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JT-60SA TF coils AC losses: acceptance tests modelling with CEA simulation codes and first extrapolations to tokamak operation

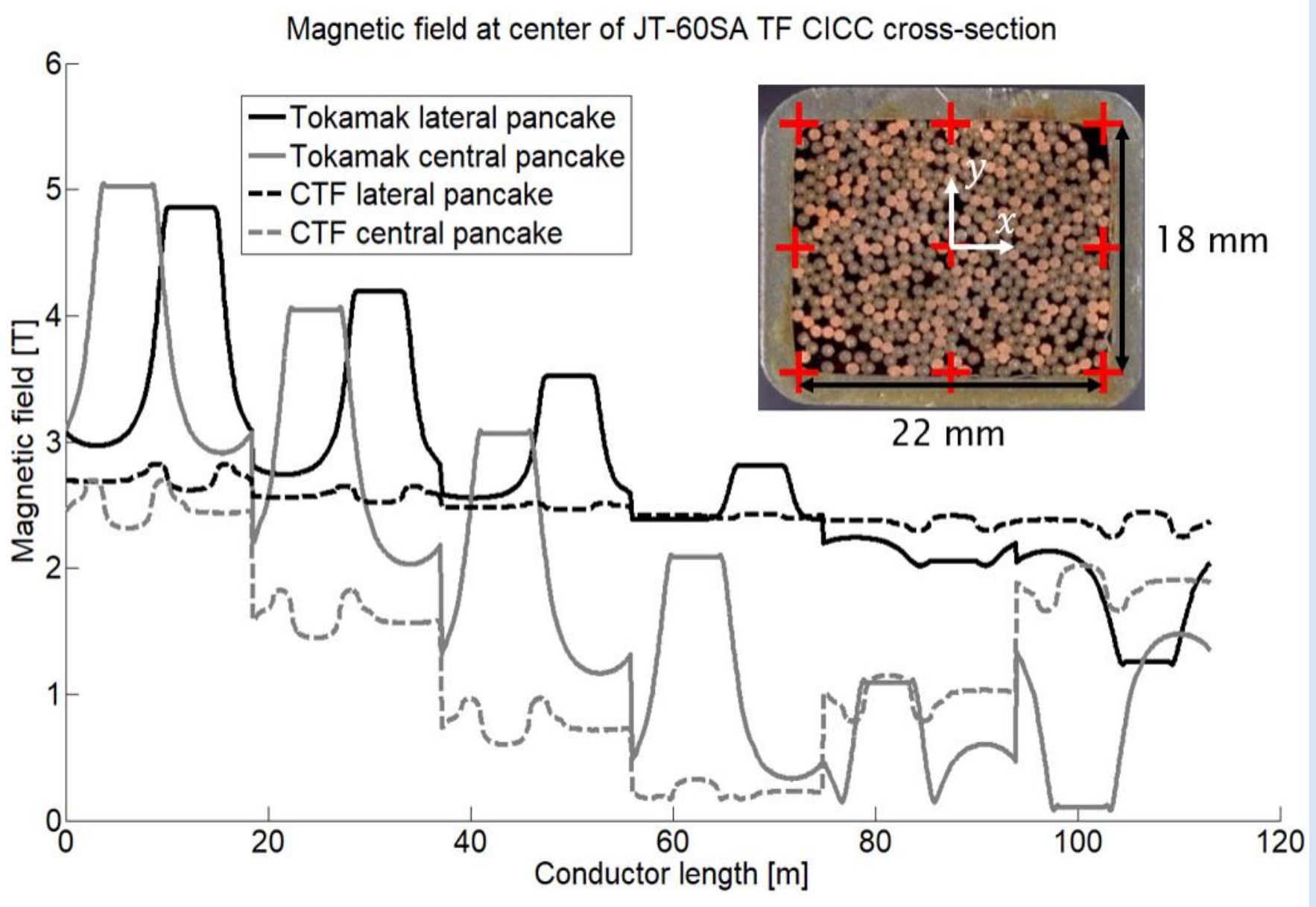
A. Louzguiti[1], Q. Le Coz[2], S. Nicollet[1], A. Torre[1], B. Turck[1], L. Zani[1]
[1]CEA, IRFM, F-13108 Saint Paul-lez-Durance, France, [2]Assystem, F-84000 Pertuis, France
alexandre.louzguiti@cea.fr

ABSTRACT

- AC losses deposited in the magnets during JT-60SA commissioning and operation will both affect the local stability of the conductor and act as a load on the cryogenic system.
- Our objective is thus to develop an accurate modeling of the AC losses generated in the magnets by different current scenarios.
- Since the TF coils have been tested in the Cold Test Facility (CTF) and will be the first ones to be fully energized during the commissioning, we have chosen to first focus our work on the AC losses deposited in the TF
- This enables us to confront our modeling to the CTF data.
- We also present a pseudo-3D thermo-hydraulic simulations to estimate the impact on the helium temperature of the AC losses generated during fast discharge of the TF current foreseen during the commissioning

AC LOSSES MODELING

- Magnetic field map computed with TRAPS code [1] at 9 points of JT-60SA TF Cable-In-Conduit Conductor (CICC) along TF coil in CTF (i.e. coil self-field configuration) and tokamak (i.e. toroidal coils configuration).



- Hysteresis losses computed with analytical formulae from [2]

$$P_h = \begin{cases} \frac{\pi|\dot{B}|\Delta B^2}{2\mu_0^2 J_c d_{eff}}\left(1 - \frac{\pi\Delta B}{3\mu_0 J_c d_{eff}}\right) \text{ if } \Delta B < B_{pen} \\ \frac{2J_c d_{eff}|\dot{B}|[1+(I/I_c)^2+0.2056(I/I_c)^4]}{3\pi} \text{ if } \Delta B > B_{pen} \end{cases}$$

$$\text{with } B_{pen} = \frac{2\mu_0 J_c d_{eff}}{\pi}\left[1 - \frac{\pi^2}{8}\frac{I}{I_c} + \left(\frac{\pi^2}{8} - 1\right)\left(\frac{I}{I_c}\right)^2\right]$$

deff is measured in [3] and Jc(B,T) is measured in [4].

- Coupling losses computed with MPAS model [5] with data from [6]

$$P_c(W/m^3) = \sum_{j=1\to N} \frac{nk_j \tau_j \dot{B}_{int,j}^2}{\mu_0} \qquad nk_{1\to N} = 0.220 \,/\, 0.254 \,/\, 0.293 \,/\, 0.340 \,/\, 2.23$$

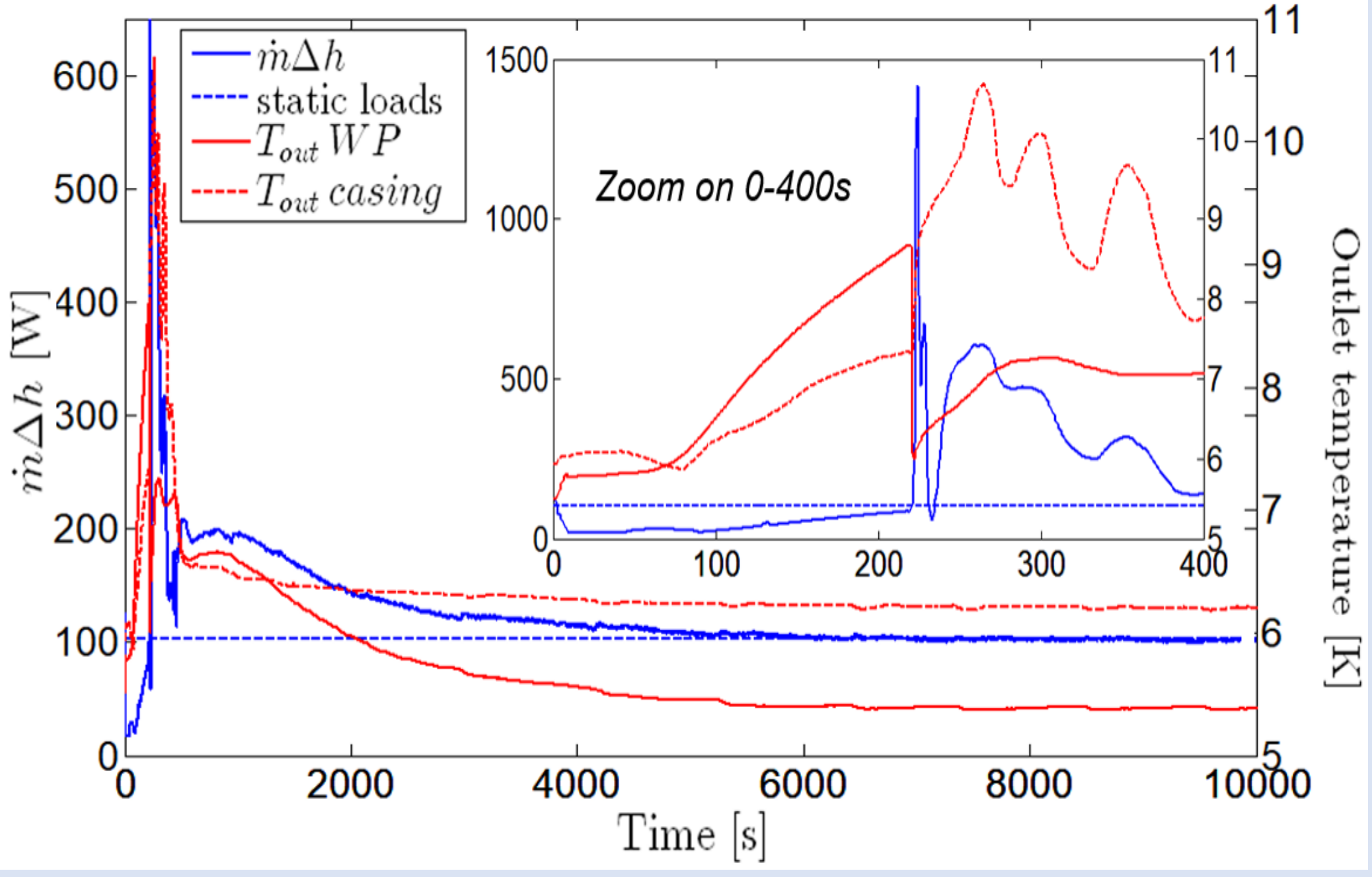
$$B_{int,j} + \tau_j \dot{B}_{int,j} = B_{ext} \qquad tau_{1\to N}(ms) = 6.02 \,/\, 14.6 \,/\, 42.8 \,/\, 85.9 \,/\, 250$$

- Eddy currents losses in TF coil casing are computed with R,L model and data from [7],[8]. Fast discharges at nominal current (25.7 kA) generates **157 kJ in CTF configuration** (with ~8s time constant) and **609 kJ in tokamak configuration** (with ~14s time constant).

COMPARISON WITH CTF DATA

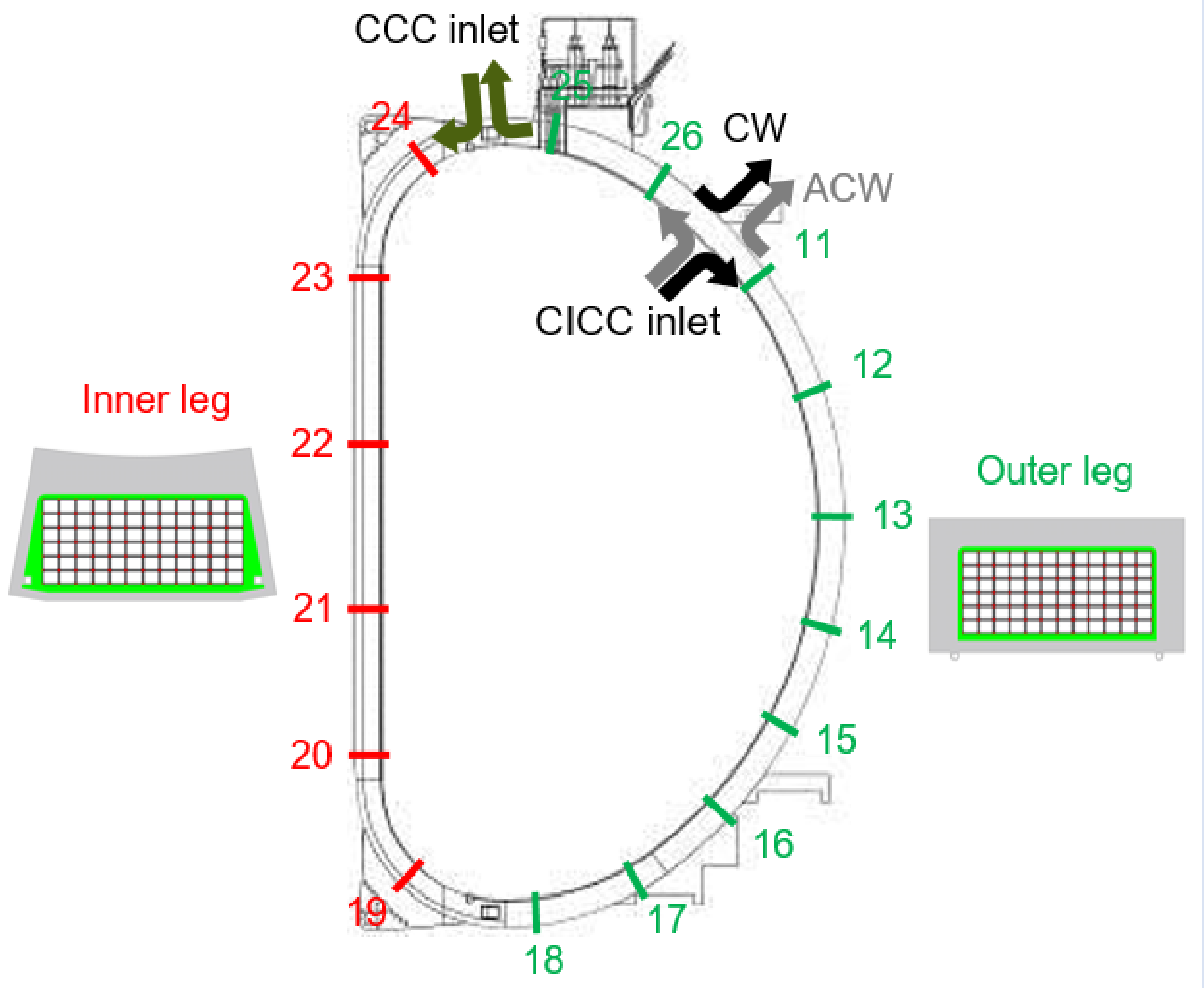
Cold Test Facility (CTF) at CEA Saclay

- CTF = facility at CEA Saclay, France where JT-60SA tokamak TF coils have been tested in self-field configuration before their delivery to QST in Naka, Japan [9]
- TFC02 coil had additional thermal sensors on the pancakes outlets for advanced tests activity, or ATAs
- Calorimetric analysis from Helium T, P, dm/dt sensors at inlet and outlet of the winding pack (WP) and casing led to **214 kJ** deposited by hysteresis, coupling and casing eddy current losses during TFC02 fast discharge

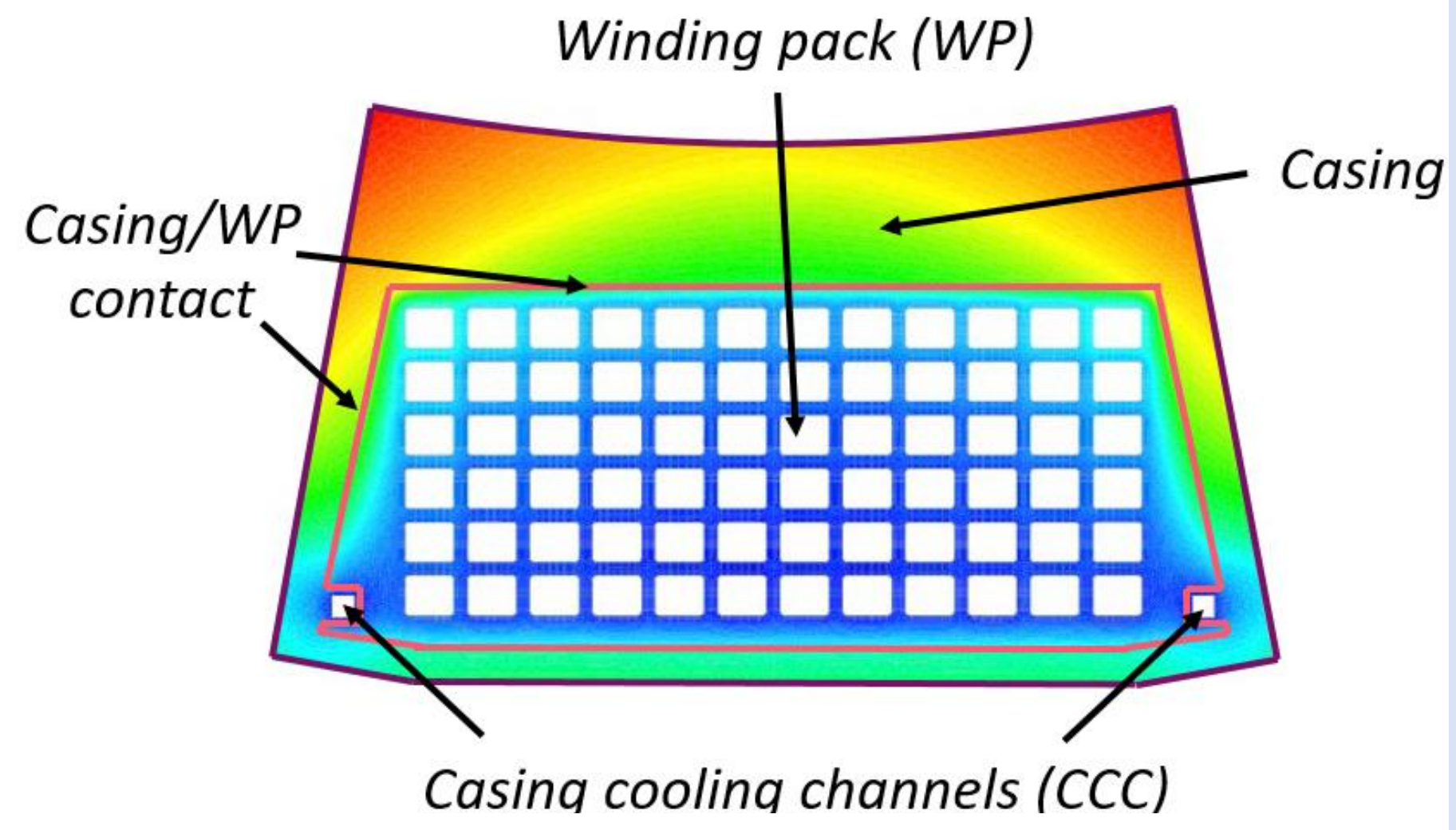


- From the AC losses modeling, during TFC02 fast discharge 5 kJ are generated by hysteresis, 21 kJ by coupling and 157 kJ by eddy currents in casing (total = **183 kJ**). This modeling is thus consistent with the experiment as the difference between 183 kJ and 214 kJ is about 15% only.

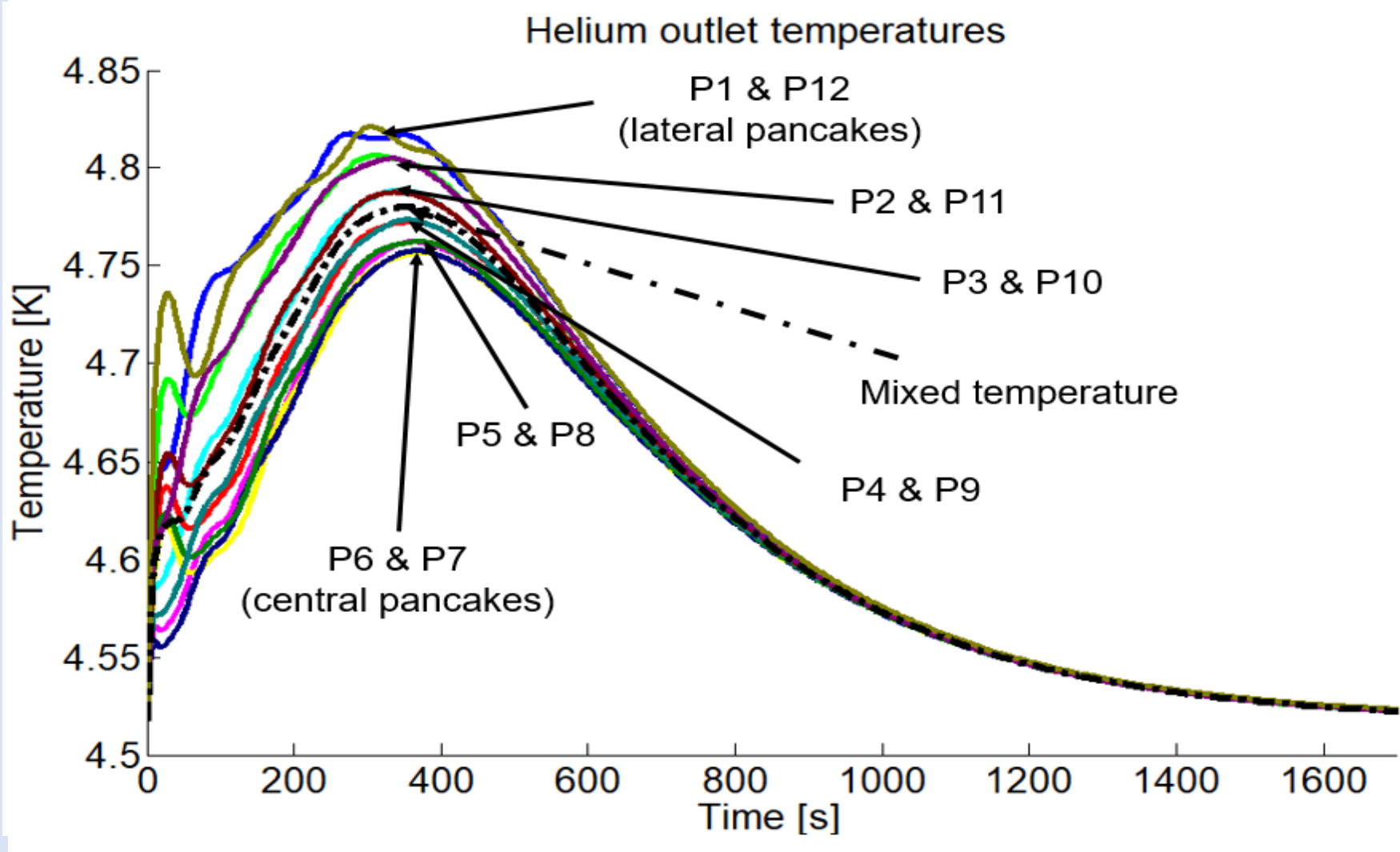
SIMULATIONS IN TOKAMAK CONFIGURATION



- TACTICS is a quasi-3D thermal/thermohydraulic simulation tool developed at CEA that couples THEA (1D thermohydraulics) and Cast3m (2D thermal) [10]-[11].
- TACTICS simulations are performed considering Helium flow operating conditions to evaluate the impact of AC losses due to a fast TF discharge in tokamak configuration at nominal current (25.7 kA)
- WP/casing thermal contact is unknown (WP deformation due to Lorentz forces), so two extreme cases are considered:

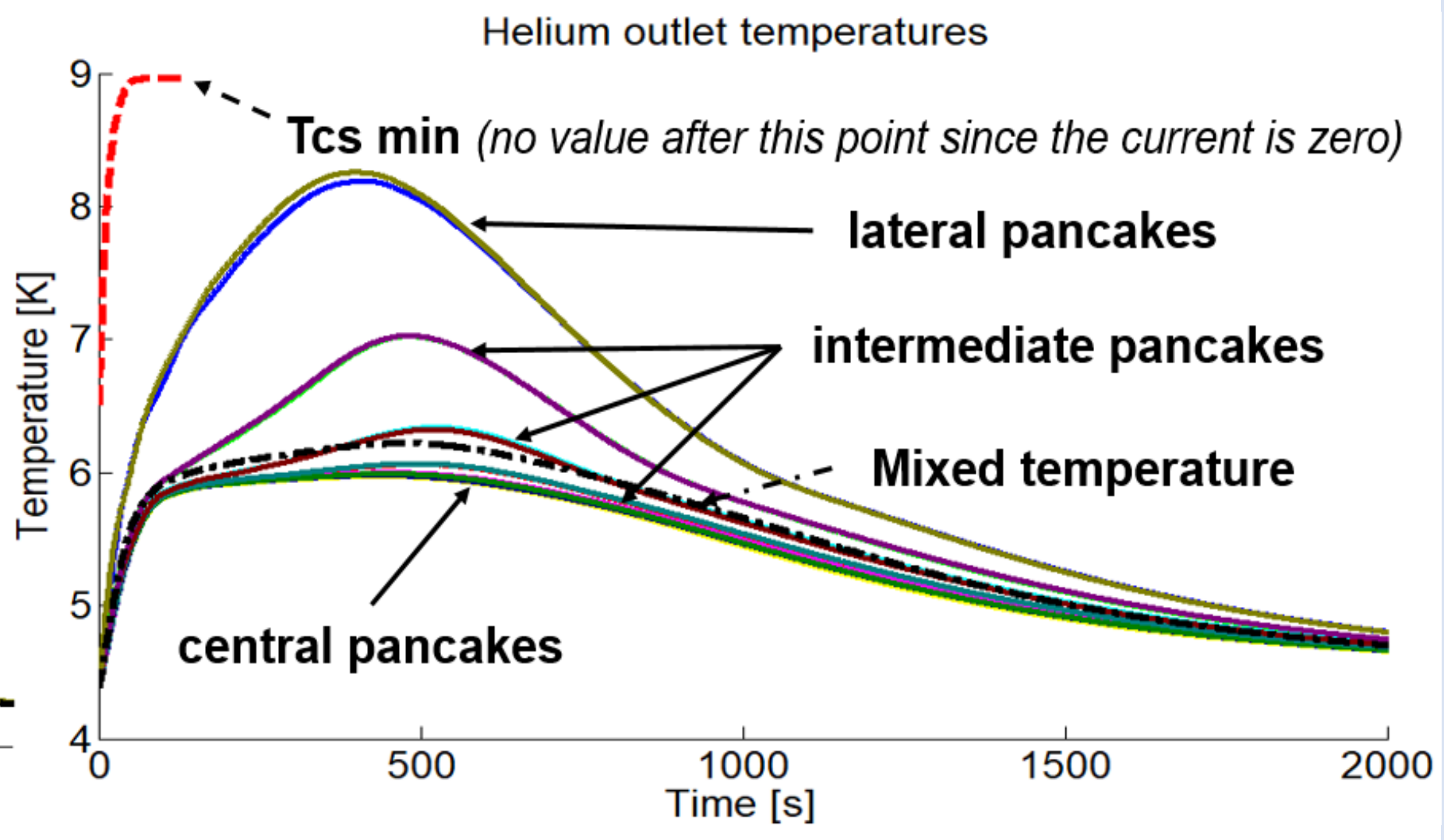


no WP-casing thermal contact



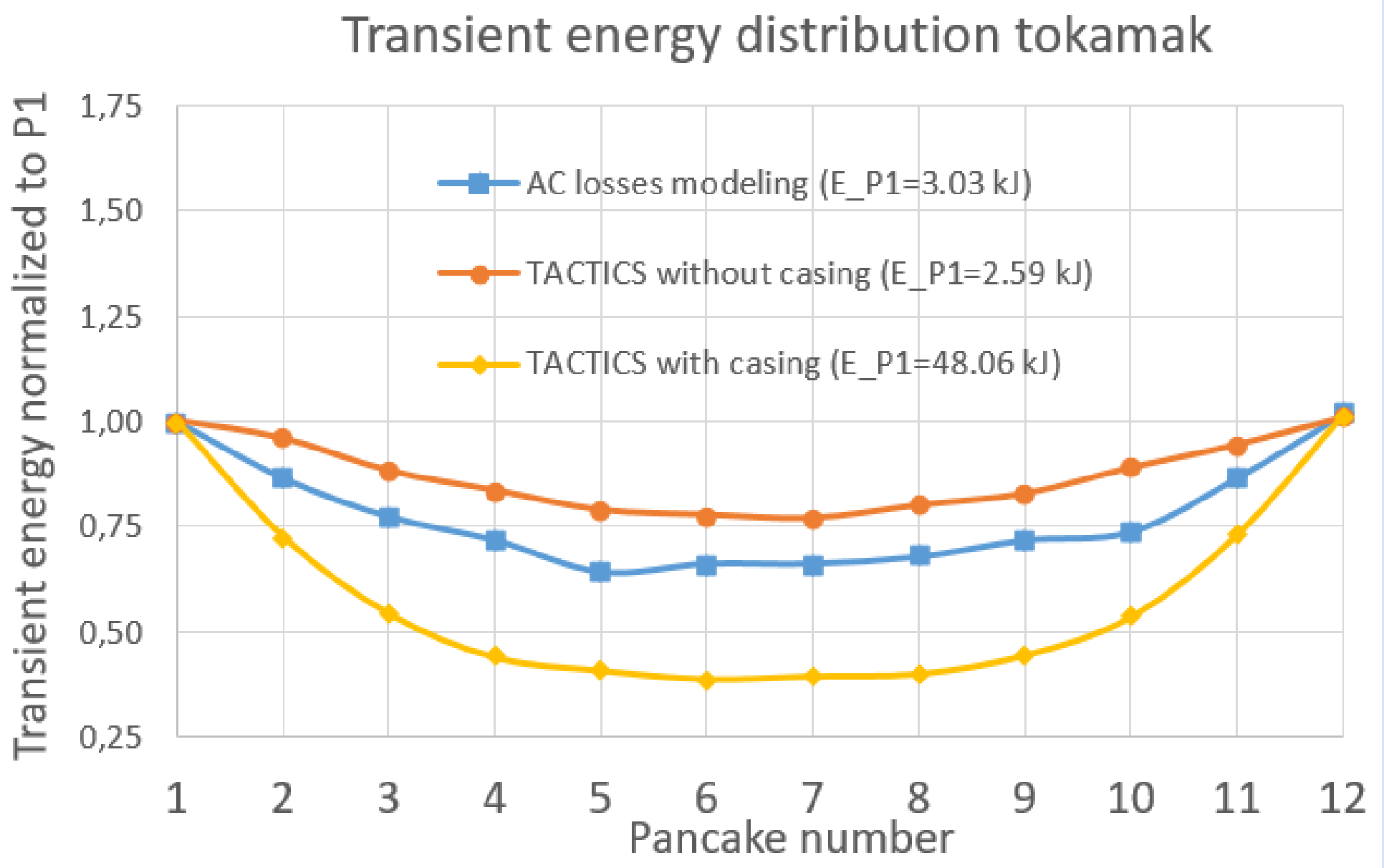
0.2-0.3K Toutlet increase, even distribution between pancakes

perfect WP-casing thermal contact



1.7-3.9K Toutlet increase, uneven distribution, no quench risk

Without contact, the energy is more evenly distributed between pancakes (due to inter-pancake conduction) while with perfect contact, the distribution is more peaked on the lateral ones (due to casing eddy currents).



CONCLUSION

- AC losses in JT-60SA TF winding pack much lower than losses in casing
- AC losses modeling in fair agreement with CTF experimental results
- Simulations in tokamak configuration to be compared (commissioning)

ACKNOWLEDGEMENTS / REFERENCES

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