

Integration and Mechanics of Waste Collection and Processes¹

GEORGE L. DRAKE, JR.
Chief of Life Support Engineering
General Dynamics/Astronautics

N65-18589

Waste collection and processing must be an integral part of any spacecraft life support system. The adaptability of the waste management subsystem to be integrated with other spacecraft systems is of significant importance and can be a major factor in the final selection. As a part of the NASA Langley Research Contract (NAS 1-2934), General Dynamics performed a study and survey of the industry to select a waste management technique. The techniques studied reflected the overall program objective of a completely integrated life support system capable of sustaining a four-man crew for 1 year with resupply at 90-day intervals. The major program objectives are as follow:

- Fully Integrated System
- Maximization of Reliability and Safety
- Minimization of Weight and Power
- Encompass Principles of Flight Type System
- Maximum Advancement of State of the Art
- Delivery of an Operating Life Support System Installed in a Test Bed for the NASA Manned Test Program

The following sections briefly describe the requirements for waste management in terms of the specific NASA Langley Research Center (LRC) contract criteria. The integration considerations are presented to show the broad interplay between a relatively simple system like the waste management and the overall spacecraft.

¹ Most of the information herein was made available through the NASA Life Support Project personnel at GD/Astronautics and GD/Electric Boat.

WASTE-MANAGEMENT REVIEW

General

The techniques used to accomplish waste management must meet the basic crew requirements and in addition provide acceptable integration capabilities with the spacecraft and various subsystems. The techniques discussed in the following paragraphs are some of those investigated for the NASA-LRC life support system. The comments associated with these techniques are valid for this life support system and should not be considered as necessarily applicable to other spacecraft and life support system configurations.

System Requirements

A waste-management system must provide for the collection, treatment, and ultimate storage or disposal of waste material generated on a spacecraft. These wastes include the normal biological products of the crew plus those produced by various spacecraft subsystems. Table I is a summary of the wastes produced by the four-man crew and the life support system under consideration.

The major problems associated with a waste-management system of a zero-gravity spacecraft include: collection of feces, odor control, bacteria control, and prevention of toxic contamination of the cabin atmosphere. In addition, the system must provide the technique for the collection and transfer of urine to the water reclamation system.

TABLE I.—*Waste-Management System Requirements*

[Four Men]

Waste	Weight, lb/day	Tasks
Feces-----	1. 3	Collection, transfer, storage, and/or treatment.
Urine-----	13. 2	
Refuse:		
Unused food and packaging.	1. 6	Storage.
Personal hygiene wastes.	. 5	Storage.
Carbon from CO ₂ reduction.	2. 5	Storage.
Solids in expendable filters.	Nil	Storage.

Techniques Investigated

Biological treatment

In the biological treatment of concentrated wastes, sufficient engineering data concerning loading rate, detention time, and degree of digestion during continuous operation are not available for precise design calculations of space-borne components. These factors are important since they dictate material balances and the size of the process equipment. Preliminary engineering requirements, however, can be determined based on known data.

The biological degradation of waste was considered unsuitable for the specific NASA-LRC mission for the following reasons:

- (1) The process does not eliminate the need for other subsystems; solids must still be disposed of at the conclusion of processing.
- (2) The process can stabilize only 40 percent of the organic waste during a reasonable time period.
- (3) The process imposes very large weight, volume, and power penalties compared to other techniques.

Freeze-drying

Freeze-drying techniques for waste management require the use of water or urine and assume that there is an excess of water and that urine will not be recovered. The specific NASA-LRC mission objectives include the requirement for recovery of water from urine; therefore, freeze-drying techniques were not considered acceptable.

Freezer storage

The freezing of waste matter for storage and odor control is a feasible and competitive technique. Also, the freezer required to implement such a technique can be used for other purposes before it becomes completely filled with waste matter.

In case of freezer failure, however, another subsystem for storage and odor control must be available. Therefore, it may be desirable to use another technique for the primary storage and/or disposal of waste matter and use the freezing technique as a backup.

Thermal decomposition

Thermal decomposition of waste has the advantage of requiring no expendable materials. This technique, however, inherently requires high temperatures, and subsystems employing thermal decomposition have high power consumptions to maintain the required temperatures. For the requirements of this mission a thermal decomposition unit would require in excess of 600 watts of power for operation. This power requirement is substantially higher than the power requirements of other techniques.

Incineration

Incineration can be used to dispose of both feces and refuse. In this technique the waste material is heated and then ignited with oxygen. The effluent combustion gases are vented overboard. This technique leaves a small quantity of powdery residue that must also be vented overboard or removed for ultimate storage.

Jettisoning

Information on the jettisoning of wastes from a space vehicle is exceedingly sparse.

There are several problems associated with jettisoning of waste in space. These can be summarized as follows:

(1) No one has developed a device for jettisoning waste.

(2) Waste must be treated and "packaged" for jettison to prevent contamination of space. No work has been done on packaging techniques.

(3) Force of jettisoning may require counteraction by control rockets.

Storage

There are available several storage techniques for feces. The feces may be stored, treated or untreated. Pretreatment before storage may be by chemical additive, drying process, or freezing.

Summary

The preceding techniques are only a few of those which were considered for the treatment process. In addition to the treatment processes investigated, fecal collection devices have also been evaluated during the NASA-LRC life support system study phase. Table II presents the various collection methods and the treatment processes evaluated.

The results of these evaluations in terms of weight and power weight penalty with respect to mission duration are shown in figure 1. Al-

TABLE II.—Techniques Studied for Fecal Waste Management

Collection and handling	Treatment or storage
Air flow—manual transfer	Room temperature storage: vacuum dried, chemically treated, sealed container
Air flow into storage	Biological degradation
Air flow—water flush, mechanical pump transfer	Freezer storage Freeze drying Thermal decomposition
Manual collection and transfer	Incineration Jettisoning

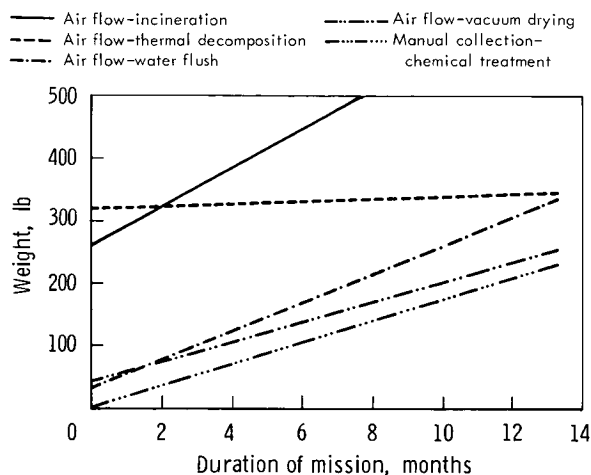


FIGURE 1.—Waste-management comparison techniques.

though this particular figure points out the weight and power parameter of the combined techniques, the final selection must also consider reliability, maintainability, safety, and integration adaptability.

The most significant point of the data presented in figure 1 is the slope of the lines representing the various combinations. The 1-year mission, as defined by the specific spacecraft model, is best satisfied from the weight standpoint by the manual-collection and chemical-treatment technique. The air-flow thermal-decomposition technique because of the low expendables would become competitive in terms of weight at about 18 months. An 18-month mission, however, may have different mission and design criteria than the one being considered here. The difference might be the inclusion of a food-management system designed to use man's metabolic waste as a nutrient for algae, thus eliminating the thermal-decomposition technique from consideration.

Figure 2 shows schematically the waste-management system selected for the NASA-LRC program (air flow collection and waste heat vacuum drying). The feces are collected in a semipermeable plastic bag. A blower is used to draw cabin air through the bag and an activated charcoal canister, the flow of air providing a means of directing the feces to the bottom

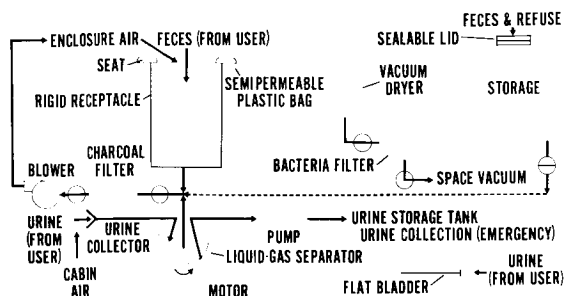


FIGURE 2.—Waste-management system.

of the bag under zero-gravity conditions. After defecation the bag is removed and placed in a chamber where it is exposed to waste heat and the vacuum of space for drying. It is then stored in a sealable container for ultimate removal during the resupply operation. The waste-management technique also provides a means of collecting urine and transferring it to the urine-collection tank of the water-management system. The urine transfer must be accomplished in zero gravity; therefore, a liquid-gas separator is provided.

SYSTEM INTEGRATION

General

So that the specific integration factors associated with the waste-management system can be fully appreciated, the overall life support system integration approach is presented.

There are numerous considerations both external and internal to the life support system that are closely associated with the selection of the life support system. These considerations must be reflected in the various subsystem specifications, which include all interface requirements of the subsystems.

Table III presents the major factors that must be considered. Those items shown in the first column are basic system criteria. The listings shown in the second column are those factors which tend to have the greatest integration potential. The following paragraphs briefly describe the significance of the potentially high integration considerations shown in table III.

TABLE III.—*Considerations Which Affect Life Support System Selections*

Basic system considerations	Potentially high integration consideration
Mission date	Power supply and power constraints
Mission duration	Waste heat availability
Crew size	ISS heat loads
Crew metabolic rates	Spacecraft wall thermal characteristics
Mission objectives	Orbital parameters and spacecraft orientation
Resupply interval	Spacecraft configuration
Zero gravity capability	Resupply techniques
Booster payload capacity	Crew safety and emergency procedures
Resupply vehicle payload capacity	

Power Supply and Power Constraint

The type of auxiliary power supply and the amount of power available for the operation of the life support system are essential in the evaluation and selection of all life support system techniques. The specific considerations of the auxiliary power supply as used in the evaluation and selection of the life support system are:

- (1) Power weight penalty: 290 lb/kw
- (2) Total power available to life support system: 2.5 kw (max)
- (3) a.c. three-phase 400 cycles, 115 to 208 volts
- (4) d.c. 28 volts

Waste Heat Availability

In addition to the regenerative heat exchanges within the individual life support system processes to reclaim waste heat, the auxiliary power supply waste heat provides significant integration possibilities. The quantity and temperature of the auxiliary power source waste heat is exceptionally high and is available from the coolant loop used in the radio-isotope power supply. The following information on coolant loop conditions at the discharge of the auxiliary-power-source regenerative heat exchanger is used to integrate the waste heat

source with the life support requirements.

- (1) Coolant temperature: 401° F
- (2) Minimum coolant temperature after heat exchange: not critical
- (3) Depending upon temperature of waste heat required, total q , Btu/hr, can vary significantly

Life Support System Heat Loads

The heat generated within the spacecraft cabin by subsystems other than the life support system can most efficiently be removed by an integrated heat transport loop which satisfies all the spacecraft thermal requirements. The total electrical power available for the subject mission is 5 kilowatts including the life support power requirements.

Spacecraft Wall Thermal Characteristics

The thermal characteristics of the cabin wall, when exposed to the incident energy of the space environment and to the varying internal heat loads, are essential in evaluating and selecting the technique for thermal and humidity control.

The preliminary cabin wall thermal characteristics used for the thermal control evaluations are:

- (1) Mean radiant internal temperature of the cabin wall is within $\pm 5^\circ$ F of the cabin air temperature
- (2) Cabin internal wall temperature is above the cabin air dewpoint
- (3) Maximum heat loss through the wall is equal to the four-man crew metabolic heat
- (4) Inside surface convective film coefficient equals 1 Btu/hr ft² °F

Orbital Parameters and Spacecraft Orientation

The orbital parameters have a significant effect upon the design and analysis of the thermal control system. The orbit and orientation of the spacecraft dictates the environment in which the space radiator must function. The specific considerations used in the evaluation of the thermal control system are:

- (1) Orbit altitude: 250 n. miles.
- (2) Orbit inclination to the solar vector: 30°

- (3) Orbit eccentricity: zero

- (4) Vehicle cylinder axis normal to the solar vector

- (5) Rotation of vehicle (cylinder) about its axis: zero

In addition to thermal control problems, the orbital parameters have some effect upon the life support system evaluations from the standpoint of emergency resupply time.

Spacecraft Configuration

The internal configuration of the spacecraft with respect to volume, number of compartments, and crew duty stations is a guiding factor in the evaluation of competitive life support system techniques. The volume of the spacecraft has a direct bearing on the gaseous stores, thermal control, and atmospheric control. The number of compartments has the same effect as the volume but, in addition, lends itself to evaluation of various techniques of the emergency life support system operation. The crew duty stations and crew location during off-duty hours have to be a consideration in the analysis and selection of various life support system functions.

The following factors were used to integrate the aspects of the spacecraft configuration into the evaluation and selection of the life support system.

- (1) Total cabin volume: 4150 ft³
- (2) Upper compartment volume: 2305 ft³
- (3) Lower compartment volume: 1755 ft³
- (4) Airlock volume: 90 ft³
- (5) Upper compartment: living and control station quarters
- (6) Lower compartment: research laboratory

Resupply Techniques

The resupply techniques for the life support system, in addition to the normal weight and volume constraints, must be compatible with the zero gravity and vacuum of space environment. The specific life support system functions which require resupply must be analyzed and selected, not only on the basis of performing a desired function, but also on their ability to integrate with reasonable resupply techniques.

Crew Safety and Emergency Procedures

The analysis of the complete life support system must consider each component or subsystem selection on the basis of crew safety. The companion problem associated with adequate crew safety is the ability of the integrated subsystems to provide modes of emergency operation consistent with a high probability of mission success.

The specific considerations used to maintain high safety standards for the integrated life support system include the following:

- (1) Instrument monitors and alarms
- (2) Physical design criteria (pressure, temperature, and environment)
- (3) Dual modes of operation
- (4) Redundancies
- (5) Dual function design
- (6) Emergency resupply reaction time

Waste Management Integration

The preceding paragraphs have briefly summarized some of the major life-support-system

TABLE IV.—*Waste-Management-Integration Chart*

General interface	Specific interface
Thermal control	Waste heat from the auxiliary power supply for feces vacuum drying unit or from the FC-75 heat transport loop
Atmospheric control	Transfer of heat by cabin air from the vacuum drying unit to the simulated radiator Integral blower heat transferred to the simulated radiator Odors associated with fecal collector to activated charcoal or toxin burner Air loss due to vacuum drying operation Odors associated with storage containers to toxin removal devices or toxin burner Storage for spent filters, and carbon from the Bosch Reactor
Water management	Urine transfer to water reclamation storage tanks Overall water balance considering fecal water loss Storage of waste water residue, liners, and evaporators
Food management	Storage of leftover food Storage of used food packaging Biological specimen freezer used for food and as a temporary waste storage backup Transport container for food is actually waste storage container
Personal hygiene	Debris and refuse from body and sanitation unit
Power supply and constraint	Blower for air flow feces collector (intermittent) Use of waste heat for the vacuum dryer to minimize power
Waste heat	Waste heat from the auxiliary power supply to minimize drying cycle time
Orbital parameters	Emergency resupply time
Spacecraft configuration	Provide for privacy Vacuum source for feces drying
Resupply	Capacity of waste management system to satisfy short-term occupancy of six crew members Design criteria of maintainability and replacement for expendables Return of waste from spacecraft to resupply vehicle Resupplied waste containers used for food storage during transfer from Earth
Safety	Emergency collection and storage for 17 days Isolation area for collection and storage to minimize toxic contamination Manual overrides of system functions Bacteria filters
Internal to the waste management	Instrumentation and control Feces transfer from collection unit to drying and storage units Storage container integrated with feces collection blower to minimize odors during waste storage Expendable supply storage (paper wipes, bags, chemicals) Urine collection device (air flow or centrifugal)

integration parameters. The specific integration factors which influence the selection of the waste management system are shown in table IV. The 34 factors noted are typical of the interplay between the spacecraft complex and the waste management system. Some of the factors have only a minimum effect on system selection while other factors, such as crew acceptance, are extremely important. In broad terms, the waste management system has some influence or is influenced by all the other life support subsystems.

CONCLUDING REMARKS

The life support system, of which waste management is a part, is a system which is very compatible with integration and because of this the individual subsystem evaluations must constantly consider this factor. Without major emphasis on system integration the resulting life support system would be no more than a collection of interdependent subsystems, each one performing its independent function without regard to the overall objective of an integrated life support system.