The Neutral Beam Test Facility (NBTF) (and the HNB ITER injectors) and Electron Cyclotron Power Sources
Note: all information contained in this presentation is for information only and may be subject to changes.
Objectives

• Describe scope of main European procurements in the NB and EC Power Sources areas
• Highlight specific technologies involved
• Give an idea of timescale / size of contracts
Technical specifications type

Build to print
- Full set of drawings supplied
- Manufacturing details from the Supplier
- F4E responsible for design (performances)
- Supplier responsible for manufacturing

Functional
- Description of functions/requirements and interfaces/boundaries provided
- Design carried out by the supplier (included in scope of supply)
- Supplier fully responsible of performances

A third type of specs, **Detailed Design**, is also adopted on some cases. In this case F4E provides a well defined design but the Supplier remains responsible to verify and endorse it.
The ITER plasma will be heated with a mix of these heating systems for a total of **73 MW** (baseline scenario) injected into the plasma.

<table>
<thead>
<tr>
<th>Heating System</th>
<th>Baseline - MW</th>
<th>Possible Upgrade - MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBI (1 MVe)</td>
<td>33</td>
<td>(16.5)</td>
</tr>
<tr>
<td>EC H&amp;CD (170 GHz)</td>
<td>20</td>
<td>(20)</td>
</tr>
<tr>
<td>IC H&amp;CD (40 – 56 MHz)</td>
<td>20</td>
<td>(20)</td>
</tr>
<tr>
<td>LH H&amp;CD (5 GHz)</td>
<td>20</td>
<td>(20 – 40)</td>
</tr>
<tr>
<td>TOTAL</td>
<td><strong>73</strong></td>
<td><strong>max 130</strong></td>
</tr>
<tr>
<td>Diagnostic Beam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(100 kVe, H⁻)</td>
<td>&gt; 2</td>
<td>(110 simultaneously available) (limited by port availability)</td>
</tr>
</tbody>
</table>
The H&CD systems are essential for ITER operation, e.g.:

- to heat of plasma to temperatures required for fusion burn
- to access the H-mode regime
- to achieve steady-state operation (non-inductive current drive)
- stabilisation of Magneto Hydro-Dynamic modes in the plasma
- vessel wall conditioning and plasma start-up assist
The ITER Heating Neutral Beam (HNB) System

2 NBIs (+1)

\[ P_{\text{beam}} = 16.5 \text{ MW} \]
\[ I = 40 \text{ A} \]
\[ V = 1 \text{ MV} \]
\[ T_{\text{pulse}} = 3600 \text{ s} \]

- Power Transmitted Line at 1 MV
- \( \text{SF}_6 \) Insulating gas
- 0.03 Pa – 0.001 Pa Vacuum

ITER-ITA data

- Bellows
- Gate valve
- Calorimeter
- Residual ion dump
- Neutraliser
- Ion Source and accelerator

16.5 MW

9 m

15 m

5 m
Basic principle: Highly energetic beams of neutralized particles (Deuterium or Hydrogen) are injected into the plasma.

Large scientific/technological step from existing NB systems ➔ A full scale Neutral Beam Test Facility is needed (NBTF/PRIMA).

The test facility is located in Padova (Italy) hosted by the Consorzio-RFX.
NB Test Facility

SPIDER
Source for Production of Ion of Deuterium Extracted from Rf plasma

MITICA
Megavolt ITER Injector & Concept Advancement
## List of main NBTF contracts launched or to be launched by F4E

<table>
<thead>
<tr>
<th>Component</th>
<th>Specs</th>
<th>CfT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISEPS (SPIDER and MITICA)</td>
<td>FS</td>
<td>CLOSED</td>
</tr>
<tr>
<td>SPIDER HVD + Tx Line</td>
<td>FS</td>
<td>On-going (negotiated)</td>
</tr>
<tr>
<td>MITICA HV Deck and Bushing</td>
<td>FS</td>
<td>CLOSED</td>
</tr>
<tr>
<td>MITICA AGPS</td>
<td>FS</td>
<td>2013Q2</td>
</tr>
<tr>
<td>PRIMA Vacuum &amp; Gas Injection Plant</td>
<td>FS</td>
<td>CLOSED</td>
</tr>
<tr>
<td>MITICA Cryopump</td>
<td>BtP</td>
<td>tbc</td>
</tr>
<tr>
<td>NBTF Cooling Plant</td>
<td>FS</td>
<td>CLOSED</td>
</tr>
<tr>
<td>Project Description</td>
<td>Delivery</td>
<td>Quarter</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>----------</td>
<td>-----------</td>
</tr>
<tr>
<td>MITICA Cryogenic Plant</td>
<td>FS</td>
<td>2013Q3</td>
</tr>
<tr>
<td>MITICA SF6 Plant</td>
<td>FS</td>
<td>2014Q2</td>
</tr>
<tr>
<td>MITICA Beam Line Components</td>
<td>BtP</td>
<td>2013Q3</td>
</tr>
<tr>
<td>MITICA Vessel</td>
<td>DD/BtP</td>
<td>2013Q2</td>
</tr>
<tr>
<td>MITICA Residual Magnetic Field Coils</td>
<td>BtP</td>
<td>2014Q1</td>
</tr>
<tr>
<td>MITICA Beam Source</td>
<td>BtP</td>
<td>2014Q2</td>
</tr>
</tbody>
</table>
NB PS Procurement is shared btw Europe and Japan

AGPS (CfT to be launched)

GRPS (CfT to be launched)

ISEPS (contract on-going)

EU scope of procurement

Japan scope of proc.
The contract will be based on Functional Specifications

1. Acceleration Grid power Supplies – AGPS Conversion System (low voltage part)
2. Ground-Related Power Supplies – GRPS

The supply includes:
- Detailed Design,
- Fabrication and factory testing,
- transport, delivery and installation on site,
- commissioning and acceptance testing on-site
- and the associated documentation an training.

Beside the NBTF system, the contract will include, as stages to be released, also the supply of the two power supplies system for the ITER Injectors in Cadarache
66kV Step-down transformer

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil immersed</td>
<td></td>
</tr>
<tr>
<td>3 input phases, 50Hz</td>
<td></td>
</tr>
<tr>
<td>Primary voltage 66kV, highest 72kV</td>
<td></td>
</tr>
<tr>
<td>Nb of pulses in lifetime 50,000</td>
<td></td>
</tr>
</tbody>
</table>

DC-AC inverters (5 units)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter topology</td>
<td>3-phase Neutral Point</td>
</tr>
<tr>
<td>- DC link voltage nominal value</td>
<td>6.5 kV</td>
</tr>
<tr>
<td>- Maximum variation under stationary regimes</td>
<td>± 6 %</td>
</tr>
<tr>
<td>- Maximum variation under transients</td>
<td>± 10 %</td>
</tr>
<tr>
<td>Output voltage waveform</td>
<td>three-level square wave</td>
</tr>
<tr>
<td>with variable duty-cycle</td>
<td></td>
</tr>
<tr>
<td>Inverter frequency</td>
<td>150 Hz</td>
</tr>
<tr>
<td>Maximum inverter decoupling + stray inductances</td>
<td>110 μH</td>
</tr>
<tr>
<td>Maximum output dc current component</td>
<td>1% of the rated output</td>
</tr>
<tr>
<td>current of the inverter</td>
<td></td>
</tr>
<tr>
<td>Output current</td>
<td>1700 A</td>
</tr>
</tbody>
</table>

AC-DC Conversion System

- At least 12-pulse operation
- DC Link Voltage: 6.5 kV: -3.25, 0, +3.25 kV) (Thyristor rectifier with DC-link voltage control
- 24KV Disconnector – GRGS
- GR Transformers - GRGT
- Active Control Correction Coils (ACCS) PS - GRCC
- Residual Ion Pump (ERID) PS - GRGD

### Electrostatic Residual Ion dump PS

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average voltage</td>
<td>25kV</td>
</tr>
<tr>
<td>Peak of alternative component</td>
<td>5kV</td>
</tr>
<tr>
<td>Voltage waveforms</td>
<td>Trapezoidal/Sinusoidal</td>
</tr>
<tr>
<td>Rated nominal current</td>
<td>60A</td>
</tr>
<tr>
<td>Period (T)</td>
<td>20ms</td>
</tr>
<tr>
<td>Slope time for trapezoidal waveform (t/T)</td>
<td>1ms / 20ms</td>
</tr>
<tr>
<td>Voltage regulation range</td>
<td></td>
</tr>
<tr>
<td>Average component</td>
<td>20– 100%</td>
</tr>
<tr>
<td>Alternative component</td>
<td>20– 100%</td>
</tr>
<tr>
<td>Max voltage ripple</td>
<td>± 2 %</td>
</tr>
<tr>
<td>Maximum pulse duration</td>
<td>3600 s</td>
</tr>
</tbody>
</table>

### ACCC PS

<table>
<thead>
<tr>
<th>PS</th>
<th>Nominal current</th>
<th>Nominal Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCPS1</td>
<td>650 A</td>
<td>1000 V</td>
</tr>
<tr>
<td>CCPS2</td>
<td>650 A</td>
<td>500 V</td>
</tr>
<tr>
<td>CCPS3</td>
<td>650 A</td>
<td>500 V</td>
</tr>
<tr>
<td>CCPS4</td>
<td>650 A</td>
<td>1400 V</td>
</tr>
<tr>
<td>CCPS5</td>
<td>650 A</td>
<td>500 V</td>
</tr>
<tr>
<td>CCPS6</td>
<td>650 A</td>
<td>1000 V</td>
</tr>
<tr>
<td>CCPS7</td>
<td>650 A</td>
<td>1000 V</td>
</tr>
</tbody>
</table>
AGPS+GRPS: Schedule

- Launch of tender 2013 Q2
- Contract duration: 31 months (including on site assembly and testing) – Stage 1 only (AGPS and GRPS for the NBTF)
SF6 gas is used as an insulating medium for the 1 MV components of the PS system.

- 32 T gas SF6 @ 6 bar
- Vacuum level 20 mbar,
- 48 hours recovery time 32 T gas SF6 @ 6 bar
- Storage in liquid form in a set of tanks

From GHS to HV equipment
From GHS to storage tanks
**MITICA Injector**

- **E-RID**
- **1 MV bushing**
- **JADA supply**
- **BS VV**
- **9 m**
- **Beam Line VV**
- **Beam source**
- **calorimeter**
- **cryopump**
- **neutralizer**
Build-to-Print specifications

**MITICA Beam Source**

**Functions**
- Produce H-/D- ions
- Accelerate to 1MV in focused beamlets

**Challenges**
- High voltage holding
- HHF components up to 20MW/m²
- HP water cooling (2.4MPa)
- Tight tolerances for grids alignment
- Precise and adjustable source positioning
Main components
- Case
- Drivers
- Caesium oven
- Electrostatic shields
- Extractor
- Accelerator
- Fluid/electrical conn.
- Support and tilting
MITICA Beam Source: requirements

**Overall dimensions**
2.5m(l) x 2.5m(w) x 3m(h) ~ 30t

**Processes**
- Copper electrodeposition
- Mo/W coating
- SS/Copper welding

**Manufacturing requirements**
- High Vacuum compatibility (cleanliness, mechanisms)
- High Voltage compatibility
- Reliability of welding
- Very tight tolerances for relative and absolute positioning

**Scope of supply**
- Manufacturing
- Assembly
- Tests
- Launch of tender 2014 Q2 (depending on procurement strategy)

- Contract Duration: 35 months
- Build-to-Print Specifications

- Three main components. Procurement based on a single CfT with three lots (tbc)
Neutraliser

- Total heat load≈5.5 MW (actively cooled)
- Max power density≈ 0.5 MW/m² (3MW/m² on Leading Edges)
- 2.4 MPa water pressure
- 5 panels made of OFHC copper UNS C10200
- 5 leading edge elements made of CuCrZr (UNS C18150)
- Case and piping made of AISI 316 LN
- Overall weight 15t, dim 3.2(l)x1.5(w)x3(h)

Panels and cooling channels

- Panels min thickness 34mm
- Gun drilled Ø18 x 1800
- EBW plugs
- Instrumented with TC
- Copper/SS and CuCrZr/SS transition welds with Ni adapters
- Welding of adaptors for gas injection and cooling (EB weld or other options to be qualified)
Residual Ion Dump (RID)

- Remove ions
- Electrostatic deflection - 20 kV
- Max heat load ~19 MW
- Max p.d. 6 MW/m$^2$
- 5 panels made of 360 CuCrZr swirl tube elements
- AISI 316 LN structure and piping
- Overall weight ~5 t, max. dim. 2.6m (L) x 1.3 m (W) x 3.2m (H)

High Heat Flux Panels
18 elements/panel 100mm(w) x 20mm (t) x 1890mm (h)
4 gun drilled holes each Ø16
SS twisted tape inside
EBW caps and stubs
Nickel transition pieces to SS
• Stops the beam
• Max heat flux 18 MW
• Max p.d. ≈ 14 MW/m²
• 2 panels made of 96 CuCrZr STE Ø20 wt=2mm
• Case and piping made of AISI 316 LN
• Panels can rotate 6°
• Overall weight ~7t, dim 3.1m(l)x2m(w)x2.9m(h)
Beam line components - schedule

• Launch of tender 2013 Q3 (depending on procurement strategy)

• Contract Duration 32 months
Presented by A. Teissier in his speech later today
Requirements

Cryopanels circuit
- ScHe @ 4.5 K - 0.4 MPa(a)
- Max Flow rate: ~50 g/s
- Max heat load: 900 W

Thermal Shields circuit
- GHe @ 80 K - 1.75 MPa(a)
- Max Flow rate: ~310 g/s
- Max heat load 21kW

Operations
- Steady state operation
- Beam pulse operation
- Max beam duration 3600s
- 100 K regeneration
- Room temperature regeneration under UHV
- Duty cycle ¼ (typ 300s/900s)
Cryoplant: scope of supply

- Design
- Manufacturing
- Instrumentation and control
- Auxiliary dedicated cooling and electrical plant
- Assembly
- Testing (functional and performance with dummy load)
- Documentation
• Launch of tender 2013 Q3

• Contract duration: 24 months (including on site assembly and testing)
The MITICA vessel is an AISI 304L stainless steel vacuum vessel to host all the internal components for the MITICA experiment; composed of the following parts:
- BSV (Beam Source Vessel);
- BLV (Beam Line Vessel);
- Top Lid;
- Rear Lid (and trolley);
- Front Lid (and trolley);
- The Dome (HVB interface);
- The vessel support structure;
- Any temporary lids necessary for intermediate and final leak tests;

Design (for NBTF) compliant to ASME VIII, div.2 (2010 edition)
Quality class 2
Mitica Vessel: Schedule

- Launch of tender 2013 Q2
- Contract Duration 30 months
RFMCs are used to simulate the residual magnetic field inside the injector.

- 3 pairs of coils
- 500 A each
- Actively cooled copper coils with glass fiber reinforced epoxy insulation
- Coil Section from 100x30 to 120x100

(alternative designs being considered)

- Launch of tender 2014Q1
- Contract Duration 36 months
The ITER Baseline includes two HNB injectors.

Components identical or very similar to those of the NBTF (e.g., nuclear environment): Beam source, BLCs, Vessel, Power Supplies

Plus additional components, not installed at the NBTF

Contractual Activities will start from 2016
Basic principle: RF power at the millimeter wavelength (electron cyclotron frequency in the ITER magnetic field) is launched into the plasma interacting and directly heating the electrons. The energy is then transferred to the ions by collisions.

<table>
<thead>
<tr>
<th></th>
<th>EU</th>
<th>IN</th>
<th>JA</th>
<th>RF</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Supplies</td>
<td>8</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>8MW</td>
<td>2MW</td>
<td>8MW</td>
<td>8MW</td>
<td></td>
</tr>
<tr>
<td>Tx. Line</td>
<td></td>
<td></td>
<td></td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Launchers</td>
<td>4 (UL)</td>
<td>1 (EL)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The specifications for ITER go beyond state-of-art gyrotrons (170 GHz, 1 MW, CW)

A design and R&D programme for the gyrotron is on-going in EU
- Vertical arrangement between MHVPS, BPS/APS, gyrotrons to minimize cable length

- RF building sized for 12 HVPS sets
EU is responsible for ca 2/3rd of the EC power supply package – India the remaining part.

Functional specs - technology available in Europe

<table>
<thead>
<tr>
<th>MHVPS Main Parameter</th>
<th>Value (tbc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{CK}$ characteristic</td>
<td>DC and ON/OFF square modulated</td>
</tr>
<tr>
<td>$V_{CK}$ nominal</td>
<td>55 kV</td>
</tr>
<tr>
<td>$V_{CK}$ range</td>
<td>0 – 55 kV</td>
</tr>
<tr>
<td>$V_{CK}$ fine regulated range</td>
<td>40 kV to 55 kV</td>
</tr>
<tr>
<td>Minimum ramp-up/down time</td>
<td>100 µs – 1 ms</td>
</tr>
<tr>
<td>Settling time</td>
<td>&lt; 50 µs</td>
</tr>
<tr>
<td>Maximum ramp-up/down overshoot / undershoot</td>
<td>$\leq \pm 1% \ (\pm 550 \text{ V})$</td>
</tr>
<tr>
<td>$V_{CK}$ accuracy</td>
<td>$\leq \pm 1% \ (\pm 550 \text{ V})$</td>
</tr>
<tr>
<td>$V_{BC}$ ripple$^1$</td>
<td>$\leq 1% \ (550 \text{ V}_{pp})$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BPS Main Parameter</th>
<th>Value (tbc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage characteristic</td>
<td>DC and ON/OFF square modulated</td>
</tr>
<tr>
<td>$V_{BC}$ nominal</td>
<td>35 kV</td>
</tr>
<tr>
<td>Modulation frequency range</td>
<td>0 – 5 kHz</td>
</tr>
<tr>
<td>$V_{BC}$ accuracy (% of nominal value)</td>
<td>$\leq \pm 0.5% \ (\pm 175 \text{ V})$</td>
</tr>
<tr>
<td>$V_{BC}$ ripple (% of nominal value)</td>
<td>$\leq 1% \ (350 \text{ V}_{pp})$</td>
</tr>
</tbody>
</table>

Each MHVPS feeds two 1 MW gyrotrons
• Launch of tender 2012 Q4

• Contract Duration  68 months (all PS sets)
  First acceptance  30 months after signature
- Two info-days for Industry on the NBTF and on the NB Power Supplies were held in the past.

http://fusionforenergy.europa.eu/5_events_en.htm

Thank You