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EVALUATION OF WATER RECLAMATION SYSTEMS AND  
ANALYSIS OF RECOVERED WATER FOR HUMAN CONSUMPTION

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## Foreword

This research study was initiated by the Biotechnology Branch, Life Support Division, Biomedical Laboratory, Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio. The study was conducted in support of project 6373, "Equipment for Life Support in Aerospace," and task 637304, "Waste Recovery and Utilization." The program was under the supervision of C. A. Metzger. Principal investigator was Albert B. Hearld with technical support provided by Master Sergeant Bobby G. McMullen. Additional support was provided by Staff Sergeant Carl Gailey and Master Sergeant Walter Bigelow.

The analytical data referenced was furnished under Contract DO (33-657)-63-377 by the Robert A. Taft Sanitary Engineering Center (U. S. Public Health Service), Cincinnati, Ohio. Robert C. Kroner was in charge of the General Laboratory Services, Water Quality Section, which performed the analyses.

All of the water recovery systems discussed in this report were developed either by the Aerospace Medical Research Laboratories or on Government contracts.

This technical report has been reviewed and is approved.

WAYNE H. McCANDLESS  
Technical Director  
Biomedical Laboratory  
Aerospace Medical Research Laboratories

## **Abstract**

Analyses were made of water recovered from human urine and from atmospheric condensate collected during manned tests inside a sealed chamber. Data on more than 200 samples were prepared for comparison with that of distilled water and tap water and with U. S. Public Health Standards for drinking water. Most of the samples were suitable for human consumption. Candidate systems for recovering potable water from urine were evaluated. Thermoelectric, electrodialysis, and vapor compression water reclamation devices were determined to be suitable for use during extended aerospace missions.

## Table of Contents

<i>Section</i>	<i>Page</i>
I. INTRODUCTION.....	1
II. SYSTEM EVALUATION.....	2
Techniques.....	2
System Operation.....	2
III. SAMPLING AND RESULTS.....	9
IV. CONCLUSIONS.....	26
APPENDIX – SURVEY OF WATER RECLAMATION SYSTEMS.....	28
REFERENCES.....	29

## List of Illustrations

<i>Figure</i>	<i>Page</i>
1 Vapor Compression System.....	3
2 Evaporator/Condenser.....	3
3 Electrolysis Unit.....	4
4 Ultrafiltration System.....	4
5 Membrane Permeation System.....	5
6 Electrodialysis System.....	6
7 Dehumidification System.....	7
8 Main Assembly – Thermoelectric Unit.....	8
9 Thermoelectric Still.....	8

## List of Tables

<i>Table</i>	<i>Page</i>
Ia-Ij. Analytical Results – Reclaimed Waters.....	16 through 25
II. Water Reclamation Systems.....	28

## SECTION I.

# Introduction

Since 1958, the Aerospace Medical Research Laboratories has been engaged in the study of techniques that have been proposed for recovering potable water from human urine, wash waters, and dehumidification water during earth-orbiting aerospace missions. The study has resulted in an evaluation of the techniques and in the testing of hardware which incorporate some of the techniques. The study is far from complete and will be continued with a more comprehensive evaluation and testing of those systems that are potentially most suitable for aerospace application.

Objectives of this program were: (1) to determine the quality of water recovered from human urine and dehumidification water with off-the-shelf equipment and with devices designed specifically for demonstrating water recovery techniques; (2) to ascertain the changes that occur in the recovered water when the pretreatment, method of processing, and/or posttreatment are altered; (3) to evaluate existing recovery systems for aerospace application and to select for further study the systems having the greatest potential; and (4) to provide industry and other agencies with data that would be of value in future development efforts and in studies of water quality, i.e., the relation between pH and COD or the chloride content of water recovered from urine by vapor distillation and by compression distillation.

## SECTION II.

# System Evaluation

### TECHNIQUES

The techniques used for reclaiming the water are listed below and are identified by the abbreviations shown in the process column of the analytical data sheets, tables Ia-Ij.

VD – Vacuum Distillation

VC – Vapor Compression

E – Electrolysis

UF – Ultrafiltration

MP – Membrane Permeation

ED – Electrodialysis

UFC – Unfiltered Condensate

FC – Filtered Condensate

TE – Thermoelectric Distillation

F Cell – Fuel Cell

Data on distilled water (DW) and tap water (TW) are included for comparison with the data on the recovered water, especially that recovered from urine. The distilled water was purchased locally. The tap water was drawn from the Wright-Patterson Air Force Base water system.

### SYSTEM OPERATION

Descriptions of the systems used to illustrate the techniques follow.

*Vapor Compression* – Two vapor compression water recovery systems were evaluated. One Model MR 08-082, was procured from Mechanics Research Division, General American Transportation Corporation, Niles, Illinois (ref 1). The vapor compression system (ref 2) was procured from General Dynamics/Electric Boat, Groton, Connecticut. An artist's concept of the MR 08-082 system is shown in figure 1. A schema of the evaporator/condenser (Electric Boat system) is shown in figure 2.

In both systems the water in the urine is evaporated under reduced pressures. The vapor is fed through a compressor into a condenser where the reclaimed product is collected. That latent heat rejected during the condensation is transferred back to the evaporator for reuse in vaporizing more water. Heat from an electric motor and/or from a heating coil is used to speed the evaporation and to replace heat lost to the surrounding atmosphere.

*Vacuum Distillation* – This system consists of a boiler in which urine is evaporated under reduced pressure. The vapors are drawn into a condenser and the product water collected is drained to a reservoir. The vapors are caused to pass through activated charcoal and/or a microporous glass fiber cloth. An excellent description of a typical vacuum distillation apparatus is contained in reference 3.

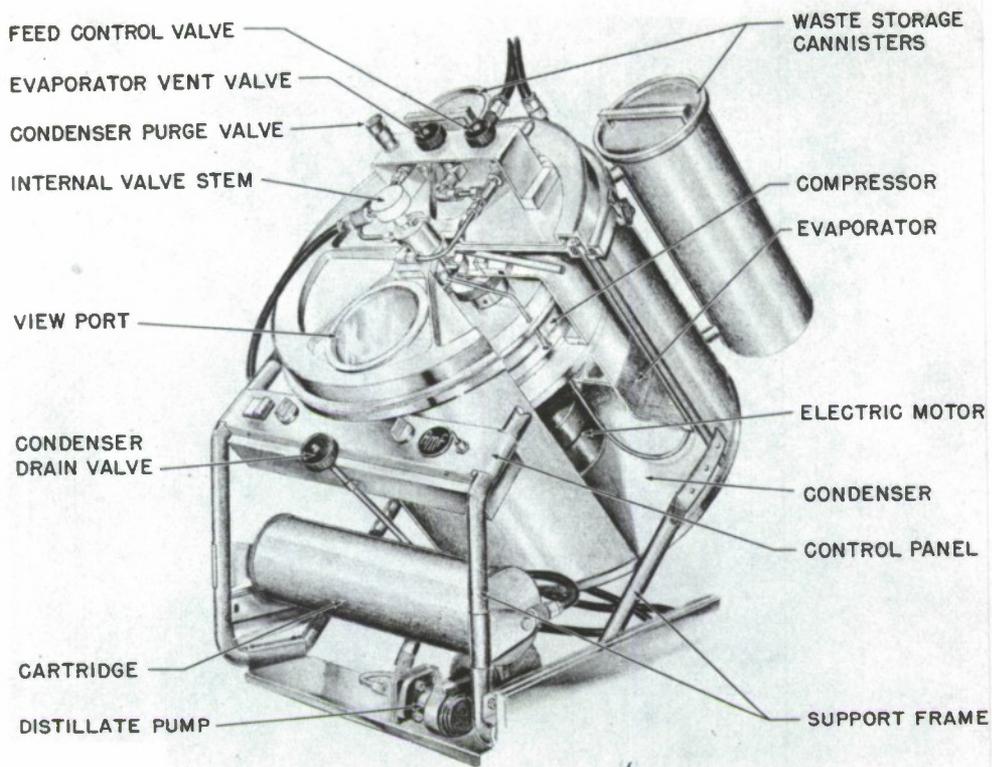


Figure 1. Vapor Compression System

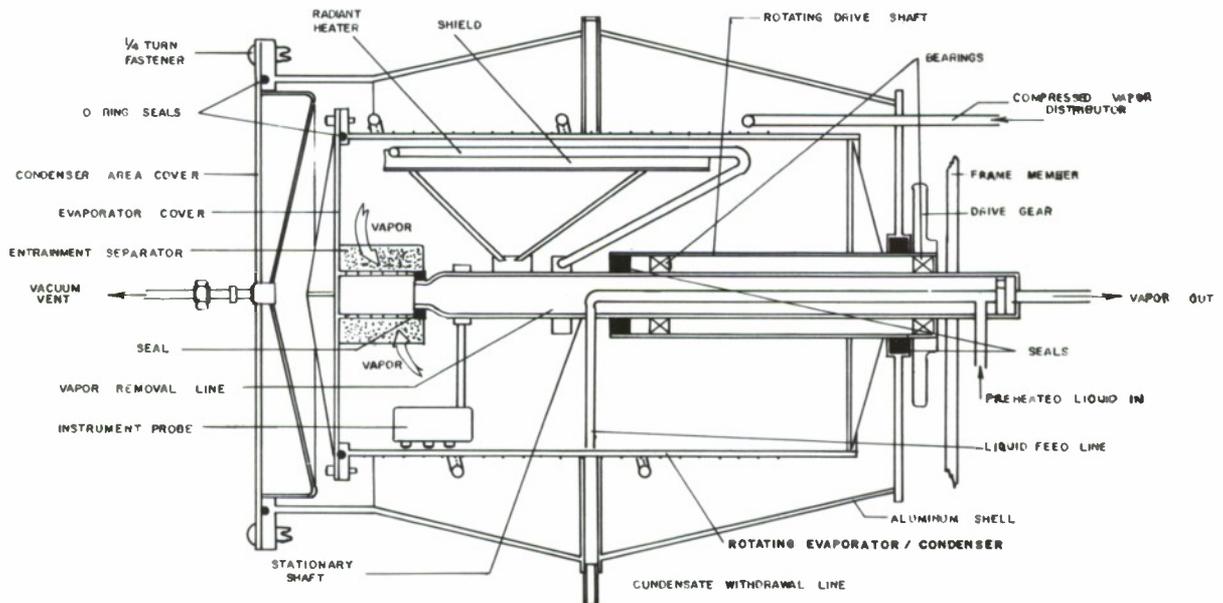
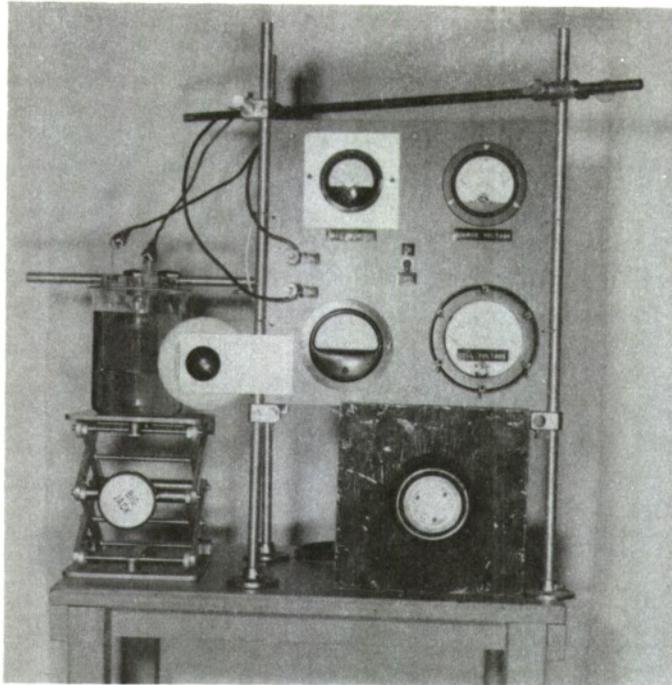
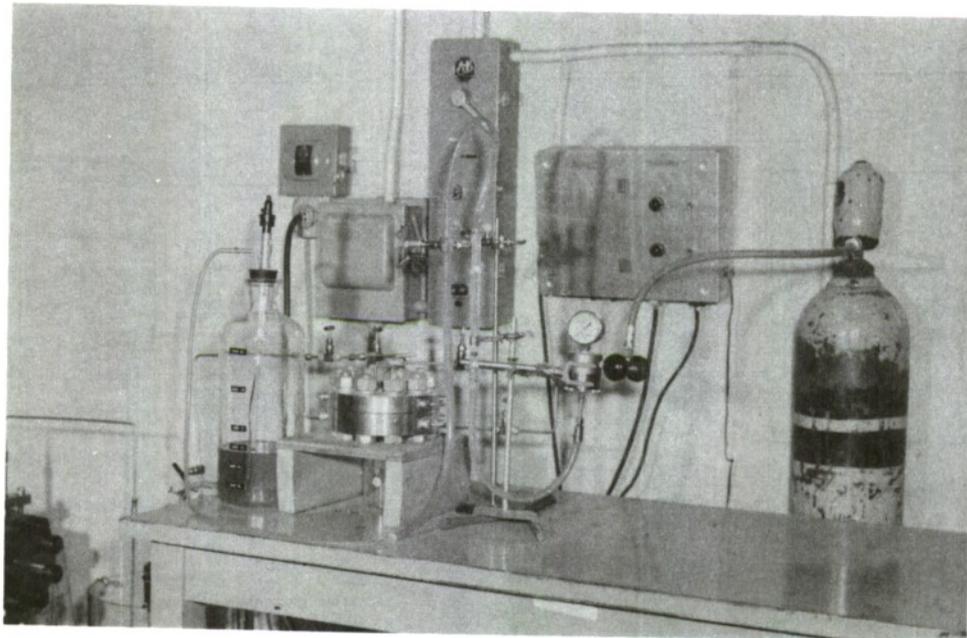


Figure 2. Evaporator/Condenser



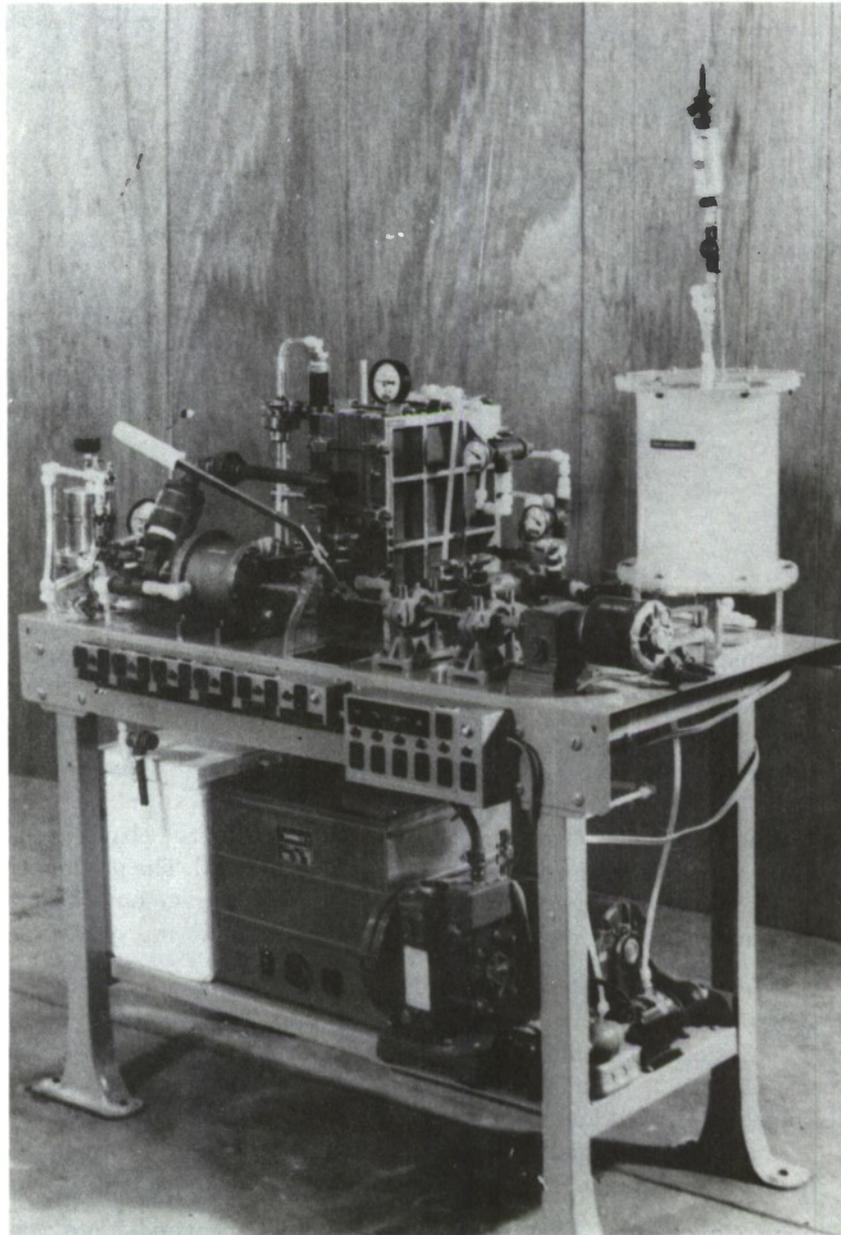
**Figure 3. Electrolysis System**



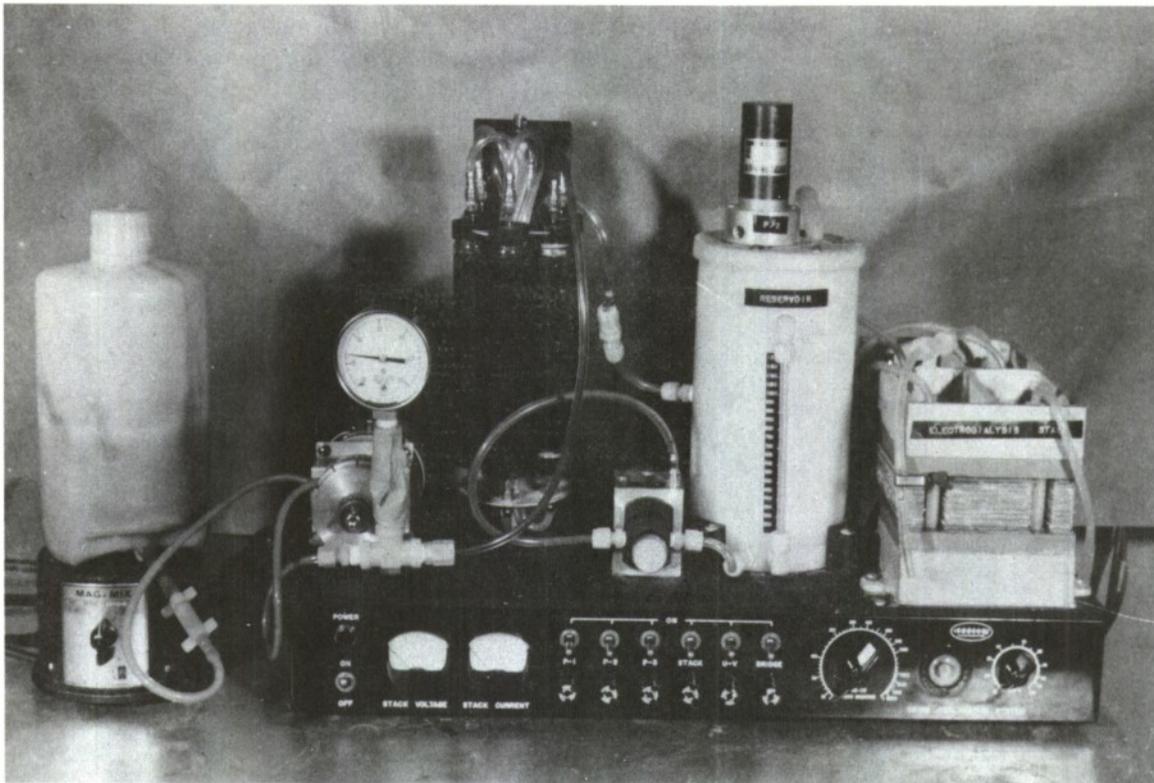
**Figure 4. Ultrafiltration System**

*Electrolysis* — the system used is shown in figure 3. A d-c current is passed through the urine from one platinum electrode to another. The chlorine produced at the anode reacts with the sodium hydroxide formed at the cathode and the hypochlorite formed decomposes the urea and other organics in the urine. The process lowers the pH of the recovered water and bacterial growth is eliminated.

*Ultrafiltration* — Urine that has been pretreated to remove urea and calcium is circulated over a membrane under a pressure greater than the osmotic pressure of the urine. Water passing



**Figure 5. Membrane Permeation System**



**Figure 6. Electro dialysis System**

out of the urine through the membrane is collected. The process is described in references 4, 5, 6, and 7. The ultrafiltration unit was procured from Radiations Applications, Incorporated, and is shown in figure 4.

*Membrane Permeation* – Hot urine is circulated through a permeator where the urine flows across two selectively permeable membranes. Water from the urine permeates the membranes and evaporates into a vacuum chamber. The vapor flows from the chamber through an ion exchange resin into a condenser where the product water is collected. The product is then pumped through a charcoal filter and a 0.45-micron (pore size) filter to a storage tank. The permeation system (ref 8) was procured from Ionics, Incorporated. Figure 5 shows the system.

*Electrodialysis* – This system (refs. 9 and 10) is shown in figure 6 and was procured from Ionics, Incorporated. Urine pretreated to precipitate a portion of the calcium and urea is pumped through a series of carbon filters into a reservoir from which it is circulated through a stack. The stack consists of compartments separated by alternating anion permeable and cation permeable ion exchange membranes and is located between a pair of electrodes. A d-c current passed through the stack results in the formation of two streams – a waste brine stream and a dilute or potable water stream. The pretreatment used consisted of silver nitrate plus oxalic acid in distilled water.

*Filtered Condensate* – Unless otherwise stated, the condensate was collected inside the AMRL Life Support Systems Evaluator during confinement studies involving four men for periods

of up to 28 days. All condensate was condensed from the atmosphere on a finned aluminum heat exchanger and drained to a sample bottle or pumped through one or more filters to a sample bottle. The samples were then submitted for analysis. Figure 7 is a schematic of one system used.

*Unfiltered Condensate* – All unfiltered condensate was collected inside the AMRL Evaluator and was submitted for analysis without being processed in any manner.

*Thermoelectric Distillation* – Urine is evaporated under reduced pressure and at a temperature of approximately 104 F (40 C). The resultant water vapor migrates to a series of condensers where it is condensed. The latent heat of condensation is thermoelectrically pumped back to the boiler for reuse. The product water flows from the condensers through a charcoal filter into a potable water storage tank. A schematic of the main assembly of the thermoelectric unit is shown in figure 8. An external view of the still is shown in figure 9. The thermoelectric distillation device is described in reference 17.

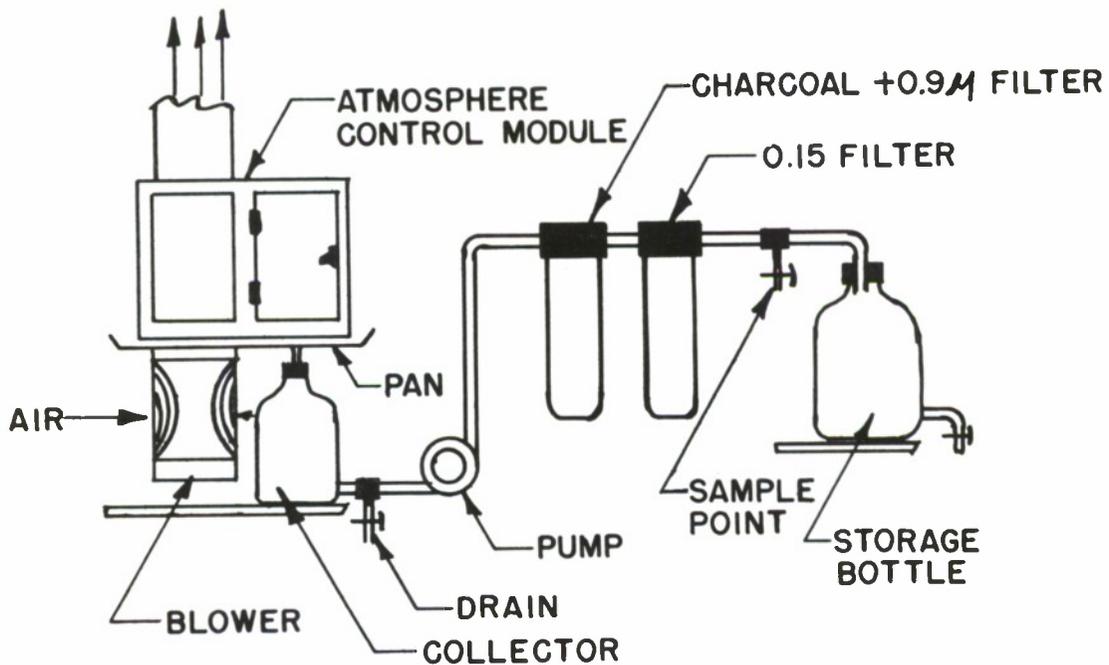
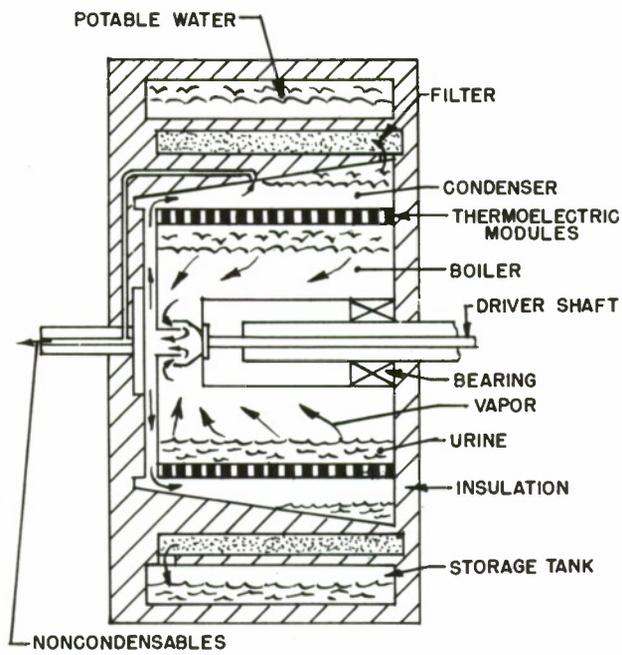
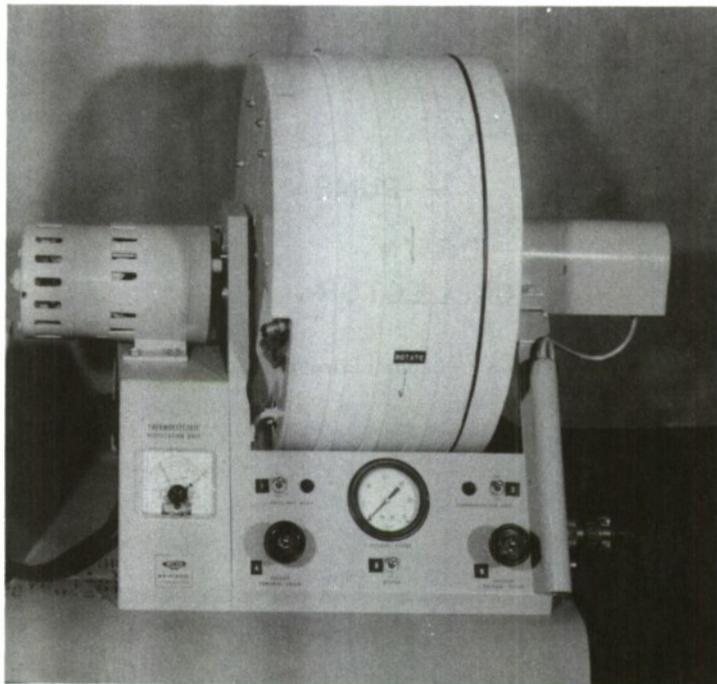


Figure 7. Dehumidification System



**Figure 8. Main Assembly – Thermoelectric Unit**



**Figure 9. Thermoelectric Still**

## SECTION III.

# Sampling and Results

More than 200 samples of water were recovered and submitted to Taft Sanitary Engineering Center (TC) for analyses. The processing varied — often from sample to sample. These differences are noted in the discussion of the samples which is contained herein. The analytical data were grouped, where convenient, in tables so as to illustrate one recovery technique. This grouping permits the data to be readily compared with the U. S. Public Health Standards for drinking water and with data on water reclamation by several techniques.

Following are the techniques used:

### **VAPOR COMPRESSION — See table Ia.**

All samples were recovered by means of the Model 08-082 vapor compression distillation unit procured from MRD Division, General American Transportation Corporation. Unless otherwise specified, the recovered water was pumped through the filters at approximately 2 gallons per hour. Three to 4 liters of urine were processed for each sample.

Data on methods of processing follow:

*Sample 1* — The urine was pretreated with one HTH (Hypochlorite 70% Cl tablet) and 10 drops of Antifoam B (Dow Corning). The water recovered was pumped through a 3 $\frac{3}{8}$ -inch inside diameter column containing 1130 grams of Hydrodarco activated carbon, 260 grams of Dowex 50W-X10 cation exchange resin, and a 1-inch thick glass wool filter.

*Samples 2 and 3* — Processed same as sample 1 except that the urine was pretreated with 10 grams merthiolate per liter of urine in lieu of the HTH tablet.

*Samples 4-7* — The urine was pretreated with merthiolate as in samples 2 and 3. The recovered water, however, was pumped up through a 4-inch diameter carbon (Nuchar C-190) column consisting of 3 inches of coarse carbon plus 12 inches of fine carbon plus 3 inches of coarse carbon at approximately  $\frac{1}{4}$ -gal. per minute.

*Samples 10, 11, 12, and 14* — Untreated urine, with 10 drops of Antifoam B added to prevent foaming, was processed. The residue from samples 10, 11, and 12 was left inside the evaporator. All water recovered was pumped through a 0.15-micron\* filter that was later found to be defective.

*Samples 15-17* — The evaporator and condenser were cleaned and flushed with distilled water. A new evaporator liner was installed and two operations to flush the machine were made with a mixture of distilled water and benzalkonium chloride (BAC). The residue from the flush was left in the evaporator. The urine processed was pretreated with 10 grams of trimethylol nitromethane and ten drops of Antifoam B were added to prevent foaming. The product was pumped through a 0.15-micron filter.

*Samples 18 and 19* — The machine was thoroughly scrubbed and flushed. A new evaporator liner was installed and the machine sterilized with cryoxide gas at  $\frac{1}{2}$  psig for 5 $\frac{1}{2}$  hours then flushed for 16 hours with air passed through a sterilized filter. Four liters of sterile injection water were processed. For sample 18, the product was drawn directly from the machine. For sample 19, the water was pumped through the 0.15-micron filter used for samples 15-17.

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\*Nominal pore opening.

*Sample 20* – Urine pretreated with 10 grams of trimethylol nitromethane and 10 drops of Antifoam B was processed on the residue left in the evaporator from samples 18 and 19. The recovered water was pumped through the filter used for samples 15-19.

*Sample 25* – Urine with 10 drops of Antifoam B, was processed. The recovered water was drawn directly from the machine. Approximately 1 liter of water was recovered. This was not enough for the spectrographic tests.

*Sample 32* – Urine with no additives was processed with the plastic evaporator liner removed from the machine. The sample was drawn directly from the machine.

#### **MISCELLANEOUS TECHNIQUES – See table Ib.**

Vapor compression, electrolysis, ultrafiltration, membrane permeation, and electro dialysis were employed in the recovery of the samples listed on table Ib. Data on the individual processings follow:

*Sample 13* (Vapor Compression) – Approximately 2500 ml of urine with one HTH-hypochlorite tablet 70% Cl added was processed in a unit procured from General Dynamics/Electric Boat (EB). The distillate was filtered through S&S #595 analytical paper to remove debris from the machine then through a sterilized 0.15-micron filter.

*Sample 22* (Electrolysis) – The sample was recovered by passing a d-c current (2 amperes) through a 1-liter beaker filled with untreated urine. A platinum plate (+) and a platinum gauze (–) were used as the electrodes. The urine was cooled by means of a water bath into which the beaker was placed. Six volts were applied to the electrodes. The electrolyzed product was filtered through S&S #595 paper.

*Sample 23* (Ultrafiltration) – Three liters of urine were pretreated with 4.3 grams of urease and mixed for 61 hours at room temperature. The digested urine was filtered through coarse filter paper to remove sediment and excess urease. Citric acid (143 gm) was added for ammonia neutralization.

*Sample 24* (Ultrafiltration) – Three liters of urine were processed after being pretreated with 4.3 grams of urease, mixed for 66 hours at room temperature, filtered and 98 grams of citric acid added.

*Samples 26 and 27* (Membrane Permeation) – The urine was processed without pretreatment.

*Sample 33* (Ultrafiltration) – The urine (2.6 liters) was processed after being pretreated with 7 grams of urease, mixed for 64 hours at room temperature, filtered and 237 grams of citric acid added.

*Sample 136* (Ultrafiltration) – This sample was processed in the same manner as sample 33 except that an unused membrane was installed in the recovery device.

*Samples 138 and 139* (Electrolysis) – For each sample, 2 liters of urine were processed for 24 hours at 9 volts and 10 amperes. All values are approximate.

*Sample 174* – This is distilled water (DW). It is included for comparison purposes.

*Sample 175* – Urine was processed by electrolysis for 24 hours at 9 volts and 10 amperes then by ultrafiltration. The first process was intended to remove the organics; the second to remove the salts.

*Sample 191* – This sample (TW) was taken from the fresh water tap of the Wright-Patterson water distribution system. It is included for comparison purposes.

*Samples 194-196* (Electrolysis) – These were recovered from urine in the manner shown for samples 138 and 139. They were pooled then treated as follows:

*Sample 194* – No treatment.

*Sample 195* – Filtered up through a 6-inch long by 1-inch diameter column of 12 x 30 mesh pecan shell activated charcoal at approximately 3 liters per hour.

*Sample 196* – Filtered through the pecan shell filter then through an ion exchange resin (Filter-Ion).

*Samples 78 and 266-269* – These were recovered by electro dialysis.

*Samples 249 and 250* – Urine was electrolyzed at approximately 9 amperes and 5-6 volts d-c for 24 hours and then forced (ultrafiltration) through a cellulose acetate membrane having a thickness of approximately 5 mils and a pore size of less than 1  $\mu$ .

### **ELECTRODIALYSIS – See table Ic.**

All samples reclaimed by electro dialysis were recovered by a system purchased from Ionics, Incorporated (I). Effort was made to follow the operating instructions outlined by the manufacturer even though the early recovery attempts were frequently attended with mechanical and electrical difficulties. Following the recovery of sample 134, a fire in the base of the unit destroyed almost all of the electrical components making it necessary to return the device to the manufacturer for repair. Samples 266-269, table Ib were recovered after the reworked unit was delivered to AMRL.

The variations noted in the samples recovered were probably the result of differences in the composition of the urine processed and because of the residue which accumulated inside the stack. Samples 85 and 102 through 113 were recovered inside the AMRL Evaluator during one of several nutrition experiments conducted by AMRL for NASA (Houston). One liter of urine was processed during each run.

### **THERMOELECTRIC – See tables Id and Ie.**

Urine processed by means of the thermoelectric distillation unit supplied by Whirlpool Corporation (W) was pretreated with 2 grams of trimethylol nitromethane (TN), with one iodine tablet (I) per liter of urine, or with 3.6 ml of a mixture of chromium trioxide, sulfuric acid, and distilled water. Each iodine tablet contained tetraglycene hydroperiodide and liberated 8 milligrams of iodine. Unless otherwise specified, the pretreatment used is indicated by (TN) or (I) at the end of the sample description.

In most cases, the product recovered by the thermoelectric device was forced through an internal charcoal filter to a water storage tank that was lined by a plastic bag. The water sample was drained from the storage tank. One liter of material was processed on each run.

Following is a discussion of the processing of the individual samples:

#### **Table Id**

*Samples 38-41* – The water recovered on each run was not further altered. (TN)

*Samples 42, 43, and 49-51* – These were recovered inside the AMRL Evaluator during a

nutrition experiment conducted for NASA, Houston. The urine was a mixture of that voided by the subjects and was 24-36 hours old when processed. Samples 42, 43, and 49 were pumped through a 0.15-micron filter. Samples 50 and 51 were from a 3-day pool of recovered water. Sample 51 was passed through a "Piodene" filter\*. (TN)

*Samples 97-99* – These represent the product produced on the dates indicated. For example, the product obtained on 1/20, 1/21, and 1/22 was pooled to provide sample 97. (TN)

*Sample 100* – This sample was the residue from the vacuum trap of the distillation unit. It was, reportedly, of the same composition as samples 97-99 except that it has not been passed through the filter of the distillation unit.

*Samples 101 and 117* – These were drawn from the storage tank of the distillation unit and are comparable in method of collection to samples 97-99. (I)

*Samples 114-116* – These samples were, after being drawn from the storage tank of the distillation unit, filtered through a Millipore AP2004200 prefilter and a HAWP 0 47 00 filter (HA 0.45  $\mu$ ). For sample 115, an S&S #595 filter was used ahead of the Millipore prefilter. (I)

*Sample 118* – This sample was recovered from the residue in the vacuum trap of the distillation unit. It was filtered through the following: 2-inch long by 1-inch diameter column of activated carbon (Columbia Type C-64 Mesh 48-150), S&S #595 filter paper, Millipore AP2004200 prefilter, and Millipore HAWP 0 47 00 filter (HA 0.45  $\mu$ ) in the order listed.

*Samples 242-246* – These were processed without pretreatment and with the plastic bag of the storage tank and carbon of the filter removed from the distillation unit.

#### **Table Ie**

*Sample 174* – Distilled water. Not processed in any manner.

*Sample 135* – Obtained by processing distilled water drawn from the same bottle as was sample 174. The sample shows the elements that were added to the recovered water by the machine.

*Sample 137* – This sample was obtained from urine following the processing of distilled water; i.e., sample 135. (I)

*Samples 149-161 and 183-185* – The urine was pretreated, refrigerated overnight, and processed the next morning. Except as noted below, all samples were circulated for 15 minutes at 165 F (73.9 C) through a heat exchanger. (I)

*Samples 183 and 184* – These were drawn from a 3-day pool of unheated recovered product. Sample 183 was then circulated for 15 minutes at 165 F. (I)

*Samples 186 and 187* – These were obtained by processing atmospheric condensate collected inside the AMRL Evaluator during a 36-hour, 3-man heat test. The inside of the Evaluator was maintained at approximately 95 F (35 C).

*Samples 189, 190, and 197* – The urine processed to obtain these samples was pretreated with 3.6 ml of a mixture of  $\text{CrO}_3 + \text{H}_2\text{SO}_4 + \text{H}_2\text{O}$  per liter of urine.

*NOTE:* Samples 186, 187, 189, 190, and 197 were processed with the plastic bag of the storage tank and the carbon of the filter removed from the distillation unit.

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\*A 6-inch long by 1/4-inch diameter column of tetramethylammonium triiodide.

## **DEHUMIDIFICATION — See tables If, Ig, Ih, and Ii.**

Condensate for the dehumidification samples except one sample, was collected inside the AMRL Life Support Systems Evaluator during a series of nutritional experiments conducted for MSC/NASA, Houston, Texas. Excess water in the atmosphere of the Evaluator was condensed by means of a heat exchanger and drained to a collector (aspirator bottle) from whence it is drawn directly or pumped through one or more filters.

All samples were stored in glass bottles and refrigerated at approximately 36 F until submitted to Taft Sanitary Engineering Center for analyses.

Details of the processing follow:

### **Table If**

*Sample 21* — This sample was recovered by means of a commercial home type dehumidifier located inside a room occupied by 4 subjects that were confined to the room for nutrition and pressure suit studies. Three days were required to collect the sample which was then filtered through a 0.15-micron filter. All components except the dehumidifier were sterilized prior to use.

*Samples 28, 30, and 34* — These were not filtered or altered otherwise.

*Samples 29, 31, 35, and 36* — These were filtered through a 0.15-micron filter.

*Sample 37* — This sample consisted of ½ of sample 36 which was refiltered by means of a second 0.15-micron filter.

*Samples 44-47* — The condensate was pumped from the aspirator bottle through a 0.15-micron filter and a 0.9-micron plus carbon filter in tandem.

*Sample 48* — Not filtered. The sample was drawn directly from the collector.

*Samples 52 and 53* — Filtered, pumped through a 0.15-micron and a 0.9-micron plus carbon filters in tandem, condensate collected over a 2-day period was pooled. Samples 52 and 53 were drawn from the pool. Sample 52 was filtered through a Piodene filter.

### **Table Ig**

All samples were pumped through a 0.15-micron filter and a 0.9-micron plus carbon filter in tandem, unless otherwise noted.

*Sample 54* — The sample was taken directly from the aspirator bottle and was not filtered.

*Sample 61* — The sample was refiltered through Piodene filter.

*Sample 64* — This sample is one-half of a mixture of two of the three lots of condensate collected during a 24-hour period.

*Sample 65* — This sample is the remaining portion of the mixture from which sample 64 was taken. The sample was refiltered through Piodene filter.

*Sample 66* — This sample represents the third or unmixed lot referenced under sample 64.

*Samples 70, 73, and 75* — Each is a filtered sample to which one iodine tablet (tetraglyciene hydroperiodide) was added. The iodine interfered with the analytical testing and very little data were obtained.

*Sample 71* — The sample was taken directly from the collector and was not filtered.

*Sample 77* – Water taken from condensate that had collected under the floor of the aft compartment of the AMRL Evaluator. It was not filtered nor treated in any manner.

#### **Table Ih**

Prior to the taking of samples, the heat exchanger upon which the water was condensed was washed and rinsed in tap water. The condensate filter system was sterilized with cryoxide gas (5 psig) prior to drawing samples 86-96 and was moved to the outside of the Evaluator after sample 96 was drawn. The air filter before the heat exchanger was changed after sample 92 was drawn. The condensate was taken directly from the collector or pumped through a 0.9-micron plus carbon filter and two 0.15-micron filters in tandem.

*Samples 86-95* – These samples were filtered.

*Sample 96* – This sample was not filtered.

*Samples 119, 120, and 122* – These were pumped through the filters used for samples 86-95. The filters had been rinsed thoroughly in tap and distilled water then sterilized at 20 psig for more than 24 hours with cryoxide gas.

*Sample 121* – Same as sample 122 except that it was unfiltered.

*Samples 123-128* – These were pumped through new 0.9-micron plus carbon and two 0.15-micron filters that had been sterilized by autoclaving.

*Sample 129* – This sample was drawn directly from the collector.

#### **Table Ji**

The condensate was drained into a collector from which it was pumped up through a 9-inch long by 4-inch diameter column of 48 x 150 mesh acid-washed carbon then through two 0.15-micron filters all in tandem.

*Samples 142, 146, and 147* – These were not otherwise altered after being filtered.

*Samples 179 and 180* – These were drawn from a pooled lot. Sample 180 was then circulated at 165 F (73.9 C) for 15 minutes. Sample 179 was not altered.

*Other Samples* – All samples other than those listed above were altered as follows. One liter of each was circulated at 165 F (73.9 C) for 15 minutes then poured back into the sample after approximately 25 ml were removed for testing.

#### **OTHER TECHNIQUES**

Samples recovered from dehumidification water collected inside the AMRL Evaluator are included with water recovered by means of fuel cells and by vacuum distillation. Details follow:

#### **Table Ij**

*Samples 140-141 and 143-145* – These are unfiltered samples drawn directly from the aspirator bottle.

*Sample 188* – This is an unfiltered sample of condensate collected during a 36-hour, 3-man heating capability evaluation (27 May 1965) of the AMRL Evaluator.

*Sample 192* – This is unfiltered condensate from a 23 June 1965, 36-hour, 3-man heating capability evaluation of the AMRL Evaluator.

*Sample 193* – This sample from the 23 June evaluation was filtered up through a 6-inch long by 1-inch diameter column of 12 x 30 mesh acid-washed pecan shell activated charcoal at the rate of 3 liters per hour.

*Samples 200 and 248* – These samples were obtained from fuel cells of the type that were used during “Gemini” flights. Further data were not made available.

*Sample 201* – This sample was reportedly obtained by vacuum distilling urine and passing the vapors through a low-temperature catalytic agent. The equipment and technique used were of a proprietary nature.

*Samples 206-209 and 247* – All were recovered by vapor distillation. Except for sample 206, the vapors were passed through a 2-micron average pore size glass fiber cloth impregnated with porous “Teflon.” For sample 206, nothing was inserted between the evaporator and the condensers. Temperatures at which the urine was evaporated were: Nos. 206 and 207 – 128 F (53.3 C), No. 208 – 100 F (37.8 C), No. 209 – 70 F (21.1 C), and No. 247 – 125 F (51.7 C). Pressures at which the evaporation occurred varied from 60 mm to 140 mm.









**TABLE 1e**  
**ANALYTICAL RESULTS - RECLAIMED WATERS**

PROCESS, SEE SECTION II MANUFACTURER SAMPLE No. (TC)	DW AMRL	TEdw W	TE		TE		TE		TE		TE		TE		TE		TE		U.S. PUBLIC HEALTH DRINKING WATER STAND- ARDS (1962)					
			TE	W	TE	W	TE	W	TE	W	TE	W	TE	W	TE	W	TE	W						
DATE SAMPLE RECOVERED**	3-17	3-17	3-25	4-15	4-16	4-17	4-18	4-20	4-21	4-22	4-23	4-27	4-28	4-29	4-30	5-4	5-10	5-10	5-11	6-11	6-14	6-23		
VOLUME OF SAMPLE (ml)	4000	2400	1825	710	1200	1285	1320	769	1250	1000	1000	1150	1300	1180	1560	1750	2000	2000	1450	2390	2140	2170		
SPECTROGRAPHIC DATA (ppb)																								
1 ZINC	29	13	5	13	110	75	37	45	53	24	55	29	26	26	20	12	<10	<10	16	<10	<10	165	5000	
2 CADMIUM	<10	<10	<6	<8	<10	<8	<7	<8	<7	<8	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	30	10 R	
3 BORON	5	6	7	14	10	37	13	7	5	7	19	25	14	14	22	9	10	15	28	13	7	200		
4 PHOSPHORUS	70	23	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	65	35	400	
5 IRON	138	8	2	49	120	145	185	135	90	85	129	390	91	68	129	95	72	60	173	7	5	68	300	
6 MOLYBDENUM	<10	<10	<6	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
7 MANGANESE	15	3	<1	1	2	2.5	2.5	1.5	1	1	1.5	3.5	8	0.5	1	<5	<5	<5	1.2	6	2.5	<1	50	
8 ALUMINUM	<13	400	>290	245	375	315	320	340	325	305	280	>500	>500	>500	>500	>500	>500	>500	>500	700	400	750	>500	
9 BERYLLIUM	<.03	<.03	<.01	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.05	<.05	<.05	<.03	
10 COPPER	7	3	<.9	5	31	29	23	23	18	12	15	14	14	13	15	3	29	<2	31	2	<2	<2	1000	
11 SILVER	<1	<.5	<.3	1.5	7	8	6	6	5.3	5	6	4.3	4	3.5	3.5	<.5	1	<.5	3.5	<.5	<.5	4	50 R	
12 NICKEL	<.5	<.5	<.3	<.5	7	9	11	5	<.5	<.5	<.5	13	<.5	<.5	<.5	<.5	<.5	<.5	8	<.5	<.5	12		
13 COBALT	<.5	<.5	<.3	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	
14 LEAD	<10	<10	<.6	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
15 CHROMIUM	27	<3	<1	11	24	29	35	25	15	16	13	65	11	7	20	16	13	7	37	<3	<3	<3	13	
16 VANADIUM	<10	<10	<.6	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	
17 BARIUM	<1	9	12	7	40	22	20	19	25	12	20	8	17	10	6	4	10	1	14	35	17	5	1000 R	
18 STRONTIUM	<2	18	11	12	7	5	4	3	2	<1	<2	<2	<2	<2	10	<2	<2	<2	<2	80	22	9	3	
19 MERCURY	-	<25	15	<50	60	90	140	115	90	<50	180	250	80	75	100	135	90	75	175	-	-	<50	-	
CATIONS (mg/l)																								
1 CALCIUM (Ca)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	14	6.4	4	
2 MAGNESIUM (Mg)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.9	2.4	2.4	2	
3 SODIUM (Na)	<1	2.5	330	10	3.5	4.0	5.5	5	5	5	6	7.5	9	4	5.5	5.5	3.8	3.4	10	13	1	120	2	
4 POTASSIUM (K)	<1	<1	59	8.2	4	3.4	3.7	4.5	4.2	4	3	4.5	5.8	3	3	5	6.3	6.3	16	0.5	<.5	100	1.4	
5 ARSENIC (As)	<.05	0.01	0.32	0.016	<.01	0.01	<.01	0.012	0.016	0.012	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.06	<.01	
6 AMMONIA (NH <sub>3</sub> /N)	0	6.3	14	44	38	25	25	29	26	23	24	34	44	50	26	93	64	68	100	35	36	16	29	
ANIONS (mg/l)																								
1 SULFATE (SO <sub>4</sub> )	2	3	4	6	5	4	2	8	14	13	11	16	7	5	1	3	4	4	7	16	8	205	17	
2 CHLORIDE (Cl)	<1	6	70	50	36	21	17	18	14	13	10	20	17	8	8	9	4	8	7.5	32	9	85	64	
3 NITRATE (NO <sub>3</sub> /N)	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	0.1	0.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	0.16	0.12	0.64	0.18	
4 TOTAL PHOSPHATE (PO <sub>4</sub> )	<.05	20	21	1.7	1.7	1.6	1.2	2.8	4	3.2	12	10	10	3	2.5	3.5	2.1	2.2	2.5	0.2	0.15	8	2	
5 ABS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.04	0.08	0.02	
OTHER TESTS																								
1 pH	6.9	7.9	8.3	7.8	7.6	7.6	7.5	7.5	7.5	7.5	8.1	8.2	8.5	8.6	8.4	9	8.9	9	9	8.4	8.3	8.1	7.6	
2 CONDUCTIVITY (μmhos/cm)	5.7	96	700	-	400	300	280	310	270	260	250	390	430	420	290	600	430	405	620	390	265	1080	260	
3 TURBIDITY-JACKSON UNITS	-	<25	<25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
4 COLOR	<5	-	-	5	5	5	5	5	5	<5	5	5	5	5	10	5	5	5	5	<5	<5	20	<5	
5 ODOR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
6 TOTAL HARDNESS (CaCO <sub>3</sub> )	4	22	18	14	12	10	10	8	10	4	10	8	10	16	12	-	5	4	4	82	46	26	58	
7 TOTAL ALKALINITY (CaCO <sub>3</sub> )	6	40	110	-	120	100	104	108	96	84	86	126	192	210	128	400	250	260	414	104	88	128	208	
8 TOTAL SOLIDS	<10	26	340	-	-	-	-	-	-	-	42	52	59	46	44	48	-	-	-	-	-	-	-	
9 CHEM O <sub>2</sub> DEMAND	4	34	100	225	140	91	48	61	52	42	<1	<1	<1	3.3	<1	64	28	64	22	15	30	300	54	
10 UREA	<.1	<.1	59	60	85	200	Brown	Pos.	Pos.	Pos.	9	6	14	20	16	8	13	10	7	<.1	<.1	30	50	
11 TOTAL PLATE COUNT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
12 TOTAL CARBON	0	<.5	8	59	17	9	3.5	3.5	1	3.5	6.5	4	7	8	6.5	4	14	3.5	11	2.8	2.8	12	102	

\*Major constituent  
 \*\*Pooled samples may be 2 to 3 days older/All dates are 1965  
 Pos. = Present in trace quantities  
 ppt = Precipitate formed. No readout obtained.  
 - = No. data available  
 R = Rejection level

**TABLE II**  
**ANALYTICAL RESULTS - RECLAIMED WATERS**

*9547*

*Date: 5/24/64*

*Det. Sub. # 4*

*Det. Sub. # 6*

PROCESS, SEE SECTION II MANUFACTURER SAMPLE No. (TC)	FC		UFC		FC		UFC		FC		UFC		FC		UFC		U.S. PUBLIC HEALTH DRINKING WATER STANDARDS (1962)
	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	AMRL	
DATE SAMPLE RECOVERED*	3-13-64	8-64	8-64	8-64	8-28-64	8-28-64	8-28-64	8-28-64	10-23-64	10-24-64	10-25-64	10-26-64	10-27-64	11-1-64	11-2-64	11-3-64	
VOLUME OF SAMPLE (ml)	~1800	3800	3800	3800	3800	3800	3800	3800	3850	3850	3850	3850	3850	3850	3850	3850	
SPECTROGRAPHIC DATA (ppb)																	
1 ZINC	25	<3	315	7	1020	83	75	21	325	330	295	385	700	525	1000	5000	
2 CADMIUM	<10	<3	91	<2	122	16	10	<2	<10	<10	<10	40	80	66	110	10 R	
3 BORON	5	22	7	30	>340	32	90	192	>250	>250	1.0	>200	>250	95	>250		
4 PHOSPHORUS	<20	<5	65	5	388	144	100	<16	7	17	<5	<5	35	35	80	300	
5 IRON	<5	<5	48	12	228	153	51	13	11	27	16	33	78	61	160		
6 MOLYBDENUM	<2	<5	10.5	8	197	72	48	1.6	29	20	18	20	13	14	56	50	
7 MANGANESE	<20	21	4	4	193	24	24	8	475	365	15	8	<3	<3	<3		
8 ALUMINUM	<0.3	<0.3	<0.3	<0.3	<0.2	<0.3	<0.3	<0.8	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3		
9 BERYLLIUM	3	33	25	2	45	7	3	<5	10	5	2	2	7	4	4	1000	
10 COPPER	<3	<3	<3	<3	0.7	0.5	<3	<8	<5	<5	<5	<5	<5	<5	0.5	50 R	
11 SILVER	<5	20	<3	<3	15	4	<3	<8	<3	<3	<3	<3	4	3	7		
12 NICKEL	<5	<3	<3	<3	<3	<3	<3	<8	<3	<3	<3	<3	<3	<3	<3		
13 COBALT	<5	<5	<10	<5	14	7	<5	<16	<5	<5	6	<5	20	28	24	50 R	
14 LEAD	4	2	2	2	8	4	4	<3	<1	2	<1	2	4	5	6	50 R	
15 CHROMIUM	<5	<5	<5	<5	<7	<5	<5	<16	<5	<5	<5	<5	<5	<5	<8		
16 VANADIUM	<3	>500	27	>500	>340	>225	>250	77	150	108	115	135	187	108	150	1000 R	
17 BARIUM	<5	<1	13	2	14	8	17	19	31	31	8	27	<1	6	8		
18 STRONTIUM	<20	40	<20	<20	<50	<36	<40	<48	<25	<25	<25	<25	<25	<25	<25		
19 MERCURY																	
20																	
CATIONS (mg/l)																	
1 CALCIUM (Ca)	3.2	5.8	4	4.8	7.2	6.4	7.2	8	16	8	6.4	7.2	3.2	5.6	4.9		
2 MAGNESIUM (Mg)	<1	<1	0.9	3	5.3	1.5	1.0	1.9	3.4	1.9	<2	<2	<2	2.4	2.9		
3 SODIUM (Na)	<1	68	<1	1.5	7	11	11	71	18	9	2	3	1	2	1.5		
4 POTASSIUM (K)	<1	0.6	3.2	0.4	1.7	7.7	4.4	8.3	6.2	4.7	1.7	1.7	0.8	1.4	1.4		
5 ARSENIC (As)	<0.1	<0.1	<0.1	<0.1	<0.1	0.01	0.01	0.05	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	.05 R	
6 AMMONIA (NH <sub>3</sub> /N)	0	20	20	24	39	32	24	15	18	16	15	18	16	ppt	15		
7																	
ANIONS (mg/l)																	
1 SULFATE (SO <sub>4</sub> )	<1	114	<1	11	7	6	14	107	14	5	1	1	<1	2	<1	250	
2 CHLORIDE (Cl)	<1	<1	10	<1	11	7	6	15	6	1	1	1	1	44	<1	250	
3 NITRATE (NO <sub>3</sub> /N)	<1	<1	<1	<1	<1	<1	<1	<1	0.7	0.5	0.1	0.2	0.3	<1	<1	45	
4 TOTAL PHOSPHATE (PO <sub>4</sub> )	<0.1	<0.1	<0.1	<0.1	0.43	0.12	0.13	0.15	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.5	
5 ABS	0.05	<0.2	0.04	<0.2	<0.2	<0.2	<0.2	<0.2	0.12	0.06	<0.2	0.02	0.04	1.6	0.02		
6																	
OTHER TESTS																	
1 pH	6.9	6.8	7.3	6.9	7	5.9	6.3	5.8	6.7	8	7.4	7.3	7.1	6.9	7.6	6.9	
2 CONDUCTIVITY (μmhos/cm)						260	300/270	245/240	500	260	210	163	183	160	270	160	
3 TURBIDITY-JACKSON UNITS	<25									<25	20	<25	<25	<25	<25		
4 COLOR										30	<25	5	5	10	20	5	15
5 ODOR		Neg.	Neg.	Neg.	Neg.	38	2	2.6	16	Neg.	Neg.	Neg.	Neg.	Musty	Neg.	Neg.	3
6 TOTAL HARDNESS (CaCO <sub>3</sub> )	8	16	14	24	40	22	22	28	54	28	16	22	8	24	24		
7 TOTAL ALKALINITY (CaCO <sub>3</sub> )	4	94	122	108	82	66	114	88	108	92	80	78	60	72	74		
8 TOTAL SOLIDS	<1	215	<1	5	136	88	99	315	248	94	28	35	12	406	94	500	
9 CHEM O <sub>2</sub> DEMAND	15	330	1100	550	1300	670	770	1600	5300	2500	1400	1800	1400	1700	1600		
10 UREA						5	15	7	11	<1	<1	<1	<1	<1	<1		
11 TOTAL PLATE COUNT																	
12 TOTAL CARBON						470/370	200/165	250/250	700/600	1675	762	438	550	388			

\* Pooled samples may be 2 to 3 days older  
 Neg. = Not detected  
 ppt = Precipitate formed. No readout obtained.







TABLE IJ  
ANALYTICAL RESULTS - RECLAIMED WATERS

PROCESS, SEE SECTION II MANUFACTURER SAMPLE No. (TC)	UFC		UFC		UFC		UFC		UFC		FCell		VD		VD		VD		U.S. PUBLIC HEALTH DRINKING WATER STANDARDS (1962)
	AMRL	4-16-65	4-17-65	4-18-65	4-19-65	4-20-65	6-10-65	6-23-65	6-23-65	6-23-65	8-5-65	8-18-65	7-20-65	7-20-65	7-21-65	7-22-65	7-22-65	8-12-65	
DATE SAMPLE RECOVERED*	4000	4000	4000	4000	4000	4000	3000	4000	3500	8-5-65	8-18-65	7-20-65	7-20-65	7-21-65	7-22-65	7-22-65	8-12-65		
VOLUME OF SAMPLE (ml)	4000	4000	4000	4000	4000	4000	4000	4000	3500	SPECTROGRAPHIC DATA (ppb)									
1 ZINC	5	300	170	140	135	65	200	23	190	85	<10	<10	16	37	55	53	<10	5000	
2 CADMIUM	35	24	16	12	12	12	50	<10	<11	<10	<10	<10	<10	<10	<10	14	<10	10 R	
3 BORON	54	130	33	75	51	225	>250	70	50	85	15	19	13	11	53	68			
4 PHOSPHORUS	135	160	65	60	40	40	150	375	450	200	>500	<25	<25	<25	<25	>450			
5 IRON	57	104	50	19	21	11	33	9	95	59	<5	<5	20	5	20	<5	300		
6 MOLYBDENUM	<10	<10	<10	<10	<10	<10	<10	<16	<6	<3	<10	<10	<10	<10	<10	<5			
7 MANGANESE	6	3	1.5	1	1	<1	2.2	29	<3	<3	10	<2.5	<2.5	<2.5	<2.5	<3	50		
8 ALUMINUM	25	<13	<13	<13	<13	33	.75	41	170	105	<10	<10	15	<10	30	59			
9 BERYLLIUM	<.03	<.03	<.03	<.03	<.03	<.05	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03	<.03			
10 COPPER	20	10	6	4	3	9	17	3	135	95	2.5	6	11	4	10	2	1000		
11 SILVER	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	4.5	<.5	0.5	<.5	<.5	<.5	<.5	<.5	50 R		
12 NICKEL	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	12	<.5	<.5	<.5	<.5	<.5	<.5	<.5			
13 COBALT	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5			
14 LEAD	<10	<10	<10	<10	<10	<10	<10	15	<11	<10	<10	<10	<10	<10	<10	<10	50 R		
15 CHROMIUM	10	16	8	<3	<3	<3	<3	<3	6.1	<3	<2.5	<2.5	<2.5	<2.5	<2.5	<3	50 R		
16 VANADIUM	<10	<10	<10	<10	<10	<10	<10	<10	<11	<10	<10	<10	<10	<10	<10	<10	50 R		
17 BARIUM	>50	>50	>50	>50	>50	>100	>50	>75	18.5	3	7.5	3.5	5.5	<1	15	8	1000 R		
18 STRONTIUM	<1	<1	<1	<1	<1	<1	2	57	<2	<1	<2	<2	<2	<2	4	50			
19 MERCURY	<50	80	<50	<25	<25	-	-	-	100	-	-	<50	<50	<50	<50	<50			
20																			
CATIONS (mg/l)																			
1 CALCIUM (Ca)	-	-	-	-	-	2.4	2.4	18	-	-	-	-	-	-	-	-	-	29	
2 MAGNESIUM (Mg)	-	-	-	-	-	1.4	1	5.2	-	-	-	-	-	-	-	-	-	<.5	
3 SODIUM (Na)	1.5	0.5	1.5	0.5	0.5	1.0	1.5	1.5	-	<1	<1	1.5	2.5	1.5	2.5	170			
4 POTASSIUM (K)	1	0.6	1	<.5	<.5	<.5	1	3	-	-	6	<1	<1	2	39				
5 ARSENIC (As)	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	-	-	<.01	<.01	<.01	<.01	<.01	0.01	0.05 R		
6 AMMONIA (NH <sub>3</sub> /N)	18	18	19	24	21	72	16	15	1.2	-	0.05	0.22	0.38	0.16	0.1	48			
7									F=2	F=2									
ANIONS (mg/l)																			
1 SULFATE (SO <sub>4</sub> )	3	2	1	<1	<1	6	10	11	5	-	-	-	-	-	-	100	250		
2 CHLORIDE (Cl)	2	<1	<1	<1	<1	1	1	12	6	-	-	1	1	3	3	240	250		
3 NITRATE (NO <sub>3</sub> /N)	1.6	<1	0.4	0.3	0.1	<1	<1	3	-	<1	<1	<1	0.6	1.1	<1	45			
4 TOTAL PHOSPHATE (PO <sub>4</sub> )	<.05	<.05	<.05	<.05	<.05	0.13	<.05	<.05	-	2.1	0.21	<.05	0.09	<.05	23				
5 ABS	-	-	-	-	-	0.17	-	-	-	-	-	-	-	-	-	0.5			
6																			
OTHER TESTS																			
1 pH	6.9	6.8	6.6	6.7	7.4	7.3	6.4	7.2	3.1	3.2	7.3	9.3	9.7	8.6	7.3	4.9			
2 CONDUCTIVITY (µmhos/cm)	300	270	290	300	300	380	142	225	4000	-	120	44	54	62	50	1750			
3 TURBIDITY-JACKSON UNITS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
4 COLOR	10	5	5	5	5	5	5	<5	15	-	0	5	5	5	5	<5	15		
5 ODOR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3		
6 TOTAL HARDNESS (CaCO <sub>3</sub> )	14	8	8	8	8	12	10	70	12	8	10	4	8	8	8	72			
7 TOTAL ALKALINITY (CaCO <sub>3</sub> )	116	116	120	140	140	146	44	84	0	-	192	36	44	24	18	192			
8 TOTAL SOLIDS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500		
9 CHEM O <sub>2</sub> DEMAND	510	160	220	160	130	132	205	74	200	270	69	31	17	110	52	2045			
10 UREA	<.1	-	<.1	<.1	<.1	<.1	Pos.	Pos.	Pos.	<.1	0.01	0.06	0.02	0.02	0.02	120			
11 TOTAL PLATE COUNT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			
12 TOTAL CARBON	75	40	36	26	26	53	55	19	40	89	2	4.8	4.8	16	14	790			

\*Pooled samples may be 2 to 3 days older  
Pos. = Present in trace quantities  
- = No data available  
R = Rejection level

## SECTION IV.

# Conclusions

Considerable variations existed in the composition of water recovered from the same system from day to day. These were, usually, the result of variations in the raw material rather than in the water reclamation system or in the operation thereof. In most cases the recovered water met the requirements of the U. S. Public Health Service for drinking water. Where the standards were exceeded, the constituent level of the recovered water was within allowable limits for aerospace use. Often, the constituent level of water recovered from urine was less than that of the tap and distilled water tested. Trace metals were not a problem.

Condensate recovered from the atmosphere of the Life Support Systems Evaluator (LSSE) showed much higher chemical oxygen demand ratings than did water recovered from urine by a change of phase process. The high COD values were indicative of large quantities of oxidizable compounds. When organic materials were present, the problem of bacterial contamination was magnified. Passing the condensate through activated charcoal did not remove a substantial amount of the organics. Further study of charcoal types and contact time is needed.

Standards in addition to those listed by the U. S. Public Health Service for drinking water should be used in evaluating reclaimed waters. Weights for pH, conductivity, total carbon, ammonia, and bacteria should be included. Extensive testing of recovered water during aerospace missions is not feasible. Minimum standards, based on the capability of the recovery device should be established.

The data in tables Ia-Ij provide opportunity to study correlations between constituents or characteristics of the recovered water, i.e., trace elements vs conductivity or chemical oxygen demand vs total carbon. Sufficient data are available in many cases to permit the inference of a meaningful pattern.

Operation and evaluation tests revealed that thermoelectric, electro dialysis, and vapor compression water reclamation devices are suitable systems for use during an extended aerospace mission. The vacuum distillation water reclamation device, when used in conjunction with isotopes for supplying energy for vaporizing the waste liquid and for pyrolyzing the contaminants in the vapor, is considered the best system for aerospace application.

# Appendix

## SURVEY OF WATER RECLAMATION SYSTEMS

The reclaiming of potable water for aerospace use has been described in references 12, 13, 14, and 15. These describe in detail the sources from which the water can be recovered as well as the quantities needed for drinking, reconstituting foods, and for personal hygiene and sanitation. Also described are various processes for reclaiming water, with expected yields, power requirements, basic designs, and other pertinent information.

Data on reclamation systems that have been surveyed by the Aerospace Medical Research Laboratories and others are included in table II. Also included is the status of the systems studied and an AMRL rating of the systems for aerospace application. Systems that have been procured and operated by AMRL may be noted by the operating hours assigned.

The data in table II do not include penalties associated with power requirement nor are the systems reported on space optimized. Each system, except where vapors are pyrolyzed, requires both pre- and post-treatment.

Another and a more detailed analysis and comparison of the various candidate systems for recovering water during extended space travel was prepared by J. A. Steele, General Dynamics/Electric Boat (ref 31) for NASA, Langley Research Center.

**TABLE II**  
**WATER RECLAMATION SYSTEMS**

System	Responsible Agent	Contractor	Reference	Volume (cu. ft.)	Weight (lbs.)	Watt-hrs/ lb. of H <sub>2</sub> O	Output lb./hr.	Recovery (%)	AMRL Operations (hrs.)	AMRL Rating	Status
1 Thermoelectric	AMRL	Garrett	16	1.2	65	>200	<0.2	<85	>85	NS	Complete
"	"	Whirlpool	17	3.5	49	146	1.0	<85	>270	A	"
"	"	"	*	—	—	—	—	—	—	—	Sep. 67
"	NASA	MRD	18	2	36	121	0.5	92	—	—	—
2 Electrolysis	AMRL	Ionics	9, 10	1.4	50	100	0.9	85	73	A	Complete
"	—	Douglas	11	—	—	—	—	—	—	—	—
3 Ultrafiltration	AMRL	RAI	4, 5	—	—	—	—	—	338	B	Complete
"	NASA	"	6	—	—	—	—	—	—	—	"
4 Ultrafiltration— Electrolysis	"	"	7	—	—	—	—	—	—	C	—
"	AMRL	In-House	—	—	—	—	—	—	—	C	Dec. 67
5 Membrane Permeation	"	Ionics	8	2	128	400	0.05	85	>50	D	Complete
6 Freeze Drying	"	s. Un. of Iowa	19	—	>85	400	0.75	75	—	D	"
7 Electrolysis Cell— Fuel Cell	"	GE	20	1.6	67	65	0.4	98	—	C	"
8 Air Evaporation	NASA	Ham. Std.	21	12	100	375	1.44	98	—	B	—
"	AMRL	—	**	—	—	—	—	—	—	B	Sep. 67
9 Vacuum Distillation	"	MRD	22, 23	2.1	>35	0	0.6	98	—	D	Complete
10 Vapor Compression	"	"	1	3.4	60	108	1.2	91	>205	A	"
"	"	Elec. Boat	2	—	—	—	—	—	>94	NS	"
"	"	Gard	24	—	—	—	—	—	—	—	Jan. 67
"	NASA	MRD	25	—	59	39	3	97	—	A	Complete
"	"	Marquardt	***	—	—	—	—	—	—	—	—
11 Vacuum Pyrolysis											
a. Electric	"	GE	26	—	—	—	—	—	—	A	Complete
b. Isotope	AMRL	"	27, 28	—	—	—	—	—	—	A	—
12 Spray Condenser	"	Garrett	29	4.5	40	—	—	—	—	NS	Complete
13 Reiterative Freezing	"	Minneapolis Honeywell	30	—	—	—	—	—	—	NS	"

NS = Not suitable  
A = Leading  
B = Promising  
C = Extensive development required  
D = Discarded

\*AMRL Exhibit MRL-66-30, Thermoelectric Water Recovery System.  
\*\*AMRL Exhibit MRL-66-112, Water Recovery by Air Evaporation.  
\*\*\*NASA Contract NAS 9-5119, Waste Collection and Processing System.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Water (reclamation) Urine Life Support Potable Water						

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