ITER DISRUPTION MITIGATION SYSTEM DESIGN AND APPLICATION STRATEGY

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1. INTRODUCTION

The ITER Disruption Mitigation System (DMS) is essential to ensure that the potentially very severe consequences of disruptive thermal and electromagnetic loads on in-vessel components and structures are minimized. The system, which passed its final design review in 2024, is based on shattered pellet injection (SPI) technology to deliver massive quantities of protium (H) and neon (Ne) to the plasma. Its main functions may be summarized as follows:

- dissipation of the thermal and magnetic energy by Ne line radiation;
- control of the current decay time;
- avoidance of runaway electron (RE) formation through fuelling with H to increase the plasma density and reduce the temperature;
- mitigation of the RE energy impact either through collisional dissipation following Ne injection, or through the control of the RE energy deposition phase by injecting tailored amounts of H.

Although the efficacy of SPI for disruption mitigation has been demonstrated on various tokamaks [1-6], with pellet injection systems for various pellet sizes commonly available [7-10], a very significant effort has been dedicated to the establishment of the physics basis for the DMS design requirements [11]. Similarly, a dedicated and intense R&D programme has been required to find and validate novel solutions for numerous technological challenges, arising from the first-of-kind nature of the ITER DMS (e.g. the harsh environment due to neutron bombardment and ambient magnetic field and the high availability and reliability demands). These joint physics and technology efforts were conducted within the auspices of the DMS Task Force (TF) established by the ITER Organization in 2018 [11].

In this contribution we present an overview of the activities to validate the ITER DMS design and to prepare for its operation by examining different injection schemes. We will also detail the strategy to exploit the DMS for the effective execution of the ITER Research Plan [12].

2. ITER DMS DESIGN

The detailed DMS system requirements, such as the required amount of injected material, optimum fragment size and velocity distribution were derived through modelling and supported by experiments conducted on several tokamaks within the ITER members institutes. In parallel, a technology programme has been addressing the validation of the design solution against the requirements. The current design of one of the three injector sets comprising the DMS embedded in an equatorial port cell is shown together with the main components in Figure 1 (there are three more in upper ports). In addition to the components required for in-situ formation of the large H and Ne pellets and for a reliable, fast-acting propellant valve for their launch, an effective gas retention system is needed to prevent the rapidly expanding propellant gas deteriorating the assimilation of the injected pellet fragments by premature cooling of the plasma. An optimised shattering geometry is located at the injector front end. The material assimilation is strongly governed by the

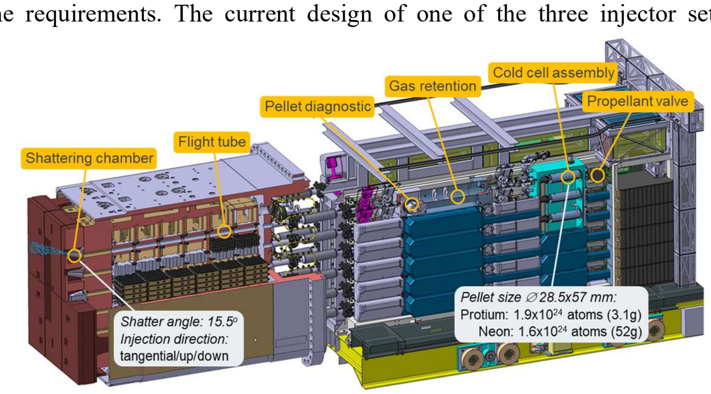

Figure 1: Shattered pellet injector components in one of the equatorial port cells.

‡ Deceased

fragment size and velocity distribution. Due to the limitation of the Parks statistical fragmentation model [13], which, for example, does not consider effects such as secondary fragmentation, experiments were conducted to characterise the fragment plume [9] and a simulation model using a discrete element code has been developed and validated over available shatter tests for different pellet [14] to predict the expected fragment size distribution for various shattering configurations. A comparison for different pellet velocities and a shattering angle of 15.5° is shown in Fig. 2 for a ITER size H pellet (Ø=28.5mm, l=57mm), indicating that for velocities of 300 m/s about 50% of the pellet material can be found in fragments larger than 4 mm as needed for improved material assimilation. The cumulative fragment size distribution from the laboratory shattering characterization experiments (diamonds in Fig. 2) is in fair agreement with the modelling. Based on the simulation results, some parameters of the Parks model are being revisited to improve the predictions [15].

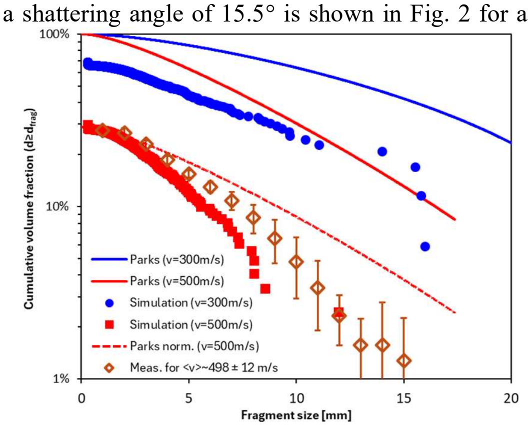

Fig. 2: Cumulative fragment volume (normalized to the original pellet volume) comparing Parks's model with simulations for two pellet impact velocities and with one laboratory shattering characterizations (averaged over five repetitions and (both scaled to the minimum detectable fragment size). Dashed line shows corresponding Parks's model scaled to measurements.

Several concepts such as fast shutters and gas muzzle breaks are being examined to minimize the propellant gas outflow towards the plasma to avoid cooling of the plasma edge in advance of the pellet fragments. To demonstrate the compatibility with this requirement, the pressure responses in the expansion chambers are benchmarked against synthetic diagnostics of CFD calculations. The complex interplay between pellet shape as imposed by the formation process, the pellet release and gas expansion on the pellet trajectory and rotation has been studied in the three available test benches established within the DMS TF technology programme [8-10] which operate with ITER size pellets.

3. STRATEGY FOR APPLICATION OF THE DMS DURING ITER OPERATION

A significant part of the first ITER campaign in the 2024 re-baseline (Start of Research Operation (SRO)) [12], is devoted to the optimisation of the DMS for effective disruption mitigation. The change of the first wall material from beryllium to tungsten (W) in the new baseline has relaxed some of the mitigation requirements as shown in Fig. 3, allowing examination of the different DMS injection schemes, such as staggered and multiple injections, to be tested at lower plasma currents without fear of damaging the W armour. Mitigation will become mandatory for $I_p > 12$ MA, which is already planned in SRO hydrogen plasmas in preparation for the Fusion Power Operation campaigns. The viability of these injection schemes will be assessed based on the material assimilation for densification, robustness of the current quench control and the implication for the overall reliability of the DMS demanding different combinations of pellet injections. SPI experiments on various tokamaks have indicated that the disruption dynamics (e.g. the thermal quench onset), are very sensitive to the target plasma temperature and possible intrinsic impurities, and that certain mitigation functions such as raising density for RE avoidance pose limitations for the application of low-Z injections for RE impact mitigation. These latest findings have implications for the initial configuration of the DMS for the SRO campaign and will be discussed.

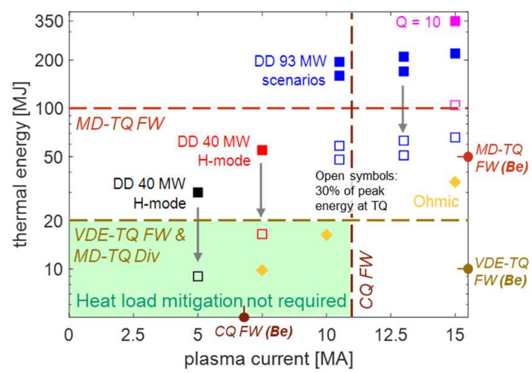

Fig. 3: Thermal load limits for W first wall (FW) and planned scenarios during SRO and FPO.

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