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PRELIMINARY EXPERIMENTS IN CAESIUM DELIVERY AND GETTERING ON THE ISIS VESPA SOURCE

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Abstract

Caesium capture by graphite at various temperatures 20 - 300 °C in the VESPA ion source test stand was explored in a preliminary experiment. An accompanying experiment was set up to evaluate the control of caesium boiler delivery in the various ISIS penning sources. Results indicate Cs flux fluctuates at constant settings, which must be accounted for to interpret graphite gettering results. Future studies to identify the cause of fluctuations are considered, and a more rigorous experiment to study the use of graphite is introduced.

INTRODUCTION

Experimental and operational ISIS pulsed Penning sources use caesium (Cs) enhanced surface production to form H^- ions , which is continuously delivered into the plasma chamber by a temperature controlled boiler and transport pipe. Insufficient supply leads to a noisy arc discharge or none at all, whilst large over-supply provokes sparking. To obtain a stable, noiseless, arc discharge from which a reliable beam can be extracted, Cs is typically slightly oversupplied so small changes in delivery or the ion source do not lead to noise.

Significant excess Cs drifts out of the plasma chamber through the beam emission aperture. In 30 days of typical operating settings 3 g of Cs is delivered to the plasma chamber, which in the operational source is condensed and captured by a 90° dipole cold box. In the experimental Vessel for Extraction and Source Plasma Analyses (VESPA) source no such mechanism exists so it is eventually deposited in and around the ion source. Build-up of Cs can lead to higher spark rates and a more regular cleaning schedule. A proposed capture mechanism and two preliminary experiments are presented, the importance of which was previously stated [1].

Instead of the present actively refrigerated Cs trap, passive capture by adsorption or reaction are being pursued. Graphite is used to getter Cs vapour in various applications including atomic clocks [2], with some evidence that effectiveness is temperature dependent as it diffuses into the bulk [3] . A preliminary experiment was prepared using an existing block of graphite, the results of which prompted an experiment into the Cs delivery method. Characterising or improving delivery may aid in reducing the quantity of Cs used by fine tuning it to minimum requirements rather than oversupplying. The former was performed in VESPA with a running ion source and extraction system. An independent vessel was prepared for the latter. Both experiments used Quartz Crystal Microbalance (QCM) sensors to calculate Cs flux. These determine the thickness deposited on the crystal from the Sauerbrey relationship between the shift in resonant frequency and the additional mass [4]. Presented flux data points are an average over ten minutes to smooth noise.

GRAPHITE GETTER

A 100x20x25 mm block of scrap POCO DFP-1 graphite was placed nearby the ion source and extraction system within the VESPA test stand, with the largest face pointed at the source, as shown in Fig. 1 below. It was attached to a frame by wires surrounded with ceramic beads to thermally isolate it from the vacuum vessel. Two 40 W resistive heaters and a thermocouple were placed in holes around the block. Three QCMs were used to measure Cs flux at different positions within the vacuum vessel.

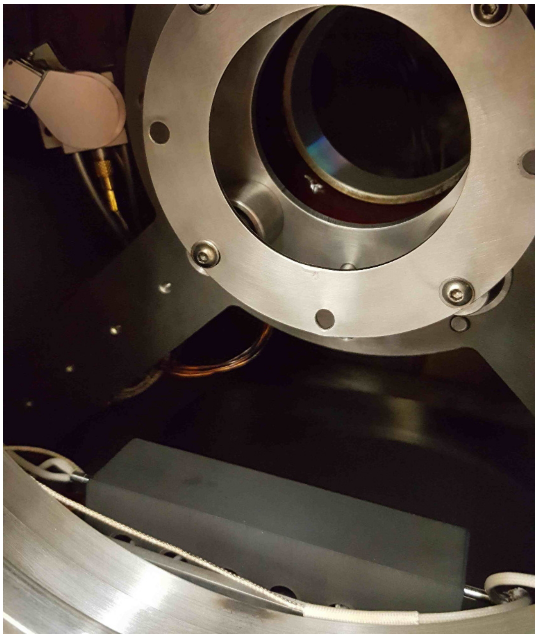

Figure 1: A photo of a scrap graphite block used in preliminary caesium gettering experiments attached to the flange.

The ion source was run for 30 days with the graphite at various temperatures to study variations in Cs flux. Changes in Cs capture should correspond to changes in flux around the vessel, and in measurements. Of the tested temperatures, runs at 40 °C, 140 °C, and 500 °C were repeated. The unweighted mean flux at each of these was found and plotted in Fig. 2 where error bars represent standard deviation.

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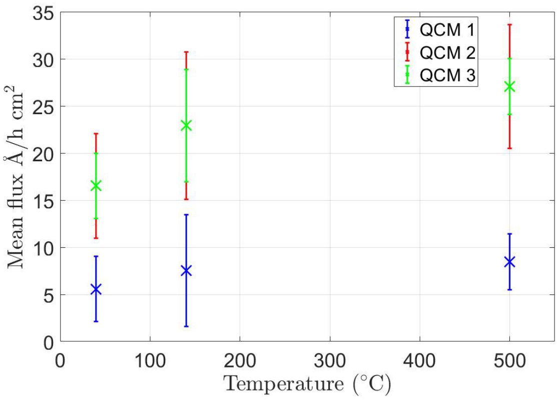

Figure 2: A plot of mean flux at three temperatures, with standard deviations used for error bars.

The trend is not statistically significant, but suggests gettering is worse as temperature increases past 40 °C. The large standard deviation may be a result of changes to ion source behaviour during long operational runs and Cs build up around the vessel, which are inevitable over days of operation and is further explored in the next section.

A black dust was observed coating some surfaces near the graphite upon opening the vessel. This is currently poorly understood but thought to be related to heating the graphite and contaminants that might be present within it. Perhaps secondary electrons and/or the nearby ion beam cause sputtering. The dust may have affected ion source behaviour and deposited onto quartz crystals, affecting rate measurements. If this effect increases with graphite temperature it could explain the increase in flux measurements.

Variations in rate of Cs delivery could also explain the large fluctuations. An experiment described in the next section begins to characterize the flow from the boiler. A new experiment will evaluate the use of four 120x60x5 mm graphite blocks. Their larger surface area may result in a clearer effect on flux.

CAESIUM DELIVERY

In operations and experiments the Cs delivery rate is controlled by boiler and transport pipe temperatures, in an open loop. Fluctuations in delivery rate to the ion source would lead to fluctuations in flux measurements in the vessel. The boiler and transport system previously described and used in all ISIS sources was directed immediately at a QCM to measure flux and study the assumption. This was performed in a small vacuum vessel shown with the sensor fixed onto a frame in Fig. 3. The vessel has a diameter of 12 cm and height of 10 cm, and the end of the transport tube was 2 cm away from the quartz.

Over 30 days the boiler was constant for 1-3 days at various temperatures, the measured flux over time is shown in Fig. 4.

Measured flux dramatically fluctuated throughout. Data between 9th and 15th March are thought to be invalid due to over exposure damage to the QCM. Noise was significantly reduced by replacing the crystal on 15th March. Due to the proximity to the transport tube, only low temperatures were applied to the boiler to avoid further damage. The tube will be positioned further out in future experiments.

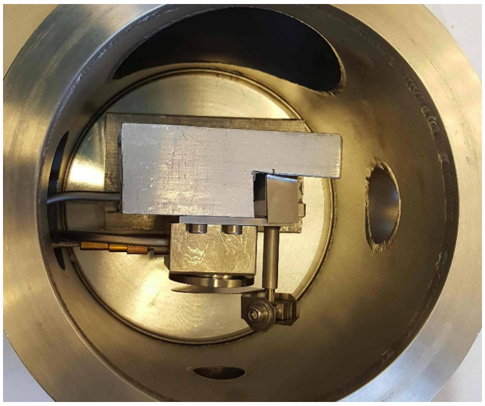

Figure 3: A photo of the pod in which an experiment on caesium delivery was performed.

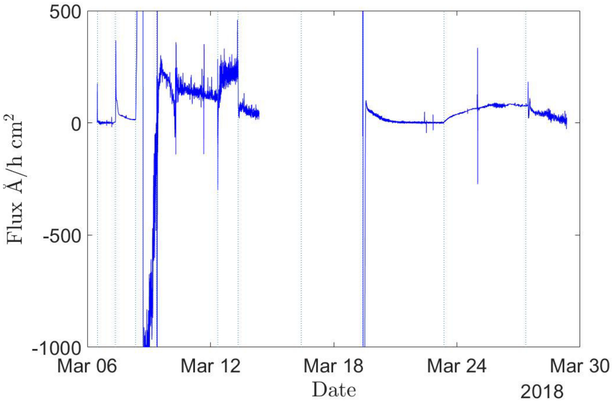

Figure 4: A plot of measured caesium flux on the sensor in the pod for the whole experiment.

After experimenting with heat loads data continued to be taken for a day, without any heat applied to boiler or transport. Cs continued to deposit onto the crystal, as shown in Fig. 5, plotting flux from when heat loads were switched off. This is effectively hyteresis, where Cs flux takes hours to respond to changes in the delivery system. Observing this without the ion source implies that Cs deposited elsewhere in the vessel desorbed, leading to a measurable flux. This could be confirmed by continuing measurements in a dirty, then a clean vessel without the presence of a boiler. If desorption is found to be a key factor, future experiments will require thoroughly cleaning the vessel between temperature changes to study other causes of fluctuation. This is a common issue and is considered likely. It has been addressed by Succi et al with the use of an Antimony film as a getter [5], which was not chosen in this first wave of experiments due to its toxicity.

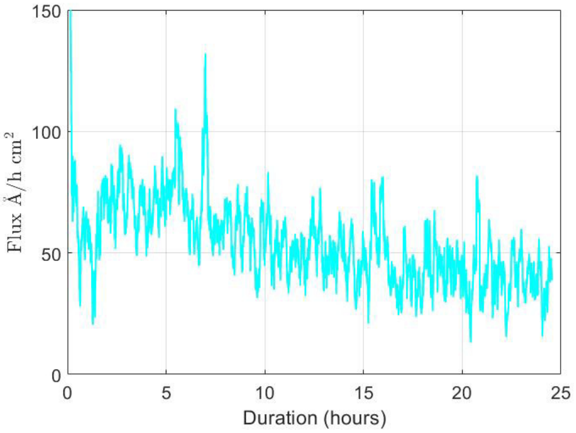

Figure 5: A plot of measured caesium flux on the sensor in the pod after transport and boiler heaters were switched off.

Experiments with caesium chromate dispensers are being considered to investigate the fluctuations in an alternative delivery method. These are used on the Spallation Neutron Source to release a very precise quantity of Cs [6] so hold promise as a continuous delivery system. Alternatively, redesigning the boiler could also permit fine tuning of caesium flux. At Fermi National Accelerator Laboratory, switching from a copper to a stainless steel boiler with smaller dimensions and a modified heating arrangement significantly improved temperature control [7] .

PLANNED EXPERIMENT

Further graphite gettering experiments will satisfy some basic requirements. Grade POCO CZR-2 graphite will be used, having been identified as the grade to getter caesium most effectively by Bhaskar et al, being able to collect 20% of its own mass [2]. The total graphite mass of 200 g will be more than enough for the 3 g of Cs delivered in a 30 day run. Baking out is a key preparatory step and it is desirable to experiment at a large range of graphite temperatures. Thermal simulations were performed using ANSYS to design an arrangement which thermally isolates the graphite, whilst exposing a large surface area in the ion source's direction.

After many iterations a prototype was settled on, a drawing of which is shown in Fig. 6, where four graphite blocks are mounted onto Macors ceramic sheets by a bolt through the middle and a nut to keep a 5 mm space between the two. The sheets are then mounted onto an existing stainless steel frame at their ends, resulting in a large thermal path and taking advantage of MACOR's low thermal conductivity. Aluminium foil, with its low emissivity, will line the inside face of the graphite to minimise radiative losses from the graphite to macor.

Each block has four holes for heaters rated to 40 W, and one for a thermocouple. In the simulations a 120 W load on one block heats it to 800 °C and the outside of the vessel to 100 °C. This permits baking in situ, and a wide temperature range to experiment with.

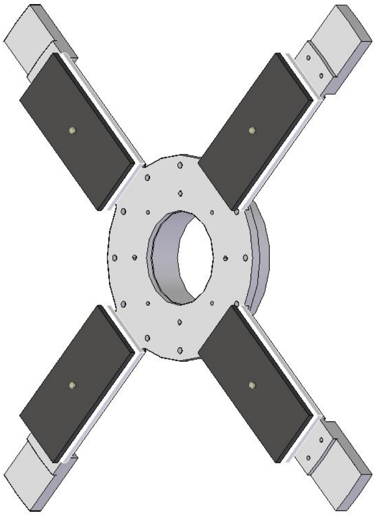

Figure 6: A drawing of graphite blocks mounted on ceramic plates, in turn mounted onto a steel frame which holds the protection electrode.

The experiment will be similar to the preliminary one presented, with additional spectroscopic measurements of the plasma. If Cs levels in the plasma are found to stay similar, whilst flux detected by QCM changes when graphite is added, removed, or heated, this would suggest some capture occurs.

CONCLUSIONS

Two preliminary experiments were performed to improve understanding of caesium consumption, gettering, and adsorption in anticipation of an investigation into caesium capture by graphite in a realistic ion source environment. Cs flux in the vessel appears to vary with graphite temperature but this cannot yet be attributed to gettering. The formation of black dust is likely related to this observation. Flux measurements appear to vary significantly even when boiler and transport parameters are unchanged. Absorption and desorption of Cs from the vessel walls contributes to this effect and must be accounted for to evaluate consistency of delivery system. Understanding and mitigating these and other effects is necessary to study the use of graphite as a caesium getter on an operational ion source.

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