Calculation of radiation heat deposition on a liquid metal divertor for the EU DEMO

Introduction

The EU-DEMO will need to exhaust extremely large heat fluxes, up to several tens of MW/m^2, during long pulses and in a high neutron fluence environment [1]. Current technology cannot provide solutions to reliably exhaust such important power loads and new concepts are under investigation. Among them, adopting liquid-metal (LM) plasma facing components, and in particular a Liquid Metal Divertor (LMD), is considered one of the most promising. Indeed: (i) LMs evaporate when exposed to the high plasma heat flux, so that the large latent heat becomes available to help the power exhaust; (ii) a LM surface does not undergo erosion since the surface material is continuously replaced; (iii) the LM vapor can efficiently radiate a fraction of the incoming SOL plasma power thus reducing the heat load impinging on the target via advection/conduction [2]. In particular, line radiation from the evaporated atoms which are not yet fully ionized contributes to redistributing part of the incoming power to the surrounding walls, as radiation is emitted almost isotropically. Nevertheless, as a large part of the radiation processes takes place in the proximity of the target, the concern exists that a non-negligible part of this radiation will anyway reach the target. For this reason, a careful assessment of radiation heat load distribution over the surfaces of the tokamak chamber and, in particular, of the divertor, is of interest in the framework of the pre-conceptual design of an LMD.

At PoliTo, we have developed a suite of tools to numerically model an LMD. These tools have been applied both for studying a possible configuration for the Italian tokamak DTT ([3][4]) -which is going to be built in the next few years in Frascati- and for supporting the pre-conceptual design of an LMD for the longer-term EU-DEMO reactor [5]. At the moment, these tools include a model for the LM evaporating surface, the transport of the LM vapor in the plasma environment, its interaction with the charged particles coming from the hot plasma core and its re-condensation over the actively cooled walls. Given that line radiation from the evaporated, non-fully ionized atoms will play an important role in redistributing part of the incoming power to the surrounding walls, the performances required to the cooling system will be reduced. A module for determining the radiation heat load distribution on the divertor targets has not been included yet.

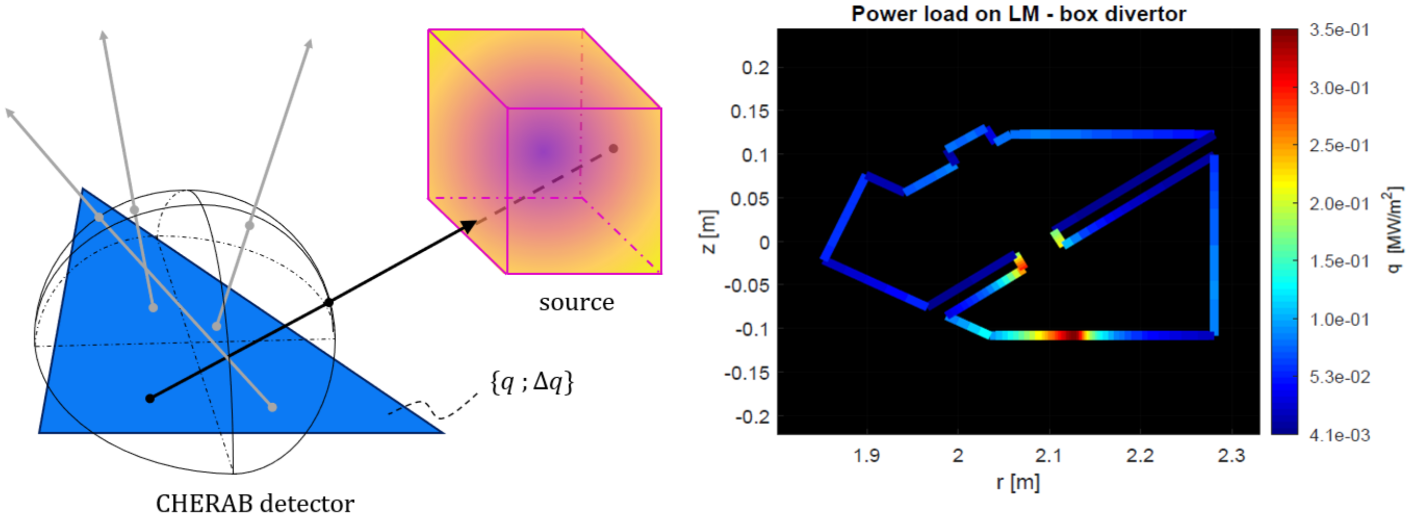

*Figure 1: **Left**: a CHERAB 3D detector shoots rays in the computational environment looking for radiation sources to be sampled. The power load q and its absolute error Δq are returned by the CHERAB code if at least one ray intercepts a source. **Right**: example of 2D power load*

distribution over the LMD concept to be implemented in DTT. Detectors are distributed all along the contour which encloses the radiation source (plasma leg, not shown).

Aim of the work

A promising candidate for determining the radiation heat load on surfaces is the CHERAB code ([6],[7]), a ray-tracing Monte Carlo tool initially developed at UKAEA, already successfully imported and exploited at PoliTo during a previous thesis work [8]. The CHERAB code takes as input the 2D distribution of the radiated power density calculated by the tools cited above (e.g. SOLPS-ITER). It then adopts a ray-tracing technique to assess the power load distribution over given surfaces (DTT and/or EU DEMO First Wall/LMD).

The thesis work will start with a preliminary phase aimed at obtaining greater confidence with the basic physics of an LMD and at understanding how the CHERAB code works, via tutorials and taking advantage of the support of the code users at PoliTo (and, possibly, of the code developers at UKAEA).

The student will then use CHERAB to determine the radiation profile on the walls and on the divertor, being careful at checking numerical convergence and power balance issues, for two reference cases:

1) A vapor-box divertor for the DTT.
2) An ITER-like LMD for the EU DEMO;

After the first successful cases will have been set up, the student will use the code to analyse a number of different plasma scenarios involving Li and Sn used as LMs. Based on the outcomes of these further calculations, the student will draw engineering conclusions which are relevant for two target design mentioned above.

Keywords: EU-DEMO, DTT, liquid metal divertor, power exhaust, radiation loads, numerical modelling, CHERAB

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References

[1] EUROfusion, “European Research Roadmap to the Realisation of Fusion Energy,” 2018.

[2] R. E. Nygren and F. L. Tabares, “Liquid surfaces for fusion plasma facing components—A critical review. Part I: Physics and PSI,” *Nucl. Mater. Energy*, vol. 9, pp. 6–21, 2016.

[3] ENEA, DTT: Divertor Tokamak Test facility - Project Proposal, 2015.

[4] G. F. Nallo, G. Mazzitelli, L. Savoldi, F. Subba, and R. Zanino, “Self-consistent modelling of a liquid metal box-type divertor with application to the divertor tokamak test facility: Li versus Sn,” *Nucl. Fusion*, vol. 59, no. 6, 2019.

[5] G. F. Nallo, G. Mazzitelli, M. Moscheni, F. Subba, R. Zanino, “SOLPS-ITER simulations for an EU DEMO with a liquid metal divertor target: Li vs. Sn”, *presented at ISLA 2019 – 5th International Symposium on Liquid metal Applications for fusion*, Urbana-Champaign, IL, USA, Sept. 30 – Oct. 3, 2019

[6] M. Carr and A. Meakins, cherab/core: Release v1.1.0, Zenodo, 2019.

[7] M. Carr, A. Meakins, A. Baciero and C. Giroud, "CHERAB's documentation," 2018. [Online]. Available: https://cherab.github.io/documentation/index.html.

[8] M. Moscheni, *Modelling the power load on the EU-DEMO plasma-facing components during a mitigated plasma disruption*, M.Sc. thesis, Politecnico di Milano – Politecnico di Torino, to be discussed in April 2020.