LIBS Application on JET and prospects for ITER

ICFDT7 - 7th International Conference on Frontier in Diagnostic Technologies, Frascati, Italy, 21-23 October 2024

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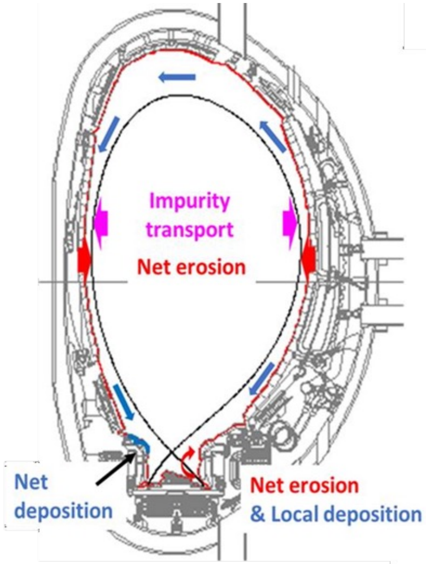
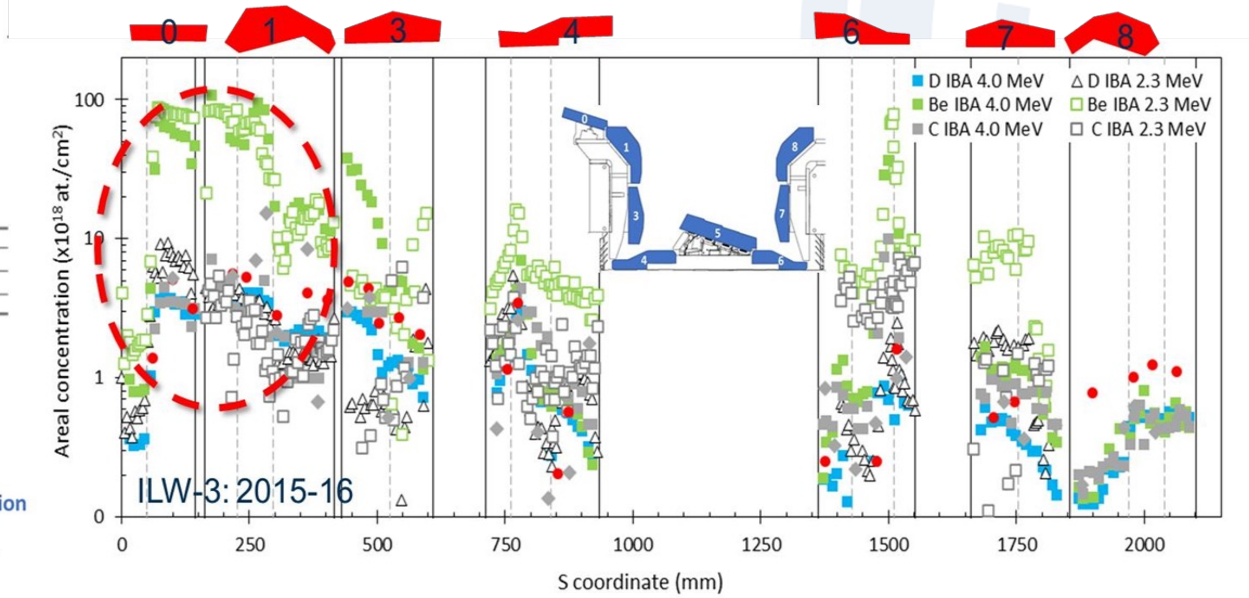
*See the author list of "Overview of T and D-T results in JET with ITER-like wall" by C. F. Maggi et al. to be published in Nuclear Fusion Special Issue

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Introduction

- ITER and future power plants such as DEMO must limit in-vessel tritium (T) retention to reduce risks of potential release during normal and off-normal operation including accidents conditions
- T-retention in ITER and DEMO will mainly be driven by co-deposition with tungsten (W) eroded from main wall
- ITER safety limit: 700 g of tritium in the reactor
- Accumulation of dust and tritium in vacuum vessel could significantly impact operation of ITER and DEMO
- Monitoring of vacuum vessel tritium inventory is essential for safety analysis
- Currently laser based techniques (e.g. LIBS and LID-QMS) are most promising
- LIBS = Laser-Induced Breakdown Spectroscopy

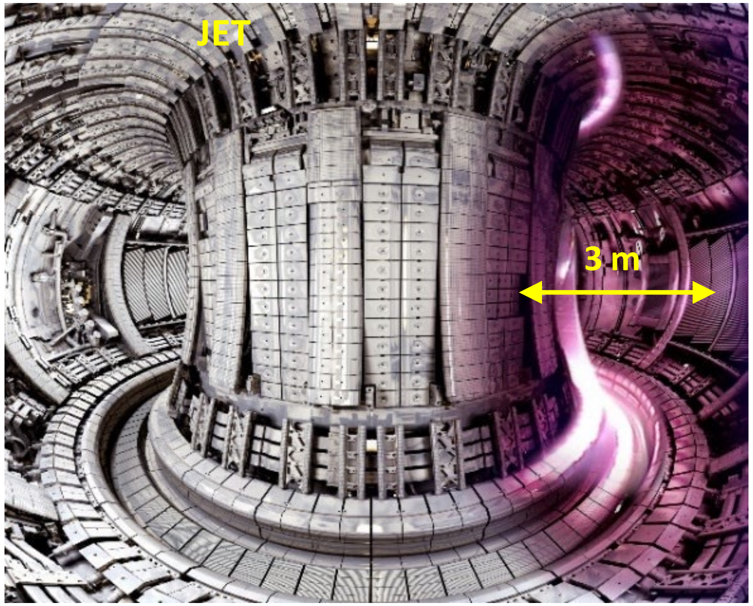




JET tokamak

JET - flagship in worldwide fusion research for 40 years (1983-2023)

- Produced up to 60-s long plasma pulses in a tokamak configuration
- Can use actual DT fusion fuel → record fusion energy output ~69 MJ
- Realistic choice of wall materials (beryllium, tungsten) but ITER will change beryllium wall to tungsten
- **Now in the decommissioning phase**
- LIBS experiment in September-October 2024
- Sample retrieval starts in October 2024
- Post-mortem analysis of JET PFCs in 2025-

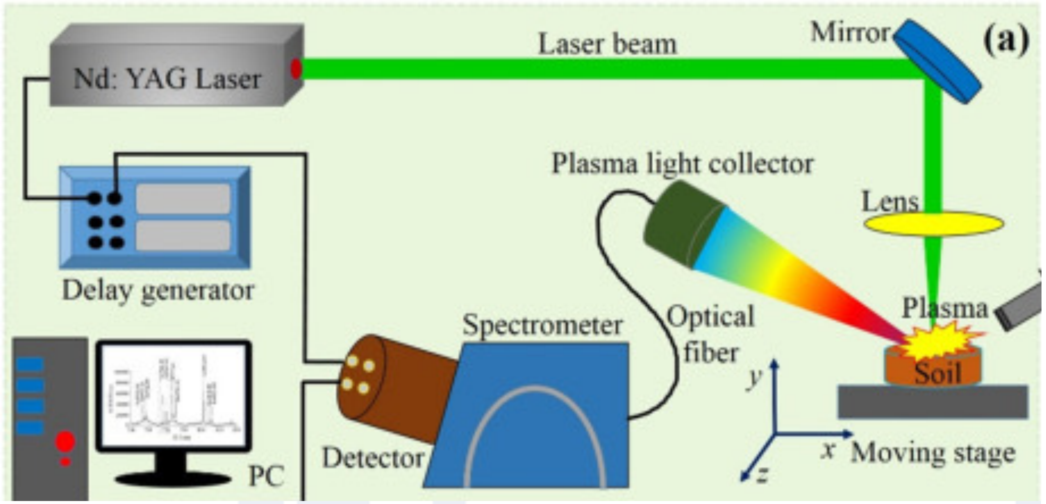


Deuterium-tritium operations at JET with ILW-like wall

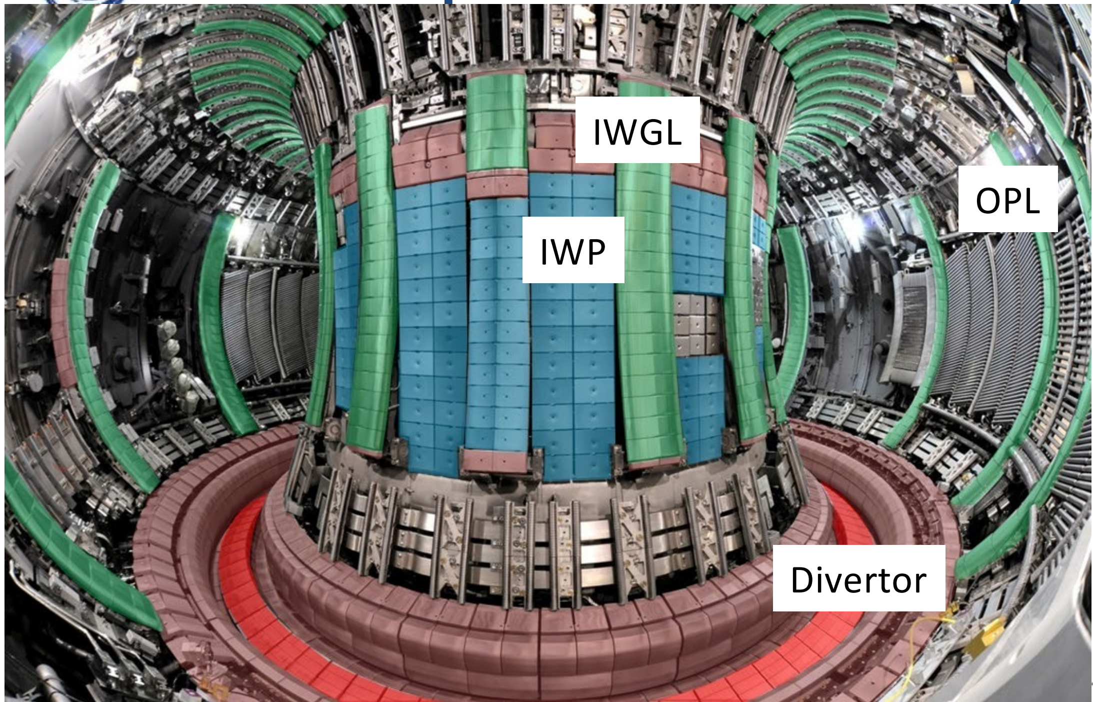
	T100 **100% T_2**	**DTE2** **2nd Deuterium-Tritium experiment**	**DTE3** **3rd Deuterium-Tritium experiment**
Date	2020-21	2021-22	2023
Tritium through-put (g, T atoms, Bq)	100, 2.0e25, 36PBq	150, 3.0e25, 54PBq	100, 2.0e25, 36PBq
JET configuration	JET-ILW ITER-Like wall	JET-ILW ITER-Like wall	JET-ILW ITER-Like wall

LIBS in fusion reactors

- Laser-induced breakdown spectroscopy (LIBS) is a type of atomic emission spectroscopy which uses a highly energetic laser pulse as the excitation source
- Laser is focused to form a plasma, which atomizes and excites species
- These excited-state species emit light at unique wavelengths
- This light can then be collected with a spectrometer
- LIBS allows detailed inspection of vacuum vessel of fusion reactor
  - ✓ Particularly critical is to assess the amount of radioactive tritium retained in the layers
  - ✓ Also possible to determine thickness and elemental composition of the co-deposits
  - ✓ LIBS provides an (almost) unlimited access to different regions of reactor wall – without the need to remove wall components from the reactor
  - ✓ LIBS parameters can be tailored such that impact on wall structures is minimized → no need for replacement after LIBS measurements



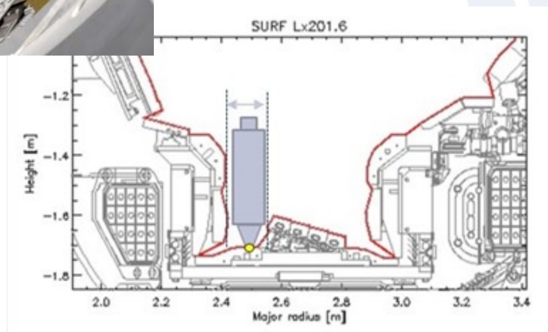
Wall components for LIBS analyses selected



Bulk Be
Be coated inconel
W – coated CFC
Bulk W

JET has several different wall materials – aim to analyse a representative set of components from each region

- Almost 50 individual wall and divertor tiles identified for LIBS measurements, corresponding to ~960 LIBS locations
- LIBS measurement campaign ~3 weeks in September-October 2024 (16h/day in two shifts)
- LIBS experiment coordinated by VTT and UKAEA RACE team



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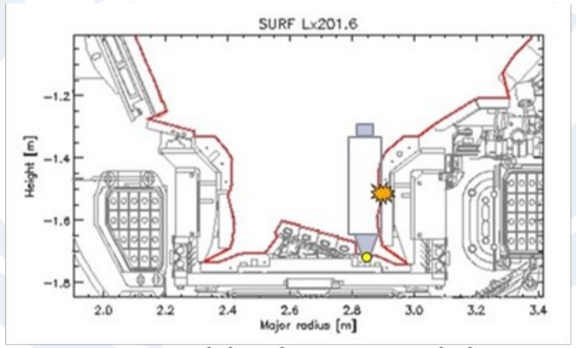
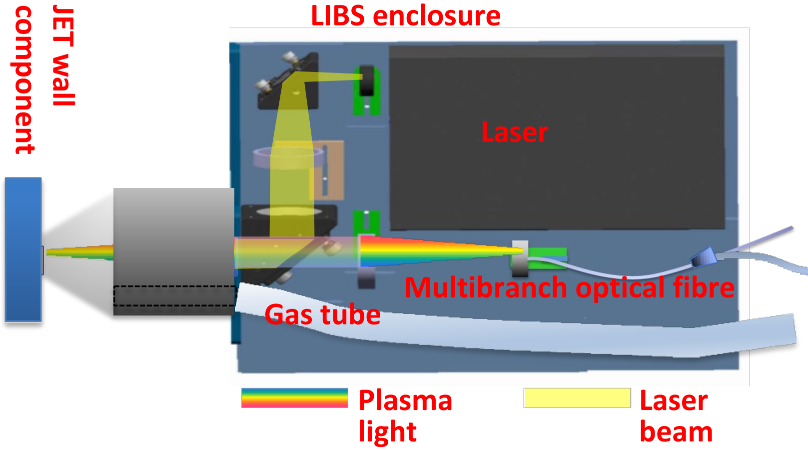
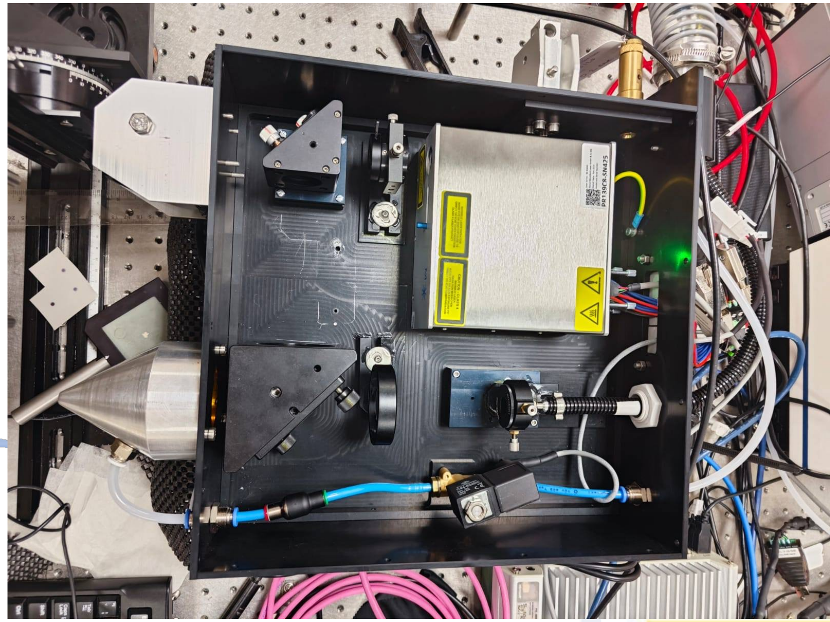
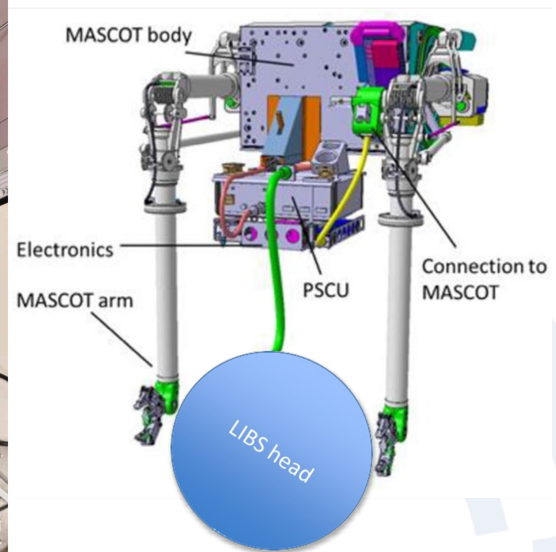


Not accessible due to tool dimensions

LIBS system at JET

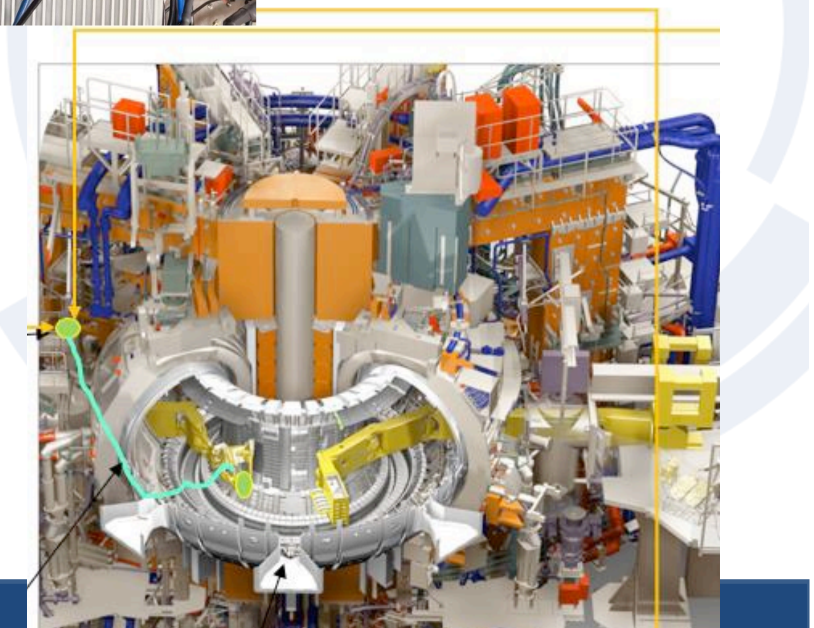


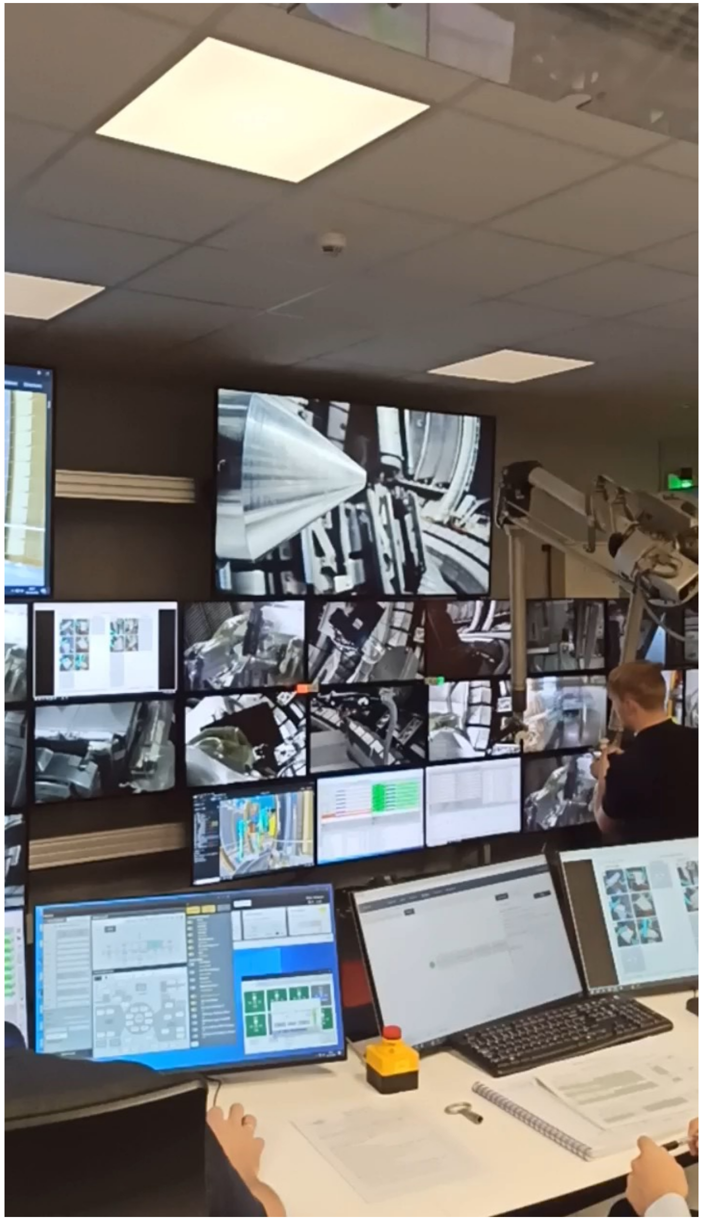




Designed at *ENEA, Italy*

- Nd:YAG-1064 nm, 800ps, 10mJ (Montfort Laser, M-NANO)
- LIBS enclosure mounted on the JET MASCOT arm
- RH boom moves the entire setup close to the wall, the outermost cone is in contact with the sample to be investigated
- Argon gas flux will be applied to increase signal intensities
- Optical fiber guides the emitted light into spectrometers, located outside of the vacuum vessel





Remote Handling Operations at UKAEA (8.10.2024)

UK Atomic Energy Authority

RACE

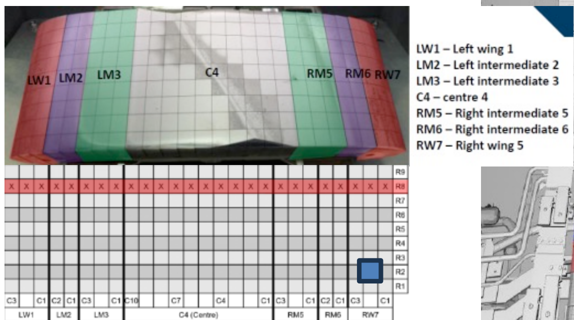
Overview spectrum from Be limiter tile, Aryelle

Aryelle 200

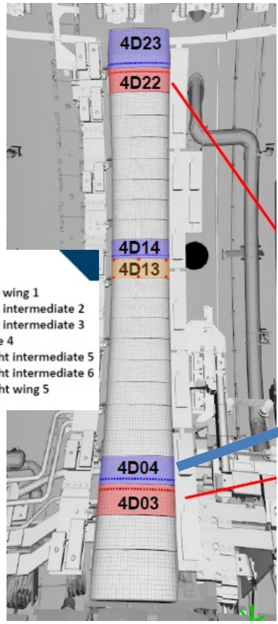
-Echelle spectrometer (resolving power 7000-15000)

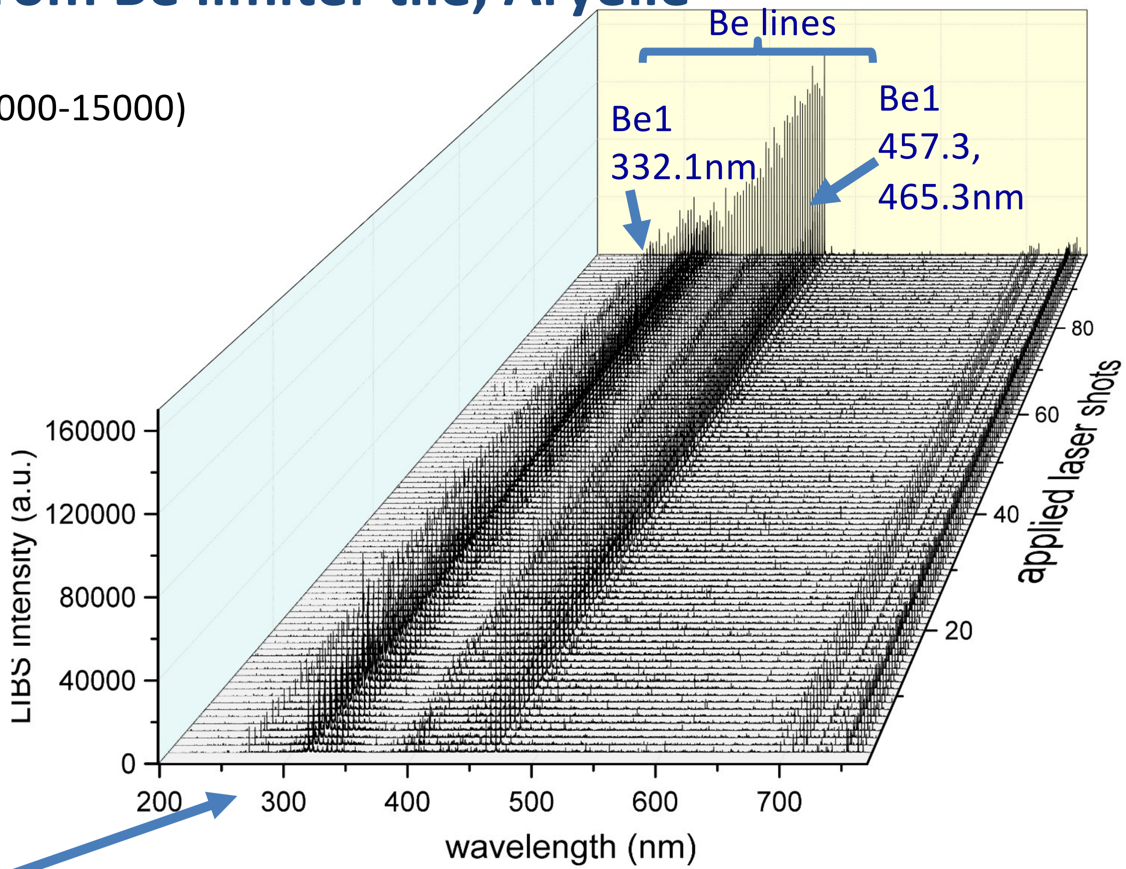
-UV-VIS-IR (250-750 nm) spectrometer

Aryelle 200 + ICCD ANDOR Istar DH334T-18F-E3

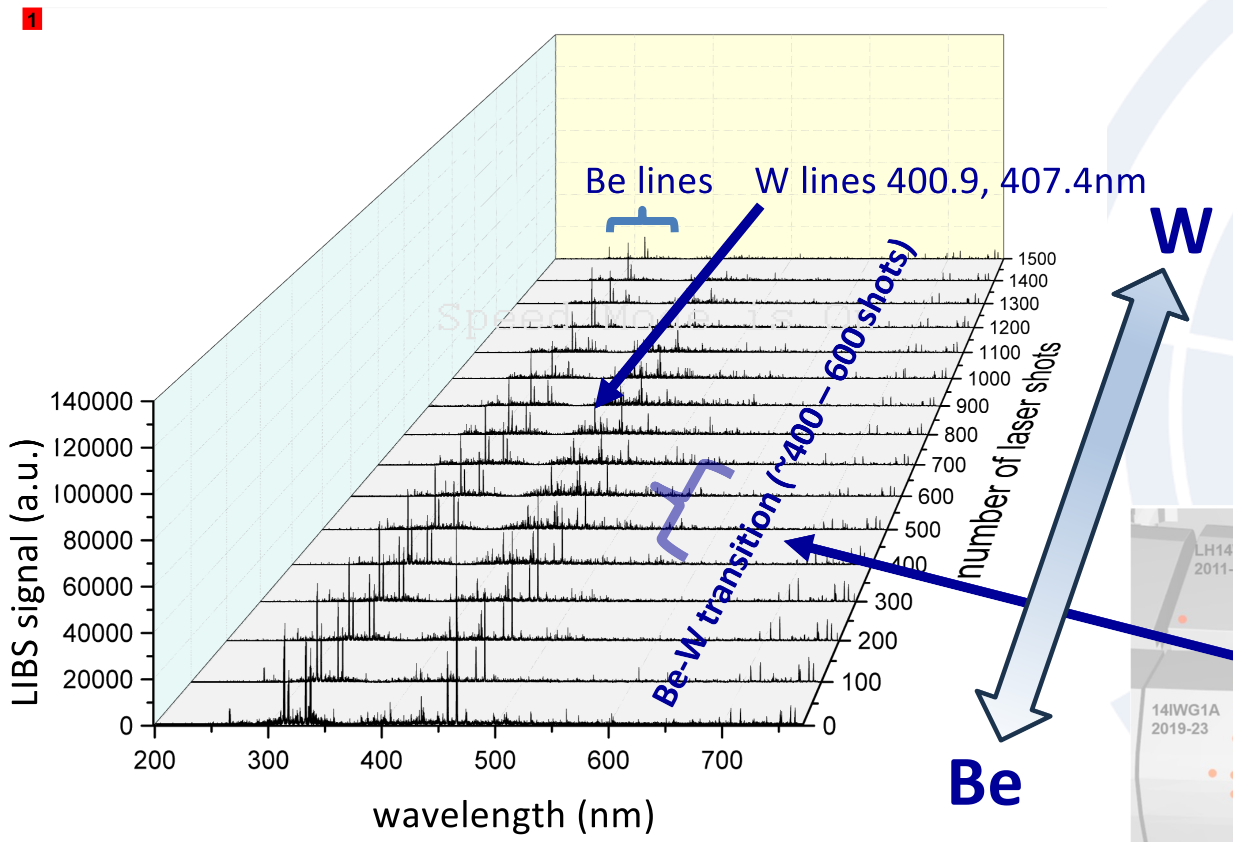


4D04_R2RW7C2

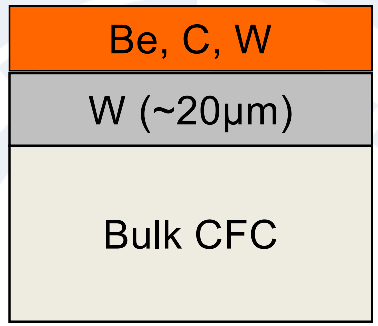


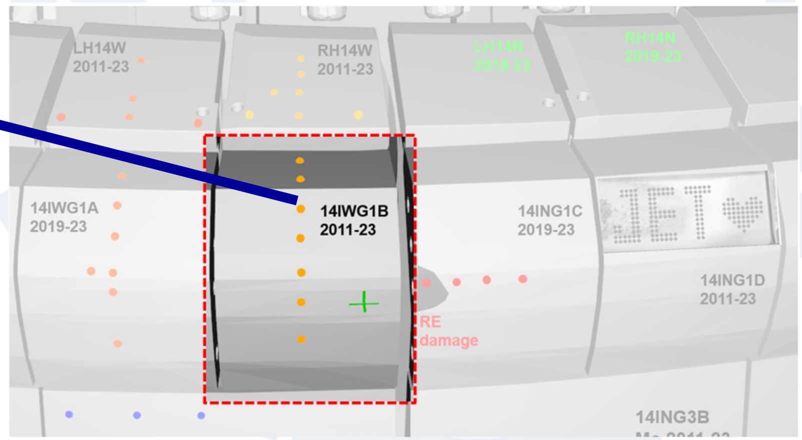


Overview spectrum from W coated CFC tile, Aryelle



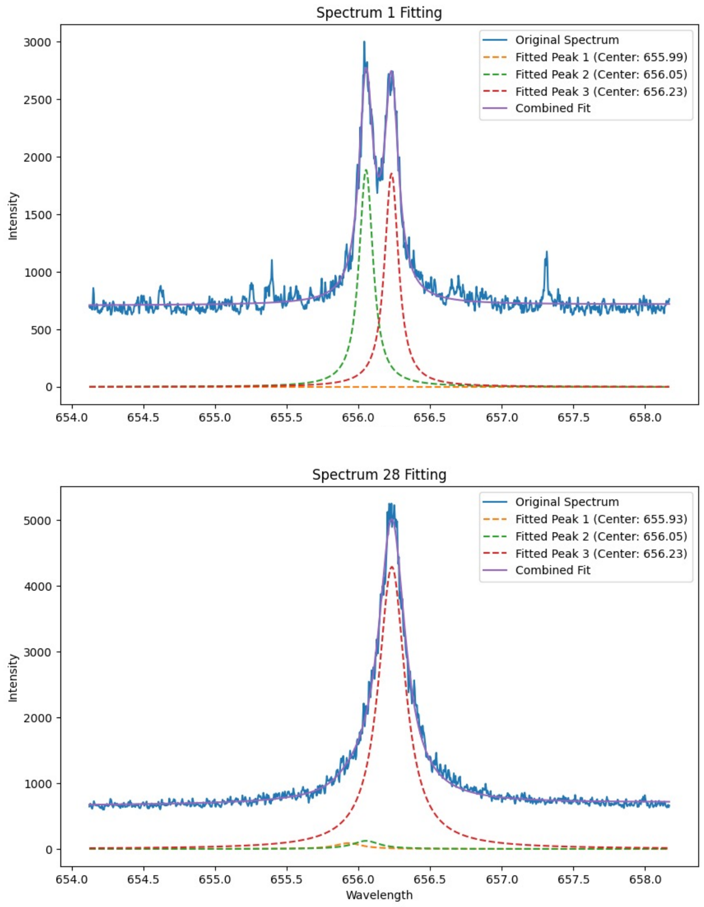
JET W coating on CFC





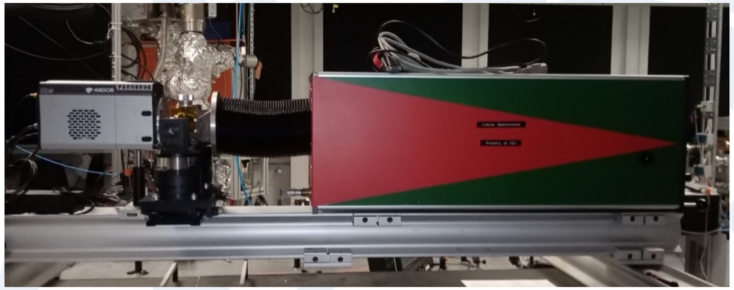
Be limiter tile 4D4, 1st results from Littrow spectrometer

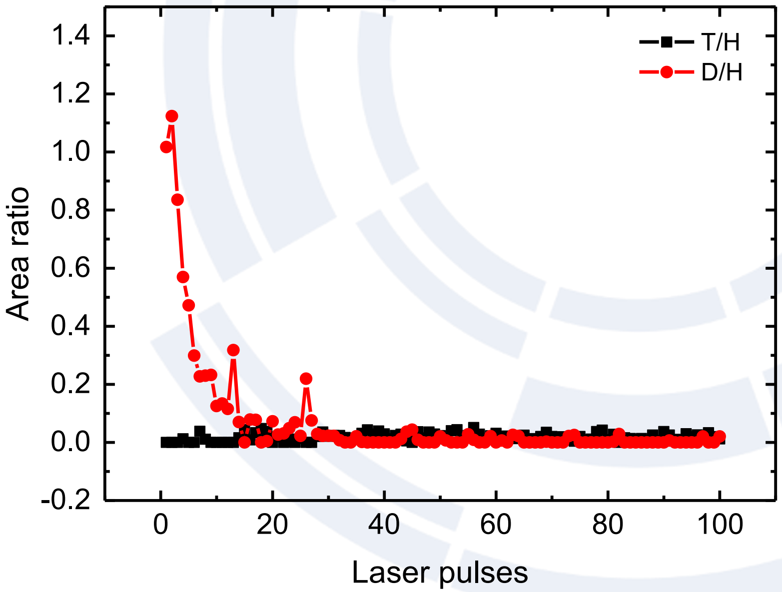
H_α-D_α: 0.18 nm
D_α -T_α: 0.06 nm



Littrow spectrometer

-High resolution (0.03 nm @ 500 nm) spectrometer





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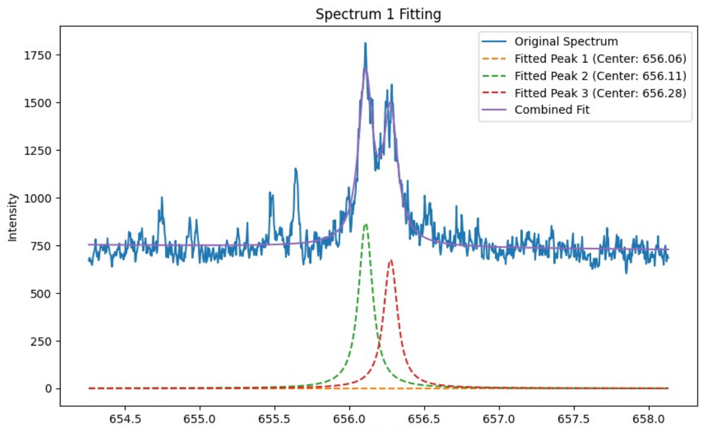
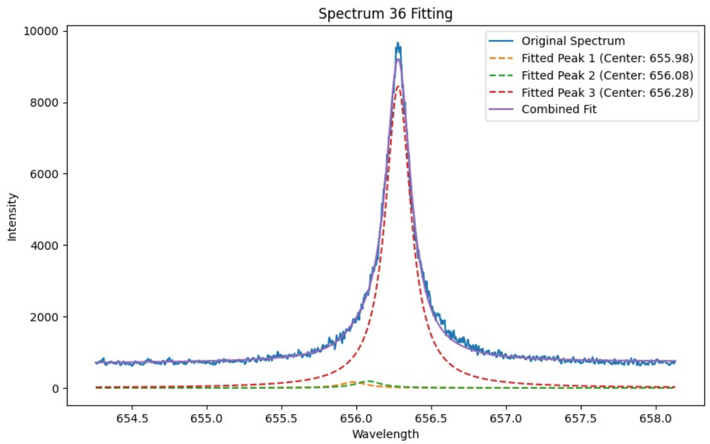
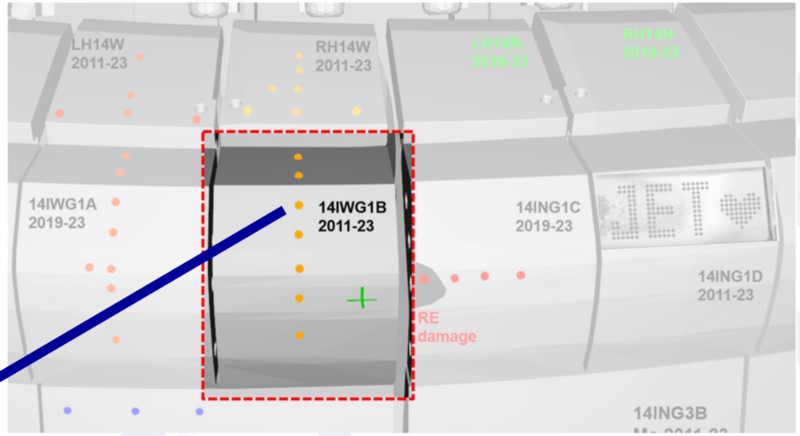
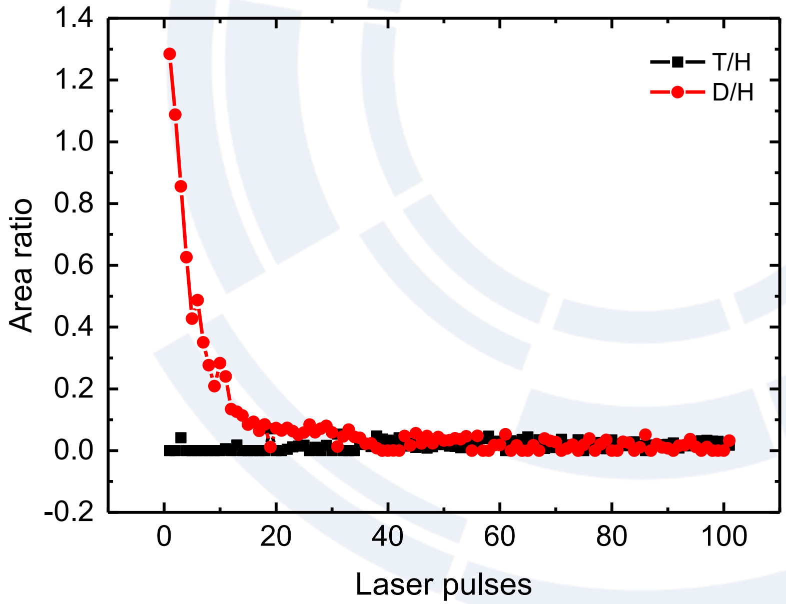


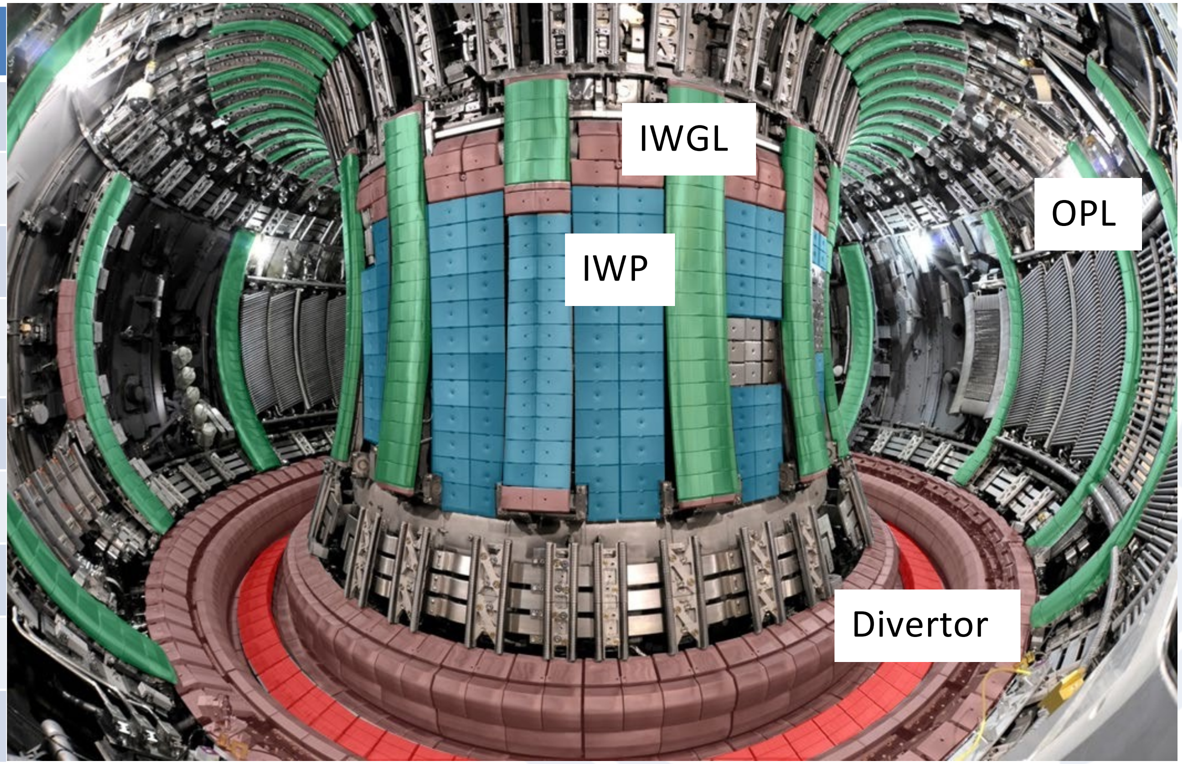






Summary of LIBS locations at JET

Location ID	Number of spots
Inner wall guard limiters	409
Outer poloidal limiters	364
Inner wall protection	13
Inner +base divertor carriers	52
Tiles 0 (HFGC)	21
Tiles 5 (LBSRP)	72
Outer divertor carriers	30
Vessel wall	6
TOTAL	967



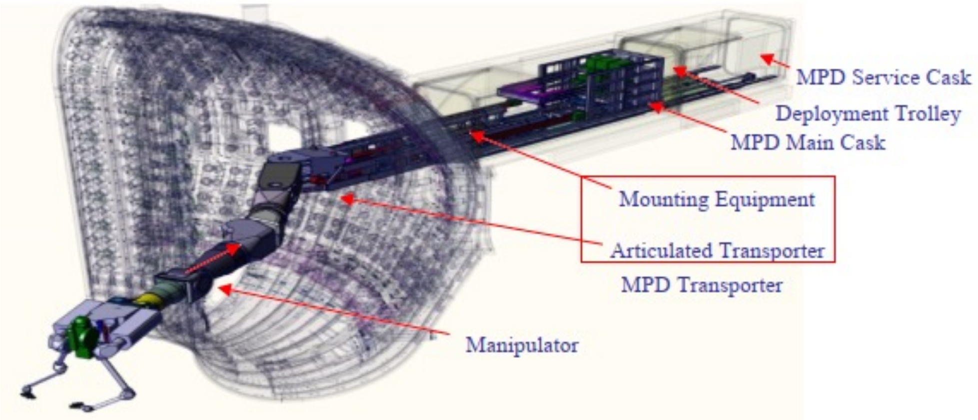
Actual number of locations: 869

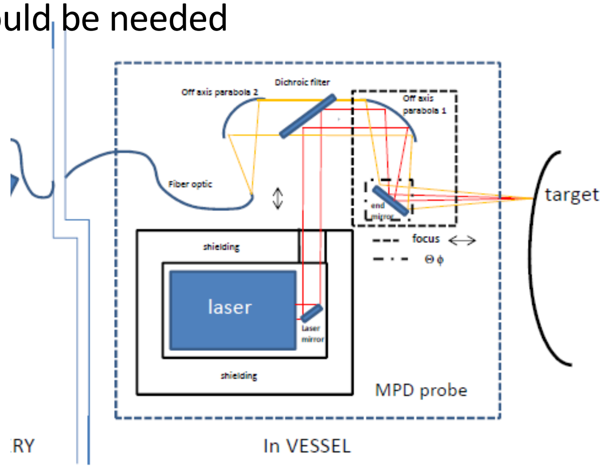
Prospects for ITER

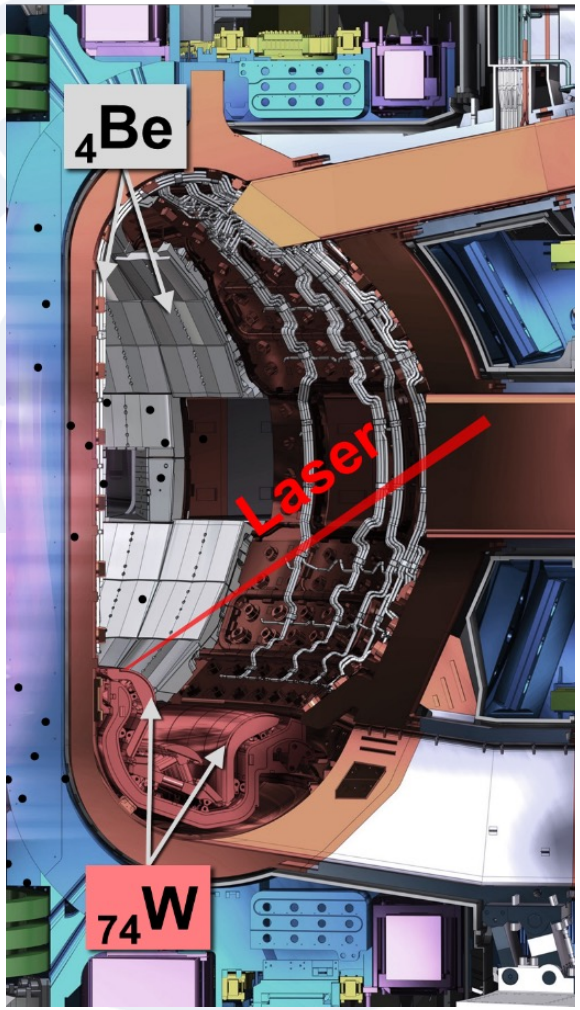
- Workshop on Dust Deposition, Erosion & Tritium, ITER IO, Feb 2014
  - ✓ Most important location for Tritium detection by LIBS is inner baffle region at divertor
  - ✓ G. Jagannathan (ITER): Remote LIBS required

- ITER Design Report 55.GC: Tritium Monitors (LIBS on MPD), Dec 2015
  - ✓ Utlilising LIBS carried on Multi Purpose Deployer (MPD)
  - ✓ Main drawback: can be applied only during major shutdowns

- P. Andrew (ITER, email discussions September 2024)
  - ✓ Historically LIBS has been on and off
  - ✓ LIBS is currently not baseline for ITER
  - ✓ Fixed LIBS with remote LASER and light collection would be needed







Conclusions

- LIBS system designed and commissioned for investigating composition and tritium content of co-deposited layers and plasma facing surfaces at JET
  - ✓ Utilizes MASCOT manipulation RH system to access different regions on the JET vessel wall
  - ✓ Consists of a sub-ns laser, necessary optics, photomultipliers and three spectrometers
- Commissioning and testing of the LIBS system completed both at VTT and at JET
  - ✓ Real JET samples (from divertor and limiters) analyzed at VTT and “clean” samples at JET
  - ✓ Data analysis of VTT and JET results still on-going
- Final LIBS experiment in September-October 2024
- ~870 locations analysed during the measurement campaign (~3 weeks, 16h/day)
- Prospects for ITER (P. Andrew, Sep 2024)
  - ✓ LIBS is currently not baseline for ITER
  - ✓ Utlilising LIBS carried on Multi Purpose Deployer expensive
  - ✓ Remote LIBS (laser+spectrometers outside vacuum vessel) would be needed
  - ✓ LIBS may come back in the future