
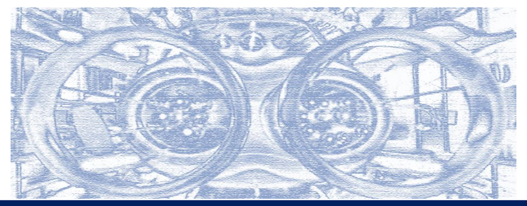
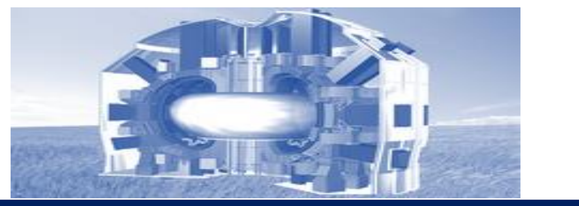


Summary of caesium evaporation and deposition during SPIDER first campaign

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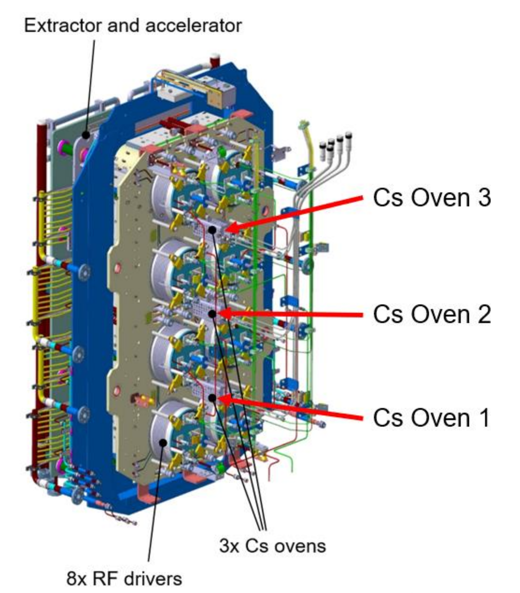
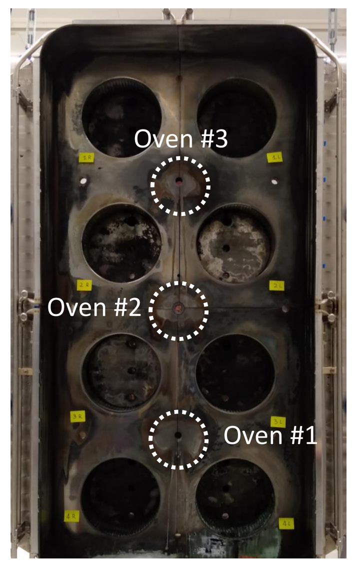
SPIDER Cs Ovens

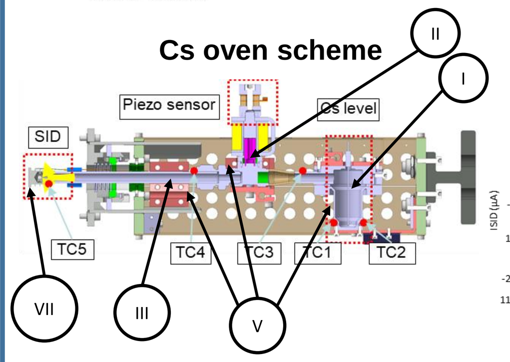
Cs oven location viewed from the rear side of SPIDER BS



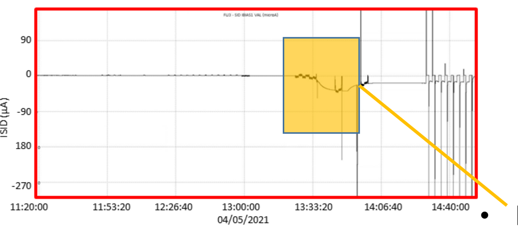
Cs oven location viewed in the plasma box after SPIDER dismantling



Cs oven scheme



Cs oven HMI



Aim of the contribution:

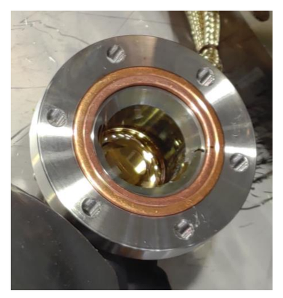
(i) To check the status of the Cs evaporation system for SPIDER after operation

(ii) To check whether the Cs deposition occurred as predicted by the numerical models (with no plasma)

(iii) To find ways to clean caesiated surfaces exposed to air in order to restore the source efficiency

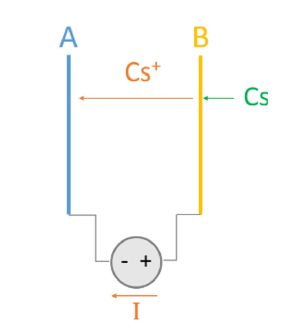
- Cs required in the source in order to lower the work function of the surfaces in the Beam Source (BS) and hence to maximize the generation of negative ions by means of the surface mechanism
- 3 Cs ovens installed on the back-plate of the source
- Oven consists of [1][2]:
  - I. Reservoir in which liquid Cs is stocked
  - II. Solenoid valve with Kalrez gasket to avoid Cs contamination
  - III. Duct which connects the reservoir to the nozzle
  - IV. Nozzle with 6 holes through which Cs goes into the BS
  - V. 3 heating cartridges, 2 for the duct and 1 for the reservoir
  - VI. 5 Thermocouples (TC), 3 on the duct and 2 on the cartridges power supplies (PS) (TC1, TC2,….)
  - VII. Surface Ion Detection (SID) diagnostic to estimate the Cs flux through the nozzle
- First Cs oven valve aperture 4th May 2021 (**In CATS, Cs flow detected only after at least one hour for first evaporation. In SPIDER it took 20 minutes**)

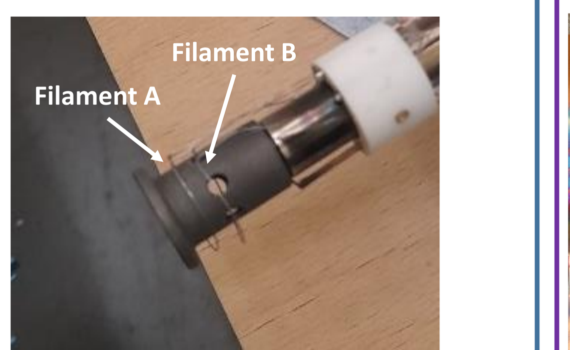
SPIDER Cs Ovens operation



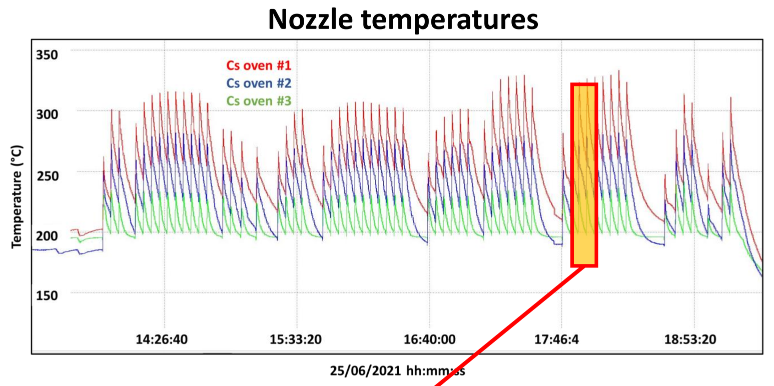
- Cs is a getter material and therefore impurities can contaminate Cs stocked in the reservoir
- Cs handling and sealing before and during ovens installation fundamental
- Picture shows Cs in the reservoir inside a Glove-Box one week after having installed the ovens in the source but with no evaporation: Cs still liquid

SID circuit

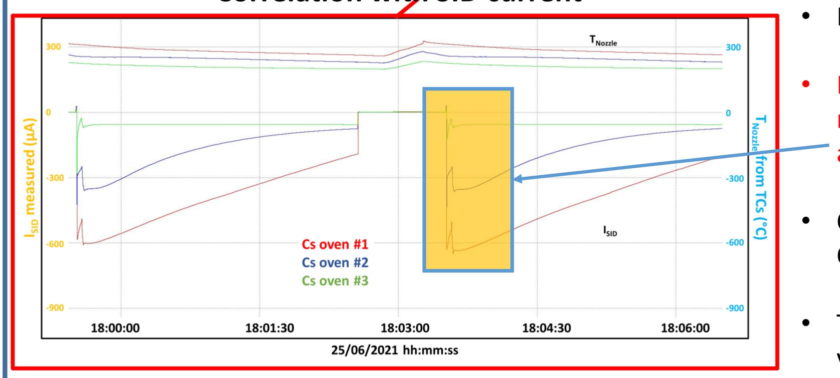




Nozzle temperatures



Correlation with SID current



- SID consists of a pair of tungsten filaments around the nozzle holes
- One filament has to be hot (B) and ionize the Cs atoms
- Bias voltage between the filaments to detect the Cs ions
- From current and CATS experience it is possible to correlate Cs flux [1]
- **SPIDER operation:** Pulsed operation (30s plasma ON – 3 minutes OFF)
- Plasma ON: SID system disconnected to avoid failures
- Plasma OFF: SID on the top oven (#3-green) gives almost immediately the measurement; the one in the middle (#2-blu) only at the end of OFF phase; the one at the bottom (#1-red) cannot reach a steady state condition in time
- Only correlation found up to now is the nozzle temperature reached during plasma ON phase: #1 and #2 reach temperatures much higher than oven #3
- To confirm this aspect, oven #1 and oven #3 have been switched after SPIDER venting for a maintenance phase. Unfortunately, the water leak incident occurred and SPIDER shut-down started.
- However, this delay response could be furthermore justified by the Macor insulator support for the SID filaments: its resistivity changes with temperature and could affect the measurement.
- Two ways to avoid this behavior: 1) changing the material of the insulator; 2) relying on the new permanent magnets in the case they are going to be installed in the rear side of the BS back-plate (the plasma would be shielded and the nozzle would not reach the temperatures detected previously)

Conclusion: SPIDER Cs evaporation system worked nicely without major problems. Only the nozzle area could be subjected to modifications if permanent magnets will not be installed (that is, Shapal instead of Macor can be used as insulator support)

SPIDER Cs Ovens inspection

Reservoir

Cs oven #1

Cs oven #2

Cs oven #3

After having looked into SPIDER Cs evaporation system, a thorough inspection of the ovens is required to check whether Cs contamination occurred or not

- **NOTE to REMEMBER:** Cs Oven #3 have been switched and placed at the bottom where the leak occurred
- After water leak incident, Cs contaminated in all the reservoirs
- From the top to the bottom Cs seemed less contaminated by water vapor: Cs hydroxide (white compound) is the same formed in CATS facility where uncontrolled impurities flew in the vessel [1]. Cs oxide (yellow compound) has been found after long evaporation campaign even in CATS
- In this condition it is impossible to verify SID measurement in terms of Cs mass evaporated with a simple weighing of the ovens, but SID measurement is reliable [1]
- From SID diagnostic, the total Cs consumed in 172h of evaporation has been **2,411 g (Oven#1: 0,763 g Oven#2: 0,783 g Oven#3: 0,866g)**
- NOTE: as soon as we placed Cs compounds outside the Glove Box, the compounds started to adsorb the air humidity. Droplets began to form and most of the surfaces cleaned themselves in less than 2h

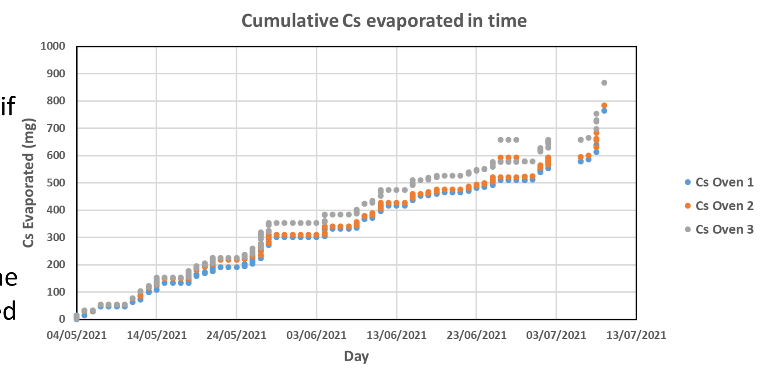
Inspection in the source

Conclusion:

(i) Kalrez gasket can be considered a good vacuum tight gasket even if Cs has be contaminated by water (it's an incident for which only a metal valve could have withstand this scenario)

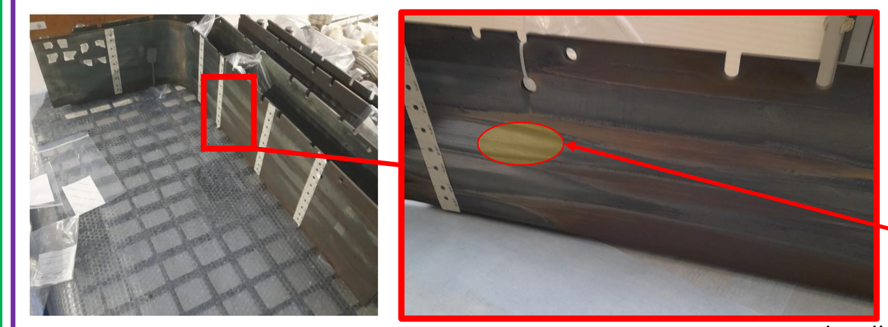
(ii) For SPIDER Kalrez will still be the solution. For vacuum condition requirements, in MITICA another solution is required

(iii) We can trust SID measurement, but it could be useful to determine another way to "weigh" the remaining Cs even if it is contaminated in order to match it with Cs diagnostics

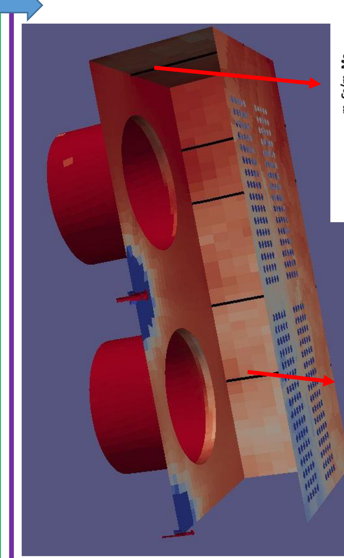


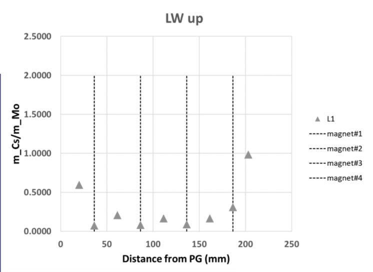
Inspection in the source

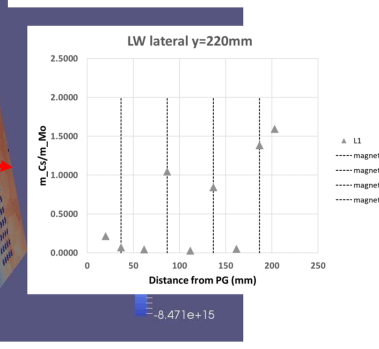
Cs deposition on Lateral Wall



Sampling can help to decide whether we can put new permanent magnets or not





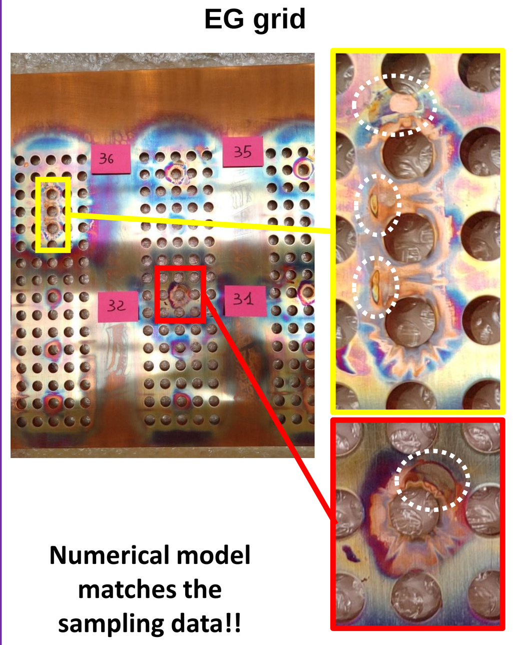


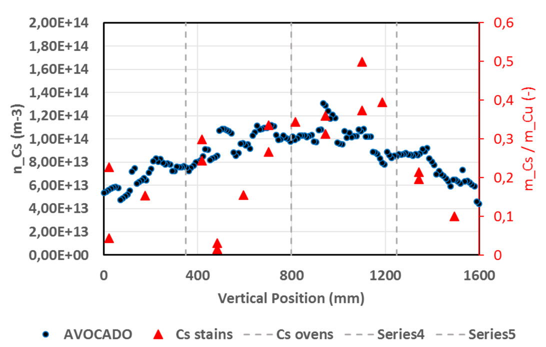
Ho do we remove Cs?

- Lateral wall (LW) of BS has 4 permanent magnets installed on its back.
- Looking at the surfaces, it is possible to identify the regions where the plasma "touched" the wall and where it has been shielded
- Inductively Coupled Plasma Mass Spectrometr (ICP-MS) chemical analyses on 5% nitric acid solution impregnated swabs taken in several spots of the surface to determine the Cs deposited
- Top part of the LW "behaves" as thought since there is less Cs where there are the magnets and therefore where the plasma touched the wall
- Lateral part of LW is different. Plasma density changes because of the RF driver location and non uniformity of magnetic field [4]. Cs+ is deposited in the permanent magnet area

Cs deposition on EG

EG grid



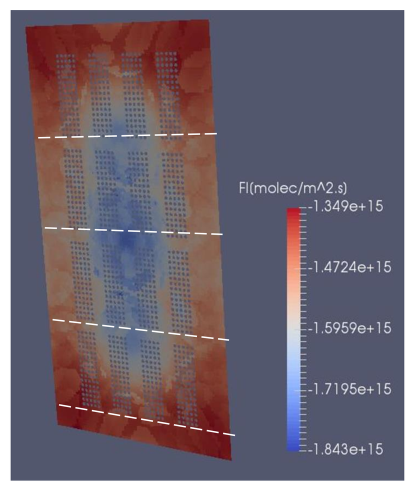


Ho do we remove Cs?

Numerical model matches the sampling data!!

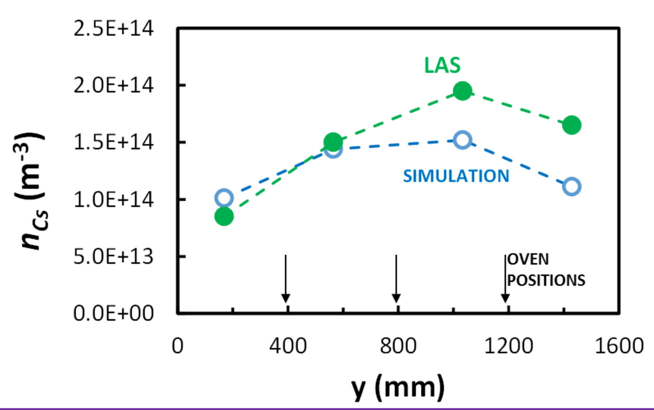
- On EG, stains attributable to the Cs oven location
- ICP-MS analyses and normalization of Cs data to the Cu detected altogether (triangles)
- AVOCADO [3] numerical simulations (blue dots) in the BS in front of the 28 holes left open to see if there is the same trend

Cs vs numerical model in vacuum



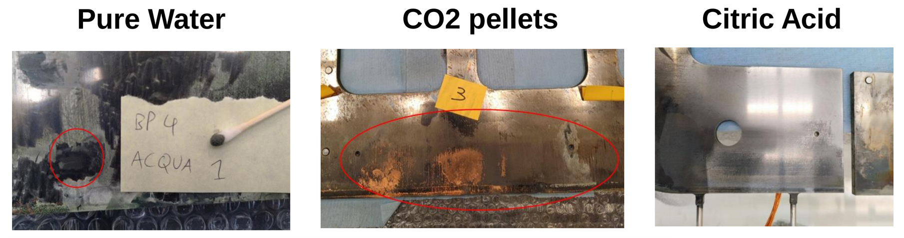
Numerical model matches the Source diagnostics data!!

- LAS (Laser Adsorption Spectroscopy) is a diagnostic installed on SPIDER with 4 line of view (white dashed lines) that gives the Cs density both in plasma ON and OFF scenario
- AVOCADO numerical simulations to determine a match with LAS data during Cs evaporation with no plasma [7]
- Data Match setting the bottom oven with a Cs flux reduced of 14%



Cs cleaning procedures

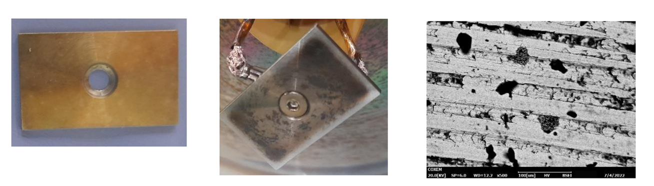
Pure Water **CO2 pellets** **Citric Acid**



SPIDER BS and in general HNB BS during experimental campaigns could face open air condition. If Cs has been evaporated, it is necessary to consider Cs cleaning techniques that save time and that are safe (disavantage the BS can be time consuming and not straight forward for radiation reasons)

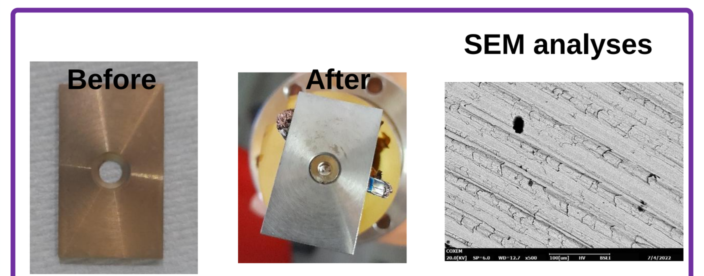
- SPIDER walls showed different types of "dirty" conditions. White and green powder probably due to the water leak condition. Dark stains on Mo coating due to oxidation

Before **After** **SEM analyses**



Ar glow discharge

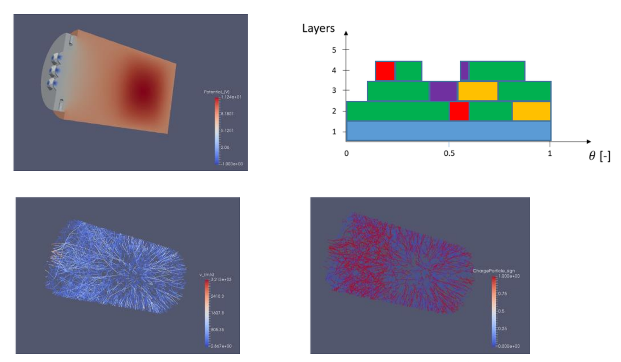
Before **After** **SEM analyses**



He glow discharge

- **Main question**: What is the requirement for a clean surface? Is it ok to have the dark stains?
- **Pure water** can remove the powders but not the dark stains. Mechanical action is required though
- **CO2 dry-ice blasting** has the same effect of water but it is not required to touch directly the surface
- **Citric or Nitric acid** can even remove the dark stains and it can be sprayed over the surface and in less than one minute the coating returns "shiny". Mo coating seems to be not affected.
- **Ar glow discharge** seems to make the surface even more polluted while **He glow discharge** gives the "shiny" effect.
- **For HNB vacuum requirements,** the use of water or, in general, liquids is not recommended. Moreover, these procedure can demand a lot of time due to the source disassembling
- **Glow discharges** would be the perfect option since no disassembling and no liquids are required. Moreover, the power supplies are already sufficient to guarantee the plasma ignition. It is still not sure if the effect is sufficient in terms of cleaning efficiency

Next steps



Modelling of Cs dynamics with plasma

- C++ code simulating plasma scenarios in defined conditions
- From all the surfaces, Cs neutrals and ions are "launched" in order to determine the trajectories considering all the collision rates/cross sections available (also Cs excitation is considered in analogy to [5])
- Determination of matrices of view-factors as outputs for the final stage
- Matlab code to consider layer Cs depositon/release considering also impurities [6]
- The main challenge is to understand which chemical process is most important and how to quantify the conditions and the speed of surface formation

Conclusions

- SPIDER Cs evaporation system worked well. It requires only few changes and for MITICA a new design is ongoing considering stricter vacuum requirements.
- The definition of a clean surface remains to be established (Are the dark stains a problem? Do we want the surfaces to be perfectly shiny?). If dark stains are ok, then CO2 pellets or pure water can be an option. Otherwise acids or glow discharges should be used. Further analyses are required though:
  - SPIDER BS components (PG, lateral walls, FSLW etc.) will be de-coated and re-coated with a new molybdenum coating → Set of Cu samples with the new coating can be tested in CATS for Cs deposition → Cleaning experiments with acid and glow discharges will be performed on the samples to have a more reliable comparison with the future SPIDER scenarios (SEM quantitative analyses will be performed on the exact same sample locations to have a proper quantitative comparison)
- Numerical models matched both Cs sampling on EG and data from LAS diagnostic in the source (when there is no plasma)
- LW Cs sampling showed 2 different Cs behavior due to magnetic field presence. Plasma density is another factor that can affect the Cs deposition. IF new permanent magnets will be installed on the Plasma Driver Plate, Cs will probably behave as the lateral side of LW
- Modelling of Cs dynamics with plasma is ongoing and required to determine the best operational scenario for the efficiency of beam generation and extraction

REFERENCES

[1] A. Rizzolo, M. Barbisan, L. Bizzotto, et al., Characterization of the SPIDER Cs oven prototype in the CAesium Test stand for the ITER HNB negative ion sources, Fusion Eng. Des., 146 (2019), p. 676

[2] M. De Muri, et al. SPIDER Cs Ovens functional tests, Fusion Eng. Des., 167 (2021), Article 112331

[3] E. Sartori and P. Veltri, "AVOCADO: A numerical code to calculate gas pressure distribution," Vacuum, vol. 90, pp. 80–88, Apr. 2013.

[4] N. Marconato, E. Sartori, and G. Serianni, "Numerical and experimental assessment of the new magnetic field configuration in SPIDER," IEEE Trans. Plasma Sci., early access, May 3, 2022, doi:10.1109/TPS.2022.3167859

[5] B. Segalini et al., "Study of positive ion transport to the plasma electrode in giant RF negative ion sources", presented at SOFT 2022

[6] E. Sartori, S. Gorno, M. Fadone, and G. Serianni, "Analytical study of caesium-wall interaction parameters within a hydrogen plasma," AIP Conf. Proc., vol. 2052, no. 1, 2018, Art. no. 020006.

[7] M. Fadone, M. Barbisan, S. Cristofaro, M. De Muri, G. Serianni, E. Sartori, Interpreting the dynamic equilibrium during evaporation in a cesium environment, Rev. Sci. Instrum., 91 (1) (2020)

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