Thermal-hydraulic characterization of the ITER Toroidal Field Insert coil

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Background

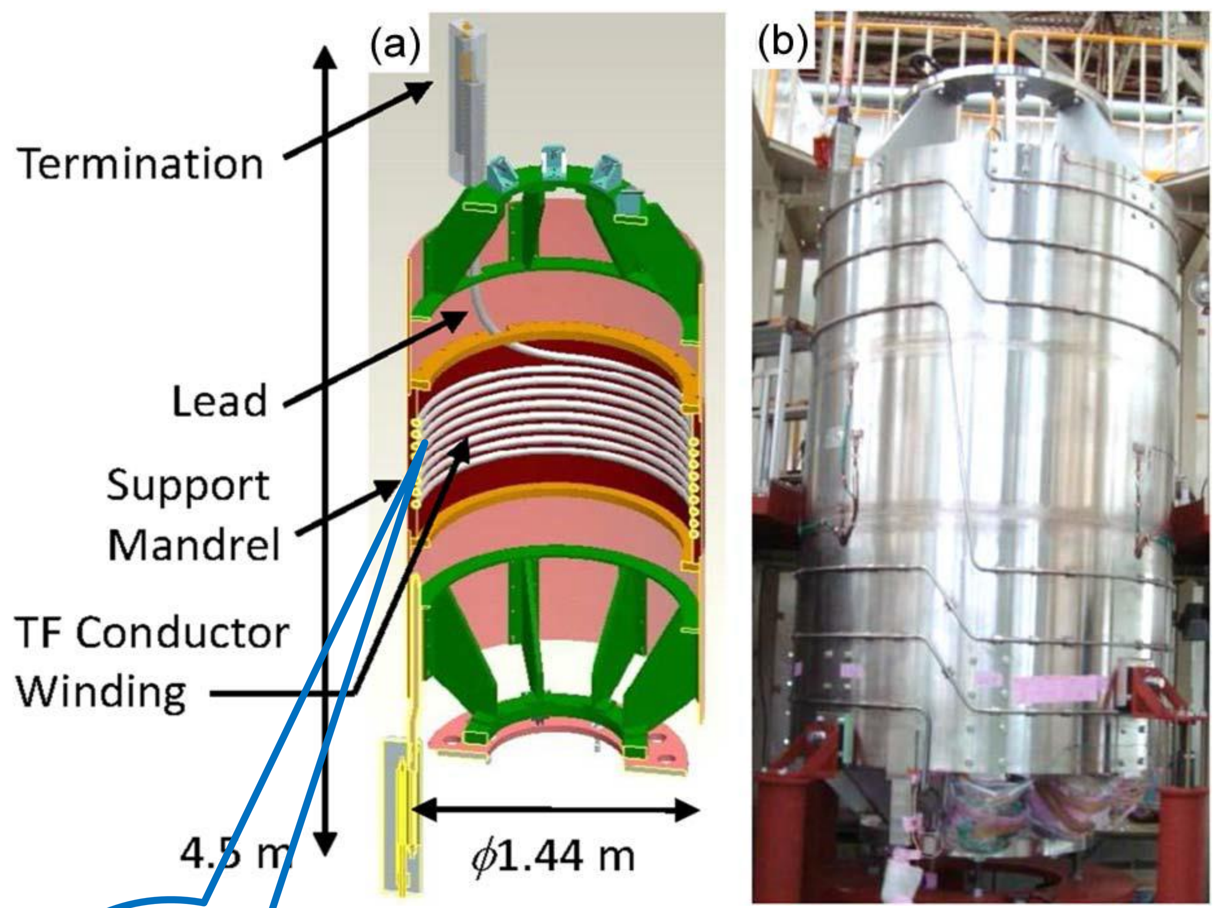
The ITER Toroidal Field Insert (TFI) coil:

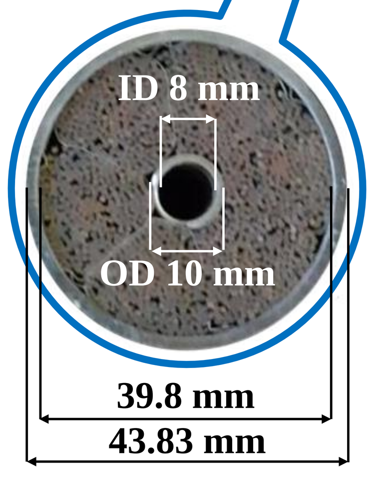
- single-layer Nb_3Sn solenoid;
- tested in 2016-2017 at QST (Naka, Japan) in the borehole of the Central Solenoid Model Coil;
- tested in ITER- relevant operating conditions;
- multiple tests performed to characterize the behavior of the coil → dedicated Δp measurements, heat slugs with resistive (RH) and inductive (IH) heaters.

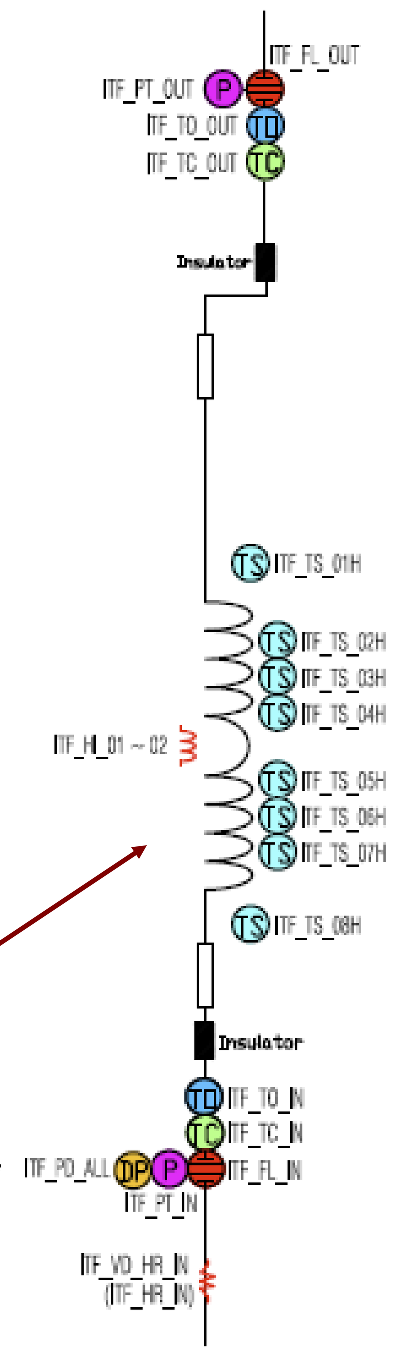
Objective

Analyze data collected during tests of the TFI to deduce (thermal-) hydraulic constitutive relations to be used in the 4C code.

Experimental setup



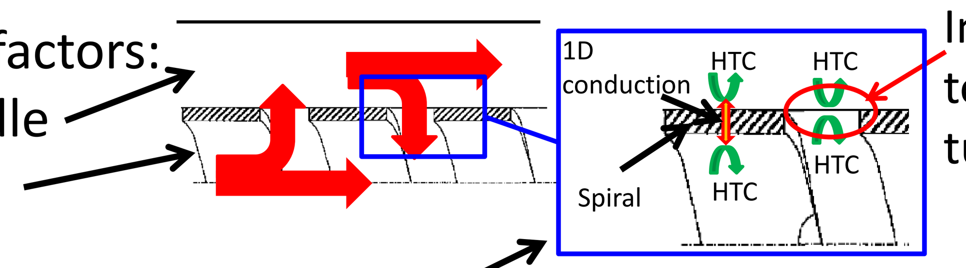




- Diagnostics: mass flow meters, pressure taps and temperature sensors
- Cernox *T* taps are glued (uncertainty on glue properties) on the TFI jacket (local kapton insulation is removed)

TH constitutive relations in the 4C code

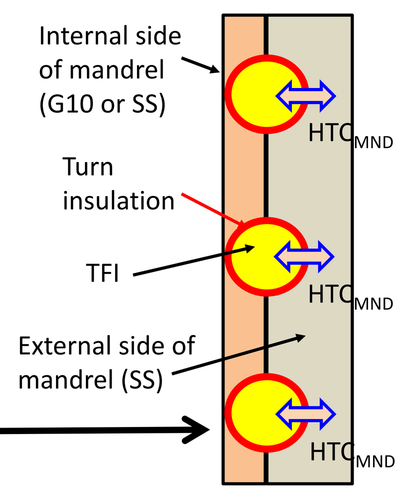
- Friction factors:
  1. - Bundle
     - Hole



Increase of $HTC_{nospiral}$ to account for local turbulence

- Heat transfer coefficients
  2. - Bundle – Hole
     - Strand – Bundle
     - Jacket – Bundle
     - Jacket – Strand
  3. - Conductor – Mandrel

TFI thermally coupled to the mandrel through turn insulation (~1.4 mm) → need to calibrate HTC_{MND}



Hydraulic characteristic

[V. I. Tronza, *IEEE Trans. Appl. Supercond.*, 2015]

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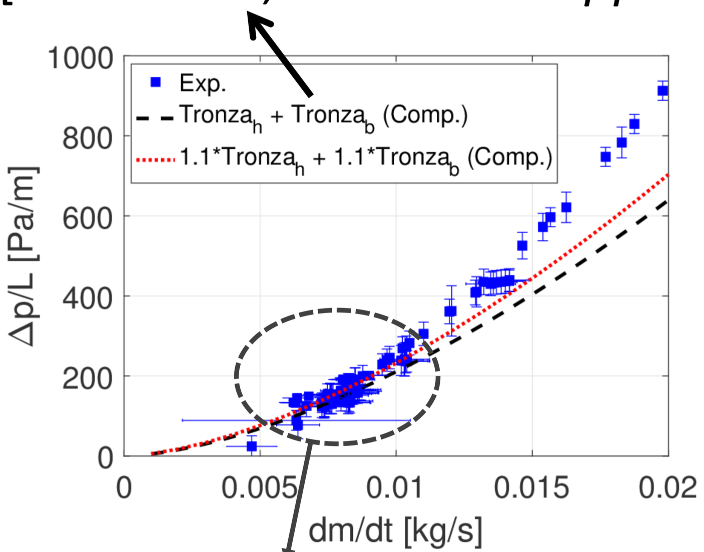
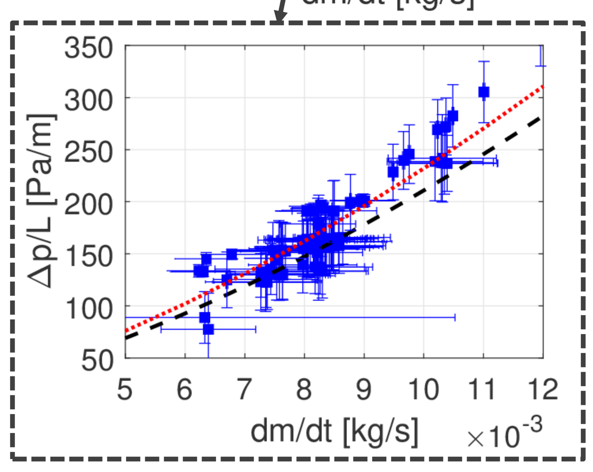
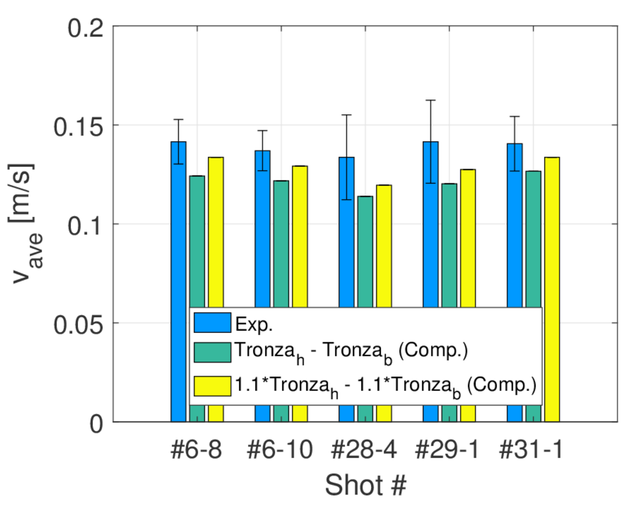


Data collected during cold operation of the conductor are in line with hydraulic characteristic in the operation range described by existing correlations





Increase of friction factor by 10% leads to a better description of average flow velocity

Calibration of 4C code TH input parameters

H_{HB} calibration

- Dedicated simulations performed to calibrate H_{HB} multiplier
- RH heat slug shot used as reference for the calibration
- Multiplier varied parametrically to fit temperature traces
- Best result has been used to simulate IH heat slugs with/without magnetic field

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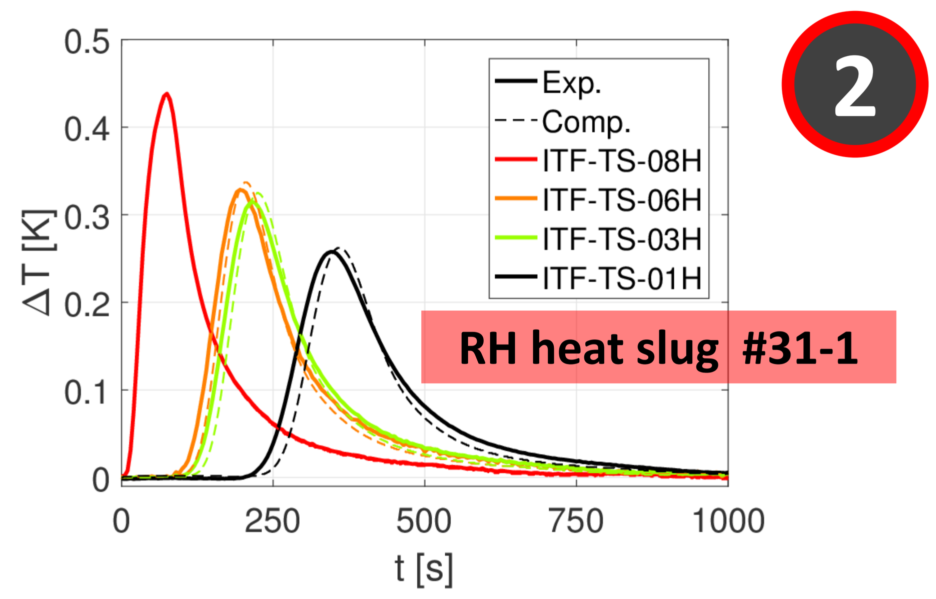
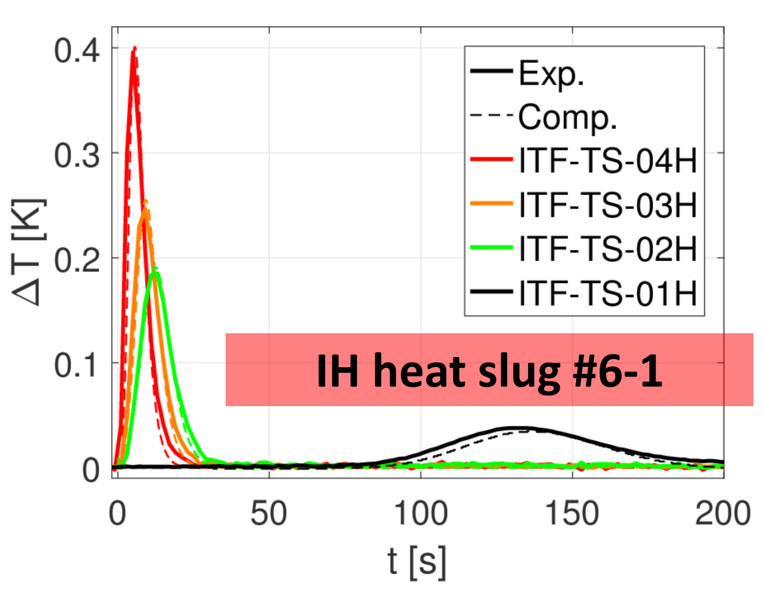
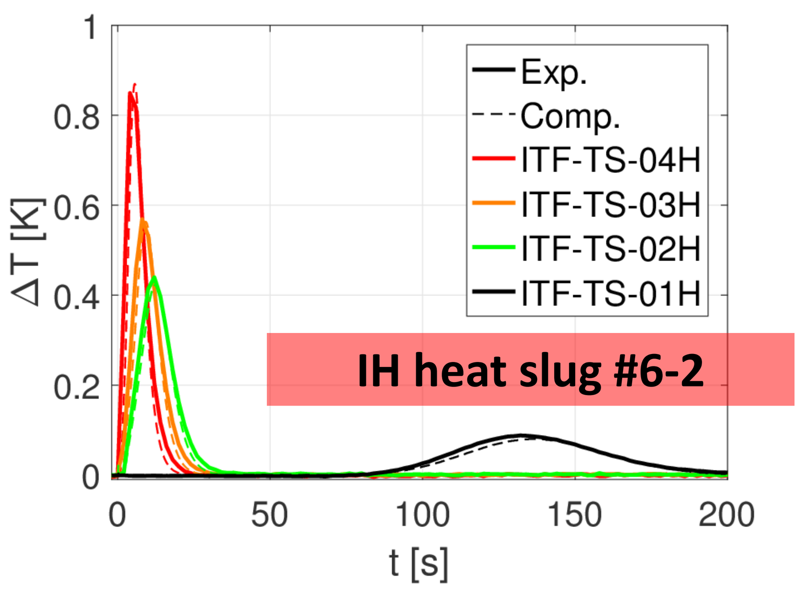
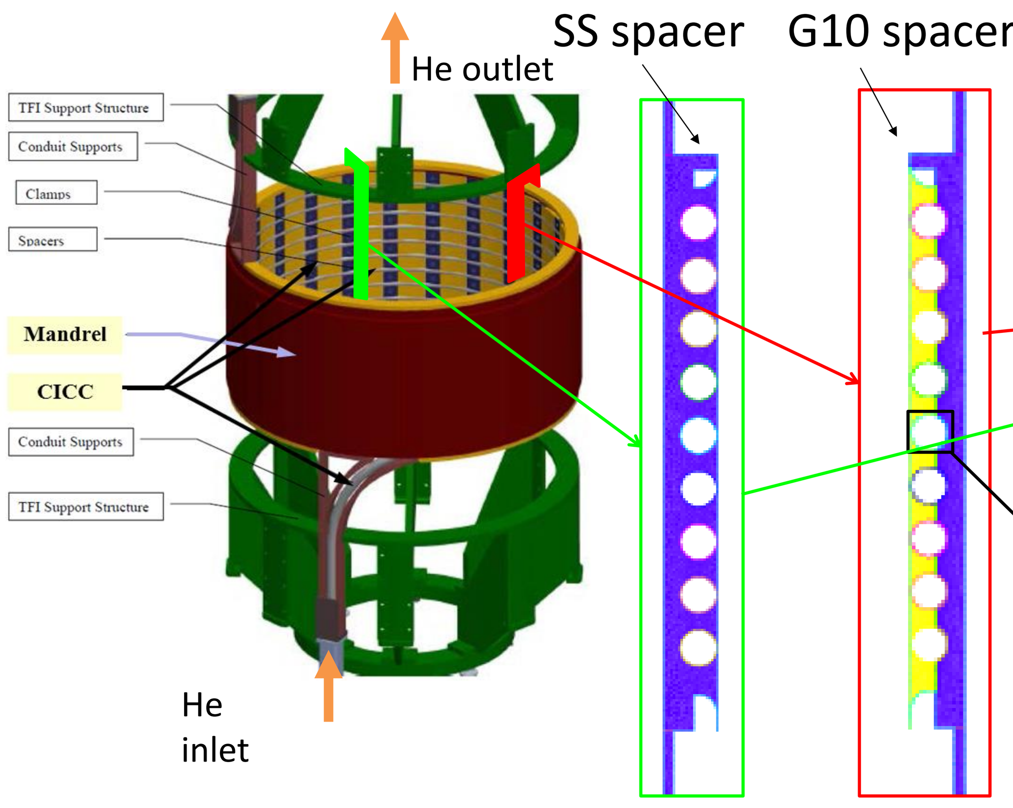


H_{HB} multiplier equal to 8 gives best agreement, similar to [R. Bonifetto, *IEEE Trans. Appl. Supercond.*, 2017].





Simple mandrel structure module



Mandrel discretized in 8 2D sections alternating the SS and G10 spacer

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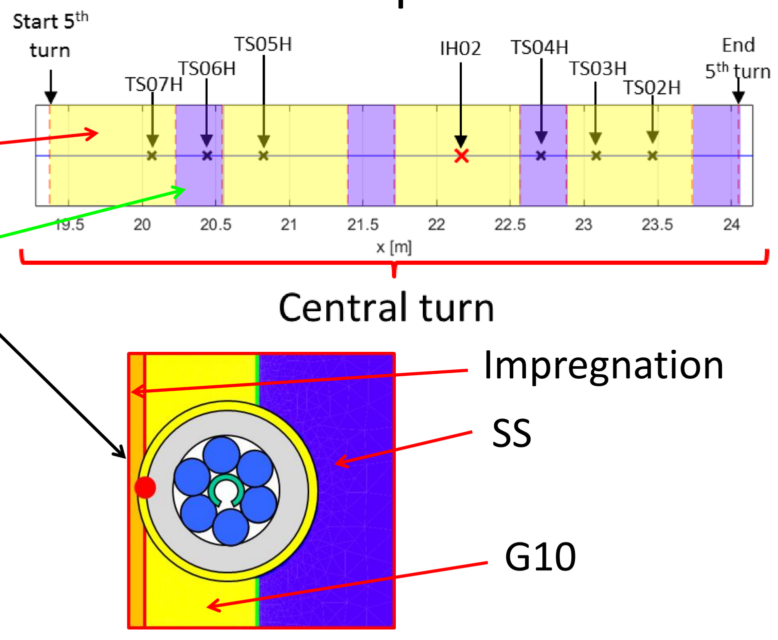
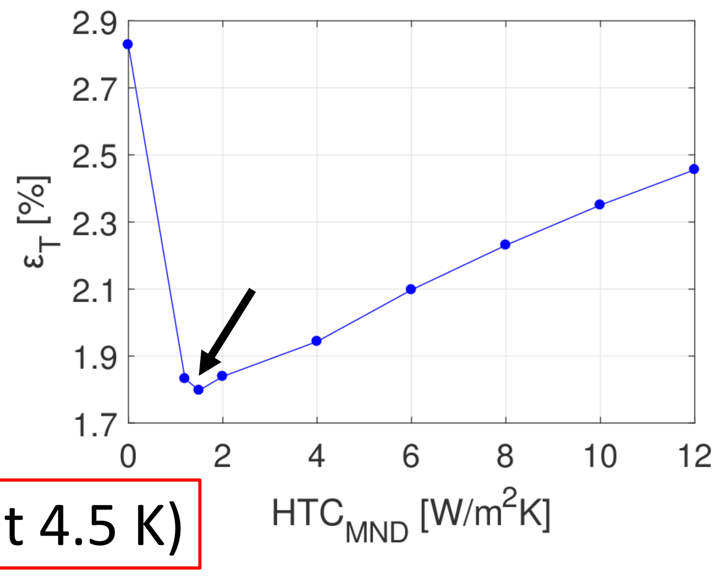


HTC_{MND} calibration

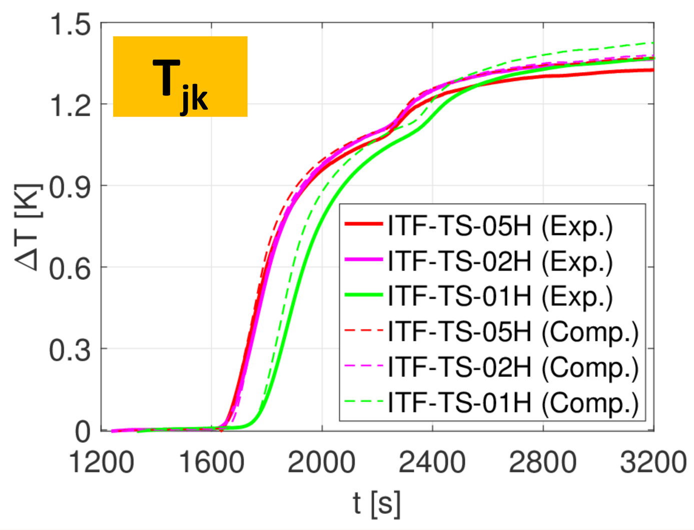
- Calibration of HTC_{MND} on T_{CS} measurement #134-1
- HTC_{MND} evaluated to minimize the average error at different T_{XX} sensors:

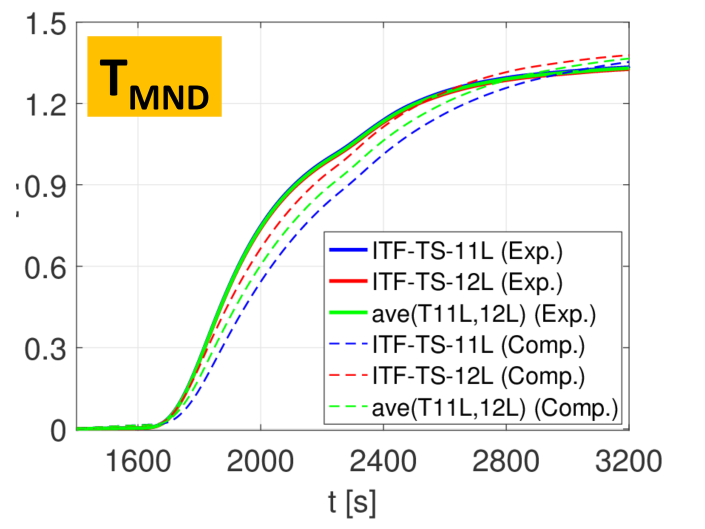
$$\varepsilon_{xx} = \sqrt[8]{\prod \frac{\|T_{xx,exp} - T_{xx,comp}\|}{\|T_{xx,exp}\|}}$$



HTC_{MND} = 1.5 W/m²K (at 4.5 K)

Consider T evolution from the beginning to when $T < T_{CS} - 0.5K$





Conclusions

- Friction factors: Tronza correlations (× 1.1) suitable in ITER operating conditions
- Heat transfer coefficients:
  - Bundle/Hole → increase $HTC_{nospiral}$ by a factor of 8 (in the same ballpark of other ITER conductor)
  - Conductor/Mandrel → HTC_{MND} ≈ 1.5 W/m²K @ 4.5 K

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