Functional Safety Assessment of a Liquid Metal Divertor for the European DEMO Tokamak

Introduction

Among the milestones indicated in the European Research Roadmap to the Realization of Fusion Energy [1], there is the design of a reliable solution for the heat exhaust problem. In a fusion reactor the hot, magnetically confined fusion core plasma is surrounded by the scrape-off layer (SOL) region, where magnetic field lines intersect solid surfaces (the divertor targets). For this reason, the latter must withstand extremely large heat and particle fluxes. For fusion to be economically feasible, these components should survive for a long time under these extreme conditions within the harsh fusion environment, characterized by high neutron fluence and large magnetic fields. The "baseline" strategy, which will be employed for the ITER experiment (which is being built in Cadarache, France) is based on actively cooled tungsten "monoblocks". Even though this solution can handle up to 20 MW/m^2 in steady state, it is unclear whether it will extrapolate to a future fusion reactor (such as the EU-DEMO, whose pre-conceptual design is ongoing within the EUROfusion consortium). For this reason, alternative solutions are under study, and even a dedicated experiment, the Divertor Tokamak Test (DTT), will shortly begin construction at ENEA Frascati, Italy. One of these alternative solutions involves the use of *liquid metals* to coat the divertor targets. This solution is attractive, since it is self-healing in nature and does not suffer from thermo-mechanical stresses.

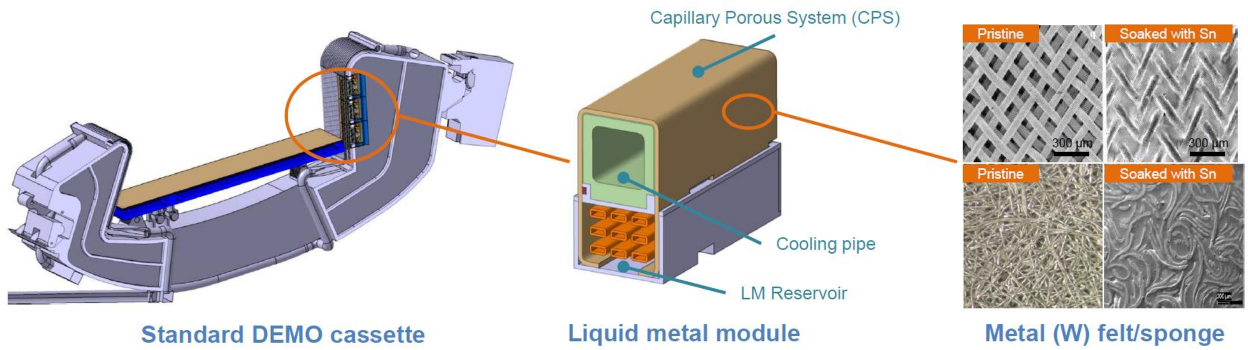

Figure 1: CAD of the standard DEMO divertor cassette (left), ENEA proposal for a liquid metal divertor module (center) and detail of possible capillary structures to be filled with liquid metal (right) [2]

Aim of the work

Within the framework of the preliminary design of a liquid metal divertor (LMD) for the EU-DEMO, *safety issues* need to be taken into account at an early stage. This work is indeed aimed at performing a preliminary but systematic safety analysis for this system, by means of the *Functional Failure Mode and Effect Analysis (FFMEA).* The FFMEA is a methodology particularly suitable for the identification of possible accident initiators of systems whose design is still at a preliminary stage, when more specific safety evaluations (e.g. at the component level) are not possible [3]. This method allows performing an early safety assessment, by postulating the loss of a function of the system rather than a specific component failure. Since the link to the component comes only at a second time, the FFMEA withstands the lack of detailed information about the design and the physical phenomena driving the system behaviour. Furthermore, for each function, the potential causes of its loss, a plausible accidental scenario and additional preventive and mitigative measures are investigated. Critical components are identified and, where applicable, the need for further information is specified. Elementary initiating events are grouped according to the way they challenge the system and to the plant response to the accident. For each group, the Postulated Initiating Event (PIE) is chosen as the event involving the most severe consequences for the plant. The PIEs definition is useful to drive and limit the set of accidental scenarios to be studied through the deterministic analyses for the quantitative risk assessment, which follows the qualitative evaluation (in this case performed through the FFMEA). For each PIE deterministic studies (thermo-hydraulic, neutronic, material, structures, etc.) will evaluate the capacity of the system (or, in general, of the plant) to withstand and mitigate its consequences and to ensure that safety limits are never overcome or will highlight the need of supplementary safety provisions. Following this analysis, representative events in terms of design basis accident (DBA) and beyond design basis accident (BDBA) will be selected from the list of PIEs.

Candidate profile: The candidate should have a keen interest in safety analysis and basic knowledge about how a tokamak fusion reactor works. The thesis work will be supported by interactions with the Ph.D. students indicated above, which are actively working in this field.

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References

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

[2] G. Mazzitelli *et al.*, "Technological aspects of the use of liquid Tin in a Liquid Metal Divertor", presented at *6th International Symposium on Liquid metals Applications for Fusion (ISLA 2019)*, University of Illinois, IL - Sept 30th - Oct 3rd (2019)

[3] US Nuclear Regulatory Commission "An approach for determining the technical adequacy of probabilistic risk assessment results for risk informed activities" (2009), available at https://www.nrc.gov/docs/ML0904/ML090410014.pdf