Status of the ITER In-Vessel Coil System and Progress on the Qualification of the In-Vessel Coil Conductor

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Outline

- Overview of ITER In-vessel coils role
- Challenges of ITER In-vessel Coils
- ITER In-Vessel coils Conductor procurement and qualification
- ELM coils design
- VS coils design and installation strategy
- Development of IVC joints
- IVC Safety components
- Summary

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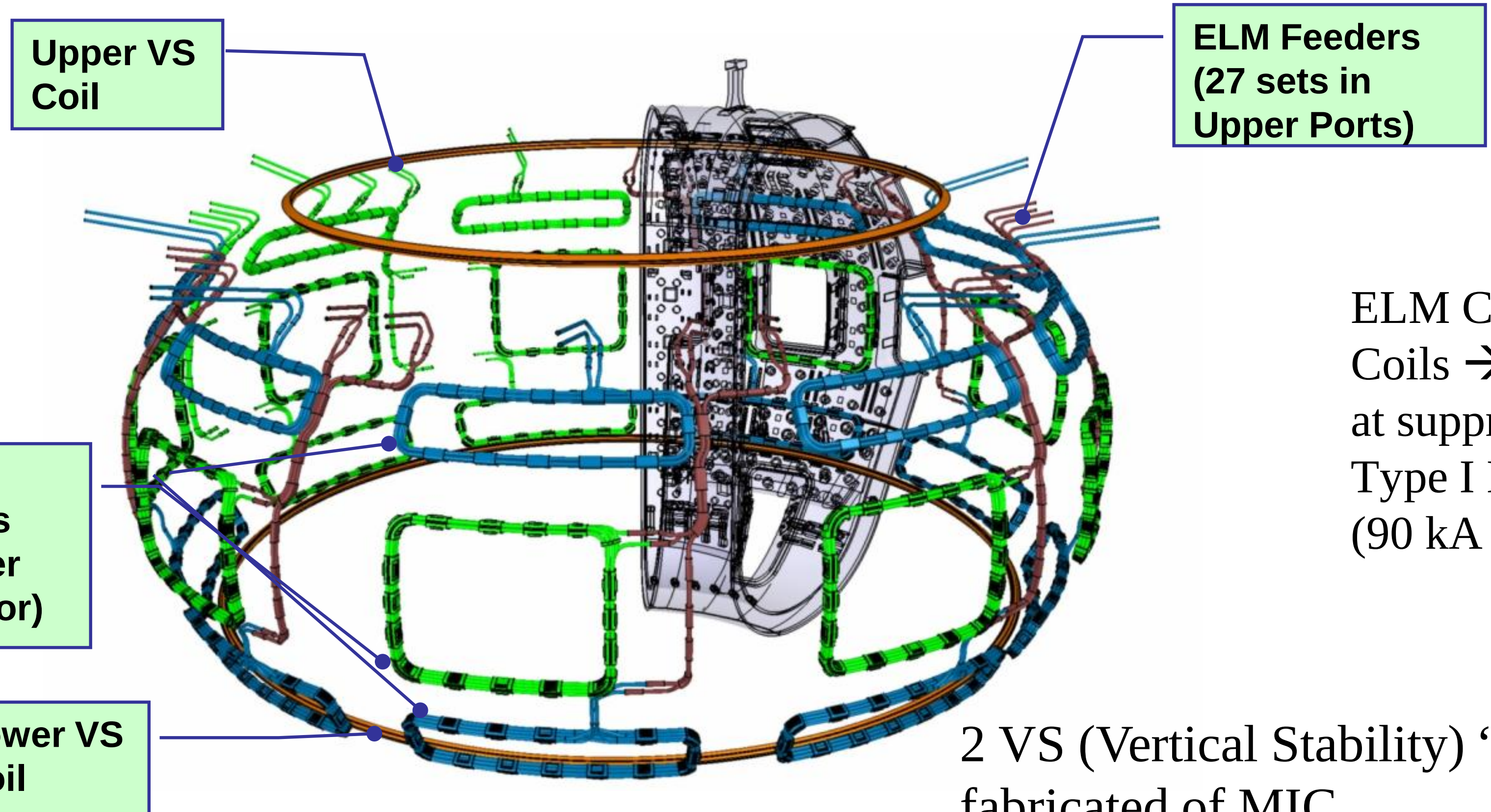
Overview of the ITER In-Vessel Coils



ELM Control Coils → Aimed at suppression of Type I ELMs (90 kA per coil)

27 ELM (Edge Localized Mode) water-cooled "picture frame" coils fabricated of Mineral insulated conductor

- 9 lower, 9 equatorial, and 9 upper coil
- 6 turns/1 coil
- 1 flow path/coil

2 VS (Vertical Stability) "ring coils" fabricated of MIC

common power supply connected to produce a radial magnetic field (60 kA per turn, 2.4 kV)

- 4 turns connected separately to cooling water and power supply

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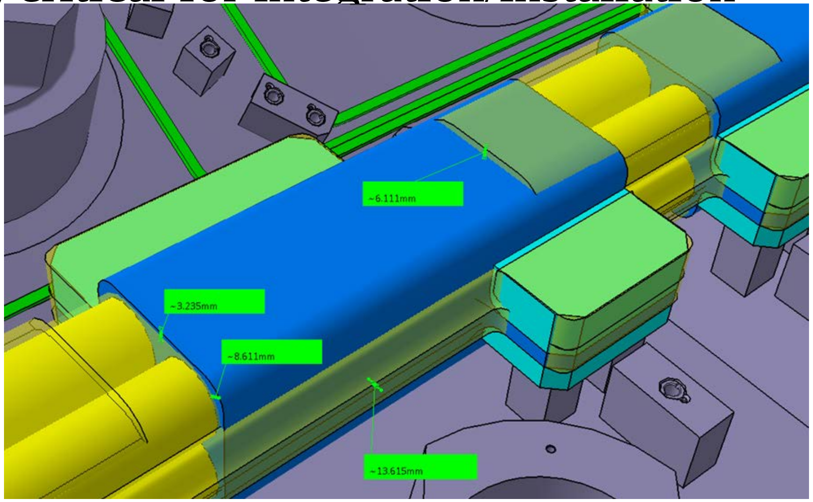
Challenging conditions

- Current requirements are driven by plasma physics; some scenarios require up to 5 Hz AC

⇒ **Cyclic and Fatigue requirements**

- Coils and coil supports sustain high heat loads (ELM- 11.38 MW, VS – 1.10 MW)
- Located behind Blanket modules – tight tolerances and gaps;
- Clearances to vacuum vessel (and diagnostics) critical for integration/installation – 2mm facing VV, 4mm. elsewhere;



- Coils actively water cooled

⇒ Supports/brackets need good **thermal contact** to conductor.

⇒ Due to heat loads and cooling layout, coils and VV can be at different temperatures;

⇒ If supports rigid, significant **thermal stresses.** Sliding concept considered.

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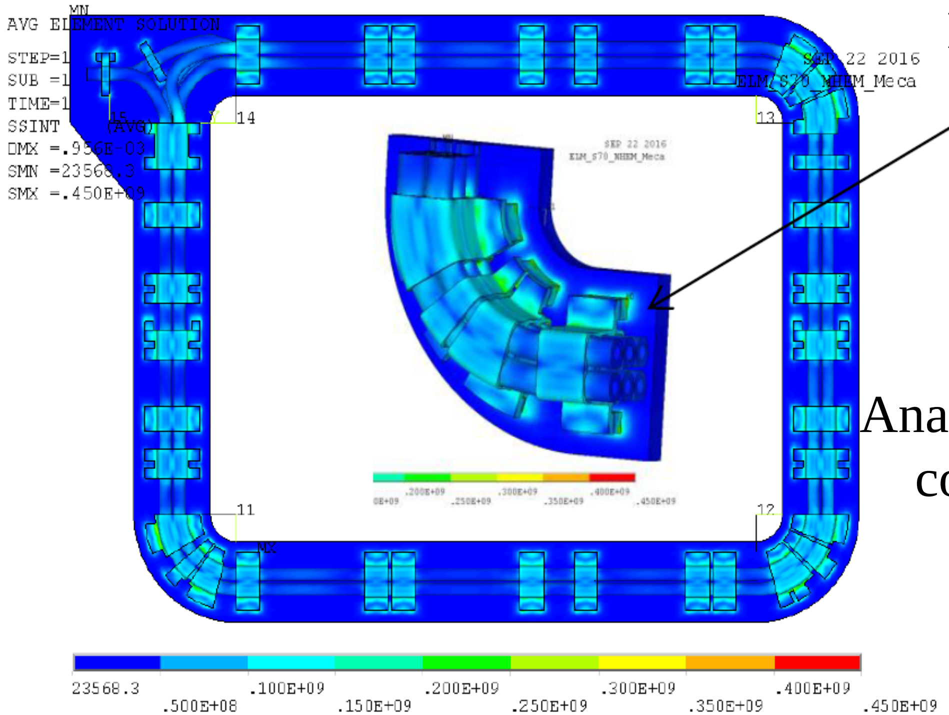
Challenging conditions

- IVC system components are cooled through a cooling system with a nominal cooling inlet temperature of 70 ˚C whereas the VV temperature is at 100 ˚C;
- During baking the IVC system is at 240 ˚C and the VV at 200 ˚C;
- Thermal stresses on the VV rail supports accumulated in the corner areas



High local peak stress 450 MPa

Sliding support as back-up plan

Analysis of rail loads and only if design code allowable is exceeded sliding surfaces will be implemented

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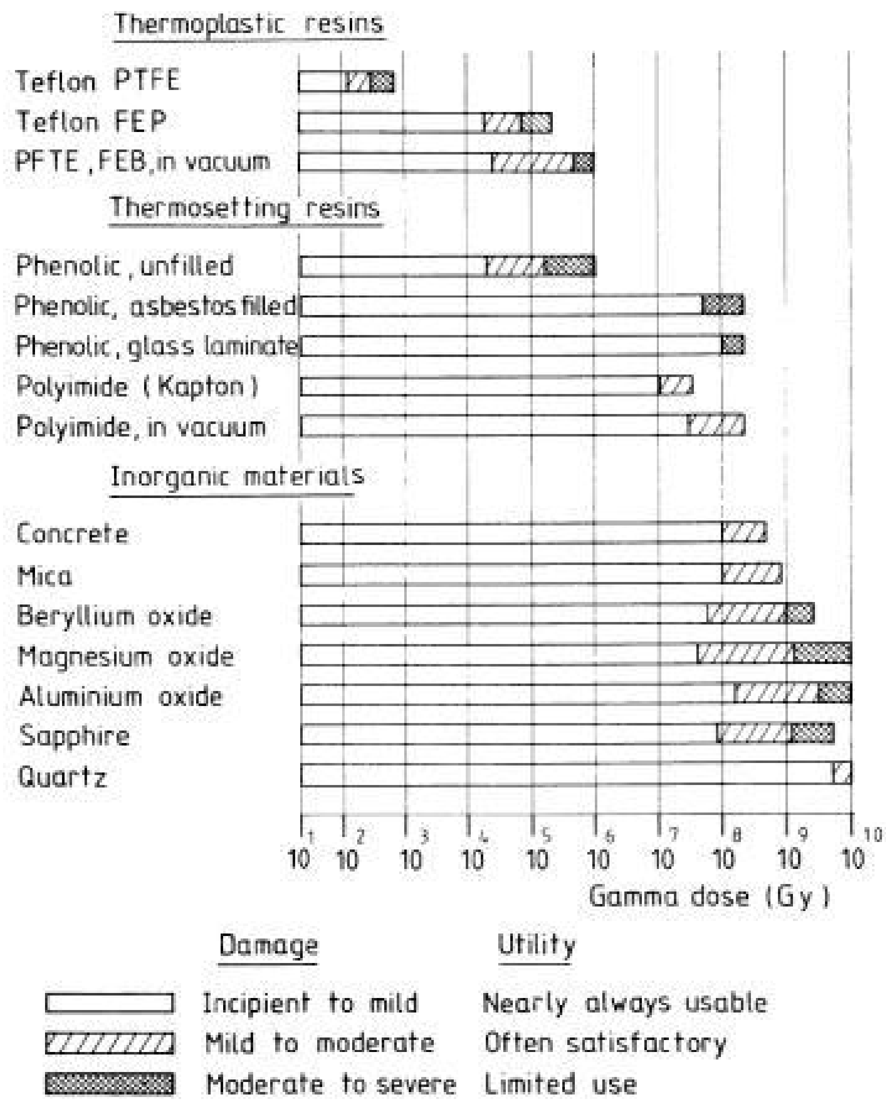
Choice of Conductor – Mineral Insulated Conductor

- Radiation Resistance Required

6 000 MGy – Tender for irradiation tests ongoing (characterize behavior of MgO and MIC under radiation flux and fluence)

- High Temperature, Operation = 250C

- Common Fiberglass Epoxy or Ceramic Polymer systems could not meet these requirements
- High purity of 99.4% Magnesium Oxide (MgO) is adopted as the insulation material for the Mineral-Insulated Conductor;
- The conductor insulation consists of compressed MgO powder to an adequate density to provide sufficient structure support of the copper conductor;



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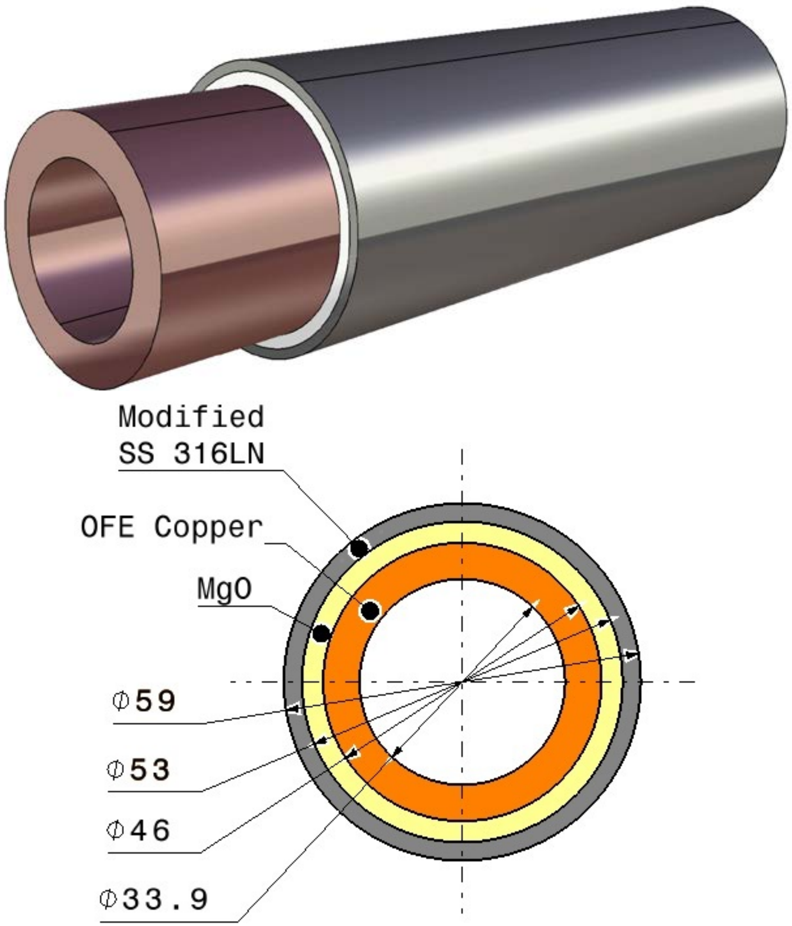
Conductor design



Total length with spares and dummy: 5010 m.

- Conductor manufacturing contracts – signed April 2017 with two suppliers (ASIPP, China and ICAS, Italy).
- Phase 1 – Qualification and Development phase. It includes all necessary processes, procedures, including mock up samples and one unit length fully tested according to IO requirements;
- Phase 2 – Production Phase – after successful completion of Phase 1 and based on revised offer, contract to be signed with one supplier only – technically compliant and cost effective;
- Schedule – MRR March-April 2018;
- End of Phase 1 – May 2018;
- Start of series manufacturing – December 2018.

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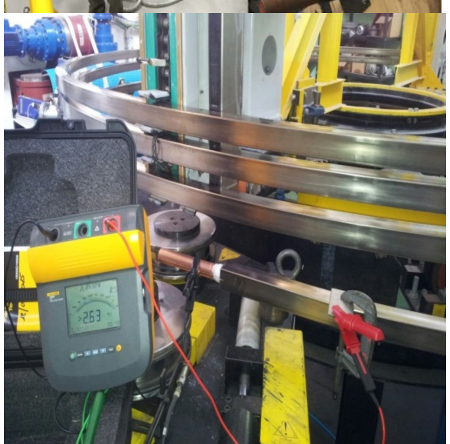
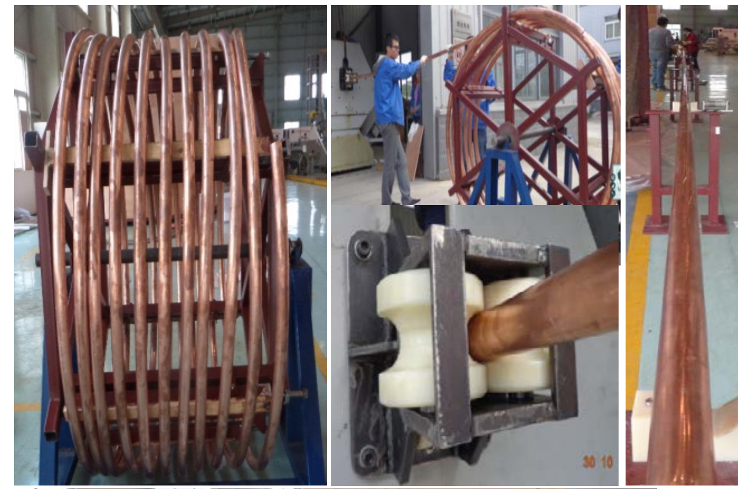
Background - IVC Conductor R&D

• 2 x ~40 m long prototype unit lengths have been successfully manufactured and tested, one with circle-in-square cross-section and one with circular cross-section; Decision was taken in January 2016 to select circular cross section.



- Conform extrusion of OFHC Cu tube
- Stainless steel jacket segments - butt welded to achieve 65 m. length;
- Insertion of Cu tube with MgO shells by pull in with a rope;

Circle-in-square Prototype



Manufacture of Circular Prototype

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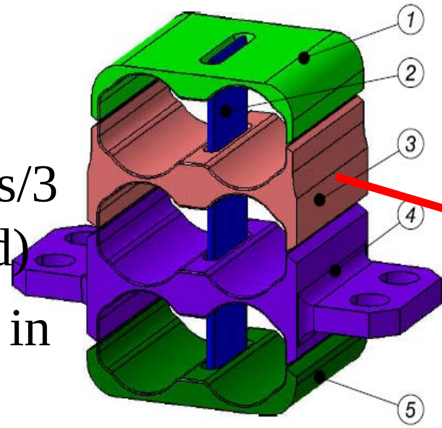
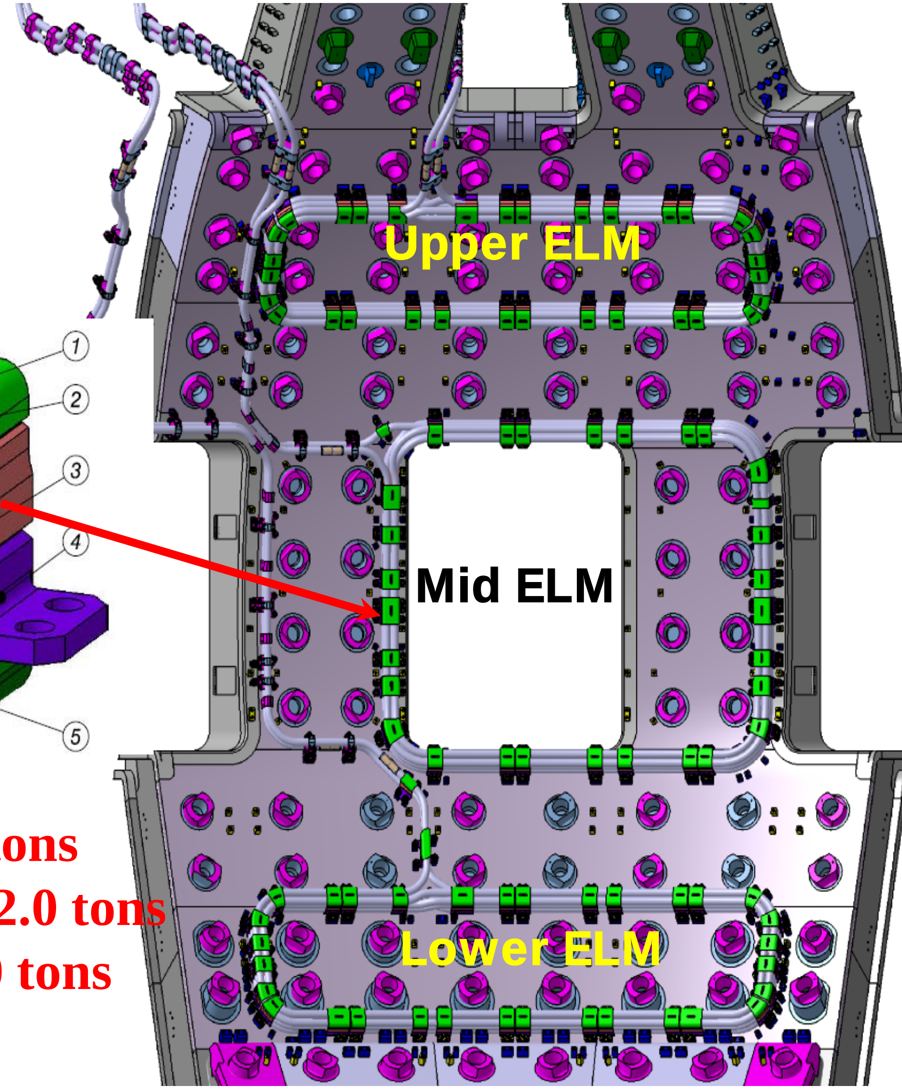
IVC System – ELM Coils

- Bracket distribution optimised considering bolt load, free conductor length, corner brackets, thermal contact;
- Rails welded to the VV sectors;
- Sliding support to reduce stresses on VV rails – R&D





- Conductor winding (6 turns/3 layers) in one part (no weld)
- Brackets are manufactured in 4 pieces
- Spread conductor to insert pieces between the layers
- Compression of all pieces
- Sidewall and comb welding under compression

Upper 1.7 tons
Equatorial 2.0 tons
Lower = 2.0 tons

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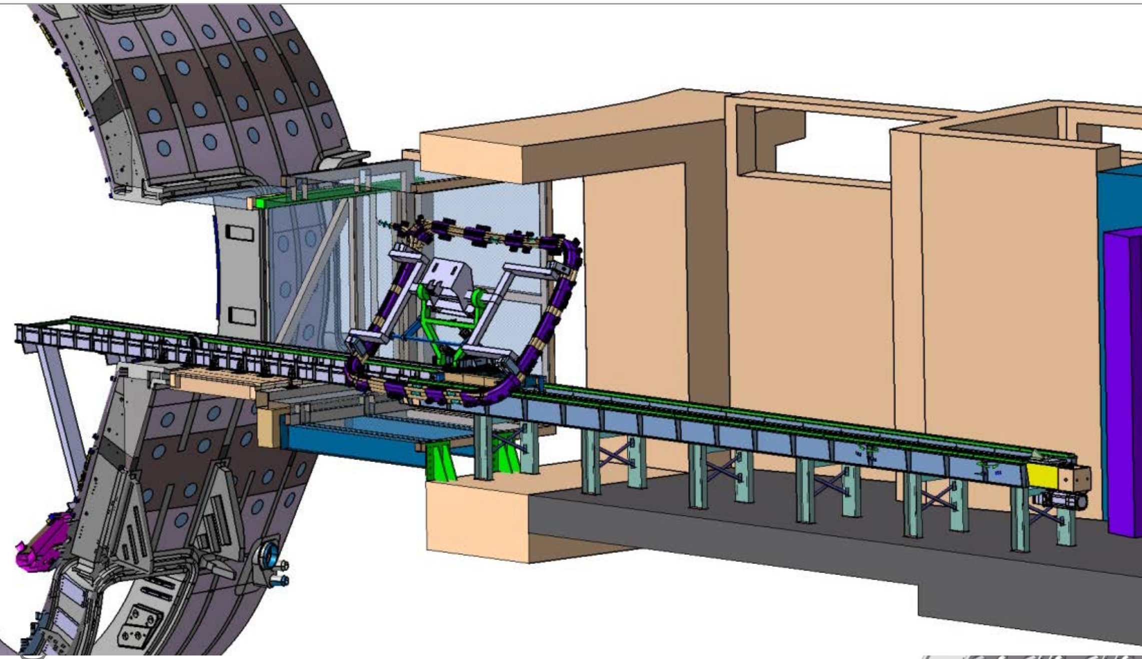
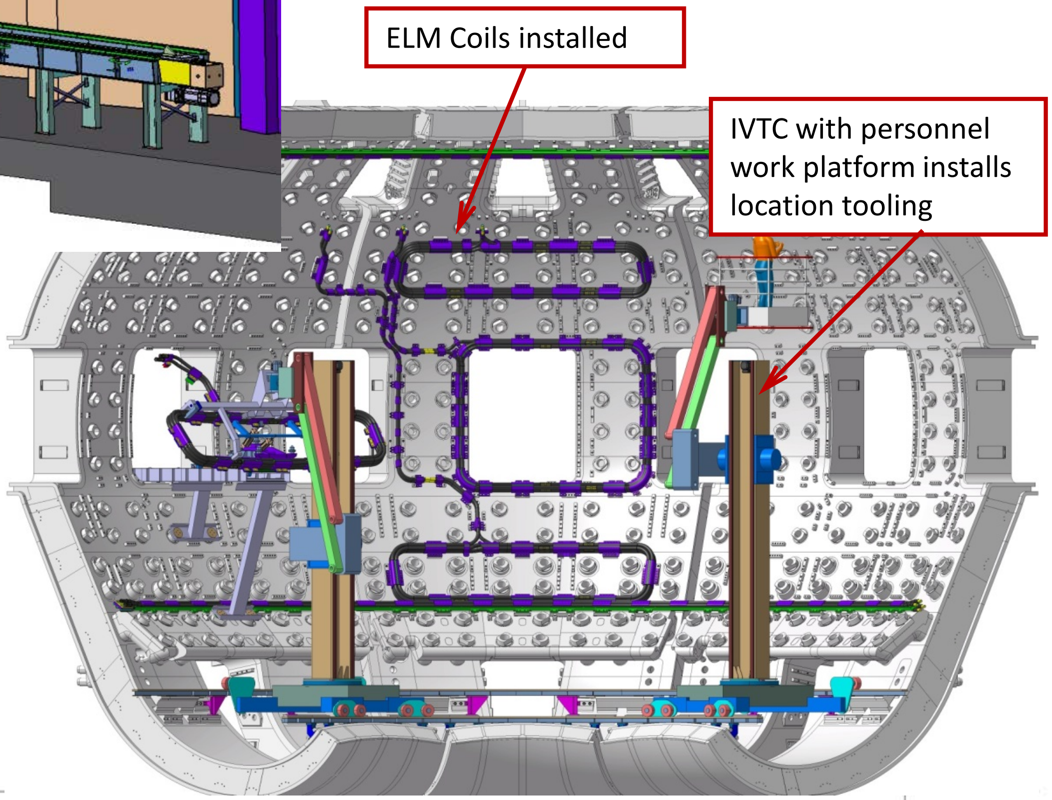
ELM coils Installation Strategy



Installation through the equatorial ports after full completion of the VV sectors



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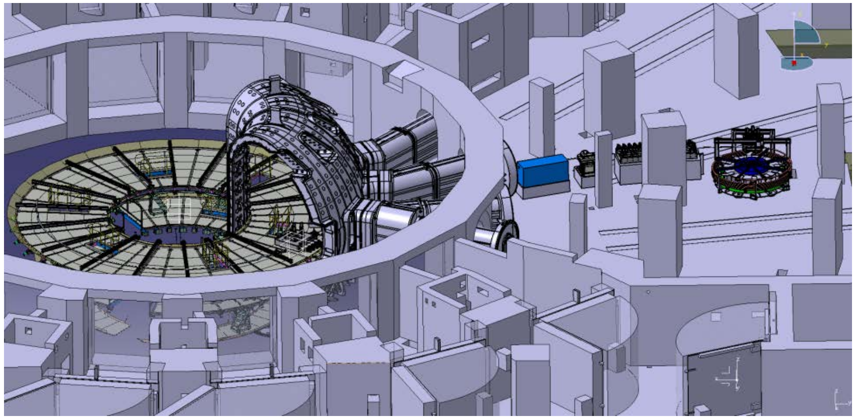
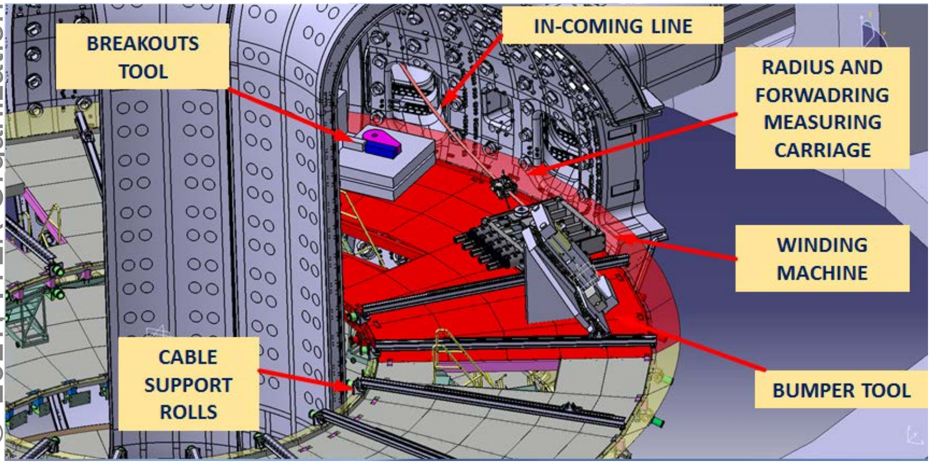
Design and Installation of VS coils

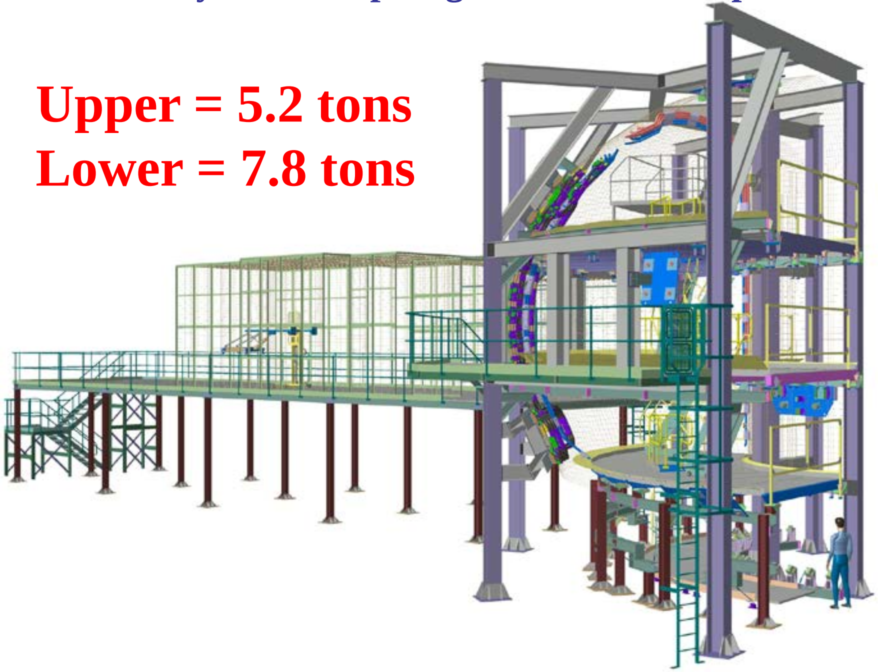
- VS coil conductor will be supplied to the assembly hall wound on a large reel (~ 4 m diameter);
- To be introduced into the VV through the Neutral beam port 2;
- A set of assembly tools will be used inside the VV: straightening unit, horizontal and vertical bending rollers, and hydraulic forming tools;
- Trial Test and Training Facility (TTTF) under development – qualifying installation and commissioning tooling.



Courtesy of Sea-Alp Eng. And Criotec Impianti



Upper = 5.2 tons
Lower = 7.8 tons



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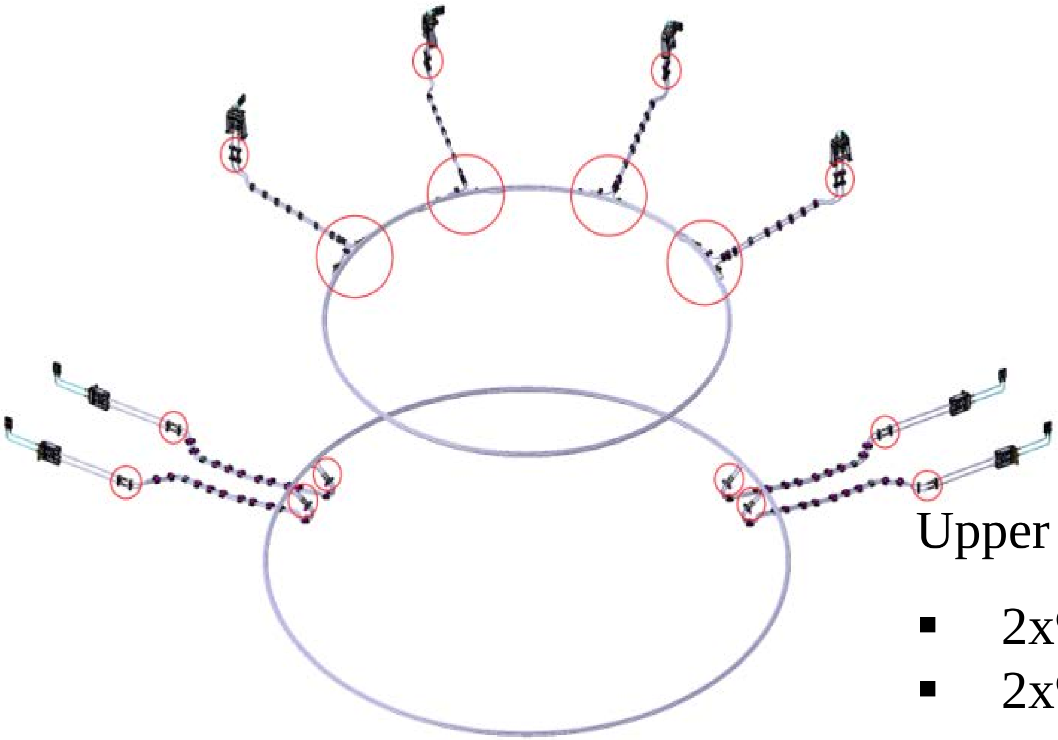
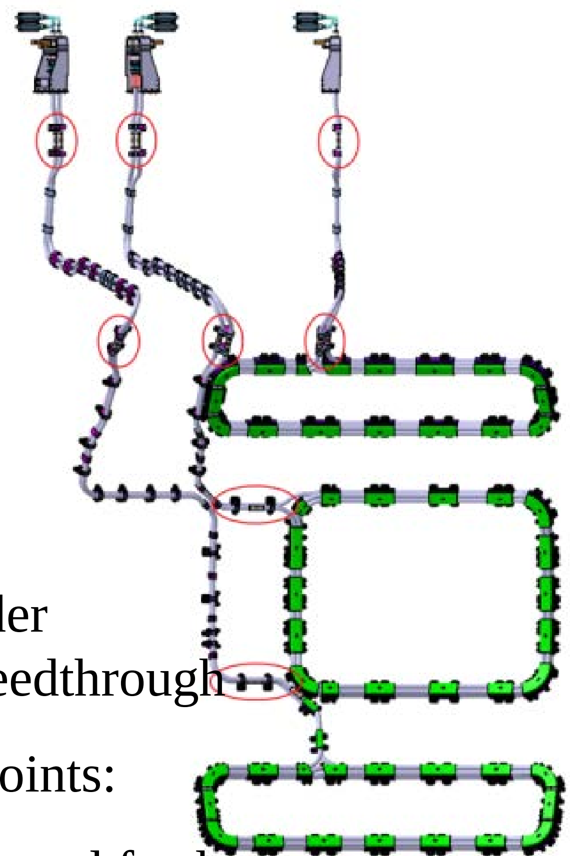
In-vessel Coil Joints - overview

There are totally 176 joints designed for ITER IVC, 32 for VS, 144 for ELM.





Upper ELM joints:

- 2x9 coil to feeder
- 2x9 feeder to feedthrough

Mid/ Lower ELM joints:

- 2x9 coil to in-vessel feeder
- 2x9 in-vessel feeder to upper
- 2x9 feeder to feedthrough

Totally 144 joints

Upper/lower VS joints:

- 2x4 coil to feeder
- 2x4 feeder to feedthrough

Totally 32 joints

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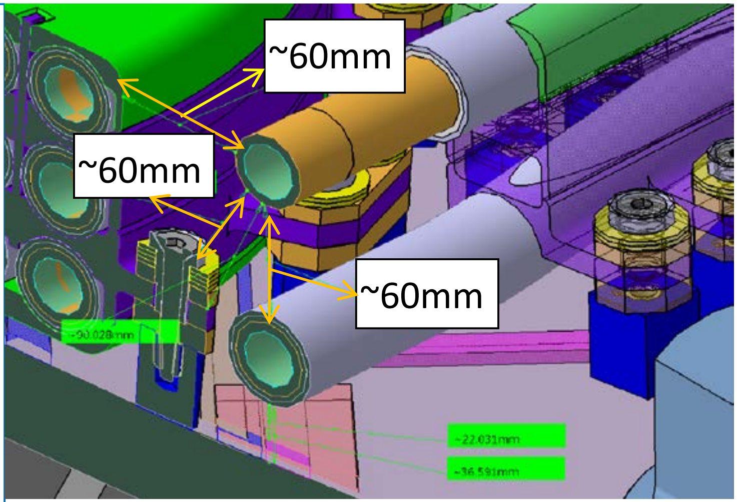
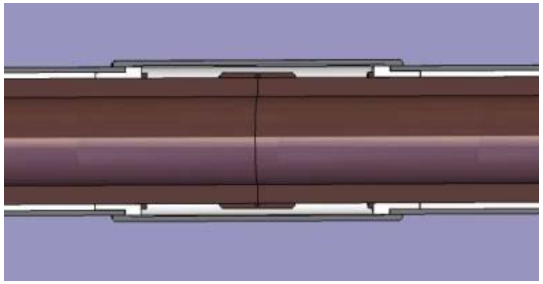
Joint development and Procurement - ongoing

- Very tight integration and assembly tolerances;
- Every single joint must be made as precise as possible;
- The coils are neither replaceable nor repairable during the whole machine operation;
- Joints must be highly reliable;
- Six types of joints according to the orientation and space reservation in the vacuum vessel





IVC Joint cross-section

- ➢ Phase 1 – Develop: equipment, tooling for copper welding, manufacture a prototype weld head; manufacturing and testing procedures, mock-ups
- ➢ Phase 2 – Manufacture equipment and tooling, test fatigue performance of joints, develop on-site testing technology;

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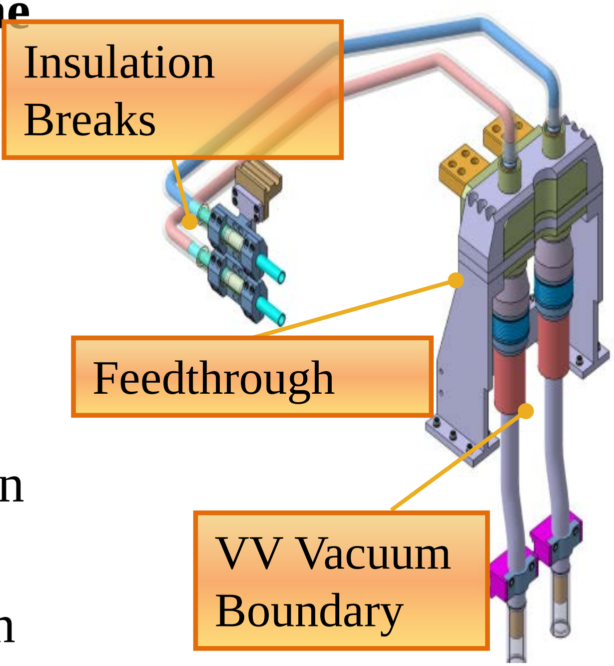
SIC/PIC components - Insulation Break and Feedthrough

- IVC VS and ELM coils conductors to **penetrate the VV Vacuum barrier** to transfer **electricity and cooling water**:
  - **Feedthroughs (FT):** decouple current and cooling water while assuring continuity of VV vacuum boundaries;
  - **Insulating Breaks (IB):** divide electrical and cooling water path ➔ avoid leakage currents in cooling water pipes.
- IVC FT have **intrinsic safety functions** (separation between environment and radiation)
  - **PIC/SIC** classified, need to respect additional safety requirements (materials, techniques, inspections);
- FT and IB preliminary design developed in last years, object of two **Design Reviews in 2017** to assess feasibility and functionality.



Summary

- *Conductor*
  - Qualification Phase until May 2018
  - Irradiation of IVC materials (*ongoing*)
    Insulation degradation in conductor
  - Cu Erosion- Corrosion (*started in summer 2017*)
- *Assembly*
  - VS and ELM coils – *ongoing*
- *R&D*
  - Feed through, Insulation Break, Brackets – *ongoing*

➢ **Procurements:**

- Conductor (ongoing – 2022)
- Joint development (2017 – 2020)
- VS tooling, feeders and in-situ winding qualification (2018 – 2022/2023)
- Feedthroughs (2018 – 2022)
- Insulating breaks (2018 – 2020)
- ELM coils (2019 – 2025)

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Thank you for your attention !

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