National Aeronautics and Space Administration

Preliminary testing of NASA's Molecular Adsorber Coating technology for future missions to Mars

CONFERENCE PAPER 10748-13 | MONDAY, AUGUST 20, 2018

Nithin S. Abraham, Doris E. Jallice
NASA Goddard Space Flight Center

Systems Contamination: Prediction, Control, and Performance | Session 04, Contamination Control Methods and Measurements I
2018 SPIE Optics + Photonics: Optical Engineering + Applications Conference | San Diego Convention Center, San Diego, California, USA

Project Team Members

TEAM MEMBER	COMPANY AFFILIATION & ORGANIZATION CODE	SUPPORT ROLE
Nithin Abraham	**NASA Goddard Space Flight Center** Code 546 Contamination and Coatings Engineering Branch	MAC Technologist/ Thermal Coatings Engineer
Alfred Wong	**Stinger Ghaffarian Technologies** Code 546 Contamination and Coatings Engineering Branch	Spray Application/ Thermal Coatings Engineer
Mark Hasegawa	**NASA Goddard Space Flight Center** Code 546 Contamination and Coatings Engineering Branch	Thermal Coatings Engineering Group Lead
Kenneth O'Connor	**Stinger Ghaffarian Technologies** Code 546 Contamination and Coatings Engineering Branch	Vacuum Chamber Operations/Thermal Coatings Engineer
George Harris	**Stinger Ghaffarian Technologies** Code 546 Contamination and Coatings Engineering Branch	Vacuum Chamber Operations/Thermal Coatings Engineer
Griffin Jayne	**Stinger Ghaffarian Technologies** Code 546 Contamination and Coatings Engineering Branch	Vacuum Chamber Operations/ Contamination Control Engineer

TEAM MEMBER	COMPANY AFFILIATION & ORGANIZATION CODE	SUPPORT ROLE
Doris Jallice	**NASA Goddard Space Flight Center** Code 541 Materials Engineering Branch	Chemical Analysis Materials Engineer
Paul Pless	**NASA Goddard Space Flight Center** Code 541 Materials Engineering Branch	Chemical Analysis Materials Technician
Jeremy Knipple	**Stinger Ghaffarian Technologies** Code 541 Materials Engineering Branch	Chemical Analysis Materials Engineer
Carlos Soares	**Jet Propulsion Laboratory** Code 353D Contamination Control Engineering	Mars 2020 Contamination Control Engineer/Group Lead
Mario Martins	**Edge Space Systems** Code 545 Thermal Engineering Branch	Vacuum Chamber Operations/Thermal Engineer
Cody Hawkins	**NASA Goddard Space Flight Center** Code 546 Contamination and Coatings Engineering Branch	Thermal Coatings Summer Intern

Abstract

The Molecular Adsorber Coating (MAC) is a sprayable coatings technology that was developed at NASA Goddard Space Flight Center (GSFC). The coating is comprised of highly porous, zeolite materials that help capture outgassed molecular contaminants on spaceflight applications. The adsorptive capabilities of the coating can alleviate molecular contamination concerns on or near sensitive surfaces and instruments within a spacecraft. This paper will discuss the preliminary testing of NASA's MAC technology for use on future missions to Mars. The study involves evaluating the coating's molecular adsorption properties in simulated test conditions, which include the vacuum environment of space and the Martian atmosphere. MAC adsorption testing was performed using a commonly used plasticizer called dioctyl phthalate (DOP) as the test contaminant.

- ***Keywords:*** *molecular adsorber coating, molecular adsorbers, getters, MAC, zeolite, coatings technology, outgassing, molecular contamination, contamination control, vacuum chamber, Martian environment, Mars, CO2, carbon dioxide, dioctyl phthalate, DOP, plasticizer*

Presentation Outline

INTRODUCTION	▪ Mars Exploration ▪ Molecular Adsorber Coatings
APPROACH	▪ Test Background ▪ Sample Fabrication ▪ Sample Conditioning ▪ Test Configuration ▪ Contaminant Source ▪ Test Run Summary ▪ Chamber Background Run ▪ Contaminant Baseline Runs ▪ Sample Test Runs ▪ Test Parameter Comparison
TEST METHODS	▪ Test Analysis Summary ▪ Gravimetric Analysis Method ▪ Chemical Analysis Methods
RESULTS & DISCUSSION	▪ Gravimetric Analysis Results ▪ Chemical Analysis Results
SUMMARY	▪ Conclusions ▪ Future Work

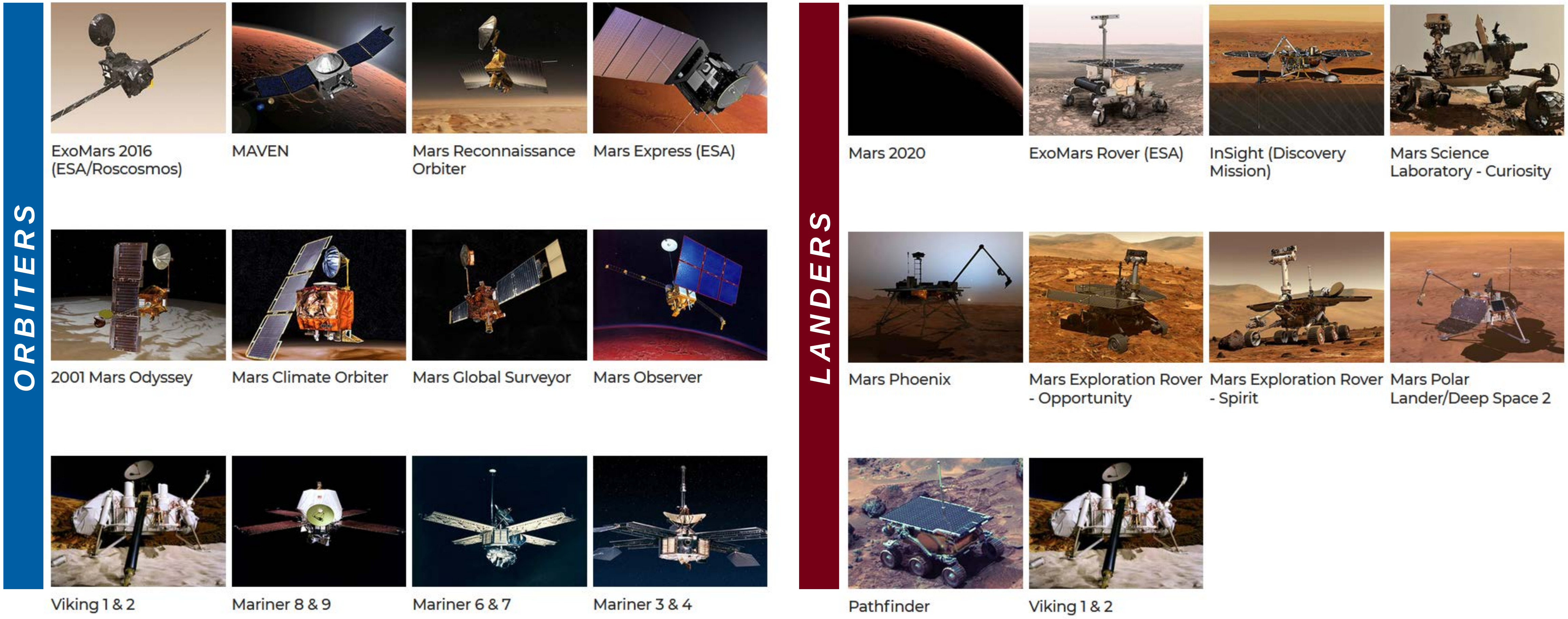
IMAGE CREDIT: NASA/JPL CAL-TECH

Introduction

- Mars Exploration
- Molecular Adsorber Coatings

Mars Exploration

- For many decades, NASA and its international partners have been at the forefront of Mars exploration through a series of missions, which have included orbiters and landers



SCREEN SHOT SOURCE: HTTPS://MARS.NASA.GOV/MARS-EXPLORATION/MISSIONS

IMAGE CREDIT: NASA

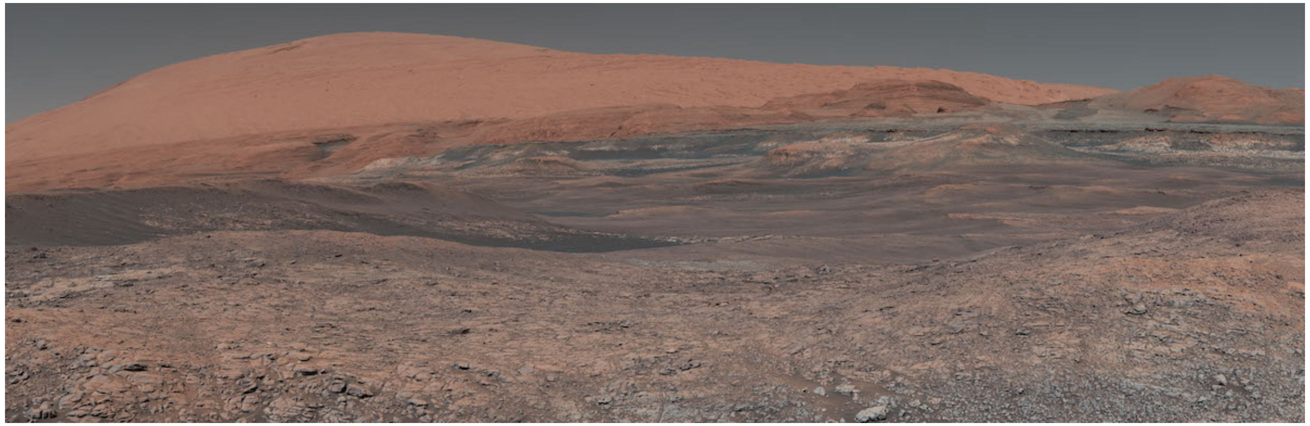
Mars Exploration

IMAGE CREDIT: NASA/KSC

- Mars is the 4th planet from the sun
- It is often referred to as the "Red Planet"
- The Mars Exploration Program (MEP) is led by NASA
- The program's **science goals** are to:
  - Determine the potential for prior habitability and biological life
  - Understand the processes and history of climate on Mars
  - Study the geological origins and evolution of Mars
  - Pave the way towards human exploration in the future

Mars Exploration

- Highly sensitive, mobile laboratories abroad the rovers perform experiments, which include trace organic analysis of collected samples
- However, **cross-contamination** can interfere with the scientific findings because the presence of molecular contaminants can disguise potential signs of life or show false positives
- Maintaining cleanliness of the spacecraft through **all the phases of the mission** has become one of the most challenging aspects on upcoming Mars missions (i.e. Mars 2020 and ExoMars rovers)
  - **Thus, there is a current need to explore innovative contamination control mitigation methods**

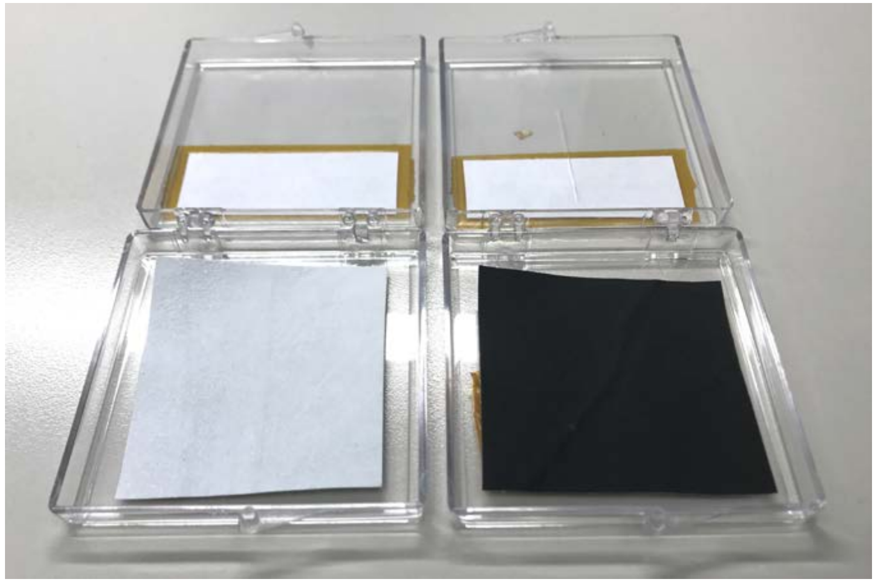


Images of Mount Sharp on Mars taken by the Mast Camera on NASA's Curiosity Rover

IMAGE CREDIT: NASA/JPL CAL-TECH

Molecular Adsorber Coatings

- MAC is an existing zeolite-based, sprayable coatings technology developed by NASA GSFC
- Used to mitigate molecular contamination concerns for various spaceflight applications
- Designed to **passively entrap outgassed species** that may otherwise deposit on critical instruments and components, and degrade the performance and the lifetime of NASA missions
  - *These outgassed contaminants may originate from commonly used materials on the spacecraft, such as adhesives, lubricants, epoxies, and potting compounds*
- Has been **ground tested** and **flight qualified** at some of the representative spaceflight conditions, which include high vacuum pressures and moderate temperature ranges
- Several NASA missions, such as ICON and JWST, have found practical applications for MAC



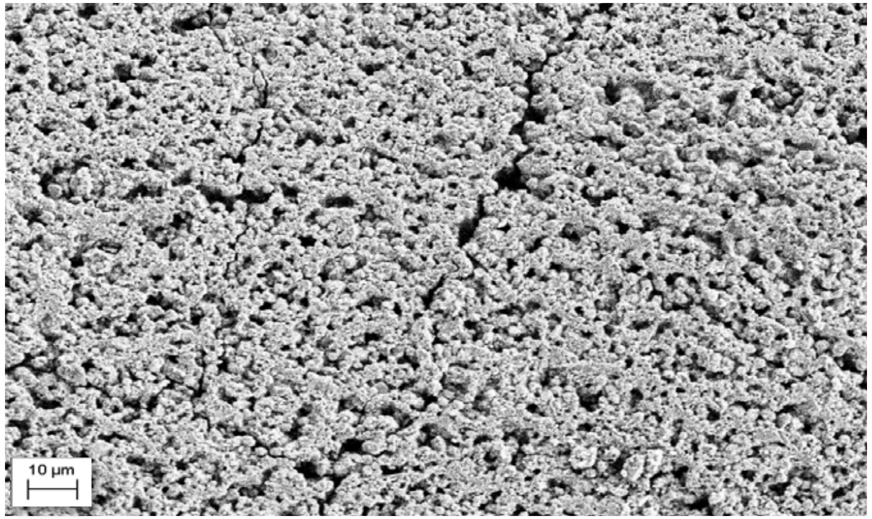


IMAGE CREDIT: NASA/GSFC

Molecular Adsorber Coatings

NASA Mission	Ionospheric Connection Explorer (ICON)	James Webb Space Telescope (JWST)
Type	Flight Application	Ground Application
Description	MAC plates were installed within ICON's contamination sensitive Far Ultraviolet (FUV) instrument to reduce the effects of on-orbit material outgassing	MAC samples have been extensively used as an effective contamination getter during vacuum chamber testing of JWST's critical flight and optical ground support hardware

IMAGE CREDIT: NASA/UC BERKLEY

IMAGE CREDIT: NASA/CHRIS GUNN

Reference: Abraham, Nithin S., Hasegawa, Mark M., and Secunda, Mark S., "Application of the Molecular Adsorber Coating technology on the Ionospheric Connection Explorer program", Proc. SPIE 9952, Systems Contamination: Prediction, Control, and Performance 2016, 99520D (September 2016)

Reference: Abraham, Nithin S., Hasegawa, Mark M., Wooldridge, Eve M., and Henderson-Nelson, Kelly A., "The use of the Molecular Adsorber Coating technology to mitigate vacuum chamber contamination during Pathfinder testing for the James Webb Space Telescope", Proc. SPIE 9952, Systems Contamination: Prediction, Control, and Performance 2016, 99520C (September 2016)

Approach

- Test Background
- Sample Fabrication
- Sample Conditioning
- Test Configuration
- Contaminant Source
- Test Run Summary
- Chamber Background Run
- Contaminant Baseline Runs
- Sample Test Runs
- Test Parameter Comparison

Test Background

- A preliminary study was performed to evaluate the molecular adsorption properties of MAC in **two relevant environments** for future Mars exploration missions

	Phase A	Phase B
Simulated Environment	Vacuum of Space	Mars Atmosphere
Test Pressure Range	High Vacuum (10^{-7} Torr)	Low Vacuum (7 Torr)
Test Gas Purge	-	Carbon Dioxide

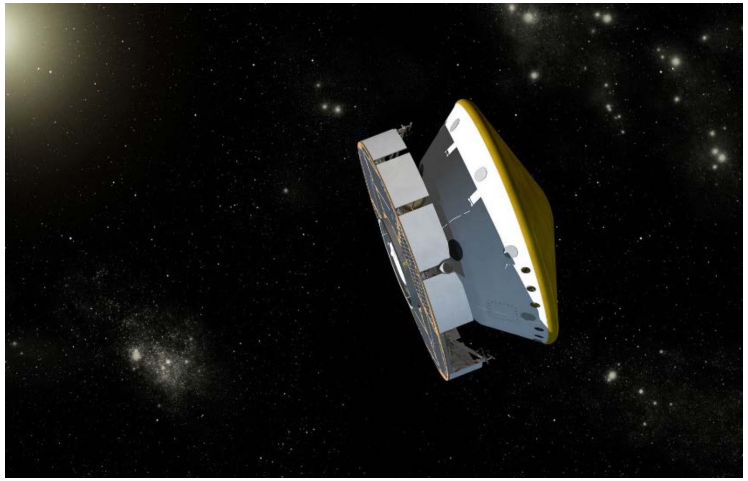


IMAGE CREDIT: NASA/JPL-CALTECH

- **Phase A simulates the voyage of the spacecraft in space to Mars**
- The cruise period can typically vary depending on the launch conditions, such as the orbit between Earth and Mars, as well as, the propulsion technology that is available
- The average journey to Mars from Earth is about **9 months**

Test Background

- A preliminary study was performed to evaluate the molecular adsorption properties of MAC in **two relevant environments** for future Mars exploration missions

	Phase A	Phase B
Simulated Environment	Vacuum of Space	Mars Atmosphere
Test Pressure Range	High Vacuum (10^{-7} Torr)	Low Vacuum (7 Torr)
Test Gas Purge	-	Carbon Dioxide

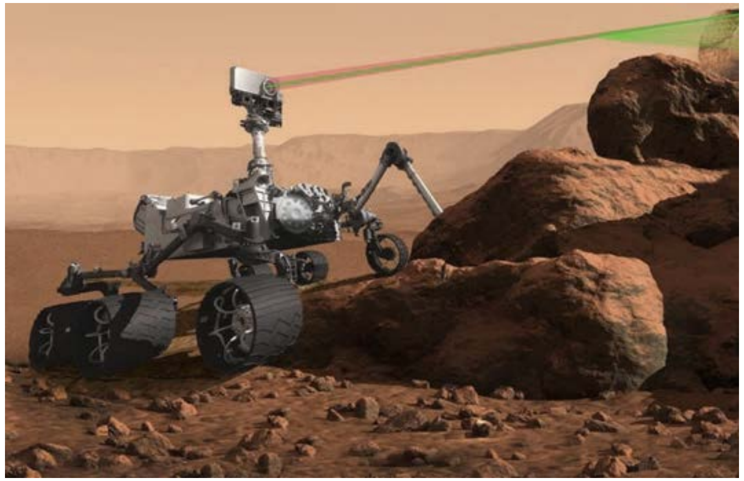


IMAGE CREDIT: NASA/JPL-CALTECH

- **Phase B simulates the contact of the spacecraft in the Martian atmosphere**
- The atmospheric pressure on the surface of Mars can vary from about 3 to 7 Torr depending on seasonal variations
- The Martian atmosphere is comprised of about **96% carbon dioxide** with trace levels of argon, nitrogen, and oxygen

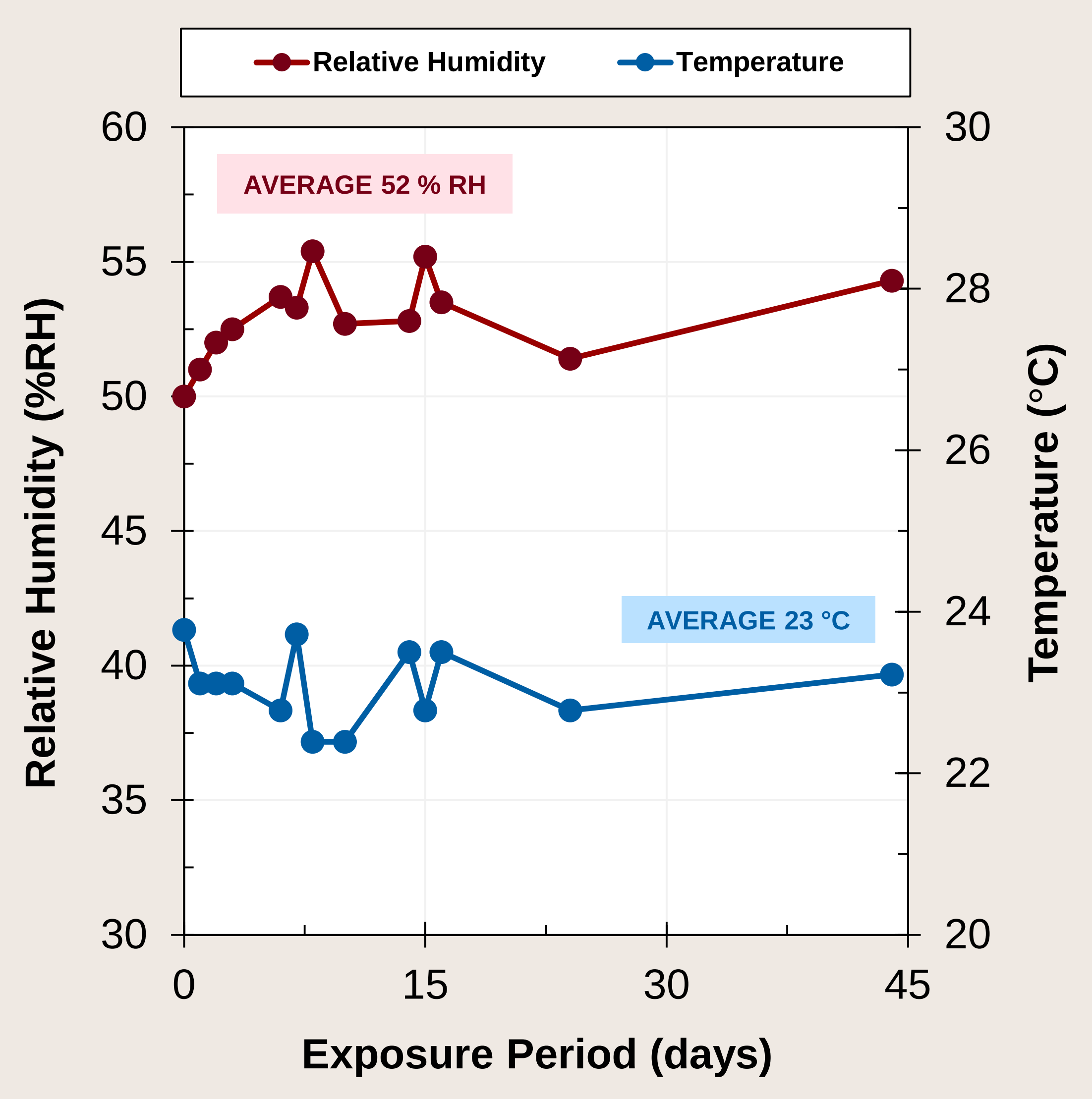
Sample Fabrication

- NASA GSFC fabricated a total of 26 aluminum foil samples
- Samples were coated with the white version of the MAC technology
- Samples were divided into **two batches** with two thickness variations
  - ***Note that 1 mil (or 1 thousandth of an inch) is equivalent to 25.4 microns***
- Coating area per sample was approximately **3.9 cm^2**

Batch ID	Number of Samples	MAC Type	Average Coating Thickness
I	13	MAC-W	7.2 mils ± 1.0
II	13	MAC-W	5.3 mils ± 1.0

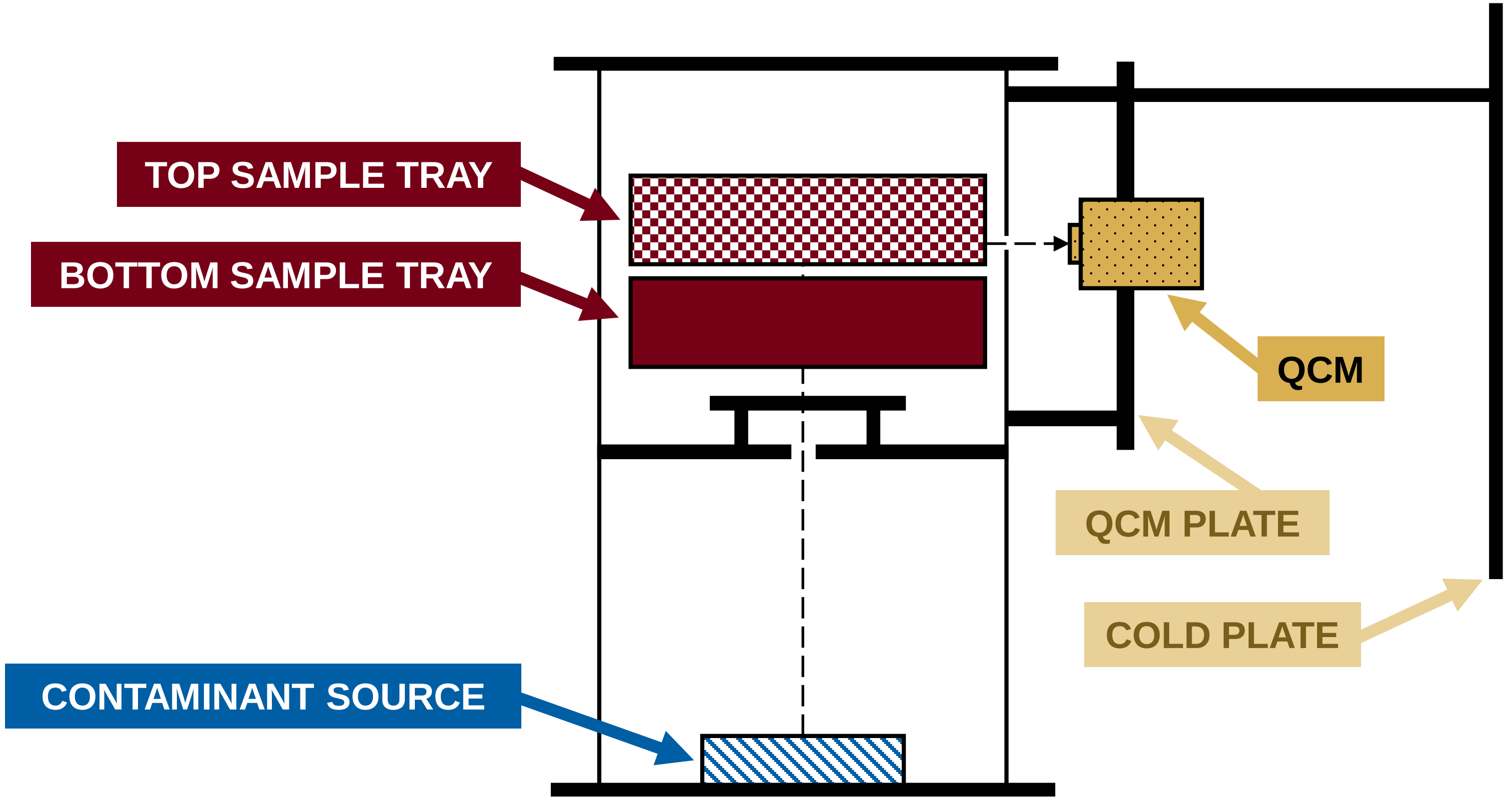
Sample Conditioning

- ATLO refers to the Assembly, Test, and Launch Operations phases of a NASA Mars mission
- During ATLO, flight hardware will be exposed to a relative humidity (RH) and temperature controlled environment until launch
- Similarly, the MAC samples were conditioned in a RH and temperature controlled laboratory for a duration of **approximately 45 days**
- This sample conditioning period simulates the expected exposure of the spacecraft components to ATLO conditions
- This period also helps evaluate any impact of moisture and trace levels of ambient, offgassed species in the room to MAC’s adsorption capabilities while not in use



Test Configuration

- Previous experiments have studied the molecular adsorption properties of MAC
- This experiment is performed by **saturating MAC samples with a known contaminant** source at a specified temperature within the confines of a test apparatus in a vacuum chamber



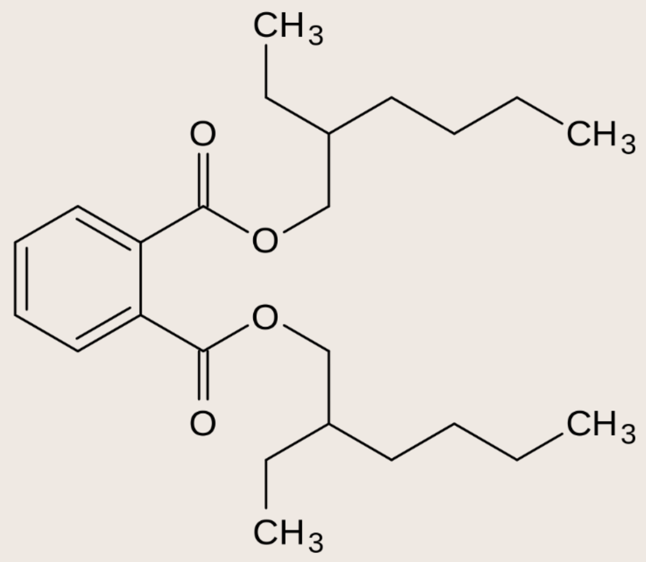
Test Apparatus	Vacuum Chamber
0.021 m^3	0.24 m^3

Quartz Crystal Microbalance

- The QCM was used to detect the flux of contaminants that escape the apparatus during the test
- The QCM rates provide a good indication for when the samples reach saturation, or approach its molecular adsorption capacity

Contaminant Source

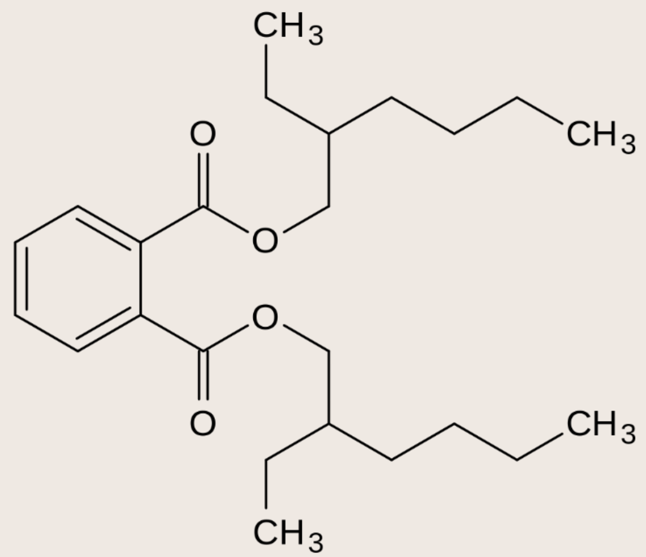
Chemical Name	Dioctyl phthalate
Chemical Formula	$C_{24}H_{38}O_4$
Molecular Weight	390.56 g/mol
Purity	≥ 99.5 %
Vendor	Sigma Aldrich



- Previous experiments have studied the molecular adsorption capacity of MAC using representative outgassed spaceflight contaminants
  - ***Simple, long-chain hydrocarbons***
    - ***Stearyl Alcohol***
  - ***Complex, silicone-based compounds***
    - ***DC-704 Diffusion Pump Oil***
- Plasticizers are also found in spaceflight applications, specifically on rinses of scavenger plates and cold fingers of vacuum chambers where spacecraft components are tested
- Therefore, a common plasticizer called **Dioctyl phthalate (DOP)** was selected as the contaminant source for these preliminary test efforts

Contaminant Source

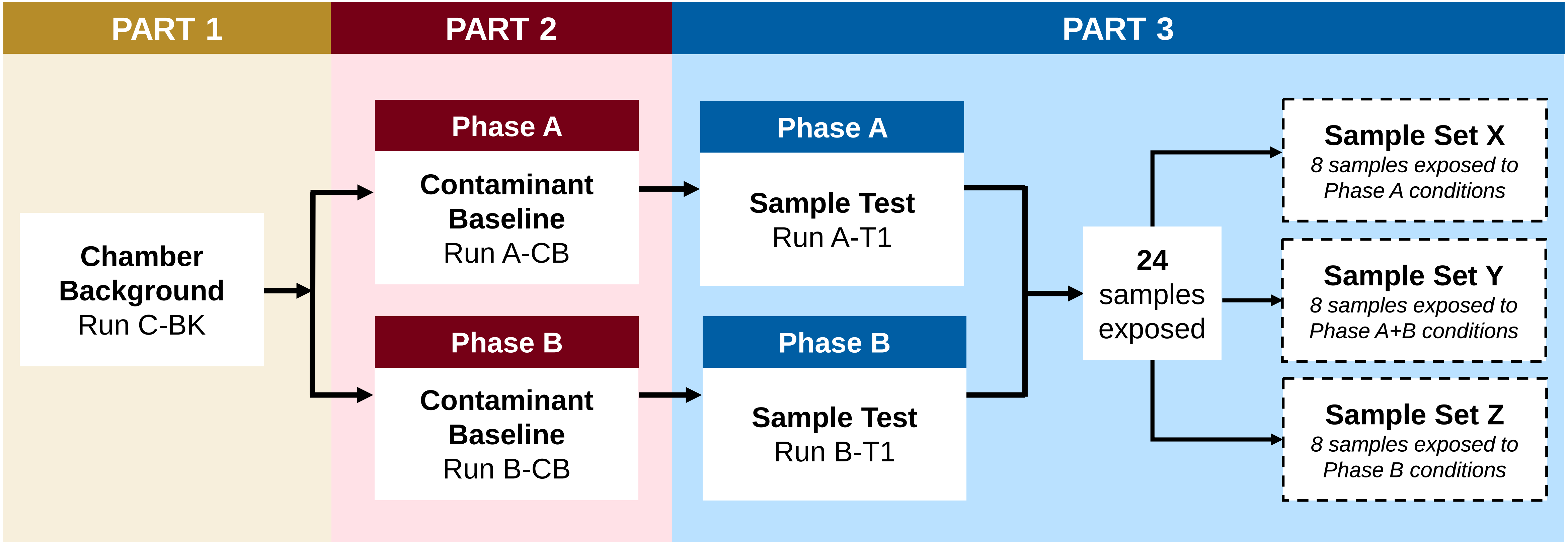
Chemical Name	Dioctyl phthalate
Chemical Formula	$C_{24}H_{38}O_4$
Molecular Weight	390.56 g/mol
Purity	≥ 99.5 %
Vendor	Sigma Aldrich



Dioctyl phthalate (DOP)

- Single component, high molecular weight plasticizer that is an ester of phthalic acid
- Commonly found in polymers, resins, elastomers, cosmetics and pesticides
- It appears as a colorless, odorless, oily non-volatile liquid
- Other chemical name synonyms include:
  - *Bis(2-ethylhexyl) phthalate*
  - *DEHP*
  - *Diethylhexyl phthalate*
  - *Phthalic acid bis(2-ethylhexyl ester)*

Test Run Summary



PHASE A	PHASE B
Space Environment	Mars Environment
High Vacuum Pressure (10^{-7} Torr)	Low Vacuum Pressure (7 Torr)
-	Carbon Dioxide Purge

PART		PHASE A	PHASE B	APPARATUS	CONTAMINANT	MAC
1	Chamber Background	X		X		
2	Contaminant Baseline	X	X	X	X	
3	Sample Test	X	X	X	X	X

Part 1. Chamber Background Run

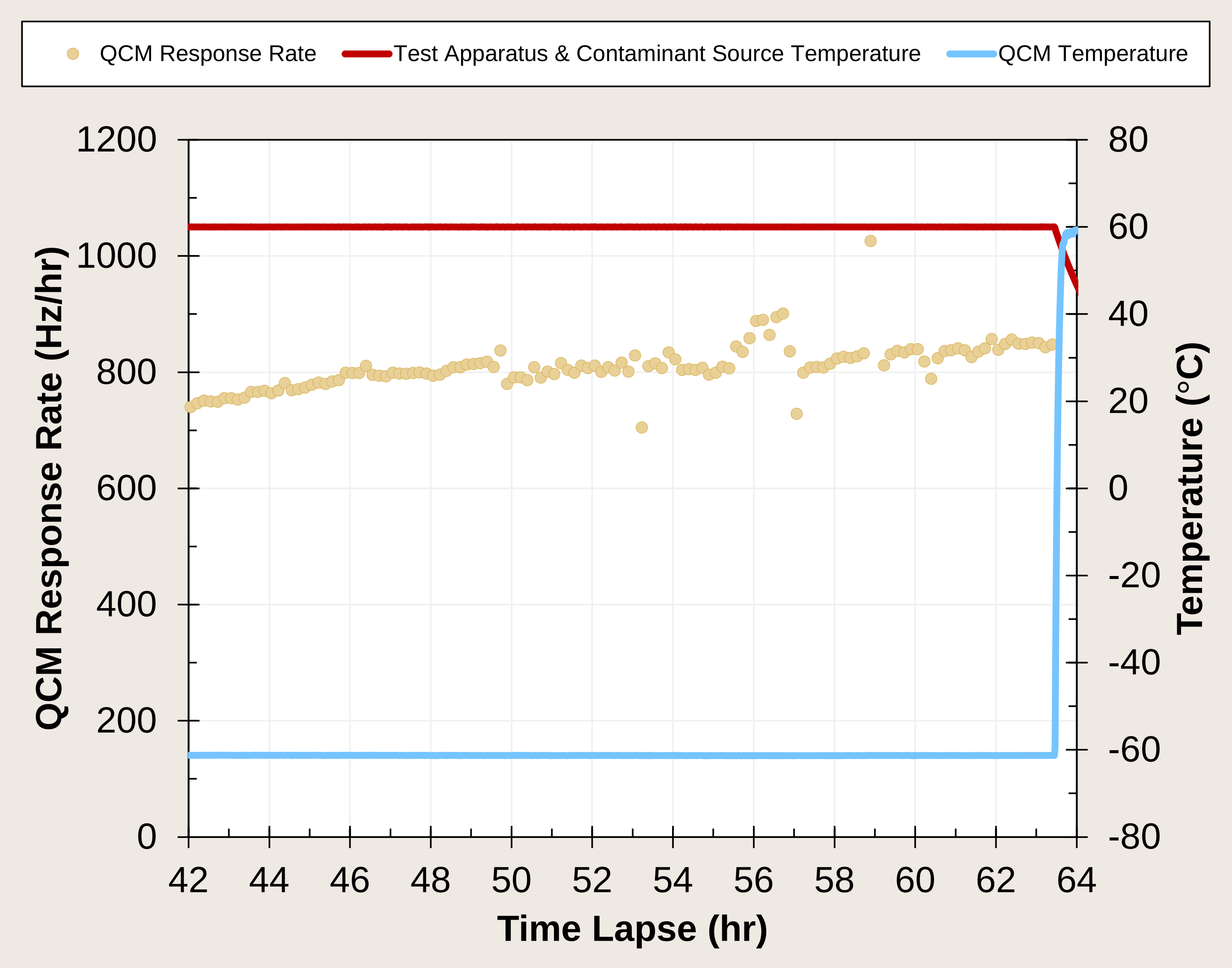
Phase A Conditions

- Performed **vacuum bake-out** of test apparatus at various temperatures
- Established final **background conditions** based on QCM response rates of the vacuum chamber

Test Duration	125 hours
Chamber Pressure	2.0 x 10^{-7} Torr
Number of Samples	-
Contaminant Mass	-
Contaminant Temperature	-
Apparatus Temperature	25, 45, 70 °C
Cold Plate Temperature	- 170 °C
QCM Temperature	- 60 °C
QCM Stabilization Rate	25 Hz/hr

IMAGE CREDIT: NASA/GSFC

Part 2. Contaminant Baseline Runs



Phase A Conditions

- Established QCM response rates of DOP at various temperatures in the absence of any MAC samples
- Criteria for DOP temperature selection:
  - ✓ *Provides an accelerated rate*
  - ✓ *Results in minimal maintenance of the QCM throughout the length of the test*

Test Duration	65 hours
Chamber Pressure	2.4 x 10^{-7} Torr
Number of Samples	-
Contaminant Mass	2.5 g
Contaminant Temperature	60 °C
Apparatus Temperature	60 °C
Cold Plate Temperature	- 170 °C
QCM Temperature	- 60 °C
QCM Stabilization Rate	840 Hz/hr

Part 2. Contaminant Baseline Runs

CHAMBER PUMPED DOWN TO ROUGH VACUUM

PUMP VALVE PARTIALLY CLOSED AND THROTTLED WHILE PURGING CO_2 INTO CHAMBER

CHAMBER ISOLATED WHEN STEADY PRESSURE OF 7 TORR WAS ACHIEVED

Phase B Conditions

- Attempted to establish QCM response rates of DOP at various temperatures in the absence of any MAC samples; however, **many challenges were experienced!**

CHALLENGE 1.

Occurrence of snow and ice build-up on the cold surfaces of the test components

Due to the presence of CO_2 in the system, which condensed on the cold surfaces

Therefore, QCM and cold plate temperatures were increased to 25 and 0 °C, respectively

CHALLENGE 2.

Difficultly reaching and maintaining temperatures of at least 60 °C

Likely due to the dominating convective heat transfer forces, and some limitations with heater power on the apparatus

Test apparatus and contaminant source temperatures were decreased to 45 °C

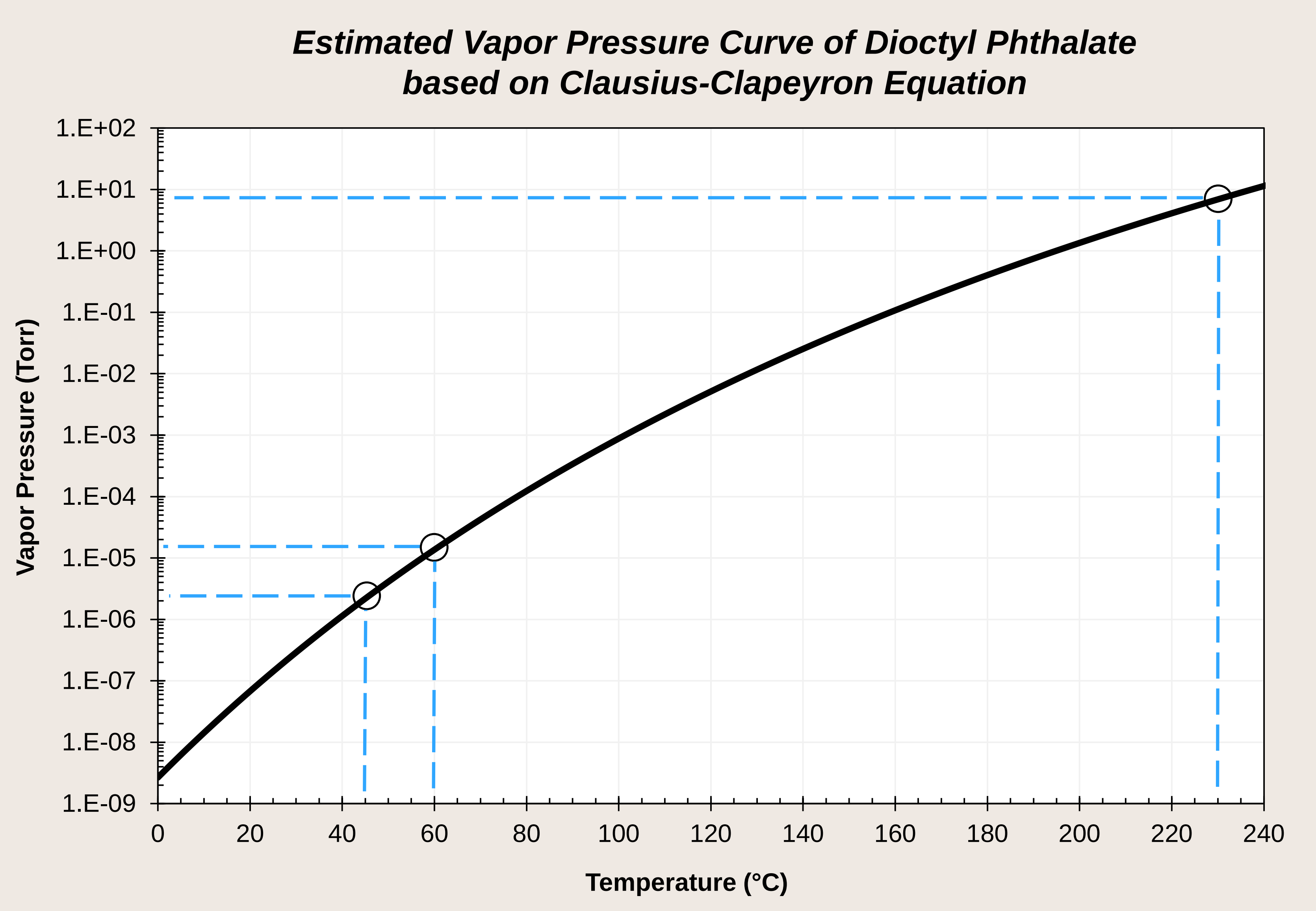
CHALLENGE 3.

Little to no detection of QCM rate deposition from either the contaminant source or the chamber background

Likely attributed to DOP not reaching its equilibrium vapor pressure

Therefore, since vapor pressure is a good indication of a liquid's evaporation rate, DOP may not easily evaporate at Phase B conditions

Part 2. Contaminant Baseline Runs



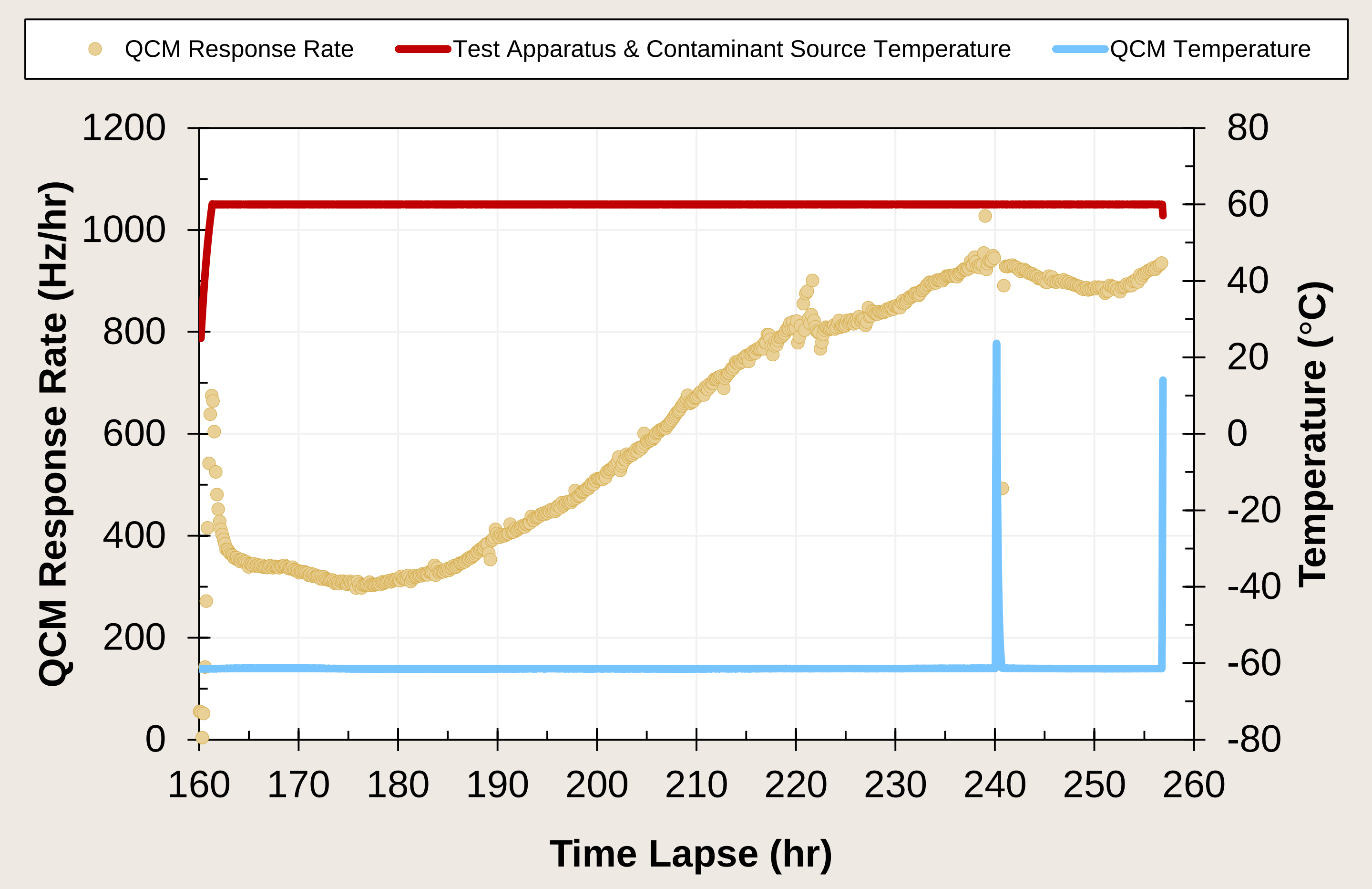
Vapor pressure of DOP at 45 °C was estimated at approximately 2.2 x 10^{-6} Torr

Estimated vapor pressure was calculated using the **Clausius-Clapeyron Equation**, where: [22]

$$ln\frac{P_1}{P_2} = \frac{H_{vap}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

- Gas constant, R, is 8.3145 J/mol-K
- Enthalpy of vaporization, H_{vap}, based on Perry and Weber data at 125 °C is 107.6 kJ/mol as referenced on NIST Chemistry WebBook [19-20]
- Vapor pressure of DOP at 25 °C per the Hazardous Substances Data Bank (HSDB) is 1.42 x 10^{-7} mmHg as referenced in the NIH Pub Chem Open Chemistry Database [21]

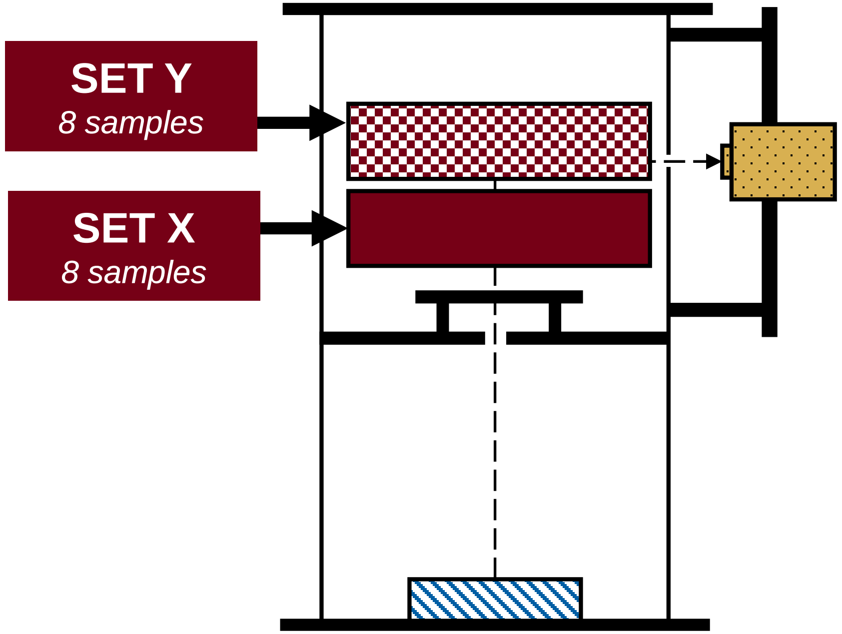
Part 3. Sample Test Runs



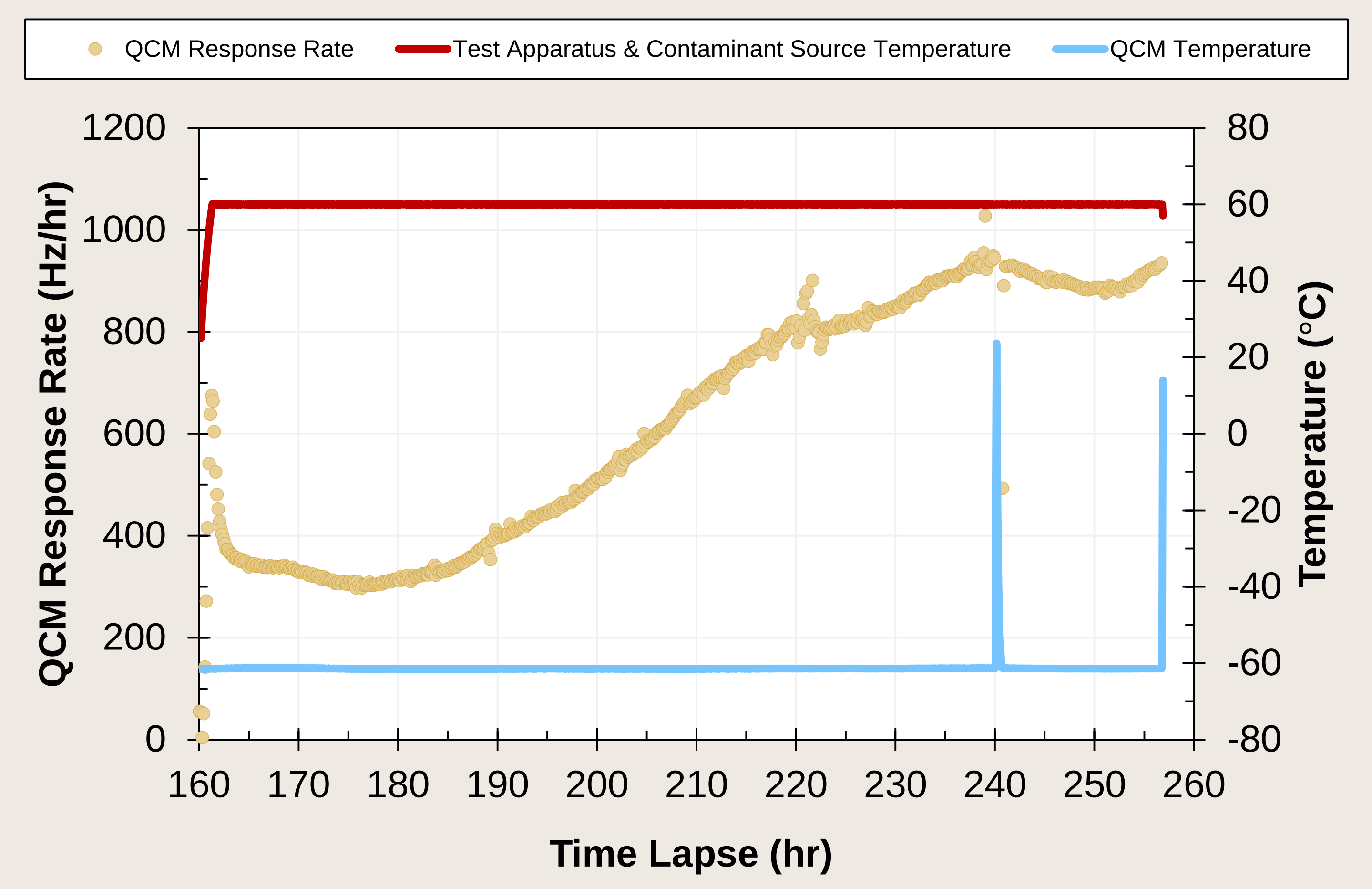
Test Duration	Apparatus Temperature	Contaminant Temperature	QCM Temperature	Cold Plate Temperature	Chamber Pressure	Sample Set (#)
100 hours	60 °C	60 °C	-60 °C	-170 °C	2.0 x 10^{-7} Torr	X (8), Y(8)

Phase A Conditions

- DOP from contaminant baseline runs was replenished to avoid depletion during sample test runs
- Total of 16 MAC samples
  - *Sample Set X and Set Y*



Part 3. Sample Test Runs

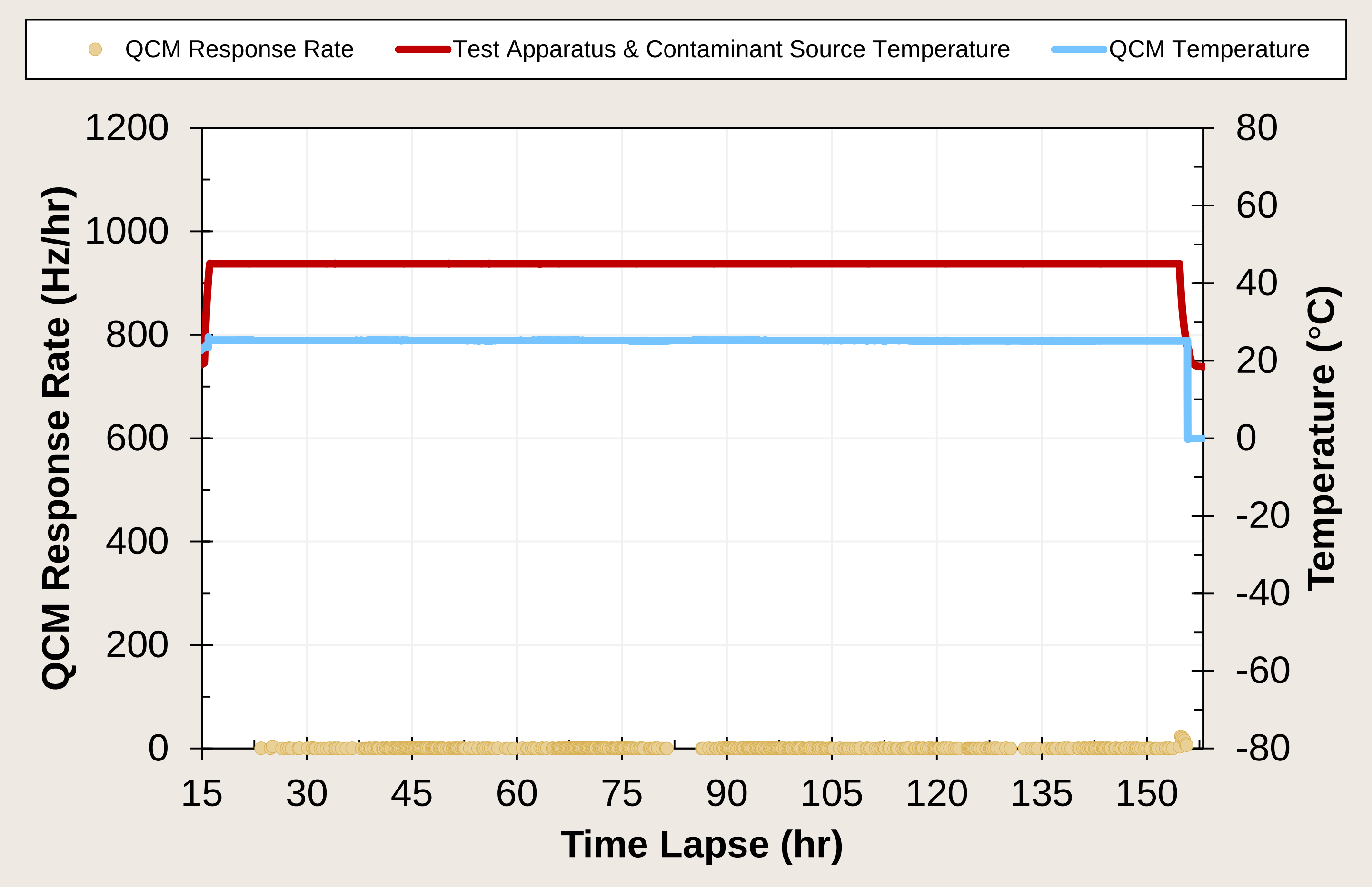


Test Duration	Apparatus Temperature	Contaminant Temperature	QCM Temperature	Cold Plate Temperature	Chamber Pressure	Sample Set (#)
100 hours	60 °C	60 °C	-60 °C	-170 °C	2.0×10^{-7} Torr	X (8), Y(8)

Phase A Conditions

- QCM rate **initially drops** from 650 to 300 Hz/hr, which is attributed to the entrapment of outgassed DOP onto the pores of MAC
- Rate **gradually increases** towards its baseline at 840 Hz/hr, which is due to the surface adsorption sites on MAC filling up, or reaching its saturation with DOP; thus, more species are exiting the test apparatus and depositing onto the QCM
- QCM rate appears to level off between 870 and 940 Hz/hr
  - *The increased shift from the baseline may be due to excessive DOP build-up on the QCM crystal*

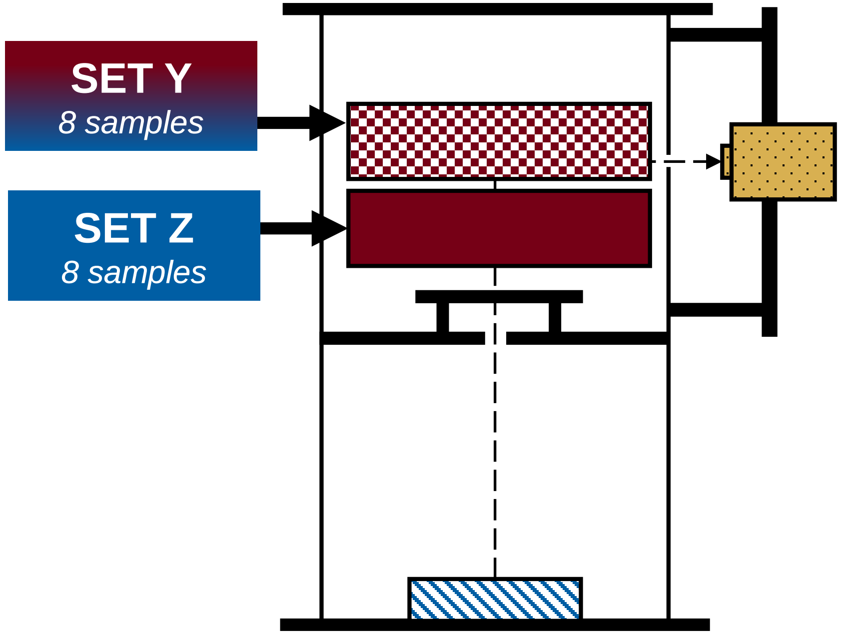
Part 3. Sample Test Runs



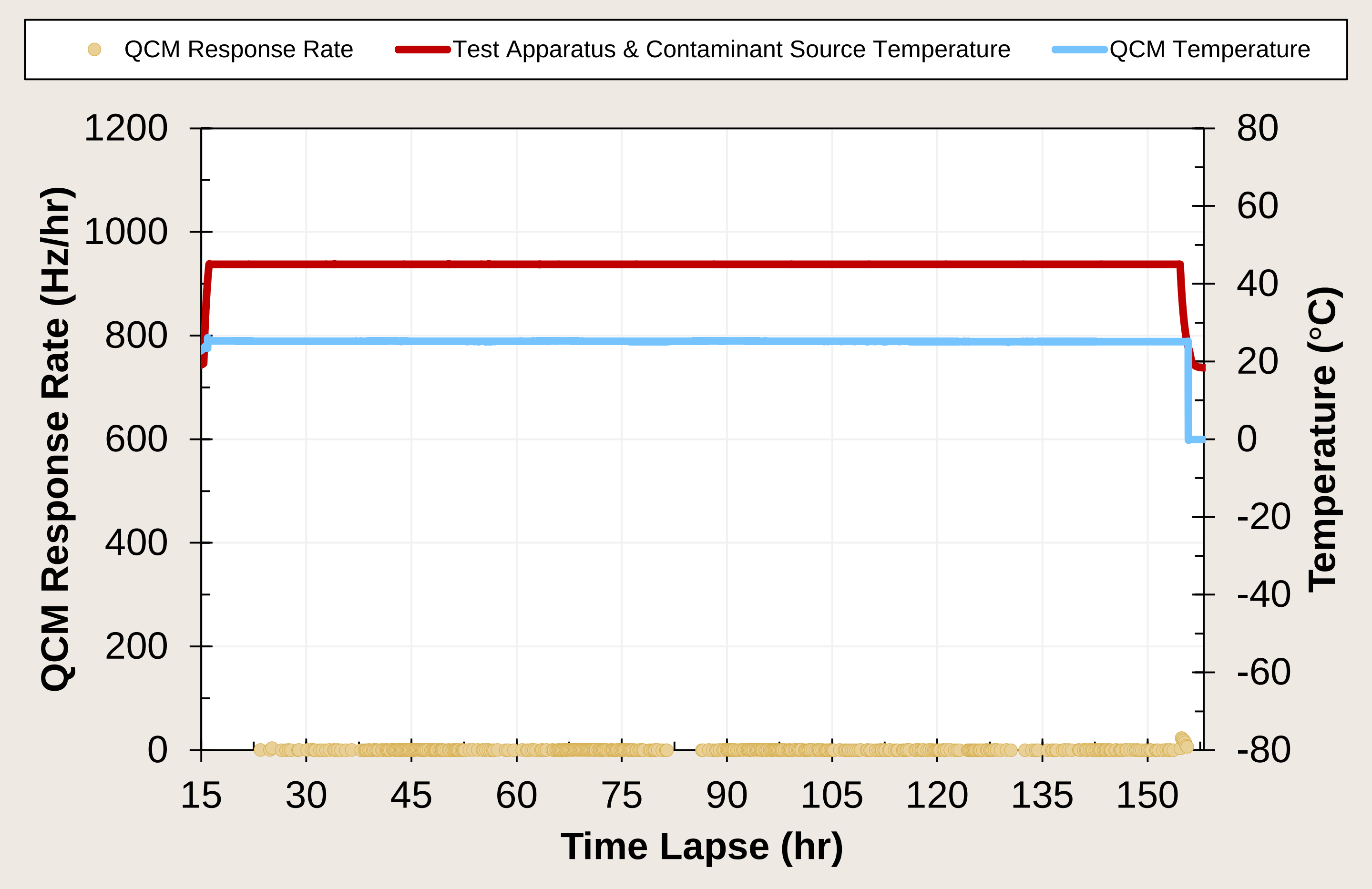
Test Duration	Apparatus Temperature	Contaminant Temperature	QCM Temperature	Cold Plate Temperature	Chamber Pressure	Sample Set (#)
140 hours	45 °C	45 °C	25 °C	0 °C	7 Torr	Z (8), Y(8)

Phase B Conditions

- Total of 16 MAC samples
  - Set Z (new samples)
  - Set Y previously contaminated during Phase A sample test run



Part 3. Sample Test Runs



Test Duration	Apparatus Temperature	Contaminant Temperature	QCM Temperature	Cold Plate Temperature	Chamber Pressure	Sample Set (#)
140 hours	45 °C	45 °C	25 °C	0 °C	7 Torr	Z (8), Y(8)

Phase B Conditions

- QCM detected little to no deposition of DOP or chamber background species, where ≤ 1 Hz/hr are likely invalid readings
- This made it **challenging** to determine when MAC will become saturated with DOP, if even possible!
- Thus, test was concluded with an additional 40 hrs more than Phase A

Measurement Period	Contaminant Mass	Mass Loss
Pre-Phase A	3.08 g	**0.74 g**
Post-Phase B	2.34 g	

Test Parameter Comparison

Part	PART 1		PART 2		PART 3	
Test Description	Chamber Background		Contaminant Baseline		Sample Tests	
Phase	A	B	A	B	A	B
Test Duration	125 hours	-	65 hours	-	100 hours	140 hours
Chamber Pressure	2.0×10^{-7} Torr	-	2.4×10^{-7} Torr	7 Torr	2.0×10^{-7} Torr	7 Torr
Number of Samples	-	-	-	-	16	16
Contaminant Mass	-		2.5 g		3.1 g	
Contaminant Temperature	-	-	60 °C	45 °C	60 °C	45 °C
Apparatus Temperature	25, 45, 70 °C	-	60 °C	45 °C	60 °C	45 °C
Cold Plate Temperature	- 170 °C	-	- 170 °C	0°C	- 170 °C	0°C
QCM Temperature	- 60 °C	-	- 60 °C	25 °C	- 60 °C	25 °C
QCM Stabilization Rate	25 Hz/hr	-	840 Hz/hr	-	870-940 Hz/hr	≤ 1 Hz/hr

Test Methods

- Test Analysis Summary
- Gravimetric Analysis Method
- Chemical Analysis Methods

Test Analysis Summary

Gravimetric Analysis

Gravimetric Molecular Adsorption Capacity

- **SAMPLE SET X** – *Phase A | 8 samples*
- **SAMPLE SET Y** – *Phase A+B | 8 samples*
- **SAMPLE SET Z** – *Phase B | 8 samples*

Chemical Analysis — Method 1 | Batch I – 7.2 mils

Solvent Rinse Extraction

- **CONTROL** – *ATLO | 1 sample*
- **SAMPLE SET X** – *Phase A | 1 sample*
- **SAMPLE SET Y** – *Phase A+B | 1 sample*
- **SAMPLE SET Z** – *Phase B | 1 sample*

→ **Pyrolysis GC/MS**

Chemical Analysis — Method 2 | Batch II – 5.3 mils

Solvent Submerge Extraction

- **CONTROL** – *ATLO | 1 sample*
- **SAMPLE SET X** – *Phase A | 1 sample*
- **SAMPLE SET Y** – *Phase A+B | 1 sample*
- **SAMPLE SET Z** – *Phase B | 1 sample*

→ **Pyrolysis GC/MS**

Gravimetric Analysis Method

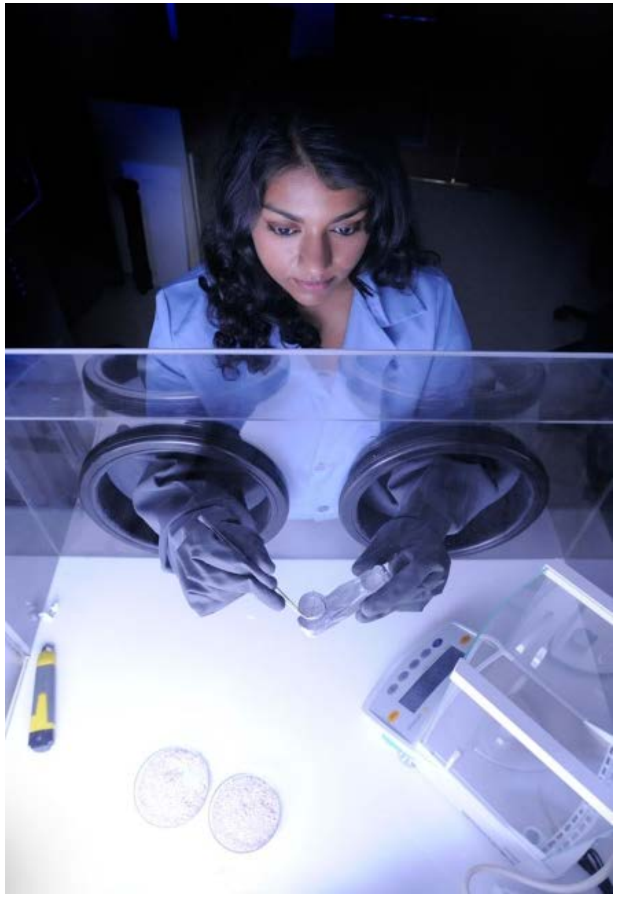


IMAGE CREDIT: NASA / PAT IZZO

- **Molecular Adsorption Capacity** is defined as the measure of MAC's **capability to adsorb or entrap outgassed materials**, or molecular contaminants
- Also referred to as molecular capacitance (units: g/cm^2)
- Dependent on various parameters, such as coating thickness, surface area coverage, type of contaminants, duration of exposure to contaminant, and other test conditions
- Calculated based on **mass changes in the coating** that are attributed to the entrapment of outgassed species
- Pre-exposure and post-exposure gravimetric measurements were performed in a **nitrogen purged dry glove box** at 25 °C and ≤ 5 %RH
- Samples were also exposed to vacuum for 48 to 72 hours prior to performing mass measurements to release any moisture
- A water absorption correction factor was incorporated to the calculated value to account for any errors associated with moisture

Chemical Analysis Methods

- 2 solvent extraction methods were performed:
  - **6 contaminated samples (3 per method)**
  - **2 control samples (1 per method)**

Chemical Analysis Objectives:

- Extract and verify the DOP entrapped in MAC
- Extract other adsorbed chemical species (if any), but only those that can be dissolved with chloroform
  - *Based on previous studies, these solvent extraction methods are not expected to remove all of the adsorbed contaminants from MAC*
- Compare results to calculated gravimetric molecular adsorption capacity

METHOD 1

Solvent Rinse

Surface of sample is rinsed with chloroform 3 times

METHOD 2

Solvent Submerge

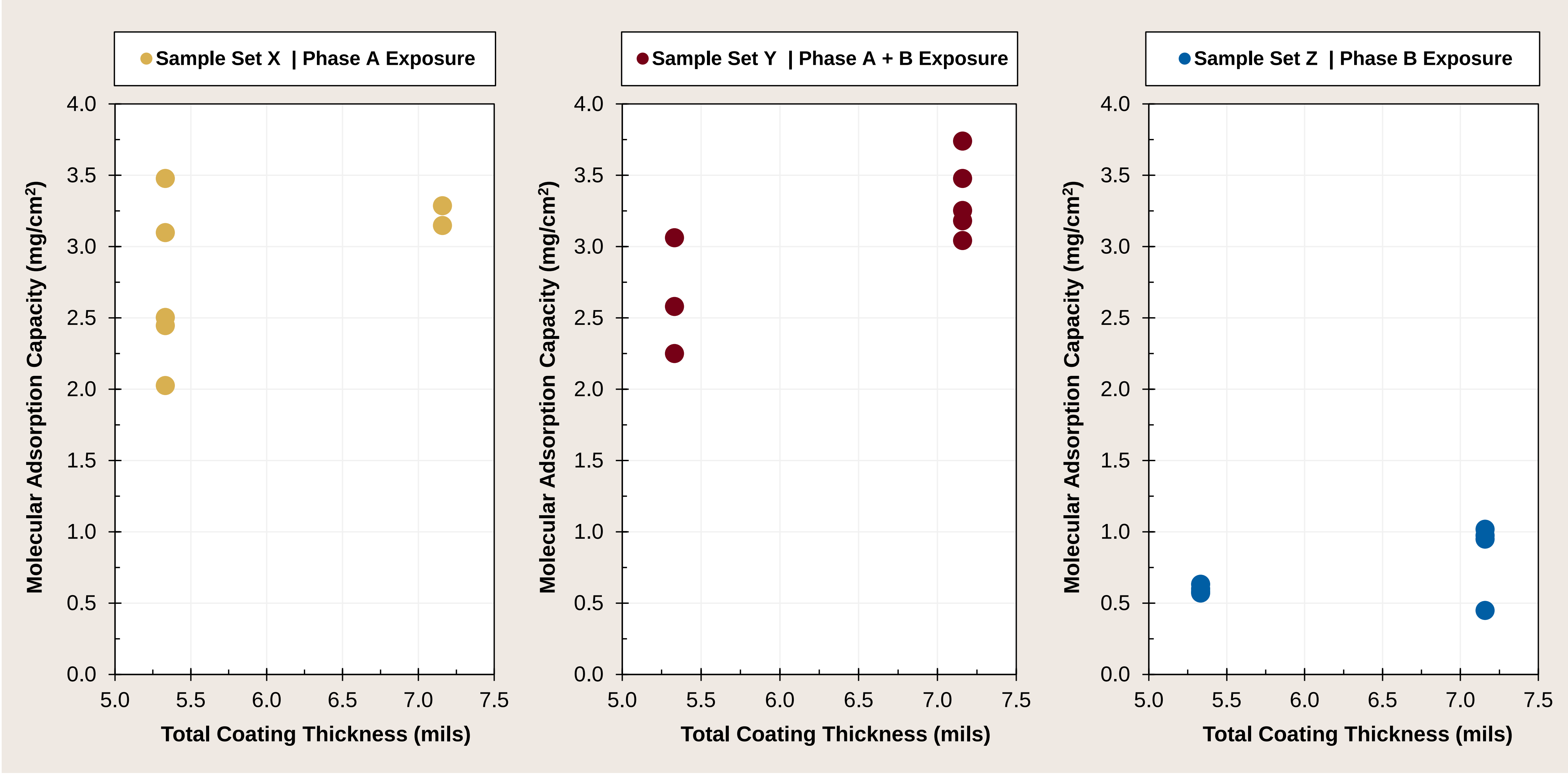
Sample is submerged in chloroform for 30 min over low heat on a heater plate

- Remaining **Non-Volatile Residue** (NVR) is weighed and analyzed qualitatively to provide a **general estimation** of the relative amounts and types of chemical species
- **Pyrolysis-Gas Chromatography/Mass Spectrometry** (GC/MS) is performed on NVR from both methods

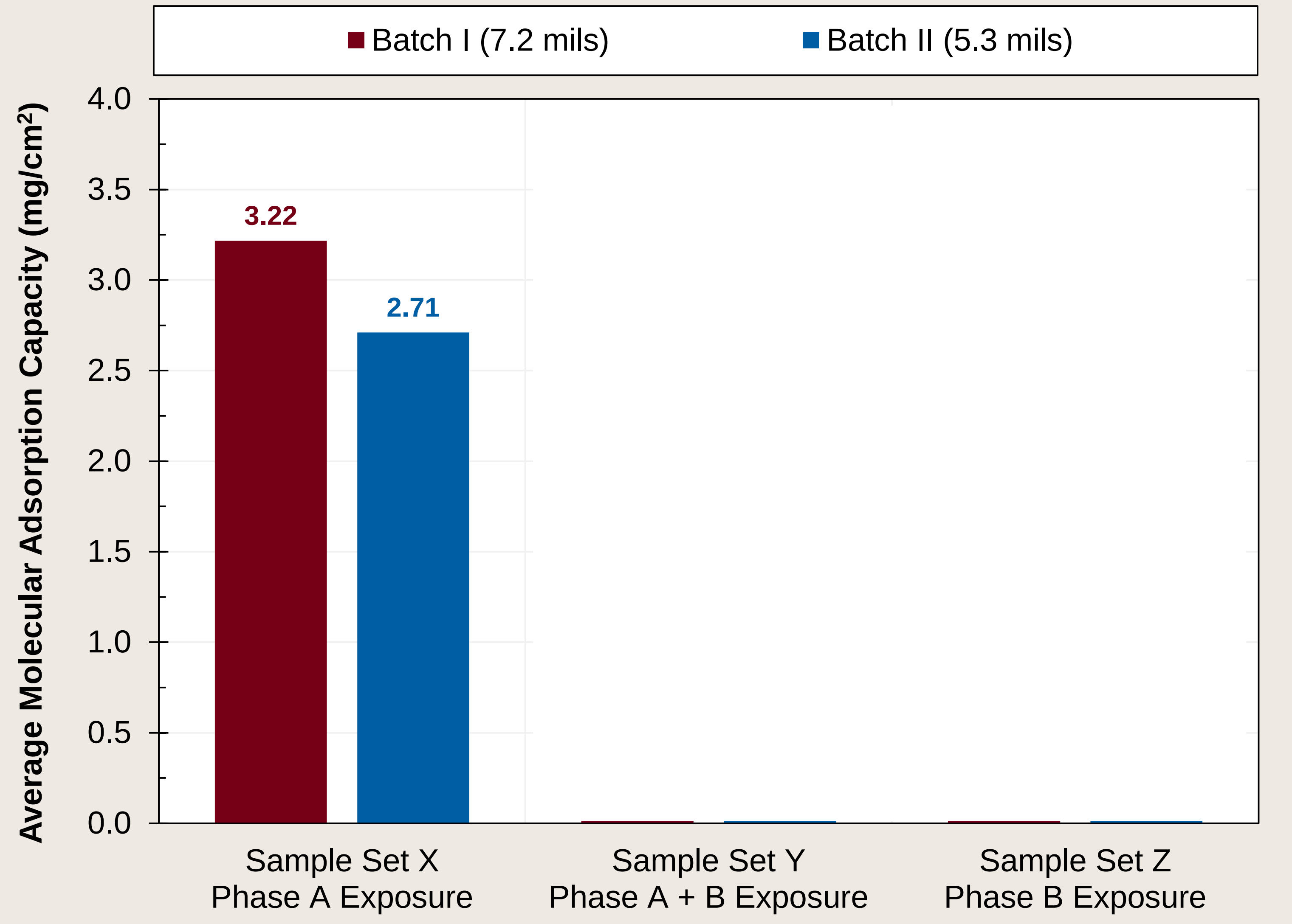
Results & Discussion

- Gravimetric Analysis Results
- Chemical Analysis Results

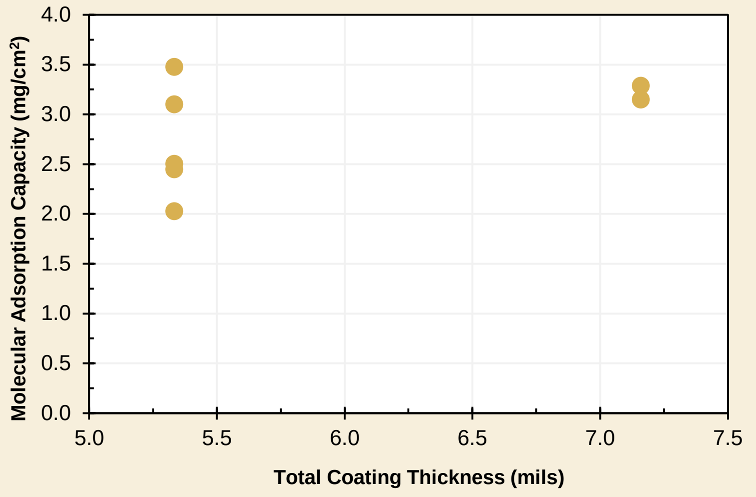
Gravimetric Analysis Results



Gravimetric Analysis Results

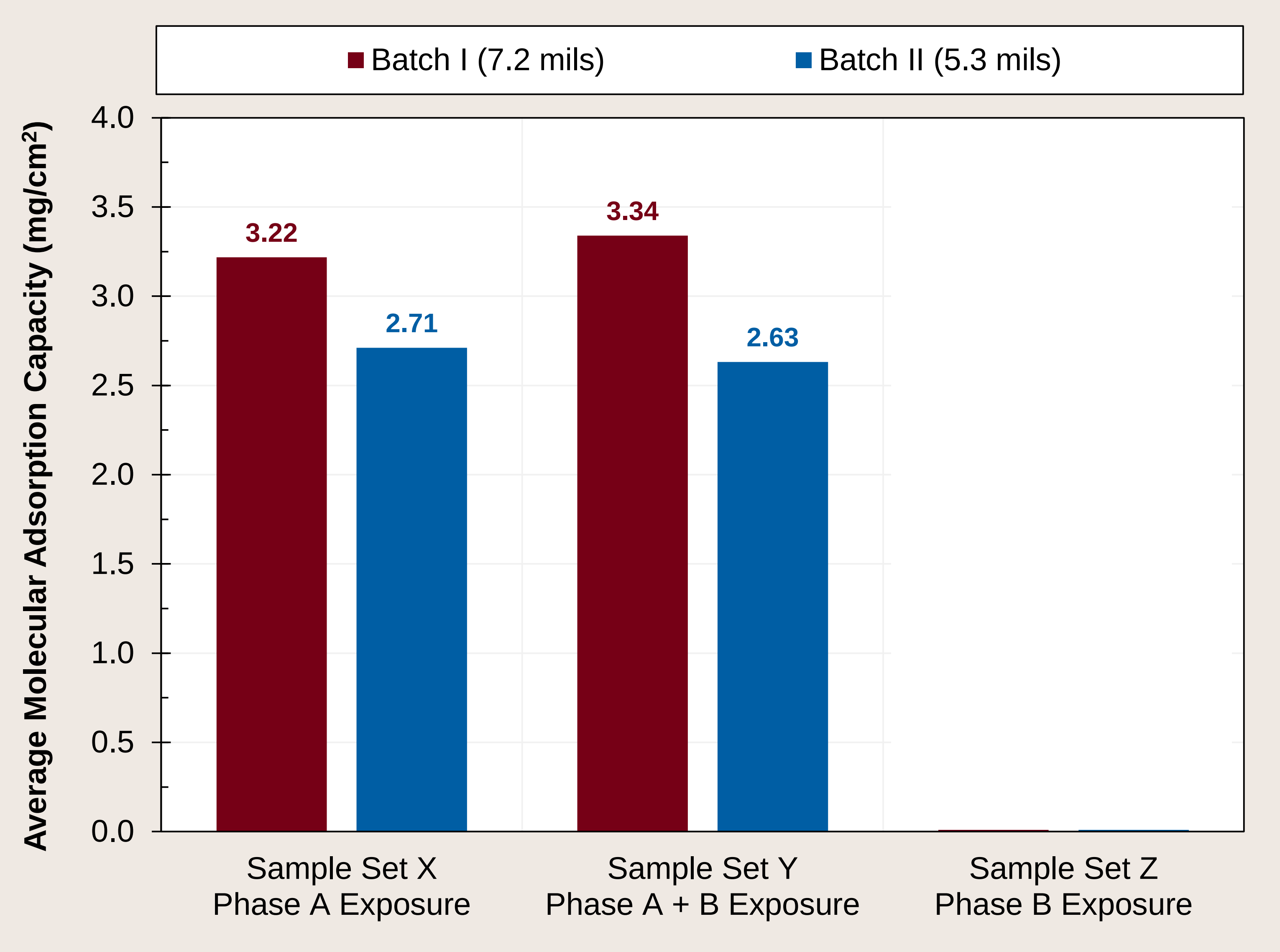


Sample Set X | Phase A Exposure

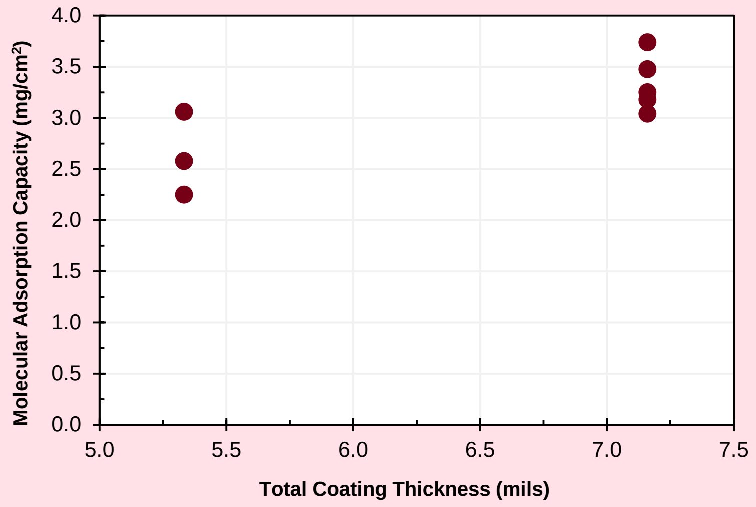


- On average, Batch II was **1.2 times less than** Batch I due to its slightly thinner coating thickness

Gravimetric Analysis Results

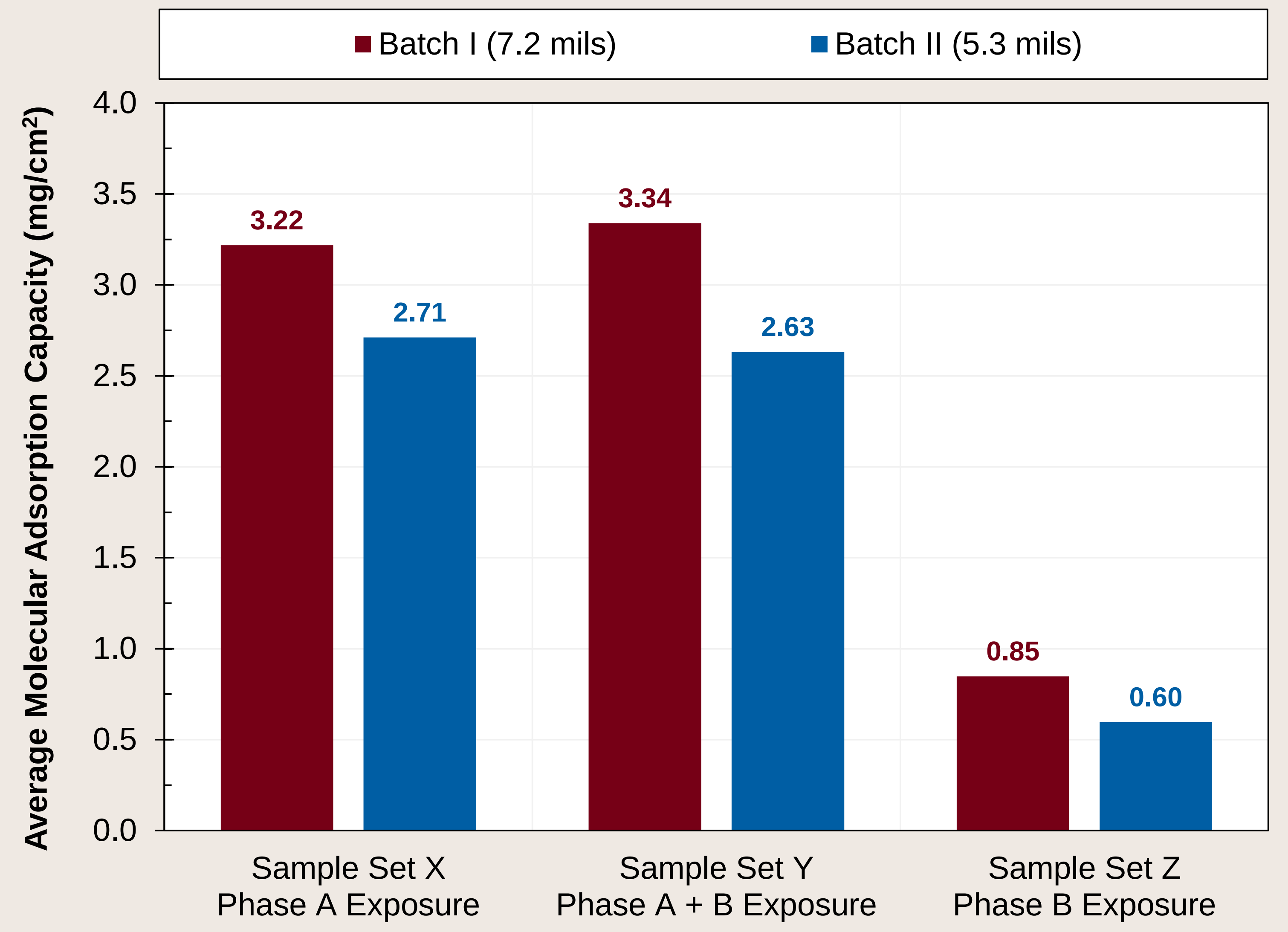


Sample Set Y | Phase A+B Exposure

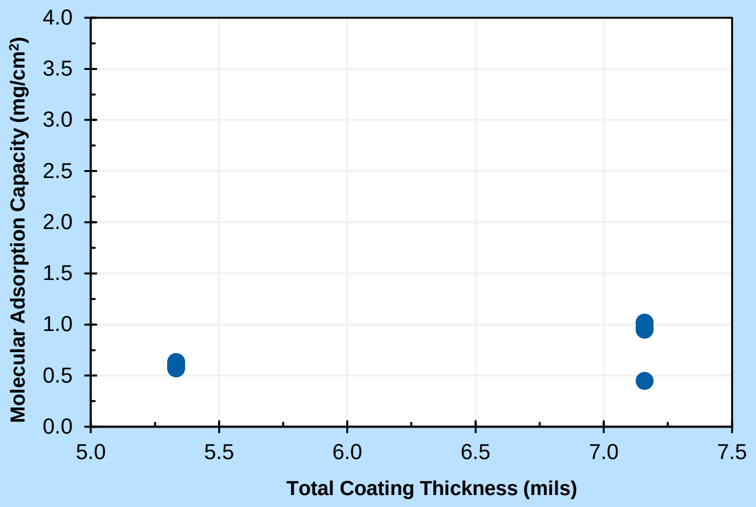


- On average, both batches in Set Y did not significantly differ from Set X
  - *Difference was within 0.1 mg/cm²*
- This suggests that Set Y **did not entrap** significant amounts of DOP during Phase B

Gravimetric Analysis Results

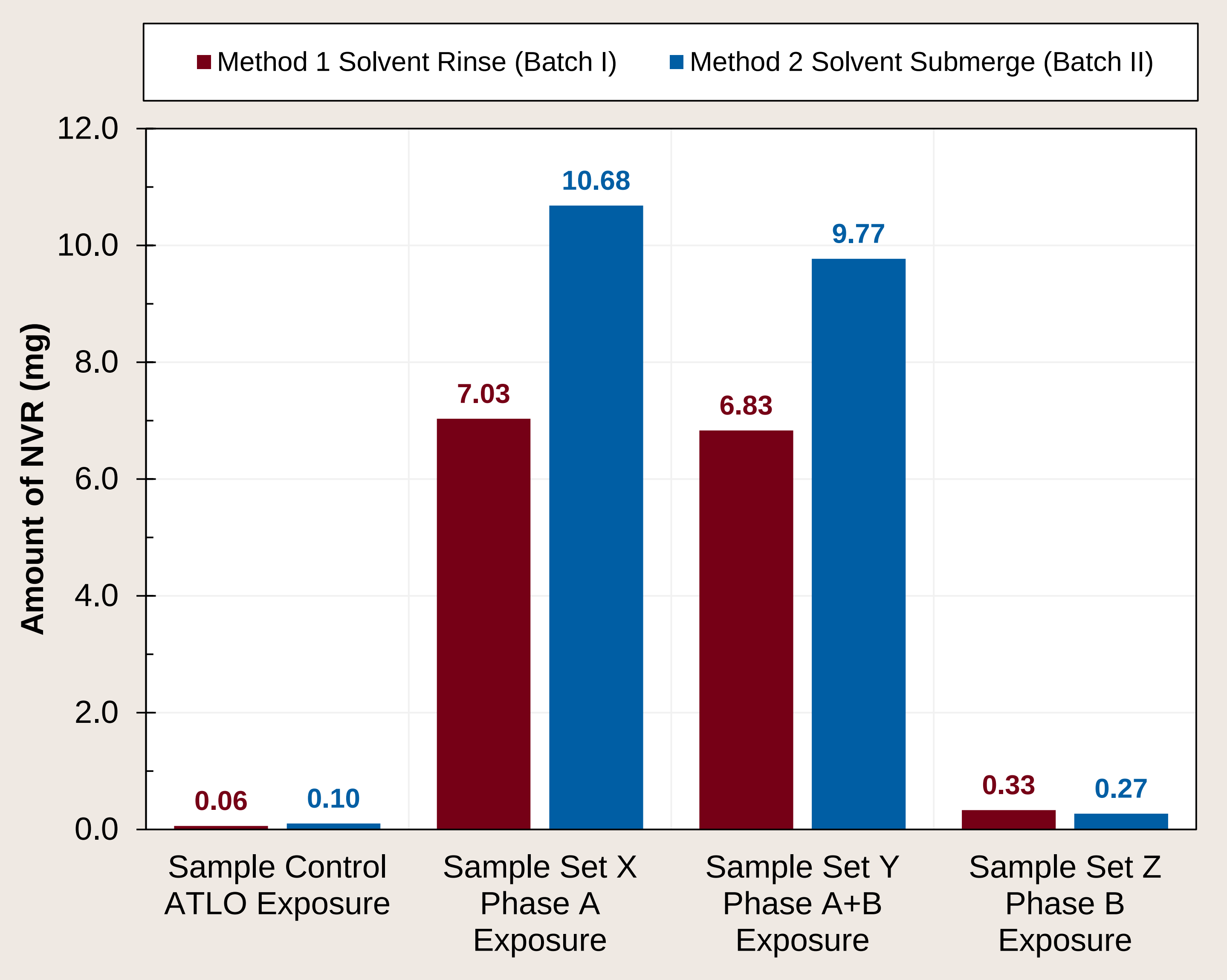


Sample Set Z | Phase B Exposure



- On average, Set Z was significantly **lower by a factor of 4** when compared to Set X and Y
- This suggests that it was unlikely that MAC approached saturation, and that very limited outgassing of DOP occurred in the low vacuum conditions of Phase B
- DOP most likely did not reach its vapor pressure at Phase B conditions; Regardless, some limited adsorption did occur within the allocated time frame of the test, possibly originating from the lingering DOP species that existed in the test apparatus from the previous Phase A exposure

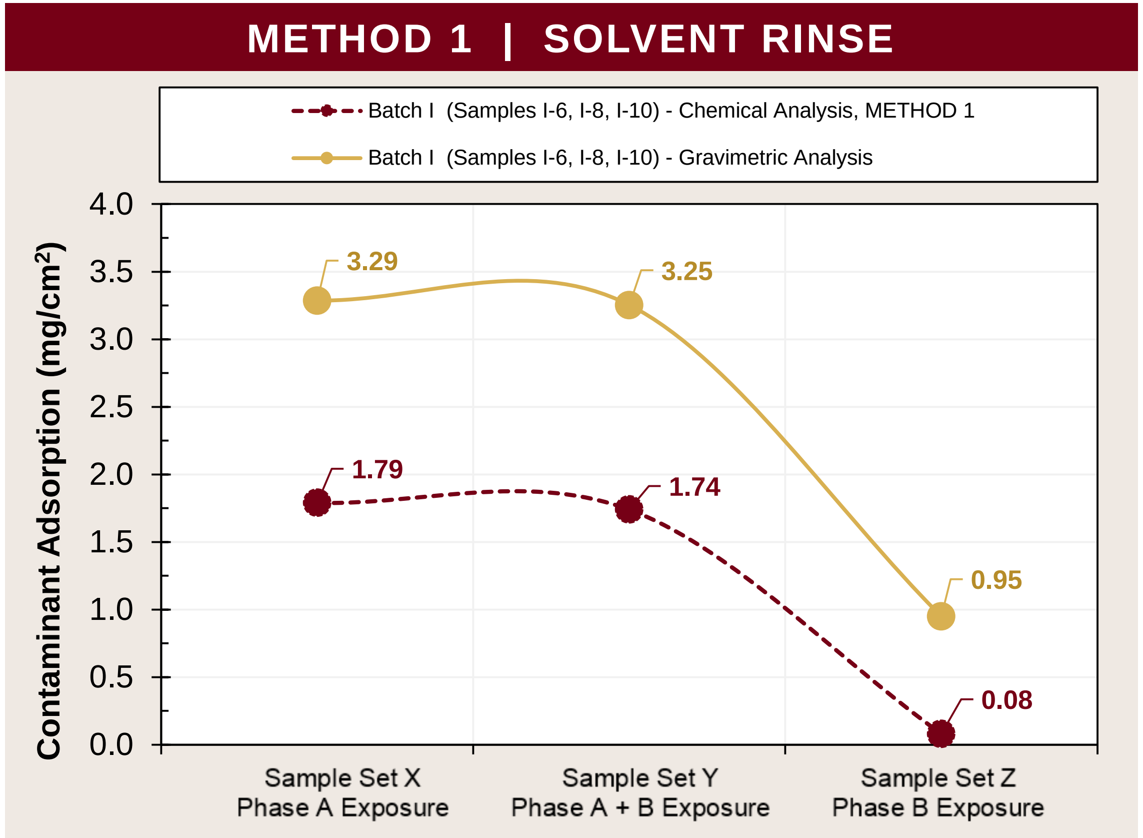
Chemical Analysis Results

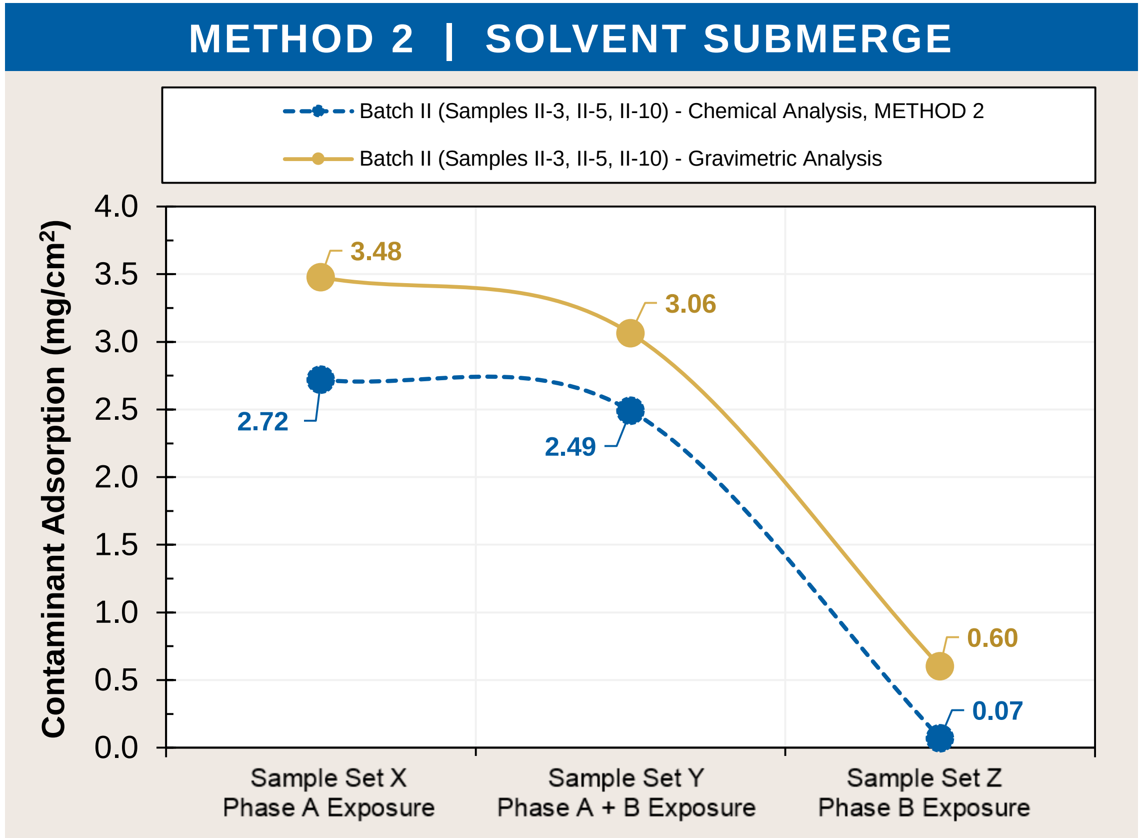


Set	Phase	Method 1	Method 2
X	A	117 x	107 x
Y	A+B	114 x	98 x
Z	B	6 x	3 x

- Method 2 resulted in higher amounts of NVR collection than Method 1
- Control (simulated ATLO exposed) samples had the least amount of NVR
- All contaminated samples collected greater amounts of NVR when compared to control samples
- Phase A appears to have the most amount of adsorbed species, whereas Phase B has the least amount of adsorbed species of the contaminated samples
- These trends are consistent with results achieved from the gravimetrically derived molecular adsorption capacity values

Chemical Analysis Results





- 3 samples with similar gravimetric values from each batch were compared to solvent extraction methods
- Solvent submerge method was closer to gravimetric values than solvent rinse methods for all phases
  - *Difference between Method 1 and gravimetric values ranged from 0.9 to 1.5 mg/cm^2*
  - *Difference between Method 2 and gravimetric values was slightly less, ranging from 0.5 to 0.8 mg/cm^2*

Chemical Analysis Results

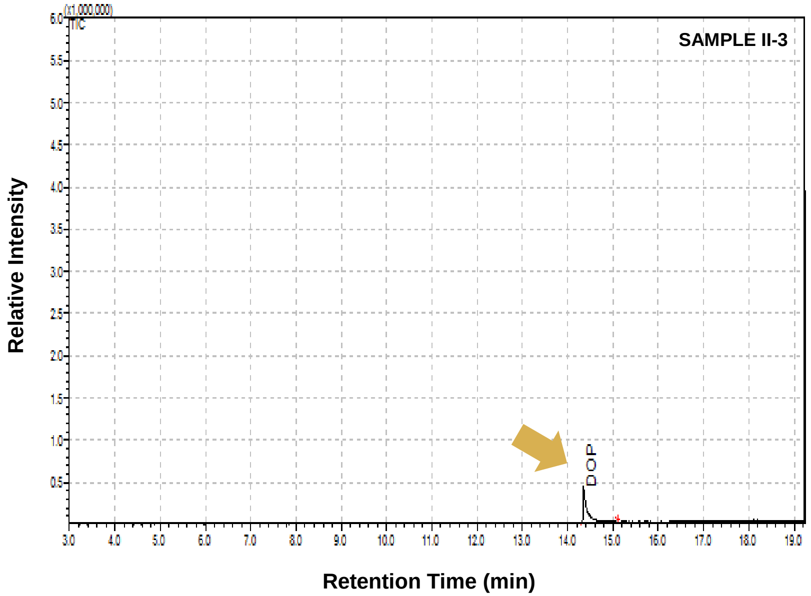
- Pyrolysis GC/MS results for all 6 contaminated samples from any phase exposure, regardless of the method used indicate that the **majority of NVR consisted of DOP**
- There were no other discernable peaks from the baseline noise

		METHOD 1 Solvent Rinse		METHOD 2 Solvent Submerge	
		Batch I (7.2 mils)		Batch II (5.3 mils)	
Exposure	**Sample Set**	**Sample**	**Chemical Species**	**Sample**	**Chemical Species**
ATLO	Control	I-14	No detectable organics	II-14	No detectable organics
Phase A	X	I-6	~ 100 % DOP	II-3	~ 100 % DOP
Phase A + B	Y	I-8	~ 100 % DOP	II-5	~ 100 % DOP
Phase B	Z	I-10	~ 100 % DOP	II-10	~ 100 % DOP

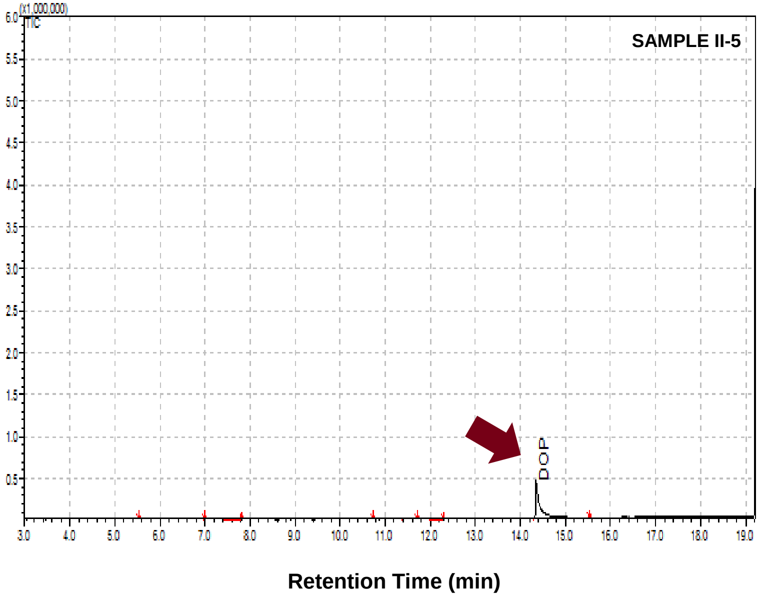
Chemical Analysis Results

- Shown are the GC/MS plots for the three contaminated samples that were analyzed using **Method 2: Solvent Submerge Extraction**
  - The relative intensity, or compound abundance, of DOP is the largest in the Phase B exposed sample
  - This is most likely attributed to the low amount of NVR compared to the samples from Sets X and Y

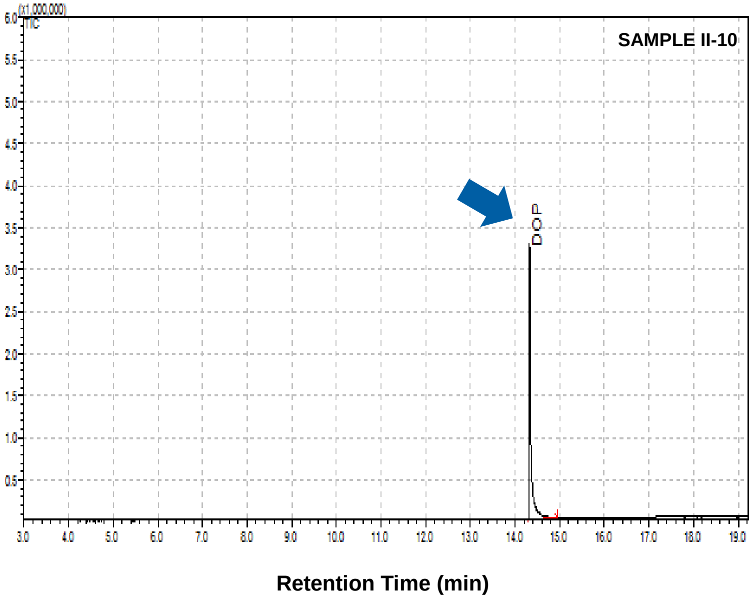
SAMPLE SET X, PHASE A EXPOSURE
Method 2, Solvent Submerge | Coating Batch II, 5.3 mils



SAMPLE SET Y, PHASE A+B EXPOSURE
Method 2, Solvent Submerge | Coating Batch II, 5.3 mils



SAMPLE SET Z, PHASE B EXPOSURE
Method 2, Solvent Submerge | Coating Batch II, 5.3 mils

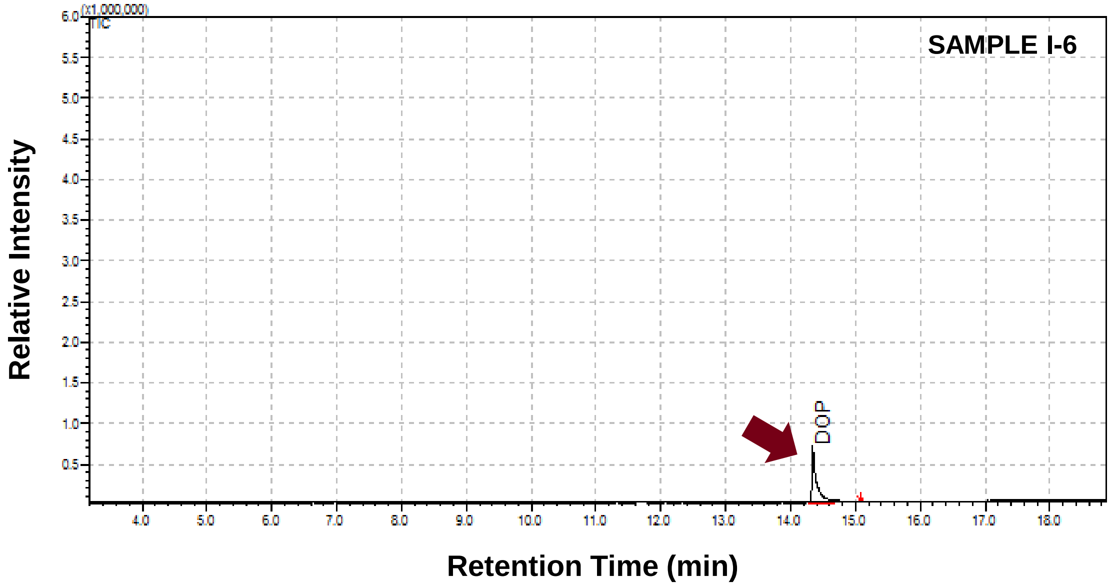


Chemical Analysis Results

- Similar trends were observed for the samples that were analyzed using **Method 1: Solvent Rinse Extraction**
- Shown are GC/MS plots that illustrate the similarities in the detection of the **DOP peak** in two Phase A exposed samples using both solvent extraction methods

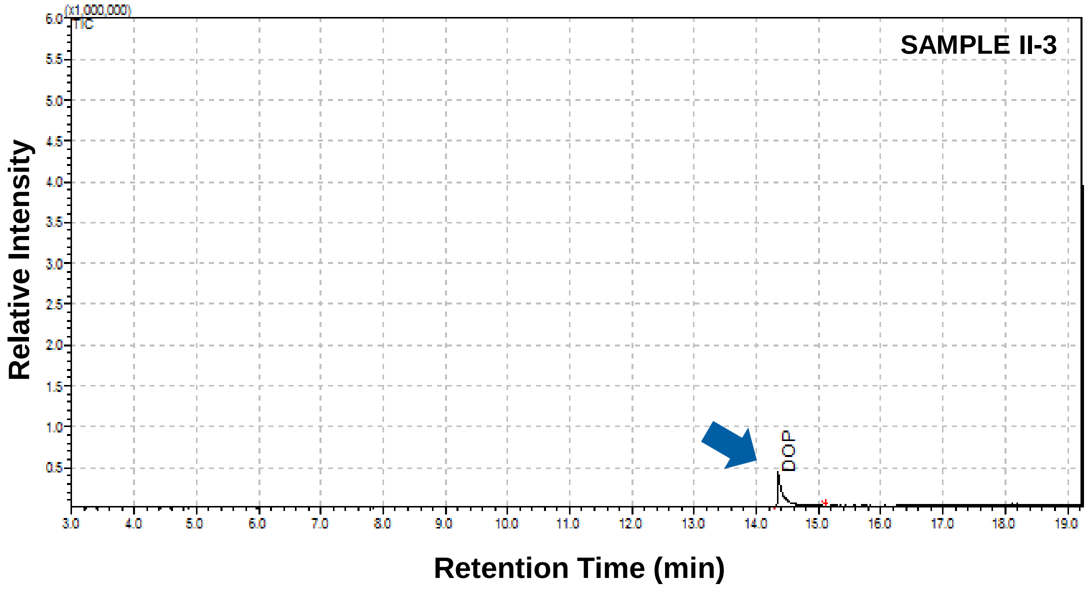
METHOD 1, Solvent Rinse

Coating Batch I, 7.2 mils | Sample Set X, Phase A Exposure



METHOD 2, Solvent Submerge

Coating Batch II, 5.3 mils | Sample Set X, Phase A Exposure

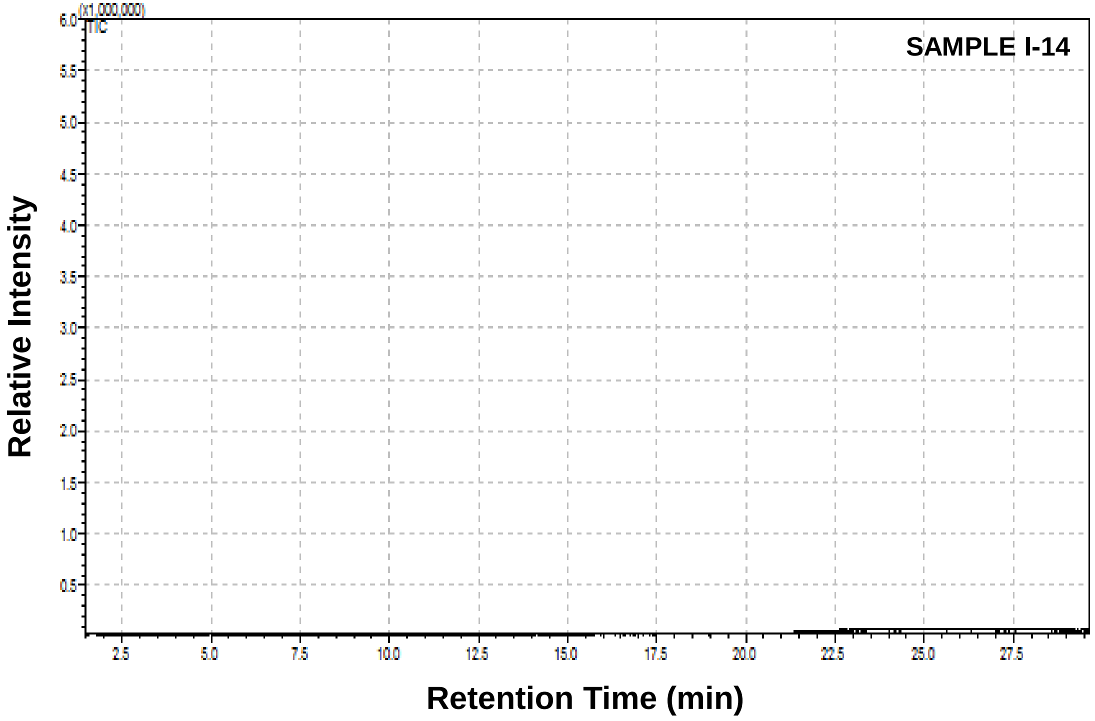


Chemical Analysis Results

- Lastly, **no detectable organics** were present on the control samples for both methods

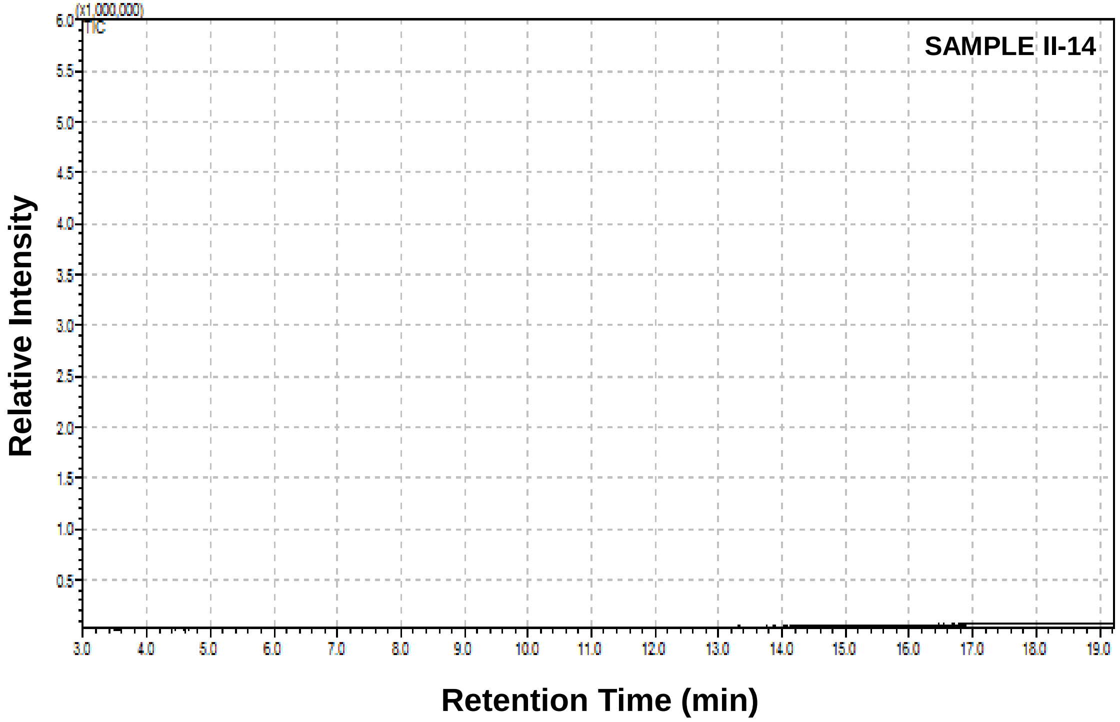
METHOD 1, Solvent Rinse

Coating Batch I, 7.2 mils | Sample Control, ATLO Exposure



METHOD 2, Solvent Submerge

Coating Batch II, 5.3 mils | Sample Control, ATLO Exposure



Summary

- Conclusions
- Future Work

Conclusions

- Preliminary test results confirm that NASA's MAC technology is effective at adsorbing high molecular weight **plasticizers, such as DOP**, in simulated spaceflight conditions that are representative of the vacuum environment of space, and the Martian atmosphere

- These results support the use of the MAC technology for applications that:
  - Require the reduction of harmful outgassed molecular species within critical hardware components
  - Need to meet challenging molecular contamination requirements

Self-portrait of NASA's Curiosity Mars rover near a rock target called "Buckskin" on Mount Sharp

IMAGE CREDIT: NASA/JPL CAL-TECH/MSSS

FUTURE WORK

- **Explore other contaminants of interest, such as low molecular weight chemical species**
- **Perform additional tests in low vacuum carbon dioxide purged systems**
- **Tailor MAC as needed for mission specific applications**

National Aeronautics and Space Administration

ANY QUESTIONS?

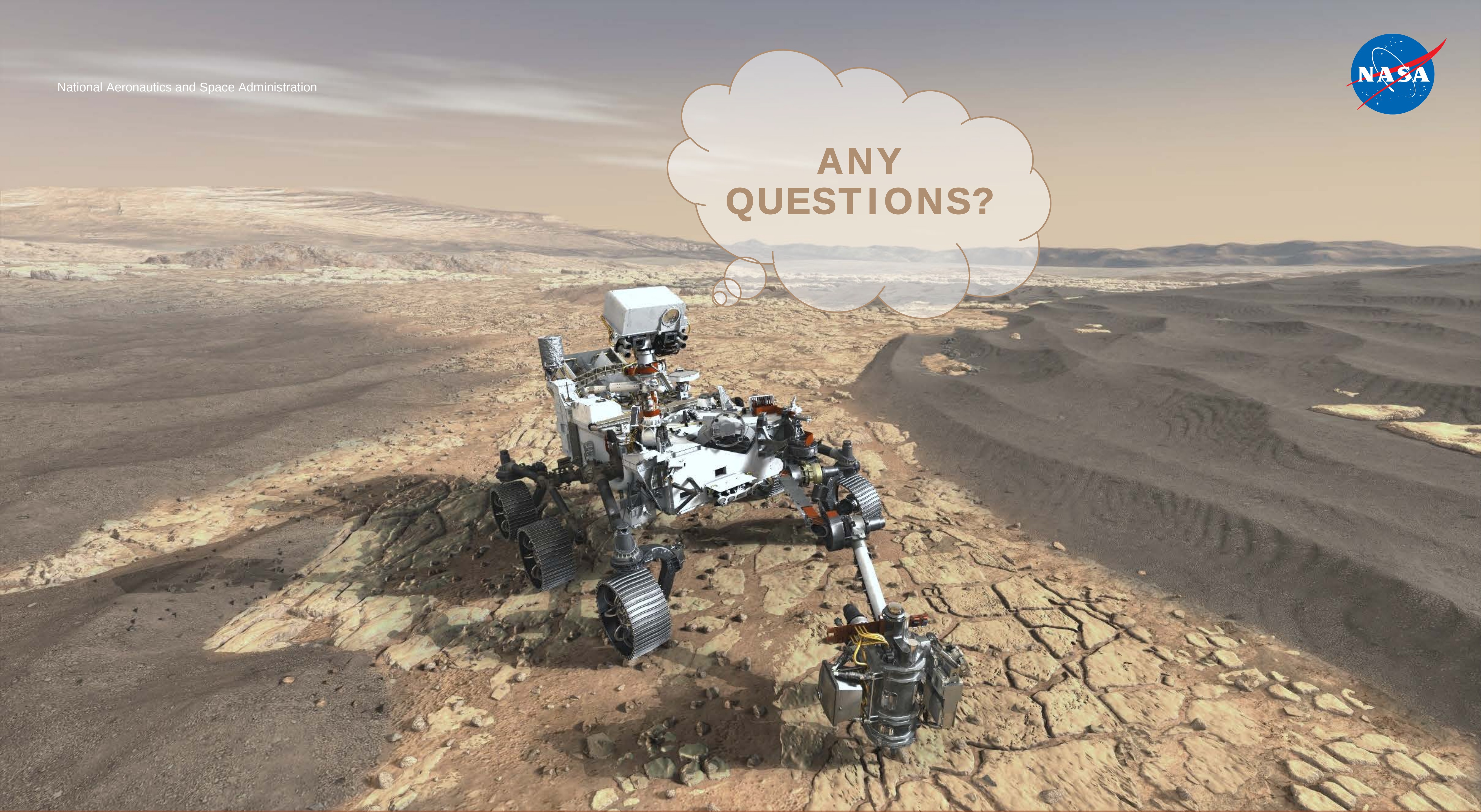


IMAGE CREDIT: NASA/JPL CAL-TECH | MARS 2020 ROVER ARTIST'S CONCEPT | **LINK:** HTTPS://WWW.NASA.GOV/IMAGE-FEATURE/JPL/PIA21635/NASA-S-MARS-2020-ROVER-ARTIST-S-CONCEPT

Acronyms

- ATLO — Assembly, Test, and Launch Operations
- CAL-TECH — California Institute of Technology
- CO_2 — Carbon Dioxide
- DEHP — Diethylhexyl Phthalate
- DOP — Dioctyl Phthalate
- EDGE — Edge Space Systems
- FUV — Far Ultraviolet
- GC/MS — Gas Chromatography/Mass Spectrometry
- GSFC — Goddard Space Flight Center
- HSDB — Hazardous Substances Data Bank
- ICON — Ionospheric Connection Explorer
- JPL — Jet Propulsion Laboratory
- JWST — James Webb Space Telescope
- KSC — Kennedy Space Center
- MAC — Molecular Adsorber Coating
- MAC-W — White Molecular Adsorber Coating
- MEP — Mars Exploration Program
- MSSS — Malin Space Science Systems
- NASA — National Aeronautics and Space Administration
- NIH — National Institutes of Health
- NIST — National Institute of Standards and Technology
- NVR — Non-Volatile Residue
- QCM — Quartz Crystal Microbalance
- RH — Relative Humidity
- SGT — Stinger Ghaffarian Technologies
- UC — University of California

References

1. National Aeronautics and Space Administration, "NASA Science Mars Exploration Program", Accessed 25 June 2018, <https://mars.nasa.gov/>
2. National Aeronautics and Space Administration, "Journey to Mars: Overview", Accessed 25 June 2018, <https://www.nasa.gov/content/journey-to-mars-overview>
3. National Aeronautics and Space Administration, "Red Planet", Accessed 25 June 2018, <https://mars.nasa.gov/#red_planet/1>
4. National Aeronautics and Space Administration, "All About Mars: Facts", Accessed 25 June 2018, <https://mars.nasa.gov/all-about-mars/facts/>
5. Farley, K.A., Williford, K, et al., "Contamination Knowledge Strategy for the Mars 2020 Sample Collecting Rover", Lunar and Planetary Science Exploration Conference XLVIII (March 2017)
6. Giuliani, M., Amerio, E., et al., "Contamination Control Approach for Exomars Mission", 11th ISME International Symposium on Materials in a Space Environment (September 2009)
7. Perry, R., Canham, J., and Lalime, E., "Developing the Cleanliness Requirements for an Organic Detection Instrument: Mars Organic Molecule Analyzer-Mass Spectrometer (MOMA-MS)", Contamination, Coatings, Materials and Planetary Protection Workshop, (July 2015)
8. Abraham, N. S., Hasegawa, M. M., and Straka, S. A., "Development and testing of molecular adsorber coatings", Proc. SPIE 8492, Optical System Contamination: Effects, Measurements, and Control 2012, 849203 (October 2012)
9. Abraham, N. S., Hasegawa, M. M., and Straka, S. A., "Black molecular adsorber coatings for spaceflight applications", Proc. SPIE 9196, Systems Contamination: Prediction, Measurement, and Control 2014, 91960F (September 2014)
10. Abraham, N. S., "NASA Applications of Molecular Adsorber Coatings", Contamination, Coatings, Materials Science, and Planetary Protection Workshop (July 2015)
11. Abraham, N. S., "NASA Applications of Molecular Adsorber Coatings", Thermal and Fluids Analysis Workshop (August 2015)
12. Abraham, N. S., Hasegawa, M. M., and Secunda, M. S., "Application of the Molecular Adsorber Coating technology on the Ionospheric Connection Explorer program", Proc. SPIE 9952, Systems Contamination: Prediction, Control, and Performance 2016, 99520D (September 2016)
13. Abraham, N. S., Hasegawa, M. M., Wooldridge, E. M., and Henderson-Nelson, K. A., "The use of the Molecular Adsorber Coating technology to mitigate vacuum chamber contamination during Pathfinder testing for the James Webb Space Telescope", Proc. SPIE 9952, Systems Contamination: Prediction, Control, and Performance 2016, 99520C (September 2016)
14. Abraham, N. S., "Application of Molecular Adsorber Coatings in Chamber A for the James Webb Space Telescope", Contamination, Coatings, Materials Science, and Planetary Protection Workshop (July 2017)
15. National Aeronautics and Space Administration, "How long would a trip to Mars take?", Published 10 Jan 2018, Accessed 25 June 2018, <https://image.gsfc.nasa.gov/poetry/venus/q2811.html>
16. Williams, M., "Mars Compared to Earth", Universe Today, Accessed 25 June 2018, <https://www.universetoday.com/22603/mars-compared-to-earth/>
17. National Aeronautics and Space Administration, "Mars Fact Sheet", Accessed 25 June 2018, <https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html>
18. Sigma Aldrich, "Dioctyl phthalate", Accessed 25 June 2018, <https://www.sigmaaldrich.com/catalog/product/aldrich/d201154?lang=en&region=US>
19. National Institute of Standards and Technology, "Di-n-octyl phthalate", Pub Chem Open Chemistry Database, Accessed 25 June 2018, <https://webbook.nist.gov/cgi/cbook.cgi?ID=C117840&Units=SI&Mask=FFF#ref-5>
20. Perry, E.S., Weber, W.H., Vapor Pressures of Phlegmatic Liquids. II. High Molecular Weight Esters and Silicone Oils, J. Am. Chem. Soc., 1949, 71, 11, 3726-3730
21. National Institutes of Health, "Bis(2-ethylhexyl)phthalate", Pub Chem Open Chemistry Database, Accessed 25 June 2018, <https://pubchem.ncbi.nlm.nih.gov/compound/8343>
22. Chemistry LibreText™ Libraries, "Clausius-Clapeyron Equation", Accessed 25 June 2018, <https://chem.libretexts.org/Textbook_Maps/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Physical_Properties_of_Matter/States_of_Matter/Phase_Transitions/Clausius-Clapeyron_Equation>
23. Jallice, D., "Materials Engineering Report MEB # 15422", NASA GSFC Code 541 (December 2016)

Contact Information

IMAGE CREDIT: NASA / CHRIS GUNN

Nithin S. Abraham

Coatings Engineer

NASA Goddard Space Flight Center

Contamination and Coatings Engineering Branch

Code 546 | Greenbelt, Maryland 20771 USA

E-mail nithin.s.abraham@nasa.gov

Phone (301) 614-7070