Overview of Cs evaporation control and monitoring in the ITER HNB ion source prototype SPIDER

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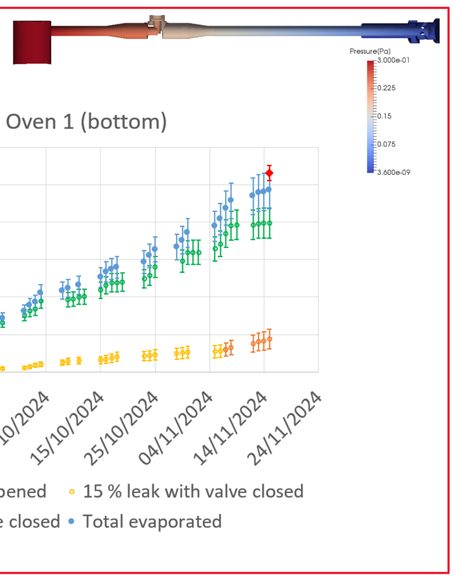
Abstract

- SPIDER is the full-scale prototype of the ITER Heating Neutral Beam (HNB) ion source. Three Caesium ovens located at the rear part of the source inject Cs to reduce the surfaces' work function and increase the production of H^-/D^-. A sufficient and uniform Cs coating is required at the Plasma Grid (PG), the first electrode of the multi-grid accelerator facing the plasma.
- This contribution presents the control and monitoring of Cs evaporation in SPIDER during the 2024 and 2025 experimental campaigns during which only ¼ of the ion source was operated, resulting in unusual caesiation conditions.
- The use of Cs enabled the extracted negative-ion current density to reach values up to 210 A/m^2 with extracted electron-to-ion ratios of the order of 1. The estimations of Cs consumption from simulations made with the AVOCADO [1] code are compared to the cumulated consumption measured after the campaigns, the data obtained from Laser Absorption Spectroscopy (LAS) and post-campaign inspections of the source are discussed to obtain information on the uniformity of Cs coverage and Cs transport.

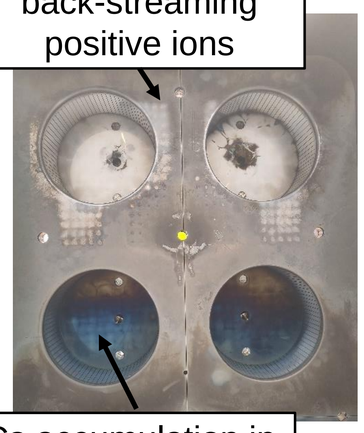
Cs ovens and evaporation control

- Cs evaporation rate estimated from reservoir temperature and oven conductance from AVOCADO simulations
- Excellent agreement with Cs consumption measured from weighing reservoir
- Cs leak due to gradual corrosion of oven valve when interacting with Cs detected by Surface Ionisation Detector (SID)



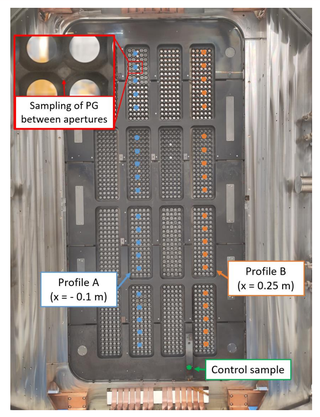
Post-campaign status of Cs in the source

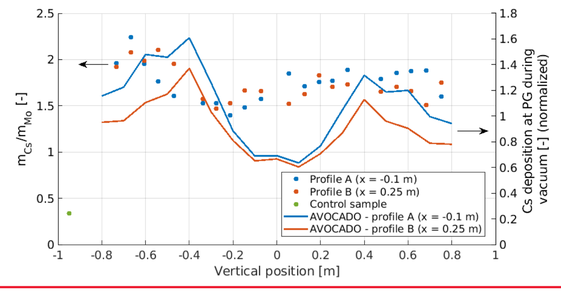
Cs sputtering by back-streaming positive ions



Cs accumulation in drivers unused during the campaign

- ICP-MS analysis of samples taken at the PG after the campaigns show how plasma has redistributed Cs with respect to evaporation in vacuum

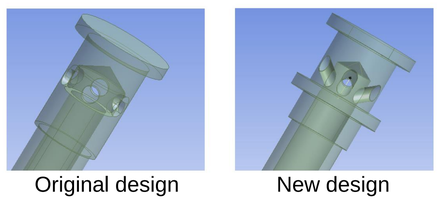




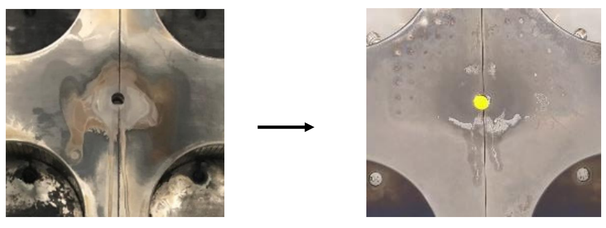
New nozzles for reduced loss and improved uniformity

- In 2024, oven nozzle design was modified [2] (apertures slanted towards PG, collar behind apertures, top/bottom ovens with asymmetric arrangement of apertures)

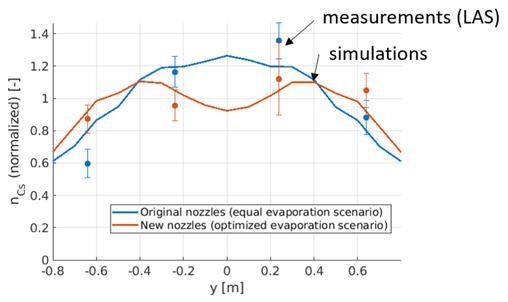
→ Reduction of Cs loss in unwanted regions on the backplate



→ Cs density measurements in SPIDER (in vacuum) confirm improved uniformity of flux at PG



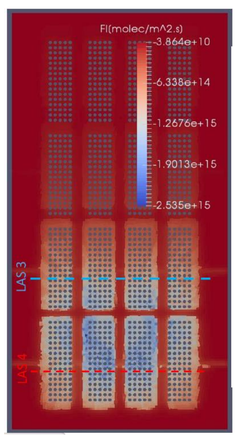
S21 (2021) [3] S26 (2025)

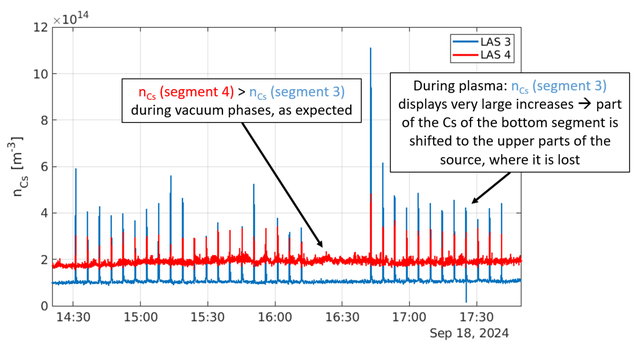


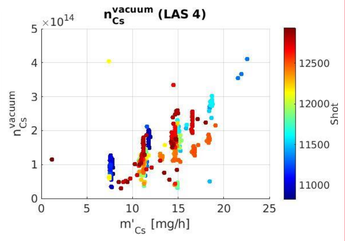
Caesiation while operating a single segment

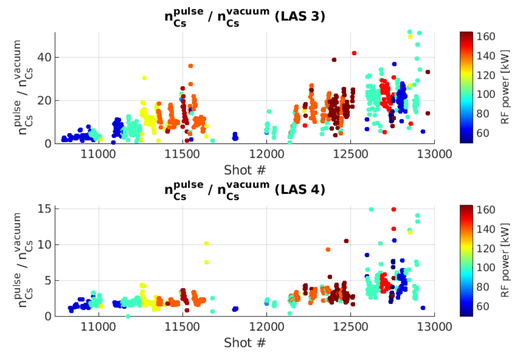
- Reaching decent j_{ext} and e/H^- ratios was found to be more difficult than in the past [4,5]

→ Attributed to the fact that when operating with ¼ of the source Cs reaches parts of the source where it cannot be retrieved and redistributed without plasma

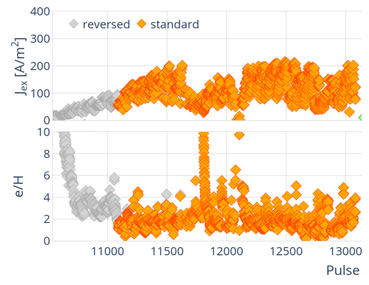






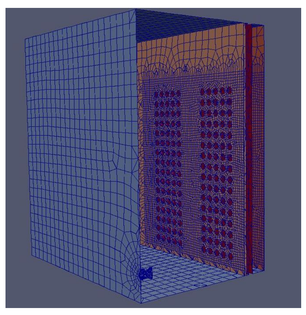


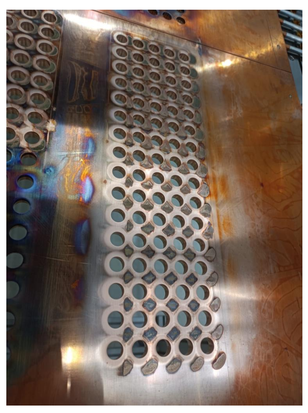
- Changing direction of magnetic filter field from Reversed to Standard configuration was beneficial [5]



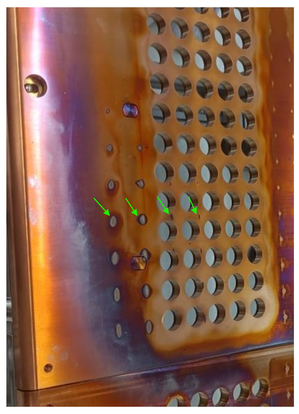
Post-campaign status of Cs in the accelerator

- Presence of Cs on Extraction Grid (EG) and Grounded Grid (GG) → possible issue for voltage holding in the accelerator
- Simulations with AVOCADO confirm that this is due to direct evaporation from nozzles during vacuum phases
- Evaporation towards the grids was increased with introduction of new nozzles → a new modification is maybe required to reduce Cs deposition in the accelerator

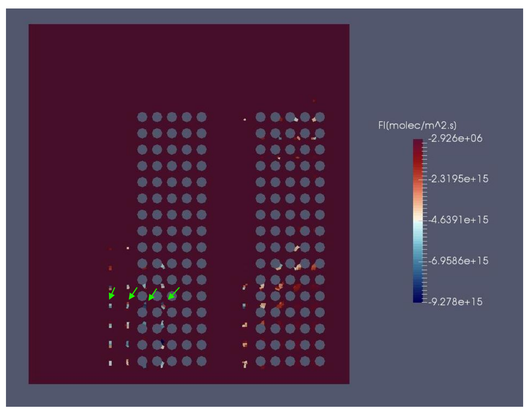




EG



GG



GG (AVOCADO)

Conclusions

- Excellent control of caesium evaporation rate with ovens
- New nozzles successful in reducing Cs accumulating at rear part of the source and improving uniformity, but too much Cs reaches the accelerator grids → new iteration of nozzle design required
- Post-campaign inspection of the source provides useful information on Cs distribution
- Caesiation while operating with a single segment was found to be very challenging but can provide useful insights for Cs transport modeling and future operation

[1] E. Sartori and P. Veltri, Vacuum, Vol. 90, pp. 80-88 (2013), DOI: 10.1016/j.vacuum.2012.09.022
[2] B. Pouradier Duteil et al., Fusion Engineering and Design, Vol 217, p. 115137 (2025), DOI: 10.1016/j.fusengdes.2025.115137
[3] M. Fadone et al., Journal of Instrumentation, Vol.19, p. C06021 (2024), DOI: 10.1088/1748-0221/19/06/C06021
[4] E. Sartori et al., Nuclear Fusion, Vol. 62 (8), p. 086022 (2022), DOI: 10.1088/1741-4326/ac715e
[5] See ICIS 2025 oral by A. Shepherd, *Beam current performance in the ITER negative ion source prototype SPIDER,* Tuesday 09/09 at 14:40

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