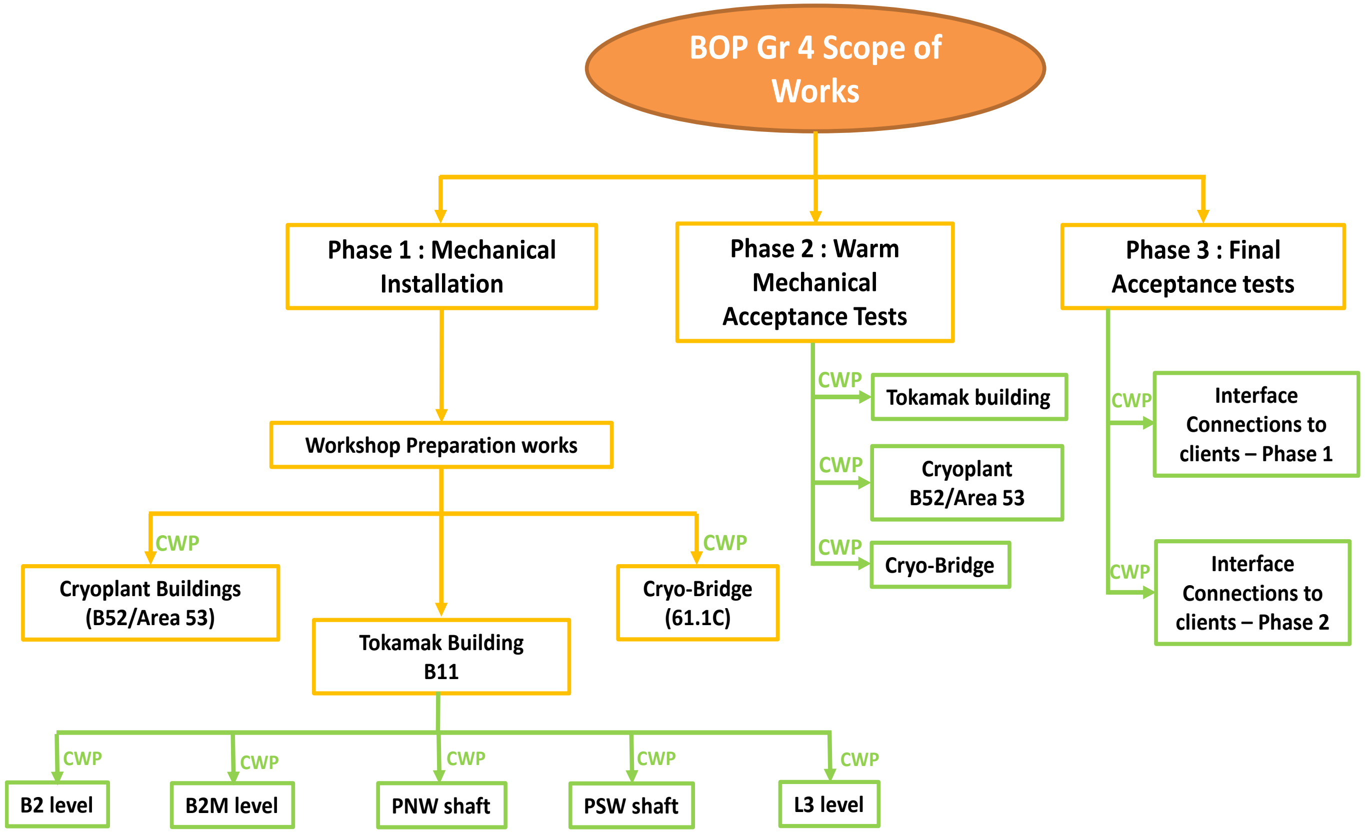
COMPLEX CRYOLINES – Installation & Testing strategy

- Installation activities started on Q4 2019

- The contract is structured in 3 main phases :
  - Mechanical Installation phase
  - Warm Tests phase
  - Cold Tests phase

- Each phase is composed of "Work Packages" identified by level in Tokamak building and by area in the plant buildings



COMPLEX CRYOLINES – Installation & Testing strategy

- Installation Contract is executed considering the same requirements applied for manufacturing :


- **Welders qualification :** A additional qualification program for process pipes welding has been put in place to authorize every welder per DN and per thickness.

- **Process pipes NDT requirements :** 100% VT, 100% RT and 100% LT

- **Level of cleanliness onsite :** The level of cleanliness has been tracked and checked all along the installation activities.

- **Follow-up of manufacturer installation documents :** Installation works performed considering as inputs mainly installation guidelines, drawings (handling/lifting areas) and procedures (MLI wrapping etc.)



COMPLEX CRYOLINES – Installation & Testing strategy

Cryoline spools inside the tokamak are installed in float mode due to the absence of interface equipment (mainly Feeders & ACBs).

The following approach has been implemented :

1. Survey of embedded plates to determine the as-built coordinates.

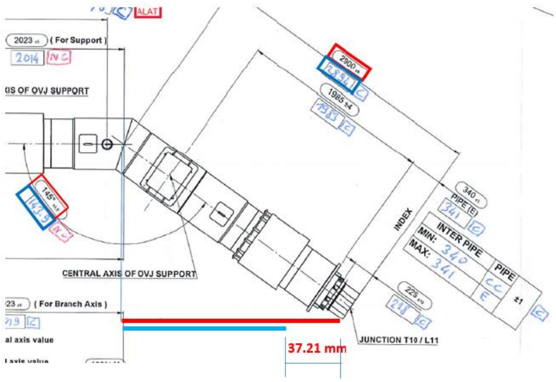
2. External support extra-length cut determind based on as-built coordinate in z direction of plates and as built dimensions of the spool

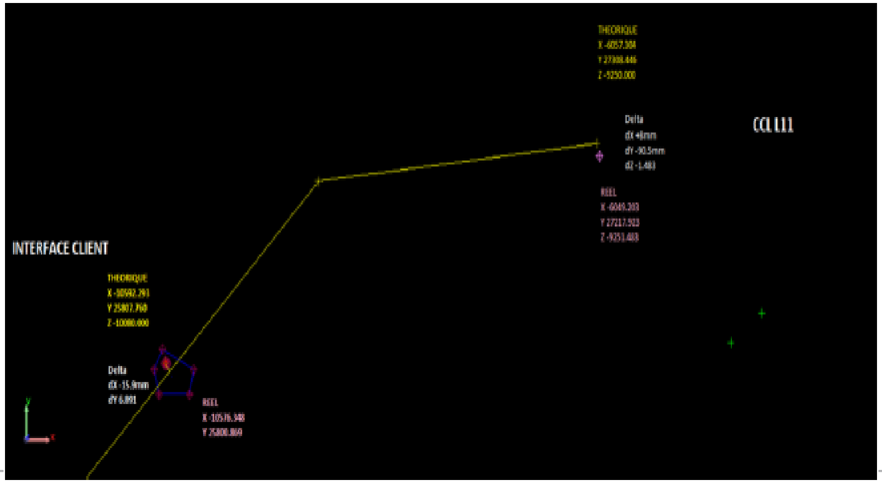
3. 3D modeling using laser tracker considering spool as-built dimensions and results from point 1) & 2)

4. Then, the required process pipe extra-length cut is determined with the objective to meet the theoretical coordinates of spool on both side within +/- 5 mm.

Golden rule

The objective is to meet the theoretical coordinates at the interface equipment within -/+ 5 mm



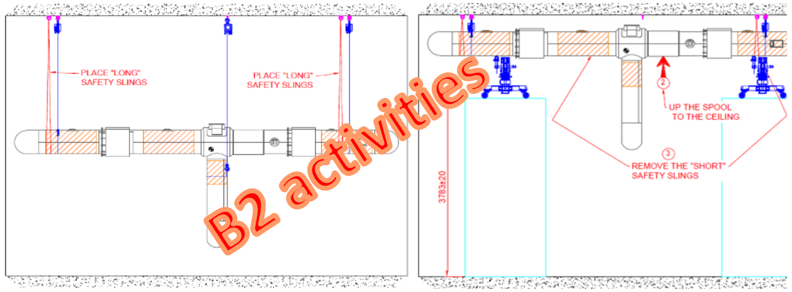


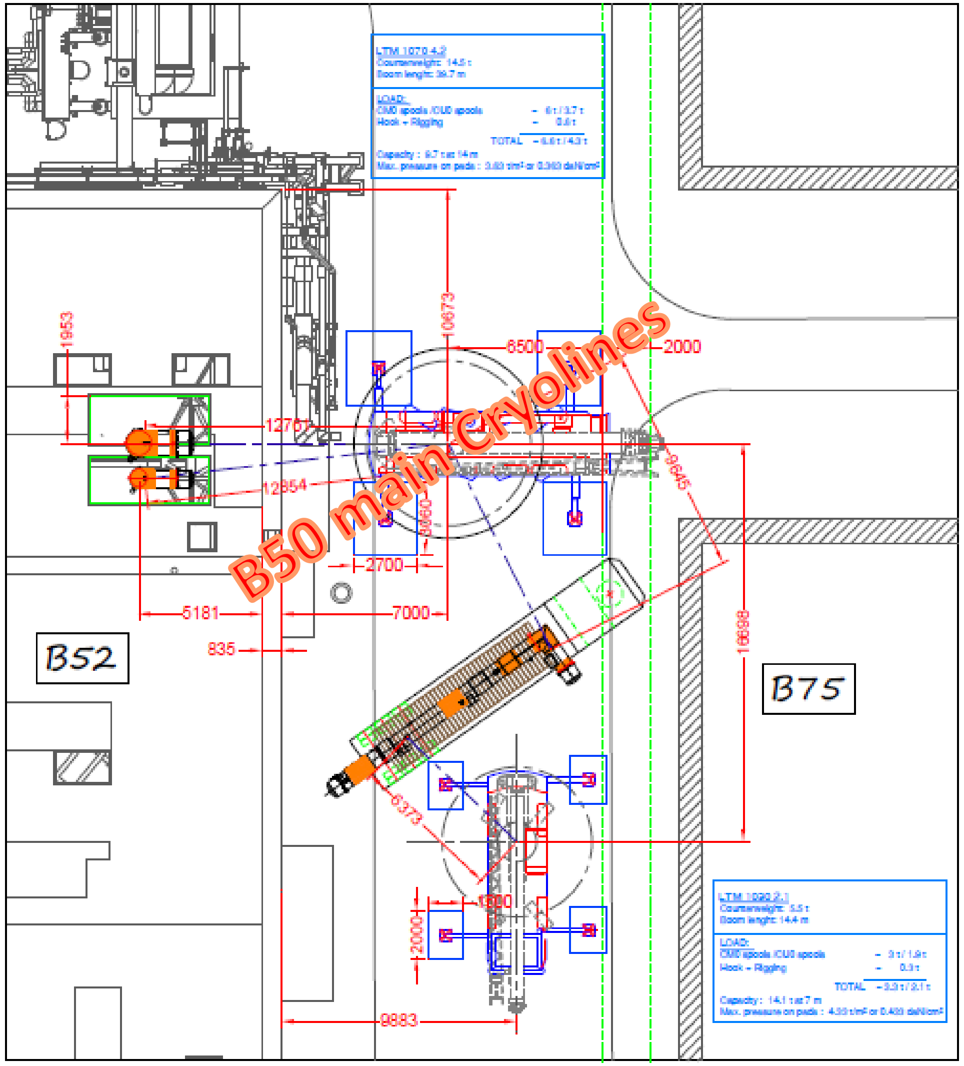
COMPLEX CRYOLINES – Installation & Testing strategy

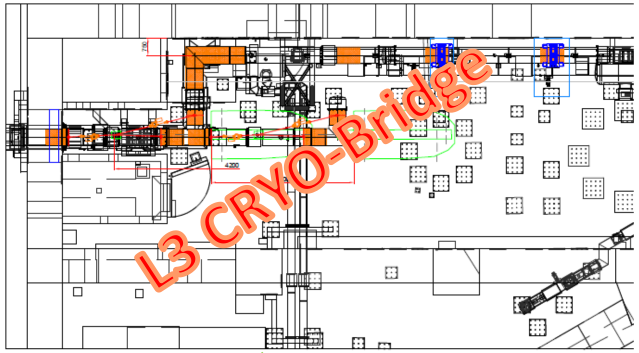
Phase 1 : Handling and lifting operations

Handling/lifting drawings
Context 3D model (Installatio
Coactivity as per sequence an

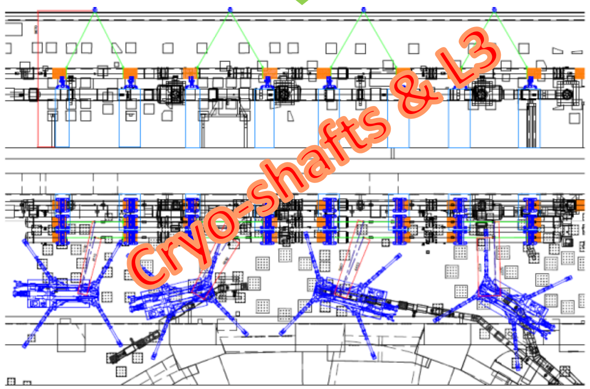
Lifting lugs welded on EPs







Dedicated crane

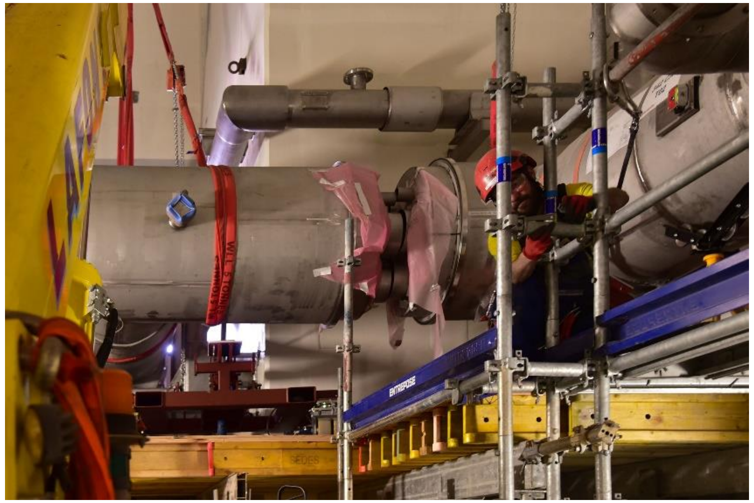


Phase 1 : Handling and lifting operations in photos (B50s)

COMPLEX CRYOLINES – Installation & Testing strategy

Phase 1 : Handling and lifting operations in photos (Tokamak B2/B2M level)

Phase 1 : Handling and lifting operations in photos (Cryolines spools crossing the Cryo-Bridge opening)

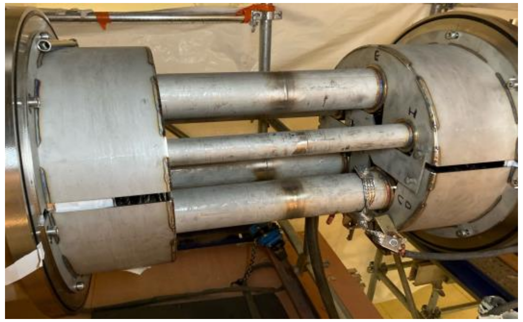


Phase 1 : Lifting operations in photos (Cryolines spools lifting/insertion inside Cryo-shafts)

Phase 1 : Handling and lifting operations in photos (Main Cryolines spools along the west wall in L3)

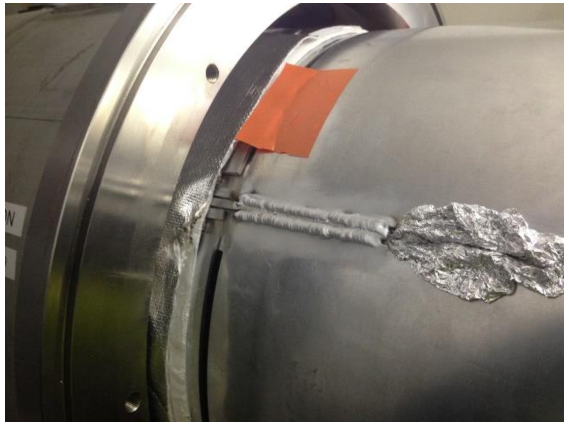
COMPLEX CRYOLINES – Installation & Testing strategy

Process pipes welding



Process pipes MLI wrapping

Thermal shield assembly & MLI wrapping



Outer Vacuum Jacket (OVJ) Closure

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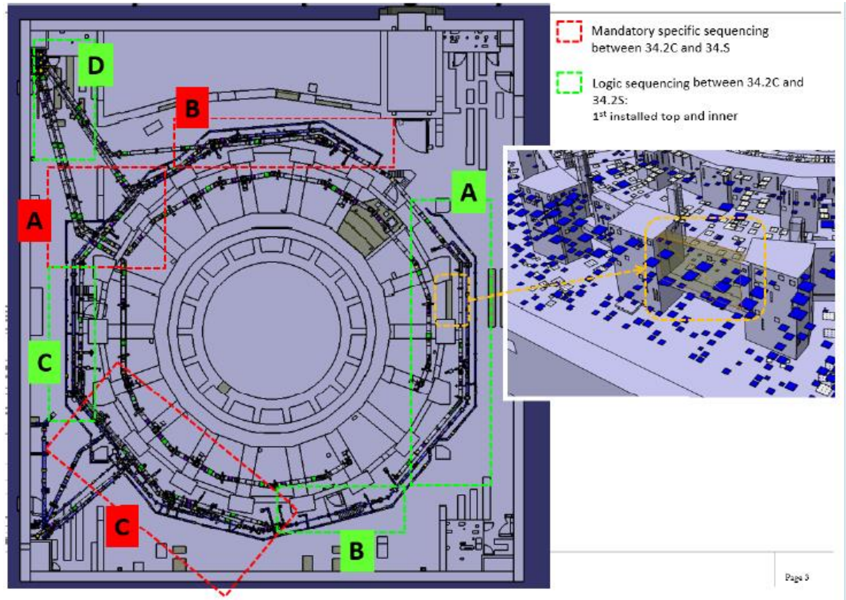
Installation Challenges, Constraints and difficulties

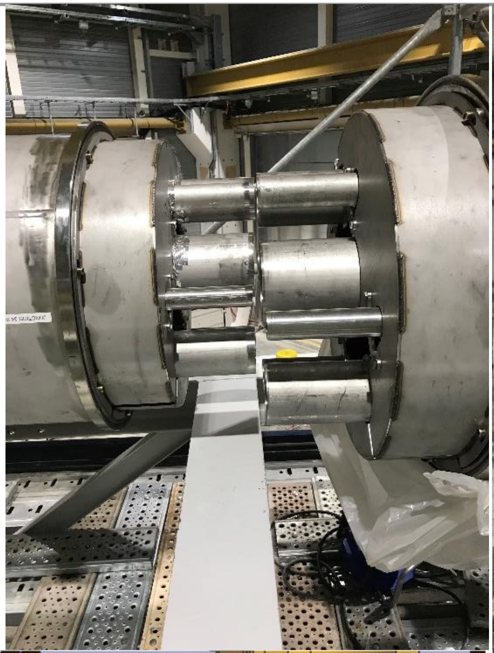
- **High level of co-activity management :** Up to 5 contractors in the same area (systems + civil works contractors)

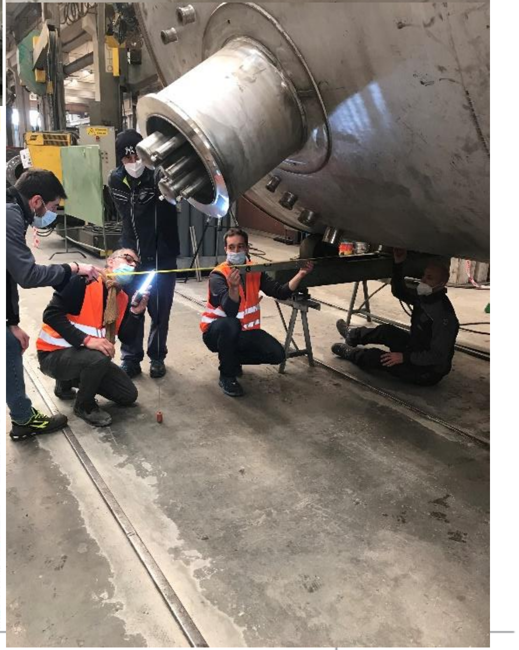
- **Installation sequence :** Detailed installation sequence has been established considering the in-context 3D model.

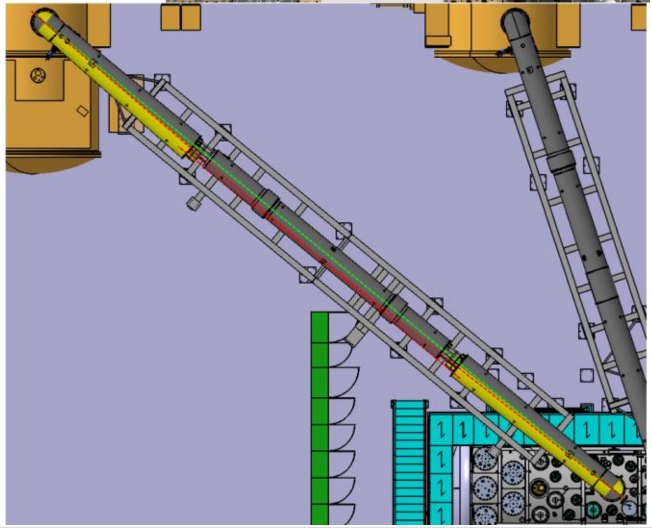


Installation Challenges, Constraints and difficulties

- Complexity of process pipes welding operation due to thin thickness (2 mm),
- Number of weld defects increases with higher DNs observed for main Cryolines activities
- Number of weld defects at the interface with LHe CBs and CTCB in B52 is more than expected
- Intermediate He leak test is not feasible due to the absence of internal fixed point/vacuum barrier. ***This results in long stand-by period***
- Radiography of welds performed in night shifts (risk of bottle neck)





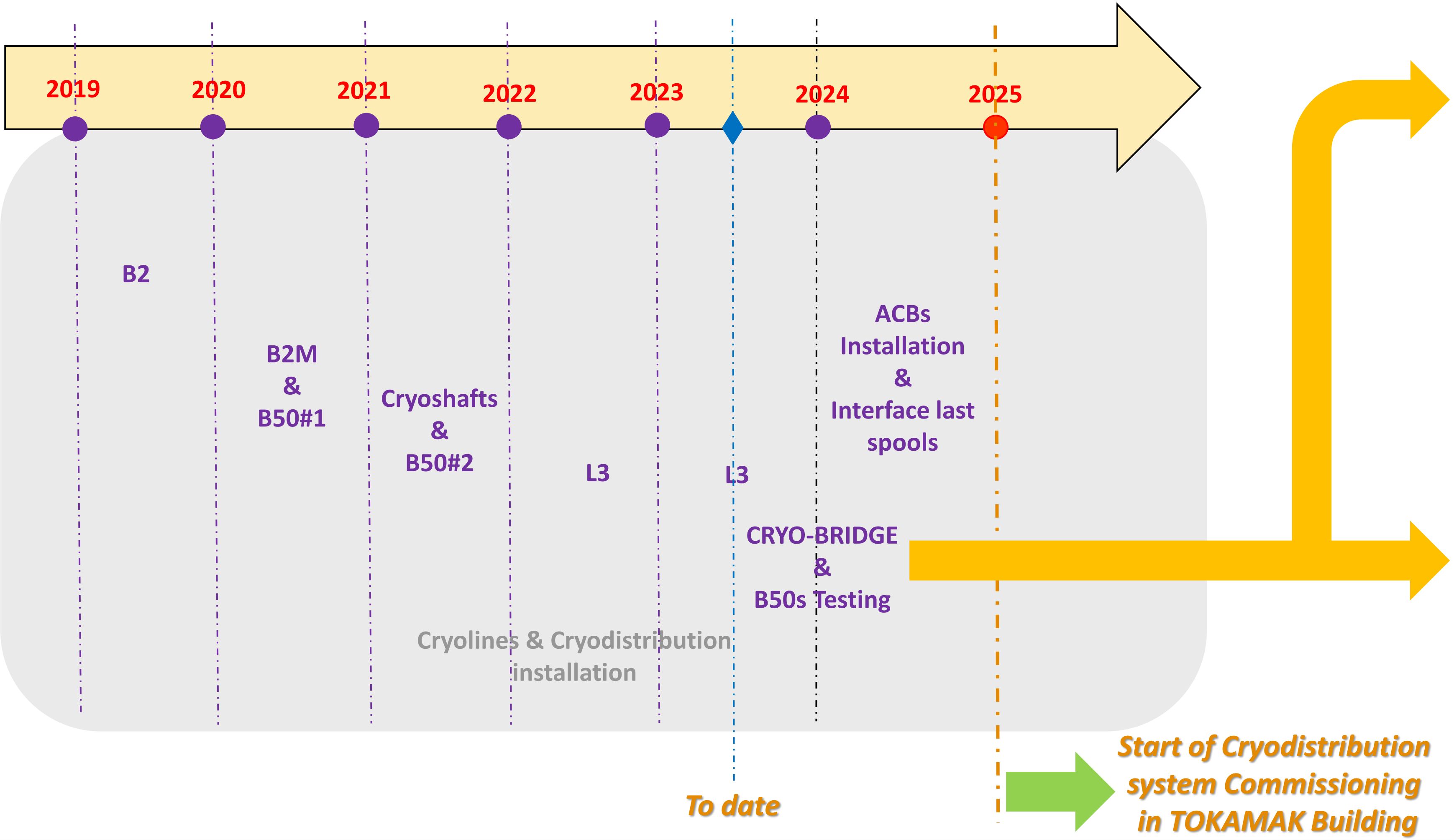


OUTLINE

Prospective & Conclusion

- Installation activities of ITER complex Cryolines has been completed successfully as per design and project requirements.

No major in-field changes have been detected



Particular warm thanks to:

- **The cryogenic project team colleagues**
- **Our industrial partners Alat and ENDEL-ORYS-CRYO DIFFUSION consortium**

Thanks for Your Attention

Questions ?