Ammonia quantification during nitrogen seeding experiments in GyM linear plasma device

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ABSTRACT

- Ionic Chromatography (IC) has been applied to absolute quantification of ammonia contained in the gas exhaust collected during dedicated experiments executed to study the nitrogen conversion in ammonia.
- During the experiments residual RGA and OES diagnostics were both used to monitoring the gas species and radicals resulting from the plasma.
- Results indicate that the nitrogen conversion never exceeds 10% and is affected by isotopic and wall material effects.

BACKGROUND

- One of the most critical problems for future fusion devices is the power load to the divertor target plates [1]. Tungsten (W) is the material chosen for the divertor's plasma-facing components from the start of plasma operations for ITER.
- Because to avoid W damage, divertor target loads should be kept below 5-10 MWm^{-2} therefore it is necessary to cool the plasma before it reaches the divertor. This can be achieved through puffing of low Z impurities into the plasma from gas valves near the divertor region (seeding) [2].
- Typical gas used for seeding is nitrogen (N_2), however besides the beneficial cooling, N_2 is chemically active in a hydrogen fuel isotopes environment, which leads to the formation of ammonia NQ_3 (Q=H,D,T), an additional inventory of radioactive material in the vessel [3].
- Thereby potential safety and operational issues for ITER have been identified and studied, in tokamak as well as laboratory experiments, to evaluate the applicability of N_2 as seeding gas in future nuclear fusion devices.

CHALLENGES / METHODS / IMPLEMENTATION

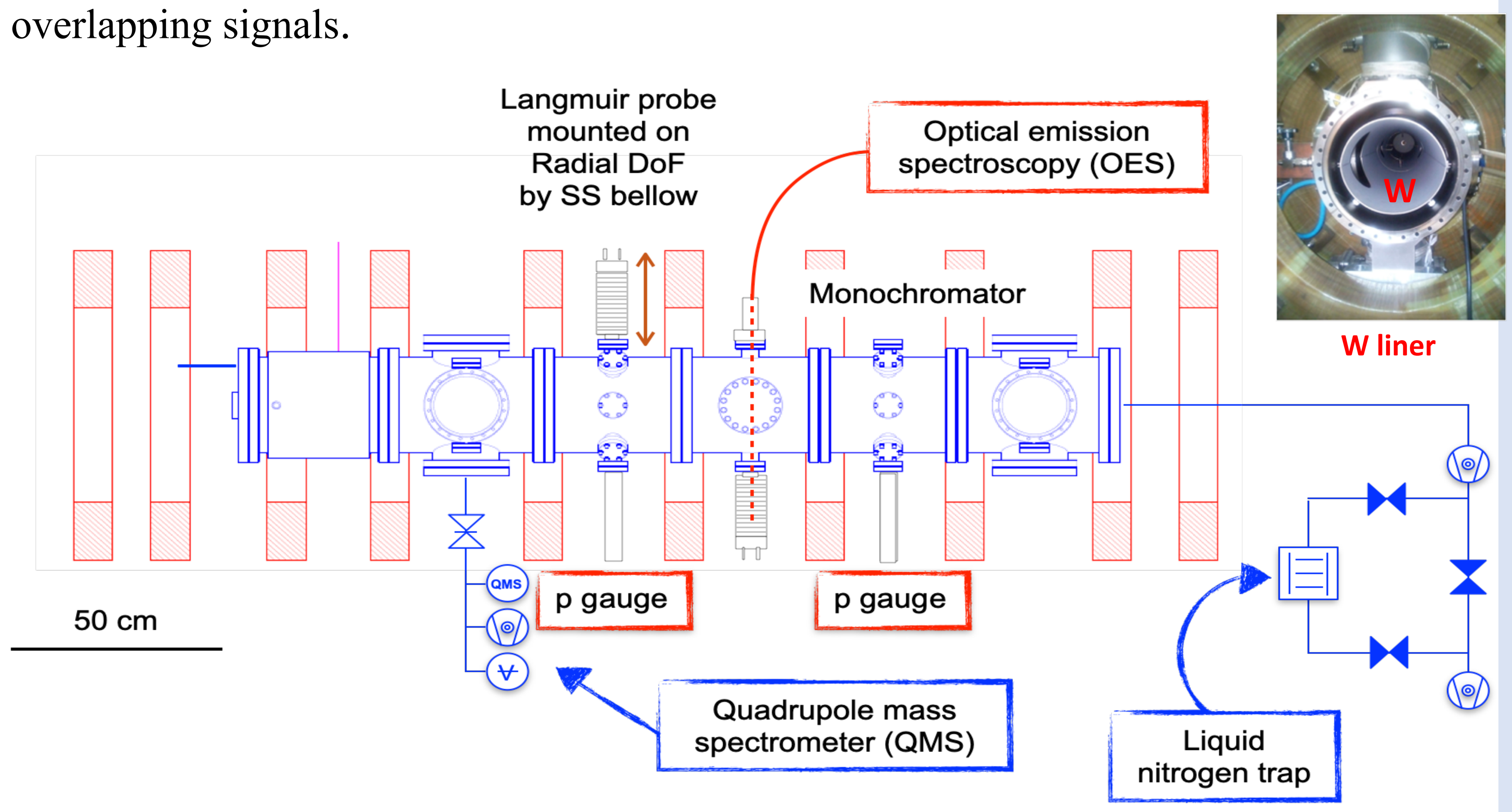
Nitrogen seeding experiments in the GyM linear device

The GyM is a linear plasma device consisting of a cylindrical vacuum vessel (R=0.125 m, L=2.11 m) mounted in linear magnetic field (up to 0.13 T) in which highly reproducible plasmas, confined in the z direction, were obtained and steadily sustained by CW microwaves power (1.5 kW, 2.45 GHz). The experiments were conducted by introducing in the GyM Q_2 (H, D) and N_2 a constant flux N_2/Q_2+N_2 ratio (in molecules per second) sets as 0.01 and total fluxes ranging from 8.3×10−2 to 1.6×10−1 mbarL at T_e=5 eV and $n_e=2\times10^{16}$ m^{-3} for 90 min.

To study the effect of wall material the GyM has been implemented with an additional W wall (liner). The liner is made of a 3 mm thick stainless steel substrate (R=0.10 m, L=2 m) with an internal surface coating of 50 µm of W with 10 µm roughness deposited by plasma spray.

Method to absolute quantification of NQ_3

In order to quantify NQ_3 the GyM has been equipped with a liquid N_2 trap constantly cooled (77 K). At the end of each experiment, liquid N_2 coolant was stopped and regeneration of the LN_2 started until ambient temperature was reached. After its complete regeneration, the trap was inserted in a line where an argon (Ar) carrier forced through the released gas, gurgling it in acidified ultrapure water. The NQ_3 determination was carried out by means of the IC systems, selected because the ability to detect NQ_3 even at trace levels, few parts per million (ppm) and absence of the overlapping signals.



W liner

Schematic of the GyM linear plasma device and surrounding diagnostic equipment

1. LN_2 Trap

2. Bubbler system

3. Ion Chromatography system

ACKNOWLEDGEMENTS / REFERENCES

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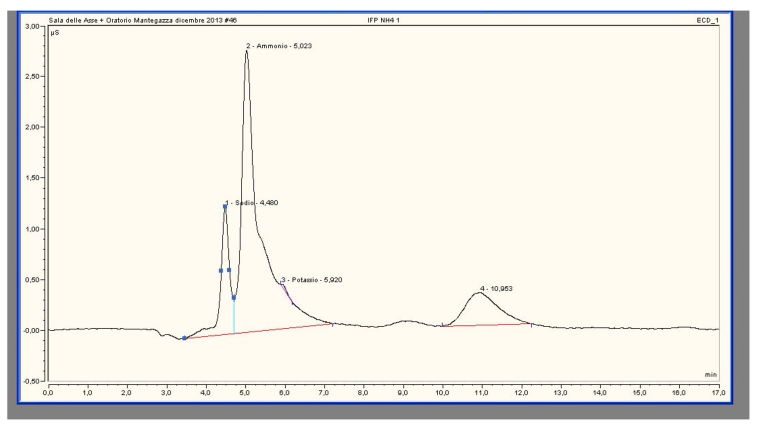
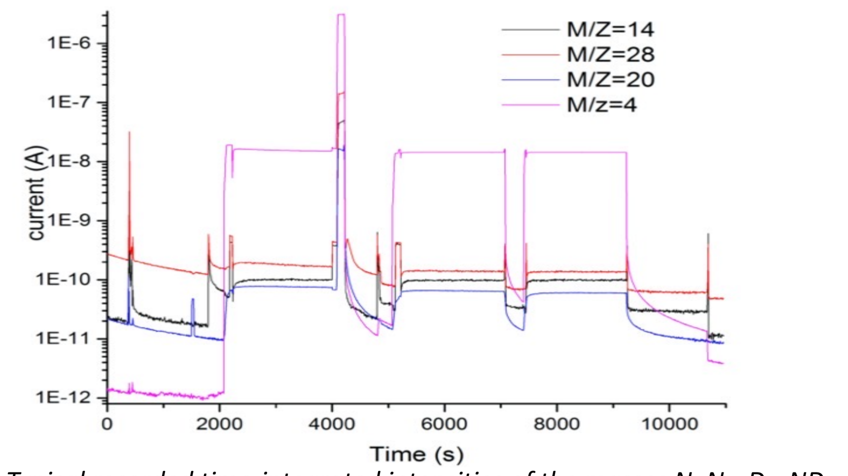
[1] J. Pamela, Tech. rep., JET-EFDA Team (2001)
2] A. Kallenbach, M. Balden, R. Dux, T. Eich, C. Giroud, A. Huber, G. Maddison, M. Mayer, K. McCormick, R. Neu et al., Journal of Nuclear Materials **415**, S19 (2011)
[3] R. A. Pitts et al, Nuclear Materials and Energy 20 (2019) 100696

OUTCOMES

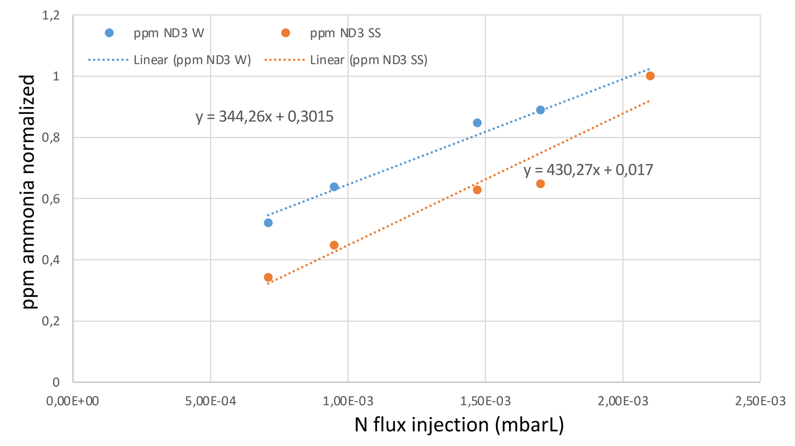
Wall material effect: IC, RGA and OES analysis



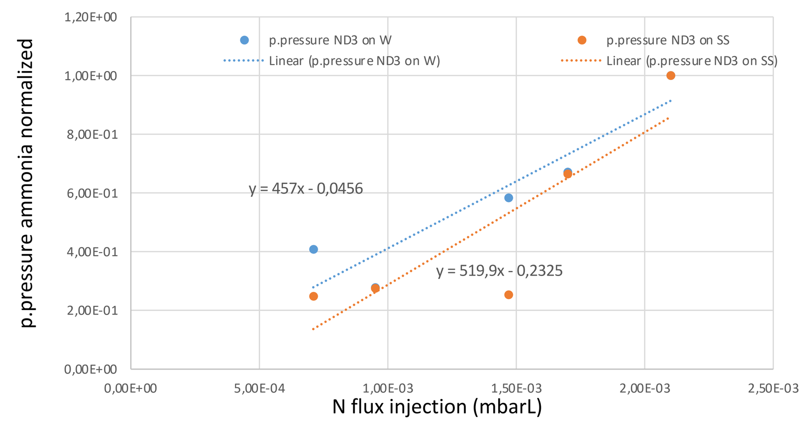
Chromatogram of the exhaust collected during experiment



Typical recorded time-integrated intensities of the masses N, N_2, D_2, ND_3

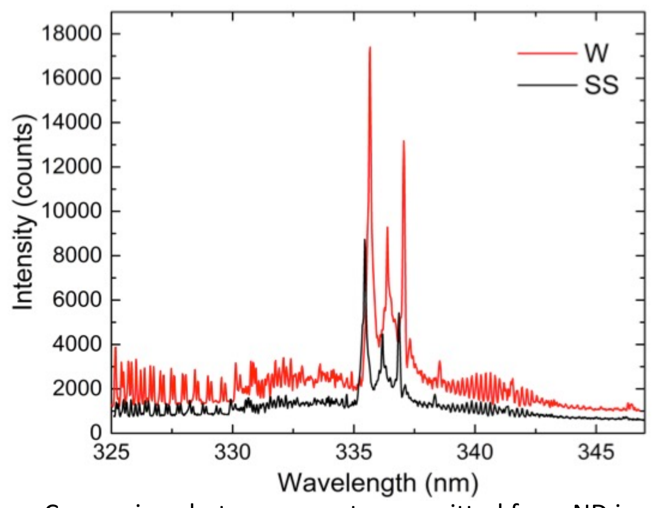


Quantity of ammonia produced in part per million (ppm) as a function of the N flux injected. To compare the effect of the wall materials, quantity have been normalized.



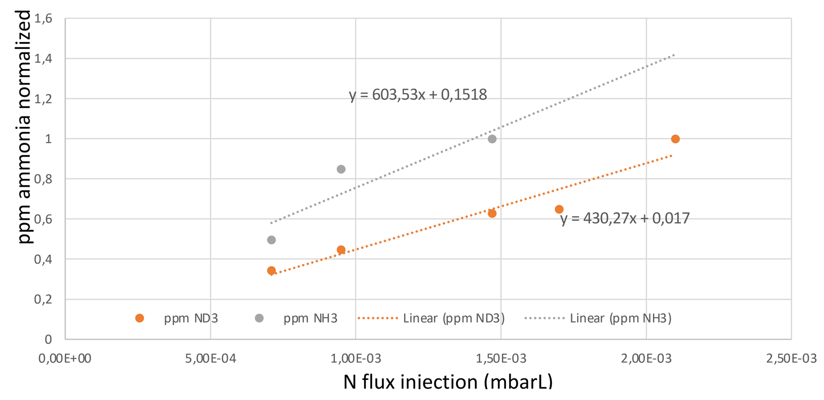
Quantity of ammonia produced in p. pressure (mbar) as a function of the N flux injected. To compare the effect of the wall materials, quantity have been normalized.

- More ND_3 is produced when experiments of the N seeding are performed whit W wall.
- Ratios $\frac{quantity\ of\ the\ ND_3\ produced\ on\ W}{quantity\ of\ the\ ND_3\ produce\ on\ SS}$ $\left(\frac{ND_3W}{ND_3SS}\right)$ calculated from both IC and RGA results have been compared with ratio $\frac{surface\ area\ of\ W}{surface\ area\ o\ SS}$ = 1,12. Surface areas are calculated for a samples of 1 cm^2 taking in to account the roughness and also the difference in dimensions of the both walls.
- $\frac{ND_3W}{ND_3SS}$ = 1,1 for IC data and $\frac{ND_3W}{ND_3SS}$ = 1,05 for RGA data
- This means that increase of the ND_3 measured during experiments performed with W wall must be ascribed at the roughness of the W, much more high than that of the SS.
- Of particular interest for this work are the indications of ND species belong to A $^3\Pi$ - X $^3\Sigma^-$ system for the transition (0,0) and (1,1) considered as reaction intermediates.
- Intensity of the ND band can be assumed as indicator of how much ND_3 is produced.
- Intensity of the ND band acquired in experiments performed with W wall are higher than intensity acquired in SS wall (same trend of IC and RGA).



Comparison between spectrum emitted from ND in experiments performed in W and SS

Isotope effect: IC, RGA and OES analysis



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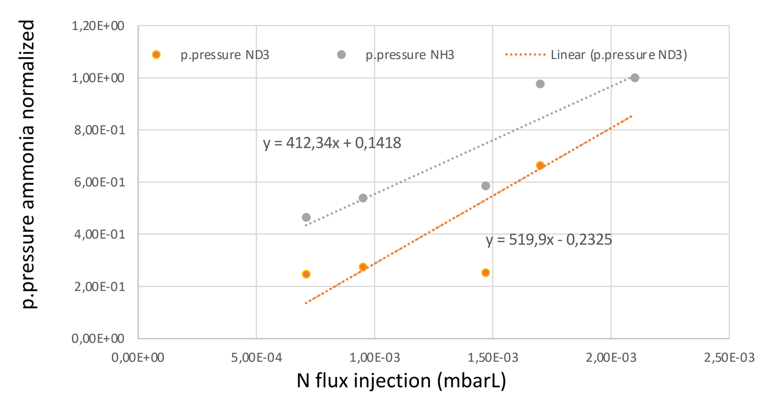

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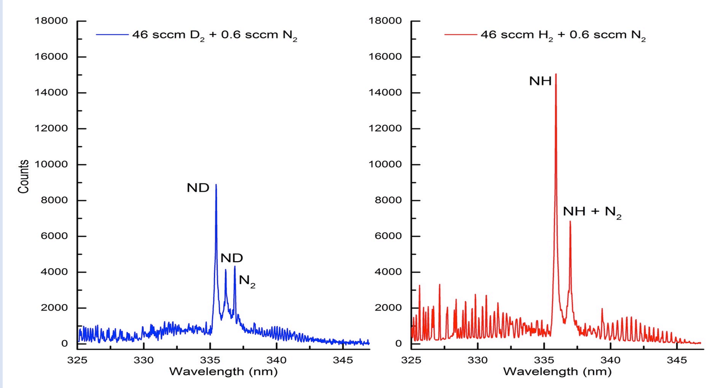
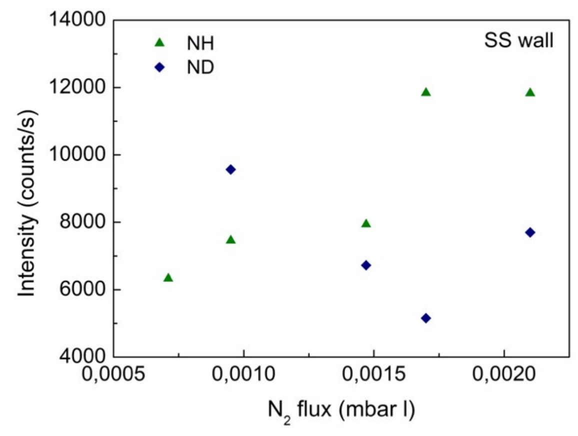


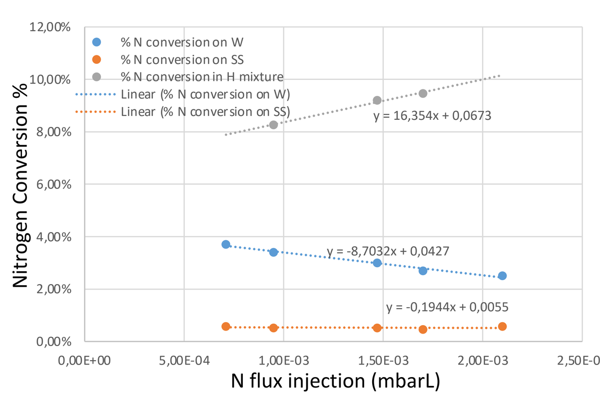
Comparison between spectrum emitted from NH(D) in experiments N seeded H (D) plasmas



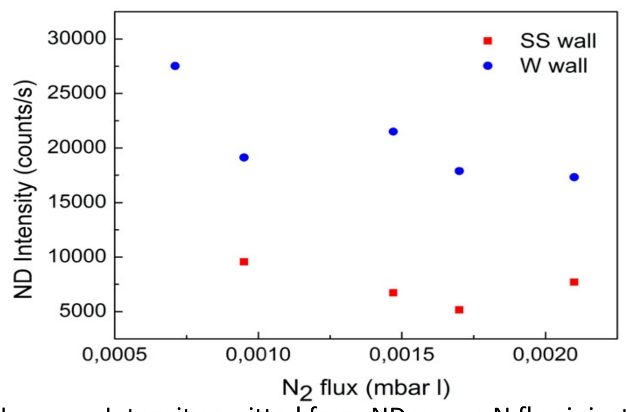
Intensity emitted from ND versus N flux injected performed in N seeded H (D) plasmas

All diagnostics used confirm that much more ammonia is produced during nitrogen seeding in H mixtures.

Nitrogen conversion %



Nitrogen conversion as a function of the N flux injected



Intensity emitted from ND versus N flux injected in experiments performed in W and SS Wall

- **N conversion never exceeds 10%.**
- **N conversion decreases as the N flux injected increases.**
- **ND intensities decrease as well as N flux increases.**

Conclusions

- Collection of the exhaust in LN_2, bubbler and IC analysis is a suitable method to the absolute quantification of the ammonia produced during nitrogen seeding experiments.
- Ammonia production is hugely influenced by roughness of the wall materials.
- In N seeded H experiments much more ammonia is formed.
- If the N_2/Q_2+N_2 ratio is kept around 0.01, the nitrogen conversion does not exceed never 10%
- Results in term of the ammonia quantification and nitrogen conversion obtained here can be useful to validate kinetic ammonia production models implemented during the last decade.