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The DTT proposal. A tokamak facility to address exhaust challenges for DEMO: Introduction and executive summary

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HIGHLIGHTS

- The DTT (Divertor Test Tokamak facility) proposal demonstrates the possibility to bridge the technological gap between the present day devices and ITER/DEMO in the area of plasma exhaust.
- DTT retains the possibility to test different divertor magnetic configurations, liquid metal divertor targets, and other possible solutions for the power exhaust problem.
- The edge conditions are similar to DEMO in terms of dimensionless parameters in integrated scenarios, compatible with plasma performance and technological constraints of DEMO.

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ABSTRACT

As indicated in the European Fusion Roadmap, the main objective of the Divertor Tokamak Test facility (DTT) is to explore alternative power exhaust solutions for DEMO so as to mitigate the risk that the conventional divertor based on detached conditions to be tested on the ITER device cannot be extrapolated to a fusion reactor. The issues to be investigated by DTT include:

- demonstrate a heat exhaust system capable of withstanding the large load of DEMO in case of inadequate radiated power fraction;
- close the gaps in the exhaust area that cannot be addressed by present devices;
- demonstrate that the possible (alternative or complementary) solutions (e.g., advanced divertor configurations or liquid metals) can be integrated in a DEMO device.

In this paper, we describe a proposal for such a DTT, presented by ENEA in collaboration with a European team of scientists. The selection of the DTT parameters (a major radius of 2.15 m, an aspect ratio of about 3, an elongation of 1.6-1.8, a toroidal field of 6 T, and a flat top of about 100 s) has been made according to the following specifications:

- edge conditions as close as possible to DEMO in terms of dimensionless parameters;
- flexibility to test a wide set of divertor concepts and techniques;
- compatibility with bulk plasma performance.
- an upper bound of 500 M€ for the investment costs.

This paper illustrates this DTT proposal showing how the basic machine parameters and concept have been selected so as to make a significant step toward the accomplishment of the power exhaust mission.
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1. Introduction

One of the main challenges, within the European Fusion Roadmap [1], is to design a power and particle exhaust system, capable to withstand the large loads expected in the divertor of a DEMO fusion power plant [2,3]. In ITER [4] (the International Fusion experiment under construction in Cadarache) it is planned to test the actual possibilities of a standard divertor working in "detached conditions". However, it is already clear that this solution is very challenging and that, consequently, the power exhaust problem could be a potential "show stopper" of the Fusion Road towards the realization of a Fusion Reactor [5].

For this reason a specific project has been launched, within the European Fusion Roadmap, to investigate alternative power exhaust solutions for DEMO, aiming at the definition and the design of a Divertor Tokamak Test facility (DTT). This tokamak should carry out scaled experiments integrating various aspects of the DEMO power and particle exhaust. DTT should retain the possibility of testing different divertor magnetic configurations, liquid metal divertor targets, and other possible solutions for the power exhaust problem. Hereby, the DTT design proposal presented in [6] refers to a set of parameters selected to reproduce edge conditions as close as possible to DEMO in terms of a set of dimensionless parameters characterizing the physics of Scrape Off Layer (SOL) and of the divertor region, while remaining compatible with DEMO as regards the dimensionless parameters dictating the bulk plasma performance. The parameters of the machine have been obtained consistent with a set of constraints related to the largest possible machine flexibility at a given cost of 500 M€. While the European Programme allocated about 60 MEUR in Horizon 2020, the Italian Government has offered to the European fusion scientific community the opportunity to get complementary funding for a dedicated facility located in Italy. In the international context the power exhaust problem is tackled within different new proposals and/or recently upgraded and ongoing experiments. In United States a smaller, but high toroidal field machine (ADX [7]) has been recently proposed by MIT. In China the superconductive EAST [8] machine has been recently upgraded and already deals with alternative divertor magnetic configurations, although with physics parameters far from reactor conditions. The here presented DTT will tackle the integrated bulk/edge power exhaust problem with physics parameters and power load scenarios as close as possible to the DEMO situation in a scaled experiment. Consequently the final successful target (although not the only one) of the DTT facility will be to propose a "reliable and robust" power exhaust scenario for DEMO; where here "reliable and robust" stands for a power exhaust solution that is fully compatible with the available technology (materials, pumps, coils,.) and the plasma performance (no degradation of the confinement)

2. Power exhaust issues

The confinement in a tokamak is the result of magnetic field configuration forming a set of closed, nested magnetic surfaces that bound the plasma. At the edge a thin region of open field lines is created (the SOL) through which charged particles and heat flowing out of the core plasma are guided into the so-called divertor, where the plasma impinges on the divertor target plates (Fig. 1). The unmitigated heat flux, in the SOL region of ITER and DEMO, is expected to be even higher than on the sun's surface [5].

The current strategy, to be tested on the ITER device, foresees optimizing plasma operations with a conventional divertor based on detached plasma conditions. This strategy relies upon different factors:

- development of plasma facing components to cope with very large power fluxes (> 5 MW/m^2);
- selection of the divertor inclination and of the magnetic flux expansion to reduce the heat flux normal to the target, i.e., by distributing the heat over a larger surface;
- removal of plasma energy before it reaches the target via impurity radiation by increasing edge plasma density and injecting impurities in the SOL region, so as to decrease the fraction of the heating power that impinges on the divertor, up to a level compatible with the materials technology (5÷10 MW/m^2);
- recycling and increase in the density by lowering the temperature close to the target, with consequent detachment (the temperature drops below ionization's, therefore the particles are neutralized and there is neither direct plasma flux nor power to the divertor targets).

However, on the basis of the current level of knowledge there is a considerable degree of uncertainty about the extrapolation to ITER, DEMO and fusion power plants [5]:

- today's experiments operate with physics SOL conditions that are very different from those expected in ITER and DEMO;
- simulations with present SOL models and codes are not reliable when extrapolating to ITER and DEMO conditions.

In addition, the risk exists that the baseline strategy pursued in ITER cannot be extrapolated to a fusion power plant for the following reasons [5]

- stability of the detachment front needs to be assessed for ITER and DEMO and fusion power plant conditions;
- problems might arise related to integration of this solution with the plasma core and the other tokamak subsystems, e.g.:
  - ○ impurity contamination of the core with consequent reduction of fusion performance
- compatibility of bulk plasma with the very high radiation fraction requested (>90% when considering bulk, SOL and divertor region)
- compatibility with pumping
- monitoring of erosion, temperature, etc.
- . . .

Moreover, a number of aspects must be taken into account restricting the use of certain materials (i.e. requirements in terms of life expectancy of reactor components, the need of keeping the temperature low in the divertor region in order to take almost vanishing the erosion rate, etc. . .).

Therefore a specific project has been launched to investigate alternative power exhaust solutions for DEMO, aimed at the definition and the design of a Divertor Tokamak Test facility. This tokamak should produce scaled experiments integrating most of the possible aspects of the DEMO power and particle exhaust.

3. DTT role and objectives

3.1. The role of DTT in the frame of european fusion research

The development of a reliable solution for the power and particle exhaust in a fusion reactor is recognized as one of the major challenges towards the realization of a fusion power plant [1,5].

There is the risk that the solution to adopt a conventional divertor (to be tested in ITER) could not be extrapolated to DEMO. In order to mitigate this risk, alternative solutions must be developed.

While several alternatives, such as the cooled liquid Li limiter in FTU [9], the Super-X divertor in MAST-U [10] are being investigated

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