Outgassing Characterization of Common Trash Items for Disposal by Nanoracks Airlock on the International Space Station

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The arrival of the Nanoracks Airlock to the International Space Station (ISS) has provided the ISS program the capability to dispose of common trash items. The concept of operations involved the crew bagging up those items into a trash bag and then utilizing the robotic arm and the airlock to jettison the trash bag. Because of the unknown thermal vacuum stability of some of the items, a molecular contamination concern was raised by the ISS program as the trash is exposed to vacuum upon the evacuation of air from the airlock and the robotic arm moving the airlock to its jettison location. In order to characterize the representative outgassing rates for ISS trash, thermal vacuum testing was performed at White Sands Test Facility. Trash was sorted into a "lower" outgassing bag and a "mixed" bag. The "mixed" trash bag contained more items that were suspected to be not vacuum stable. Load cells were chosen as the primary means for measuring mass loss. A sharp decay in the outgassing rate was observed in the first 30 minutes followed by a slower decay. As expected, the "mixed" bag lost more mass. While Quartz Crystal Microbalances (QCMs) are often utilized to

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measure long term outgassing rates and the sticking coefficients of contaminants at different operating temperatures for vacuum stable materials, these measurements proved difficult due to the amount and the inclusion of materials with suspect thermal vacuum stability. Because of high rates of material outgassing, the facility was unable to maintain the CQCM temperature setpoint of 80 K QCMs.. The QCMs operating at the warmer temperatures also saturated on occasion due to high levels of condensed matter. Though testing was able to confirm high risk of outgassing contamination for the program, true sticking coefficients could not be determined, available measurements are provided herein.

I. Introduction

The arrival of Nanoracks Airlock (NRAL) in December 2020 to the International Space Station (ISS) provided additional capability to deploy satellites from ISS, house experiments, and transfer hardware between inside to outside ISS (and vice versa) [1]. NRAL is located on the port side of ISS and attached to the Node 3 endcone as shown in Figure 1. One new capability with the arrival was its utilization for trash disposal in the event of trash buildup inside the cabin. Several teams including NASA, Nanoracks, Leidos, and Boeing developed an approach to use the airlock to deploy trash. The concept of operations involved the following: 1) The crew fills trash contained within transfer bags into a single trash bag that could contain up to 272 kilograms. 2) The crew zips up the trash bag and seals the airlock. 3) The airlock is pumped down to 2 psi or less (approximate duration of 181 minutes; the cabin air is recirculated) and then, the remainder is vented to space (approximate duration of 53 minutes from ~2 to 0.04 psi) utilizing the Node 3 Vent and Relief Valve (VRV). 4) When pressure reaches 0.04 psi or less, the airlock can be removed from Node 3. The Space Station Remote Manipulator System (SSRMS) then grapples/moves the airlock and trash bag to the jettison location (duration nominally ranges between 0.8 to 2.2 hours). 5) The trash bag is jettisoned.

Not all common trash items proposed for disposal have been characterized individually for thermal vacuum stability as they were intended to remain inside the cabin. Because many of trash items are not vacuum stable, one of the concerns raised during review was the high likelihood of molecular contamination to ISS surfaces in vacuum as the trash is taken to its jettison location. The present work seeks to characterize the materials outgassing, the release of volatiles, for common trash items on the ISS.

Characterization of some bulk trash outgassing was performed in the Essex vacuum chamber at White Sands Test Facility (WSTF) to help characterize this risk. The WSTF testing was intended to provide representative order of magnitude materials outgassing rates for trash bags. Scaled-down trash bags with selected trash items underwent testing in a vacuum chamber. The authors acknowledge that there are variables that affect the trash bag outgassing rates. The trash being disposed on-orbit is at the discretion of the crew. There will be variability depending on crew preference, crew number, usage durations, increment activities, and flight operations. There is the potential of contaminant introduced during use (e.g., transfer of residues from food, hygiene products, the body, and other hardware to clothing, packaging, cleaning wipes/textiles, and personal protective equipment). Nonetheless, the NASA vehicle office acquired a number of used, on-orbit common trash items (e.g., crew clothing, towels, etc.) for testing in order to partially account for this effect.

II.Materials Outgassing Testing at White Sands Test Facility

Two identical scaled-down Leidos trash bags were filled with common trash items deemed less or more likely to have significant outgassing. The trash bag was comprised of an inner urethane coated nylon liner and an external beta cloth layer. To represent a flight-like on-orbit situation with minimal trash sorting constraints, the "mixed" outgassing test article included many of the same items as the "lower" outgassing bag, but with suspected higher outgassing items included (e.g., wet trash). For wet trash, only residual amount of liquid remained (i.e., much of liquid had been squeezed out by the crew). Common trash items were selected from the SSP 50477, Joint Crew Provisioning Catalog [2]. Used clothing and sleeping bags from SpX-22 and Crew-1 missions were obtained and tested. The contents of the lower and mixed outgassing bags are listed in Tables 1 and 2, respectively. In order to categorize common trash items that may be placed in each bag, the team evaluated best-available information about material compositions of common trash items using ASTM E 595 data. ASTM E 595 is a screening test that determines a material's thermal vacuum stability (TVS) by measuring the total mass loss in vacuum of the material subjected to 125°C for 24 hours [3]. Most of the common items from the catalog did not have ASTM E 595 TVS data or ASTM E 1559 outgassing rate data [4].

Pre-test weights in kilograms were 4.42 and 5.00 for the lower and mixed outgassing bags, respectively. Each test article was maintained for eleven hours at 60°C ± 4°C and less than 5.0×10^{-5} torr. 60°C is the predicted maximum operating temperature of the trash bag in the Nanoracks Airlock. Eleven hours was determined to be the maximum duration of a nominal trash deploy event on ISS. Thermocouples were placed on the external layer of test article to monitor the temperature. There were periodic pressure bursts from materials outgassing. The maximum on-orbit mass is expected to be 272 kg.

During the test, mass loss was measured using Futek model QSH02257 load cells. Mass loss rates were determined from the load cell data taken during chamber pump down to vacuum and chamber hold at vacuum conditions. The load cells instead of the QCMs were used as the primary means for determining the outgassing or mass loss rate arising from the test article. Load cell increase in weight upon vacuum chamber evacuation (first eleven to twelve minutes of each run) was neglected.

In addition to the load cells, there were two 15 MHz, MK10 Thermoelectric Quartz Crystal Microbalances (TQCMs) that looked at condensable component deposition rates. Crystals used included QCM Research crystals with temperature set points of -10°C and -40°C and a CrystalTek Cryogenic Quartz Crystal Microbalance (CQCM) with a set point of 80K. The test article has a zipper around half the circumference of bag on one end. The QCMs were placed approximately half a foot from the end with the zipper.

TQCMs and CQCM were used to determine the sticking coefficients of contaminants that may condense on ISS contamination sensitive surfaces. Contaminant deposition on CQCM was intended to represent collection of all types of outgassed molecular species. Deposition on TQCMs (operating at -10°C and -40°C) represents those species that condense at temperatures of ISS contamination-sensitive surfaces (e.g., payloads and radiators). Data was collected every second for all data acquisition systems (e.g., thermocouples, chamber pressure, QCMs, load cell).

A background chamber run was performed prior to the lower outgassing bag test. It became apparent during the background run that there would be difficulty reaching the originally requested 80K set point. Minimum CQCM temperature was 123K prior to CQCM saturation during the background test.

During final testing, lower CQCM and TQCM collector setpoint temperatures were observed to drive increased deposition of condensable compounds, resulting in faster crystal saturation and required bakeoff. The lowest temperature setpoint crystal CQCM (approximately -175°C or 98K for the lower outgassing bag and approximately -143°C or 130K for the mixed bag) would undergo frequent cycles of saturation and bakeoff. Unfortunately, the facility was unable to maintain the initially requested CQCM temperature setpoint of -193.15 °C (80K). Saturations also occurred for the -10°C and -40°C TQCMs, but they were less frequent. QCMs have been widely used to measure outgassing rates for materials that are vacuum stable [4]. CQCM sensors were able to achieve approximately -175 °C (98K) for the lower outgassing bag and approximately -143 °C (130K) for the mixed bag. During its frequent cycles, the CQCM would reach a minimum temperature in the range between 98 to 130K before warming up to bakeoff the mass on the QCMs (i.e., up to 80°C). In addition to the difficulties in maintaining the CQCM temperature of -193.15 °C (80K), an electronic box ventilation issue interfered with the temperature control on the CQCM during the lower outgassing bag test. Only partial bakeouts occurred during a portion of the lower outgassing bag test. Though -193.15°C (80K) temps were difficult to maintain, comparisons between the CQCM sensor data at approximately -175°C (98K) for the lower outgassing bag and approximately -143°C (130K) for the mixed bag with the warmer TQCM sensors at -10°C and -40°C can still provide a measure of the fraction of contaminants that would remain on the warmer TQCMs (i.e., sticking coefficients for the surfaces that are expected at -10°C and -40°C).

III. White Sands Test Facility Measurements

The mass loss and percent mass loss encountered by the test articles are shown in Table 3. As expected, more mass was lost for the mixed bag, which had more materials that are suspect. Mass loss measured in the vacuum chamber by the load cells was compared with benchtop scale pre-test and post-test weights. Subsequent changes in the mass determined from the load cells were then corrected with the benchtop scale measurements due to the bag's changing center of gravity. This was more evident for the lower outgassing bag. The changes in the mass and pressure in the vacuum chamber are shown in Figures 3 (lower outgassing bag) and 4 (mixed outgassing bag).

In order to determine the outgassing rates, the corrected load cell measurements per second are averaged on a per minute basis resulting in mass loss per minute values. The outgassing rates for the two bags are shown in Figures 5 and 6. Two outgassing regimes were observed for both runs. There is an initial rapid decay of the rate followed by a slower decay. Demarcation of the two regimes occurs around the 30-minute mark. The decay rates are described by the exponents from power law fits as employed in the data reduction from ASTM E 1559 tests of vacuum stable materials [5]. The electronic box ventilation issue during the lower outgassing bag run may have contributed to the lower correlation coefficient of the power law fit in Figure 5 and a greater difference between the benchtop scale and the load cell measurements in Table 1.

Each of Quartz Crystal Microbalance consists of a pair of quartz crystals. One is kept isolated from and the other is exposed to the environment. The difference in resonant frequency between the two crystals, called the beat frequency, can then be correlated to the amount of molecular contaminant mass that accumulates on the exposed crystal using a QCM sensitivity factor of 1.96×10^{-9} g/cm^2/Hz. The ratios of the condensed masses from the CQCM sensor at approximately -175°C (98K) for the lower outgassing bag and approximately -143°C (130K) for the mixed bag and TQCMs at -10°C and -40°C are shown in Figures 7 and 8, respectively for the lower and mixed outgassing bags. As discussed in the previous section, the condensed mass collected on the CQCM does not represent Total Mass Loss because the CQCM was only able to get to a temperature range between 98- to 130K (not 80K). The inverse of the ratio (i.e., sticking coefficient) shown in Figures 7 and 8 can still provide a measure of the fraction of contaminants that would remain at warmer operating temperatures. The mixed outgassing bag ratios are larger compared to the lower outgassing bag. The mixed outgassing bag lost more mass, as expected, but the higher factors indicate significantly less of that mass condensed on the TQCMs operating at ISS temperatures.

These results were used by the ISS Program to gauge a representative amount of outgassing contaminants from a trash deploy and to mitigate the amount of contaminant that a sensitive surface (e.g., radiators) could receive by controlling the deployment trajectory so that the airlock's view to sensitive surfaces was minimized. The ISS performed its first trash deployment from the Nanoracks Airlock on July 3, 2022 and publically released images from the deploy are shown in Figure 9 [6-8]. The first jettisoned trash bag contained approximately 78 kg.

IV.Conclusion

The International Space Station has demonstrated the capability to dispose of common trash items in space using the Nanoracks Airlock. Because some of the items are not vacuum stable, the amount of contamination from the trash was identified as a concern for the ISS Program. Thermal vacuum testing of the trash was conducted at White Sands Test Facility to characterize representative outgassing rates. Load cells were utilized to monitor the change in mass and Quartz Crystal Microbalances were employed to determine the sticking coefficients of contaminants that may condense on ISS contamination sensitive surfaces. The facility was unable to maintain the CQCM temperature setpoint of 80 K achieving approximately -175°C (98K) for the low outgassing bag and approximately -143°C (130K) for the mixed bag. As such, , the true sticking coefficients could not be determined.

The common trash items were separated in lower and mixed categories. The lower trash bag contained materials deemed to be more vacuum stable while the mixed bag contained materials that are not vacuum stable or had unknown Thermal Vacuum Stability test results. As expected, the mixed bag lost more mass. Two outgassing regimes were observed. First, a sharp decay in the outgassing rate up until the 30 minute mark followed by a slower decay until the completion of the test. The power law fit correlation was lower for the lower trash bag than the mixed bag potentially due to an electronics box ventilation issue that was corrected during the lower trash bag test. A comparison between condensed masses on the CQCM to the TQCMs at -10°C and -40°C indicated that less of the outgassed mass deposited on those sensors in the mixed outgassing test even though the mixed bag lost more mass.

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[6] https://images.nasa.gov/details/iss067e174422

[7] https://images.nasa.gov/details/iss067e173472

[8] https://www.nasa.gov/image-article/trash-container-pictured-trajectory-away-from-station/

Figures and Tables

Table 1 "Lower" Outgassing Bag Contents

Item	Mass %
Plastic Ziplock Bags	13.5
Pink Poly	1.1
Bubble Wrap	0.8
Hefty Bags	0.3
Packing Foam (Plastazote, Minicell)	1.5
Clothing	26.8
Undergarment	5.1
Sleeping Bags	2.2
Transfer Bags	11.6
Paper	16.9
Toothbrushes	2.9
Disposable Razors	2.3
Hair Brush/Comb	2.2
QTip Travel Pack (Cotton Swabs)	0.6
Leidos Trash Bag	12

Table 2 "Mixed" Outgassing Bag Contents

Item	Mass %
Plastic Ziplock Bags	3.1
Pink Poly	0.7
Bubble Wrap	0.9

Hefty Bags	0.1
Packing Foam (Plastazote, Minicell)	0.5
Clothing	16
Undergarment	6.5
Sleeping Bags	1.1
Transfer Bags	11.6
Paper	7.9
Toothbrushes	2.4
Disposable Razors	0.7
Hair Brush/Comb	0.7
QTip Travel Pack (Cotton Swabs)	0.5
Toothpaste	0.4
Washcloth	8.9
Shampoo/Conditioner	1.3
Lotion	1.4
Styptic pencil	0.2
Deodorant	1.0
Shoes	2.2
Wipes	4.0
Desiccant ($CaSO_4$, Silica Gel)	1.5
Bulk Overwrap Bag	1.3
Gloves (Deer Skin, Nitrile)	2.3
Leather Belt	4.1
Pens and Markers	4.2
Printer Cartridges	1.3
Moleskin Notebook	0.9
Flashlight	0.8

Diapers	0.2
Used Wet Bags	1.0
Leidos Trash Bag	10.3

Table 2 Test Article Mass Loss Comparison Between Benchtop Scale and Load Cells

	Benchtop Scale		Load Cells	
	“Lower” Bag	“Mixed” Bag	“Lower” Bag	“Mixed” Bag
Δm (g)	110.8	260.7	141.5	265.4
% mass loss	2.5	5.2	3.0	5.1

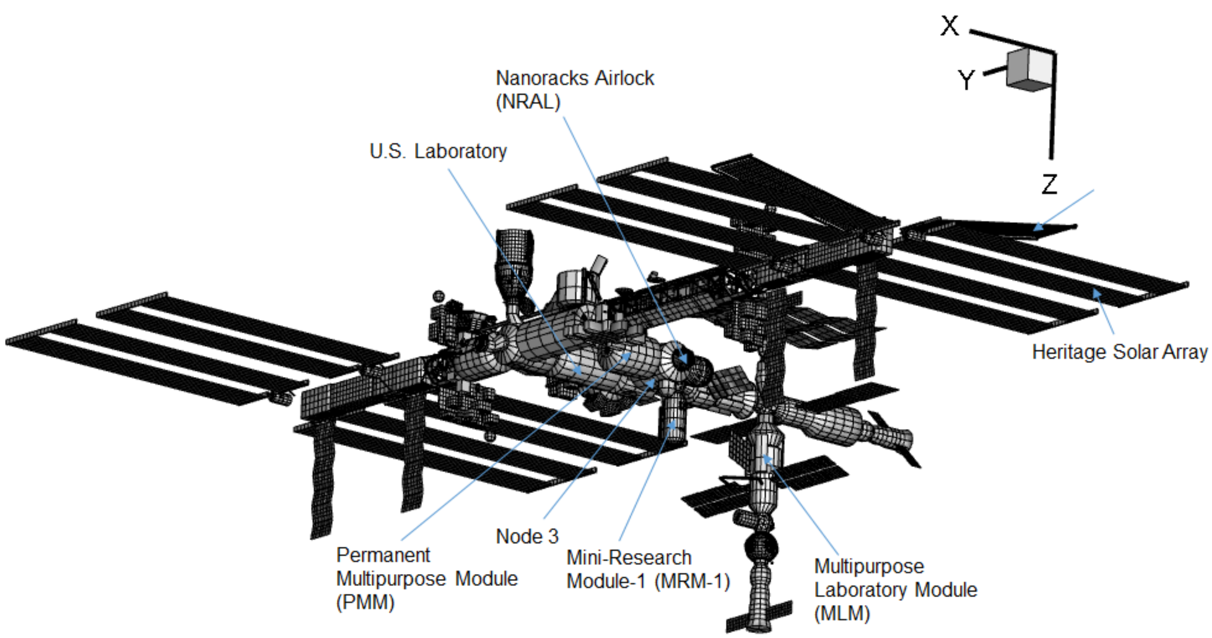

Fig. 1 Geometric model of International Space Station in July 2022 During First Trash Deploy.

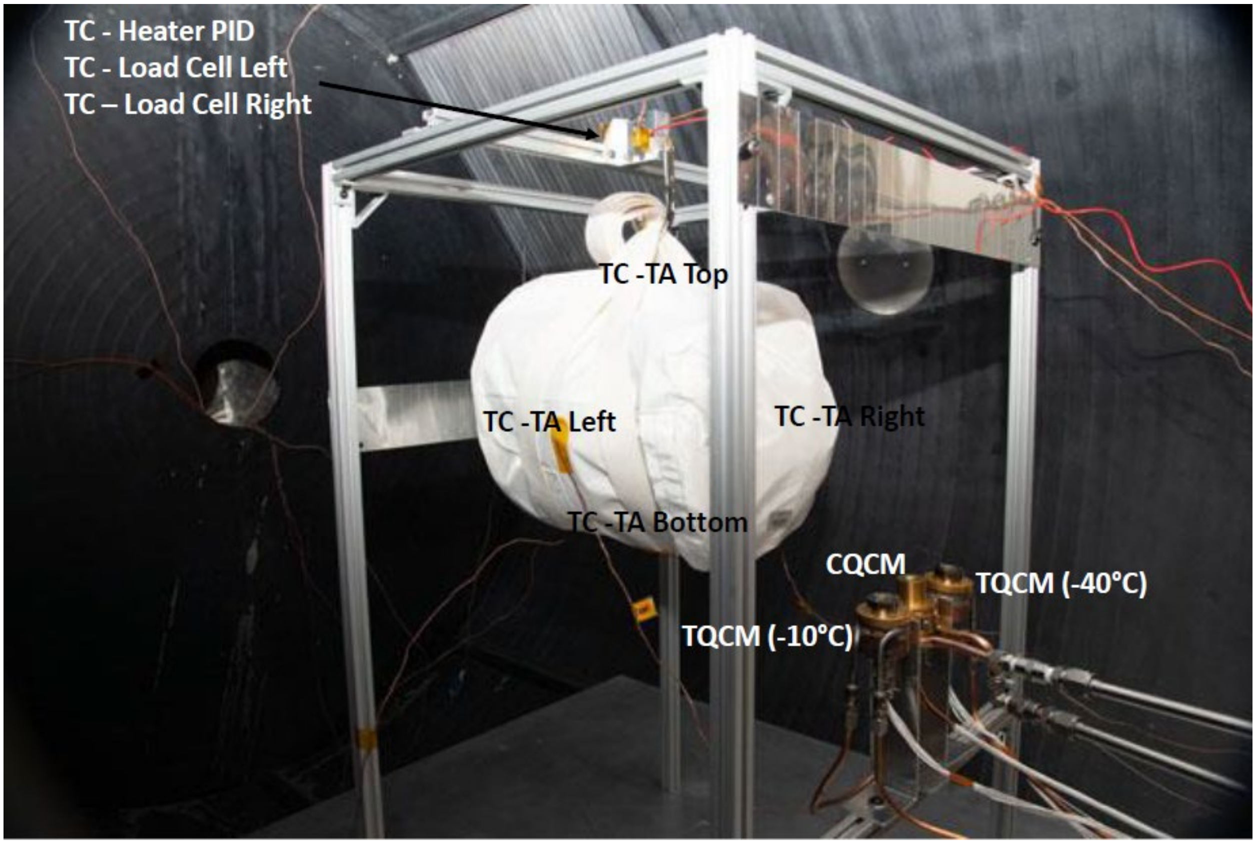

Fig. 2 Test Article (TA) inside the WSTF Essex Vacuum Chamber (Thermocouples, TC; Quartz Crystal Microbalance, QCM).

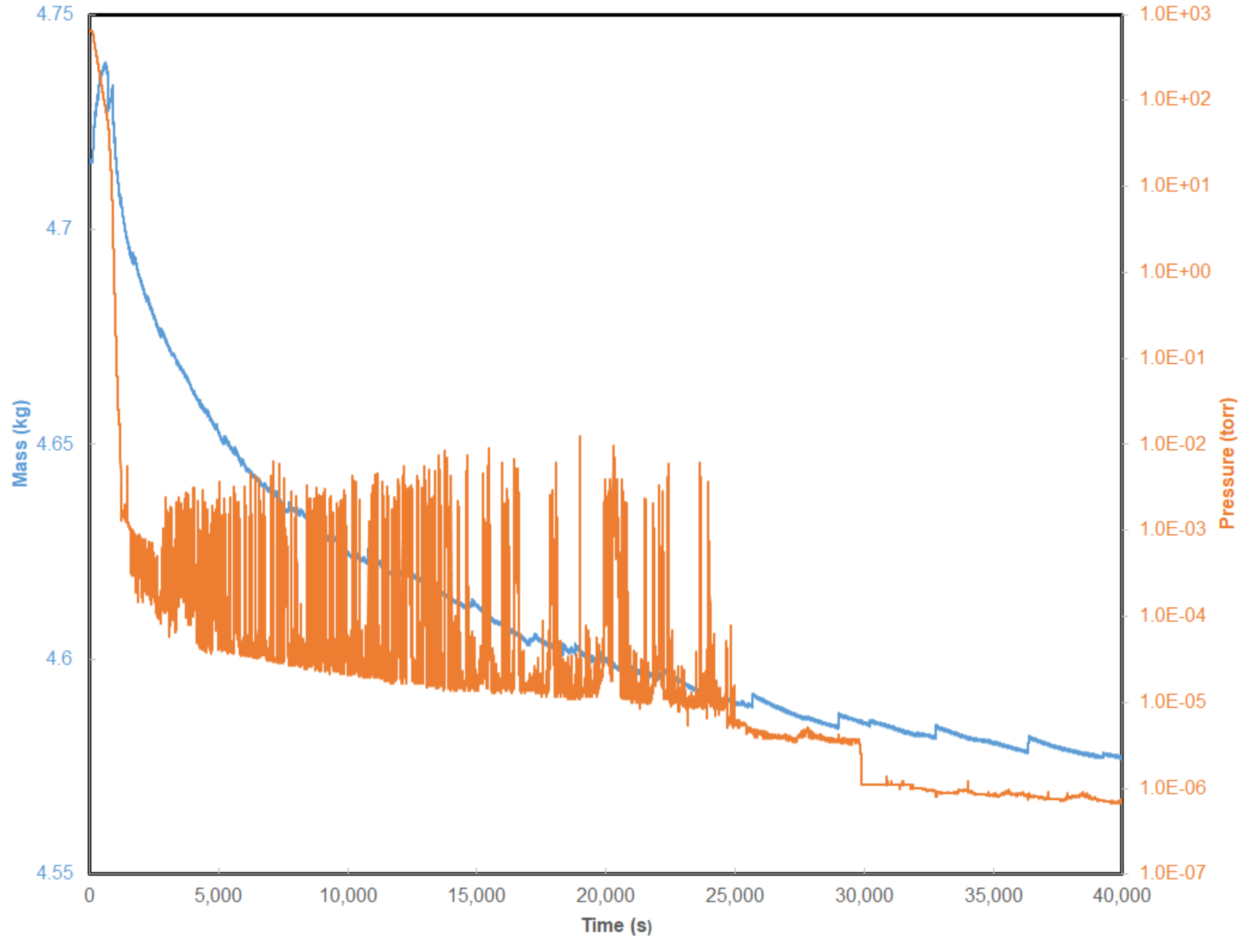

Fig. 3 Pressure and Mass Measurements for "Lower" Outgassing Bag. Pressure spikes due to outgassing bursts are observed.

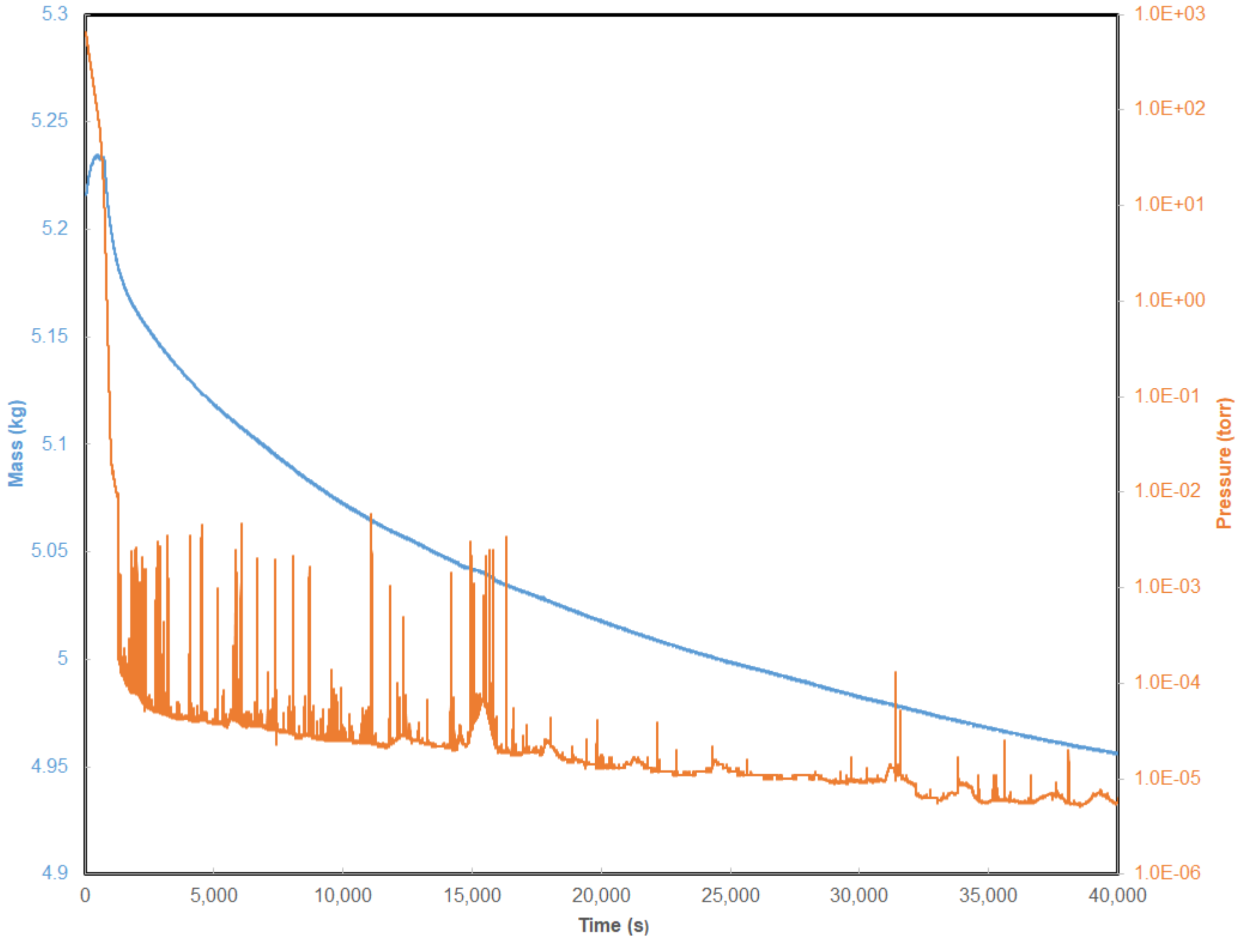

Fig. 4 Pressure and Mass Measurements for "Mixed" Outgassing Bag. Pressure spikes due to outgassing bursts are observed.

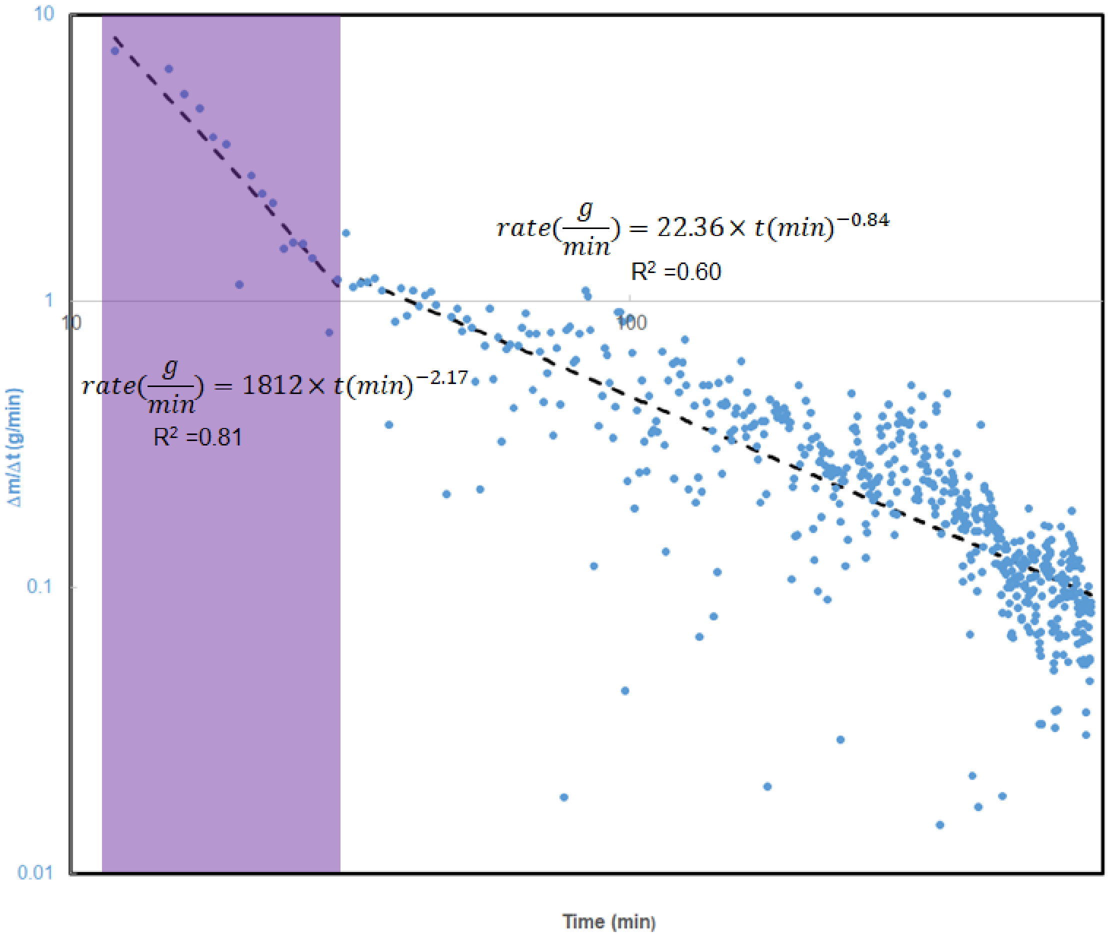

Fig. 5 "Lower" Outgassing Bag Mass Loss Rates (with power law fits).

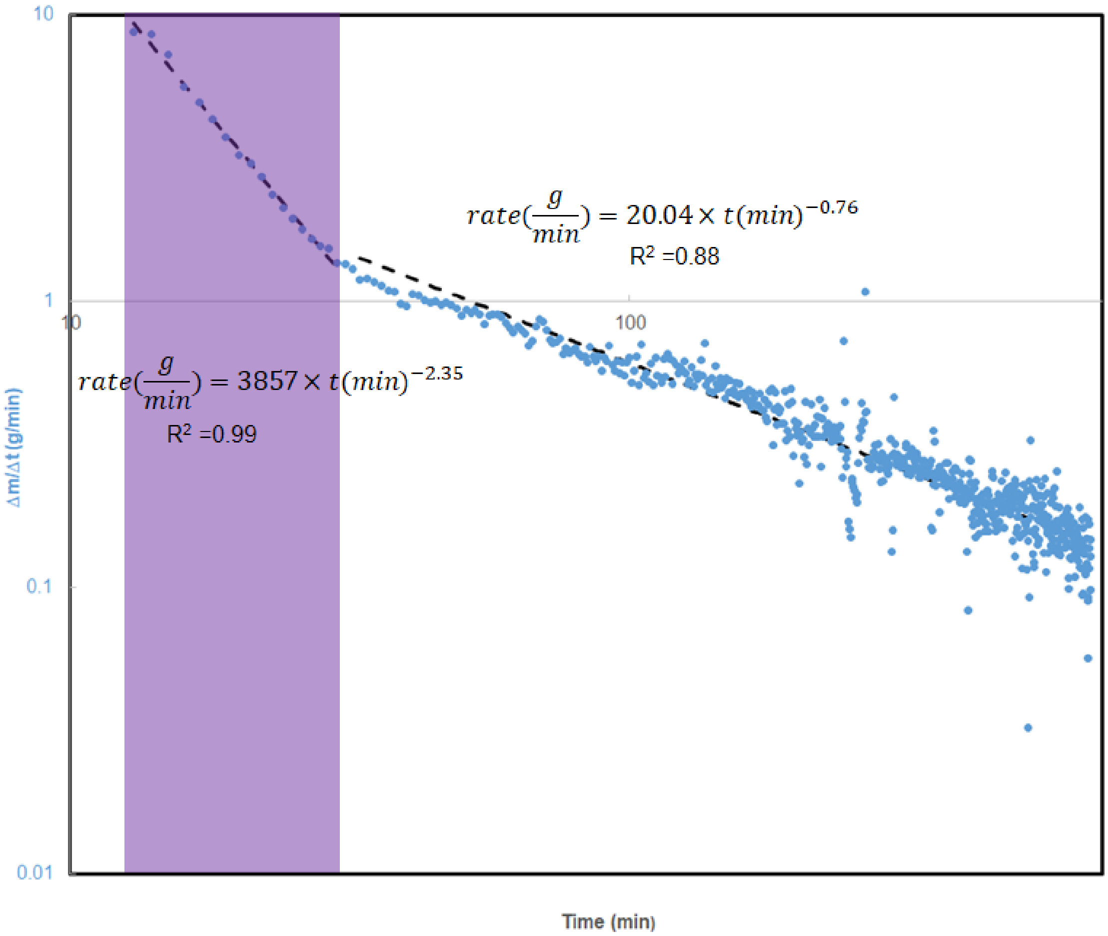

Fig. 6 "Mixed" Outgassing Bag Mass Loss Rates (with power law fits).

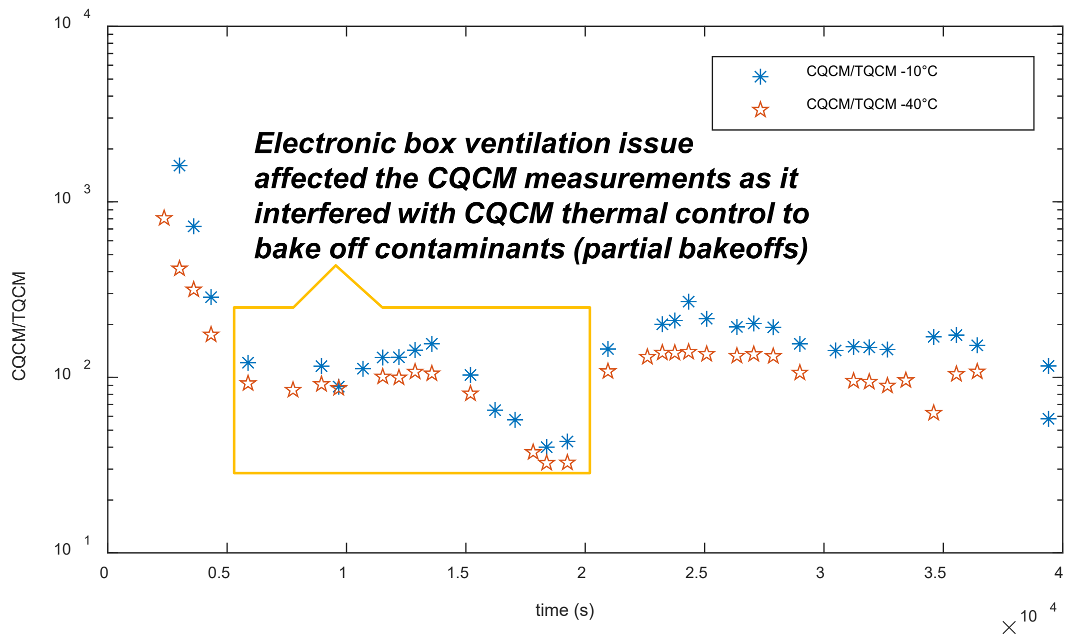

Fig. 7 Ratio of the Condensed Masses on CQCM at approximately -175 °C (98K) and TQCMs at -10°C and -40°C for "Lower" Outgassing Bag.

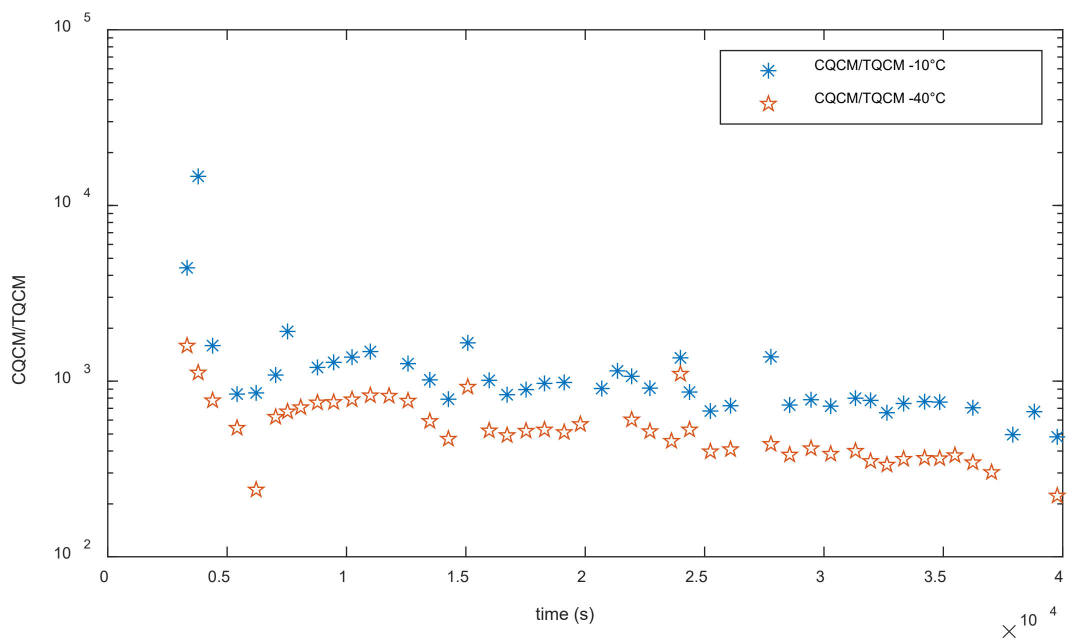

Fig. 8 Ratio of the Condensed Masses on CQCM at approximately -143 °C (130K) and TQCMs at -10°C and -40°C for "Mixed" Outgassing Bag.

Fig. 9 Released images from the first trash deploy from the Nanoracks Airlock: Left - Nanoracks Airlock on a robotic arm [6]; Right - Trash container after being jettisoned from the Nanoracks Airlock [7].