ACHIEVEMENT AT THE ITER NEUTRAL BEAM TEST FACILITY AND PROSPECTS FOR THE R&D ACTIVITIES WITHIN THE ITER RESEARCH PLAN

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1. INTRODUCTION AND GOAL OF THE CONTRIBUTION

The ITER Neutral Beam Injection Heating and Current Drive system consists of 2 (upgradable to 3) Heating Neutral Beams (HNB) and 1 Diagnostic Neutral Beam (DNB). In order to reach burning plasma condition and control the fusion performance, the HNBs system will provide heating power at a level of 33 MW by firing high energy beams of neutral particles, i.e. hydrogen at 0.87 MeV or deuterium at 1 MeV, into the ITER plasmas.

As the target parameters have never been reached simultaneously [1], the ITER Neutral Beam Test Facility (NBTF) was set up at Consorzio RFX premises (Italy) aimed at developing the injector prototype and attaining the challenging requirements. The facility includes two test beds [2]: the full-scale HNB prototype, named MITICA, that will enter into operation in 2026, and SPIDER, with 100 keV particle energy, aimed at testing and optimizing in advance the ITER-size ion source, in operation since 2018.

This contribution describes the R&D strategy for the establishment of HNB at ITER that meets the target performances and the related long-term schedule, in particular highlighting the recent contributions of activities at NBTF on both devices.

2. OVERVIEW OF EXPERIMENTS AND DEVELOPMENTS IN SPIDER

SPIDER shutdown [3] was completed and operation successfully restarted in 2024: the refurbishment and improvements demonstrated effective and remarkable results, right on the expected path towards target performances.

SPIDER recent operation was primarily aimed at the characterization of the bottom segment of the source, by operating most of the 300 beamlets simultaneously for the first time.

The main goal was to investigate the relationship between current density and RF power at the required ITER pressure of 0.3Pa at the bottom segment, with regard to the attainment of the ITER NBI requirement (330A/m^2) at 100kW/driver (Figure 1). Results are in line with expectations from the half-size source test facility ELISE [8] and goals. Temporary limitations regard the configuration of radiofrequency generators have been observed, but new components are already under the final stages of procurement.

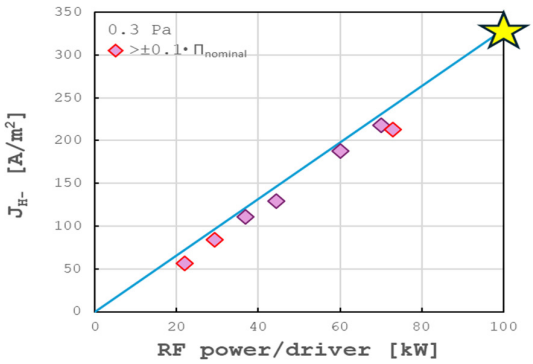

Figure 1 Negative ion current density as a function of the RF power at 0.3Pa filling pressure

3. STATUS OF MITICA ACTIVITIES

In 2021, during the first MITICA power supply integrated tests, a pair of events occurred involving unexpected breakdowns and overvoltage, which led to the damage of a few components [3]. Activities for the power supply restoration and improvements in order to prevent reoccurrence of issues progressed and are approaching onsite final activities.

The procurement for the new protections designed to prevent overvoltage on the refurbished components, with the help of interpretative discharge models [4], are under completion. The new protection components have been designed to absorb surge voltage up to 1 MV [5], manufactured in Japan and shipped to Italy. Those will be installed and the integrated test will be examined again.

Voltage holding in vacuum at 1 MV level, with electrodes of the MITICA beam source dimensions and complexity is a challenge in a fully unchartered territory, characterised by strong non-linearities in the possible extrapolations from smaller devices. Addressing this issue in advance is a strong and strategic risk mitigation in the plan that leads to the start of the full MITICA operation. The execution of HV insulation tests in vacuum started (Figure 2), reaching more than midway towards the target parameters and gathering lots of precious information regarding

the behaviour of such a huge device under these conditions, using the power supply sub-systems not affected by the cited events, in advance of the completion of the repair.
The main objectives of the tests are the following:

- experimentally assess HV DC holding capability of MITICA beam source insulation in vacuum before starting beam experiments
- identify and possibly cure weak areas, before the real Beam Source is completed and installed
- determine minimum number of intermediate electrostatic shields necessary for withstanding 1 MV
- benchmarking and validating the codes used for the electrostatic design of MITICA components at high voltage [6]

Significant steps forward have been reached on all other systems towards the start of full MITICA operation.

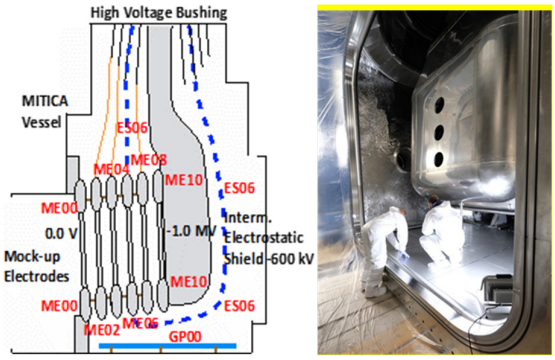

Figure 2 HV insulation tests in vacuum: scheme and source mock-up installed in the vacuum vessel

4. LONG TERM STRATEGY AND INTEGRATION WITHIN THE ITER RESEARCH PLAN

The plan of the R&D related to ITER NBI has been revised to meet the needs of the new ITER Research Plan (IRP), following the overall ITER re-baseline in 2024. Hence, the overall NBTF plan of activities with the relevant time schedule is now fully integrated with the ITER research plan, identifying links with the inputs expected by the HNB development. The first main milestone, in 2032, shall demonstrate the soundness of the configuration for HNB operation (870 kV, 330 A/m2, 10 s), and in particular to start the procurements for HNB components.

With this goal, SPIDER and MITICA will alternate between operational phases and maintenance phases, during which the lessons learned from previous experimental campaigns will be integrated into the design, together with inputs generated in the associated party laboratories.

The NBI community is significantly involved in supporting directly the NBTF with dedicated experiments and inputs for SPIDER and MITICA on most critical aspect:

- The half-size source test facility ELISE, at IPP [7][8], has already demonstrated the ITER target in hydrogen for 10 s and more than 90% for 600 s with only 75% of the RF power, a record in the performance of negative ion sources
- QST are contributing with expertise on voltage holding with large-area electrodes simulating a nested structure of electrostatic screen in the high-voltage bushing [9][10]. Considering the technical input from QST on voltage holding with area-effect and experimental results in the MITICA BS mock up, the final configuration (number) of intermediate electrostatic shields necessary for withstanding 1 MV is discussed and decided.

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