HIGH-POWER STRAY RADIATION EXPERIMENTS FOR THE ITER UPPER LAUNCHER WITH A REAL-SIZE MOCK-UP - FIRST RESULTS

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1. INTRODUCTION

The Electron Cyclotron Heating and Current Drive (ECH/ECCD) system is a key element of ITER, providing plasma heating, current drive, and magnetohydrodynamic (MHD) control through the delivery of 170 GHz millimetre-wave radio-frequency (RF) power. With the proposed new baseline [1] an installed ECH power of 48 MW foreseen in Start of Research Operation and later up to 80 MW. The power is delivered from the 1 MW gyrotrons to the tokamak by 48-80 transmission lines (TLs) of 50-mm corrugated waveguide. At the tokamak ports, the TLs end at 1, later 2 Equatorial Launchers (ELs) of 24 TLs each, mainly for plasma core heating, and at 4 Upper Launchers (ULs) of 8 TLs each, mainly for heating the plasma edge and to stabilize MHD instabilities.

Inside the ULs the power is transmitted quasi-optically by four mirror sets, of which the last one can be steered to aim the beams at a precise plasma location. Besides the launcher, the UL procurement package includes the last fraction of transmission lines, including diamond windows forming part of the machine nuclear confinement. The UL design has progressed through several development phases and is currently in its Final Design phase [2] with the Final Design Review having been held in June 2025. For the UL and associated components, the design has been based largely on engineering analysis, but complemented with some experiments and prototyping. Part of the integrated engineering analysis methodology consisted in coupling the RF electromagnetic (EM) analysis with the thermo-mechanical analysis [3]. Since the impact of stray radiation on launcher walls or on components such as the mirror steering mechanism has been identified as one of the UL main risks, a special effort has been put into identifying and establishing a well-fit methodology for simulating the beam propagation and stray radiations in the UL [4].

Two experiments have been set up and performed for benchmarking the RF-EM engineering tools against stray radiation measurements. The first experimental campaign was performed in the MISTRAL stray radiation chamber [5] in Greifswald, Germany in January 2025. Here, a mock-up of steering mirror components has been exposed to stray radiation to evaluate the heat load on the sensitive steering mechanism of the UL mirror 4.

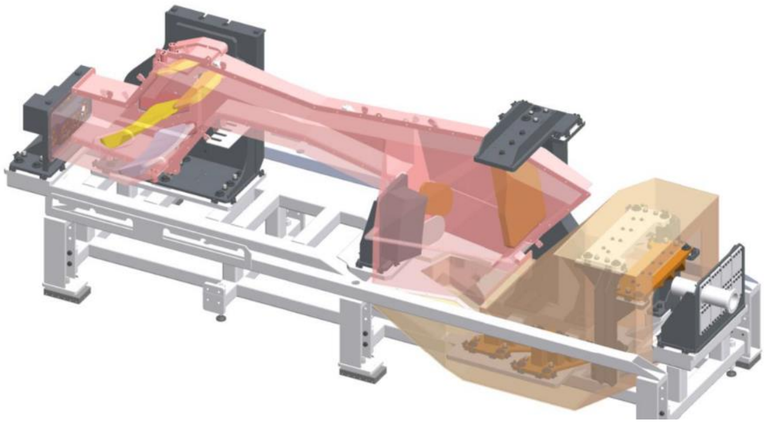

Figure 1: 3D CAD-drawing of the UL mock-up for high-power stray radiation testing at FALCON. (© IDOM)

This contribution describes the second experimental campaign conducted at the FALCON test facility at SPC-EPFL in June-August 2025., consisting in high-power stray radiation testing of a real-size mock-up (see Fig. 1 / Fig. 2 top, designed by IDOM) of the full UL plug RF-facing volume with the in-vessel mirrors and the main structure walls. The UL mock-up wall (Fig. 2, pink) consists of a d_{wall} = 2 mm thin stainless steel metal sheet with (close to) the same inner shape and surface properties as the actual UL inner surface, designed to produce measurable temperature increase with 0.5 – 1 MW seconds-pulses. The mock-up mirrors also reproduce the shape of the actual UL mirrors but are made of uncooled mono-block copper. At the end of the UL, an RF coupling box (Fig. 1: beige) was added with 2 additional sets of mirrors to couple the power directly into an RF-load, with the coupling box's interior covered with plywood panels to prevent back-reflection of stray radiation. At the input, a Diamond Window Unit serves as interface between the evacuated TL and the mock-up at atmospheric pressure.

The mock-up was tested with typically 1 s / 0.58 MW RF pulses on each of the TL-inputs (1 TL failed), limited by the heat load of panels in the RF coupling box. For measuring the power absorbed in the mock-up wall, two infrared cameras were placed at various view angles with identical pulses. Additionally, thermocouples were placed at well-chosen positions such as on the mirror back-faces, calorimetry was used to measure the power of the beam, and the experiment was used to also test prototypes of UL-bolometers and arc detectors. The beam pattern at the DWU-output has been measured prior to and after the experiments, for reconstructing the full amplitude and phase profile at this position. This profile is being used to simulate in FRED the stray radiation with an entire as-built model of the mock-up including the RF coupling box. This simulation shall be benchmarked against the experimental measurements to confirm the validity of such simulations for the real UL.

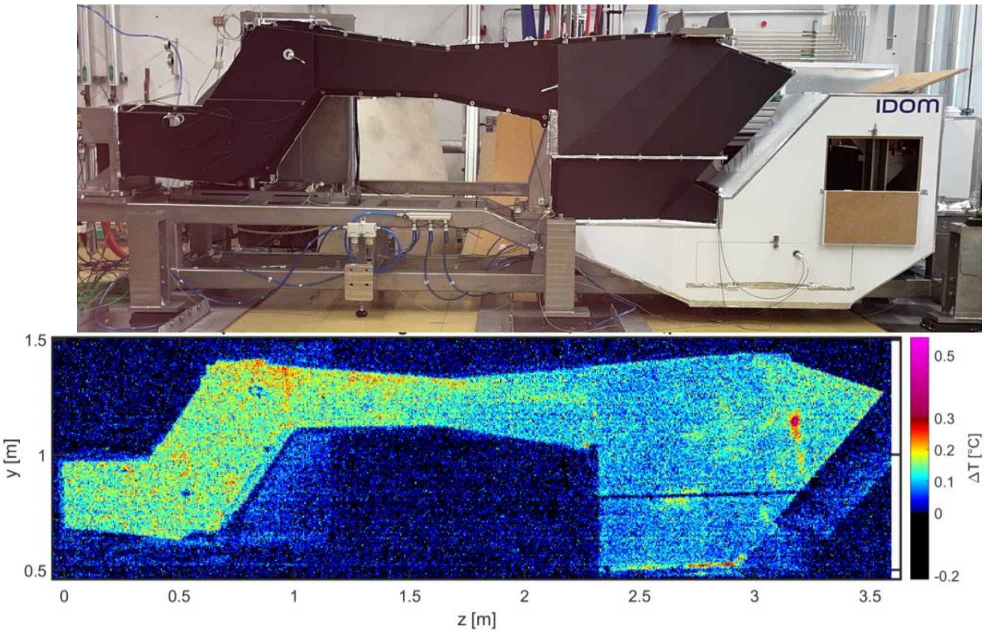

Figure 2: Top: UL-mock-up photo in FALCON. The outer UL mock-up wall is painted with black high-IR-emissivity paint. Bottom: Temperature increase from Infrared image after gyrotron pulse (background-subtracted, adapted colours).

Fig. 2 (bottom) shows the preliminary result of the temperature increase in a global IR-camera view of the right-hand side mock-up-wall, for a test of TL No. 6. Here, the measured temperature increase averaged over the entire right face of the mock-up wall is $\Delta T/\Delta t = 0.13$ °C/1s (preliminary), which would correspond to an average of stray power density $I_{stray} = \rho \cdot C_p \cdot \Delta T/\Delta t \cdot d_{wall} = 1.1$ kW/m^2 (mass density ρ [kg/m^3] and heat capacity C_p [J/K/kg] of stainless steel and the pulse length Δt [s]). Assuming a similar heating in the other mock-up walls, the total absorbed stray power in the mock-up wall corresponds to $P_{stray,tot} = 7.5$ kW.

A detailed analysis of the experimentally measured overall stray radiation power, stray pattern and of the hot spot location and amplitude will be presented and compared to simulation results.

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