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*Manager, Advanced Programs, Manned Space Systems, Fairchild Killer, Republic Aviation Division*

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SPACECRAFT HOUSEKEEPING AND ITS RELATIONSHIPS TO LOGISTICS

Peter H. Needham
Manager, Advanced Programs
Manned Space Systems
Fairchild Hiller, Republic Aviation Division
Farmingdale, L.I., New York 11735

ABSTRACT

Spacecraft housekeeping includes waste collection, containment, pretreatment, transfer, utilization, and disposal. Wastes are categorized as to their sources, production rates, and attributes. Equipment and procedural concepts are identified and similarly categorized so as to facilitate selection for specific mission models. Housekeeping operations are related to the logistics elements of maintenance, up-cargo supply, and down-cargo return to earth. Computer programs are useful for housekeeping and logistics data bank maintenance, report preparation, data search, and modeling.

INTRODUCTION

The 33-foot diameter baseline space station, or its equivalent shuttle delivered modular space station, the free-flying research applications modules, and the NASA, DOD, other U.S. agency, international, and commercial satellites represent the major systems of the earth orbital space program. They will provide fundamental scientific knowledge, will observe the earth resources and environment, will exploit the environment of space, and will increase communications capabilities, and will provide the technology and facilities for further lunar and planetary exploration. They will require the delivery to space of large quantities of materials, new equipments, and supplies. They will produce scientific data and specimens, manufactured items, and waste materials. Recycling of the waste materials to their original useful condition, or by conversion to a useful product, will reduce the re-supply up-cargo and waste materials down-cargo elements of logistics. A substantial portion of the waste materials will be failed parts, a major item of the maintenance element of logistics.

The space transportation system booster, orbiter, orbit-to-orbit shuttle, nuclear shuttle, and space tugs will deliver the new equipments, payloads, and resupply items, as well as retrieve or return those items destined for examination, use, modification, or disposal. The space transportation system will also facilitate performance of in-orbit maintenance and modification of satellites at the satellite location, or by transfer of the satellite to a space station maintenance facility. Some elements of the space transportation system, for example, a tug, may stay in orbit for long periods of time and require resupply and disposal of its wastes.

The housekeeping function is primarily the collection, sorting, storing, treatment, handling, transfer, processing for reuse, and disposal of waste materials. These functions are directly relatable to the tasks, experiments, systems, maintenance, and logistic supply of the spacecraft.

Figure 1 illustrates a generalized space station and elements of the space transportation system; materials transfer aspects of housekeeping and waste processing and disposal are also shown.

WASTES

Wastes will be produced by the systems and laboratory facilities and equipments required to support life, maintain and operate the spacecraft, and perform the spacecraft tasks and experiments. Approximately 1500 waste items have been categorized as to their sources, attributes, and production rates for a generalized space station. Equipment and procedural concepts have been similarly categorized so as to permit preliminary equipment and procedure selection for specific mission models.

The waste sources will be all of the crew, experiment and system areas of the spacecraft. The wastes will include those produced by the crew and the experiments, as well as system items such as failed parts, damaged modules, and used filters. The wastes will also include items which are no longer required because an experiment has been completed or an updated system or module is available.

The waste production rates have been expressed in pounds per man per unit time for man-dependent items such as those produced in a galley, ward room, personal hygiene area, or sleep area. Food packages, metabolic wastes, clothing, and bedding are examples of such wastes. Wastes which are system-dependent items have been expressed in pounds per 10 years; production rates for such items are a function of system reliability, the maintenance procedure, or the consumption rate; examples are failed items and process byproducts. The wastes have been expressed in pounds per experiment for experiment-dependent items. Examples are biological materials such as used agar, animal carcasses, plants, excess metallic or plastic materials, and exposed film. Quantities for experiment wastes can be factored up where it is assumed that similar or repetitive experiments will be performed in a particular laboratory facility.

The waste attributes include liquid, solid, gas, or combined states; stable, radioactive, biological, inflammable, or potentially explosive characteristics; hot, cold, or ambient temperatures; irregular or easily handled shapes; very high or very low masses; sharp or soft textures; and high or low economic or scientific value. The waste may require monitoring or maintenance of environmental and/or other conditions.

Consumables and expendables data have been similarly tabulated in terms of destinations, characteristics, and consumption or use rates. Container, handling, and
transfer concepts and procedures are identical or very closely related for consumables, expendables, and wastes. A container, for example, used to package a replacement part, may be used to repack a failed part. Some items, such as general purpose instruments and tools, will be brought to a laboratory facility from a supply or warehouse area and then returned to storage for later use. In these cases, the incoming items may be considered as new items and the outgoing or return to storage items as waste items. The return is a housekeeping function and, since the same type of work is required to bring the item to the laboratory, the supply may also be considered a housekeeping function. Under this assumption, the supply and return of the item and, in fact, the transfer of all materials, equipment, and wastes, may be considered as on-board logistics operations. The methods selected for on-board logistics have a pronounced effect on the storage areas; the pantry, supply, or warehouse modules; pallets, containers, and transfer aids; shuttle-to-space-craft transfer, loading and unloading; and the shuttle and the ground operations.

WASTE UTILIZATION

A multiplicity of processes are available for consideration for utilization or reclamation of wastes. The processes fall under the headings of physical separation, electrolysis, oxidation, reduction, decomposition, building material production, fuel production, and food synthesis. A requirement for use of a waste utilization process appears to exist for any waste item generated at a rate in excess of 100 pounds per month. Probable examples of such items are wash water, galley wastes, clothing, bedding and towels, wipes, filters, carbon dioxide, dead batteries, used agar gel; biological, chemical, and medical glassware; and failed electromechanical parts.

WASTE CONTAINERS AND MECHANICAL TRANSFER

Figure 2 illustrates several special purpose waste container concepts; they are related to the waste characteristics shown in Table 1.

The container designs shown range from 12 to 18 inches in diameter and from 12 to 36 inches in length with capacities limited to 35 pounds based on the assumption that 25% of the mass of a 5th percentile man (132 pounds) is a safe inertial load for repeated handlelings. The transfer from the area of origin to the areas of use or disposal may be accomplished by the unassisted man or by mechanical transfer aids as shown in Figure 3. Unassisted transfer task times have been estimated for various housekeeping functions such as pick-up, move in a straight line, move around a corner or through a hatch, and stow. These incremental times may then be added up to determine the total unaided transfer times for a particular mission model. Similarly, one or more of the transfer aids may be selected for the particular mission model. The vehicle, line, bowstring, or extendible element concepts could be selected for straight line transfer. The fireman’s pole, pneumatic transfer tube, rail, or conveyor arrangements could round corners. The automated car system could be advantageous for the warehouse concept; in this concept, materials are brought to or taken from each area in a car which travels along a rail. The car can be pushbutton controlled and can employ a mechanism for automatic container removal and return to a storage area. Further data relating to unassisted transfer times and to cost and installation of transfer aids is required to perform trade-off studies for particular mission models.

WASTE PRETREATMENT AND DISPOSAL

On-board storage will be required because waste disposal will not occur simultaneously with the generation of waste. Three specific problems are created by the necessity for storage: prevention of the decomposition of biodegradable waste, prevention of the spread of pathogenic organisms from hospital and biological experiment laboratories, and the necessity for reducing the volume of waste products to be stored. Waste items which have a biodegradable characteristic will be treated by desiccation or refrigeration to prevent the growth of organisms. Waste items which have a pathogenic organism characteristic will be sterilized by exposure of the organisms to ionizing radiation, moist heat, dry heat, or chemicals such as ethylene oxide. Waste items which have a large bulk characteristic will be compacted mechanically; in some cases, the compaction may be preceded by shredding or conversion to a pulp and combination with other materials to manufacture structural panels, blocks, or extruded items.

Waste disposal is the physical separation of waste products from the space station. The candidate concepts are:

- Return to earth via the shuttle
- Jettison via rocket propelled vehicle to earth atmosphere for incineration, to an earth parking orbit, or to a solar orbit
- Pyrolytic incineration

Trash which cannot be stowed on board and is awaiting the arrival of a shuttle may also be temporarily disposed of by transfer to an empty fuel tank or an inflatable bladder which would subsequently be returned to earth. Use of the space shuttle is probably the most economical method of waste disposal, unless it develops that alternate return trip missions for the shuttle (e.g., for satellite maintenance) can be achieved subsequent to resupplying the station. Jettisoning via rocket propelled vehicles would probably be limited to hazardous radioactive waste items, the return of which to earth would involve substantial risk, although atmospheric incineration of normal waste products could be achieved if logistically desirable. Pyrolytic incineration of waste requires large energy inputs and the necessity for on-board condensation of gases and disposal of these residues to prevent deterioration of optically sensitive exterior surfaces.

Jettisoning or venting of waste products overboard as a general means of disposal is totally unacceptable. The creation of a debris atmosphere could present impact hazards for the shuttle or other spacecraft, result in the deposition of condensable gases on optically critical surfaces of the spacecraft and experiments, and degrade the optical properties of the local atmosphere sufficiently to have significant effect on many optical experiments.

SEARCH/REPORT COMPUTER PROGRAMS

A computer program has been developed for processing of the large body of data accumulated on the sources, attributes, and quantities of waste materials, consumables
and expendables; on the equipment and tasks requirements for on-board handling, transfer and storage of materials; and on processing concepts for utilization and disposal of waste materials. The computer program has the following capabilities:

- Storing and providing fast access to data banks containing the information
- Search and retrieval of data based on "key words" describing common attributes and properties
- Updating by revision and inclusion of new data
- Data book report printout of the contents of the data bank in order to facilitate updating

Related computer programs are also being developed to process the consumable and waste data; the handling, transfer, and container data; and the spacecraft and experiment definition data to produce a cargo item file. This data may be used in computer simulation models to analyze variations of system concepts and schedules and to prepare logistics plans.

CONCLUSIONS

Spacecraft housekeeping involves the collection, containment, pretreatment, transfer, utilization, and disposal of crew, experiment, and system wastes. The system wastes are related to the maintenance element of logistics. The containment and transfer functions are similar for both waste materials and incoming materials and are related to on-board logistics operations. The utilization of waste materials reduces the requirement for resupply up-cargo logistics operations and for waste material down-cargo logistics operations. Waste disposal by return to earth via the shuttle also affects the down-cargo logistics operations. Computer programs are useful to process and examine the housekeeping and logistics data.
<table>
<thead>
<tr>
<th>Waste Condition</th>
<th>Waste State</th>
<th>Non-Toxic Sterile, or Inert</th>
<th>Toxic, Noxious Contaminated or Active</th>
<th>Hot (Above Safe Skin Contact Temperature)</th>
<th>Cold (Below Safe Skin Contact Temperature)</th>
<th>Radioactive</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Solid</td>
<td>Metal, plastic, glass, textile, paper</td>
<td>Flexible Bag</td>
<td>Sealable Impermeable Bag</td>
<td>Insulated Container</td>
<td>Insulated Container</td>
<td>Shielded Container</td>
</tr>
<tr>
<td></td>
<td>Flexible, rigid sheet, rod, tube</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spongy, bulky, granules, sharp, brittle, dense</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Liquid</td>
<td>Acid, alkali, oil, water, emulsion, gel</td>
<td>Flexible Bag</td>
<td>Sealable Impermeable Bag</td>
<td>Bag in Insulated Container</td>
<td>Bag in Insulated Container</td>
<td>Bag in Shielded Container</td>
</tr>
</tbody>
</table>
Figure 1. Generalized Space Station and Shuttle Orbiter
Figure 2. Waste Container Concepts

Figure 3. Mechanical Transfer Systems Concepts