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CHAPTER 2
WASTE MANAGEMENT SYSTEM

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Introduction

Defecation and urination have been bothersome aspects of space travel from the beginning of manned space flight. Ideally, waste management systems for use in space would permit elimination of body wastes and their collection to be accomplished as simply as they are on Earth. In the weightless environment, however, this is a difficult goal to achieve. Waste handling equipment must not only be designed to function in zero gravity, but must do so within the constraints of size, weight, and power imposed by spacecraft systems. These restrictions resulted in the use of the waste management systems described in this chapter.

The urine collection and transfer processes, with only minor modifications, were essentially the same for Apollo missions as they were for all prior United States space missions. Very simply described, the prime system used prior to Apollo 12 by unsuited crewmen employed the urine transfer system. This system consisted of a rubber cuff connected to a flexible collection bag. A new system, the urine receptacle assembly, was developed for Apollo and served as the prime system on Apollo 12 and all subsequent missions. This system employed a device which did not require intimate contact of the crewman during urine collection. The urine transfer system served as a backup system during the latter missions. Each of these approaches is illustrated in figure 1.

When crewmen wore space suits during launch, extravehicular activity, and emergency modes, a special device was provided for collection and intermediate storage of urine. This device, known as the urine collection and transfer assembly, is shown in figure 2 as it was worn over the liquid cooling garment. The assembly was connected by a hose to the spacecraft waste management system. Several modified devices were used when urine samples were collected for postflight analysis.

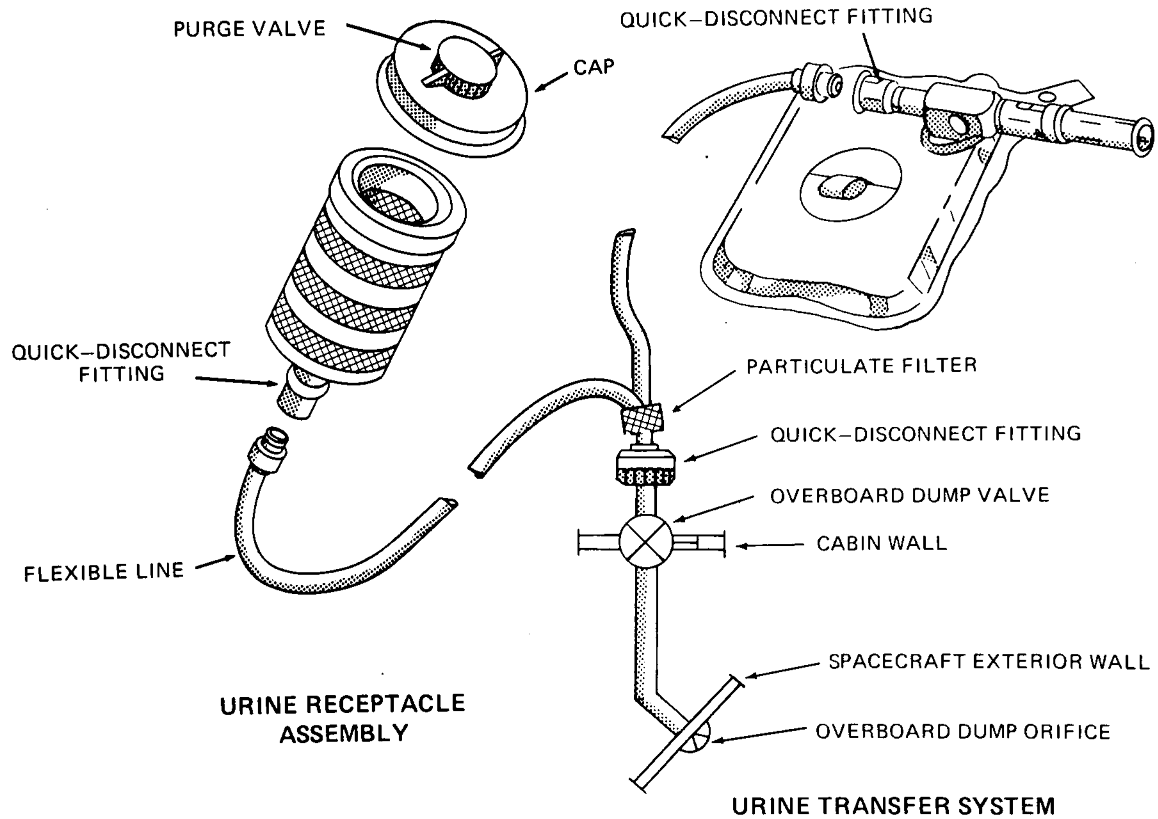

Figure 1. Apollo urine collection systems – the urine receptacle assembly and urine transfer system.

Figure 2. Urine collection and transfer assembly worn over the liquid cooling garment.

Efforts had been made prior to the first Apollo flight to simplify the waste collection systems to allow waste collection without intimate contact devices and to permit direct overboard dumping of urine. Because of problems encountered during the development phase, the improved systems were not available in time to be used for Apollo missions.

In the absence of a system providing positive means for the removal of feces from the body, an extremely basic system had to be relied upon for inflight fecal collection. The device used was a plastic bag which was taped to the buttocks to capture feces. After defecation, the crewmember was required to seal the bag and knead it in order to mix a liquid bactericide with the contents to provide the desired degree of feces stabilization. Because this task was distasteful and required an inordinate amount of time, low residue foods and laxatives were generally used prior to launch. During flight, in addition to low residue foods, some use was also made of drugs to reduce intestinal motility.

During lunar surface activity and free space extravehicular activity, the use of the bag fecal collection system was not feasible. Should it have become impossible for a crewman to have prevented defecation during these activity periods, the fecal containment system – a pair of undershorts with layers of absorbent material – would serve to contain any excreta.

The following sections describe the Apollo waste management system in detail and briefly evaluate its performance.

Apollo Waste Management System

The function of the waste management system (WMS) was to control the disposition of solid and liquid wastes and waste stowage gases. The basic requirements of the system included collection and stowage of feces, collection and overboard dumping of urine, removal of urine from the pressure garment assembly, provision for urination while in the spacecraft couches, and venting of waste stowage gases. A urine and fecal waste stowage vent and a vacuum subsystem were part of the overall waste management system (Sauer, 1971).

The waste management system consisted of a urine subsystem and a fecal subsystem. The principal elements of the urine subsystem were the urine receptacle assembly (URA), the urine transfer system (UTS), the urine collection and transfer assembly (UCTA), and, for several missions, modified urine collection devices to provide samples to be retained for postflight analysis. The main elements of the fecal subsystem were a fecal and emesis collection device, a waste stowage compartment, a waste stowage bag, and a fecal containment garment (the "fecal containment system") for contingency and suited conditions. Figure 3 is a schematic representation of the waste management system elements within the Command Module (URA not shown).

Urine Subsystem

The urine subsystem consisted of three devices for collecting and transferring urine: the urine transfer system, the urine collection and transfer assembly, and the urine receptacle assembly. The remainder of the system consisted of a particulate filter to prevent clogging of the orifice of the urine dump nozzle (see figure 1) and a hose for transferring urine from any of the collection devices to the waste management panel for dumping.

Urine Receptacle Assembly (URA). The urine receptacle assembly (figure 4) was an open-ended, cylindrical container that could be hand-held. The receptacle was connected by a quick-disconnect fitting to a flexible urine dump line, which in turn was connected by a quick-disconnect fitting to the waste management panel. The receptacle could accommodate a maximum urine flow of 40 ml per second. Although the receptacle's volumetric capacity was only 480 ml, the effective system capacity was 700 ml with concurrent urination and dumping.

The URA contained a honeycomb cell insert that supported a 40μ hydrophilic screen. The honeycomb insert provided a large contact area that acted as a bundle of capillary tubes. The capillary action produced by each cell (0.32 cm pore size) of the honeycomb tended to hold the fluid in place in the zero-g environment until it could pass

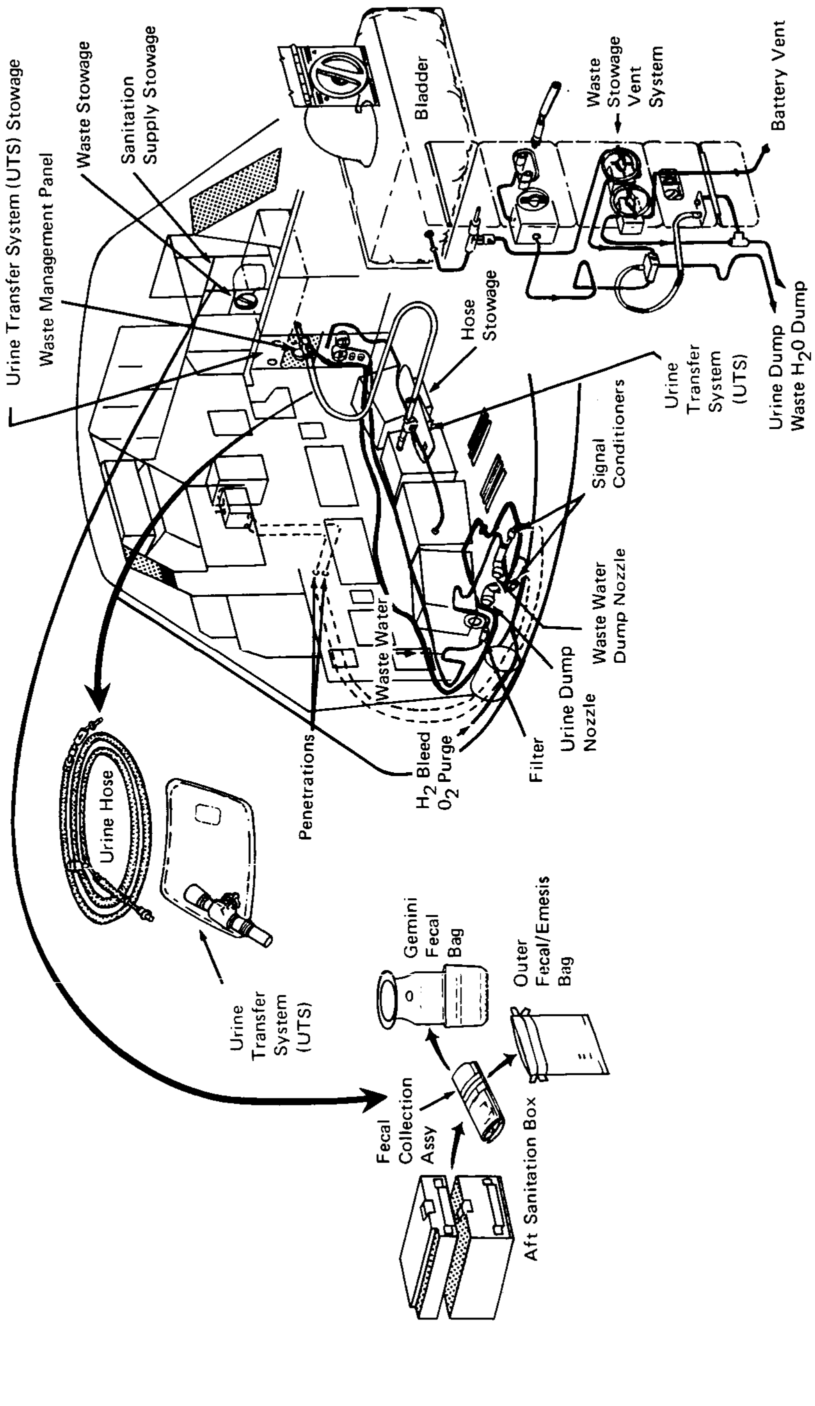

Figure 3. Waste management system (NASA, 1969).

into the urine dump line. A sealing cap installed during periods of nonuse blocked out cabin airflow and permitted the interior of the URA to be exposed to the space vacuum for venting between uses, if desired.

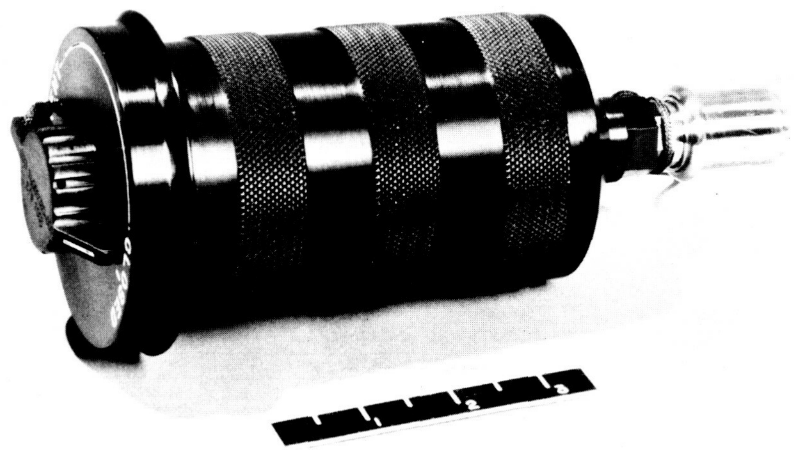

Figure 4. Urine receptacle assembly.

For use, the URA was taken from its stowage position, the cap removed from the receiver chamber, and the device connected to the 3.05-m long urine transfer hose, which in turn was connected to the waste management panel. The overboard dump valve on the waste management panel was rotated to the "dump" position, allowing the system to be vented to space at a pressure differential of 3.4×10^4 N/m^2 (5 psi). The man voided by directing his urine stream into the receiver chamber of the URA. When the receiver chamber had emptied, 60 seconds were allowed for clearing the hose and lines prior to closing the urine dump valve. The cap was replaced on the receiver chamber and the URA returned to its mission stowage position.

The urine transfer hose was made of flexible, convoluted fluorocarbon sufficiently strong to withstand the pressure differential and supple enough to facilitate easy handling in zero g. The hose also could be used to join the space suit urine quick-disconnect fitting to the waste management panel to facilitate emptying the urine collection and transfer assembly.

Installed between the waste management panel quick-disconnect and the hose was a 215-micrometer filter. Urine was filtered to prevent clogging the orifice of the urine dump nozzle. The dump nozzle orifice had a diameter of 0.1397 cm, which restricted gas flow to a maximum of 0.01 m^3/minute and liquid flow to 453.6 gm/minute. This prevented excessive loss of cabin oxygen during system use. Because ice formation at the dump nozzle could block flow, the nozzle was fitted with two redundant 5.77 watt heaters.

Urine Transfer System (UTS). The urine transfer system (figure 5) consisted of a roll-on cuff, a receiver, a valve with a manifold, a collection bag, and a quick-disconnect fitting. The roll-on cuff was a rubber tube that functioned as an external catheter between the penis and the receiver/valve. The cuff was designed to be used for one day (five or six urinations) and was then replaced. Ten additional color-coded cuffs per crewman were stowed. The receiver to which the cuff attached was a short tube containing a low-pressure differential check valve [262 N/m^2 (0.038 psi)] and a bypass valve.

Figure 5. Apollo urine transfer system (UTS) with roll-on cuff.

The UTS could be used in two different modes: (1) dumping during time of voiding, and (2) dumping subsequent to voiding. In the first mode, the hardware was interconnected to the overboard dump system during the time of voiding, as shown in figure 1. As a consequence, the urine was immediately dumped overboard as it was voided. In the second mode, the UTS was not connected to the overboard dump system during the micturition. In this mode, urine was collected in the UTS bag. Following micturition, the UTS was connected to the overboard dump system and the urine vented overboard. The urine collection bag had a capacity of approximately 1200 ml. For reasons of sanitation, each crewman was provided a personal urine transfer system.

Urine Collection and Transfer Assembly (UCTA). The urine collection and transfer assembly (figure 6) was designed to facilitate urination when crewmen were wearing pressure suits, for example during extravehicular activities. The urine collection and transfer assembly consisted of a roll-on cuff and a collection bladder worn around the waist. The UCTA was worn over the fecal containment garment. Urine in the device could be drained either while the crewman was in the suit or after the suit was removed by connecting the urine transfer hose to the spacecraft waste management panel.

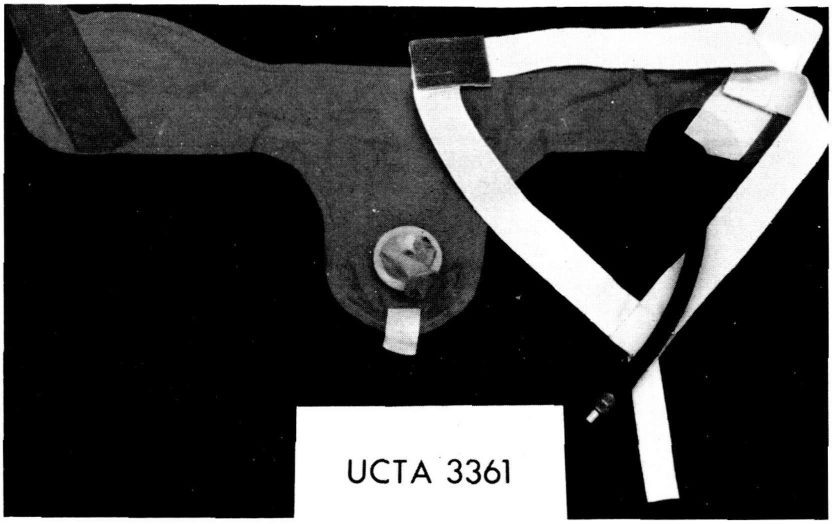

Figure 6. Apollo urine collection and transfer assembly (UCTA).

Ancillary Urine Hardware. Two ancillary urine collection devices were used. These were the return enhancement water bag (REWB) and the biomedical urine sampling system (BUSS).

The REWB, provided for the flight of Apollo 14, made available additional water storage volume onboard in the event of a partial water system failure. The REWB was also used for Apollo 15 and subsequent missions to pool urine for up to 24 hours in order to circumvent overboard dumping during certain mission periods.* After the pooling period, the REWB containing urine was dumped in a similar manner as was the urine transfer system, except that an additional urine filter was installed downstream of the REWB to prevent possible system plugging with urine precipitates formed as a result of urine storage for 24 hours.

During the Apollo 16 mission, three return enhancement water bags (one for each crewman) were provided to recover 24-hour pooled urine samples collected inflight with the urine transfer system. Boric acid preinstalled in the REWBs preserved the urine. These samples were collected to permit an investigation of fluid and electrolyte disturbances suspected to have occurred during prior missions. Figure 7 depicts schematically the urine collection system for Apollo 16.

Inflight urine samples were again collected during the Apollo 17 mission. In this case, the samples were required for a study that focused on the cations and anions critical to body fluid regulation. Twenty-four-hour urine samples were collected from each crewman on each man-day of Command Module occupancy by use of the biomedical urine

*It was desirable, for example, to circumvent urine dumping for the conduct of lunar optical experiments. Dumped urine tended to form a cloud of vapor around the spacecraft which fouled the optics with particulate matter and interfered with observations.

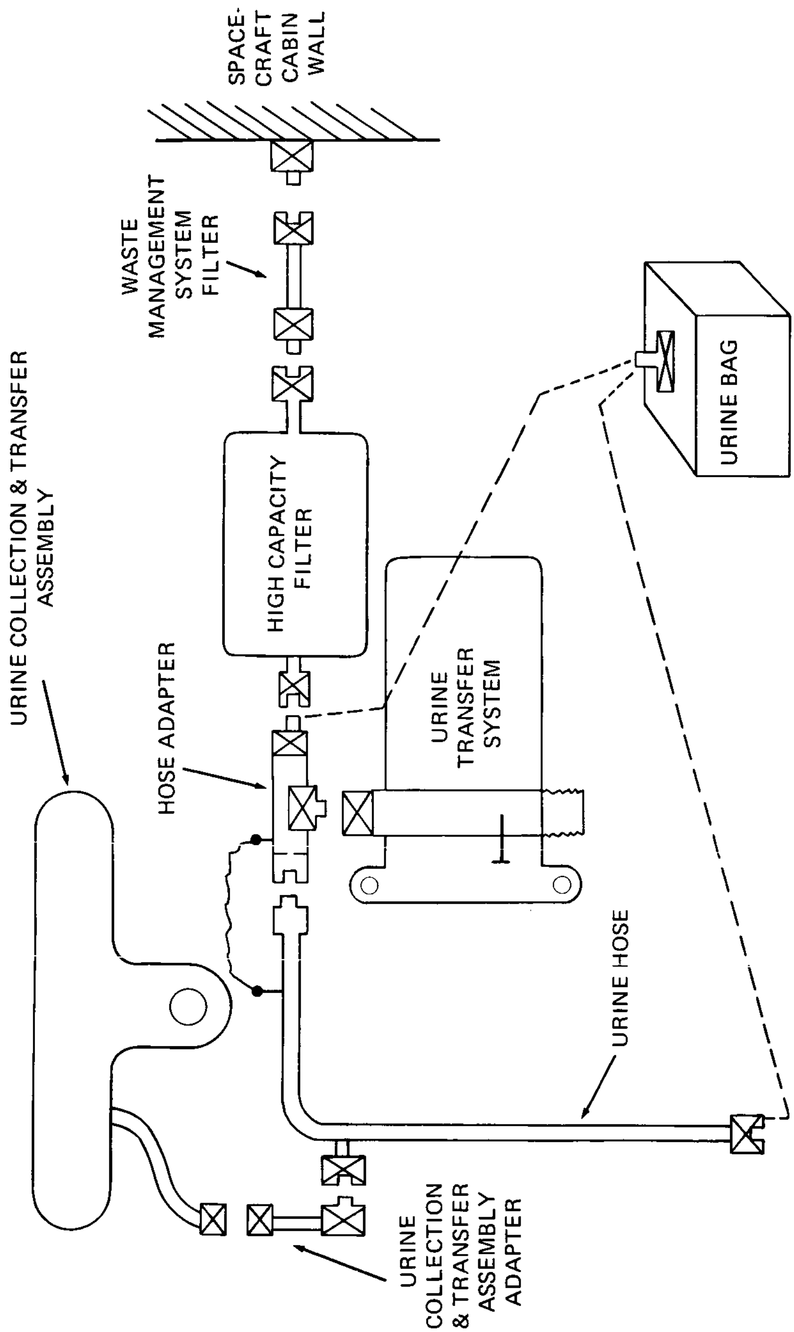

Figure 7. Apollo 16 urine collection system.

sampling systems. The BUSS consisted of two flexible plastic film containers – a 24-hour pooling container and a collection container (figure 8). One BUSS was used per man-day. This provided for transfer of a sample of pooled urine for return to Earth, with transfer of the remaining urine volume to the Command Module urine overboard dump system for disposal.

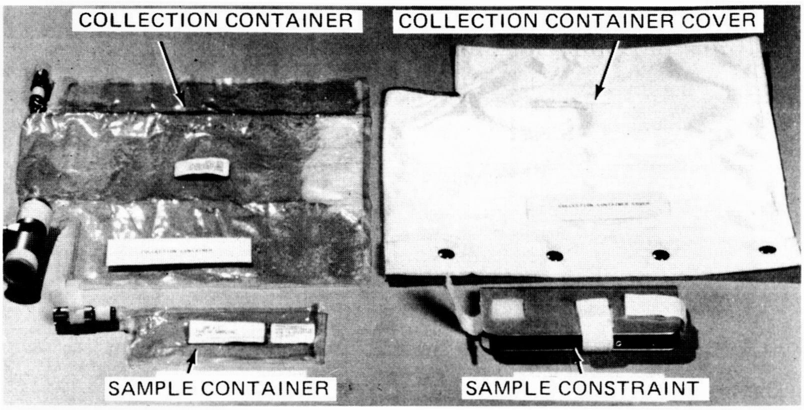

Figure 8. Biomedical urine sampling system (BUSS).

The BUSS collection container measured 30 cm^2 and incorporated a receiver/valve assembly at one corner similar to the receiver assembly used on the UTS. The collection container had a capacity of 3000 ml. The pooling bag for each BUSS contained a known amount of preinstalled lithium chloride so that postflight volume determination could be made from returned samples. (The collected sample volumes and calculated pooling volumes are listed in table 1). The pooling bag also contained boric acid for urine preservation. At the end of each 24-hour pooling period, the container was interconnected with its sample container by mating quick-disconnects, and a representative portion of the 24-hour pool was forced into the sample container. This container had a capacity of 125 ml. The sample container was then stowed for postflight recovery and the urine in the collection container was dumped overboard.

Fecal Subsystem

The fecal subsystem consisted of a fecal collection assembly, tissue dispensers, a waste stowage compartment, and a waste stowage bag. For suited conditions, the fecal containment system was provided.

The fecal collection assembly consisted of a fecal bag and an outer fecal/emesis (FE) bag bound together with a plastic wrapper. The fecal bag (figure 9) was a plastic sack with a flange at the opening and a finger cot in the center of one side. A surface of Stomaseal® tape was used for adhering the flange to the buttocks. Tissue wipes and a germicide pouch were stored in a pocket on the outside lower end of the bag. The outer transparent FE bag was used for storing the used fecal bag. Internal and external seals at the mouth of the bag made it capable of containing a 3.4×10^4–N/m^2 (5 psi) gas differential pressure.

Table 1

Apollo 17 Urine Sampling Results

Crewman	Time of Sampling, GET*		Sample Volume (ml)	Calculated Pooling Volume (ml)
	Preflight, Predicted (hr:min)	Actual (hr:min)		
CMP	18:30	18:50	110.7	1154
	35:00	34:36	85.5	811
	58:45	58:22	91.0	1875
	83:30	83:22	89.9	1034
	107:00	110:00	83.2	1500
	133:00	133:00	86.3	769
	156:10	156:10	74.8	1667
	180:45	180:40	104.9	2000
	208:00	208:30	70.4	1500
	230:25	230:28	84.0	1200
	252:50	252:45	93.7	1304
	276:50	276:30	89.8	938
	300:30	299:50	116.1	1667
LMP	18:30	18:30	84.8	750
	35:00	34:40	78.8	448
	58:45	58:20	118.0	789
	83:30	83:20	74.8	789
	107:00	110:00	78.8	1250
	230:25	230:30	71.9	714
	252:50	252:15	80.9	1111
	276:50	276:25	87.1	1304
	300:30	300:15	104.7	1579
CDR	18:30	18:46	82.0	395
	35:00	34:40	38.7	337
	58:45	58:10	94.0	750
	83:30	83:15	60.1	652
	107:00	110:00	71.1	938
	230:25	230:28	90.2	1000
	252:50	252:50	96.9	1429
	276:50	276:30	106.6	1154
	300:30	299:52	137.3	2500

*Ground elapsed time.

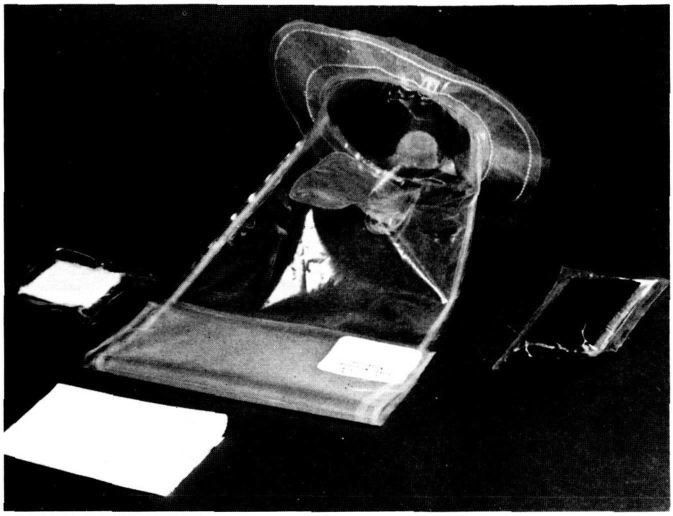

Figure 9. Fecal bag.

Briefly, the fecal collection system was used in the following way. The finger cot was employed to position the fecal bag over the anus. The finger cot was also used after defecation to separate fecal matter from the anal area and push it to the bottom of the bag. The bag was then removed from the buttocks, and the anus was cleaned with tissue wipes. These were disposed of into the fecal bag. The user then secured the germicidal liquid pouch and, after cutting the corner off the outer pouch, deposited it along with the inner pouch into the bag. The bag was then sealed. The germicidal liquid was a mixture of sodium orthophenylphenol and sodium chlorophenylphenol of amaplast blue LXT (NASA, c. 1967). The bag was kneaded to rupture the inner pouch and mix the germicide with the wastes. The inner bag was placed into the outer bag which was rolled into the smallest possible volume and then placed in the waste stowage compartment. This compartment featured a split membrane inside the door to prevent fecal bags from floating back out into the cabin once they had been placed within the compartment. For later Apollo missions, the volume provided by the waste stowage compartment was inadequate. Consequently, a waste stowage bag was provided for additional volume for the disposal of fecal bags. Both waste stowage volumes had an overboard venting capability for gases generated in the feces.

Data on returned fecal samples from Apollo crewmen are listed in table 2.

The fecal containment system (FCS) was a pair of underpants of absorbent material worn under the liquid cooling garment (LCG) during suited periods (e.g., extravehicular activity). Figure 10 shows the garment. If an uncontrolled bowel movement had occurred, the underpants would have contained the feces. During lift-off and reentry, the fecal containment systems were stowed.

Experimental Fecal/Emesis System Flown Aboard Apollo 16. Three modified fecal collection bags were flown to evaluate their performance on the Apollo 16 mission. The

Table 2
Apollo Fecal Samples

Mission Number	Label	Weight (gm)	Average Sample Weight/Mission (gm)
7	S/N* 2270	81.3	210.1
	S/N 2276	119.8	
	S/N 2277	229.8	
	S/N 2278	326.2	
	S/N 2280	340.2	
	S/N 2282	236.2	
	S/N 2299	228.1	
	S/N 2300	96.1	
	S/N 2312	233.7	
8	1	186.5	156.9
	2	85.6	
	3	198.6	
9	CMP	168.0	265.3
	CMP	190.7	
	CMP	317.5	
	LMP	385.1	
10	S/N 3513	40.0	52.4
	S/N 3527	40.9	
	S/N 3512	76.3	
11	1	208.1	122.6
	2	230.6	
	3	129.0	
	4	35.1	
	5	10.0	
12	LMP	79.7	117.6
	Unlabeled	219.1	
	LMP	143.1	
	LMP	41.6	
	CDR	133.0	
	CMP	3.3	
	CMP 79:00 GET	165.7	
	CMP 101:00 GET	109.3	
	CMP 225:00 GET	163.9	
16	LMP	134.97	185.1
		247.88	
		234.52	
		204.90	
		103.25	
	CDR	133.15	95.1
		16.17	
		135.92	
	CMP	54.69	102.6
		49.28	
		203.82	
17	CDR	48	97
		35	
		175	
		97	
		138	
		91	
	CMP	255	200
		223	
		284	
		182	
		66	
		191	
	LMP	181	167
		37	
		193	
		255	

*Serial number.

bags were of the same basic design as the Gemini-type fecal bag with the following exceptions: (1) a modified seat flange, for better fit of seat flange to buttocks; (2) a wider finger cot; and (3) an improved seal for keeping the device closed during performance of personal hygiene.

Figure 10. Fecal containment system for use during extravehicular activity.

Lunar Module Waste Management System

The Lunar Module waste management system incorporated systems used in the Command Module. These systems were used in similar fashion in both the Lunar Module and Command Module. The principal difference was that there was no overboard dumping of wastes on the lunar surface. The urine subsystem in the Lunar Module consisted of in-suit urine containers (identical to the Command Module system), a urine transfer hose, a manually operated waste control valve, and a large (8900 cm^3) waste fluid container. To drain the in-suit device, the waste fluid container was attached to the in-suit urine container by a urine transfer hose, and the suit was then slightly overpressurized. Because of a 6.9×10^3–N/m^2 (1.0 psi) pressure differential, when the control valve opened urine flowed from the in-suit container to the waste fluid container at a rate of approximately 200 cm^3/minute. As a backup device, two 900-cm^3 waste containers were provided for direct attachment to the in-suit container. On Apollo 15 and subsequent missions, a low pressure container was installed in the descent stage of the Lunar Module. A line interconnected this tank with a urine receiver in the ascent stage. This receiver was a simple funnel-like receptacle that permitted urine collection without intimate contact.

The fecal containment subsystem in the Lunar Module was identical to the Command Module fecal subsystem.

Table 3 presents a summary of the waste management system elements used during each of the Apollo missions.

Table 3

Waste Management Systems Used on Apollo Missions

Mission Number	Waste Management Equipment
7	UCTA, UTS, FE
8	UCTA, UTS, FE
9	UCTA, UTS, FE
10	UCTA, UTS, FE
11	UCTA, UTS, FE
12	URA, UCTA, UTS, FE
13	URA, UCTA, UTS, FE
14	URA, UCTA, UTS, REWB, FE
15	URA, UCTA, UTS, REWB, FE
16	URA, UCTA, UTS, REWB, FE
17	BUSS, URA, UCTA, UTS, FE

UCTA = urine collection and transfer assembly
UTS = urine transfer system
FE = fecal/emesis bag
URA = urine receptacle assembly
REWB = return enhancement water bag (for samples)
BUSS = biomedical urine sampling system

Overall Waste Management System Performance

In general, the Apollo waste management system worked satisfactorily from an engineering standpoint. From the point of view of crew acceptance, however, the system must be given poor marks. The principal problem with both the urine and fecal collection systems was the fact that these required more manipulation than crewmen were used to in the Earth environment and were, as a consequence, found to be objectionable. The urine receptacle assembly represented an attempt to preclude crew handling of urine specimens but, because urine spills were frequent, the objective of "sanitizing" the process was thwarted. The fecal collection system presented an even more distasteful set of problems. The collection process required a great deal of skill to preclude escape of feces from the collection bag and consequent soiling of the crew, their clothing, or cabin surfaces. The fecal collection process was, moreover, extremely time consuming because of the level of difficulty involved with use of the system. An Apollo 7 astronaut estimated the time required to correctly accomplish the process at 45 minutes.* Good placement of fecal bags was difficult to attain; this was further complicated by the fact that the flap at the back of the constant wear garment created an opening that was too small for easy placement of the bags.** As was noted earlier, kneading of the bags was required for dispersal of the germicide.

*Entry in the log of Apollo 7 by Astronaut Walter Cunningham.

**The configuration of the constant wear garments on later Apollo missions were modified to correct this problem.

Attempts to improve the fecal collection system, as exemplified by the modified fecal/emesis collection bags flown on Apollo 16, failed in the crew's estimation. During postflight debriefings, crew comments indicated that the experimental bag was not significantly better or easier to use than the baseline Gemini-type bag. Further development of the bag was, therefore, not pursued.

Summary

Although there were inherent design limitations in the waste management systems used for the manned Apollo missions, performance of the individual systems *per se* was reasonably satisfactory. However, there were some problems. In addition to being marginal from a hygienic standpoint, use of the collection devices required many steps and the expenditure of a considerable amount of time. The problem of odor was continually present because of the lack of a positive means of eliminating defecation odors.

The Apollo waste management system's design and operations pointed to the need for several improvements in future missions. These were the following:

1. Future systems should not require intimate contact.
2. The time required for system use should be significantly reduced.
3. The waste management system should provide some technique of automatically removing feces from the buttocks area.

These considerations were taken into account in the design of the improved Skylab waste management system.

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