Progress of the Neutral Beam Test Facility Project

V. Toigo on behalf of NBTF team
Consorzio RFX, Padova, Italy
# Heating systems at ITER - summary

<table>
<thead>
<tr>
<th>ITER operational phase</th>
<th>Time line</th>
<th>Power requirement (MW)</th>
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<td>NB</td>
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<td>First plasma</td>
<td>2025</td>
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<td>Pre fusion power op. 1</td>
<td>2028 – 2030 (mid)</td>
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<td>Pre fusion power op. 2</td>
<td>2032 (mid) – 2034 (FQ)</td>
<td>33</td>
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<td>Fusion power op (DT)</td>
<td>2036 onwards</td>
<td>33</td>
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<td>Upgrade potential</td>
<td>50</td>
<td>40</td>
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<tr>
<th>EC system</th>
<th>IC system</th>
<th>NBI system</th>
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<tbody>
<tr>
<td>170 GHz</td>
<td>40-55 MHz</td>
<td>870 keV H₀, 1 MeV D₀</td>
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<tr>
<td>NTM, ST control, (j(\rho)) control, EC-assisted startup,</td>
<td>High fusion gain, ST control, wall cleaning,</td>
<td>Bulk current drive, rotation,</td>
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<td>24 gyrotrons (24 x 0.8 MW)</td>
<td>2 antennas (2 x 10 MW)</td>
<td>2 injectors (2 x 16.5 MW)</td>
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</table>
H&CD configuration for the Staged Approach

First Plasma (FP) Dec. 2025
FP Finished and Start of Assembly II Jun. 2026
End of Assembly II Jun. 2028
Start of Pre-Fusion Power Operation-I (SP) Dec. 2028
End of Pre-Fusion Power Operation-I and Start of Assembly III Jun. 2030
End of Assembly III Sep. 2031
Pre-Fusion Power Operation-II (TP) Jun. 2032
End of Pre-Nuclear Shutdown for Assembly IV Mar. 2035
Fusion Power Operation (DT) Dec. 2035

Engineering Operation (SC Magnets) (6 Months)
Assembly II (24 Months)
Integrated Comm. II (6 Months)
Pre-Fusion Power Operation-I (18 Months)
Pre-Fusion Power Operation-I (18 Months)
Assembly III (15 Months)
Integrated Comm. III (9 Months)
Pre-Fusion Power Operation-II (21 Months)
Assembly IV (12 Months)
Integrated Comm. IV (9 Months)

6.7MW ECRH
20MW ECRH
73MW IC/EC/NB
Upgrades

Source: The ITER Research Plan, Version 1.3, 06 Aug 2018 IDM ref. W7W4NZ
ITER H&CD systems

Neutral beam injection (NBI)
- 870 keV H<sup>0</sup>
- 1 MeV D<sup>0</sup>
- 33 MW

Ion Cyclotron (IC)
- 40-55 MHz
- 20 MW

Electron Cyclotron (EC)
- 170 GHz
- 20-30 MW
Negative ion beams in ITER

- Additional heating: ECRH, ICRH, NBI

- 2 (+1) HNB: Heating Neutral Beam
- 1 DNB: Diagnostic Neutral Beam
- NBTF: Neutral Beam Test Facility

2 HNBs (+1): deuterium

- \( I_{\text{acc}} = 40 \text{ A} \)
- \( V = 1 \text{ MV} \)
- \( t_{\text{pulse}} = 3600 \text{ s} \)
- \( P_{\text{beam}} = 16.5 \text{ MW} \)
- divergence < 7 mrad
- aiming ± 2 mrad
- non-uniformity < 10%
- \( e^-/D^- < 1 \)

EUDA & JADA procurement
Challenges of ITER NBIs

- Generation, extraction, acceleration of 40A negative deuterium beam:
  - Non-uniformity <10%
  - Caesium distribution
  - Inductively coupled plasma: RF coupling to plasma; RF coils in vacuum
  - Co-extracted electrons; generation of electrons in accelerator

- 5-steps acceleration of negative deuterium ions to 1MV
  - Divergence <7mrad; aiming not exceeding ±2mrad range
  - Voltage holding at low pressure with free charges and radiation

- NBI operation for one hour (RAMI)
  - Thermal and thermomechanical issues
  - Beam stability
  - Radiation from ITER
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Worldwide coordinated effort addressing these challenges: ITER-IO, QST, IPP, NIFS, IPR, Consorzio RFX and negative ion beam community.
Aims of ITER Neutral Beam Test Facility (NBTF)

- Accompanying facility in preparation and support of ITER operation:
  - To realise and commission prototype NBI systems: e.g. HV components @1MV, cryopumps, …
  - To achieve nominal parameters of source and beam
  - To optimize HNB operation
  - To improve reliability and availability of injectors
  - To finalise HNB design
  - To solve HNB issues during ITER operation

- NBTF hosts two experiments:
  - SPIDER: optimisation of ion source: current density, uniformity, stability
  - MITICA: full-size prototype of ITER NBI: high voltage holding, beam optics, aiming
NBTF hosts the two experiments: the negative ion source **SPIDER** and the 1:1 prototype of the ITER injector **MITICA**.

Each experiment is inside a concrete biological shield against radiation and neutrons produced by the injectors.

Thanks to these shielding the assembly/maintenance area will be fully accessible also during experiments.
Optimisation of production of negative ions in terms of:

- Density
- Uniformity
- Stability
- Co-extracted electrons

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<tr>
<th></th>
<th>Unit</th>
<th>H</th>
<th>D</th>
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<tbody>
<tr>
<td>Beam energy</td>
<td>keV</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Maximum Beam Source pressure</td>
<td>Pa</td>
<td>&lt;0.3</td>
<td>&lt;0.3</td>
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<tr>
<td>Uniformity</td>
<td>%</td>
<td>±10</td>
<td>±10</td>
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<tr>
<td>Extracted current density</td>
<td>A/m²</td>
<td>&gt;355</td>
<td>&gt;285</td>
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<tr>
<td>Beam on time</td>
<td>s</td>
<td>3600</td>
<td>3600</td>
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<tr>
<td>Co-extracted electron fraction</td>
<td></td>
<td>&lt;0.5</td>
<td>&lt;1</td>
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SPIDER Components

Vacuum-insulated beam source

Beam Source
Vacuum Vessel
Beam Dump
STRIKE
High resolution calorimeter
SPIDER power supplies

- Ion Source Power Supply
- Transmission Line
- Multi-winding transformers
- Acceleration Grid Power Supply
- High Voltage Deck (HVD)
SPIDER beam source inside vacuum vessel
First SPIDER operations

SPIDER operation started on 4 June 2018 .... just a few days before the official inauguration made in presence of the ITER DG, Dr. B. Bigot
MITICA full scale prototype of ITER HNB

Optimisation of neutral beam in terms of:
- Performances
- Reliability
- Availability

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<tr>
<th></th>
<th>Unit</th>
<th>H</th>
<th>D</th>
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<tbody>
<tr>
<td>Beam energy</td>
<td>keV</td>
<td>870</td>
<td>1000</td>
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<tr>
<td>Acceleration current</td>
<td>A</td>
<td>46</td>
<td>40</td>
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<tr>
<td>Max Beam Source pressure</td>
<td>Pa</td>
<td>0.3</td>
<td>0.3</td>
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<tr>
<td>Beamlet divergence</td>
<td>mrad</td>
<td>≤7</td>
<td>≤7</td>
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<tr>
<td>Beam on time</td>
<td>s</td>
<td>3600</td>
<td>3600</td>
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<tr>
<td>Co-extracted electron fraction (e−/H−) and (e−/D−)</td>
<td></td>
<td>&lt;0.5</td>
<td>&lt;1</td>
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MITICA components

- CRYOGENIC PUMPS
- CALORIMETER
- RESIDUAL ION DUMP
- NEUTRALIZER
- BEAM SOURCE
Vessel, made of Stainless Steel; 15m × 5m × 5 m; divided into Beam Line Vessel (BLV) and Beam Source Vessel (BSV) (delivered and installed).

Rear Lid Handling System (delivered and installed)

BLV in Feb 2019: welding of ports and other internal supports, before final machining

BLV – On-going final machining
MITICA Beam Source

- Contract signed with Alsyom-Seiv (F) in Oct 2018
- Delivery on site by summer 2022
- Presently: realisation and test of prototypes of critical components
MITICA Beam Line Components

- Two-stages contract:
  - stage 1 completed
  - stage 2 under preparation
  - delivery planned for Q3 2023

- Three suppliers awarded Stage 1:
  - AVS Tecnalia (E)
  - SIMIC (I)
  - De Pretto Industrie – ATT Angelantoni Consortium (I)
MITICA Cryogenic Pumps

- Delivery planned for Q4 2020
- Cryopanel: 2 x 8m x 2.8m
  - 5000m$^3$/s in hydrogen; 3800m$^3$/s in deuterium
  - Cryogenic power at 4.5K: 800W (supercritical He)
  - At 81K (thermal radiation shield): 17.4kW (gaseous He)
- MITICA Cryopump procurement subdivided in three lots:
  - Support Frame and Assembly by SDMS (F)
  - Charcoal coating of pumping surfaces by SDMS (F)
  - Aluminium expansion profiles by Ravanat (F)

Aluminium profile extrusion (MGOP/SDMS)  
Hydroforming process (Ravanat)  
Charcoal coating process (SDMS)
Auxiliary Systems

- Cooling plant for 70MW: 1000m³ water basin; 17MW at cooling towers
- Cryogenic plant & cooling plant: installed; under test and commissioning
- Gas injection and vacuum system: GSD-Shared Plant Unit; 2 independent vacuum and gas injection systems; for MITICA under installation; for SPIDER operating
MITICA Power Supplies

- 1MV Insulating Transformer
- 1MV Faraday Cage (hosting Ion Source PSs)
- HV Bushing
- Vacuum Vessel
- HV Transmission Line
- 1MV AGPS-DC Generator
- RIDPS
- AGPS Conversion system 60MW CW

V. Toigo - MevArc - 17 September 2019
MITICA: Commissioning of HV components

- Combined tests HVD1 + 1MV JADA insulating transformer

- Successful execution of integrated insulation tests on 9 July 2019:
  - -1.2MV, 1h: Insulating Transformer (via HVD1)
  - -1.06MV, 5h: HVD1 + Insulating Transformer
  - 5 pulses from -1.06MV to -1.265MV
MITICA: BSV – HVB Integration

- **HVB transport**
- **Lowering, positioning and fixing of HVB to Support Structure and BSV**
- **Final positioning of curved element**
- **Short-circuiting device inside BSV**

*Final insulation tests planned for autumn 2019*
### MITICA Activities

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<thead>
<tr>
<th>Category</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
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<td>HVD1 &amp; HVD1-TL Bushing (Siemens)</td>
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<td>ISEPS (Ocem)</td>
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<td>GRPS (Ocem)</td>
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<td>Installation JADA components (Synecom)</td>
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<td>Beam Line Components</td>
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Thank you for your attention
Overall planning of development of NBI for ITER

- SPIDER operation
- MITICA operation
- ITER operation with HNBs

V. Toigo - MevArc - 17 September 2019