Italian National Agency for New Technologies,
Energy and Sustainable Economic Development

Additional Heating and Diagnostics

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Introduction

DTT Power requirement

The main task of DTT is to test divertor solution and material in an integrated way at reactor relevant conditions: P/R = 15 MW/m

Given the machine radius (2.11 m) and the radiated power, an additional power of 45 MW is required in the plasma is to get the goal

This power must be injected in DTT using most effective, reliable and efficient systems available now

The additional heating power is a tool to cover the necessary tasks to operate DTT: main heating, current drive, plasma control…

The Additional Power for DTT

DTT Heating Systems

Electron Cyclotron Resonant Heating (ECRH): high frequency e.m wave coupled to electrons

Ion Cyclotron Resonant Heating (ICRH): Radio Frequency wave coupled to ions

Neutral Beam Injector: high energy accelerated neutral particle to heat ions by collisions

All these systems will be installed in ITER and are considered for DEMO: this allows to reduce R&D activities and to use confirmed technologies

Time schedule of Heating Power for DTT

Availability of Heating Power

After the basic commissioning of DTT a relevant level of additional power must be delivered to plasma, in order to test and access to the first scenarios. After this initial phase the power will be increased progressively up to reach the **45 MW** at plasma, 5 years after the start of DTT operation.

Installed Power

	I_p - B_T	ECRH	NBI	ICRH	time
Day-0	2 MA – 3T	8 MW	0	0	First plasma (1 y)
Day-1	4 MA - 6T	16 MW	7.5 MW	4 MW	First 2 years
Full Power	5.5 MA - 6T	32 MW	7.5 -15 MW	4 - 12 MW	Power Completion 5y after Day-0

The ECRH System-I

ECRH system is based on electronic tube (Gyrotron) capable to generated 1 MW at high frequency.

Gyrotron (similar to ITER one)

- Frequency: 170GHz
- Output power: 1MW
- Pulse length: 100s
- Efficiency: >40% (Depressed Collector)

High Voltage Power Supply

- Solid state Technology for 2 HVPS
- 1 Main HVPS for 2 Gyrotrons : -60kV/90A
- 1 Body PS for 1 Gyrotron: +30kV/ 1A
- Reduced ripple ±0.05% & Modulation up to 5KHz
- Real Time control status of gyrotron to guarantee reliability

Transmission of the Power

- High transmission efficiency: 90%
- Quasi Optical Approach (W7-X)
- Multi beam Evacuated line (8 beam in single line)
- High power handling

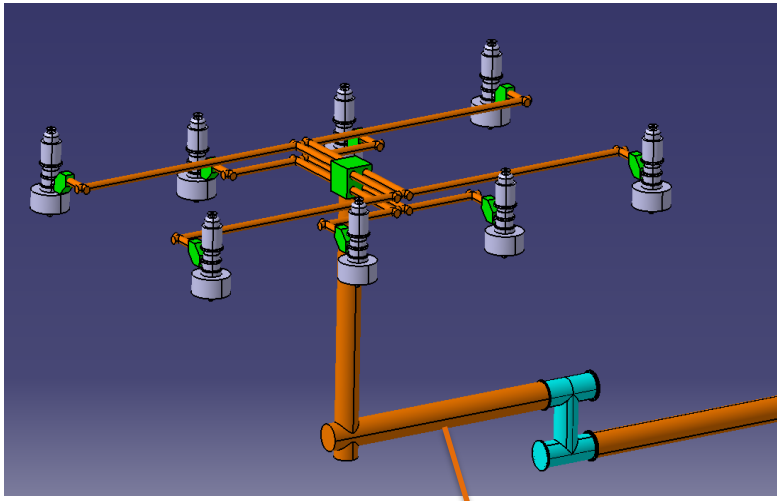
Antenna

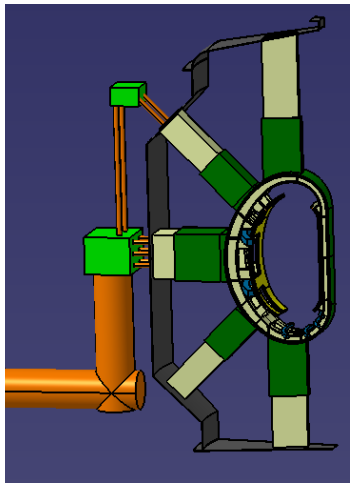
- Independent movable mirrors in 2 directions
- Multi-materials Mirrors (cooled under vacuum)
- Fast movement (~50 ms)
- Plug-In structure
- Remote maintenance compatible

ECRH System Architecture: Cluster

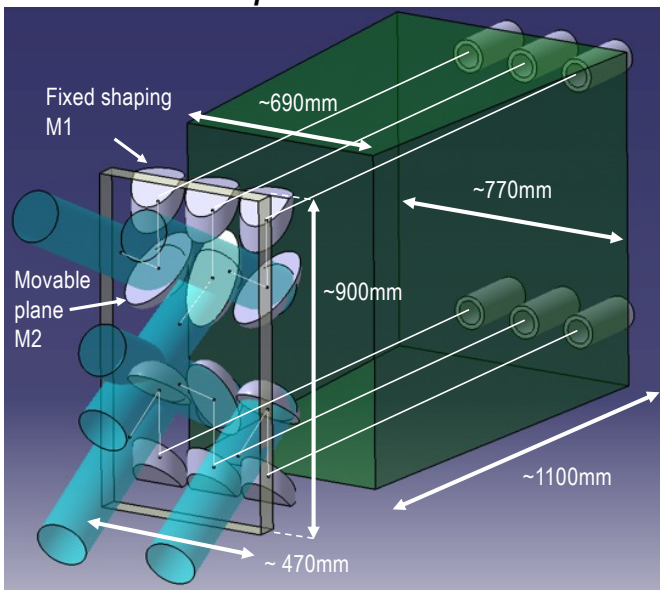
Modular approach reduces cost and R&D, the system will be based on **4 identical clusters** of gyrotrons, TL and launchers:

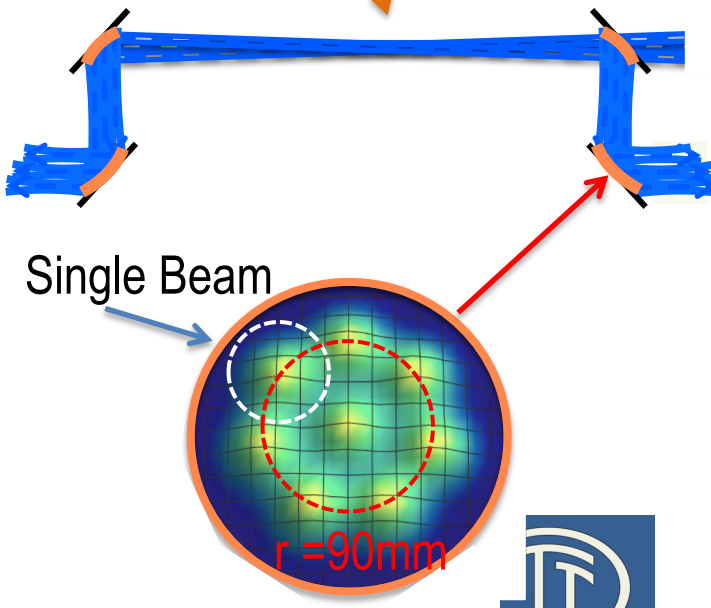
- 4 MHVPS + 8 BPS(+ eventually 8 APS)
- 8 Gyrotrons
- 1 Multi-Beam Transmission Line
- 8 Independent launchers





Equatorial Launcher





ECRH system in summary

Item	#	Proc. Based on	Procurement Type
Gyrotron	32	Func. Spec.	Contract, manufacturing, SAT, FAT
Liquid free Crio magnets	32	Tec. Spec by gyrotron suppliers	Contract, manufacturing, SAT, FAT
MHVPS and BPS	16 +32	Funct. Spec. by gyrotron suppliers	Detail design, manufacturing, FAT, transportation, installation, SAT, and documentation
Gyrotron Ancillary: (PS for filament heater, Collectors coils, cathode coils..)	32 x 4	Funct. Spec. by gyrotron suppliers	Detail design, manufacturing, FAT, transportation, installation, SAT, and documentation
Vacuum system and Mirrors for TL	4 +	Detailed design	R&D with prototypes; construction of standard and custom parts; assembly.
Antennas	4	Detailed design	R&D with prototypes; construction of standard and custom parts; assembly.

The ICRH System

ICRH system is based on RF transmitters, i.e., 3-stages amplifiers based on grid tubes, capable to generate 1-2 MW power level.

Transmitters

- Frequency: 60 - 90 MHz
- Output power: 1-2 MW
- Pulse length: 100s
- duty cycle: > 6% (preferable 12.5%).
- Efficiency > 50-70%

Power Supplies

- Solid state Technology for 2 High Voltage Power Supply
- 1 HVPS for end-stage amplifier : 28kV/180A
- 1 HVPS for driver amplifier: 20kV/16A
- real-time control of end-stage anode voltage
- 6 auxiliary power supplies for grids and filaments

Transmission Lines

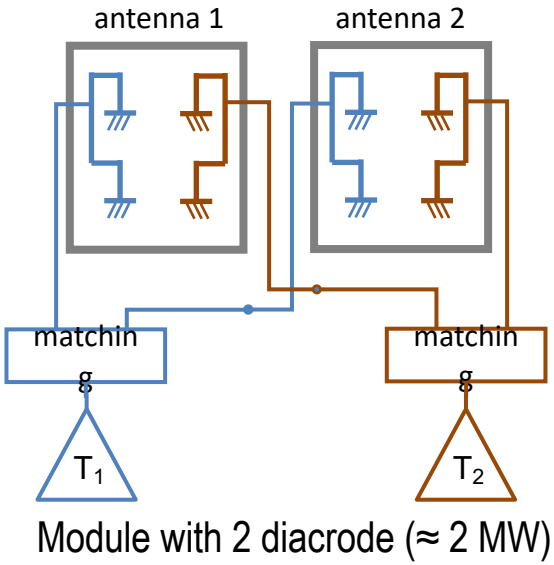
- ~120m of 50Ω rigid coaxial lines 9 3/16”
- Pressurization with dry air at 3 bar
- External conjugate-T matching scheme (impedance transformer + tee & trombones)
- Testing facility with dummy load

Antenna

- Radially movable antenna
- Stainless steel, copper plating, boron coating
- Crucial water cooling and vacuum pumping
- Development of vacuum barriers (feedthrough)
- Remote maintenance compatible

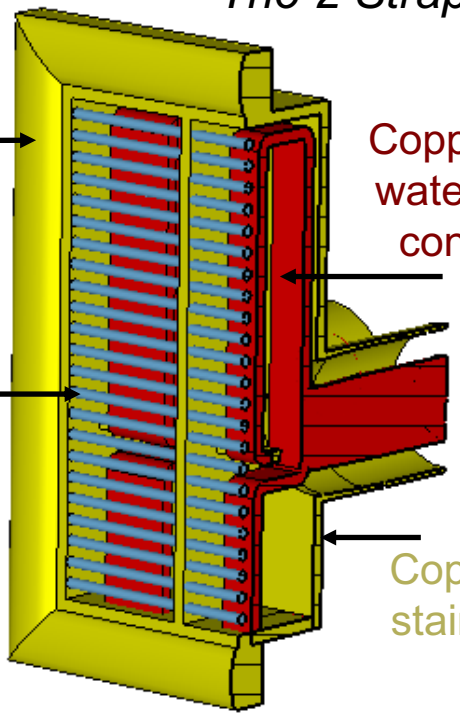
ICRH modules

Two types of modules (3MW @plasma) under consideration: 2 Diacrodes or 4 Tetrodes



Module with 2 diacrode (≈ 2 MW)

The 2 Straps Antenna



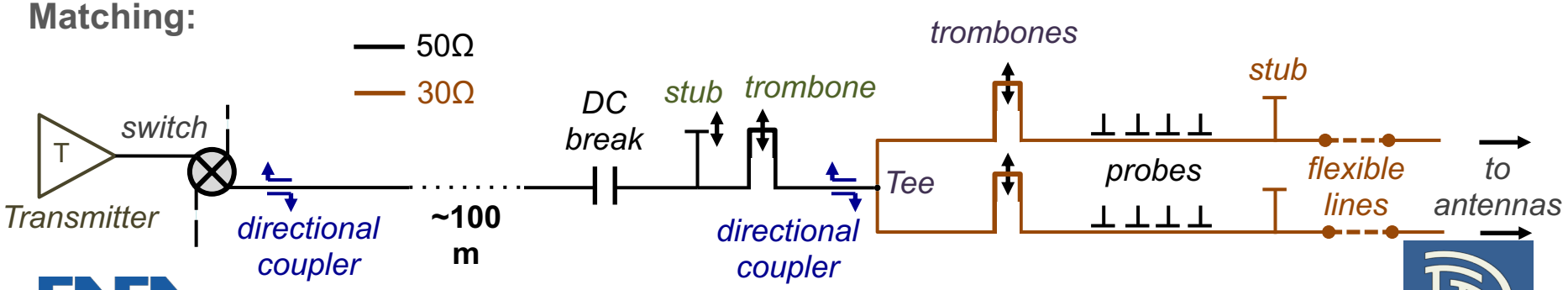
Boron-coated, water-cooled, Tungsten frame

Boron-coated, Copper-plated, water-cooled stainless steel circular rods

Copper-plated water-cooled, conductors

Copper-plated stainless steel box

Matching:



ICRH system in summary

Item	#	Main Charact.	Type of procurement
Transmitter - low-power units, - grid tubes & cavities, - HVPS - aux power supplies - cooling system - control & tuning - integration & tests	6-12	1-2 MW	a) : transmitter as an integrated system (excl. cooling), i.e., outsourcing of detailed design, R&D, construction, integration, qualification and documentation to 1 supplier. b): different suppliers for each sub-item, control system and integration up to DTT team
Transmission line & coaxial components	6-12	50Ω, 9 3/16”	- Definition of diameters, flange and insulator - Component design, R&D (if any), manufacturing and low-power tests up to supplier.
Feedthrough	12-24	double conical alumina	- thermo-hydraulic analysis and detailed mechanical design, - manufacturing & hydraulic tests.
Antenna	6	10 cm stroke	- detailed design of cooling circuit, - detailed mechanical design - antenna manufacturing and hydraulic tests, - moving system

The NNBI System

NNBI system is based on plasma sources generating negative ion accelerated up to 400 kV, neutralized and injected in DTT with an angle of 30° (at vessel).

Plasma Sources

- 12 independent sources based on RF plasma
- Cs hoven and heaters
- 4 Grids (1200 holes)
- Extraction current 38A
- Efficiency

Vacuum Vessel

- Beam Source Vessel
- Beam line vessel
- Gas Injector
- Primary and High Vacuum System
- Absolute valve
- Duct

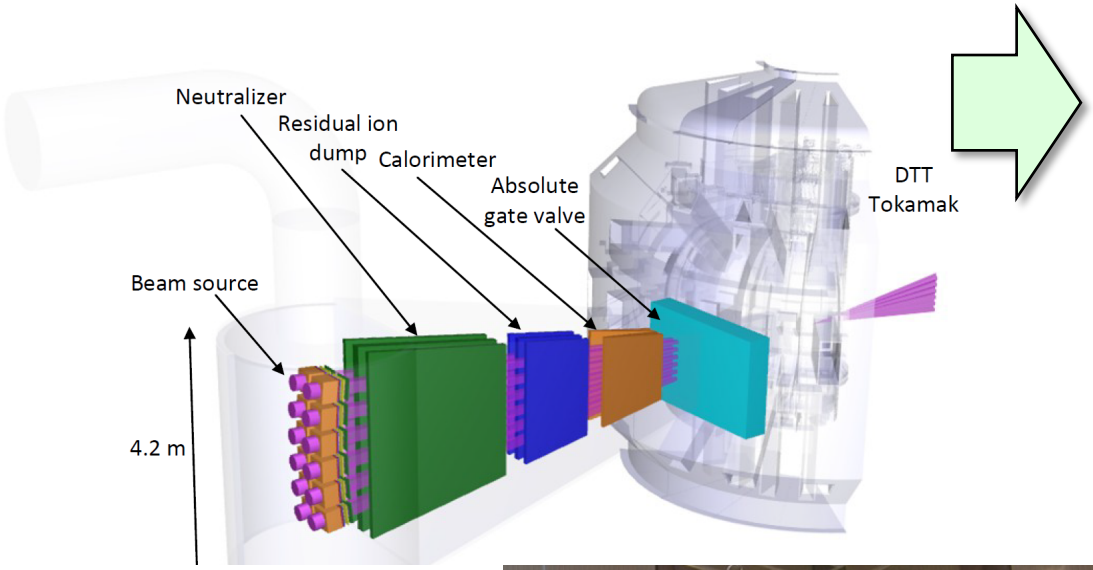
Main Power Supply

- 2 x 200 kV HV rectifiers for grids (2 stages)
- HV (400kV) Floating Deck to supply RF sources
- ion source power supply
- high voltage deck
- SF6 transmission line
- Busbar system

Beam Line

- Neutralizer
- Residual Ion Dump
- Calorimeter

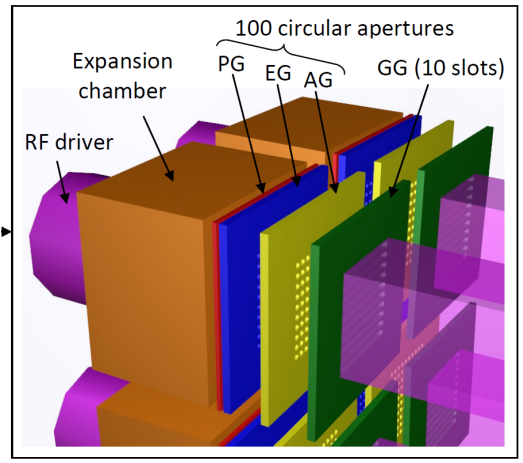
Overview of the beamline design (conceptual design)

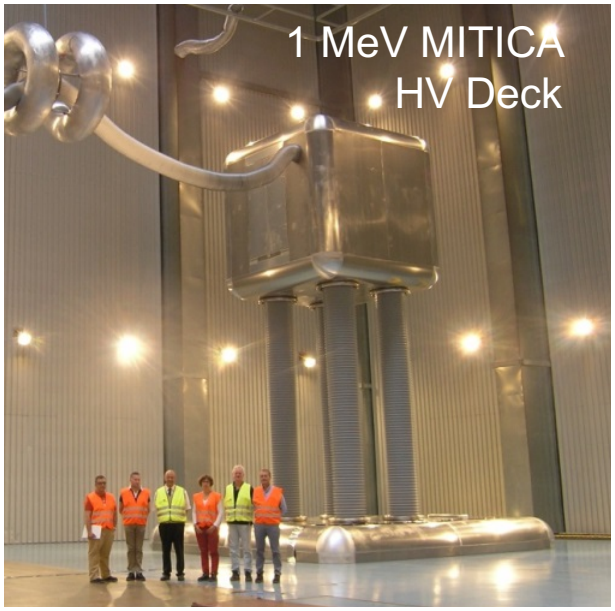


Main components of the beamline:

- Beam source
- Neutralizer
- Residual Ion Dump
- Calorimeter
- Vessel
- Absolute gate valve
- High Voltage Bushing

Focus on one subsource





NNBI system in summary

Item	Proc. Based on	Type of procurement
Plasma Source and Beam Line	Detailed design	R&D with prototypes for critical parts; construction of standard and custom parts; assembly, documentation
vacuum vessel, HV bushing	Detailed design	R&D with prototypes of the critical parts; construction of standard and custom parts; assembly, documentation
Gas injection and vacuum system	Functional Specifications	Detail design, construction of standard parts, assembly, documentation
Power supply system procurements	Functional Specifications	Detail design, development and test of prototypes where necessary, manufacturing, factory routine tests, transportation, commissioning and acceptance tests, documentation
Control, protection and data acquisition system	Functional Specifications	Detail design, construction of standard parts, assembly, documentation
Diagnostic systems	Detail design	R&D with prototypes of the critical parts, construction of standard and custom parts, assembly, documentation

Diagnostics for DTT

Fusion machines require many diagnostics systems for:

Machine protection: e.g. thermal wall loading, plasma displacements, systems faults….

Plasma operation real time control: e.g. plasma current, shape, position, density, MHD activity, impurity content …

Physics studies: e.g. plasma turbulence, kinetic profiles, neutrons and e.m. radiation, plasma exhaust.

Diagnostic installation is a continuous process. High priority fundamental diagnostics will be installed for Day-0 and Day-1, while others will be installed progressively for the second stage (full power)

Diagnostics for DTT : expected needs

- **Magnetic probes (Rogowsky, Mirnov coils)**
- Thermocouples , strain gauges
- **Lasers for: interferometry**/polarimetry, **Thomson scattering** , Phase Contrast Imaging PIC (turbulence) and related optics
- Microwave radiometers, **ECE reflectometry**
- **Hard X-Ray , γ-ray and neutron detectors**
- **Soft X-Ray, Bolometry**
- **Langmuir Probes**
- **VIS cameras+ IR cameras** + image identification software
- Optical fibers (radiation hard, to bring collected radiation outside the torus hall)
- Optical relays: periscopes, mirrors
- **Spectroscopy** cameras for spectrometers
- Gas analyzers
- **Vacuum equipment: pumps, fast baratrons, gauges**
- Data acquisition tools: computers, digitizers, amplifiers, pulse generators…
- Ancillary equipment : cubicles, powers supplies, electrical cables, optical fibers, optical mounts and benches, mechanical supporting structures

Contacts for more information

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Diagnostics

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