FUSION FOR ENERGY

NUCLEAR INTEGRATION ACTIVITIES FOR CONTROL OF RADIATION LOADS TO ITER SUPERCONDUCTING MAGNETS

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introduction
nuclear integration at ITER

- Ensure that systems are fit for the nuclear environment they are subject to:
  - ❑ evaluate radiation loads,
  - ❑ monitor design changes,
  - ❑ study/implement remedial actions, e.g. additional shielding but also other.
- Challenges:
  - ❑ Large number of systems.
  - ❑ Evolving designs.
  - ❑ Intricate & far reaching impacts in nuclear responses everywhere.
  - ❑ Complex & world-wide distribution of procurement responsibilities.
- Need for solid systems engineering approach, involving all stakeholders and sustained during design evolution and construction, which trades-off between different performance, cost and schedule requirements.
- Also need for intensive nuclear analyses using extensive and detailed 3D models, state-of-the-art acceleration techniques and massive computer resources.
- Illustrated here via example of superconducting magnets.

introduction
superconducting magnets & radiation loads

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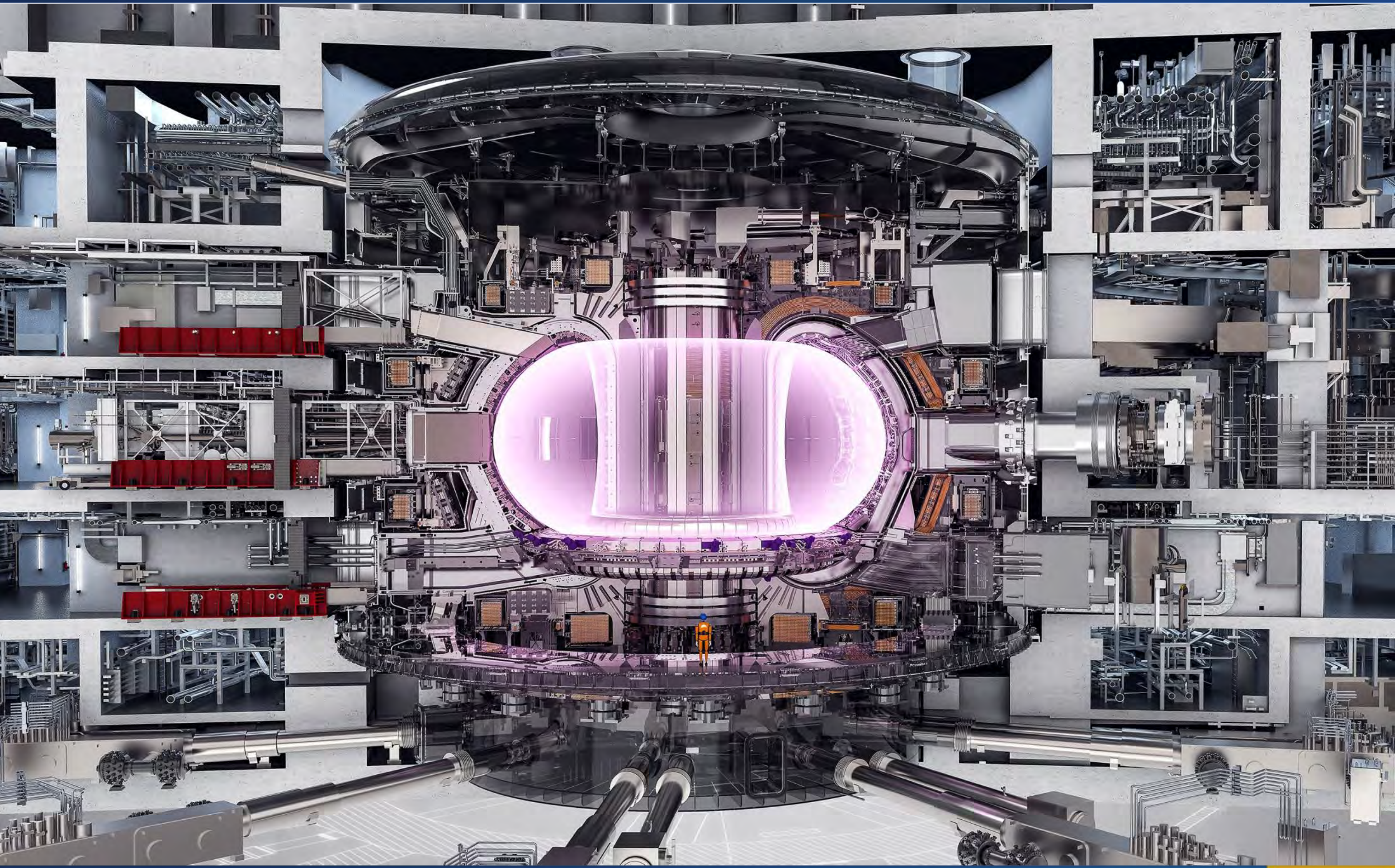

introduction
superconducting magnets & radiation loads

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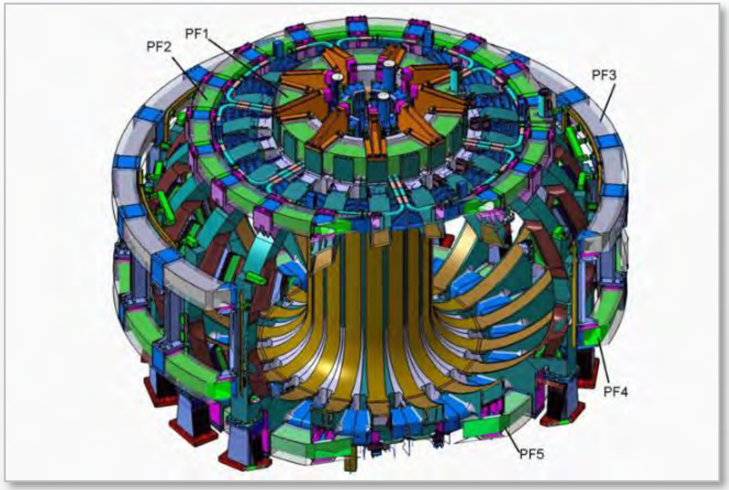
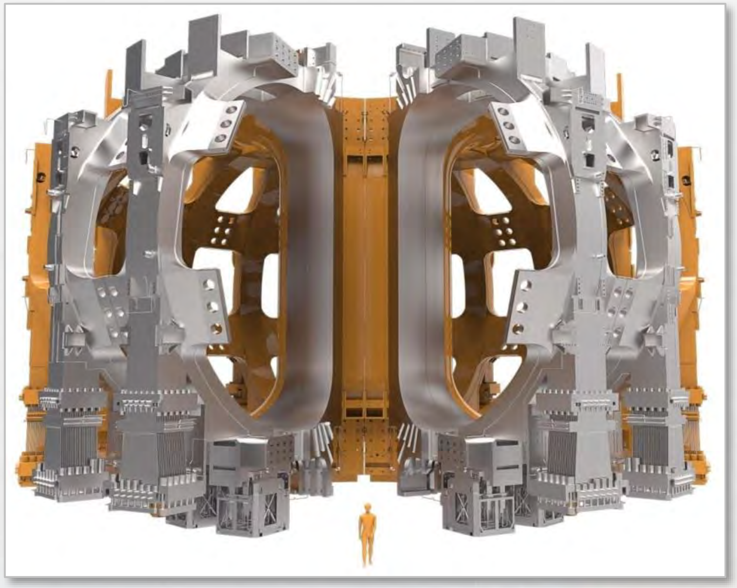
- ITER superconducting magnets:
  - 6 x poloidal field coils (10 to 25m diametr), NbTi + Cu cooled at 4K
  - 18 x toroidal field coils (10m x 7m, 450t), NBSn + Cu cooled at 4K
- Radiation sources:
  - 500 MW DT burning plasma (14.1 MeV neutrons).
  - Activated water in in-vessel cooling system, a.k.a. TCWS (<7 MeV photons from N-16 and <3.5 MeV neutrons from N-17).
- Responses of interest: on-load heat deposition, dose to insulator, fast fluence to superconductor.
- Affected by the design of all in-vessel, vessel and thermal shields.





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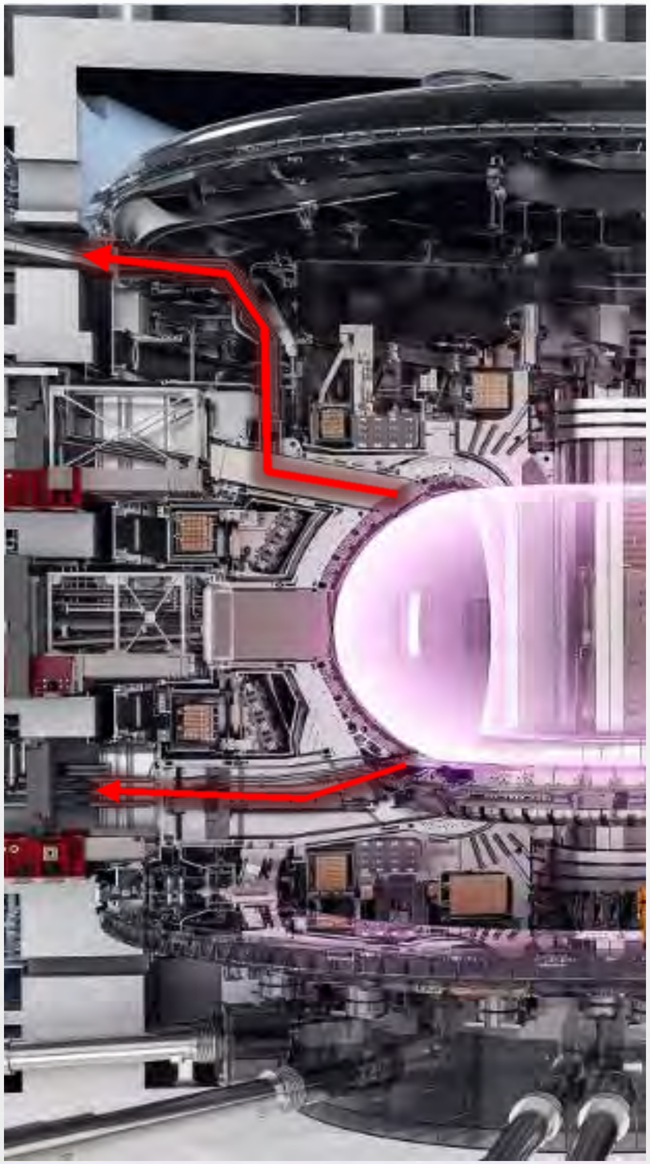
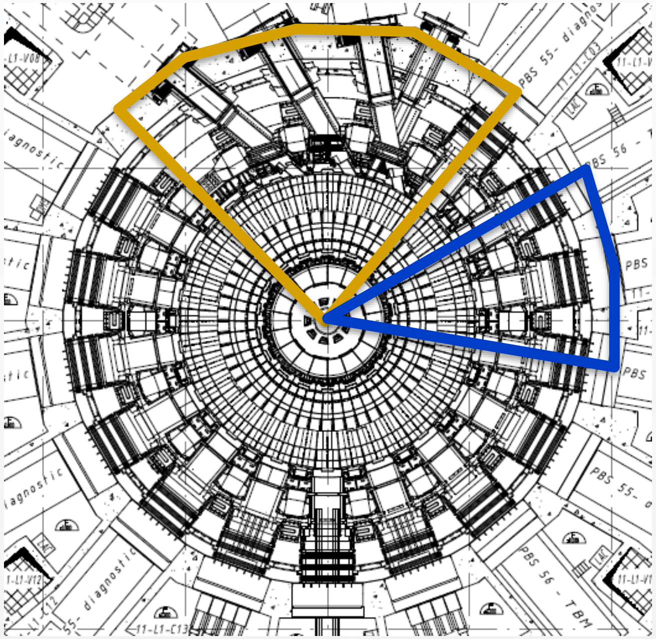
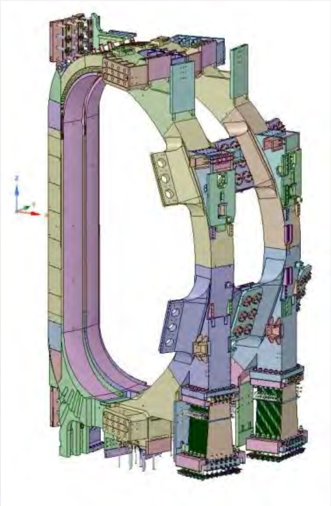
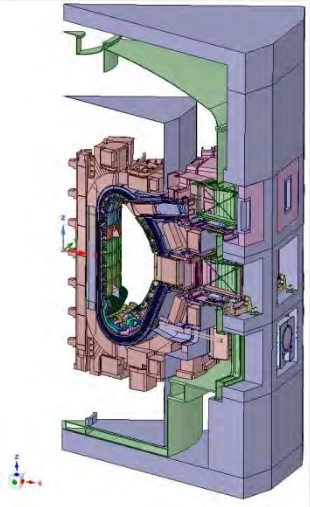


computer models and methods

- Basis of modelling:
  - ❑ Representative 40deg regular sector model: *C-lite* (preliminary) or *C-model* (final).
  - ❑ 80deg irregular sectors model: "***NBI model***".
- Plasma source.
- TCWS source.
- MCNP6.1 + FENDL2.1 libraries (also 3.1b test).
- ADVANTG WW and source biasing, 5×10^9 to 1×10^{10} original source particles.
- F4 and F6 tallies: TFC poloidal sectors and radial winding pack layers, PFC conductor turns, integrals.







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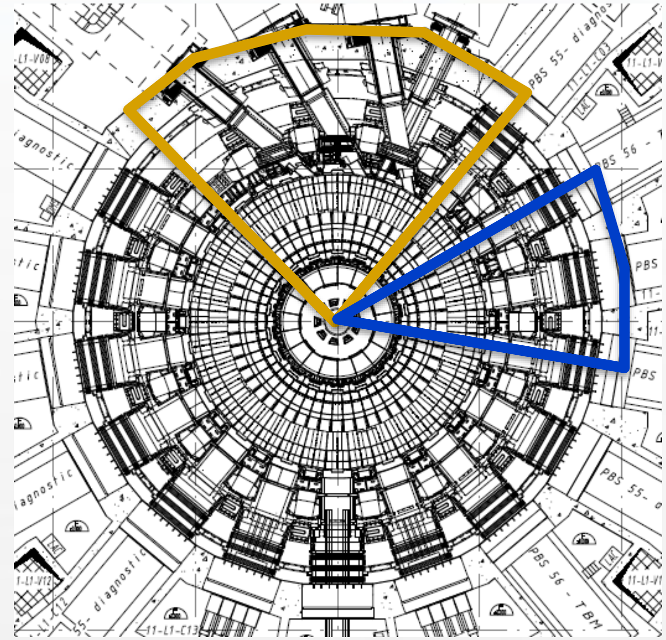

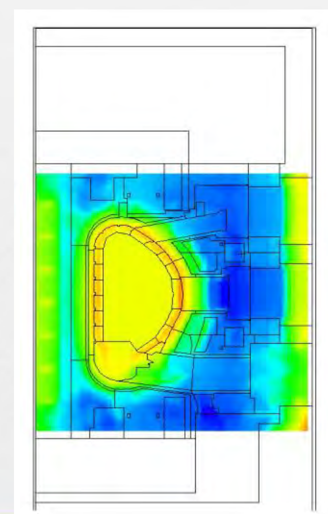

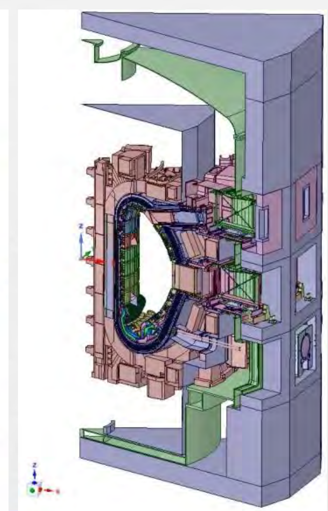

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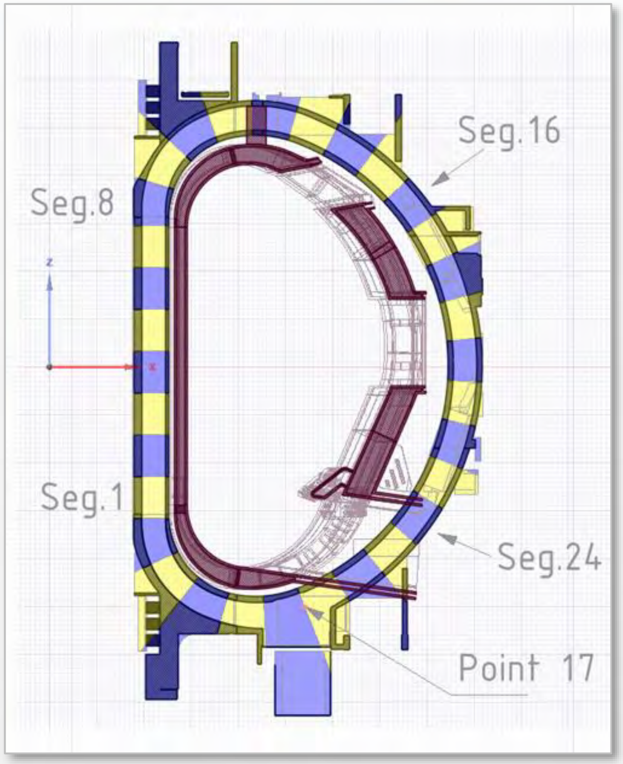
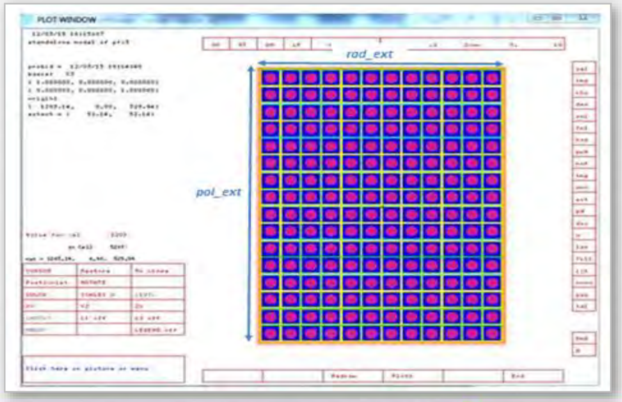
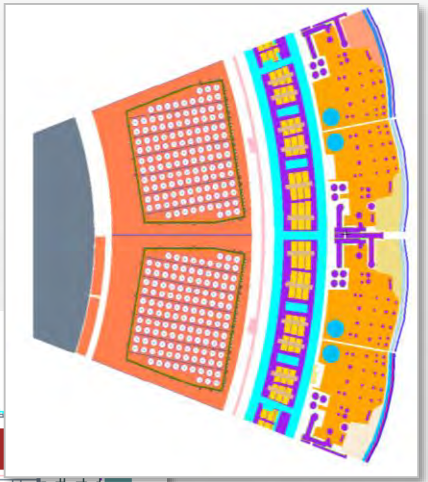
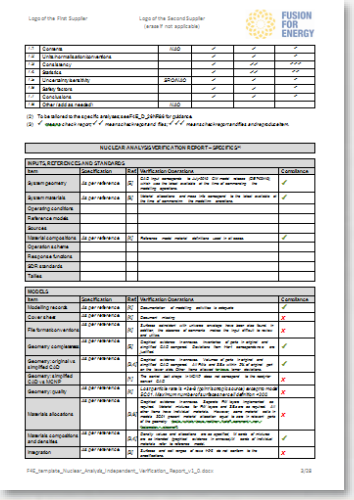


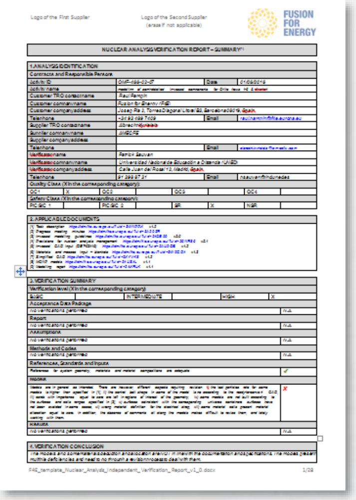


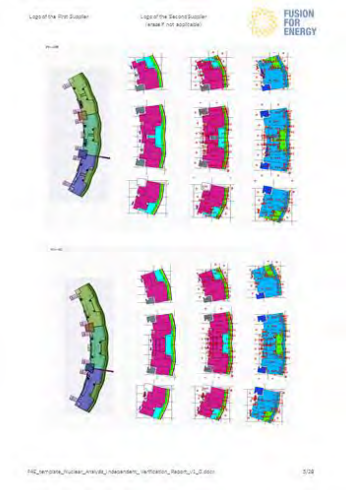
computer models and methods
ITER reference neutronics models

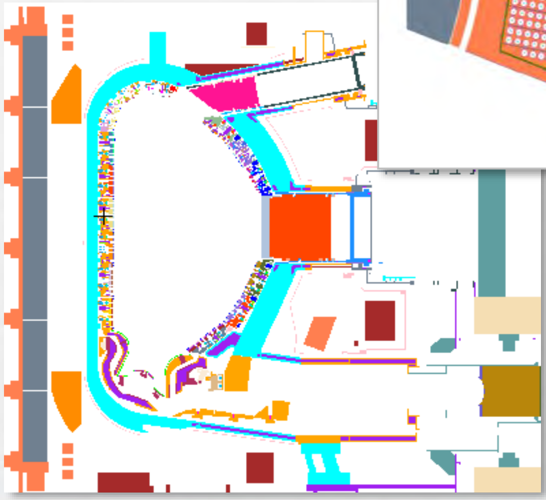
- C-lite → C-model: large investment in order to:
    - ❑ update component representations,
    - ❑ increase detail and minimise need for corrections.
- Emphasis in quality assurance:
    - ❑ Automated conversion to MCNP from validated CAD data.
    - ❑ Standardised modelling methods.
    - ❑ Independent verifications of component representations.



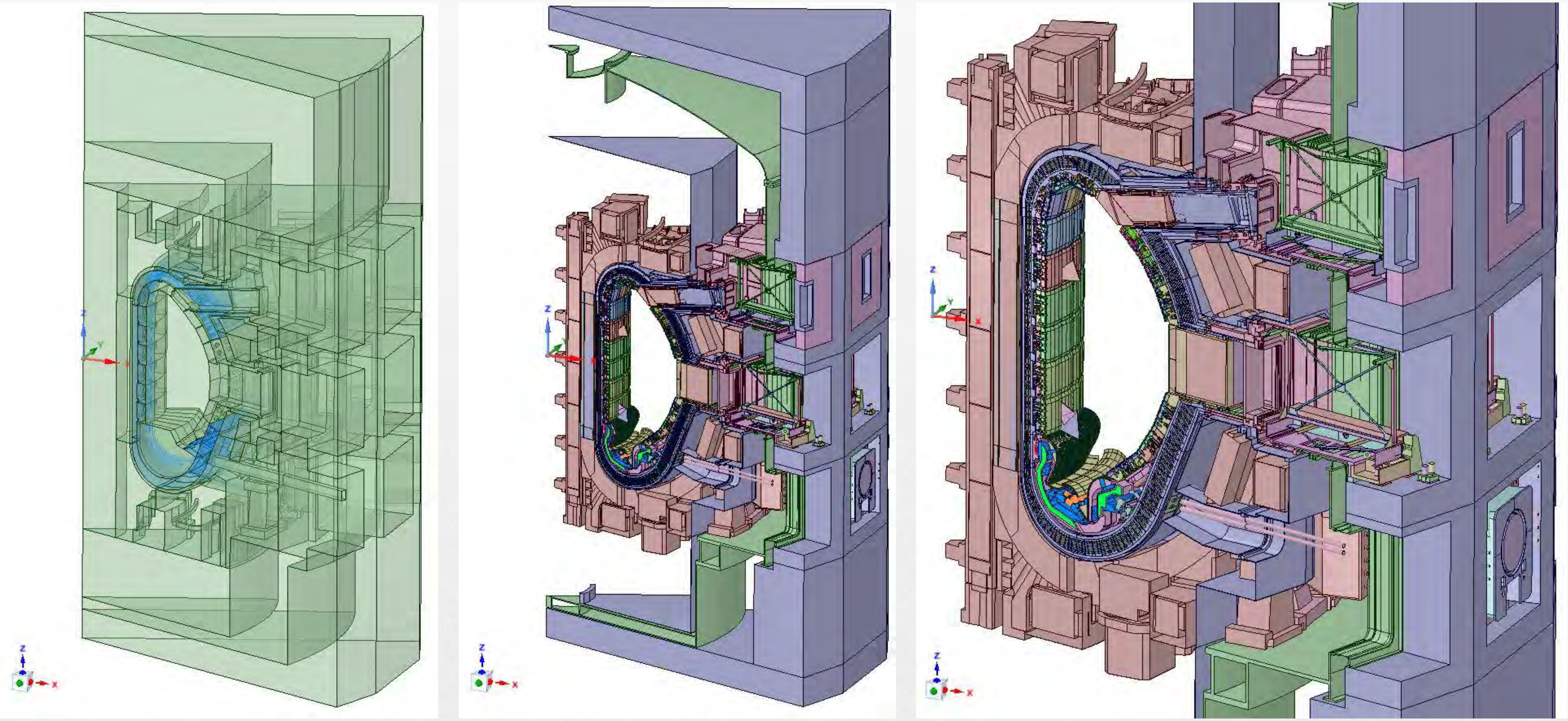








computer models and methods
ITER reference neutronics models



computer models and methods
model improvements and design changes

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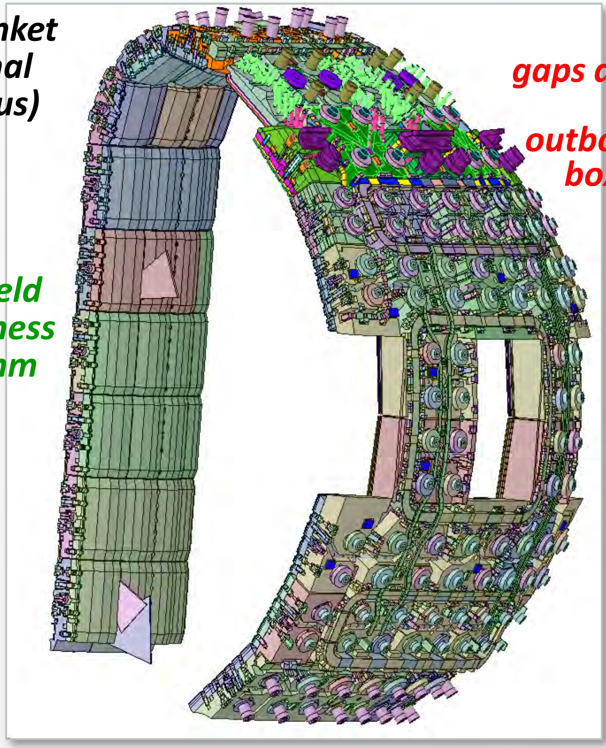
detailed blanket models (final design status)

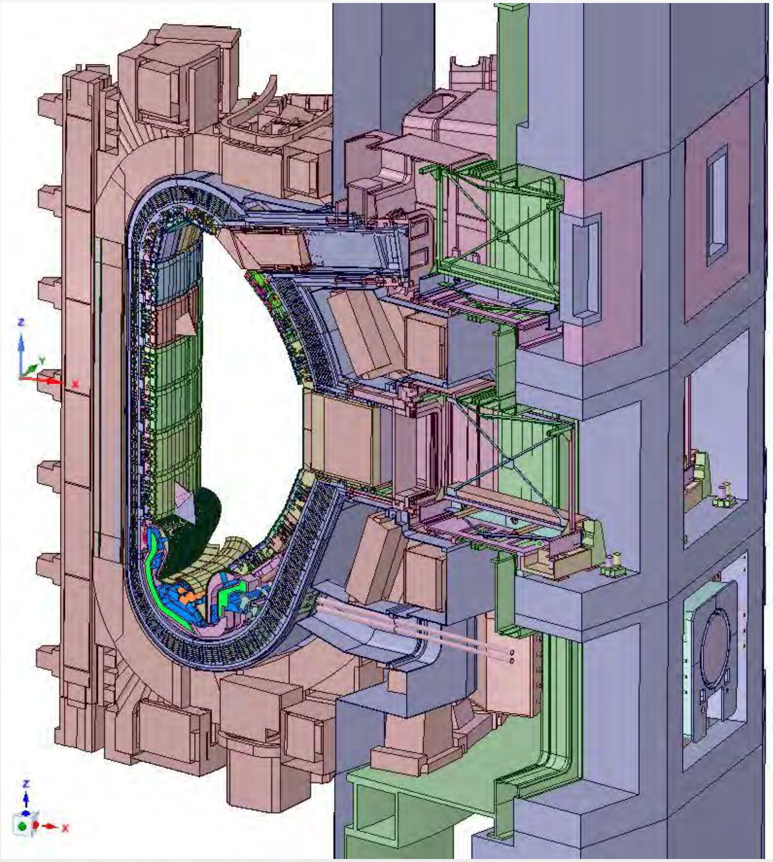


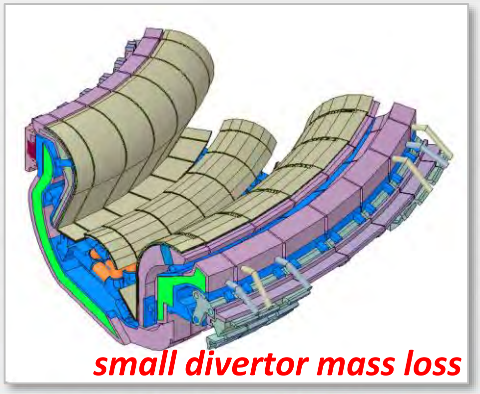
gaps around UPs increased

outboard manifold shield box (MSB) mass loss

inboard shield blocks thickness added 20 mm

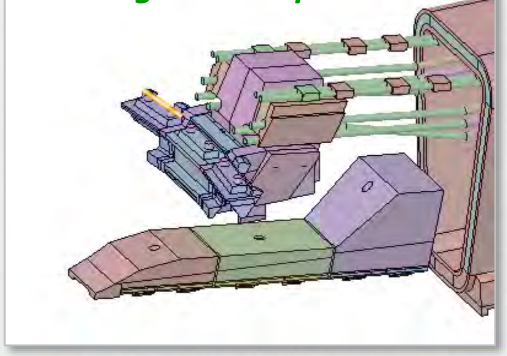
doglegs around EPs





small divertor mass loss

shielding in lower port added



computer models and methods
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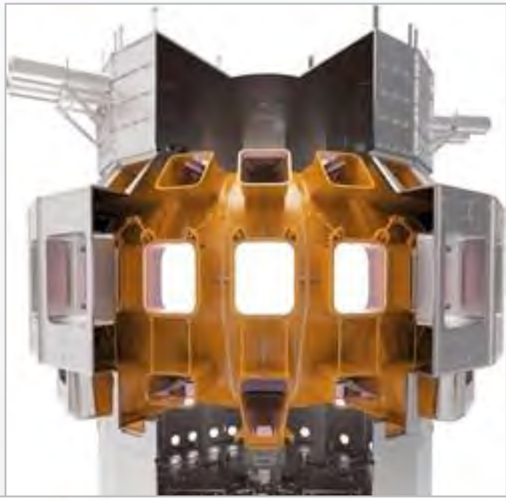
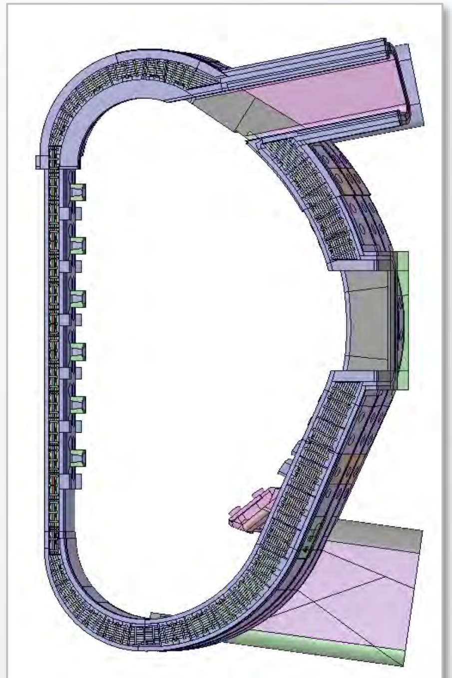
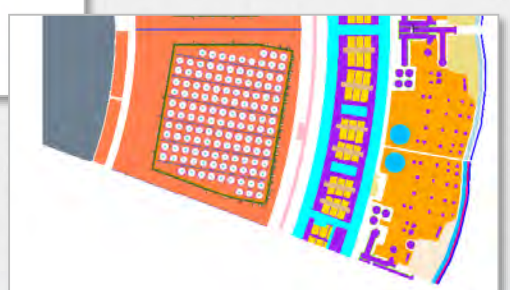


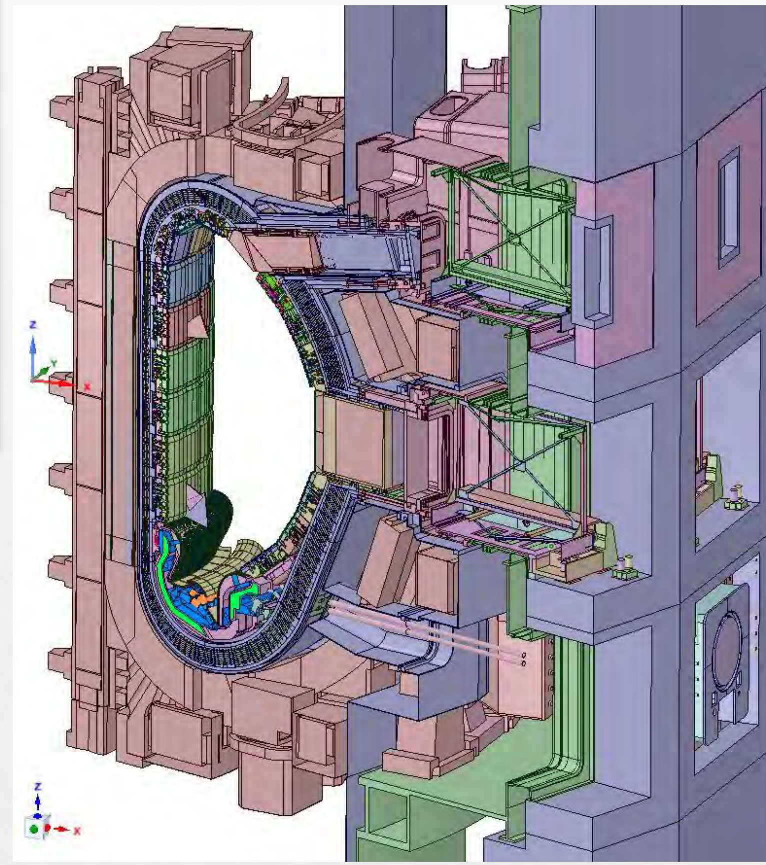
Figure 4-3: ANS Interfaces

thermal shield additional nuclear shield plates (ANS) removal

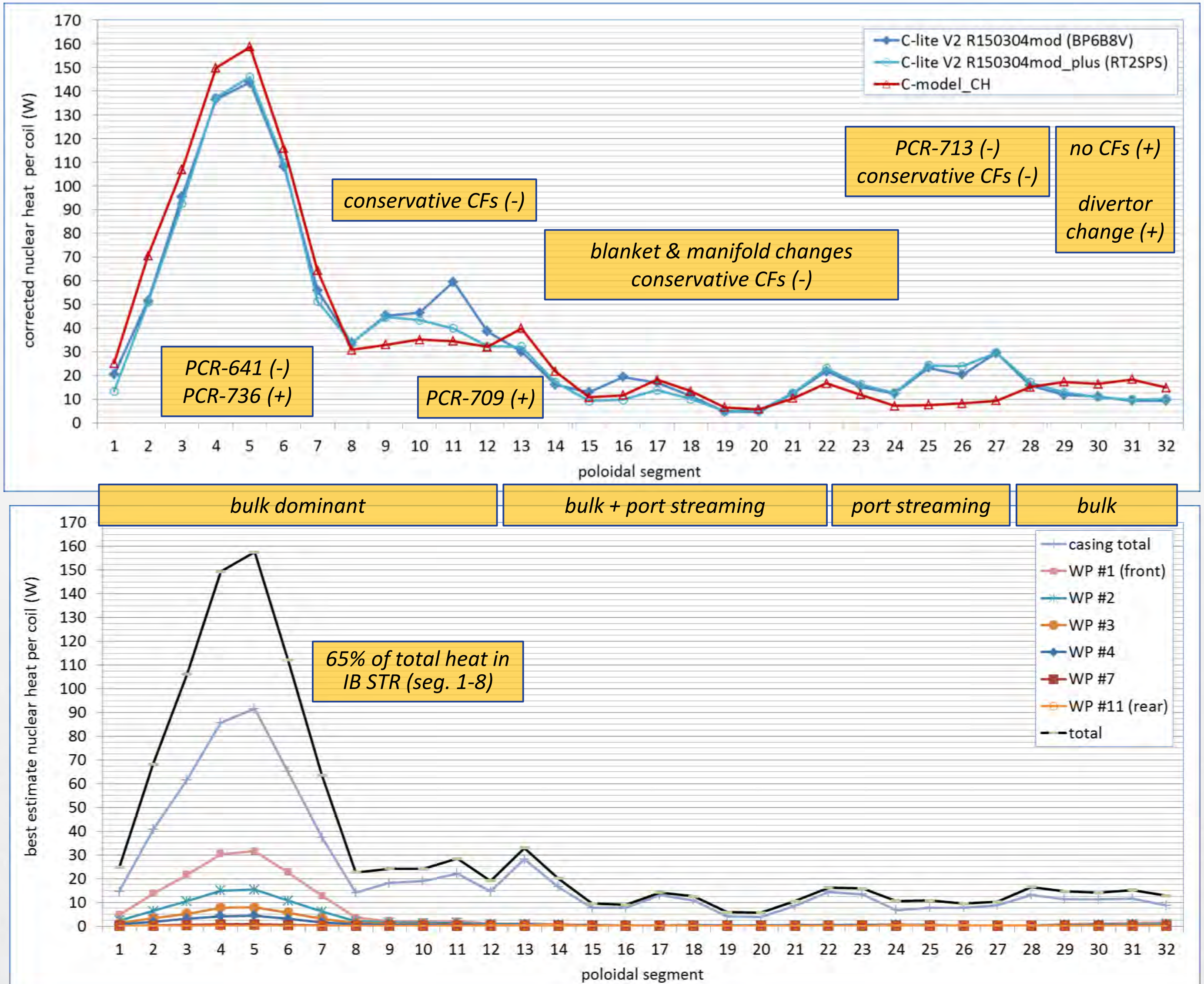


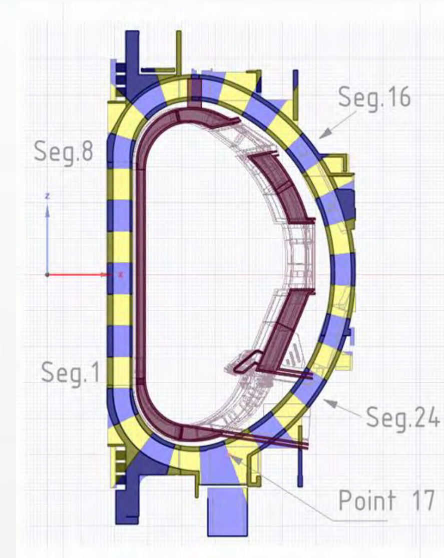
VV heterogeneous model (manufacturing design status)

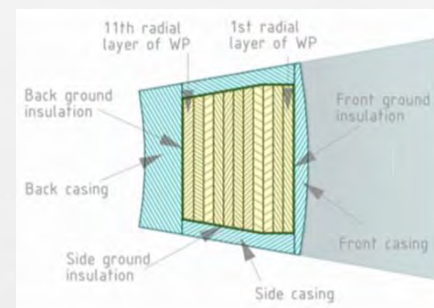




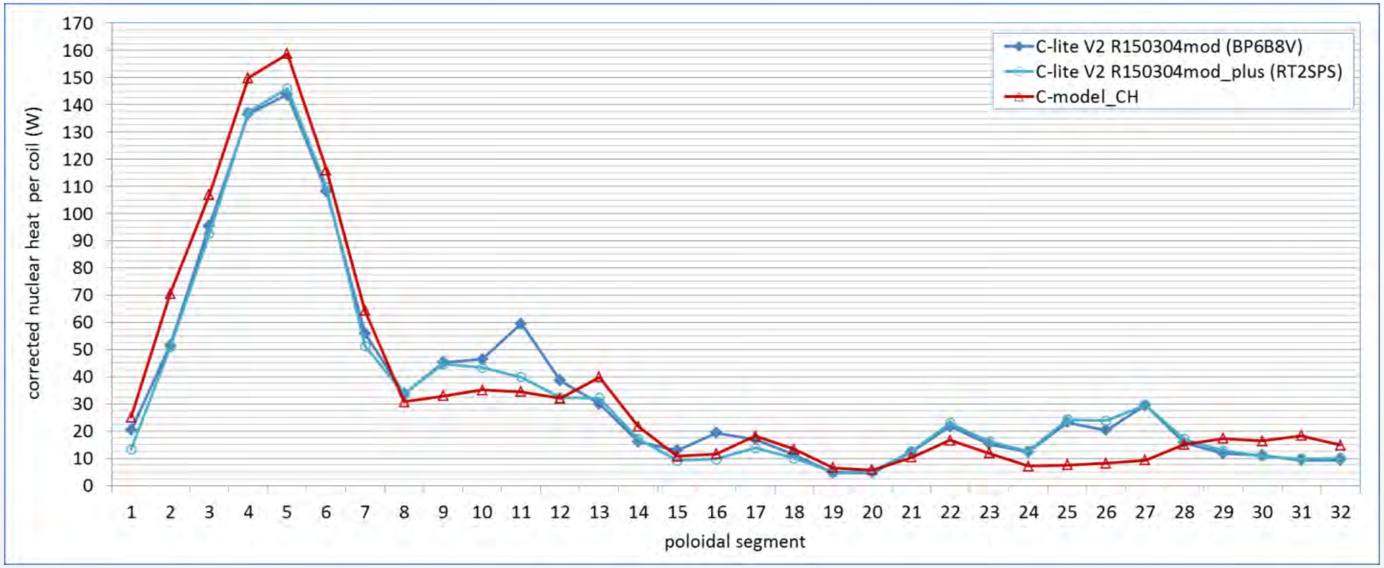
nuclear responses in TFCs profiles

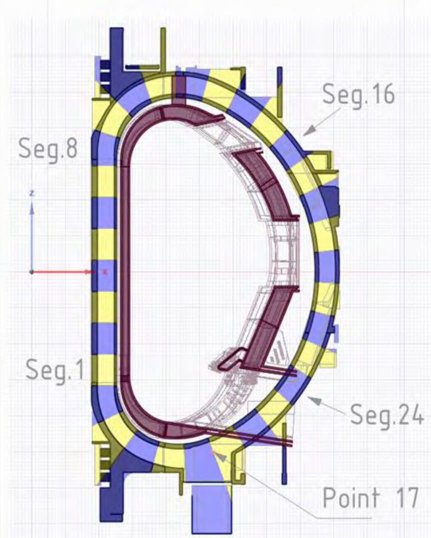


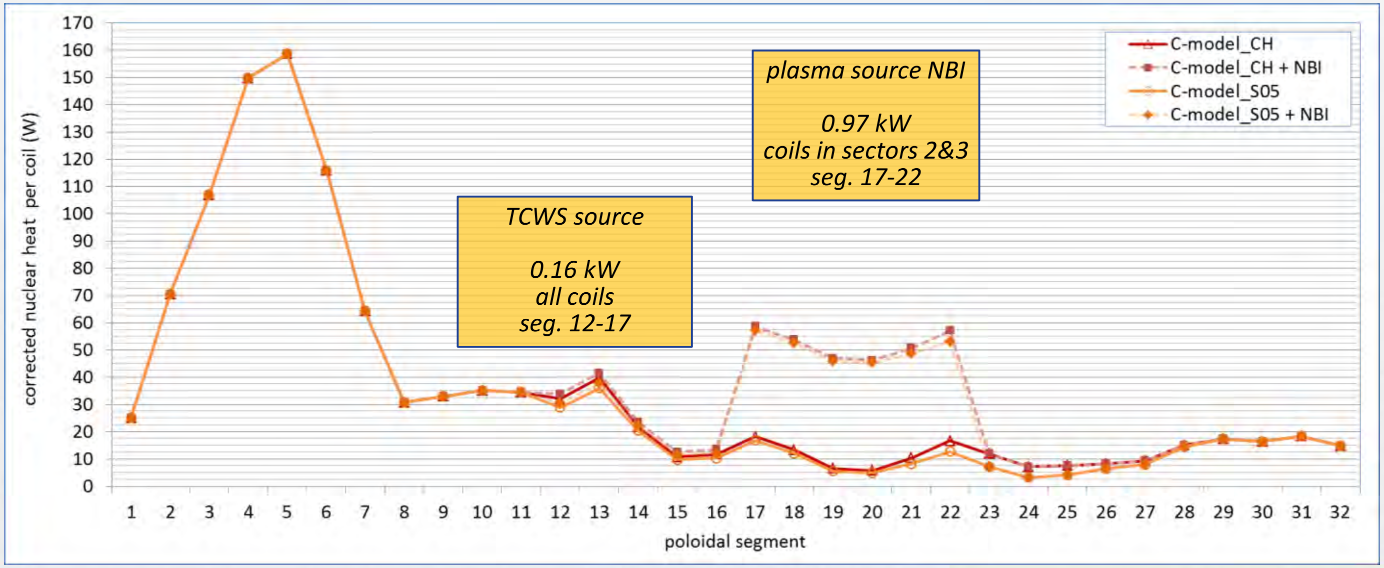


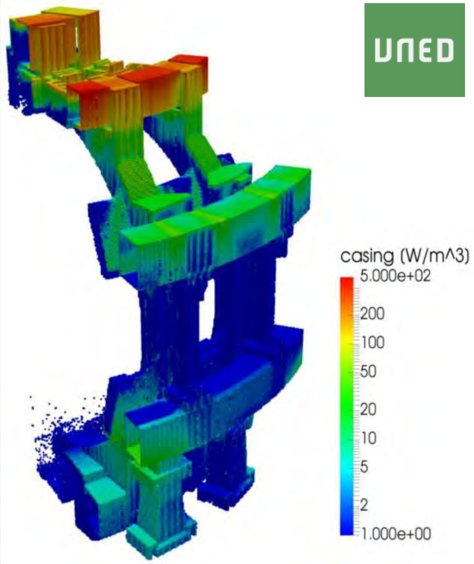


nuclear responses in TFCs NBI & TCWS contributions



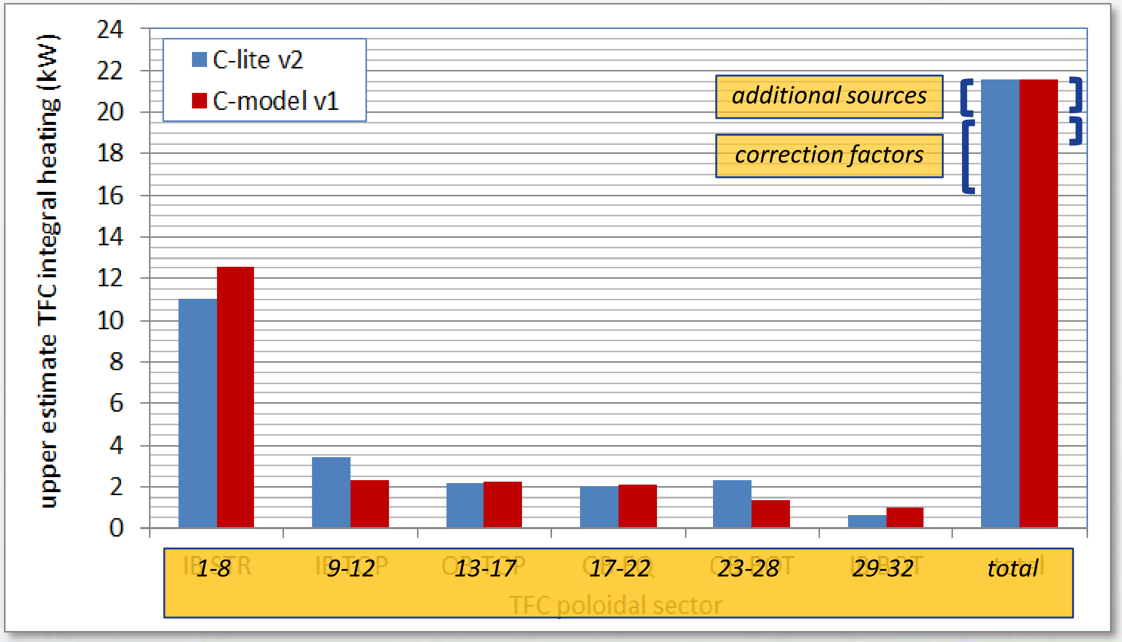






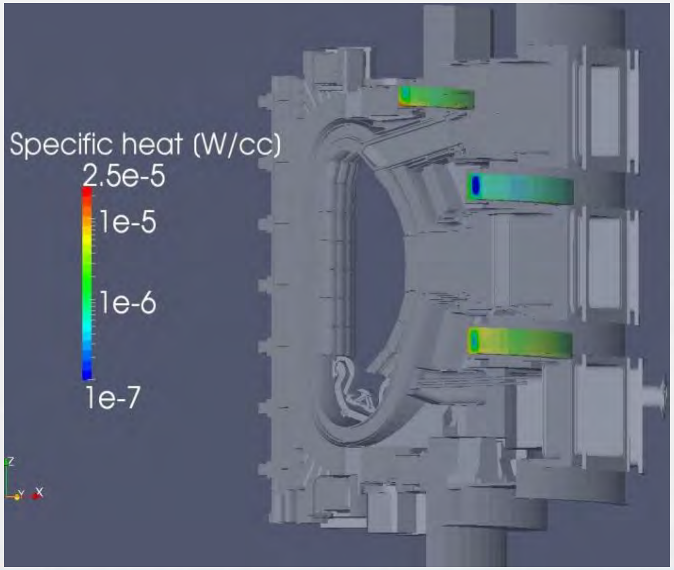
nuclear responses in TFCs
integral heating upper estimate

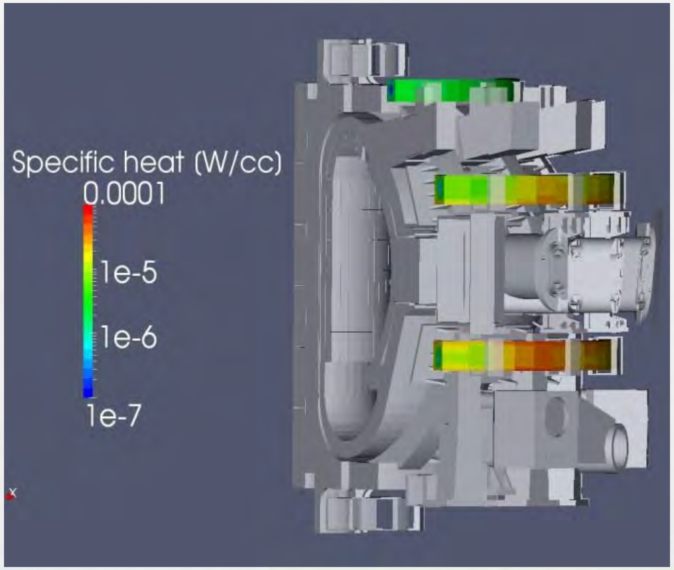
- Despite changes in profiles, upper integral estimate stable at 21.6 +/- 3.0 kW.
- However, more heating goes now into the winding pack of the inboard leg.
- Other measures (not shielding related):
  - ❑ Allocation of best performing conductor in NBI coils.
  - ❑ Increase of cryoplant capacity to 24 kW.
- To watch out: further in-vessel design changes and port plug design.

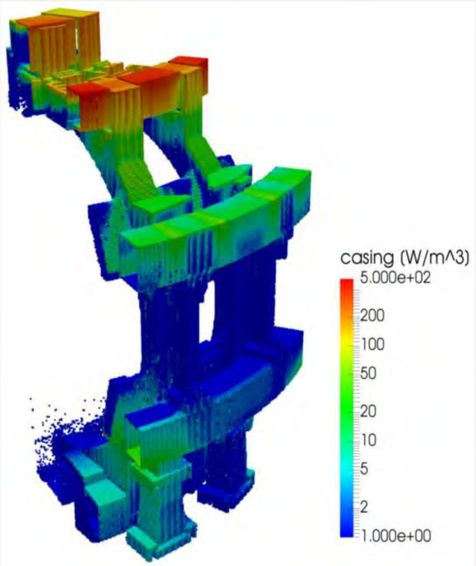


nuclear responses in PFCs preliminary profiles

- Preliminary (C-lite) results available, final (C-model) analyses ongoing.
- Review of TCWS contribution also ongoing.
- Noticeable differences in deposition locations and profiles from regular plasma neutrons, NBI plasma neutrons, and TCWS (gamma).
- However, the three integral contributions have similar magnitude; preliminary total upper estimate at 1.9 +/- 0.3 kW (does not account for C-lite → C-model changes).







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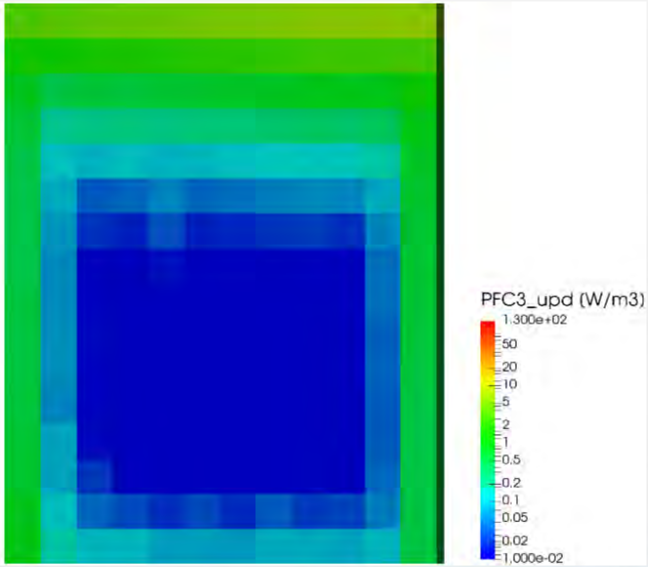

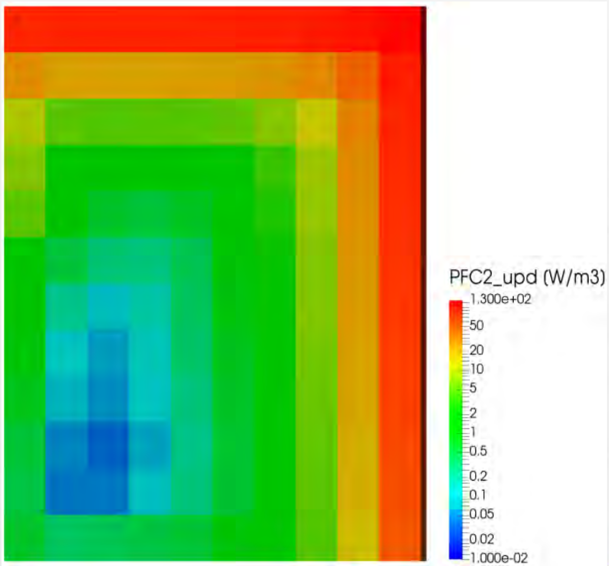

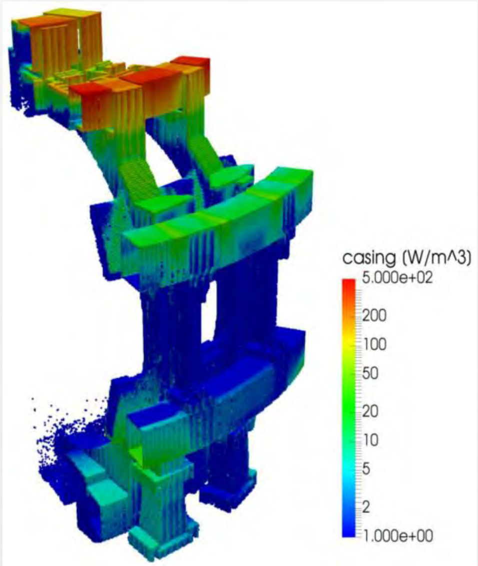

nuclear responses in PFCs
preliminary upper estimate integral heating

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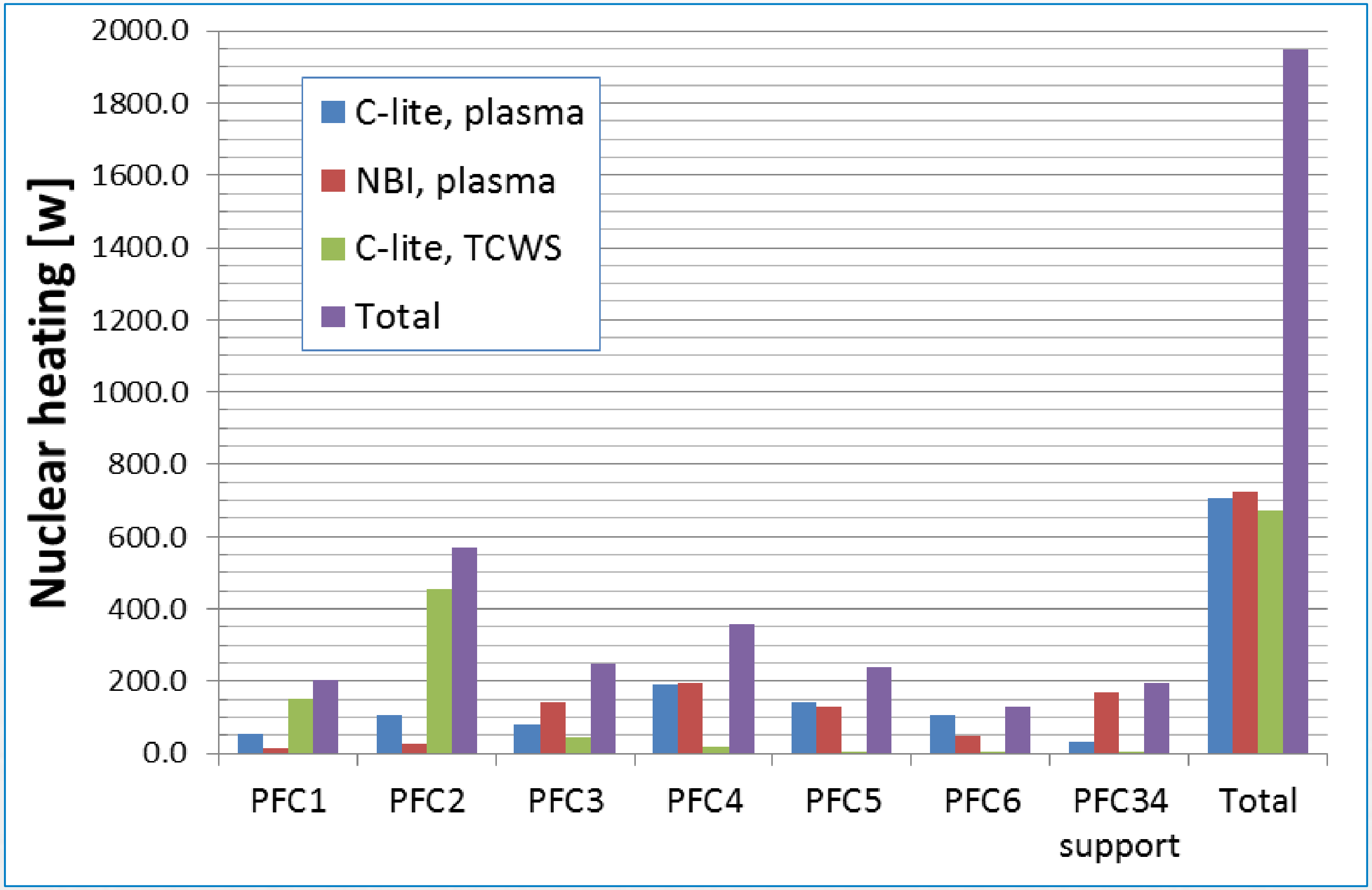

nuclear responses in PFCs
updating & mitigating contributions

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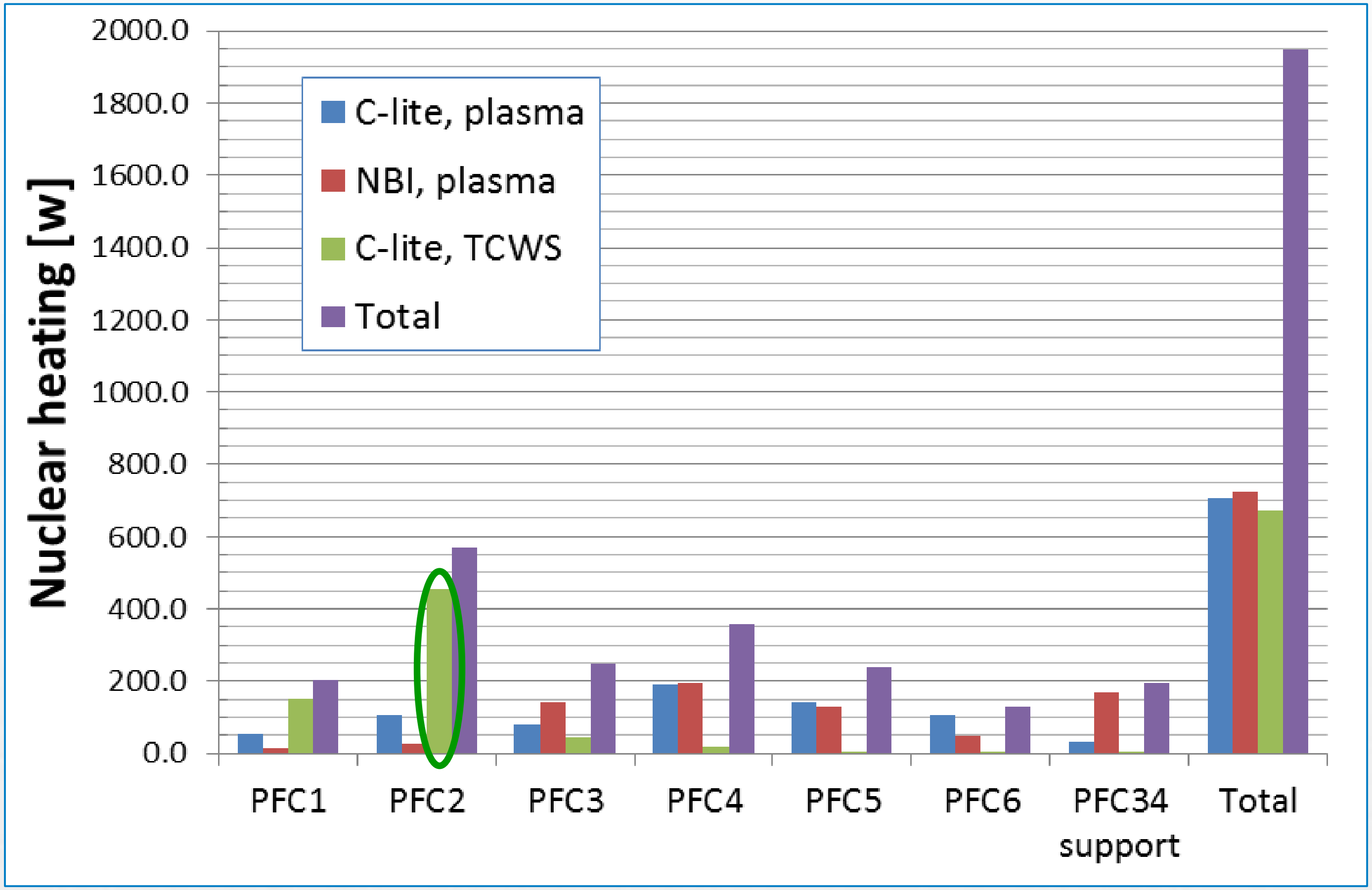
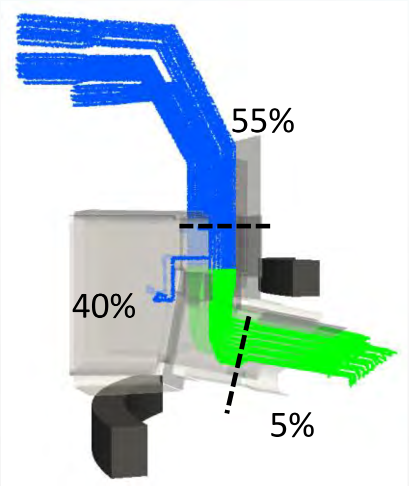
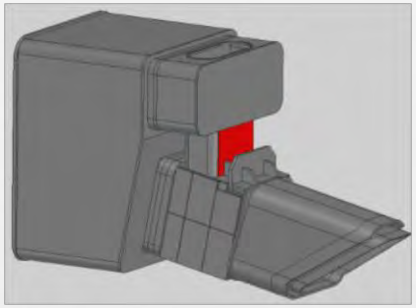
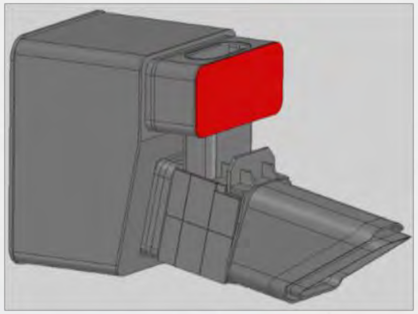
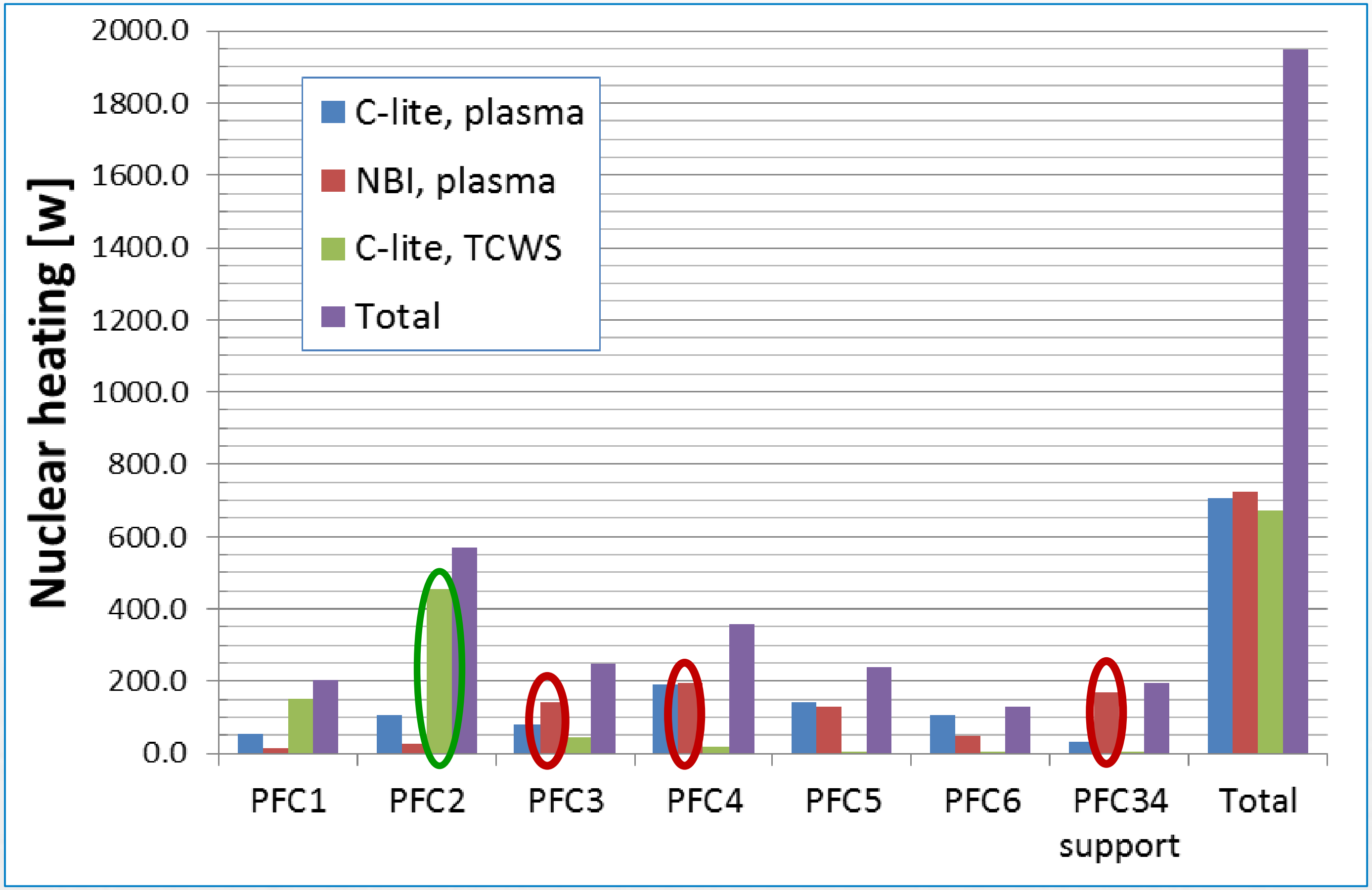


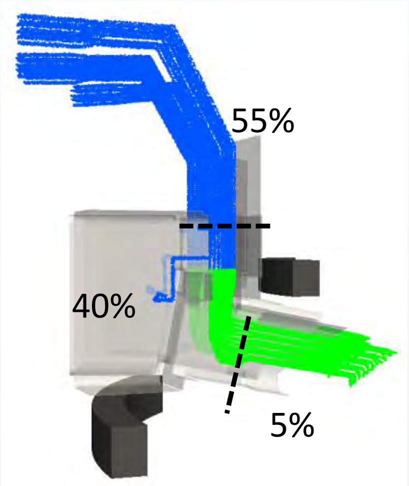


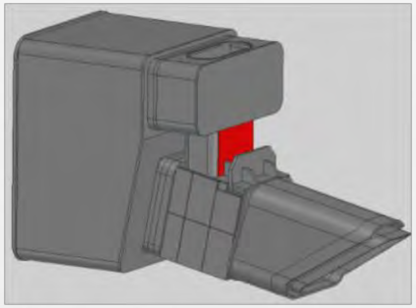


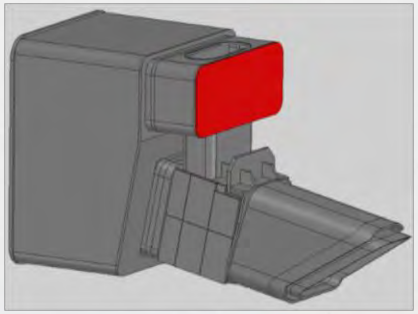


nuclear responses in PFCs updating & mitigating contributions









conclusions

- Ensure that ITER superconducting magnets are fit for their nuclear environment: evaluate loads, monitor design changes and study/implement shielding and other remedies.
  - ❑ Example of challenges of nuclear integration in ITER, and of a systems engineering approach aimed at optimal compromise and overall success.
  - ❑ Also example of intensive nuclear analyses using extensive and detailed 3D models, state-of-the-art acceleration techniques and massive computer resources.
- Large effort invested in order to update component representations, reduce systematic uncertainties, and emphasise quality assurance.
- Toroidal field coils:
  - ❑ Integral and profile heating values computed to account for improved modelling and design changes affecting these parameters.
  - ❑ Some design changes had noticeable detrimental effect (e.g. at thermal shield), counteracted by introduction of additional shielding elsewhere (e.g. at lower port).
  - ❑ Consequently, heating profiles suffered some changes but the upper integral value remains stable at 21.6 +/- 3.0 kW. Minor contributions from TCWS and NBI.

conclusions

- Toroidal field coils (cont'd):
  - ❑ Other mitigating actions (not shielded related) also taken.
  - ❑ Radial/poloidal profiles for the coils in different VV sectors have also been obtained.
- Poloidal field coils:
  - ❑ First preliminary profiles and conservative integral PFC heating found at 1.9 +/- 0.3 kW. NBI and TCWS contributions at same level as regular plasma.
  - ❑ Estimates of NBI and TCWS contributions considered in this and earlier work are outdated (but conservative) and being revised.
- Further remedial actions necessary:
  - ❑ Additional gamma shielding in UP chimney & chimney box.
  - ❑ Additional neutron shielding in NBI ducts.
  - ❑ Control design evolution of in-vessel, port plugs, TCWS piping (guard duct).

Thank you for your attention!

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