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Since 1996

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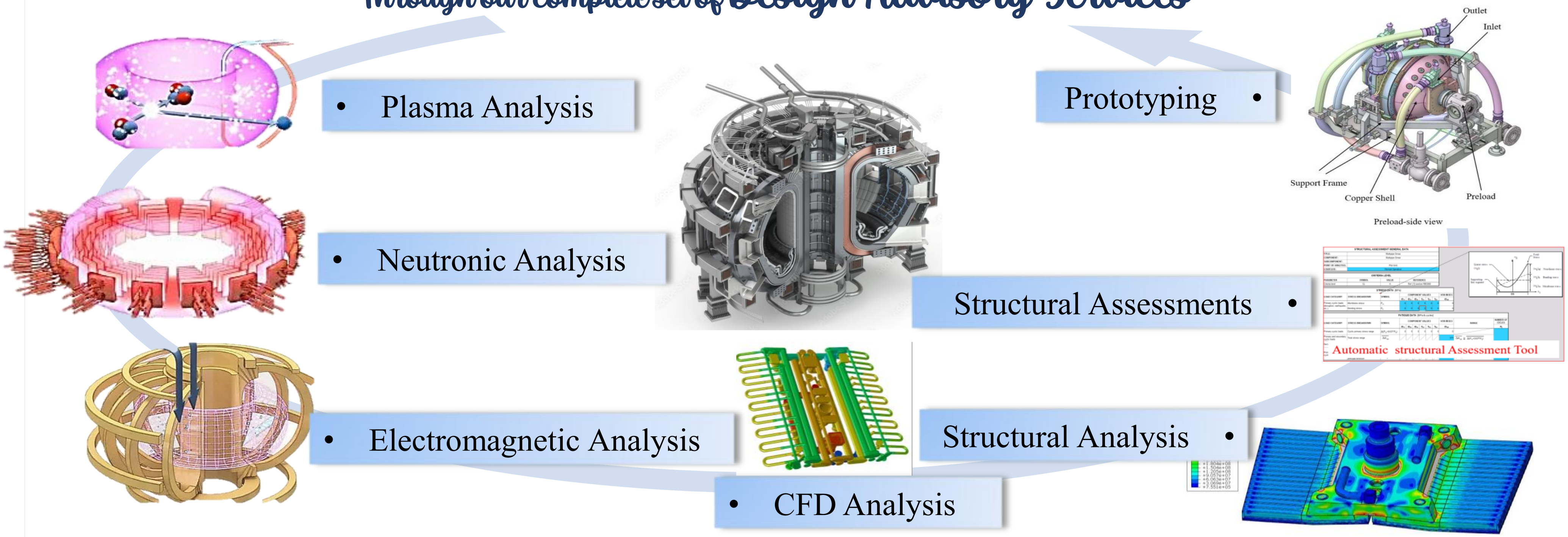
Your Way To Fusion Machine

Through our complete set of Design Advisory Services



Thanks to more than 28 years of experience and collaboration in Fusion Machines like ITER, DEMO, W7X, JET, DTT, FTU, STEP and …, LTCalcoli has a demonstrated capability of assisting the design of a fusion machine by proposing design modifications to solve electromagnetic and structural issues, verifying the Fusion Machine design according to standards using ***automatic internally developed design tools*** *and address toward prototypes.*

Services

CAE Solutions

- Electromagnetic Analysis
- Electro-mechanical analysis
- Plasma Disruption with MAX FEA
- Structural mechanics
- Thermal analysis
- Thermo-structural analysis
- Fluid dynamics (CFD)
- Vibroacoustic
- Fatigue analysis
- Fracture Mechanics
- Elasto-Plastic Analysis

Design Solutions

- Structural integrity studies according to SDC-IC, ASME and RCC-MR.
- Engineering consultancy from design to prototype
- Design by Analysis
- Design by Rule

Trainings

- Finite Element Method Theories
- Simulia Abaqus
- Ansys Workbench
- Ansys APDL
- Hypermesh

Partners

LTCalcoli has an established experience in the design by analysis of Thermo-Nuclear Fusion Reactors from a strong and long-term collaboration with:

- ✓ ITER Organization
- ✓ ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development):
  - o FTU (Tokamak Upgrade)
  - o FAST
  - o DTT
  - o IGNITOR
- ✓ W7-X IPP
- ✓ STEP (in Consortium with IDOM UK)
- ✓ EUROFusion Program:
  - o DEMO
  - o VNS
- o CEA - WEST
- ✓ JET
- ✓ MaritimeFusion
- ✓ CNR ISTP (the Italian National Research Council Institute for Plasma Physics)

90% of LTCalcoli revenue is coming from contracts on Fusion Machines

Certifications

TÜV SÜD
ISO 9001

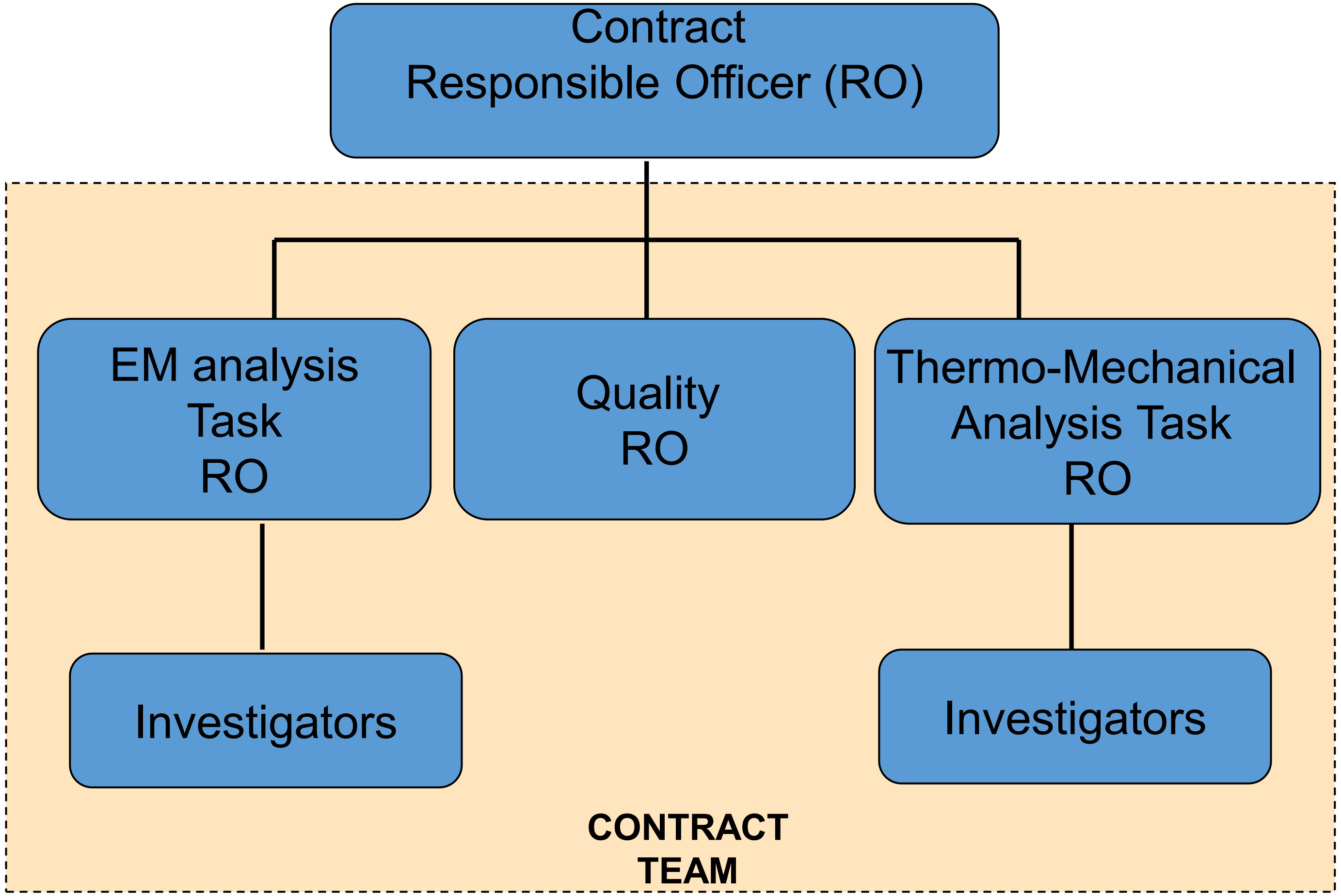
CYBER ESSENTIALS
CERTIFIED

Organization

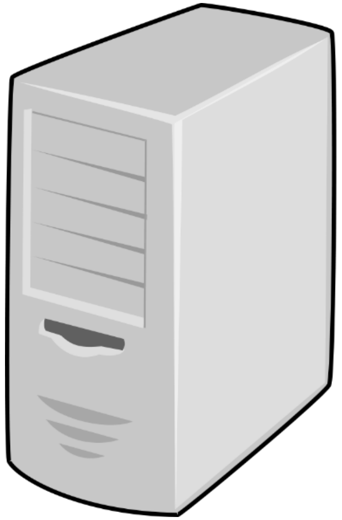
Each Contract has its "reference numerical code", used for each communication with Customer (mail, presentation, report ..)

Each Data referred to the Contract is stored in the "Referenced Code" area

Each Computer and each Computational Server is backed up every night into the storage servers



Resources



Servers

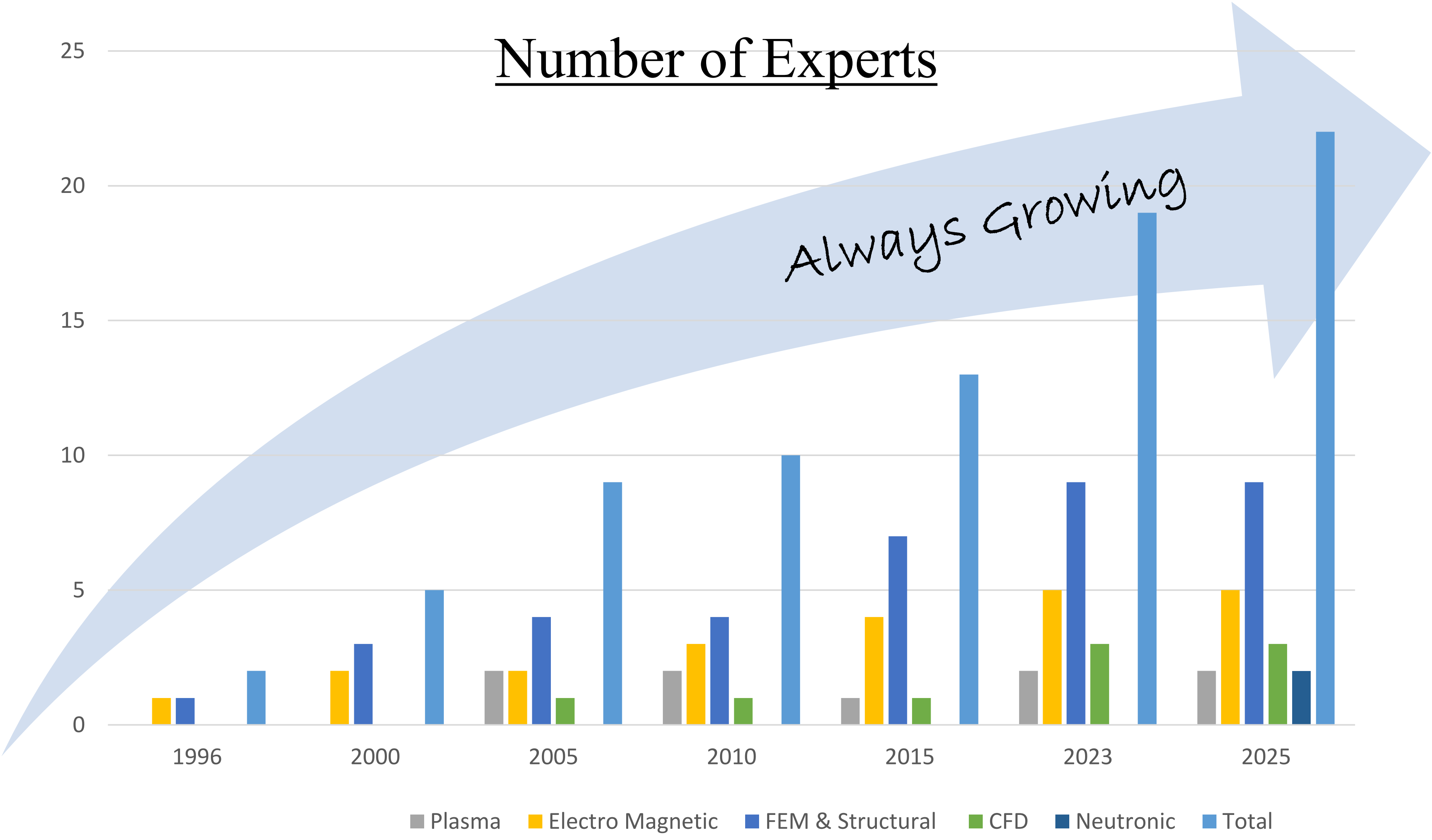
- #1 DELL 64 Cores – 768 Gb RAM
- #1 DELL 48Cores – 768 Gb RAM
- #1 HP 24 Cores – 720 Gb RAM
- #1 HP 24 Cores – 520 Gb RAM
- #1 DELL 32 Cores - 128 Gb RAM
- #1 DELL 24 Cores – 192 Gb RAM
- #3 Storage servers for data managing

Softwares

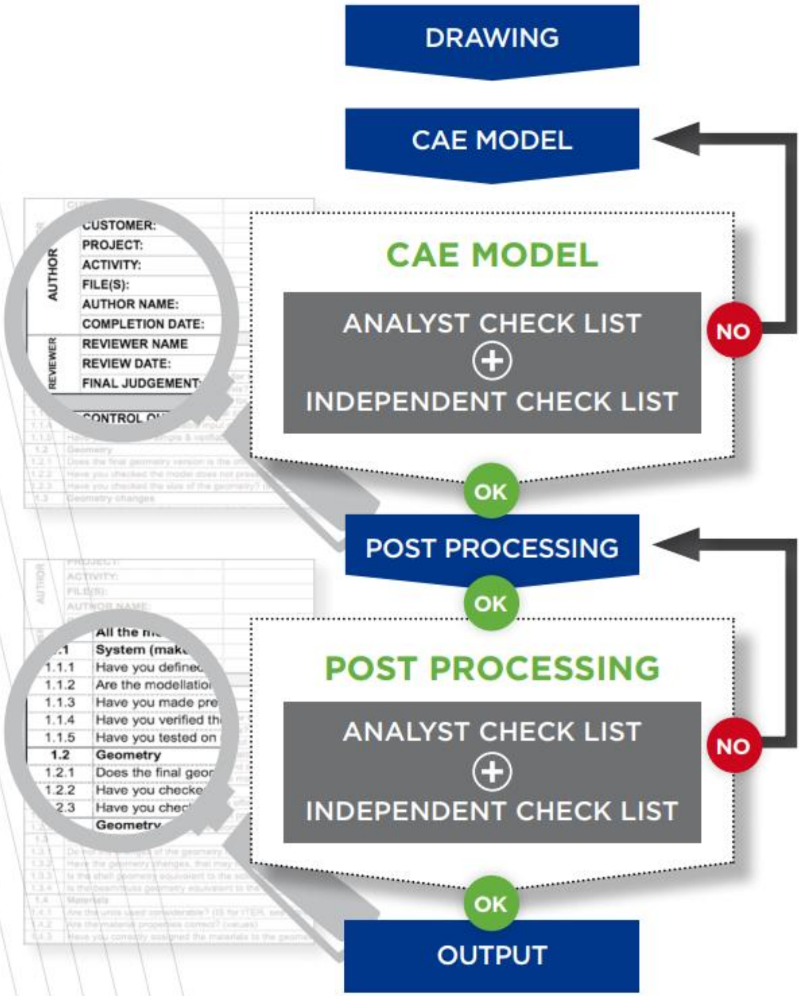
- DS/Simulia (ABAQUS)
- ANSYS/Mechanical
- ANSYS/Fluent
- MSC Nastran/Patran/ADAMS/MARC
- Altair Hypermesh
- Intel Fortran
- Matworks Matlab
- CATIA V5

Resources

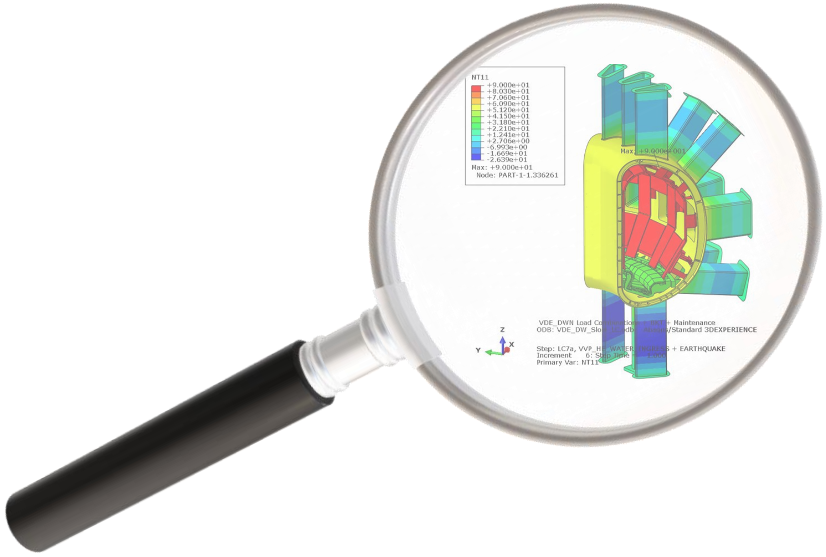
Number of Experts



Quality Procedures



- Any task will go trough quality control procedure at different levels of activity.
- At each level the task will be controlled at least by two investigators. One analyst investigator and one independent investigator



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LTColud

LTCloud™

All the power of Virtual Prototyping on Cloud Application

Optimize the product by yourself in 3 steps:

STEP 1 Choose your model

STEP 2 Insert your parameters

STEP 3 View your results

Benefits

- Minimizing model optimization cost
- Benefiting from super-computing infrastructure while paying only for the effective use
- Saving time acting directly on the calculation model
- Updating the results easily by changing the pre-defined parameters
- No need for FEM knowledge
- Reducing time to market

(19) Europäisches Patentamt / European Patent Office / Office européen des brevets

(11) **EP 2 757 495 A1**

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(54) **System for parameterized finite element analysis**

(57) A Finite Element Modeling (FEM) system, providing Finite Element Analysis (FEA) for numerical modeling of physical systems in a variety of engineering disciplines, comprising means for generating a finite element model, data processing means, result delivering means for delivering the results so obtained to a user, wherein the finite element model generated is further parameterized, and a user interface is provided for changing the parameters of the finite element model and for entering such parameters into said data processing means.

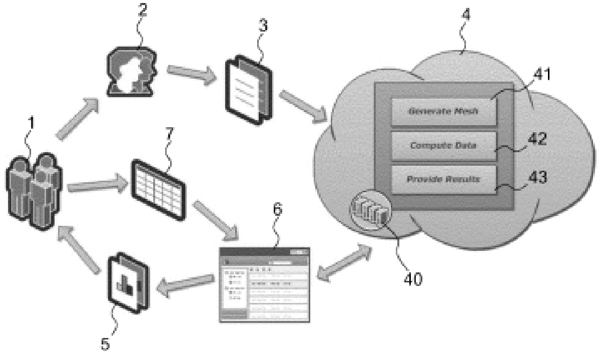

Fig 2

EP 2 757 495 A1

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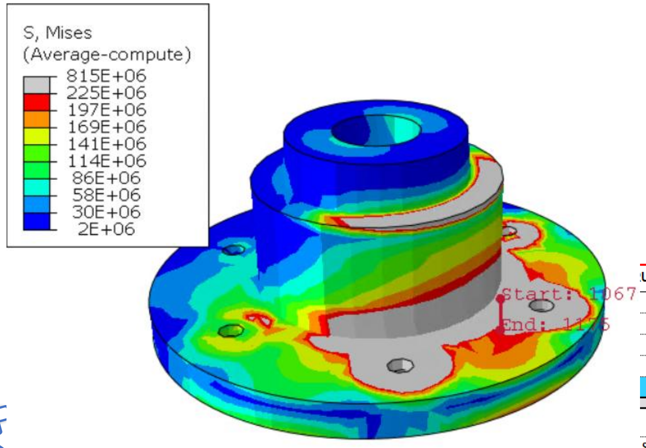
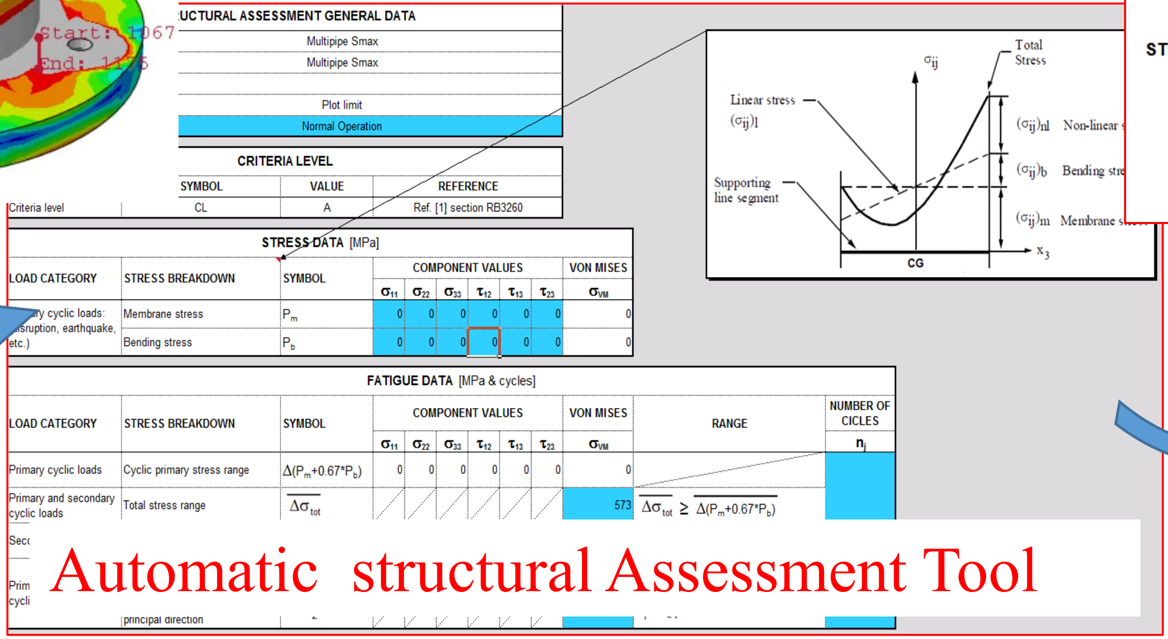
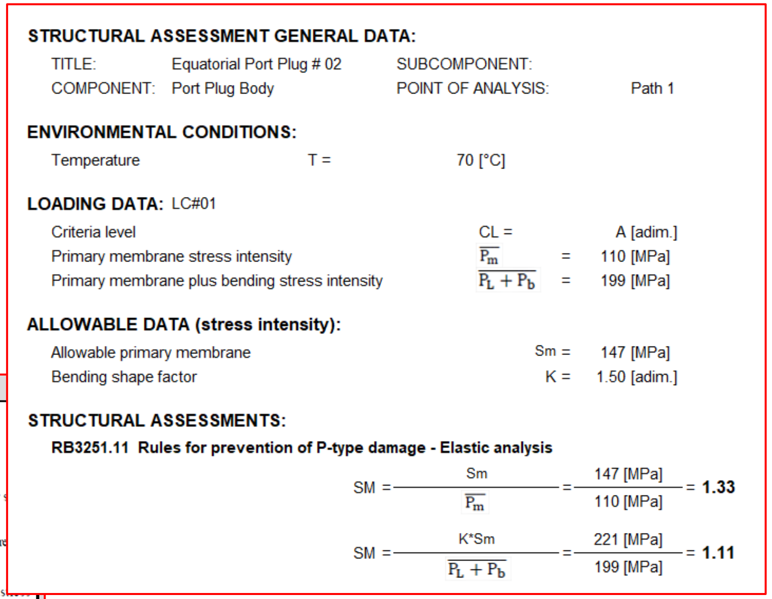
Automated Tools for performing structural assessments

Automated Tools





Automatic structural Assessment Tool



STRUCTURAL ASSESSMENT GENERAL DATA:

TITLE: Equatorial Port Plug # 02 SUBCOMPONENT:
COMPONENT: Port Plug Body POINT OF ANALYSIS: Path 1

ENVIRONMENTAL CONDITIONS:

Temperature T = 70 [°C]

LOADING DATA: LC#01

Criteria level	CL =		A [adim.]
Primary membrane stress intensity	P_m	=	110 [MPa]
Primary membrane plus bending stress intensity	$P_L + P_b$	=	199 [MPa]

ALLOWABLE DATA (stress intensity):

Allowable primary membrane	Sm =	147 [MPa]
Bending shape factor	K =	1.50 [adim.]

STRUCTURAL ASSESSMENTS:

RB3251.11 Rules for prevention of P-type damage - Elastic analysis

$$SM = \frac{Sm}{P_m} = \frac{147\ [MPa]}{110\ [MPa]} = \mathbf{1.33}$$

$$SM = \frac{K*Sm}{P_L + P_b} = \frac{221\ [MPa]}{199\ [MPa]} = \mathbf{1.11}$$

Automatic report generation

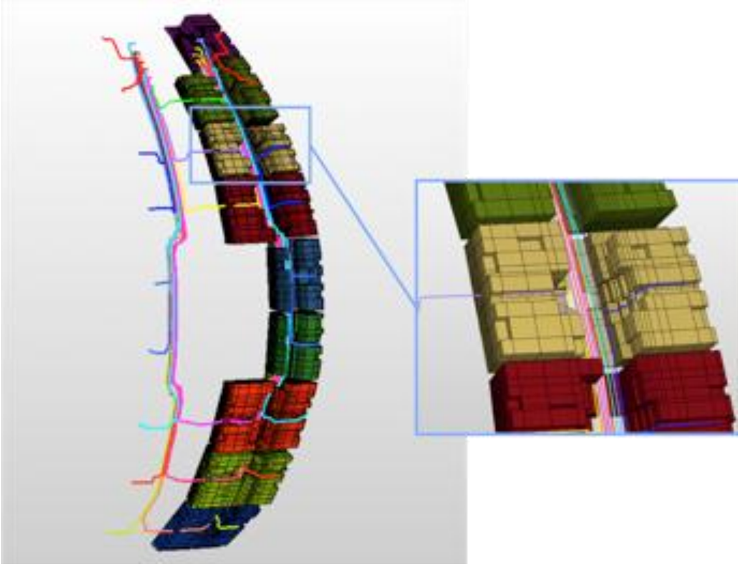
Automated Tools

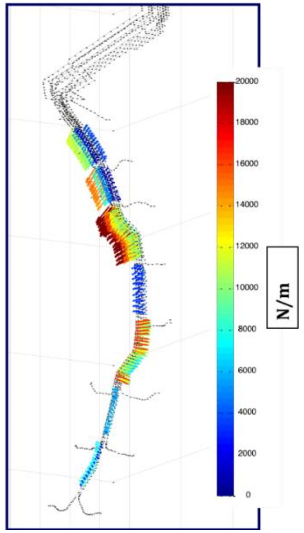
EM Wire Element in Ansys

The **“EM wire element**” are developed for the evaluation of eddy currents on in-Vessel and Out-Vessel pipes avoiding the use of solid elements in electromagnetic analysis

LTCalcoli has developed and introduced into Ansys EM code the **“EM wire element”** defined as “grid to grid” element for the EM modelling of pipe, see picture below, used for the evaluation of the EM loads on pipes, avoiding the use of solid elements in electromagnetic analysis.

The evaluation of the EM loads acting on the pipes in general can be carried out with good accuracy by assimilating the to 1-dimensional conductors with electrical properties equivalent to those of the pipes themselves.





EM-wire elements of blanket manifold – Lorentz Forces per unit length on the pipes modelled with “EM wire element”

Example of Activities

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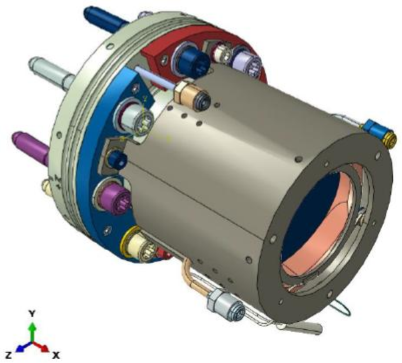
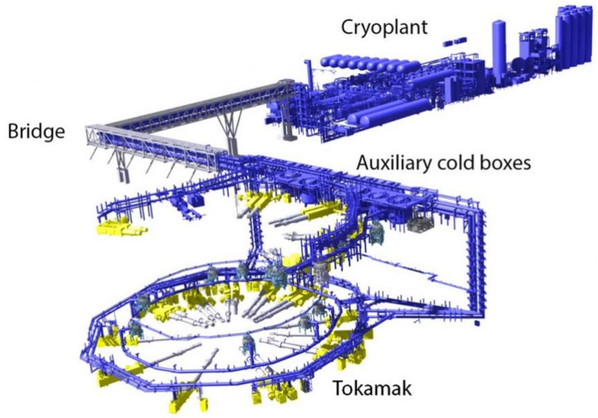
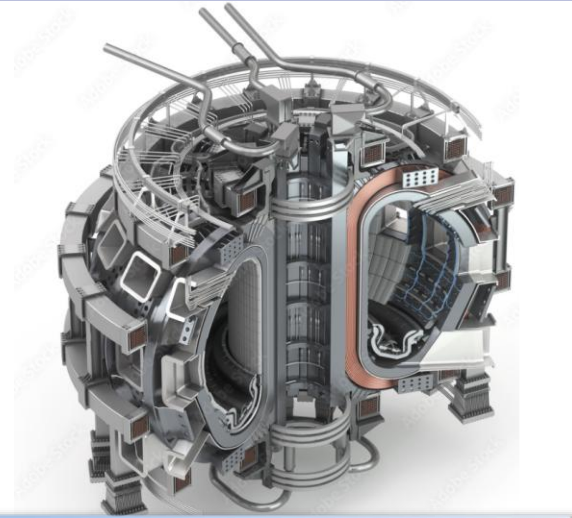
Applications



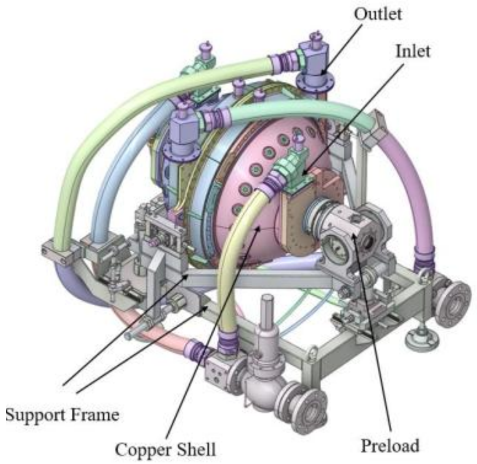
Optical Systems



Cryogenic components

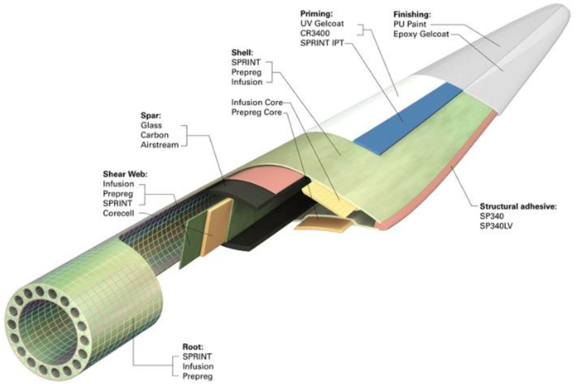


Harsh Environment components



Vacuum Systems

Thermal Insulation systems



Composite Material Components

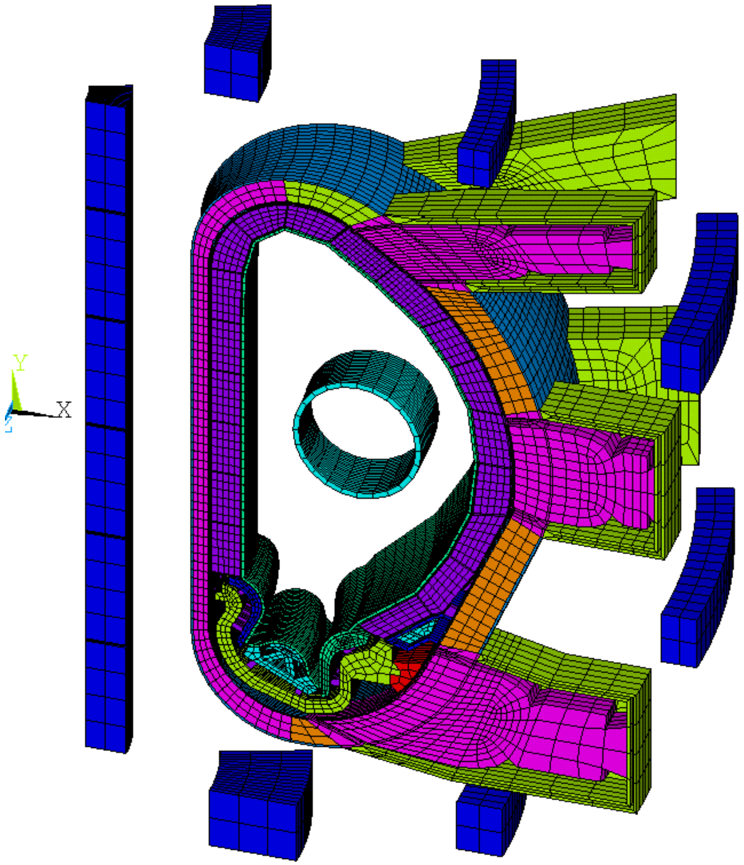
Example 1

ITER Blankets EM analysis:

All the FEM realised by means of Ansys are based on the ITER EM Global Model (GM) which is a general model of the ITER VV including all the details impacting the EM loads on the in vessel components

For each BSM analysis the GM has been refined to get the needed level of detail in the region of interest

For each BSM two or three disruptions have been analysed (worst cat. II and worst cat. III)



Analysis on BM#02:

- fast DW VDE III with 36 ms lcq
- fast DW VDE II

Analysis on BM#10 FE model:

- Up Major Disruption II with 36 ms lcq
- Fast UP VDE III with 16 ms ecq

Analysis on BM#12:

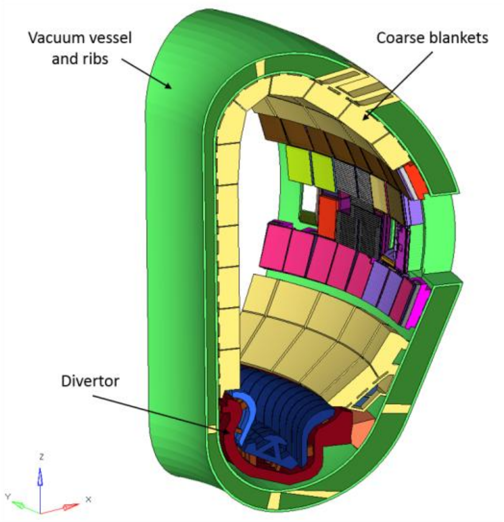
- fast UP VDE III with 36 ms lcq
- fast DW Major Disruption II with 16 ms ecq

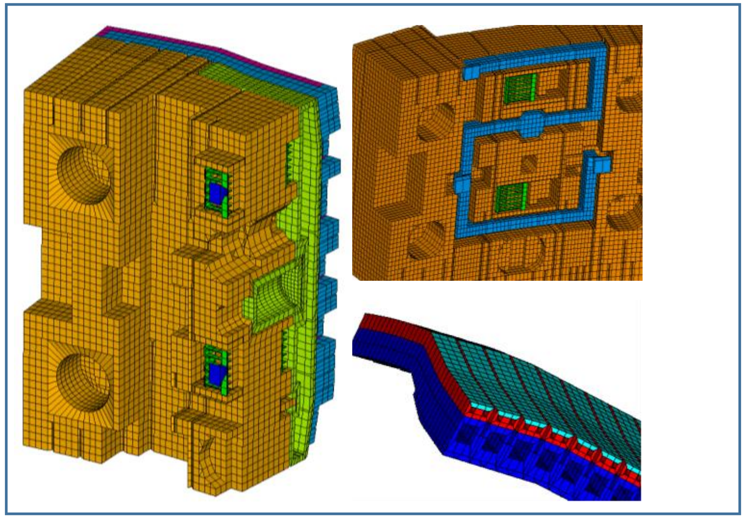
Analysis on BM#16st:

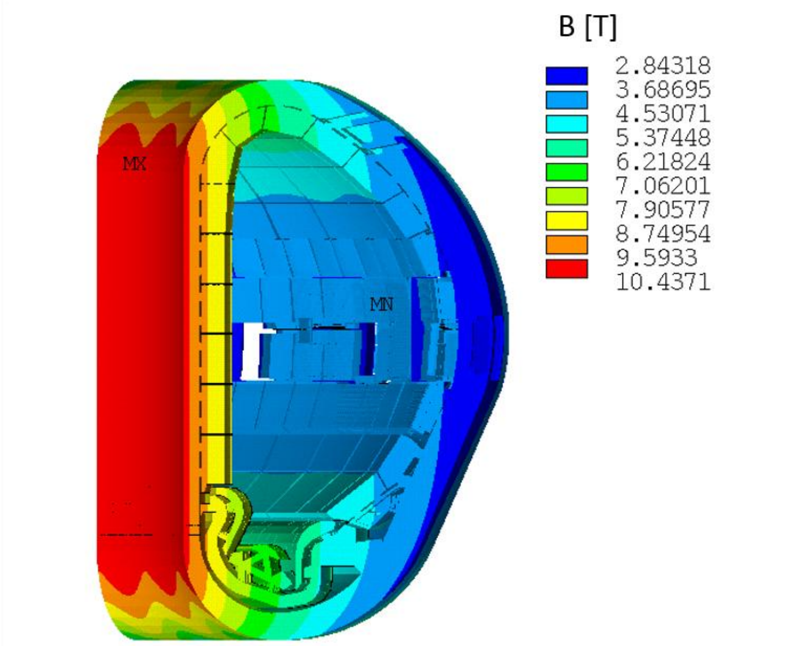
- fast DW VDE III with 36 ms lcq
- DW Major Disruption II with 16 ms ecq
- DW Major Disruption III with 16 ms ecq
- DW Major Disruption II with 16 ms ecq

Example 2

A complete analysis of ITER FW 10

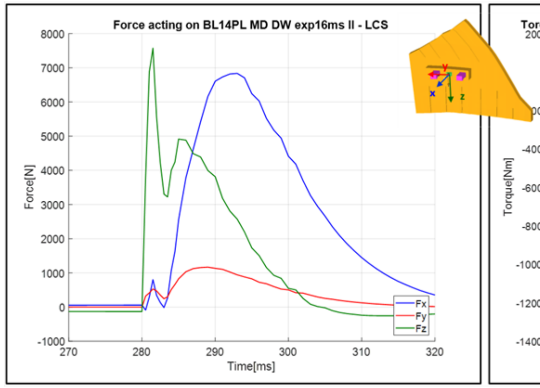


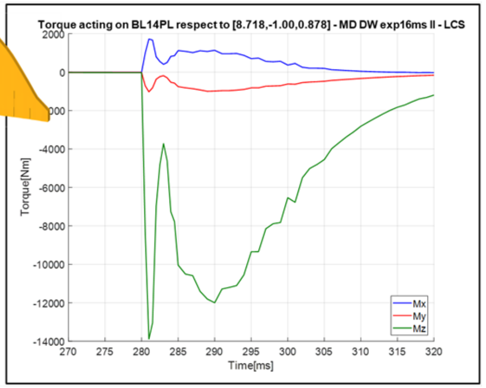




EM Analysis

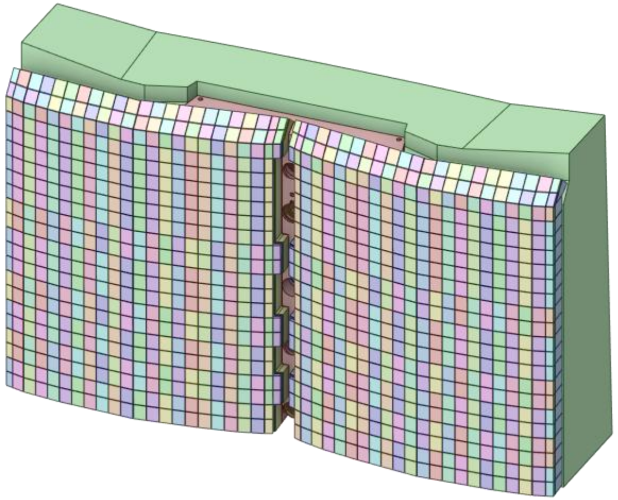
- Full transient EM analysis
- Analysis of VDE / MD cat. I / cat. II / cat. III
- Computation of the Lorentz forces and ferromagnetic forces.

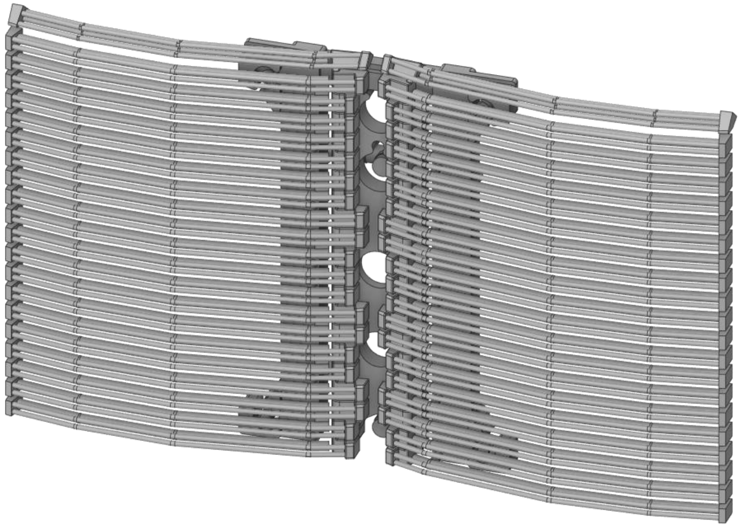


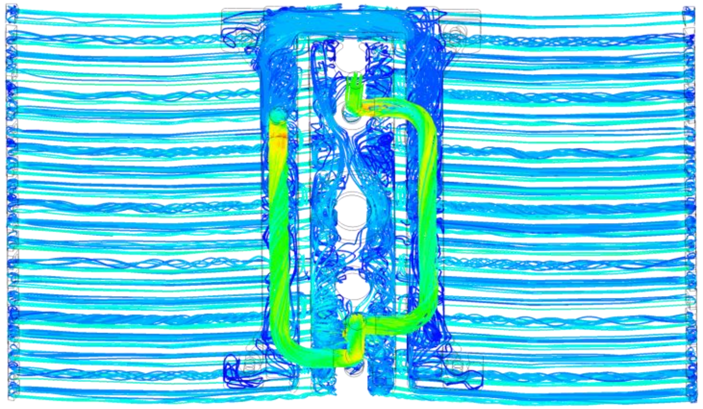


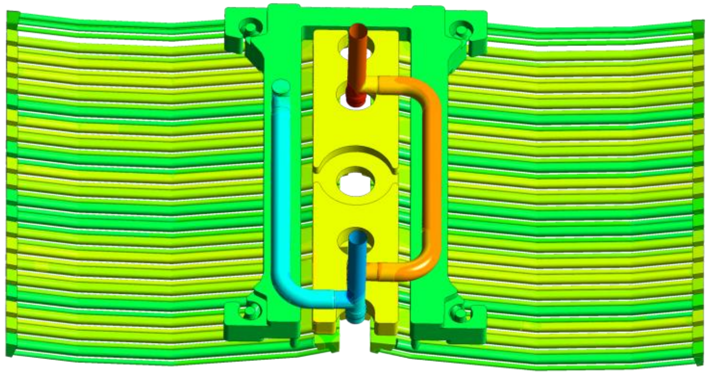
Example 2

A complete analysis of ITER FW 10







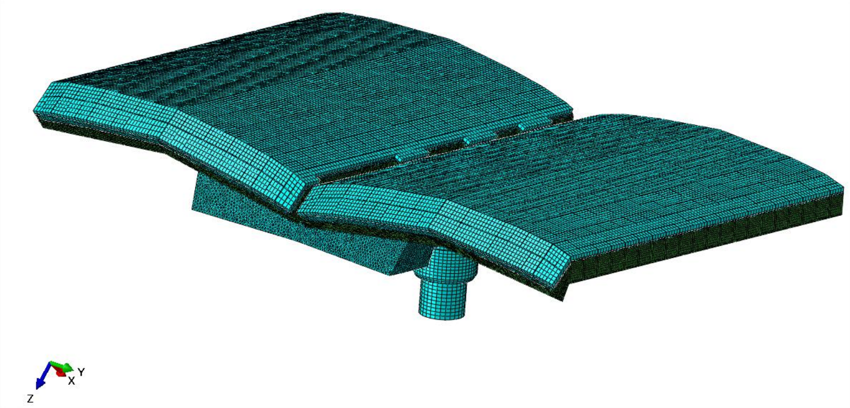


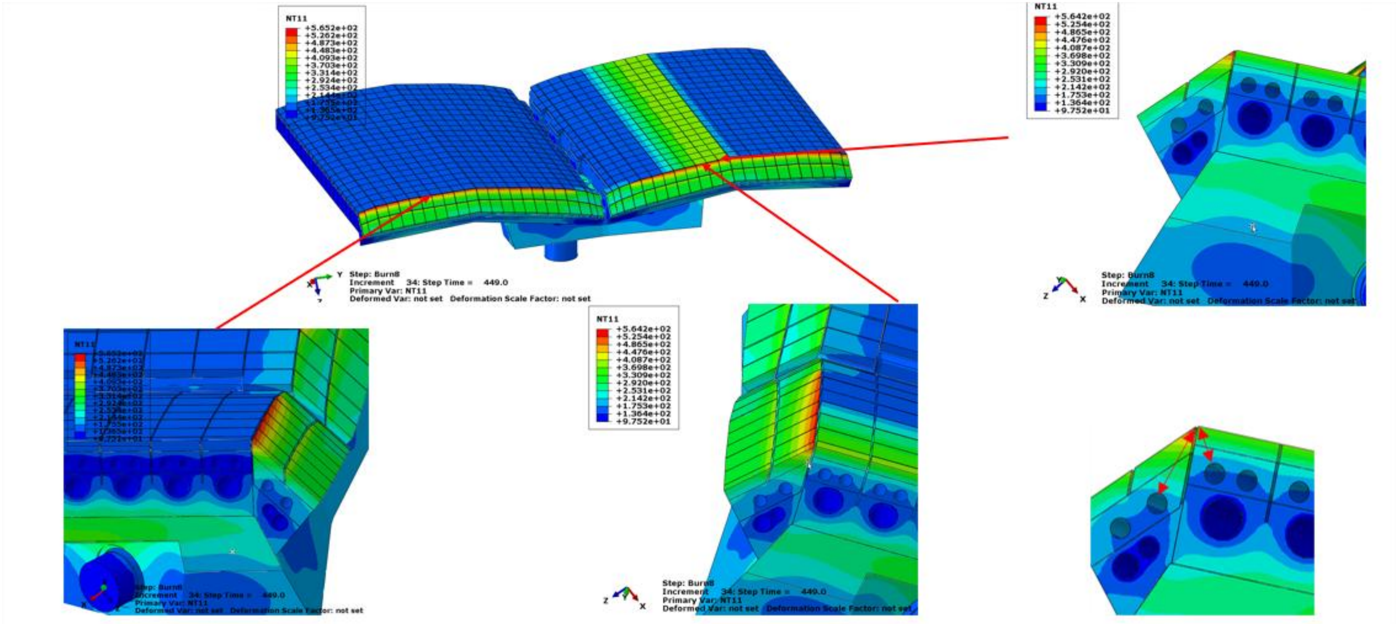
CFD Analysis

- Steady state and full transient CFD or coupled Thermal-CFD analysis
- Mesh quality, checks and convergence criteria following the ITER best practices
- Post-processing: analysis of the pressure drop, velocity of the cooling fluid.
- Computation of Heat Transfer Coefficients (HTCs).

A complete analysis of ITER FW 10

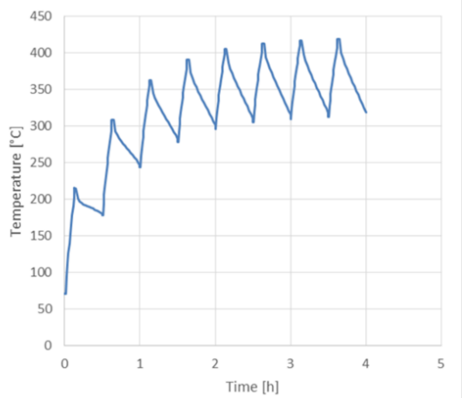
Example 2





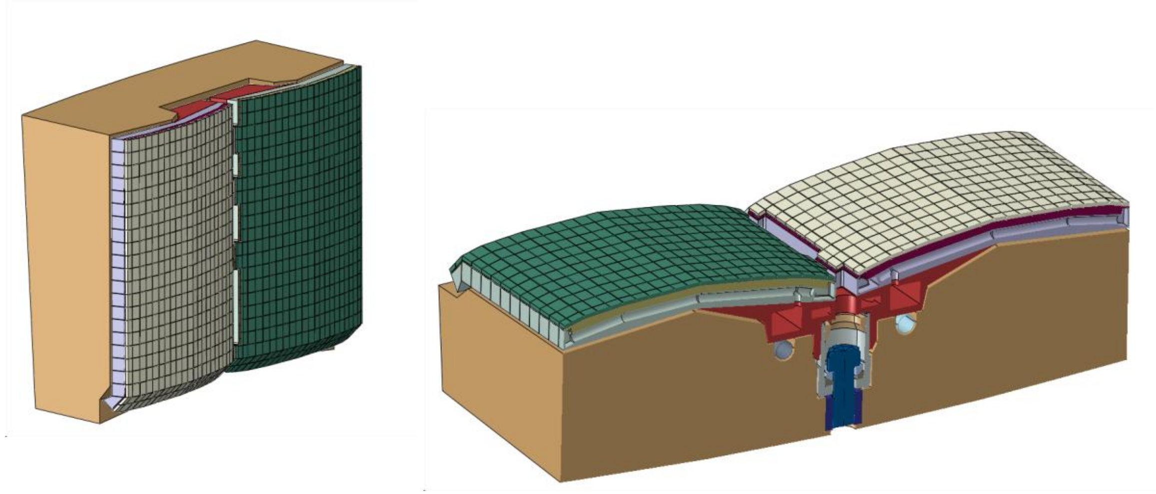
Thermal FE Analysis

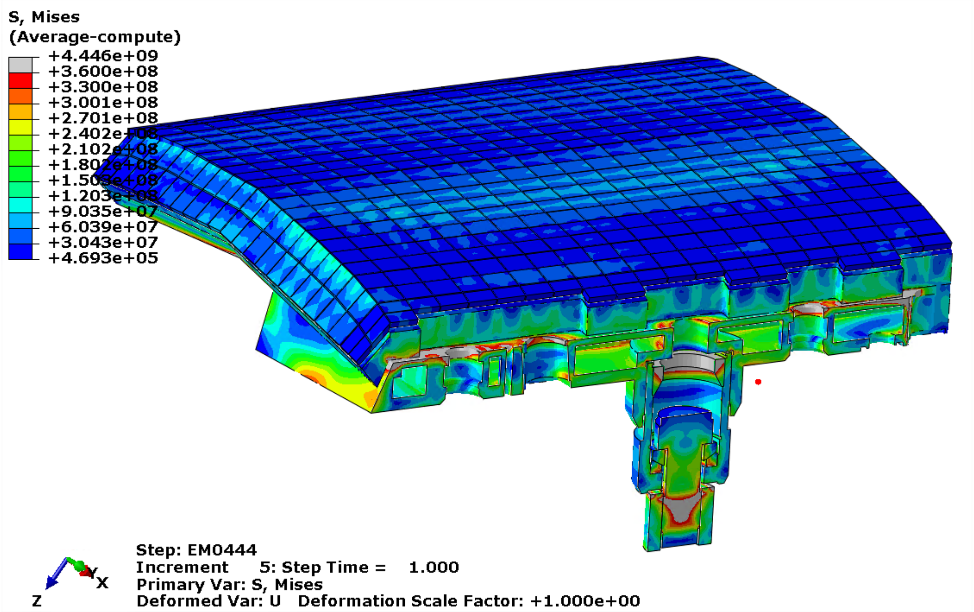
- Steady state and/or full transient Thermal FE Analyses
- Mesh quality, checks and convergence criteria in accordance with ITER best practices
- Neutronic loads and Plasma flux mapping
- Estimation of the thermal contact conductivity
- Post-processing: Temperature field, time history, thermal stabilization analysis



Example 2

A complete analysis of ITER FW 10





Thermo-Mechanical FE Analysis

- Non linear Static FE Analysis
- Mesh quality, checks and convergence criteria in accordance wih ITER best practices
- Thermal load and EM load mapping
- Post-processing: Stresses, displacements, reactions and gap analysis
- Full transient dynamic analysis with EM load for DAF evaluation
- High quality analysis reports

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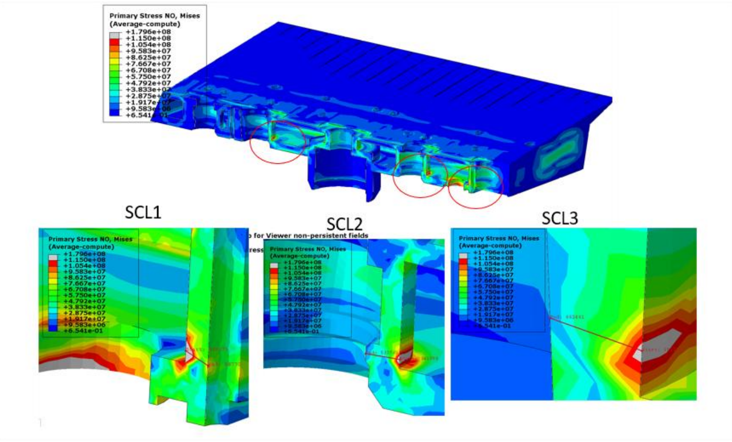
Example 2

A complete analysis of ITER FW 10



STRUCTURAL ASSESSMENT GENERAL DATA:

TITLE:	ITER	SUBCOMPONENT:	Beam Discontinuity
COMPONENT:	FW10	POINT OF ANALYSIS:	Path 1

ENVIRONMENTAL CONDITIONS:

Temperature	T	=	360	[°C]
Neutron damage, fluence	Φt	=	0.00	[dpa]

LOADING DATA: LC#01

Total stress range	$\Delta\sigma_{tot}$	=	1300	[MPa]
Cyclic primary stress intensity	ΔP_{eff}	=	0	[MPa]
Number of cycles	nj	=	15000	[adim.]
Elastic strain range	$\Delta\varepsilon_1$	=	0.6589	[%]
Plastic strain due to primary stress range	$\Delta\varepsilon_2$	=	0.0000	[%]
Local plastic strain amplification	$\Delta\varepsilon_3$	=	0.0000	[%]
	$\Delta\varepsilon_4$	=	0.0000	[%]
Total strain range	$\Delta\varepsilon$	=	0.66	[%]

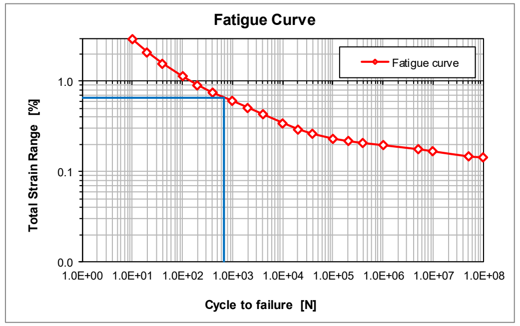
Linear FEM analysis

ALLOWABLE:

Fatigue cycles	Nj	=	6.83E+02	[cycles]

STRUCTURAL ASSESSMENTS:

Fatigue usage fraction $\frac{nj}{Nj} = \frac{15000}{683} =$ 21.96



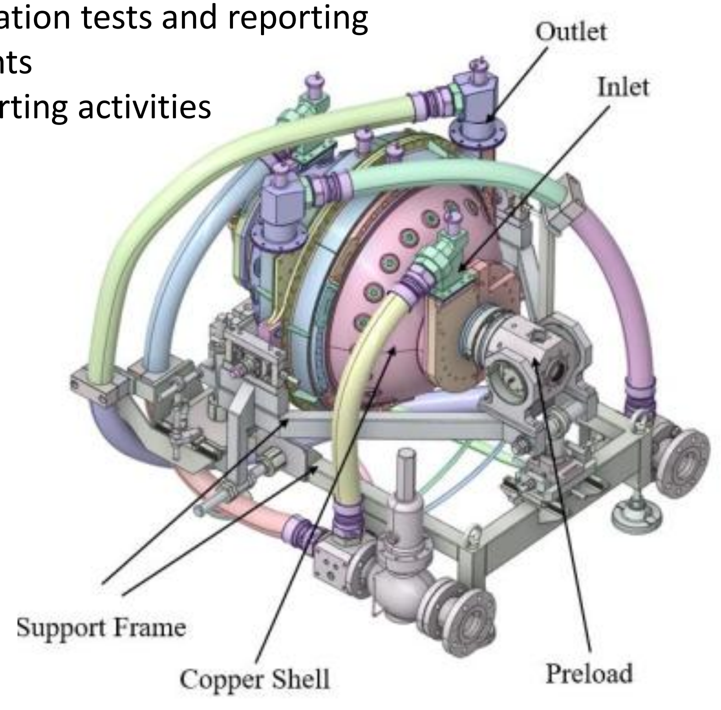
Structural assessments

- Structural assessments with ITER SDC-IC and Nuclear code (RCC-MR)
- Stress and load categorization
- Stress linearization
- Linear and elastic-plastic M-type static strength assessments
- Linear and elastic-plastic C-type cyclic strength assessments (fatigue and ratcheting)
- Buckling assessments
- Structural Integrity Reports in accordance with the ITER procedures

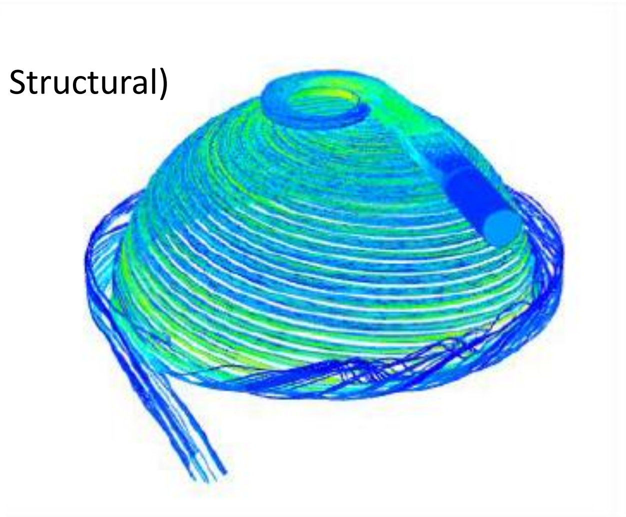
Example 3

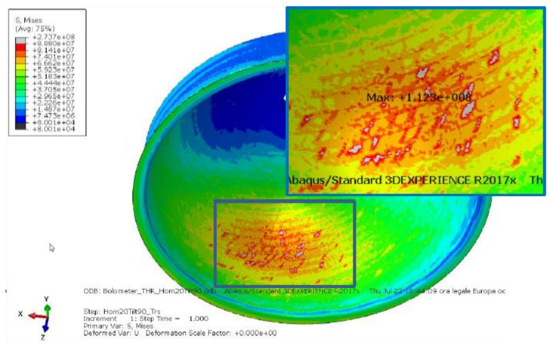
Bolometer -Prototyping activities

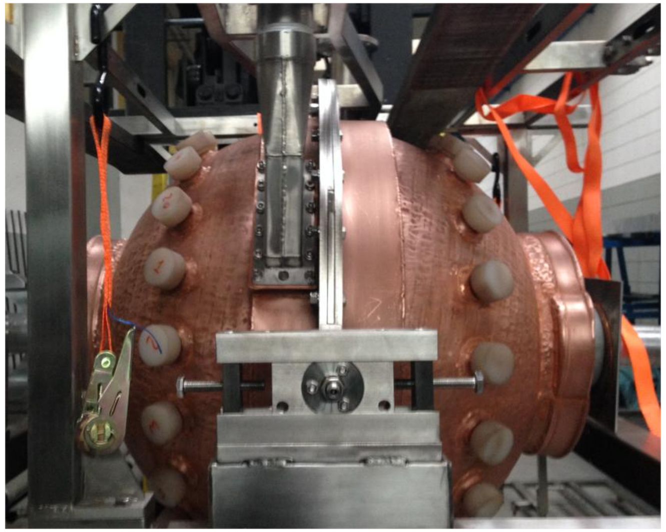
- Design of the porotype (CATIA)
- Design by analysis activities (Optical, CFD, Thermal and Structural)
- Validation tests and reporting
- Patents
- Reporting activities



Preload-side view



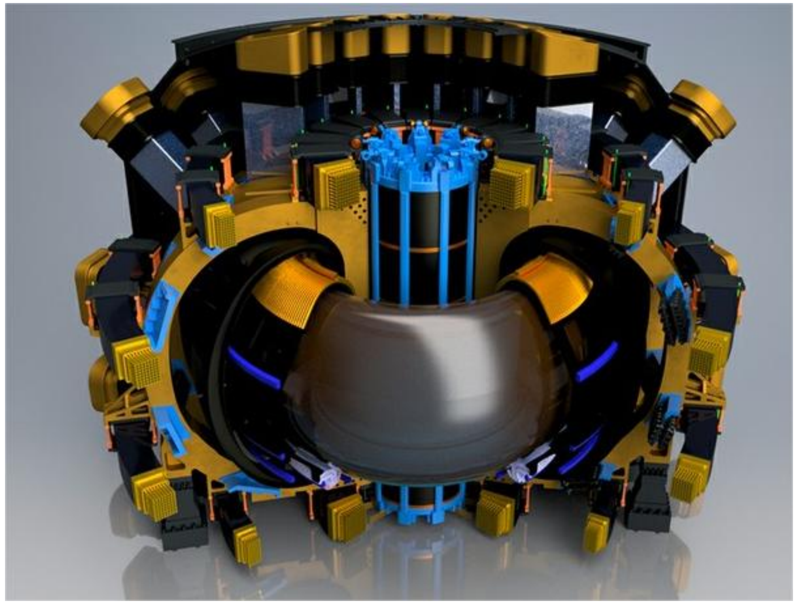


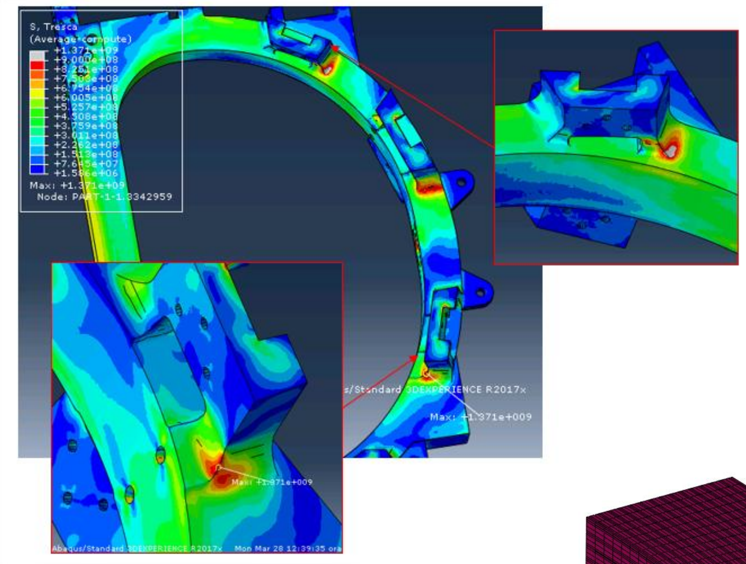


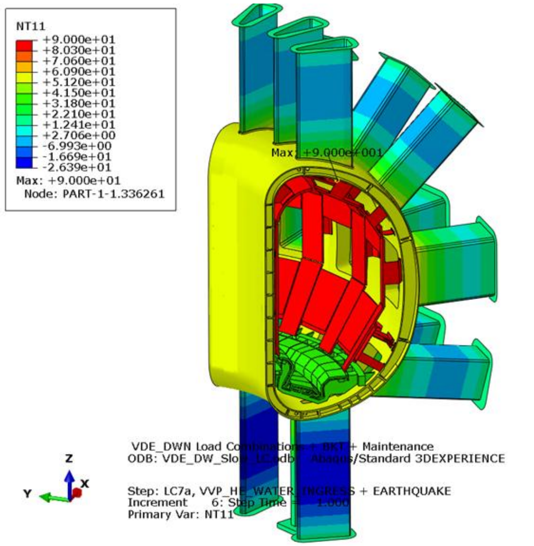
Design ⇄ Analysis → Prototype

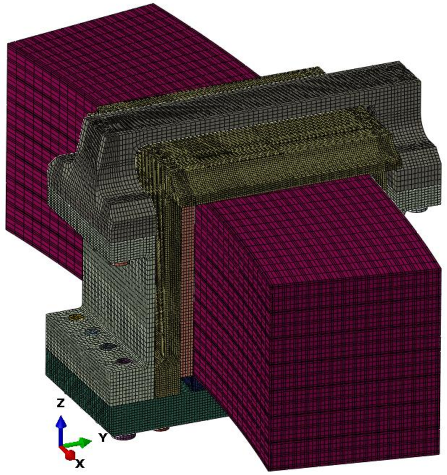
Example 4

ENEA DTT: An example of a complete Tokamak analysis









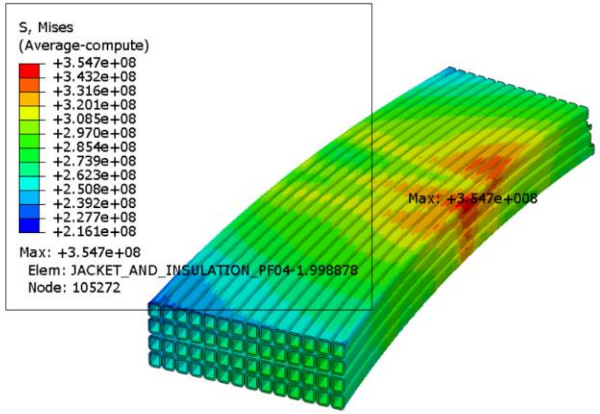
Tokamak FE analysis

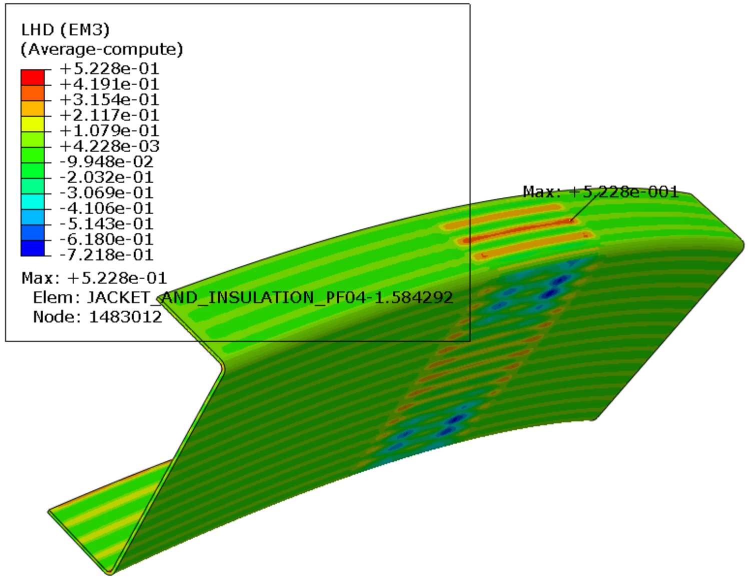
- Design by analysis activities on: Toroidal coil / Poloidal Coils / Vacuum Vessel / Support / Divertor
- EM – CFD – Thermal – Structural – Seismic FE Analysis
- Independent analysis review

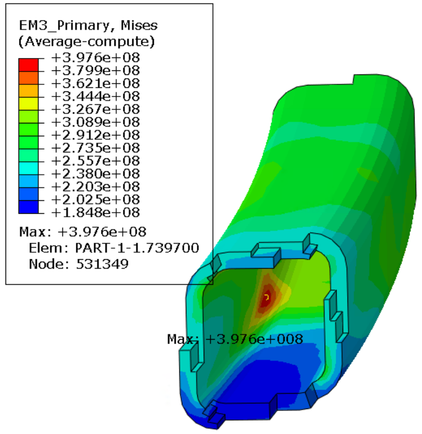
Composite Application

Superconductor Coil – structural analysis of composite materials

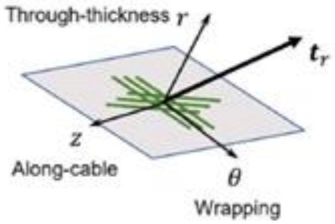
- Themo-structural analysis of a section of the Coil to verify structural strength
- Analysis with orthotropic material properties to simulate insulation layers
- Detailed analysis performed by extensively using the sub-modelling approach
- Failure Index calculated in Abaqus by considering the criterion set by the customer for this project







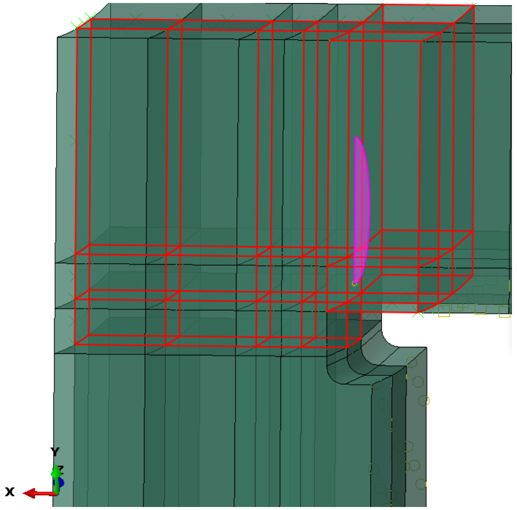
$$\frac{\sigma_r}{\sigma_{r0}} + \left(\frac{\tau_r}{\tau_{r0}}\right)^2 < 1$$

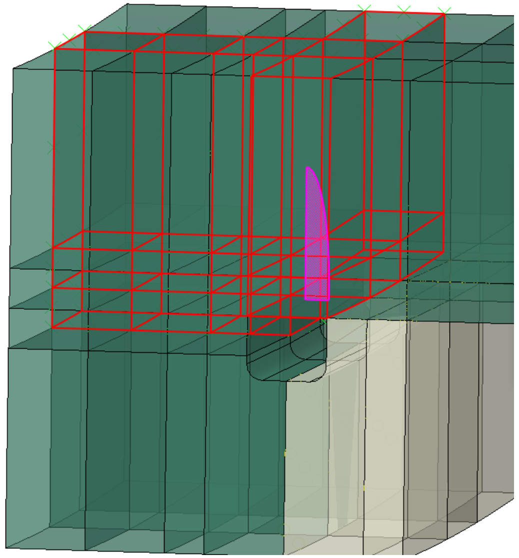


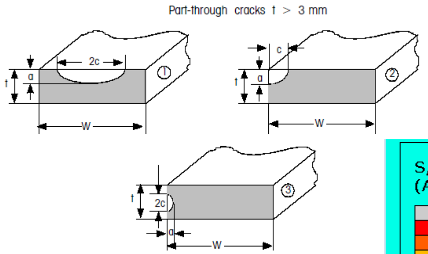
Fracture Mechanics

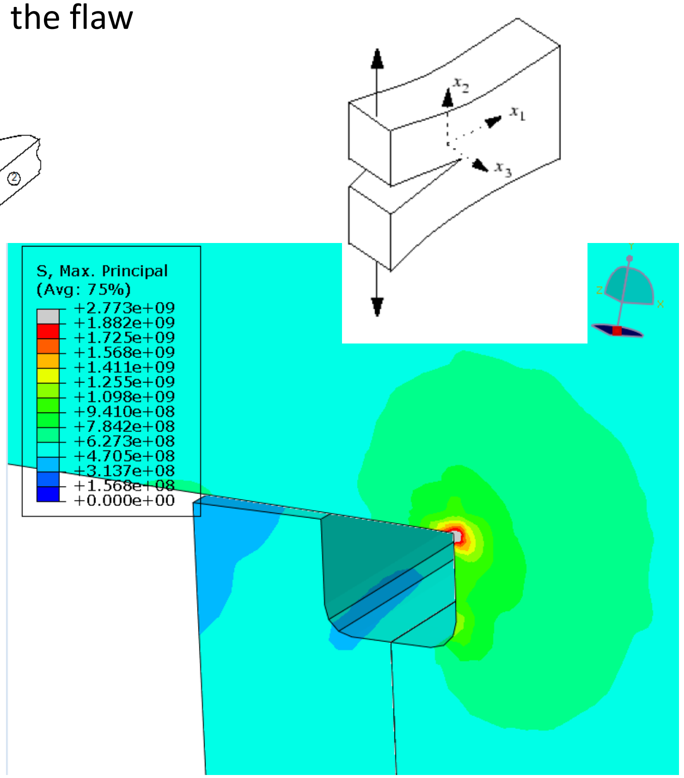
Fracture mechanics – structural analysis with flaws

- Structural analysis of a component of fusion machine incorporating initial flaws (LEFM)
- Calculation of SIF with Abaqus XFEM approach to model corner and semi-elliptical cracks (metallic materials)
- Detailed analysis performed by extensively using the sub-modelling approach with very fine mesh around the flaw
- Verification of the component with the flaw by using handbook methods based on FEM results





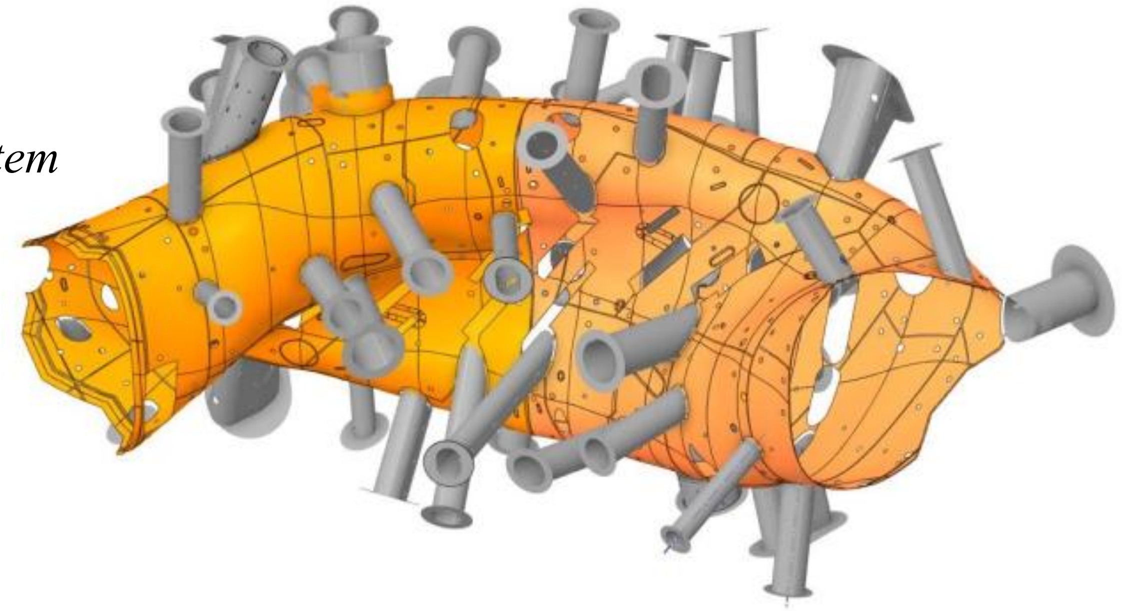


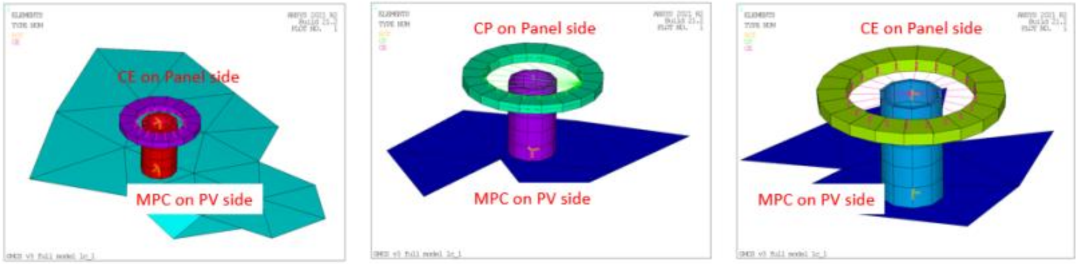


Example 5

W7-X

- *Developing the FE model of the whole W7X insulation system*
- *Modelling about 1000 connections between the insulation system and plasma vessel using APDL programming*
- *Performing Implicit Dynamic analysis*
- *EM analysis*



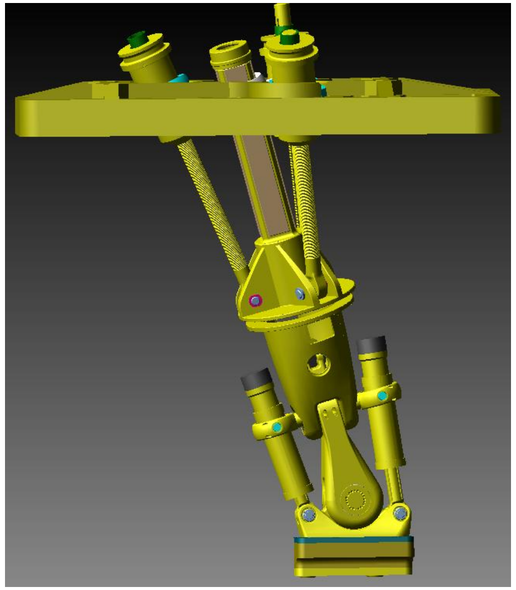


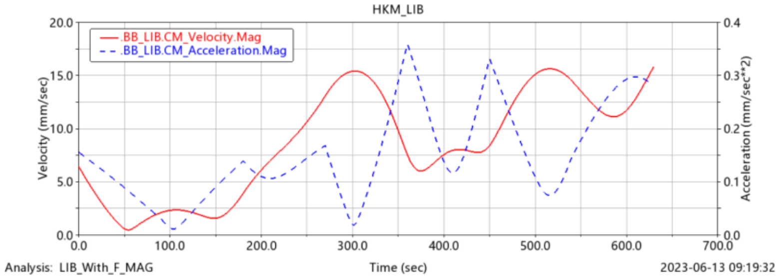
Connections created automatically by APDL programming

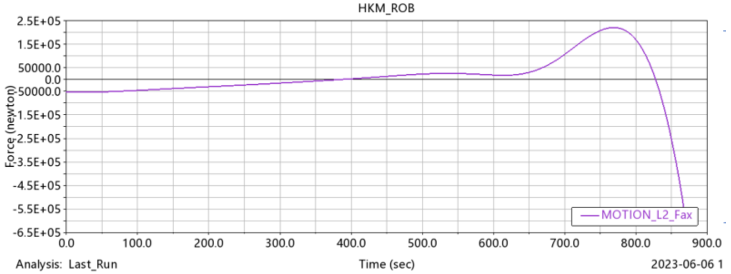
Multi-body application

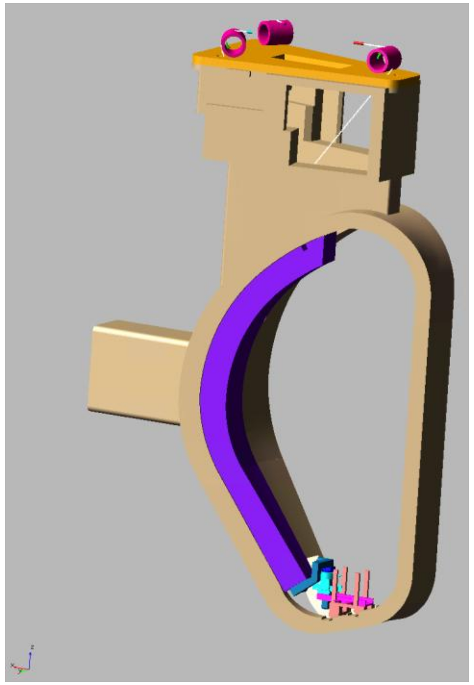
Multi-body simulation – load analysis with MSC ADAMS

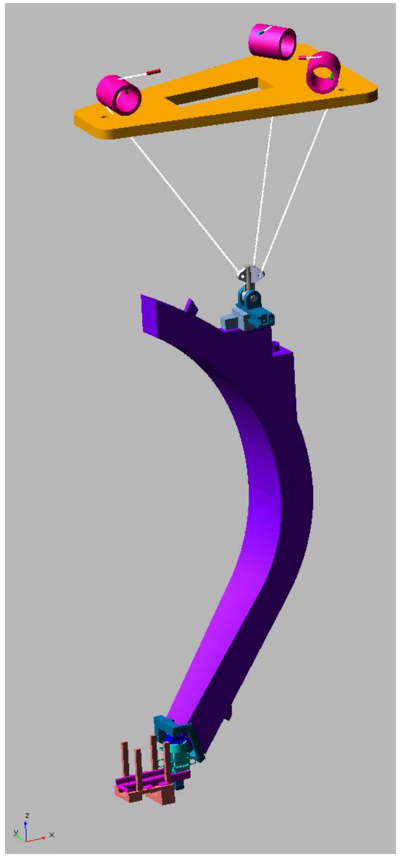
- MBD simulation of mechanisms (remote maintenance systems, Nuclear plant)
- Extract loads to be used for structural analysis
- Predict the performance of the system (speed, power required, trajectory)
- Flexible bodies can be added, based on Abaqus FE modal analysis



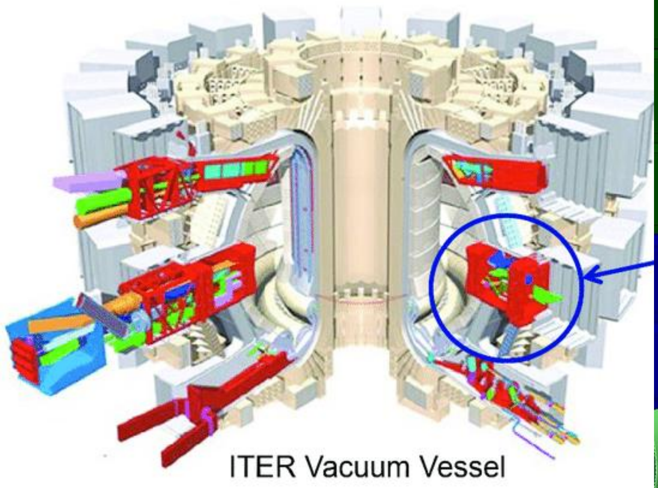


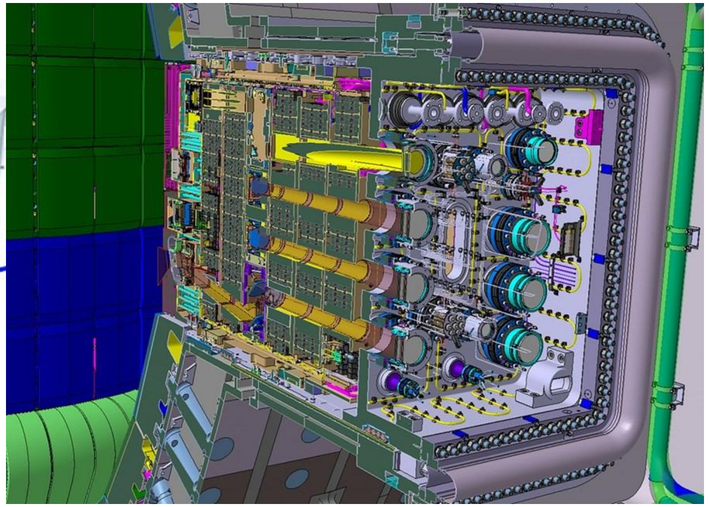






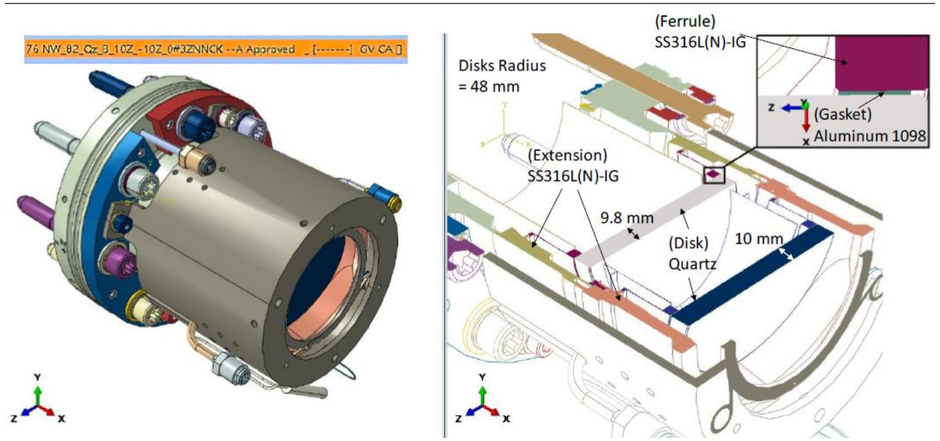
Optical systems

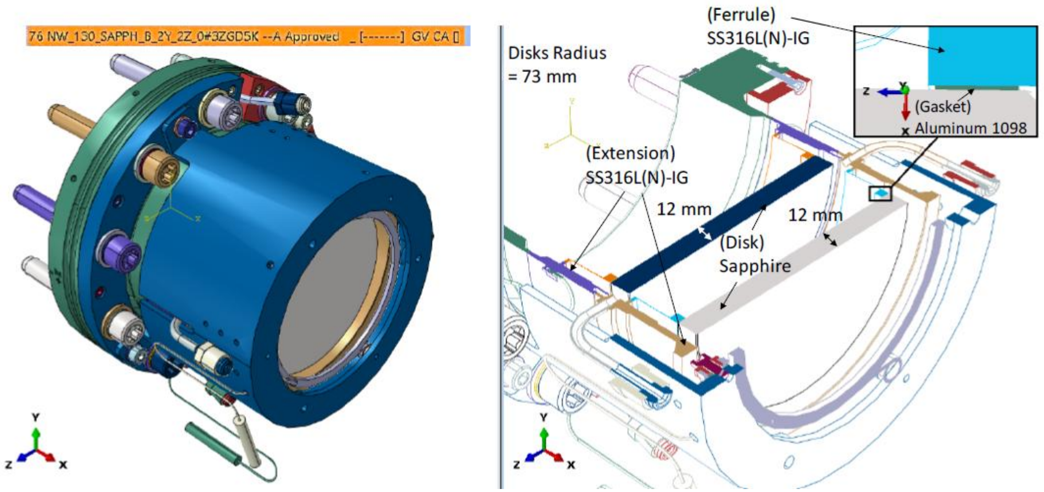




Precision optomechanical design by analysis for ensuring:

- ✓ No risk in manufacturing aftermath (glass-metal Diffusion Bonding)
- ✓ Vacuum and cleanliness maintainability facing cyclic loading
- ✓ Structural integrity and flanging leak-tightness facing plasma and disruption
- ✓ Thermal stability facing signal beams, lasers and other heats





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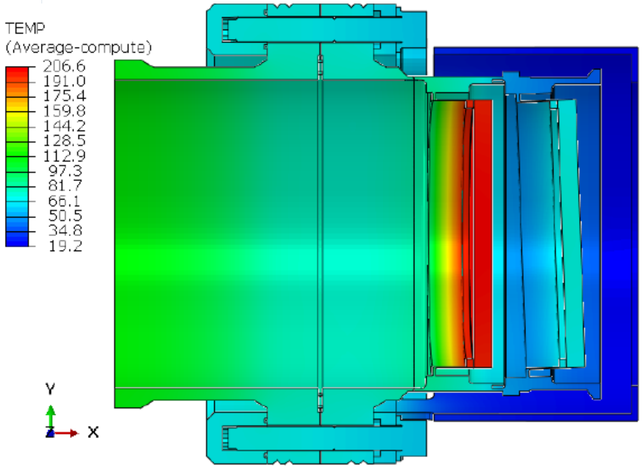
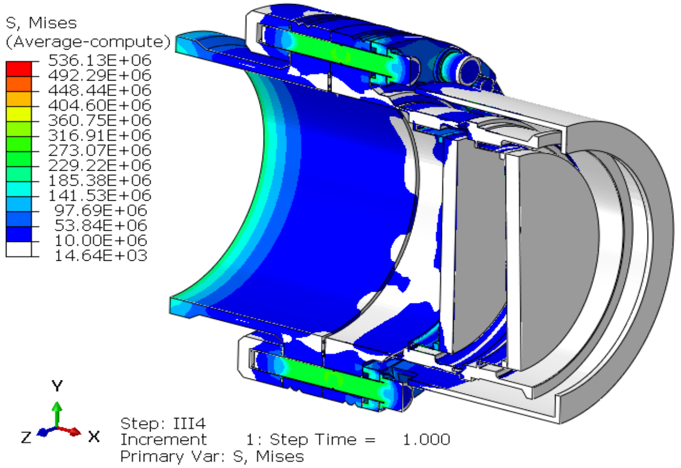
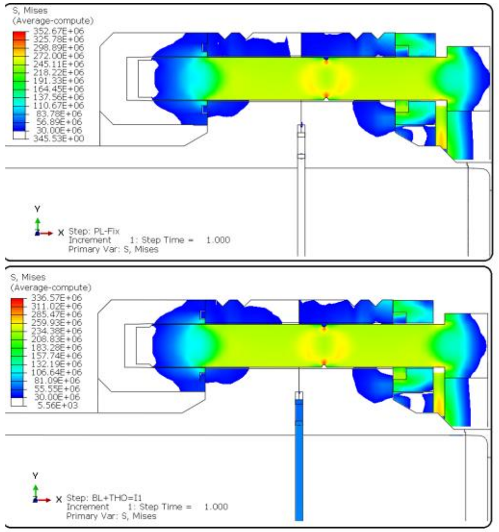
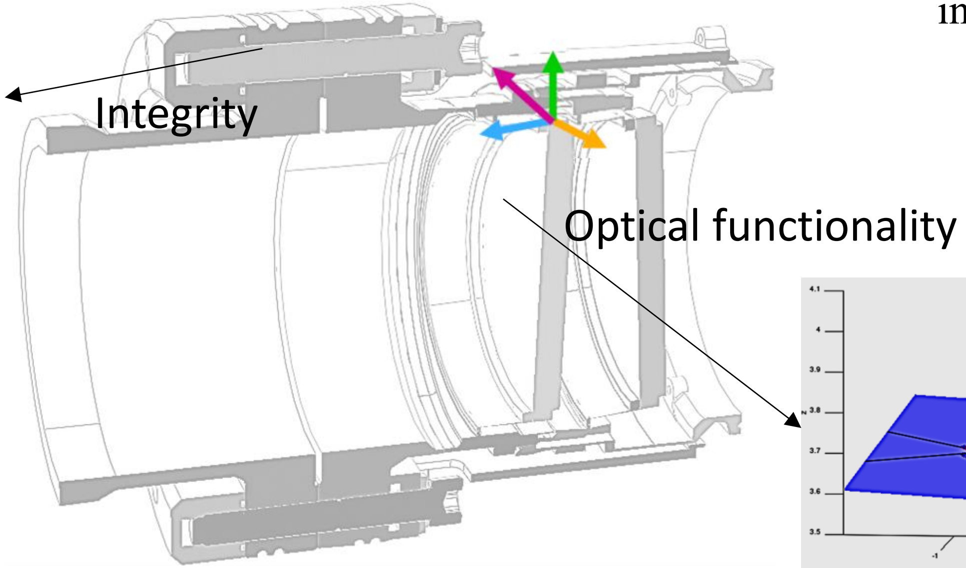
Optical systems

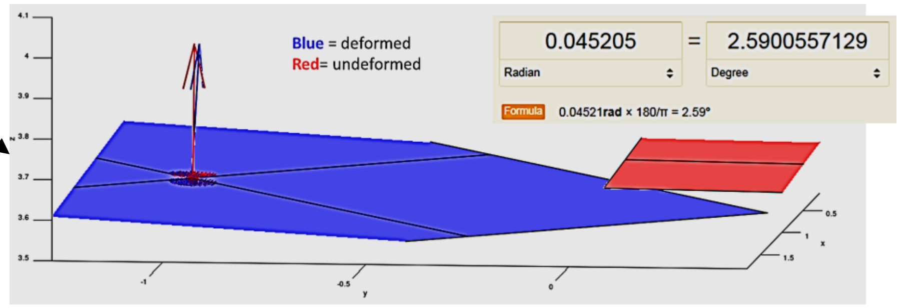




- Orthotropic glass materials
- Multi-metallic cyclic plasticity
- Thermal shrinkage and expansion effects (assembly thermoelasticity mismatch)
- Subcomponents fatigue life
- Ratcheting and shakedown induced by beam and other loads
- Geometrical and material optimization for integrity and functionality

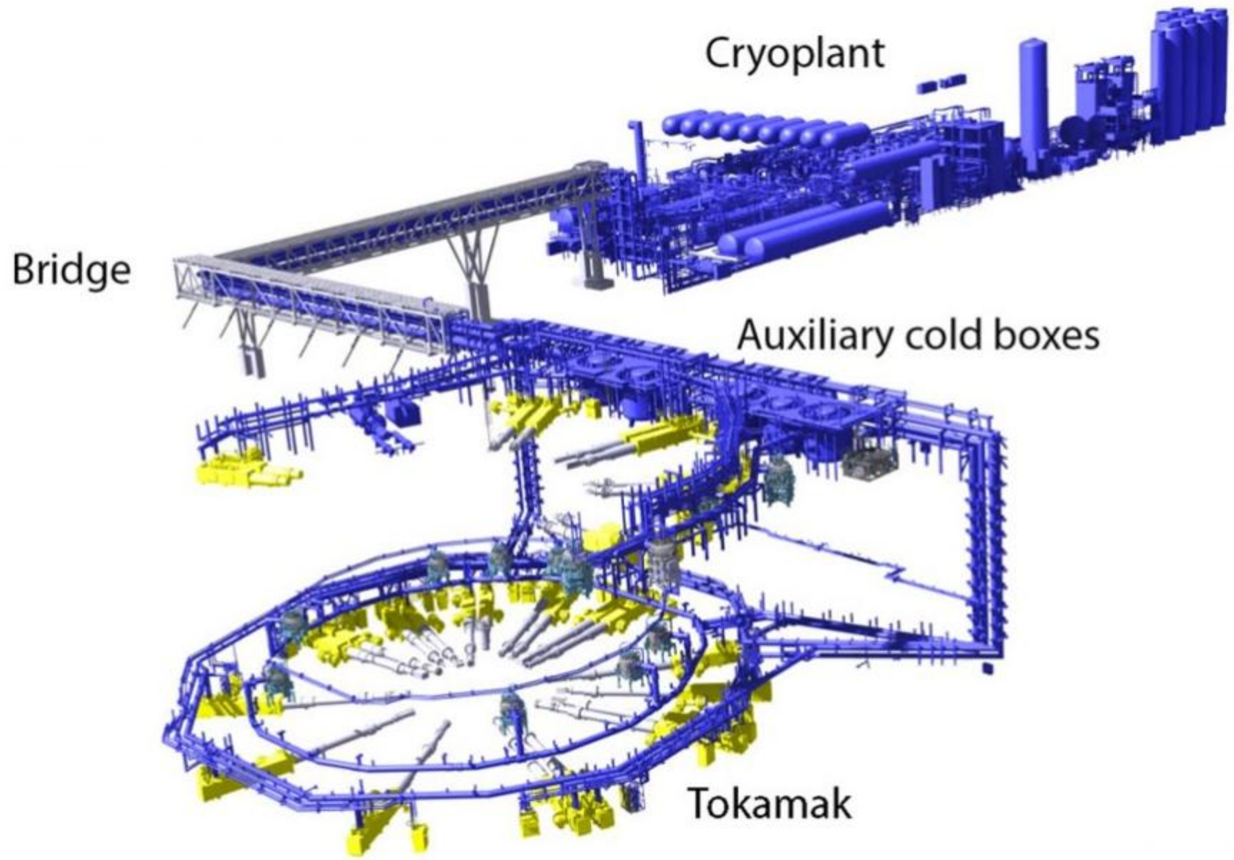






July-2025

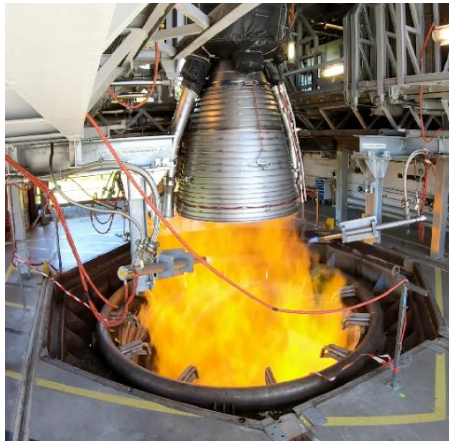
Cryogenic Applications



- Cryogenic system of the tokamak
- Thermal and Structural analysis
- Sub-models to verify all the joints and connections
- Structural assessment based on standards

Space Applications

Rocket Engine Components

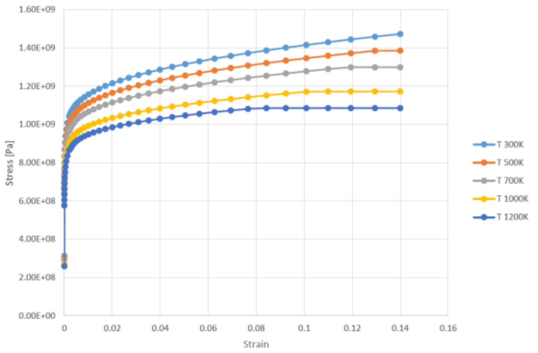


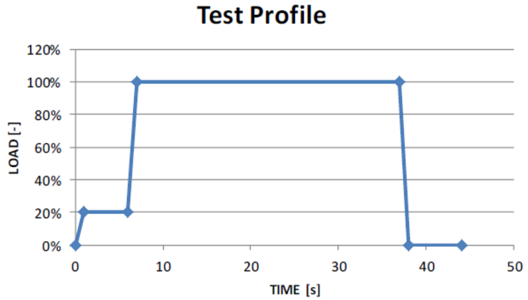
Launching System Components

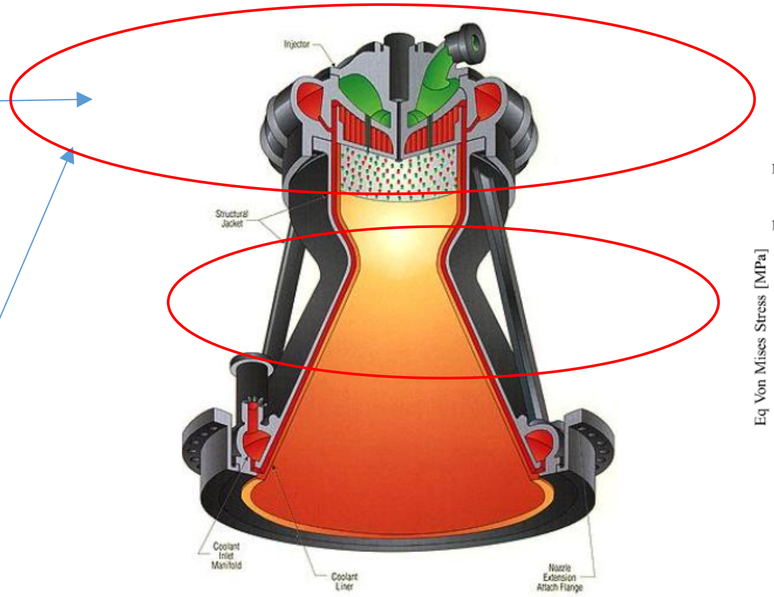
Rocket Applications

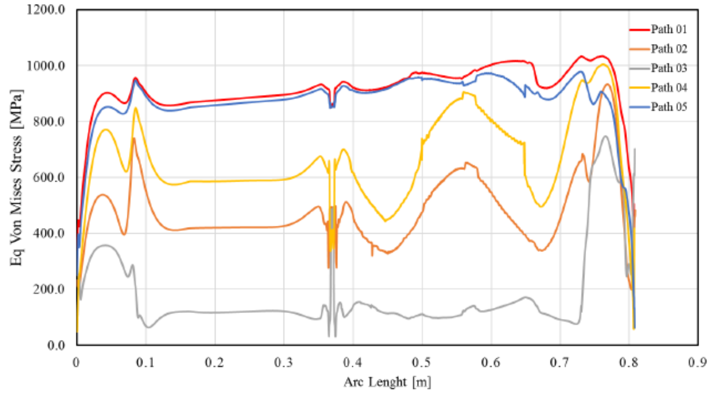
Rocket engine injector head thermo-structural analysis

- Themo-structural analysis of a section of the rocket engine of a small size launcher
- Firing test has been simulated by FE analysis
- Complex non-linear material physical properties and thermal interactions incorporated in the model
- Transient temperature field and stress distribution have been calculated
- Yield and Ultimate Safety factors calculated at every step of the simulation







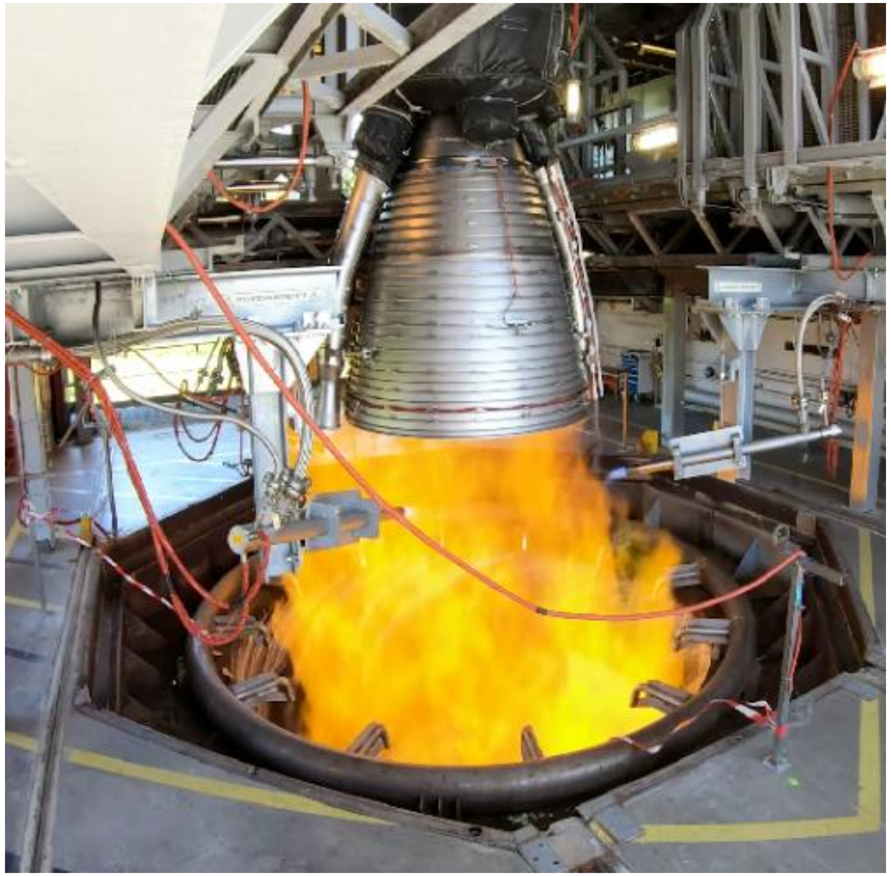


Reference picture, real images are company confidential information that cannot be shown

Rocket Applications

Thermo-structural analysis of Ariane 6 launch site components

- Themo-structural analysis 500 [s] test has been simulated by FE analysis
- Complex non-linear material physical properties and thermal interactions incorporated in the model
- Transient temperature field and stress distribution have been calculated



Recent Contracts with ITER

- **ITER Framework Service Contract** IO/20/CT/6000000304 *"***Design Analysis for the ITER TOKAMAK Engineering***"* – (2020-2028) – Capgemini Leader of the Consortium composed by Capgemini, LTCalcoli, ENEA Frascati, Università di Palermo.
- **ITER Framework Contract ITER** IO/20/CT/6000000323 *"***Diagnostic Infrastructure Development and Engineering Service***"*– (2020-2026)- Vitrociset Leader of the Consortium composed by Vitrociset, ENEA, ISTP, LTCalcoli, University Tor Vergata
- **ITER Framework Service Contract ITER/17/CT/6000000207** *"Engineering Technical Support for Tokamak Engineering Department" Lot 1 – Design Supporting Analysis"* – (2017-2022) - LTCalcoli Leader of the Consortium composed by LTCalcoli, ENEA Frascati, Università di Palermo, Sogeti HT
- **ITER Framework Service Contract ITER IO/16/CT/SAP 6000000181** *"Diagnostic Systems Engineering Services"*– (2016-2022)- Consortium composed by LTCalcoli, Vitrociset, IFP-CNR, RFX
- **ITER Contract n° IO/12/43-586:** *"Electromagnetic analysis Support"*– support to ITER EM analysis division in developing the ITER EM Global Model, Maxwell forces for different ferromagnetic components, EM dimensioning of In-vessel as Out- vessel components, EM loads on Cables and cable trays ... – (2012-2014)
- **EUROFUSION Contract:** "EM, Thermo-mechanical Design analysis of the new DEMO Design Concept", (2014, 2010)

- **ITER Contract n° 43-599***: "Engineering Support for Mechanical, Thermo-Hydraulic and Electromagnetic Analysis of the ITER Diagnostic Components" – (2012-2017)*
- **ITER Contract n° IO/CT/60-104***: "Engineering Support to ITER Diagnostics"* – Support to ITER diagnostic Group in definition, performance, design and design analysis of ITER Diagnostics *(2012- 2014)*
- **ITER Contract n° ITER/CT/11/60-080***: "Engineering Technical Support for the ITER TOKAMAK Directorate"* – EM, Thermal and Mechanical Analysis for the Design Assessment Analysis of ITER Vessel and In-Vessel components *(2011- 2016)*
- **ITER Contract *n°* *ITER/08/382 Amd #1*:** *"Analysis and optimization of the active and passive magnetic field reduction system of the ITER neutral beam injector"* –(2010-2011).
- **F4E Contract n° F4E-2008-OPE-06-06-08 (ES-AC)** – *Task 8: Electro-Mechanical analysis for Preliminary Design of three First Wall modules: Blk 2, 10, 18. (2011- 2012)*

ITER Contract n° IO/10/43-318: *"Design Analysis of various ITER Diagnostics components"* –(2011-2012)
ITER Contract n° IO/08/41-241: *"Electromagnetic analysis for the In-Wall Shielding"* – Evaluation of eddy currents and related EM forces for In-Wall Shielding blocks in Special Configuration during plasma disruption events. – (2008-2009)

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- F. Lucca, M. Roccella et al, *Impact of the D_Shaped Plasmas on the new Limiters and on the Vacuum Vessel of FTU*, ISFNT5 (1999)
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