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FOREWORD

This report was prepared by the Life Support Department, Systems Division, Whirlpool Corporation, St. Joseph, Michigan, under contract No. AF33(657)-9131. The work was performed in support of Project No. 6373, "Equipment for Life Support in Aerospace," Task No. 637305, "Life Support Accommodation, Integration and Analysis," with Lt. Ralph Herbst originally acting as contract monitor. After Lt. Herbst's transfer, the contract monitor was Mr. Courtney A. Metzger, Chief, Requirements and Evaluation Branch, Biotechnology Division, Biomedical Laboratory, 6570th Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio, the organization initiating the study. The experimental research on this project was initiated 1 June 1962 and completed 20 May 1963, with the delivery of laboratory models.

The authors are indebted to Mr. Edward Stone, Test Supervisor, and his staff for the design and fabrication of flexible plastic components; to Mr. William Martin, Design Supervisor, and his group for the preparation of final drawings; and to Mr. W. Robandt and Mr. R. Claustre for Model Shop facilities of the Whirlpool Research Laboratories. Dr. R. C. Crowell, practising urologist in St. Joseph, Michigan, contributed valuable assistance in the field of anatomy and physiology of the urinary system and the lower digestive tract.

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ABSTRACT

An evaluation of techniques for human waste receiving, collection and storage during an aerospace mission, with the crewman wearing, or not wearing, a pressure protective garment is presented. Laboratory models, utilizing the most promising techniques, were designed, fabricated and evaluated. A centrifugal urinal, powered by a hand-wound spring motor, was developed for urine collection. Although the principle proved to be satisfactory, further work is required to improve pumping capacity, eliminate air entrainment with the urine, and devise air-urine separation techniques. A disinfectant dispenser operable in zero gravity and a spherical bladder-equipped urine storage tank with means for addition of disinfectant were developed. A flexible plastic in-suit urinal was fabricated, with means for discharging collected urine into the centrifugal urinal. A flexible plastic collector for fecal matter, held in place by a body harness and containing a disinfectant for stabilization purposes, was developed, as was a storage box for containment of used collectors. Further research is required in the areas of penis seals, better control of liquid fecal matter, and odor control.

PUBLICATION REVIEW

This technical documentary report is approved.

Wayne H. McCandless

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory

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SECTION I

INTRODUCTION

Background

The proper collection and storage of human waste is vital to the successful completion of manned aerospace missions. Conditions of weightlessness impose unique requirements for fluid and solids handling equipment. Limitations on water supply, power consumption, and mass and volume of hardware, and the need for high reliability, crew safety, and minimum contamination of cabin atmosphere, demand exceptional care in the selection of principles and devices for waste management.

Objectives

1. To determine the most promising human waste collection and storage techniques by means of a comprehensive engineering evaluation of all practical and applicable methods. The situations of the crewman in shirtsleeves or in a pressure suit are to be considered.

2. To design laboratory models of equipment, utilizing the techniques selected as a result of the feasibility study.

3. To fabricate and evaluate full scale engineering models in accordance with the proposed design.

Requirements

1. Units operating

   Crew - three men
   Mission length - 7, 14, and 30 days (models for 14-day mission)
   Power available - 115 volt AC (400 cycles) or 28 volts DC
   Cabin environment
   - Condition of weightlessness
   - 60-75°F temperature
   - 30-50% relative humidity
   - 7.35 - 14.7 psia atmospheric pressure
   - 0.1 lb/min leakage rate
   - No contamination of vehicle cabin atmosphere
   - Simple and efficient cleaning means for collectors if exposed to cabin atmosphere
   - Minimum mass and volume consistent with functional requirements

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2. Units Stored but Not Operating

"G" Loads

Acceleration - 4.5G peak lateral axial with respect to axis of vehicle with possible 8G peak axial, for 10 min total duration
Deceleration - less than during acceleration, probably approximately 2G peak
Impact - 25G axial and 10G lateral

Vibration

Acceleration - 0.4 cps - 400 cps for 1 min peak, 10 min total
Deceleration - up to 500 cps for 15 min
Random - 0.2 cps - to 50 cps

3. Fecal Matter Collection and Storage

Crewman in unpressurized suit or in shirtsleeves
No storage attached to crewman or suit
Collection outside suit, separate from urine
Means provided for crewman to clean himself
Individual, portable, combined collection and storage units preferred

4. Urine Collection and Storage

Crewman in pressurized or unpressurized suit or in shirtsleeves
Storage inside pressurized suit permissible - 8 hrs max
Collection and storage outside suit when unpressurized

5. Spare Parts and/or Special Tools

Those required for replacement or repair to be furnished by contractor

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SECTION II

MICTURITION AND URINE COLLECTION

Biological Aspects

Anatomy of the Urinary System

The primary organ of the urinary system is the kidney, which serves as a blood plasma filter capable of removing excess water and dissolved waste products of cellular metabolism. Urine drains from the nephrons, functional units of the kidney through tubules, calyces, and the ureter to the bladder, which serves as a reservoir for urine between intervals of micturition. Bladder capacity of the normal human being varies from eight ounces to over one quart (237 to 946 ml), according to Marshall and Lazier (Ref.20). The bladder is drained by the urethra, which is surrounded, in turn, by the internal sphincter, the prostate gland, and the external sphincter. Both sphincters act as valves. The cavernous urethra, the final and largest portion of the urethra, largely lies within the corpus cavernosa urethrae, a roughly cylindrical sac of spongy tissue. The external opening of the urethra on the end of the penis is known as the meatus. Figure 1 is a simplified schematic drawing of the male urinary system. Average length of the urethra is approximately eight inches.

Figure 2 is a side view median section of the male pelvic region in somewhat simplified detail, illustrating the location of the organs of the urinary system and their location relative to the digestive tract and associated organs. Length and diameter of the penis vary considerably with individuals, as well as with their immediate environment and psychological state. Crowell * determined the average penile dimensions of 30 subjects varying in age from 19 to 80 years. All measurements were taken with the penis in the flaccid condition, and dimensions did not appear to vary with age. Average length was 11.7 cm (4.61 in), and circumference was 9.7 cm (3.82 in). If the penis were circular in cross section, which it is not, the average diameter would be approximately 3.0 cm (1.18 in). The average distance from the anus to the base of the scrotum was 7.6 cm (2.99 in). External anatomy of the penis includes the shaft, the glans (or head) and the prepuce. The latter may be removed by circumcision. Internally, thin muscle layers surround cylindrical sacs of spongy tissue called corpora cavernosa. Figure 3, a cross section through the shaft of the penis,

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*Crowell, R.C., M.D., 1962. Private Communication. Practicing Urologist, St. Joseph, Michigan.

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illustrates these structures, which are richly supplied with blood vessels. Under proper stimulation, erection results when blood inflates these sacs. An involuntary erection may be caused by a restriction placed too tightly around the penis. Under such conditions, blood cannot drain from the corpora cavernosae to relax the penis. Unless the restriction is removed, trapped blood will cause a thrombosis with severe pathological damage to the organ.

Urinary Physiology

Urine does not pass from the kidney to the bladder in a steady stream. Rhythmic peristaltic contractions of the ureter, traveling like waves at a speed of 20 to 25 mm per second, occur at one to five minute intervals to carry urine into the bladder. The bladder is capable of accommodating to the volume of its contents. Bladder pressure increases momentarily each time urine enters, but because of the accommodation characteristic, pressure will drop to a value only slightly above the initial pressure. A considerable quantity of urine, consequently, can collect in the bladder with only a moderate rise in pressure. If the process continues beyond the adaptable limit of the bladder, however, a rapid rise in pressure is experienced with relatively small additions of urine.

The micturition reflex is initiated by sensory end organs in the bladder when pressure reaches a certain threshold value, usually 15 to 18 cm of water, but possibly at much lower pressures. Under normal conditions, unless voluntarily restrained, micturition occurs after 250 to 300 ml of urine have collected in the bladder. Best and Taylor (Ref. 2) found that the micturition reflex is initiated at lower volumes if the accumulation rate is abnormally high. Micturition, although essentially reflex in nature, may be restrained voluntarily by inhibiting the contraction of the detrusor muscle and contracting the external sphincter. At low urine volumes, inhibition of micturition is apparently subconscious, although control becomes conscious as the bladder continues to distend. Although there is some disagreement among authorities, Evans (Ref. 9) states that sensation of the desire to micturate appears when 400 ml of urine have collected in the bladder, and becomes painful when 700 ml have collected. Severe pain results if micturition is voluntarily inhibited to the extreme. Micturition proceeds involuntarily when an internal bladder pressure of 100 cm of water has been reached.

According to Best and Taylor, contraction of the detrusor muscle during micturition causes bladder pressure to rise as high as 130 cm of water. Crowell* states that practicing urologists more commonly observe average bladder pressures of 64 cm of water. Consequently, urine is expelled with considerable force. Although the detrusor muscles

*op. cit.

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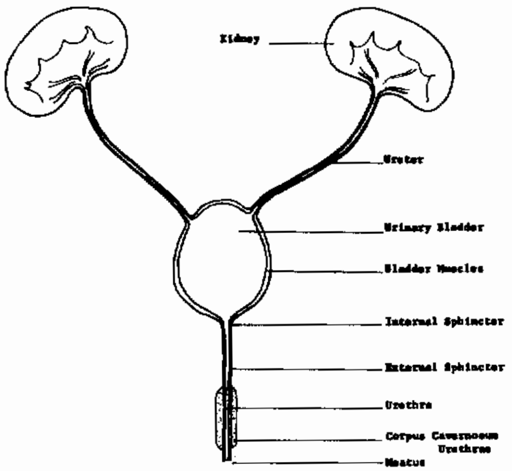

Figure 1
Simplified Schematic
Drawing of Male
Urinary System

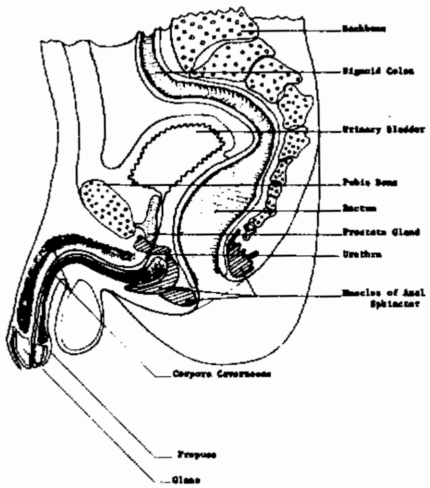

Figure 2
Side View Median Section
of Male Pelvic Region

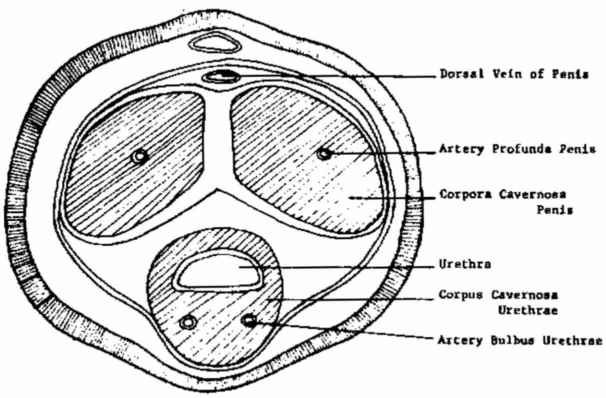

Figure 3
Cross Section through Penis

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of the bladder are primarily responsible for expelling urine during micturition, the abdominal muscles play a minor role. The act of micturition is usually initiated by, and the flow of urine can be accelerated by, contraction of these abdominal muscles.

The bladder is usually evacuated almost completely at each micturition, although the ability to empty the bladder varies considerably from person to person. The total solids output in the urine per day has a very definite relationship to the urine solute concentration and to the total urine volume. Mills, Thomas and Yates (Ref. 21) assessed urinary creatinine excretion, which is independent of ordinary variations in diet, and from these values calculated bladder emptying volumes. An air "head space" is never present in the bladder, whether empty or full, because of the unique ability of the bladder to conform to its contents. After micturition, the last remaining urine in the urethra is expelled by contraction of the bulbocavernosus muscle which surrounds the urethra.

The formation and accumulation of urine, and the frequency and rate of micturition, are influenced by a number of factors. Information is available in the literature on the effects of diet, fluid intake, disease, temperature, humidity, exercise, emotion, posture, acceleration, rapid decompression, altitude or ambient pressure, and gravitational fields. Most of the reported investigations were conducted with limited groups of test subjects and with questionable control of other variables. It is apparent, however, that a very complex relationship between physiological factors, as well as differences between individuals, will determine actual urine production and rate of micturition in any given case. Measurements of micturition rates of a small group of subjects in the Whirlpool Life Support Department showed clearly the magnitude of variations that might be expected. The volume of urine excreted during a single micturition varied from 66 ml to 325 ml, with an average of 189 ml; the time per micturition varied from 6.6 seconds to 25.5 seconds, averaging 12.24 seconds; and the average rate of micturition varied from 600 ml/min to 1646 ml/min, with an average of 939.125 ml/min. The higher rates were achieved when subjects consciously inhibited micturition until considerable pain was evident.

Urinary Tract Microorganisms and Sanitary Implications

Although sterile urine is excreted from the normal kidney, the lower urinary tract can harbor a variety of saprophytic or even pathogenic microorganisms under certain conditions. Urine can be contaminated by contact with the lower tract or the external surface of the penis.

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Wilson and Miles (Ref. 34), Schackman and Messent (Ref. 31) and Serrano (Ref. 30) have isolated and identified large numbers of potentially pathogenic organisms in the urinary tract, including Staphylococcus albus, Mycobacterium smegmatis, Streptococcus faecalis, Escherichia coli, Streptococcus viridans, Neisseria gonorrheae, Proteus vulgaris, Pseudomonas aeruginosa, Aerobacter aerogenes, Streptococcus pyogenes, Staphylococcus aureus, diphtheroids, and the pathogenic fungus Candida albicans. The actual incidence of microorganisms in the human urinary tract may be higher than generally supposed. Because of the very short generation times of microorganisms, mutations with characteristics quite unlike the parent cells can be produced at surprising rates. Because isolation procedures satisfactory for the parent cells are often completely useless for the mutants, many organisms existing in the urinary tract could easily be overlooked by routine isolation procedures. Gillespie (Ref. 11) reported an excellent example of this fact. Although pathogenic fungi have been found in the urinary tract, Guze and Haley (Ref. 13) present evidence that these fungi would not likely be present except perhaps in poorly regulated cases of diabetes or in urinary tract infections.

The pelvic and penile skin areas are frequent sources of microbial contamination of urine, or even sources of infection for the urinary tract. Pillsbury, Schaffer and Nicholas (Ref. 25), Wilson and Miles (Ref. 34), and Evans, et al. (Ref. 10) have found a number of skin inhabitants, including S. albus, S. aureus, S. viridans, Sarcina lutea, Staphylococcus epidermidis, Propionibacterium acnes, M. epidermidis, anaerobic diphtheroids and unidentified gram negative rods. It is obvious from the above findings that many of the organisms found in the urinary tract are also normal skin contaminants. The fact that voided urine is not sterile complicates the problem of urine collection. Surfaces soiled by urine must be cleaned or disinfected to avoid production of odors and toxic gases.

Pathological Effects in Skin Bathed with Urine

A common condition, often observed in infants, is called "diaper rash." This may also occur in incontinent and chronically ill adults. Work by Cooke (Ref. 6) conclusively demonstrated that the presence of excess ammonia in urine was the cause of diaper rash, and that an organism now called Brevibacterium ammoniagenes was capable of breaking down urea in voided urine to ammonia in large quantities. Later work by Brown, Tyson, and Wilson (Ref. 4), and Brown and Wilson (Ref. 5) identified other microorganisms which produce ammonia from the breakdown of voided urine. Diaper rash, or "ammonia dermatitis," may cause severe damage to the penis if allowed to progress beyond the simple dermatitis stage.

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Nagamatsu, Johnson, and Silverstein (Ref. 24) point out that the simple macerating effect of fluids in constant contact with the skin can be very serious even in the absence of ammonia or toxic irritants. They employed protective ointments such as aluminum pastes or petroleum jelly to prevent urine from soaking the skin of the incontinent male geriatric patients on whom penile bags and clamps were employed to collect urine. Other ointments have been employed in similar cases. Shovlain, et al. (Ref. 32) used a water-repellent perianal cream containing quaternary ammonium disinfectant, Kaessler (Ref. 17) used a preparation consisting of silicones, glyoxyl diureide and hexachlorophene in a talc base, and Bleier and Niedelman (Ref. 3) found ointments containing a quaternary ammonium germicide effective in the treatment of ammonia dermatitis.

Volume and Composition of Normal Human Urine

The volume of urine voided during a 24-hour period varies with water intake and environmental factors, and ranges from 1000 to 2000 ml, averaging 1260 ml, according to Hawk, Oser, and Summerson (Ref. 14), and 1500 ml, according to Evans (Ref. 9). The specific gravity of voided urine varies from 1.016 to 1.022, and pH varies from 4.6 to 8.0. Average titratable acidity of a 24-hour urine specimen is 200 to 400 ml of 0.1 normal acid, which represents 20 to 40 milliequivalents of acid per 24 hours, according to Long (Ref. 19). Table I lists the major components of urine as reported by two sources. A great variety of other compounds exist in rather low concentrations. According to Long, urine contains cellular debris and degraded tissue as well as the following chemical constituents:

Cholesterol	Imidozoles
Flavines	Indoles and related compounds
Inositol	Amino acids
Ketones	Purines
Lipids	Porphyrins
Many organic acids	Metabolites of tryptophan
Phenolic acids	Enzymes
Sugars (mostly lactose)	Hormones
Choline	Vitamins

Urine, like all body fluids, contains dissolved gases. Hong, et al (Ref. 15) studied the partial pressure of oxygen carbon dioxide and nitrogen in freshly excreted urine. They noted that nitrogen and oxygen tensions of urine are relatively constant, and the partial pressure of these gases in the urine, especially nitrogen, depend upon their partial pressure in the alveoli. They further noted that variations in the total gas pressure of the urine were dependent upon the highly variable partial pressure of carbon dioxide. In urine samples collected from subjects breathing air at standard conditions, the average partial pressure of nitrogen was 550 mm of mercury. The partial pressure of carbon dioxide in these samples,

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TABLE I

COMPOSITION OF 24-HOUR VOLUMES OF NORMAL URINE

Constituent	Grams-Source A (Ref.14)	Grams-Source B (Ref. 29)
Water	1200	-
Total Solids	60	-
Urea	30	6.0 - 18.0 (as N)
Uric acid	0.7	0.08 - 0.2 (as N)
Hippuric acid	0.7	-
Creatinine	1.2	0.3 - 0.8 (as N)
Indican	0.01	-
Oxalic acid	0.02	-
Allantoin	0.04	-
Amino acid nitrogen	0.2	-
Purine bases	0.01	-
Phenols	0.2	-
Chloride (as NaCl)	12.0	4.0 - 8.0 (as Cl)
Sodium	4.0	2.0 - 4.0
Potassium	2.0	1.5 - 2.0
Calcium	0.2	0.1 - 0.2
Magnesium	0.15	0.1 - 0.2
Sulfur, Total	1.0	-
Neutral sulfur	0.12	-
Inorganic sulfate (as S)	0.8	0.6 - 1.8
Phosphate (as P)	1.1	0.7 - 1.6
Ammonia	0.7	0.4 - 1.0 (as N)

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however, varied from 40 to 210 mm of mercury. It was also found that the partial pressure of oxygen averaged 58 mm of mercury in urine samples collected from subjects breathing pure oxygen. Total gas pressure of urine from air-breathing subjects was found to vary from 700 mm to 840 mm of mercury (the higher value found in subjects given sodium bicarbonate diuresis). If urine should be collected or stored at pressures much lower than suit or cabin pressures, it is likely that boiling and foaming will complicate system operation. This problem would be less serious if crewmen breathe pure oxygen at lower pressures.

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Collection of Urine

General Requirements for Collection Devices

1. Equipment must be anatomically and physiologically compatible with the crewman, and must adapt to individual variations between crewmen.

2. Transfer of urine from the penis to storage or reclamation facilities must be accomplished without danger of releasing urine to the interior of the cabin during attachment of the device to the penis, actual micturition, detachment, and handling after use.

3. Equipment should be convenient to use, aesthetically acceptable, and reasonably comfortable to the crewman throughout the collection process. Sharp edges and corners capable of inflicting injury should be avoided, and the possibility of infection arising from the use of equipment should be eliminated.

4. Equipment must be highly reliable, with adequate strength to withstand rough handling and the forces encountered in launch, re-entry, and other maneuvers, and with minimum maintenance requirements.

5. Equipment should require minimum cleaning to maintain sanitary conditions. Any required cleaning should involve little effort, auxiliary equipment, or supply items.

6. Volume, power requirements, and mass of equipment must be minimized consistent with proper function. An optimum combination of disposable and multi-use items for the specified mission should be achieved.

7. Atmospheric contamination must be minimized by preventing the excape of urine odors during collection, and by avoiding putrefaction of urine solids remaining on equipment after use.

8. The accumulation of urine solids within equipment items should be avoided to prevent obstruction of orifices and interference with moving parts.

Special Requirements for In-suit Urine Collection

1. Transfer of urine from within suit, whether direct or after temporary storage within suit, should be accomplished with minimum manual manipulation.

2. The collection process should not require the loss of significant quantities of air from the pressurized suit.

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3. The collection system should be available for instant use by the crewman, without conscious effort on his part, as the crewman may be subjected to conditions causing involuntary micturition, such as high accelerations during launch.

Urine transfer under Weightless Conditions

Fluids will not flow from a higher to a lower level in a weightless environment, but must be moved by positive displacement pumps or other means utilizing pressure differences. Fluids may be transferred directly through the air in the form of a jet, if velocities are not so high that the stream will separate into droplets, and if the fluid can be recaptured without splashing. Unless transfer distances are short, jet transfer is not suitable if the system is subjected to lateral accelerations, causing a shift in the point of impingement. Although fluids could theoretically be transferred by entrainment in an airstream, this approach is not attractive because of the additional equipment required to separate fluid from the air after recapture.

If fluid transfer involves the use of containers, the behavior of fluids under weightless conditions must be considered in their design and use. Fluids will not remain in open containers subjected to accelerations, and fluids injected into an open container will not remain within its confines. Air and fluids in closed containers cannot be separated by conventional methods of venting, as air will be found in randomly located bubbles with the fluid in contact with all wetted interior surfaces. Rotation of the container will permit venting of air along the axis of rotation, but the problem is simplified if air is not allowed to mix with fluid in the container. This may be accomplished by insertion of a flexible bladder in the container and admitting only fluid on one side of the bladder. An air vent in the opposite side will permit air to be discharged as the fluid enters.

Description and evaluation of Urine Collection Units

Urine collection techniques described in the literature are:

1. The bellows collector, a self-opening, bellows-type collapsible container with a three-way valve and an attached penis receptacle, has been described by Des Jardins, Zeff and Bambenek (Ref. 7). It is an independent portable unit requiring no outside power or vacuum source, and is reusable. In use, the container is first collapsed, the penis is inserted in the receptacle, the shutoff valve is opened, and the container is allowed to gradually open itself during micturition. Urine is removed from the container by squeezing the bellows.

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This device appears to be satisfactory with respect to convenience, compatibility, strength, and reliability. It appears, however, that loss of urine during detachment would be a problem. A significant amount of urine will remain in the tubular portion of the penis receptacle, between the penis and the valve, after micturition. Mass and volume are not given in the report and cannot be considered in the evaluation. The device, as described, is unsatisfactory with respect to cleanability, buildup of putrescible solids and odor problems.

2. The double-end bag with clamp stripper is described by Miner, et al. (Ref. 22), who considered and rejected a deflatable crimped plastic bag clamped to the penis, because difficulties were anticipated in the control of clamping pressure and in emptying the container. Another concept, the use of a central vessel built into a feces collection unit and operated by a suction bulb was discarded because of complexity, the odor problem, and possible inadequacy of the suction bulb. Their proposed urine collection system incorporates a rigid plastic penis receptacle fitted with a coated-sponge retaining ring, a rubber urinal bag open at both ends, a clamp-stripper and an end clamp. A round, diverging conical section at the neck of the bag serves as a primary penis seal. The clamp-stripper is clamped on the bag at the end of the penis following micturition, and is also utilized to strip urine into the water recovery unit when the end clamp has been removed. Disposal after several days of use, or re-use after cold aqueous sterilization of the bag, is contemplated. The complete device, exclusive of any sterilization accessories, weighs 120 gm.

   This device is satisfactory with respect to convenience, safety and reliability. Compatibility is questionable because of individual variations in penis size and configuration. Proper sealing on the glans of the penis is questionable for the same reason, so urine leakage may be a problem. If the bag is used for any length of time without sterilization, odor and accumulation of urine solids within the bag will create problems. Single use of the bag, or the requirement for an aqueous sterilization system, will add mass and volume to the system.

3. A system employing urine collection through the wall of the inflated pressure suit has been developed by Redden (Ref. 26). Requirements for this system included urine collection with the crewman in a pressurized suit for a period of 72 hours,

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and the collection of urine samples. A commercially available gum rubber urinal is used in conjunction with a connector within the suit; a valve in the suit wall; a suit valve connector; an inlet valve; a urine collection bag with outlet, inlet and sample valves; a sample vial; and miscellaneous connecting tubing. The entire unit, including the mounting bracket, weighs 724 grams.

The system appears to be less than satisfactory in most respects. The conventional urinal allows the penis to be immersed in urine for long periods; reliability is poor because numerous small orifices and sealing surfaces may become incrusted with urine solids; cleaning of the system will be laborious; odor production could be anticipated; and mass and volume are somewhat excessive. Retention of urine during disassembly is questionable, and use of the system is rather inconvenient for the crewman.

Urine collection units fabricated by the Whirlpool Corporation prior to this study are:

1. The strap-on, or personal urinal, illustrated in Figures 4 through 7, is an adaptation of a urinal used in Mercury flights, and is suitable for use while the crewman is wearing a pressurized suit. The primary improvement is the addition of an "iris diaphragm" closure providing an adjustable penis seal. This seal is fabricated from pure natural rubber latex to minimize skin irritation. The unit may remain attached to the penis without discomfort throughout the pressurized period. A sheet-plastic, flap-type, one-way valve is provided below the closure to prevent backflow of urine when the penis is withdrawn. The attached flexible plastic bag can be sized to contain all urine excreted during the specified period. This bag may be detached from the closure and discarded after urine has been removed, or with the closure permanently attached, can be emptied and re-used after suitable disinfection. The urinal also permits a choice of methods for urine removal. The entire device may be detached from the crewman and emptied during unpressurized intervals, or a connection may be made through the suit wall to the bag, which can be emptied through a tube leading to a storage tank while the suit is pressurized. As pressure suits contemplated for future aerospace flights will not incorporate anti-G bladders, and the suit wall of air-retaining material will move away from the crewman's skin during pressurization, adequate space in the suit will be available for this type device.

   This unit provides a simple, low-mass technique for in-suit urine collection. The iris diaphragm satisfies the anatomical and physiological requirements previously discussed.

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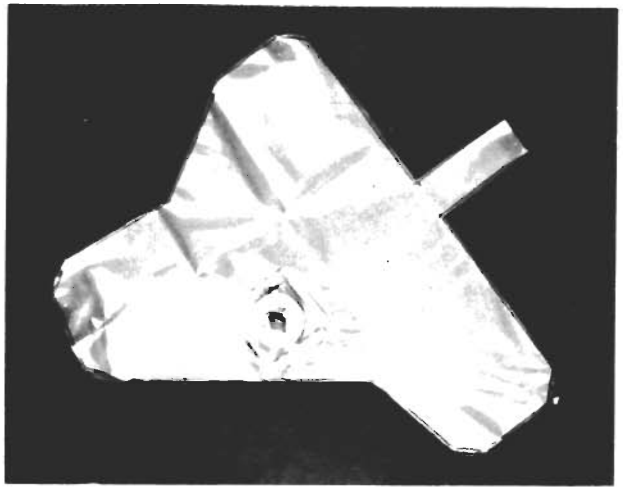

Figure 4
Personal Urinal

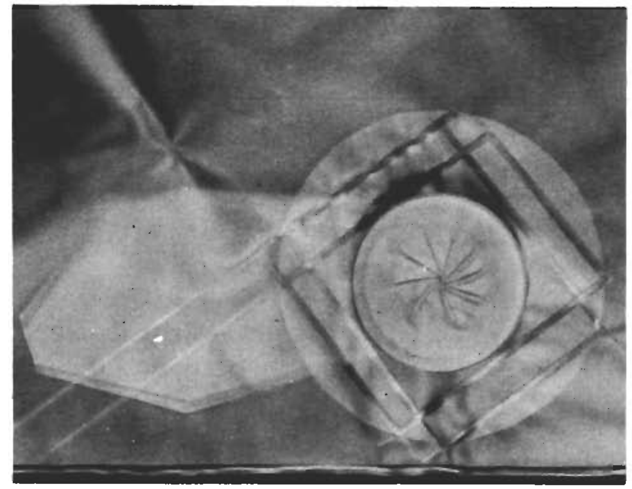

Figure 5
Iris Diaphragm-Closed Position

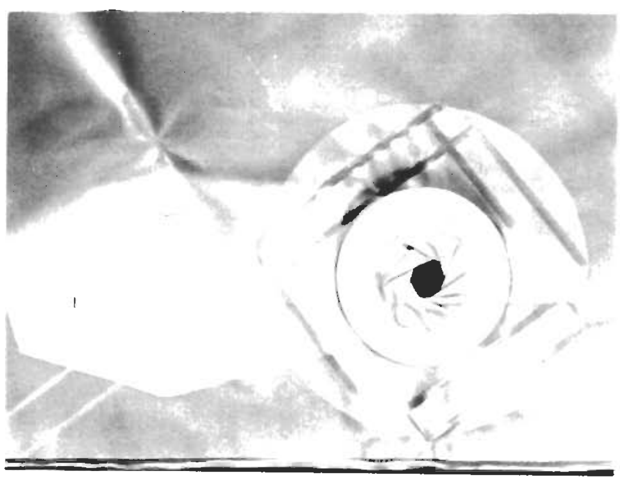

Figure 6
Iris Diaphragm-Half Open Position

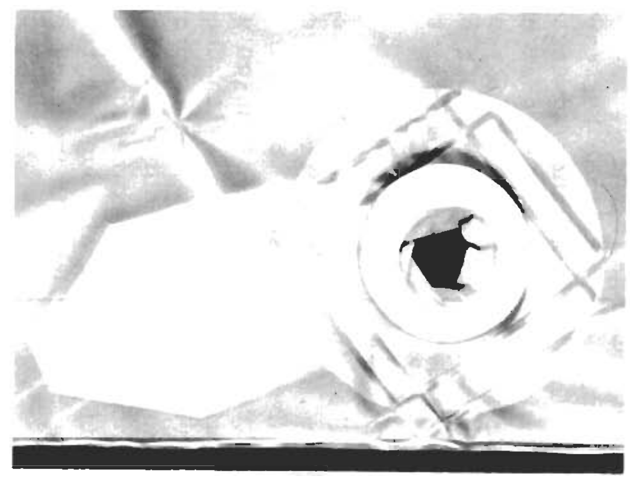

Figure 7
Iris Diaphragm-Open Position

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Convenience and safety are satisfactory. The few components involved require little maintenance and are not subject to the buildup of putrescible solids, particularly if the bag portion is disposable. Low volume is a further advantage, and odor production is not anticipated. Further development may be required to eliminate the possibility of urine loss. Reliability of the original thin plastic bag is questionable, but use of higher strength material will not affect the utility of the device.

2. The single-use urinal illustrated in Figures 8 and 9 may be used during periods when the crewman is wearing an unpressurized suit, or is in shirtsleeves. This unit is identical to the strap-on urinal with a detachable iris diaphragm closure, with the exception that a smaller flexible plastic bag is provided to contain only that urine excreted during a single micturition. After addition of disinfectant, urine may be stored in the bag if desired, although preferably it should be stripped into a bulk urine storage tank or water recovery system.

   This unit is satisfactory with respect to compatibility, convenience, safety, maintenance, odor production and solids buildup. Loss of urine may be a problem and strength of the bag may be questionable. Mass and volume of a large number of disposable bags may limit use of the device to shorter missions.

3. The centrifugal urinal (wall mounted), illustrated and described in Figure 10 is intended for use by crewmen in shirtsleeves or wearing deflated pressure suits, occupying vehicles permitting relatively free movement of the crew. It may be powered by a small electric or spring motor, or operated by a handcrank. This urinal has been operated satisfactorily in an inverted position. Consequently, no difficulties are anticipated at zero gravity. This unit will be compatible with the anatomy and physiology of the crewman as it requires no positive penis seal. It is satisfactory with respect to urine loss and escape of odors. Wall mounting reduces the convenience factor if free movement within the space vehicle is restricted. The original model, as constructed, presents problems in maintenance and reliability. Buildup of putrescible solids may cause malfunction. The unit is also larger and heavier than necessary.

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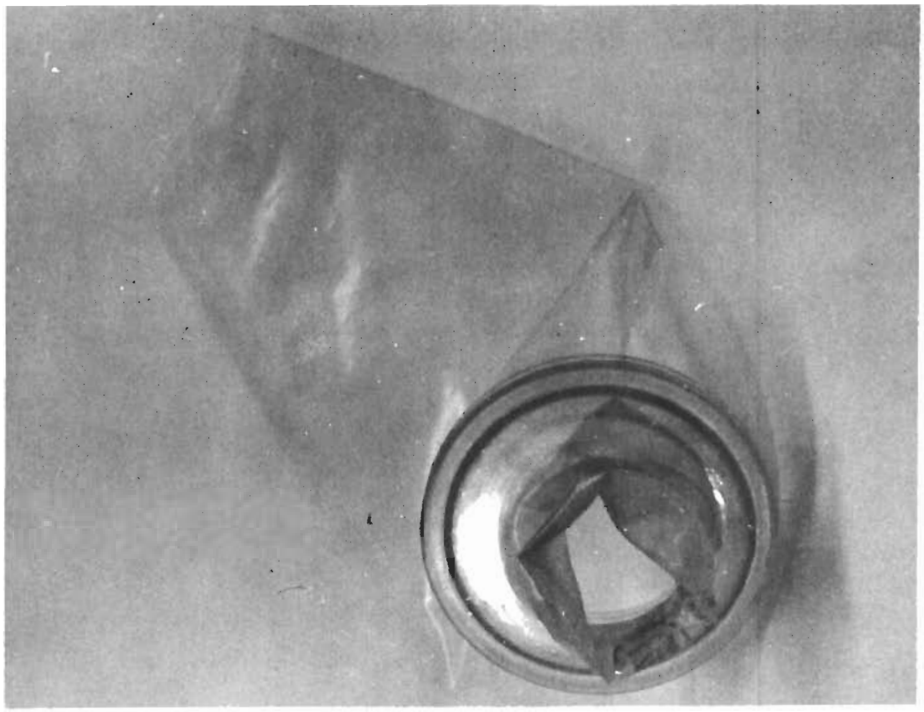

Figure 8
Urine Collection Bag
Urinal Entry Device Open

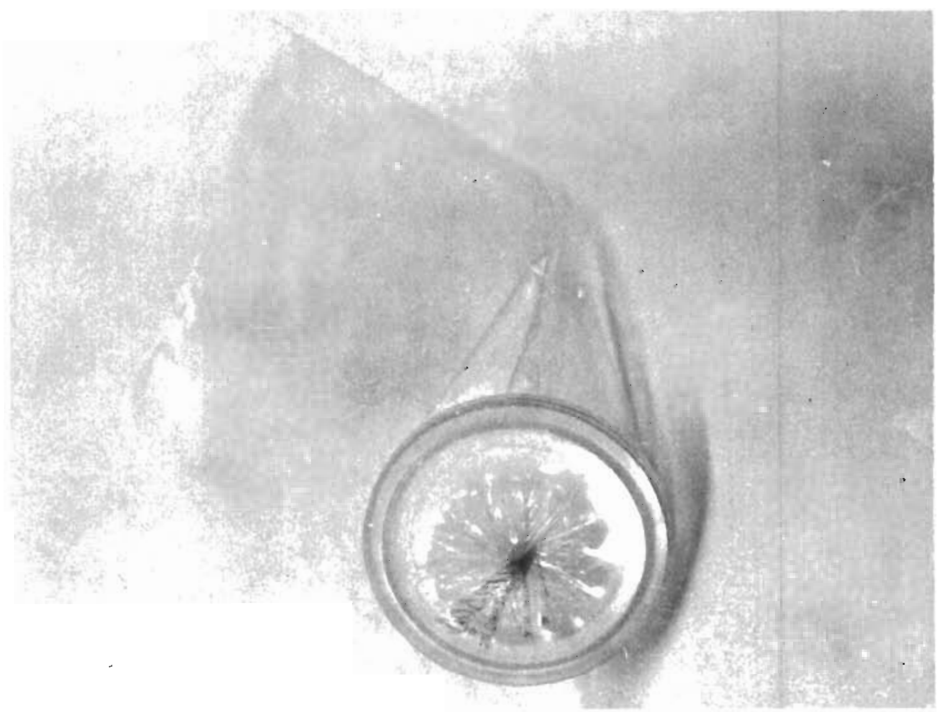

Figure 9
Urine Collection Bag
Urinal Entry Device Closed

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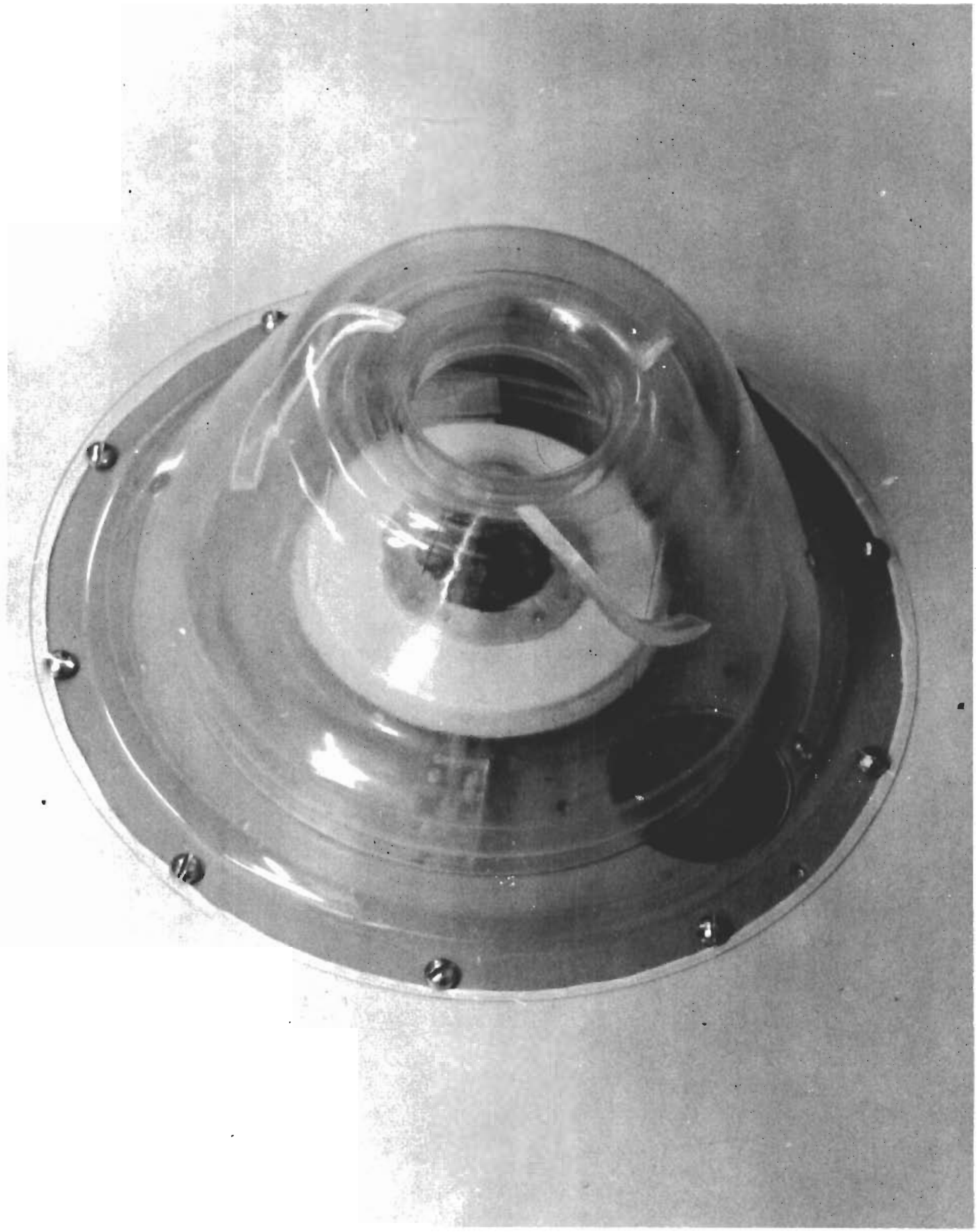

Figure 10
Centrifugal Urinal,
Wall Mounted

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Concepts proposed by the Whirlpool Corporation prior to the present study (no models fabricated) are:

1. Sponge urinals, consisting of open-cell plastic sponges enclosed in flexible plastic bags with suitable penis receptacles attached, could be used for collection of urine under weightless conditions. No special penis seal or one-way valve would be required, as urine is retained by the sponge. Pressure applied to the bag would force its contents into the storage tank. Two versions of this concept (rolled tube and "accordion") were designed. Sponge urinals would be satisfactory with respect to compatibility, urine loss, safety, strength and reliability. Production of odor caused by buildup of putrescible solids could be avoided by impregnation of sponge with a suitable antimicrobic agent. The bag volume available for urine is reduced by the volume of the sponge structure, and convenience in use is questionable.

2. The indwelling catheter consists of two concentric rubber tubes with a total outside diameter of .157-inches to .260-inches (sizes F 12-20). The catheter is inserted into the urethra until the leading end enters the bladder. Air forced into the outer tube expands a small balloon below the tip of the catheter, retaining the device in position until the balloon is deflated. Attachment of the inner rubber tube to a storage tank would complete the system.

   The use of this device for urine collection in space vehicles would be completely unsatisfactory. According to Shackman and Messent (Ref. 31), use of such catheters is very often accompanied by growth of <u>S. albus</u> in the urethra. Practicing urologists find that patients retaining indwelling catheters are very prone to urinary tract infections, according to Crowell *. Such infections may be acute, with a patient proceeding from normal health to a febrile infection in 12 hours. The possibility of backflow of urine from the storage tank to the bladder would also present serious problems, and the inconvenience of insertion and difficulties in cleaning make this device one of the least attractive of those discussed.

3. Direct connection of the penis to the storage tank would be possible if the crewman may move freely about the interior of the space vehicle. Micturition would be accomplished

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*Op. cit.

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by inserting the penis into a suitable connection, equipped with a seal and one-way valve, mounted in the wall of the storage tank. If fluid pressure within the tank were less than that exerted during the act of micturition, most of the voided urine would be forced into the tank.

The technique would be questionable with regard to convenience, as the crewman is required to move to the storage tank location to micturate. Without the addition of energy in some form, it is doubtful that urine pressures exerted during the initial and final stages of micturition would be sufficient to overcome tank pressure. The disposition of this final volume of urine presents a serious problem offsetting any advantages of simplicity.

4. The use of a portable centrifugal urinal for urine collection appears to be a feasible technique after preliminary study. The device would be essentially a sophisticated centrifugal pump, driven by a hand-wound spring motor, with a penis receptacle at the inlet. A coiled, flexible plastic tube could be used to transfer urine from the outlet to the bulk urine storage tank or water reclamation system. Sanitation of the unit would be accomplished by injecting, with a dispenser, a small quantity of disinfectant into the inlet after each use. The need for an auxiliary urine transfer pump would be eliminated, and a simple valve, actuated by fluid pressure when the device is pumping urine, would prevent entry of air into the storage tank.

   If properly designed, a portable centrifugal urinal would satisfactorily meet all requirements.

Summary and Conclusions

Results of the above evaluation are summarized in Table II. It is recommended that a compact portable centrifugal urinal be designed for use by the crewman in shirtsleeves or while wearing an unpressurized suit. Compared with the next most feasible method (the single-use disposable urinal with iris diaphragm closure), the centrifugal device has the advantage of greater convenience and does not require the additional operation of stripping urine into the storage tank. Further, it removes the possibility of contact dermatitis. It is also probable that the centrifugal urinal can be designed to weigh less than a 7-day supply of disposable urinals, and certainly less than a 14-day or 30-day supply.

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TABLE II

COMPARISON OF URINE COLLECTION DEVICES

Key:

S - Satisfactory

Q - Questionable

U - Unsatisfactory

Device	Requirements: Anatomical and Physiological Compatability	Loss of Urine to Capsule Atmosphere	Convenience and Safety in Use	Strength and Reliability	Maintenance Requirements	Contamination of Atmosphere (Odor)	Buildup of Putrescible Solids	System Mass and Volume
Bellows Collector	S	Q	S	S	U	U	U	Q
Bag with Stripper	Q	Q	S	S	Q	Q	Q	Q
Coll. Through Suit Wall	U	Q	Q	U	U	U	U	U
Strap-on Urinal	S	Q	S	Q	S	S	S	S
Single-use Urinal	S	Q	S	Q	S	S	S	Q
Centrif. Urinal-Wall Mtd.	S	S	Q	Q	Q	S	Q	Q
Centrif. Urinal-Portable	S	S	S	S	S	S	S	S
Sponge Collector	S	S	Q	S	S	S	S	S
Indwelling Catheter	Q	S	Q	S	Q	S	Q	S
Direct Connection	S	Q	Q	S	S	Q	S	S

Note: No detailed comparison of the devices is shown for use while the crewman is wearing a pressurized suit, as only the collection through suit wall system, the strap-on urinal, and the indwelling catheter could be considered for this usage. This will be discussed in the section on conclusion and recommendations.

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With the crewman in a pressurized suit, it is recommended that a device similar to the strap-on urinal, designed to occupy available space within the suit, be developed for use with a urine transfer system permitting emptying of the urinal between periods of suit pressurization. This approach will be advisable because of the possibility of involuntary urination by the crewman under conditions anticipated while wearing the pressurized suit. The suggested method appears to offer advantages of greater simplicity than the concept of transferring urine outside the suit during the process of micturition. Free movement of the crewman will be possible as he is not attached to an outside collection container, and the urinal can be emptied at his convenience. The in-suit urinal could be emptied into the centrifugal urinal, thereby eliminating the requirement for two separate connections to the urine storage tank.

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Design of Units for Urine Collection and Transport

Portable Centrifugal Urinal

The centrifugal urinal, in its most simple form, is merely a modified centrifugal pump. During use, the eye of the pump is open to permit direct impingement of the urine stream at the center of the rotating impeller, which then imparts sufficient energy to the fluid to carry it through any necessary conduits to the point of storage. In the present application, the pump must develop sufficient flow capacity to accept urine at the maximum input rate, and must pump this liquid against a resistance head defined by the size and configuration of the system. Under weightless conditions, no gravity heads will be involved. Only lost head in tubing, valves, and various restrictions will be encountered. It is also necessary to minimize entrained air, energy input, mass and volume. To permit convenient use in rather cramped quarters, by crewmen in unpressurized suits or shirtsleeves, the device must be easily grasped and operated, preferably in one hand.

At the time the centrifugal urinal was designed, little information was available regarding maximum urine flow rates and total volumes excreted during a single micturition. Based on rather limited tests on laboratory staff members, it was concluded that a maximum flow rate of 21.7 ml per second, and a maximum volume of 325 ml per micturition, would be reasonable values. Later investigations, however, at both Wright-Patterson AFB and our laboratories, proved these values to be rather low. Present design criteria for urine collection devices include maximum flow rates as high as 45 ml per second, with volumes ranging up to 800 or 900 ml per micturition. By the time this information was available, hardware had already been delivered under the present contract and modifications were not possible.

Conventional centrifugal pump theory cannot be applied directly to a device of this type, primarily because of the open pump eye and large variations in urine flow rate from beginning to end of each micturition. It was necessary, therefore, to determine impeller characteristics, rotational speeds, and various dimensions by experimental procedures. The apparatus described below was constructed to permit determination of acceptable urinal design with a minimum expenditure of time and effort.

A transparent plastic pump housing, incorporating a shaft seal and bearing, was fabricated. A number of housing inserts were prepared, so that clearance around the impeller could be varied. Different outlet configurations could also be provided by selection of proper inserts. Impellers of various types were also constructed. The pump housing was mounted, with impeller axis vertical, on a test stand, and was powered by a universal motor controlled through a variable rheostat to permit rotational speed variation. A "micturition simulator" was mounted above the housing. It was designed to discharge 325 ml of

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colored fluid, compounded to simulate urine characteristics, into the pump in 15 seconds. The micturition simulator was a vertically-mounted cylinder of transparent plastic, containing a spring-loaded piston to force this fluid through a calibrated nozzle into the pump. A hand-wheel and ball-bearing screw were provided to retract the piston to a latched position when the cylinder was being filled with fluid. The test stand was also equipped with a voltmeter, wattmeter, and a small bladder-equipped spherical vessel connected to the pump by plastic tubing. A stroboscopic light was used to determine impeller speeds and to examine flow patterns within the pump housing. Vaneless impellers, or "spinning discs", were first investigated, on the assumption that air entrainment would be reduced if vanes were omitted. Flat discs, as well as impellers with concave conical upper surfaces were tested. A 2-inch diameter dished impeller, with a 160° included angle, was superior to others tested. Experimentation with housing design indicated that an involute configuration around the impeller did not improve performance, as is the case in conventional centrifugal pumps. It was also necessary to provide a check valve in the line beyond the pump outlet to prevent surging and to reduce air entrainment. The pump with a vaneless impeller, as described above, pumped fluid to a height of four feet, with a flow rate of 21.7 ml per second and the impeller rotating at 4500 rpm.

Motion pictures, at normal and high speeds, were made of the pump mounted on the test stand and operated under normal gravity conditions. The test stand, with the addition of an accelerometer, and with the pump operating, was photographed during a zero gravity flight at Wright-Patterson AFB, where similar motion pictures were taken. Although this flight proved the system will operate without loss of fluid under weightless conditions, quality of photography was not adequate to permit any definite conclusions regarding differences in flow characteristics under normal and zero gravity conditions.

Because elimination of electrical power requirements for operation of the urine collection system was preferable, an investigation of alternate power sources was conducted. The concept of a battery-operated, direct-current motor was discarded in favor of a hand-wound spring motor, because of unfavorable tradeoff when weight and volume of spare batteries, or rechargeable batteries with a charging device, were considered. A commercially available spring-wound shaver was modified for use in the final model of the centrifugal urinal. In an attempt to match power output of the spring motor to power requirements of the pump, further experimentation on the test stand showed that, with proper clearances in the pump housing, the addition of six backward-curved vanes to the impeller reduced power input approximately 65%. The required pumping rate could then be obtained at an impeller speed of 1900 rpm with no increase in air entrainment. It was also

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necessary to redesign the check valve to open at very low pressure differentials with minimum hydraulic losses. This valve is described below. The high frictional losses of commercially available shaft seals made them unacceptable for this application, so a special low-drag face-type seal was developed. A ball bearing was also utilized to further reduce frictional losses. A final modification of the spring motor, the substitution of a heavier clockspring and a lower ratio in the gear train, resulted in a design that will meet originally assumed requirements under weightless conditions with an impeller speed of 1000 rpm. As previously stated, however, the centrifugal urinal does not satisfactorily handle the infrequent high-rate, high volume micturition, particularly when it is operated at normal gravity, and must pump against any significant gravity head.

The design was completed by addition of an entry cone, arranged to slide in and out of the housing, the axial movement limited by a wire ring detent operating in grooves in the housing and cone. In the down position, a rubber seal at the lower end of the cone is forced into contact with the impeller surface, preventing escape of any fluid that may remain in the housing after use. A cap or cover, provided to close the open end of the entry cone during storage, is secured to the pump housing by means of a lanyard of plastic covered stainless steel wire. The centrifugal urinal is illustrated in Figures 11 and 12.

Check Valve

A check valve, located in the discharge line from the centrifugal urinal, improved system operation by eliminating surging of urine back into the urinal as micturition rates diminish. It also served to reduce entrainment of air with the urine.

A spring-loaded disc-check valve was initially utilized, and this functioned satisfactorily on the test board with the urinal powered by an electric motor. When the urinal was driven by the spring motor, in the final design, limited power input made it necessary to reduce frictional losses in the check valve. This was accomplished by the replacement of the disc and spring by a hollow conical element molded of thin silicone rubber. The extended tail of this element was held in place by a perforated retainer disc. With fluid flow in the proper direction, the element tends to collapse, allowing passage of fluid. With backflow, however, the skirt of the element expands against the housing, checking flow. This valve will function satisfactorily at zero gravity under orbiting conditions, although excessive back pressure will distort the element and permit leakage.

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Figure 11
Portable Centrifugal Urinal

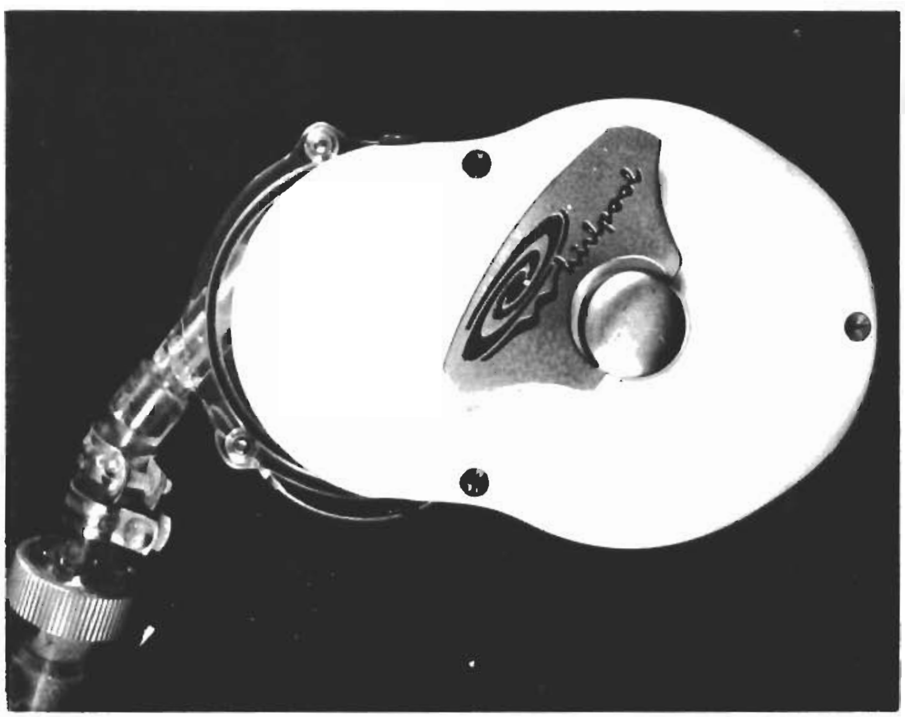

Figure 12
Portable Centrifugal Urinal - Rear View

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Disinfectant Dispenser

Although other means are utilized to stabilize collected urine during storage, it was considered advisable to flush the centrifugal urinal after each use with a small quantity of disinfectant solution. This procedure will not only prevent possible cross-infection between users, but will prevent possible growth of microorganisms on the interior surfaces of the urinal.

The dispenser was designed on the general principle utilized in bottles commonly used to spray window cleaning solutions and other household products. To permit use under weightless conditions, several design alterations were necessary. The bottle was molded of transparent plastic to eliminate the hazards inherent with glass containers, and was made in two flanged halves. Each half is cylindrical with one hemispherical end. A diaphragm, shaped to conform to the interior surface of a bottle half, and provided with a beaded flange to mate with a groove in the threaded flange of the lower half, was molded of neoprene latex. A knurled coupling nut is used to clamp the two halves together with the diaphragm in place. An air vent is centered at the end of the lower half. Air entering this vent, to replace ejected fluid, is prevented by the diaphragm from contacting the fluid. As it is not feasible to utilize gravity-dependent ball-check valves in the dispensing head, sleeve-type check valves were designed. The final variations from conventional dispenser design involved changing the direction of the nozzle from radial to axial, and designing a nozzle orifice to produce a thin stream, rather than a spray pattern.

The dispenser is sized to contain sufficient disinfectant to meet the needs of a 3-man crew on a 14-day mission. One stroke of the plunger will dispense one ml of disinfectant, which is adequate for disinfecting the urinal after each use. The dispenser must be charged with solution before each mission. This is accomplished by separating the two halves, forcing the diaphragm against the lower half, inserting a disinfectant tablet, and assembling the halves. The dispensing head may then be removed, the dispenser filled completely with distilled water, and the head replaced. Depressing the plunger a few times will expel any air in the head, and after the captive nozzle cap is in place, the unit is ready for use. It is visualized that the dispenser will be mounted in a clamp, directly above the centrifugal urinal in its storage position. It will then be possible to dispense disinfectant by the use of one hand only, without danger of misdirecting the stream. The dispenser is illustrated in Figure 13.

In-Suit Urinal

The in-suit urinal is provided to permit the collection of urine during the period the crewman is wearing a pressurized suit. The device is a flexible plastic bag of proper size to contain all urine excreted during an eight-hour period. It is equipped with a penis seal, flexible

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Figure 13
Disinfectant Dispenser

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plastic flapper valve to prevent backflow of urine, and a flat outlet tube to facilitate discharging the contents into the centrifugal urinal.

The penis seal, of the "iris diaphragm" type, is constructed of two concentric rigid plastic rings over which the beaded ends of a latex sleeve are secured. The smaller diameter ring is brought within the plane of the larger ring, which is constrained to rotate around it. This action twists the latex sleeve, closing the opening, much as the neck of a rubber balloon may be twisted to prevent the escape of air. Before micturition, the user rotates the outer ring until a fluid-tight seal is effected, regardless of anatomical dimensional variations. As the ring may be rotated by grasping it through the wall of the pressure suit, the seal may be adjusted as required. The urine bag may be discarded after a single use,and the seal detached and used with a clean bag for the next micturition, if desired. A semirigid collar, cemented to the urine bag, can be snapped into a groove in the inner seal ring to reassemble the unit.

The outlet tube on the urinal is formed of flexible plastic film, and is so designed that it may be repeatedly folded on itself, and the folded portion tucked into an attached pouch. This procedure seals the tube during the period the urinal is taped to the leg of the user. A rigid outlet tube was ruled out because of the possibility of discomfort to the user.

Although the in-suit urinal may be emptied while attached to the crewman, usual procedure after suit depressurization would involve tightening the seal, as the penis is withdrawn, to prevent escape of urine, and removing the urinal through the zippered suit opening. The outlet tube may then be unfolded while holding the base of the tube closed between the thumb and forefinger. An adapter is provided to facilitate transfer of urine to the centrifugal urinal. The tubular end of the adapter is forced into the in-suit urinal outlet tube, and the opposite end of the adapter is snapped over the entry cone of the centrifugal urinal. Hand pressure on the urine bag is utilized to force its contents into the rotating centrifugal urinal. After urine is stripped from the bag and outlet tube with the fingers, the adapter may be removed and the outlet tube refolded and placed in the pouch. The in-suit urinal may then be stored for future use or discarded after removal of the iris diaphragm. If reuse of the urinal is contemplated, a small tablet of disinfectant should be inserted to prevent putrefaction of residual urine. The unit is illustrated in Figures 14 through 16.

Urine Transport System

The balance of the urine collection and transport system includes a length of coiled Tygon tubing, 3/8-inch inside diameter, leading from

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Figure 14
In-suit Urinal
Outlet Tube Closed

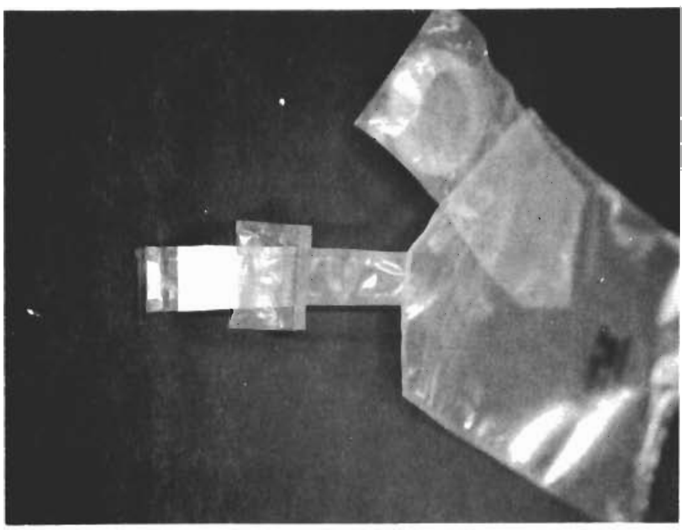

Figure 15
In-suit Urinal
Outlet Tube Unfolded

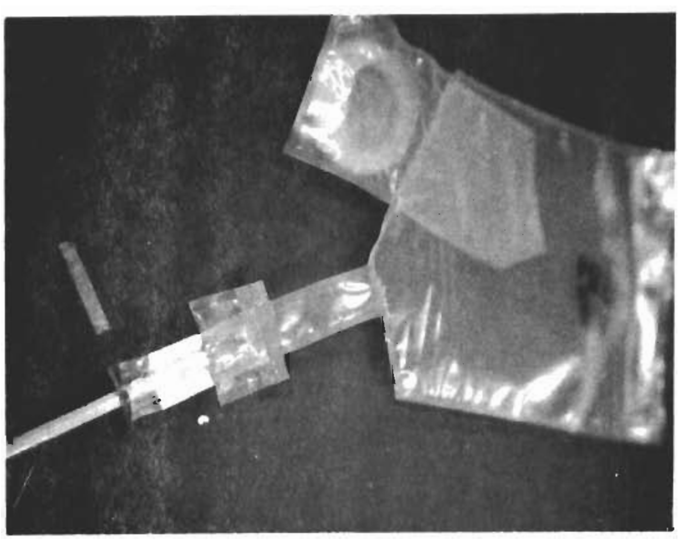

Figure 16
In-suit Urinal
Insertion of Adapter

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the check valve to a plug valve, and a short length of tubing from the plug valve to the urine storage tank. The plug valve is utilized to direct urine flow from the urinal to the tank, or from the tank to urine reclamation equipment when tank is discharged. Hose clamps are used to secure tubing at connection points.

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SECTION III

DEFECATION AND FECES COLLECTION

Biological Aspects

Anatomy of the lower Digestive System

Partially digested food leaves the stomach through the pyloric sphincter and enters the upper end of the small intestine, which is divided into three portions. The upper one-third is the duodenum, the central portion is the jejunum, and the lower part is known as the ileum. Various phases of digestion and nutrient absorption are completed in the small intestine. Water, with undigested or indigestible material, passes through the ileocolic valve into the caecum and eventually into the large intestine (colon). The ileocolic valve consists of a sphincter-like muscle surrounding a double-folded valve structure that allows free passage of material from the ileum to the large intestine, but prevents movement in the opposite direction. The colon is divided into five segments. Adjacent to the ileocolic valve is the ascending colon, followed in order by the transverse, descending and sigmoid colons. The sigmoid empties into the rectum which terminates at the anal opening. A schematic drawing of the lower digestive tract is shown in Figure 17.

Physiology of Defecation and Colonic Movement

One function of the colon is the extraction of water from undigested residue, accomplished by a series of movements taking place principally in the upper portions of the colon. These motions essentially knead the residue to expose more surface for water absorption and move it slowly along the tract by peristalsis. The other function of the colon is to form residues into fecal masses and propel them analward for later evacuation. This is accomplished by simultaneous contraction of rather large areas of the lower colon, rather than by true peristaltic movement, which sweeps the residue through the colon and empties it into the rectum. This occurs at widely separated intervals and usually is stimulated by eating, drinking, or perception of food aromas. The desire to defecate is experienced when fecal matter enters the rectum which normally is empty. The desire may also be intiated voluntarily by closing the glottis and violently attempting to exhale. This action, known as the valsalva maneuver, may raise intra-abdominal pressure as much as 200 mm of mercury, according to Best and Taylor (Ref. 2).

The act of defecation is begun by assuming a squatting position, voluntarily relaxing the external anal sphincter, and usually straining to increase abdominal pressure by means of the valsalva maneuver. These actions, together with stimuli from the distended rectum, initiate peristaltic or mass movement throughout the entire colon and the remainder of residue is carried into the rectum for evacuation. The

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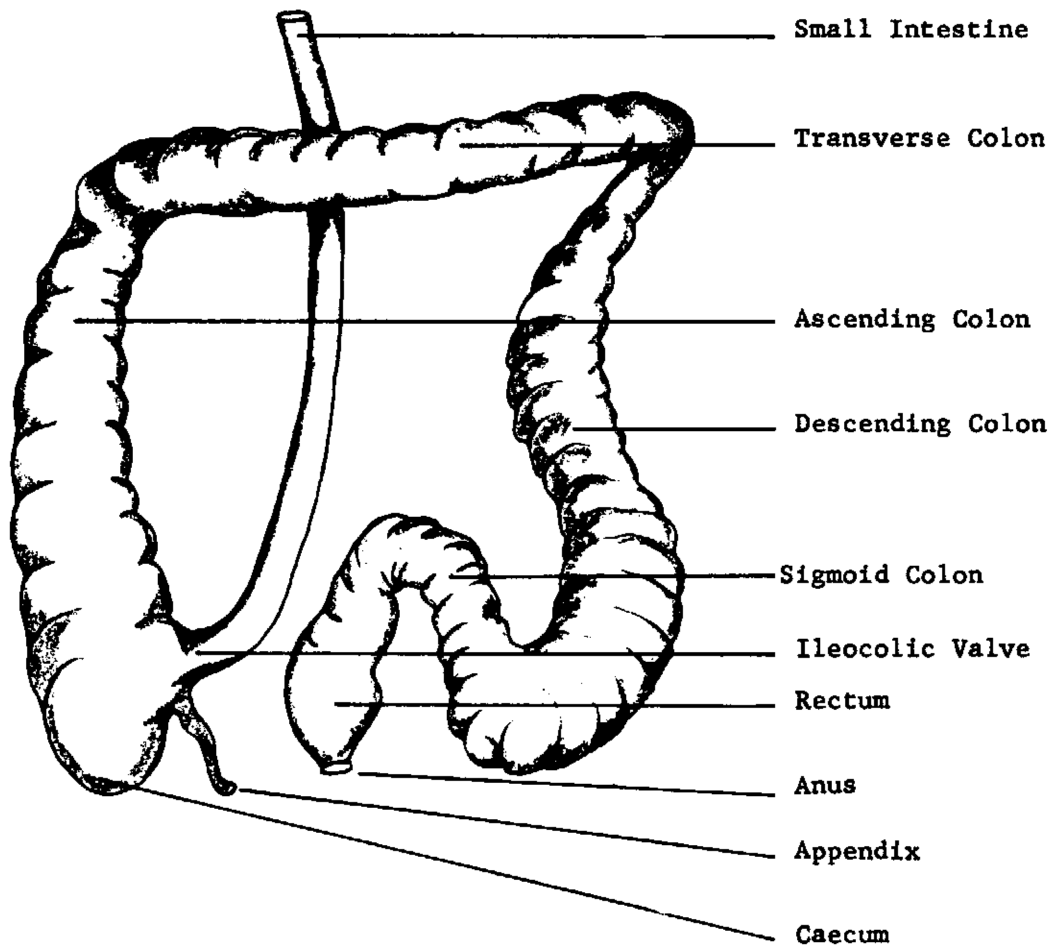

Figure 17
Schematic Drawing of Lower Digestive Tract

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final act of defecation is accomplished by contraction of the longitudinal muscles of the lower colon and rectum, according to Best and Taylor. The strength of contraction and pressure exerted on the feces increases from the colon to the rectum. Highest pressures are reached nearest the anus, and are of considerable magnitude, usually well above those developed in the bladder during micturition, according to Crowell *.

Feces, therefore, are not drawn from the body by gravity but are expelled by force. They will, consequently, be evacuated with velocity and direction. Experiments conducted in the Whirlpool Corporation laboratories have shown that a man, literally "standing on his head", can defecate into a fecal matter collection device against the force of gravity. The health and physical condition of the subject, as well as the consistency of the fecal matter, will influence the magnitude of expelling forces. These forces, however, are not dissipated in opening the anal sphincters, which are relaxed and open prior to actual evacuation of the feces.

It is commonly observed that average intervals between defecations vary widely with different individuals. In the same individual, interval variations may result from changes in diet, type of physical activity, and other factors. These variations normally have no adverse effect upon the health of the individual until periods between defecations become abnormally long and a condition known as constipation results. Impairment of performance, mental attitude, and health in general may then occur. Complete cessation of defecation will eventually result in death. Almy (Ref. 1) observed that constipation can result from disturbance of the colonic motility effecting defecation by an emotional reaction to life stresses. He found that emotional effects caused diminished gastrocolic reflexes (mass peristalsis of the colon) and increased segmental contraction of the colon, and that even temporary alteration of the habits of daily life could affect defecation. Best and Taylor (Ref. 2) state that no other part of the digestive system is so profoundly affected by emotional disturbance as is the large intestine. Feelings of anger, guilt, resentment and hostility cause hyperfunctioning of the colon. Fear causes relaxation of the colon.

A common cause of constipation is neglect of the desire to defecate. This desire is felt when the volume of rectal contents is increased by 15 to 25 ml, and if the desire is ignored, the sensory mechanism will adapt to the new pressure until the volume has again increased by a like amount. If the cycle is repeated for a period of sufficient length, the irritability of the rectum is lost and no further desire is experienced. On the other hand, defecation can become a conditioned reflex independent of the rectal stimulus if subjects are properly trained to defecate on schedule. Munro (Ref. 23) reported that a significant number of patients, paralyzed below the waist, could be trained to defecate successfully if a conditioned reflex were maintained.

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*op. cit.

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Microbial Flora of the Feces and Intestinal Tract

Unlike the urinary system, the digestive tract is richly supplied with microorganisms. The relatively small number of organisms present in the small intestine are largely fermentive in metabolism, have some digestive effect, and serve the body by synthesizing certain vitamins. Organisms, primarily putrefactive bacteria, are abundant in the large intestine, and appear in great profusion in evacuated feces. Contrary to common opinion, the most abundant species in the normal fecal flora is not E. coli. The work of Eggerth and Gagnon (Ref. 8), Lewis and Rettger (Ref. 18), Zubrzycki and Spaulding (Ref. 36) and others proved that anaerobic bacteria of the genus Bacteroides outnumber all other types. Bacteroides melaninogenicus was the most frequently isolated species. Zubrzycki and Spaulding found this to be true in 80 to 90% of 150 fecal samples examined. They found the following average bacterial counts:

Organism	Cells per Gram
Anaerobic (primarily Bacteroides)	1×10^9
Coliform	1×10^8
Entercocci	1×10^8
Spore forming bacteria	1×10^4
Staphylococci	1×10^2
Yeasts	1×10^2

Organisms of the genera Pseudomonas, Proteus, Clostridium and non-specific lactose fermenting organisms were present in about 20% of the samples.

Zubrzycki and Spaulding suggest that a floral equilibrium exists in the normal intestinal tract. The introduction of new species, particularly pathogens, is resisted because the overwhelming mass of existing flora crowds out the newly introduced organism before it can gain a foothold in the intestinal tract.

If feces are allowed to remain in contact with the human skin for appreciable periods of time, growth of putrefactive organisms, such as Proteus vulgaris, will produce ammonia. A typical ammonia dermatitis may result. Other toxic compounds, such as skatole, are also present in fecal matter.

Volume and Composition of Feces

The volume of fecal matter excreted by adults varies widely with individuals, and the same individual may excrete varying quantities

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from time to time because of variations in health, diet, water intake, and activity levels. Consequently, the results of investigations by workers in this field are not uniform. Representative data are summarized below:

Feces Production (gm/day)	Comments	Source
75 - 170	Mixed diet	Best and Taylor (Ref. 2)
135 average	-	Evans (Ref. 9)
100 - 150 (102.8 av.)	-	Ingram (Ref. 16)
110 - 170	Mixed diet	Hawk, Oser, and Summerson (Ref. 14)
350 max.	Diet of raw vegetables	Hawk, Oser, and Summerson (Ref. 14)

A similar lack of agreement among authorities exists in statements regarding the influence of starvation on feces production. It becomes apparent, therefore, that reliable data on the anticipated volume of fecal matter produced by subjects in aerospace vehicles cannot be obtained from previous studies, in which variables were not carefully controlled. Further studies will be required, preferably with subjects living under weightless conditions with strict control of diet, water intake, and other variables. Until this information is available a volume of 100 grams per man per day will be assumed as average.

The composition of normal human feces has not been thoroughly studied. Goldblith and Wick (Ref. 12), in a rather comprehensive study, found that only about 32% of the components of dry feces have been identified in any way. Contrary to popular belief, feces are not derived primarily from food, but are produced in the digestive tract from inspissated mucus, bile and other digestive secretions, desquamated epithelial cells, and bacterial cells. Bacteria may comprise as much as 50% of the dry weight of feces, according to Evans (Ref. 9), but usually approximately one-third of the dry weight, according to Best and Taylor (Ref. 2). The dry solids content of fecal matter has been reported by Ingram (Ref. 16) as 20 - 25 grams per day with a mean of 21.1% of the total; by Best and Taylor as 20% to 30% of the total; and by Hawk, Oser, and Summerson (Ref. 14) as 25 to 45 grams per day. Goldblith and Wick (Ref. 12) have prepared data on the approximate composition of major components of feces, as shown in Table III.

Ingram (Ref. 16) listed a variety of organic constituents of normal feces. As shown in Table IV, the list furnishes a qualitative guide to the presence of compounds, although no quantitation is given.

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TABLE III

COMPOSITION OF MAJOR COMPONENTS OF FECES

(Modified from Goldblith and Wick) (Ref. 12)

Component	Weight (grams)
Total bulk	150
Water	99
Dry matter	27
Fat	4.7
Protein	?
Nitrogen	1.5
Carbohydrates	?
Minerals	2.1
Sodium	0.12
Potassium	0.47
Calcium	0.64
Magnesium	0.20
Chloride	0.09
Phosphorus	0.51
Sulfur	0.31
Copper	Trace
Iron	"
Lead	"
Manganese	"
Nickel	"
Zinc	"
Arsenic	"
Vitamins	0.015
Bile Pigments	0.15

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TABLE IV

ORGANIC CONSTITUENTS OF FECES

Indole	Hydrogen
Skatole	Carbon dioxide
Paracresol	Proteoses
Paraoxyphenylpropionic acid	Peptones
Volatile fatty acids	Peptides
Hydrogen sulfide	Ammonia
Methane	Amino acids
Methyl mercaptan	Fats, free fatty acids and soaps.

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Other reports on composition and characteristics of feces are:

1. Lipids constitute 17.5% of the dry weight of feces. About 33% of this is free fatty acid and about 42% is neutral fat, (Ref. 16).

2. Lipids constitute 5 to 25% of the dry weight of feces. Neutral fats account for 7.3% of the total lipid, while free fatty acids and soaps constitute 5.6% and 4.7% respectively (Ref. 2).

3. The average pH of fresh feces ranges from 7.0 to 7.5 (Ref. 2).

4. The color of feces is due to stercobilin produced by bacterial reproduction of bile pigments. The odor is caused by indole, skatole, methyl mercaptan and usually hydrogen sulfide (Ref. 14).

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Collection of Fecal Matter

General requirements for Collection Devices

1. As with urine collection equipment, feces collectors must be compatible with the anatomy and physiology of the user. Individual anatomical variations may present greater complications in the latter case.

2. Retention of feces during defecation and handling of equipment is of primary importance. The consistency of fecal matter may vary from liquid to rather dense solids, so sealing of the collector around the anal area must be positive. Generally speaking, however, the adhesive characteristics of the feces may tend to prevent escape of the material after it has contacted collector surfaces.

3. The collection equipment must be aesthetically acceptable, comfortable and convenient to use. Because of the previously discussed effects of emotion on the defecation process, the use of objectionable equipment may be deferred until a constipation problem has developed.

4. High reliability and adequate strength are required.

5. Equipment should require little maintenance to prevent unsanitary conditions. Cleaning of surfaces soiled by fecal matter in aerospace applications may be so difficult that complete elimination is the only practical solution. All surfaces subject to soiling should be disposable or covered by disposable material.

6. Mass and volume should be minimized, considering the collection system as a whole. The choice between disposable collectors and reusable equipment must be made on the basis of trade-off studies of crew size, mission length, and other pertinent factors.

7. Contamination of the cabin atmosphere resulting from the use of feces collection equipment should be minimized. Odorous and toxic gases emanating from fresh fecal matter are more abundant and disagreeable than those produced by fresh urine. Flatus produced during defecation creates additional problems.

Transfer of Fecal Matter under Weightless Conditions

Feasible methods of transferring fecal matter from collection equipment to storage facilities in the present application are limited in number. Water entrainment, a method conventionally used on earth, is not practical because of severely limited water supplies aboard the vehicle. Entrainment of the material in an airstream within a duct may be possible, but the provision of fans and blowers will impose

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prohibitive weight and volume penalties upon the system. At the present time, it appears to be most practical to provide for the discharge of fecal matter into gas and fluid tight packages or containers at the time of defecation, and manually transport the containers to the storage facilities.

Description and Evaluation of Units for Collection of Feces

Of the developments previously reported in the literature, the following have been selected for evaluation:

1. A seat-type collector with a center drawer was described by Des Jardins, Zeff and Bambenek (Ref. 7). Their final design consisted of a frame, Fiberglas seat, and sliding drawer section. A flexible, disposable plastic container with a bottom opening was placed over an anal-sealing form to collect feces. A porous orifice ring molded to the container was compressed between the user's perineal region and the form. A vacuum reservoir, hand pump and valve were arranged in a closed circuit with the container so that flatus and feces were forced into the container during defecation. Suitable provisions were made for sealing the container and deodorizing gases before release to the cabin atmosphere. This system was developed after consideration and rejection of a magnetized absorbent clay collector; an anal insert collector, a device operated by outside vacuum; a collapsible container collector; and a reusable container collector. The final design is too large and heavy for the missions specified in the present application. It is anatomically and physiologically compatible with the user, retains feces in the collection container, and avoids atmospheric contamination. Strength and reliability are questionable, however. The device is not particularly convenient to use, and considerable maintenance is required.

2. The seat-type collector with Velcro Fastener, devised by Miner, et al. (Ref. 22), was developed as an improvement of the collector described in the previous paragraph. Before the final design was conceived, an air-jet system; a thigh-clamped seatless feces collector; and a thigh-clamped seatless device with a handle, were considered and discarded. In the final design, a Fiberglas seat houses a disposable rubber feces bag incorporated into an air suction system which includes a deodorizing canister. A spring-loaded feces bag closure mechanism, a feces bag storage container, a toilet tissue dispenser, and a hold-down belt complete the unit. This system is also too large and heavy for the present application. Improvements over the previously described device have been made, and the unit satisfies compatibility, feces retention, atmospheric contamination, and probably strength and reliability requirements. Maintenance, however, is a problem.

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Weight and volume of disposable bags are rather high, and regeneration of the deodorizing cartridge may be an unpleasant chore. It is assumed that materials required for regeneration must be carried in the vehicle, adding to the mass of the system.

Several seat-type feces-collecting devices were designed by the Whirlpool Corporation during early investigations, but these are not suitable for the present application because of excessive volume and mass. The following units are intended for use by small crews (two to three men) engaged in missions of only a few weeks duration. Low mass and volume are achieved by the use of disposable components.

1. The insertable fecal waste discharge system, illustrated and described in Figure 18, is intended to permit the collection of feces and flatus without contamination of the atmosphere. No auxiliary pumps or vacuum systems are required. This system, however, was discarded because of physiological infeasibility. The distender will be forced from the anus by the act of defecation.

2. The draw-closure fecal waste bag, an early hand-held collection device is shown in Figure 19. A feature of this unit is a "seat" that is not soiled during defecation. This concept was rejected because of questionable feces retention under conditions of weightlessness at the time of withdrawal from the anus.

3. The strap-on fecal collector, illustrated in Figures 20 and 21, is a variation of the device described above. The "seat" has been modified to conform more closely to the anal region, and is molded to fit the individual user. A shoulder strap has been added to eliminate hand holding, and the collection bags are supplied in roll form. Again, this device is questionable with regard to feces retention. The necessity for individual anal molds detracts from acceptability, and the collection bag design is not suitable.

4. The foam collar fecal collector, illustrated in Figures 22 and 23, utilizes an open-cell foam collar to effect sealing to the anal region. This concept permits escape of flatus through the collar, and the shoulder strap eliminates hand holding. This device is rather bulky and heavy, and disengagement without loss of contents is questionable under weightless conditions.

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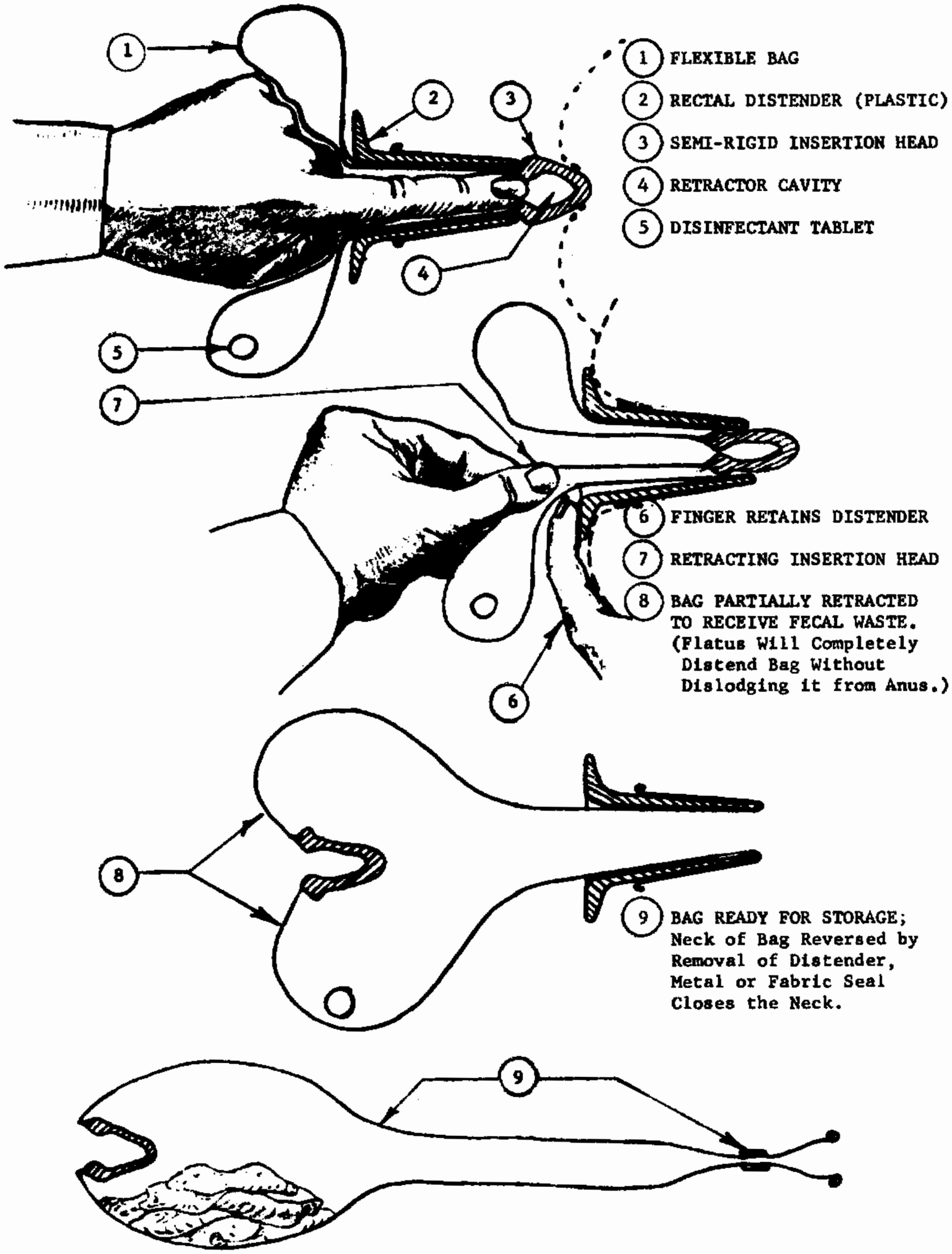

Figure 18
Insertable Fecal Waste Discharge System

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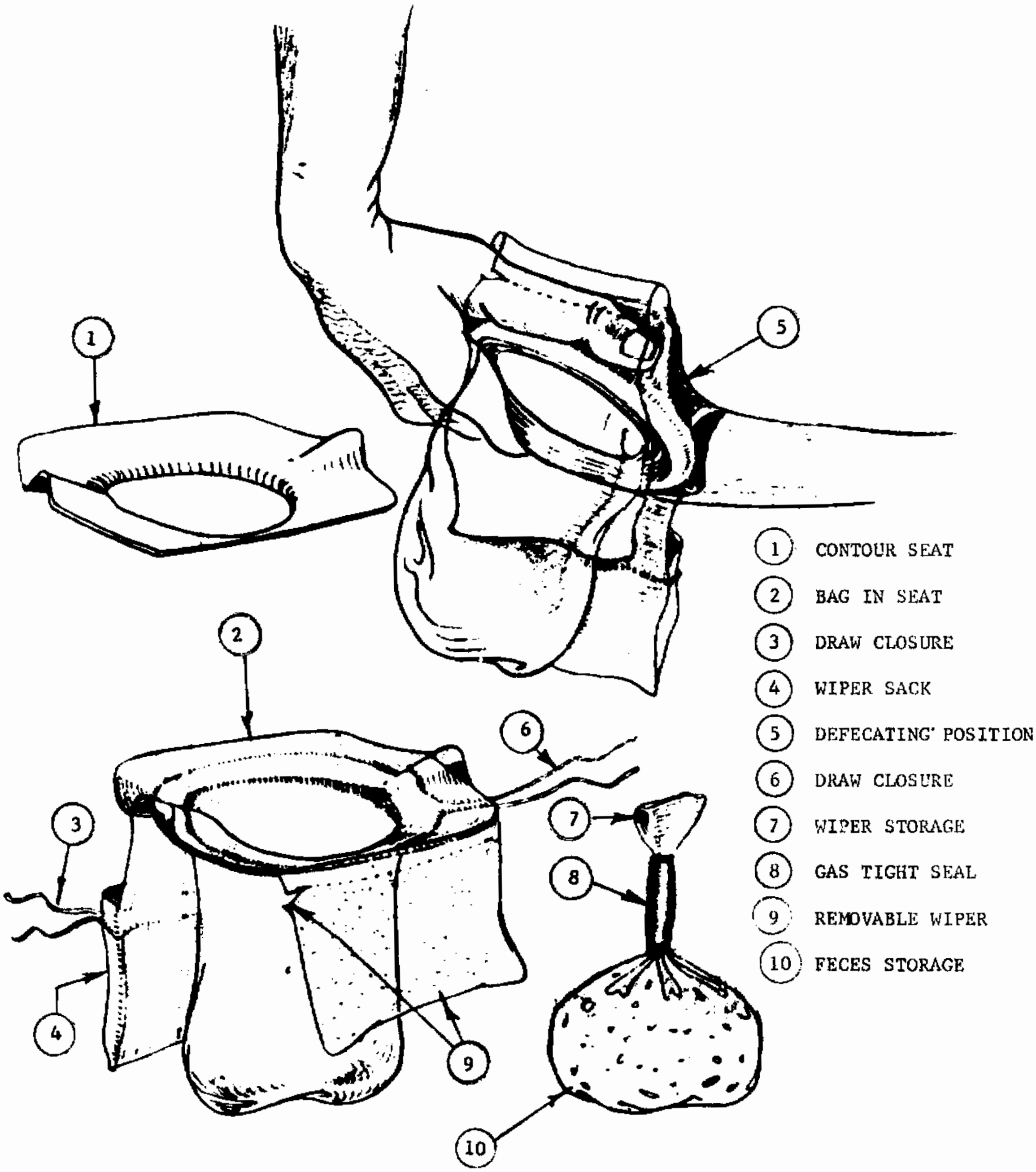

Figure 19
Draw-Closure Fecal Waste Bag

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Figure 20
Strap-on Fecal Collector

Figure 21
Strap-on Fecal Collector in Place

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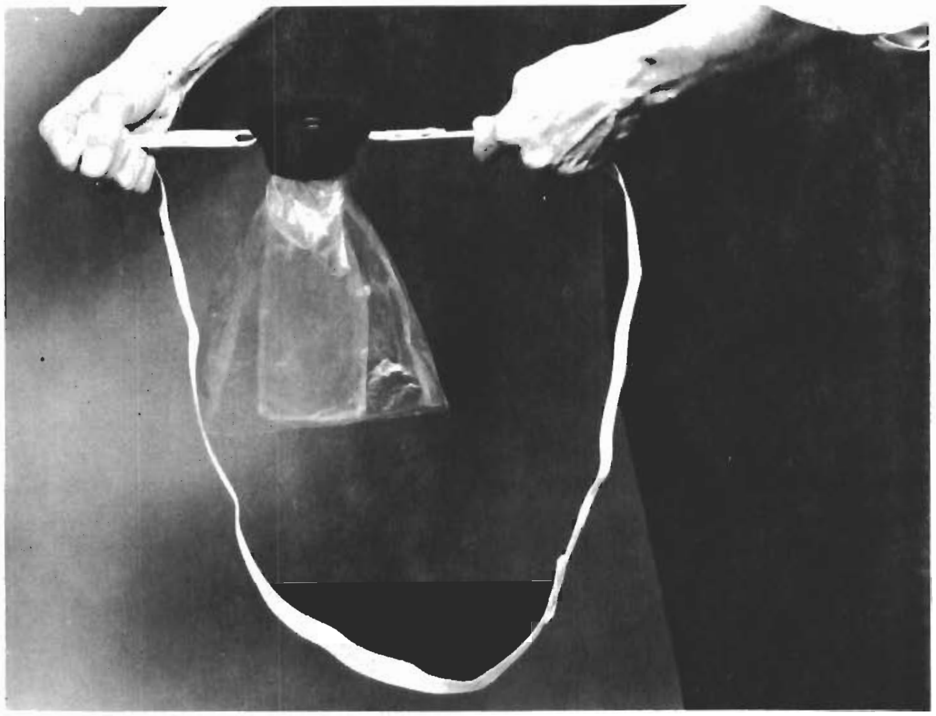

Figure 22
Foam Collar Fecal Collector

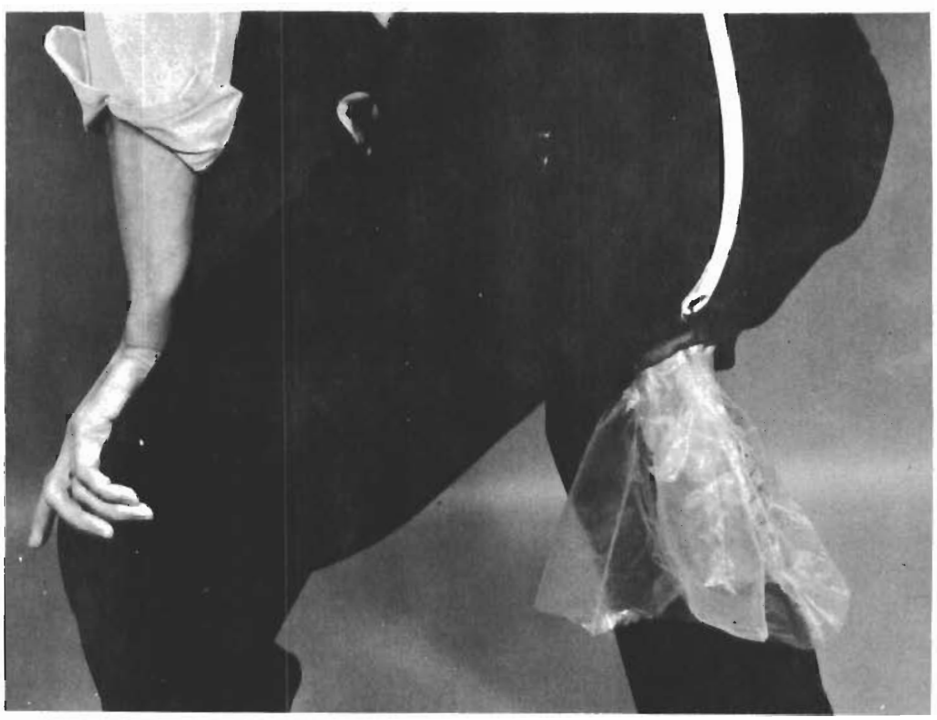

Figure 23
Foam Collar Fecal Collector in Place

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5. The glove defecator is illustrated in Figure 24. This device is the result of an extensive program of testing and modification to provide minimum mass and volume consistent with effective performance. It has, therefore, a number of advantages over previous developments. The provision of a simple method of closing the collection bag by finger action following defecation, and greater flexibility in use, contribute to feasibility for the present application. As the entire device is disposable, there are no cleaning and maintenance problems, there are no moving parts to fail, and no additional supplies are required.

Summary and Conclusions

From the above evaluation it is apparent that the seat-type collectors are unsuitable for the specified application, primarily on the basis of greater weight and volume than alternate selections. Of the previous Whirlpool developments, only the glove defecator appears to satisfy the requirements. It was concluded, therefore, that a modification of this device should be designed, incorporating certain of the features of the other concepts. For example, it is considered desirable to attach the collector to the body in some manner that will not require continued use of the hands during the defecation process.

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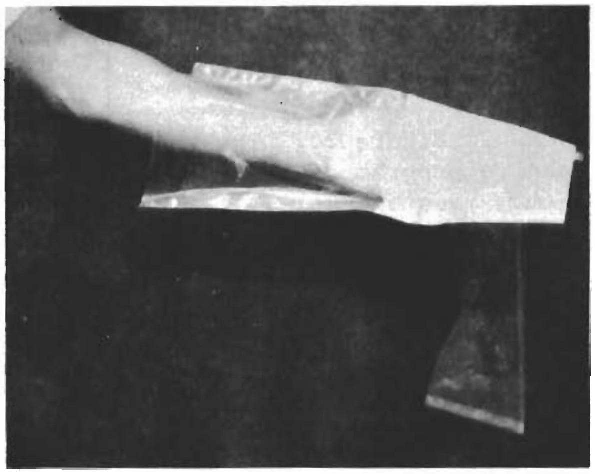
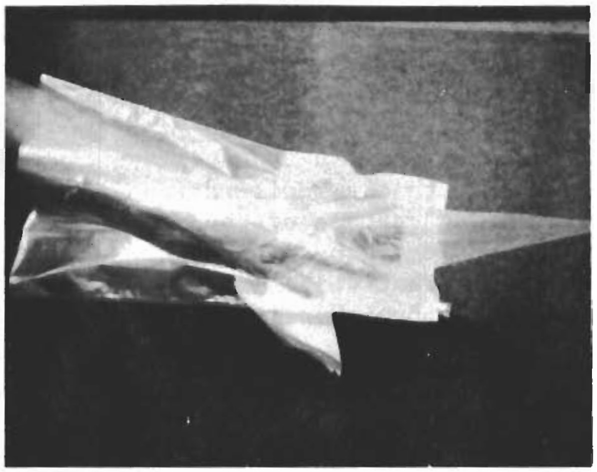
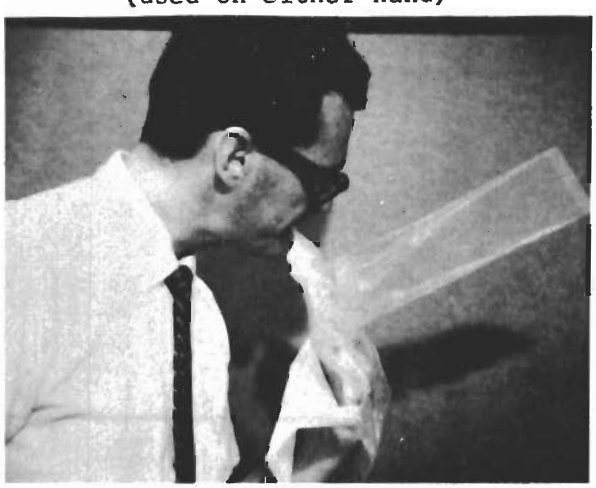


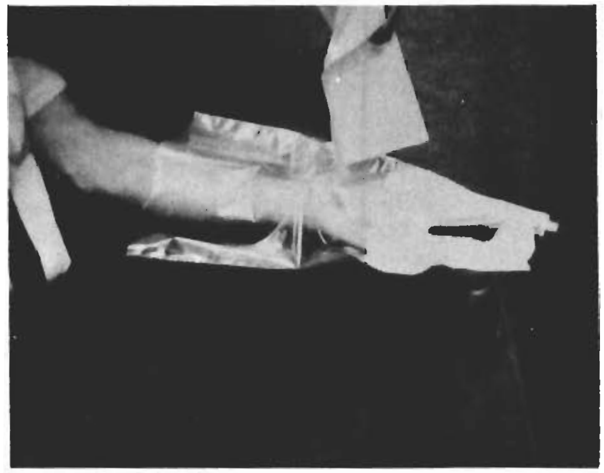
A. Top View



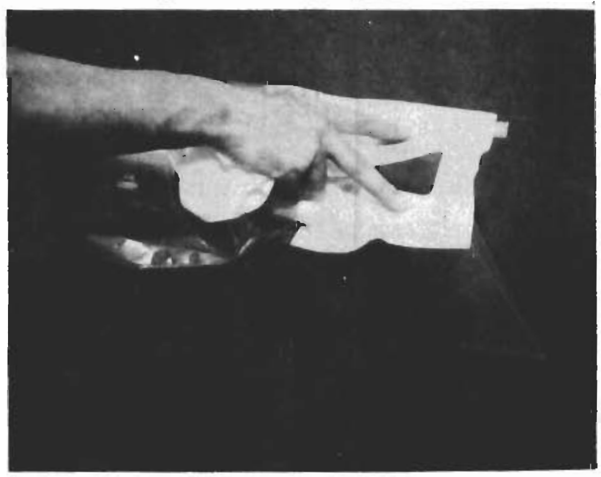
B. Finger Crotch
(used on either hand)



C. Inflation of
Area Beyond Fingers



D. Absorbent Paper



E. Triangular Opening

F. Operating Position

Figure 24
Glove Defecator

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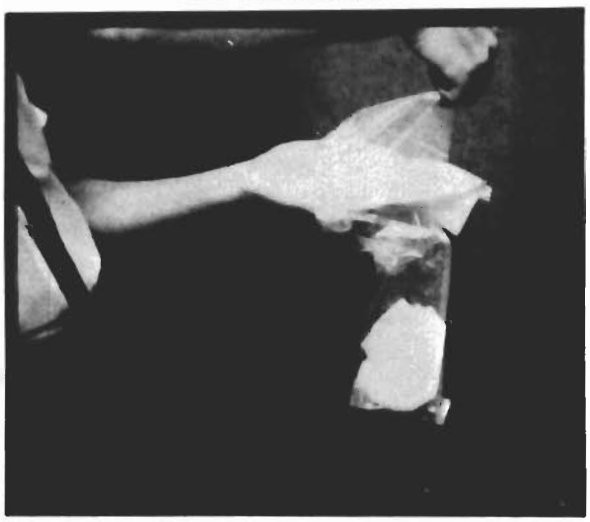
G. Deflation



H. Glove Removal

I. Germicide Pouch (water soluble)

J. Kneading Germicide Into Feces

K. Folding Bag

L. Sealing Wire

Figure 24 continued
Glove Defecator

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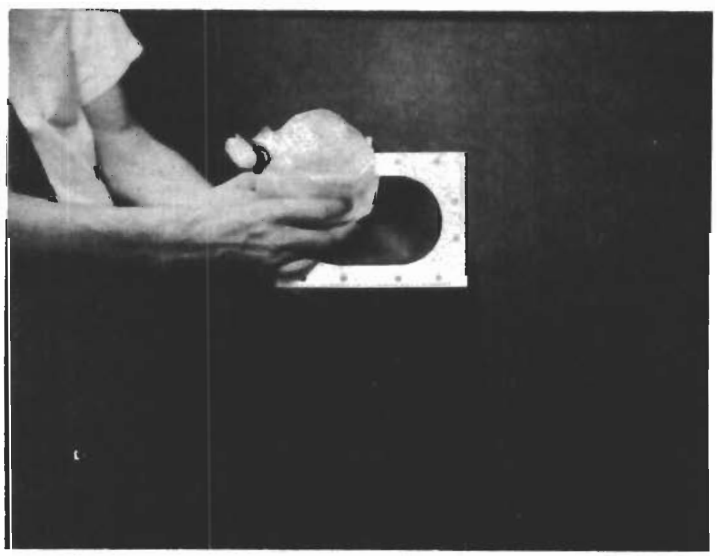
M. Air Expulsion



N. Final Configuration

Figure 24 continued
Glove Defecator

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Design of Units for Collection of Fecal Matter

Collector for Fecal Matter

The collector is constructed primarily of transparent flexible plastic film selected for low gas and moisture permeability, high strength and resistance to puncturing, combined with flexibility. The bag portion of the collector is heat sealed into a 3-3/4-inch diameter opening in the flat bib portion, which is covered with a layer of facial grade wadding to improve the comfort factor. The bib portion is reinforced by the addition of strips of polyethylene impregnated paper board (heat sealed) to enhance conformation to the body, and is provided with a pouch for the storage of toilet tissue. Tabs of Velcro are heat sealed to the ends of the bib for attachment to the harness. The pouch of disinfectant included in the bag will be described in the waste storage section of this report.

When the collector is attached to the harness, the bib opening will be oriented over the anal opening, and defecation may be initiated. Upon completion of this action, the collector is detached from the harness, and the upper portion of the bag is grasped in the hand and may be twisted to effect a seal. The body may then be cleaned with toilet tissue, which is forced into the opening of the bag portion as hand pressure is relaxed. After kneading the disinfectant into the feces, the user folds the bag into a compact package, which is tucked into the pouch formerly containing the toilet tissue. The collector is then placed in the storage compartment.

Harness for Fecal Matter Collector

The harness may be worn continuously, or may be worn only during defecation. The basic harness is a commercially available Lister's suspensory, modified by the substitution of snap fasteners for the metal buckles, and the addition of Velcro patches for the attachment of the fecal matter collector. The harness, with collector attached, is illustrated in Figures 25 and 26.

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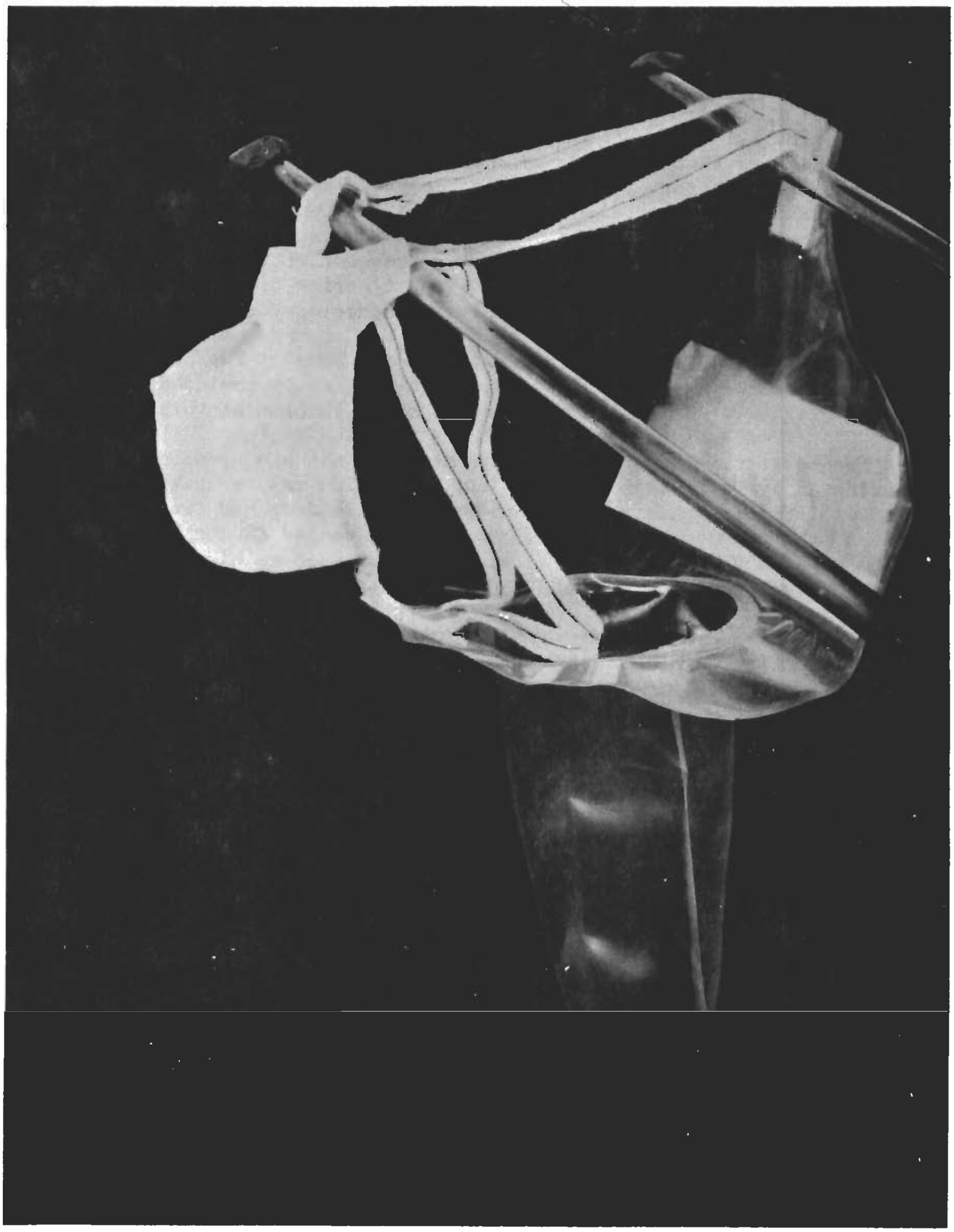

Figure 25
Fecal Matter Collector

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Figure 26
Fecal Matter Collector - in Position

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SECTION IV

STORAGE OF HUMAN WASTES

Basic Considerations

Quantities of Wastes Stored

It will be assumed that urine production will average 1500 ml per man-day, and average feces production will be 100 gm per man-day. It will also be assumed that the specific gravity of urine is 1.019, and that of fecal matter is 1.000. Total quantities of human waste generated during the specified missions are presented in Table V.

TABLE V

MASS AND VOLUME OF HUMAN WASTES PRODUCED DURING AEROSPACE MISSIONS WITH THREE-MAN CREWS

	Urine		Feces	
	Mass Kilograms (Pounds)	Volume Cubic Cm. (Cubic Ft.)	Mass Kilograms (Pounds)	Volume Cubic Cm. (Cubic Ft.)
7-Day Mission	32.102	31,500	2.100	2,100
	(70.773)	(1.112)	(4.630)	(0.074)
14-Day Mission	64.204	63,000	4.200	4,200
	(141.545)	(2.225)	(9.260)	(0.148)
30-Day Mission	137.580	135,000	9.000	9,000
	(303.312)	(4.767)	(19.842)	(0.318)

Nature of Waste Storage Problem

Storage of human wastes in an aerospace vehicle presents certain problems, particularly if solids, liquids, vapors and gases, cannot be jettisoned. For missions under 30 days with a three-man crew, it is not feasible to use bulky and heavy equipment for reclaiming useful products from human wastes. A possible exception may be production of potable water from urine, but this is not a requirement in the present

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study. Although no specific data are available on the applicable air purification system, it will be assumed that operation of the waste storage system should not impose significant additional loads on the air system. Carbon dioxide should not be produced by the storage system, and oxygen should not be consumed by stored waste. Ideally, electrical energy should not be required, and the use of solar energy should be avoided to eliminate added mass of collectors or concentrating devices.

Mass and volume of the waste storage system must be minimized, and the usual engineering requirements of adequate strength, corrosion resistance, proper function, appropriate useful life, etc., will apply in the design of system components.

The health and safety of the crew are of paramount importance in an aerospace mission. Neither should be jeopardized by the presence of human waste. It is vital that storage methods are as reliable as possible, and in the event of failure of individual components of the system, hazards should be minimized. Because of the importance of this problem, it is discussed in more detail in the following section.

Biological Waste Storage Requirements

Microorganisms, particularly bacteria, are universally present in great profusion in human feces, and will grow on the organic compounds present. Urine, although usually sterile at the point of secretion, is quickly contaminated with bacteria unless rigorous aseptic procedures are taken both in collection and storage. Such aseptic techniques could not be insured in aerospace vehicles of the present or near future.

Growth of these organisms results in odor and gas production. A health hazard is created by the proliferation of pathogenic organisms. These problems may occur simulataneously or individually.

Odor production usually results from the degradation of proteinaceous materials, amino acids or related nitrogen containing compounds. Ammonia can be produced from a variety of nitrogen compounds as can the mercaptan compounds. Most mercaptans possess very disagreeable odors even in concentrations as low as one part per billion in air. Indole and skatole, which impart the odor of feces, are produced by bacterial degradation of the amino acid tryptophan. Most of these compounds are toxic as well as malodorous, and their accumulation in the aerospace vehicle atmosphere would constitute a health hazard.

Bacterial growth in urine results in the production of carbon dioxide and ammonia gas. Bacterial degradation of feces results in the production of carbon dioxide, methane, hydrogen and small amounts

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of hydrogen sulfide. Gas production in feces begins even before evacuation, and continues rapidly for about 100 hours after defecation. At the end of this period, usually about 5 or 6 ml of gas at standard conditions have been produced per gram of feces, according to Wheaton, et al. (Ref. 33). Gas production rates generally follow a logarithmic curve; i.e., gas is produced over a very long period of time but at a constantly decreasing rate. Untreated fecal samples stored in sealed vessels normally show very little measurable pressure change after 100 hours. The ultimate pressure produced by a fecal sample sealed in a closed container is a function of the fecal weight, vessel head space and temperature. A 100-gram fecal sample sealed in a vessel with less than 100 ml of head space over the feces will rapidly develop pressures as high as 100 psi. Pressures of this magnitude cannot be tolerated in waste storage vessels unless very heavy wall sections are employed. Lighter vessels with excessive head space may be utilized to reduce maximum pressures, but a high volume penalty will be imposed.

The presence of pathogenic organisms in stored waste could pose a serious health problem to the astronauts. These organisms could be transferred to the host by contamination of the food or water supply, by inhalation, or through cuts or abrasions of the skin. The route of entry would depend somewhat on the species or organisms concerned. Pathogenic bacteria of many species could be present in body waste, especially feces. Some of the viruses such as infectious hepatitis, virus, or the Echo viruses may also appear.

Proper storage of body waste by a method which kills the microorganisms present, or renders them incapable of further growth, will prevent further odor and gas production, and eliminate the health hazard. As fecal waste contains odorous compounds in the large intestine before evacuation, however, sealed containers must be used to prevent these compounds from volatilizing into the cabin atmosphere.

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Waste Stabilization Methods

Heat

Waste may be sterilized by incineration, pyrolysis, dry heat, and wet heat. If jettisoning material from the aerospace vehicle is prohibited, incineration and pyrolysis are eliminated from serious consideration. Roth, Wheaton, and Morris (Ref. 27) have discussed the use of dry and wet heat as stabilization methods, and have calculated that 102,000 cal are required to sterilize 1 kg of waste by wet heat, and 477,000 cal to stabilize the same amount of waste by dry heat. Zeff, et al. (Ref. 35) have calculated minimum mass penalties for solar and electrically heated waste storage units. For a 14-day mission with a three man crew, they estimate a mass penalty of 2.5 kg for the solar unit, and over 12 kg for the electrical unit. Heat stabilization, as Roth, et al. point out, has the serious disadvantage that aseptic storage after treatment is required. Heat produced by the process must be dissipated by means adding further mass penalties. A further problem lies in the difficulty of heating liquids at zero gravity in the absence of heat transfer by free convection.

Cooling

The preservation of wastes by cooling below $0^{\circ}C$ has been discussed by Roth, et al. (Ref. 27). They report that 81,300 cal are required to freeze 1 kg of waste. The mass penalty for radiation cooling is reported by Zeff, et al. (Ref. 35) to be 0.68 kg for a 14-day three-man mission. For a thermoelectrically cooled unit, the penalty is approximately 12.0 kg. The major disadvantages of freezing as a waste storage method are the requirement for maintaining the waste at a low temperature to prevent putrefaction, and the serious consequences that would result in the event of malfunction of equipment.

Desiccation

Although Zeff, et al. (Ref. 35) concluded that a freeze-drying type low temperature unit was the most promising of the methods studied, venting of water vapor to space is required. Such units will not be acceptable for this reason, and desiccation at higher temperatures requires excessive power. Chemical desiccation of human wastes is also not feasible because of the large quantities of desiccant requir ed. Based on data provided by Roth, et al. (Ref. 27), the 150.8 pounds of waste (urine and feces) produced on a 14-day mission with a three-man crew will require over 600 pounds of Molecular Sieve 4-A for complete dehydration. Almost 40 pounds will be required for feces alone. Desiccated waste, in addition, may be hazardous to the crew if containers are accidentally ruptured. As low temperature desiccation will not kill certain pathogenic bacteria, the dry powder, released to the cabin atmosphere where it will be inhaled, will be the source of viable organism growth in the respiratory tract.

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Filtration

The use of microbiological membrane filters, such as Millipore or Gelman types, has been recommended by Sandage (Ref. 28) for waste sterilization in aerospace systems. The waste must be relatively clear water or the small pore filters required will clog very rapidly and require frequent replacement. Solid wastes such as feces could not be filtered. Aseptic techniques are required in filter replacement, or a device must be available to sterilize the assembled filtration equipment, increasing weight and volume penalties. Filtration would serve only as a method for separating urine and microorganisms. Means would be required for killing organisms entrapped on the filter. Filtration complicates, rather than simplifies, waste stabilization. The replacement of the very fragile filter membranes by a crewman wearing pressure suit gloves will be difficult with questionable reliability. It is significant that although Sandage (Ref. 28) recommended filtration of reprocessed waste water, he further recommended a final chemical disinfection of the filtered water.

Radiation

Various types of radiation (ultraviolet, gamma, alpha, beta, etc.) have been used for sterilization of wastes. The high concentrations of penetrating radiation required to effectively destroy microorganisms in waste are hazardous to human beings, so heavy shielding is required. This factor prohibits the use of such methods for the present aerospace application.

Other Stabilization Methods

Conventional aerobic and anaerobic digestion processes are unsuitable for use in small aerospace vehicles because of lengthy time requirements and the gas production. Wet oxidation (Zimmerman Process) requires heavy pressure vessels and associated equipment, and the Atomized Suspension Technique (Gauvin) involves the use of equipment for particle size reduction prior to treatment, as well as condensers, centrifugal separators, etc. Both processes generate large quantities of heat difficult to dissipate at the required high rate from an aerospace vehicle.

Chemical Waste Storage

Germicidal chemicals for the stabilization of stored wastes can be used as gases, liquids, or solids. Each of these has certain attendant advantages and disadvantages.

Germicidal gases with possible potential for use in aerospace waste treatment are beta propiolactone, ethylene oxide, and perhaps formaldehyde. Ethylene oxide is usually employed as a gas. Beta propiolactone must be used as an aerosol. Formaldehyde is usually released from formalin

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or paraformaldehyde by heating. These are all toxic gases and formaldehyde is especially irritating. Such germicides must be used by placing the waste in a specialized sealed vessel in which the gas can be contained, as release of any of these gases to the cabin atmosphere could be catastrophic. Ethylene oxide, in particular, is combustible to the point of being explosive, and therefore must be mixed with carbon dioxide or freon, increasing its mass by a factor of nine. Although such gases are efficient germicides with rather good penetration in waste, (except for beta propiolactone) action is not rapid. Gas should remain in contact with waste for at least 24 hours. After contact, excess gas must be either vented to space vacuum or adsorbed on a suitable adsorbent. Beta propiolactone and formaldehyde could be very difficult to remove completely from waste. The instrumentation of a proper contact chamber would require appreciable mass and volume, and the safety reliability of the chamber must be very high. The disadvantages of this method outweigh the advantages, particularly when compared to certain alternate storage methods.

Liquid compounds or solutions of solid germicides are very effective for stabilization of wet or dry wastes. To prevent their escape to the atmosphere as droplets, liquid disinfectants can be stored in soluble or breakable capsules, hand-operated squeeze bottles, or a central "tank" with a distribution hose. During use, no toxic vapors would be released to the atmosphere as in the case of gases. Certain germicidal liquids are toxic or irritating to the skin, and their use requires proper precautions. This, however, is not a difficult problem. No special treatment containers would be required; plastic bags will suffice. Germicidal liquids vary in viscosity from that of water to heavy gels. They can also easily be utilized to sanitize waste collection hardware.

Solid germicides are suitable for use on wet wastes only, as they must dissolve in water contained in the waste before they become effective. These germicides readily dissolve and mix with urine, and feces also contain more than enough water to dissolve them. Kneading of the germicide into feces will be required to obtain the necessary contact. Solid germicides can be dispensed in the form of pressed tablets that present neither vapor nor particle hazards in the cabin atmosphere. Handled as coated tablets, solid germicides would not be toxic or irritating to the skin. No special equipment is required for handling solid germicides.

Both liquid and solid germicides possess many advantages for waste stabilization in aerospace vehicles. No special equipment or instrumentation is required. Minimum volume and weight, together with the most reliable waste stabilization system available for short

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and medium length missions, are provided. Microorganisms are killed and the waste rendered incapable of supporting further growth. Consequently, there is no problem of recontamination, spreading of disease organisms, or secondary gas production. Many germicidal chemicals will reduce the odor of freshly evacuated feces. Disadvantages of liquid and solid germicides include toxicity and irritation, but these can be reduced to a low level by proper selection of germicide.

The selection of suitable germicides is complicated by the fact that the disinfection of massive quantities of organic matter involves unusual problems. Most contaminated objects have clean or only slightly soiled surfaces on which microorganisms constitute most of the organic matter present. In concentrated wastes generated in aerospace vehicles, organisms are distributed through a massive quantity of organic matter that "ties up" or inactivates most germicides. Some germicides, such as the heavy metal ions, can be used in high concentration to overwhelm this inactivating effect. The volume and weight limitations imposed by aerospace vehicles, however, usually do not allow problems to be overwhelmed by excessive use of materials. Therefore, the only acceptable germicides are those that are effective at low concentration and are not greatly inactivated by organic matter. Further, most germicides only kill or inhibit certain groups of microorganisms. Urine and fecal wastes may contain an infinite variety of microorganism species. All wastes are not attacked by identical groups of microorganisms, so a specific germicide is not equally effective on all wastes. Many germicides, such as most phenolics and mercurials, are not suitable because of their toxicity. Still others, including most antibiotics, phenolics, quaternary ammonia compounds and halogen compounds are eliminated because they are either ineffective in usable concentrations or too readily inactivated by the wastes. Of the hundreds of preparations tested in our laboratory, three have proved effective for germicidal stabilization of feces. Table VI shows the effect of 1 to 5% concentrations of these germicides on a typical fecal sample.

The germicide concentrations shown in this table are expressed as percent of weight of sample, e.g., a 5% concentration would be 5 grams of germicide added to 100 grams of feces. Obviously, rather small quantities of these germicides can be used to stabilize fecal waste. The methods in which they would be employed, i.e., tablets, liquids, gels, etc., would depend on the specific application. These germicides would work equally well for stabilization of urine. However, because of the low concentration of solids in urine, even smaller amounts of germicide would suffice. In addition to these compounds, a 0.4% concentration of a mixture of 50% tris(hydroxymethyl) nitromethane and 50% sodium bisulfite provides very good long term stabilization of urine. This germicide can be used as a liquid or a solid.

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TABLE VI

EFFECT OF FECES STABILIZATION GERMICIDES

Germicide	Germicide Concentration					
	5%	4%	3%	2%	1%	Control
8-quinolinol sulfate	$84x10^{4}$*	$62x10^{5}$	$65x10^{5}$	$67x10^{5}$	$71x10^{6}$	$73x10^{8}$
Mixture of Sodium orthophenolphenolate Sodium chlorophenolphenolates	0	0	0	$361x10^{4}$	$200x10^{6}$	$73x10^{8}$
Neomycin sulfate plus Myrislyl gamma picolinium chloride	0	0	0	0	$10x10^{1}$	$73x10^{8}$

*Note: Counts expressed as number of live bacteria per gram of feces after 14 days storage.

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The above compounds are not necessarily the ultimate in waste stabilization germicides; however, our results do very aptly point out the feasibility of this waste storage concept. Further study is required to perfect the germicidal preparations and improve the methods for distributing them in the waste material.

Summary and Conclusions

The use of chemical methods for stabilization of urine in the present application is recommended because of low mass requirements and residual sterilizing effects. Appropriate germicidal agents can be introduced into both the in-suit urinal and centrifugal urinal to prevent putrefaction of residual urine. Similar agents will suffice for bulk stabilization of urine in the bladder-equipped storage tank. The general concept of germicides in water-soluble pouches, packed in the glove-defecator, is recommended for the stabilization of fecal matter. The sealed defecators may then be stored in suitable compartments.

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Design of Units for Waste Storage

Urine Storage Tank

The urine storage tank is required for the temporary storage of urine prior to reclamation or disposal. It is sized to contain urine excreted by a three-man crew during a twenty-four hour period, and includes provisions for the daily addition of disinfectant to prevent bacterial decomposition of the urine during storage.

Conventional vessels are not suitable for the storage of fluids under conditions of weightlessness. Venting of air from a tank being filled with fluid is complicated by the fact that fluid will tend to cover all interior surfaces of the tank, including the vent opening. This problem may be solved by the use of a flexible bladder or diaphragm separating the tank into two compartments, the relative volumes of which are determined by the amount of fluid on one side of the diaphragm. With the tank empty, and the diaphragm in contact with the fluid side of the tank, fluid may be added and air on the opposite side of the diaphragm will be expelled through an air vent as the diaphragm is forced across the tank. Discharge of tank contents may be accomplished by either applying air pressure through the air vent, or by applying suction to the fluid inlet. A spherical tank is usually selected to permit the use of a symmetrical diaphragm.

Two flanged hemispherical stainless steel tank halves are bolted together with the beaded skirt of a hemispherical neoprene latex diaphragm clamped between the tank flanges. A fitting is provided on each tank half, one for the passage of urine, and the other for the venting of air. To permit the addition of disinfectant wafers without loss of urine from the tank, a special plug is provided. This device is essentially a short cylinder through which a piston, equipped with an "O"-ring, may be moved by the rotation of a knurled piston extension threaded to the outside of the cylinder. A wire screen is welded over the bottom of the cylinder. Before the tank is discharged, the plug is turned to bring the piston to the bottom of the cylinder, against the screen. When the tank is empty, the diaphragm will be forced against the opposite side of the screen, leaving only a negligible volume of urine in the mesh of the screen. The plug may then be removed, a disinfectant wafer inserted, and the plug replaced, bringing the piston in contact with the surface of the wafer. As the tank fills with urine, the diaphragm moves away from the screen, allowing urine to enter the cylinder and dissolve the wafer. The process is then repeated when the tank is filled.

The disinfectant is identical to that used in the disinfectant dispenser, previously described. A tablet weighing 4.5 grams is used in the dispenser, and a wafer weighing 11 grams is used in the urine storage tank. Both are wrapped in a water-soluble polyvinyl alcohol film to

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prevent particles from contaminating the vehicle atmosphere. The disinfectant is tris(hydroxymethyl)nitromethane, which has proved to be effective in concentrations of 0.2% (0.2 grams per 100 ml of urine), after extensive testing in our laboratories. The urine storage tank is illustrated in Figure 27.

Feces Storage Box and Fecal Disinfectant

The compartment for the storage of used collectors for fecal matter is a rectangular aluminum box, with a large opening at one end, and a small vent tube at the other. The opening is covered with two rubber discs, each slit along the greater portion of a diameter, and mounted with the slits at right angles to each other. This arrangement permits the hand, containing a fecal matter collector, to be inserted, the collector placed in the box, and the hand withdrawn without escape of box contents under weightless conditions. The inner surfaces of the top and bottom of the box are lined with foam rubber sheets. When a collector is inserted, it is rotated until its long axis is vertical and wedged between the cushions. This procedure will permit the orderly placement of collectors within the box, allowing maximum utilization of space.

Although no production of gas from disinfected feces should occur, a vent is provided at the rear of the box. This vent may be connected to the inlet of the ECS system, or a fan and charcoal filter may be provided to remove any odors that may develop.

To facilitate removal of the contents of the box at the end of a mission, a flexible plastic film liner is provided. An opening matching the vent hole is provided at the closed end of the liner. The length of the liner is greater than the length of the box. Surplus material at the open end of the liner is folded back to form a cuff before insertion in the empty box. The entire front panel of the box, held in place with screws, is removable for this operation. When the box is filled, it is only necessary to remove the front panel, unfold the liner cuff, twist to close the open end, and withdraw the liner. The box is illustrated in Figure 28.

The antimicrobic agent, recommended to prevent putrefaction and gas production by stored fecal matter, is a mixture of 70% orthophenylphenolates dissolved in an anhydrous glycol. In this form, the material may easily be mixed with the feces by gently kneading the flexible bag portion of the collector described in a previous section. We have found that 10 gm of this disinfectant is sufficient to adequately sterilize the feces produced in any single defecation. To avoid premature release of this material, it is enclosed in a package made from a water soluble film (polyvinyl alcohol). Placed in the compartment formed by folding over the bottom of the bag and holding the fold in place with tape, the package will be protected from damage before use.

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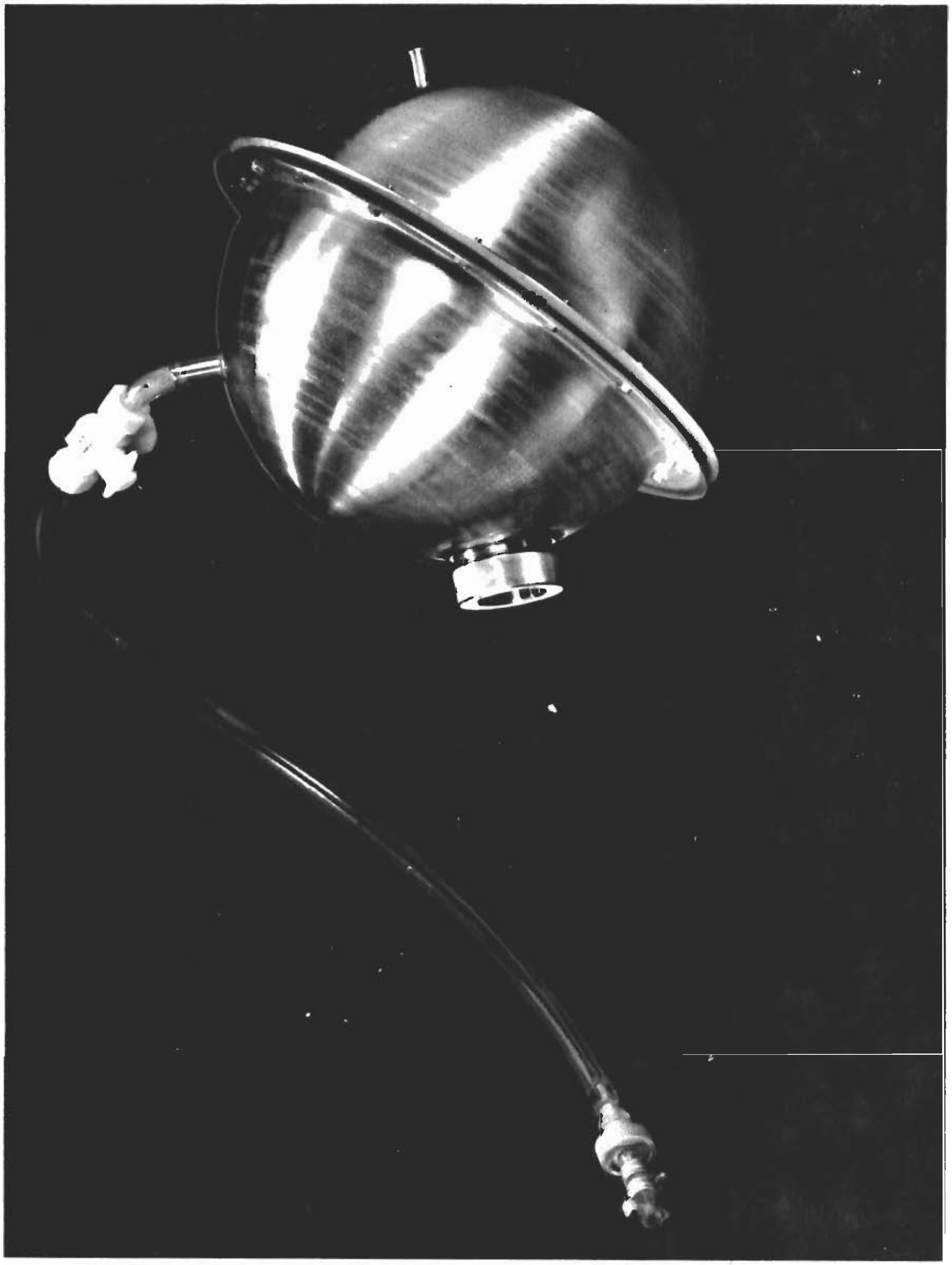

Figure 27
Urine Storage Tank

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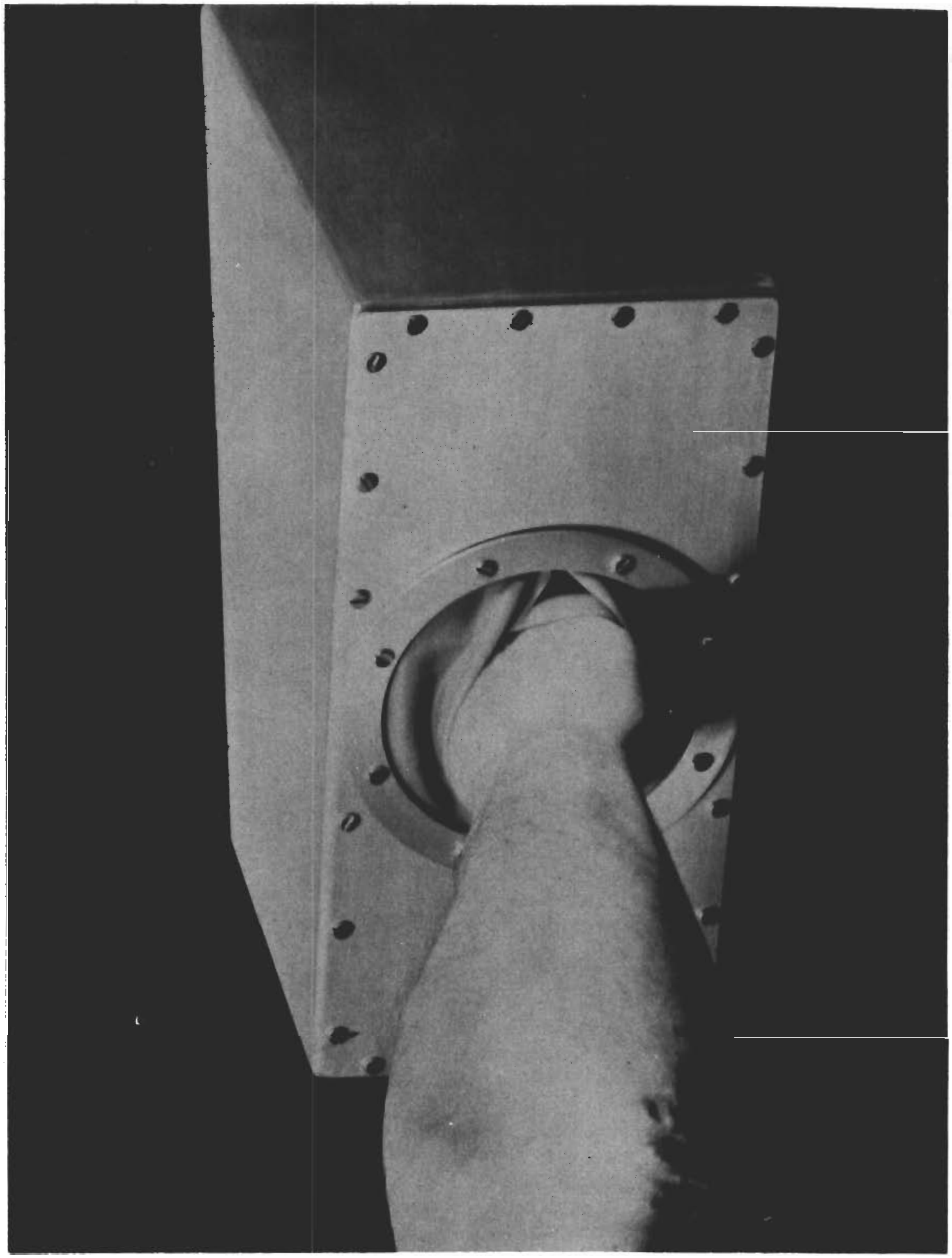

Figure 28
Feces Storage Box

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SECTION V

TECHNICAL RECOMMENDATIONS

Urine Collection

In-Suit Collection

Further research and experimentation is required to develop improved penis seals that are necessary to prevent leakage of urine from the collector worn by a crewman in a pressurized suit. The iris diaphragm seal described in this report has been found to be quite effective for certain individuals. In other cases it is not possible for the user to adjust the device to effect an absolute seal without restriction of the urethra and inhibition of micturition. This difficulty is apparently caused by the wide variation in physical penis dimensions, the location of the urethra within the penis, and other anatomical characteristics. Data on the range of these variations are not available in the literature, and the acquisition of such information on a large number of subjects involves many difficulties. It is quite possible that a custom-made penis seal will be required for each crewman.

Shirt Sleeve Collection

The centrifugal urinal developed under this contract appears to have certain advantages over other devices. For example, the elimination of the penis seal requirement circumvents many problems. Further research is required, however, to devise means of limiting the amount of air entrained in urine after passing through the impeller. Subsequent work has indicated that a smaller bore in the entry cone reduces air entrainment. If the complete absence of air in collected urine is a necessity, it is probable that a separate device will be needed to separate air from urine. The development of such a device will be a major project in itself. The centrifugal urinal could be modified by the use of a longer and heavier spring to handle high micturition rates (45 ml/sec), and operate for a longer period per winding.

Collection of Fecal Matter

Flexible Collector

The collector developed under this contract is expected to function satisfactorily under weightless conditions with normal bowel movements. There remains some question, however, regarding the degree of control possible with this equipment in the event of diarrhea. The behavior of rather liquid fecal matter in such a collector at zero gravity has not yet been determined experimentally.

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Atmospheric Contamination

Fecal odors will be released to the cabin atmosphere during use of this device, but it has been assumed that the environmental control system will have the capability of removing such odors rapidly. Adsorbents in that system must be provided to handle flatulence when the crewman is not defecating, as well as various body and respiration odors. It would appear to be more economical, therefore, to place any additional adsorbents in that system, rather than to provide a separate canister for the adsorption of defecation odors. Prolonged testing under actual or simulated conditions will be necessary, however, to validate this assumption.

Storage of Human Wastes

Fecal Matter Stabilization

The system proposed for disinfection of fecal matter, kneading a semi-liquid antimicrobic agent into the fecal mass manually, will be effective in the prevention of putrefaction, with low mass and volume. There may be, however, certain aesthetic objections to this operation. Further research is required on other possible methods of mixing a disinfectant with fecal matter without manual operations. The basic problem in this area is ensuring that the antimicrobic agent is brought into intimate contact with all parts of the stool.

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