REDUCED ORGANIC OUTGASSING IN THE NASA OSIRIS-REX AND HAYABUSA2 CURATION FACILITY BY CAREFUL SELECTION AND IMPLEMENTATION OF CLEANROOM CONSTRUCTION MATERIALS.

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Introduction: In October 2021, NASA Johnson Space Center (JSC) Astromaterials Acquisition and Curation Office in JSC bldg. 31 completed construction and commissioning of the OSIRIS-REx and Hayabusa2 cleanroom laboratory suites along with new precision cleaning and advanced curation laboratories:

- *OSIRIS-REx Curation Cleanroom: ISO Class 5*
- *Hayabusa2 Curation Cleanroom: ISO Class 5*
- *Final Precision Cleaning Cleanroom: ISO Class 5*
- *Advanced Precision Cleaning Cleanroom: ISO Class 6*
- *PreClean Precision Cleaning Cleanroom: ISO Class 6*
- *Advanced Curation Cleanroom: ISO Class 7*

The new curation facilities are designed for initial receiving, basic characterization, curation processing, and preliminary examination of carbonaceous asteroidal material. The facilities are also designed to enable long-term pristine sample storage to preserve the scientific integrity of each sample to enable decades of future research by the international science community.

The scientific study of organics in general is critical for both missions. The OSIRIS-REx mission executed a stringent contamination control plan [1] where all sample hardware at time of sample acquisition would be at Level 100 A/2 per IEST-STD-CC1246D (non-volatile residue (NVR) < 500 ng/cm^2). In addition, the mission imposed a requirement of <180 ng/cm^2 for amino acids (and hydrazine) [1]. Given these mission requirements, long-term storage preservation requirements, and information from the Organic Contamination Baseline Study at JSC [2], the JSC Curation team decided to carefully select cleanroom construction materials that would not hinder the scientific search for amino acids and the study of organics in the samples [3].

Material Selection: Before final design (2016-2018), our team researched cleanroom candidate construction materials for the HVAC system, floors, walls, ceiling, and plenum areas. An extensive cleanroom literature and industry search was first conducted for finding construction materials that have low particulate shedding and outgassing properties along with good mechanical properties for cleanability, chemical resistance, and minimizing electrostatic charges. Afterwards, our team chose several candidate materials that would be further tested for their specific outgassing characteristics using ASTM E-595 per ASTM E-2312 as well as developing a better understanding of the organic compounds using DART-MS analyses at JSC. The information gained from these two analyses provided the foundation for the final design selection of the cleanroom materials [3].

Material Implementation: While material selection is important before and during the facility design phase, the construction phase is where these choices are implemented by the prime construction contractor through final product and material submittals. Due to fluid construction constraints and specific product selection based on a *basis of design*, these submittals are the last check point and changes are often submitted due to engineering/construction conflicts, especially when renovating an existing building. Any new material or equipment/product change must be identified and scrutinized for low particulate shedding and outgassing properties. In some cases, quick testing of new material is required, and compromises must be made in real-time. As an example, we chose Stonchem 441 flooring due to low ASTM E-595 outgassing results during design. However, due to installation problems on the existing floor slab, we were required to use our 2nd choice, Arizona PF 750 epoxy flooring.

Additionally, some specialty equipment required working with the construction contractors to finalize equipment design and materials. For example, we worked with seven subcontractors to custom manufacturer a first of its kind low outgassing Fan Filter Unit (FFU). Traditional FFUs contain silicon or urethane sealants and painted surfaces that can significantly outgas. Our solution was to manufacture 194 custom FFUs using a Nailor 304 stainless steel diffuser shell, custom variable speed motor with an untreated aluminum impellor, and a Kondoh Industries Cambridge GIGA Master ULPA filter that has the world's first low organic outgassing and low boron glass media with TOC of <0.5 ng/cm^2/24 hours. We replaced the traditional gel seal with a new silicone gel seal (DOWSIL CY 52-276 gel) that met the low outgassing requirement that was researched and tested by Kondoh Industries. The FFUs were also custom fitted with dimmable LED lighting encased in sealed stainless steel, PTFE, and polycarbonate lens with low outgassing epoxy. This new FFU design significantly reduced the outgassing and has no trace of silicone on witness plates in the cleanroom system.

Organic Testing of Cleanrooms: Air Liquide Balazs Nanoanalysis was contracted to provide sampling kits and analyses for organic and inorganic testing. We exposed an 8-inch ultrapure polished semiconductor silicon witness wafer to laboratory air for 24 hours. After exposure, the witness plates were sent for Thermal Desorption Gas Chromatography Mass Spectroscopy (TD-GC-MS). This analysis predominately measures organic compounds from C6 to C28 with a reporting limit of 0.1 ng/cm^2 [Fig. 1].

	Hayabusa2	OSIRIS-REx	Advanced Clean	Final Clean
Balazs Organics on Wafer	ng/cm^2 (* = Below Detection Limit: < 0.1 ng/cm^2)			
Low Boilers C7-C10	0.3	0.3	0.3	0.3
Medium Boilers >C10-C20	3.5	4.3	2.8	3.7
High Boilers >C20	0.2	0.3	0.3	0.3
Sum >=C7	4	4.9	3.4	4.3
2-(2-Butoxyethoxy)ethanol	0.2	0.2	*	*
Caprolactam	0.3	0.3	0.3	0.8
Triacetin	0.6	0.8	0.6	0.2
Texanol	0.1	0.2	0.1	0.2
TXIB	0.3	0.4	*	0.2
Methyl palmitate	0.1	0.1	*	0.2

Fig. 1: Organic contamination on silicon witness plates.

	Hayabusa2	OSIRIS-REx	Advanced Clean	Final Clean
Balazs Organics in Air	ng/L (* = Below Detection Limit: < 0.1 ng/L)			
Low Boilers C7-C10	7	5.3	9	7.7
Medium Boilers >C10-C20	6.7	5.2	7.8	21.3
High Boilers >C20	0	0	0	0
Sum >=C7	13.7	10.6	16.8	29
Acetic acid	0.1	0.1	0.1	0.2
Benzene	0.2	0.2	0.2	0.2
C10-C15 Hydrocarbons	0.7	1.1	0.8	2.4
C12 Hydrocarbon + Naphthalene	*	*	0.1	*
C16-C24 Hydrocarbons	2.6	2.9	4.3	14.8
C3-C4 Benzene	0.9	0.6	1.1	1
C4 Benzene + Decamethyltetrasiloxane	*	*	0.2	*
C6-C9 Hydrocarbons	2.9	2.5	3.8	3.2
Cyclo(Me2SiO)4	0.2	*	0.3	0.1
Cyclo(Me2SiO)5	0.2	*	0.3	0.2
Dimethylpentane	*	0.1	0.2	0.1
Ethylbenzene	0.2	0.2	0.3	0.2
m,p-Xylene	0.5	0.5	0.8	0.6
o-Xylene	0.2	0.2	0.3	0.2
Styrene	0.1	*	0.1	*
Toluene	0.9	0.8	1.3	1.1
TXIB	*	*	0.1	0.2

Fig. 2: Molecular airborne organic contamination in air.

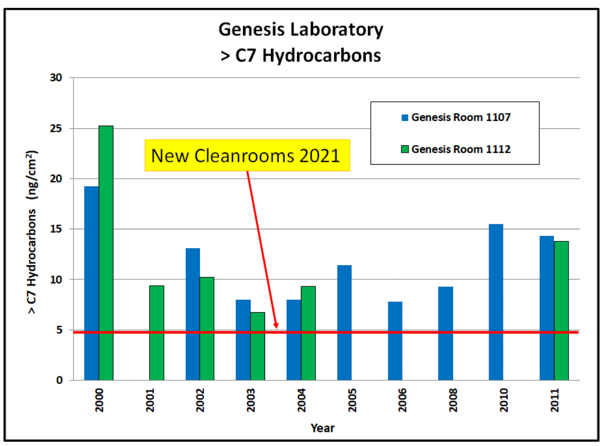

Fig. 3: Comparison of surface organic contamination between new Genesis Curation Lab vs. new 2021 cleanrooms

Airborne volatile organics in air were sampled with an adsorbent tube connected to a pump (100 mL/min.) for 6 hours. After exposure, the adsorbent tube was analyzed by TD-GC-MS with a reporting limit of 0.1 ng/L. This analysis achieves a better measurement of hydrocarbon load and volatile organic compounds [Fig. 2].

Inorganic Testing of Cleanrooms: For inorganic testing, we exposed an 8-inch ultrapure polished semiconductor silicon witness wafer to the laboratory air for 24 hours. After exposure, the witness plate was sent to Balazs for Vapor Phase Decomposition Inductively Coupled Plasma Mass Spectrometry (VPD ICP-MS): 35 elements with reporting limits ranging from 10^8 to 10^{10} atoms/cm^2 [Fig. 4].

Balazs Inorganic	Detection Limit	Hayabusa2	OSIRIS-REx	Advanced Clean	Final Clean
35 Elements	1x10^{10} atoms/cm^2	1x10^{10} atoms/cm^2 (* = Below Detection Limit)			
Aluminum (Al)	0.05	0.28	*	*	0.3
Antimony (Sb)	0.005	*	*	*	0.006
Arsenic (As)	0.05	*	*	*	*
Barium (Ba)	0.001	0.002	*	*	0.002
Beryllium (Be)	0.3	*	*	*	*
Boron (B)	0.5	63	60	54	51
Cadmium (Cd)	0.003	*	*	*	*
Calcium (Ca)	0.1	4.8	1	0.1	11
Cerium (Ce)	0.001	*	*	*	*
Chromium (Cr)	0.01	0.01	*	0.01	*
Cobalt (Co)	0.005	*	*	*	*
Copper (Cu)	0.01	0.01	0.02	0.04	0.02
Gallium (Ga)	0.005	*	*	*	*
Germanium (Ge)	0.05	*	*	*	*
Hafnium (Hf)	0.05	*	*	*	*
Indium (In)	0.001	*	*	*	*
Iron (Fe)	0.05	0.15	*	*	0.09
Lanthanum (La)	0.04	*	*	*	*
Lead (Pb)	0.01	*	*	*	*
Lithium (Li)	0.05	*	*	*	*
Magnesium (Mg)	0.05	0.82	0.28	*	1.5
Manganese (Mn)	0.01	*	*	*	*
Molybdenum (Mo)	0.005	*	*	*	*
Nickel (Ni)	0.05	*	*	*	*
Potassium (K)	0.05	0.89	0.06	*	1
Sodium (Na)	0.05	1.4	0.14	0.1	1.8
Strontium (Sr)	0.002	0.009	*	*	0.008
Tantalum (Ta)	0.05	*	*	*	*
Tin (Sn)	0.005	0.24	0.16	0.19	0.13
Titanium (Ti)	0.05	*	*	*	*
Tungsten (W)	0.05	*	*	*	*
Vanadium (V)	0.01	*	*	*	*
Yttrium (Y)	0.07	*	*	*	*
Zinc (Zn)	0.05	0.1	*	*	0.12
Zirconium (Zr)	0.005	*	*	*	*

Fig. 4: Inorganic contamination on silicon witness plates.

Summary: Careful section and implementation of cleanroom materials can significantly reduce organic and inorganic contamination beyond normal cleanroom baselines [2]. Fig. 3 shows measurable organic reduction when these results are compared to Genesis's ISO Class 4 cleanrooms after construction [2]. As seen in Genesis organic data, we anticipate even lower organic results in 2 years as newly installed materials continue to outgas. Material testing and selection must begin before commencing the design phase and continue through the construction submittal process when new materials require further selection, scrutiny, and testing. Custom FFUs are attributed to the significantly reduced organic results along with careful selection of cleanroom HVAC system components, flooring, walls, and paints.

Reference: [1] Dworkin, J.P. et al. (2018) Space Sci Rev, 214: 19. [2] Calaway, M.J. et al. (2014) NASA/TP-2014-217393. [3] Calaway, M.J. et al. (2019) LPS L abstract# 1448.

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