

FACILITY FORM 602

N 66-17221

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| (ACCESSION NUMBER) | (THRU) |
| 35 | 1 |
| (PAGES) | (CODE) |
| TMX 56123 | 05 |
| (NASA CR OR TMX OR AD NUMBER) | (CATEGORY) |

SPACE VEHICLE WATER RECLAMATION SYSTEMS

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Presented at the AIChE 55th National Meeting on
Aerospace Life Support Systems

GPO PRICE \$ _____

CFSTI PRICE(S) \$ _____

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65

Houston, Texas
February 7-11, 1965



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INTRODUCTION: THE NECESSITY AND POTENTIAL SOURCES FOR WATER RECLAMATION

Man's basic physiological need for water is universally recognized. Since it is not likely that we shall find any sources of water in space, all water requirements of the crew members on a space mission must ultimately be met from the quantity of water that exists on board the vehicle in one form or another at launch. For space missions, like Mercury, of relatively short duration, the most simple, straightforward approach is to include enough stored water to satisfy these needs. For longer missions, water reclamation systems become important. This is best understood by an examination of the daily water balance for man, as shown in the first figure.

The numbers appearing on this figure are not intended to represent the actual consumption and products of all people, nor even for any one individual. These quantities and amounts will vary from one person to another, and will vary with a single individual with workload, diet, environmental temperature, and many other factors. These numbers do represent, however, an average of what may be expected and can be used as a starting point for system definition; and, what is perhaps more important, they can be used

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to illustrate the significance of reclamation systems and to provide a basis for making decisions concerning these systems.

The diet which is postulated here is one of about 3000 kcal per day, and utilizes a freeze dehydrated food with a residual water content of about 10 percent. For space missions anticipated in the near future, all food will be provided from stores on board the spacecraft. For this reason, we can regard the water that is in the food, and that is metabolically derived from it as a water input to each man in the crew. Since the average internal water consumption amounts to some 5.50 pounds per man per day, this leaves an additional requirement of 4.69 pounds that must be made up from stores or reclaimed from waste products containing water. Figure 1 shows this need, in relation to the daily material balance of man, wherein man requires (in addition to this water) some 1.92 pounds per day of oxygen; and 1.50 pounds of food, which contains 0.15 pound of water, even in the freeze dehydrated form. It may be noted that the 0.66 pound of metabolic water which appears on the input side of the figure actually derives from the oxidation of the hydrocarbons in the food, providing a somewhat significant amount of water in the output balance at the cost of some oxygen. On the output side, man produces some 3.24 pounds per day of urine, 0.29 pound of feces, 2.20 pounds of transpired water, and 2.24 pounds of carbon dioxide. Contained in these outputs are: 3.08 pounds of water in the urine, 0.22 pound in the feces, and

2.20 (essentially all) in the transpired water. Note also that the 2.24 pounds of carbon dioxide would yield on decomposition 1.63 pounds of oxygen. Here it may be seen that less oxygen is bound in the carbon dioxide than was consumed; the remainder appears as water of metabolism.

Sources of water for reclamation are: water that has been recovered from the humidity control system, water that has been used for bathing and other personal cleaning, urine, and water derived from the feces. Not all of these potential sources possess equal attractiveness since they vary in amount, and in the degree and kind of contamination. Water derived from the humidity control system will probably be the least contaminated from the standpoint of solids, since it has already undergone a phase change; however, this water will contain small amounts of dust and other particles, airborne micro-organisms, and quantities of dissolved gases. The amount of this source, depending upon the temperature and workload of the occupants, may vary by a considerable amount from the numbers shown here.

Water derived from the washing or cleaning system need not appear in this figure since it can be considered a closed system. Appreciable quantities of this water do not enter the environmental control system, nor is it operated on by the individuals, other than for its intended use, that is, for cleaning. For the purpose of this paper, we will consider this as a closed, 100-percent

efficient system, requiring no makeup water. The amount of contamination which this water will contain will vary with the quantity used, the environment, and other factors. These contaminants will include: dissolved gases, skin oils and surface micro-organisms, debris, and aerosols as well as the cleaning agent and trace quantities of any or all contaminants found in urine and feces. Some researchers feel that an amount of wash water equal to 4 or 5 pounds per man per day will be adequate.

Urine, as derived from healthy individuals, is normally sterile and contains well-known contaminants. It is also an excellent media for bacterial growth. A major problem with the reclamation of water contained in urine is the urea. Urea will decompose under bacterial attack, or will show gradual breakdown, proportional to temperature, liberating quantities of ammonia. The amount of output of urine will vary from one individual to another, but for the purposes of calculation we may assume that an average man's output contains about 3.08 pounds of water.

The last potential source, that of water contained in the feces is small, that is, approximately 0.22 pound per man per day. Its level of contamination is very great, and the difficulties in recovering this water indicate that this is the least attractive of all the potential sources.

WATER RECLAMATION

The necessity for water reclamation is well understood, and is most forcefully demonstrated by a consideration of the vehicle launch weight savings at that point in time when the requirement for stored water, at 4.69 pounds per man per day exceeds the weight of a system to recover water from wastes. For simple distillation systems this point occurs at about 10 days. Thus, Apollo and Gemini might be expected to include water reclamation systems when considering the mission duration alone. The energy sources used in these vehicles, however, are fuel cells, whose byproduct is water and, therefore, no water shortage is foreseen and no reclamation will be performed. As mission durations exceed about 30 days, fuel cells will most certainly be replaced by other power providing systems that have lesser weight. Then, significant launch weight savings can be shown.

It is possible through applications of today's technology to perform enough reclamation on man's waste products to render a space crew independent of all stored water requirements. Figure 2 illustrates such a balance, wherein, essentially all the wash water and humidity water is reclaimed for reuse. Systems reclaiming water from urine are shown to require an overall recovery efficiency of about 80.8 percent, principally because of the metabolic water produced by man. As is shown, water contained in the feces can be totally discarded.

The question immediately arises as to why it should ever be necessary to recover more than this amount, since this degree of recovery apparently balances the water cycle. To understand why, consideration must be given to the requirements of other systems aboard the spacecraft. As was pointed out in figure 1, the carbon dioxide which is given off by man contains only 1.63 pounds of oxygen per man per day, whereas, man requires some 1.92 pounds of oxygen per day. When mission durations increase to about 60 to 90 days, it becomes economical to recover oxygen from carbon dioxide for breathing, rather than supply oxygen from stores. Attention must then be given to the oxygen balance. Some of the oxygen consumed went into the manufacture of water, and some into the manufacture of carbon dioxide. If the oxygen cycle is to balance, then some of this oxygen must be reclaimed from water. Figure 3 illustrates the overall water recovery efficiency which is required to balance both the water and the oxygen cycle. It may be seen that now, 97.2-percent reclamation of water is required, as contrasted with the 93.8 percent which was required before the oxygen cycle was closed. This requirement calls for a process of reclaiming water from urine which has an overall efficiency of 91.6 percent.

Figure 4 carries this train of thought one step farther. On all space vehicles, leakage of the vehicle atmosphere will occur, even with the most painstaking care in sealing of the vehicle. In addition, loss of this atmosphere will occur during airlock cycling,

and during the transfer of supplies. Assuming a very tight vehicle, and minimum losses through airlock cycling, by use of scavenger pumps, it is estimated that multiman vehicles of some 3-month duration, or longer, may have a leakage as little as 2 pounds per day. Performing the mathematics involved, it can be shown that the weight and weighted power penalty for a system to reclaim all of the water from urine to make up for losses in oxygen and water vapor from the vehicle will have a crossover point at about 50 days. This means that recovering all of the water required for man's needs (both for drinking water, and to balance the oxygen cycle, and recovering sufficient oxygen to eliminate oxygen stores to make up for leakage and other losses) will require 100-percent recovery of all water from the potential sources other than those contained in the feces.

METHODS OF WATER RECLAMATION

Penalties

Economy of water reclamation systems can be thought of in terms of their weight and power requirements. If a system uses electrical power, a weight penalty is assigned to that system that corresponds to the weight of the solar-cell array, or other power source, that would have to be placed on board to generate this power. For our estimates, the conversion factor used is 300 pounds per kilowatt of power used. If a system utilizes the waste heat

from electronic and other heat producing components that must be on board for other reasons, then it is penalized for the increased size and weight of the space radiator needed to radiate this same quantity of heat at a lower temperature. This amounts to 0.005 pound per Btu per hour. If a system requires active cooling, then it is penalized for the weight of a space radiator that will perform this function. This penalty amounts to 0.01 pound per Btu per hour. These are launch weight penalties and may be assigned to any flight-type system regardless of its function.

In addition to these weight penalties, the overall system weight must be adjusted to accommodate the weight of supplies, the pre- and post-treatment requirements and other expendables needed by the system. This must be cumulative over the time period of expected use, that is, if a system is slated to be operational for a period of 3 months, then the weight of supplies, such as pre- and post-treatment chemicals must be added to the system weight in quantities required for the 3-month operation.

Present-day technology provides a variety of systems that would be capable of performing water reclamation from human waste effluents on board a space vehicle. Some of the more promising techniques are being evaluated for the purpose of selecting the most optimum system for the task. Generally speaking, this would be the one with the lowest adjusted weight penalty with respect to the particular mission duration. Various system concepts and projected

improvements in the state of the art over the next 5 years are summarized and presented in figure 5. These curves denote system weight vs. time of use: the first being electro dialysis;¹ the second, vacuum compression distillation; the third, closed-cycle air evaporation; the fourth, reverse osmosis; and the fifth, that weight penalty which is projected from the work which is being conducted at the Langley Research Center on system improvements. The basis of comparison was as follows: All systems were sized by direct scale down to accommodate the average urine production of one man for the number of days stated. This amounts to 3.24 pounds per day, of which 3.08 pounds is available water. The entire system or any component thereof may operate no more than 20 hours per day and any system is penalized for the amount of available water it is unable to recover. Figure 6 shows the weight vs. time penalties for wash water reclamation systems. The basis here is 4 pounds of wash water per man per day, with the other penalties applying as in the comparison of the urine water reclamation systems. These curves represent the projected weight of (1) Electro dialysis; (2) Vacuum Compression Distillation; (3) Reverse Osmosis; (4) Multi-filtration; and (5) Langley Research Center's In-House Effort.

¹Data for electro dialysis curve obtained from C. Berger and C. E. Hansen from Astropower Laboratory of Douglas Aircraft Co., Inc.

For reclamation of water from the humidity control system, it can be shown that the technique of multifiltration is the system of choice for missions of durations less than 1 year.

As these figures show, the type of reclamation system chosen is a function of the demands that are placed upon it. That is, optimum urine reclamation techniques are not necessarily the same as optimum wash water reclamation techniques.

MULTIFILTRATION RECLAMATION SYSTEMS

The dehumidification water subsystem (see fig. 7) consists of a canister of Barneby-Cheney KE-1 activated charcoal, which serves to remove the impurities contained in this source. In series with this canister is a Pall ACF 4463 UWA 0.45 μ bacteria filter. A non-virulent culture of type 1 polio virus strain LS-a was passed through this subsystem to demonstrate the effectiveness of the bacteria filter. All effluents proved to be negative for the presence of the polio virus. The weight penalty associated with the reclamation of condensate from the humidity control system by this technique amounts to 0.009 pound per man per day.

The wash water subsystem called out under this effort is very similar except that it introduces an ion-exchange cartridge in the line. Figure 7 shows a Pittsburgh type CAL activated carbon canister, chosen for this subsystem on the basis of its comparatively high capacity for benzalkonium chloride (the washing compound of

choice under this contract) and for urea. The ion-exchange resins chosen were Rohm and Haas XE-168, weakly basic anion exchange resin. This combination was recommended by Rohm and Haas to give a higher capacity on a weight basis than a single mixed bed, or strongly acidic cation and strongly basic anion exchange resins in series. In addition to these, a bed of Duolite C-3 cation exchange resin was included for removal of urea, not adsorbed by the activated carbon. The Duolite C-3 is followed by a bed of Rohm and Haas XE-168 in order to adjust the pH of the final effluent. The quantities of cation and anion exchange resins used were determined by the operating capacities for these resins. The launch weight penalty of the wash water reclamation by multifiltration amounts to about 0.09 pound per man per day.

The techniques used in multifiltration makes possible the reclamation of 100 percent of the dehumidification and wash water used; these percentages are adjusted for the initial hydration of these filters. Referring to figure 5 again, it may be noted that the reclamation of wash water by multifiltration becomes economical with respect to weight for time periods prior to about 100 days; thereafter, a regenerative system is optimum.

COMPRESSION DISTILLATION

In the area of water reclamation of urine, only a few types of systems are most competitive. They may be roughly divided into those that employ a phase change, and those that do not.

Of the phase change techniques for the reclamation of water from urine, one process, that of vacuum compression distillation has been examined in great detail at the Langley Research Center. The principle of vacuum compression distillation is illustrated in figure 8. Several outstanding features make this type of system unique. It conserves the heat of vaporization of water, which represents a considerable saving over a direct evaporation process, since the heat of vaporization of water is about 1000 Btu's per pound. The conservation of this heat energy is a built-in feature of this type system, resulting from the fact that the driving function which causes the system to operate is a vapor compressor, rather than a heat source, as is used in conventional distillation.

In the construction of the system, the evaporator and condenser are brought into a heat-transfer relationship with each other, so that they share a common wall, which serves as a heat-transfer surface. The compressor, in compressing the vapor from the evaporator, also provides the conditions necessary to cause these vapors to condense at a higher temperature than the operating temperature of the evaporator. This promotes heat energy transfer across the common wall from the condenser to the evaporator, thus conserving, or reusing the heat of vaporization.

In operation, a purge valve is opened, and the system pressure is reduced until the vapor pressure of the waste liquid in the evaporator is reached. The compressor is then activated and

saturated vapors are moved into the condenser with an attendant rise in pressure. Invariably, these vapors will possess some degree of superheat, due to the compression. When the vapors contact the condenser walls, they give up their superheat and condensation occurs. Since condensation occurs at a higher temperature than evaporation, the heat of condensation can be recycled in the system. Under these conditions, the only energy required to sustain operation is that required to elevate the temperature of the saturated vapor in the condenser by compression to whatever value it must have to promote the desired rate of heat flow, which in turn, is a function of the desired water recovery rate.

A key factor here is the nature and area of the heat-transfer wall. If adequate heat transfer can be attained without resorting to high differential pressures, then the work load on the compressor is minimized and distillation is effected with low overall power consumption.

The Vacuum Compression Distillation System that has been evaluated is a flight prototype system having zero g operating capability. It was fabricated for the LRC under contract NAS1-1225. (See fig. 9.) It stands about 2 feet high, and weighs about 60 pounds. The cross section shown in figure 10 shows all the features of this device. It is basically a can-within-a-can type of structure with provision for rotating the inner can, the evaporator, during operation. It is driven by a gear train from the

main drive motor at about 70 rpm. This provides the centrifugal force necessary to insure operation under zero gravity conditions and acts to cause the waste liquid to spread uniformly along the heat-transfer wall. This not only solves the problem of phase separation under zero g, but places the waste liquid in a most advantageous position to absorb heat from the heat-transfer wall. When water vapor condenses on the outer wall of this rotating component, the condensed water will (due to this centrifugal force) be slung off, and will take up a position around the outer wall, maintained in this rotating position by vapor rotational coupling, thus insuring the phase separation. A small purge to vacuum is maintained during system operation to remove noncondensable gases such as ammonia and carbon dioxide. An additional advantage of this method of operation is that excessive quantities of such gases are not generated since phase change is effected at temperatures below 120° F.

Residue will build up in any type of water reclamation system employing phase change, unless provision is made to remove it. In the Vacuum Compression Distillation System there is a 0.005-inch-thick vinyl plastic liner, retained in place by a hard vacuum. This liner provides the capability of removing the residue and storing it with a minimum health hazard to the crew. The residue can be dried prior to this operation by opening the purge to the space vacuum, and allowing the residual water contained in the

residue to escape. While this is one way of coping with the residue buildup, it plays havoc with the heat-transfer characteristics of the wall. Operating on pure water as a control, the recovery economy of the system was brought from 35.3 watt-hours per pound to 20.7 watt-hours per pound, simply by removing the liner.

A partial analysis of the condensate for purity is included in figure 11. This analysis was made on condensate obtained from an input of human urine with no post-treatment whatever. These figures were subsequently upgraded by the introduction of an entrainment filter in the system.

Operating characteristics of this system are summarized in figure 12. No attempt has been made to operate a sterile system; therefore, plate counts were not taken. However, through the cooperation of the Electric Boat Division of General Dynamics in Groton, Conn., we did run an inhibited polio virus in the system and had no carryover into the condensate. This would seem to indicate that with suitable safeguards against entrainment carryover, the product water would be relatively free of micro-organisms.

AIR EVAPORATION SYSTEM

The second system which utilized phase change to effect the purification of water is shown in schematic form on figure 13. This system may be called an "air evaporation system" since it consists of a closed evaporation-condensation loop which utilizes air as a

circulating medium. This air carries the water vapor from the evaporator to the condenser. The raw urine enters a holding tank, wherein pretreatment additives are introduced. The result of this pretreatment is that the urine is rendered sterile, and, in addition, the urea, and other organics which are contained in the urine are rendered less susceptible to temperature destruction.

The pretreated urine is then fed to a series of wicks within the evaporator. The temperature and pressure of the evaporator are such that the water contained in the wicks evaporates, and recondenses in the heat exchanger on the other side of the loop. It is then separated from the air by a centrifugal separator, and led to a holding tank. Charcoal is provided in the loop to remove breakdown products of the urea and other organics, and prevent them from being picked up by the recondensed water.

The operation of this system requires that heat energy be added to the system, prior to the wicks, at a rate of about 1000 Btu's per pound of water to be evaporated. In addition, this same quantity of heat energy, 1000 Btu's, must be removed in the heat exchanger to recondense the water. If this energy were to be supplied by electrically operated heaters, the total electrical requirement would be 338 watt-hours per pound of water, with a resulting weight penalty of 17.4 pounds for the total power supplied for one-man operation. This penalty would, if applicable, render the system very unattractive. The heat energy supplied to

the system is derived, however, from a source of waste heat that is being carried from other heat sources to the radiator. Utilizing this source of heat penalizes the system for only that additional radiator surface area which is required to radiate the same quantity of heat energy, at a slightly lower temperature, lowered by the amount of heat which was utilized by the evaporator. The system is, therefore, penalized only 2.9 pounds per man for the total energy requirements including the waste heat. The overall weight penalty for this system amounts to the sum of the basic weight of the system, the waste heat penalty, the weight of the pre-treatment chemicals, and disposable wicks, and the weight of the charcoal used. Since the evaporation of water contained in the wicks is carried to near-dryness, the system is nearly 100-percent efficient. The only loss of water from the system is that which is contained in the wicks when they require replacement, and that trapped in the charcoal. The principal advantage of this system is its recovery efficiency and the low weight. The drawbacks, particularly for long-term missions, are the expendables which must be supplied.

The last two systems which will be discussed are electrodi-
alysis and reverse osmosis. Neither of these processes involve a
phase change.

ELECTRODIALYSIS

The mechanism of electrodi-
alysis (see fig. 14) consists of a
series of compartments that are separated by semipermeable membranes

having alternate properties. The membranes labeled "C" in the diagram are permeable only to positively charged ions such as sodium. The membranes labeled "A" in the diagram are permeable only to negatively charged ions such as chloride. If a stack of such compartments are placed in a field of d-c current, then positively charged ions will tend to migrate toward the cathode, and negatively charged ions will tend to migrate toward the anode. The overall effect is that these ions migrate into adjacent compartments where they are "trapped." By judiciously connecting many such "stacks" in series one can obtain from the system a concentrate and a dilute stream.

Electrolysis is very economical of electrical power since the power requirements are a function of the quantity of ions in solution and not so much upon the quantity of water that is processed.

The disadvantages of electrodialysis as a method of reclaiming water from urine would include the fact that urea and other non-ionizable substances cannot be removed by this technique. Therefore, the system must be penalized heavily for the expendable items required for pre- and post-treatment, primarily activated charcoal, in the presently conceived systems. Another disadvantage is that for various reasons the recovery efficiency is limited to about 95 percent, and in order to achieve better reclamation efficiencies, additional systems must be added to the basic electrodialysis unit.

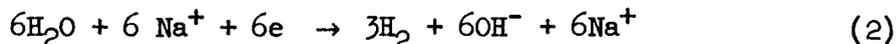
REVERSE OSMOSIS

Reverse osmosis is the process whereby a contaminated waste product, such as urine is placed next to a dialyzing membrane, and subjected to a hydrostatic pressure that exceeds the osmotic pressure of the solution. Under these conditions, water will pass out of the salt solution depending upon the selective properties of the membrane. Unfortunately, most membranes that will pass water will also pass urea. Therefore, pre-treatment is necessary to remove the urea and other organics in urine in order to obtain a potable product from the pressure cell. Figure 15 shows a block diagram of such a system. The practicality of such systems depend (as do the practicality of electro dialysis systems) upon effective pre-treatment techniques to remove urea and other organics from the waste stream. The LRC is promoting research in this area under contract NAS1-4373. The pre-treatment in this unit consists of an electrolytic pre-treatment technique that has been worked out to decompose urea into carbon dioxide, nitrogen, hydrogen, and water. This decomposition takes place by way of the following series of reactions:

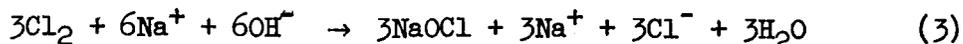
Anode:



Cathode:



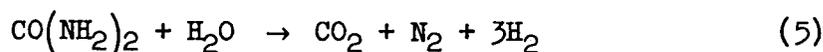
The chlorine produced at the anode reacts with the sodium hydroxide formed at the cathode to give hypochlorite ion,



the hypochlorite ion oxidizes the urea via the known reaction



The sum of (1), (2), (3), and (4) is



The hypochlorite formed via reaction (3) is, of course, a powerful oxidizer and disinfectant. In addition to attacking and decomposing the urea, it decomposes other organic compounds and sterilizes the water. Total bacterial count in test samples has gone from 9,900,000 to less than 5 per milliliter during an electrolysis run.

The reverse osmosis system, utilizing the electrolysis pre-treatment, operates to remove the remaining inorganic salts from the input. The osmotic pressure of the feed stream to the unit is due to the inorganic salts, and has been found to be about 175 pounds per square inch. That is, in order to produce purified water through the osmotic membrane, the pressure of the input, or contaminated side must exceed this 175 pounds. As water moves through the membrane from this stream, the salt concentration of the

remainder increases, and the osmotic pressure rises, necessitating higher operating pressures. Each unit molarity of dissolved salts contributes 381 pounds per square inch of osmotic pressure. Thus the ultimate water recovery is limited by the maximum pressure in the reverse osmosis cell. Water recovery without removal of these dissolved salts is limited to about 96.5 percent at a pressure of 5000 pounds per square inch.

Some of the advantages of this type of system are: (1) low weight, size, and power requirements; (2) operation is at ambient temperature; (3) byproducts from the electrolysis process are non-toxic and utilizable; (4) sterilization is inherent in the system; and (5) no expendables are required - a great advantage on long-term missions.

The electrolysis pre-treatment which has been perfected for this process was needed in order to make the system competitive with other systems. In doing this, a pre-treatment technique has been developed which shows merit when applied to other reclamation processes, particularly by eliminating the problems that are created by the urea in urine. For example, the compression-distillation system is penalized for the weight of the liners that contain residue in the system. Elimination of the urea results in a decreased amount of residue, and therefore, a decrease in the weight of these liners which are charged to the system. Applying the concept to waste heat air evaporation systems results in a decreased weight penalty for

wicks and charcoal. Applying the concept to electro dialysis results in decreased weight penalties for the pre-treatment chemicals and charcoal.

CONCLUDING REMARKS

In summary, a number of water reclamation system concepts have been reviewed, and their various advantages and disadvantages discussed. The efforts which are being made at the Langley Research Center, as well as elsewhere, are directed toward improving the state of the art. Referring to the dotted curve on figure 5, it is expected that these weight penalties can be met by incorporating new system concepts, such as the electrolysis pre-treatment, and others which are now in the planning stage.

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| OUTPUT | MATERIAL BALANCE, LB | WATER BALANCE, LB |
|---|-------------------------|----------------------|
| URINE (95% H ₂ O) | 3.24 | 3.08 |
| FECES (75.8% H ₂ O) | 0.29 | 0.22 |
| TRANSPIRED | 2.20 | 2.20 |
| CARBON DIOXIDE (1.63 lb O ₂) | 2.24 | |
| OTHER LOSSES | <u>0.14</u> | <u> </u> |
| | 8.11 | 5.50 |
| INPUT | | |
| FOOD | 1.5 | 0.15 |
| OXYGEN | 1.92 | 0.66 |
| METABOLIC WATER | <u>4.69</u> | <u>4.69</u> |
| | 8.11 | 5.50 |

NASA

Figure 1.- Man's daily balance.

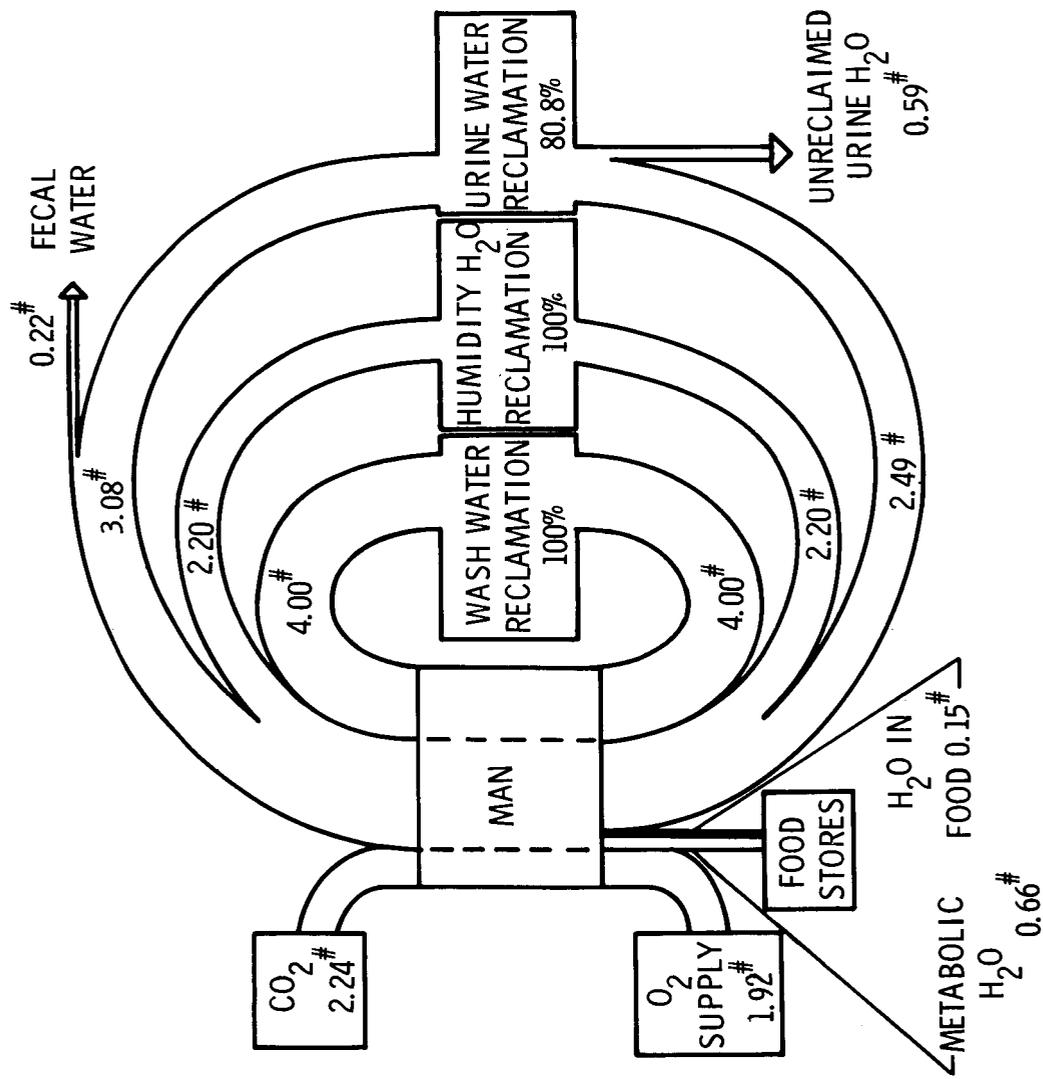
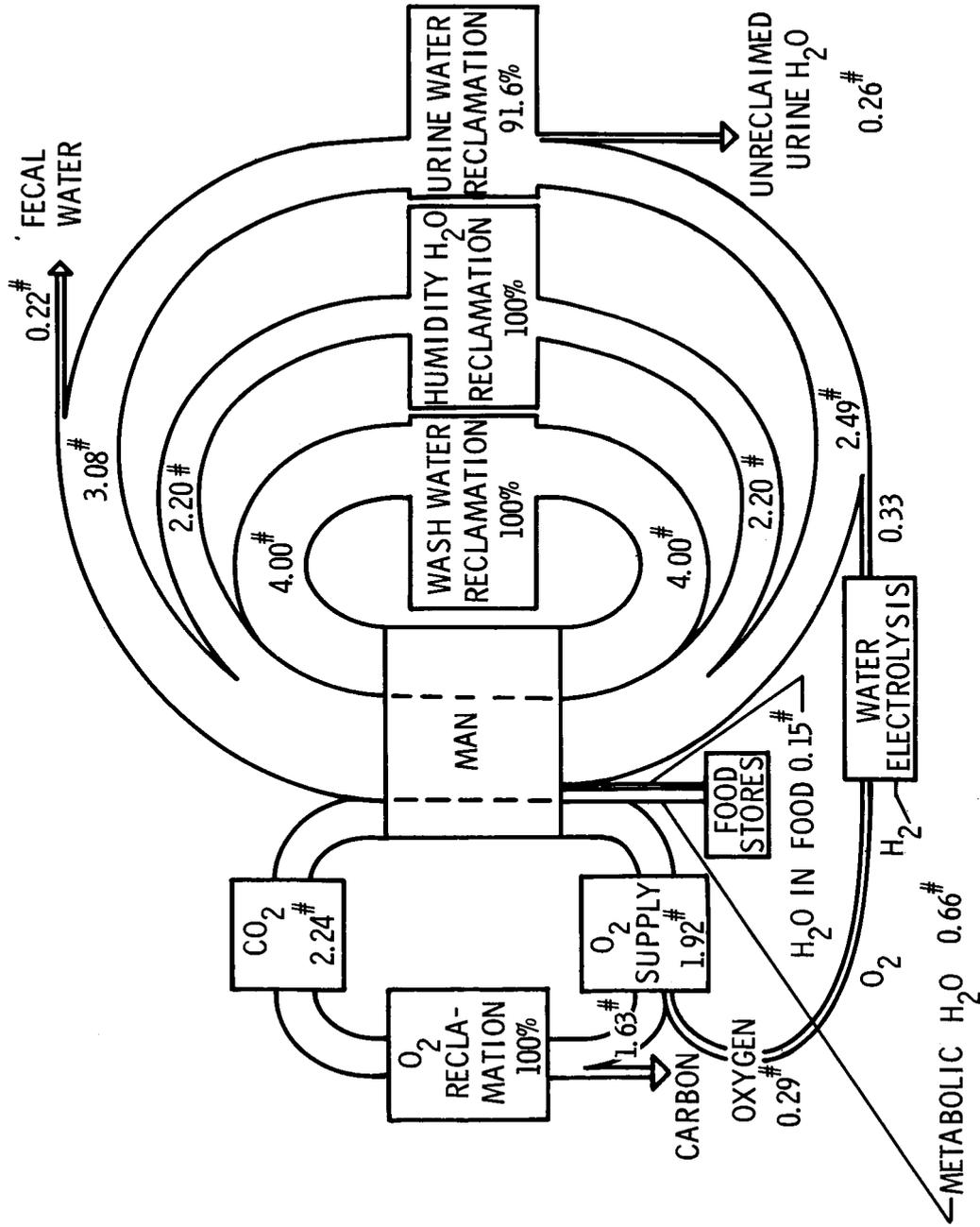


Figure 2.- Water reclamation for water balance only.



NASA

Figure 3.- Water reclamation with electrolysis to complete oxygen cycle.

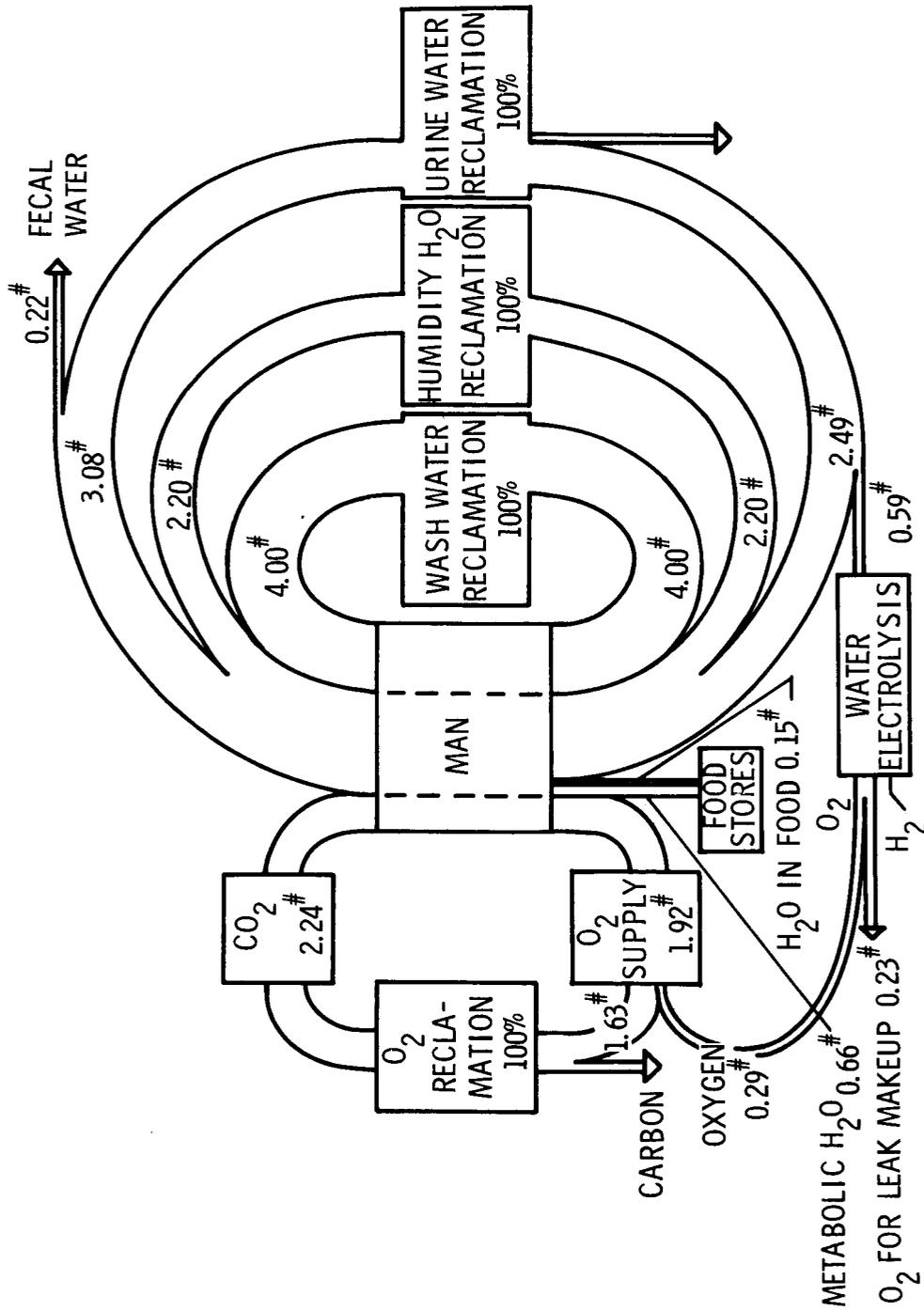


Figure 4.- Water reclamation with electrolysis to complete oxygen cycle and help compensate for cabin losses.

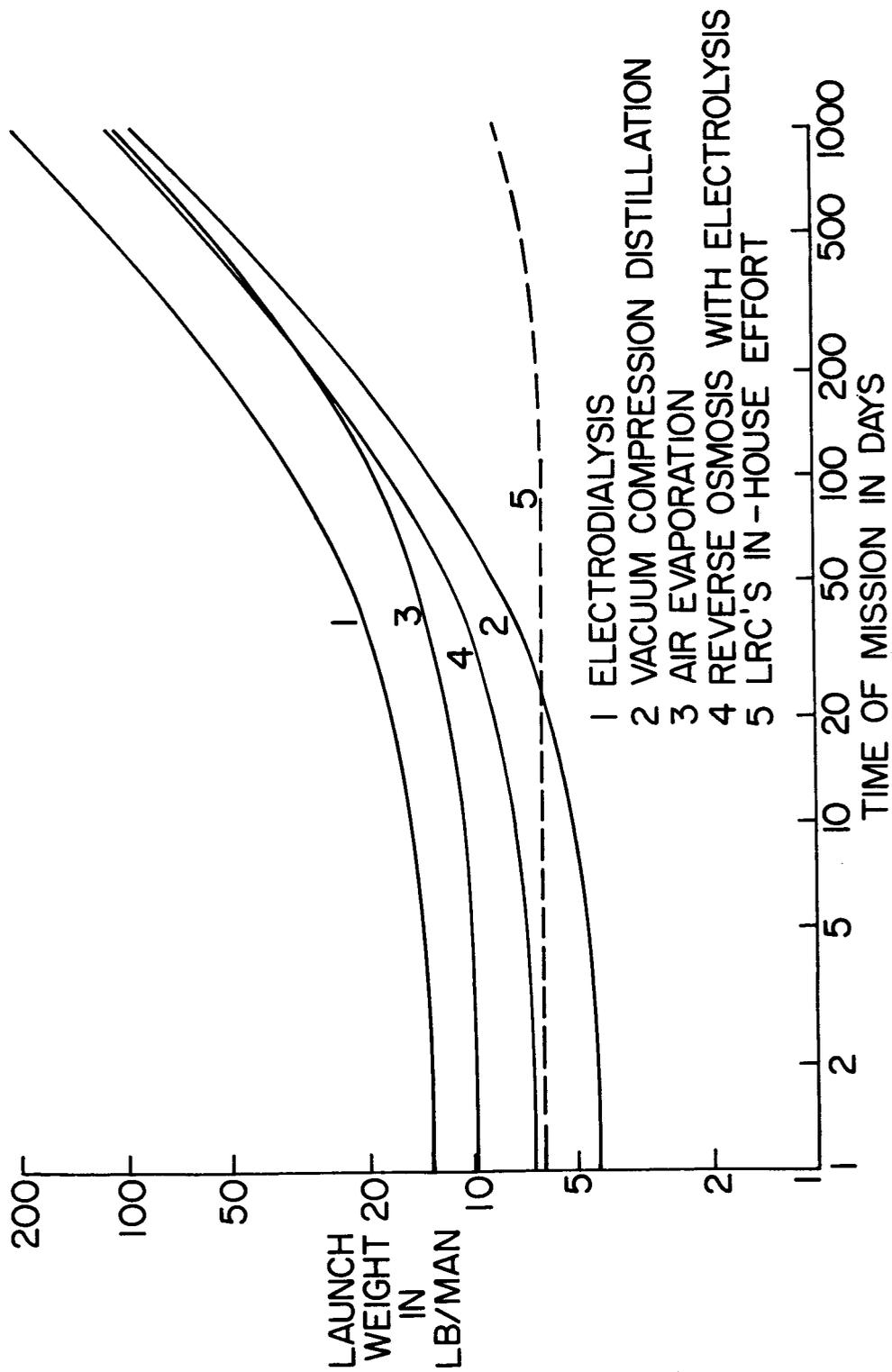
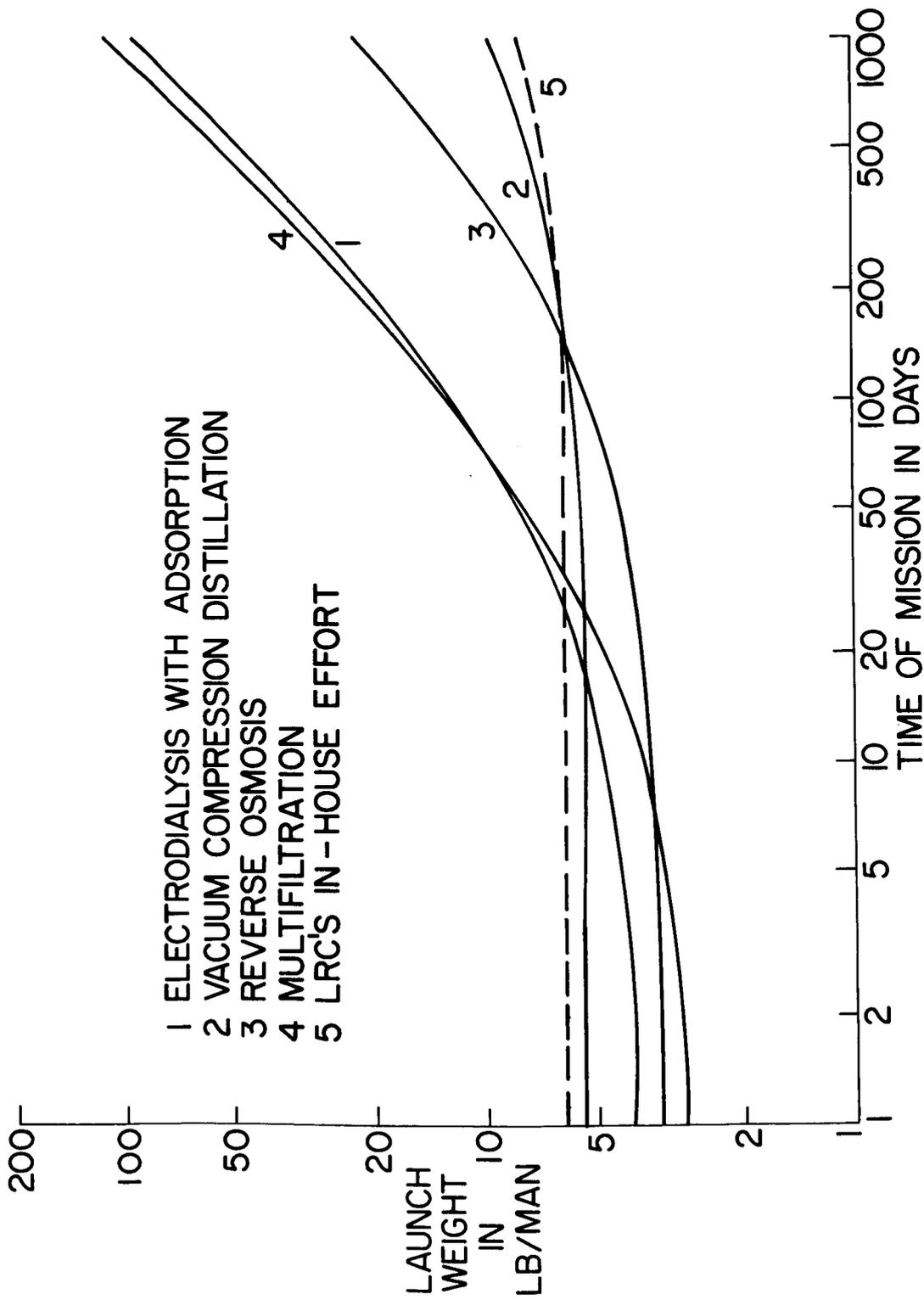


Figure 5.- Urine water reclamation systems.



- 1 ELECTRODIALYSIS WITH ADSORPTION
- 2 VACUUM COMPRESSION DISTILLATION
- 3 REVERSE OSMOSIS
- 4 MULTIFILTRATION
- 5 LRC'S IN-HOUSE EFFORT

Figure 6.- Wash-water subsystems.

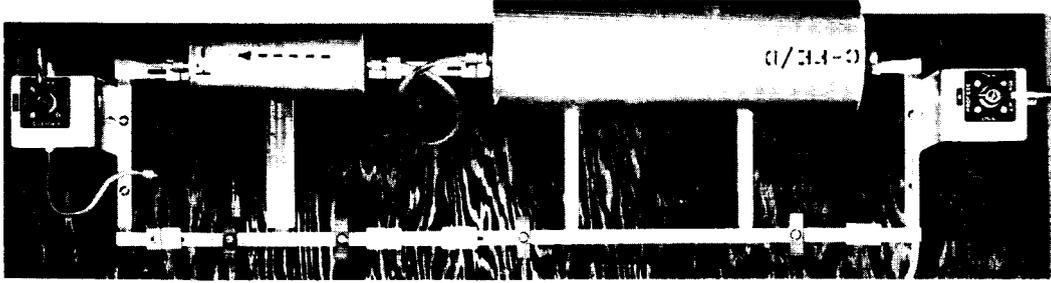


Figure 7.- Dehumidification water subsystem.

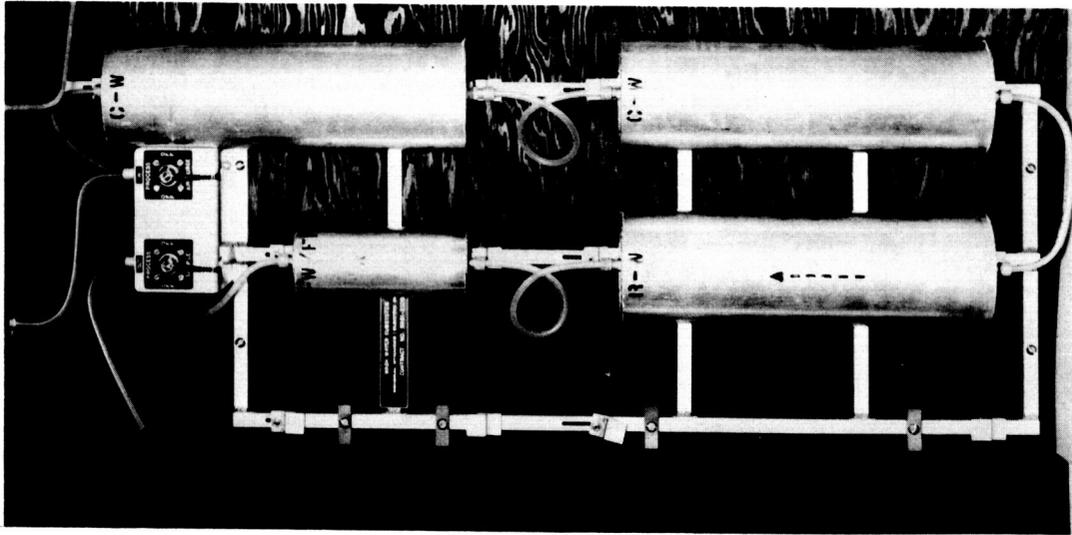
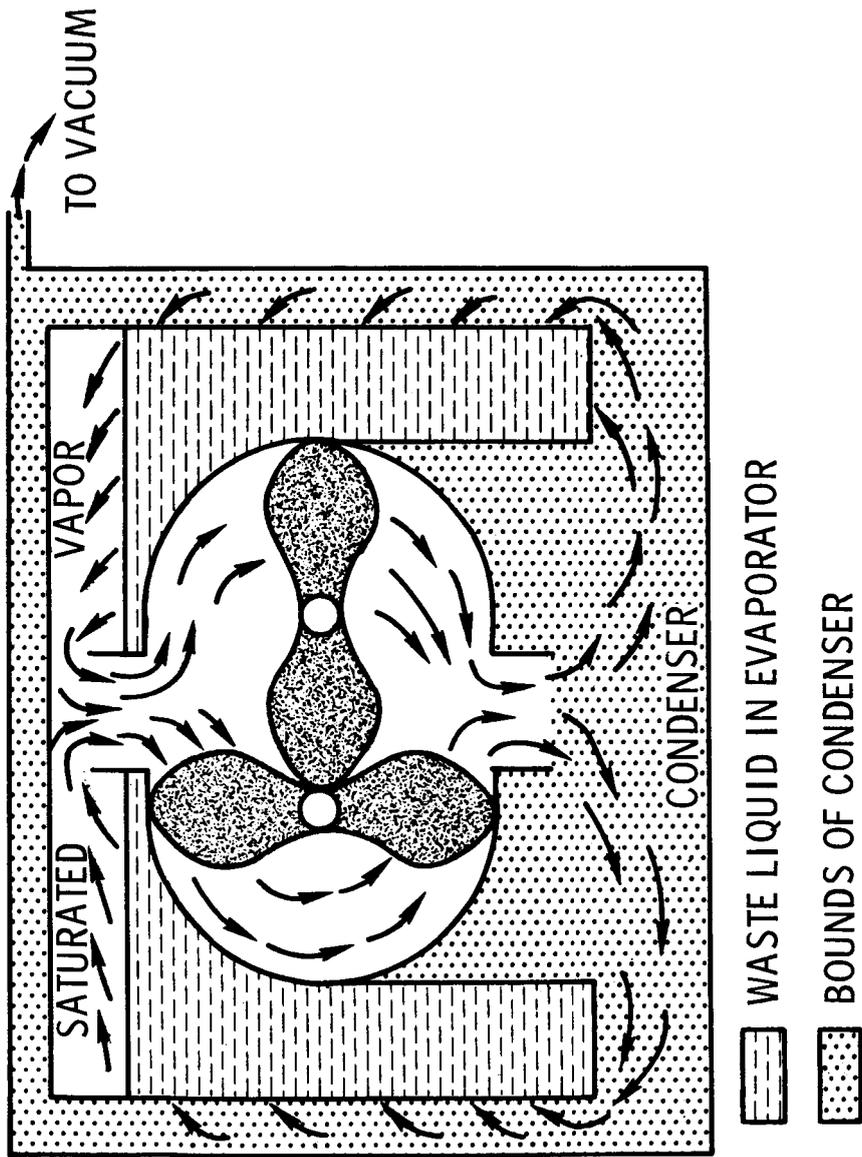
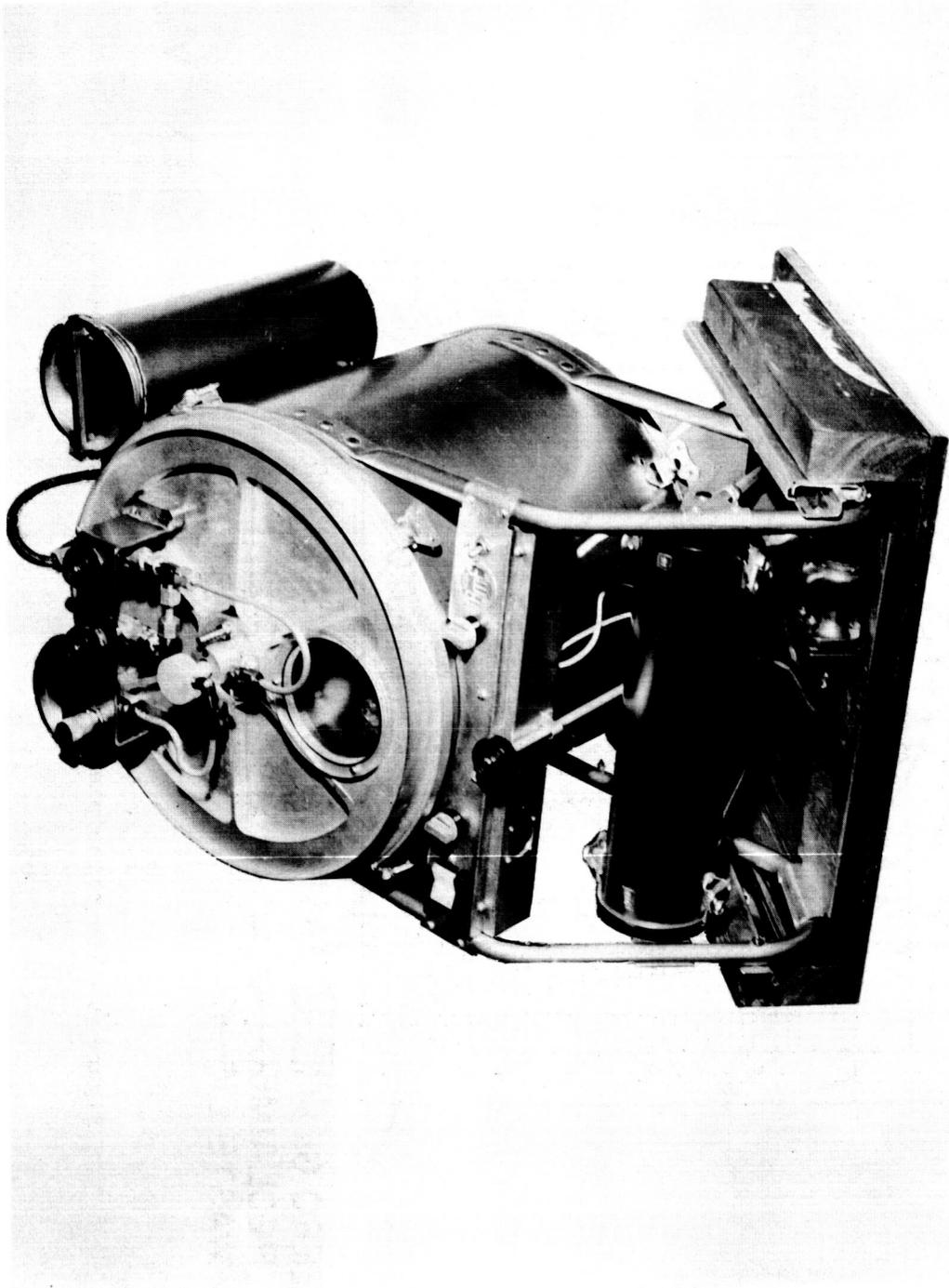


Figure 8.- Wash-water subsystem.



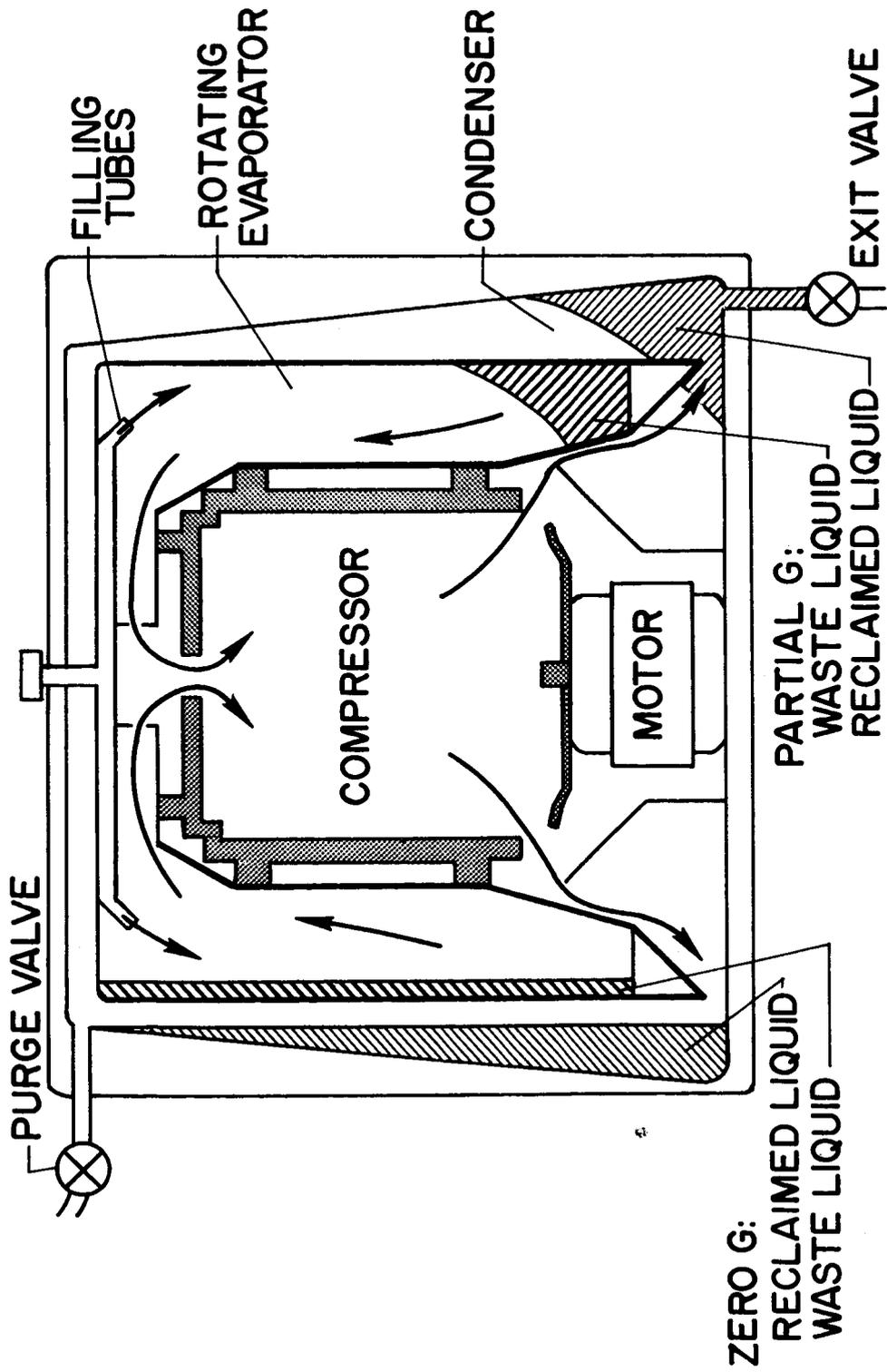
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Figure 9.- The principle of vacuum compression distillation.



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Figure 10.- Water reclamation system.



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Figure 11.- Water reclamation system.

| | |
|------------------|---------------------|
| COLOR | NONE |
| ODOR | SLIGHTLY DETECTABLE |
| pH | 6.7 TO 8.8 |
| AMMONIA NITROGEN | 3.6 TO 5.4 PPM |
| UREA NITROGEN | NONE |
| CHLORIDE | 2 PPM |
| OXYGEN CONSUMED | 2 PPM MAXIMUM |
| TOTAL SILICA | 2.4 PPM |
| TOTAL SULFATE | 2.96 PPM |
| ASH | NONE |
| CONDUCTANCE | 35 TO 42 μ MHOS |

* HENRY SOUTHER ENGINEERING CO., SAMPLES WERE TAKEN AFTER MORE THAN FOUR HR OF OPERATION ON HUMAN URINE.

NASA

Figure 12.- Partial analysis of condensate from vacuum compression distillation system.

| | |
|---|------------------------|
| RECOVERY RATE | 3.14 LB/HR |
| RECOVERY ECONOMY | 38.6 WATT-HR/LB |
| CHEMICAL PRETREATMENT USED | 0.6 G/LB OR 0.13% |
| POST-TREATMENT REQUIRED FOR POTABILITY | NEGLECTIBLE |
| OPERATING TEMPERATURE RANGE | |
| EVAPORATOR | AMBIENT TO 120 |
| CONDENSER | 90 TO 130° F |
| OPERATING PRESSURE RANGE | |
| EVAPORATOR | 1.2 TO 3.4 IN. HG. |
| CONDENSER | 1.4 TO 4.5 IN. HG. |
| WATER LOST THROUGH PURGE | LESS THAN 1.1% |
| RATE OF PURGE OF NON-CONDENSABLES INCL. | |
| ATMOSPHERIC LOSS THROUGH LEAKS | LESS THAN 0.6 LITER/HR |
| SYSTEM WEIGHT | 59 LB |
| RECOVERY EFFICIENCY | 97.3% |

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Figure 13.- Operating characteristics of vacuum compression distillation water reclamation system.

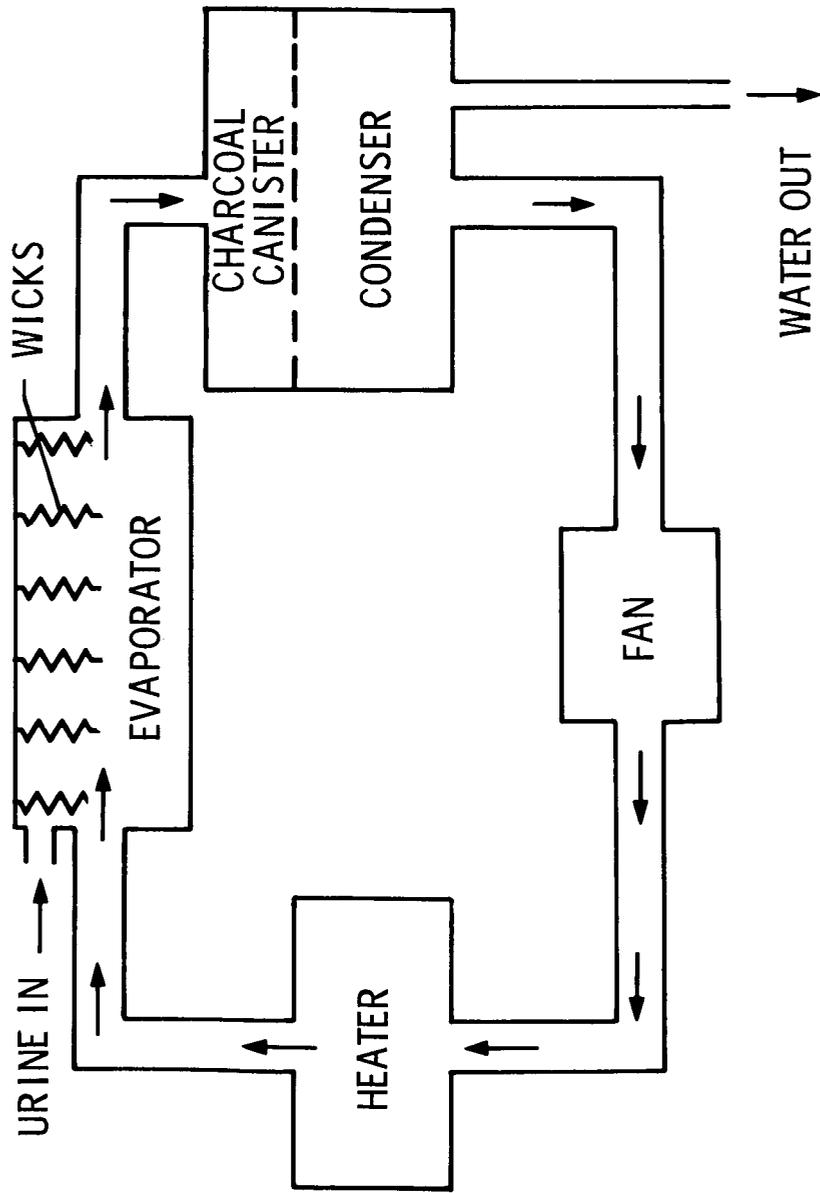
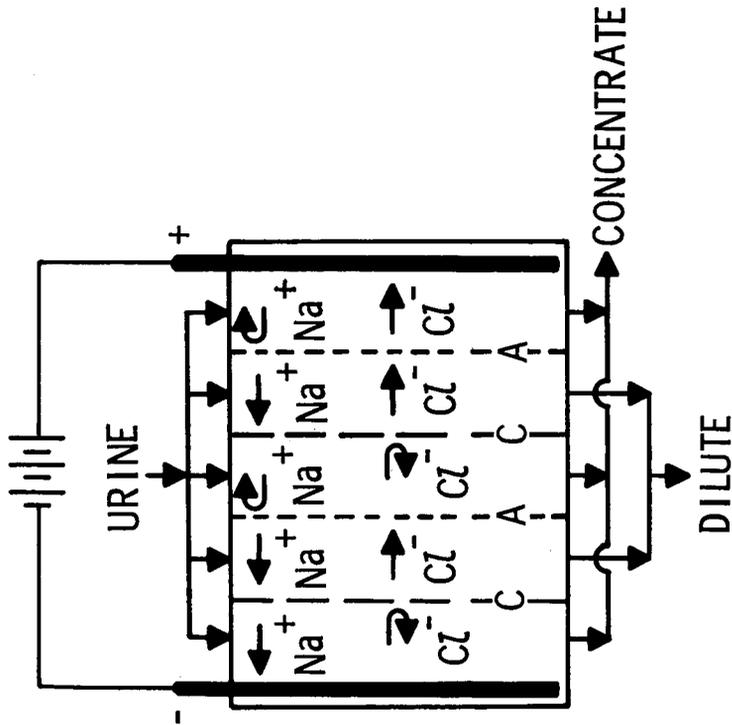


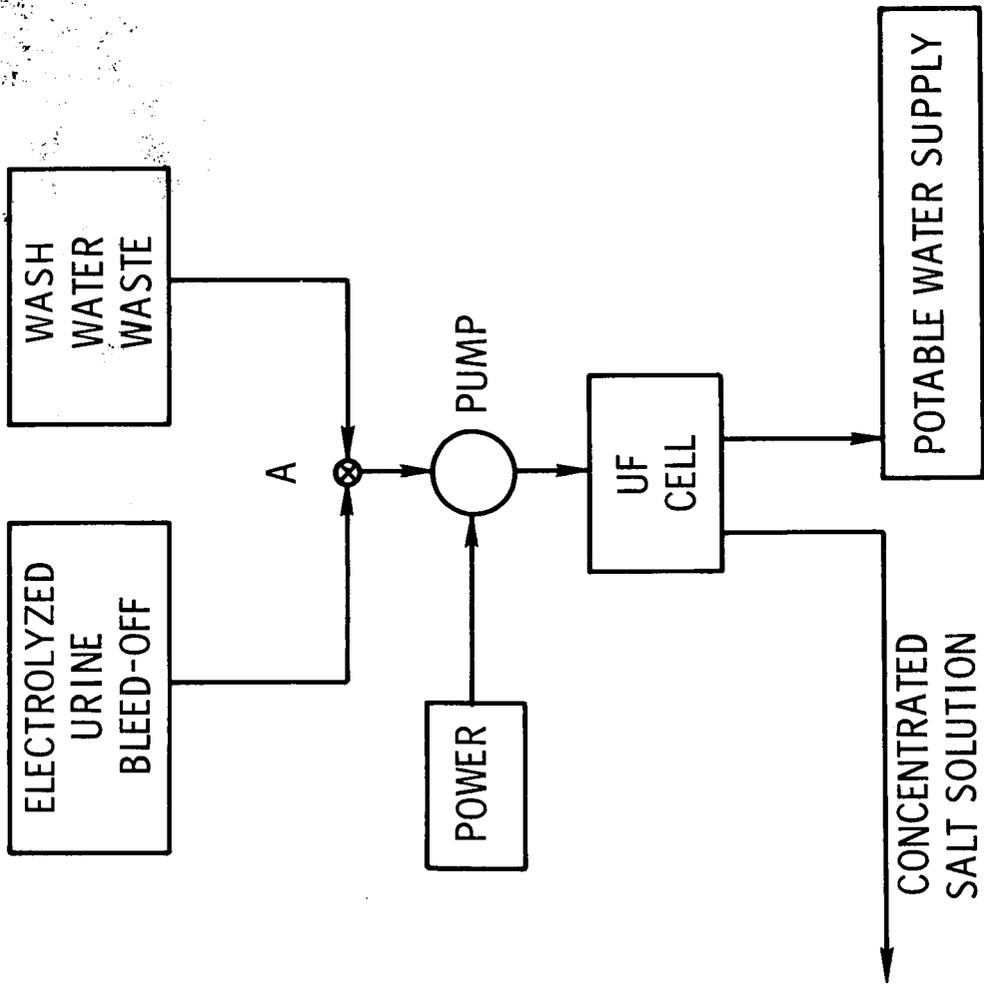
Figure 14.- Air evaporation system.



A = ANION TRANSFER MEMBRANE
 C = CATION TRANSFER MEMBRANE

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Figure 15.- Electro dialysis cell.



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Figure 16.- Ultrafiltration module.