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WEST

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Long discharges in steady state with D_2 and N_2 on the actively cooled tungsten upper divertor in WEST

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Context and Objectives

- In future fusion devices (ITER, DEMO) [1, 4]
→ Impurity injection to enhance the "edge" radiative fraction ~90%
→ "Cool" the edge plasma and prevent Plasma Facing Components (PFC) damages.
- Nitrogen (N_2): viable seeding candidate for the size and conditions of present day divertors. However, potential reactivity of N_2 with hydrogen isotopes can lead to tritiated ammonia (NT_3) as well as ND_x and NT_y formation.

→ Should be considered: regen. of cryo pumps and processes in de-tritiation plants [5].

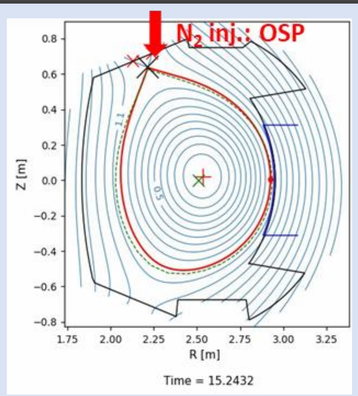
- AUG N_2 seeding through the private flux region (Inertial W coated PFCs & H-mode) [6]
- JET-ILW N_2 seeding in the OSP region (GIM 10) (Inertial W coated PFCs & L-mode) [7]

Experiments in WEST [8, 9]→ Long pulse operation in W divertor and N_2 seeding [10, 11]
- Ammonia formation in a full actively cooled tungsten device
- Improve the understanding of physics of ammonia production, decomposition and transport in a magnetically confined plasma devices.

Experiments

I_p = 400kA, B_T = 3.7T, P_{LH} = 3.0 MW in USN (No active pumping)
5 long discharges (~50s range) - 1 ref w/o N_2 and 4 with N_2 inj from OSP
40 pulses after the last boronisation : 452 s (7:32 min) of plasma
30 pulses or 166s (2:46 min) in LSN & 10 # or 286s (4:46 min) in USN

# 55787 : No N_2 injection – Ref pulse	(53 s - 147.78 MJ)
# 55789 : N_2 injection 30sec @~0.1 Pam^3s^{-1}	(50.5 s - 141.24 MJ)
# 55790 : N_2 injection 35sec @~0.18 Pam^3s^{-1}	(49 s - 136.73 MJ)
# 55792 : N_2 injection 35sec @~0.21 Pam^3s^{-1}	(49.6 s - 138.35 MJ)
# 55794 : N_2 injection 20sec @~0.2 Pam^3s^{-1}	(34.7 s - 90.75 MJ)
Total	**(236.8 s – 654.8 MJ)**

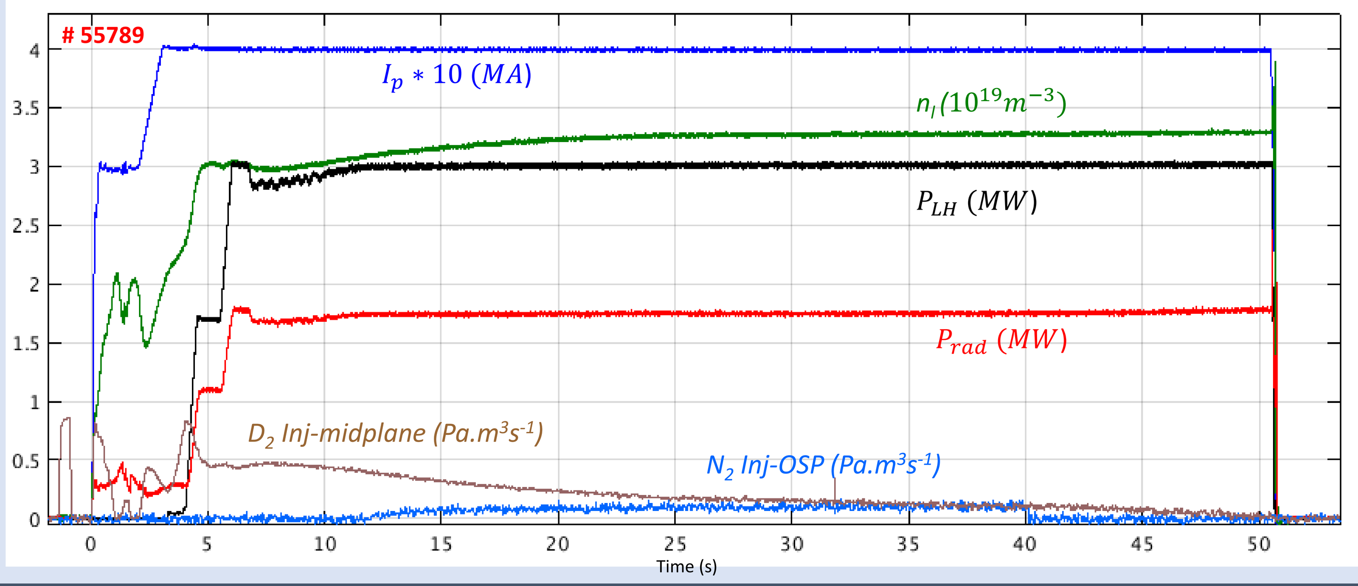


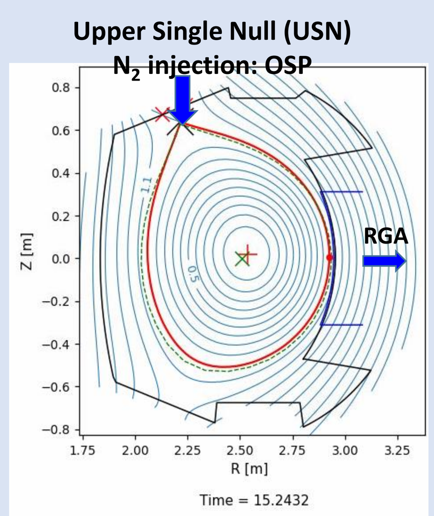
For the whole session, the N_2 injected through the OSP region is ~ 18,65 Pam^3
Reminder: session of Dec 2018, total of 5.4 Pam^3 injected though OSP (6 pulses with injection for 6s @0.15 Pam^3s^{-1}).
For # 55792, a total of :
9.49 Pam^3 of D_2 has been injected ($4.58x10^{21}$ D & $4.58x10^{21}$ e^- injected)
6.32 Pam^3 of N_2 has been injected ($3.1x10^{21}$ N & $21.3x10^{21}$ e^- injected)

Exp with active pumping (cryo pumps) on
- AUG → up to $7.8x10^{21}$ Ns^{-1} through the private flux region
- JET-ILW → up to $1.4x10^{22}$ Ns^{-1} through the SOL (GIM 10 and OSP on tile 5)

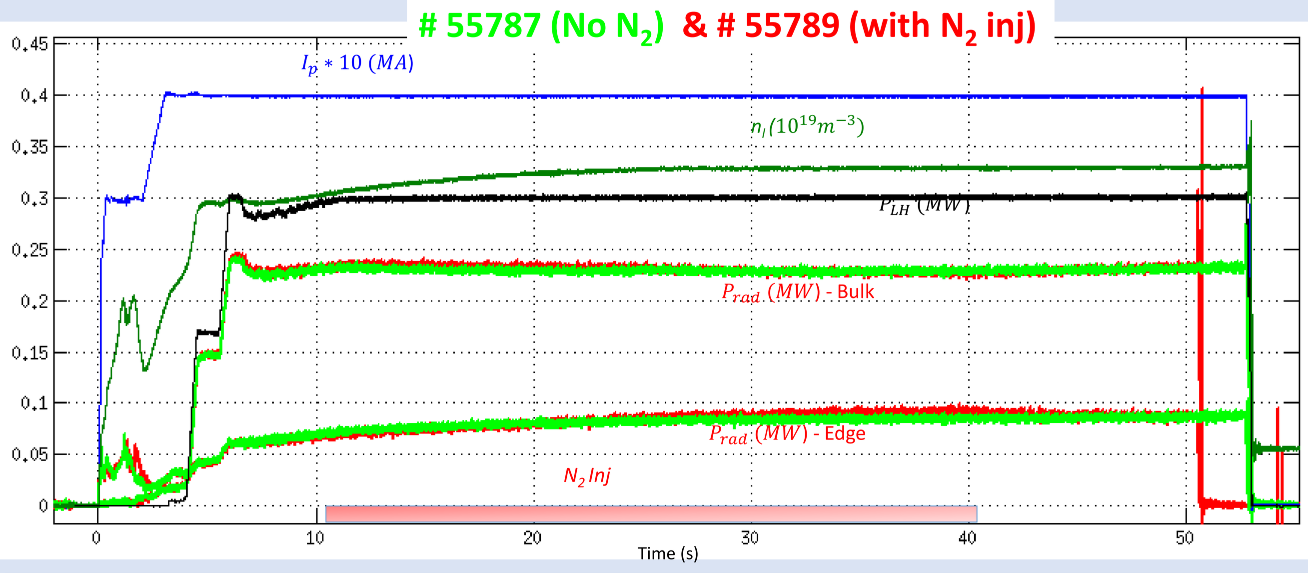
Main plasma parameters and typical plasma discharge

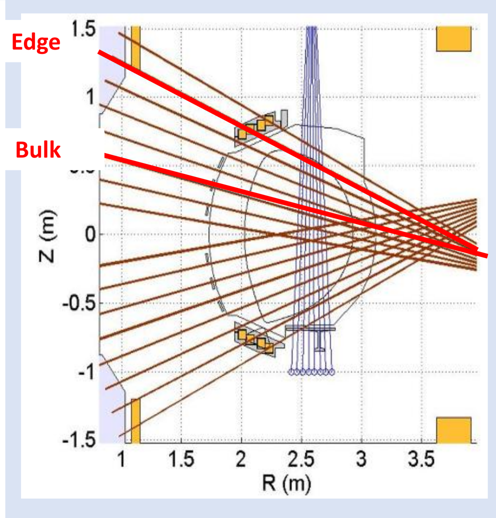
- I_p= 400 kA, B_T=3.7 T, P_{LH}= 3.0 MW, n_e=$3.3x10^{19}m^{-2}$, P_{RAD}= 1.7 MW (f_{RAD}~ 55%), L-mode.
- Repetitive 5 long discharges (~50s range) - 1 ref w/o N_2 and 4 with N_2 inj from OSP (18,65 Pam^3)
- USN, no active pumping, 40 pulses after the last boronisation : 452 s (7:32 min) of plasma
Main radiative impurities: W, O, Cu (LH) and C.





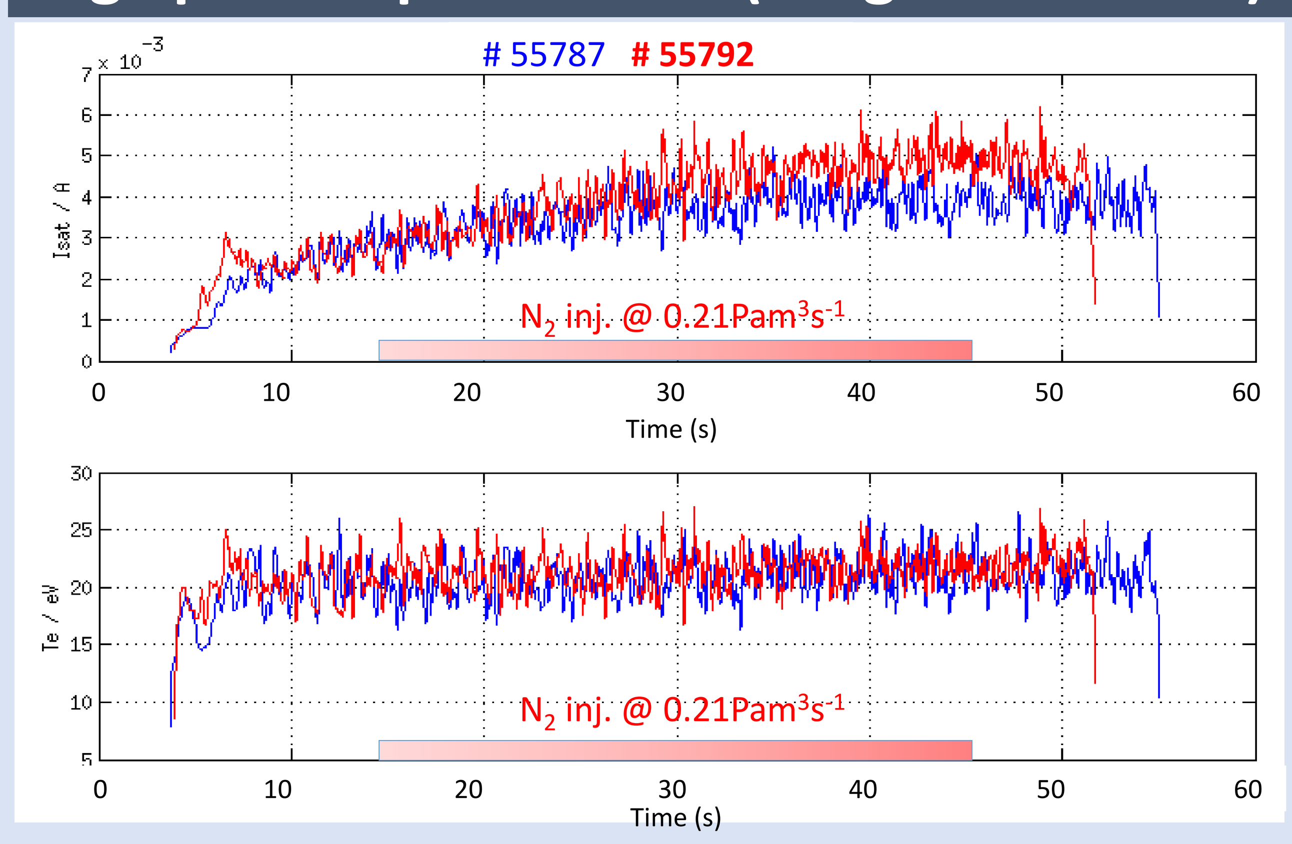
N_2 injection effect on edge plasma





- Over all these experiments, in the absence of active pumping, the cumulative effect N_2 over the duration of the injection is very weak and legacy is negligible
- Very weak increase of the edge radiation
- Improved confinement mode observed during similar series of pulses [12]

Edge plasma parameters (Langmuir Probes)



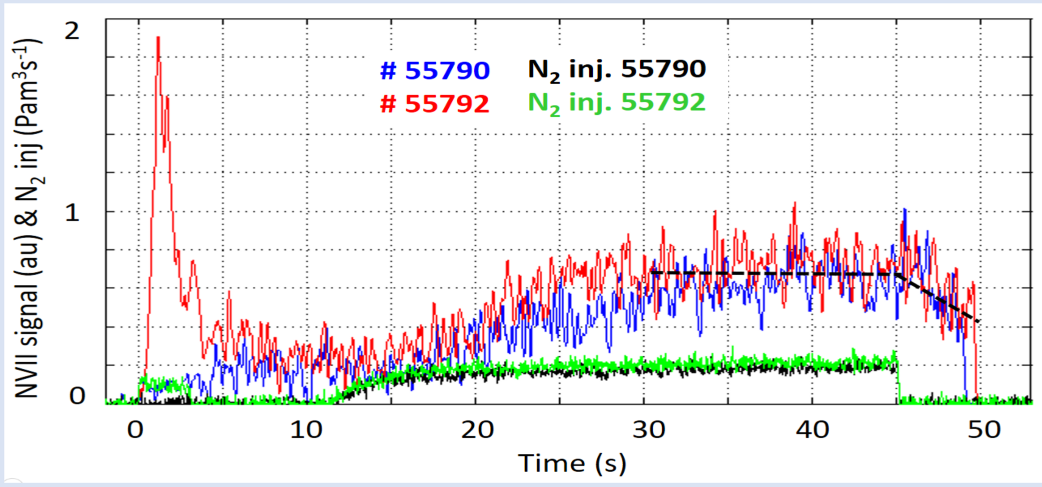
I_{sat} and T_e at the target , close to the OSP region.

55787 (w/o N_2) and 55792 (with N_2, strongest injection)

- Increase of I_{sat} as N_2 is injected

- No effect at all on T_e.

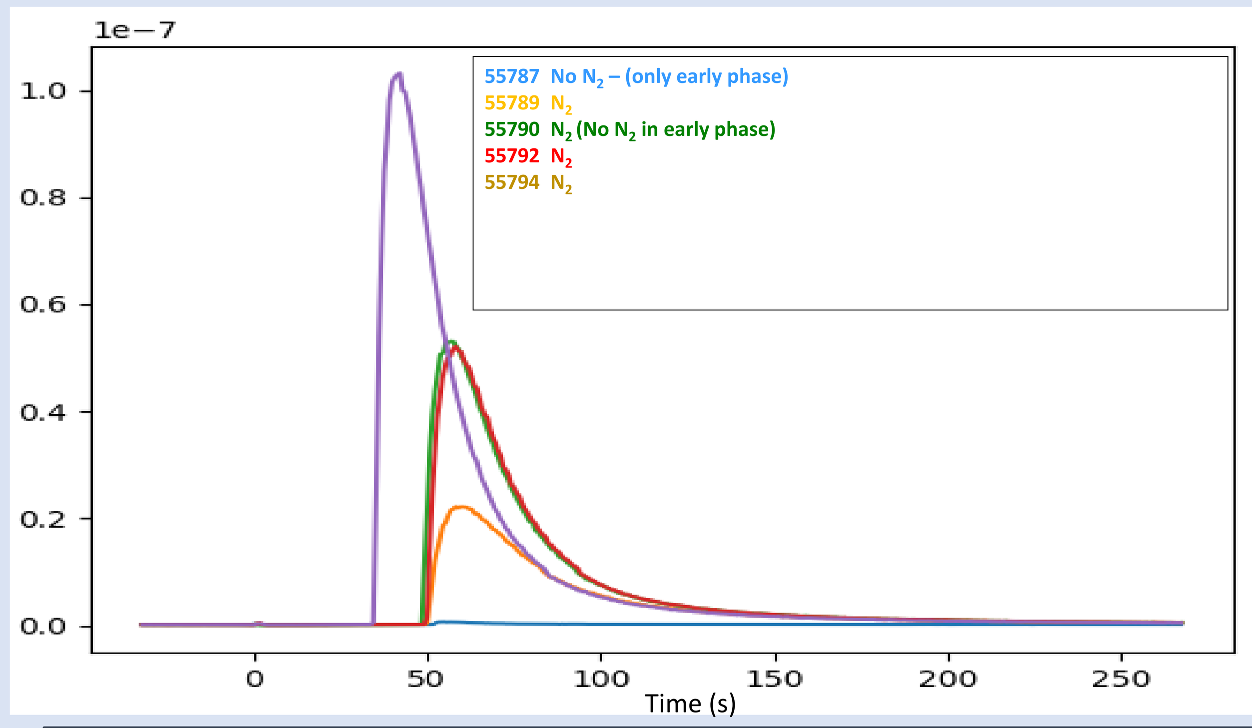
N plasma radiation (UV range)



For the pulse **# 55790 (b),** following a strong N_2 injection during 30s no NVII signal is observed in this early plasma phase contrary to pulse **55792 (r)** where N_2 is injected in the early plasma phase (green signal from 0 to 3s)
→ No N_2 legacy
Steady state phase of the NVII signal for t>30s whilst it drops as the N_2 injection is stopped.

- Since no active pumping → both steady state and the drop are signatures of a reservoir filled from pulse to pulse & only partially recovered in between pulses by outgasing→ W coating reservoir [13, 14]
- After 4 pulses (18.65 Pam^3 of N_2 inj.), no legacy/limit (± same initial level at the beginning of each pulse)

N_2 recovery after the discharge

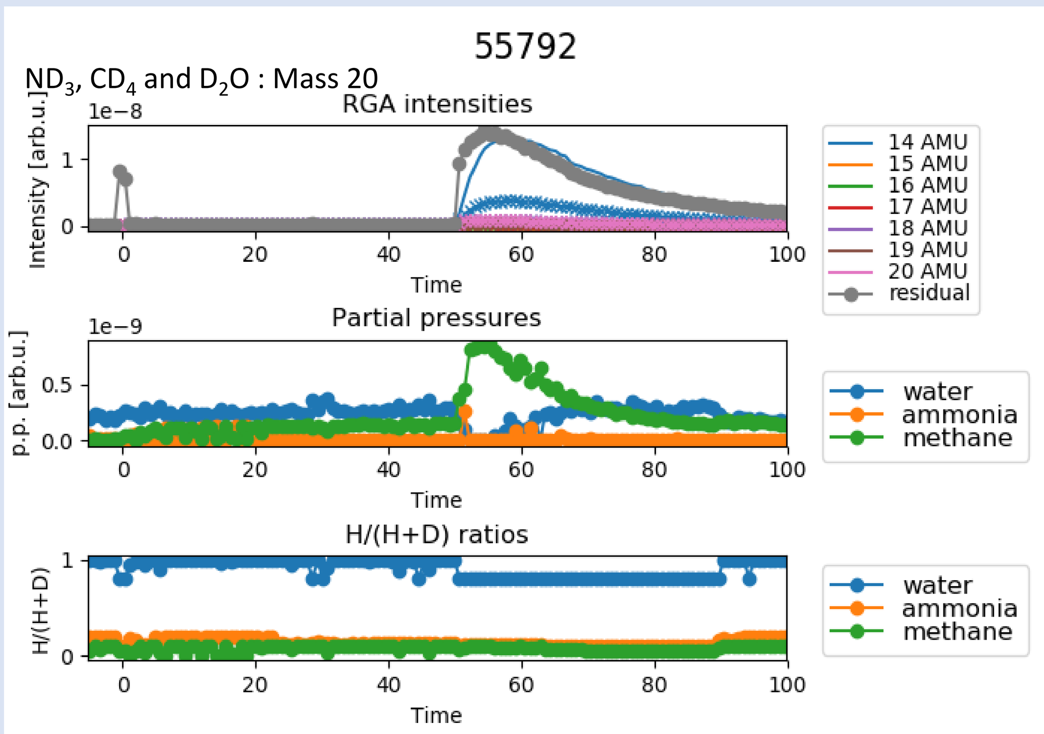


Particle balance dominated by D_2 (H_2) and N_2
Negligible legacy effect.

- Same behaviour of N_2 during the discharge independently of the amount injected.
- Negligible N_2 recovered/pumped during the pulse.

~30% of the N_2 released after the discharge.
Negligible N_2 recovered/pumped during the pulse.

RGA Analysis – ND_3 ?



- Even in # 55792 which contained the most nitrogen, there is no ND_3 detected in the RGA (Pulse and outgasing phases).

- In AUG → No ND_3 in the mid-plane during the pulse, but detected during the outgasing phase.

- Likely the same behaviour as in JET: "ND_3" created too far away from the RGA system.

- The produced ammonia sticks to the walls and is then released on long time scales and below the sensitivity of the RGA [10].

CONCLUSIONS [11]

Long discharges (>55s) in steady state, in Upper Single Null, L-mode, N_2 injection through OSP.
- 5 long pulses: 237 s of plasma (~4min), 18.65 Pam^3 of N_2 injected (up to 35s @0.21 Pam^3s^{-1}).

- Although no active pumping, weak effect on the radiated power (edge and bulk)
- Steady state reached & drop of the radiation as the injection is stopped
- No ND_3 detected during the pulse and during the outgasing phase.
- No legacy although "only" 35% of N2 recovered (up to 70% during disruption).

- N_2 balance over such long time scales and in the absence of active pumping suggests:
- Majority of the injected N_2 retained in the upper divertor W coating (15-20µm).
- Porosity larger than W bulk enhancing the volume of this N reservoir → No saturation
- Prior to saturation, not enough N is available for ND_3 formation → no ND_3 detected
- Consistent with experimental results in both JET-ILW and ASDEX-Upgrade

- Further experiments with the fully actively cooled lower divertor made of ITER-like Plasma Facing Units (bulk) and enhanced N_2 injection.

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