Measurements of the W concentration in the low- and mid-temperature range

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Outline

- Temperature regions in JET tokamak plasma
- Overview of the XUV and VUV diagnostics in JET
- Mid-temperature W structures used in JET diagnostics
  - XUV UTA – 4-7 nm measurements and density estimation
  - VUV UTA – 14-40 nm – utilization in fusion plasma
- Low-temperature W lines:
  - Transient and ELM measurements of W VI to W VIII line spectra
  - Estimation of temperature and W density in the outer SOL region
JET plasma – shape and parameters

Te and ne in the core and pedestal region (JET PPF)

Te and Ti in SOL

(Fundamenski et al, JNucMat 2001)

#97018: 6 s, 8 s
JET VUV and XUV spectrometers

- **Horizontal l-o-s:**
  - One VUV spectrometer:
    - 10-100 nm with a resolution of ~0.5 nm

- **Vertical l-o-s**
  - Two VUV spectrometers:
    - 14.8-148.5 nm with a resolution of ~0.5 nm
    - 14-44.4 nm with a resolution of ~0.1 nm
  - One XUV spectrometer:
    - 4-7 nm

Note – vertical l-o-s spectrometers are a scarce resource during T campaigns
Mid-temperature range (pedestal, L-mode core)
ASDEX and theory

XUV UTA

Temperature dependence

Continuum without visible lines (below 2 keV)
Continuum with overlapping lines (over 2 keV)

VUV UTA

Temperature dependence

short wave - 15-19 nm
- 1-1.3 keV
middle - 19-28 nm
- < 1 keV
long wave to 45 – 1-1.3 keV

Putterich et al PPCF (2008)
Using XUV $c_W$ – L-H transition study

- **Study of an isotope (and heating type) dependence of the L-H threshold has to include radiative power loss**
- **Radiative power loss – impurities (mostly tungsten)**

$c_W$ during ICRH heating (isotope dependence)

For most L-H transitions we get $c_W$ of the order of $10^{-4}$ for ICRH ramps and much less (an order of magnitude or more) for NBI ramps (data for D) – studies of the source of W in those two heating types

E Solano, in prep.
JET VUV and XUV spectra

- L-mode W ablation spectra (ablation at 3.1 s)

![Graphs showing VUV and XUV spectra for different times and conditions.](image-url)
Using the spectra – VUV PPF creation

- **PPF – processed file (intensity vs time, $c_w$ vs time)**
  - Current: integration over a part of the UTA
  - Proposed: using characteristic points inside UTA to exclude mid-Z lines

![Graph showing comparison between current and proposed PPF methods. The proposed PPF uses characteristic points inside UTA to exclude mid-Z lines, while the current method integrates over a part of the UTA. E Solano, in prep.]
Summary

\[ \text{\(C_W\) from XUV (only with the vertical l-o-s) for > 1 keV} \]

\[ \text{SXR signals (many l-o-s, tomographic reconstruction) - high temperature} \]

Combination with bolometry, \(z_{\text{eff}}\) and other data in Sertoli et al (J of Pl Phys, 2019)

\[ \text{VUV signal, both l-o-s for T \sim 1 \text{ keV and less} - no data for estimation} \]
Low temperature range (SOL)
Transient event – W VI and W VII lines

Example of the tungsten spectrum from W event in JET pulse #94605 (H-mode C-C phase, 15 MW NBI)

**Strongest lines:**

- 21.6218 nm  W VII, \(4f^{14}5p^{5}(^2P_{1/2})5d\ (1/2,3/2) \ 1 \rightarrow 4f^{14}5p^6 \ 1S_0\)
- 26.1168 nm  W VII, \(4f^{14}5p^{5}(^2P_{3/2})5d\ (3/2,5/2) \ 1 \rightarrow 4f^{14}5p^6 \ 1S_0\)
Intensity of the W VII lines – mode

- Lines are visible predominantly in H-mode plasma
- More prominent during NBI heating than RF heating, (not always, depend on the origin of W)
- Synchronized with ELMs
Why did we see it now, not before?

- Changes in the vertical line of sight position
- W VII intensity dependent on configuration

Graph showing intensity counts over time for different configurations:
- VT conf
- CC conf
- V5 conf

#91895
**W Temperature and density**

- **Temperature estimation from W VII line ratio**
  - 3.3T, 2 MA, from 6.6 to 18.7MW NBI, from 3 to 6.4 MW RF

\[ I_{ij} = n_e n_g \varepsilon_{ij} \left( T_e, n_e \right) \]

PEC (ADAS)

\[ C_W = \frac{4 \pi I_{ij}}{n_e^2 l \varepsilon_{ij}} \]

\[ n_e = 10^{20} \text{ m}^{-3} \]

\[ l = 0.1 \text{ m} \]

<table>
<thead>
<tr>
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<th>94605</th>
<th>94645</th>
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<td>Electron temperature of W VII plasma emitting region (eV)</td>
<td>9.68</td>
<td>9.50</td>
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<td>W concentration from W VII line intensities</td>
<td>2.77·10^{-3}</td>
<td>9.42·10^{-4}</td>
<td>1.15·10^{-3}</td>
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<td>Electron temperature of W VI plasma emitting region (eV)</td>
<td>3.93</td>
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<td>W concentration from W VI line intensities</td>
<td>1.13·10^{-1}</td>
<td>7.83·10^{-2}</td>
<td>2.54·10^{-2}</td>
<td>2.56·10^{-2}</td>
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**Estimated W concentration of 10^{-3} to 10^{-1} too high – atomic constants?**
Conclusions

- **XUV UTA spectrum**
  - Temperature dependent, estimation working and widely used

- **VUV UTA spectrum**
  - Used as an indicator, no data about temperature dependence, no data for concentration estimation
  - Overlaps with lines from different elements
  - In JET – the only one available for horizontal l-o-s

- **VUV W lines (W VI to W VIII)**
  - New-observed SOL feature visible by vertical l-o-s
  - $T_e$ estimation is reasonable, but W density most probably overestimated

- **Experimental problem – vertical l-o-s spectrometers are a scarce resource in T campaigns**