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The DTT device: Role and objectives

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HIGHLIGHTS

- The main goal of the Divertor Tokamak Test facility (DTT), as indicated in the European Fusion Roadmap, is to explore and qualify alternative power exhaust solutions for DEMO.
- The DTT facility will test the physics and technology of various alternative divertor concepts under plasma conditions that can be confidently extrapolated to DEMO.
- The DTT facility will ultimately show whether alternative configuration or liquid metal plasma facing components are technologically viable, maintainable and economical.

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ABSTRACT

The main goal of the Divertor Tokamak Test facility (DTT), as indicated in the European Fusion Roadmap, is to explore and qualify alternative power exhaust solutions for DEMO. This paper illustrates its role and objectives.

1. Introduction

The heating power in fusion devices can leave the reactor vessel either via charged particles, neutral particles or radiation. While neutral particles and radiation are not affected by the magnetic field and the corresponding power fluxes are relatively evenly distributed over the large interior surface of the vessel, the charged particles, that leave the closed flux surfaces, follow the magnetic field lines and interact with the vessel wall on a relatively small surface area. Power exhaust via charged particles can, thereby, lead to high, localised power densities, which threaten the integrity of the divertor. In addition the interaction of energetic ions with the wall leads to sputtering, which releases impurities into the plasma and erodes the target surfaces. The impurity concentration in the core has to be limited in order to avoid excessive core radiation and, hence, confinement degradation (typically for high Z impurities) and fuel dilution (typically for low Z impurities). Taking into account the thermo-mechanical properties of the materials currently being considered for fusion application in the fusion environment and the design tolerances, it is imperative to limit the stationary target heat fluxes to 5–10 MW/m^2 and ion temperatures at the target to about 5 eV [1–3].

In conservative European DEMO scenarios approximately 90–95% of the effective heating power of the plasma has to be exhausted via radiation or neutrals rather than charged particles in order to reduce the heat flux to the divertor and allow for an economically viable lifetime of the divertor [4]. Such a high radiation level should be obtained by a controlled seeding with impurities [5]. It is, however, not certain that the impurity seeded conventional single null solution will reliably allow for such a high radiation fraction, while maintaining an energy confinement that is sufficient for fusion performance. The constraints on plasma exhaust can be relaxed by allowing for more radiation in the divertor, distributing the heat load by charged particles over a larger target area or increasing the heat and particle load capability of the divertor tar-

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gets. Any of these options would allow for less core radiation and, hence, improve the likelihood that the energy confinement will be sufficient for the targeted fusion performance.

2. DTT role

The development of a reliable solution for the power and particle exhaust in a reactor is recognised as one of the major challenges towards the realisation of a nuclear fusion power plant [6,7]. In order to mitigate the risk that the conventional divertor solution that will be tested in ITER may not extrapolate to DEMO due to its higher core radiation fraction, alternatives must be developed. While several alternatives, such as the cooled liquid Li limiter in FTU [8], the double null (DN) [9], the Super-X divertor [10] in MAST-U [11] or the snowflake divertor (SFD) [12] in TCV [13], DIII-D [14] and NSTX [15] are being investigated in present devices, the extrapolation between present device and DEMO is considered too large [2,6,7].

DTT is part of the general European programme, specifically within the strategy to address the issues of Mission 2 on heat exhaust [6,7], including many other R&D issues (plasma experiments, modelling tools, technological developments for liquid divertors, etc.). The role of the DTT facility is to bridge the gap between today's proof-of-principle experiments and DEMO. DTT should, in particular, have the potential to, together with the understanding of the conventional divertor that will be gained in ITER, bring such alternative solutions to a sufficient maturity level that they could be adopted on DEMO integrating plasma core, scrape-off layer (SOL) and divertor physics and technology.

3. DTT objectives

The DTT facility will test the physics and technology of various alternative divertor concepts under plasma conditions that can be confidently extrapolated to DEMO [16–18]. The tests must show whether the alternative concept can be developed into a viable and controllable exhaust solution for DEMO, including Plasma Facing Components (PFCs), diagnostics and actuators, which can be integrated with all other aspects of a power plant. DTT will, thereby, close the gaps that exist between the power exhaust studies using alternative solutions that can be carried out in present day devices and DEMO.

Taking into account the alternative configurations proposed for DEMO [7,19], the DTT facility will test the geometries of the SFD [12] and the X-divertor (XD) [20,21], the DN [9] and some aspects of other advanced configurations including the Super-X divertor (SXD) [11]. The DTT facility will feature a large degree of flexibility to have a high possibility to also test any promising future concepts as they are proposed. The flexibility of the proposed DTT will also allow for a test of liquid metal plasma facing components in the divertor once their technological feasibility in a reactor has been shown and their beneficial performance is supported by a sound physics basis.

The experience gained in the DTT facility will ultimately show whether the implementation of any alternative exhaust solution in DEMO, alternative configuration or a liquid metal PFCs, is technologically viable, maintainable and economical.

In summary, as stated in [1,2,6,7,22], the DTT facility should close the gaps in the exhaust area that cannot be addressed by present devices, hosting experimental tests to demonstrate whether:

- it is possible to operate with a heat exhaust system capable of withstanding the large load of DEMO;
- the possible solutions (e.g., advanced divertor configurations or liquid metals) can be integrated in a DEMO device, taking into account the constraints on plasma bulk performances, poloidal field coil system, materials, space for the blanket and neutron shielding as well as the other contributions expected in the area of heat-exhaust system within the EU fusion programme [6,7,22];
- an integrated exhaust scenario is viable (showing superior power exhaust performance of alternative solutions while maintaining adequate particle exhaust and core performance compared to the baseline approach);
- divertor operation is possible with edge and bulk parameters ν^*, ρ^*, β, T and n/n_G as close as possible to ITER/DEMO, even taking also account of high core radiation fraction in DEMO, where ν^* is the normalized collisionality, ρ^* is the normalized Larmor radius, β is the plasma kinetic pressure normalized to the magnetic pressure, T is the plasma temperature and n/n_G is a normalized plasma density.
- as for advanced configurations:
  - ○ the SF leads to a greater broadening of the SOL through enhanced transport in the null region;
- the postulated stabilising effect of the XD and SXD geometries on the location of the detachment and radiation fronts is valid in DEMO relevant condition;
- alternative configurations provide easier access to detachment than the conventional single null divertor, on the basis of a longer connection length;

- as for liquid metal targets:
  - ○ a closed loop liquid metal heat removal system is viable in a tokamak at relevant edge and SOL parameters;
  - ○ the full liquid metal cycle, including the recovery of eroded and evaporated material and the treatment of any retained hydrogen is able to meet the safety requirements of a power plant.

In parallel to the physics investigations, the EU fusion roadmap also addresses a number of engineering challenges in the area of power and particle exhaust [6,7]. The DTT facility will also offer the possibility to test several divertor target technology solutions in relevant conditions, in view of their application to DEMO and future fusion power plants.

4. Conclusions

The DTT facility is a key element of the European strategy to address the great challenge of power and particle exhaust in a nuclear fusion power plant. Its specific role is to mitigate the risk that the conventional divertor solution (to be tested in ITER) may not extrapolate to DEMO by developing alternative solutions. While several alternatives, such as the cooled liquid Li limiter in FTU, the Super-X divertor in MAST-U or the Snowflake divertor in TCV are being investigated in various existing tokamaks, the extrapolation from present devices to DEMO is considered too large. The role of the DTT facility is to bridge the gap between today's proof-of-principle experiments and DEMO. DTT should, in particular, have the potential to bring such solutions to a sufficient level of maturity and integration of physics and technology aspects.

The tests carried out in DTT should show whether the alternative concept can be developed into a controllable exhaust solution for DEMO, which can be integrated with all other aspects of a power plant. DTT will, thereby, close the gaps that exist between the power exhaust studies using alternative solutions that can be carried out in present day devices and DEMO.

At the time this paper is being written, the EUROfusion programme is being revised, waiting for the outcome of a midterm review and the assessment of alternative exhaust solutions. The General Assembly of EUROfusion plans to make its decision on the basis of the analysis of a number of national proposals examined by a panel of qualified international experts.

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