The design of the ECRH system of DTT

21st joint workshop on electron cyclotron emission (ECE) and electron cyclotron resonance heating (ECRH)

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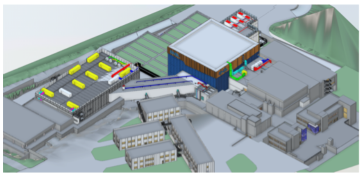
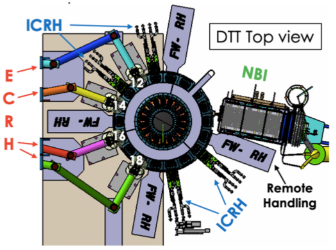
Divertor Tokamak Test facility (DTT)

Main Parameters			
R [m]	2.19	Pulse length [s]	100
a [m]	0.70	P_{TOT} [MW]	45
I_P [MA]	5.5	V_{plasma} [m^3]	≈30
B_T [T]	6.0	P_{sep}/R [MW/m]	15
β_N	1.5	<Te> [keV]	6.1
n_e/n_G	0.42	<ne> [10^{20}m^{-3}]	1.8

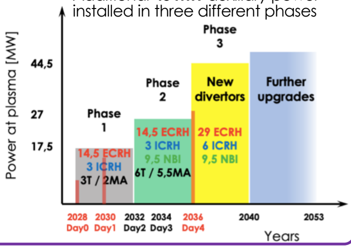
DTT is a fully superconducting tokamak project [1] under construction (~6 years) in ENEA (Frascati) according to the European Fusion Roadmap mission.



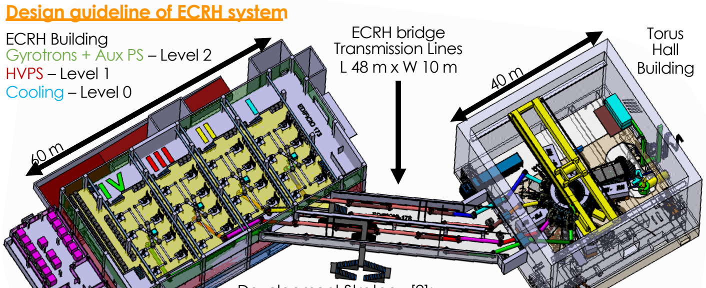
Purpose: **study of the power exhaust problem in an integrated** environment and DEMO relevant conditions



Additional **45 MW** auxiliary power installed in three different phases



Design guideline of ECRH system



Development Strategy [2]:

- Automatic operation of the system:
  - high reliability & modularity
  - reduce maintenance (increasing availability)
- Prefer existing and assessed technology (exploitation of ITER and W7-X experience) although challenging solutions for DTT are considered

ECRH Tasks:

- **Core Heating & CD**
- **MHD control (ST, NTM & ELMs)**
- **Assisted Breakdown**
- **Current ramp-up & ramp down**
- **L- to H-mode transition**
- **Profiles tailoring (J, Te)**
- **Mitigation of impurity accumulation**
- **Wall cleaning**

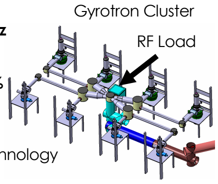
ECRH system architecture:

- 4 Clusters, connected to 4 DTT sectors, each one composed by:
  - **8 Gyrotron sources** (fed in pairs by **4 MPS + 8 BPS**)
  - **1** Evacuated Quasi-Optical Single/Multi-Beam **Transmission Line + 2 RF Loads**
  - **8 Independent launchers** in the same tokamak sector, but different port
- RF Loads

Call for tender: **November 2022**

Gyrotron

- Frequency: **170 ± 0.3 GHz**
- Power: **1 MW**
- Pulse length: **100 s**
- Gaussian content: **> 98%** (TEM_{00} purity mode)
- Efficiency: **> 40%**
- Reliability: **~ 95%**
- Depressed collector technology

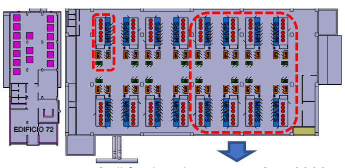


HV Power supplies

16 sets HVPS:
1 x Main HVPS for 2 gyros: **-55kV, 100A**
1 x Body PS for 1 gyro: **+35kV, 100mA**

- rise time **50μs**
- **Up to 5kHz** modulation (50%)
- Ripple **< 0.5%**
- Energy on fault **<10J**
- Power in the cooling system **< 5%**

- Joint procurement with F4E for **16 gyrotrons**
- FwC signature with Thales: **May 2022**
- Pre-series gyrotron acceptance (FALCON, SPC): **August 2023**
- Expected contract completion: **November 2027**

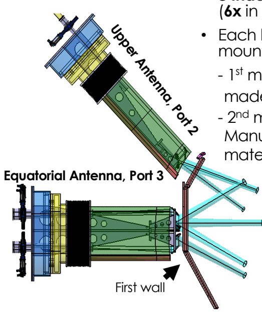


Call for tender: **November 2022**

Evacuated Quasi-Optical (EQO) Transmission Line (TL)

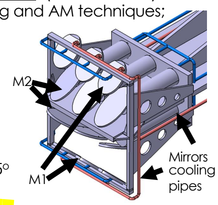
See Poster 1-15

Launcher Design



- **8 Independent** beams front steering concept per DTT sectors (**6x** in *port 3* and **2x** in *port 2*) real time controlled
- Each launcher consists of 2 mirrors, water cooled, with identical mounts (modularity)
  - 1st mirror (M1) with **shaped** surface and **fixed** (138 x 196 mm) made of 12 mm CuCrZr alloy + 2 mm of copper
  - 2nd mirror (M2) **flat** and **2 axes steerable** (138 x 264 mm) Manufacturing solutions are brazing and AM techniques; material to be defined

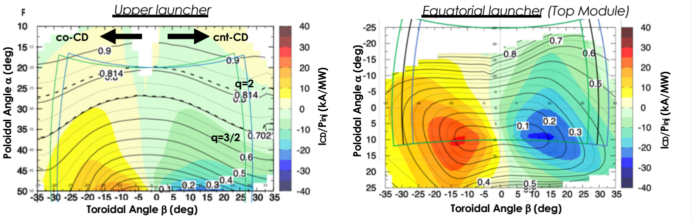
Present steering range:
Upper antenna
α≈20°-50°, β±25°
Equatorial antenna
Top: α=[-25°;+10°], β±25°
Bottom: α=[-10°;+25°], β±25°



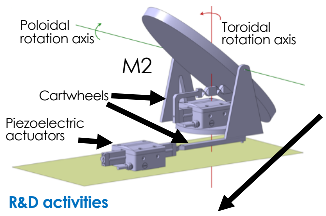
EC beam tracing support in launcher design

See Poster 2-2

Wave absorption and CD efficiency characterized with GRAY code for the reference scenario (**full-power, I_P flat-top, n_{e0}~2.5 10^{20} m^{-3}** [3])



Access to the whole plasma core region with complete absorption assured by both EC launchers; Optimal UL toroidal injection angle β ~ -20°: max I_{CD} with Δρ < 0.05 (≈ 3.5 cm)



Innovative actuation system [4]

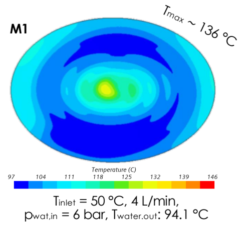
Guidelines: **fully in-vessel**, flexible, compact, lightweight, fast (1°/50ms), accurate (~0.1°)
Environment: strong var. magnetic fields, UHV, X-Ray, nuclear (γ and n) and mw stray radiation
Candidate: **Piezoelectric walking drives**
- fast response, lightweight, non-magnetic
- UHV compatible (**10^{-6}mbar**)
- Positioning resolution: **0.02 nm**
- Max. operating/baking Temp.: **60/120 °C** (water cooling required)
- Max. pol/tor speed: **20/13 °/s**
- Max. **pol**/tor **torque**: **2** /3.5 **Nm**

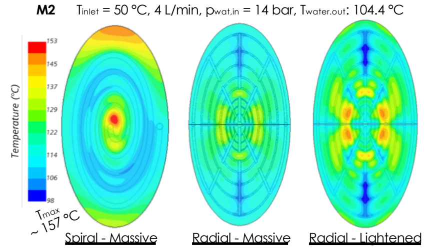
R&D activities

- Selection of the actuator
- Design of driving mechanism (Cartwheel, Ti or CuNi alloy)
- Design of flexible cooling piping
- Position sensors (fiber optic encoder/interferometer)

- Analysis/mitigation of magnetic effects
  - **Mirror material choice**: Need to reduce weight and eddy currents during operation, keeping the thermal deformation as low as possible

Launcher mirrors cooling





0.93 Kg vs 3.2 Kg

First CFD Simulations with CuCrZr alloy [5]
- Massive and lightened mirrors
- Different cooling strategies (spiral and radial) analysed

CuCrZr keeps the thermal deformation low.
Need to reduce eddy currents using less conductive material.

POSTER Nr. **1.17**

REFERENCES
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[2] S. Garavaglia et al., Fusion Eng. Des. **168** 2021 112678
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[5] A. Allio et al., IEEE Transactions on Plasma Science, *accepted for publication*