

# Preparation of the ITER Central Solenoid Assembly

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# Summary

- ITER Central Solenoid
- CS Overview
- Manufacturing status
  - Module
  - Structure
  - Tooling
- CS Assembly process overview
- Two special processes
  - Pre-compression
  - Joint extension assembly

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# ITER Central Solenoid

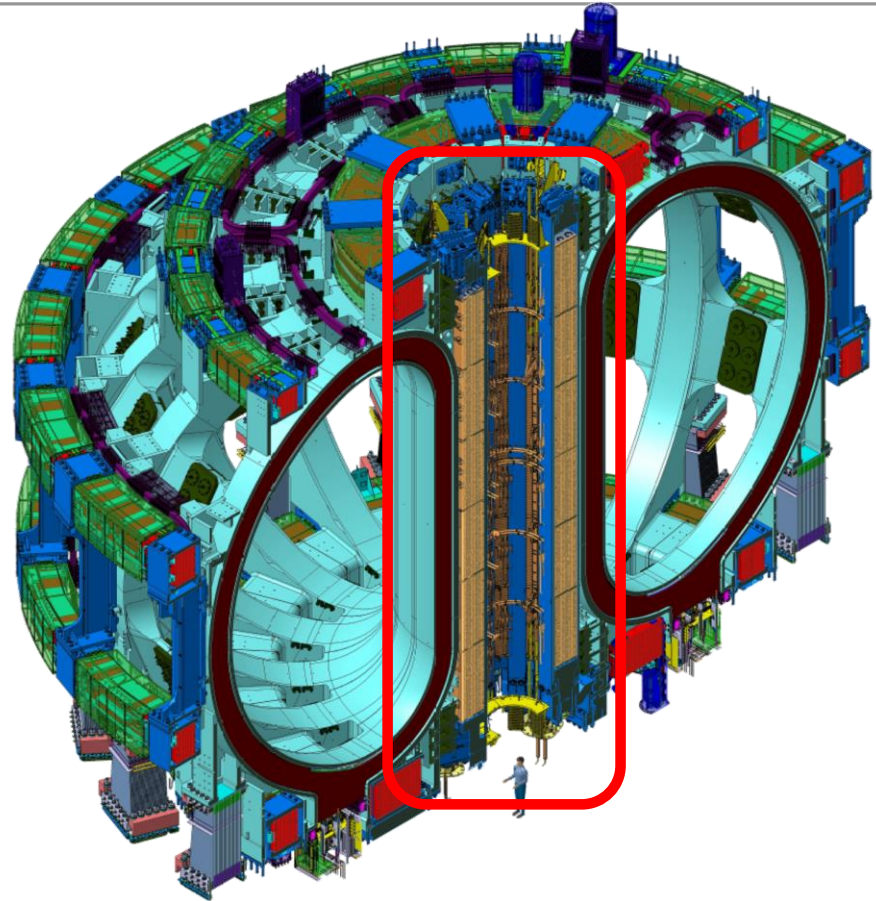
- **Function**

- Induce **15 MA** of plasma current
- Shape the plasma → 6 modules

- **Steps**

- Design
- Qualification
- Manufacture
- **Assembly**
- Installation
- Commissioning
- Operation

This talk



# ITER Central Solenoid

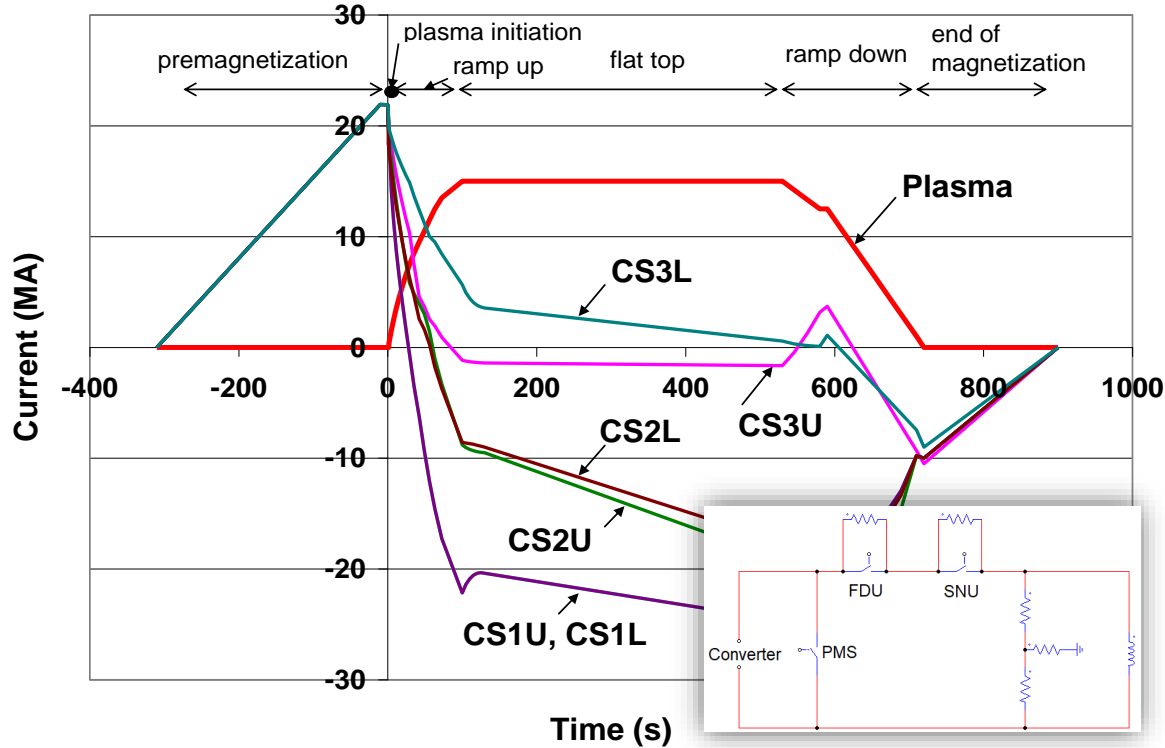
## Key parameters

### • Electrical

Parameter	Unit	Value
Maximum operating current	kA	45
Peak field	T	13
Peak module nominal voltage at initiation	kV	10
Peak current decay	kA/s	5
Ground insulation voltage test	kV	30
Expected Iter life cycle number		60000

### • Mechanical

Parameter	Unit	Value
Module weight	tons	120
CS weight with structure	tons	1000
CS height	M	15.5
CS maximum outer diameter	mm	4312
Axial pre-load	MN	210



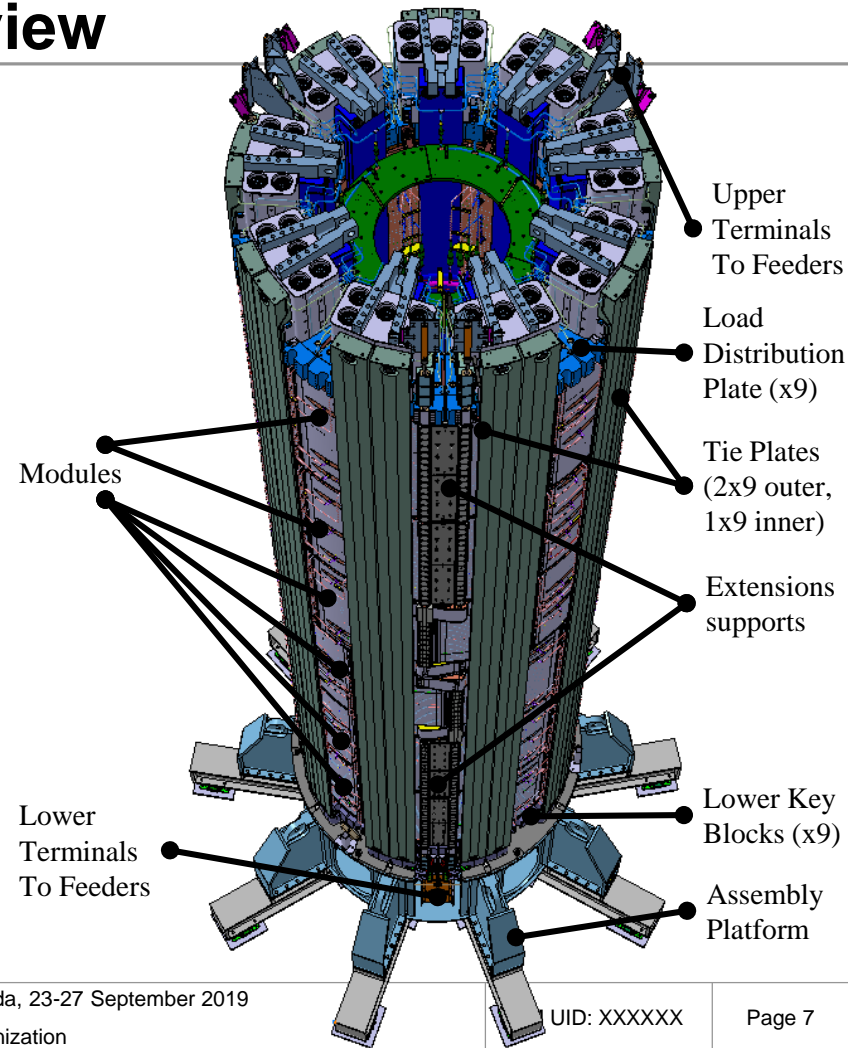
Time current evolution in CS coils and plasma

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# CS Overview

- Lower Key Blocks (LKB): 9 LKB ensure the mechanical interface in between CS and lower TFC gravity supports.
- Upper Key Blocks (UKB): 9 UKB ensure the mechanical interface in between CS and upper TFC structure through centering rods.
- Tie Plates (TP): Each sector is equipped with three TP (two at the Outer Diameter (OD), and one at the Inner Diameter (ID)). TPs are locked to LKB and UKB.
- Multi Jack bolts Tensioners (MJT): Each UKB is equipped with 5 MJT screwed into the UKB and pushing on the LDP (see next bullet) to apply the pre-compression load.
- Load Distribution Plate (LDP): 9 LDP are stainless steel plates that distribute the load from MJTs uniformly on the modules stack upper surface.



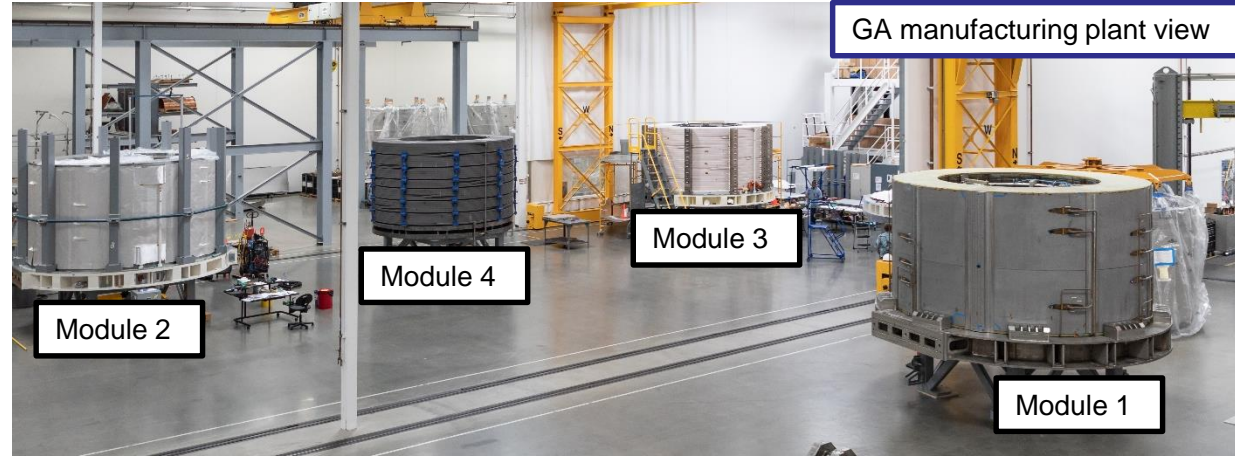
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# CS Structure Manufacturing status

- About 50% completion
- 7 modules at different manufacturing stages
- All modules tested at 4K full current
- First module Q4-2020 at IO site



- Remaining critical processes
  - Ground insulation qualified for post cool down Paschen test (15 kV)
    - Quench detection wire exit preparation
  - Termination preparation
    - High resistance at termination (>4nΩ)
    - A new process at qualification stage

	Fabrication of CS Module											CS Module Manufacturing %
	Part 1				Part 2			Part 3			46.99%	
	Receiving Inspection	Winding	Joint& Terminal Prep	Stack&Joint/ He Pen	Heat treatment	Turn Insulation	Ground Insulation	VPI	Piping	Final Test		
	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.10	0.05	
Module 1	100%	100%	100%	100%	100%	100%	100%	100%	100%	30%	0%	88.00%
Module 2	100%	100%	100%	100%	100%	100%	100%	61%	35%	0%	0%	74.60%
Module 3	100%	100%	100%	100%	100%	100%	80%	0%	0%	0%	0%	63.00%
Module 4	100%	100%	100%	100%	100%	60%	50%	0%	0%	0%	0%	56.00%
Module 5	100%	100%	100%	66%	0%	0%	0%	0%	0%	0%	0%	31.60%
Module 6	100%	42.9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	9.29%
Module 7	100%	14.3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6.43%

# CS structure manufacturing status

Upper Key Block



M190 Superbolt ready for shipment



- All components at final manufacturing stage
- All parts to be delivered Q3-2020

Tie Plate



Load Distribution Plate



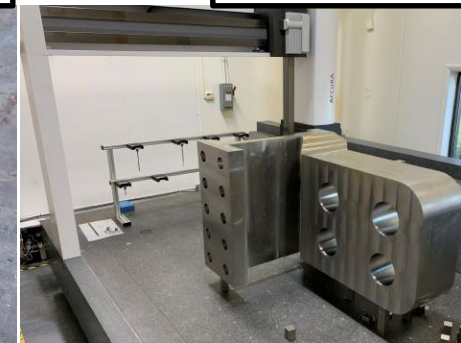
Lower isolation plate



LKB all manufactured



Flexible brackets



# CS Tooling manufacture

Module lifting fixture



Tightening tooling ☺



- All components at final manufacturing stage.
- All parts to be delivered Q1-2020

Assembly Platform



Drilling fixture



Test Load



Bus bar tooling

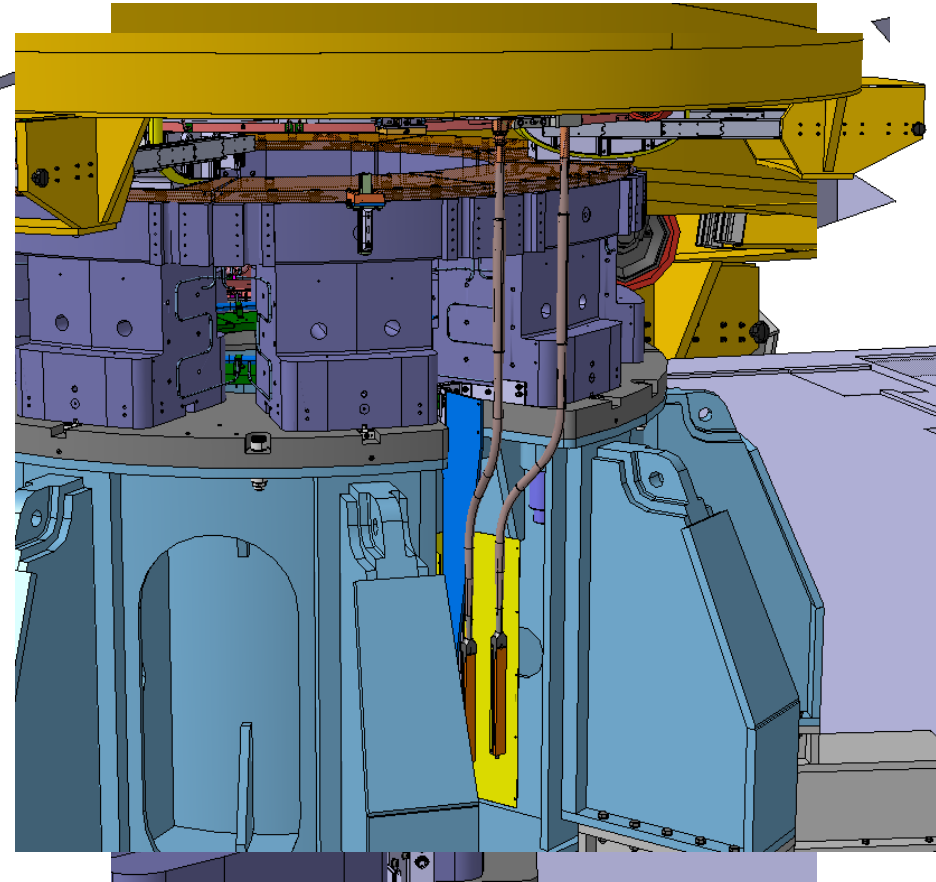


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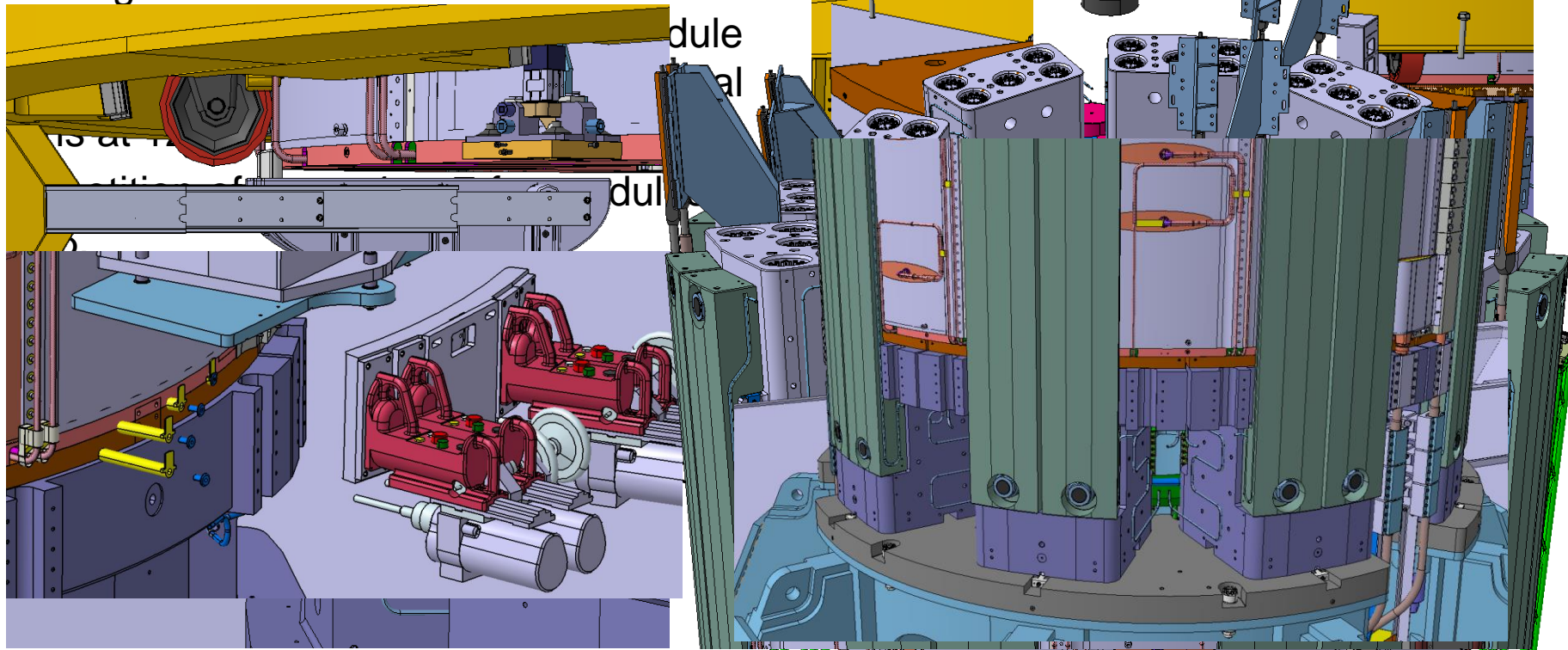
# CS Assembly Process Overview

- Installation of the assembly platform and definition the reference coordinate system,
- Installation and locking of the 9 LKB on the platform,
- Machining and installation of the 9 lower isolation plates to ensure the stack mid-plane at the tokamak mid-plane within a tolerance of  $\pm 3$  mm,
- Installation of the first module on the platform, shifted 350 mm in the radial direction to allow coaxial joint assembly,
- Installation of extensions, assembly and insulation of coaxial joints,



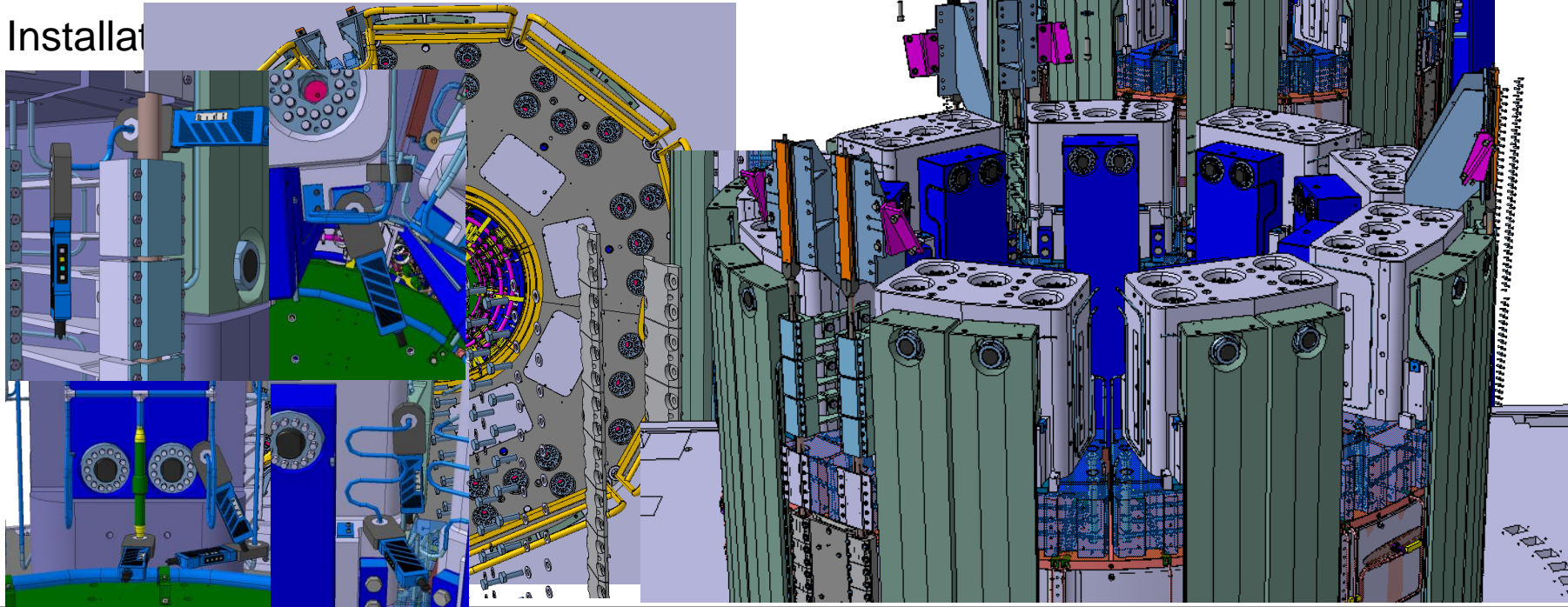
# CS Assembly Process Overview

- Final position of the module 1,
- Drilling holes in between LKB interface



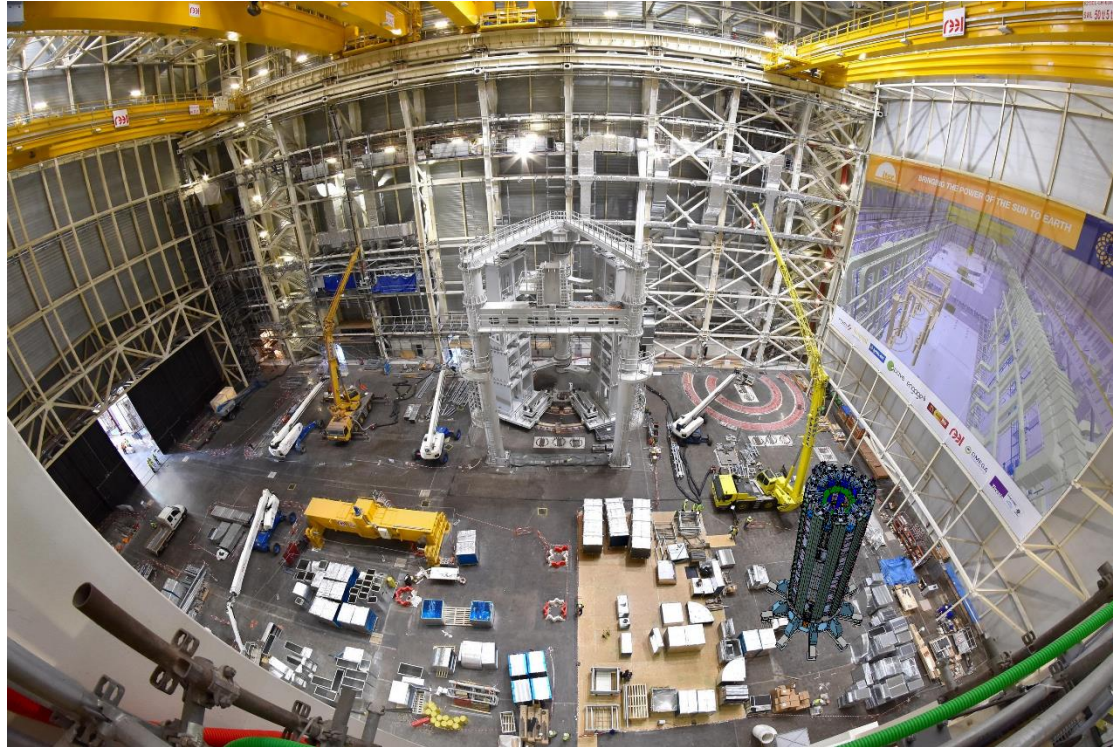
# CS Assembly Process Overview

- Pre-compression of the stack with the 45 MJTs,
- Installation of the extensions supports.
- Installat



# CS Assembly Process Overview

- All these operations to be done in coordination with other components integration, as TF coils pre-assembly, in the Iiter Assembly Building.



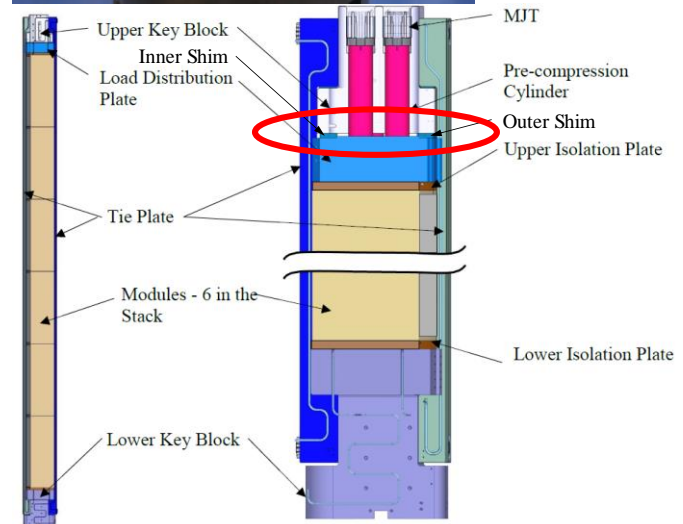


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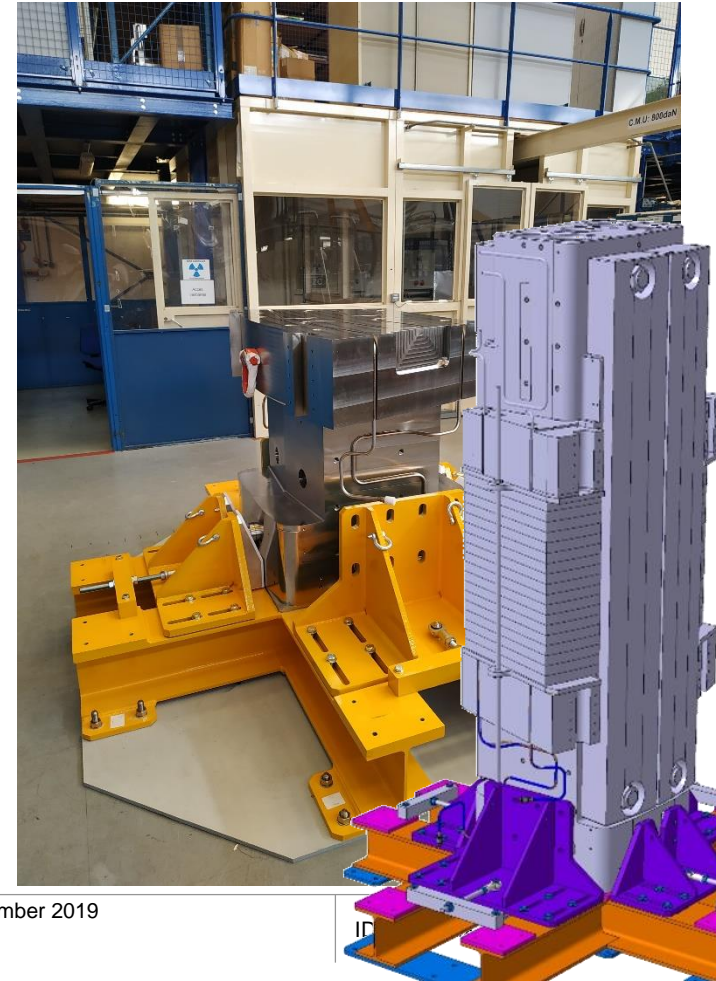
# Pre-compression

- The baseline pre-compression is fully manual.
- 1080 jackbolts in total.
- As the expected stack compression is expected to be 25 mm as a minimum, at least two shimming steps are foreseen.
- Each shimming steps requires to unload, insert shims, re-load all MJTs.
- A minimum of 120 000 torqueing steps is then expected.
- A total duration of one month and a half is expected



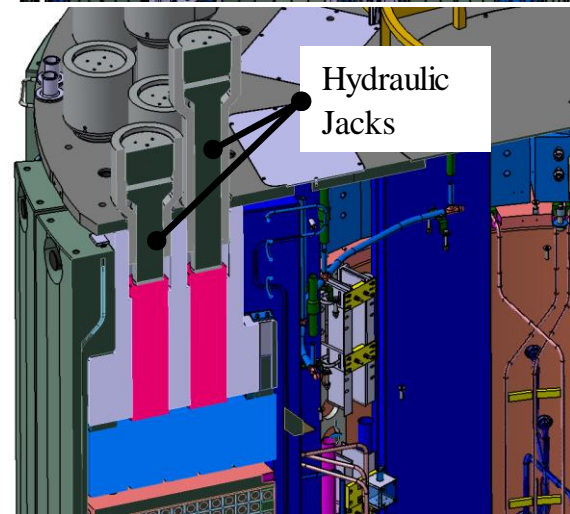
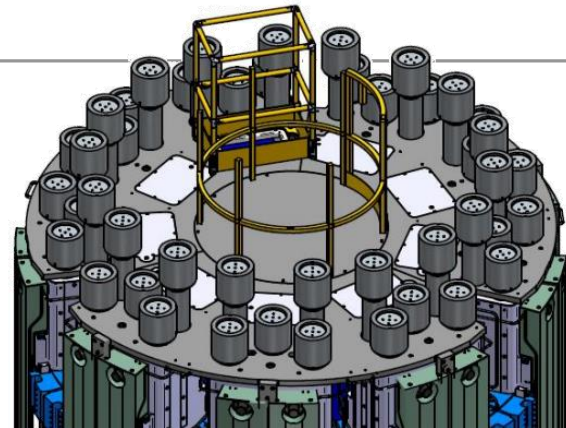
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- A total duration of one month and a half is expected
- A sector mockup is under preparation at CEA to test this process. Test is scheduled in October 2019.



# Pre-compression

- In parallel, IO has investigated an alternative hydraulic process using customized jacks.
- The main advantages are
  - one step process,
  - no need for intermediate shimming,
  - uniform load,
  - time sparing.
- Jacks are replacing MJTs on UKB
  - Step head design to minimize hydraulic pressure
  - 210 MN reached for 1000 bars
  - Fluid is water
- Hydraulic circuit arrangement to minimize risks linked to leaks
- A decision to change the baseline process to be taken after manual pre-compression test



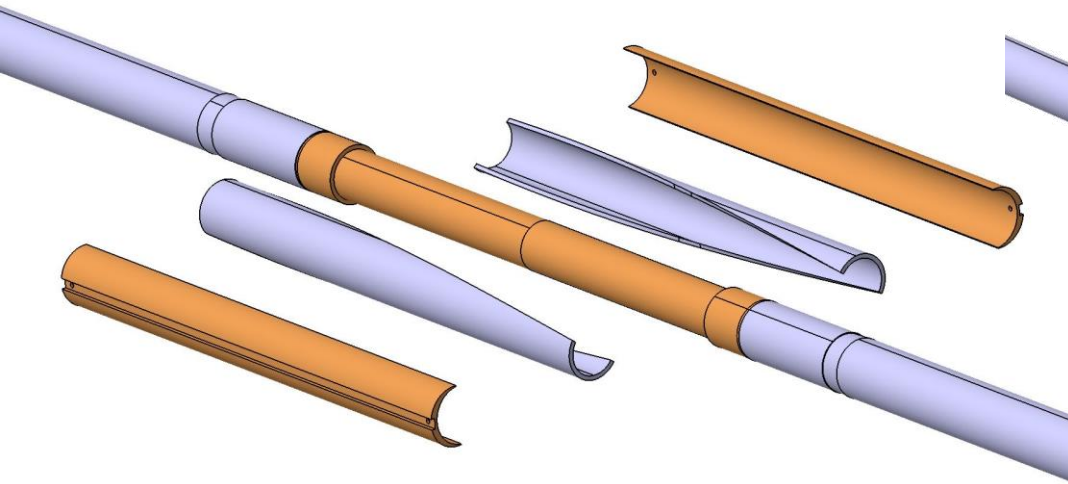
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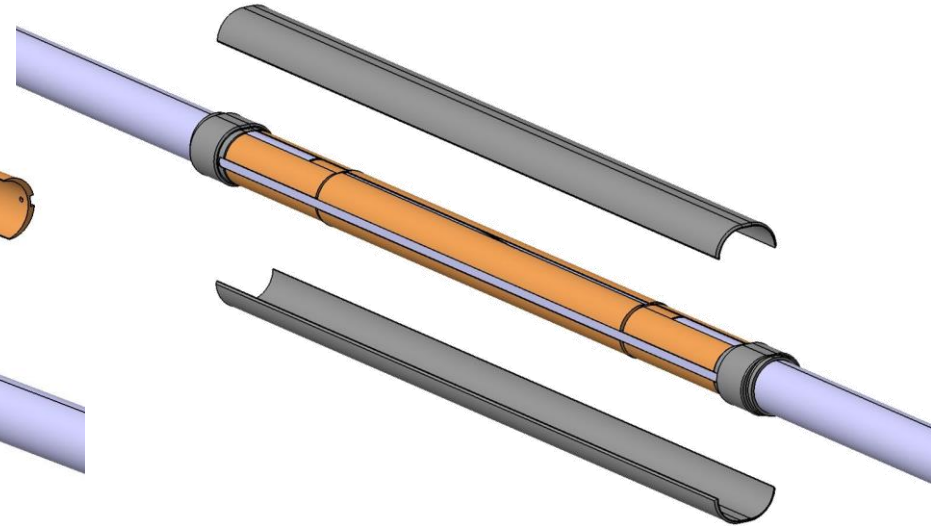
# Joint extension assembly

- The joint extension assembly baseline process is the soldering of two twisted laced unions.

Soldering of laced union and copper crescent



SS Jacket welding



# Joint extension assembly

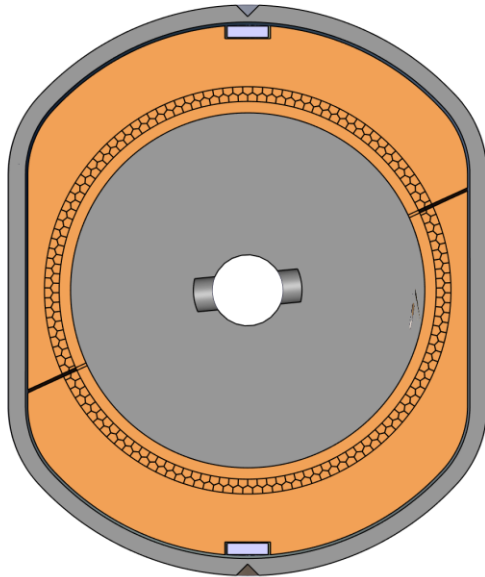
- This process has to be done in vertical position using a dedicated tooling developed by GA.
- This tooling allows to adjust the extension position at both sides (Module and Feeder).
- This design succeed to achieve the required resistance  $<4.1 \text{ n}\Omega$



CS1L

# Joint extension assembly

- Based trial feedbacks, USIPO and IO have investigated several adaptations of the design layout to simplify the assembly:
  - Reduction of parts number: no copper crescent, long weld collar.



Courtesy of D. Everitt, USIPO



# Joint extension assembly

- Based trial feedbacks, USIPO and IO have investigated several adaptations of the design layout to simplify the assembly:
  - Straight unions rather than twisted unions: easiest to manufacture but risk of coupling current

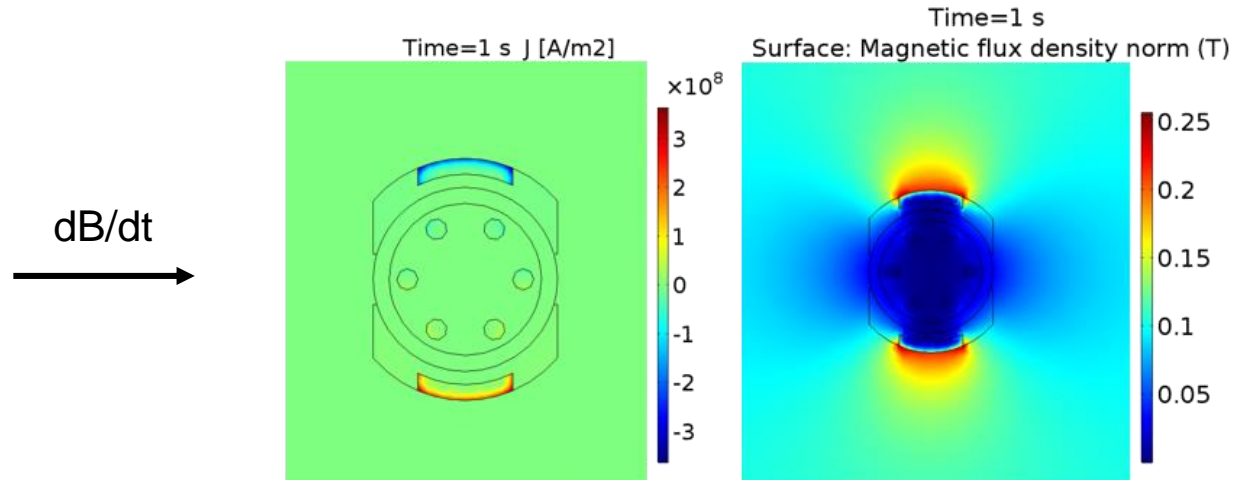
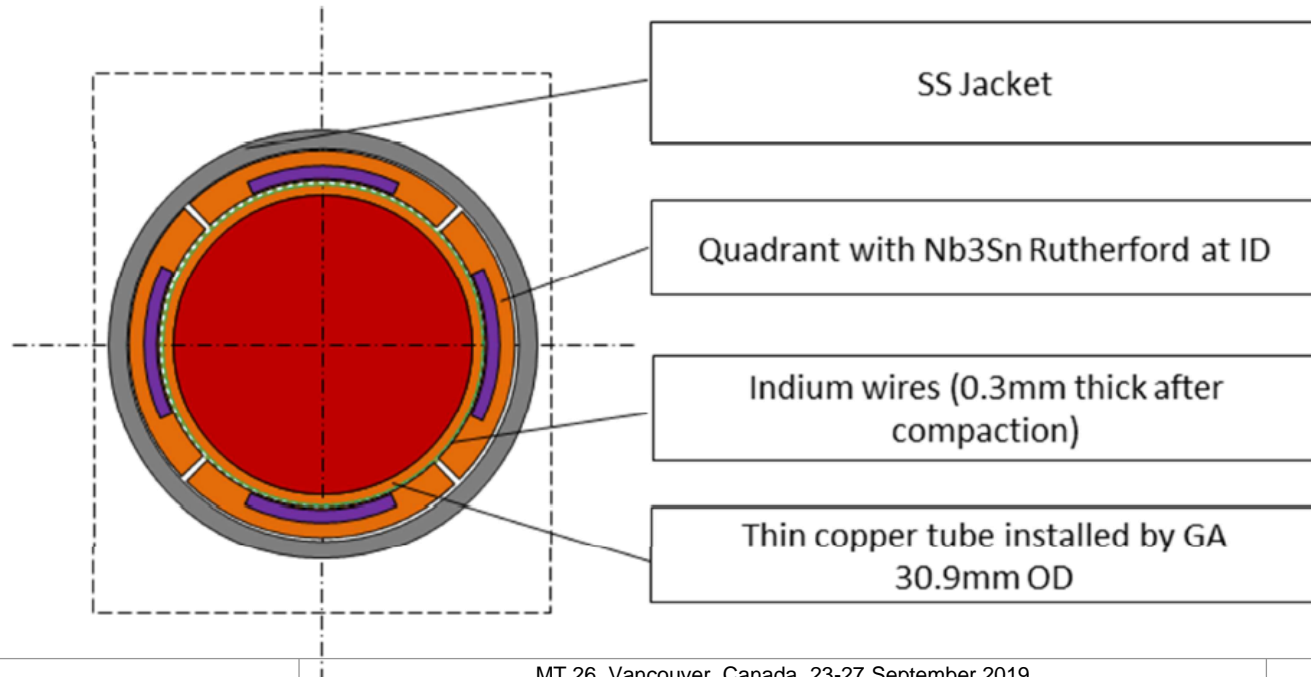


Fig. 7. COMSOL calculation of induced current (left) and field map (right) in the PRD joint.

A. Torre, Presented at MT26 (2LPo2C-06)

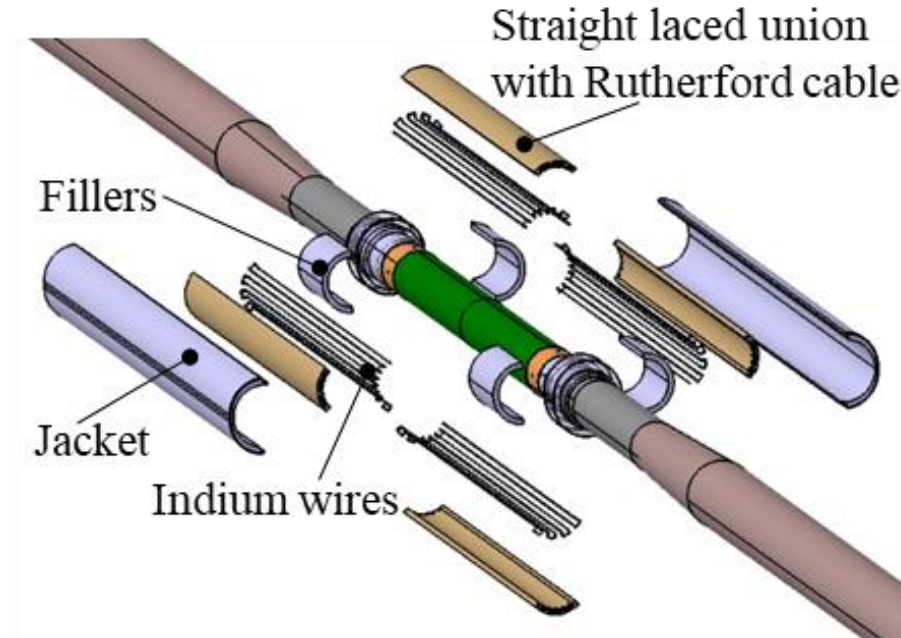
# Joint extension assembly

- Based trial feedbacks, USIPO and IO have investigated several adaptations of the design layout to simplify the assembly:
  - Indium clamped joint rather than soldering at assembly stage,



# Joint extension assembly

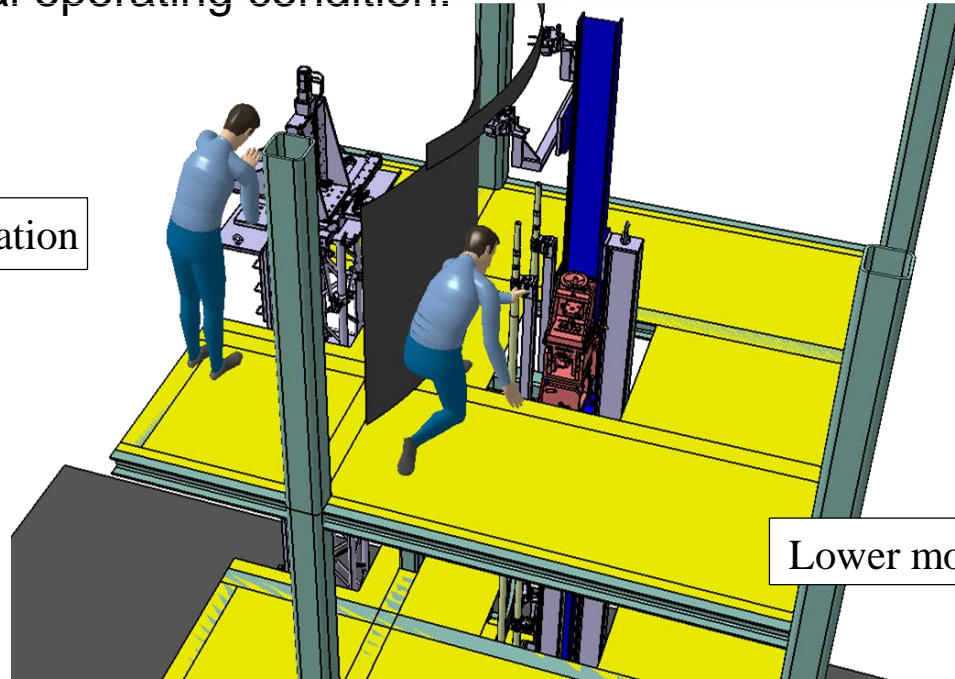
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# Joint extension assembly

- All these layouts will be tested and qualified.
- A mockup to simulate to CS stacking condition is under preparation at CEA for IO to these processes in real operating condition.

Upper module configuration



Lower module configuration

# Conclusion

- The CS components are all at manufacturing stage,
- Some structure parts and tooling are already delivered,
- USIPO has developed a very detail assembly process in collaboration with IO,
- IO is preparing the stacking phase to be ready for Q1-2021,
- Most critical operations are being reviewed to simplify the process as far as possible,
- Trials on dedicated mockups are planned in 2019 and 2020.

# IO, USDA and GA CS Team



MT 26, Vancouver, Canada, 23-27 September 2019

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