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WASTE MANAGEMENT AND PERSONAL HYGIENE
FOR EXTENDED SPACECRAFT MISSIONS

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WASTE MANAGEMENT AND PERSONAL HYGIENE
FOR EXTENDED DURATION SPACECRAFT MISSIONS

ABSTRACT

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Spacecraft missions of extended time duration require waste management and personal hygiene facilities that will be reliable, sanitary, psychologically acceptable, have man-vehicle-system compatibility, and have use procedures duplicating (or closely simulating) earthbound modes.

This paper contains a discussion of the specific nature of the major problems relative to waste management and personal hygiene on long term multiman missions. Equipment requirements, design concepts, and status of equipment development are discussed sequentially.

More specifically, for waste management, the major considerations of collection, transport, storage, treatment, and rejection of excreta are reviewed. For personal hygiene, shaving, showering, superficial body cleansing, oral hygiene, and cleaning of clothes and equipment are considered.

Author

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INTRODUCTION

The recent successes of manned space flights indicate the necessity for an active period of life support equipment design for extended spacecraft missions. Accordingly, one end product will be the design of a Waste Management and Personal Hygiene System.

The selection of this system presents a variety of interesting and complicated challenges to engineering ingenuity. Primarily the design features should be threefold: (1) fully integrated with the man-vehicle complex, (2) psychologically acceptable, and (3) provide optimum reliable sanitation. Designs must incorporate these features in a manner that will not incur appreciable compromise on the basic vehicle supplies and must be operational throughout the intended mission profile. Designs must be compatible for use by both a space-suited astronaut and an unsuited crew member.

An assortment of waste management methods for collection, transport, storage, processing and/or jettisoning does exist, some implemented in hardware, others just as concepts. Basically each method can do the job for which it was intended, but with varying degrees of applicability to spacecraft use. No system presently exists which will satisfy all of the necessary design requirements.

To select a system design, the individual techniques for collection, transport, storage, processing and/or jettisoning must be objectively evaluated to determine system applicability. The evaluation must determine the direct use potential of individual methods, of combinations of these

methods, as well as of entire integrated systems. Trade-off factors must encompass weight, volume, power requirements, complexity, reliability, state of development, and all other meaningful aspects.

This paper contains a discussion of the problems, requirements, design considerations, and potential designs. Constant consideration has been given to the man-vehicle-waste management and personal hygiene system interface. Included is a brief review of the techniques for collection, transport, storage, processing, and rejection of urine and feces. Typical system design concepts are included to illustrate synthesis and implementation of these techniques for a vehicle-integrated Waste Management System.

The authors share a basic philosophy, which is "that a significant design advancement, in the form of an optimum Waste and Personal Hygiene System Design, is being made through an objective and practical approach in system engineering."

PROBLEM DISCUSSION

Generally, the problems associated with design of equipment for micturition and defecation are posed largely by use during zero gravity flight. The specific problems include the physical attachment, direction of excreta flow, containment in zero gravity, sanitation techniques, and collection for transport to a disposal capability for storage, reclamation, or rejection .

Micturition

Collection of urine must be accomplished while the crew member is either wearing or not wearing a pressure suit. If a member is wearing a

suit, urination must be possible while the suit is both pressurized and unpressurized. Because of the unpredictable behavior of liquids in zero gravity, complete confinement of the urine must be provided from the terminal of the urethral orifice to the urine-collecting capability.

This requires the following basics:

- (a) Physical attachment to the penis
- (b) Flow direction and containment means
- (c) Micturition termination droplet transport
- (d) Confined collection by positive retention of the urine
- (e) Odor control

From the points of view of safety, sanitation, and psychological acceptance, storage of urine inside the pressurized suit should be accomplished only in emergencies, or when a useful purpose is being served by this storage. Possible useful purposes that can be served by the storage of urine inside the suit are as a raw supply for producing breathing oxygen and as an expendable refrigerant for emergency cooling.

In considering an unpressurized suit, no need exists for supplementary oxygen and emergency suit cooling. Accordingly, storing urine inside the unpressurized suit has no potential advantages. Thus for unpressurized suit use and unsuited crew members, a common collection capability appears to be the most practical means. Also, where the suited crew member is pressurized inside an unpressurized compartment, the same collection facility can be used.

Defecation

For defecation, the basic equipment design problems of zero gravity containment, transport, and collection are similar in nature to micturition but differ in detail. Problems of sanitation, cleanliness, transport for disposition, and disposition itself, all pose diversified challenges to engineering ingenuity. As with micturition, the requirement for use while dressed in an unpressurized space suit may compound the basic defecation design problems. Specifically, the excreta must be retained during the functional procedure, and it must be transported from the collection equipment to the storage, reclamation, or rejection area. The body area must be cleansed, and the collecting and transport equipment must be cleansed and sanitized.

Although general treatment of the defecation procedure by early designs could in some cases suffice, generally, their use procedure designates several steps that need considerable improvement before sanitation and psychological acceptance reaches the level of our everyday existence. Despite the extensive training and orientation given the astronauts, the almost inbred rejection toward handling feces and associated equipment makes it a detrimental design aspect. For example the wiping and paper locating procedures, and the fold up and roll up techniques common to early design attempts (although accomplishing the designated task), are psychologically objectionable and, without utmost care, could be somewhat untidy. Careful evaluation of the man-vehicle-system waste management problem by NASA has concluded that every effort should be made to provide equipment designs that will at least meet the following basic criteria:

- (a) Be psychologically acceptable
- (b) Perform reliably as required without appreciable compromise to (and be generally compatible with) other vehicle system components.
- (c) Be all inclusive, that is, perform all operations necessary for the collection, transport, and storage of excreta, and be self-cleansing and sanitizing.
- (d) To have a use procedure closely simulating or duplicating that normally used on earth. Because of zero gravity use, however, some portions of this normal procedure have room for improvement.
- (e) To provide a use sequence in which there is no necessity to bring the hands near or have possible contact with the excreta. Even more preferable is a design which requires no manual manipulation or activity whatever, with only the physical activity of being firmly seated, defecating, and rising required.

Thus the most preferable equipment for managing excreta during defecation and for transport and storage of the fecal material after defecation may be equipment which is positive acting, clean, and simple to use, and which readily integrates with the man-vehicle system. A desirable feature will be the means for the equipment to be self sanitizing. Of prime importance is the fact that use of the unit should in no way appreciably compromise the vehicle system or its primary supplies.

System Considerations

The major equipment design considerations of vehicle integration (that is, weight, volume, power, reliability, maintainability, stowing, et cetera), must be carefully evaluated for functional compatibility with other vehicle systems. In addition, the usual requirements of structural integrity during and after anticipated launch, orbit, and reentry stresses must be accommodated in a manner that will assure operational competence after being exposed to these environments.

Systems considerations of weight, volume, and structural integrity are most important to launch, reentry, and landing phases of a mission profile. Power requirements, reliability, maintainability, sanitation, stowing, et cetera are most prominent considerations during the period of use; that is, translunar or transplanetary periods and the orbit phases. Understandably the most desirable approach is one which offers the optimal design criteria for each of these system requirements. For example, from preliminary investigations, it can generally be assumed that a system utilizing rejection of wastes to space should be lighter in weight, require less power, less maintainability, et cetera, than a system containing a processing procedure for storage or reclamation.

Figure 1 shows the tabulated weights for urine and feces on a daily per man basis. Figure 2 indicates the magnitude that stored feces can achieve from a weight viewpoint over the time required for extended missions. Thus the trade-off advantage for the process-containing system occurs in the unique design of the total system concept or in the value of the reclamation products.

This latter item, "value of reclamation products," is especially important to considerations for earth orbital and lunar orbital vehicles and translunar and transplanetary spacecraft, since acceptable techniques do exist for producing semipure and potable water from metabolic wastes. On extended spacecraft missions this reclaimed water can be used directly for an evaporative heat exchanger, electrolyzed to produce breathing oxygen and hydrogen, or in a potable state used for drinking water and food preparation. In a near potable state it can be used for personal hygiene or sanitation and cleansing of clothes and equipment. Multistage purity, however, is only one of many aspects that must be considered when evaluating reclamation processes for vehicle system needs.

Vehicle compatibility aspects must also consider the impact of the systems' use, as well as its specific demands upon the vehicle. Simplified examples include the desirability for privacy, local containment and removal of noxious odors, as well as the cleansing and sanitation of the equipment after each use.

In summary, the outstanding general criteria for an optimum waste management system are as follows:

Operability in zero gravity after exposure to all gravitational conditions

Light weight

Low volume

Simple to maintain

Reliability - designs based on known and proven mechanization methods

- Structurally sound - unaffected by mission profiles
- Self sanitizing and cleansing
- Powered by a natural resource of space (vacuum, solar, et cetera)
- Control odors
- Comfortable and convenient to use
- Process all wastes to useable products (for example urine to water, O_2 , and H_2 , fecal solids used as algae nutrients)
- Independency of spacecraft systems (yet integratable with spacecraft systems)
- Design simplicity

TECHNIQUES OF WASTE MANAGEMENT

Collection and Transport

Micturition. - There are three main problems that are common, but with varying degrees, to suited-pressurized, suited-unpressurized, and unsuited crew members for micturition on space missions. The first concerns the comfort and sanitation associated with the physical attachment to the penis. The second is containment and transport of the urine under zero gravity (or subgravity) conditions, the third, cleansing and sanitation of the total equipment.

Physical attachment in a pressurized suit: The problem of physical attachment while the astronaut is in a pressure suit is the most critical of those problems under consideration. Stresses provided by psychologically unacceptable and/or uncomfortable equipment could seriously hamper

task performance. Of even more importance is the seal which must be positive and leak tight. Liquid released inside a pressurized space suit in zero gravity would be uncomfortable and hazardous, even to the point of producing drowning. One commonly used attaching method is the "motormen's friend" type or its modifications, where the equipment is individually sized and remains fixed in place throughout the time the suit is pressurized. This, however, is uncomfortable and irritating when actively worn. Therefore it is preferable to provide a means for fastening a sealing device in proper location on the penis only during the time period necessitated by the complete voiding procedure. An alternate approach would be to design the device for remaining in place throughout the suited tour, sufficiently comfortable and non-irritating, so as to be readily acceptable to the crew members. Potential solution requires only temporary attachment during voiding, a specification that can be accommodated by many acceptable attaching schemes. For example, an inflatable ring-type collar on a funnel-type receptacle is one simple design; another features a mechanically expanded and contracted punctured diaphragm, controlled on the outside suit surface. A crude version of this same basic principle is the "Chinese finger" receptacle design where the required extension during use could be mechanized from outside the suit. When released after micturition, the device would contract to a larger diameter, thus providing only approximate confinement of the penis and an acceptable comfort level. These schemes all require a sanitation means for cleansing the receptacle

after the suit is doffed. An alternate and probably more preferable means would be a disposable attaching device, perhaps of a water soluble material.

Unpressurized suit or unsuited: Micturition in an unpressurized suit can be accomplished in the same manner as in a pressurized suit except that means for the positive air flow to drain the transport tube must be provided. Latest suit design versions, however, include a spinal trace closure that continues through the crotch and up the front to above the navel. This closure will provide ready access to minimize problems of physical attachment.

The problems of micturition while unsuited are also comparatively simple by comparison to those of the suited astronaut. The active area can easily be reached and thus a positive and sanitary act is possible with proper equipment design.

Design implementation: Modes for collection inside a pressurized or unpressurized suit have already been presented. The transport capability from the suit interface must be made in a positive manner so that a liquid can be cleanly and quickly moved to its disposition facility. Among the ways commonly accepted as the most practical for moving liquids in zero gravity are combinations of hydrophilic and hydrophobic materials with a prime mover such as pressure differential, mechanical wiping, or positive pumping.

From a NASA funded contract, Project Hydro John, a waste management system for advanced spacecraft, a preliminary design for a urine collection

and transport facility having a cleansing and sanitizing capability, was developed and is shown in figure 3. It features use with a pressurized suit, use with an unpressurized suit, or use without a suit. It performs the temporary sealing function, and transports the urine to the disposition area in a positive manner. For the suited man, pressurized or unpressurized but with fastened closure, the collecting hose is removed from the urinal at the quick-disconnect and attached to the mating suit fitting. After voiding, the hose is reconnected and flushing initiated.

Defecation.- Two of the problems common to micturition are similarly common to defecation: containment and transport of the excreta in zero gravity, and cleansing and sanitation of the total equipment. Defecation, however, offers additional prominent problems such as using psychologically acceptable procedures for the defecation function, and cleansing of the rectal orifice after termination of the function. From a mechanical standpoint, the excreta itself offers problems to a collection and transport means through its variable physical state, normally a semisolid. Specifically the problem is containment for transport and cleansing of the containment and transport equipment. Some potential solutions to these problems are presented and discussed later in this section.

In a pressurized suit: In some instances defecation while in a pressurized suit may be required. As yet it appears unlikely that an acceptable, that is, comfortable, clean and sanitary mode for implementing this need will be devised. Rather the practical aspect is to provide a supplementary means such as a secondary pressure protective device in the form of an enclosure about the waste management facility. The

astronaut could then pressurize the enclosure, depressurize the suit, and proceed as with an unpressurized suit. This secondary pressure protective enclosure use is commonly termed the "Oasis Concept."

In an unpressurized suit, or unsuited: Defecation in an unpressurized suit should be accomplished in a manner simulating earthbound procedures, except that zero gravity compensation must be made by fastening the buttocks or entire body to the collection facility. Latest suit design versions are using a closure that traces the spine, continues through the crotch, and terminates just below the navel. This closure will easily accommodate the earthbound defecation position. After defecation is terminated, cleansing of the rectal orifice requires that a manual wiping procedure be effected, and that the active area be cleansed by some other means such as rinsing. If a wiping procedure is used, the disposal of the cleansing medium, probably paper, compounds the undesirability of this collection mode. Likewise with rinsing, removal of the rinsing medium is a necessity.

Design implementation: Briefly surveying the collection and transport means of feces, the span is from the simple but crude techniques to the more complex but sophisticated. In the simple but crude category a defecation glove can be used. This resembles a surgeon's glove and actually is used to catch the excreta. By stripping the glove off, effecting an inside-out maneuver, the excreta is contained in the inside. Sealing and disposition of the unit then follows. Progressively more desirable means were presented in reports (refs. 1 and 2) where bags were generally used for collection, and pressure differential and manual

techniques used for prime movers. All techniques presented a potentially messy operation which is detrimental to their psychological acceptance.

A preliminary design which satisfies many of the prime requisites of a feces collection and transport facility is shown in figures 4 and 5.

The unit satisfies the basic requirements for collection and transport in a positive sanitary manner. The use sequence simulates earthbound procedure with additional features which are extremely conducive to psychological acceptance (specifically, cleansing of the rectal orifice and avoidance of manual activity). The design is based largely on known and proven mechanized techniques and available data of behavior of liquids and solids in zero gravity. These are applied in a mode that clearly establishes positive action, and thus the design can be used in gravitational, subgravitational, and zero gravitational conditions.

The advantages of this unit for collection, transport, and cleansing are obvious. The pump-blender and flush water create sludge that can be pumped away assisted by the high volume air flow as the initial waste transport medium.

Storage

The storage of metabolic wastes can be accomplished by storing urine and feces separately or by storing them together. Storing separately offers compatibility with:

- (1) Processing or rejection techniques that are different for urine and feces.
- (2) Processing or rejection techniques that require physical separation for their function.

(3) Collection and transport methods whose implementation requires their separation (such as the space suit urine collection and storage bag in extra-vehicular use).

Basically the storage design techniques must accommodate zero gravity operation while providing sufficient containment means and volume, odor control, restricted bacterial growth, and compatibility with the vehicle as well as other waste management facets.

Urine storage.- The simplest and most direct means for storage of urine is the storage bag. A bag can be used with the suit pressurized, unpressurized, or without the suit. It can be inside the suit system, but external suit mounting has specific advantages. A bag can also be used as the storage container of a vehicle-mounted system. To avoid "sloshing" and assist zero gravity containment, a wicking-absorber material such as virgin llama wool or Refasil is used. Another storage capability can be a container which has a zero gravity mechanization in the form of an expulsion piston. During operation, the expulsion piston in the storage tank progressively moves (as required) to induce the raw liquid waste through a check valve into the processing chain, or rejection device.

Feces storage.- Storage of feces in a pressure suit can possibly be accomplished once an acceptable means for collection and transport is devised. For its many obvious undesirabilities, the practicality of storing of feces inside a pressure suit is questionable to say the least, but may become a necessity if emergency operations so dictate. A reasonable

solution to this, however, has been discussed before as the "Oasis Concept" where a pressurized enclosure is used to house the defecation facility and to provide protection necessary to depressurize and repressurize the suit.

The storage of feces itself, however, has been discussed in recent reports (refs. 1 and 3) and can be accomplished by various methods. Major design challenges appear to be in the means of containment, retardation of bacterial growth, and odor control.

Generally the bagging technique is being fostered as the operational mode. Bagging, then sealing the bag in a container, for example, appears to eliminate the problems of containment, bacterial growth, and odor control. Other bacterial control techniques include freezing and incineration. A storage tank concept can offer these features plus other features of system compatibility especially when used with waste-processing systems.

Processing and Reclamation

Waste systems for advanced missions may find techniques for the ultimate recovery of useable products from human wastes most advantageous. The major recoverable constituent of human wastes is water (with the possibility of oxygen recovery from this water if so required). Water balances for closed ecologies clearly indicate that recovery of water for long-term missions is essential to minimize logistic problems. Further examination of water balances shows that approximately 60 percent of water excreted by man is found in urine and feces (with more than 93 percent of this contained in urine). Recovery of this water could provide a major saving in supplying the crew's metabolic requirements.

Preliminary investigation indicates that recovery of water from fecal material will require system complexities not presently commensurate with yield percentages, that is, maximum availability of water, 100 grams per man per day. This appears to be a general conclusion as indicated by the comparatively large number of water recovery techniques which are geared to processing of urine. Of the techniques most discussed and investigated, the major processes fall into one or more of the following categories:

- (a) Phase Change Processes
- (b) Membrane Processes
- (c) Biological Processes

Specific techniques within these processes must be individually evaluated with respect to applicability for aerospace applications. Not only must the effectiveness of each technique be determined, but the present state of development and an evaluation of future development must be realistically appraised. The scope of efforts in water recovery systems can be best presented by the following descriptive passages of major techniques that have been considered or investigated.

Phase change processes. - There are many specific processes which require a change of phase as the major process technique. In general, distillation (or evaporative) processes involve heating of the liquid until a vapor phase forms. The vapor is then cooled until condensation occurs, thereby completing the separation of liquid from dissolved solids in the original liquid. Distillation may be conducted at ambient, reduced,

or increased pressures. Selection of the operating pressure determines the temperatures at which a given liquid will distill. Operating temperatures are significant since they govern the decomposition rates of impurities in urine.

In summarizing experimental results of distillation techniques briefly, the following generalizations seem to hold true. Atmospheric (or ambient) distillation produces a product with unmistakable ammonia odor and a comparatively high pH but no coliform bacteria. The ammonia is thought to be the result of hydrolysis of urea with subsequent re-absorption of ammonia gas in the condensate. Ammonia can subsequently be removed from the product by cation exchange resins.

Vacuum distillation: Vacuum distillation results indicated that lower temperatures decreased the amount of urea decomposition. It was found, however, that the probability of coliform presence was increased with the decreasing temperature, indicating that sterilization is enhanced with elevated temperatures. The results show that additional sterilization is required with vacuum distillation techniques.

Addition of feces to the raw material for vacuum distillation increased the bacteriological content of the product. In addition, water was found to possess a distinct fecal odor. System complexities are sure to result if fecal material is included for processing. These, however, are certainly not insurmountable.

Pretreatment of urine with chemicals (that is, sulfuric acid) does aid in reducing ammonia carryover into the distillate; however, other problems are created by side reactions. For example, acid treatment caused hydrolysis and subsequent liberation of other volatile products, thereby only substituting the original problem for a second problem equally as important.

Vacuum pyrolysis: This water recovery system utilizes the principle of a modified vacuum distillation in which the vapors are passed over a heated catalyst to destroy any volatile organics and ammonia which are present. In this system, organic volatiles are destroyed and the ammonia oxidized to nitrogen oxide in the catalyst chamber. This vapor is then condensed and collected as potable water, ready for use. Potable water has been successfully recovered from urine and a combination of urine and feces.

As a general conclusion it may be said that simple distillation can produce potable water products from urine when used in conjunction with other processes. These processes could include pretreatment of urine, treatment of vapors, or modification or product water ion-exchange. The problem remains, however, to choose the combination of techniques which best satisfies the specific requirements as previously stated.

More sophisticated phase-change techniques under present development include vapor compression, freeze drying, incineration, and refrigeration freezing. The first two techniques mentioned still include the liquid-to-vapor phase-change, the remaining processes utilize a liquid-solid, and

a liquid-solid-liquid phase change, respectively, to accomplish purification and/or storage adaptability.

Vapor compression: Vapor compression systems utilize heats of condensation for vaporization of the incoming liquid. As such, heat rejection to outer space for the condenser section is not required. The process, simply described, involves evaporation of raw water followed by compression of vapor to the corresponding operating temperature of the condenser. The compressed vapor then condenses to form the product while the heat rejected in condensation is transferred to the evaporator for reuse in the vaporization cycle.

Vapor compression has the effect of improving the physical requirements for a vacuum distillation system and with proper application can appreciably alter the quality of the recovered product. In data collected to date, chemicals, filtration, ion-exchange, and treatment with activated carbon can be used to attain potable water.

Incineration techniques: Techniques for processing of fecal material prior to storage and/or rejection utilize as an initial step dehydration of feces to provide a dry residue ash for final disposition. To insure minimum residues, comparatively high incineration temperatures are used which result in extremely lightweight ash. Incineration also has the effect of leaving sterile residues for easier storage and/or rejection in keeping with "sterile-space philosophies."

Handling of the gaseous products becomes quite a problem because of the abundance of impurities present. In addition oxygen must be supplied to support combustion of solids followed by subsequent cooling to recover

condensates. While storage techniques may be enhanced by this technique, water recovery and subsequent disposition of both condensable and non-condensable products of the combustion present potential problem areas unless ingeniously coped with.

Freeze drying: Freeze drying (or lyophilization) involves a phase change from solid to vapor. In this process, urine is frozen. Sublimation of the ice is then allowed to occur. The vapors are then condensed (as a solid) and re-melted for subsequent recovery. Temperatures and pressures must be closely controlled to avoid melting. This requires operating temperatures of approximately 19.4° F at pressures of 3 mm Hg. Although equipment designs and system requirements appear stringent, the advantages of extremely high yield percentages (that is, close to 99 percent), good quality water, adaptability to zero gravity operation, elimination of bacterial contamination, ease of phase separation, and use of space vacuum as a natural resource require that this technique merit close consideration for applicability.

The process of freeze crystallization is a liquid-to-solid phase-change process where the raw liquid is cooled until ice crystals appear. This in effect separates the liquid fraction of urine from the salts in solution. Although initial energy requirements appear to be much lower for freezing than vaporizing, experimental results indicate that salts are physically entrained within ice crystals, thereby requiring subsequent re-freezing to provide high quality water.

Other variations of these processes include zone refining, column crystallization, and countercurrent crystallization. The basic operating principles are essentially the same for all these techniques; major variations manifest themselves in design considerations applicable to each individual system. In most cases only preliminary investigations of these systems have been performed, and these investigations have revealed process complexities relegating them to lesser importance in near future applications.

Membrane processes.- Water recovery systems utilizing membrane processes as the major purification technique are functionally divided into two categories, those utilizing electrical power and those relying predominantly upon liquid diffusion. Membrane processes function solely by their treatment of liquids, thereby eliminating the problems and power penalties present where phase-change processes are required.

Two types of membranes which are selectively permeable to the water contained in urine are (1) an ion-exchange membrane which consists essentially of sieves having molecular dimensions with fixed ionic groups in the pores; and (2) a membrane which will pass water by virtue of a solvent-like action. These membranes possess the property of selectively controlling the passage of inorganic salts, water, urea, and high molecular weight materials. An apparent disadvantage is that the processes result in two products, one, the desired water product, the other, a concentrated salt solution requiring subsequent disposal.

Ultrafiltration: Membrane processes not requiring direct application of electrical power include ultrafiltration, membrane permeation, ion-exchange, and osmotic processes. Passage of water through the membranes

is accomplished by hydraulic pressures (to 50 atmospheres), temperature gradients, natural concentration gradients, and self induced electro-osmosis. It would appear that the nature of the driving forces mentioned previously severely limit rates of passage and hence process rates. To date only ultrafiltration rates have been increased through use of higher pressures and have produced encouraging results in saline water conversion programs. The degree of direct near-future applicability to aerospace programs should be more fully evaluated before decisive conclusions are reached.

Electrodialysis: The major process utilizing electrical transport as the driving force is electrodialysis and related osmotic processes. In this process ions are transferred through the membrane by imposition of an electromotive force. However, because of the basic principles of operation only ions can be removed. Urea, being a large un-ionized molecule, will not pass through the membrane, thereby necessitating another process step before the desired potability of the product is obtained. The process appears to have merit but lack of information at the present time precludes any firm conclusions concerning physical dimensions and/or requirements.

Elf (electrolysis cell-fuel cell): A further use of ion-exchange membranes is the electrolytic dissociation of the water contained in urine followed by recombination of the gases in a fuel cell to produce potable water. Experiments to date with the ELF system (electrolysis cell-fuel cell) have demonstrated that high efficiencies are attainable

with the ion-exchange membrane electrolysis cells for extended periods of time.

Analyses of gases generated from the electrolysis of urine show that these gases are relatively free from contaminating substances. Electrolysis cell designs are such that gas phase-liquid separation are inherent in the cell operation and as such will operate in zero gravity. Transport of gases between the cells is by natural pressure gradients caused by depletion of gases by the fuel cell. Latest designs of wicking techniques in the fuel-cell unit will permit zero operation through phase separation and transport. Detailed analyses determine that water obtained from system operating with raw urine is odorless, colorless, and has pH of 5.2 to 5.4. Results from water samples collected also indicate chemical impurities are not added to the water from the normal fuel-cell processes. The quality of gases generated by the electrolysis cells indicate, that, at worst, only trace contaminants could be added to the water from this source.

Biological systems.- The use of algae cultures for the revitalization of gaseous atmospheres in aerospace systems has received considerable attention. The medium used to support the cultures of algae is enriched with some form of fixed nitrogen such as an ammonia ion or urea. The ability of algae to use urea suggests the use of urine itself for support of these cultures in a photosynthetic gas exchanger. However, preliminary experiments indicate that algae cultures will not flourish on raw urine or diluted raw urine even though the chemical composition does not greatly

differ from that of synthetic media. The reasons for this have not been explained and will require extensive research study before system development can continue.

Photochemical dissociation of water is another technique that has been considered, but again development of a feasible system is not likely for near-future applications.

Product use.- Thus far, systems have been discussed in terms of recovery of potable water. However, this is not the limit of useable products recoverable from human wastes. For example, intermediate quality water can be used as an emergency expendable refrigerant. In this case most tail-end treatments of distillation processes, for example, would not be required. Some treatment may be desirable to prevent excessive fouling of heat-transfer surfaces but it is obviously apparent that the purity of such water need not approach the stringent specifications required of drinking water.

Another important recoverable product is supplementary breathing oxygen. The success in obtaining oxygen gas from electrolysis of water contained in urine indicates that where other than fuel-cell power supplies are utilized, recovery of oxygen from urine is easily and economically achieved. This oxygen can be made available over a range of pressures limited only by the structural integrity of the electrolysis system. Extremely high pressures are undesirable from a system complexity standpoint but pressures compatible with spacecraft pressures are easily attainable.

This capability could be utilized to supplement normal supplies or to provide emergency gas supplies. This additional recovery capability is another indication of the kind of system flexibility required for maximum use capabilities.

Another product obtainable from water reduction is hydrogen which can be used for process reduction of CO₂, for fuel, et cetera.

Rejection

If engineering evaluations indicate that storage and/or processing of wastes is unnecessary for the missions under consideration, means for rejecting to free space will be needed. In accord with "sterile space philosophy," the waste products must receive germicidal treatment before or during ejection.

Techniques for implementing expulsion include a small airlock-type chamber in which the "bagged" or canned excreta that has been pre-treated for bacterial retardation can be placed, the chamber door sealed closed, the outboard door opened, and the payload propelled into space by some small propulsion means.

Another concept uses a sanitizing tank, which receives the waste suspension and holds it for a sufficient dwell time to allow a germicidal agent to act on the bacteria and other pathogens that may be present in the suspension. This technique permits direct rejection to space of the liquid waste suspension.

Direct ejection of the liquid waste suspension to space offers significant advantage over methods which eject vapor. In addition to not requiring an evaporator, storage of the resulting residue is not required.

Direct liquid ejection is accomplished with only negligible evaporation (because of the high ejection rate), the entrained waste suspension is simultaneously ejected, and thus no residue is left in the treatment tank. Even if all the waste suspension is not ejected, the quantity remaining is simply mixed with the next batch.

SYSTEM DESIGN SYNTHESIS

The prior discussion included preliminary design concepts for collection and disposition of both urine and feces. This section of the technical discussions will synthesize representative preliminary system designs. The systems will contain:

1. Collection, transport, and storage
2. Collection, transport, and reclamation
3. Collection, transport, and rejection

Collection, Transport, and Storage

The block diagram, figure 6, shows the system components for concept 1, and indicates their function. The collection and transport subsystem consists of the collector, blender, and the simple sludge pumps. The collecting tank is the storage capability in this concept. The distillation unit serves to semi-purify the liquid wastes for reuse as flushing and cleansing water. Figure 7 is a block diagram showing integration of this waste management system with other vehicle systems.

Collection, Transport, and Reclamation

Waste management system concept 2 is similar in mechanization to concept 1, except for the following:

a. The vacuum distillation unit that provided semi-pure water for flushing and cleansing is replaced by a vacuum pyrolysis reprocessing system. Although vacuum pyrolysis has proven potable water reclamation capability from urine (and wash water) some experimental tests indicate the process with or without minor modifications may satisfactorily produce potable water from fecal waste liquids after being passed through a solids filter, such as is designated by the storage tank in the schematic.

b. The vehicle integration block diagram will change in that potable water is produced as a function of the waste management system, as shown in figure 8.

Collection, Transport, and Rejection

Waste management system concept 3 differs from concepts 1 and 2 in that the storage in the sanitizing tank is only a temporary measure to assure sufficient dwell time for the germicidal agent to be effective. The rejection portions of this system have been previously described. The system has no water recycling means and therefore places the additional requirement of providing the flushing and cleansing water for each use on the vehicle system. Figures 9 and 10 indicate the vehicle system and its integration compatibility.

PERSONAL HYGIENE

In addition to the physical well-being of the crew members, personal hygiene has a decided impact upon their psychological attitude during

the mission's duration. Sanitation and hygienic procedures should, if possible, duplicate, or at least closely simulate, those used on earth. This philosophy has a major impact upon the design of the equipment for personal hygiene and its respective integration into the vehicle system. It is best illustrated when each personal hygiene category is examined.

Oral Hygiene

The problem of decay will be relatively minor when compared to the problem of gum stimulation. Mechanical removal of detained food particles and exfoliated cells will be aided by the abrasive and detergent nature of a carefully selected dental cleanser, one which is non-toxic and can be ingested. Pastes are conducive to zero gravity usage and some have been formulated and tested to meet the foregoing requirements. The means of application on the teeth can be accomplished directly through a dispenser-brush combination. By triggering the dispenser spring-loaded mechanism, a premeasured amount of paste is slowly applied to the teeth through a hollow handle during brushing. The brush bristle can be cleansed by an enclosed snap-on rinsing adapter attached to part of the water recovery system. Mouth rinsing can be accomplished by using a squeeze bottle water container and swallowing the rinse. Recent developments indicate the formulation of chewing gum types that have given acceptable results in dental hygiene tests.

Shaving

Small rotary machines that incorporate a "vacuum cleaner" collection technique (to prevent whisker debris from loading the environmental control filters) are presently in the development stage. The two

prototype models deviate in their method of power: one is pneumatically driven and the other has a rechargeable battery. The requirements for the mission being considered range from a sterilization technique and adjustments for the blades through interchangeable heads to separate units. Blade shaving in zero gravity appears to be impractical.

Showering

Several acceptable showering design concepts for zero gravity use have recently evolved. Of these, the shower suit is the only prototype tested. Results leave much to be desired in the showering, rinse, and drying procedures. A shower stall (fig. 11) having an inflatable structure and canted mosaic segments in each panel minimize many of the objections to the "suit." The sprayed water is directed about the enclosure by the canted surfaces until the initial impulse decays sufficiently for the inlet air bleed to perform a draining procedure. Showering should be staggered at 12-hour intervals to minimize the water reprocessing rate. Consideration must be given to integrating the shower system with the vehicle system, that is, using the shower drain water for washing clothes and/or equipment, and drawing the shower's water supply from the water supply. Although air drying of the man's body and the shower is incorporated into the shower design, final "towelling" is desirable. This then dictates a minimum of two towels per man to be used after superficial washing and showering for final drying. The towels can be dried after each use and washed and dried in the facilities discussed under "bathroom design."

Superficial Body Cleansing

One of the less thorough means of cleansing may be dictated by logistic and vehicle integration requirements, such as the wipe-down pads and towels, and/or the aerosol spray-and-towel technique. Generally, this technique encompasses the types of washing which normally is done in the wash basin and/or with a washcloth. A wash basin facility (zero g design) can be developed about the same basic design techniques (fig. 11) used for the shower; that is, using the canted mosaic segmented panels. The controls for flow drainage, temperature, et cetera, are in the foot stirrups, which are activated by moving the feet. Initial drying is done by warm air flow, and final drying by towel.

Bathroom Design

In addition to the shower facility, the wash basin, and biological waste management capability, the personal hygiene area should contain suction ducts strategically located about the area to contain debris, to facilitate temporary high air flows, and to assist in drying towels and equipment after use. An auxiliary blower should be cut into the ductwork system to provide the increased local flows upon demand only. The clothes and equipment washer-dryer cubicle should be included. In addition to the considerations mentioned, availability of medical supplies and first aid equipment is a necessity. The specific mission's logistics will essentially dictate the extent and scope of medical supplies and facilities.

The remaining personal hygiene factors, clipping nails and cutting hair, presently appear to be accommodated by zero gravity designs and/or techniques as follows:

Nail clipping. - Nail clipping is accomplished by one of the suction intakes, and under a collapsible hood, thus collecting the clippings on the intake filter.

Hair cutting. - Hair cutting is accomplished in the normal manner under a see-through hood to which a suction hose and filter/collector have been attached. After cutting, final suction cleaning of the head is accomplished in closer proximity to remove any cuttings still clinging.

Clothes and Equipment

Providing sufficient changes of clothing (1 for every third day) will add less complexity to the system than using a small washer-dryer cubicle. For extended missions, however, the washer-dryer (used intermittently) will be advantageous. The wash water for clothes and equipment can come from the shower and wash basin drainage supply, but the rinse water would have to be at least vacuum distilled, but preferably vacuum pyrolyzed. (Multistage purification techniques can be used to considerable advantage in a mission of this type). Heat for drying clothes and equipment and for warming water supplies could come from:

- (a) waste vehicle system heat
- (b) solar exposure through lens-reflector systems
- (c) a combination of the two.

MANAGEMENT OF OTHER WASTES

The space mission under consideration requires the management of other wastes in addition to that of urine and feces. Specifically the wastes necessitating management include:

Food spillage and particles

Containers from consumables

Paint/coatings flakes

Lint/clothing particles

Soap/detergent solids

Body wastes (desquamated epithelium, hair, nails, sebum, saliva, vomitus, fecal particles, mucus, seminal fluids, et cetera)

Management of these wastes have the same general problems as those of feces and urine; that is, collection, transport, and disposition.

Collection

Collection of these wastes will largely be made with filters incorporated as part of the environmental control and water reprocessing subsystems. (Specific collection techniques are further discussed under "personal hygiene.") A series of built-in "suction" capabilities and a portable suction device are required to implement effective collection. In addition, bags of vomitus, temporary collection of containers, et cetera, should be available.

Transport

Transport of all these collected waste materials will be encompassed by physically removing filter cartridges and bags and carrying to a proper area of disposition.

Disposition

Since this class of wastes is outside the realm of preferred "reclaimables," it will be most efficient to either store, process and store, or reject.

Store.- Storing of the class of wastes being discussed would necessitate:

- (1) Treatment to retard decomposition and its associated detriments.
- (2) Sizable volume.
- (3) Means of loading wastes without cabin contamination.
- (4) Means of transferring total supply at vehicle resupply time.

Process and store.- Processing for storage differs from the previous storage discussion in that the processing considered is that which is required to reduce the wastes to a means most convenient to their management. Periodic incineration appears to be the simplest and most effective means. A small external lock could be provided, serviced with cabin oxygen during periods of incineration, and the toxics exhausted to vacuum after process completion. The incineration process could be completed during periods when the lock is exposed to solar rays by use of a lens-reflector system. The resulting ash can either be accumulated within the lock for removal (at resupply time) or rejected to space.

Rejection to space.- Wastes can be rejected to space directly and without processing. This is in direct contradiction to a generally accepted philosophy of maintaining "sterile space," (even though all of the waste matter will eventually sublime). Other rejection techniques (such as launching a waste carrying vehicle to burn-up through reentry) although sound in theory, do not appear practical for these missions.

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Figure 1.- Summary physiological wastes

Source	Total weight, lb/man/day	Weight solids, lb/man/day	Weight water, lb/man/day
Urine	3.33	0.17	3.16
Feces	<u>0.27</u>	<u>0.07</u>	<u>0.20</u>
Total	3.60	0.24	3.36