Radiation patterns in DTT relevant to bolometric tomographic reconstructions

G. Apruzzese[1], E. Peluso[1,2], L. Senni[3], A. Belpane[4,5], I. Casiraghi[6], A. Castaldo[1], V. D'Agostino[1,2], M. Gelfusa[2], P. Mantica[6], F. Bagnato [7], L. Gabellieri[7], A. Murari[4,7,8], S. Palomba[7]

[1] *ENEA, Nuclear Department, C.R. Frascati, Italy*

[2] *Università degli Studi di Tor Vergata, Rome, Italy*

[3] *CNR-Institute for Applied Mathematics (IAC), Rome, Italy*

[4] *Consorzio RFX, Padua, Italy*

[5] *University of Tuscia, Viterbo, Italy*

[6] *CNR - Institute for Plasma Science and Technology (ISTP), Milan, Italy*

[7] *DTT S.c.a r.l., Frascati, Italy*

[8] *Istituto per la Scienza e Tecnologia dei Plasmi, CNR, Padua, Italy*

Introduction

The Divertor Tokamak Test (DTT) is a compact, fully superconducting tokamak under construction at the ENEA Research Centre in Frascati, Italy [1]. Designed to investigate power-exhaust solutions and plasma-facing component protection under reactor-relevant conditions, DTT will address key issues relevant to divertor and core physics. Its diagnostic programme includes a bolometric system for two-dimensional reconstruction of the plasma radiated power. These measurements are crucial for studying radiation patterns, detachment dynamics and radiative cooling strategies. For this reason, predictions of the radiation patterns expected in DTT plasmas are essential for assessing the diagnostic capabilities and guiding the design of the tomographic system. In this work, radiation distributions representative of DTT operational scenarios are analysed with particular focus on their implications for bolometric tomographic reconstructions. The reconstruction of plasma radiation emissivity profiles is an important step for the interpretation and validation of tomographic diagnostics in magnetic confinement fusion devices. In particular, synthetic emissivity distributions (phantoms) are widely used for the development and testing of inversion algorithms, the optimization of diagnostic geometries, and the analysis of asymmetric radiation phenomena [2,3] associated with impurity events, local fluctuations and even transport. Since experimental measurements of DTT are not yet available, synthetic radiative distributions must be generated. In this work, a methodology based on the combination of scenario-based plasma profiles, including those related to impurities species and the magnetic topology has been developed and preliminarily tested. Plasma profiles used in this work were modelled using the ASTRA (Automated System for Transport Analysis) and FACIT codes [4,5]. A numerical procedure has been, then, developed to generate two-dimensional emissivity maps from radiated power density profiles $P_{rad}(\rho)$ to be tested as possible phantoms corresponding to the 1D profiles provided by modelling. The analysis is explicitly restricted to the region inside the Last Closed Magnetic Surface (LCMS), where the radiative emissivity is reconstructed on a (R,Z) mesh grid starting from radiated power density $P_{rad}(\rho)$ profiles [4,5] obtained from the outputs of the aforementioned codes.

Methodology

The computational domain is discretized using a regular rectangular mesh compatible with the synthetic diagnostic framework previously developed[3], where each elementary polygonal pixel on the poloidal plane corresponds to the poloidal projection of a voxel. Closed magnetic flux surfaces, obtained from equilibrium calculations, are used to identify the mesh regions intersected by each normalized poloidal flux coordinate ρ_{pol}. For each selected flux surface, the corresponding radiated power density is interpolated from the input scenario profiles and assigned to the intersected pixels. A dedicated filling algorithm is then applied to reconstruct continuous emissivity distributions inside the LCMS, including regions not directly crossed by sampled flux contours. The resulting emissivity field is converted into two-dimensional images suitable for synthetic diagnostic studies and tomographic benchmarking. The initial ideal case consists of iso-radiating surfaces . An additional perturbation model, described in Eq. (1), has been introduced to simulate a localized non-axisymmetric radiation structure in the plasma edge region.

$$P_{\mathrm{rad}}(\rho) = \frac{\varepsilon_0'(\rho)\,(N_0 - N)\big|_\rho + N\big|_\rho\,\varepsilon_{\mathrm{asym}}(\rho)}{N_0\big|_\rho} \qquad (1)$$

Here, N_0 refers to the number of pixels lying along the flux surface identified by ρ_{pol} ; N represents the number of pixels belonging to the region characterized by the altered emissivity $\varepsilon_{asyn}(\rho)$, and therefore (N_0 -N) corresponds to the number of pixels outside this region where the emissivity $\varepsilon_0'(\rho)$ compensates the unbalance set along the curve. The emissivity profile outside the perturbed region has been consistently modified in order to maintain the radial consistency of the initial radiated power distribution. As a synthetic example, a localized region between two flux surfaces has been selected and its emissivity increased by a factor 1.5 with respect to the unperturbed value. Both the iso-radiating map and the non-axisymmetric one were used as input phantoms for a tomographic code, based on a Maximum Likelihood (ML) approach [3]. For the preliminary results, the reduced bolometric DTT layout [3] , shown in Figure1 has been considered.

The radiation density profiles derived from the reconstructed phantoms have been compared with the original radiation density profile obtained from the modelling codes. Since the applied ML code used for the tomographic inversion associates a variance to the reconstructed emissivity maps, it has been possible to associates uncertainties to the reconstructed profiles. The iso-radiating emissivity map has been used as an initial test to check the feasibility of the methodology, then the non-axisymmetric one has been studied aiming at mimicking fluctuations of the radiation pattern still compatible with the modelled radiation density profile.

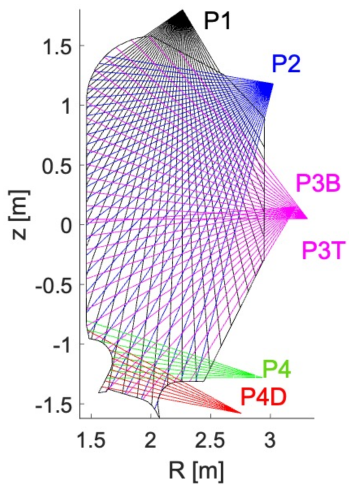

Figure 1: DTT layout using 120 LoS

Results

The preliminary work described in this contribution focused on using estimates for DTT on the flat-top phase of a full-power scenario. The iso-radiating phantom and the corresponding reconstructed obtained from the ML inversion are presented in Figure 2 a) and b), respectively. The radial profiles $P_{rad}(\rho)$ are illustrated in Figure 2 (c) and show excellent agreement between the ML reconstructed and that predicted by the ASTRA-FACIT modelling.

The non-axisymmetric case is illustrated in Figure 3 and again shows an excellent agreement.

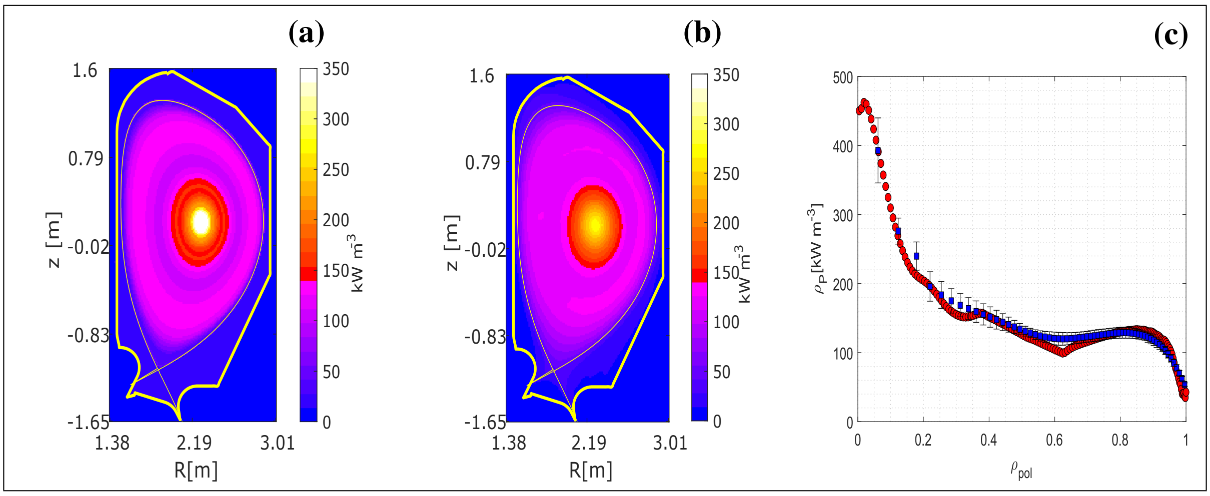

Figure 2: Axisymmetric synthetic phantom for the flat-top scenario (a) and its reconstruction (b). The original 1-D P_{rad} profile (red markers) and its reconstruction (blue markers) (c).

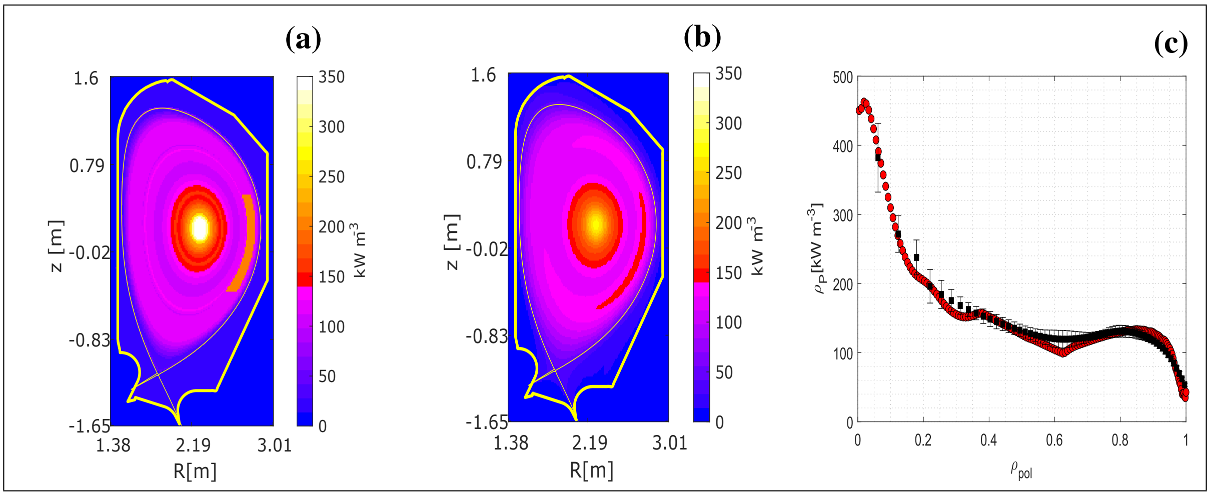

Figure 3: Non-axisymmetric synthetic phantom for the flat-top scenario (a) and its reconstruction (b) . The original 1-D P_{rad} profile (red markers) and its reconstruction (black markers) (c).

Conclusions

Emissivities from a modelled DTT plasma scenario with ASTRA and FACIT codes were employed to produce symmetric and non-axisymmetric emissivity maps compatible with modelled radiation density profiles. The former phantom is a simple initial case study, while the latter mimics a fluctuation in the radiation pattern that is still compatible with the modelled density profile. Both have been studied with a tomographic code already applied on DTT [3] providing reconstructions that are satisfactory for both cases. Indeed both the emissivity map and the radiation density profiles, $P_{rad}(\rho)$, have been correctly reproduced. These results confirm the robustness of the method and its suitability as an initial step toward a more advanced tool for validating DTT bolometric diagnostic under realistic plasma conditions. The study here described has been based on the knowledge of the one-dimensional radiated power density profiles, as input. Future work will aim at extending the approach to full two-dimensional emissivity distributions and at investigating emissivity patterns in the X-point region.

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