PARTICULATE STUDY OF NEG PUMPS IRRADIATED IN THE CEBAF TUNNEL*

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Abstract

Non-evaporable getter (NEG) pumps are being used to maintain ultra-high vacuum in the beamline of superconducting radio-frequency (SRF) accelerators, such as the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab. Because of the sensitivity of the performance of SRF cavities to particulate contamination, it is important to evaluate the integrity of the NEG material after exposure to high radiation during beam operation. The particulate count from two NEG pumps based on ZAO® getter alloy was measured with a particle counter in a clean-room. The pumps were assembled onto a hermetically sealed setup which was placed in the CEBAF tunnel. The setup was exposed to 24 h beam operation for ~ 230 days. The total gamma-rays dose measured on the test setup was ~ 1.6 Mrad. The total neutron dose measured at ~ 75 cm of the test setup was ~ 11 krad. The particulate count from the two pumps was measured again in the clean-room after irradiation. Whereas an increase of particulate counts was measured, compared to before irradiation, subsequent measurements indicate the absence of systematically loose particulate. The pumping speed of one of the irradiated pumps was also measured to be consistent with that of a non-irradiated one, corroborating the absence of significant damage to the ZAO® NEG material due to irradiation.

INTRODUCTION

Non-evaporable getter (NEG) pumps are being installed in the pump drops of both the warm girders and the cryomodules that are installed in the Continuous Electron Beam Accelerator Facility (CEBAF) after refurbishment [1]. The NEG pumps being used are made of a sintered alloy of zirconium, vanadium, titanium and aluminum, referred to as ZAO®. This type of pump offers high pumping speed and pumping capacity for hydrogen, which is the main residual gas of clean ultra-high vacuum systems, with a smaller size and weight compared to ion pumps. Residual hydrogen gas adsorbed on the surface of SRF cavities at 2 K may enhance or trigger field emission from particulates present on the surface [2–4]. The NEG pumps from SAES Getters have low particulate emission and they have been qualified for use in the vacuum system of SRF cavities [5–7]. They have also been used to pump the cavity string for LCLS-II and LCLS-II HE cryomodules [8]. This manuscript presents the results of a study to evaluate any significant change with respect to emission of particulate after the NEG pump was exposed to gamma and neutron radiation produced during beam operation in the CEBAF tunnel.

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EXPERIMENTAL SETUP

Preparation for Installation in CEBAF Tunnel

Two NEG pumps, a CapaciTorr® Z 400 [9] and a CapaciTorr® HV 200 [10] were loaned by SAES Getters for this study. Both pumps are made of the ZAO® alloy. The CapaciTorr HV 200 is the same model as the one used in the pump-drops of refurbished cryomodules and warm girders. The HV 200 and Z 400 pumps have a nominal hydrogen pumping speed of 200 l/s and 400 l/s, respectively.

The NEG cartridges were cleaned in isopropyl alcohol with ultrasonic agitation for 5 min, followed by blow-down with filtered nitrogen and placed in a sealed nylon bag. Figure 1 shows a picture of the pumps inside the clean room (CR). A four way cross was cleaned using ultra-high vacuum (UHV) cleaning protocols, consisting of ultrasonic cleaning with a detergent, solvent rinses and blow down with filtered nitrogen. The parts were transferred to the clean-room in a sealed nylon bag, then assembled with the NEG pumps as shown in Fig 2.

(a) (b)

Figure 1: NEG pumps CapaciTorr HV 200 (a) and Z 400 (b) in the clean room.

Each NEG pump was cleaned with ionized nitrogen on above a particle counter (Lighthouse Solair 3100) inside the

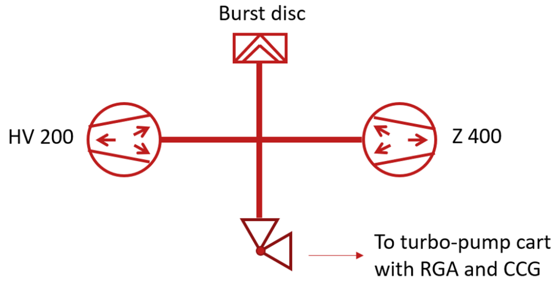

Figure 2: Schematic of the vacuum setup with the two NEG pumps.

clean room until zero particles were counted. The particle counter samples a volume of 4814 cm^3 every 10 s. After particulate blow-down, the pump was inserted in a vacuum manifold, evacuated, helium leak checked and activated by heating it for 1 h at ~ 550 °C with a NEG POWER MINI power supply from SAES Getters. The pump was cooled under vacuum overnight, then it was removed from the vacuum manifold and cleaned with ionized nitrogen over the particle counter. This process was repeated until each pump has gone through three activation cycles. These steps are done to minimize the particulate released by the NEG pumps [6]. The activation voltage was 11 V for the HV 200 and 14.5 V for the Z 400, as recommended by the manufacturer. The pumps are then assembled into the 4-way cross and each one is activated one last time, after evacuation and helium leak check with a cart equipped with a turbo-molecular pump, a full-range cold-cathode gauge (CCG) and a residual gas analyzer (RGA). Afterwards, the right-angle valve (RAV) at the end of the 4-way cross was closed. The pressure measured by the CCG on the turbo-pump cart before closing the RAV was 7.3×10^{-8} mbar. The setup was then placed into a sealed nylon bag and moved outside the clean room.

Installation in CEBAF Tunnel

On July 14, 2023 the setup with the two pumps was placed on a wooden frame near the beamline at the exit of the cryomodule installed in zone 1L23 and ~ 75 cm from the NDX detector close to the input of the cryomodule in the adjacent 1L24 zone. The chosen location was one of the "radiation hot spots" in the accelerator, therefore providing an opportunity to deliver a high radiation dose in a shorter time. Four pairs of opti-chromic dosimeter rods were taped to the nylon bag enclosing the pumps. Figure 3 shows a picture of the placement of the vacuum setup in the CEBAF tunnel. Beam operation in CEBAF for experimental nuclear physics occurred between September 11, 2023 and May 20, 2024, with a break between December 19, 2023, and January 12, 2024.

DOSE AND PARTICULATE ANALYSIS

The Radiological Control Group surveyed the vacuum setup and moved it from the CEBAF tunnel to a Radiologically Controlled Area in the Test Lab building on JLab's campus in July 2024. The average dose from the opti-chromic rods was (1562 ± 185) krad. The total dose measured by the

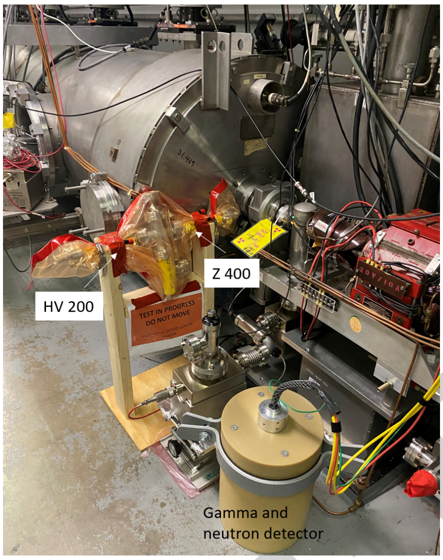

Figure 3: Picture of the vacuum setup with the NEG pump placed close to the beamline in the CEBAF tunnel.

NDX detector, integrated over the periods of beam operation, was 150 krad of γ-rays radiation dose and 11 krad of neutron radiation dose.

The vacuum setup with the pumps was transferred to the chemical room in the Test Lab. The nylon bag broke into pieces as a result of the radiation exposure. The vacuum setup was wiped clean with isopropanol and transferred to the ISO 4 clean-room. Each NEG pump was removed from the cross, after slow-venting of the vacuum setup to prevent particulate movement or migration, and it was blown with ionized nitrogen gas above the particle counter.

The pumps were stored in the clean room for about four months, and the parts for the vacuum setup shown in Fig. 2 were brought back into the clean room after standard UHV cleaning. The particle counts were collected by the particle counter when blowing each NEG pump with ionized nitrogen before installation on the 4-way cross before and after removing them from the 4-way cross, after one final activation.

Figure 4 shows plots summarizing the total particulate counts after each operation, listed in the x-axis. The HV 200 pump had significantly higher particulate counts compared to the Z 400 pump after the initial cleaning, but became comparable already after the first activation. This difference may be related to a non-optimal cleaning process done to the HV 200 pump. An increase of particulate count was measured for both pumps after removal from the vacuum setup after irradiation, with higher values for the Z 400 pump. However, the increase in total particle count is relatively modest and could be related to the assembly, disassembly, evacuation and venting processes that occurred between the blowing with nitrogen after the third activation and the blowing after irradiation. Both pumps remained cleaned after long-term storage in the clean-room and the particulate count was the lowest after the final activation. Therefore, the data suggests no permanent damage was done to the pumps as a result of γ-rays and neutron radiation dose, which might have resulted in an excess of loose particulate.

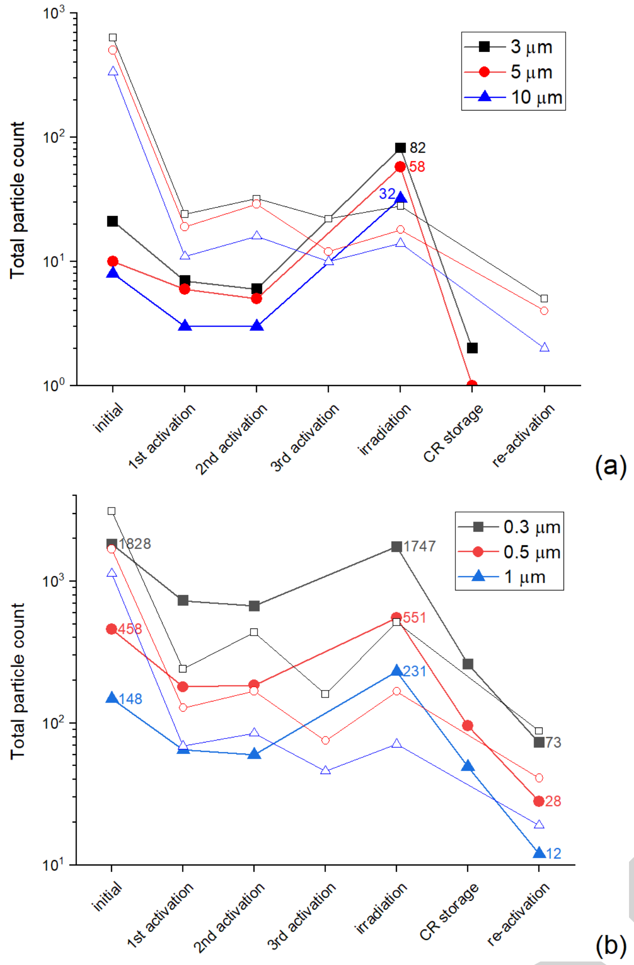

Figure 4: Total particulate count from the NEG pumps measured in the ISO 4 clean room after each preparation step: (a) particulate size ranging between 3 µm-10 µm, (b) particulate size ranging between 0.3 µm-1 µm. Empty symbols are for the HV 200 pump, the solid symbols are for the Z 400 pump. Data not shown for the Z 400 pump after irradiation indicate zero particulate count.

PUMPING SPEED

The HV 200 pump was shipped back to SAES Getters in November 2025 and its pumping performance was measured by the vendor on a dedicated vacuum test bench according to ASTM standard. The HV 200 NEG cartridge was fully protruded inside the vacuum chamber and a standard activation was run (1 h duration, 550 °C). The test was carried out at a sorption pressure of 3×10^{-6} Torr, with the NEG pump at room temperature.

The pumping speed curve comparison between a brand-new pump and the irradiated pump is reported in Fig. 5. The long exposure at a high dose level has a marginal effect on the pumping speed featured by the CapaciTorr® HV 200 pump for both H_2 and CO. More interestingly, the sorption capacity slope for CO barely changes, indicating that the saturation of the getter surface is scarcely affected by the exposure. A longer re-reactivation time could further improve the recovery of the initial pumping performance; further tests will be carried out for a deeper characterization.

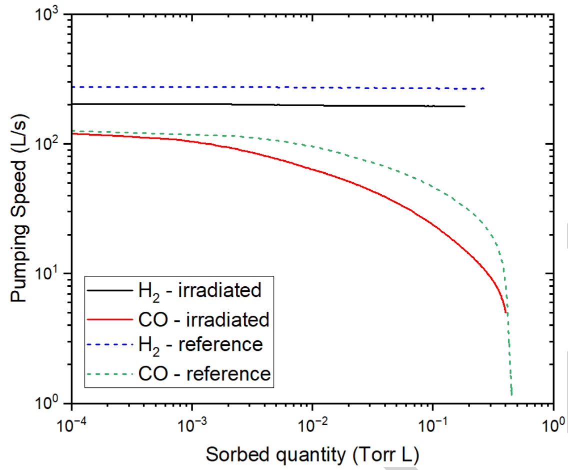

Figure 5: Sorption curves for H_2 and CO at room temperature and 3×10^{-6} Torr for the irradiated CapaciTorr® HV 200 pump and a pristine pump of the same type.

CONCLUSION

The results from exposure of two NEG pump to ~ 1.6 Mrad of γ-rays and ~ 11 krad neutron radiation dose from beam operation in the CEBAF tunnel did not result in a significant increase of loose particulate, which could impact the cleanliness of the beamline, nor in a significant reduction of the pumping speed. Such results do confirm that the ZAO® material is well suited for usability in radiation hard environments for prolonged time, allowing for reliable and long-lasting performance for particle accelerator facilities.

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