The ITER Neutral Beam Test Facility in Padua – Italy: a joint international effort for the development of the ITER heating neutral beam injector prototype

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Abstract.
The paper describes the international effort to develop the negative neutral beam injectors for ITER with the construction of a test facility where two testbeds will be installed. The first testbed is a ITER full size negative ion source where the necessary ion current density has to be produced and it will also support the development of the diagnostic neutral beam injector to be installed in ITER. The second testbed is the prototype of the ITER heating neutral beam injector.

1. Introduction

The development of the neutral beam injectors for ITER presents several challenging issues on physics and technology. Initially two Neutral Beam Injectors (NBI) systems will be installed on ITER, each designed to deliver 16.5 MW up to one hour to the ITER plasma. To fulfil this requirement the beam source has to provide a current of 40 A (46 A) of negative ions, D^- (H^-) and an acceleration to 1 MeV (0.87 MeV). The optics of the beam has to be very accurate in order to minimise the power load on the acceleration grids, on the beam line components (neutraliser, residual ion dump and calorimeter) and on the ITER duct. The trajectory of the particles and therefore the beam optics is determined by the non linear coupling of the space charge with the externally imposed electric and magnetic field. In the case of negative ions, stripping losses and ionisation generate additional electrons inside the accelerator, leading to enhanced localised power load on the grids. The final design of the grids results from the balance between the needs of the accelerator optics, where the co-extracted electrons must be dumped before they are accelerated to high energy, and the cooling requirements.

In order to deal with this issue, accurate evaluation of the particle trajectories and of the power load on the grids is performed under different operational conditions (pressure, voltage distribution, current density…). A suitable way of dumping the power of the electrons exiting the accelerator (≈800 kW) is required in order to protect the neutraliser and the cryo-panels from excessive heat loads.

Another crucial issue is the 1 MV holding capability of the system with the beam on. Models and experimental tests are ongoing, or planned, to optimise the design.

These requirements have never been achieved simultaneously and therefore, in order to minimize the risks and the time to provide ITER with reliable NBIs, the need of a strong experimental demonstration and to optimize critical components and systems has been strongly endorsed by the ITER Organization and the ITER parties involved in the development of the neutral beam injectors, namely EU and Japan for the in kind contribution of HNBs and India for the DNB.

A Neutral Beam Test Facility has been proposed and is now entering the construction and procurement phase, following the recent formal endorsement of the necessary Additional Direct Investment by the ITER Council. The Neutral Beam Test Facility will be hosted in Italy by Consorzio RFX in the CNR research area of Padua.

The facility requires the construction of new buildings covering a surface of 2 hectares and the adaptation of the existing 400 kV power substation.

The facility site and the experimental devices installed in it have been assigned the name of PRIMA (Padua Research on ITER Megavolt Accelerator). The site will be ready to host the first experimental components and systems 1.5 years after the start of construction.

The PRIMA facility will host two experimental test stands, SPIDER and MITICA.

The first test stand will optimize a full size negative ion source (fig.1) to full power and pulse length in H^- or D^-. Its mission is to demonstrate the capability to create and extract a current of D^- (H^-) up to ≈50 A (≈60 A). The ions are extracted over a wide surface (≈1.52 x 0.56 m^2) with uniformity within 10% of the mean value.

This test stand has been assigned the name SPIDER (Source for the Production of Ions of Deuterium Extracted from an RF plasma) and will be in operation in ≈3.5 years from the start of the procurement phase.

The main requirements of SPIDER are described in Table 1.

TABLE 1: MAIN MITICA REQUIREMENTS

	Unit	H	D
Beam energy	keV	100	100
Maximum Beam Source pressure	Pa	<0.3	<0.3
Uniformity	%	±10	±10
Extracted current density	A/m2	>350	>290
Beam on time	s	3600	3600
Co-extracted electron fraction (e-/H- or e-/D-)		<0.5	<1

The design and documentation for all the most important experimental plants and components of SPIDER are ready, or very close to being ready, for the procurement phase. The India Domestic Agency will collaborate in the construction of this device, and SPIDER will be also used as a prototype for some components and technologies to be applied in the DNB.

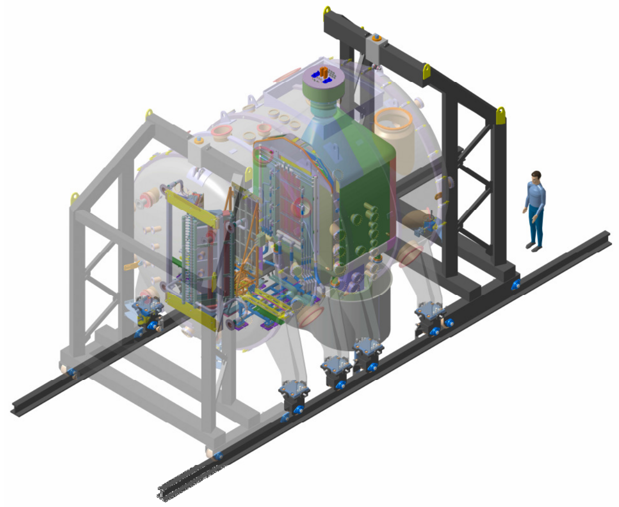

Fig. 1: SPIDER the full size negative ion source

The second test stand is the prototype of the ITER injector (fig.2), which aims at developing the knowledge and technologies to guarantee the successful operation of the two injectors to be installed on ITER. This test stand has been assigned the name MITICA (Megavolt ITer Injector and Concept Advancement). The Japanese Domestic Agency is charged with the procurement of the 1 MV power supplies, the 1 MV transmission line and the electrical bushing between the transmission line and the injector vacuum vessel for MITICA. Most the design and associated documentation for the procurement of the plant and many of the components for MITICA are well developed and close to being ready for starting of procurement. The remaining components and systems are foreseen to be ready for starting of procurement within the next two years.
The main requirements of the ITER heating neutral beam injector are described in Table 2.

TABLE 2: MAIN MITICA REQUIREMENTS

	Unit	H	D
Beam energy	keV	870	1000
Acceleration current	A	49	40
Maximum Beam Source pressure	Pa	0.3	0.3
Beamlet divergence	mrad	≤ 7	≤ 7
Beam on time	s	3600	3600
Co-extracted electron fraction (e-/H- or e-/D-)		<0.5	<1

The European laboratories CCFE-Culham, IPP-Garching, KIT-Karlsruhe, and other research institutions are also collaborating on PRIMA, supporting the design of some components, exploiting accompanying experimental devices and contributing to beam modelling, where also the Japan, India and Russia Domestic Agencies are contributing.

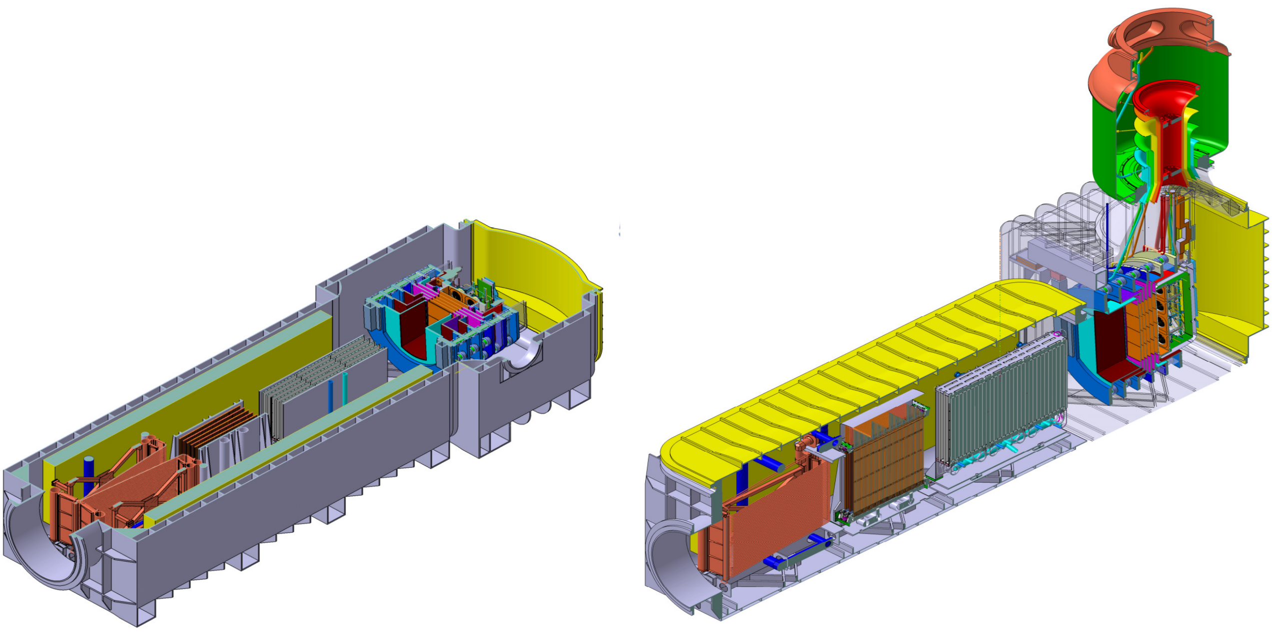

Fig.2: Two section views of the ITER heating NBI prototype MITICA