DOMESTIC APPLICATIONS FOR AEROSPACE WASTE AND WATER MANAGEMENT TECHNOLOGIES

By Frank DiSanto
Manager, Vehicle and Electromechanical Engineering
General Electric Company

and

Robert W. Murray
Program Manager, Life Systems
General Electric Company

Abstract

The tools for solving many of today's pollution problems have been developed by aerospace technologists. Of major importance are the approaches used to identify very complex problems, to select the best solution, and to implement vast programs. None of these approaches or technical processes is unique to the aerospace community. They have, in fact, been borrowed from government, academic, and industrial sources, refined and repeatedly used in solving aerospace problems and are now ready for general use in solving today's pollution problems.

This paper explores some of the aerospace developments in solid waste disposal and water purification, which are applicable to specific domestic problems. Also, the paper will provide an overview of the management techniques used in defining the need, in utilizing the available tools, and in synthesizing a solution.

Specifically, several water recovery processes will be compared for domestic applicability; e.g., filtration, distillation, catalytic oxidation, reverse osmosis, electrodialysis, etc. Also solids disposal methods will be discussed; e.g., chemical treatment, drying, incineration, wet oxidation, etc. The latest developments in reducing household water requirements and some concepts for reusing water will be outlined.

The Need

In 1872 London, the Government's Metropolis Water Act called for inventions to solve the "shocking wastage of water that was going on in the lavatories of the metropolis." The solution was the Valveless Water Waste Preventer patented by Thomas Crapper. As a reward, Crapper was appointed Sanitary Engineer to His Majesty and created a long- and little-known series of inventions which evolved into the commode and sanitary drain designs as we know them today. As today's water supplies become more limited, it is again time to call for new ideas to conserve water. Do you realize that 45 percent of your household water usage goes for flushing the commode and only 5 percent for drinking? What a waste of a valuable resource!

Since we are talking about handling of wastes, do you realize that a cow generates as much excreta as 16 humans, and that the wastes from livestock and poultry production alone are 1.7 billion tons per year or 4 times the amount of waste and trash produced in the cities? The problems of pollution and conservation span the full spectrum from urban domestic dwellings to rural farms. We are continually bombarded with statistics to show the complexity and magnitude of the problem; however, it does not really hit home until you are told to boil your water before it is safe to drink, or you are stopped from building your new home because an acceptable sewage disposal method is not available.

The aerospace community is being challenged by nearly everyone with the now standard statement, "We can put a man on the moon, but we cannot..." The nation's space activities and earth environmental problems have many areas of commonality, a few of which are both very complex, technical problems, and there are many thousands of skilled engineers and scientists solving them. The biggest difference is that putting men on the moon involved the actual landing of a few dedicated men, while improving our environment requires the commitment and support of millions of people with a diverse view of priorities.

This conference, "Space for Mankind's Benefit," is focusing priorities and depicts many sophisticated systems developed for space or using space to benefit man through better weather forecasts, communication and navigation, and development of natural resources. A more mundane topic is space technology developed for waste management and water recovery, which are applicable to domestic uses. When we think of the earth as a large spaceship, then the relationship of the space technology (or tools) to earth's ecology becomes more apparent.

The Available Tools

The tools developed to solve very complex aerospace problems are not unique to the space business. In fact, they have been borrowed from government, academic and industrial sources, refined and repeatedly used. Two of these management sciences, namely, systems approach and optimization techniques, are worthy of more detail.

SYSTEMS APPROACH

The systems approach is merely a means of providing a structured consistency to a program. The complexities of the space program have necessitated the development of this approach. The complexities of the pollution problem on earth are even greater than that required to put a man on the moon. However, now the tools are available to solve the overall problem and the individual problems of each community and household.

Basically stated, the systems approach is characterized by the following ground rules:

1. Start at the highest and most general echelon of cognizance to determine the boundaries of the overall system

2. Define the systems (concepts) and processes in stages of increasing detail, translating functional requirements into hardware requirements

3. Do not prejudge solutions; any solutions in mind should serve as guides, rather than points of departure, in the planning process.

Figure 1 gives a detailed treatment of the structure of the systems approach by highlighting the four principal states or steps involved:

1. Translation

2. Analysis

3. Tradeoff

4. Synthesis.

The translation, or initial formulation of the problem (need), is an important step that sets the course of all the work that will follow. Translation includes the interpretation of objectives, and, in addition, all recognized constraints on the problem solution criteria shall also be determined. Some categories of constraints, such as timing and policy, may also be used as selection criteria in developing the future program plans. The difference between these two uses is that constraints are generally applied as absolute limitations, whereas selection criteria are applied in the cycle to determine the relative merit of possible approaches. During the cycle, a number of feedbacks may be required, as shown in Figure 1, to improve and reevaluate the output.

OPTIMIZATION TECHNIQUES

Optimization is the process by which the best system is identified for the predetermined criterion of the study. A typical method of effectiveness and cost modeling is shown in Figure 2.

A general approach or model to system optimization is summarized in Figure 3. It can be seen that optimization is a reiterative process consisting of the following steps:

1. Design several concepts that satisfy the operational requirements and constraints

2. Compute resultant values of effectiveness and resource use

3. Evaluate these results and make generalizations concerning appropriate combinations of design and support factors, which are then reiterated in the model.

This then is the general method of attacking very complex problems. Some of the tools are the actual hardware developments.

AEROSPACE HARDWARE DEVELOPMENTS

A vast amount of new technology is being developed for advanced space missions where waste management and water recovery are key elements to a successful mission. Ecology-minded citizens are now realizing that the earth is not dissimilar from a space vehicle and that many of the space developments are also applicable to earth-type problems. Even the space-developed zero-gravity operational technology is found useful in designs for ship systems which must operate during extreme pitch and roll conditions.

Most of the NASA hardware developments have centered around low water use devices and water recovery. However, many other ancillary developments have also resulted from a quest for safer and more acceptable systems; e.g., bacteria sensors.

Low Water Use Devices

Commode. The recent development of the fourth generation Hydro-John (under NASA Contract NAS 9-9741) has shown that flushing and cleanliness can be achieved with less than 1 lb of water compared to 40 lb for a typical earth commode flush (Fig. 4). A second advantage of the Hydro-John is that wiping tissues are not required. This is an advantage for remotely located toilets where maintenance is a problem; also the cost saving on the tissue may be more significant than the water saving. If water for flushing is not available, the Dry John (Fig. 5) has been successfully used for over 600 man-days in chamber tests. This unit collects, stores, and vacuum dries the wastes. It is discussed further on page 224.

Urinal. Probably the greatest waste of water is committed when the conventional commode is flushed after urination. This technique uses 40 lb of water to flush away 1 lb of liquid. Commodes with a "half flush" are in use in Europe. Separate male/female urinals have been designed for space use which have a flush capability requiring only 0.25 lb of water.

Showers. The shower configurations being tested at NASA each show a significant reduction in water requirement. Typically, a shower requires less than 10 lb of water compared to the conventional 160-lb requirement. The aerospace shower features temperature control of both the water and the air in the shower enclosure. These features alone would save a significant amount of water in the home since much water is wasted in achieving the proper water temperature for showering and only a few commercial models provide for stopping and starting the waterflow without the possibility of being scalded or chilled.

Clothes Washer. Conventional clothes washers generally require over 300 lb of water heated to approximately 120° F, and in the household of a large family, the automatic washer is used at least once a day. NASA is developing a low water usage washing machine. General Electric has developed and tested a washer which uses only 1 lb of water per pound (dry weight) of clothing to be washed.

Dishwasher. The development of dishwashers has not stressed conservation of water. Cleanliness of the dishes is the main goal, as it should be for a commercial product. Consequently, over 100 lb of hot water are used for dishwashing per day for an average four-member family. No known aerospace concept is being developed; however, there will be a requirement for a dishwasher in a space-station-type vehicle where disposable dishes and utensils are not contemplated.

Garbage and Trash Disposal. Garbage and trash disposal does not require a large quantity of water; however, this disposal problem is of interest since the solids may be processed in the same way as fecal solids. The Integrated Waste Management Program (AEC Contract AT [30-1]-4104) uses the approach of handling all the liquid and solid wastes by common processes; namely, distillation for water recovery and incineration for solids disposal. This approach in a household would initiate the separation of nonburnable trash, e.g., cans and bottles, which is difficult to separate after the trash leaves the home.

Water Recovery

Space-type water recovery systems can be generally categorized as distillation type or filtration type, although some designs must use distillation and filtration to provide an acceptable product. Some systems also require pre- and post-chemical treatment. Chemical and sterility requirements from NASA for recycled water are much more stringent than those of the U.S. Public Health Service. Consequently, as public water supply standards become more stringent, the aerospace technology may be applied.

Distillation. The General Electric concept utilizes distillation and high-temperature catalytic oxidation with no pre- or post-treatment required. The product is pure and sterile. Distillation is achieved by use of waste heat, radioisotope heaters or vapor compression.

Several evaporator designs have been developed for operation in zero gravity; these use centrifuges, flash evaporators or membrane diffusers to achieve liquid/steam separation. The centrifuge design is also useful for solids separation. Air evaporation is another distillation technique which uses a heated airflow to evaporate water from a wick-type material. Both pre- and post-treatment are required.

Filtration. Filtration has been broadly defined to include processes such as electrodialysis, reverse osmosis and multifiltration. Reverse osmosis and multifiltration are most promising in that the process is simple and much development has been completed. For example, the Space Station Prototype will use a reverse osmosis unit for water recovery from wash water. Multifiltration was used in the NASA four-man, 90-day test to recover water for personal hygiene, laundry, and housecleaning. This unit used several particulate filters followed by an activated carbon column, two ion-exchange resin columns, and a final activated carbon column. The development of flocculants has permitted more efficient filtration.

Pre- and Post-treatment. There are a multitude of chemicals being developed for pre- and post-treatment for systems which cannot handle waste ammonia generation and/or do not sterilize the effluent. These range from electrolytic and dichromic acid pretreatments to chlorine and silver ion posttreatments. Usually, the pretreatment is used to complex the waste urea to prevent ammonia generation. The posttreatment is usually required to control microbial growth. A newly developed electrolytic-type chlorine generator eliminates the need of handling of gaseous chlorine.

Solid Waste Processing

Basically, there are three advanced space vehicle methods for processing solids; namely, drying, such as is used in the General Electric Dry John commode, wet oxidation, and incineration.

Drying. Drying is accomplished by venting the closed waste container to vacuum, flowing an airflow through the container, or circulating and drying the airflow with a desiccant. Drying does not necessarily kill micro-organisms; however, the lack of water does prevent propagation and the resulting odors. Feces have been stored at ambient pressure, after drying, for in excess of 1 year without any gas generation problem.

Wet Oxidation. Among the several methods used for combustion of waste material is the Zimmerman or wet oxidation process. Waste material, entrained in water, is placed in a pressure reaction chamber and air or oxygen is introduced under pressure to oxidize the organic content of the waste. The mixture is heated to 500-600°F in the closed chamber where a pressure of about 2000 psi is developed. Holding time depends upon temperature and composition of the waste, but about 1 hr is generally sufficient to oxidize 80 percent of the organic material and yield a sterile inoffensive end product.

Incineration. Incineration typically reduces solid waste volume and weight by 95 to 99 percent. The present General Electric incinerator for space applications uses a batch-type process. Continuous processes have been operated in the laboratory, but require more development to prevent clogging of the incinerator feed mechanism. Large-capacity, continuous-feed mechanisms are used in commercial incinerators.

Ancillary Equipment

Aerospace development of water purity and sterility monitors is of special interest. Typically, pH and water conductivity are monitored and TOC, NH_3, Cl, and other ions can be detected. Bacteria sensors are of several types; namely, chemiluminescent, spectrographic, 4-hour incubation, chromatographic, and a real-time electromagnetic device that is in a very preliminary stage of development at General Electric.

The Solution

INTEGRATED SYSTEMS

With experience in the development of waste management systems for both space vehicles and homes, plus the experiences gained from research, development and marketing in the home appliance field, the various criteria which hardware must meet for either space or domestic applications can be compared knowledgeably. These criteria described in Table 1 are essentially the same for both applications, but differ in relative importance depending on the application.

A current contract sponsored jointly by the AEC and NASA is the Integrated Waste Management-Water System being developed at the General Electric Company. In this development, all wastes are collected in the evaporator where the water is distilled at a low temperature and the remaining solids are centrifugally removed from the evaporator (Figs. 6 and 7). The distilled water vapor contains impurities which are catalytically oxidized and vented to a space vacuum. The resulting ultrapure and sterile water vapor is condensed and the water is ready for reuse and consumption. The solid wastes are sterilized, dried, thermally decomposed, and incinerated with the resulting gases vented to a space vacuum. The small amount of remaining ash is sterile and may be stored or jettisoned. Methods of eliminating the vents to space have also been identified.

The high-temperature portion of the system is integrated and insulated to permit heating by one radioisotope heater or electrical heater. Radioisotope heating provides reliable high-temperature heating and significantly reduces the system's electrical power requirements.

System Performance

System performance is briefly outlined as follows:

1. Collect and Process. Feces: 1.2 lb per day for four defecations. Urine: 14.0 lb per day from approximately 24 micturitions. Respiration and Perspiration: 20.0 lb per day at a continuous slow rate from the environmental control system. Wash Water: 24.0 lb per day. Trash: 1.2 lb per day — food, packets, wipes, and paper.

2. Water Recovery. Drinking Water: 30.0 lb per day. Wash Water: 24.0 lb per day.

3. High Temperature Thermal Energy. The system will have the capability of operation with a radioisotope heat source (RITE) or with an electrical heat source. Output: 400 Thermal Watts at End of Mission (Life). Fuel Form: Plutonium 238.

Integrated waste and water management systems can be derived for domestic use via the following concepts:

1. Concept 1. This system concept (Fig. 8) utilizes back contamination control devices to separate the community water supply from the system and to separate the waste collection devices from the washing and food preparation devices. In the home, back-contamination control is usually accomplished by an air gap between the potable water inlet and the water use device.

The waste liquid with a high-solids content, e.g., urinal, commode and garbage-trash disposal, is processed separately from the waste liquid with a low-solids content, e.g., wash water. This separation may be necessary to more efficiently process the wastes. For example, reverse osmosis may be used for water recovery in the wash water circuit and distillation for the commode circuit. Distillation will operate efficiently for the total water recovery process; however, the operational cost may be prohibitive since evaporation of each pound of water requires approximately 1200 Btu or 350 W-hr of energy. If the complexity is warranted, a vapor compressor can be added to the circuit to permit reuse of the heat initially used to evaporate the water, thus significantly reducing the overall energy requirement.

The solids from the waste liquid are separated and may be converted into either a sterile, dry material with little volume reduction or a sterile ash with a 95 to 99 percent volume reduction. The recovered water would either be drained to the sewage line or receive further processing to assure sterility and acceptability for watering the lawn or washing the family car. All excess water, over capacity inputs or potential overflows caused by component failure, will be bypassed to the sewage drain.

2. Concept 2. This concept (Fig. 9) contains all the elements of the first concept with a different arrangement. In concept 2, the wash water is processed to provide a sterile flush water for the urinals, commodes, and garbage/trash disposal. The resulting waste liquid is then processed to remove the solids and the resulting water is released to the sewage drain. The water is thus used twice before draining, and the reused water can be of a lower quality.

3. Concept 3. The third concept (Fig. 10) is a step closer to the NASA concept in that the water is recycled, and there is only a minimal reliance on the sewage drain during normal operation. The drinking and food preparation water is connected directly to the community water supply with no

connection to and, possibility of, back contamination from the remainder of the system. The wash water is recycled in the wash water circuit and the commode flush water is recycled to the commodes. There is no direct connection between the two circuits so that the possibility of contamination is minimized. Normally, only excess water is drained to the sewage line.

In 1872 London, Thomas Crapper was given Government grants to innovate and evolve waste management systems to solve the "shocking waste of water." So too, in 1971, NASA, 100 years later, has given grants via its aerospace technology programs in manned flight-waste management systems.

Future manned space vehicles will provide more earth like procedures for personal hygiene and waste management systems. Because the space vehicle is a smaller closed ecology than earth, space systems will provide more efficient and more microbiologically safe systems than are presently used on earth.

We cannot close our eyes to this technology. It is time to update Thomas Crapper's technology just as he updated the sanitary methods used over 100 years ago.

Bibliography

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TABLE 1. TRADEOFF/SELECTION CRITERIA AND RATIONALE

Criterion	Domestic	Space Vehicle
Feasibility	Must be feasible to manufacture on mass production basis. During development, compatibility with existing plumbing must be proven.	Must be feasible to make on a "cabinet work" basis. R&D must show proof of principle or reduction of practice but highly specialized materials and components can be used.
Cost	Must be competitive with products already on the market. Product improvement may occur over a period of years.	Cost important, but performance is overriding consideration.
Reliability	Motors usually guaranteed for one year, with 90-day guarantee on other components. Trouble-free operation is always the goal, but a service organization exists to take care of malfunctions. Operating environments are not severe and replacement is expected within a reasonable period.	Must be high.
Maintainability	Traded off against cost. Equipment designed for servicing by repairman rather than user.	Repairs must be made quickly and easily. (It should be noted that repairs will be performed by highly trained personnel.)
User Acceptability	Consumer acceptance in a mass market is key. Color, overall form and esthetic appeal extremely important.	Performance is key item. Esthetic appeal significant but secondary to function.
Safety	Underwriters Laboratories plus federal and state laws govern but failsafe devices usually not redundant.	Redundant failsafe devices required.
Performance	Nominal performance specifications since manufacturer has no control over operation and cost considerations may rule out improvements which consumers are unwilling to pay for.	Stringent performance specifications throughout the anticipated use life. Cost must be considered, but performance most important.

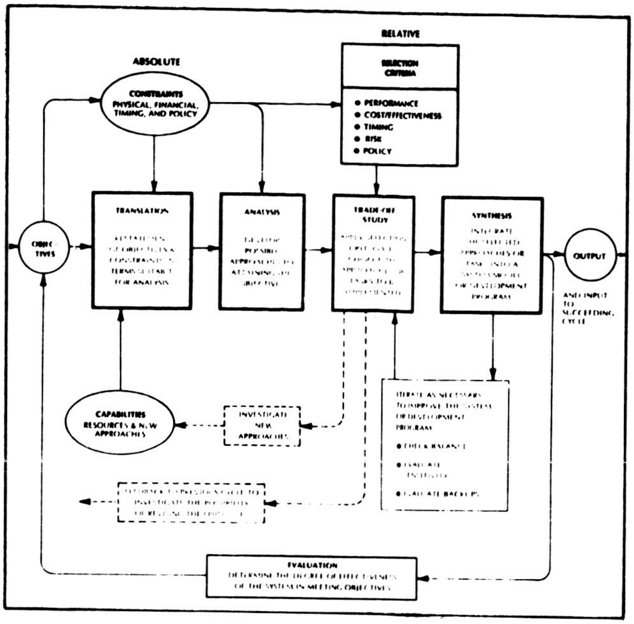

Figure 1. Steps within systems approach.

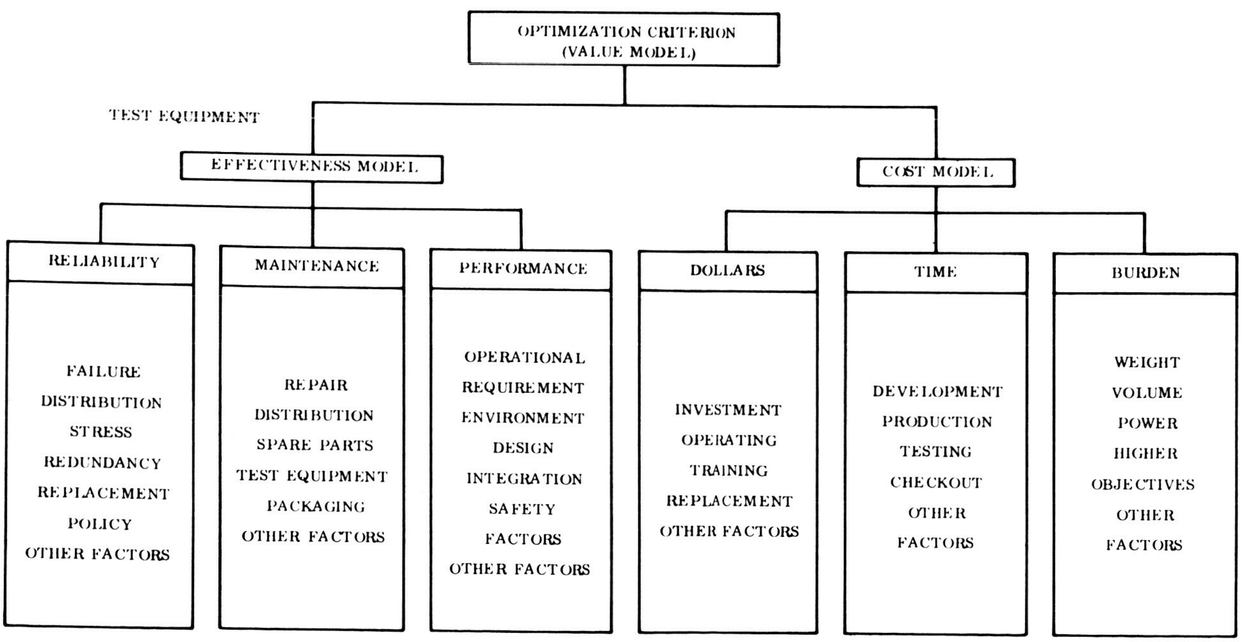

Figure 2. Optimization criteria.

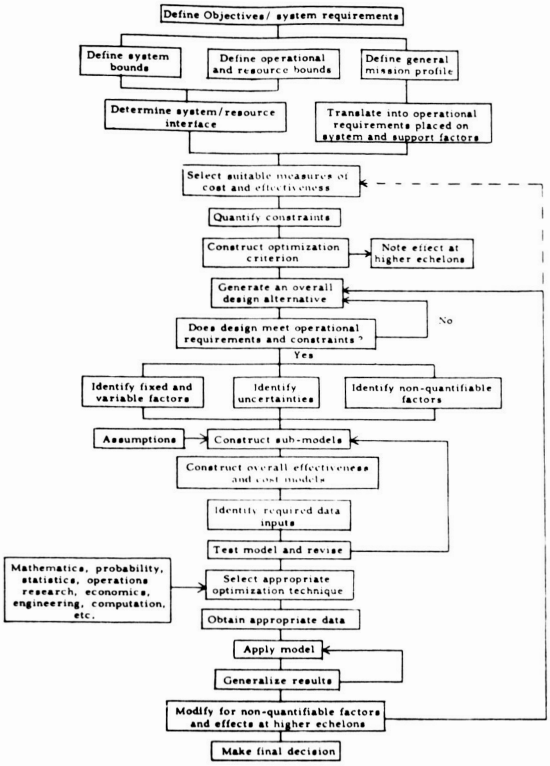

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Figure 3. Optimization technique (flow diagram).

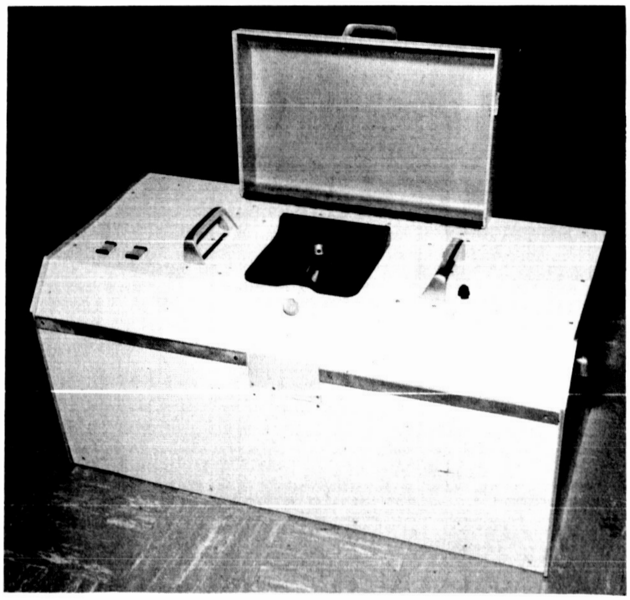

Figure 4. Modified Hydro-John separates solid waste from flush water.

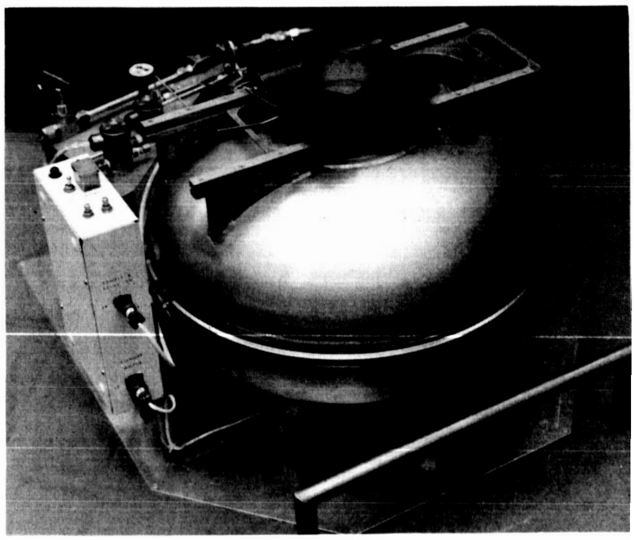

Figure 5. Dry John does not require flush water.

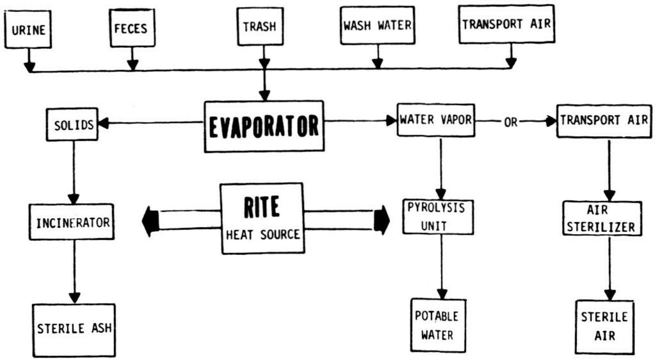

Figure 6. WM-WS functional diagram.

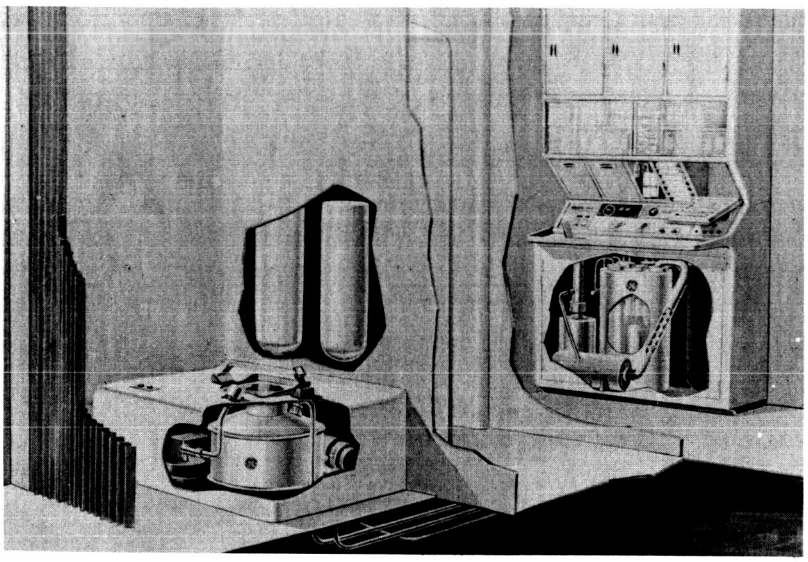

Figure 7. Artist's concept, integrated waste management-water system using radioisotopes.

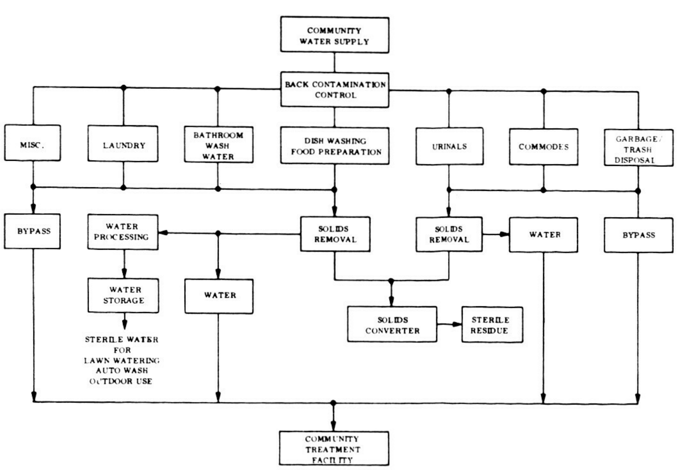

Figure 8. Concept 1, integrated system.

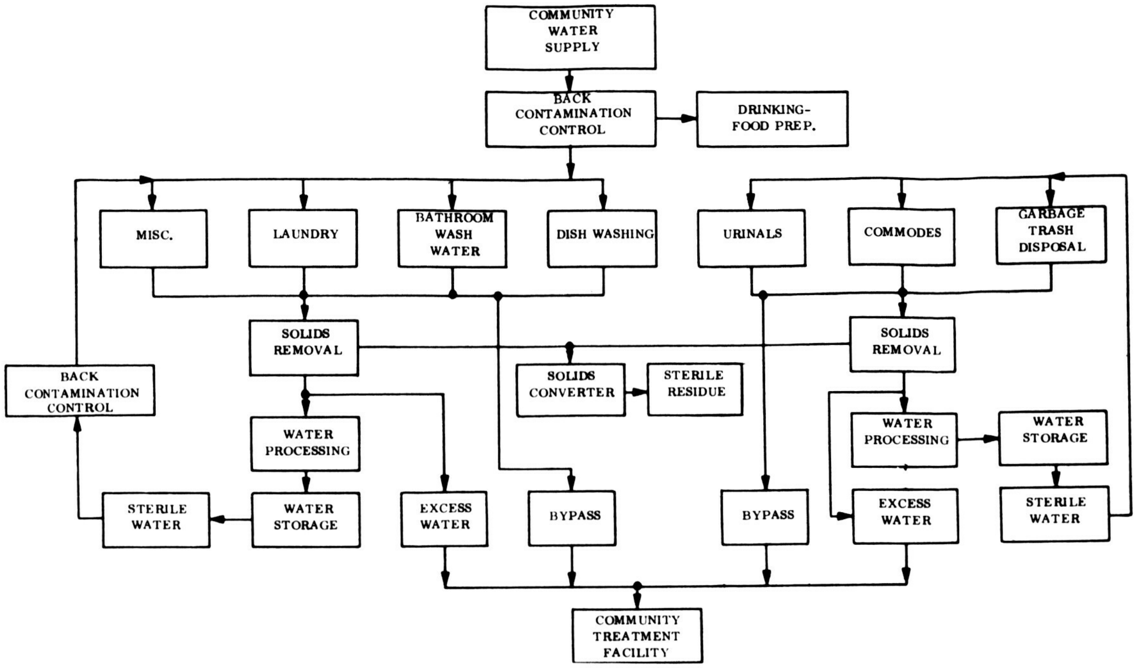

Figure 9. Concept 2, integrated system.

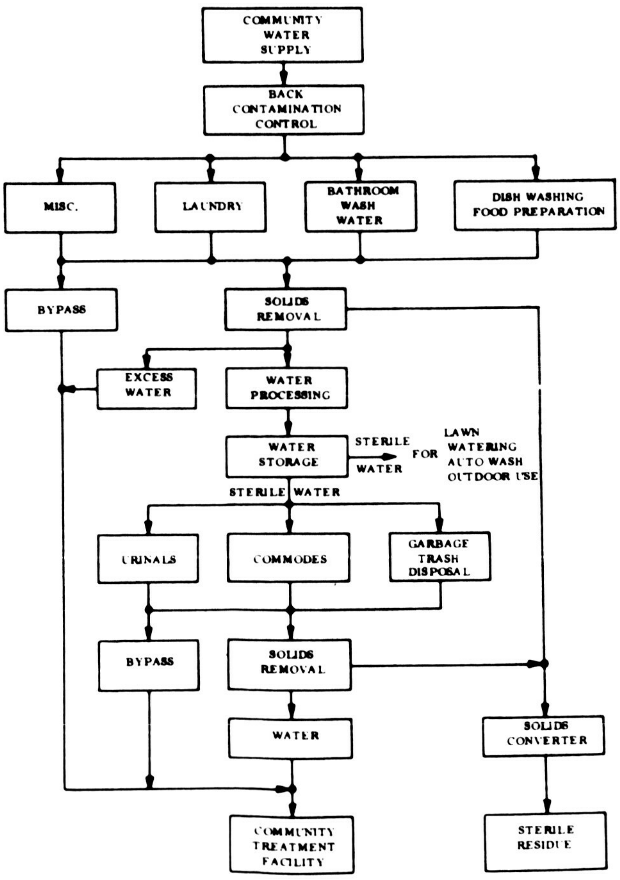

Figure 10. Concept 3, integrated system.