

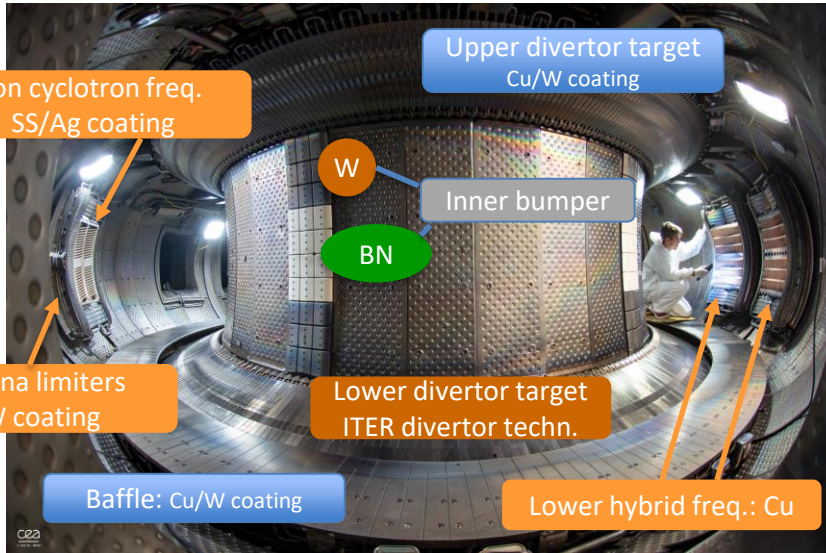
Light and metallic impurity identification in the 225-300 Å range in the WEST Tokamak

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- ITER plasma facing material: W
- Tore Supra, C wall (shut down 2011) → WEST (started 2016): W wall



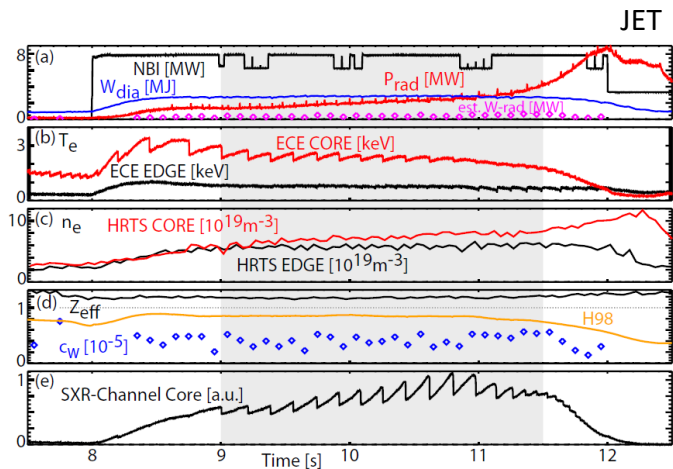
Major radius (m)	2.4	Heating power (MW)	7 + 12 (LH, ICRH waves)
Minor radius (m)	0.7	Plasma duration (s)	20-100...
Plasma volume (m ³)	12	Energy conf. time (s)	0.8
Vol. average density (m ⁻³)	3-5 10 ¹⁹	Temperature (keV)	2-6

[Bucalossi NF 2022]

Impurity contamination much more complex in WEST

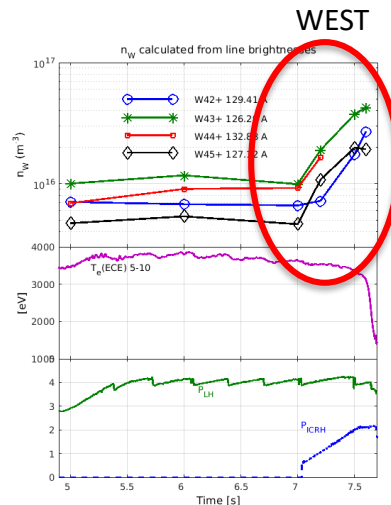
- In ASDEX-U, JET, WEST: investigations of W sources and contamination

W accumulation due to collisional transport



Pueterich et al. FEC 2012

Prevented by electron heating but...



Guirlet et al. PPCF 2022

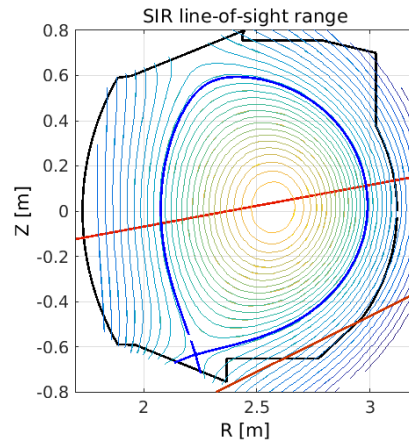
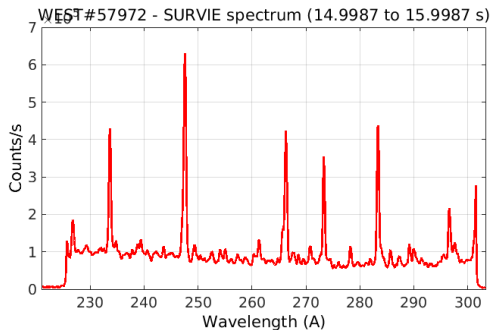
Impurity contamination must be monitored and mitigated in real time
Spectroscopy allows detailed impurity inventory in plasmas

- Introduction and scope
- **Means and methods**
- Results
- Summary and conclusion

- Two Schwob-Fraenkel, extreme UV spectrometers [Schwob RSI 1987]
 - Concave (2 m) 600 g/mm grating
 - 10-15 ms resolution
 - Absolutely calibrated [Guirlet J. Inst. 2017]

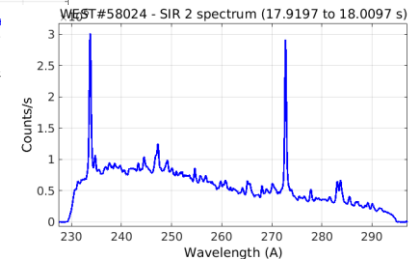
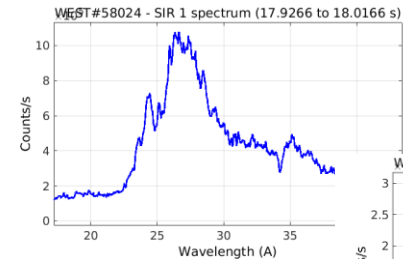
→ SURVIE

- Single detector: 225-302 Å
- Single line of sight
- Data fed to real time network
- Plasma control algorithms
- Long term impurity monitoring



→ SIR

- Two mobile detectors in 15-340 Å
- Mobile line of sight
- Physics studies



- Abundant literature: magnetic fusion (AUG, JET, LHD,...) and EBITs
- NIST atomic spectra database <https://www.nist.gov/pml/atomic-spectra-database>
Most complete (elements/ions, transitions, wavelength domain)



NIST Atomic Spectra Database Lines Data

[W \(all spectra\)](#): 108 Lines of Data Found

Wavelength range: 220 - 300 Å
Wavelength in: vacuum below 2000 Å, air between 2000 and 20000 Å, vacuum above 20000 Å
Highest relative intensity: 3000

Example of how to reference these results:
Kramida, A., Ralchenko, Yu., Reader, J., and NIST ASD Team (2022). *NIST Atomic Spectra Database* (ver. 5.10), [Online]. Available: <https://physics.nist.gov/asd> [2023, May 9]. National Institute of Standards and Technology, Gaithersburg, MD. DOI: <https://doi.org/10.18434/T4W30F>

[BibTex Citation](#) (new window)

- HULLAC : [1] A. Bar-Shalom et al., J. Quant. Spectrosc. and Radiat. Transfer, **71**,169 (2001)
Electron excitation, ionisation, auto-ionisation rate coefficients

- Introduction and scope
- Means and methods
- **Results** (see also poster by C. Desgranges et al.)
- Summary and conclusion

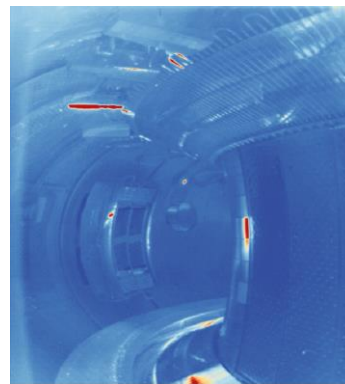
- Impurity injections
 - Voluntary : gas puffing, boronisation
 - Incidental : plasma start-up
- Incidents
 - Plasma-antenna interaction
 - Plasma-facing components

→ Time correlations (IR, Vis, rad. power...)

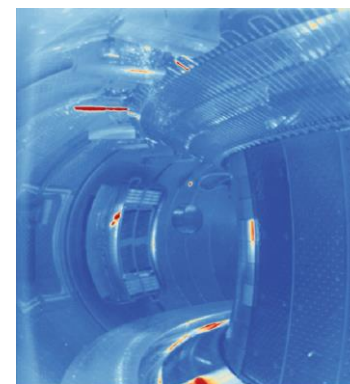
→ Comparison SURVIE/SIR

- Impurity injections
 - **Voluntary : gas puffing, boronisation**
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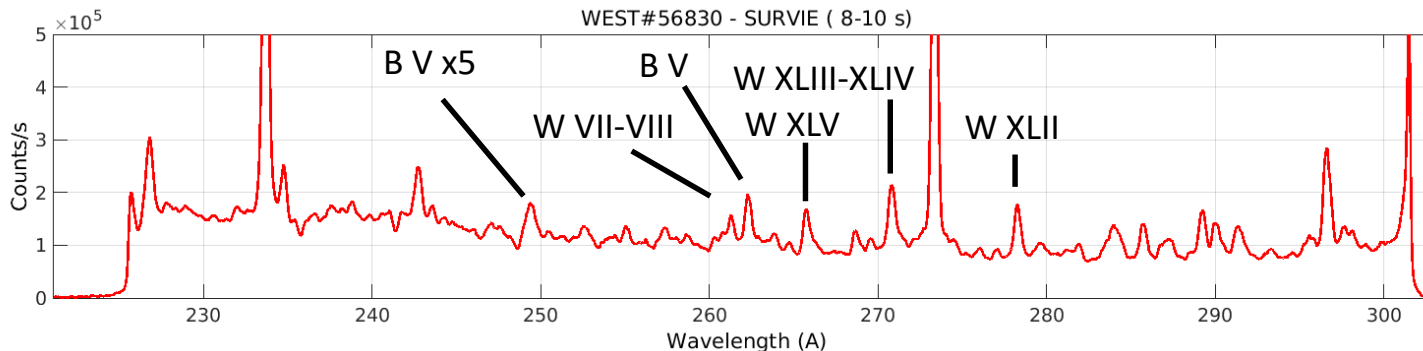
B powder dropper [Bodner NF 2022]



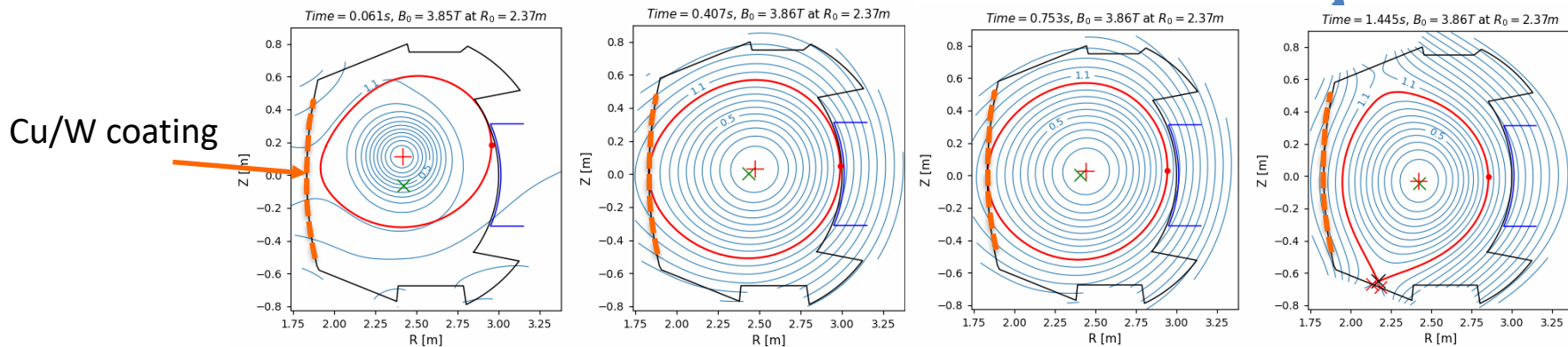
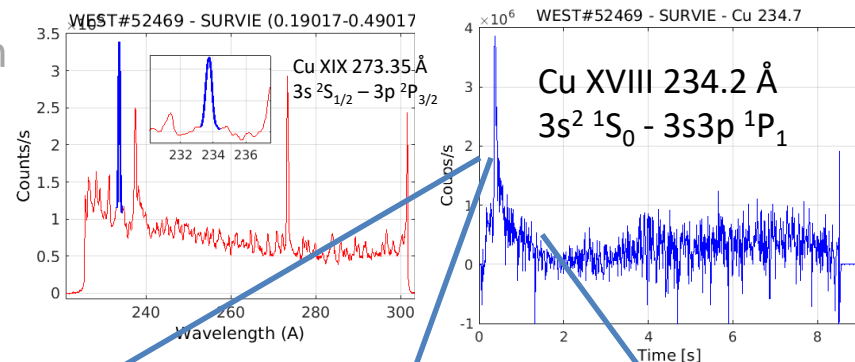
Before injection



During injection



- Impurity injections
 - Voluntary : gas puffing, boronisation
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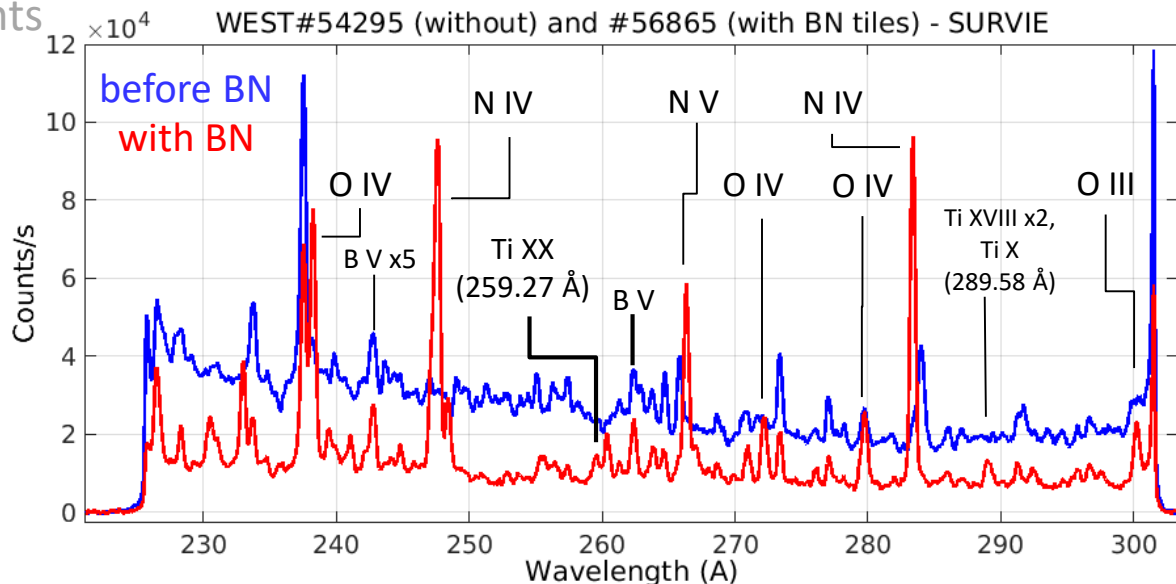
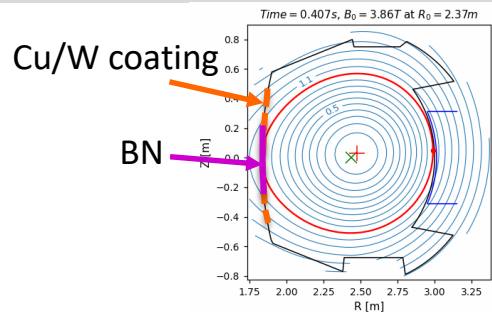


- Impurity injections
 - Voluntary : gas puffing, boronisation
 - **Incidental : plasma start-up**
- Incidents
 - Plasma-antenna interaction
 - Plasma-facing components

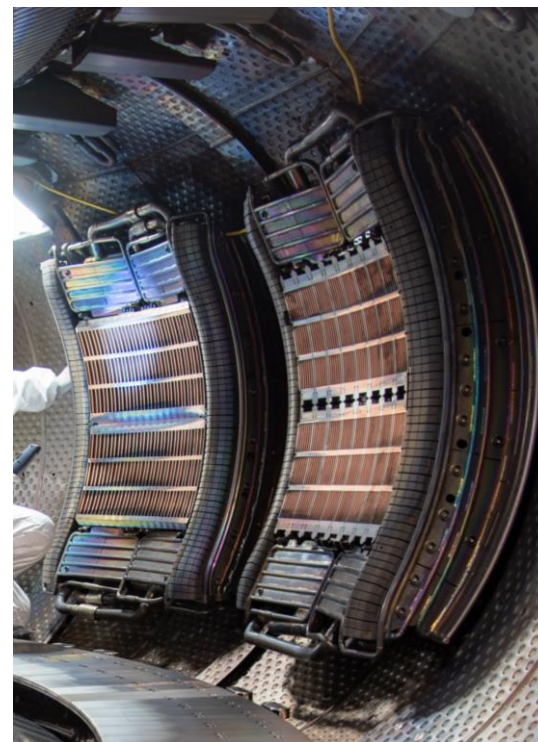


BN tiles on inner bumpers:

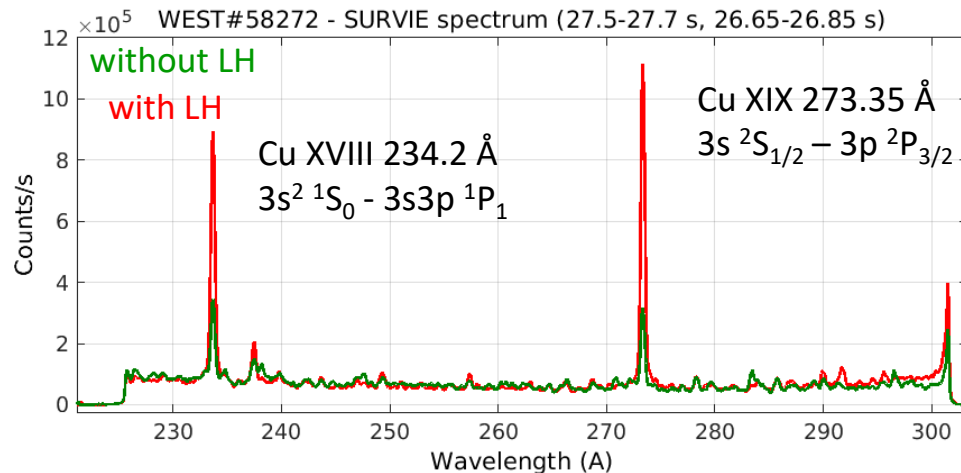
- O outgassing,
- Ti from expansion joints



- Impurity injections
 - Voluntary : gas puffing, boronisation
 - Incidental : plasma start-up
- Incidents
 - **Plasma-antenna interaction: LH couplers**
 - Plasma-facing components



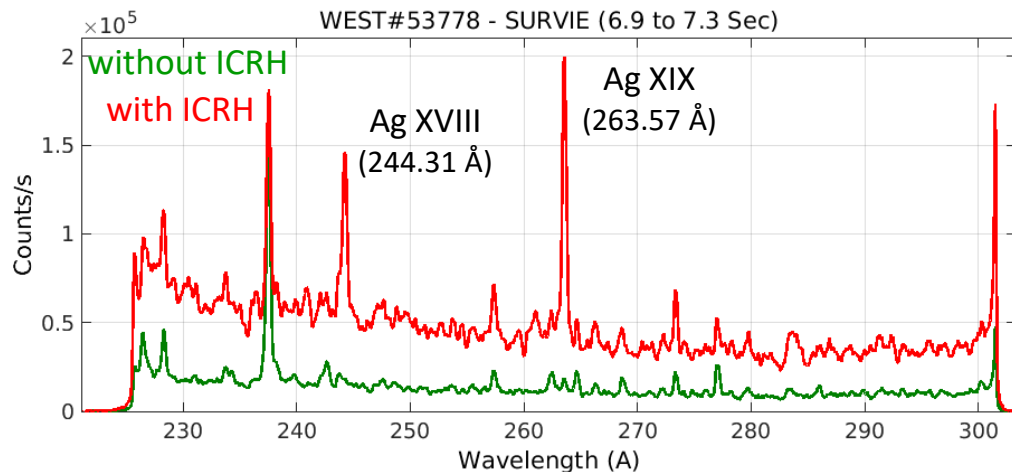
During/after an arc in an LH coupler



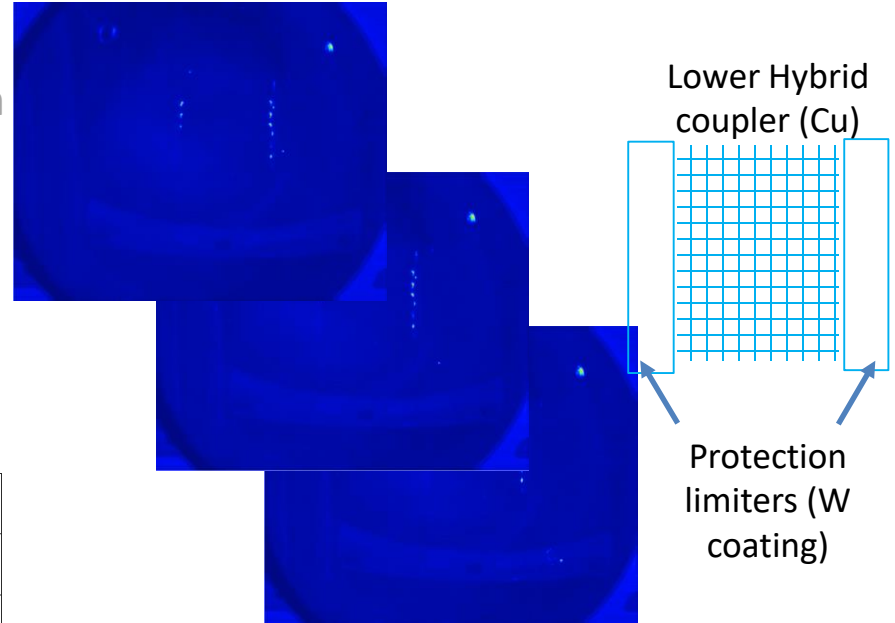
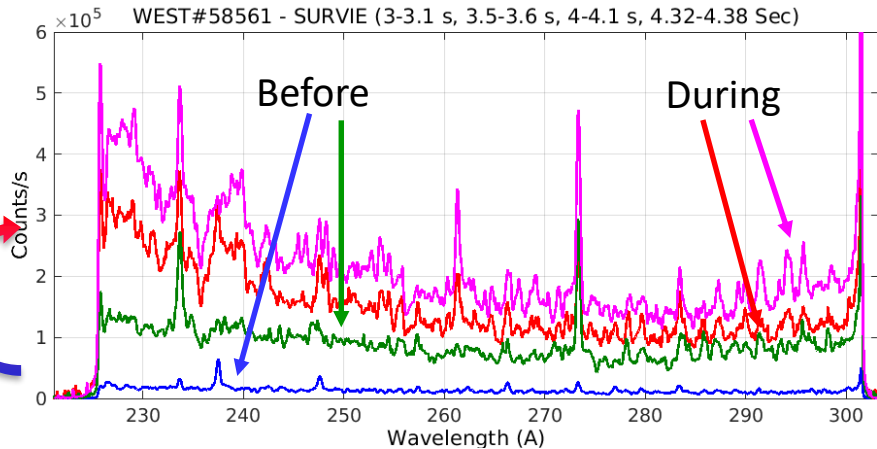
- Impurity injections
 - Voluntary : gas puffing, boronisation
 - Incidental : plasma start-up
- Incidents
 - **Plasma-antenna interaction: ICRH antenna**
 - Plasma-facing components

Ion Cyclotron
antenna

SS / Ag coating



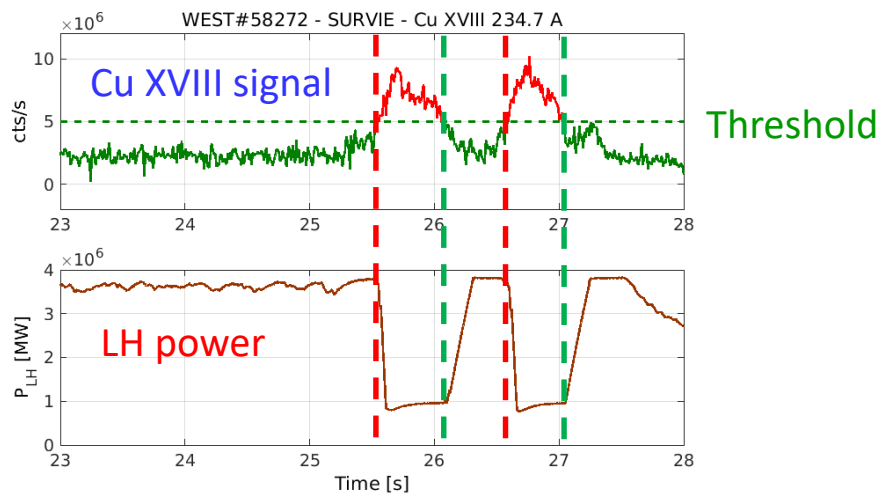
- Impurity injections
 - Voluntary : gas puffing, boronisation
 - Incidental : plasma start-up
- Incidents
 - Arcs in antennae
 - **Plasma-facing components**



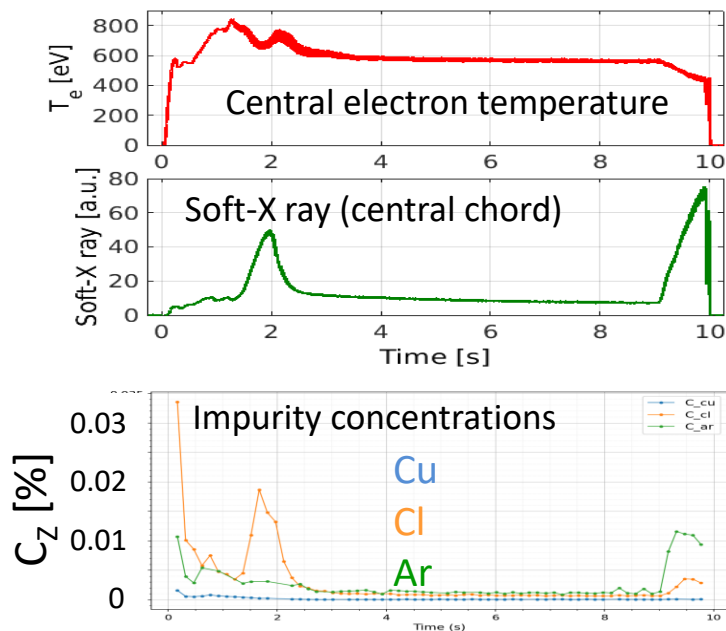
The incident reveals a quasi-continuum

- Set of typical spectra in various scenarios / spectral line tables

- Real time monitoring and control of incidents



- ‘Control room’ impurity density

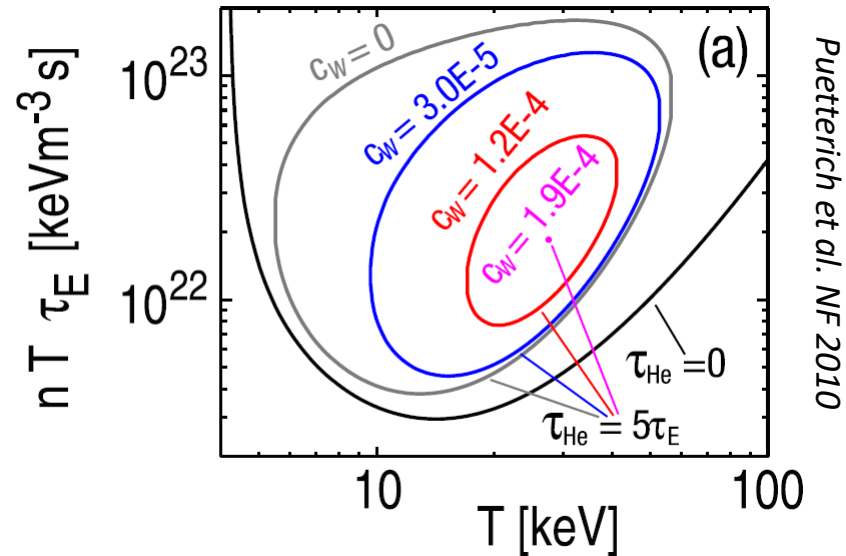


- Introduction and scope
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- Results
- **Summary and conclusion**

- EUV spectroscopy proves adapted to WEST impurity set
- About 15 elements can be monitored in the 225-302 Å range of SURVIE
- Impurity concentrations made available in the control room
- Use of W and increasing number of requirements → Tokamaks emit (very) complex VUV-EUV spectra
- If correctly and completely identified, they can/must be used for various purposes:
 - Impurity contamination/transport studies
 - scenario control and tokamak safety in real time
- High spectral ($\lambda/\Delta\lambda \sim 200 @20 \text{ \AA}, 2000 @200 \text{ \AA}$) and time (10 ms) essential
- Future (ITER): need for automatic analysis of measured spectra

The logo for CEA (Commissariat à l'énergie atomique et aux énergies alternatives) features the lowercase letters 'cea' in a white, rounded, sans-serif font. A thin green horizontal line is positioned directly beneath the letters. The logo is centered within a red square, which is itself set against a larger red background with a pattern of small, lighter red dots.The logo for IRFM (Institut de Recherches Fondamentales en Mécanique) features the lowercase letters 'irfm' in a white, stylized, cursive font. A green and yellow graphic element, resembling a stylized 'i' or a drop, is positioned to the left of the letters. The logo is centered within a light gray rectangular area.

Tokamaks: the larger, the dirtier? **NO !!!**



Need for (real time) impurity monitoring and control