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BEHAVIOR OF HEAVY METAL IONS IN FTU PLASMAS

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4 See the appendix of G. Pucella et al., Proceedings of the 28th IAEA Fusion Energy Conference 2020

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ABSTRACT

The high field, high density tokamak FTU closed its 30-years of operation at the end of 2019

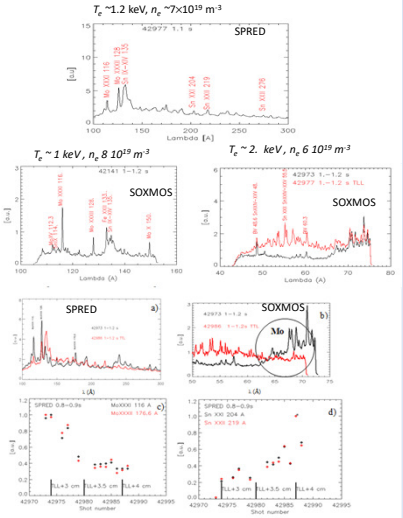
- Emissions from the heavy elements Tin, Tungsten and Yttrium have been collected and partially identified in the plasmas of the FTU tokamak with Te between 1 and 3 keV.
- In the Tin case the study was motivated by experiments on FTU where Tin Liquid Limiter TLL [1] ,was used to mitigate the plasma-wall interactions.
- in the case of Tungsten, recognized as the best choice for plasma facing components in next generation devices, aim of the work was to extend data availability in the low-intermediate electron temperature range
- in the case of Yttrium, the study was stimulated by its application to inertial fusion experiments [2].

Tin from Tin Liquid Limiter

During Tin Liquid Limiter insertion [1] Clear emissions from Sn IX-XXII are measured with the SPRED and SOXMOS spectrometers, those ions are localized at the edge (*r/a*= 0.75, 0.85)

few Sn lines identified [5] between 40 and 60 Å and no lines between 10 and 25 Å from the higher ionization stages that were reported in literature [6,7]

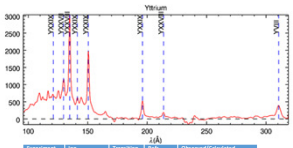
During the last campaign with TLL insertion it was observed that Mo emission decreases shot by shot until it stabilizes at low values after about 10 shots



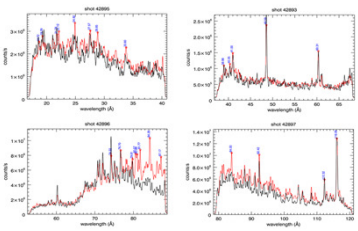
Yttrium LBO injection

In the Frascati laser facility ABC experiments, Yttrium targets are used to obtain intense radiation sources that were analyzed both in low (2-50 Å) and high spectral resolution (5.2-5.8 Å) [2] .

Y was injected in standard 5 T, 500 kA FTU discharges at intermediate densities (6-8 10^{19} m^{-3}) and T_e on axis in the range 1.7-2.0 keV .The plot shows the *difference* of the SPRED spectra taken at 0 and at 60 ms after the laser trigger evidences line emissions from Y (listed in the table)



Experiment. λ (Å)	Ion	Transition	Refs	Observed/Calculated λ (Å) from Refs
121.1	YXXIX	$3p_{1/2}$-$3d_{3/2}$	8	120.98/121.35
129.7	YXXVII	$3p$-$3s3p^2$	8	129.717/128.52
134.9	YXXVIII	$3s^{2}{}^{1}S_0$-$3s3p\,{}^{1}P_1$	8 9	135.276/134.437 135.285
150.5	YXXIX	$3s$-$3p$	8 10	151.037/150.542 151.035/150.720
196.1	YXXIX	$3s^2$-$3p$ $3s_{1/2}$-$3p_{3/2}$	8 ∞	196.212/195.175 196.215/195.565
213.8	YXXVIII	$3s^{2}{}^{1}S_0$-$3s3p\,{}^{1}P_1$	9	213.744
310.7	YVII	$4s^{2}4p^{2}\,{}^{1}D_2$ $4s^{2}4p4d$ $(2P)^{3}F_3$	11	310.722/310.721



No prominent spectral lines was observed in the spectra after Y LBO obtained with the SOXMOS : a sea of small lines overlapping, for the most part, on similar ones from the intrinsic metals, presumably from Mo
No spectral features attributable to Y could be detected with the visible spectrometers

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Introduction

FTU is a circular machine (R_0=0.93 m, a=0.29 m) with a stainless-steel Vacuum Vessel, and Mo poloidal and toroidal limiters: Fe, Ni ,Cr and Mo are FTU dominant impurities

TLL experiments offered the possibility of exploring Sn spectral features.

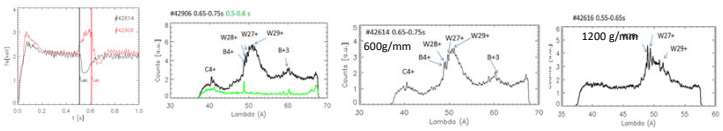
The knowledge of the complex tungsten emission spectra is necessary as a matter of course, and to characterize its behavior also on FTU, W was injected by Laser Blow Off techniques.

Our interest in Yttrium arises from its application to inertial fusion experiments [2].

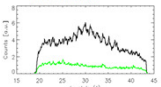
From the beginning of 2017 to the end of 2019, a 2 m grazing incidence SOXMOS spectrometer [3] was installed on FTU to observe the plasma emission along the diameter on the equatorial plane in the range from 20 to 340 Å, to complement the EUV survey spectrometer SPRED [4]. The XUV spectrometer is equipped with interchangeable 600 g/mm or 1200 g/mm gratings, providing very good spectral resolution (0.05 Å for the higher dispersion grating), and a typical time resolution of 6 ms. The SPRED instrument, on the other hand, has a spectral resolution of 2 Å for the higher dispersion grating (100-300 Å), and a time resolution of 20 ms.

Tungsten LBO Injection

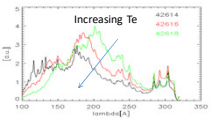
Tungsten was injected with LBO during standard discharges at 500 - 700 kA/5.3 T at low density (0.6×10^{20} m^{-3}) with and without ECRH heating
The measured spectra on FTU, collected from 15 to 70 Å with SOXMOS spectrometer in shots with T_e on axis between 1. and 3. keV, confirms what already found in other devices [12-14].



XUV spectra in two discharges with Te 1.5-2 keV and 2-3 keV, are quite similar.
The on axis Te time evolution shows in both cases a strong perturbation after the W LBO. W emissions primarily originate from W+27-W+29 4d–4f transitions.
ADAS corona equilibrium calculations for Te 1.2 and 3 keV localize such ions at core/medium radius.

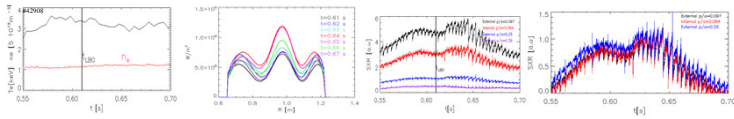


No isolated line emerged in the spectrum at 15-40Å



SPRED spectrometer (100-300Å) basculated on a shot-to-shot basis to collect emission from region at different Te

r/a =0 (black Te 1-1.4 keV*)*
r/a=0.4 (red Te 0.5-0.8 keV*)*
r/a=0.6 (green Te 0.3-0.5 keV*)*



In these experiments the FTU plasmas do not present barriers of any kinds; the Prad emissivity profile time evolution indicates that W effectively reaches the plasma core, the SXR decays after the LBO in the core and 'medium' radius are quite similar indicating that W is not confined, i.e. no W accumulation is observed.

Summary

Results of the studies on Sn, W and Y emissions performed on FTU, during its last 2 years of operation, have been reported.

- The emission spectra of Sn during TLL insertion campaign in discharges with on axis T_e ~1.5-2 keV , showed in the region between 20 and 300 Å emission lines from Sn ion states up to SnXXII. Spectra analysis evidenced that during the TLL campaign the Sn covers the limiters, Mo line emissions decrease in the spectra while Sn emissions get stronger.
- W has been injected with LBO techniques in discharges with on axis T_e in the range 1 - 3 keV: lines from W+27 - W+29 have been recognized in the spectral range 40-70 Å. No W accumulation is observed, in agreement with the expectations.
- Y has been injected with LBO techniques in discharges with on axis T_e ~ 1.7-2 keV and its spectra in the region 50 to 300 Å showed some emerging lines above 100 Å, identified as emission by YVII and YXXVII-XXIX lines.