The Trash Compaction Processing System (TCPS) Technology Demonstration and Risk Reduction Updates FY23-FY24

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The Next STEP Phase B Trash Compaction Processing System (TCPS) is being developed for a technology demonstration on the International Space Station (ISS) to process common spacecraft consumables trash such as food packaging and clothing to reduce trash storage volume, recover water, safen (e.g. reduce biological activity), and shape the trash for storage, jettison, reuse (e.g., radiation shielding) and/or recycling. Sierra Space is developing the flight demonstration hardware and National Aeronautics and Space Administration (NASA) continues to conduct risk reduction activities to explore operational scenarios, setting the stage for successful on-orbit tests. After the flight demonstration on ISS, the TCPS becomes available to be infused into NASA short- and long-term missions. This paper will discuss the rationale for the updated requirement definitions outlined in the 2023 International Conference on Environmental System TCPS paper and the ongoing risk reduction activities. In addition, drawing from lessons learned in the development of the TCPS, a discussion of other compression technologies will be introduced for various mission types.

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Nomenclature and Acronyms

AAA	=	avionics air assembly
ECLSS	=	Environmental Control and Life Support Systems
Gen 1	=	1st Generation HMC
Gen 2	=	2nd Generation HMC
HMC	=	Heat Melt Compactor
ICES	=	International Conference on Environmental System
ISS	=	International Space Station
LEO	=	Low Earth Orbit
LTL	=	low temperature-liquid cooling
MTL	=	*moderate-temperature liquid cooling*
NASA	=	National Aeronautics and Space Administration
NextSTEP	=	Next Space Technologies for Exploration Program
psig	=	pounds per square inch, gauge
SCCS	=	Source Contaminant Control System
SMAC	=	Spacecraft Maximum Allowable Concentrations
TCPS	=	Trash Compaction and Processing System
WSTF	=	White Sand Test Facility

I. Introduction

CURRENTLY, common trash is stored in flame-retardant containment bags and incinerated upon reentry in a expendable resupply spacecraft.[1] For missions beyond Low Earth Orbit (LEO), mass and volume must be reduced by other means, such as jettison.[2] Additionally, for these long-duration missions, it may not be feasible to jettison trash as frequently as needed due to planetary protection policies. The storage of trash not only occupies living spaces but also presents a biological hazard if the trash is not properly contained in an enclosed volume within the spacecraft. Therefore, methods must be developed to process this trash to be safely stored, reused/recycled, or jettisoned. On average, one crew member produces approximately 1.1 kg of common trash a day.[3] For four crew members, the trash volume that needs to be stored could significantly clutter the living space.

Since 2003, the National Aeronautics and Space Administration (NASA) has been developing various trash compaction technologies, including the Trash Compaction Processing System (TCPS), formerly known as the Heat Melt Compactor (HMC),[4] to reduce trash volume, biologically safen trash items,[5] and form the tiles into a cylindrical or cube shape for ease of storage and use as radiation protection.[6] Currently, NASA and Sierra Space are developing the ground and flight hardware for technology demonstrations aboard the International Space Station (ISS) in 2026. The various trash compaction technologies have been thoroughly described in previous International Conference on Environmental Systems (ICES) papers.[7,8,9] These papers described the technology development, including the risk reduction activities that provided the rationale for developing the TCPS flight demonstration science test objectives and requirement definitions.

Unlike the trash compactors that are used in terrestrial homes to reduce trash volume, the Navy Plastic Melt compactor uses heat to melt plastic found within the trash. The TCPS is designed to process spacecraft trash using both concepts. For use inside the sealed environment of a pressurized volume such as a spacecraft, the TCPS must operate in an enclosed environment where the liquid and gas effluents can be managed.

The Environmental Closed-Loop Life Support System (ECLSS) has been in operation on the ISS since 2001. Many lessons learned were documented regarding the human inhabitants alongside the operation of these ECLSS in enclosed environments in microgravity. The lessons learned from previous ISS ECLSS hardware have been written into the TCPS science objectives and technical requirements. The 2023 TCPS ICES paper summarized these objectives and requirements to provide a reference regarding the TCPS technology. This year's paper will present the updated TCPS science objectives and technical requirements. The requirement definitions in the Next Space Technologies for Exploration Partnerships (NextSTEP) Appendix F TCPS Phase B solicitation was broadly written with the aim of providing the proposer leeway for offering varying designs. Once the contract was awarded, the requirements were refined. In 2023, the System Readiness Review, Preliminary Design Review, and Safety Phases 0, 1, and 2 were completed.[10] In January 2024, Sierra Space completed the program Critical Design Review and was awarded the contract to build the TCPS ground (flight-like) testing hardware. The ground hardware will act as both a testbed and technology demonstration hardware, allowing further risk reduction for the flight unit. The goals of the TCPS flight demonstration are to test and prove the function and effectiveness of the hardware, examine and refine crew interaction in a spacecraft environment and assess the application of the technology for future short- and long-term space missions to the Moon and Mars.

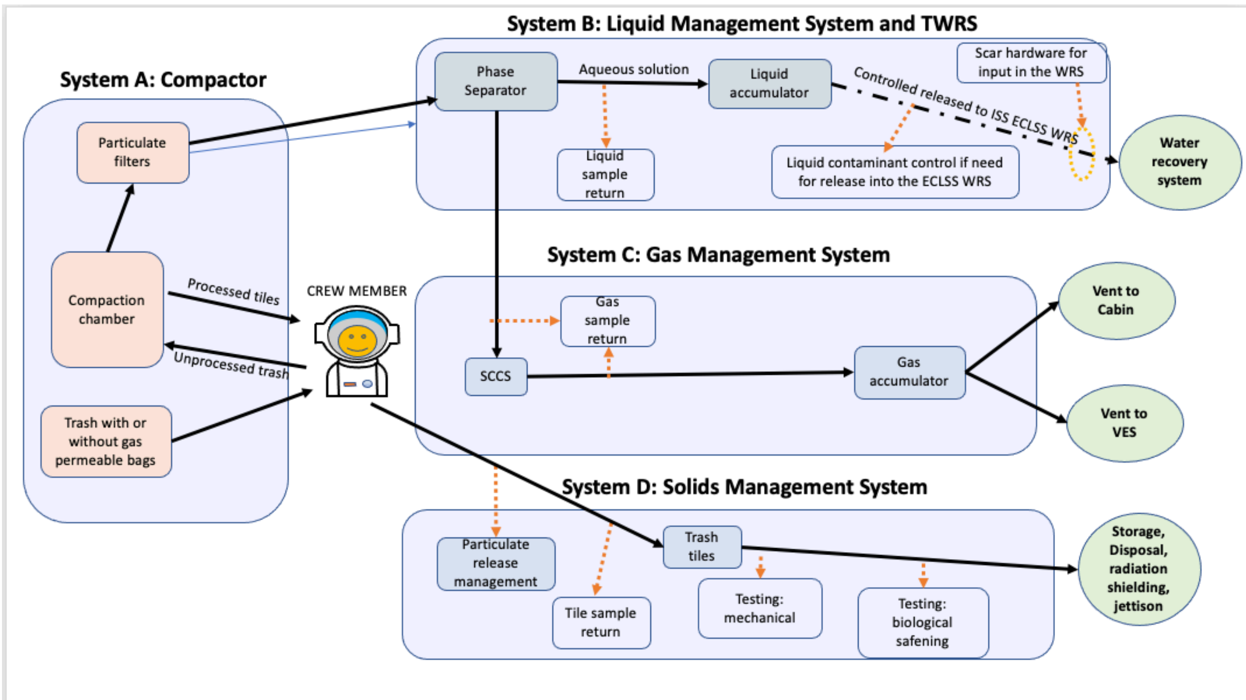

Figure 1. The four TCPS subsystems.

In addition to discussing the rationale for refining the requirements, this paper will also summarize the ongoing NASA risk reduction activities. The risk reduction activity topics are:

- Different types of trash input types to include different trash batches (nominal, high liquids, high cloth, benign, hygiene, non-typical)
- Different processing parameters (e.g. temperature and pressure)
- The processing of the trash batches with and without trash bags
- The use of different trash bags
- Microbial studies of the processed tiles and of the hardware
- Tile densities, flammability, mechanical stability, water activity
- Trade studies to evaluate the equivalent system mass
- Processing of the gas effluents and methods for releasing them
- Processing of the recovered water and methods of recycling it
- Crew interaction
- Off-gassing of individual trash components

II. The TCPS Technical Updates

A. Science Objectives and Success Criteria

There are only minor changes to the TCPS science objectives. Instead of starting the on-orbit test campaign upon installation on ISS, selected pre-made (nominal, high liquids, high cloth, benign) trash batches will be launched and tested with the hardware. Gas and water samples will be returned to the ground for testing. Once the effluents (gas and wastewater) analyses are completed and evaluated to meet spacecraft requirements, then the TCPS can then be used to process actual trash produced by the crew. Similar pre-made trash batches will also be tested on the ground unit.

B. Technical Requirement Updates

The NextSTEP Appendix F TCPS Phase B solicitation technical requirements were written based on the lessons learned from the previously completed Phase A activities, as well as the risk reduction activities on the HMC Gen 1 and HMC Gen 2. Summaries of the rationale for the requirements were discussed in the 2023 ICES publications.[3,9,10] In addition, these requirements were written with the intent of allowing varying proposals to meet the desired technical outcome. After the Phase B award, several areas in the technical requirements were updated, such as the required/desired cooling loops, trash batches, aerosol testing, and verification methods.

The first major technical requirement change is the use of the cooling loops. Requirement 6.4[3] requires that the system must be able to accommodate the use of all three cooling loops: avionic air assembly (AAA), low temperature loop (LTL), and medium temperature loop (MTL), individually and in combination. Due to the difficulty of hardware designs and volume allocation, the TCPS will be designed for two cooling scenarios: AAA for avionics with LTL for cooling and AAA only. This approach will allow the system to process at least one 2.2 kg trash batch per 12 hour period.[10]

The other change concerns the trash batch composition. The original requirement stated that the TCPS shall be able to process the nominal, high-liquid, and foam trash models. [3] Instead of processing foam, the system will now process high-liquid batches instead. There are several reasons why processing foam has been given a lower priority. First, due to the high density of the Zotek foam, the compression volume ratio is quite low when processing it in the HMC, resulting in a minimal volume reduction. The highest compression pressure used is 12 psia. While the Sierra Space flight hardware unit may be able to reduce the foam volume better because the unit's highest compression pressure is 22 psig, the data suggests that the additional volume reduction will be negligible. Another reason foam might not be reasonable to process in the TCPS is that the dimensions of the compression chamber of the TCPS are 11 inches x 11 inches square, which means the foam must be sized and placed accordingly in the chamber. It is impractical to have the crew cut the foam to size (e.g., dust contamination of the crew volume and the use of a razor in microgravity). If the foam pieces are within the size limit, then they can be placed in the compaction chamber. For longer space missions where foam must be compressed, larger pieces of foam can be designed to be removed in pieces like building block pieces for processing. A third reason that Zotek foam should not be processed is the potential for off-gassing of hazardous components.[11]

Previously, NASA developed the standard trash batches (nominal, high-liquid, high-cloth) to allow for the evaluation of different trash compaction hardware with a consistent test article. For example, the high-liquid trash models were designed to test the maximum amount of liquid that a given hardware configuration can process. Recently, NASA has added other trash models based on hygiene items and non-typical (see Table 1 below) trash batches that comprise of components listed in the crew provisions catalog.[12]

III. Risk Reduction Activities

There are two important lessons that can be learned from operating ECLSS on the ISS: the crew's interaction with the hardware, and hardware failure modes in an enclosed environment. Historically, technical areas that may not be a concern in terrestrial applications have become major concerns in an enclosed environment (i.e., odor, ergonomics, and acoustics). Therefore, leveraging the lessons learned from the various operations of the ECLSS system on the ISS, the TCPS risk reduction activities aim to minimize crew interaction issues and technical failures on orbit. In addition, NASA risk reduction activities data combined with Sierra Space ground unit operation data will serve as a baseline to compare on-orbit data for the purpose of troubleshooting on-orbit operation issues and evaluating the TCPS for future mission scenarios. For example, if aerosol studies are conducted with the ground units, new aerosol particles detected on orbit following a trash processing run can confidently be mapped to the TCPS hardware. The comprehensive risk reduction activities on multiple hardware configurations have prepared the TCPS for a technology demonstration on ISS. The technology demonstration on ISS will test the hardware for operation in microgravity as well as to evaluate performance parameters that are not feasible to test on the ground.

For FY24, the risk reduction activities include testing different types of trash batches (Zotek foam, typical hygiene items, CHAPEA analog trash batches, non-typical items, etc.) and evaluating the Source Contaminant Control System (SCCS).[i] Additionally, the evaluation covers different containment scenarios (the use of bags, processing trash without bags, vapor-permeable bags) and assesses the trash batches' moisture levels, the amount of water removed, tile densities, and off-gasing components in the processing of nitrile and latex gloves. The discussion and results for water collected, evaluation of the SCCS, and processing of foam are outlined in a separate publication.[13] This paper will discuss the components of the hygiene items and non-typical trash batches, the trash batches' moisture analysis, TCPS tile densities, and the White Sands Test Facilities (WSTF) flammability test results completed in 2013.

A. Hygiene Items and Non-typical Trash Batches

In total, there are eight different trash batches: nominal, high liquid, high cloth, benign, hygiene, foam, non-typical, and CHAPEA.[ii] The rationale for testing a wide variety of trash batches is to validate that the TCPS can process a variety of materials and confirm that the system has mitigation and safety measures in place to address any processing issues related to these items. The hygiene and non-typical trash batches, as shown in Table 1, were added this year. The goal of testing the non-typical trash components is to evaluate scenarios where these items are accidentally placed in the trash meant for standard processing during a mission. Initial analysis of these components involves assessing the possible melting of the material at the TCPS peak temperature (150˚C) and any off-gas components that could be destructive to the hardware or harmful to the crew.

Three items were identified as possible sources of off-gas components or particles that may permanently coat the compaction chamber and associated plumbing, potentially harming the mirrors in the inline FTIR analyzer. These items are highlighter pens, ink cartridges, and two-part epoxy. These components will be tested separately in a vacuum oven, and gas samples will be collected using a sorbent collection tube and analyzed using GCMS. The rest of the components will be included in the non-typical trash batches to be processed through the HMC. The CHAPEA trash batches were collected during the first analog crew missions. The components of the CHAPEA trash batches will not be listed here, but generally represent the types of trash generated by a crew.

Table 1. Example items comprising hygiene and non-typical trash batches

Non-Typical Items		Hygiene items		
Athletic Running shoe	Medium Binder clips	Aelita Kit[1]	Hygiene Towel, Wet Towel	Petrolium Jelly
Nylon Running shorts	Rubber bands	Comfort Kits[2]	ID Clips	Washcloths
Socks	HEPA filter	Cotton Swab	Lipstick	Wet Napkins
Men's leather belt with metal buckle	Plastic bags	Dental Floss	Makeup	Wet Wash Dispenser Assembly,
Exercise Shirt	Hand Therapy Ball	Deodorant	Mirror	Dry Towels
Thermal protective gloves (deerskin)	Open End Wrench	Dry Wipes	Nail Clippers	Dry Napkins
Electric razor	2-Part Epoxy	Emesis Bag Assembly	Nail Clippers	Soap and Plastic Bag
Adjustable tether	Scientific calculator	Facial Cleansing Wipes Assy	Nitrile gloves	Syptic Pencil
Mini-Flashlight	Thread sealand/glue	Gloves Dispenser Assembly	No-Rinse Shampoo	Toothbrush
Flight pen (ink)	Magnetic Strip Assembly	Gloves Dispenser Pouch	Personal Hygiene Kit Container, PHK	Toothpaste
Mechanical Pencil	Nylon Brush for a drill	Hair Brush and/or Comb	Razor (Electric)	Towels
Highlighter pens	Oxygen Sensor	Hair Clipper	Razor (Manual) and Cartridge /	Tweezers
Permanent markers	pH strips	Hand Cream	Scissors	
Black printer ink cartridge	Syringes	Dry and Wet Wipes	Shaving Cream and Gel	
Label Maker Cartridge	First aid supplies	Hygiene Disposal Bag	Soap / Body Bath Pouch	

[1]Aelita kit consist of shampoo and wipes for cleaning the hair
[2]Comfort kits is the hygiene kit with toothpaste

B. Tile Density

The TCPS tile density requirement specifies a minimum tile density of 375 g/L for a nominal trash batch.[3] This density benchmark is crucial for achieving optimal volume reduction and ensuring the mechanical stability of the compacted trash tiles.

Figure 2 shows the compaction pressures of the various trash compaction units and Table 2 shows both the pressures and the resultant product tile densities by batch type. Here, the tile density values are dependent on multiple

[i] The gas effluent treatment system consisting of the activated carbon bed and the catalytic oxidizer
[ii] CHAPEA is the Crew Health And Performance Exploration Analog test on Earth simulating a long duration mission on Mars

parameters: the trash batch types and the possible compaction pressures of each hardware unit. The tile densities for the high-liquid trash batches tend to be higher than those of the high-cloth trash batches. During the compaction process, as the trash is compressed, liquids are expelled, and the heat melts the plastic materials, bonding the trash components into a stable shape. High compaction pressures, along with the applied heat, lead to denser tiles, which in turn result in better volume reduction and enhanced stability of the tiles. The high-cloth trash batches have a lower quantity of plastics. Therefore, the final tile densities of the high-cloth trash batches are lower, resulting in tiles that tend to delaminate (Figure 3). This result is one of the many arguments for the use of bags to contain the trash, both for easy handling by the crew and to prevent the delamination of the produced tiles.

Of note in Figure 2 is the high tile density (679 g/L) resulting from operating the compaction at 50 psig shown in Table 2. Additionally, it was shown that most of the tiles processed using the HMC Gen 3 were below the required 375 g/L due to the compaction pressure being less than 14 psig. Sierra Space's NextSTEP Phase A hardware compaction pressure is 22 psig, leading to tile densities generally greater than 375 g/L (with the exception of the high cloth as noted above). The processing of the CHAPEA trash resulted in tile densities higher than 375 g/L, attributed to the fact that the batches do not contain cloth items.

Table 2. Maximum compaction pressures by system

Compaction System	Maximum Compaction Pressures (psig)
HMC Gen 2	12
HMC Gen 3/ MMI	7
TCPS Collins	50
TCPS Next STEP Phase A Sierra Space	22

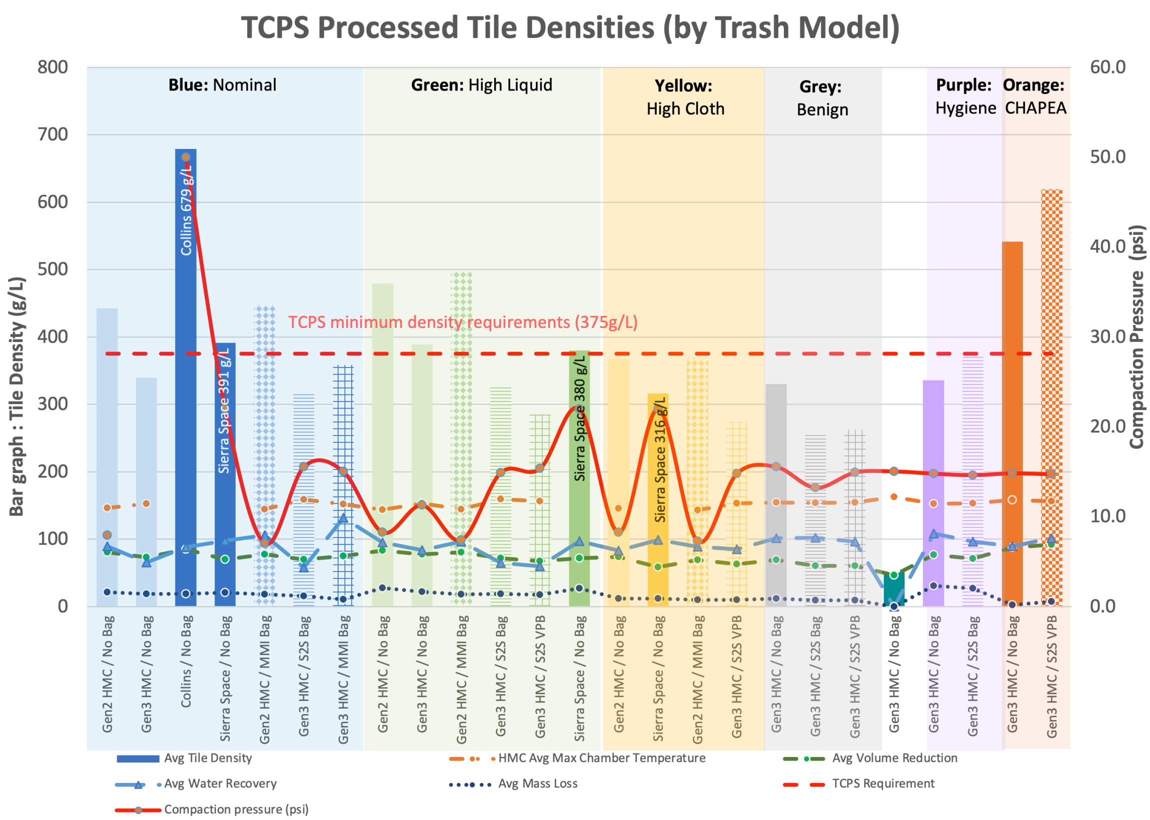

Figure 2. TCPS/HMC Tile density according to compaction pressure.

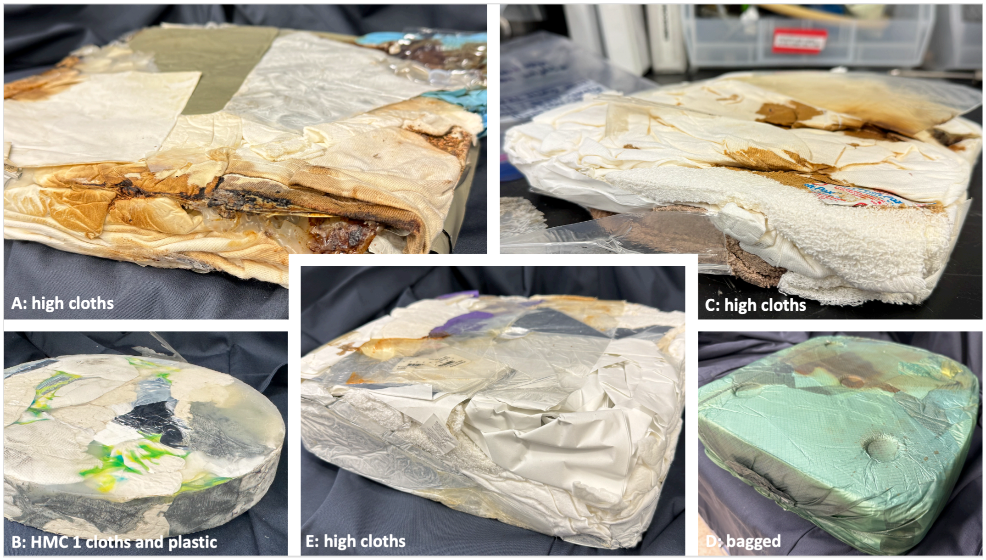

Figure 3. Pictures of various tiles showing cloth trash batches

C. Moisture Analysis

The previous TCPS water recovery amounts were calculated based on the estimated quantity of water in the trash models when they were prepared. It is noted that a small leak was detected in the HMC which allowed room air (adding humidity) into the process. Therefore, accurate water collection measurements were not obtained. As a result, moisture analysis was conducted to assess the actual water content of the various trash models prior to and after processing. According the ASTM C566-19 Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying, the percent moisture is calculated according to Equation 1.

$$percent\ moisture = 100 \frac{*(Wet\ mass - Dry\ mass)}{Dry\ mass} \quad \text{Equation 1}$$

Figure 4 shows pictures of one of the trash batches used and the moisture analysis setup. Table 3 shows the results of the water content in the various trash models. The moisture contents of the nominal, high-cloth, and high-liquid, and benign trash models are 24.1 ± 0.2%, 12.2 ± 0.2%, 34.5 ± 0.3%, and 12.3% ± 12.3% respectively. The estimated amounts of water in the nominal, high-cloth, high liquid, and benign models are 24.4%, 13.7%, 34.5%, and 11.3% respectively. The percent difference between the estimated and measured water content of the nominal, high-liquid, high-cloth, and benign models are 1.3%, 10.9%, 0%, and 8.8% respectively.

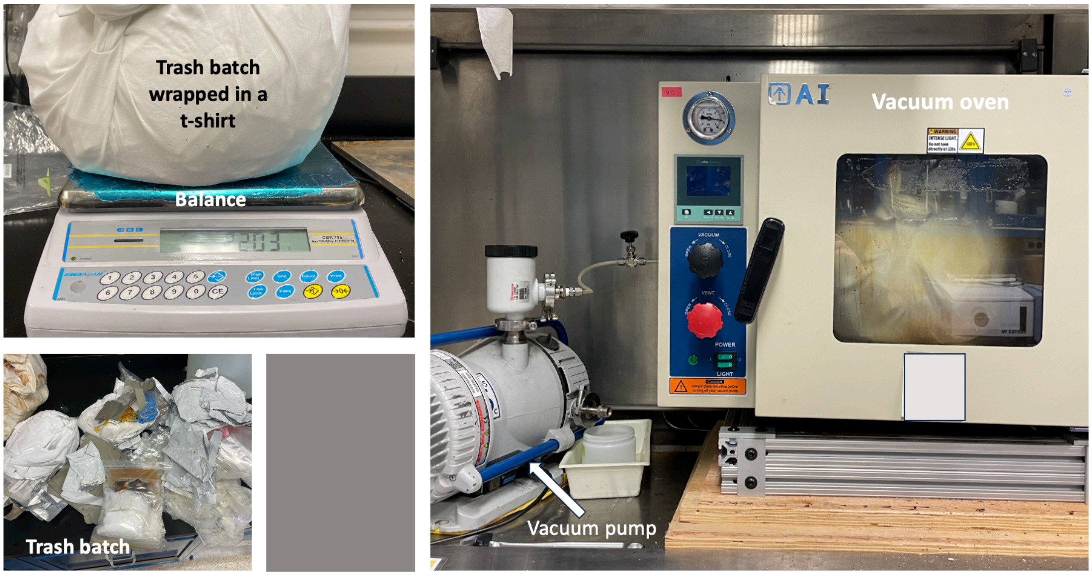

Figure 4. Trash model example used for moisture analysis using heat and vacuum *(photo credit NASA ARC)*

Table 3. The measured amount of liquid and moisture present in each trash model

Trash Model	Mass of the trash Initial[1]	Final[2]	Moisture contents[3]		Average moisture contents			Estimated amount of water in the trash batch[5]		% difference[6]
	g	g	g	%	%			g	%	
Nominal	2190	1761	429	24.4	24.1	±	0.2	431.8	24.4	1.3
Nominal	2206	1781	425	23.9						
High Cloth	2207	1970	237	12.0	12.2	±	0.2	264.3	13.7	10.9
High Cloth	2203	1959	244	12.5						
High Liquid	2206	1643	563	34.3	34.5	±	0.2	563.9	34.5	0.0
High Liquid	2198	1632	566	34.7						
Benign	2200	1948	252	12.9	12.3	±	0.6	223.3	11.3	8.8
Benign	2210	1978	232	11.7						
Hygiene B[7]	1150	831	319	38.4	38.4	na[8]	na[8]	333.3	40.8	6.1
Hygiene A	1311	829	482	58.1	58.1	na[1]	na[1]	492.5	60.2	3.4

[1] Both the wet and dry trash items
[2] Mass loss after oven dried
[3] According to ASTM C566-19. The moisture content is equal to the 100*(wet mass-dry mass)/dry mass
[4] The average moisture content is equal to the mass loss divided by the initial mass *100
[5] The estimated amount of water in the trash batch is calculated based on the individual moisture contents of the trash items
[6] The percent difference is the (estimated value - the average)/estimated value *100
[7] The trash model was made up where 150mL of water was added to the towel and allow to air dried in the lab, a typical use case on ISS.
[8] only one test run was completed

D. White Sand Test Facility (WSTF) Off-gassing and Flammability Testing[14]

Both off-gassing and flammability tests for the Heat Melt Compactor (HMC) Generation 1 tiles were completed at WSTF in 2013.[14] The off-gas testing aimed to identify whether the processed tiles released toxic components over time. This was done by placing six HMC Gen 1 tiles in a 41.0 L chamber maintained at 49°C and 82.0 kPa, with an atmosphere of 79.1% nitrogen and 20.9% oxygen, for 72 hours. The total surface area and mass of the tiles were 4,690.3 cm^2 and 2,458 g, respectively. After the test duration, a gas sample was collected and analyzed. Table 2 lists the off-gas component concentrations compared to the Spacecraft Maximum Allowable Concentrations (SMAC) values. The results indicated that the gas emissions within 72 hours did not exceed the SMAC thresholds. However, due to the limited test duration time, the dry conditions of these initial tests, and the off-gas components of the various trash batches, further extended testing under varying humidity levels is recommended to validate the necessity of containment bags for off-gassing concerns.

Flame propagation and off-gassing tests were conducted on a 9-inch cylindrical HMC Gen 1 unaltered tile.[14] Flammability tests[15] were conducted to determine the flame propagation characteristics through a given processed tile. Six tiles, selected for their varying compositions with three major components (plastic, cloth, and food packaging) were tested. The tests were performed in a controlled atmosphere within a 1.4 m³ volume chamber, maintaining conditions of 75.9% nitrogen, 24.1% oxygen, and 101.4 kPa. The setup involved mounting the sample vertically on a specialized ring stand/needle rake fixture, with the igniter located 0.64 cm below the sample's front leading edge (Figure 5). This orientation directed the most flammable component of the sample downward towards the igniter, to accurately assess flame propagation and off-gassing behavior under the specified test conditions. Figure 6 shows pictures of the tiles before and after ignition.

Table 4. The offgas compnents concentrated compared to the SMAC values.

Components	SMAC mg/m3	Measured ug/g	Components	SMAC mg/m3	Measured ug/g
2-Furfural	7.89	0.02	Ethylbenzene	130	0.005
2-Heptanone	23.35	0.005	Furan	0.07	0.06
2-Methylbutanal	21.1	0.02	Heptanal	28	0.006
2-Methylfuran	0.13	0.009	Heptane	204.47	0.005
2-Methylpropenal	0.14	0.007	Hexamethylcyclotrisiloxane	90	0.48
2-Pentanone	70.2	0.007	Hexane	176	0.005
3-Methylbutanal	21.1	0.03	Isobutyraldehyde	17.7	0.01
Acetaldehyde	7	0.28	Isopropyl alcohol	150	0.08
Acetic acid	7.4	0.005	Methane	3500	0.003
Acetone	52	0.29	Methyl acetate	120.73	0.1
Acrylonitrile	2.9	0.002	Methyl alcohol	90	0.19
Benzaldehyde	17.3	0.01	Methyl ethyl ketone	30	0.03
Benzene	1.5	0.008	Methyl formate	12.3	0.03
Butene	57	0.005	Methyl isobutyl ketone	140	0.005
Butyraldehyde	17.1	0.01	n-Butyl acetate	189.11	0.02
C10-C11 Saturated and unsaturated aliphatic hydrocarbons	131	0.12	n-Butyl alcohol	80	0.02
C6 Saturated aliphatic hydrocarbon	211	0.005	n-Hexanal	24.6	0.25
C7 Unsaturated aliphatic hydrocarbon	200.28	0.006	Octamethylcyclotetrasiloxane	280	0.31
C8 Saturated and unsaturated aliphatic hyc	35	0.07	Octane	348.92	0.02
C9 Saturated aliphatic hydrocarbons	314	0.06	Pentanal	21.1	0.07
Carbon disulfide	3.1	0.02	Pentane	588.28	0.01
Carbon monoxide	63	1.3	Propane	898.81	0.005
Carbonyl sulfide	4.9	0.009	Propionaldehyde	14.3	0.02
Chloromethane	41.17	0.007	Propylene	857.64	0.005
Dimethyl disulfide	0.1	0.005	Styrene	42.5	0.005
Ethyl acetate	179.34	0.04	Toluene	15	0.005
Ethyl alcohol	2000	1.6	Trimethyl silanol	4	0.01
Ethyl formate	90.72	0.06	Vinyl acetate	10.5	0.03

The samples were observed to smolder for at least 15 minutes following removal of the ignition source. With no way to cool the sample post-test, several nitrogen purges were performed to ensure complete extinguishment of the test sample due to oxygen consumption before removal from the test chamber. All the tiles shown in Figure 6 failed the flammability tests, as the tiles smoldered for an extended length of time (15 minutes to 1 hour). The tiles showed melting/dripping, and the tiles with higher percentages of plastic smoldered longer and tended to be more flammable. Therefore, the flammability results disqualified these tiles from being stored on-orbit without flame-retardant bags. For the flight demonstration tests, the processed tiles will be stored in containment bags - currently zip lock bags used on the ISS and the cargo transfer bag - until on-orbit data confirms that they can be safely stored without such containment. This approach allows for precautionary measures while evaluating the tiles' behavior in a controlled environment.

The tiles tested were based on 500 g trash samples that are thinner and smaller than the current TCPS tiles. The current TCPS tiles are made from a 2.2 kg trash batch that is 2 inches thick and 11 inches square. In summary, the flammability tests conducted on the trash tiles produced from the HMC Gen 1 indicated that the processed tiles need to be placed in Nomex or other flame-retardant coverings.[16, 17] Since different trash batches have been used for testing and the trash batch components have been better defined since 2013, a follow-up flammability study of tiles produced from the ground hardware needs to be completed.

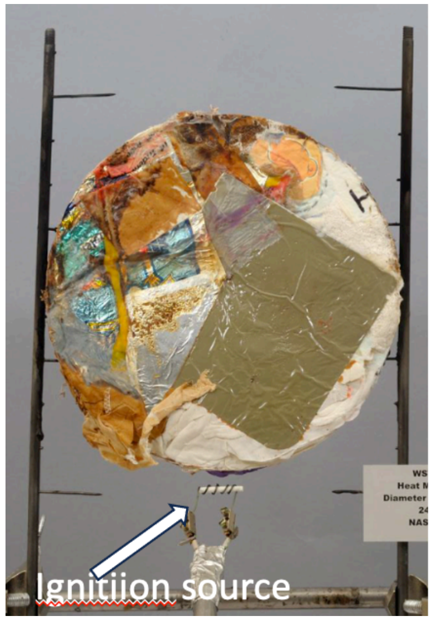

Figure 5: Tile orientation relative to the ignition source at WSTF

Table 5: HMC 1 flammability analysis data

Test #	Diameter	thickness	Weight	burn Length	Propagation Burn time	Weight Loss	Relative O2 Consumption	% weight loss	Quantify of Sparks	Quantify of Cinders	Quantify of Flame Jets	Quantify of burning Material	Effect on K-10 paper
	cm	cm	g	cm	sec	g	%	%	none	none	none	large	Ignition
1	20.3	2.4	358.96	20.3	137	158.873	36.1	44.3	none	none	none	large	Ignition
3	20.4	1.8	438.21	20.3	269	113.49	35.5	25.9	none	none	small	large	Ignition
4	20.4	2.5	458.93	20.3	274	128.56	35.4	28.0	none	none	none	large	Ignition
5	20.4	2.4	450.15	20.3	114	109.44	31	24.3	none	none	none	large	Ignition
6	20.4	1.6	376.89	20.3	183	121.04	34.4	32.1	none	none	none	large	Ignition
8	20.4	2.1	374.64	20.3	148	72	17	19.2	none	none	none	large	Ignition

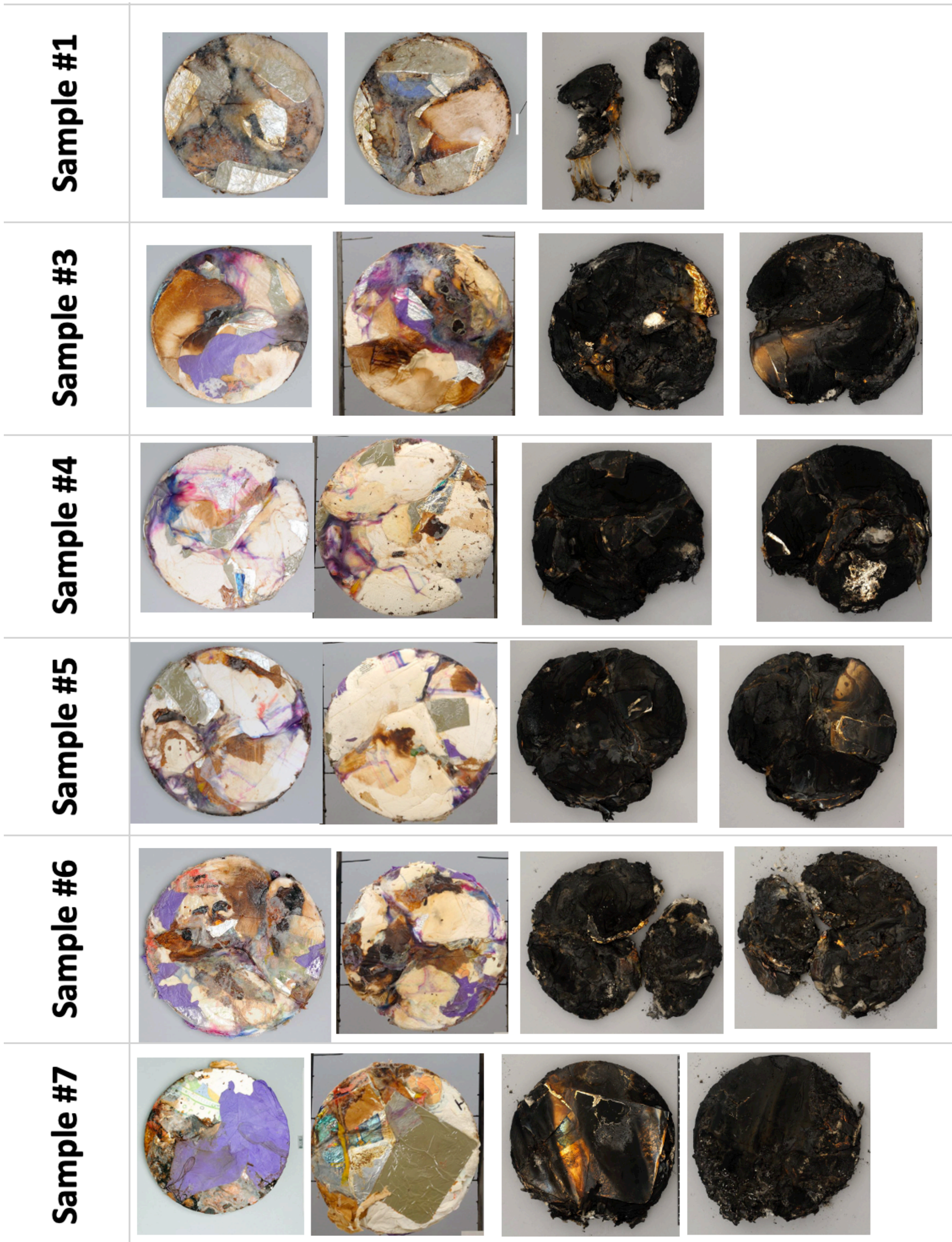

Figure 6: Pictures of the tiles before the flammability test and after.

IV. Technology Infusion

NASA has been developing trash compaction technologies since 2005, building on technology of the Navy's Plastic Melt Compactor. As NASA plans to conduct both short and long duration transit and planetary missions beyond LEO, the trash management system must be designed to accommodate specific mission types. Currently, the ISS crews separate and bag wet, and dry trash separately. These small trash bags are then further stored in larger containment bags and transferred to the empty resupply ship for incineration in Earth's atmosphere upon reentry.

The TCPS design currently uses heat to safen the trash. For certain missions, such as short duration planetary missions, a nonheated trash compaction variant may offer mass, power, and volume savings. Two trash compaction approaches that do not use heat are the mechanical or previously called CEV compactor (Figure 7)[18] and the VacCompact (Figure 8). This mechanical compactor was initially developed before the development of the HMC as an alternative to making "trash footballs" with duct tape.[18] Currently, researchers at NASA's Ames Research Center are reassessing and testing different standardized TCPS trash batches to evaluate its use in short duration/transit space missions. The VacCompact trash compaction approach uses commercially-available compression camping bags to compress and shape the trash for easy storage.

As the TCPS technology matures and moves toward an on-orbit demonstration, data assessment will be crucial to identify areas suitable for infusion. The TCPS, which heats and compresses trash, necessitates the management of water and gas effluents and the use of spacecraft resources such as the cooling loops, power and disposal/recycling systems. These operational requirements may result in cumbersome hardware components that may potentially be unsuitable for all mission types. For example, for short-duration planetary missions, it may not be feasible to install the TCPS in pressurized rovers. Therefore, alternative trash compaction methods might be better suited for shorter missions or rover-based operations, offering greater flexibility. Lessons learned from the TCPS development are applicable to these alternative low-fidelity trash management technologies, offering valuable insights for future advancements.

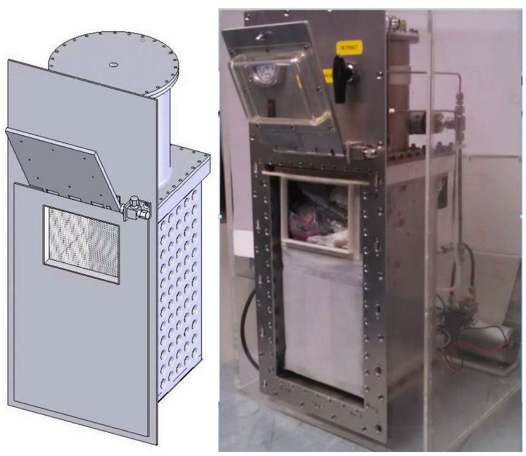

Figure 7. The previously called CEV compactor[18]

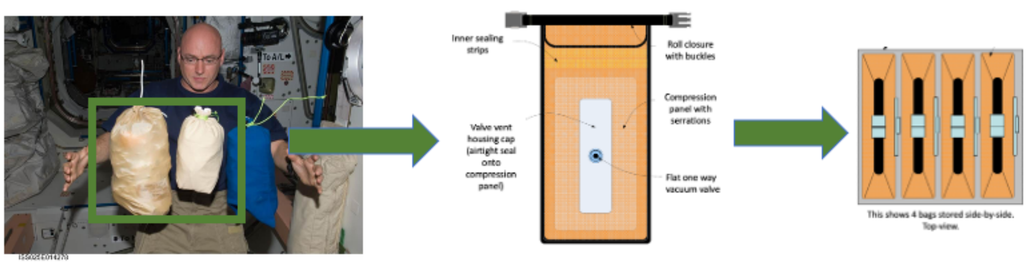

Figure 8. The VacCompact for volume reduction. (Photo credits: NASA)

V. Conclusion and Future Work

The development of TCPS flight hardware is essential to provide a method for processing spacecraft trash, especially for long-duration missions where trash volume and mass can adversely affect the crew habitat and contribute to higher mass budgets for the spacecraft. The risk reduction activities aim to demonstrate the technology for use during space missions, prepare the technology for on-orbit tests, and minimize on-orbit operational failures. The TCPS flight demonstration will be the first spacecraft trash processor with water recovery tested on a spacecraft.

The on-orbit test in microgravity, along with crew and on-orbit hardware operations, will provide data to further optimize the TCPS for longer-duration exploration missions.

VI. Acknowledgments

The TCPS technologies have been in development for the better part of two decades. Many people have been involved in the development process, making the list far too long to name here. However, we would like to specifically acknowledge Steven Levi Vary for help with the moisture analysis tests as well as the previous trash compaction program managers and developers for their contributions to advancing this technology: John Fisher, Jeffrey Lee, Jim Broyan, Barry Finger, James Clawson, Keisha Willingham, John Hogan, and Marilyn Murakami.

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