EC Stray Detection system Status and Planning

A. Moro, C. Sozzi (ISTP - CNR)

C. Piccinni (IPP – Garching)

and with the support of A. Simonetto (ISTP-CNR) for mm-wave measurements and analysis

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

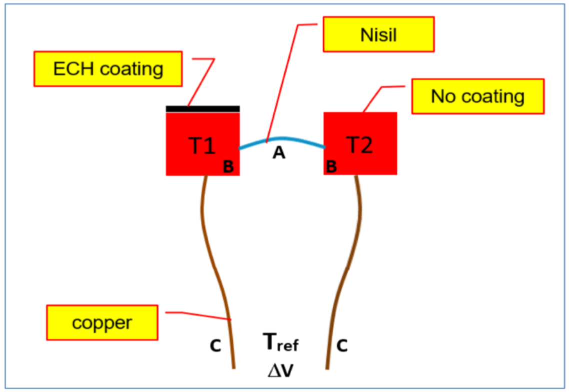
Outline

- Task status
  - ECH sensor type proposal and integration

    outcomes from ITER detector FDR
  - ceramic coatings characterization @ CNR
- Planning for 2023
  - additional design efforts for JT-60SA adaptabillity
  - tests on adapted bolometer

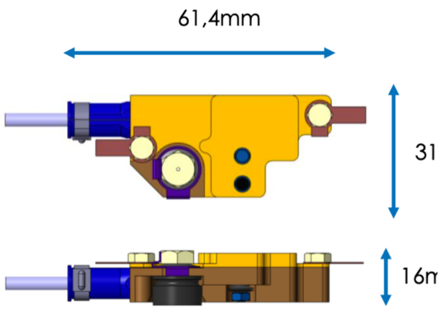
Task Status: ECH sensor for ITER

Differential thermocouple bolometer had its FDR in July, participation* in the frame of IO-F4E-EUROfusion-QST collaboration

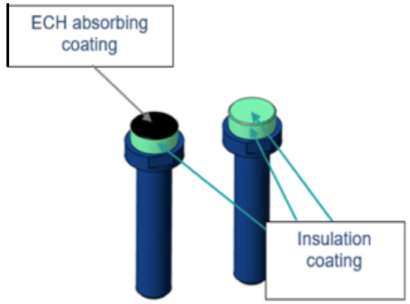


- ΔV between bolometers
- ΔV ➟ ΔT ➟ ECH power
- Thermal model (i nodes)
- Algorithm for $T_i(t)$

* Courtesy of A. Sirinelli



2 cylinders, ∅ 4mm



Coating sprayed over the top of Mo screw

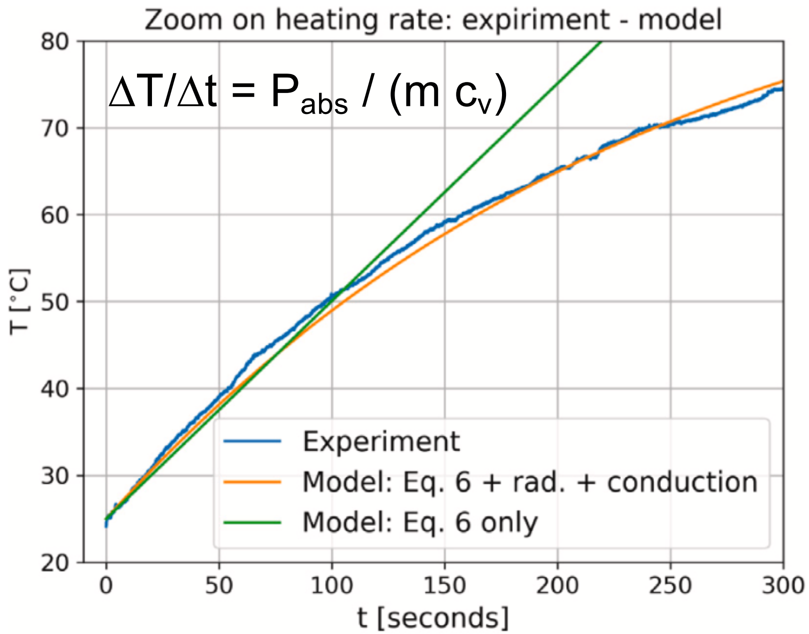
The goal of the detector is **to measure EC stray radiation inside the vessel to optimize the ECH operations and to minimize the heat loads on in-vessel components.**
The system is a passive component, not used for machine protection.

Main Specification	Value
Overall Sensor volume	$V=61.4x31x16\ mm^3$
Sensor weight	m=170 g
Temperature range	ΔT=[100-816 ℃]
Thermal response	1 K/s
Response time	~ 10 s considering thermal equilibrium (optimized to 0.3s-1.0s using $\Delta T/\Delta t$, T_{abs} at relatively low temperature and shorter time scales)
Accuracy	100 kW/m^2 considering thermal equilibrium (optimized to ~30 kW/m^2 using $\Delta T/\Delta t$, T_{abs} at relatively low temperature and shorter time scales)
Power resolution	100 kW
Signal amplitude	~ few mV [0-10 mV]

Task Status: ECH sensor for ITER

JT-60SA related open issues (not exhaustive)

- In the sensor analysis the EC stray radiation level is computed **considering thermal equilibrium**, resulting in **too low temporal resolution.** The potential of the sensor can be fully exploited at relatively lower temperature and shorter time scales (~ seconds, bolometer response 0.3 s) neglecting radiation and conduction:
  $\Delta T/\Delta t = P_{abs} / (m\ c_v)$
- **Offline analysis** and additional tests using both **steady state temperature and heating rate** in the sensor could the temporal resolution.
- **Long-term calibration** requires reproducible ECH scenarios (ECWC possibility).
- **Ex-vessel calibration:** dedicated RF power source or heater device (electric hot air gun) to heat up the bolometers with a given energy flux.

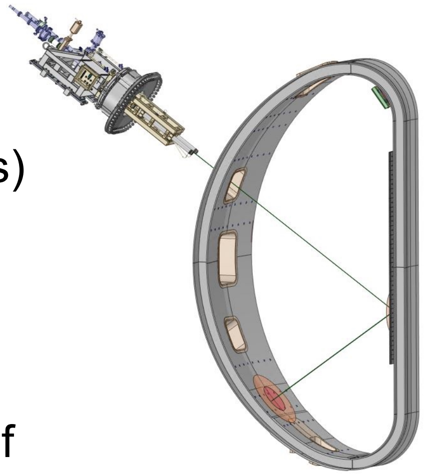


J. W. Oosterbeek et al.,
Fusion Engineering and Design 183 (2022) 113256

Task Status: Feasibility study and design integration

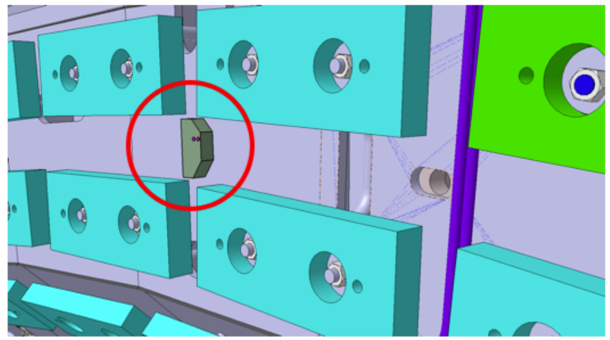
<u>Preferred option:</u>
- 2* sensors close to ECH ports (LFS, P8, P11)
- no direct illumination (shadowed by tiles)
- 2nd reflection (with support of beam tracing analysis for expected P_{den})
- in proximity of thermocouples

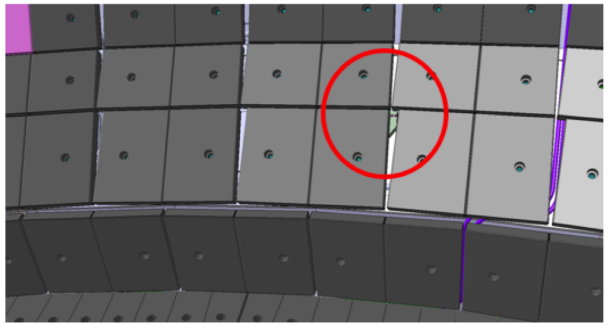
<u>Backup option:</u>
- 2* sensors inside ports (LFS) for a proof of principle (P1, P4)
- in proximity of thermocouples



w beam radius: 0.8647 frac. power
2w beam radius: 0.9997 frac. power

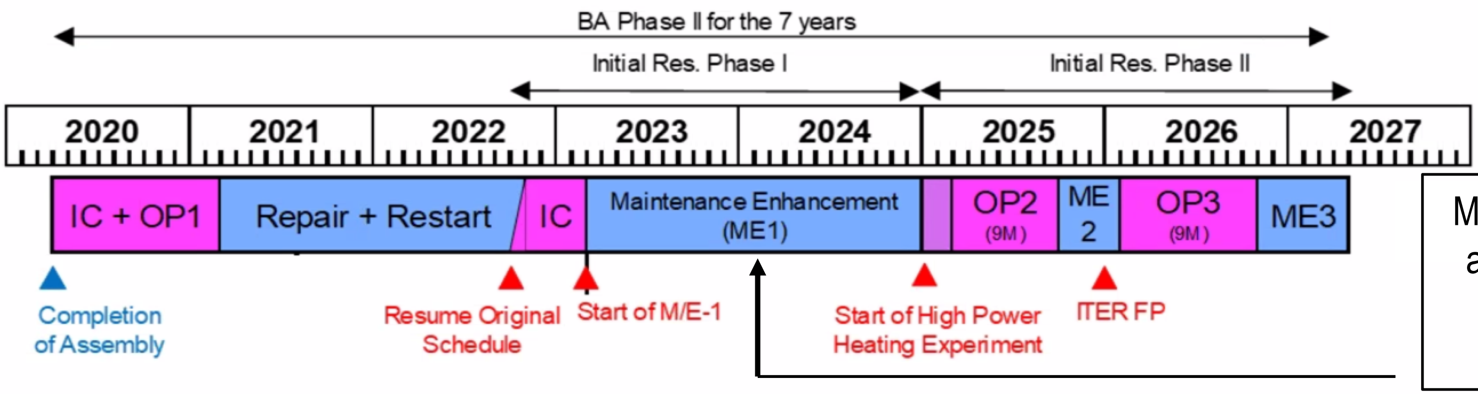
*2 ITER sensor prototypes available for JT-60SA





Possible locations according to the preferred option.

Initial Research:
EC P_{den} as low as 7.5 kW/m^2 up to 2 MW/m^2 in steady state and transients
up to 4 MW/m^2 for 5 s
3 kW/m^2 total radiation from plasma @ back of first wall (PID [3])



Maintenance Enhancement phase as target for feasibility study and sensor installation proposal
Timeline to be updated!

Task status: coatings characterization

ECH coating is the most critical parameter for the performance of the sensor

- The absorption in the 82-138 GHz range has to be 80%
- The development of absorbing coating for JT-60SA consists in defining its composition, the substrate preparation and the deposition process and measure absorption performances.

<u>20 ceramic coating samples with different coating thickness characterized at ISTP-CNR</u>

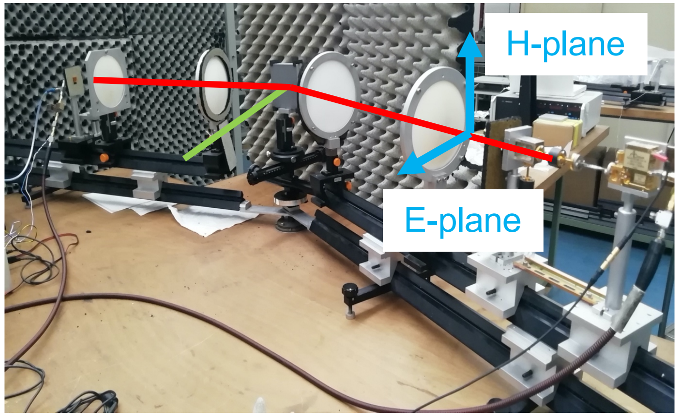
Coating Sample	Thickness ranges (µm)
Ti_2O_3	[50-250]
Cr_2O_3	[40-250]
$Al_2O_3Ti_2O_3$	[30, 120]

⇒ determine material properties ($\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$, $n = \sqrt{\varepsilon_r'}$, $\tan\delta = \varepsilon_r''/\varepsilon_r'$) and mm-wave absorption coefficient

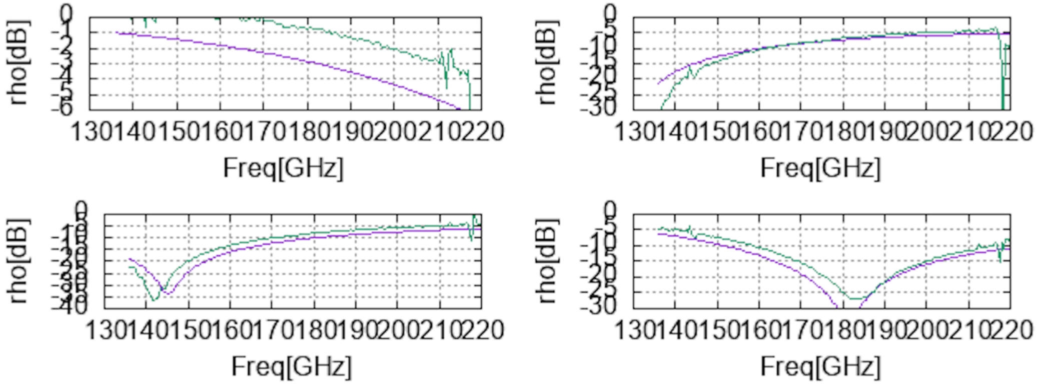
⇒ provide adapted coated cylinder specifications

⇒ (material & thickness) for integration into the ITER prototype

- W-band and G-band measurements to cover the 70-220 GHz range
- 2 launched polarizations (E-plane, H-plane), incidence angle scan (25-70 deg)
- Raw data available, analysis on-going (SOFT2022)



$Al_2O_3Ti_2O_3$ samples – reflectivity vs freq. – H plane 65 deg incidence



2023 Planning

- Prototyping, basic sensor testing, calibration and commissioning plan **to provide a diagnostic qualification proposal attractive for QST and ITER**
    - confirmed commitment by IO (2 prototypes for JT-60SA)
    - confirmed QST interest supporting IO diagnostic development (with caveats concerning sensor location and hw)
- Additional required tests have been identified to characterize the adapted sensor (heating rate as a function of T_{abs} for example)
- Absolute calibration methodology
- Need of resources to extend the working group (to cope with C. Piccinni leave)
    - engineer profile is strongly needed (diagnostic integration)
    - survey with W7-X colleagues started