Excavation of Exploration Toilet Fecal Canister from ISS Operations and Future Mission Impacts

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Space exploration requires accommodations for crew members similar to survival on Earth including food and water, clothing, and protection from the environment. In addition, allowances for biological processes such as breathing, defecation and urination must be provided. In a micro-gravity environment, these are particularly challenging. Optimizing the consumables needed for these activities is a vital part of the spacecraft design allows more mass and volume for science cargo and the other crew needs such as food and clothing. NASA has collected use rates for the consumables needed for defecation and urination over the decades of human-rated space travel. Most recently, the exploration toilet demonstration on International Space Station (ISS) provided data on defecation in the form of a returned fecal canister which collected 13 days of fecal deposits, wipes, gloves and compaction plates. The canister was excavated by a dedicated team of engineers at Johnson Space Center (JSC) to provide the latest information on deposit size and weight, number of wipes and gloves used, and compaction efficiency which directly relates to the number of canisters needed. Although this was only one canister, the data found has been directly applied to manifest decisions for the Orion Artemis-2 mission. Future canisters will add to this data set. Details on what was found and how it compares to historical numbers as well as how it will be used for exploration missions will be covered in this paper.

Nomenclature

AES	=	Advanced Exploration Systems
EDO	=	Extended Duration Orbiter
ISS	=	International Space Station
JSC	=	Johnson Space Center
KTO	=	Russian acronym for Solid Waste Container
LR	=	Logistics Reduction
NASA	=	National Aeronautics and Space Administration
STS	=	Shuttle Transportation System
US	=	United States
UWMS	=	Universal Waste Management System
WHC	=	Waste and Hygiene Compartment
WCS	=	Waste Collection System
WMS	=	Waste Management System on Orion

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I. Introduction

NASA contracted Collins Aerospace to develop an updated toilet for use in exploration missions with goals of reductions in mass and volume, which are key objectives of successful hardware used for long range missions. The Universal Waste Management System (UWMS) project built on previous toilet designs and delivered a toilet for the International Space Station (ISS) and the first crewed Orion mission, Artemis-2. Nomenclature of both units is Toilet and, in this paper, UWMS and Toilet are used interchangeably. Delivery of the Orion Toilet (seen in Figure 1) was in December 2019 and the unit was installed into the Artemis-2 vehicle in March 2021 for launch in 2025. The ISS unit, seen in Figure 2 along with the Toilet Integration Hardware, launched to ISS in October 2020.

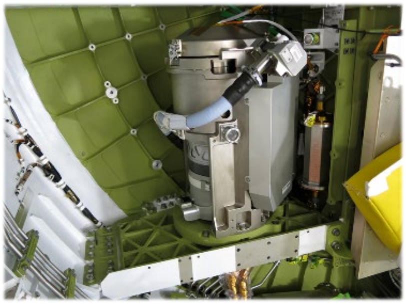


Figure 1. Orion Toilet installed in Artemis-2 Vehicle.

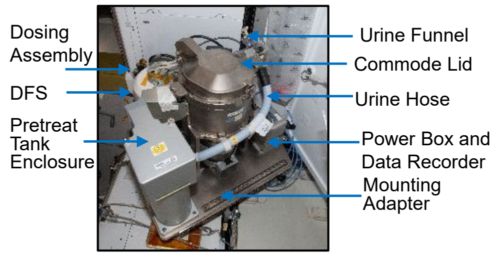


Figure 2. ISS Toilet with Toilet Integration Hardware in Node 3.

The ISS unit installed in Node 3 has experienced technical challenges as part of the checkout and operational use.[1,2,3] Despite these challenges, a limited checkout was performed in 2021 with a single crewmember using UWMS at a time, that is, a male crewmember used Toilet (nomenclature used on ISS and Orion) for a week; then a female crewmember used Toilet for a week, then another male crewmember used Toilet for three days. Although three crewmembers, 2 male and 1 female, used Toilet for multiple days, only the first two - male and female - contributed to the returned fecal canister. Future use of Toilet for completion of the technology demonstration will provide additional fecal canister for evaluation on the ground.

II. Historical Context and Data

Current space toilet designs are built on the evolution of toilets both on the ground and in spacecraft. Early spacecraft provisions for dealing with metabolic waste were very simplistic and comparatively crude. Liquid waste (urine) was collected via a roll-on cuff (designed for male anatomy only) that was connected to a collection bag or captured in a small hand-held honeycomb cylinder and vented from the spacecraft[4]. Fecal material was collected in bags (see Figure 3) and stored in a locker within the spacecraft for the duration of the mission and then removed, analyzed, and disposed. Collection of the waste was often inefficient and uncomfortable for crewmembers. Fecal collection was particularly challenging. A bag was adhered to the body with adhesive which was irritating to the skin and sometimes ineffective in securing the bag properly.[4]

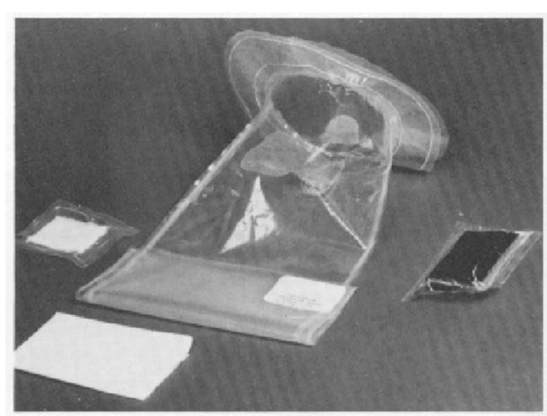


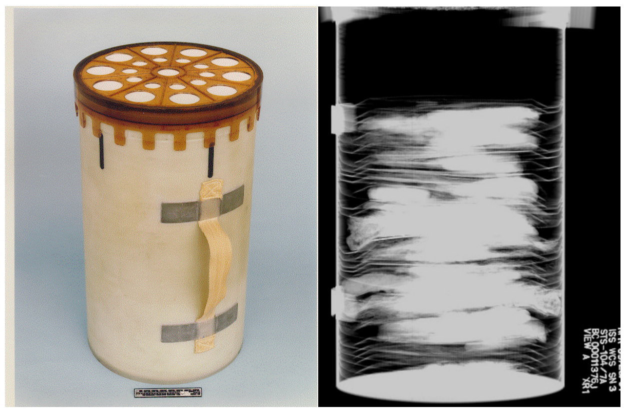
Figure 3. Apollo Fecal Bag with consumables.

Apollo 10 crewmembers recorded in official transcripts multiple "escapes" of fecal material within the spacecraft and attempts to retrieve and collect it.

Shuttle toilets were more hygienic and easier to use. Fecal material was collected in a single large oval tank for these relatively short duration missions. The tanks were removed and evaluated after the flight. The toilet on Shuttle Extended Duration Orbiter (EDO) missions used multiple removable fecal canisters.

As previously stated, fecal collection during the Apollo missions was accomplished with a passive system – feces were collected in a bag, which was considered very unhygienic. As can be seen in Figure 3, some form of wipes were used for body cleaning after defecation.

During the Shuttle program, more consideration was given into the types and quantity of consumables needed for body cleaning after defecation. After the return of STS-104, on which the Extended Duration Orbiter (EDO) WCS was used, a ground evaluation, or "fecal" dig, was performed on three fecal canisters. The canisters were further evaluated on the ground to determine overall packing efficiency and to better quantify consumables used per defecation. In addition, each canister was also X-rayed prior to disassembly to document the filled configuration (see Figure 4).



(a) (b)

Figure 4. Shuttle Fecal Canister from STS-104/7A – a) Filled Configuration and b) X-rayed.

Once opened each of the fecal deposits was examined for any leakage as well as whether the fecal bag was sealed. Each fecal bag was then opened and the consumables were removed and counted. Based on historical data, the crew used several types of wipes including dry wipes, wet wipes, and toilet tissues for body cleaning during defecation. These items were found in each of the fecal bags during the evaluation. The average consumables and overall results of the evaluation are summarized in Tables 5 & 6 later in this paper.

III. Current Consumables and ISS Data

US crewmembers on ISS primarily use the toilet in Node 3 that was designed by the Russians. The Waste and Hygiene Compartment (WHC) uses a hard metallic canister for fecal deposits (KTO is the Russian acronym for the canister), see Figure 5.

Figure 5. WHC KTO used by US crew on ISS.

Data on consumable usage has been collected during the ISS life and is recorded in Tables 4 and 5 below. The KTO functions similarly to the Toilet fecal canister; deposits are made into fecal bags along with wipes and gloves and then pushed down into the container. Air flow, however, is directed to the bottom of the container, which is different than Toilet or Shuttle EDO WCS. No compaction plates are used in the WHC and compaction is not part of trained operations although some crewmembers have reported performing hand operations to rearrange the contents of the container and compaction using a repurposed handrail. The KTO requires assembly (it is flown in two pieces) as well as application of caps when full. Both activities require crew time.

IV. ISS UWMS Evaluation On-Orbit

In 2021, the ISS UWMS was evaluated on-orbit by three crewmembers during a limited checkout period. During this period, the system was only used by one crewmember per day for multiple days. A male crewmember used Toilet (nomenclature used on ISS and Orion) for a week; then a female crewmember used Toilet for a week, then another male crewmember used Toilet for three days. Although three crewmembers, 2 male and 1 female, used Toilet for

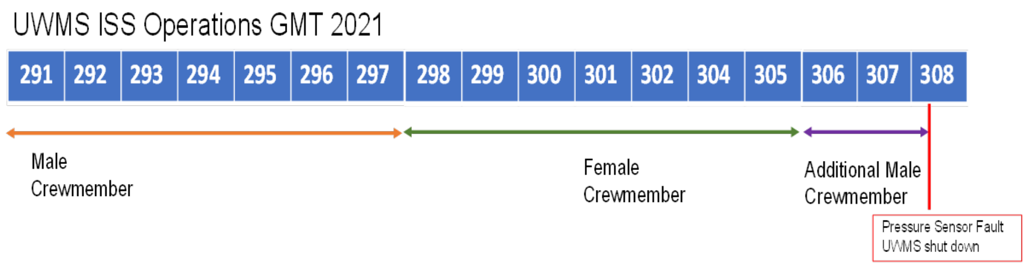


Figure 6. 2021 Timeline of UWMS Limited Checkout with a Single Crewmember per day.

multiple days, only the first two – male and female - contributed to the returned fecal canister. The timeline for this checkout period is shown in Figure 6. During this period, only two of the three crewmembers (one male and one female) used UWMS for defecation; this is the canister that was returned to the ground and further evaluated.

Configuration of the UWMS on ISS is shown in Figure 7. The UWMS is installed in a stall adjacent to the ISS WHC in Node 3. After their fecal deposit is made into individual fecal bags, crewmembers add dirty wipes and gloves and seal the bags before pushing it down into the fecal canister. Then they use the Fecal Compactor to insert a compaction plate and push the contents of the canister to the bottom. Although the quantity of compaction plates used is at crew discretion, it allows additional deposits to be contained in the canister. Crew can choose from US Dry Wipes, Russian Dry Wipes, US Wet Wipes and US Disinfection Wipes for use in cleaning the body after use as well as cleanup of the Toilet.

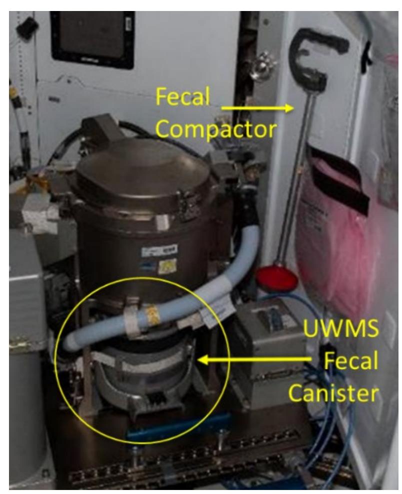


Figure 7. UWMS on ISS, Node 3.

The two crewmembers each participated in both defecation and urination individually as well as dual operations (both defecation and urination at the same time) during this period. There was significant knowledge gained during this brief period as detailed in previous papers[1,2,3]. Especially significant was the filled fecal canister that was returned for evaluation by the principal investigator and team at JSC. Data from this canister provided information on capacity of this canister. The canister is common to the toilet used on ISS (UWMS-1) and the similar toilet (UWMS-2) installed in the Artemis-2 vehicle for use in Orion's first crewed mission. A previous paper discussed the updated capacity found as well as number of consumables such as wipes, and gloves used by crew[1]. Both factors provided updates for the Artemis-2 manifest. This paper details the process and additional details of the excavation process as well as comparisons to data from toilet use on previous spacecraft.

V. Dig Data

Prior to the excavation of the UWMS fecal canister, the exterior of the canister and canister lid were examined,

(a) (b) (c)

Figure 8. Returned UWMS Fecal Canister – (a) Returned from ISS, (b) Returned packaging removed and (c) X-ray of the returned canister.

and the canister assembly was weighed. X-rays were also taken to show the location of the contents, which verified that the canister was full (See Fig. 8).

Data from the returned UWMS canister was obtained by removing the fecal deposits and compaction plates in reverse order of placement into the canister. Compaction plates were inspected for location, number of deposits compacted, position relative to the canister sides and discoloration and/or presence of fecal material (outside the individual fecal bags). Table 1 provides the data collected on the deposits and compaction plates. Table 2 gives depth from the top rim of the canister to 4 positions around the circumference.

Figure 9 below shows an image of the inside of the fecal canister before the removal of each compaction plate.

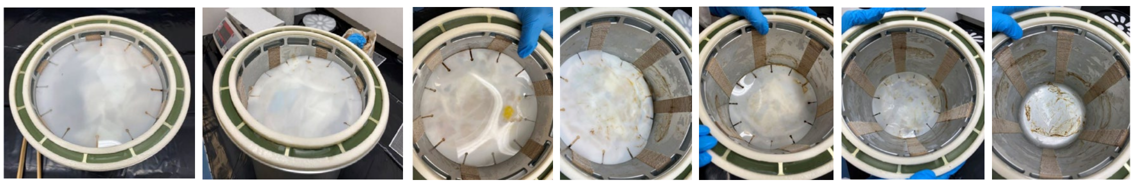
Table 1. Compaction Plates and Number of Deposits in Fecal Canister.

Compaction Plates	
	# deposits
Between Plate 1 (top) and lid	0
Plate 1 and Plate 2	1
Plate 2 and Plate 3	2
Plate 3 and Plate 4	1
Plate 4 and Plate 5	3
Plate 5 and Plate 6	5
Plate 6 and can bottom	1

The canister contained a total of six compaction plates and thirteen fecal deposits. Figure 10 shows the configuration of the inside of fecal canister after the removal of each compaction plate.

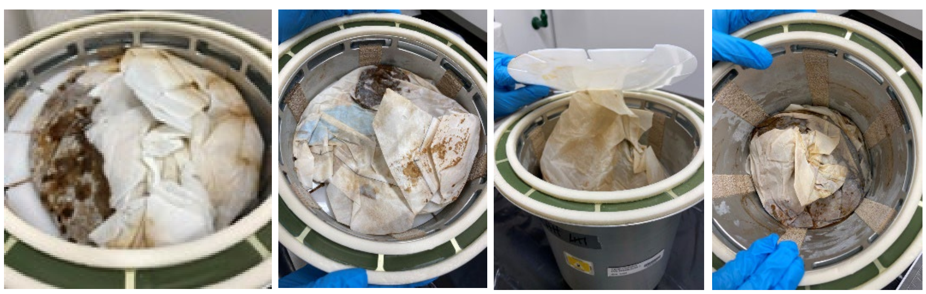
Table 2. Compaction Plates Location, Description and Depth in Fecal Canister.

Compaction Plates Location, Description and Depth							
Plates numbered from top		**depth loc 1**	**depth loc 2**	**depth loc 3**	**depth loc 4**		**notes**
Plate 1		0.63	0.81	0.81	1.13		
Plate 2		1.50	1.25	1.13	2.25		noticeable canted
Plate 3		2.38	2.38	1.94	2.63		pretty flat, top has yellow staining, bottom is moist
Plate 4		missing data					compressed well between plates
Plate 5		5.75	4.38	4.75	5.75		concave- higher on sides
Plate 6		6.38	9.00	7.75	7.25		plate is concave, fouled
							liquidy fecal matter on sides of canister below plate 6



(a) (b) (c) (d) (e) (f) (g)

Figure 9. Compaction Plates 1, 2, 3, 4, 5, 6, and bottom of Fecal Canister.



(a) (b) (c) (d)

Figure 10. Fecal Canister contents after removal of Compaction Plates 1, 2, (photos not available for 3 and 4) 5, and 6

Each individual deposit included a fecal bag, fecal deposit, various types of wipes, i.e., US dry wipes, wet wipes, Russian dry wipes, disinfectant wipes, and gloves which are crew preference for selection and quantity. The deposits in-situ within the fecal bag were photographed on a grid paper to show relative size and weighed. Each element included was removed from the fecal bag. The wipes and gloves were counted. Fecal material itself was weighed and the consistency was noted. Process is shown in Figure 11 for deposit #1.

(a) (b) (c) (d)

Figure 11. Process of evaluating each deposit. (a)-(b) Fecal bag measured and weighed. (c) Fecal Bag opened. (d) Wipes and gloves removed from bag and counted.

Table 3. Fecal Dig Data

Crew Member	# Fecal Bags Used	Consumables Use	US Dry Wipe	Gloves	Russian Dry Wipe	US Wet Wipe	Disinfectant wipe	Fecal Deposit Average Weight (lbs)	Overall Average Weight (lbs)
TOTAL	**13**		**0**	**12**	**46**	**64**	**3**		
Male	6	*total*	0	0	11	25	0		
		avg per use	0	0	1.83	4.17	0.00	0.221	0.420
		mass per use (lbs)		0.00	0.04	0.21	0.00		
Female	7	*total*	0	12	35	39	3		
		avg per use	0.00	1.71	5.00	5.57	0.43	0.427	0.503
		mass per use (lbs)		0.02	0.12	0.28	0.02		
Overall	**13**	***total***	**0**	**12**	**46**	**64**	**3**		
		avg per use	**0.00**	**0.92**	**3.54**	**4.92**	**0.23**	**0.333**	**0.490**
		mass per use (lbs)		**0.01**	**0.08**	**0.25**	**0.01**		

Consumables and fecal material data from the dig is shown in Table 3. The dig data was compared to feedback from the crew in questionnaires to note the change from male to female usage. Note that no US dry wipes were found. Subsequent feedback from crewmembers indicated a crew preference for the Russian dry wipes. The Orion program is not flying Russian dry wipes. Figure 12 shows a comparison of the Russian and US dry wipes.

VI. Overall Comparisons

Data obtained from the UWMS fecal dig is displayed in Tables 4 and 5 as compared to current use on ISS using the WHC KTO and to previous use on Shuttle EDO that was obtained by a similar dig event. No data was taken on the remaining moisture content of the fecal deposits. Data obtained from dig data for Shuttle EDO (3 canisters) and ISS/KTO consumables usage data.

Table 4. Comparison of average number of wipes and gloves used per deposit for US crew used toilets.

	Avg fecal mass (lbs.)	US Dry Wipes	US Wet Wipes	Toilet Tissues	Russian Dry Wipes	Disinfectant Wipes	Gloves
Shuttle	.169	1.5	2.3	0.6	-	-	1
ISS/UWMS	.333	0	4.92	-	3.54	.23	.92
ISS/KTO	0.29	1	2	-	3	-	2

Table 5. Comparison of efficiency, number of deposits and volume of canisters

	Volume (in^3)	# Deposits	# Compaction Plates	Avg. Fecal Bag volume (in^3)	Vol. Efficiency (#deposits/in^3)
Shuttle	678	23	23	5.35	.034
ISS/UWMS	501	13	6	5.35	.026
ISS/KTO	915	30	none	2.25	.033

Evaluation of the data obtained from the UWMS Fecal Canister excavation indicates that the Volumetric Efficiency (number of deposits per cubic inch) is similar to prior canisters for Shuttle and ISS KTO. Differences can be seen in the volume of the fecal bags; the bags used with the WHC KTO are significantly smaller than those used on both the Shuttle EDO and ISS UWMS toilets. However, the KTO does not use compaction plates to gain compaction efficiency although some hand compaction with a handrail is done per anecdotal data from some crew members. Average fecal deposit mass for the shuttle missions was seen to be much smaller than those seen for UWMS and the KTO on ISS. However, it should be noted that this is based on a very limited data set.

It appears that the smaller volume of the Toilet canister does not make a significant difference in the efficiency of deposits that may be contained in the canister per volume. Compaction appears to contribute to a better packing efficiency, and size of the fecal bag does not appear to have much impact.

VII. Impact on Current and Planned Exploration Missions

Data obtained from the returned UWMS fecal canister has already influenced the manifest of Orion's Artemis-2 mission. Updates were made to the quantities needed for fecal canisters, canisters lids, compaction plates and consumables such as wipes and gloves. In addition, an alternative to the Russian dry wipe is being evaluated for quantity and performance for use on this mission. More data is expected when the technology demonstration resumes on UWMS. Two additional canisters are planned for return as well as 3 soft-sided Alternate Fecal Canisters. This will add to the available data and continue to provide valuable insight for the near-term Artemis missions as well as longer and later Mars exploration missions.

VIII. Conclusions

Although there is a great deal of data from early spaceflight missions as well as the ongoing presence of crewmembers on ISS, the most recent collection of data from crew toilet use adds to the knowledge base. Demonstration by crewmembers and honest and forthright documentation of usage quantities and patterns is very valuable as planning continues for long range Mars Transit and Surface exploration activities. Although there is past data available, space exploration with new human male and female crew members means an ever evolving and very personal need for recent and relevant data to allow efficient, comfortable, and lowest mass alternatives for collection and storage of metabolic waste.

IX. Acknowledgments

This paper summarizes work that was performed by numerous NASA and contractor engineers, analysts, functional specialists, technicians, and crewmembers. While NASA programs MCO, ISS and Orion provide significant funding of the activities discussed, NASA recognizes the significant contributions of commercial partners, small businesses, and academic institutions.

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