*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, O-3.016 (2006)*

# Two-dimensional multi-spectral line measurements during impurity pellet ablation in LHD

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**Introduction.** Nowadays, further developments of pellet ablation models [1] and modern pellet applications [2] as a diagnostic tool in high temperature plasma are being restricted due to lack of information on structure of the cold secondary cloud which surrounds the pellet ablating in plasma. Theoretical predictions of pellet cloud parameters [3, 4] are far from a few results of measurements [5-[7]. Study of radiation of polystyrene balls of Tracer Encapsulated Solid Pellet (TESPEL) [[7] using the recently developed NIOS (Nine Images Optical System) gave us a unique possibility to study impurity pellet cloud in different carbon and hydrogen lines simultaneously. Stark broadening of hydrogen lines and ratios of their intensity to the continuum intensity could be used for measurements of spatial distributions of the cloud $N_{cl}(r,z)$ density and $T_{cl}(r,z)$ temperature correspondingly. Results of first NIOS applications in LHD are reported.

**Experimental setup.** The sketch of TESPEL cloud measurements using NIOS system is shown in Fig. 1. Nine identical lenses produce nine images of the 16 ×16 cm observation

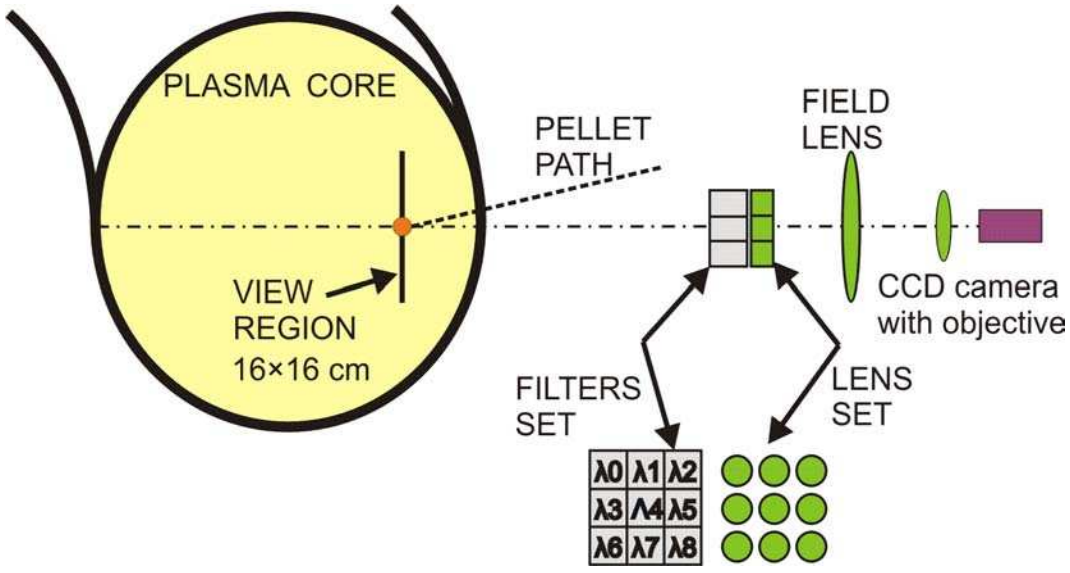


*Fig. 1. Layout of NIOS measurements in LHD.*

Table 1. Parameters the NIOS interference filters

| Filter | Hα | $H_\beta$ | Cont | CII 515 | CII 723 |
|---|---|---|---|---|---|
| $\lambda_{centre}$, nm | 655.5 | 486.5 | 497.0 | 515.0 | 723.6 |
| $\Delta\lambda_{FWHM}$,nm | 5 | 10 | 5 | 10 | 5 |

region. In front of the each lens an interference filter is installed, which is transparent in a definite spectral interval. The 9-image region is observed by the PCO "PixelFly" CCD camera with a

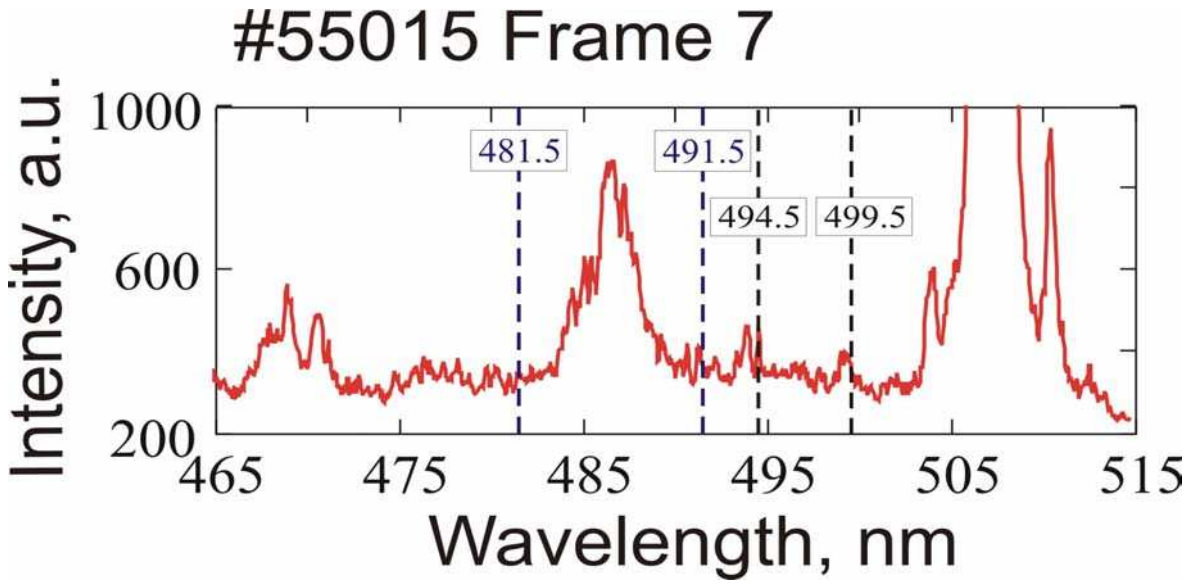


*Fig. 2. Sample of time-resolved wide-view angle spectral measurements of TESPEL ablation cloud [7] for choosing the $H_\beta$ and Continuum filter parameters.*

variable exposure time. The camera was triggered at the time corresponding to the predetermined radial TESPEL position in plasma. Set of spatial and spectral calibrations of the NIOS were performed which allowed to juxtapose 9 snap-shots measured in different spectral ranges. Details of the NIOS experimental setup will be published elsewhere soon [9]. TESPEL pellets of 0.9 mm in diameter and 300-400 m/s with Ti tracer inside were injected in NBI-heated LHD plasmas. The parameters of the five filters used in this experiment are summarized in Table 1 and were chosen for measurements of $H_\alpha$, $H_\beta$, Continuum (Cont, 497 nm), CII (515 nm) and CII (723 nm) cloud radiation intensities. The choice was based on the time-dependent spectral measurements of TESPEL cloud emission done earlier [7]. For instance, parameters of $H_\beta$ and Cont filters were chosen according to data shown in Fig. 2.

**Results and discussion**. Sample of the CCD frame with 5 NIOS images is shown in Fig.3. It is seen that the cloud tilt angle is the same in all images and its value is close to the

vacuum magnetic field tilt angle value of 15 degree calculated for the TESPEL position. The Abel inversion procedure was used to determine the local $I_{H\alpha}(r,z)$, $I_{H\beta}(r,z)$, $I_{Cont}(r,z)$ intensities under assumption of the cloud axial symmetry relative to the $Z$ axis accepted as the magnetic field direction. Cloud temperatures $T_{cl,H\alpha}(r,z)$ and $T_{cl,H\beta\alpha}(r,z)$ were determined using both $I_{H\alpha}(r,z)/I_{Cont}(r,z)$ *and* $I_{H\beta}(r,z)/I_{Cont}(r,z)$ ratios correspondingly by means of the known relationship from Ref. [10] under assumption of the LTE existence.

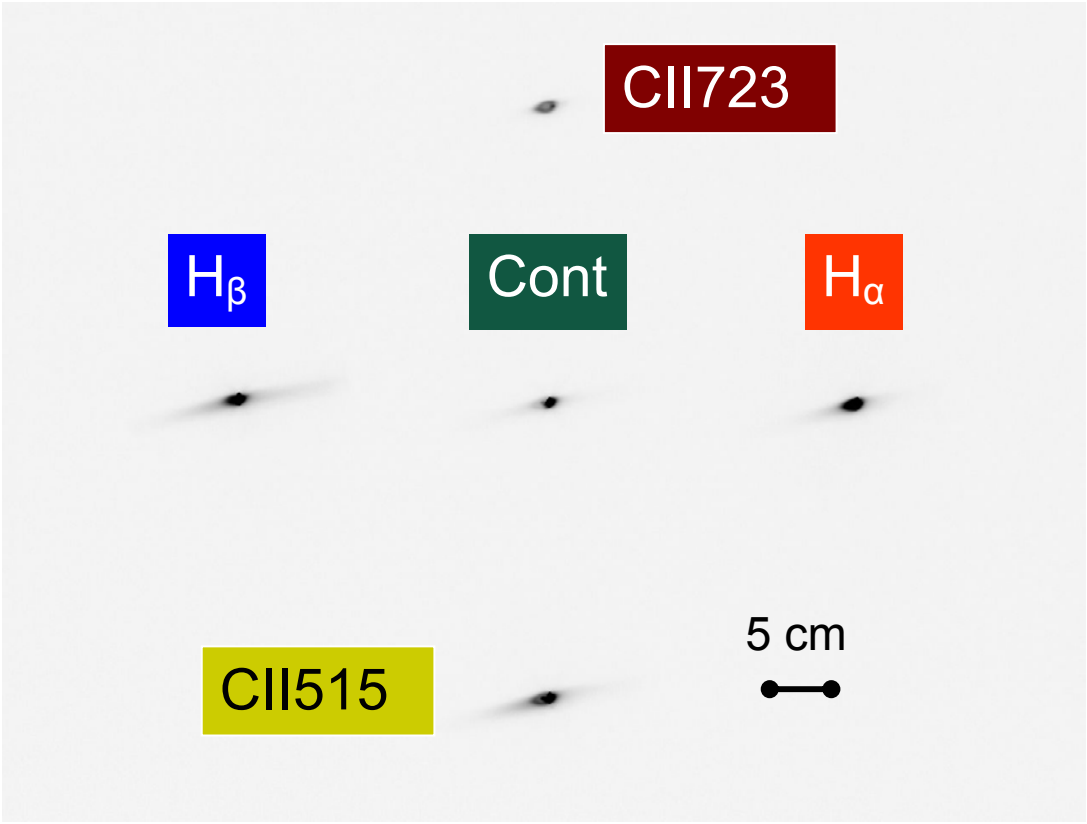


*Fig. 3. Sample of NIOS measurements in the #65303 LHD shot. Exposure time is 10 μs. NIOS is triggered at R =4.3 m.*

In Fig. 4 cloud longitudinal $I_{H\alpha}(0,z)$, $I_{H\beta}(0,z)$, $I_{Cont}(0,z)$ intensity profiles are shown. There are the apparatus saturation in $H_\alpha$ and $H_\beta$ intensity profiles at $Z$-$Z_p$= ± 8 mm region ($Z_p$ is the pellet position). Evaluated $T_{cl,H\alpha}(0,z)$, $T_{cl,H\beta}(0,z)$ profiles are shown in Fig. 4 as well. One can see that the $T_{cl} \approx$ 10-20 eV and $T_{cl,H\alpha}$ values are higher up to 2 times than $T_{cl,H\beta}$. A difference of evaluated $T_{cl,H\alpha}$ and $T_{cl,H\beta}$ values motivate us to further verification of the radiation spectral composition measured by the filters. The LTE existence also has to be proved for TESPEL cloud because its averaged density of about (1-2)×$10^{16}$ $cm^{-3}$ [7] are smaller than the typical $10^{17}$ $cm^{-3}$ density values of hydrogen clouds where an existence of

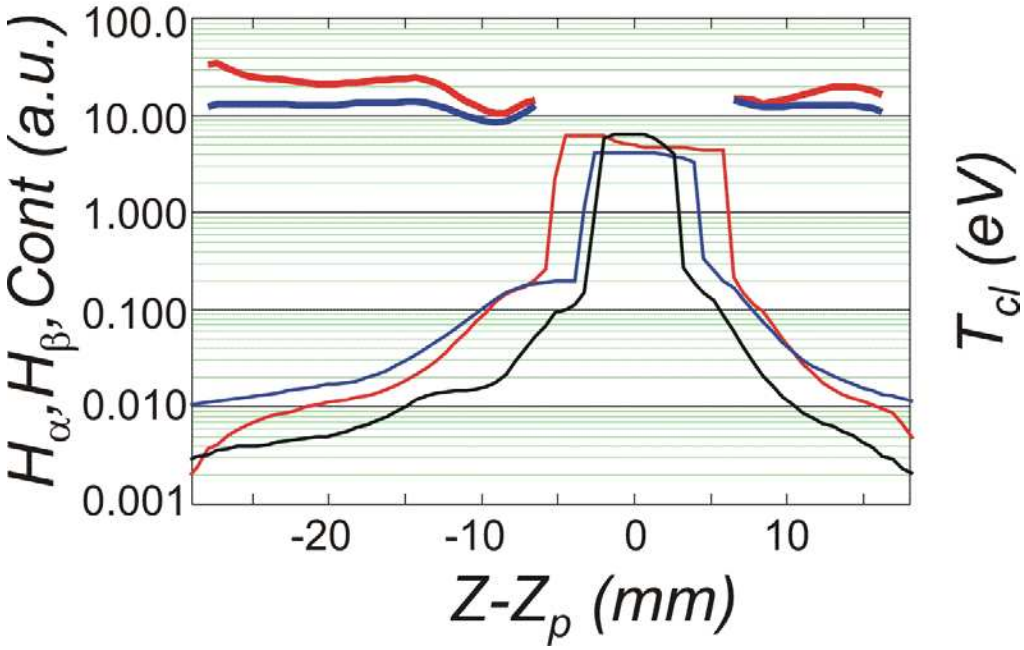


*Fig.4. Toroidal intensity profiles $I_{H\alpha}(0,z)$ (thin red), $I_{H\beta}(0,z)$ (thin blue), $I_{Cont}(0,z)$ (thin black) in the #65303 LHD shot. Evaluated $T_{cl,H\alpha}(0,z)$ (thick red) and $T_{cl,H\beta\alpha}(0,z)$ (thick blue) profiles are shown as well.*

LTE was shown [6]. The local TESPEL cloud density measurements are needed to clarify this problem and foreseen in further NIOS experiments. For that, 9 filters will be installed in NIOS to measure the $H_\beta$ Stark broadening two-dimensionally.

**Summary.** NIOS has been put in operation at LHD for TESPEL cloud studies. Evaluated $T_{cl}$ values are of about 10-20 eV. The LTE existence has to be proved for TESPEL cloud by means of the density measurements. Further verification of the radiation spectral composition measured by the filters has to done.

**Acknowledgements.** This work was partially supported by RFBR grants ## 05-02-17269, 06-02-17333 and grant of RF President for young scientist supporting # MK-7792.2006.2.

## References

[1] Kuteev B.V., Journal of Technical Physics, 1999, v. 44, № 9, p. 1058-1063.
[2] P. R. Goncharov,T. Saida, N. Tamura *et al*., Rev.Sci. Instrum. 2003 **74** pp.1869-1872.
[3] Lengyel L.L. *et al.*, Nucl. Fusion **39** (1999) pp. 791-813.
[4] Morozov D.Kh. *et al*., Nucl. Fusion, 2004 **44**. p. 252
[5] D.H. McNeill, *et al*., Phys. Fluids B **3** (1991) p.1994-2009.
[6] Sergeev V.Yu. *et al*., Fusion Eng. And Design **34-35** (1997) pp. 323-327
[7] N. Tamura V.Yu. Sergeev, D. Kalinina *et al.*, Europh. Conf. Abs., (2003) **22C,** p. 0607
[8] Sergeev V.Yu., *et al.*, J. Plasma Fusion Res. SERIES **4** (2001) pp. 605-608.
[9] V.Yu. Sergeev *et al*., will be sent to Rev.Sci. Instrum.
[10] H.R. Griem. Plasma spectroscopy. MVGRWA-HILL, NY, 1969.