2nd IAEA Technical Meeting on First Generation Fusion Power Plants

Engineering Aspects on the Development of a Reactor Concept for DEMO

D. Filsinger, Ch. Köhly, J. Rey, C. Polixa
Institute for Nuclear and Energy Technologies
Forschungszentrum Karlsruhe, Germany

D. Nagy

KFKI-Research Institute for Particle and Nuclear Physics
Association EURATOM/HAS
Budapest, Hungary

MCP.O-8

Outline

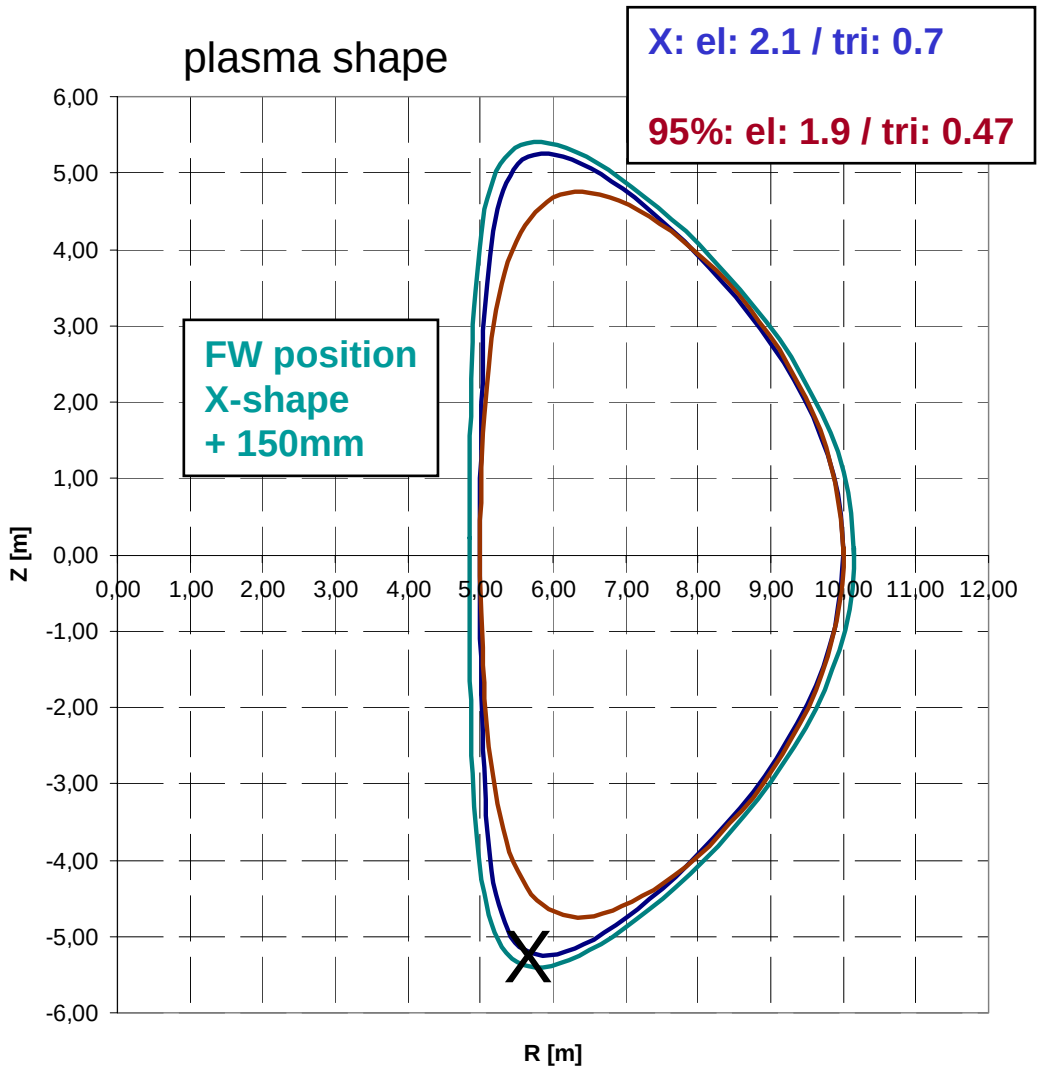
- Introduction – DEMO reactor layout
- Some features of integration concept
- Maintenance concept
- Integration overview
- Blanket concept
- Attachment Systems
  - Blanket to MMS
  - MMS to Hot Ring Shield
  - Hot Ring Shield to Vacuum Vessel
  - Design of Hot Ring Shield
- Summary and Outlook

Introduction

- Provisional DEMO parameters

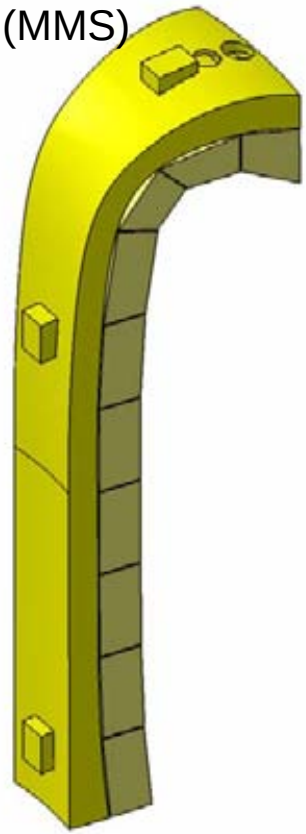
Parameter	DEMO Provisional Parameters
R (m)	7.5
a (m)	2.5
B (T)	6.2
I (MA)	17.0
Elongation (X, 95)	2.1, 1.9
Triangularity (X, 95)	0.7, 0.47
Fusion Power (MW)	2385
Gross Electric (MW)	1544
Net Electric (MW)	1000
Heating Power CD + extra (MW)	134+40
Zeff	2.33
H factor	1.3
Divertor peak heat load (MW/m^2)	10
P He pump (gross MW)	194
β_N thermal, total	3.0, 3.6
Ave neutron wall load (MW/m^2)	1.55
Bootstrap fraction	0.59
T (keV)	15.4
n ($10^{20} m^{-3}$)	1.08
γ_{CD} (10^{20} A/Wm^2)	0.42

D. Ward, UKAEA, 2006



Two distinctive features of integration concept

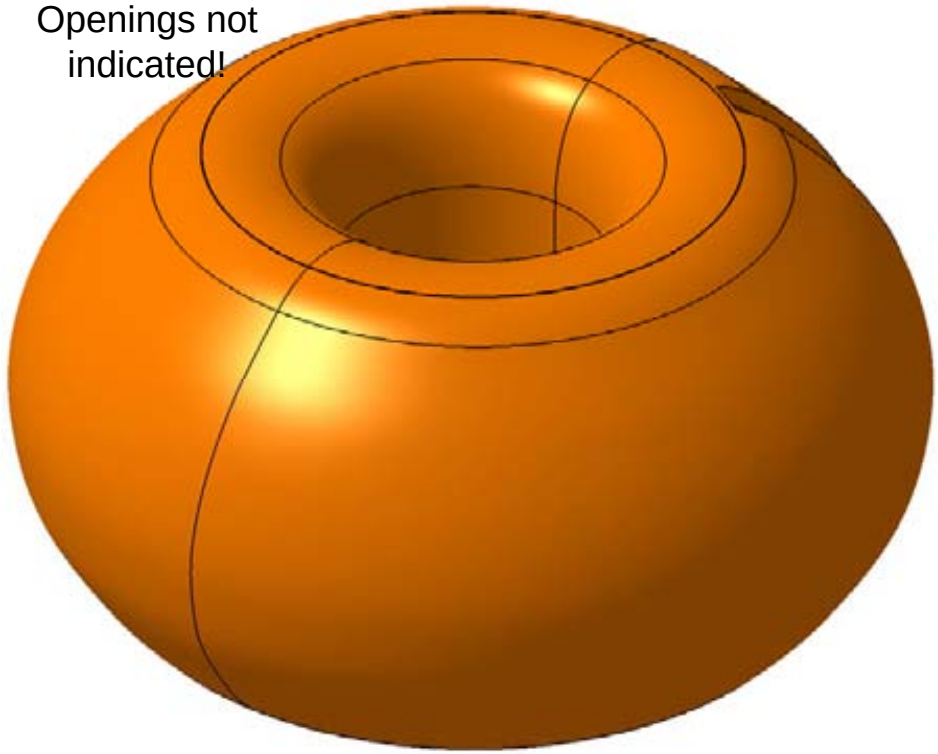
Multi Module Segment (MMS)



Blanket elements preassembled

Hot Ring Shield (HTS)

Openings not indicated!

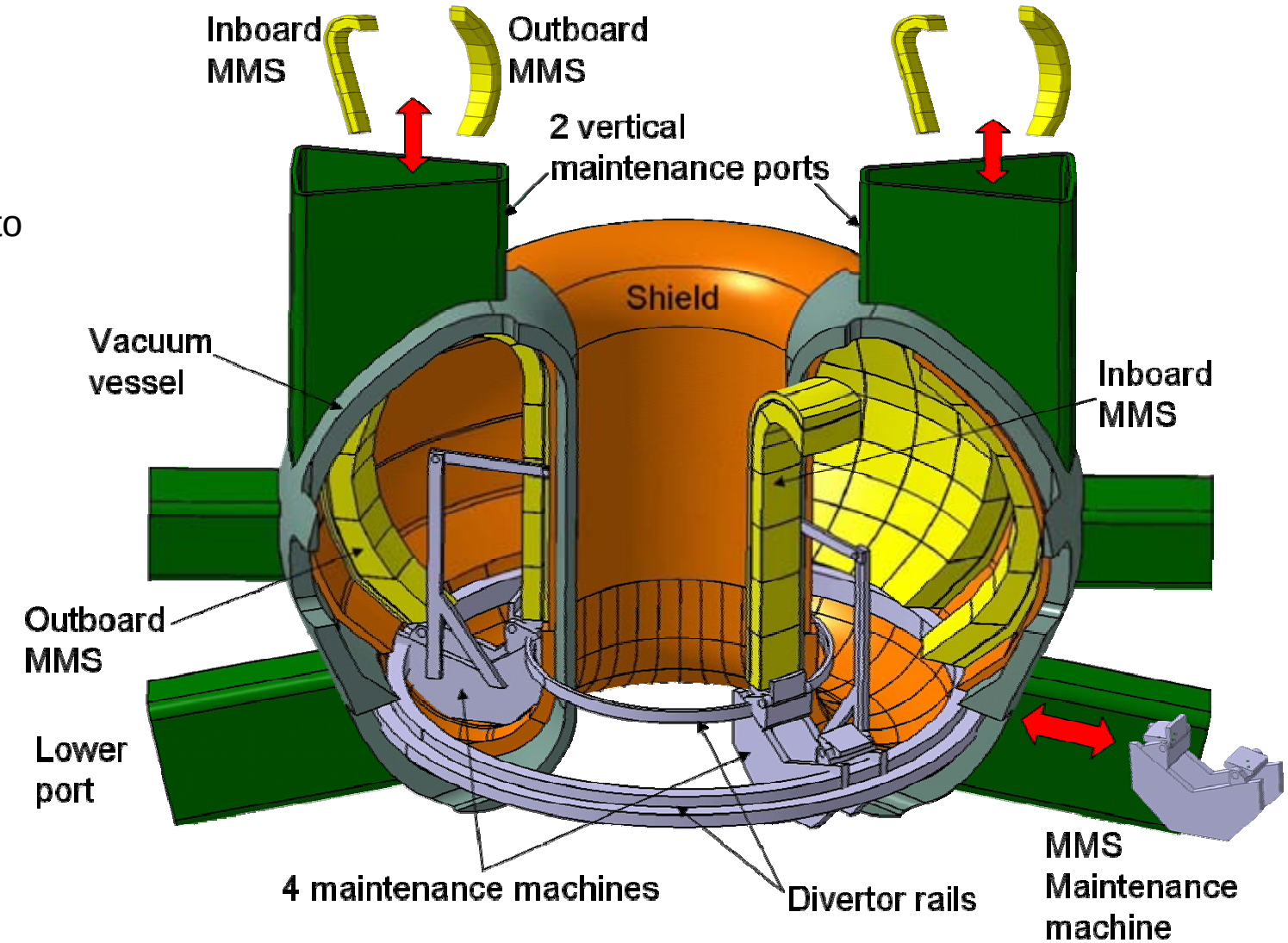


Self-supporting, toroidally closed structure

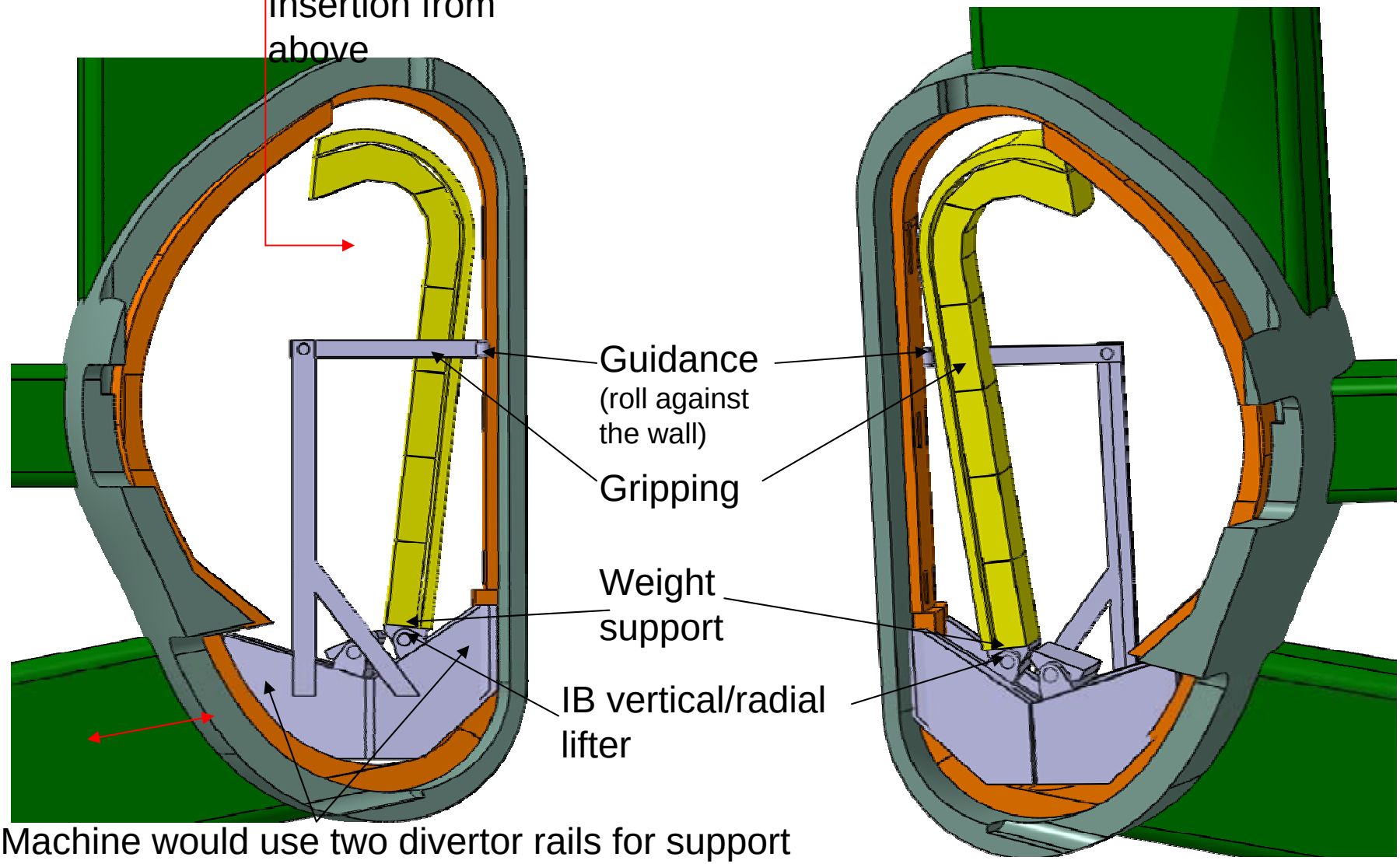
Kept at high temperature

Maintenance Concept 1

- 50-60 MMS elements to exchange
- 2 vertical maintenance ports used
- IV toroidal transporter
- Divertor must be removed



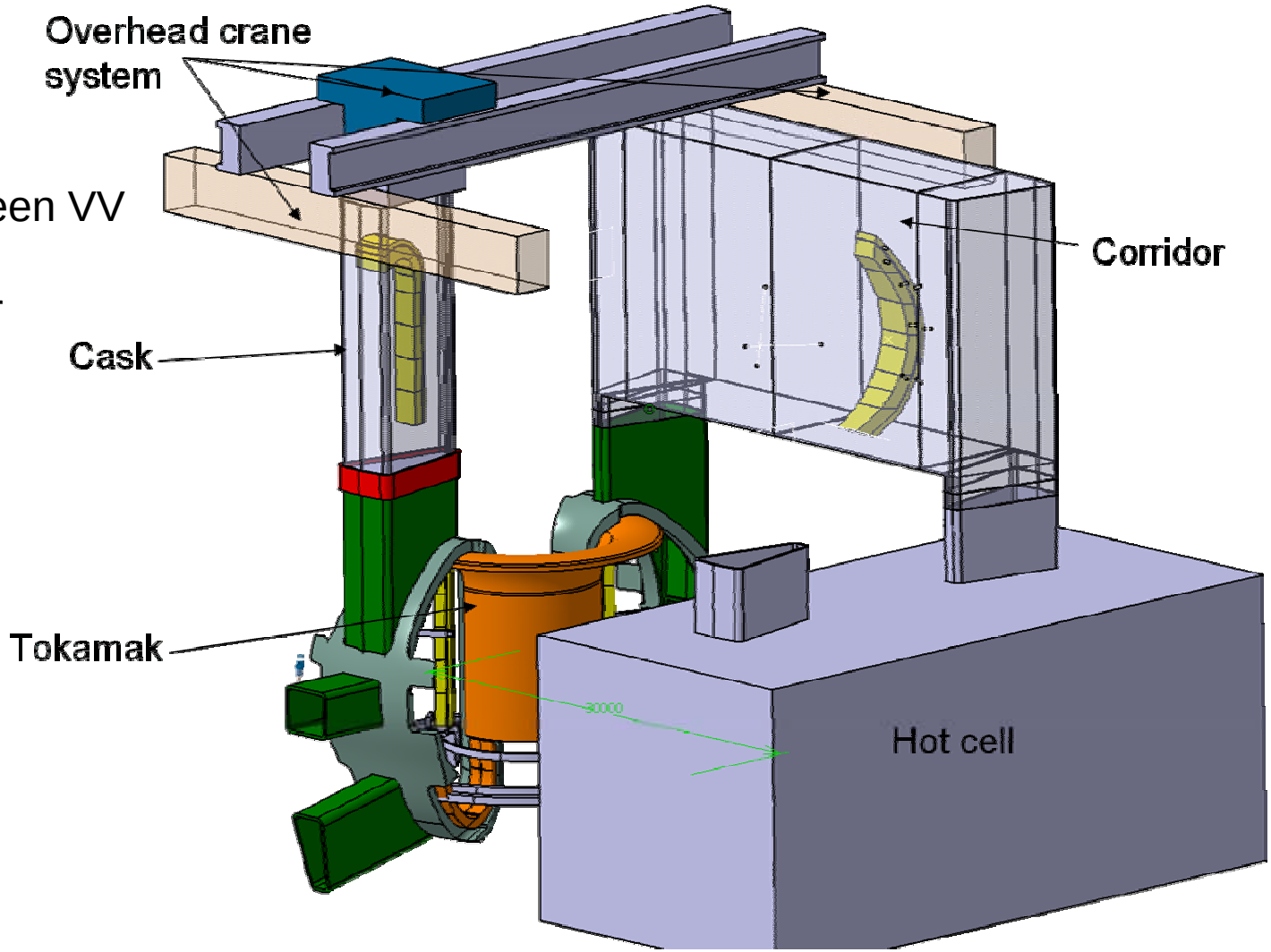
Maintenance Concept 2: IB Transport position



Machine would use two divertor rails for support

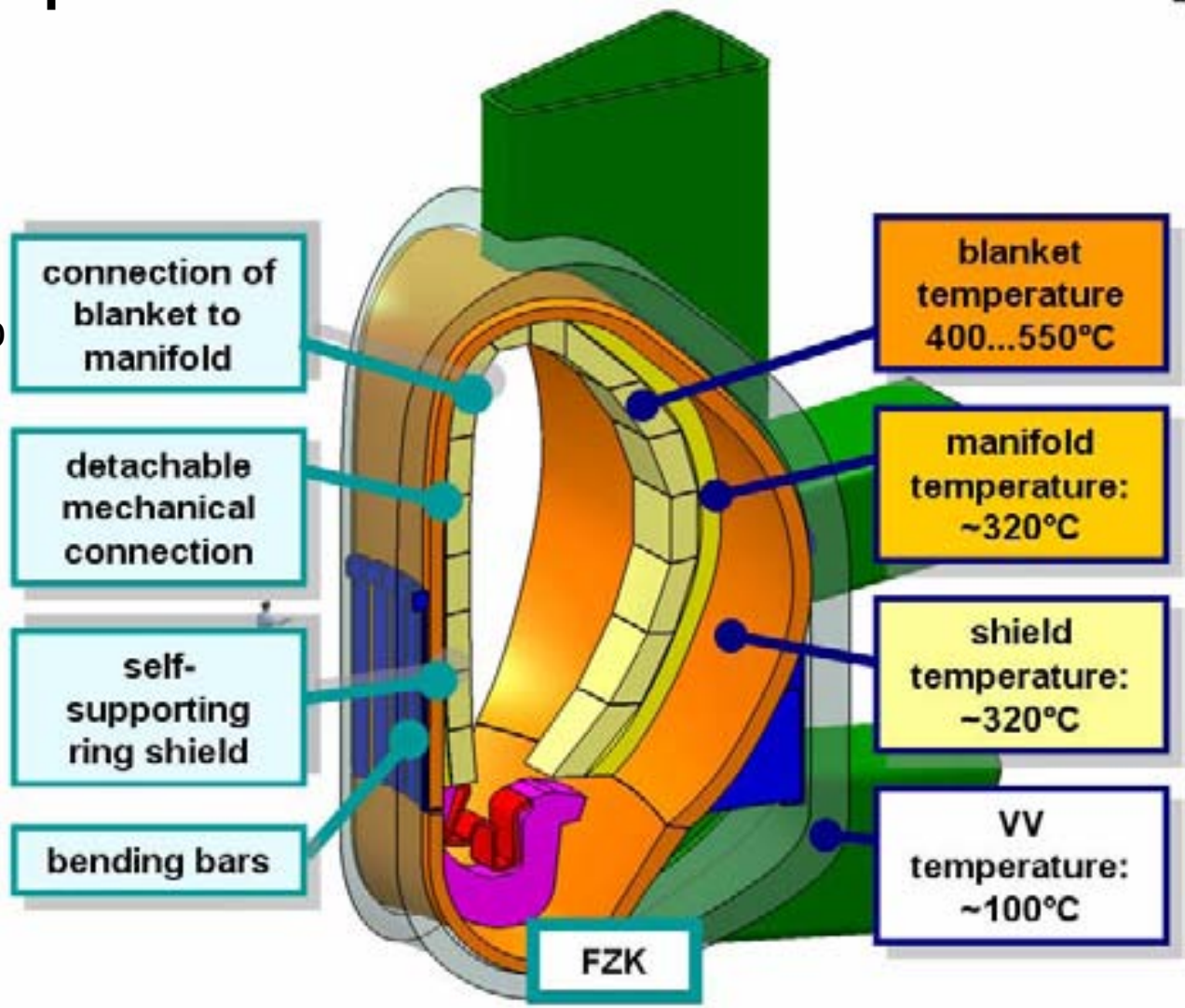
Maintenance Concept 3: Out-of vessel maintenance options

Transport between VV and HC:
Cask or corridor



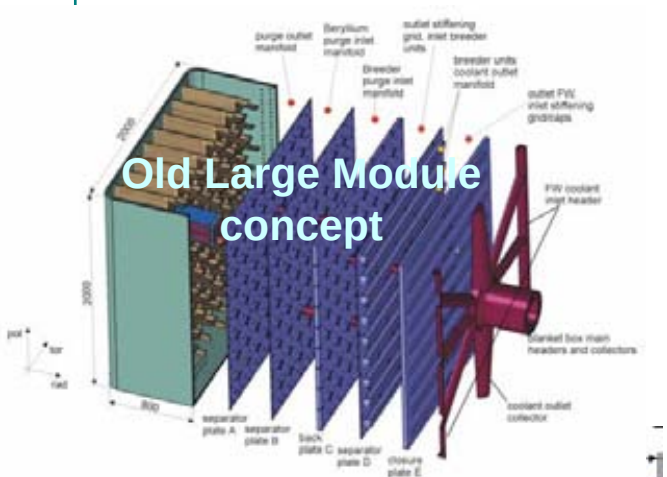
Integration Concept

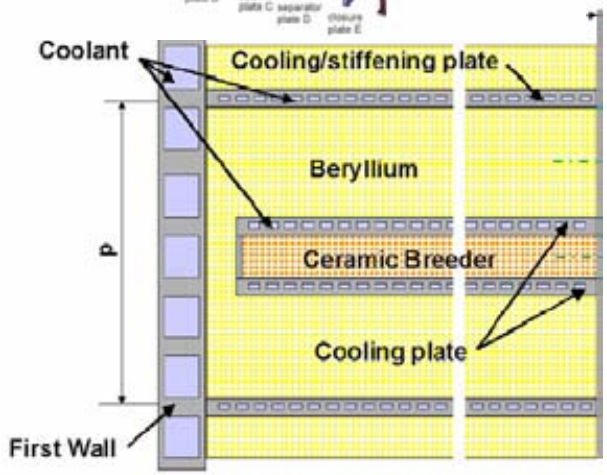
- independent from the blanket type (HCPB or HCLL)
- Main in-vessel components to integrate into the reactor:
  - breeding blankets, manifold, hot ring shield, VV
- Main boundary conditions:
  - temperature differences (thermal expansions)
  - remote handling requirements
  - Pressure loads, thermal loads, EM loads

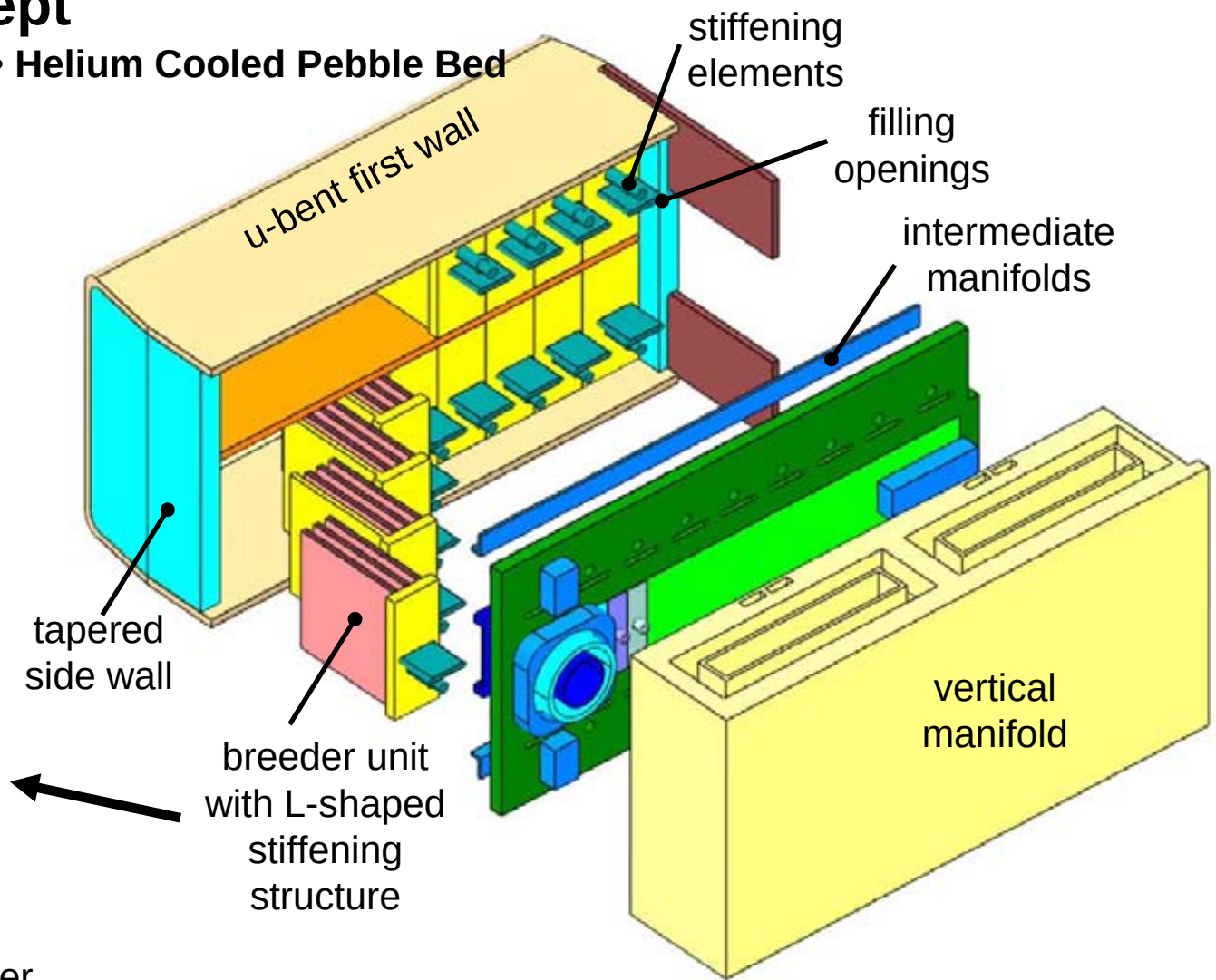


Blanket Concept

- **Helium Cooled Pebble Bed**

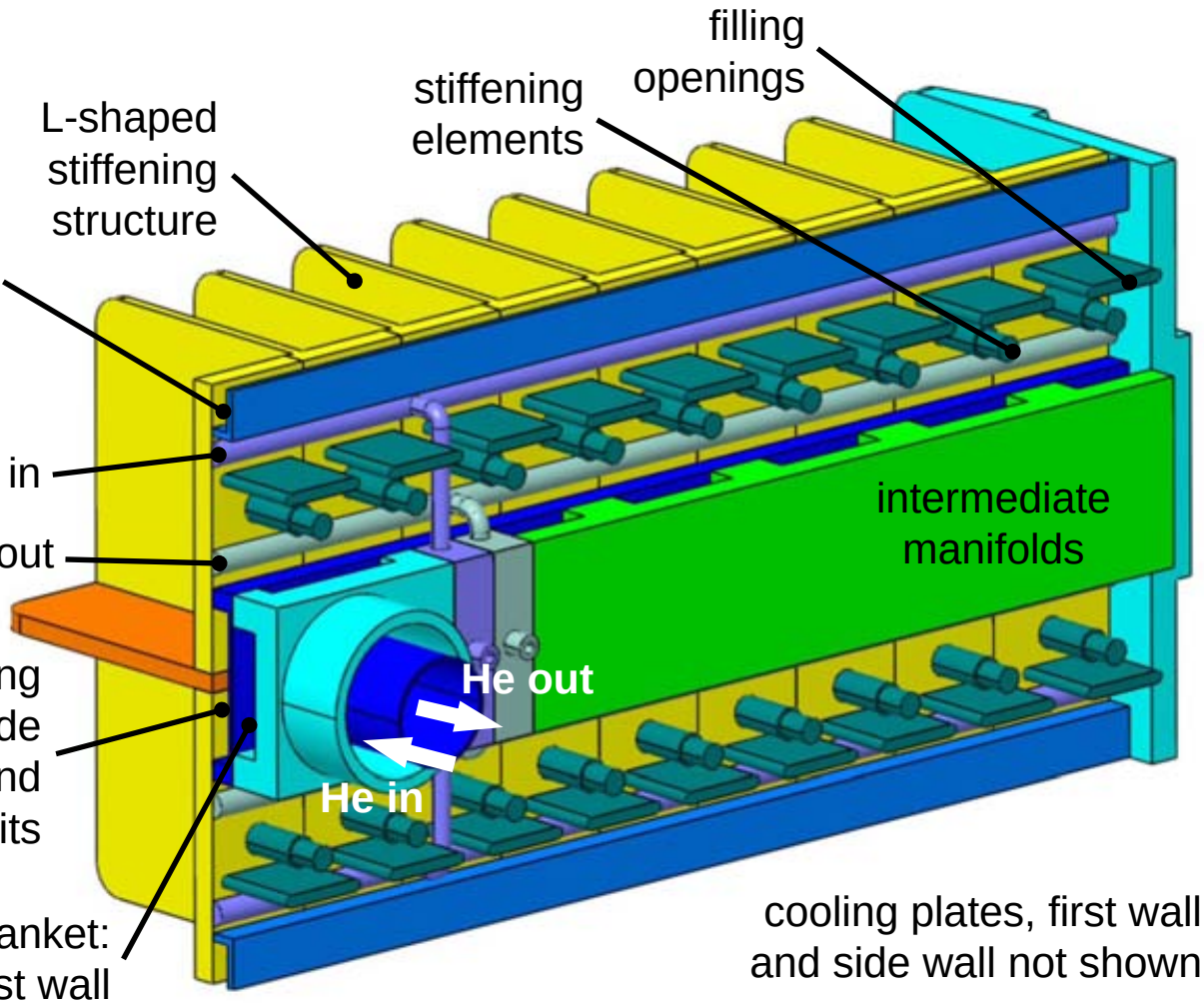






Solid breeder
Beryllium as neutron multiplier

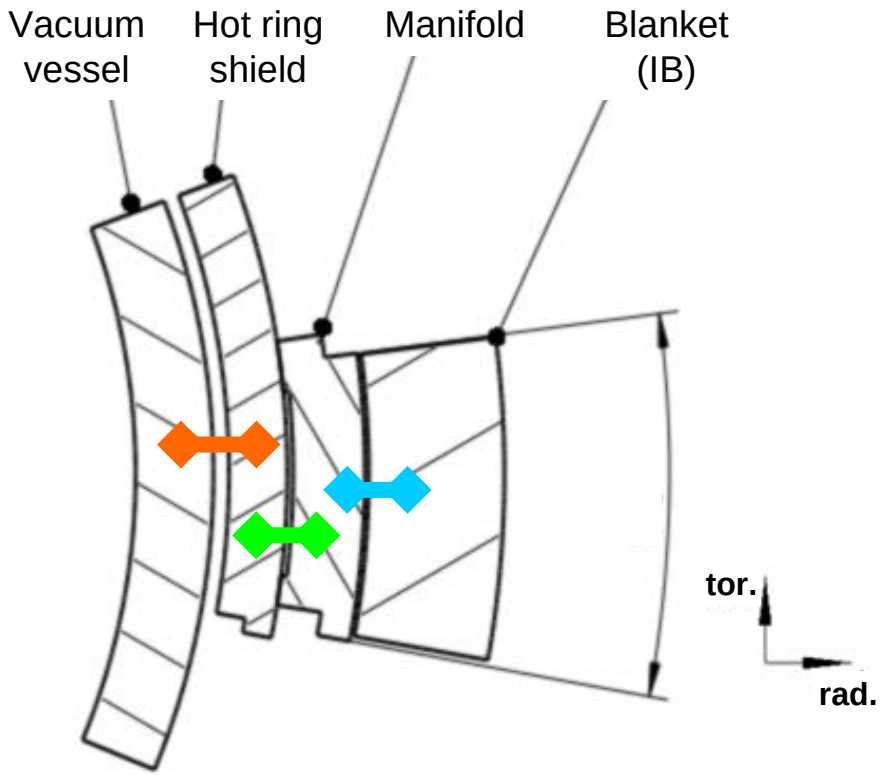
Blanket Concept: Assembly Drawing



p, p_v= 8MPa

Attachment System

- **Blanket module – manifold**
  compensate thermal expansions
- **MMS – hot ring shield (HRS)**
  remote handling
- **HRS – vacuum vessel (VV)**
  compensate thermal expansions

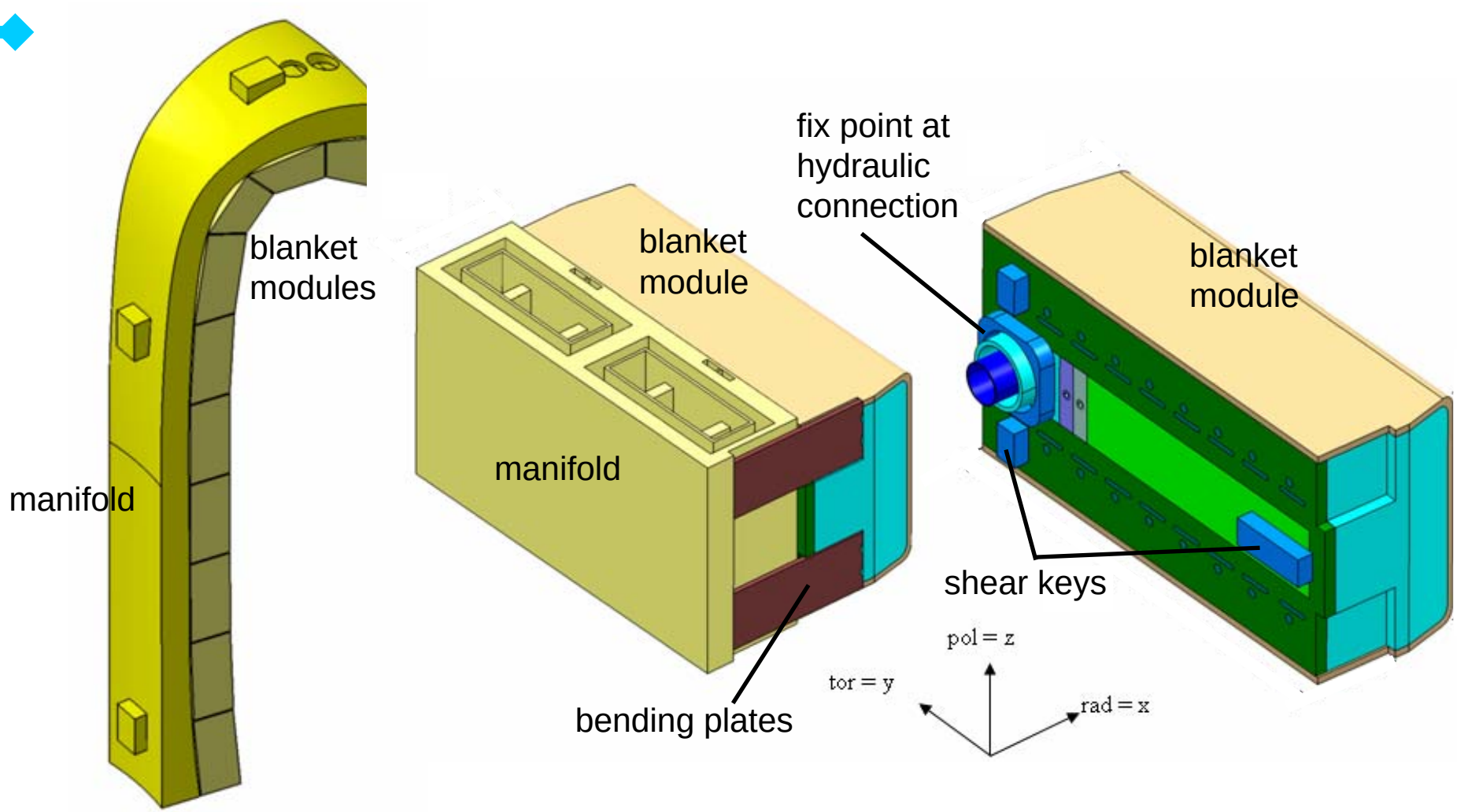


T(VV) < T(HRS) ≅ T(Manifold) < T(Blanket)

Attachment: Blanket Module - Manifold

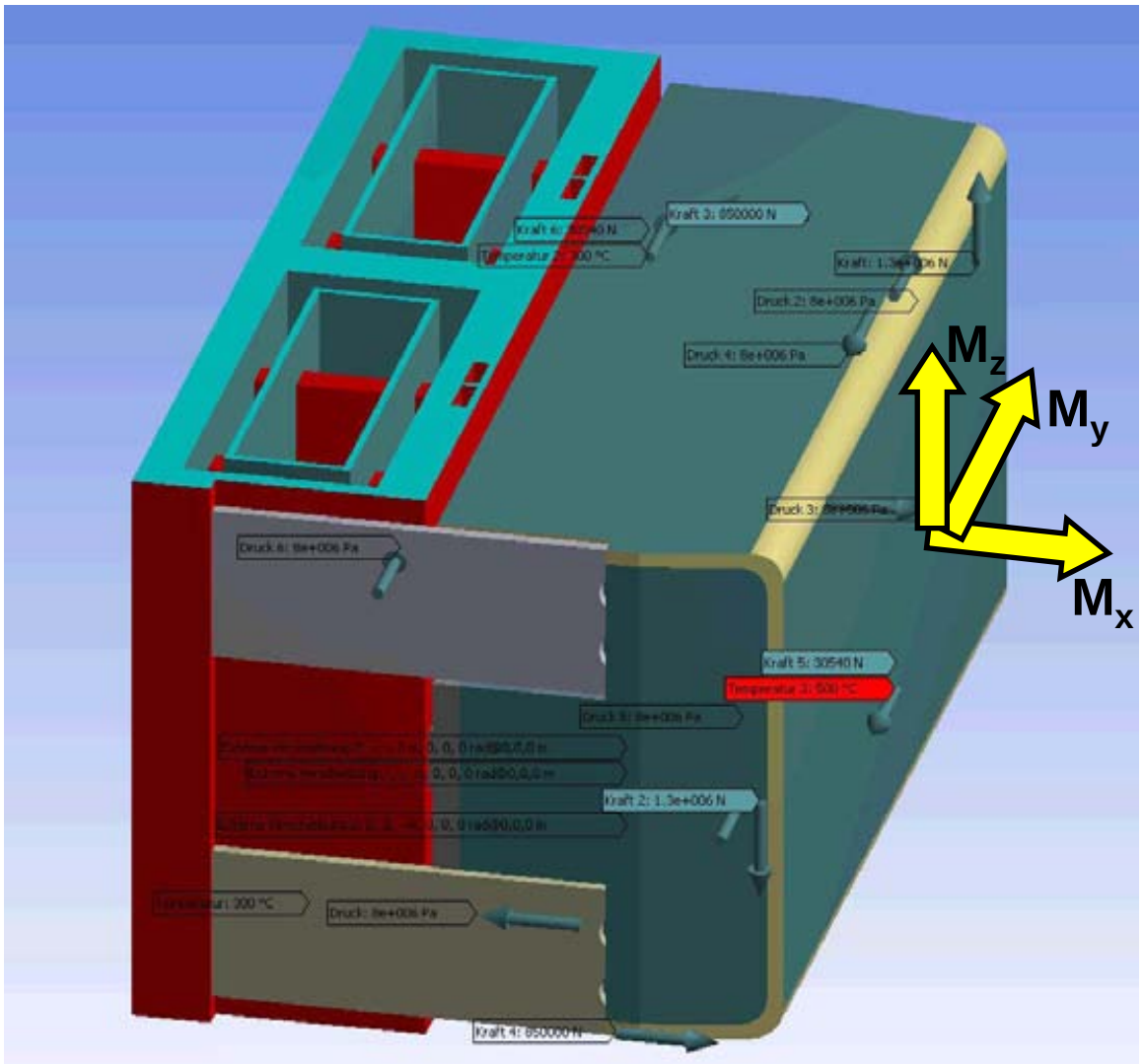
- Requirements / boundary conditions
  - No need for remote handling inside the vessel
  - Tolerate the different thermal expansions of the blanket modules and the manifold
    - T(FW)= 500°C; T(Manifold)= 300°C → T
  - Resist electromagnetic loads during transient plasma events (disruptions)
    - EM loads (M_r, M_t, M_p) on FW surface → F

Attachment: Blanket Module - Manifold

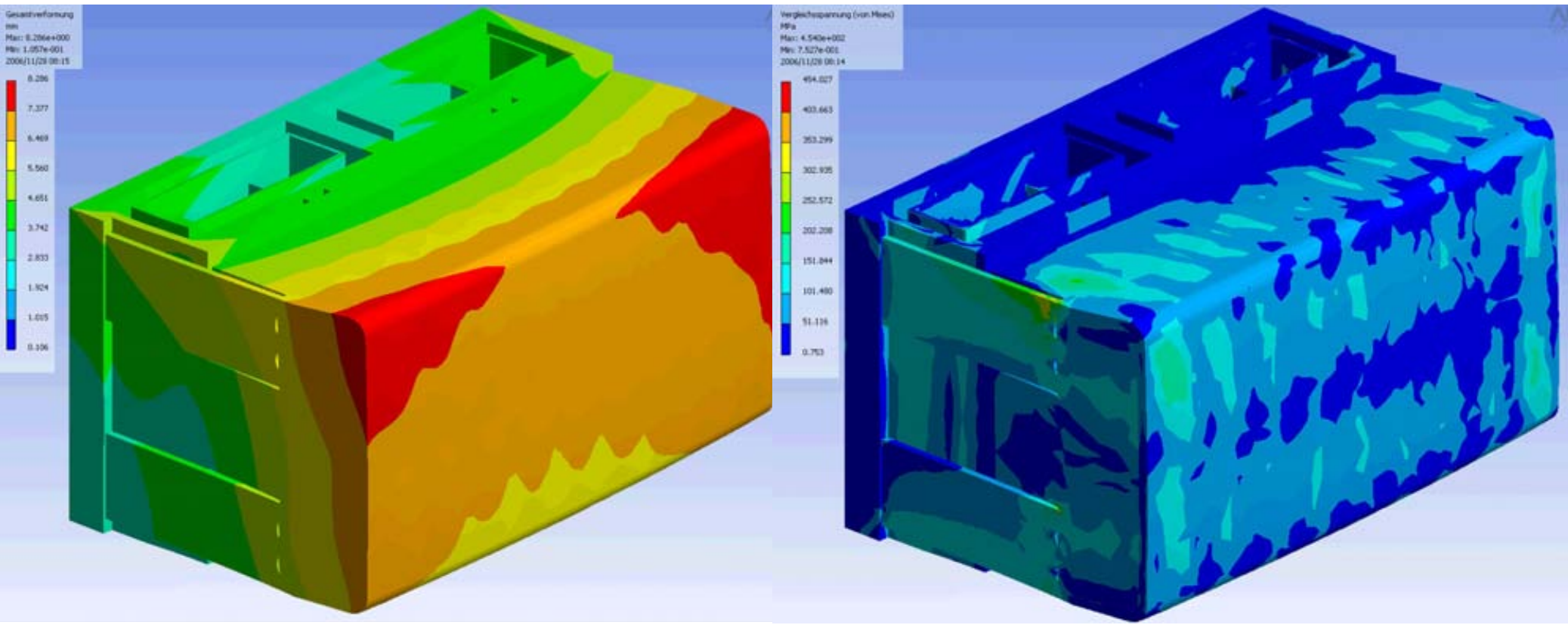


Attachment: Blanket Module - Manifold

- FE model
  - Module and manifold
  - Weight of module and manifold
  - Pressure boundary conditions
  - Thermal boundary conditions
  - EM loads on module (highest loaded module)

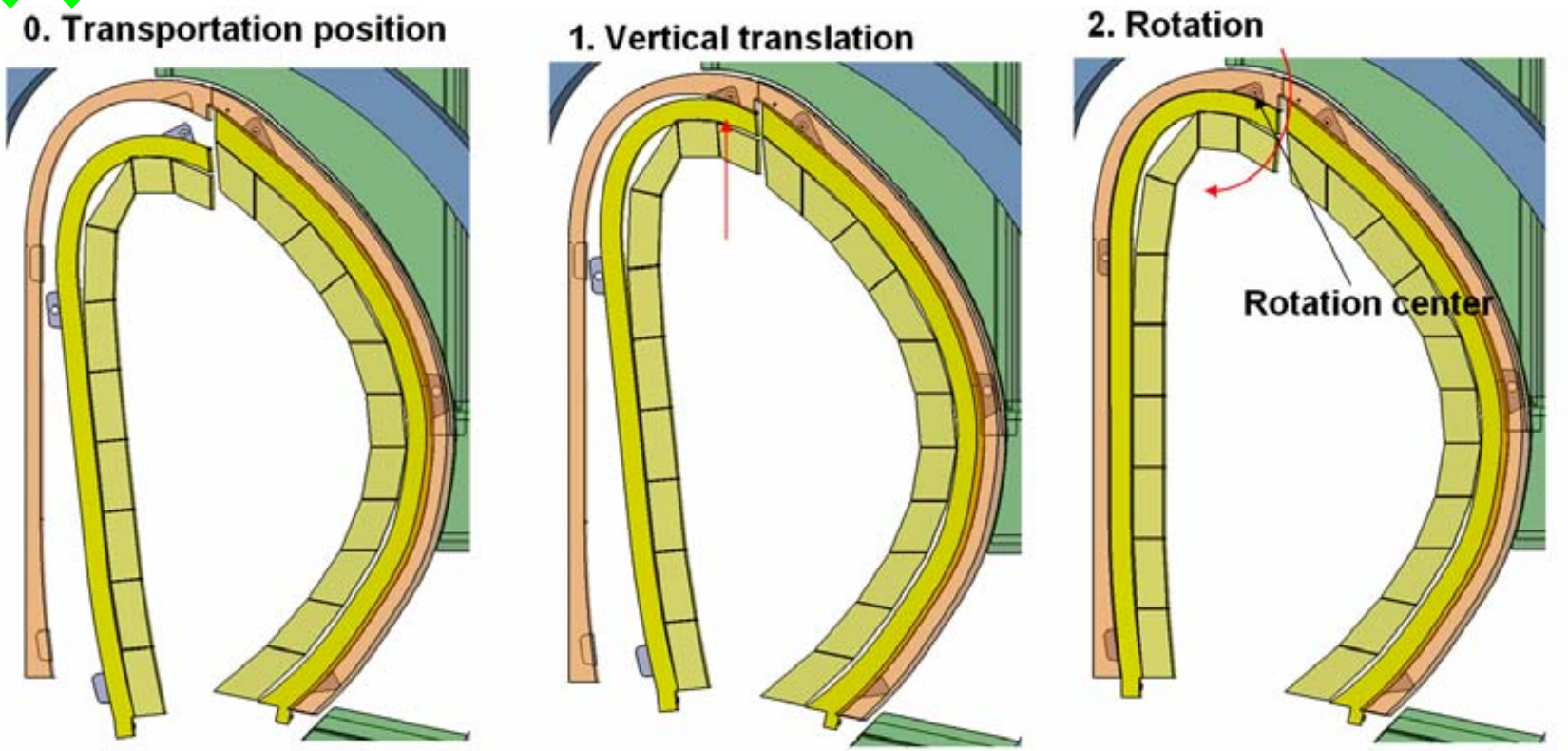


Attachment: Blanket Module – Manifold Evaluation



FEM result: Deformation and stress distribution;
off-normal operating conditions: faulted conditions and disruption.

Attachment: MMS – Hot Ring Shield Insertion



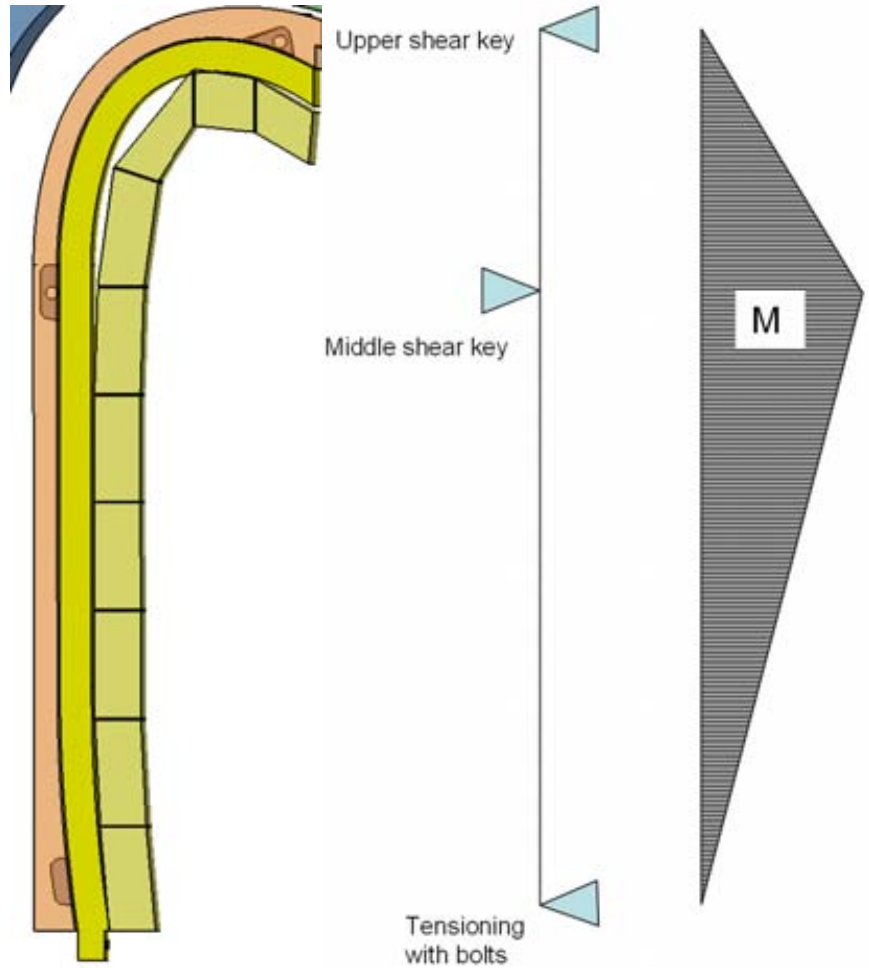
Weight ~ 100t

height ~ 12 m

- Installation kinematics, options very constrained
- Must be performed remotely
- Two phased installation kinematics
- Upper shear key can serve as a rotation center
- Shape of shear keys defined by movement

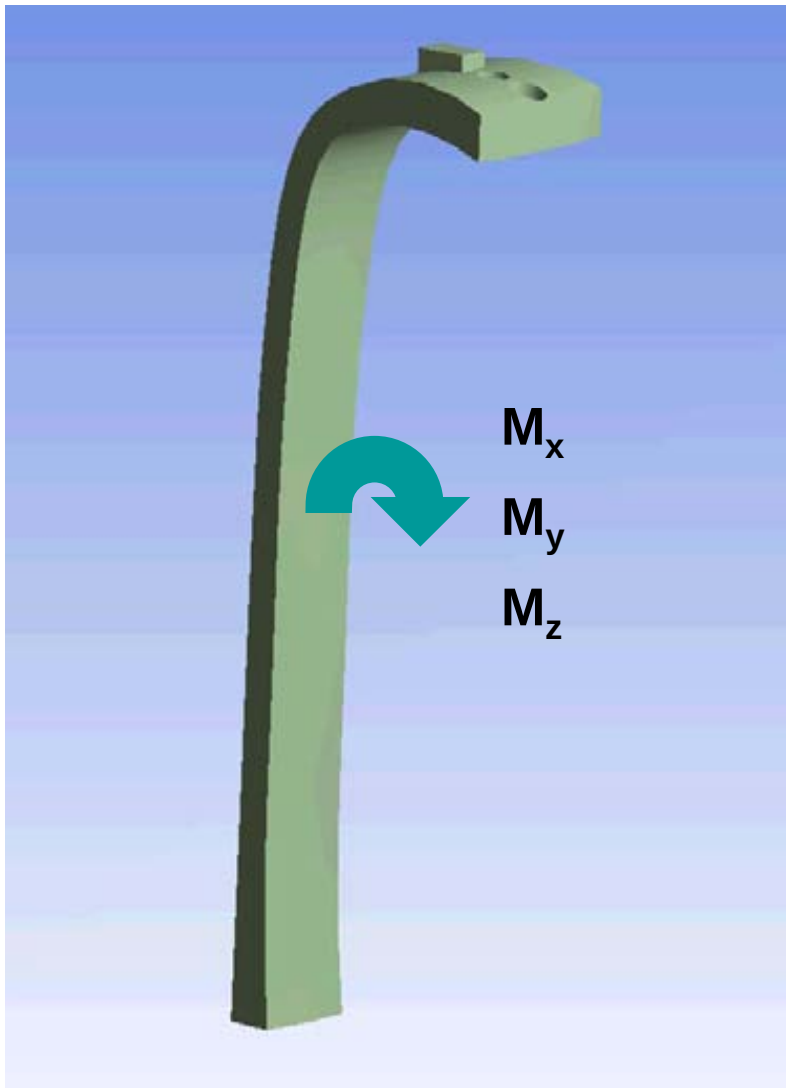
Attachment: MMS – Hot Ring Shield

- Main issues
  - Remote handling
  - Very limited access from the first wall for handling
  - Large disruption forces (larger than own weight)
- Concept
  - 3 levels of shear keys (upper, middle lower)
  - One level of bolts (lowermost part)
  - Tolerances handles after insertion
  - Tensioning might be necessary to prevent accelerations in case of disruptions

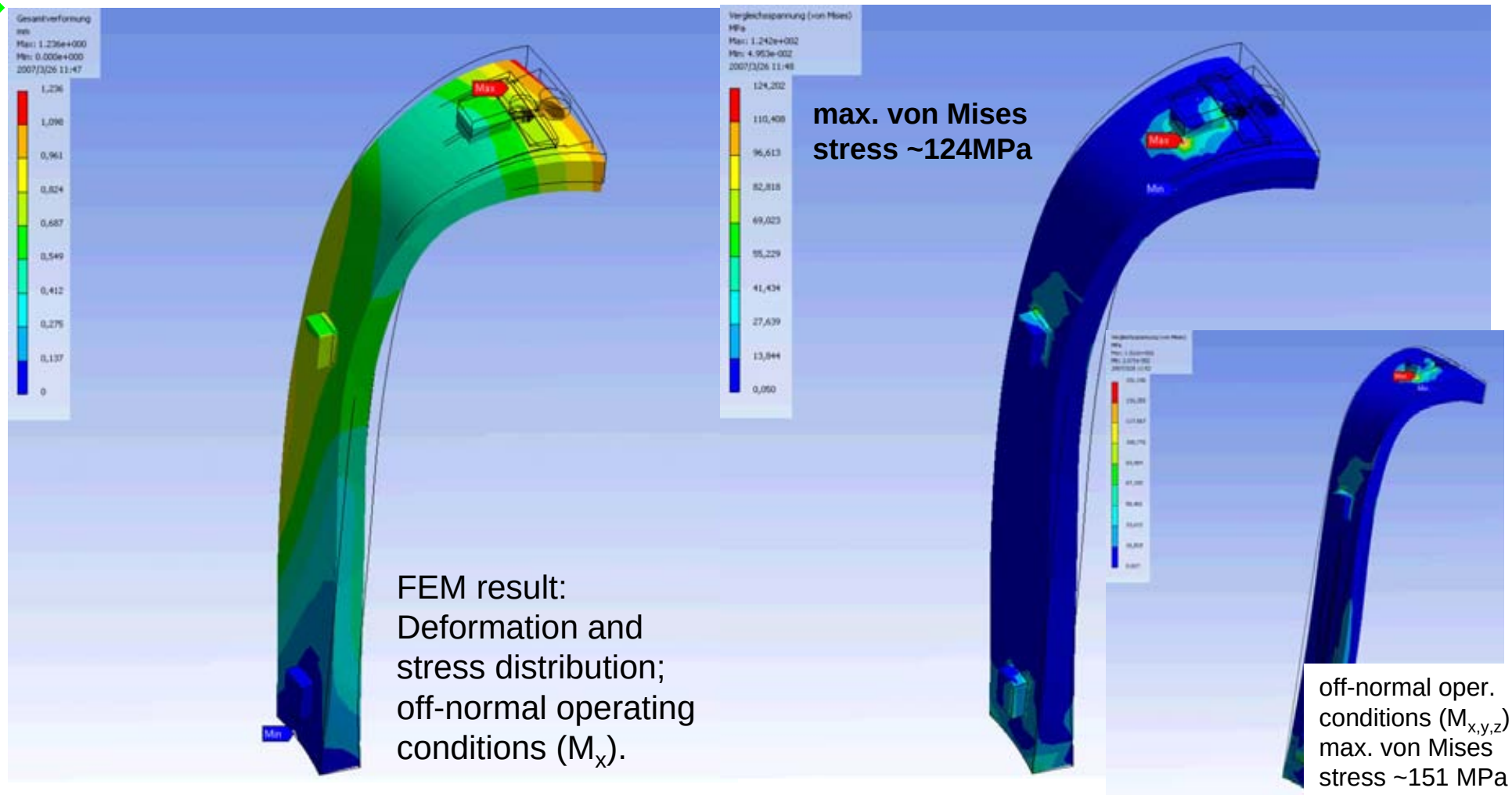


Attachment: MMS – Hot Ring Shield

- FE model
  - Simplified MMS
  - Weight of MMS
  - Thermal boundary conditions
  - EM loads on MMS

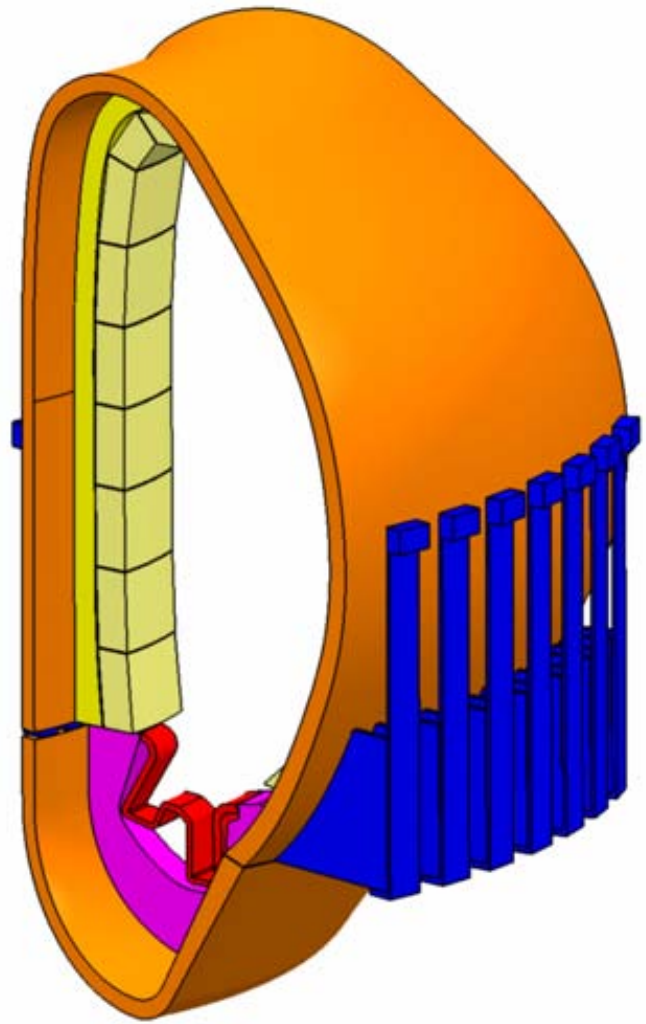


Attachment: MMS – Hot Ring Shield
Evaluation of MMS: Gravity Load + EM Loads



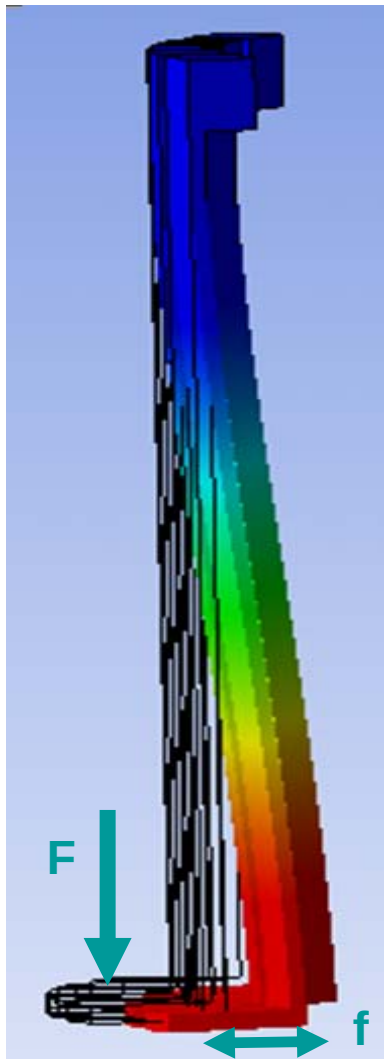
Attachment: MMS - Hot Ring Shield – Vacuum Vessel

- Closed (360°) HRS
- Attachments
  - MMS- HTS at shear keys
  - Supported by VV
    - 40 IB bending bars
    - 64 OB bending bars



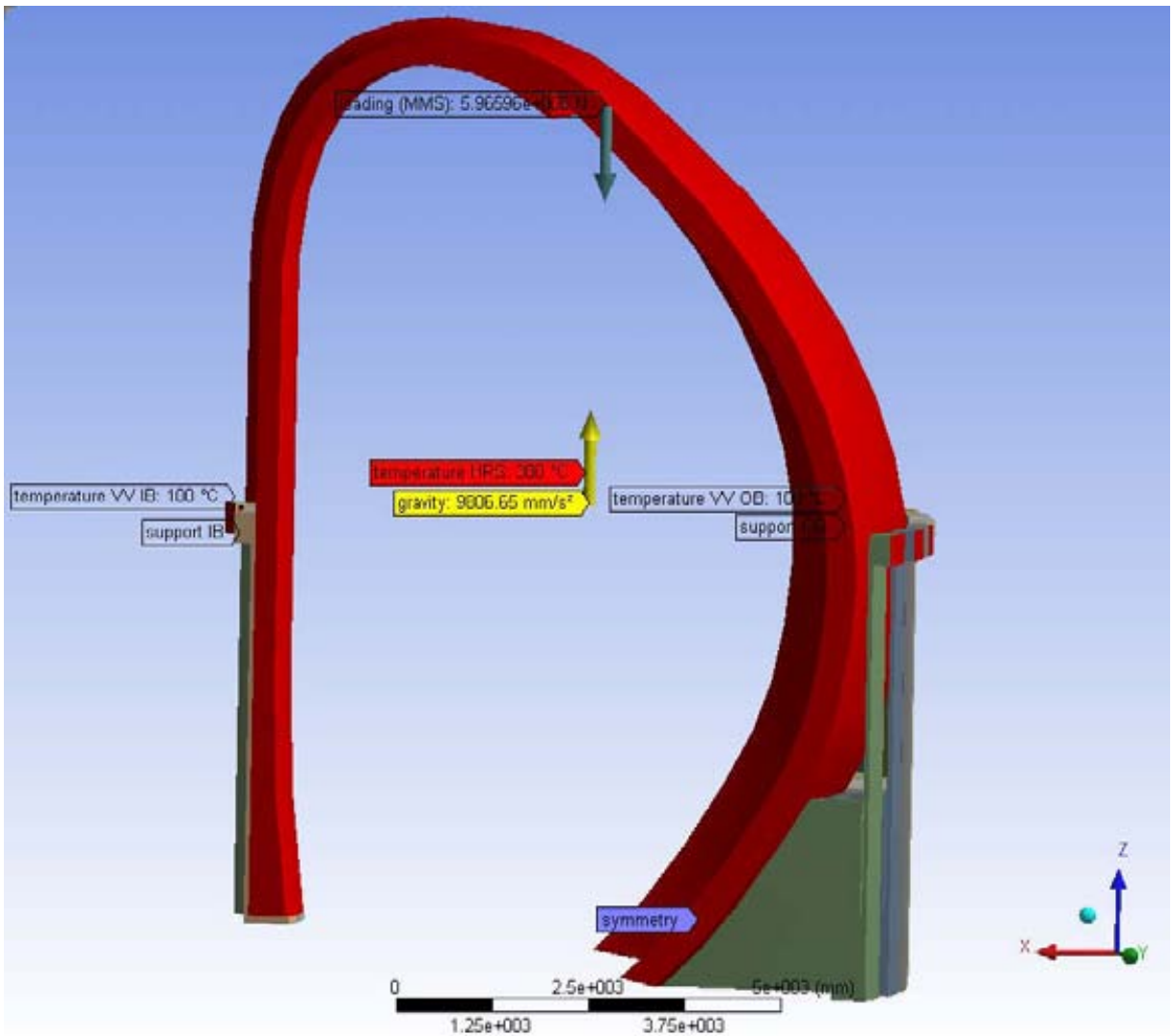
Attachment: Hot Ring Shield – Vacuum Vessel Bending Bars

- Requirements / boundary conditions
  - Support the weight of HRS and MMS (F)
  - Tolerate different thermal expansions (f)
  - Support loads during disruptions
  - Remote handling for scheduled maintenance is not needed



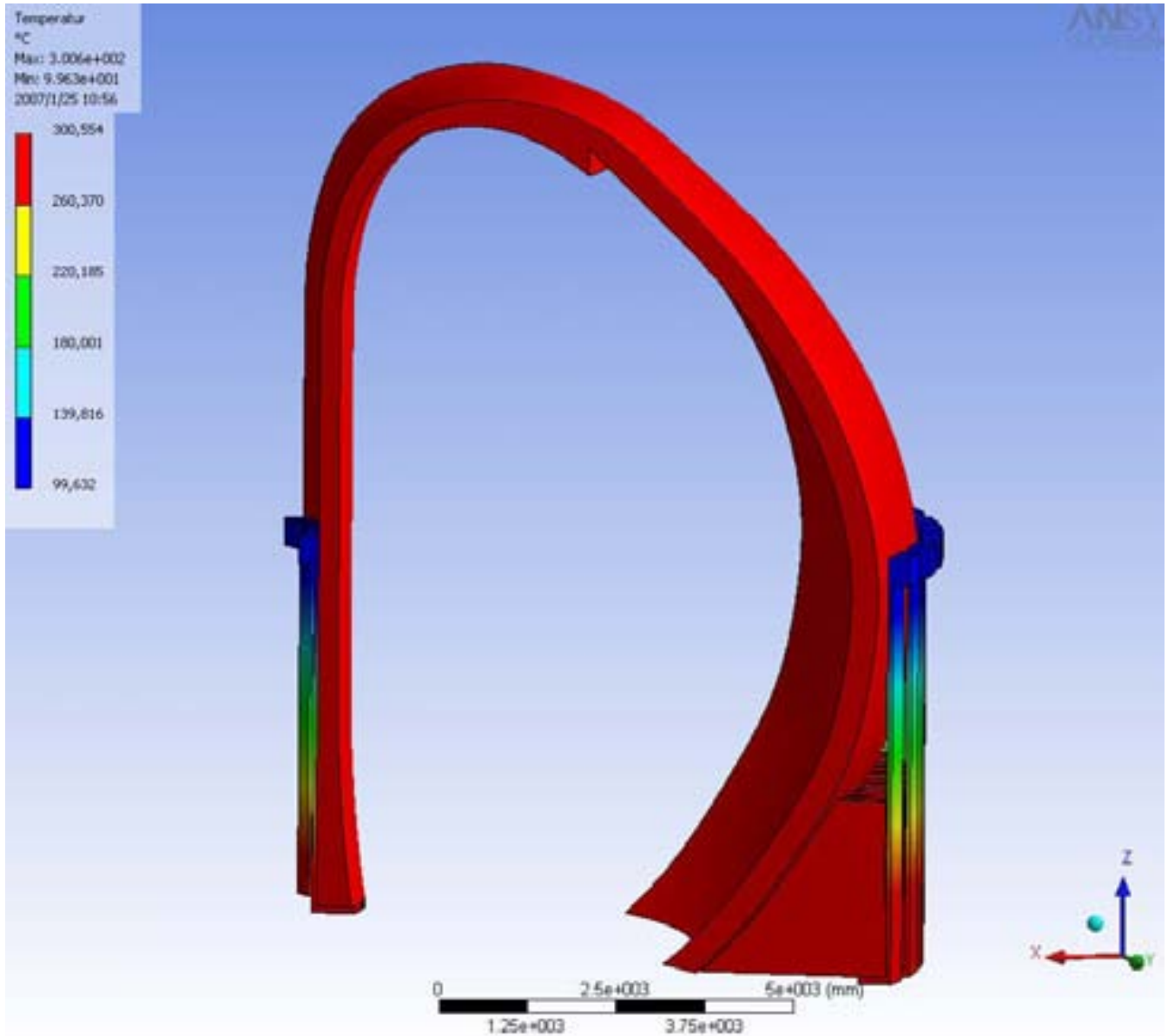
Attachment: Hot Ring Shield – Vacuum Vessel Bending Bars

- FE model
  - Cyclic symmetric segment
  - Weight of shield and MMS
  - Thermal boundary conditions
  - Resulting EM load (=0 !)



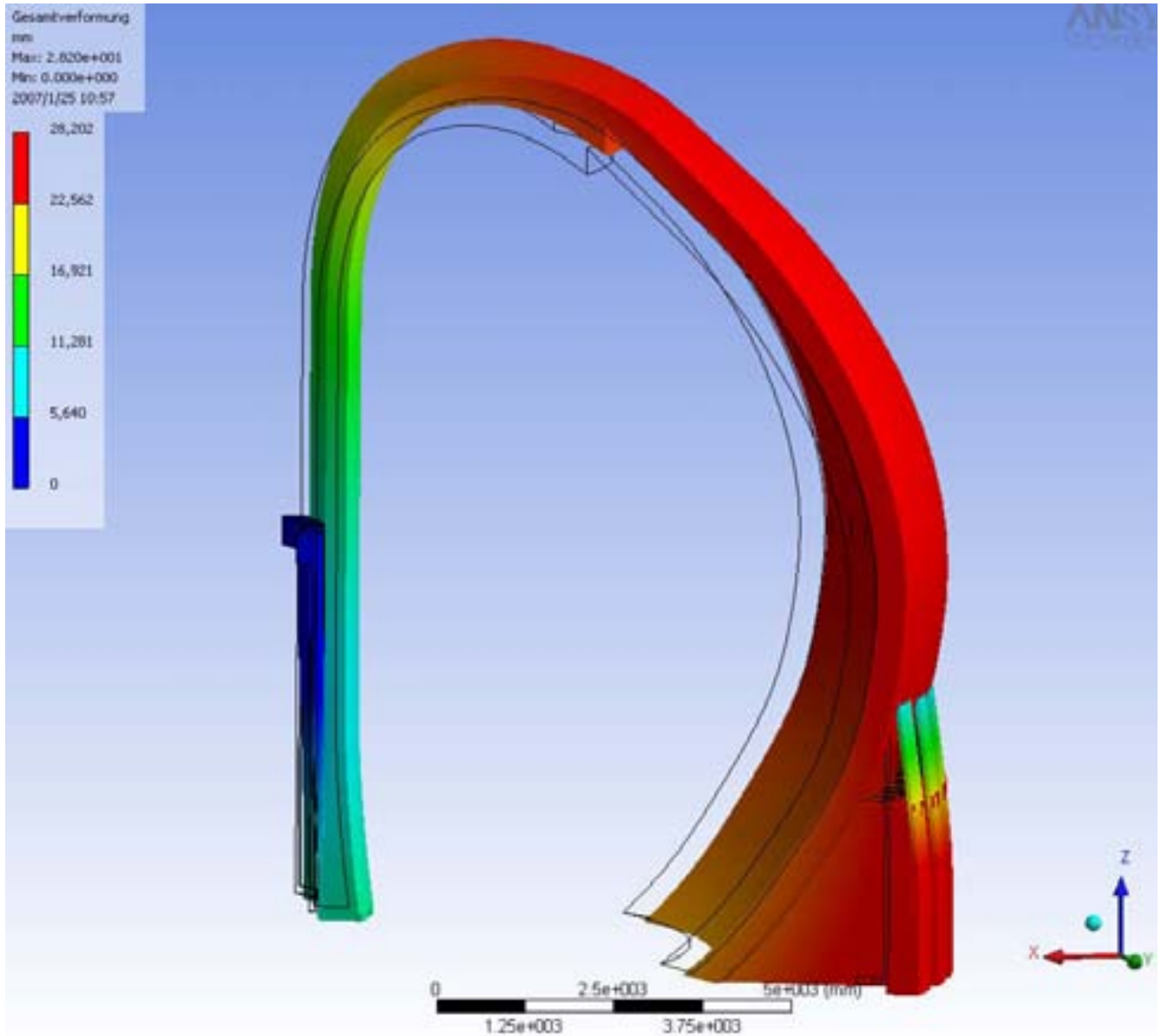
Bending Bars

- Temperature distribution

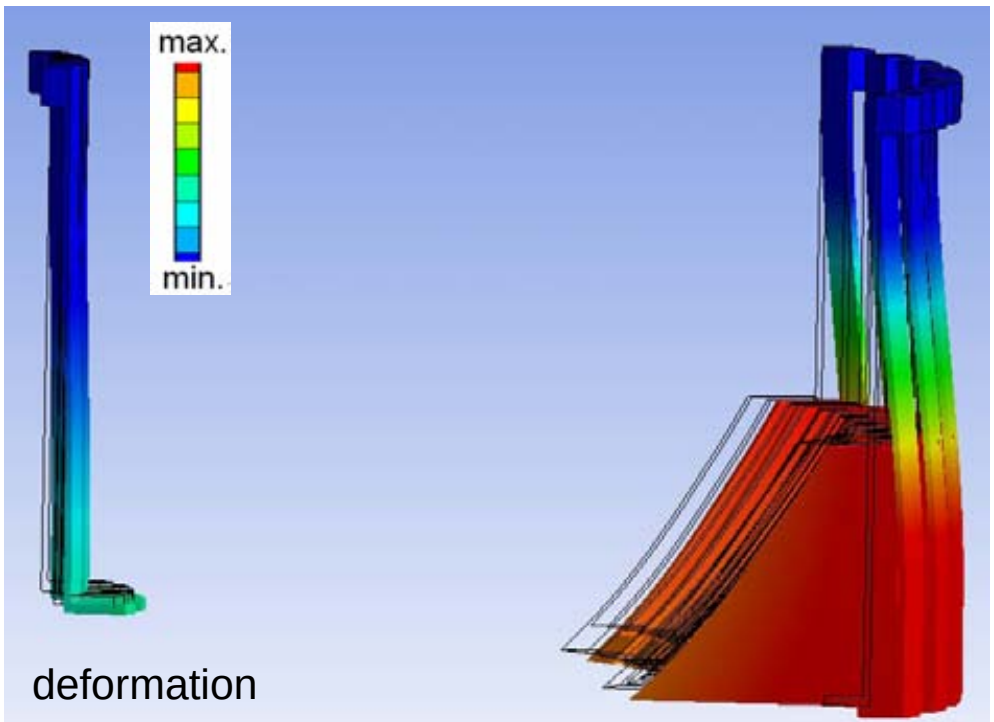


Bending Bars

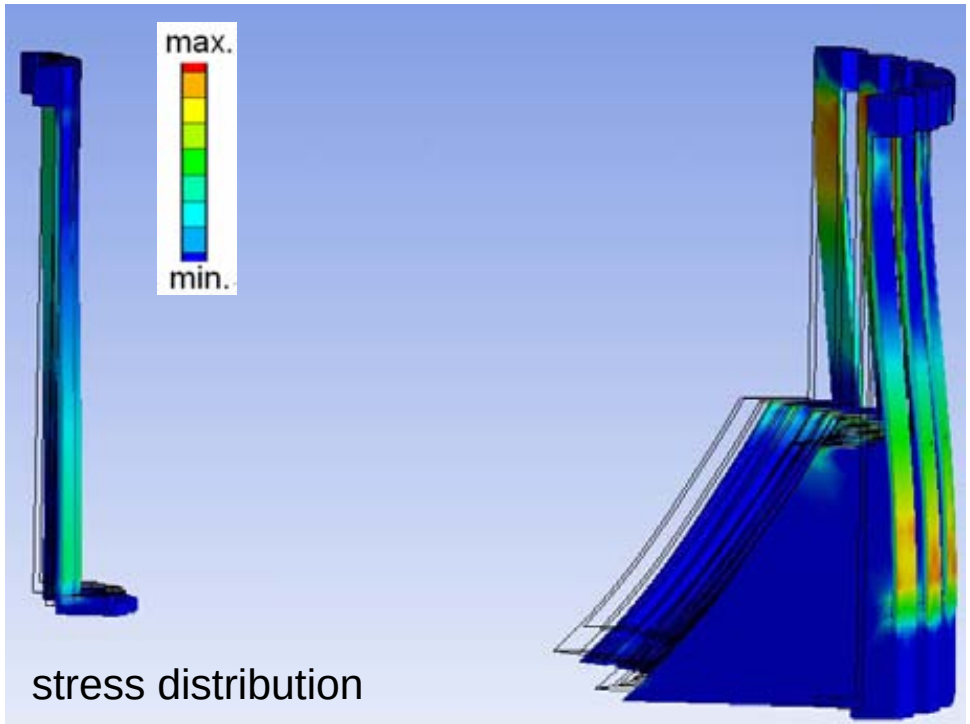
- Total deformation
  - Cyclic symmetric segment
  - Weight of shield and MMS
  - Thermal boundary conditions



Bending Bars: Evaluation



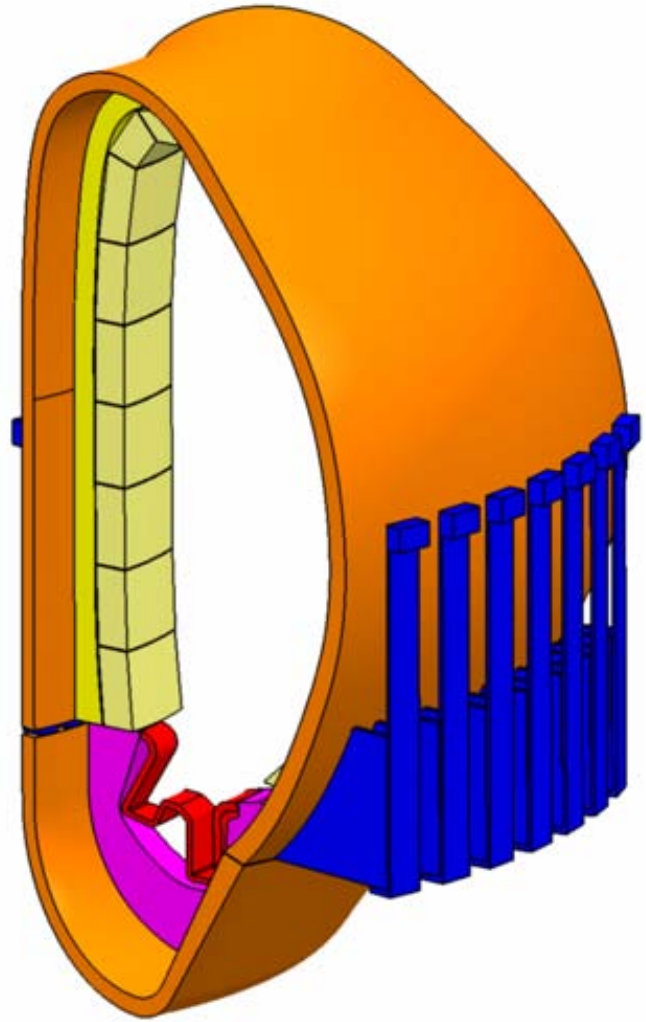
deformation



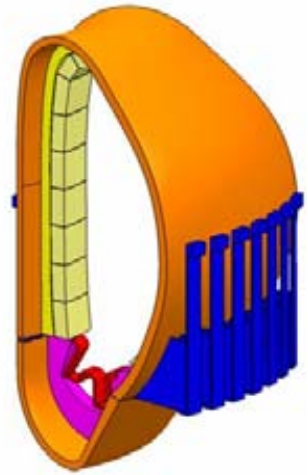
stress distribution

Design of Hot Ring Shield

- Toroidally closed structure closed (360°) HRS
- Supports MMS
- Supported by VV
- Cooled by He at 300 C
- provides adequate shielding

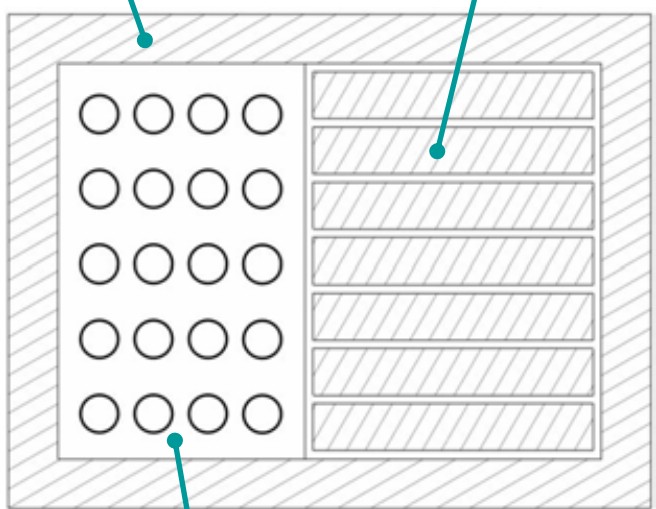


Design of Hot Ring Shield



- HRS composition
  - from thermal layout (heat generation in HRS: approx. 2.5%-5.0% of fusion power)
  - and strength evaluation:

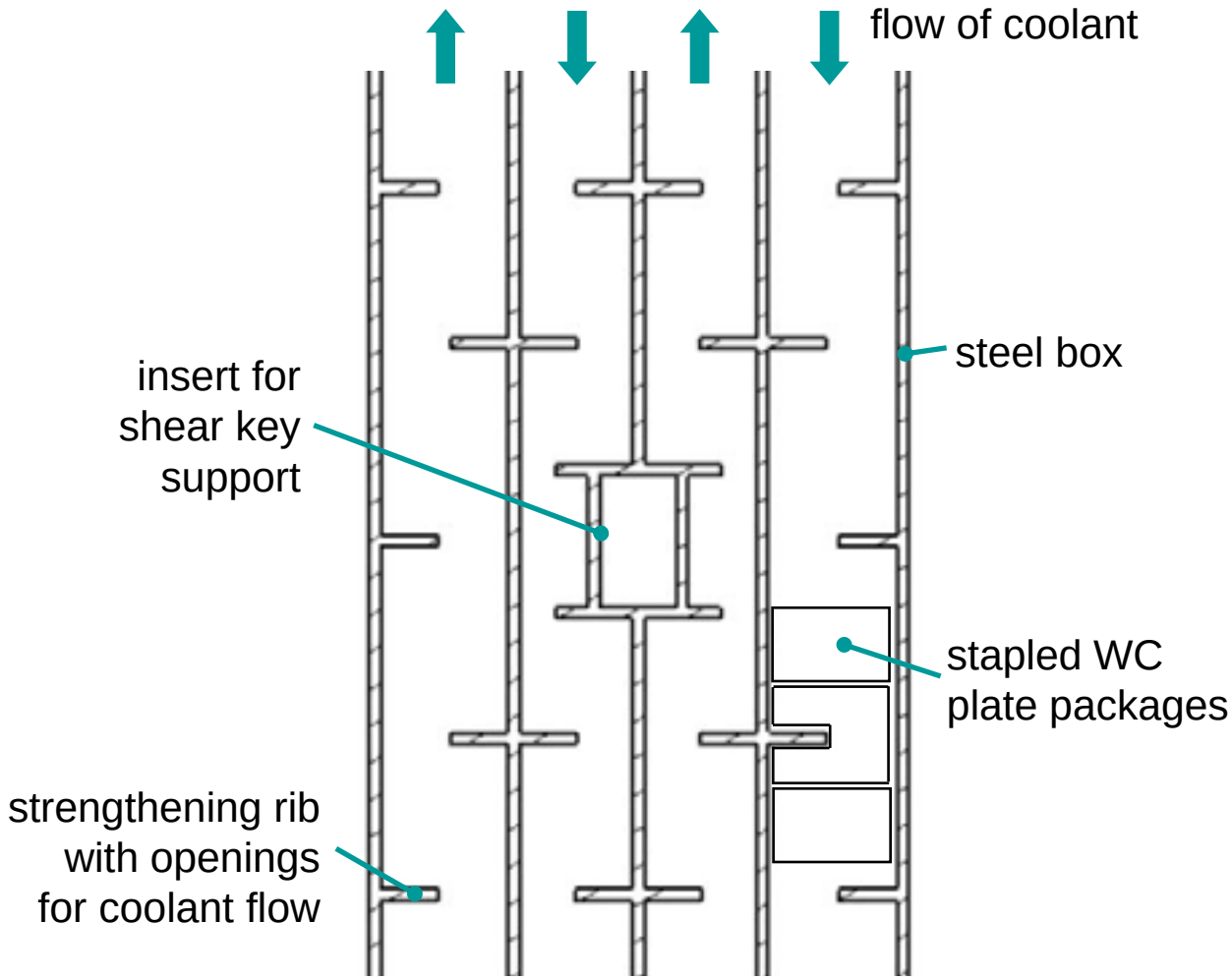
    ~10% He
    ~25% steel
    ~65% WC



principle build-up of HRS in the radial-toroidal plane

Design of Hot Ring Shield

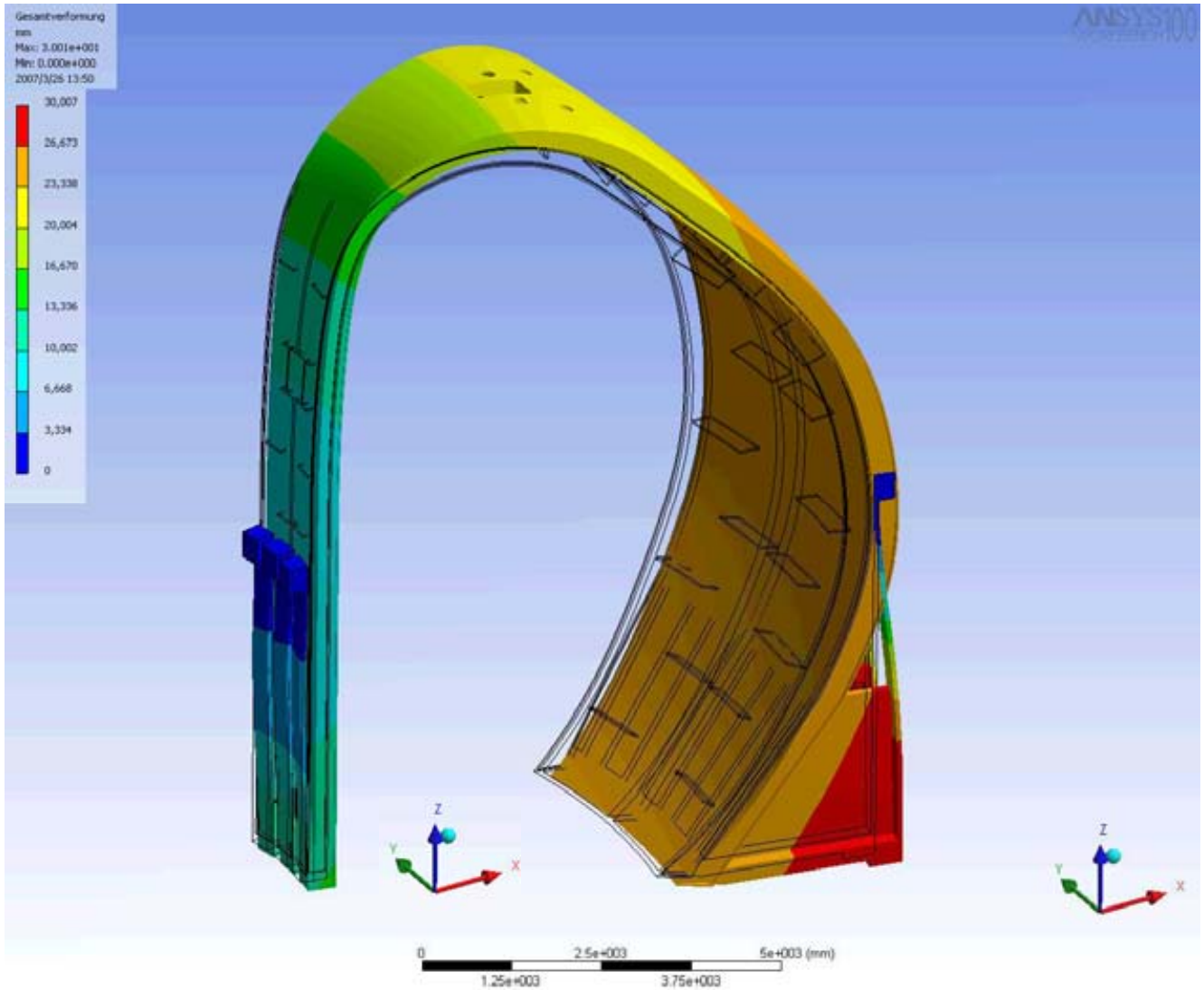
- HRS composition
  - strengthened
  - cooled



principle HRS configuration
in poloidal-toroidal plane

Design of Hot Ring Shield Evaluation

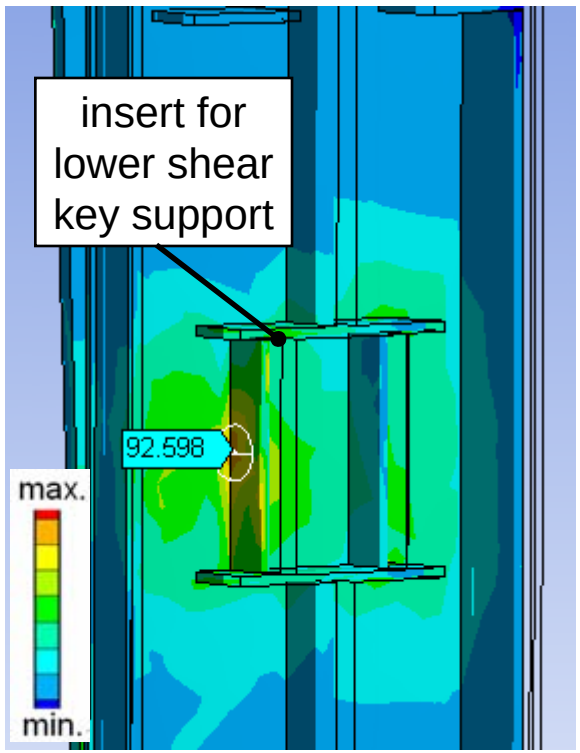
- FE model
  - Cyclic symmetric segment
  - Weight of shield and MMS
  - Thermal boundary conditions
  - Force loads at shear key positions

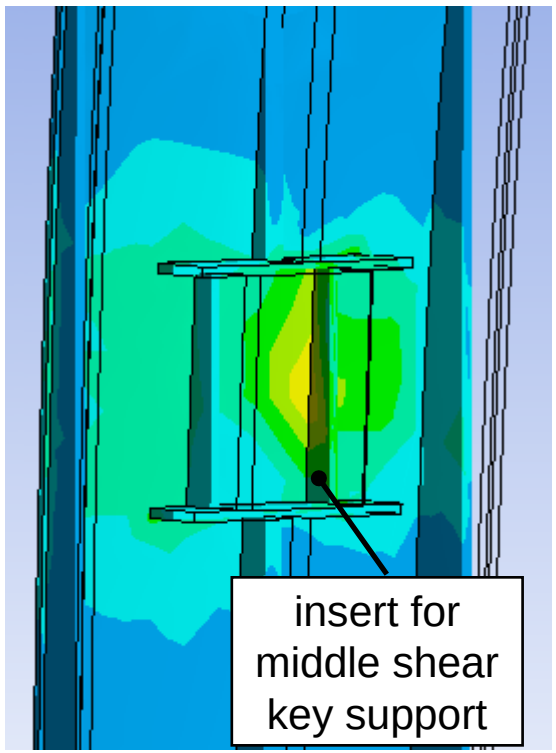


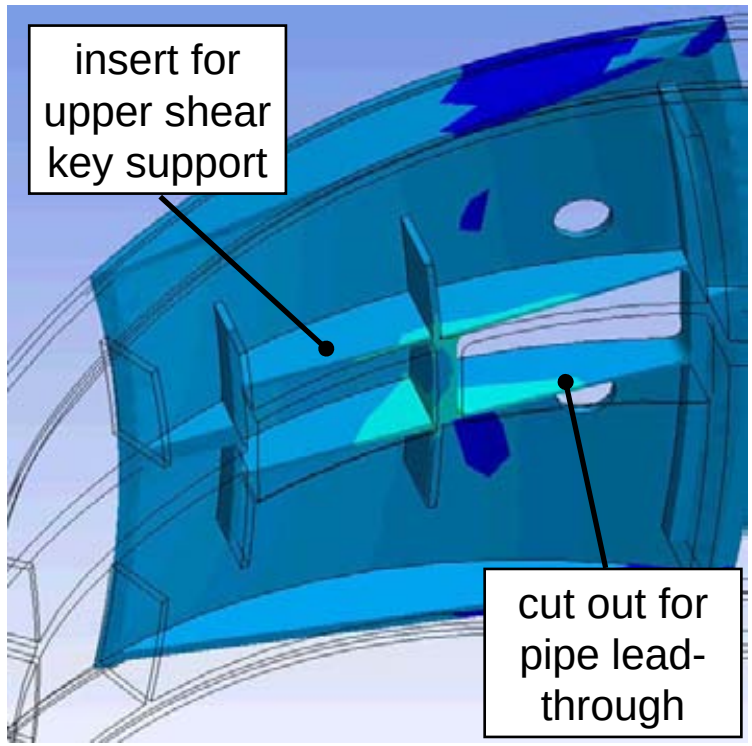
deformation under temperature load

Design of Hot Ring Shield
Evaluation of HRS: Gravity Loads + EM Loads

- Local evaluation at shear key position

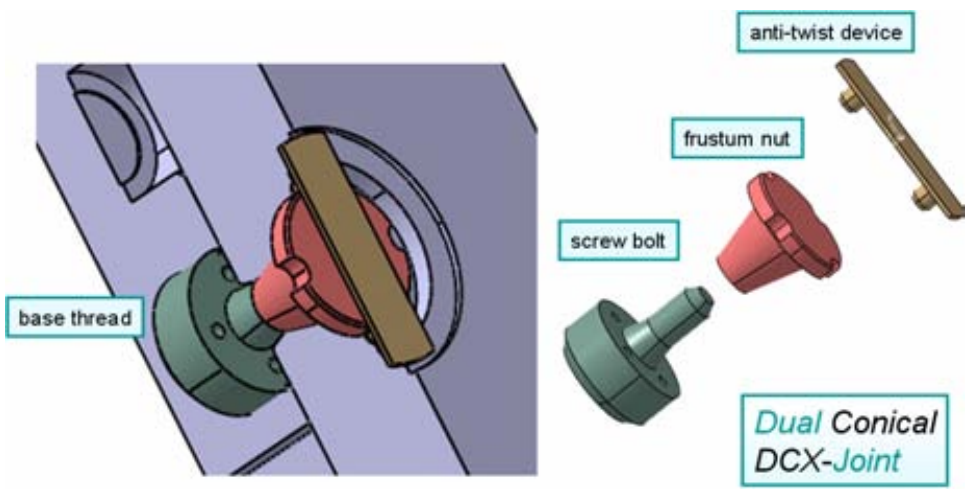


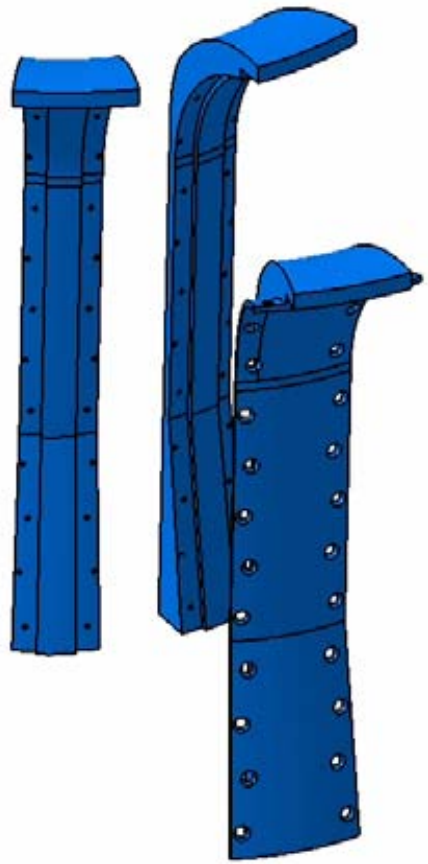


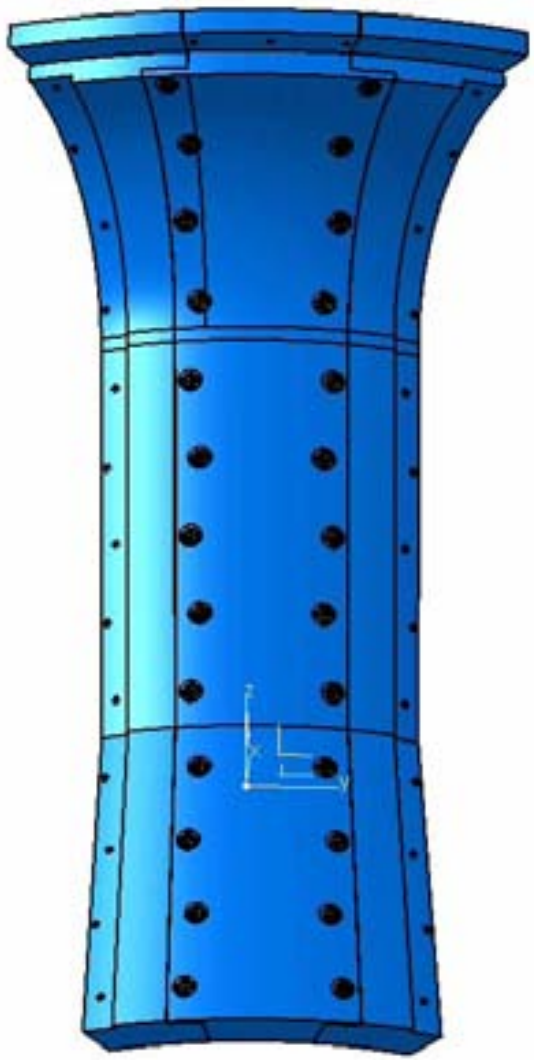


Design of Hot Ring Shield

- Requirements for joining of HRS segments
  - RH – suitable
  - Join elements completely removable (thread defects)
  - Removable locking device
  - Adjusting join tolerances







Summary

- Introduction of a promising integration concept for the blankets into a possible DEMO device
- The concept is far from being ready, but promising solutions have been proposed to the arising issues:
  - Attachment systems
  - Radial build
  - Maintenance scheme
  - etc
- Still more work to do
  - Detailed design solutions
  - Fabrication, manufacturing issues
  - cooling
  - etc