

# ITER Pre Compression Ring Test Facility FEM analysis

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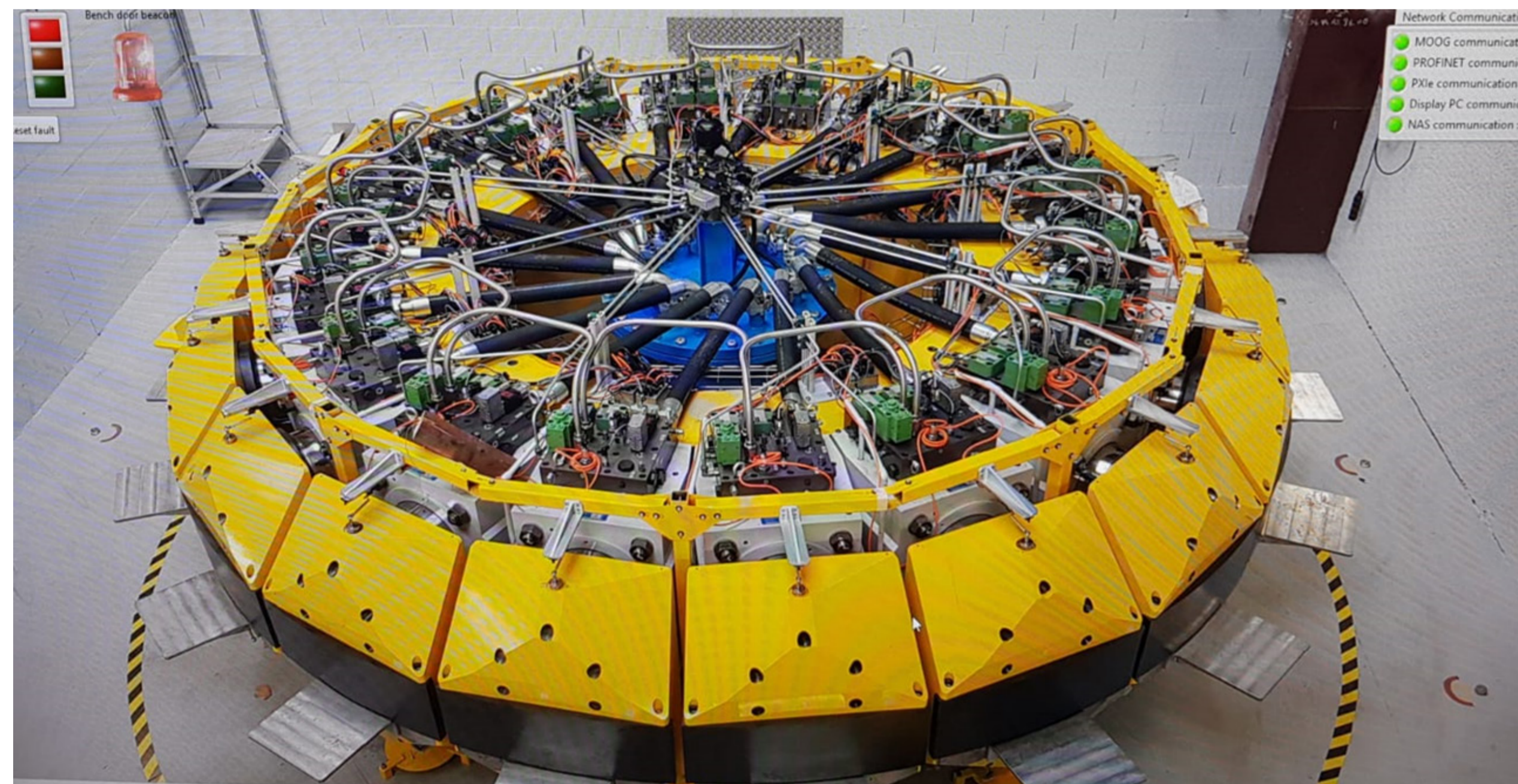


# FUSION FOR ENERGY

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## ABSTRACT

The Pre Compression Ring (PCR) system is a key component of ITER magnetic system that radially constraints the Toroidal Field (TF) coils against the out of plane magnetic forces. Due to its peculiar characteristics (one of a kind component, unidirectional S2 fiberglass in epoxy matrix) an experimental campaign has been planned on both reduced and full scale specimens. The tests purpose is the validation of the manufacturing technique verifying the compliance with the structural requirements. The Pre Compression Ring Test Facility (PCRTF) aims at reproducing the loading condition whom the PCR is subjected to in the tokamak assembly with a safety margin. For this purpose a detailed non linear 3D FEM model was developed permitting the simulation of the tests to be performed of the full scale PCR and on two different reduced PCR sub-assemblies. The analyses permitted to assess not only the stress field inside the specimens themselves but also the stress, displacements and global forces for the modules of the testing rig. This led to a fine optimization of the PCRTF components also investigation several off-design scenarios that may occur during the assembly and the operation of the facility.



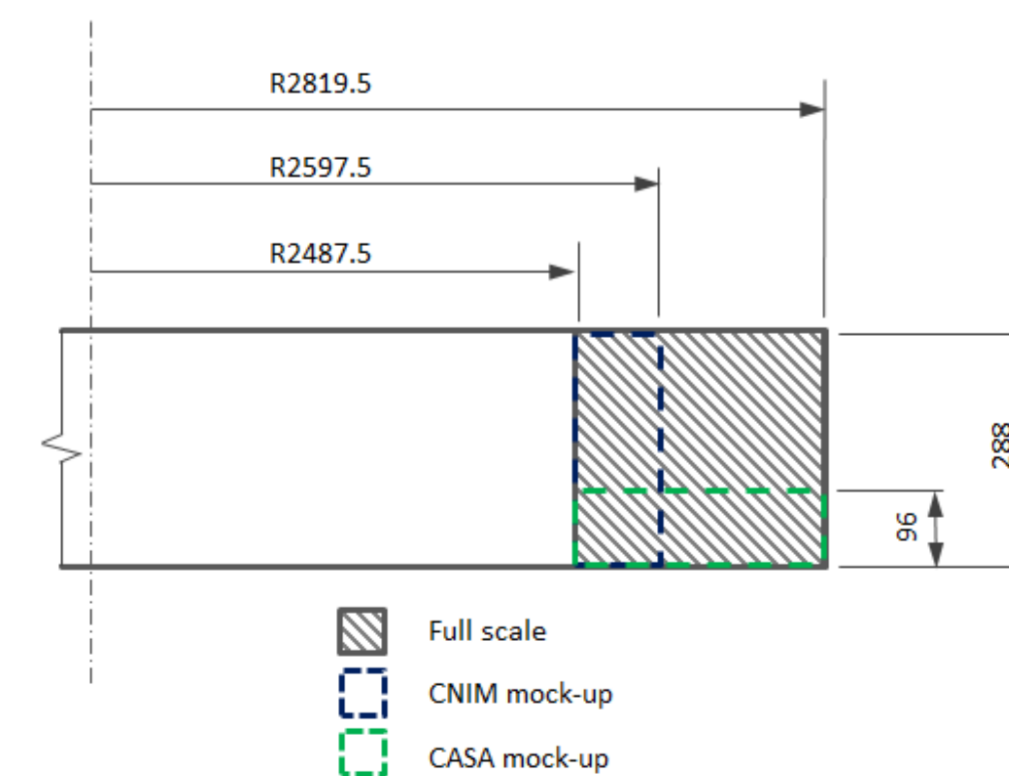
## THE TESTING MACHINE

The machine is composed of 18 identical sub-systems: two actuators (vertically arranged) are connected to a spreader. A steel "cushion" flange acts as interface with the PCR inner surface. The actuators push the PCR outward simulating the effect of the pre-load in the tokamak assembly. The cushion shape has been optimized in order to uniformly distribute the pressure on the surface preventing the PCR from local breakage [1]. The actuators deliver up to 36 k tons of radial force.

## THE SPECIMENS

The PCRTF has been designed to test:

- Full scale PCR (Ri = 2487.5 mm, Re = 2819.5 mm, h = 288 mm)
- CNIM mock-up, 1/3 of radial dimension (Re = 2597.5 mm)
- CASA mock-up, 1/3 of height (h = 96 mm)



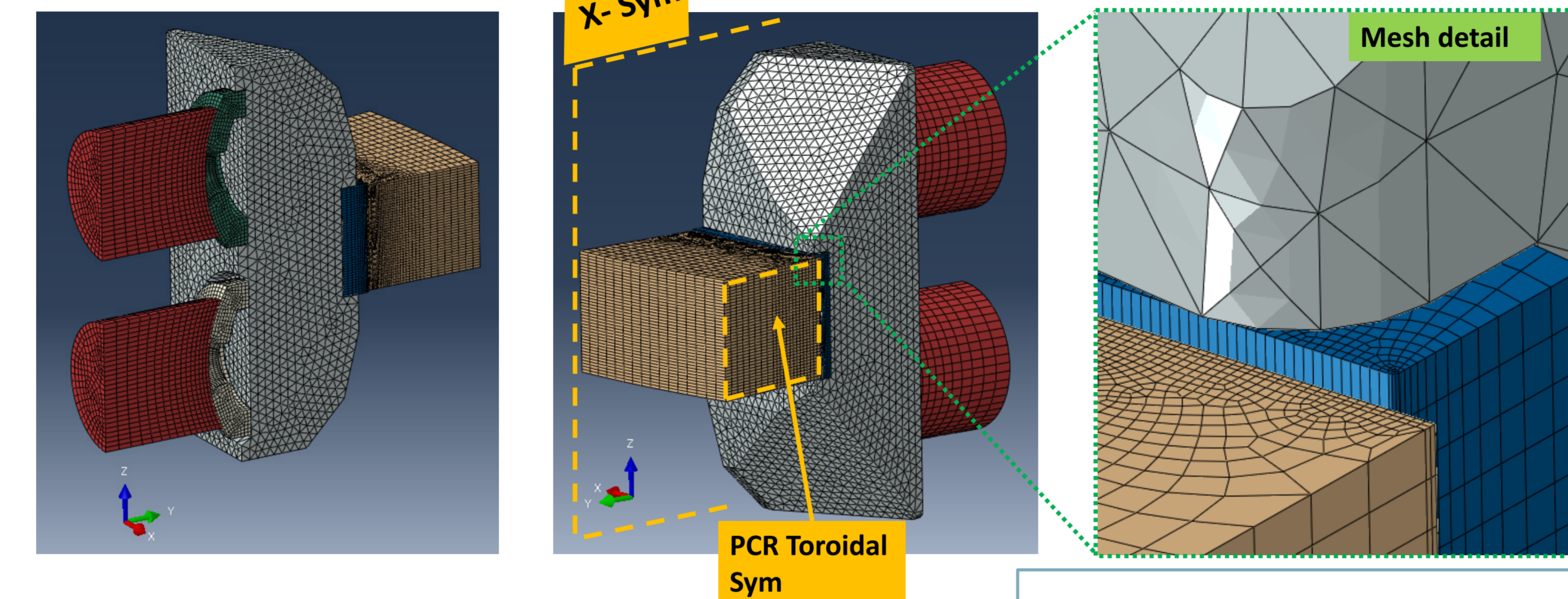
## PCR specimens material data

	E <sub>11</sub> [GPa]	E <sub>22</sub> [GPa]	E <sub>33</sub> [GPa]	G <sub>12</sub> [GPa]	G <sub>23</sub> [GPa]	G <sub>31</sub> [GPa]	ν <sub>12</sub>	ν <sub>23</sub>	ν <sub>31</sub>
CNIM	15.3	59.35	22.4	4.91	4.52	4.91	0.271	0.435	0.271
CNIM layer	19.4	62.7	23.5	5.92	5.45	5.92	0.266	0.44	0.266
CASA	15.69	50.99	15.69	5.02	5.45	5.02	0.27	0.44	0.27

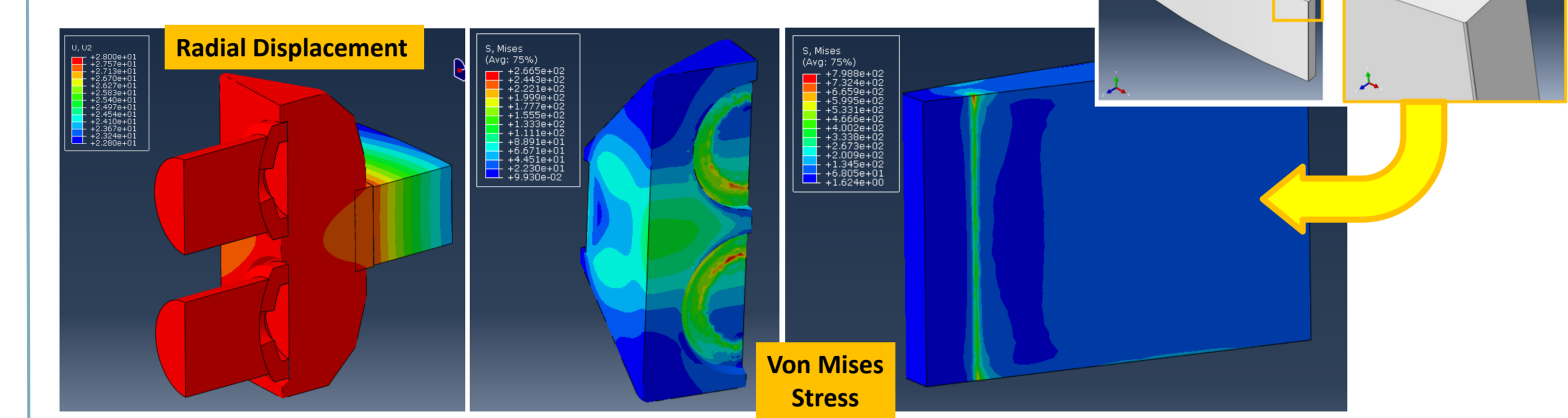
- Main References**
- [1] L. Reccia et al., Optimization of the ITER Pre compression Ring Test Rig Flange, IEEE Trans. on Applied Superconductivity PP(99) 2017
  - [2] J. Knaster, M. Ferrari, et al., "The pre compression system of the toroidal field coils in ITER", Fusion Engineering and Design 82 (2007)
  - [3] P. Rossi et al., "Overview of the testing activities on ITER sub-scale pre-compression rings" Fusion Engineering and Design 87 (2012)
  - [4] N. Mitchell, A. Devred, "The ITER magnet system: configuration and construction status", Fusion Engineering and Design 123 (2017)

## FEM ANALYSES: NORMAL CONDITIONS

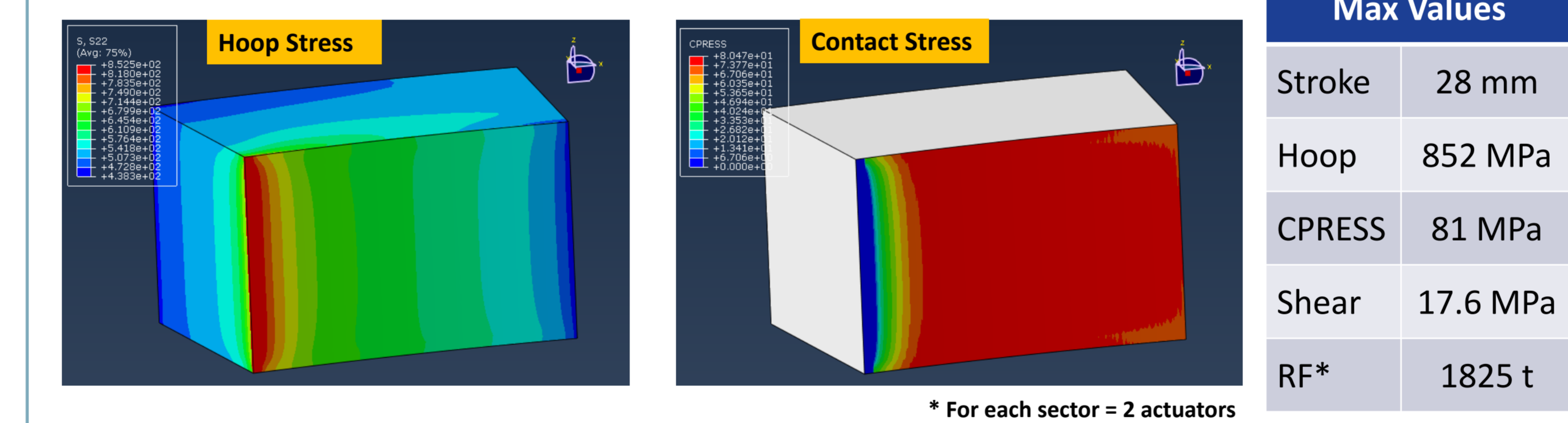
The FEM model has been developed in ABAQUS. The mesh amounts to about 203k solid elements and 240 k nodes. The interactions between the components are modeled with non linear contacts.



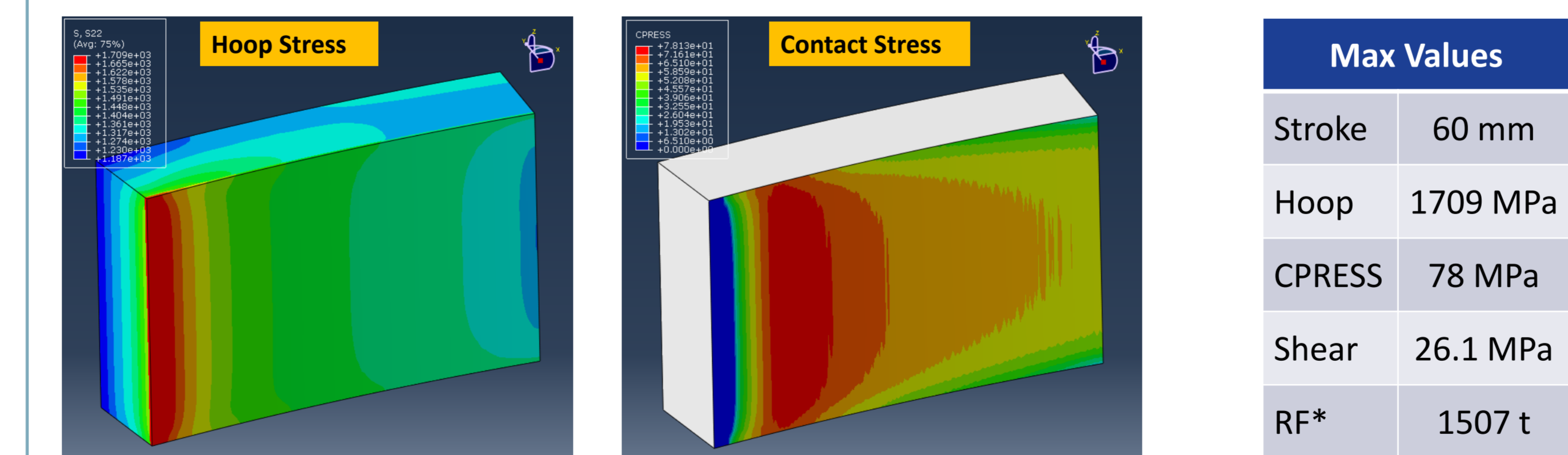
## PCRTF stress and displacements



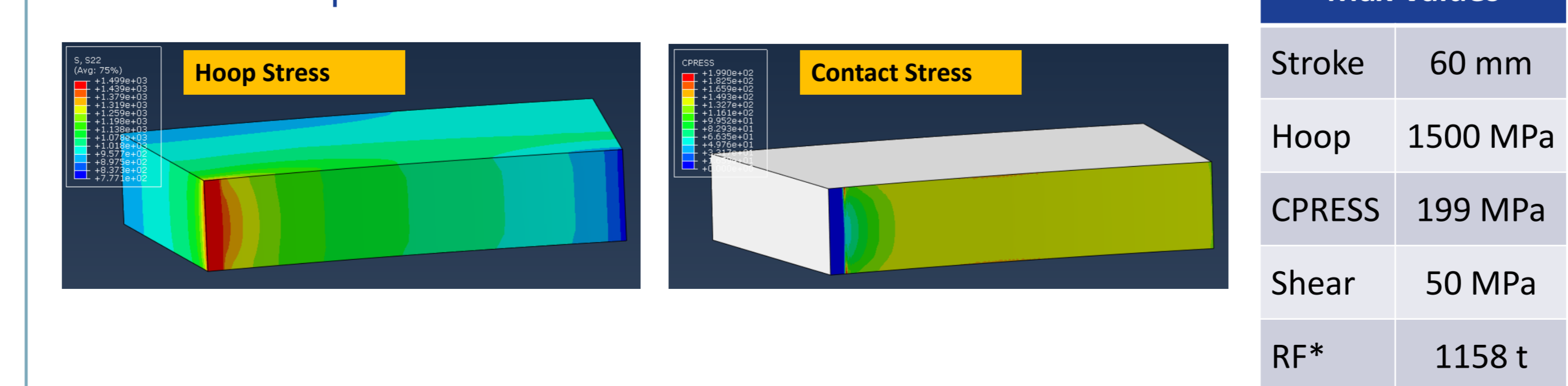
## CNIM full scale



## CNIM mock-up



## CASA mock-up



## FEM ANALYSES: OFF-DESIGN CONDITIONS

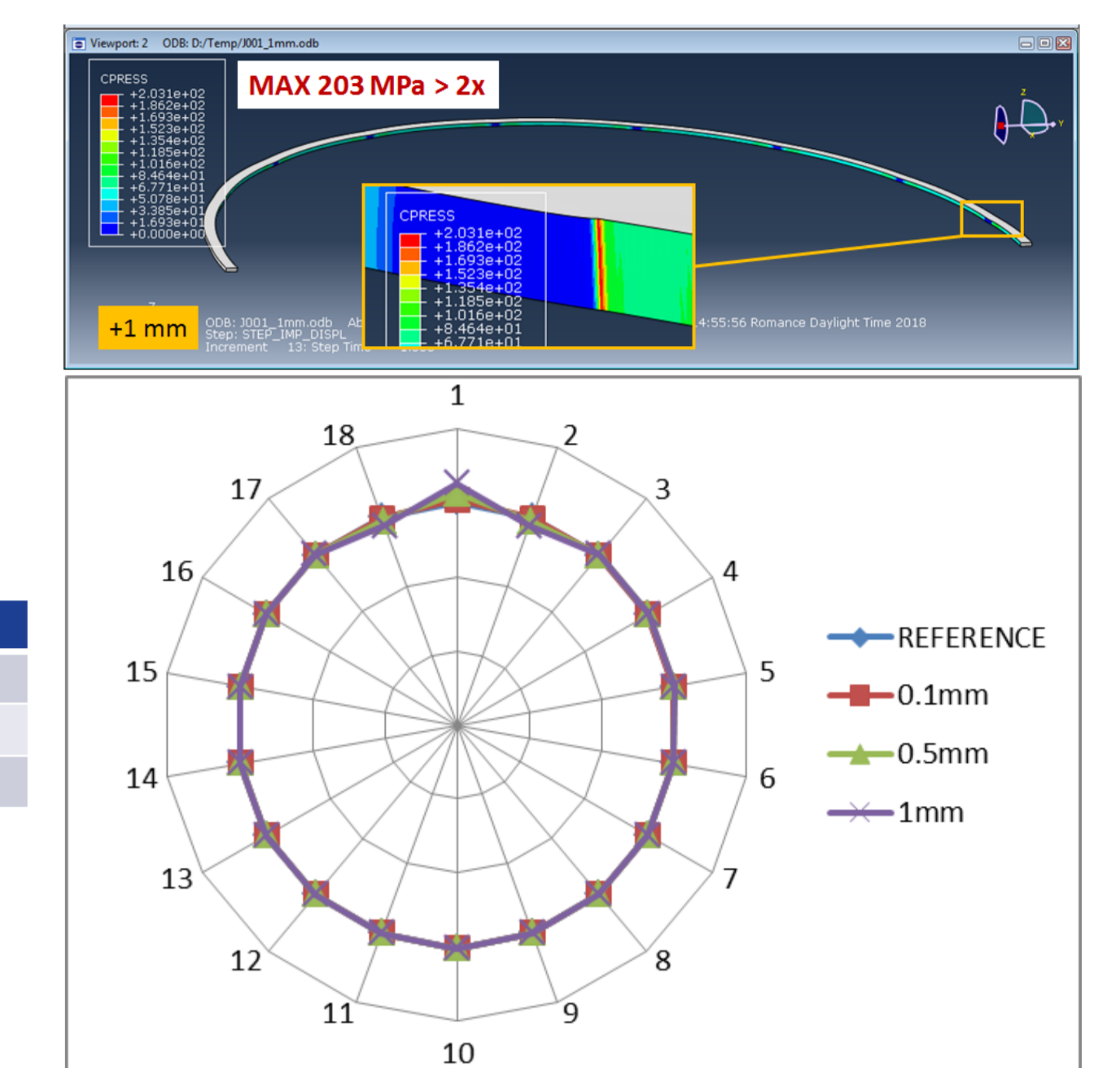
### Radial misalignment

A '2D-like' FEM model is used to analyze the problem. Half specimen is represented. Cases analyzed:

1. ± 0.1 mm
2. ± 0.5 mm
3. ± 1 mm

Stress [MPa]	±0.1 mm	±0.5 mm	±1 mm	Nominal
Contact	79	87	203	78
Hoop	1716	1719	1727	1716
RF variation	1.4%	4.5%	9%	-

The stresses are reasonable up to 0.5 mm misalignment, 5 times the accuracy of the machine (0.1 mm)

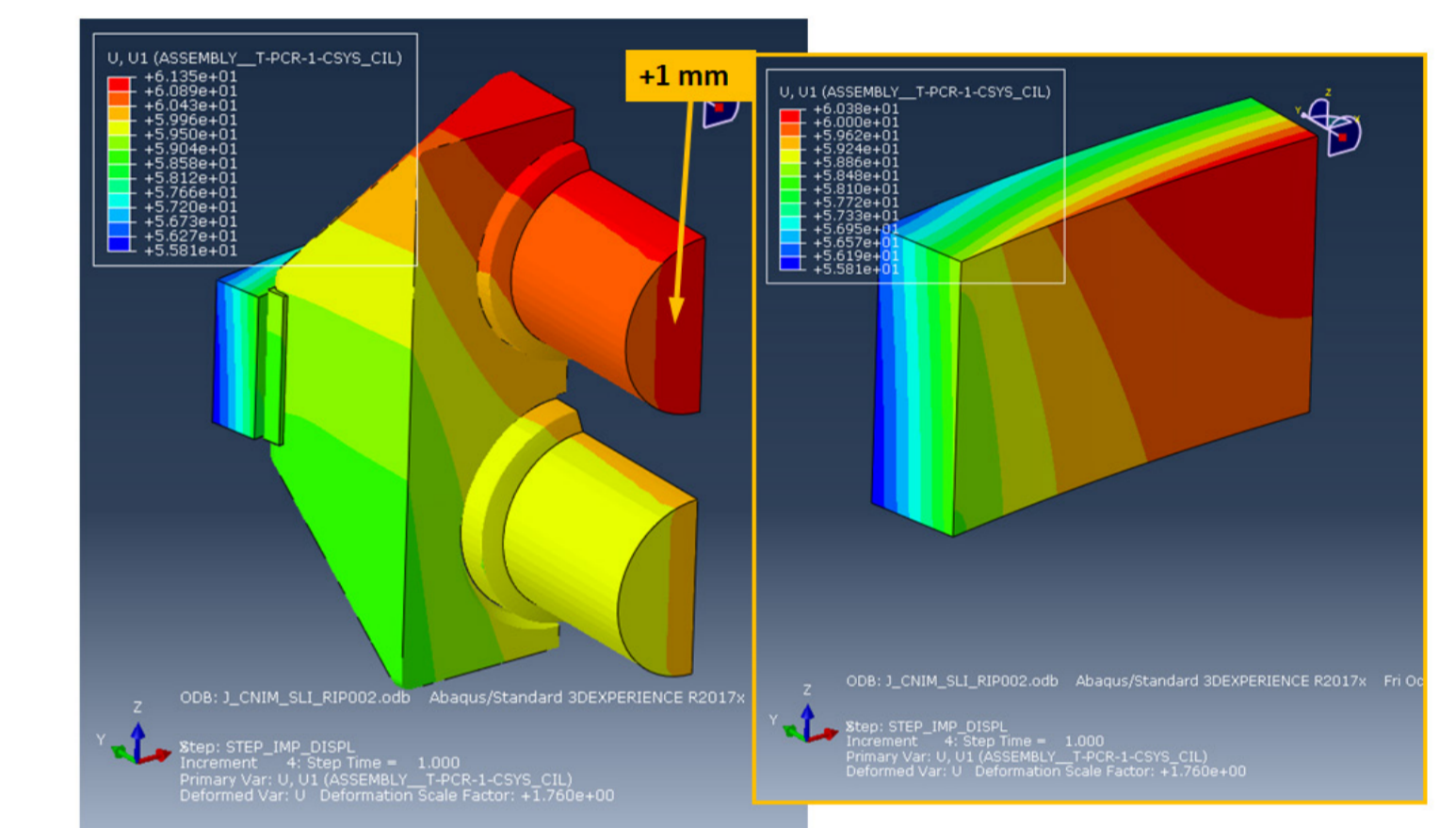


### Vertical misalignment

An extra stroke is applied to the upper actuator (± 0.1, ± 0.5, ± 1 mm).

The impact on the stress is negligible; on the other hand the actuators forces' unbalance is remarkable.

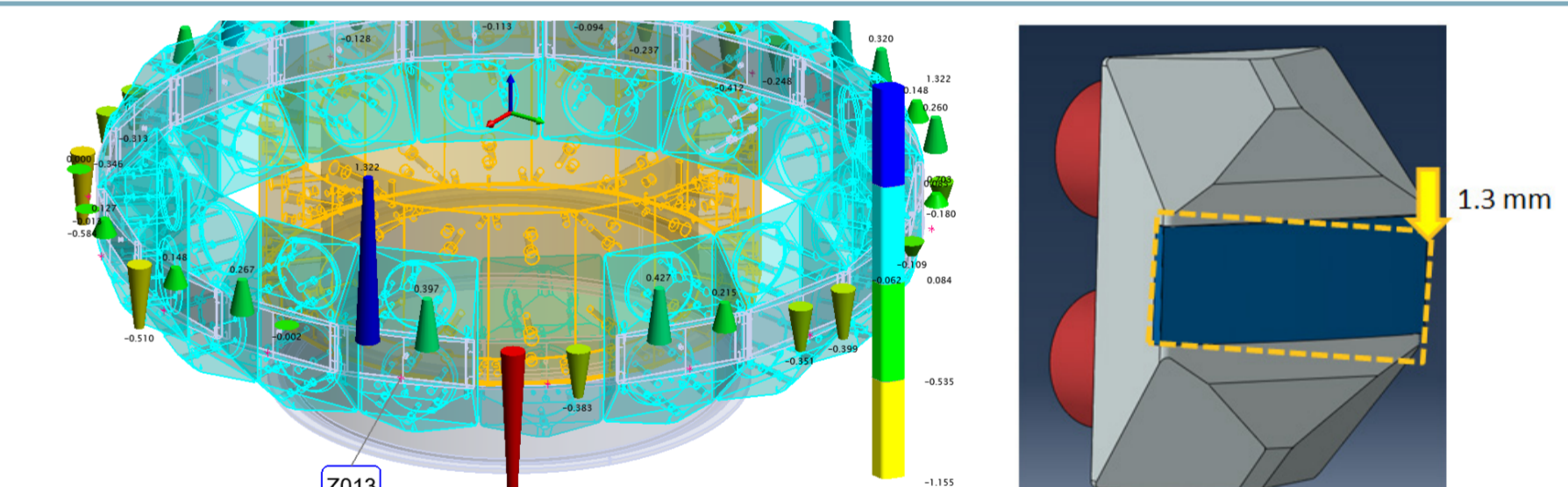
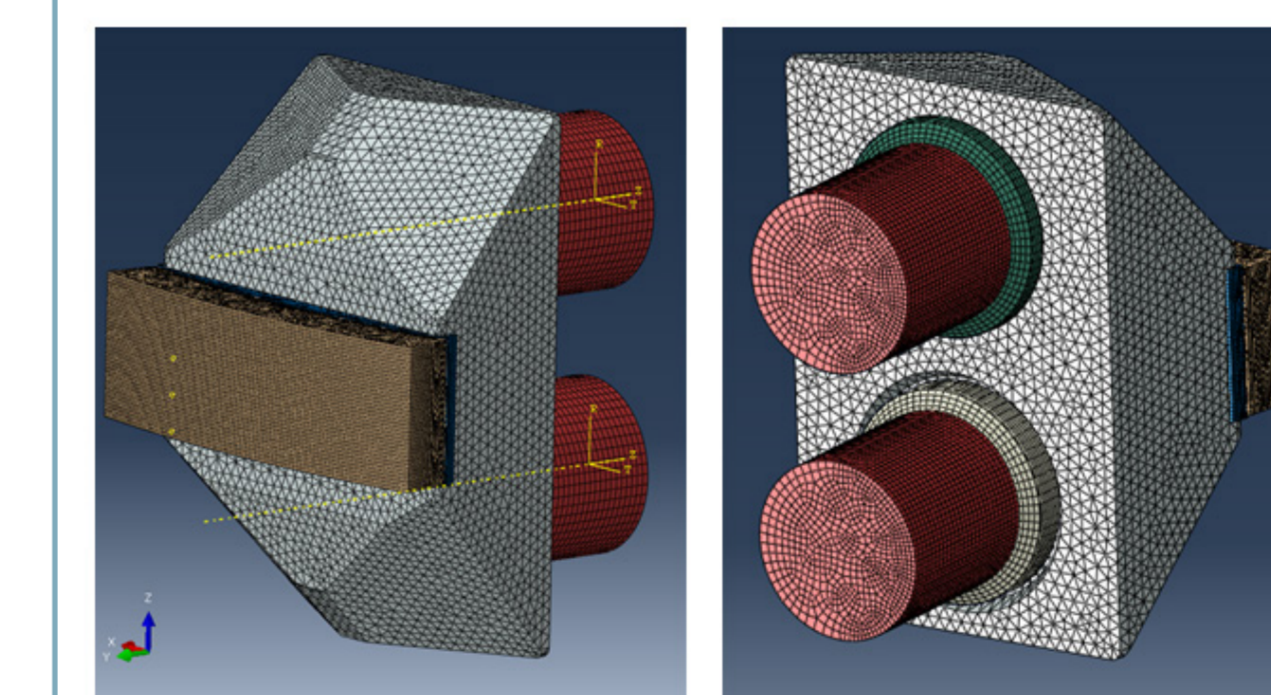
Stress [MPa]	±0.1 mm	±1 mm	Nominal
Contact	78	79	78
Hoop	1723	1741	1716
RF variation	2.3%	26%	-



### Cushion rotation

After the completion of the installation of the machine a metrological survey has been performed. Not negligible misalignments of the cushions have been observed.

No longer symmetric problem → new FEM model (complete sector)



Stress almost unchanged simulating the measured misalignment

## CONCLUSION

The PCRTF structural behaviour has been analysed with regard to three types of specimen: CNIM full scale PCR, CNIM mock-up and CASA mock-up. The stresses in the PCRTF components are within the material limits. Regarding the specimens, CNIM full scale PCR and mock-up exhibit uniform and limited contact stress (<80 MPa) benefitting of the flexible ending of the cushion. Also hoop, radial and shear stress are in line with the scope of the test, which is applying a relevant hoop stress accepting a limited bending in the unsupported area of the specimen. Further to the ideal test condition, some off-design cases have been analyzed. Simulating the rotation of the cushion, as well as the radial and vertical misalignment of the actuators, the domain of operation of the test machine was defined.