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WASTE MANAGEMENT SYSTEM FUNCTIONAL MODEL

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Space Division
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13. ABSTRACT

A functional model for the collection and storage of fecal wastes in a biologically safe and psychologically acceptable manner for aerospace vehicles has been designed, fabricated and successfully tested. The design is a commode type collector similar to the previously developed "Dry-John slinger" system; however, the new design extends the useful life of the previous unit by use of a replaceable liner. The functional model provides vacuum drying and storage of 200 man-days of feces and toilet tissue prior to liner replacement. Each liner contains a motor-slinger and an air flow bacteria filter. The filter prevents contamination of all downstream lines and permits changing of the liner without contamination of the cabin. The full liner can be sealed and stored while the new liner functions for an additional 200 man days; thus, the useful life of the basic hardware is governed by the number of available liner assemblies, and cabin storage. Additional features of the functional model are a quick acting slide valve assembly to open and close the commode, provision for feces sampling and a subassembly for dispensing a disinfectant onto the feces.

Areas that require further effort to improve this design are optimization of weight and power, balancing of slinger speed with blower capacity, selection of liner materials, and biological analysis of the stored feces over a long period.

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Feces Processing						
Feces Sampling						
Feces Storage						
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Vacuum Drying Wastes						
Waste Management System						

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SUMMARY

The object of this program was to design, fabricate, and test a waste management system to collect and store fecal wastes in a microbiologically safe and psychologically acceptable manner. A space mission capability of four men for 90 days was required, with the permissible use of a replaceable liner capable of handling and storing 200 man days of human fecal matter.

The program resulted in a commode type functional model that was successfully used to collect and vacuum dry human feces and toilet tissue for a test period of 43 man days (nominally, four uses per day). The unit was designed and fabricated with a replaceable liner removed at the end of the first test period and stored at room temperature for 7 days. During the storage period, all liner penetrations were sealed and the liner interior monitored for gas build-up. There was no pressure change which indicated that a bacteriostatic environment was present in the liner.

The program objective of studying the feasibility of sampling each defecation resulted in a sampling device (designed by the contract monitor) with suitable penetration of the commode and liner (designed at General Electric). The device was successfully tested.

A subassembly for the automatic dispensing of a disinfectant was also designed and fabricated. It was operated during the 10-day collection test; however, since biological studies of the feces were not part of this contract, an exact evaluation of the effectivity was not made.

The system as delivered occupied a nominal envelope of 30 x 32 x 22 inches high, weighed 108.5 pounds and required 198 watts. Power was used only during collection of the feces. Storage and vacuum drying takes no power. Allowing 10 minutes of operation per use, 132 watt hours per day are needed. (Average is 5.5 watts/hour.)

Further work on this type of collector should include biological assays of the stored feces and zero-g tests to permit optimization of power, weight, and materials.

FOREWORD

The research and development program described in this report, was conducted by the Life Support Engineering Operation of the Space Systems Organization, Space Division, General Electric Company, King of Prussia, Pennsylvania. The program was performed under contract number F33-615-69-C-1372 for the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The technical monitor was Mr. C. A. Metzger. The period of research began in February 1969 and ended in October 1969. This technical report has been reviewed and is approved.

C. H. KRATOCHVIL, Colonel, USAF, MC
Commander
Aerospace Medical Research Laboratory

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INTRODUCTION

BACKGROUND

Current manned space vehicles do not have a permanently installed facility for the collection of human waste in the life support system. The various methods of collecting feces have been limited to the individual bag-type collector, hand held or stuck-on. Initially, diaper types were used.

Several versions of bag concepts have been or are planned for use on the Gemini, Apollo and AAP programs. Tissue and/or other media are used for wiping and are deposited within the bag, which is then manually sealed. If bacteria deactivation is by chemical means, manual kneading of the chemical into the feces is required to ensure adequate mixing. The sealed bag is then placed in a storage container. If bacteria deactivation is by drying, the bag is fabricated of a material which is permeable to gas and water vapor (but not liquid water) and once used must be manually transported and placed in a separate drying unit. After drying, the bag is manually removed and placed in a separate storage container.

The increased internal volume and available electrical power of future manned space vehicles will for the first time permit installation of an earth-type waste collector. Various processes to obtain a commode-type collector have been investigated and research and development hardware programs have been completed. One of these units, which was developed by the General Electric Company and subsequently refined for the Air Force's Aerospace Medical Research Laboratory, was successfully used by four men during a 60-day space mission simulation.

The following comments on the test results are quoted from a recent AIAA paper[1]: "An Air Force AMRL/General Electric 'Slinger' commode that dried fecal matter under vacuum was the most successful waste collection unit used in the simulator to date. The commode was designed for 120 man days. It became filled on the forty-fifth day (180 man days) with 11.5 pounds of dehydrated fecal matter generated by the four crewman, before it had to be emptied. An additional 2.7 pounds of fecal matter was collected in the remaining 15-day period. The crewman used the unit over 200 times during the 60-day test. No odors or problems were encountered by the crewman at any time during the test."

The success of the Air Force's feces collection unit prompted an investigation of ways to increase the useful life of the collector. This report documents the design, develop-

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[1] Ingelfinger, A. L.,; Secord, T. C., Life Support for Large Space Stations, American Institute of Aeronautics and Astronautics, Paper No. 68-1032, 1968.

ment, and fabrication of a functional model waste management system for the collection and storage of human feces from four men on a simulated 90-day space mission.

PROGRAM OBJECTIVES

The following are the salient program objectives:

- Develop and fabricate a functional model that collects and stores fecal wastes in a microbiologically safe and psychologically acceptable manner.
- Develop a conventional-type facility (earth-like procedures) that has high psychological acceptability and does not require daily handling of the waste material.
- Provide for space missions of four men for 90 days using, if necessary, a replaceable container capable of handling and storing at least 200 man days of human fecal matter.
- Insure that the filled replaceable container is easily sealed and has a capability of satisfactorily storing dried feces at room temperature for a period of 50 days.
- The model shall be designed and fabricated to function for two simulated aerospace missions of 90 days each.
- Provide for operation in a weightless environment and permit no escape of the waste or odors to the surrounding atmosphere.
- Consider provisions for feces sampling and automatic dispensing of a disinfectant into the storage container in the initial design phase.
- Permit no gas build-up in the waste management unit after 24 hours of drying.
- Assure operation in standard aerospace environment, with a capability of operating in a pure oxygen environment.

SYSTEM SPECIFICATION

The characteristics of the completed system are given in the following specification table. The assembled functional model is shown in Figure 1.

SPECIFICATION TABLE

Functional Model (As Delivered)

1.	Mission Life:	400 man days (Based on usable fecal storage volume of 1.5 cubic feet)
2.	Feces Collection Method:	Slinger-commode with air transport
3.	Feces Storage Method:	In replaceable liner in commode
4.	Bacteria Control:	(a) Bacteria filter (.08 microns) for air flow (b) Disinfect and vacuum dry feces
5.	System Weight:	108.5 pounds, including second liner assembly
6.	System Envelope:	30 x 32 x 22 inches high
7.	System Power:	(a) 165 watts of 115/200 volts 3 ∅ 400 Hz ac (b) 33 watts of 28-volt dc (c) 10-watt pulse (d) Average use 5.5 watts/hour
8.	Duty Cycle:	(a) 165 watts and 33 watts only during manned use estimated at 10 minutes on, 350 minutes off (b) Pulses are once and twice per 10 minute use. Pulses are 1 second or less.
9.	Air Velocity:	100 fpm minimum in transport tube
10.	Blower Output:	24 cfm at 4 inches water pressure
11.	Slinger Motor:	4,000 rpm, 16 oz inches torque
12.	Odor Control:	Axial flow filter with odoroxidant pellets
13.	Disinfectant:	Iodine solution 1 cc per defecation (475 milli-second pulse)

Estimates for Flight Optimization

1.	System Weight:	60 pounds
2.	System Envelope:	28 x 30 x 22 inches high

3. System Power: (a) 120 watts of 115/200 volt, 3 Ø 400 Hz ac
(b) 25 watts dc
(c) 7 watts pulses
(d) 4 watts/hour average

4. Slinger Motor: 3,000 rpm 12 oz inches torque pending trade-off studies

5. Odor Control: Combine with ECS

6. Disinfectant: Need further evaluation of materials and biological studies

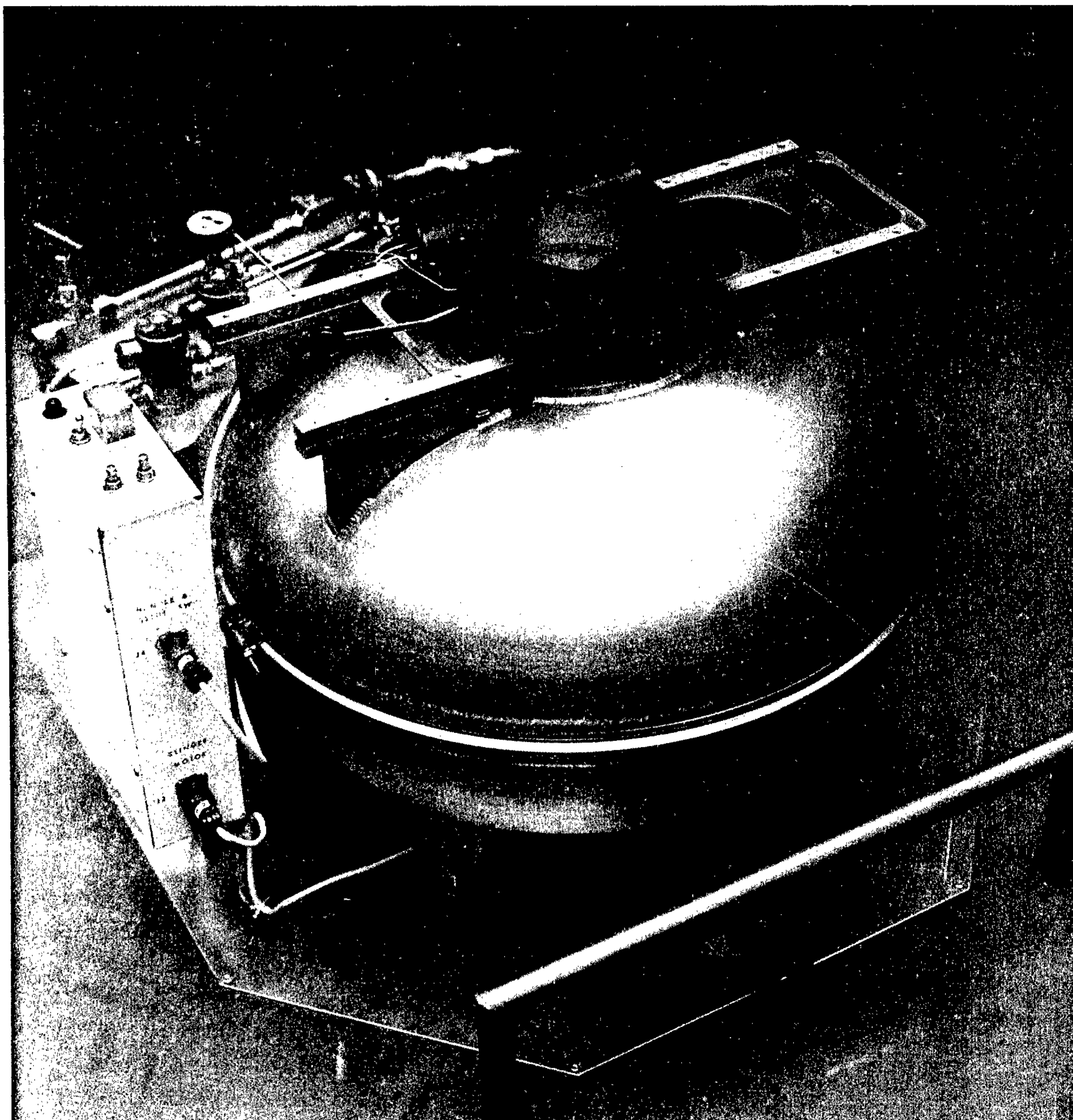


Figure 1. Waste Management System - Functional Model

SECTION II

SYSTEM DESIGN AND OPERATION

GENERAL DESCRIPTION

The System Block Diagram (Figure 2) shows the basic system. Figure 3 shows the assembly of the Functional Model in detail. The Piping Block Diagram (Figure 4) and the Electrical Block Diagram (Figure 5) show the arrangement of the components and their interconnection. Figures 6 and 7 are photographs of the assembled system. Additional photographs of detailed parts are included in the Operation and Maintenance Manual[2] (separately bound). This section will describe how the detailed parts are grouped together, and how they operate in the system.

FUNCTIONAL OPERATION

The basic operation of the system can be explained with the aid of the System Block Diagram (Figure 2). The major components of the system are a Split Container Assembly with an Inner Liner Assembly where the feces is collected, disinfected, dried, and stored. A Valve and Seat Assembly provides a seal (the seal valve) at the inlet to the container, and solenoid valves control the outlet of the container.

With all power off, the inner liner is connected to the vacuum vent through the open vacuum solenoid valve. All other liner penetrations are sealed. When the user first turns on the power, he moves a handle at the seal valve. This causes the vacuum solenoid valve to close, the blower solenoid valve to open, and the slinger and blower to start. The next operation of the user is to slide a plate to open the seal valve; however, since the blower is operating, cabin air is immediately drawn into the container, preventing any backflow of debris or bacteria from the commode to the cabin.

The user positions himself on the seat (which rests on the seal valve) and defecates. The feces is drawn onto the slinger plate by the air flow (and by gravity when used in the laboratory). Rapid rotation of the slinger plate, which contains 20 tines, drives the stool into the tines which shreds and slings the fecal particles against the inner liner. The user wipes himself with toilet tissue and deposits the tissue into the container. Pressing a switch activates the disinfectant solenoid valve and timer. A predetermined quantity of disinfectant is injected, strikes the slinger plate, and is sprayed over the feces on the liner. Throughout this cycle, cabin air is drawn through the container, filtered and deodorized by the bacteria and odor-control filters, and returned to the cabin.

[2] Katz, J. R., Waste Management System - Functional Model, Operation and Maintenance Manual, General Electric Company, October, 1969.

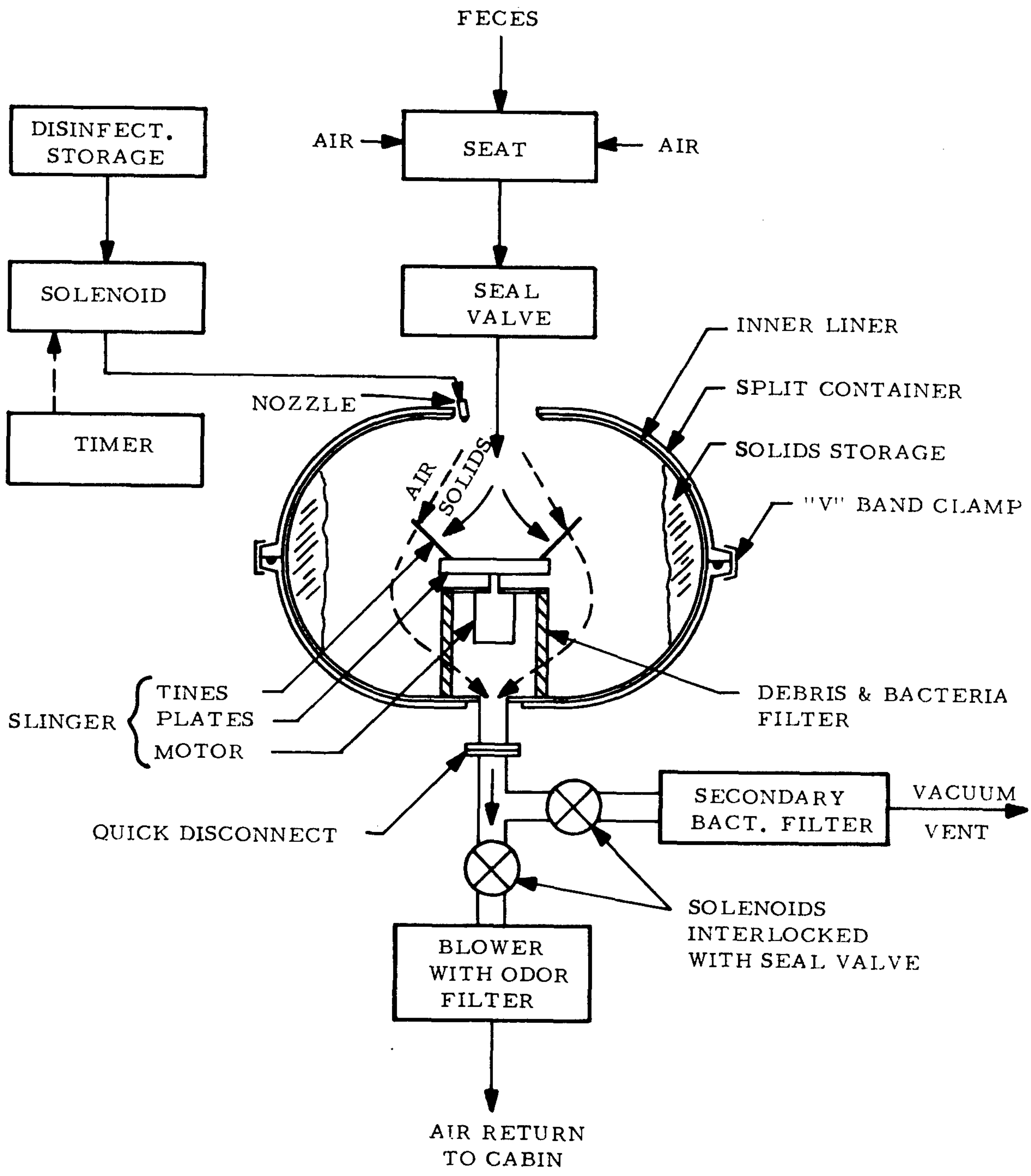


Figure 2. System Block Diagram

To turn off the unit, the seal valve is closed which stops the power to the slinger motor and blower. Simultaneously, power is removed from both the blower solenoid valve and vacuum solenoid valve, closing the first and opening the second. This exposes the contents of the liner to a low pressure which vacuum dries the feces.

In the operation of the collection cycle, the slinger action has the two-fold purpose of (1) separating the solid particles from the transport air and (2) spreading the feces in a thin layer over the internal surface. When the power is turned off and the vacuum solenoid valve returns to its normally open position, the thin layer of feces is exposed to space vacuum (or a vacuum pump in the laboratory). With sufficient pumping speed available, the wet feces freezes and is vacuum dried by sublimation. The thin layer makes this process very rapid, without the need for additional heat or power. Complete drying is accomplished in a few hours. Quick freezing also has the advantage of rapidly immobilizing bacteria.

FUNCTIONAL GROUPING

Split Container Assembly

The split container has two halves. The upper half is a weldment of a spun shell (P-2)* flanges and brackets. The lower half is also a spun shell (P-6) with flanges and legs. The two parts are clamped together with a V-band (P-7). Bosses, clamps, and screens are provided for mating parts, and O-rings are used for seals.

The container is fabricated with a V-band clamp for ease of installation or removal of a liner assembly. Also, for ease and speed in changing the liner, the container is attached to the floor with three compression clamp latches (P-24), one per leg, and the valve assembly attaches to the container with four latches. There are a minimum of attachments between the container and structure, and ample clearances for access are provided.

Liner (Bladder) Assembly

The liner (P-10) is a rubber bladder with four holes, two large and two small. At the inlet end (large hole), there is a transport tube (P-14) clamped to the liner by a ring (P-13) providing a sealed surface. Similarly, at the outlet end, support tube (P-15) is clamped to the liner by a ring. The support tube provides a means to attach the motor (P-52), slinger (P-56), and bacteria filter (P-53).

*part numbers refer to Figure 3

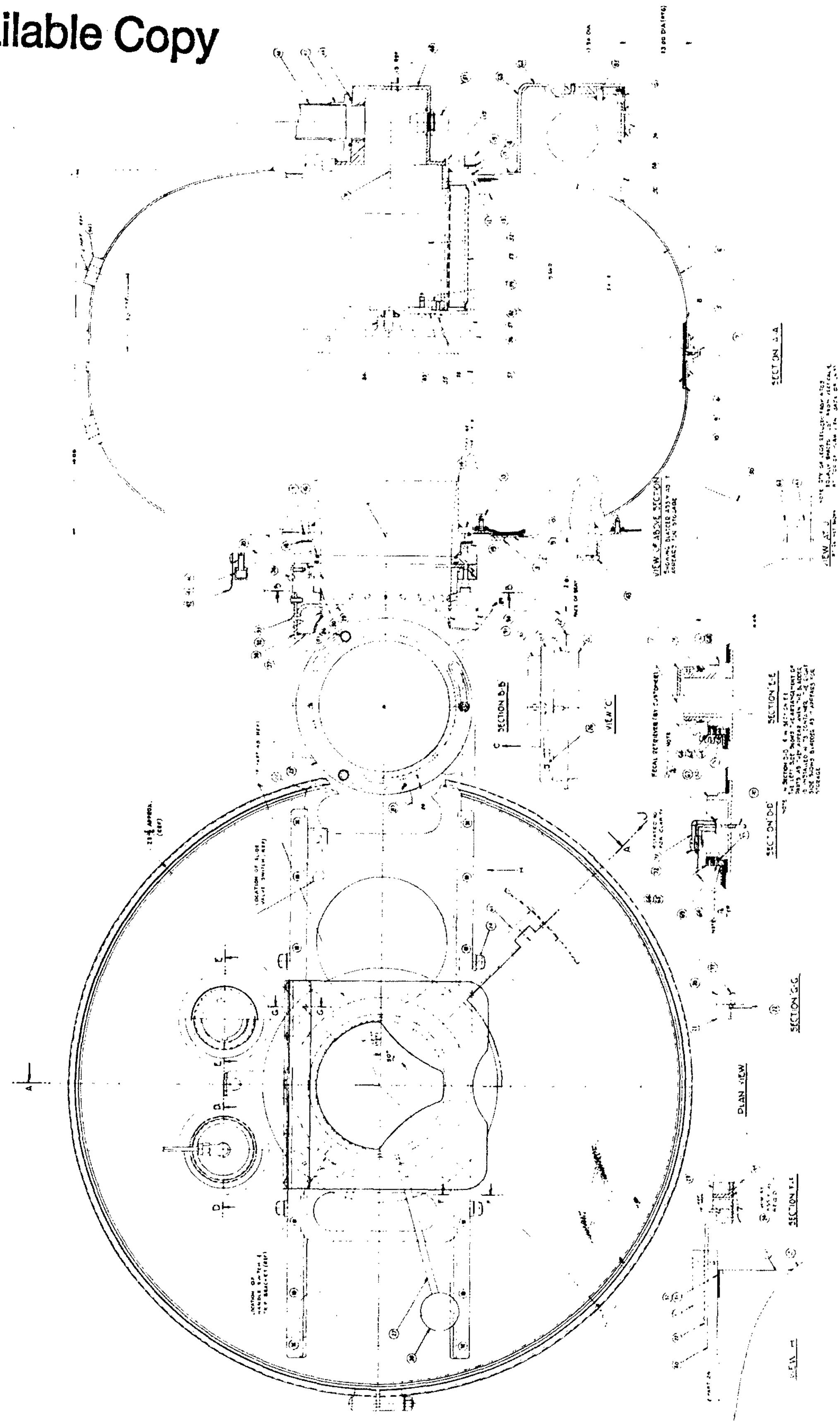


Figure 3. Functional Model Assembly

One of the small sized penetrations is for the disinfectant adapter (P-67). This part is bonded to the liner. The fourth penetration is for taking a feces sample. It, too, is bonded to the liner. (See Part 68)

To take a feces sample, the user removes the cap (P-73) and inserts a Fecal Tube Retriever Assembly into Part 68. The functional model is then used in the normal manner. The retriever has a slotted tube oriented in such a manner in the liner that the slinger will cause part of the stool to be "slung" through the slot into the tube. After defecation is complete, the retriever is removed, automatically closing the slot, and placed in a plastic bag. The cap is replaced to provide a seal during the vacuum drying cycle.

Valve and Seat Assembly

The seal valve subassembly consists of a frame (P-20), housing (P-21), valve plate (P-22), and a clamping mechanism activated by a handle (P-27). Turning the handle causes rotation of an actuator ring (P-25), which causes the orifice ring (P-30) to rise or lower by cam action. The latter action clamps the valve plate against an O-ring in the frame. The valve assembly is clamped to the upper half of the shell in such a manner as to seal the frame against the transport tube (P-14) with another O-ring.

The seat is fastened to the valve assembly by a hinge and rests on the orifice ring. The seat contours are based on the recommendations of The Bathroom: Criteria for Design by Alexander Kira.[3] (The book is the results of research studies at Cornell University.) The contours aid in centering the man over the open valve, provide comfortable support, and partially seal the container assembly from the cabin. With the user seated, air flow is drawn into the container through a row holes in the orifice ring directly under the seat. The air passes over the user's buttocks to carry the stool through the transport tube to the slinger.

Piping System (See Figure 4)

Transport Air

The path of the air after it leaves the container assembly during operation is through the blower solenoid valve, the blower, and odor control filter. Tubing of 1 1/4 inside diameter connects the components.

Air Jet

To help the user to center himself on the seat and aid in separating the stool from the man, a low pressure air jet is provided. This is activated by a momentary "on" switch

[3] Kira, Alexander, The Bathroom: Criteria for Design, Bantam Books, 1967, Copyright 1966, Cornell University, Ithaca, New York.

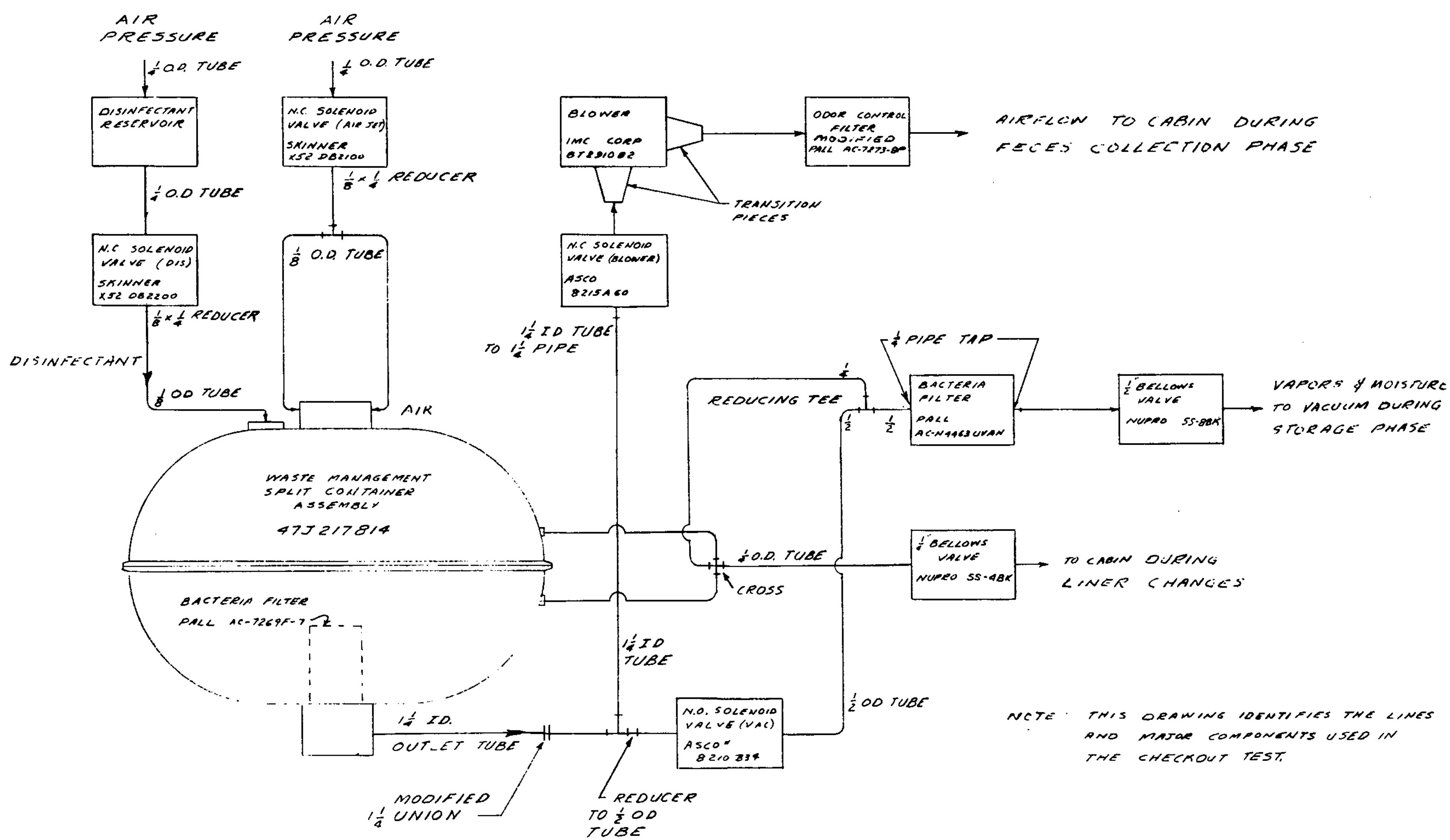


Figure 4. Piping System

which controls the air jet solenoid. The jet outline is on the valve assembly right under the seat.

Disinfectant Lines

The disinfectant storage consists of a tank under low pressure air. Inside the tank is a rubber bladder containing the disinfectant (a dilute solution of Wescodyne). The disinfectant discharge is through a solenoid valve to the adapter (P-67) bonded to the liner assembly. The amount of disinfectant dispensed is a function of the pressure and a timer which controls the solenoid opening time.

Vacuum Lines

Vacuum is applied to the interior of the liner through a solenoid valve which is normally open when the power is off. The moisture removed from the feces by vacuum freezing and evaporation passes through the container bacteria filter, the solenoid valve, the secondary bacteria filter and the hand-operated bellows valve. The second bacteria filter is provided in the vacuum line to prevent contamination of space in case of a failure in the system. The bellows valve downstream of the filter permits closing the system to vacuum while the liner assembly is changed (once during the normal mission).

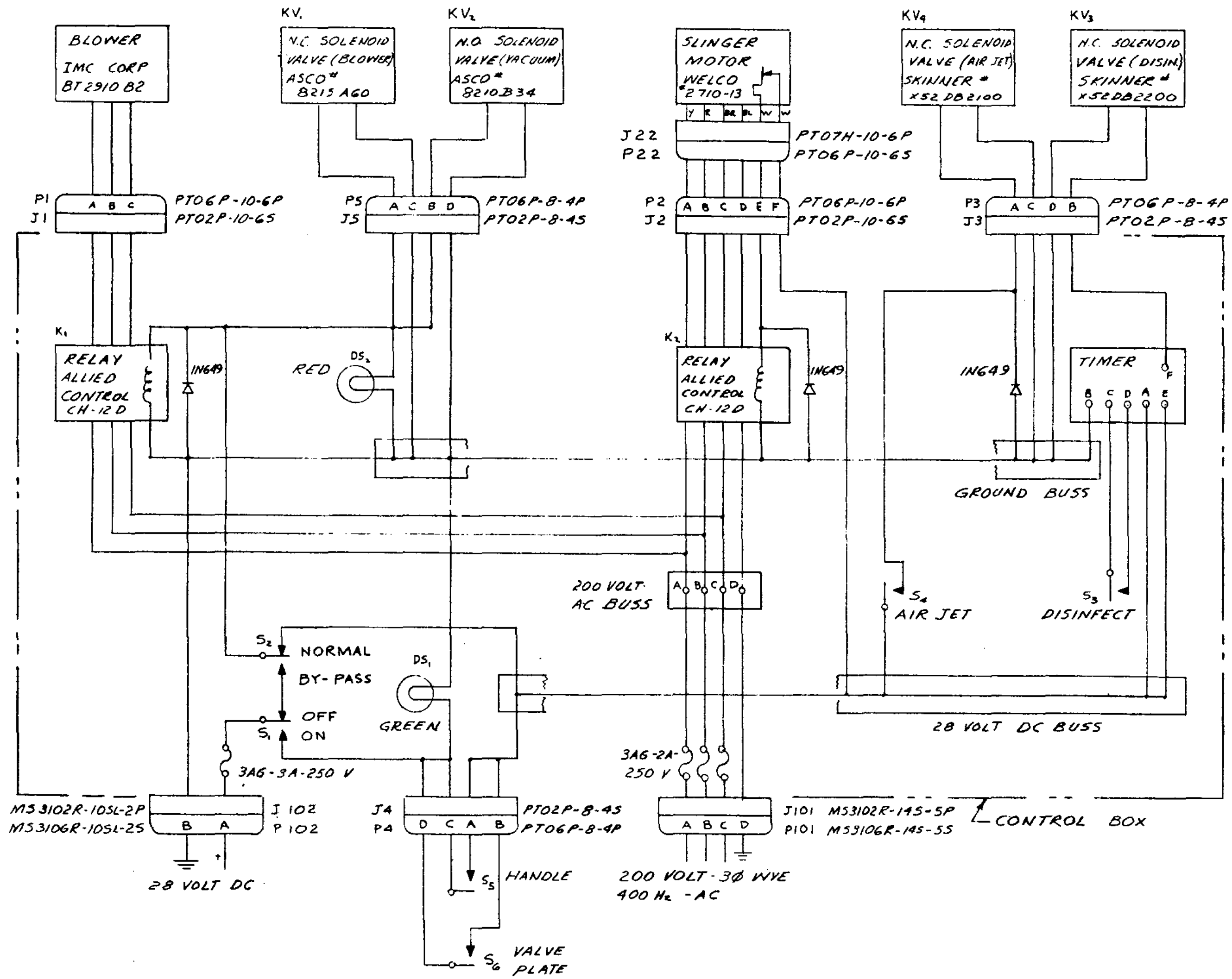
To keep the liner against the shell interior, vacuum is continuously applied between the liner and the shell. The 1/4" bellows valve is normally closed; however, during changing of the liner, the valve is used to bleed in air from the cabin.

Electrical System (See Figure 5)

Control of the various functions is by six hermetically sealed switches, three relays, and a timer. Placing toggle switch S-1 in the "on" position with switch S-2 in "Normal" turns on the green light and permits switches S-5 and S-6 to function. The latter two switches are part of the seat and slide valve assembly and act automatically with the use of the slide valve.

With either the handle or slide switch closed, the blower and slinger motor receive power through relays. Power is also provided to the blower and vacuum solenoid valves and made available to the air jet and disinfectant solenoids. Pressing the disinfectant switch (S-3) closes the relay in the timer circuit for a timed cycle resulting in a measured quantity of disinfectant being dispensed. Switch S-4 controls the air jet solenoid valve. Air will be discharged as long as the switch is held closed.

Putting switch S-1 in "off" and S-2 in "by-pass" turns on the blower, opens the blower solenoid valve, and closes the vacuum valve. This position is used only during check-out and changing of the liner. The slinger motor, air jet, and disinfectant lines are by-passed during this two phases.



NOTES:

1. CONNECTORS ARE BENDIX PYGMY OR MS AS NOTED
2. SWITCHES S1 & S2 ARE MICROSWITCH 5AT1
3. SWITCHES S3 & S4 ARE MICROSWITH MC2711
4. SWITCHES S1 THROUGH S6 USE HERMETICALLY SEALED MICROSWITCH 1HS1

Figure 5. Electrical Block Diagram

In Figures 6 and 7, the relationship of the mechanical, piping, and electrical parts are shown on the assembled functional model.

WEIGHT, POWER, AND VOLUME

Weight Summary

Because the functional model was designed for laboratory use instead of flight, commercial components were frequently used and considerable clearances for access were provided. In addition, emphasis was placed on function; as a result, weight, power, and volume are not optimum. The system weight of 108.52 pounds is summarized in Table I.

Power Summary

Power is required only during the collection cycle. No power is needed for drying since space vacuum is readily available.

Motor power for the blower and slinger is drawn from the 115/200 volt 3 phases 400 Hz ac source. The solenoid valves and controls use 28 volt dc. Based on manufacturer's ratings, the blower requires 85 watts, the slinger 80 watts, for 165 watts of ac power. The vacuum solenoid valve and blower solenoid valve each draw 16.7 watts dc. Together, 198 watts are required during operation. Two other solenoid valves are used, but only for pulses (less than one second) and not at the same time. These are the air jet and disinfectant valves, either of which draw 10 watts.

Volume Summary

The largest single component is the split container. As shown in Figure 3, the container is 23 in. in diameter by 14 in. high. Adding to these dimensions, the V-band flange, legs, the valve and seat assembly, and the peripheral equipment results in an overall envelope of 30 x 32 x 22 in.

Optimization Guidelines

All three items - weight, power, and volume must be considered for optimization since they are dependent on each other. For example, nearly one third of the weight is in the piping assembly. In this assembly, relatively large (1 1/4 in. diameter) tubes are used to minimize air flow friction. This permits use of a blower that can only generate several inches of water static pressure. If the lines are reduced in diameter, weight and volume are reduced; however, the increased frictional losses mean that more power will be needed for the blower. For this investigation, thin-wall aluminum tubing could have been used instead of copper or stainless stell, but the fabrication costs would have been higher, and permissible laboratory handling greatly reduced. Optimization, therefore, also requires a trade-off with end item usage. For flight, significant reduction in the piping system weight can be made.

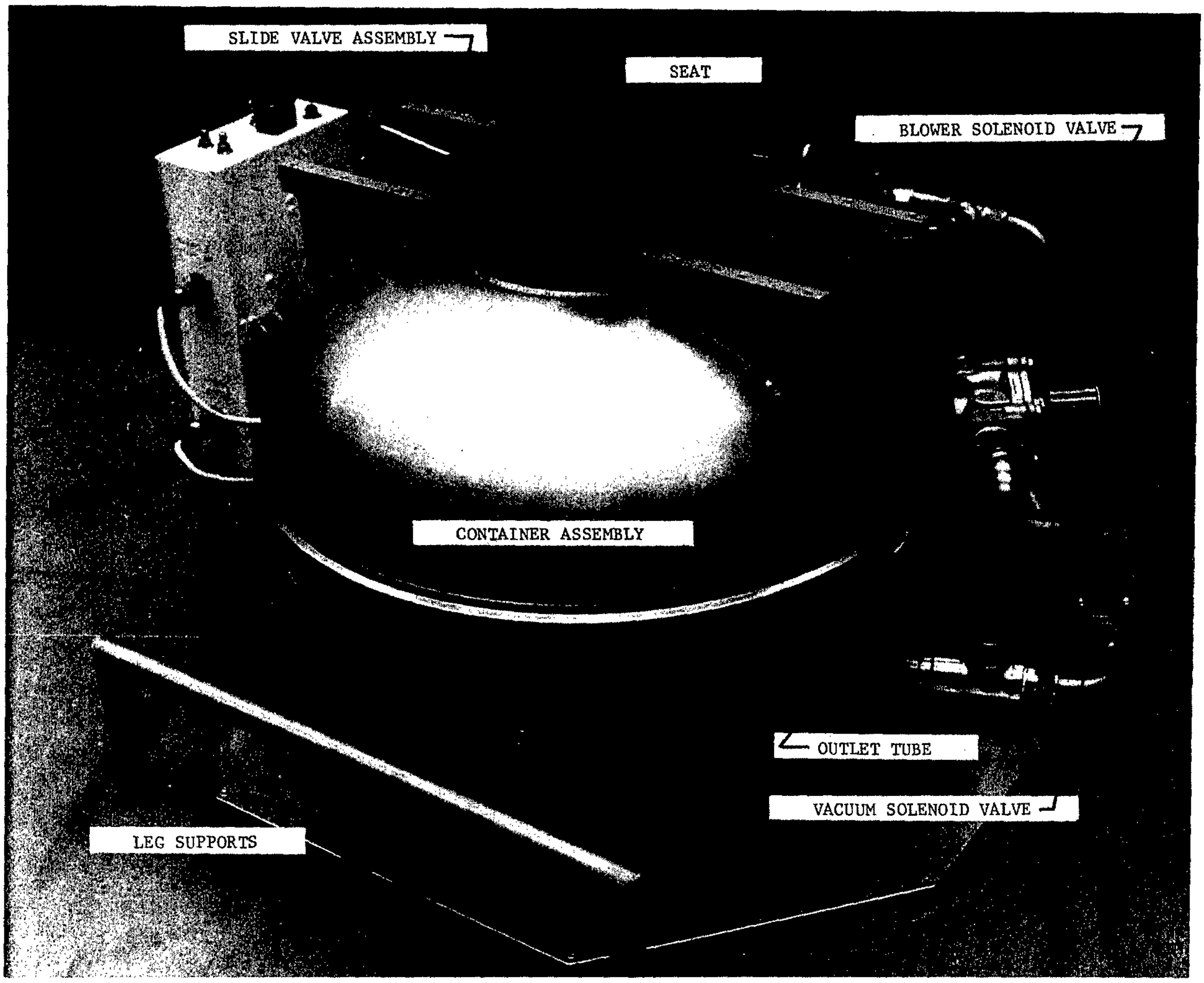


Figure 6. Waste Management System - Functional Model Front View

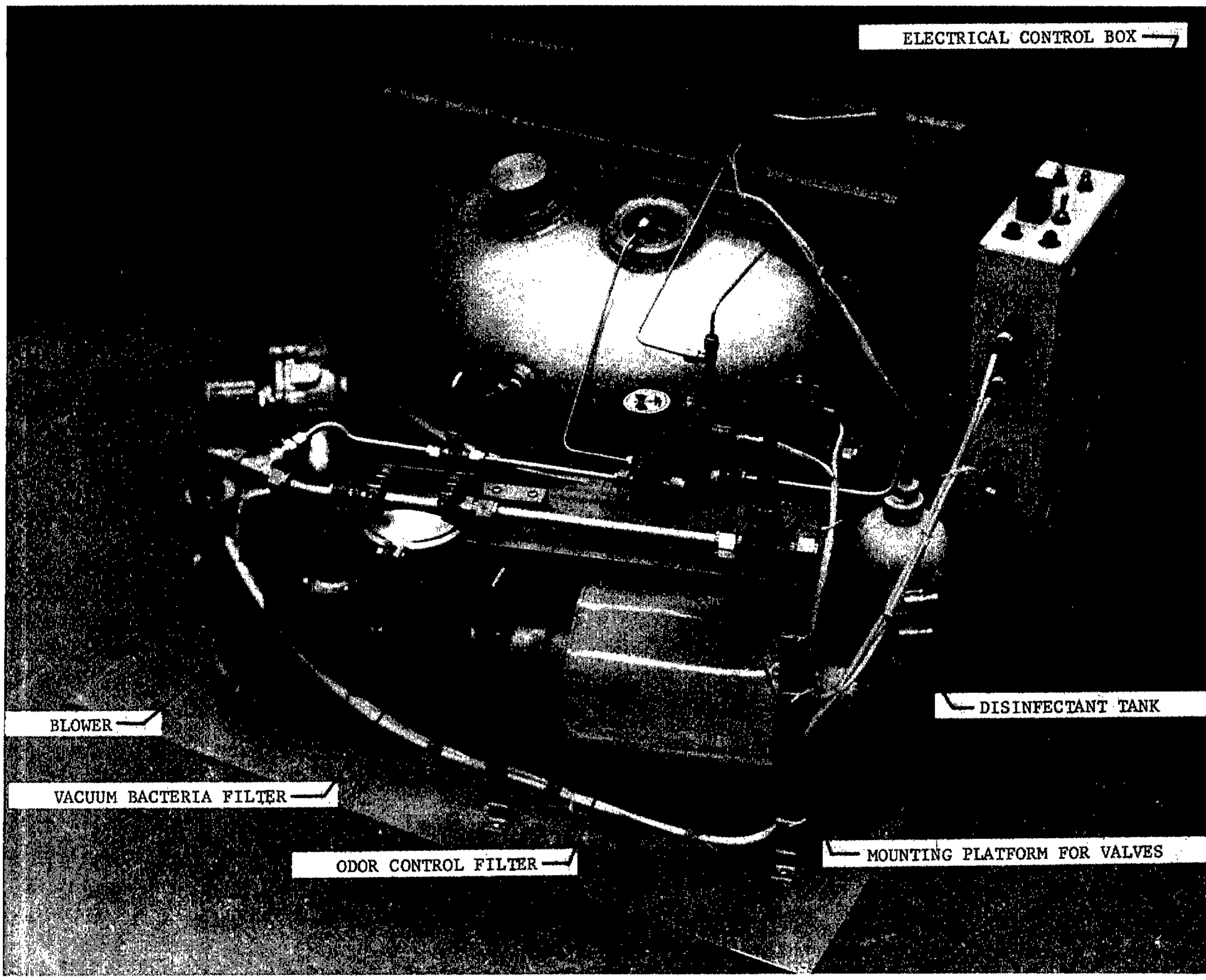


Figure 7. Waste Management System - Functional Model Rear View

TABLE I. SYSTEM WEIGHT SUMMARY

Item	Weight Pounds	Weight Kg
Split Container Assembly	20.57	9.33
Liner Assembly	16.70	7.57
Seat and Valve Assembly	9.58	4.35
Piping System	34.69	15.74
Electrical Controls	4.00	1.81
Support Structures	4.28	1.94
Toilet Tissue	2.00	.91
	91.82	41.65
Second Liner Assembly for 90 Days of Use	16.70	7.57
	108.52	49.22

In the liner assembly, the selected liner material was latex because of cost and delivery. The liner weighs over 3 pounds. Thinner, lighter materials are feasible, but special molds and development would have sky-rocketed costs beyond the scope of this investigation. For example, buna rubber was investigated. Since buna is less permeable than latex, a thinner, lighter liner could have been fabricated; however, the cost of a mold for buna rubber was greater than the entire material budget. A latex liner will prove the concept feasibility, but other materials could be better.

A reduction in slinger motor power is possible. Previous slinger-type commodes used 1, 500 rpm motors. Breadboard tests in this investigation showed that the distribution of the feces at 1, 500 rpm was less than 360° arc. Since feces sampling was desired, full 360° coverage was necessary to statistically enhance the change of obtaining a sample. A motor speed of 3, 000 rpm was preferred, but for a 400 cycle motor, this speed is not readily available. (A 16 pole motor is needed.) The nearest "standard" motor was a 4, 000 rpm 12 pole motor. A 3, 000 rpm motor can be fabricated, and torque (power) requirements virtually "tailor-made." This entails time and money. Before such an expenditure is made, the slinger design parameters should be throughly determined.

For example, tests run on the functional model show that slinger speed and design of tines influence the air flow induced by the blower. An engineering trade-off is required to optimize the design.

The fabrication and use of the hardware contributed significantly to the evaluation of the design; therefore, specific recommendations will be more meaningful after the tests are described in the next sections.

SECTION III

TEST PROGRAM

FECES COLLECTION TEST

Test Objectives

The objectives of the first test phase were (1) to prove that the unit would collect and store feces in an acceptable manner; (2) to measure the weight of feces collected and the moisture removed. The test was to run for 10 days, 4 uses per day.

Test Description

The work statement stated that feces shall be collected and weighed once a day after the fourth use, and the amount of moisture removed determined. By design, moisture is continuously removed from the functional model between collection periods; therefore, a system of continuous weight measurement had to be devised. Ideally, the entire system would be placed on a scale and directly weighed before and after each use; however, a scale of 100 pounds or more capacity typically is not calibrated closer than 1/4 pound. To obtain continuous monitoring with measurement accuracy within a few grams, a platform balance was fabricated, which would indirectly measure the feces and moisture weights.

Figure 8 shows how the balance was fabricated and the assembly set up. A sheet of plywood reinforced with aluminum channel was fastened to two pillow blocks containing ball bearings. The functional model was fastened on one side of the platform, and a counterweight fastened to the other. An arm was fabricated and attached to the platform and located to apply a load to an optical weight balance. The smallest division on the balance was 1 gram.

The platform was calibrated as follows: All connections of pneumatic and vacuum lines, and power cables were brought out over one of the pillow blocks to minimize drag effects. Weights were added in small increments to the container periphery. (Nickels, which are 5 grams a piece, were used.) The weight added to the container caused a reduced load at the optical balance. A plot was made to get a correction factor from the slope of the curve. All calibrations and ~~all~~ weighing were done after the container was evacuated to a vacuum of 29.5 in. of mercury or better, minimizing the effects of internal air.

To weigh the feces and moisture, the following steps were used. First, the tare weight on the balance was read and recorded. (Several readings were taken and averaged.) Protective blocks were placed under the platform to prevent damage to the balance. The user then defecated, using the functional model in the normal manner. Toilet tissue was

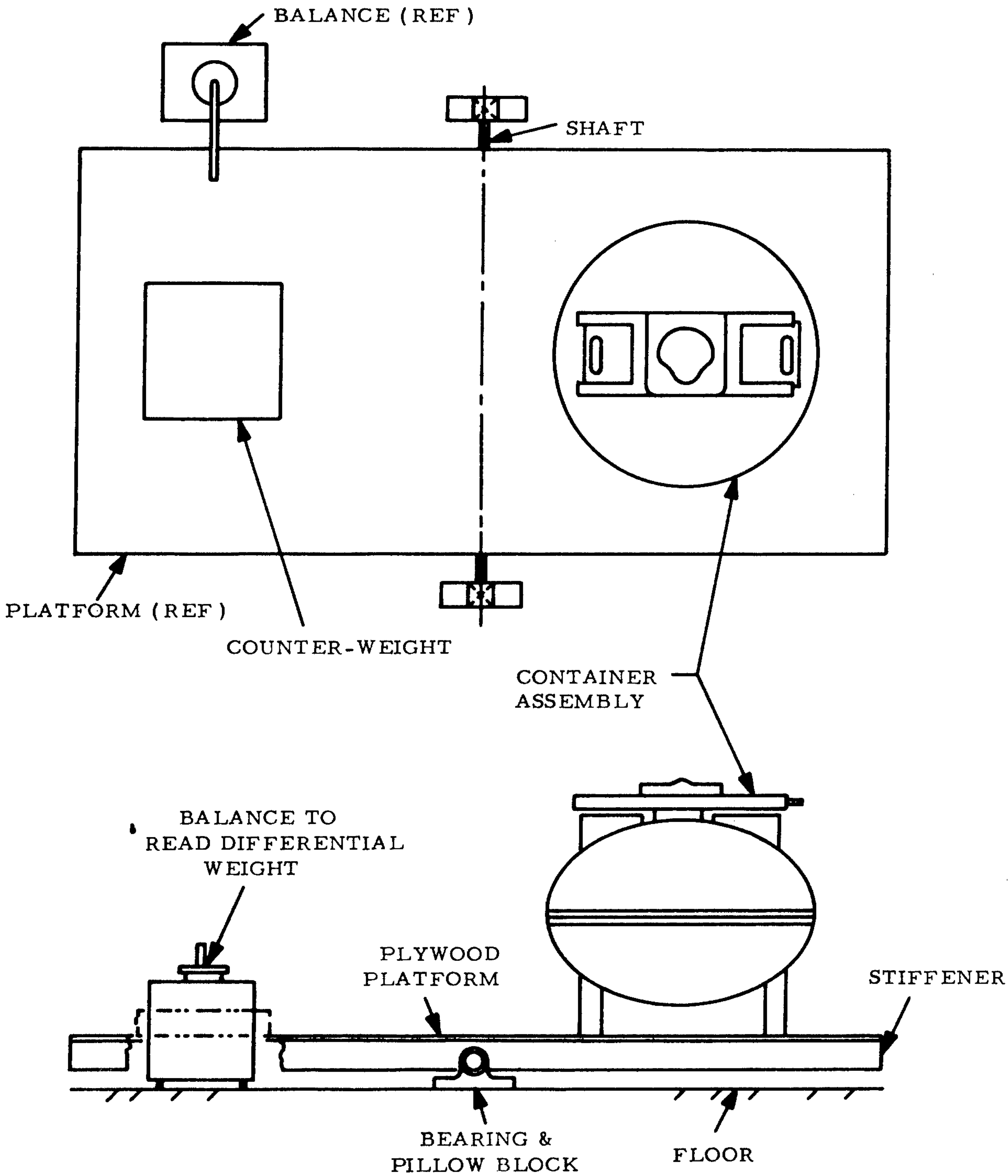


Figure 8. Plywood Platform as a Balance

placed in the container. The power was shut off, automatically causing the interior atmosphere to be evacuated as per design. The protective blocks were removed, and the new balance reading was recorded. The difference in the two readings gave the apparent weight of stool and toilet tissue. From previous measurements on the tissue, its weight was known to be 0.6 grams per sheet; thus, counting the sheets permitted subtraction of the tissue weight leaving the apparent feces weight. This was adjusted by the platform correction factor to give the net fecal weight.

When the next preuse balance reading was taken, the change in weight from the previous post use reading was a measure of the moisture removed. Of course, this number was also corrected by the platform factor.

The necessary vacuum was obtained by the use of laboratory vacuum pumps. To prevent the moisture from entering the pump, a cold trap was made by inserting a vacuum flask in the line between the pump and the container. The flask was immersed in a mixture of alcohol and dry ice (temperature of -110 F). The weight of ice recovered in the trap was taken as the actual moisture removal, and the platform technique weight was compared to this value.

Results of Collection Test

Forty three samples were collected on 11 days of use during an elapsed time period of 15 days. Table II lists the daily weight summary. Referring to Table II, the total moisture removal was 3,066 grams by the cold trap measurements, and 2,759 grams by the platform measurements. This is a correlation within 10%. The fecal weight was 3,586 grams total; however, on October 5, during usage number 20, a negative fecal weight was recorded (probably because of a shift in tissue inside the container assembly). This is reflected in Table II with a 290% moisture removal. The comparison with the cold trap moisture removal shows the cold trap to be 22% high, not inconsistent with the total picture. If the total weights are reduced by the daily summary of October 5, the fecal sample is 3,500 grams with 2,510 grams of moisture removed, which is 71.5 % moisture. The average defecation is 3,500 ÷ 40 or 87.5 grams. This is below the 150 grams per defecation expected. Even after adjusting the fecal weight upwards by 10% (the difference between platform moisture and cold trap moisture weights), the average stool in this test is only 96 grams.

After the liner assembly was removed, a check of the weight of collected feces was made. The total weight of liner assembly, feces, and toilet tissue was 8,700 grams (19.8 pounds). The weight of a typical liner assembly as given in Table I when increased by the weight of the test plug is 7,761 grams (17.12 pounds). The approximate weight of feces and toilet tissue is therefore 939 grams (2.07 pounds). From Table II, the weight of dry feces and tissues is 988 grams (2.18 pounds) an agreement within 5%.

TABLE II. DAILY WEIGHT SUMMARY OF COLLECTED FECES

Usage Numbers	Date of Summary	Number of Tissues	Results From Platform Measurements: Corrected Fecal Weight, Grams	Results From Platform Measurements: Corrected Moisture Removed, Grams	Percent Moisture Removed	Cold Trap Moisture Grams
1 to 4	27 Sept.	31	231	149	64.5	154
4 - 5	28 Sept.	14	153	115	75.0	120
6 - 8	30 Sept.	23	186	184	99.0	200
9 - 13	1 Oct.	28	497	326	65.5	369
14 - 19	3 Oct.	36	626	395	63.0	426
20 - 22	5 Oct.	19	86	249	290.0	305
23 - 26	7 Oct.	22	426	292	68.5	325
27 - 31	8 Oct.	27	249	170	68.4	249
32 - 35	9 Oct.	17	384	280	72.9	291
36 - 39	10 Oct.	25	371	273	73.6	328
40 - 43	13 Oct.*	27	377	326	86.5	300
Totals		269	3586	2759		3066

*Liner Removed - 13 October 1969

NOTES: (1) Dry Feces = 3586 - 2759 = 827 grams

(2) Tissue Weight = 269 x 0.6 = 161 grams

(3) Combined Dry Weight = 988 grams

During the first few days of use, considerable odor was detected. The cause was not certain. To begin with, the liner material itself might have been a contributing factor or reaction with the disinfectant, or the vacuum was insufficient to cause freezing of the feces. Wet feces would cause odor; hence, a second vacuum pump was added in parallel with the first, to increase pumping capacity. This did help, but odor was detected from the pumps; hence, the pump outlets were ducted to a bed of activated charcoal. Even the ice from the cold trap had an odor (at -110 F). Apparently, odor-causing volatiles will pass from the feces to the cold trap and possibly through the vacuum pump.

Odor was not detected when the user was seated. Sufficient air flowed through the holes in the orifice ring (P-30 of Figure 3) to prevent any backflow; however, if the user was standing when the valve was open, the pumping effect of the 4,000 rpm slinger plate (with its tines) affected the blower air and caused turbulence with an escape of odor. Several measurements of air flow were made, and are discussed next.

During assembly, the odor control filter showed excessive pressure drop. A plenum was added to the inlet and outlet of the filter until a flow of nearly 30 cfm was obtained through the filter at four inches of water pressure. Adding all the piping, the added friction caused a drop in volume to just under 24 cfm. When the odor problem occurred the slinger motor was disconnected, and a velocity measurement made. Theoretically, if 24 cfm flowed evenly through the 5 inch diameter transport tube, the velocity would be 122 fpm. A measurement with an anemometer confirmed this velocity. Since the velocity in a typical vertical down-flow clean room is 100 fpm, the blower induced flow should have been adequate; however, connecting the slinger resulted in turbulent flow at the inlet. Also, the toilet tissue in the tank was agitated and actually circulating within the container.

The turbulence obviously was causing some backflow. The easiest way to prevent odor from escaping when using the present design is to have the user seated when the slide valve is open. The long range approach is to balance slinger speed and tine design against blower suction and flow capacity.

NOTE

> In the previous Dry John design, no odor was detected; however, there the blower was more powerful, and the slinger motor slower and weaker.

Another point to consider in the odor control problem is that considerable lengths of vacuum ducting were used for test purposes. Short, direct vacuum lines will result in higher pumping speed, lower absolute pressure, with greater likelihood of freezing the fecal moisture.

The moisture removal was monitored on October 1 after two large fecal samples were collected. The platform balance was read hourly. The moisture removal rate results are shown in Table III. Figure 9 is a plot of Table III. The average removal rate was 23 grams/hour, with extremes of 13 and 51.6 grams/hr. Using the average rate of removal of 23 grams/hr. and the typical bowel movement as 150 grams of which 71.5% is moisture (as determined in the collection test) then:

$$\text{Drying Time} = \frac{(71.5\%\ (150)}{23} = 4.65 \text{ hrs.}$$

Four stools per day will be dried in 18.6 hours, leaving a time margin of 5.4 hours. The design is adequate to handle the specified input.

FECES STORAGE TEST

Test Objective

The reason for using a replaceable liner for the collection, drying, and storage of feces is that replacing a full liner with a clean one extends the life of the mission. (Hence, the name Extended Life Dry John.) To be an effective system, the stored feces must not generate gases. The objective of the storage test was to determine if any gases would develop in the feces collected and dried during the "10-day" test.

Test Description

At the end of the 10-day test (or more precisely, after the last defecation) the vacuum pumps were permitted to operate over the weekend. From previous data, virtually all drying is complete after overnight operation. The liner was removed as per the procedure in the Operation Manual with one exception. Instead of sealing every liner penetration, the outlet from the support tube (which is the normal air/vacuum outlet) was filled with a plug and needle valve. The valve was connected to a mercury column. The entire liner assembly was placed in a polyethylene bag in a storage container. The bag was not sealed. At regular intervals for the test period, the mercury column was read and compared to barometric pressure. In addition, since it was possible for the rubber liner to expand under internal gas pressure, measurements from the top of the storage container to the transport tube cap were made (see Figure 10 for a schematic).

Results of the Storage Test

The test was run for eight days, exceeding the required five days. The results showed no change in pressure or height of cap; therefore, there was no gas buildup. This indicated a bacteriostatic condition of the dried feces.

TABLE III. MOISTURE REMOVAL RATE FROM FECES

Time	Balance Reading Grams	Hourly Moisture Removed Grams	Corrected Moisture Removed, Grams	Accumulative Moisture Weight, Grams
8:30	420	--	--	--
9:30	476	56	51.6	51.6
10:30	494	18	16.6	68.2
11:30	528	34	31.4	99.6
12:30	553	25	32.1	122.7
13:30	568	15	13.9	136.6
14:30	592	24	22.2	158.8
15:30	606	14	13.0	171.8
16:30	---	--	--	--
17:30	644	38*	35.1	206.9

*Two (2) Hours

NOTES: (1) Average moisture removal rate 23 grams/hr

(2) Fecal sample totaled 344 grams (uses 11 and 12 on October 1)

(3) Average removal rate for October 1 was 65.5% (Table II)

(4) Removal of 92% moisture in nine (9) hours of test is indicated

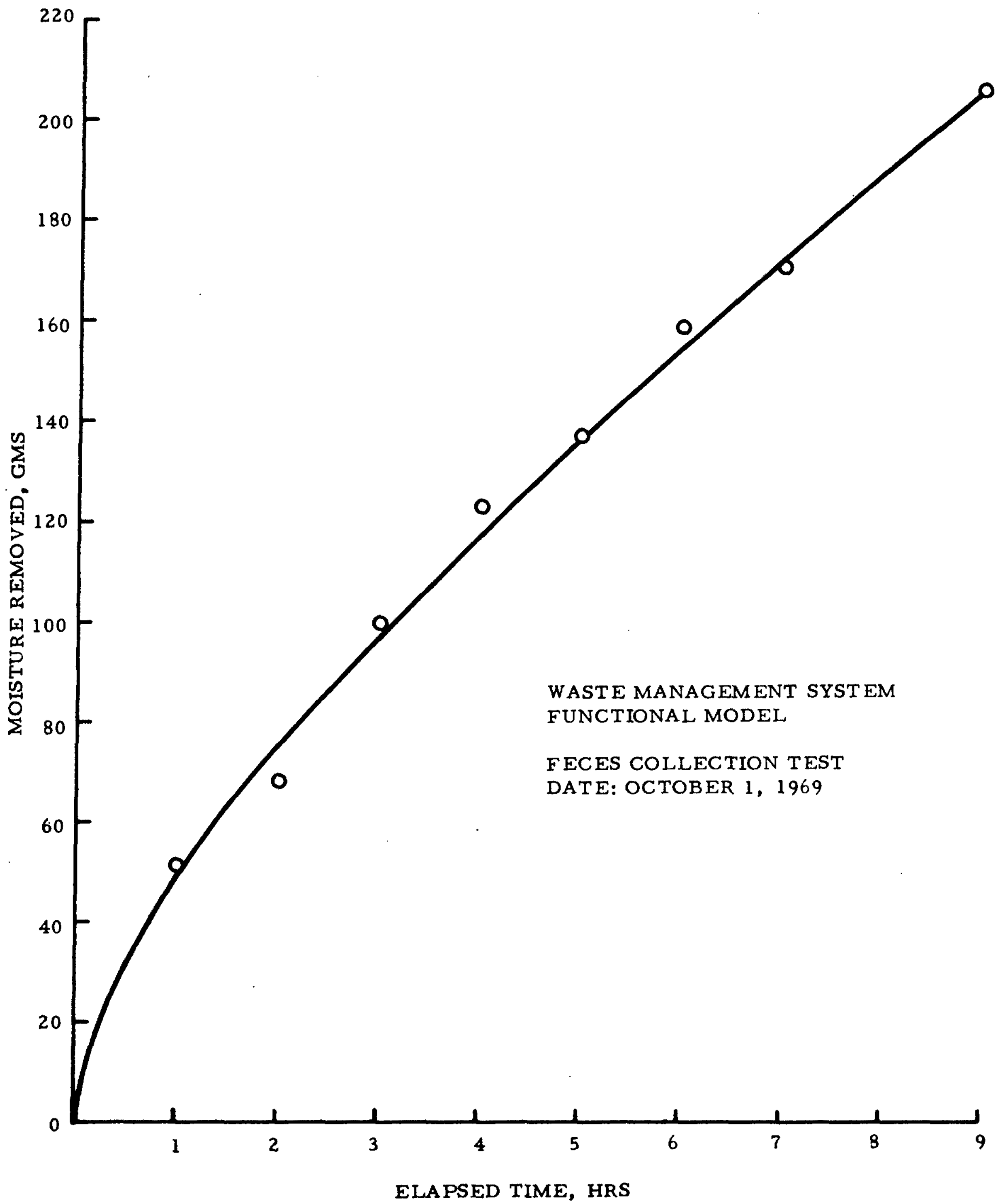


Figure 9. Moisture Removal - Vacuum Drying

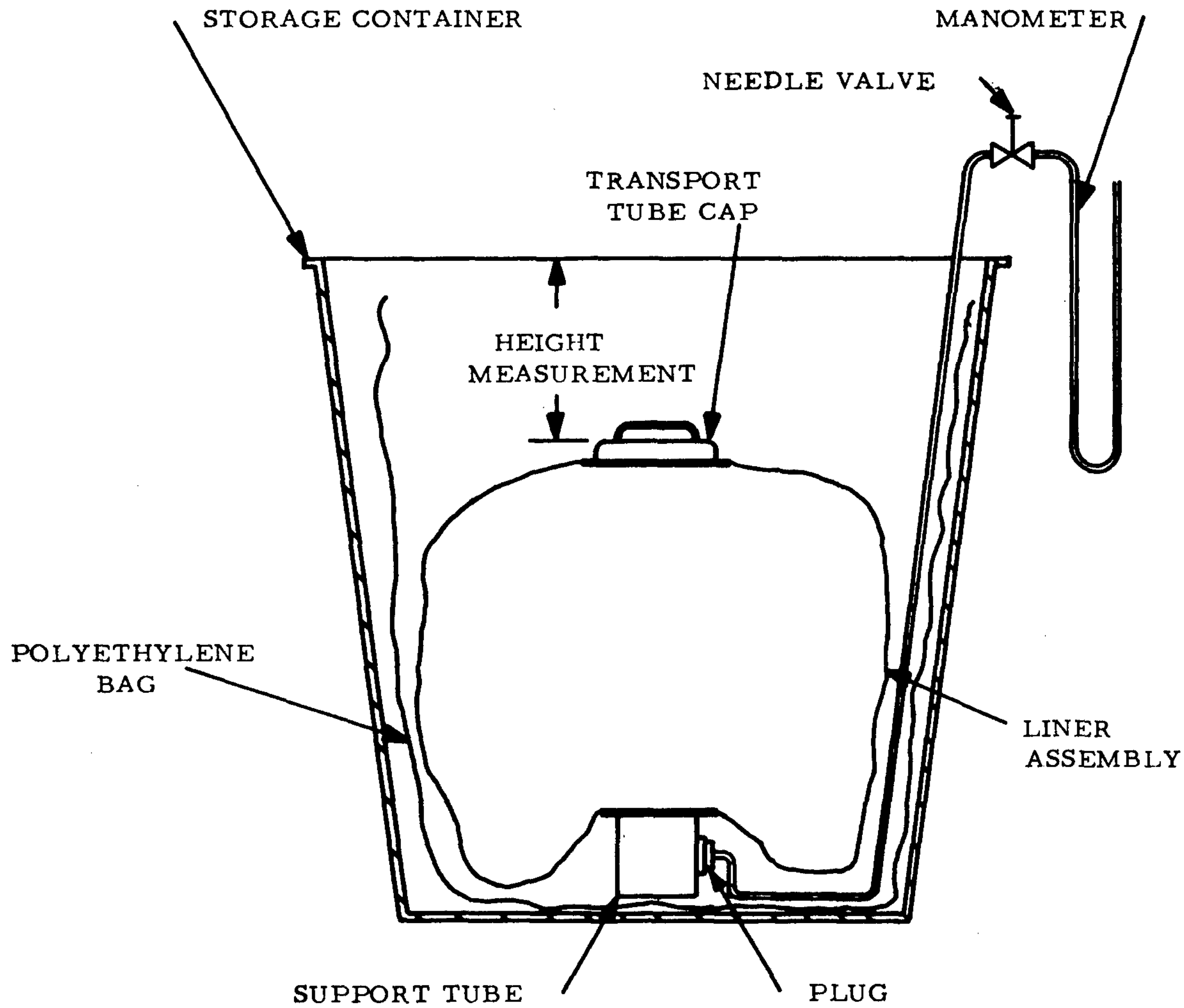


Figure 10. Set-Up of Storage Test

SAMPLING TESTS

Test Objective

During the early stage of the contract, a device that could be inserted into the container assembly to obtain a sample of the feces was designed by the contract monitor. It was tested on a breadboard set-up at General Electric. The liner assembly and container were designed with an adapter housing and boss to accept the sampling unit (formally entitled Fecal Tube Retriever Assembly). See Figure 11. The objective of this test was to measure the effectiveness of the design, and verify operating procedures on the Functional Model.

Test Description

During the Feces Collection Test, the retriever assembly supplied by the contract monitor was used in the Functional Model. The retriever was weighed before and after use, the net change being the sample size.

Sampling Test Results

Two difficulties were immediately encountered and corrected by procedural changes. The Operation and Maintenance Manual reflects the corrected procedure.

The first of the difficulties was that of odor control. Opening the slide valve before removing the cap from the sampling adapter (Fecal Retriever Housing) resulted in back-flow out the adapter. The procedural change incorporated was to turn the slide valve handle to start the blower, remove the cap and insert the retriever; then, open the slide valve plate. For retrieval removal, the valve plate must be closed first. With the valve plate closed, the blower draws in air only at the sampling adapter with a velocity sufficient to overcome the slinger effect. (The computed velocity for 20 cfm is 815 fpm.)

The second difficulty encountered was the use of toilet tissue. If the tissue was deposited into the container with the sampler open, the tissue could (and several times did) get into the sampler slot and prevent closure and removal. The procedural change was to close the sampler slot (by twisting the cap) after the defecation but before wiping with the tissue. If the tissue wrapped around the outside of the sampler, the wiping action of the housing scraped off the tissue permitting easy removal of the retriever.

Table IV summarizes the measurements made when the sampler was used. A sample was always obtained. The average sample collection was 3% of the fecal weight.

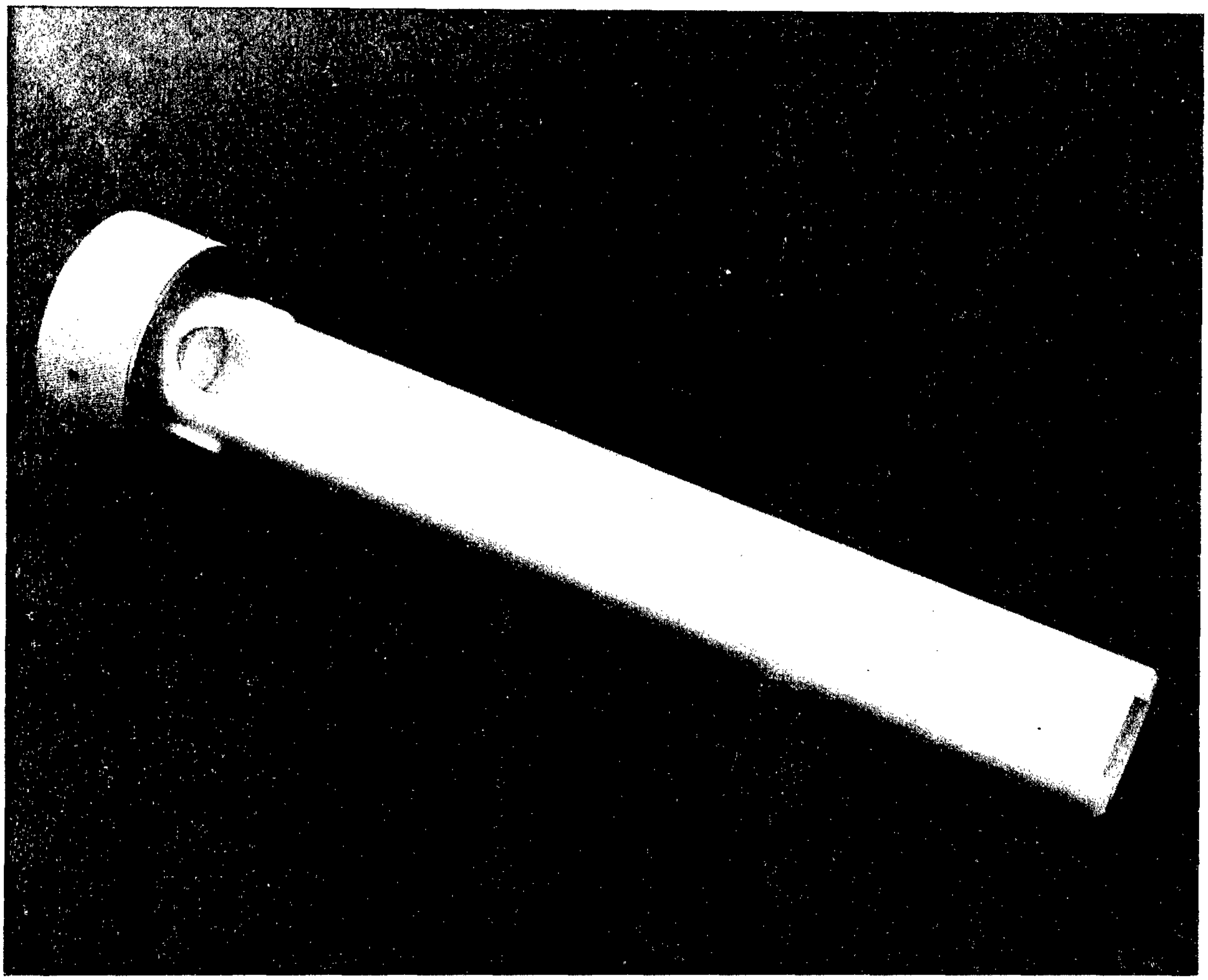


Figure 11. Fecal Tube Retriever Assembly

TABLE IV. RESULTS OF FECAL RETRIEVER USES

WMS Use Number	Date	Corrected Fecal Weight Grams	Sample Weight Grams	Sample Size Retrieved %
--	Sept. 29	---	Trace	---
9a	Sept. 30	10.7	0.5	4.7
9b	Sept. 30	91.5	2.7	3.0
13	Oct. 1	51.5	0.7	1.4
14	Oct. 2	76.5	3.9	5.1
35	Oct. 8	55.5	1.2	2.2
36	Oct. 9	119.0	2.2	1.9

DISINFECTANT DISPENSING TEST

Test Objective

The purpose of disinfectant dispensing is to sanitize and deodorize the feces. During the feces collection test, the disinfectant supply system was tested to assure operation of the disinfectant system.

Test Description

A source of air regulated to 10 psig was connected to the disinfectant tank. During assembly, the tank had been filled with a water solution of Wescodyne F53, and the timing circuit adjusted to give one cubic centimeter per actuation.

Results of Disinfectant Test

The dispensing of the disinfectant was observed through the open valve plate. Upon pressing the disinfectant switch, a slug of solution could be seen striking the slinger plate. From preliminary tests with a clear plastic tank, it is known that the slinger will dispense the liquid over a 360^{o} arc in a plane essentially level with the slinger plate. The tines and blower-induced air flow cause some vertical dispersion; however, samples of the feces to measure the bacteria-kill ratio were not taken since this was beyond the scope of the investigation; and once the disinfectant was added, it was not possible to determine if the disinfectant helped control the odor.

The manufacturer (West Chemical Products, Inc., Long Island City, N.Y.) recommends 75 ppm of iodine, by diluting one part Wescodyne to 213 parts of water. The concentration may be doubled for porous surfaces. The test container had a much stronger solution being diluted only 1:10 for two reasons. First, the fecal moisture itself would tend to dilute the solution; and second, sufficient concentrate could be injected in a short pulse, with minimum water. Since the feces is vacuum dried, adding excessive water with a dilute solution would result in a loss of water to space vacuum. At the conclusion of the collection test, the remaining solution was removed from the disinfectant tank. The solution itself was losing its color, a sign that it was becoming less effective; the latex liner showed a very dark (nearly black) spot where the liner apparently was pressed against the stand pipe inside the disinfectant tank. Before shipping the unit, the stand pipe was shortened, and a spherical end bonded to the tip of the pipe to reduce the load concentration.

Two weeks after disassembly, the bladder was examined again. The concentrated black spot had spread through the entire bladder. Apparently, the iodine diffused through the rubber. Since there is sufficient concentrate for 90 days use in the disinfectant tank, the question must be raised as to the possibility of diffusion through and deterioration of the bladder with the given chemicals. More effort in this field is needed.

SECTION IV

SYSTEM EVALUATION

GENERAL

The basic concept of collecting, drying, and storing feces in a commode by the use of slinging and vacuum drying techniques, is an effective method of human wastes management. A design similar in operation to everyday ground use can be fabricated for zero gravity space applications. The use of a replaceable liner to extend the life of the basic system is feasible.

The particular design fabricated and tested under this contract showed positive advancement in the state-of-the-art of waste management, but also pointed out areas that can be improved. Positive advancements were obtained in the design of seat, slide valve assembly, packaging arrangement, feces sampling, and disinfectant addition. Improvements are needed in liner materials, and in optimizing the parameters of weight, power, envelope, and function.

DESIGN ACHIEVEMENTS

The contoured seat is an improvement over previous designs for several reasons. It is smaller, lighter and fireproof, compared to the previous plastic types. The seat can be easily cleaned and, if necessary, removed for autoclaving. The contour is based on supporting a man on the ischial tuberosities, the bottom-most protruberances of the pelvic structure. Combined with the leg support, a semi-squat position results which aids in the spreading of the buttocks for easier defecation. From the standpoint of comfort, support on pelvic bone structure is superior to support on the fleshy part of the thighs. Subjective opinions of the users were favorable when the leg supports were used. A slightly higher leg support would improve the comfort level. After adapting himself to this design, one subject felt that the normal home toilet seat was relatively uncomfortable. A drawback in the small seat design, expressed by one volunteer, is the need for a separate urinal. Because the test unit did not have a flight-type urinal, a bottle was used, and this had an adverse psychological effect on the volunteer.

The slide valve assembly worked smoothly and effectively. The basic concept provided a quick, easy clamp for opening or closing the container. The O-rings provided adequate sealing and the valve can be rapidly attached or removed. Detail design changes can be incorporated to lighten the valve assembly and simplify fabrication; or, if desired, the sliding plate can be made to operate under pneumatic, hydraulic, or electrical power.

An improvement in the packaging arrangement over previous Dry John systems was to install the bacteria filter inside the liner assembly; thus, there is a better utilization of container volume. The filter will remove all particles of .08 microns or larger; thus, all downstream lines will be clean and biologically safe.

Feces sampling and disinfectant addition are two new features to the Dry John concept. Either feature can be used without a liner type of design. In fact, fabrication is simplified, if there is no liner. The new features proved to be an effective way to disinfect or sample feces without the need for individual bags and manual handling of feces by the astronauts.

AREAS FOR DESIGN IMPROVEMENTS

Optimization guidelines are discussed in Section II. Necessary parameters need to be pinpointed before this concept can be developed to a flight unit. One such parameter, previously mentioned, is the optimum slinger motor speed and torque for the mission. Along with slinger speed design, the effect of the tines causing backflow should be evaluated since the blower induced air flow is affected by the slinger. Also, zero gravity tests are required to determine optimum air velocity in the transport tube (hence, blower capacity).

Biological evaluation of the disinfectant should be made. From the tests run and the discoloration of disinfectant liner, materials must be thoroughly evaluated.

One major feature of the functional model that was evaluated during this contract was the use of a liner to extend mission life. The liner assembly was fabricated and successfully tested, but it can be improved. As predicted, the storage volume of a clean liner assembly is much less than the container; (1.0 cubic feet stored versus 1.5 cubic feet in use) however, the 16.7 pounds of weight is far above the predicted 5.0 pounds. The liner itself is over 3 pounds and the motor with support is 6 pounds. A thin, molded liner of relatively impermeable, inert material is required to permit design optimization. A lighter motor and support is needed.

The plumbing lines were installed with considerable clearances for easy access and maintenance in evaluation tests. More compact packaging can be obtained for flight design. The air flow lines and vacuum lines should be short, of relatively large diameter with few bends and restrictions. Vacuum line restrictions in the present design can be reduced by changing the angular flow-path bacteria filter to one with axial flow, and replacing the bellows valve with a ball valve. Considerable weight savings can be obtained by using thin-wall aluminum tubing and fittings instead of the copper and stainless steel used for the functional model. The heavier materials were used for ease of fabrication and to permit more rugged laboratory handling.

One of the filters used in the plumbing lines external to the container is an odor control filter. This filter is considerably oversized to provide a long flow path through the bed of odor-control pellets and permit a high percentage of odor removal. To keep pressure drop low, a large diameter is used to cause low velocity through the bed. As a result, there are enough odor removal pellets for two 90-day missions. Making the unit smaller will compromise the odor removal efficiency or pressure drop or both. For flight, it may be better to duct the liner outlet directly to the environmental control system of the vehicle (if they are located close together). Otherwise, this is another area for design optimization, where a smaller, efficient filter must be developed.

When the feces collection and storage tests were completed, the liner was opened in an isolator, the motor removed, and the isolator sprayed with peracetic acid. With the motor removed, the liner, and all other parts were autoclaved. The machined metal parts were then removed and reused. For laboratory (ground) use, this "salvage" technique saves many parts. The liner and filter were discarded. For a flight unit, it may not be desirable or economically advantageous to attempt such a salvage on a unit after recovery. If it is, however, an autoclavable motor would aid in the clean-up procedure, for then the entire liner assembly could be autoclaved together.

During the clean-up and disassembly of the parts, examination revealed a worn O-ring in the slinger motor mount plate. A better seal for the high speed shaft should be provided for a flight design; however, no problem is foreseen during use of the functional model.

During the clean-up, there was some discoloration on the slinger-motor harness sleeving. It is not known if this was dirt, mold, or other contamination. If it was biological, it is not known if there was contamination in the initial assembly (assembly was not performed under aseptic condition), or whether some migration through the filter or seals had occurred. Because the parts had been sterilized during disassembly, a microbiological test culture would have proven useless. What is evident is that further testing and development of this hardware should include biological analysis.

Last, but not least of the areas for further investigation is the use of air jets for location of the user and stool separation. The design of the contoured seat virtually eliminates the need for air jets in locating the man. In the laboratory, due to the effect of gravity, it was difficult to evaluate the use of air jets to aid in stool removal. It can be stated, however, that the low pressure jet (10 psi) is difficult to feel. Higher pressure may be useful. Wiping with tissue physically removes the stool, and the air flow through the orifice ring and transport tube will carry the tissue and stool into the slinger. Again, zero-gravity tests are recommended for full evaluation of fecal separation and transport.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

The basic concept of feces collection and storage by slinging and vacuum drying is an effective method of waste management. A split-container commode design with a replaceable liner for extending the mission life of the collection system is feasible. Sampling and disinfecting of the feces is possible with this concept. Design optimization involving size, weight, power, and materials is necessary before a flight configuration is completed. Optimization studies should include biological analysis of the system and stored feces, and zero gravity tests to confirm or permit refinement of the stool transport-slinger concept.