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The Trash Compaction Processing Systems (TCPS) Ground Unit Control Sample Testing

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The Trash Compaction Processing System (TCPS) is being developed by NASA and Sierra Space to process crew trash for long-duration missions. The system compacts and thermally processes mixed spacecraft waste to reduce volume and stabilize the material while managing gas and liquid effluents. A Ground Unit (GU) located at Sierra Space in Madison, Wisconsin was used to run a series of tests using standardized control samples representing different trash conditions, including nominal, high liquid, high cloth, benign, and foam.

Gas grab samples were collected during processing and analyzed to identify the compounds present in the effluent stream and compare the concentrations to the NASA spacecraft maximum allowable concentrations (SMACs). Additional testing included odor testing at White Sands Test Facility, aerosol measurements, microbiology, and tile characterization. Overall, the compounds detected in the gas samples were well below the SMAC limits for all trash models tested. The results from this testing are being used to help guide the verification approach and test planning for the TCPS Flight Unit that is planned for on-orbit testing on the International Space Station.

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Acronyms and Nomenclature

ARC	=	NASA Ames Research Center
BAA	=	Broad Agency Announcement
CS	=	Control Sample

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ECLSS	=	Environmental Control and Life Support System
FU	=	Flight Unit
GC-MS	=	Gas Chromatography–Mass Spectrometry
GU	=	Ground Unit
ISS	=	International Space Station
JSC	=	NASA Johnson Space Center
SMAC	=	Spacecraft Maximum Allowable Concentration
TCPS	=	Trash Compaction Processing System
VES	=	Vacuum Exhaust System
WSTF	=	White Sands Test Facility

I. Introduction

Long-duration human spaceflight missions require robust waste management systems that minimize crew time, reduce health risks, and integrate safely with spacecraft Environmental Control and Life Support Systems (ECLSS). To address these needs, the National Aeronautics and Space Administration (NASA) has been developing technologies to process crew-generated trash for both short- and long-duration missions, including transit and planetary surface missions. These technical approaches have been developed by NASA as well as external partners from universities and commercial entities, and the development of these systems has been documented extensively in the literature [1–5].

The Trash Compaction Processing System (TCPS) is designed to process common spacecraft waste by reducing its volume, biologically stabilizing the material, managing gas and liquid effluents, and compacting the processed waste into a stable form suitable for storage during long-duration missions. In 2018, NASA released a Broad Agency Announcement (BAA) under Solicitation Number NNH16ZCQ001K-TCPS for U.S. industry to develop the next generation TCPS. In 2022, Sierra Space Corporation was awarded the contract to develop and demonstrate the next generation TCPS [6] for the International Space Station (ISS). In 2024, the contract was modified to further develop the system for on-orbit testing on the ISS.

Currently, NASA is preparing to launch the TCPS for on-orbit testing in early 2027. The system is designed to compact, thermally process, and stabilize crew trash while controlling gas and liquid effluents. The operating domain of the TCPS includes the compaction subsystem, liquid management subsystem, gas management subsystem, and solid waste handling subsystem (Fig. 1).

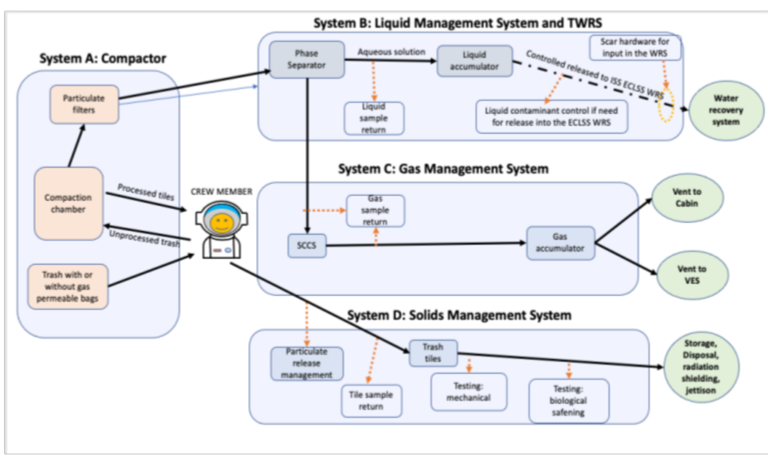


Fig. 1 Trash Compaction Processing System (TCPS) architecture.[5]

The development of TCPS evolved through several earlier waste processing technologies. Initial approaches relied on crew manually compacting trash. This progressed to the Navy Plastic Melt Compactor, followed by the Heat Melt Compactor developed at NASA Ames Research Center (ARC)[4]. Subsequent development included the Plastic Melt Compactor developed by Orbital Technologies Corporation (ORBITEC[7]) under SBIR Phase I and Phase II programs. Later, Sierra Nevada Corporation (now Sierra Space) further advanced the technology through development work performed for Materials Modification Inc. (MMI). More recently, prototype systems were developed during the NextSTEP Phase A program by Collins Aerospace and Sierra Space. These efforts ultimately led to the current NextSTEP Phase B Sierra Space Ground Unit (GU) and Flight Unit (FU) systems.

In parallel with industry development, NASA Ames Research Center has been conducting risk reduction activities to support the development of the next generation TCPS hardware. These activities include refining science objectives, developing test procedures, and ensuring that lessons learned from previous waste processing systems are incorporated into the current design[8]. Ongoing risk reduction work includes off-gas characterization of processed tiles, evaluation of non-control sample materials, chemical emissions analysis from individual waste components[9], aerosol characterization, and microbiological testing[8, 9].

Table 1 Overview of TCPS risk reduction activities conducted to support Ground Unit testing and preparation for Flight Unit demonstration on the International Space Station.

Category	Activity	Objective	Outcome
Materials Processing	Processing various waste types, including non-control sample materials	Evaluate processing efficiency for diverse waste streams	Improved system adaptability to real waste conditions
Off-Gas Characterization	Study of off-gassing from processed tiles	Identify hazardous volatile compounds	Established filtration and mitigation strategies for spacecraft safety
Component Off-Gas Testing	Off-gas characterization of individual waste components	Determine chemical emissions and impact on spacecraft air quality	Developed material selection criteria and safety protocols
Thermal and Acoustic Studies	Assessment of system acoustic emissions	Ensure acceptable noise levels for crewed environments	Implemented design modifications to reduce noise
Odor Management	Evaluation of odor formation during processing	Reduce potential for unpleasant spacecraft cabin environment	Integrated odor filtration and neutralization solutions
Ground Unit Testing	Full-scale testing of the TCPS ground unit	Validate hardware performance under simulated space conditions	Refined operational parameters and system reliability
Preparation for Onboard Testing	Evaluating test protocols for flight demonstration	Ensure seamless transition from ground to space operations	Developed standard operating procedures for flight readiness
Radiation Stability of Processed Tiles	Assessing the structural and chemical stability of processed tiles under simulated space radiation	Determine material degradation and potential secondary emissions	Ensured compliance with spacecraft shielding requirements
Combustion Testing	Evaluating the flammability of processed waste materials in microgravity conditions	Identify fire risks and establish safe handling guidelines	Implemented fire mitigation strategies for space applications
Particulate Testing	Measuring particle release during TCPS processing	Prevent contamination of spacecraft air supply	Developed advanced filtration techniques to capture fine particles
Microbiological Testing	Analyzing microbial activity before and after waste processing	Ensure biohazard safety and prevent microbial growth	Developed sterilization protocols and microbial barrier methods

Additional studies have examined radiation stability of processed tiles, combustion behavior to assess fire risk, and particulate emissions to evaluate potential contamination hazards. These investigations are necessary to ensure that TCPS meets operational safety requirements while maintaining acceptable environmental conditions within the spacecraft cabin.

The Materials Modification Inc. (MMI) unit currently located at NASA Ames Research Center is being used for several of these risk reduction activities. In addition, the Sierra Space Ground Unit (GU), located at Sierra Space in Madison, Wisconsin, is being used to support development of the Flight Unit (FU) and to evaluate operational scenarios for on-orbit testing. These activities are intended to ensure that the flight hardware will meet program requirements. This paper describes the testing conducted on the Sierra Space Ground Unit.

II. Methodology

Sierra Space completed fabricating the GU in July 2025. NASA and Sierra Space worked on a GU test campaign from July 2025 to September 2025. ARC made a total of 21 CS and sent to Sierra Space for testing.

A. Control Samples

There are several types of Controlled Samples (CS) used for TCPS testing, including nominal, high liquid, high cloth, benign, foam, hygiene, and non-standard categories. These CS types have been described in previous TCPS development and testing publications. Because trash composition can vary significantly even in a controlled ISS environment, CS were developed to normalize trash compositions so that hardware developers can assess system performance under repeatable conditions. Each CS type contains representative trash items, such as towels or food packaging, identified in spacecraft trash returns or crew provisions.

The classification of CS types is based on the Advanced Exploration Systems (AES) Logistics Project Exploration Waste Model developed at NASA. This model, provides an analysis of the solid and liquid waste streams expected during long-duration exploration missions and complements logistics supply projections described in Goodliff et al., 'Logistics Needs for Future Human Exploration Beyond Low Earth Orbit.'The nominal control sample formulation is shown in Table A-11 in Appendix A The model assumes closed-loop life support systems similar to those on the ISS, including approximately 85% urine recovery, carbon dioxide reduction through the Sabatier process, and venting of waste gases. Additional assumptions include clothing containing approximately 9% water content and approximately 20% of clothing remaining in use at the end of a mission. Waste generated from science utilization or broken equipment is excluded, but waste streams expected to enter TCPS are included under the "TCPS input/day/4CM" column.

Controlled samples are generated by scaling the nominal waste components based on the assumptions described in Appendix A to ensure that each batch represents the expected distribution of spacecraft trash while maintaining a specified total mass.

Currently, TCPS controlled samples consist of both dry and wet componentsTable **B**-14Table **??** in Appendix A. Dry components are shelf-stable and require no special storage conditions, while wet components are perishable and typically require cold storage until use. To reduce operational constraints, proposed modifications aim to transition from perishable materials to shelf-stable components by replacing certain wet materials with dried powders that can be rehydrated during preparation.

ARC is preparing 21 controlled samples categorized as nominal, high cloth, high liquid, benign, and foam. All sample types except foam have a target mass of approximately 2.2 kg. The foam model depends on the TCPS chamber volume and has an approximate mass of 450 g.

The CS components are grouped into three categories: dry components such as T-shirts and food packaging; wet components without shelf-life constraints such as wet wipes and toothpaste; and wet food components with shelf-life limitations such as pudding. Dry components require no modification to the preparation procedures. Wet components without shelf-life constraints are grouped in a rehydratable pouch and heat sealed. Wet food components with shelf-life limitations are replaced with shelf-stable powder equivalents. The components listings are shown in Appendix Fig A-2.

The following substitutions are used for the modified CS preparation:

- Beef franks previously used in the CS are replaced with the ISS equivalent beef patty.
- Canned peaches are replaced with dried apricots.
- Wet food items are replaced with dried powders to which water is added prior to use:
  - Commercial off-the-shelf vanilla pudding is replaced with a mixture of milk and vanilla pudding powders.
  - Pineapple drink is replaced with pineapple powdered drink mix.
  - Orange pineapple drink is replaced with orange powdered drink mix.

For the modified wet components, the crew will add water to the food pouch using procedures similar to those currently used on the ISS. Water is withdrawn from the Potable Water Dispenser using a syringe and added in a specified quantity to the pouch. The dry food components are mixed in a rehydratable pouch, and the crew uses the standard drinking straw assembly to add water, mix the contents, and cut the pouch before placing the material into the TCPS compaction chamber.

These procedures provide a framework for preparing TCPS controlled samples for both ground and flight testing while minimizing crew time and eliminating the need for cold storage.

B. Sample Collection and Analysis

Sierra Space collected gas, liquid, tiles, microbilogical swabs and strips, and aerosol samples for analysis at the various NASA laboratories. After 21 runs, microbilogical swabs and strips were analyzed at the Kennedy Space Center Microbiological Laboratory and those results are discussed in Barrett et al. (2026) and TCPS GU operations are discussed in Klopotic et al (2026).

The CS formulation for the GU was a modified versions of the earlier formulations. All liquid components in the CS were changed to the dried version. This change was made to eliminate having to launch wet components that need the scars refrigerated storage. In addition, Several different types of packing of the items were used to take into consideration the minimizing he crew prep time required before tesing.

C. Gas effluent sample collection

Gas effluent samples were collected during the TCPS Ground Unit testing campaign to evaluate the gases generated during trash compaction and processing. These samples were collected to better understand the composition of the gas stream and to support evaluation of potential impacts to the spacecraft cabin environment. The gas samples were collected in certified gas sampling canisters provided by the NASA Johnson Space Center (JSC) analytical laboratory and shipped to JSC for analysis. The JSC analytical lab supports spacecraft atmosphere monitoring and toxicology evaluations for human spaceflight programs, including the International Space Station. The samples were analyzed using gas chromatography–mass spectrometry (GC-MS) following a method similar to EPA TO-15 to identify volatile organic compounds in the gas stream. The measured concentrations were then compared to the spacecraft maximum allowable concentrations (SMACs) defined in JSC-20584[10] to evaluate potential impacts to cabin air quality and crew exposure Samples were collected across several representative trash models used in the TCPS testing campaign. These included Nominal (N), High Liquid (HL), High Cloth (HC), Benign (B), and Foam (F) trash models. These models were developed to represent typical crew trash as well as conditions that may generate higher levels of gas or odors during processing.

One gas sample was collected from the raw or "dirty" gas stream during early testing to evaluate the composition of the untreated gas generated during compaction. Additional gas samples were collected from the processed gas effluent during multiple Ground Unit test runs to capture variability across trash compositions and processing conditions.

These gas sample results are being used to support the evaluation of TCPS gas effluent relative to spacecraft atmospheric limits and to inform safety assessments and operational planning for future Flight Unit testing and on-orbit operations.

Table 2 Gas effluent samples collected during the TCPS Ground Unit testing campaign across representative trash models (Benign, High Liquid, High Cloth, Nominal, and Foam).

Date Performed	Trash Model	Gas Sample ID
7-Jul	Benign	B17-GU-SS-B2-1-I-1_JSC_G (Dirty)
11-Aug	High Liquid	B11-GU-SS-HL1-0-I-0_JSC_G
8/13/2025	High Cloth	B9-GU-SS-HC4-1-U-1_JSC_G
8/14/2025	Nominal	B4-GU-SS-N4-1-U-1_JSC_G
9/16/2025	High Liquid	B14-GU-SS-HL4-0-U-1_JSC_G
9/17/2025	High Liquid	B15-GU-SS-HL5-1-U-1_JSC_G
9/22/2025	Nominal	B39-GU-SS-N10-1-I-1_JSC_G
9/24/2025	Foam	B21-GU-SS-F10-na-1_JSC_G

D. Odor Sample Collection

The objective of the odor test plan is to evaluate if the operation of the TCPS will generate odor during processing and after processing into the crew cabin and during tile storage. The high liquid CS would contain the most liquids and therefore may generate the most processed gas odor, as a result, four different high liquid processed tiles samples were sent to WSTF for analysis.Odor testing of the TCPS compacted trash tiles was conducted at the NASA Johnson Space Center White Sands Test Facility (WSTF) using the odor evaluation procedure defined in NASA-STD-6001, Test 6: Odor Test. The objective of the test was to evaluate potential odors generated from compacted trash tiles produced by the TCPS Ground Unit. Grab gas samples were collected at several locations around the TCPS Ground Unit during tile fabrication to better understand the odor sources that could be present during operation. The samples were collected in Summa canisters and represent different operational conditions including background air, immediate gas release when the chamber door is opened, simulated crew distance from the chamber, the surrounding work area, the processed exhaust stream, and the chamber pumpdown exhaust. These locations were selected to capture both the worst-case release conditions and the typical crew exposure conditions during TCPS operation. Together these samples provide a more complete picture of where odors could originate and how they may propagate into the surrounding environment during compaction and processing of crew trash.

A compacted trash tile generated from a TCPS high-liquid control sample was provided to WSTF for testing. The article was placed in a certified clean, odor-free stainless steel container and conditioned at room temperature prior to odor evaluation. Total conditioning time before odor testing was approximately 140 hours.

Odor testing was conducted in a 41.7 L test chamber under controlled laboratory conditions at approximately 22 °C, 82 kPa pressure, and a nominal atmosphere of 79.1% nitrogen and 20.9% oxygen. During testing, the gas generated from the sample was diluted with matrix gas as required to ensure safe exposure levels for the odor panel.

Odor intensity was evaluated by a trained odor panel following the NASA-STD-6001 rating scale ranging from 0 (undetectable) to 4 (extremely detectable). Panel members evaluated the odor intensity independently and also provided qualitative descriptions of the odor characteristics following the WSTF procedure To evaluate if there are odor radiating from the TCPS into the crew cabin, six grab samples were taken at the various location away from the compactor. These samples for evaluate for odor based on the STD 3001b and component testings. The location of the sample collection is listed here.

Table 3 Odor testing conducted at NASA White Sands Test Facility (WSTF) for TCPS processed High Liquid tiles.

Test	Sample Description	Sierra Space ID #	Sea to Summit Bag?	Tested in Zipper Closure Bag?	WSTF #
1	High Liquid Control Tile	B12-GU-SS-HL2	No	No	25-49020
2	High Liquid Control Tile	B15-GU-SS-HL5	Yes	No	25-49043
3	High Liquid Control Tile	B14-GU-SS-HL4	No	Yes	25-49042
4	High Liquid Control Tile	B13-GU-SS-HL3	Yes	Yes	25-49041

Table 4 Odor Summa Canister Grab Sample Locations

Sample Location / Description	SS ID #	To Evaluate	WSTF #
3 ft in front of the compaction chamber before opening the door after processing (background)	1	Background odor (3 ft from chamber, height centered on door)	25-49044A
3 ft in front of the compaction chamber after opening the door following processing	3	Immediate odor release after the compaction chamber is opened (flush and centered with trash tile)	25-49044B
Between the compacted tile and the inside of the chamber door during tile removal	2	Simulated crew perception at defined standoff distance (3 ft from chamber, height centered on trash tile)	25-49044C
45° offset from the compaction chamber, ~3 ft from the tile removal location (right side)	4	Environmental odor in crew vicinity during operation (45° offset from Double MLE, 3 ft away from door opening)	25-49044D
At the gas effluent outlet venting to the cabin	5	Odor from exhaust outlet venting to cabin (processed/cleaned gas from ISS drawer exhaust port to cabin)	25-49044E
At the cabin pump-down vent prior to the start of the processing cycle	6	Odor from exhaust port (pumpdown filter) on Double MLE	25-49044F

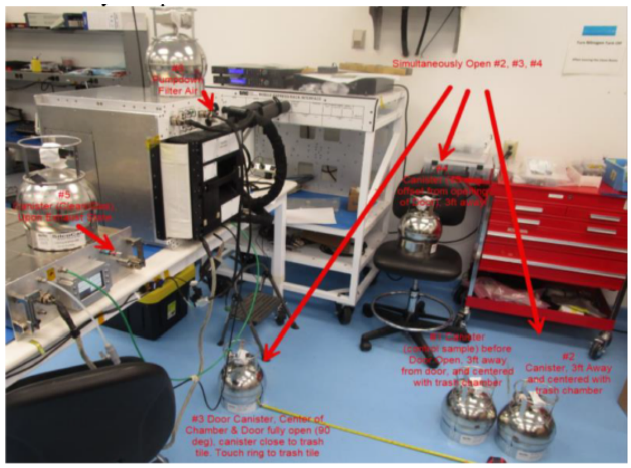


Fig. 2 Locations where SUMMA canisters were placed to collect grab gas samples for odor testing during TCPS Ground Unit operation.

III. Results and Discussion

A. Gas Effluent Analysis

Table 5 summarizes the compounds detected in the TCPS gas effluent samples collected during the Ground Unit testing campaign and compares the measured concentrations to the NASA 7-day spacecraft maximum allowable concentrations (SMACs) defined in JSC-20584. For each sample, the compound representing the highest fraction of the SMAC limit is shown. This approach allows the results to be evaluated relative to the spacecraft atmospheric safety limits and identifies the compound that would be most limiting from a crew exposure perspective.

Table 5 Comparison of detected TCPS gas effluent compounds relative to NASA 7-day SMAC limits.

Trash Model	Key Compound Detected	Measured Concentration (mg/m^3)	7-Day SMAC (mg/m^3)	% of SMAC	Sample ID
Benign	Carbon Disulfide	0.18	30	0.60%	B17-GU-SS-B2-1-I-1_JSC_G (Dirty)
High Liquid	Acetaldehyde	0.11	45	0.24%	B11-GU-SS-HL1-0-I-0_JSC_G
High Cloth	Pentane	0.037	3000	<0.01%	B9-GU-SS-HC4-1-U-1_JSC_G
Nominal	Acetone	0.19	1200	<0.02%	B4-GU-SS-N4-1-U-1_JSC_G
High Liquid	Acetaldehyde	0.11	45	0.24%	B14-GU-SS-HL4-0-U-1_JSC_G
High Liquid	Acetaldehyde	0.11	45	0.24%	B15-GU-SS-HL5-1-U-1_JSC_G
Nominal	Acetone	0.19	1200	<0.02%	B39-GU-SS-N10-1-I-1_JSC_G
Foam	Chloromethane	0.017	19	0.09%	B21-GU-SS-F10-na-1_JSC_G

Table 6 compares the gas components and associated concentrations reported in the HMST toxicology assessment for the Phase A hardware with those measured during TCPS Ground Unit (GU) testing.

Table 6 Comparison of detected TCPS gas effluent compounds relative to NASA 7-day SMAC limits.

Compound	Phase A Dirty (ppm)	Phase A Clean (ppm)	GU Dirty (ppm)	GU Clean (ppm)	Cabin Conc. (ppm in 1 m^3)	7-Day SMAC Limit (ppm)
2-Butanone (Methyl ethyl ketone)	6.689	0.219	ND	0.023	4.6E-5	10
2-Methyl-2-propanol	ND	ND	ND	0.048	9.6E-5	0.033
2-Propanol (Isopropanol)	1.037	0.775	0.045	0.170	3.4E-4	60
Acetaldehyde	38.65	1.017	0.013	0.185	3.7E-4	12.5
Acetone	8.955	0.927	0.016	0.165	3.3E-4	22
Butanal (Butyraldehyde)	3.819	ND	ND	0.007	1.4E-5	5
Carbon disulfide	254.3	1.017	ND	0.094	1.9E-4	0.032
Chloromethane	0.052	ND	ND	0.044	8.8E-5	0.048
Decamethylcyclopentasiloxane	3.14	0.003	ND	0.224	4.5E-4	7
Dimethyl carbonate	ND	ND	ND	0.099	2.0E-4	—
Methanol	—	—	0.015–0.14	—	—	—
Pentane	—	—	0.026–0.037	—	—	—
Propane	—	—	0.029	—	—	—
Propanal	—	—	0.027	—	—	—
Trimethylsilanol	—	—	0.051	—	—	—
Additional minor VOCs	trace	trace	trace	trace	—	—

The results show that the compounds detected across the different trash models were all well below the applicable SMAC limits. The highest fraction of the SMAC observed in the tested samples was associated with carbon disulfide in the benign control sample, which represented approximately 0.60% of the 7-day SMAC. Other detected compounds such as acetaldehyde, acetone, pentane, propane, methanol, trimethylsilanol, and chloromethane were present at even lower fractions of the allowable limits. In all cases the measured concentrations were well below 1% of the applicable SMAC values.

Some variation in the compounds detected was observed between the different trash models, which is expected based on the composition of the control samples. The high liquid samples showed the presence of aldehydes such as acetaldehyde and propanal, which is consistent with the higher moisture content and food related materials present in these samples. The nominal and high cloth samples were more associated with hydrocarbons and ketones such as acetone, pentane, and propane, which are commonly associated with plastics, textiles, and packaging materials present in crew trash. Methanol was also detected in several samples at low concentrations, which is consistent with decomposition of organic materials. Trace amounts of trimethylsilanol were detected in the benign sample, which may be associated with silicone based materials. The foam control sample showed trace levels of chloromethane, which may be associated with the polymeric materials present in the foam.

Overall the results indicate that the gases generated during TCPS processing under the tested Ground Unit conditions do not present an atmospheric toxicity concern relative to the spacecraft SMAC limits. Even for the control samples intended to represent bounding cases, such as the high liquid and foam models, the measured concentrations remained well below the allowable exposure limits. The total VOC levels measured in the GU testing were also significantly lower than the earlier Phase A estimates used in the initial toxicology assessment. These results provide additional confidence that the TCPS generated gases are not expected to pose a risk to cabin air quality and support the continued evaluation of the system for spacecraft applications, including upcoming Flight Unit testing and future on orbit operations.

B. Odor Grab Samples

The odor testing results for the six grab gas samples show that the gases released during TCPS operation produced only weak odors Table7[11]. The measured odor values ranged from about 0.4 to 0.8 on the NASA-STD-6001 odor scale, which means the odor was either very faint or only slightly detectable. The highest value was observed for the sample collected right after the chamber door was opened near the trash tile, which makes sense since this location is closest to where the gases are first released from the compacted trash. Samples taken farther away from the chamber, as well as the surrounding area samples, showed slightly lower odor values. The processed exhaust gas and the pumpdown exhaust samples also had low odor ratings. Overall, the results suggest that the gases released during TCPS Ground Unit operation have only mild odor levels under the tested conditions.

Table 7 Comparison of detected TCPS gas effluent compounds relative to NASA 7-day SMAC limits.[11]

Sample #	Sampling Location	Average Odor Value	Odor Characterization	Example Odor Descriptions
1	Background air (before chamber door opened)	**0.5**	Neutral	Soft lime, faint citrus, air, slight sweetness
2	3 ft from chamber after door opened	**0.7**	Neutral	Tangy, alcohol, air with hint of trash
3	Flush with trash tile immediately after door opened	**0.8**	Neutral / Irritating	Lemon zest, plastic, synthetic oil
4	45° offset from chamber door opening	**0.4**	Neutral	Air with hint of trash, mild oil
5	Processed exhaust gas (ISIS drawer exhaust port)	**0.5**	Pleasant / Neutral / Irritating	Pine-sol, used cooking oil, chile flakes
6	Pumpdown filter exhaust during initial chamber cycle	**0.7**	Neutral / Irritating	Citrus, perfume, herbal

The gas analysis of the grab sample collected during the TCPS Ground Unit testing showed a mixture of low levels of volatile compounds and common gases that are expected from mixed crew trash materials. The compounds detected included aldehydes, ketones, alcohols, hydrocarbons, and a few halogenated and silicone related compounds. Some of the compounds identified in the sample included acetaldehyde, acetone, methanol, isopropyl alcohol, pentane, propane, benzene, chloromethane, and carbon disulfide, along with several longer chain hydrocarbons. Methane was also detected in the sample at a higher concentration compared to the other compounds, which is consistent with gases that can be generated from decomposition of organic materials. Overall, the concentrations measured for the different compounds were relatively low and represent trace gases released during the compaction and processing of the trash tiles. The types of compounds detected are generally consistent with the materials present in crew trash such as food waste, plastics, packaging, and textiles. There were a total of six grab sample collected, but only one gas sample analyzed.

Table 8 Comparison of compounds detected in the TCPS grab gas sample collected from the chamber pumpdown filter with NASA 7-day SMAC limits.

Compound	SMAC (mg/m^3)	ppmv	Compound	SMAC (mg/m^3)	ppmv
1-Chloro-1,1-difluoroethane	102	0.02	Ethyl alcohol	2000	0.05
Acetaldehyde	4	0.13	Formaldehyde	0.12	0.01
Acetone	52	0.23	Isobutane	190	0.004
Benzene	1	0.002	Isopropyl alcohol	147	3.9
Bromomethane	2	0.02	Methane	3500	49
Butene(s)	11	0.007	Methanol	26	0.13
C10 Saturated HC	—	0.002	Methyl ethyl ketone	30	0.002
C10 Unsaturated HC	—	0.008	n-Butane	4507	0.03
C12 Saturated / Unsat HC	—	0.005	n-Propyl alcohol	74	0.003
C13 Saturated / Unsat HC	—	0.01	Octamethylcyclotetrasiloxane	280	0.003
C6 Saturated HC	—	0.001	Pentane	177	0.03
Carbon disulfide	1	0.62	Propane	4139	0.27
Carbon monoxide	63	0.57	Toluene	15	0.004
Carbonyl sulfide	88	0.02	Tridecane	5	0.006
Chloromethane	35	0.3	Trimethyl silanol	4	0.001
Decamethylcyclopentasiloxane	100	0.01	Undecane	318	0.007
Decane	232	0.004	Unidentified CFCs	—	0.24
Dichloromethane	49	0.01	Unidentified fluorinated compounds	—	0.38
Dodecane	278	0.01	—	—	—

C. Odor Tile Samples

Fig 3 and Table 9 shows the odor ratings for the four processed high-liquid CS tiles[12]. The trash processed without using the Sea to Summit bag and not stored in a Ziploc bag had the highest odor rating of 2.6, which is slightly above the acceptable odor limit of 2.5. This configuration represents the maximum odor generation condition where the processed trash tile is directly exposed without any containment after compaction. The other configurations where the tiles were processed or stored in bags showed lower odor ratings, generally between about 1.7 and 2.1, which are below the acceptable threshold. These results indicate that the use of bagging helps reduce the odor released from the compacted trash tiles. Overall, the results suggest that storing the processed tiles in bags after compaction is an effective approach to manage odors and keep them within acceptable limits for crew environments.

Fig. 3 Pictures of the high liquids processed tiles sent to WSTF for odor analysis[12]

Table 9 Comparison of detected TCPS gas effluent compounds relative to NASA 7-day SMAC limits.

Configuration	**Average Odor Value**	**Odor Characterization**	**Example Panel Descriptions**	**Tile Sample ID**	**WSTF Test No.**
Tile only (no bag)	**2.6**	Neutral	Mild trash, fruit peels, wet rug, sweet/savory notes	B12-GU-SS-HL2	25-49020
Sea-to-Summit bag + Ziploc	**1.7**	Neutral / Revolting	Wet soil, synthetic oil, salty, soy sauce	B13-GU-SS-HL3	25-49041
Ziploc bag only	**1.9**	Neutral	Trash odor, mild food smell	B14-GU-SS-HL4	25-49042
Sea-to-Summit bag	**2.1**	Neutral / Revolting	Fruity, mild trash, pasta alfredo, soy sauce	B15-GU-SS-HL5	25-49043

From the WSTF tile gas analysis reports (NASA-STD-6001 Test 7) , the GC-MS analysis screened for more than 150 volatile compounds. Approximately 60, Table 10 compounds were detected across the tile samples, primarily consisting of aldehydes, alcohols, hydrocarbons, and siloxanes associated with mixed crew trash materials.

Table 10 Gas compounds detected during NASA-STD-6001 Test-7 off-gas analysis of the four TCPS high-liquid compacted trash tile configurations. Quantities are reported as µg per assembled article.

Component	SMAC (mg/m^3)	HL2 – No Bag (µg)	HL3 – Sea-to-Summit + Ziploc (µg)	HL4 – Ziploc Only (µg)	HL5 – Sea-to-Summit (µg)
2,3-Pentanedione	0	1.1	1.1	1.1	1.1
2-Furfural	7	89	89	89	89
2-Hexanone	40	89	89	89	89
2-Methylbutanal	21	1.7	1.7	1.7	1.7
3-Methylbutanal	21	1.2	1.2	1.2	1.2
Acetaldehyde	4	38	38	38	38
Acetone	52	18	18	18	18
Acrylonitrile	0	4.2	4.2	4.2	4.2
Benzaldehyde	173	0.94	0.94	0.94	0.94
Benzene	1	5	5	5	5
Benzyl alcohol	13	27.2	27.2	27.2	27.2
Bromomethane	2	5	5	5	5
Butene(s)	11	1.8	1.8	1.8	1.8
Butyraldehyde	15	0.07	0.07	0.07	0.07
C10 aliphatic hydrocarbons	—	29.8	29.8	29.8	29.8
C11 aliphatic hydrocarbons	—	48.8	48.8	48.8	48.8
C12 aliphatic hydrocarbons	—	52.7	52.7	52.7	52.7
Carbon disulfide	1	1400	1400	1400	1400
Carbon monoxide	63	430	430	430	430
Carbonyl sulfide	88	15	15	15	15
Chloromethane	35	18	18	18	18
Decane	232	38.1	38.1	38.1	38.1
Dodecane	278	26.1	26.1	26.1	26.1
Ethyl alcohol	2000	3	3	3	3
Methanol	26	22	22	22	22
Pentane	177	7.3	7.3	7.3	7.3
Propane	4139	1.8	1.8	1.8	1.8
Trimethyl silanol	4	10	10	10	10
Undecane	318	21.3	21.3	21.3	21.3

IV. conclusion

This paper described the testing conducted on the Sierra Space Ground Unit (GU) of the Trash Compaction Processing System (TCPS) to support development of the Flight Unit planned for testing on the International Space Station. The GU testing was used to evaluate system performance and collect data needed for safety review, verification planning, and future on-orbit operations.

Testing included gas analysis, odor testing, aerosol measurements, microbiological testing, and liquid characterization from the processed trash. The gas analysis showed that the compounds detected during TCPS processing were well below the NASA 7-day SMAC limits. Odor testing of the grab gas samples collected around the hardware showed very low odor ratings. Odor testing of the compacted tiles showed that tiles stored without containment had the highest odor rating, slightly above the acceptable value of 2.5. When the tiles were stored in bags, the odor ratings were lower and remained within acceptable limits.

Controlled samples were used to provide a consistent trash composition for testing. Some wet food components were replaced with shelf-stable powder equivalents to reduce the need for cold storage and simplify preparation for testing.

The results from the GU testing are being used to support Flight Unit verification and planning for the TCPS on-orbit demonstration. These data will also help inform operating procedures and future development of waste processing systems for long-duration missions.

V. Appendix A

Table A-11 Control Sample Formulation

General Category	HMC Batch Constituent	Assumed mass (g/CM/d)	Total mass (Modification to) (g/CM/d)	Moisture Concent (%)	Component Mass/batch Required (g)	liquid mass/component required (g)	solid mass/component required (g)
Cloth	Cotton T-shirts	173.30	173.30	6.00%	**210.78**	*12.65*	*198.14*
	Towels	76.10	83.00	6.00%	**100.95**	*6.06*	*94.89*
Wipes	Dry lab. Chem Wipes	29.90	29.90	6.00%	**36.37**	*2.18*	*34.18*
Personal Hygiene	Nitrile Gloves	23.50	23.50	0.00%	**28.58**	*0.00*	*28.58*
Personal Hygiene	PET plastic	3.70	3.70	0.00%	**4.50**	*0.00*	*4.50*
Paper	Computer Printer Paper	20.20	8.50	6.00%	**10.34**	*0.62*	*9.72*
Adhesives	Duct Tape	2.10	2.10	0.00%	**2.55**	*0.00*	*2.55*
	Kapton Tape	1.60	1.60	0.00%	**1.95**	*0.00*	*1.95*
	Velcro	5.00	5.00	0.00%	**6.08**	*0.00*	*6.08*
Food Packaging and storage (modified packaging materials are being evaluated.For example, alternate to BOB)	Thermo pouch (dark khaki green packaging)	56.30	56.30	0.00%	**68.48**	*0.00*	*68.48*
	Beverage pouch	18.30	18.30	0.00%	**22.26**	*0.00*	*22.26*
	Rehydrateable Pouch	64.00	64.00	0.00%	**77.84**	*0.00*	*77.84*
	Overwrap (white packaging)	69.30	69.30	0.00%	**84.29**	*0.00*	*84.29*
	Dessicant	6.40	6.40	0.00%	**7.78**	*0.00*	*7.78*
	Bite size pouch	31.80	31.80	0.00%	**38.68**	*0.00*	*38.68*
	Straw Assembly	8.20	8.20	0.00%	**9.97**	*0.00*	*9.97*
	Septum Adapter Assembly	6.20	6.20	0.00%	**7.54**	*0.00*	*7.54*
	BOB	29.20	29.20	0.00%	**35.52**	*0.00*	*35.52*
Packaging Materials - Flight	Ziploc Bag	75.60	8.50	0.00%	**10.34**	*0.00*	*10.34*
	Bubble Wrap	75.60	8.50	0.00%	**10.34**	*0.00*	*10.34*
Foam	Zotek F30	0.00	0.00	0.00%	**0.00**	*0.00*	*0.00*
Wipes	Huggies Simply Clean Wipes Fragrance Free	59.80	83.00	70.00%	**100.95**	*70.67*	*30.29*
Wipes	Disinfectant Wipes	4.60	21.00	70.00%	**25.54**	*17.88*	*7.66*
Personal Hygiene	Shampoo (add to Towels)	7.30	7.30	70.00%	**8.88**	*6.22*	*2.66*
Personal Hygiene	Toothpaste (add to Towels)	3.70	3.70	70.00%	**4.50**	*3.15*	*1.35*
Personal Hygiene	Deodorant	0.00	20.00	0.00%	**24.33**	*0.00*	***24.33***
Sweat Solids	Sodium Chloride	18.00	18.00	4.00%	**21.89**	*0.88*	***21.02***
Personal Hygiene	Chewing Gum	7.30	7.30	30.00%	**8.88**	*2.66*	***6.22***
Food (do a residual food test by taking the foods out of the bags and measure residue) and compare to model here.	Beef Patty	8.94	6	70.00%	**7.61**	*10.42*	***4.47***
		8.54	6		**7.27**		
	Scrambled Eggs	8.34	6	80.00%	**7.10**	*5.68*	***1.42***
	Macaroni	10.63	7	10.00%	**9.05**	*0.90*	***8.14***
	Rice pilaf	9.55	7	80.00%	**8.13**	*6.50*	***1.63***
	Sweet & Sour Chicken	16.82	12	80.00%	**14.32**	*11.46*	***2.86***
	Cream Spinach	5.19	4	80.00%	**4.42**	*3.53*	***0.88***
	Orange Drink	11.00	11	97.00%	**13.38**	*12.98*	***0.40***
	Apple Cider Drink	11.00	11	97.00%	**13.38**	*12.98*	***0.40***
	Pineapple Drink	11.00	11	97.00%	**13.38**	*12.98*	***0.40***
	Dried Apricots	4.17	3	50.00%	**3.55**	*5.84*	***5.84***
		9.55	7		**8.13**		
	Strawberries	0.61	0.4	90.00%	**0.52**	*0.46*	***0.05***
	Vanilla Pudding	6.67	5	80.00%	**5.67**	*4.54*	*1.13*
	Macadamia Nuts	6.06	4	2.50%	**5.16**	*0.00*	*5.16*
	Tortilla	10.36	7	20.00%	**8.82**	*0.00*	*8.82*

1. The Total Daily Waste

Fig. A-1 presents the nominal CS formulation. The column labeled "Assumed rates (g/CM/day).' represent the assumed generation rates of each component according to the AES Logistics Project Exploration Waste Model. For example, T-shirts contribute 173.30 g/CM / day, towels 76.10 g / CM / day, and Dry Lab Wipes 29.90 g / CM / day. To calculate the amount of each component to include in a CS, take sum of the "Assumed rates" in g/CM/day. This sum is 904.39g attributed to the total daily waste in the nominal category.

2. The Scaling Factor

To determine the mass of each waste component to add to the nominal CS, scaled the Total Daily Waste mass to the Total Waste Desired mass. For example, to make up a 1.1 kg total nominal CS, divide the desired mass by the total daily waste (1100g / 904.39 = 1.216). The scaling factor is 1.69 for a 1100 g nominal CS.

3. Recalculate the Component Contributions

To determine how much of each component to use in the nominal CS, calculate the adjusted mass of each component. For each component, the adjusted mass is calculated, as shown in Equation 1.

• Example Calculations: o T-shirts: 173.30g × 1.216 = 210.78g o Towels: 76.10g × 1.216 = 100.95g o Dry Lab Wipes: 29.90g × 1.216 = 36.37 g D. Verify Total Mass Verify the CS mass by summing the "component mass/batch" column.

VI. Appendix B: Control Sample Preparation

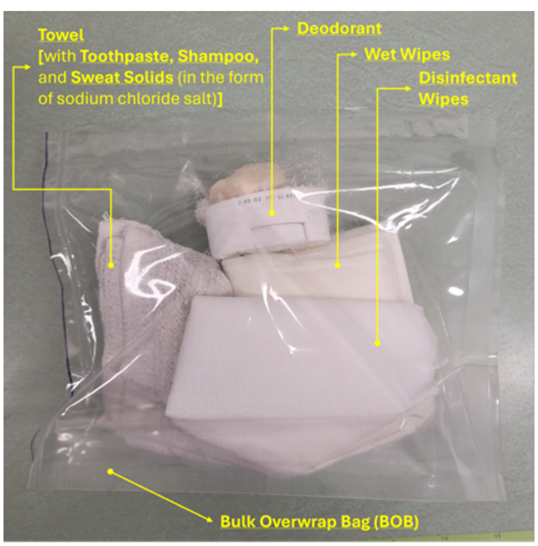
1. Dry Components

The dried components are dry lab chem wipes, polyethylene terephthalate (PET) bottles, adhesives (duct tape, Kapton tape, hook and loop fasteners), food packaging materials (thermo pouch, beverage pouch, rehydratable pouch, overwrap, desiccant, bite size pouch, straw adapter assembly, septum adapter assembly, bulk overwrap bags), and flight packaging materials (resealable bag, bubble wrap, and Zotek® F30 foam). These components do not require cold storage, remain shelf-stable, and do not require any special preparation.

Table B-12 Control Sample Formulation: Dry components

Components	Constituents	Mass (g) Per 1100g of CS		Components	Constituents	Mass (g) Per 1100g of CS
Cloths	T-Shirts	210.78		Food packaging	Thermal pouch	68.48
	Towels	100.95			Beverage pouch	22.26
Wipes	Dry lab chem wipes	36.37			Rehydrateable pouch	77.84
Personal hygiene	Nitrile gloves	28.58			Overwrap	84.29
	PET plastic	4.50			Dessicant	7.78
Paper	Computer printer paper	10.34			Bite size pouch	36.68
Packaging Materials	Ziploc Bag	10.34			Straw adapter assembly	9.97
	Bubble warp	10.34			Septum adapter assembly	7.54
Adhesives	Duct tape	2.55			BOB	35.52
	Kapton tape	1.95				
	Hook and loop fasteners	6.08				

Table B-13 Control Sample Formulation: Wet with No Shelf life



Components	Constituents	Mass (g) Per 1100g of CS
Wipes	Fragrance free wet clean wipes	100.95
	Disinfectant wipes	25.54
Sweat Solids*	Sodium chloride	21.89
Personal hygiene	Shampoo	8.88
	Toothpaste	4.50
	Deodorant	24.33
	Chewing gum	8.88

Table B-14 Sea to Summit Bag Modification

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