 ISBN 978-80-7378-225-2

Spectroscopic Measurements on the COMPASS Tokamak

D. Naydenkova,[1, 2] J. Stöckel,[2] V. Weinzettl,[2] D. Šesták,[2] J. Havlíček[1, 2]

[1] Charles University in Prague, Faculty of Mathematics and Physics, V Holešovičkách 2, 180 00, Prague, Czech Republic.

[2] Institute of Plasma Physics AS CR, v.v.i., Association EURATOM/IPP.CR, Za Slovankou 3, 182 00 Prague, Czech Republic.

Abstract Spectroscopic measurements are standard measurements at COMPASS tokamak. The two wide spectral range spectrometers HR 2000+ were used for registration of the most intensive spectral lines in ultraviolet and visible wave ranges with ≈ 10 ms temporal resolution during the discharges. The temporal evolution of integral visible light and H_α were measured by a photomultipliers with ≈ 1 μs resolution. Evolution of He lines during discharge duration was studied. Afterglow in helium was found. Evolution of working gas composition during one day of tokamak operating mode is presented.

Introduction

The COMPASS tokamak, a divertor device with an ITER-relevant geometry (R = 0.56 m, a = 0.23 × 0.38 m, Ip = 200–400 kA, BT = 1.2–2.1 T and pulse length up to 1 s), was re-installed at IPP Prague [*Pánek et al., 2006*].

Visible spectroscopy is one of the standard diagnostic used on many tokamaks in a similar way [*Sudkewer, 1981*, *Pospieszczyk, 2005*]. The main aim of spectroscopic measurements in COMPASS is to study the visible and near ultraviolet radiation of excited neutral atoms and ions from the edge plasma. At the current phase of COMPASS operation, the spectra in the range of wavelengths 250–475 nm and 457–653 nm with temporal resolution 20 ms and 10 ms were measured. It is also used photomultiplier (PMT) based measurements with high temporal resolution (≈ 1 μs). Spectral resolution is realized by means of interference filters in this case.

In this article we study visible and near UV radiation from circular plasmas on the COMPASS tokamak with stable or pre-programmed plasma position and similar discharge parameters. Although, helium ash transport is widely studied elsewhere [*Synakowski et al., 1995, Hamamatsu et al., 1998*], we investigate helium as an impurity implanted to carbon limiters by a glow discharge procedure and desorbed in high-temperature plasma discharges. Helium influx and its changes during individual discharges as well as in a sequence of shots will be described in the next chapters. We will also pay attention to composition of after-glow discharges.

Diagnostic setup

Few ports in different cross-sections are used for spectroscopic measurements at tokamak COMPASS [*Weinzettl et al., 2011*]. Upper-angular port at 12/13 tokamak cross-section is used for photomultiplier based measurements and wide-range minispectrometers [*Naydenkova et al., 2009*]. High spectrally resolved measurements (see Table 1) are realized by means of two HR 2000+ minispectrometers from Ocean Optics. Plasma radiation is transferred from the tokamak to the detection systems by means of 20 m long optical fibres.

Poloidal view to cross-section 12/13 is shown in Figure 1. Different colours represent observation areas of different one-chord diagnostics: H_α line observation area for PMT based diagnostic, UV spectrometer (HR 2000+ based), integral visible light and VIS spectrometer (HR 2000+ based). Measurements are realized by means of optical fiber splitter in the last case.

Table 1. Basic parameters of HR 2000+ spectrometers.

	VIS spectrometer	UV spectrometer
Detection range	460–663 nm	247–473 nm
Optical resilution	0.15 mn	0.17 nm
Sensitivity	41 photons/count	75 photons/count
Integration time	1 ms–65 sec	1 ms–65 sec

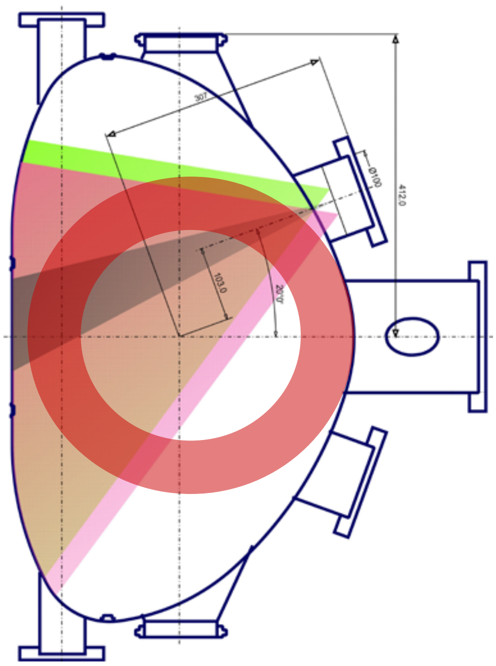

Figure 1. Poloidal view to cross-section 12/13.

We are focused on study of the edge plasma and so-called scrape of layer (SOL) regions of tokamak discharge, where so-called radiation shell of light impurities is located. Radiation shell is usually thin cylindrical layer of edge plasma, where conditions for excitation and de-excitation of impurities are fulfilled. In Figure 1 it corresponds to dark grey circle region.

Results

Plasma position

In the frame of plasma position tests, measurements allowing a comparison of the results of optical and magnetic diagnostics were performed. Pre-programmed plasma shift in horizontal or vertical directions was realized for set of shots. They were compared with the one with stable plasma position.

Main parameters of plasma discharge with stable plasma position are shown in Figure 2 (see panels b and c). It is possible to see perfect correspondence in two independent H_α measurements, which were realized by means of PMT and the spectrometer.

Figure 3 shows discharge with vertical shift of plasma position (see panel c). A change in integral visible plasma radiation corresponding to plasma shift was observed. There is no correspondence in measurements of Hα radiation measured using PMT based system and the spectrometer in this case. Results received from the spectrometer show changes of H_α radiation connected with plasma position shift; at the same time PMT measurements do not. It can be explained by too wide chord of integration of PMT measured signal in this case. As a consequence, it shows that spatially resolved measurements are essential for plasma radiation studies and correct data interpretation.

He impurity

Helium is a working gas for glow discharges, which precede the tokamak high-temperature discharges. Therefore, its line radiation is observed in all studied plasma spectra. However, helium has no ionization peak at the beginning of the discharge, which is, for example, very characteristic for H_α line radiation, since helium is trapped in carbon limiters and it takes some time to start releasing it. It was also confirmed spectroscopically that gas puffing does not bring any new helium. It is possible to follow intensities of the most intensive He_I (587.56 nm) and He_{II} lines (468.57 nm) in Figure 2 and to observe their linear increase with discharge time. The behaviour of He lines during discharge is different from lines of hydrogen (working gas) and carbon (typical impurity). An increase of electron density during current flat top phase of discharge corresponds more or less to He_{II} line evolution, meanwhile intensities of Hα and carbon lines remain constant. We suppose that this effect can be connected with helium ionisation only. The afterglow discharge with opposite plasma current and loop voltage polarity begins in few milliseconds after the end of regular discharge. Only He_{I} line radiation is observed at this time (radiation of hydrogen, which is still present in vacuum chamber, is strongly suppressed).

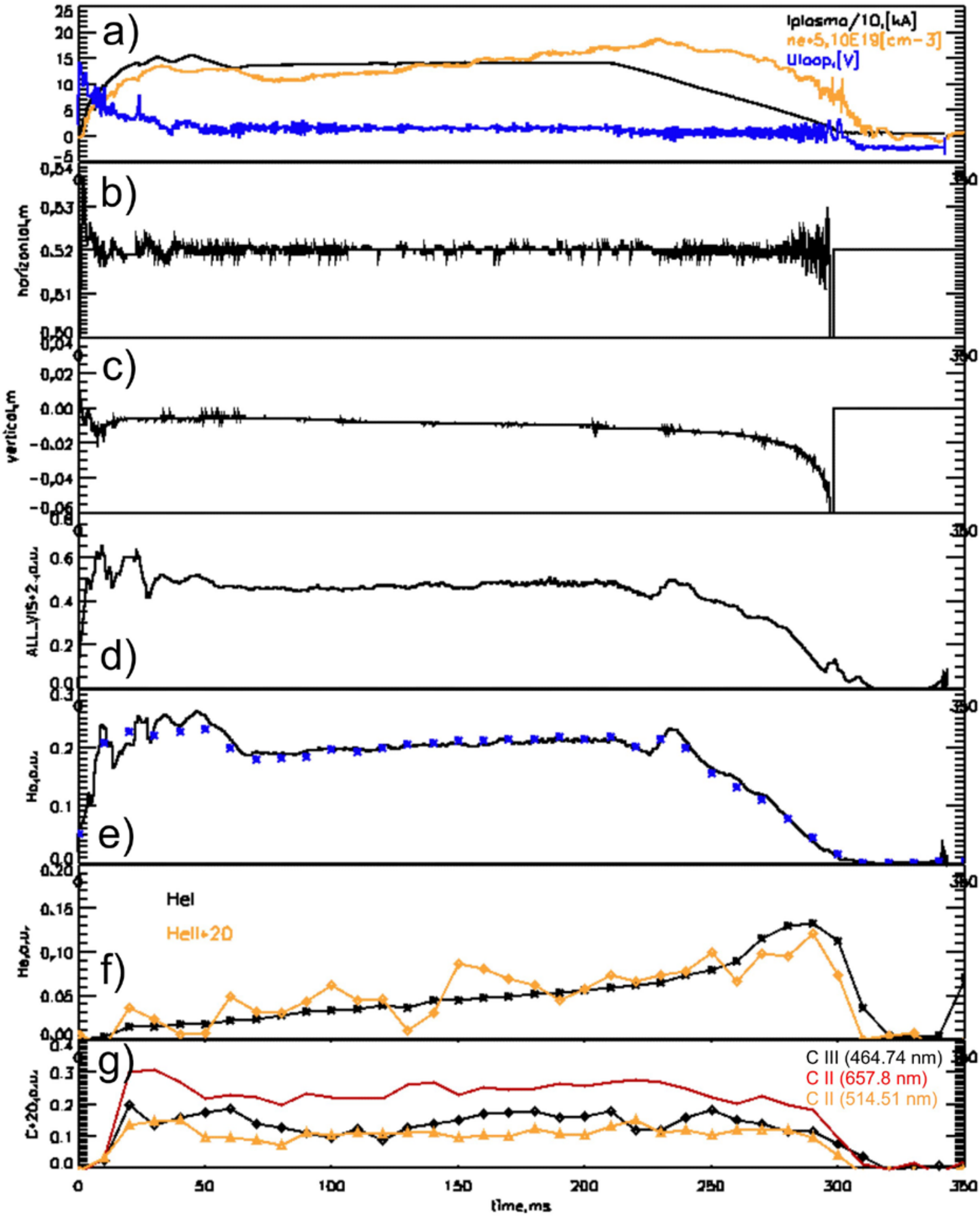

Figure 2. Temporal evolution of (a) plasma current, electron density and loop voltage, (b) horizontal and (c) vertical plasma position, (d) integral visible light, temporal evolution of (e) H_{α} (656.27 nm), (f) He_{I} (587.56 nm) and He_{II} lines (468.57 nm) and (g) carbon intensity spectral lines for discharge with stable plasma position #3120.

Next studies were focused on evolution of hydrogen and helium spectral lines in ultraviolet and visible plasma regions over many sequent tokamak discharges. Evolution of H_α (656.27 nm) and He_I (587.56 nm) spectral lines is presented in Figure 4. All studied discharges had similar main plasma parameters. The aim was to track behaviour of helium during one operation day.

The glow discharge was done before shots #3115 and #3122 to clean vacuum chamber from impurities.

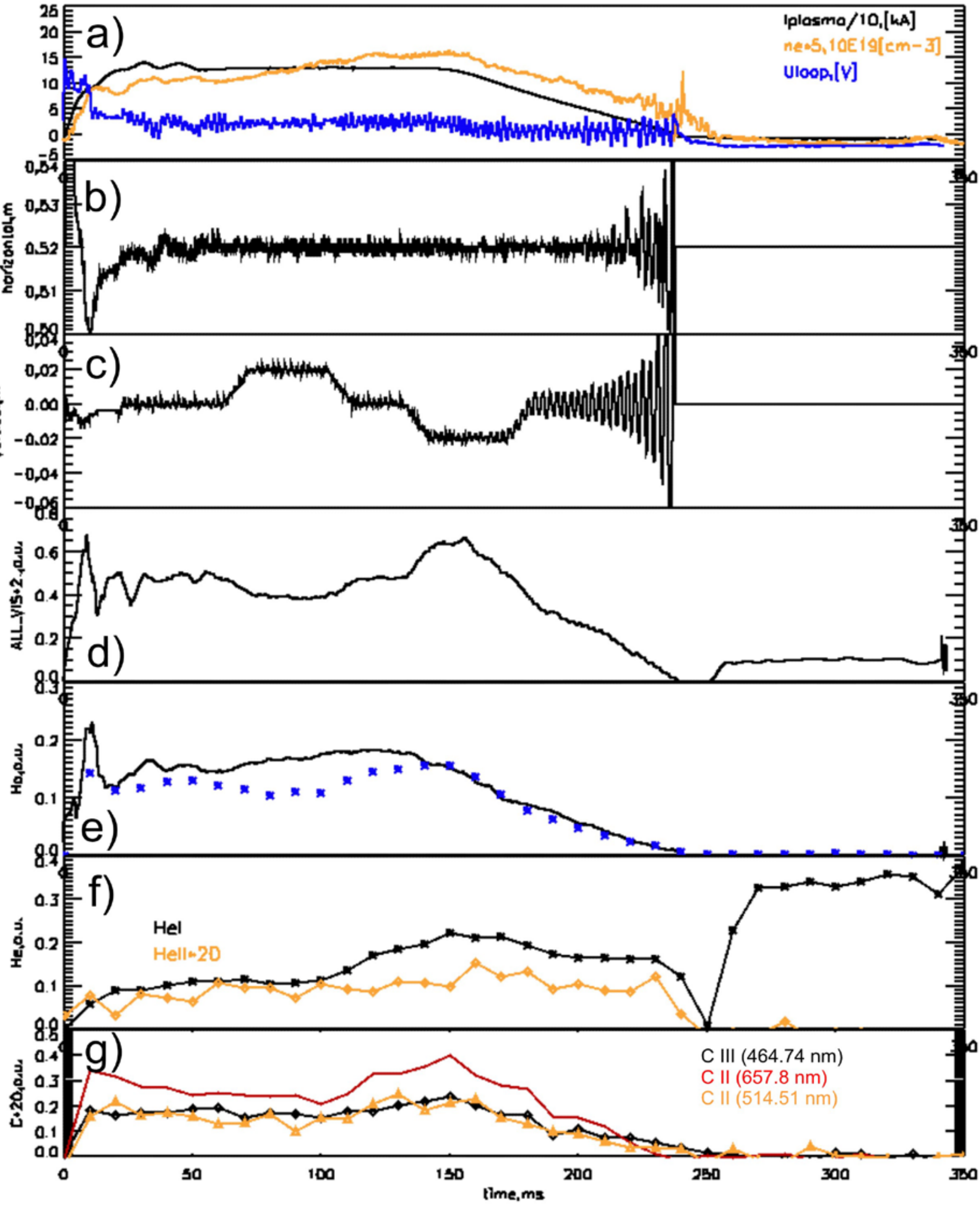

Figure 3. Temporal evolution of (a) plasma current, electron density and loop voltage, (b) horizontal and (c) vertical plasma position, (d) integral visible light, temporal evolution of (e) H_α (656.27 nm), (f) He_I (587.56 nm) and He_{II} lines (468.57 nm) and (g) carbon intensity spectral lines for discharge with pre-programmed shift of plasma position in vertical direction #3145.

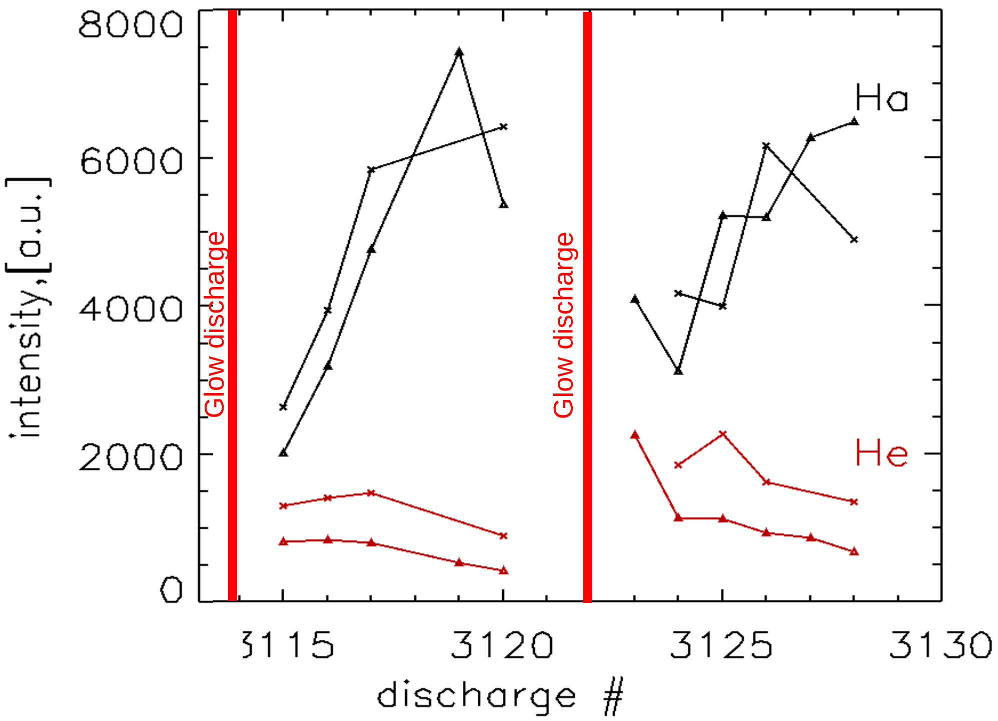

Figure 4. Temporal evolution of He_I (587.56 nm) and H_α lines (656.27 nm) in discharges with circular plasma during one experimental day.

After 4–5 high-temperature discharges after glow discharge, He lines intensity saturates and slowly starts to decrease; meanwhile, all hydrogen lines increase all the time. It is an indication of exchange of helium with hydrogen in the carbon limiter tiles. By next glow discharge, content of hydrogen and helium is approximately returned to its previous level. A typical situation is shown in Figure 4.

Conclusion

The diagnostic set for visible plasma radiation measurements at the COMPASS tokamak includes two spectrometers covering near ultraviolet and visible wavelength range. It allows studying of temporal evolution of spectral lines of working gas and the most intensive impurity lines with temporal resolution about 10 ms. It is sufficient for registration of plasma composition. Discharges with higher intensity of He lines usually correspond to lower radiation of H_α line and vice versa. He_I and He_{II} intensities grow during flat top phase of discharge. It allows supposing drift of helium to confined volume and its full ionisation, it causes loosing of energy of confined particles. During the ramp down phase of discharge H_α and carbon ions lines intensities decrease but He increases and reaches to maximum just after start of the phase. Afterglow in helium is observed after the end of the majority plasma discharges.

We investigated helium influx and its changes during individual discharges as well as in a sequence of shots. Since He_I and He_{II} lines were increasing all the time during current flat-tops of the realized discharges, it can be concluded that the most probable source of He are carbon limiter plates. It gets there because of diffusion of helium into cavities during glow discharges, and releases back to plasma because of surface activation or heating by plasma radiation. Our conclusion is supported by observation of the helium content behavior during a day. Its inflow saturates after few hydrogen high-temperature discharges after the cleaning glow discharge in helium and slowly starts to decrease. It seems that helium is stepwise replaced by hydrogen in carbon limiter tiles, what is indicated by permanent hydrogen inflow increase during a day.

We also paid attention to composition of after-glow discharges. There, only He_I spectral lines were observed. Probably, these low-current discharges are initiated in neutral helium gas and there is not enough energy for either helium ionization or hydrogen excitation and ionization.

Additional studies of gas composition between discharges, thermal evolution of carbon plates surface, and working gas pressure evolution during day of operation are required to understand helium recycling processes after vacuum chamber cleaning procedure in glow discharges.

Acknowledgment. The work was performed in the frame of the grant GA CR No. 202/09/1467.

References

K Hamamatsu, C S Chang, T Takizuka, M Azumi, T Hirayama, S Cohen and T Tani, Numerical analysis of helium ash removal by using ICRH-driven ripple transport *Plasma Phys. Control. Fusion* 40, 1998, 255 doi:10.1088/0741-3335/40/2/007

D. I. Naydenkova et al., First spectroscopic measurements at COMPASS tokamak. WDS 2009 — Proceedings of Contributed Papers, Edited by Jana Šafránková and Jiří Pavlů, MATFYZPRESS, Prague. Part II: Physics of Plasmas and Ionized Media, pp. 158–162, 2009, ISBN 978-80-7378-102-6.

R.Pánek, et al., COMPASS-D magnetic equilibria with LH and NBI current drive. Czechoslovak Journal of Physics, Vol. 56, Suppl. B, pp. 125–137, 2006.

A Pospieszczyk, Spectroscopic Diagnostics of Tokamak Edge Plasmas, Phys. Scr., Vol. 2005, T119 2005, doi:10.1088/0031-8949/2005/T119/013

S Sudkewer, Spectroscopic Diagnostics of Tokamak Plasmas, Phys. Scr., Vol 23, Num. 2, 1981, doi:10.1088/0031-8949/23/2/002

E. J. Synakowski, R. E. Bell, R. V. Budny, C. E. Bush, P. C. Efthimion, B. Grek, D. W. Johnson, L. C. Johnson, B. LeBlanc, H. Park, A. T. Ramsey, and G. Taylor, Measurements of the Production and Transport of Helium Ash in the TFTR Tokamak, Phys. Rev. Lett. 75, 3689–3692, 1995.

V. Weinzettl et al., Overview of the COMPASS diagnostics. Fusion Engineering and Design 86, 1227–1231, 2011.