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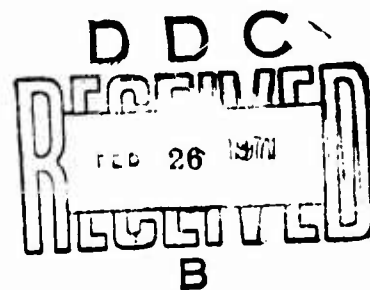


**APPLICATION OF RADIOISOTOPES TO WATER
RECOVERY SYSTEM FOR EXTENDED
MANNED AEROSPACE MISSIONS**

COURTNEY A. METZGER

AUGUST 1970

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AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
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SUMMARY

The object of this program was to design, fabricate and test a water reclamation system to recover sterile, potable, drinking water from human waste and use radioisotopes for the total thermal energy required. The system was designed to recover 24 pounds of water in a 24-hour period. An additional goal for this effort was to design an automatic system with a minimum of moving parts and energy requirement. It incorporates low temperature (90-120 F) and low pressure (50 mm Hg) evaporation, membrane filtration of the vapors, and low temperature (270 F) catalytic oxidation. Radioisotopic energy sources (four 75 watt units for the evaporator and one 45 watt unit for catalytic oxidation) interchangeable with electric heaters were used for the thermal energy.

Urine collected in a public rest room was pretreated and mixed with water in a 1:1 ratio to simulate a urine-atmospheric condensate composite. Two tests of 39 and 36 days each were accomplished, resulting in the recovery of over 1400 pounds of water. A high ammonia level was encountered after approximately 55 days of operation. This high concentration was due to a failure of the liquid sensor allowing the evaporator to increase in temperature and boil dry. Thirty-nine water samples analyzed microbiologically were found to conform to the water standards. Two samples were found to be contaminated and it was concluded that septic technique during sample collection was the cause.

The use of radioisotopes to furnish the thermal energy in conjunction with the vacuum distillation-vapor filtration and catalytic oxidation shows excellent promise for the accomplishment of water reclamation in aerospace systems. The process also may be applicable for bare base operation and manned missile silo facilities.

Further work on this process should include a fail safe liquid sensor, improved filter and catalyst, and an improved evaporator design for operation in a weightlessness condition.

FOREWORD

The research and development program described in this report was performed by the Chemical Hazards Branch, Toxic Hazards Division of the Aerospace Medical Research Laboratory. The program was performed in support of Project 6373, "Equipment for Life Support in Aerospace." The project engineer was Courtney A. Metzger.

The author wishes to acknowledge the contributions to the project and this paper of Dr. Earnest W. Johnson and his staff of the Monsanto Research Corp, for the design and fabrication of the radioisotopes, Mr. E. Hyer and personnel of Zone Shop 3, WPAFB, Ohio, for the fabrication of the system, Messrs. Robert Kroner, William Stang and Raymond Taylor, FWPCA, Analytical Control Laboratory, Cincinnati, Ohio and Mr. A. West, AMRL, WPAFB, Ohio in the performance of the microbiological analysis and consultation and Messrs. M. W. Draper, B. L. Pate, and E. S. Coleman, of the Support Services Division, AMRL, for compiling complete drawings of the system and assistance in the design.

The period of research began in April 1968 and ended in March 1970.

This technical report has been reviewed and is approved.

CLINTON L. HOLT, *Colonel, USAF, MC*
Commander
Aerospace Medical Research Laboratory

SECTION I

INTRODUCTION

Of the great number of processes and systems studied to obtain potable drinking water from human waste, the most promising systems require considerable thermal energy for their operation. Most researchers agree that a process using heat for evaporation and catalytic oxidation or vapor pyrolysis for removal of organic substances from the vapors is a promising design for future flight hardware. During the very early investigations and design studies of processes, many were discarded because of the requirement for high heat load (electric energy). The required electrical energy was not available from the vehicle power supply and will not be available in the near future when a water reclamation system is needed. This will also hold true for base operation and missile facilities when there is an emergency, and the availability of an operating water recovery system may mean the difference between life or death. The design engineer also favored a system requiring high temperatures to eliminate bacteria and follow-on catalytic oxidation for removal of organic compounds. However, the requirement for high thermal energy slowed or stopped all engineering progress toward the design and development of systems using this process.

Early in 1960 a system was developed, fabricated, and tested by the General Electric Co. on contract to the Office of Life Sciences, NASA. The completed system produced bacteria-free potable water; however, the energy required to accomplish the process exceeded 300 watt-hours per pound of water produced and the developed equipment was not space-oriented.

Several years passed and considerable effort was expended in the design and testing of various water reclamation systems which included thermoelectric distillation, membrane permeation, electrodialysis, reverse osmosis, ultra-filtration, vapor compression, air evaporation, vacuum distillation-vapor pyrolysis and vapor diffusion.

From the many processes and systems developed, only a limited number were found worthy of further design consideration, and even some of the processes selected for additional development are questionable with regard to their acceptability as flight hardware.

It is the opinion of the author and other researchers that the process and system design summarized in this report and the similar process of Vacuum Distillation-Vapor Pyrolysis (ref 1) have the qualities and design characteristics that are compatible with the development requirements for flight hardware. Processes requiring high thermal energy became more attractive after the test and acceptance of a radioisotope heat source which was installed in closed environments occupied by man for extensive periods (30 to 90 days).

The characteristics and availability of plutonium-238 as a heat source prompted the investigation and study of this material to supply the thermal energy required for various life support systems. Studies revealed that a water reclamation system using thermal energy totally derived from radioisotopes should be the first life support subsystem to be considered for development and fabrication. These studies were joint Air Force and Atomic Energy Commission efforts and are described in previous reports (ref 2 and 3).

Concurrently, the General Electric Co. was developing a vacuum distillation-vapor pyrolysis water reclamation system under contract to the Air Force. The pyrolysis unit of this system required thermal energy at approximately 1200 F. Before final design of the complex system was completed, plutonium-238 became available in limited supply. A joint research effort between AEC and AF resulted in the development and fabrication of isotope heat sources that supplied the total thermal energy (evaporator and pyrolysis unit)

for this system. This was the first life support system that used isotopes for thermal energy and is described in another report (ref 4).

The follow-on VD-VF Catalytic Oxidation Water Recovery System using isotopes was redesigned and fabricated by the Aerospace Medical Research Laboratory (AMRL). The research, design and fabrication and a summary of the results of the evaluation and tests of the system are discussed.

SECTION II

SYSTEM DESIGN AND OPERATION

The AMRL conducted an investigation (1967-68) of methods to remove organic contaminants from the waste water vapors. The evaluation and test of the vacuum distillation-vapor pyrolysis process showed that the removal could be accomplished by subjecting the catalyst to high temperature (1200 F). During this same period the Arde Co., Mahwah, New Jersey, developed a low temperature (240 F to 280 F) catalyst, designated Ardox®, that showed good promise. Also during this period of time, the AMRL designed and developed a Vacuum Distillation-Vapor Filtered Water Recovery System (ref 5). This design permitted incorporation of a catalytic oxidation unit with a minimum modification of the system. To accomplish this, the charcoal bed and top membrane were removed and replaced by a catalytic oxidation unit charged with the Ardox catalyst. The system was subjected to several 30-day tests using electric heaters as the source of thermal energy. The low temperature catalytic oxidation technique with vapor filtration showed good potential for use in recovering high quality sterile water from human waste.

To evaluate a complex system the AMRL initiated an inhouse effort to design, develop, fabricate, test and evaluate a system substituting isotopes to furnish the thermal energy, and the AEC agreed to provide the required isotopes. The drawing numbers for the system will be found in reference 6. The system was designed to operate continuously for a minimum of 90 days, reclaiming potable water from 24 pounds of human waste (9 pounds of urine and 15 pounds of atmospheric condensate). Figure 1 shows the general flow diagram for the system. The integrated laboratory system and test set-up shown in figure 2 was used for the evaluation of the process with the isotopes in place to obtain the data presented.

The initial design consideration was to develop a system requiring a minimum of moving parts and maintenance. The use of isotopes eliminated electric heaters that had exhibited a high percent of failure. The final design resulted in only two pumps and a metering device for transporting the waste product from the storage tank to the evaporator and to remove recovered water from the water storage tank. The use of space vacuum and the vehicle coolant system for the condenser completed the support required for operation. Approximately 4 pounds of the Ardox catalyst were used for each test.

The system was subjected to two separate continuous runs of 39 days (reference figures 3 and 4) and 36 days (reference table I and figures 5 and 6). All urine processed was collected in a closed 6-liter container placed in a public rest room with no selection of the donors or control over their diet. Before the container was placed at the collection station, 15 ml of a 4:1:4 mixture of sulfuric acid, chromium trioxide, and distilled water was placed in the urine collector along with 2 to 3 drops of anti-foaming compound per liter. This pretreatment was necessary to prevent the breakdown of urea to ammonia. When 6 liters was collected, the container was taken to the laboratory, and the measured urine was mixed with an equal volume of distilled water to approximate a 50:50 urine-atmospheric condensate mixture. This solution was then poured in the urine storage tank. A timer in the system allowed approximately 400 ml of the solution to be pumped from the storage tank into the evaporator every 20 minutes.

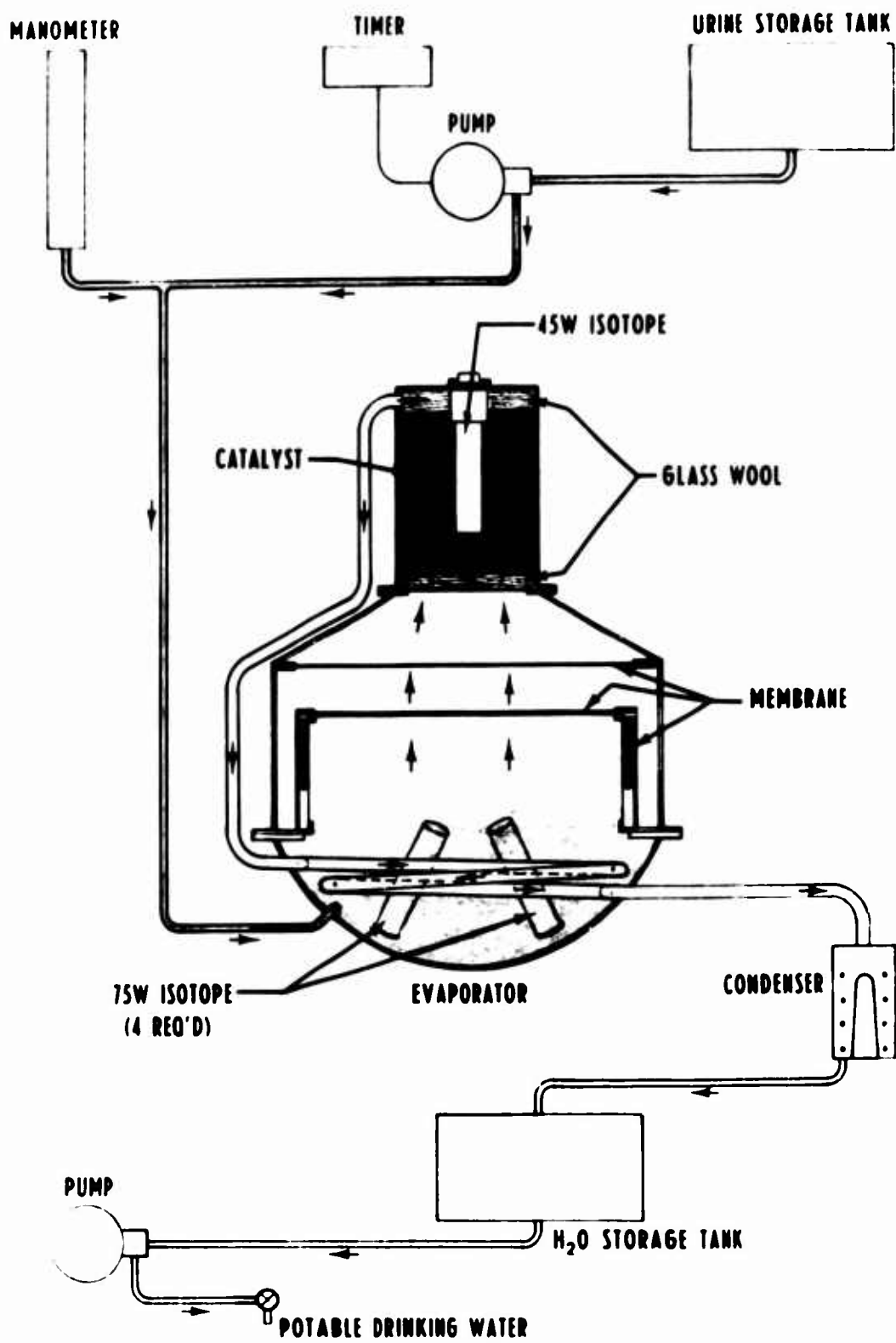


Figure 1 — VD VF H₂O Recovery System Using Radioisotopes

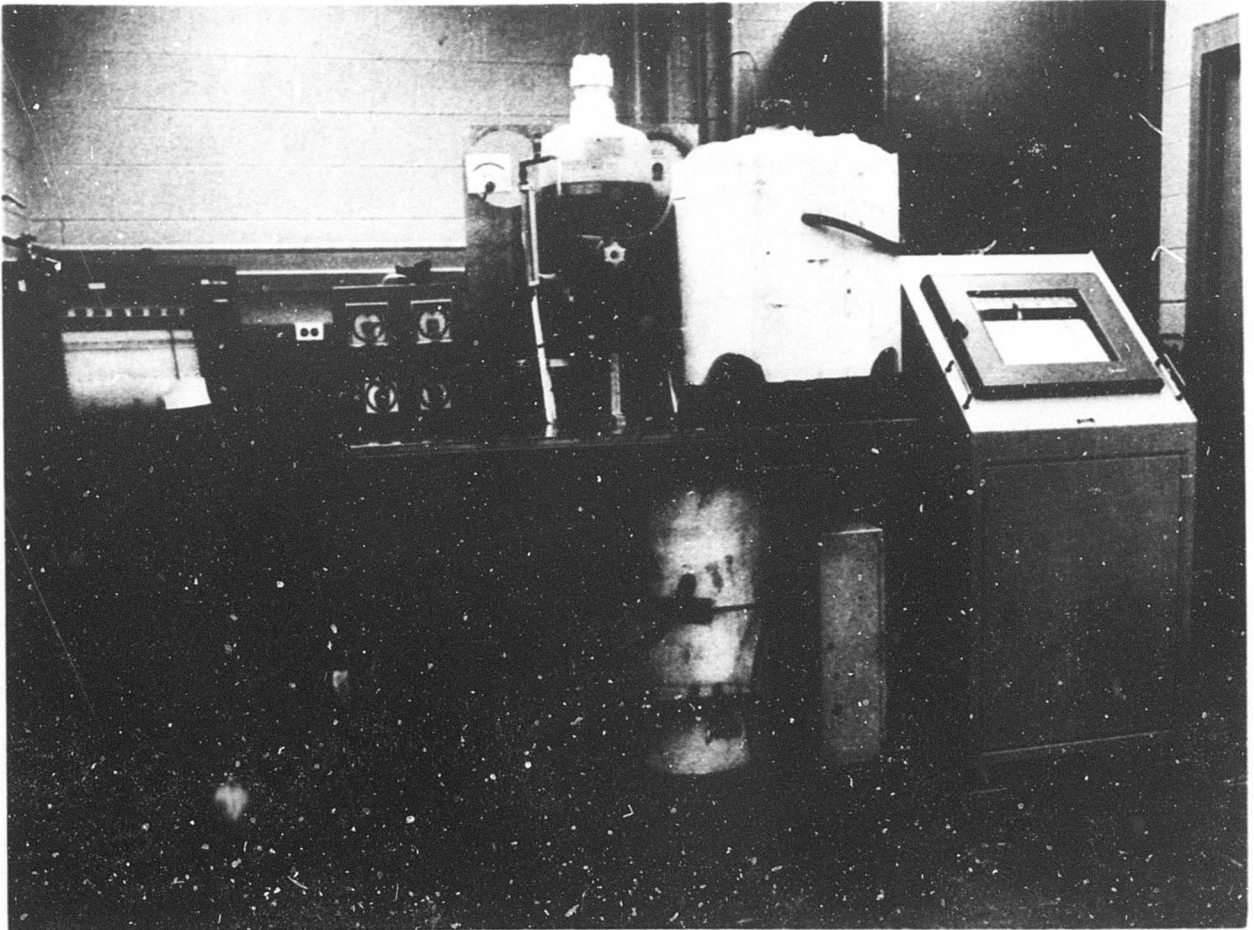


Figure 2 — VD-VF H₂O Recovery System

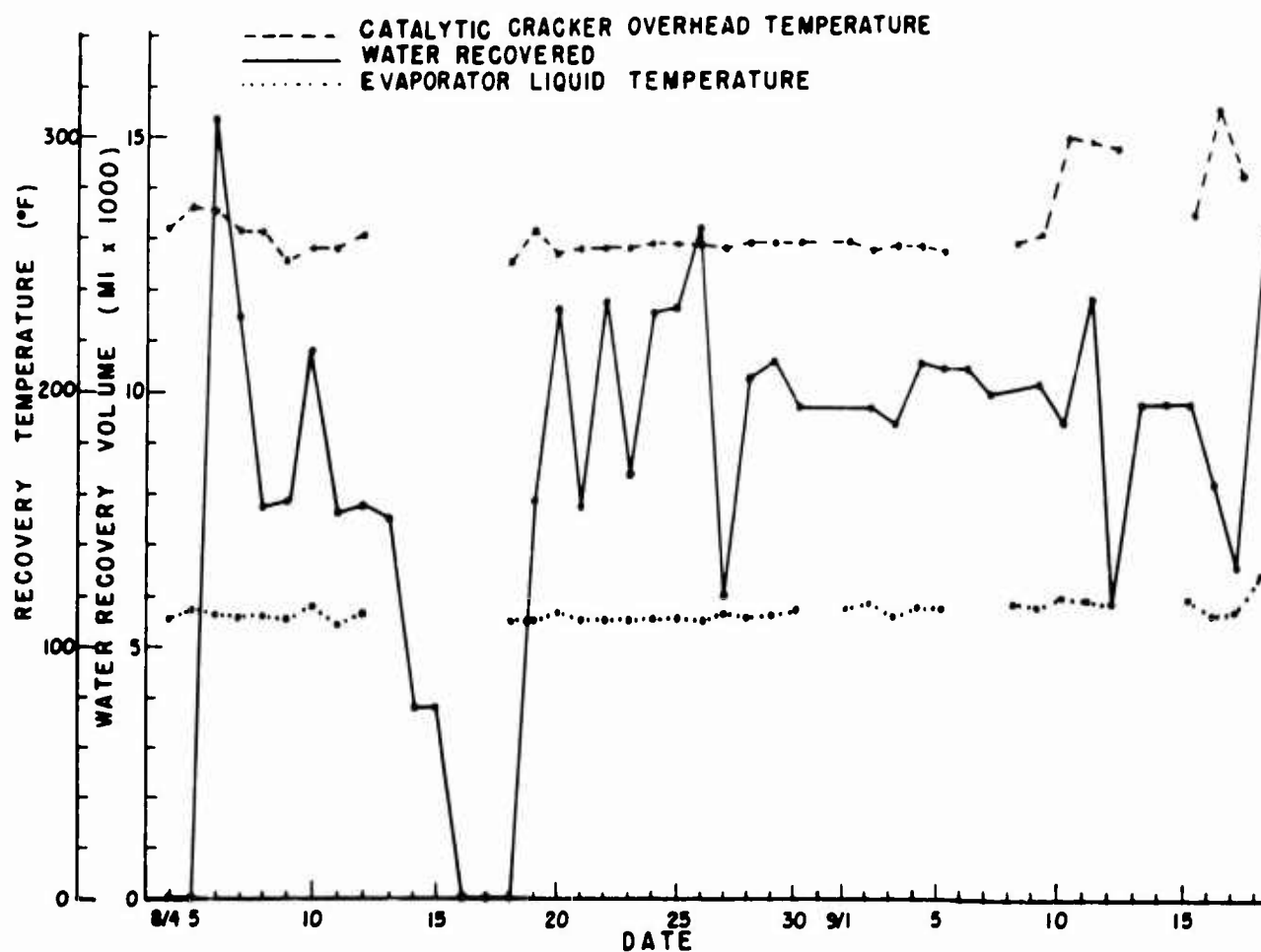


Figure 3 — Operation Temperature H₂O Recovery

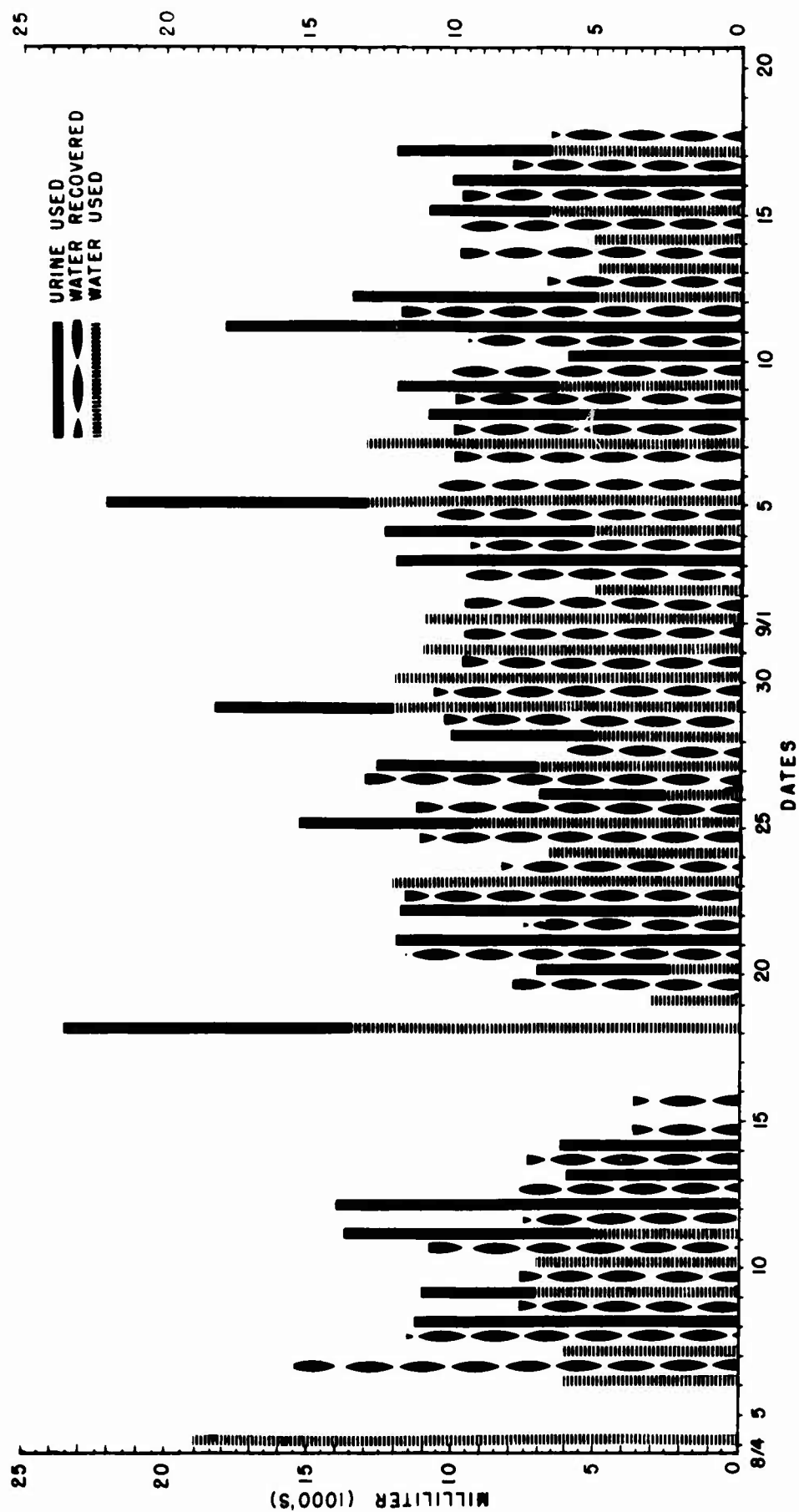


Figure 4 — Phase I — Urine and Condensate Evaporated — H₂O Recovered

TABLE I
DAILY INPUT AND PRODUCTION RATE — PHASE II

<i>Date 1969</i>	<i>Urine Input ml</i>	<i>Condensate Input ml</i>	<i>Water Recovered ml</i>
10-20	3945	15,500	0
10-21	3510	10,000	9345
10-22	8900	0	11,980
10-23	7800	4200	10,595
10-24	7000	2300	10,460
10-25	8000	3570	7620
10-26	6000	3000	11,430
10-27	6666	3323	7690
10-28	6666	3333	7680
10-29	9000	3000	11,380
10-30	7000	3500	11,370
10-31	9000	4790	10,290
11-1	8000	4000	10,330
11-2	6000	3000	9875
11-3	3560	1820	11,235
11-4	- 0 -	- 0 -	16,610
11-5	- 0 -	13,877	1830
11-6	5633	4660	10,398
11-7	6000	4000	9704
11-8	7800	5200	9665
11-9	6650	3700	10,910
11-10	4500	3250	9225
11-11	6000	4000	10,125
11-12	5000	3000	9700
11-13	6000	2000	7800
11-14	2000	3000	5200
11-15	7800	5200	9630
11-16	6000	4000	10,170
11-17	5830	3140	8690
11-18	4200	2800	6930
11-19	4000	3500	7280
11-20	4000	2660	6425
11-21	6000	4000	7425
11-22	3500	2000	5230
11-23	5600	3000	8550
11-24	3000	200	5395
11-25			4340
Totals	200,560 ml	142,523 ml	322,512 ml

Shut-Down 11-25-69 1000 hours

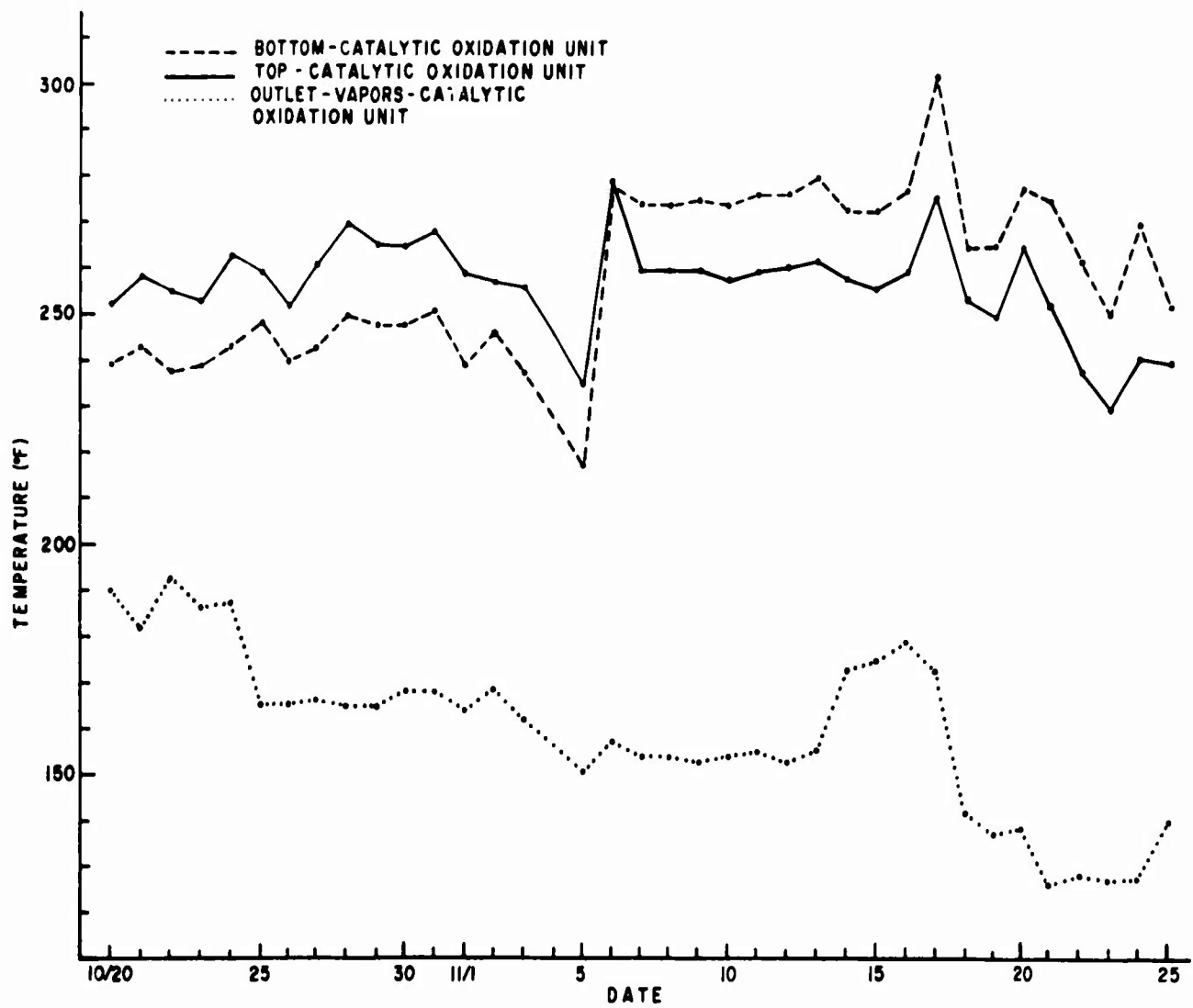


Figure 5 — Operating Temperatures

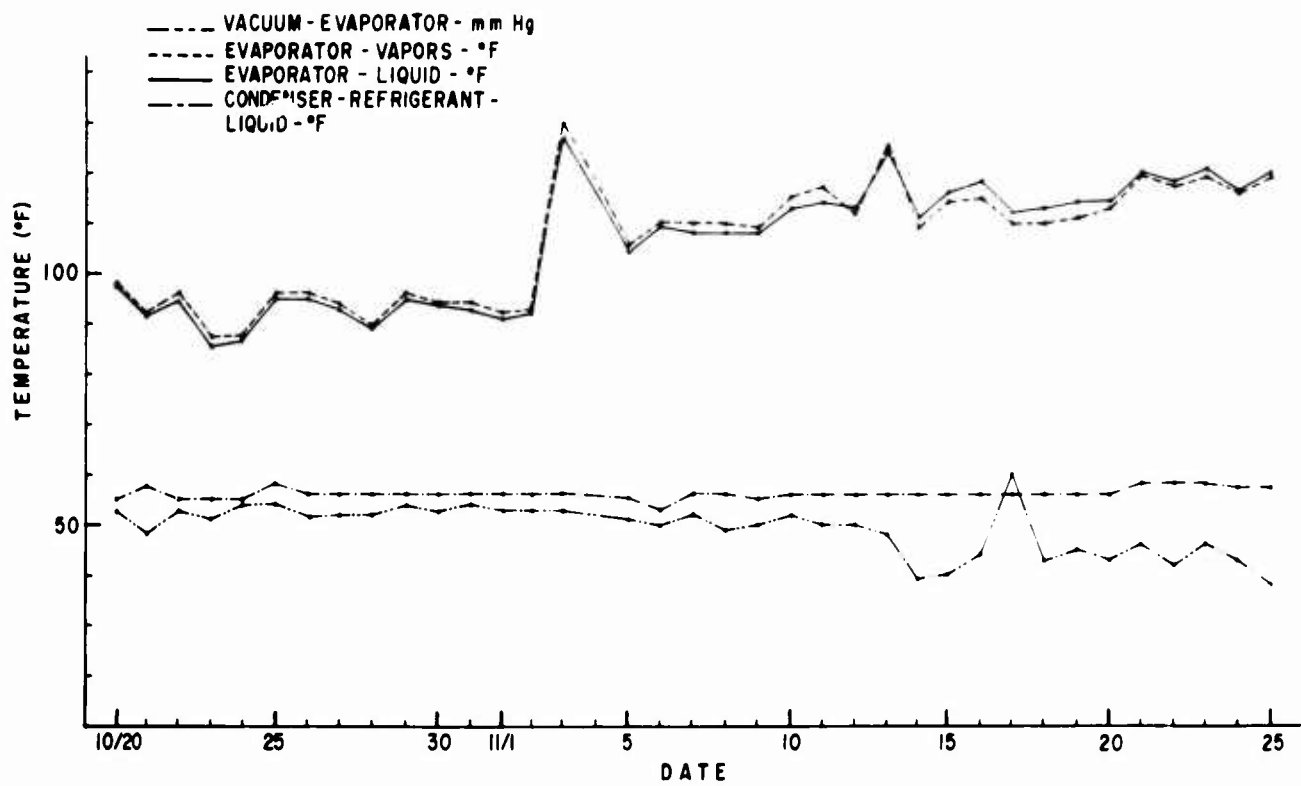


Figure 6—Operating Temperatures and Pressure

Evaporation occurs at temperatures between 100 to 120 F and at pressures of 40 to 75 mm Hg. The vapor passes through a 0.4 micron Pall Ultipor® filter to remove microbial contaminants (A backup filter can be incorporated as shown in figure 1) and then through the catalyst. The catalytic oxidation unit is maintained at 240 to 280 F (ref figures 4 and 5). If any organisms pass through the filter, they are apparently removed in this unit. The vapor leaves the catalytic oxidation unit and passes through the evaporator giving up most of its heat to the evaporator. The vapors are then passed through the condenser and the water is condensed and stored for future use. Once the waste solution enters the pump, and until the potable water is pumped off, the process is under vacuum. A flowmeter installed at the beginning of the process meters approximately 12 to 14 cc of room air per minute needed for the catalytic oxidation of the vapors.

The isotopes maintain the temperature in the evaporator and in the catalytic oxidation unit at 100 to 120 F. The temperature in the evaporator is the key to satisfactory operation of the system. The volume of waste and the pressure in the evaporator control the temperature when the isotopes are used to supply the thermal energy. Failure of one of several component subsystems will cause system failure; e.g., sensing device, allowing the evaporator to go dry or overfill, loss of vacuum, urine pump slows and/or stops, urine tube rupture, etc. Build-up of solids in the evaporator is another cause of failure. However, tests have shown that the mixture of 50-50 urine with condensate should not be a problem in processing 24 pounds/day for up to 40 days. The system design includes two complete evaporators and after 30 days of operation the second evaporator is valved into the system and used for the next 30 days. The first evaporator is then subjected to vacuum drying of the solids for approximately 72 hours. The lower half of the evaporator is removed, placed in a plastic bag for storage, and a new lower half evaporator is then installed. Besides the valve operation and transfer of the isotopes, the removal of the lower half of one evaporator is required only one time during a 90-day test. The urine solids remain in the used evaporators until the mission returns to earth.

The four isotopes for the evaporator provide 73 ± 2 watts and the catalytic oxidation unit isotope provides 48 ± 2 watts. The detailed design of the fuel sources is presented below.

RADIOISOTOPE CAPSULE DESIGN

Five heat sources were designed and fabricated by the Monsanto Research Corp., Miamisburg, Ohio, under the direction of the U.S. Atomic Energy Commission, Division of Isotopic Development. The AMRL requirements for the sources to be compatible with the VD-VF water recovery system are as follows:

	<i>Evaporator Unit</i>	<i>Catalytic Oxidation Unit</i>
Number of Sources	4	1
Wattage, Each capsule	73.3 ± 1.5	48 ± 2.0
Operational Temperature	100-120 F	240-280 F
Outer Dimensions	1 inch O.D. x 0.45 inch long	

The capsules were designed and fabricated in accordance with Life Support II Heat Source Specification, Monsanto Research Corp. drawing No. 1-13297. A configuration of the capsule is shown in figure 7. The capsule assembly (fig 8) consists of 2 concentric cylinders (clad tube and liner tube) fabricated to fit at close interface tolerances to enhance the thermal conductivity. The capsules were designed for a 5-year life to meet long duration testing and storage.

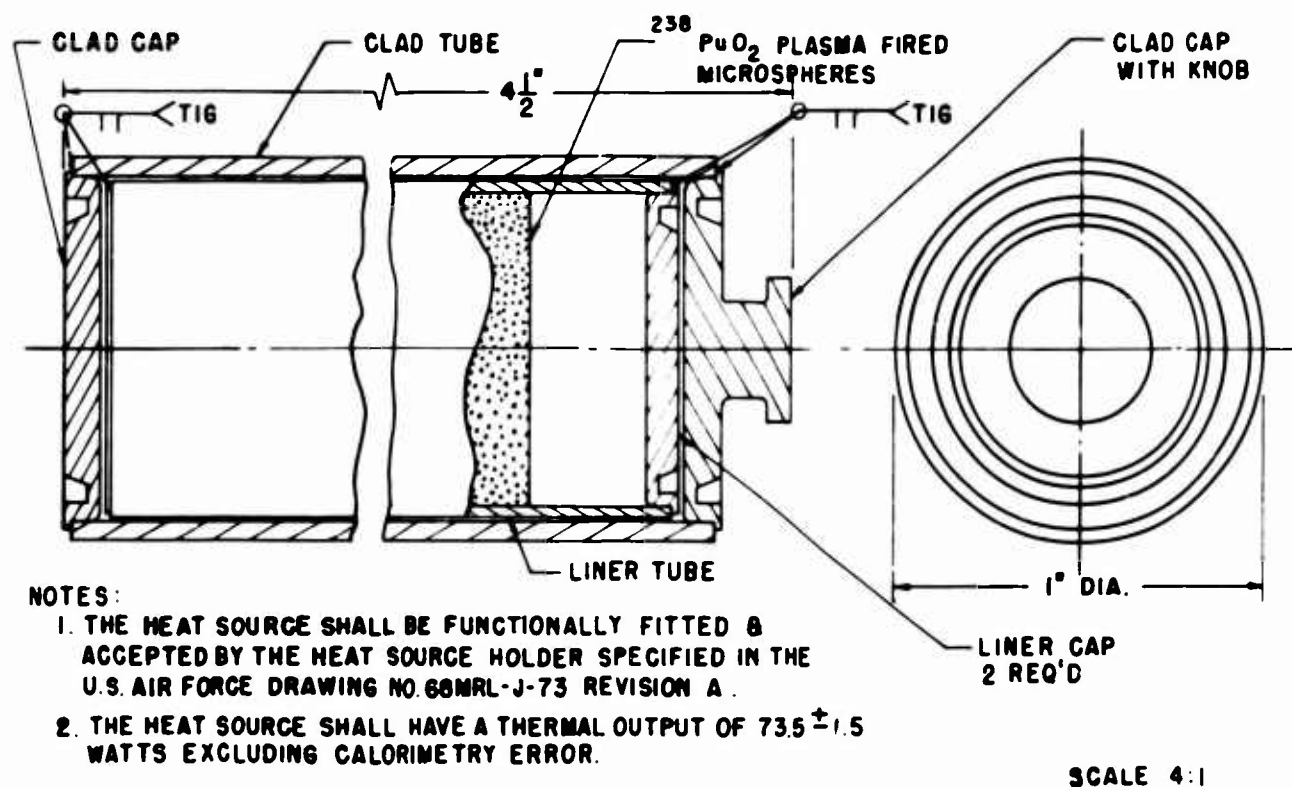


Figure 7 — Radioisotope Configuration

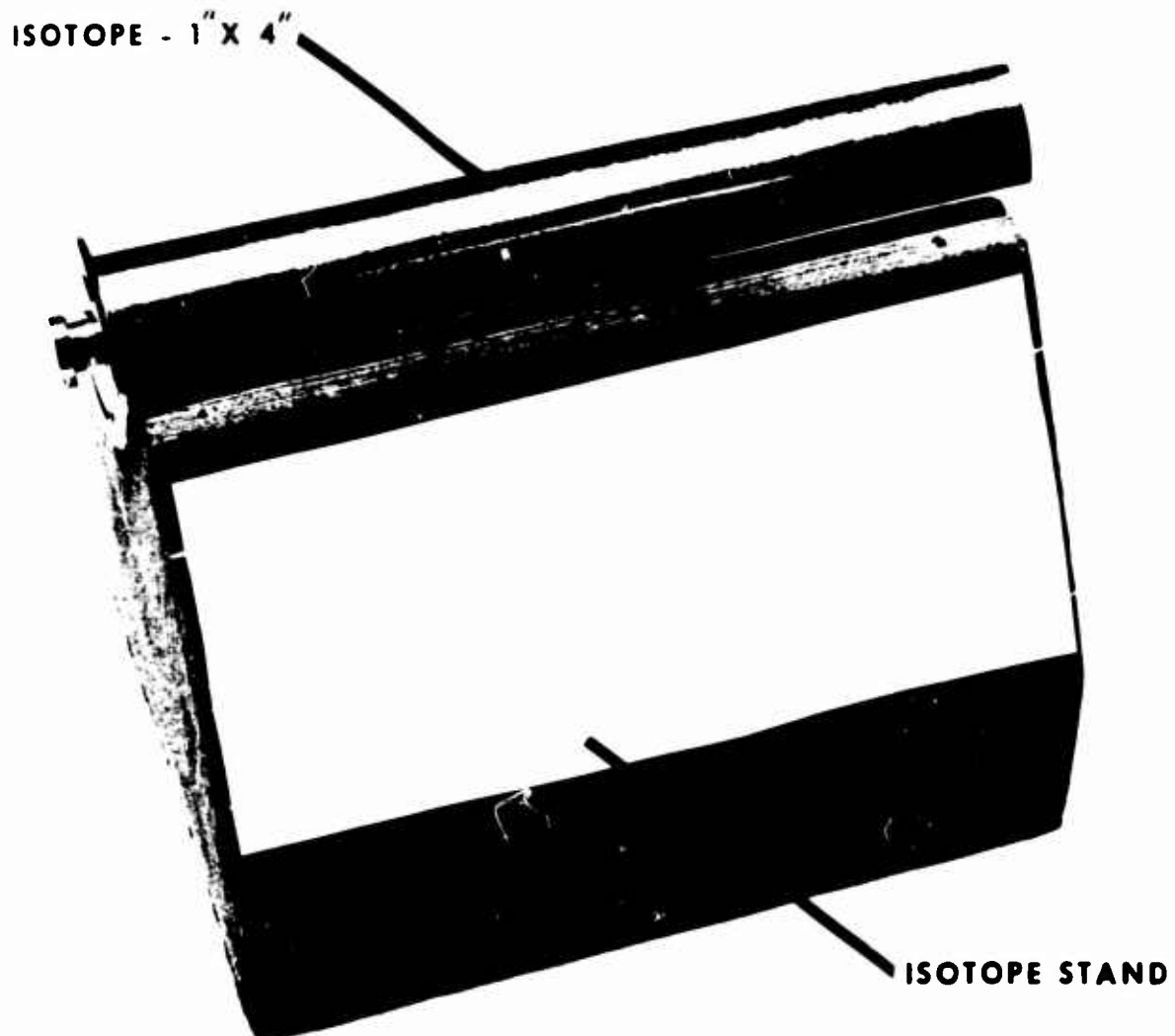
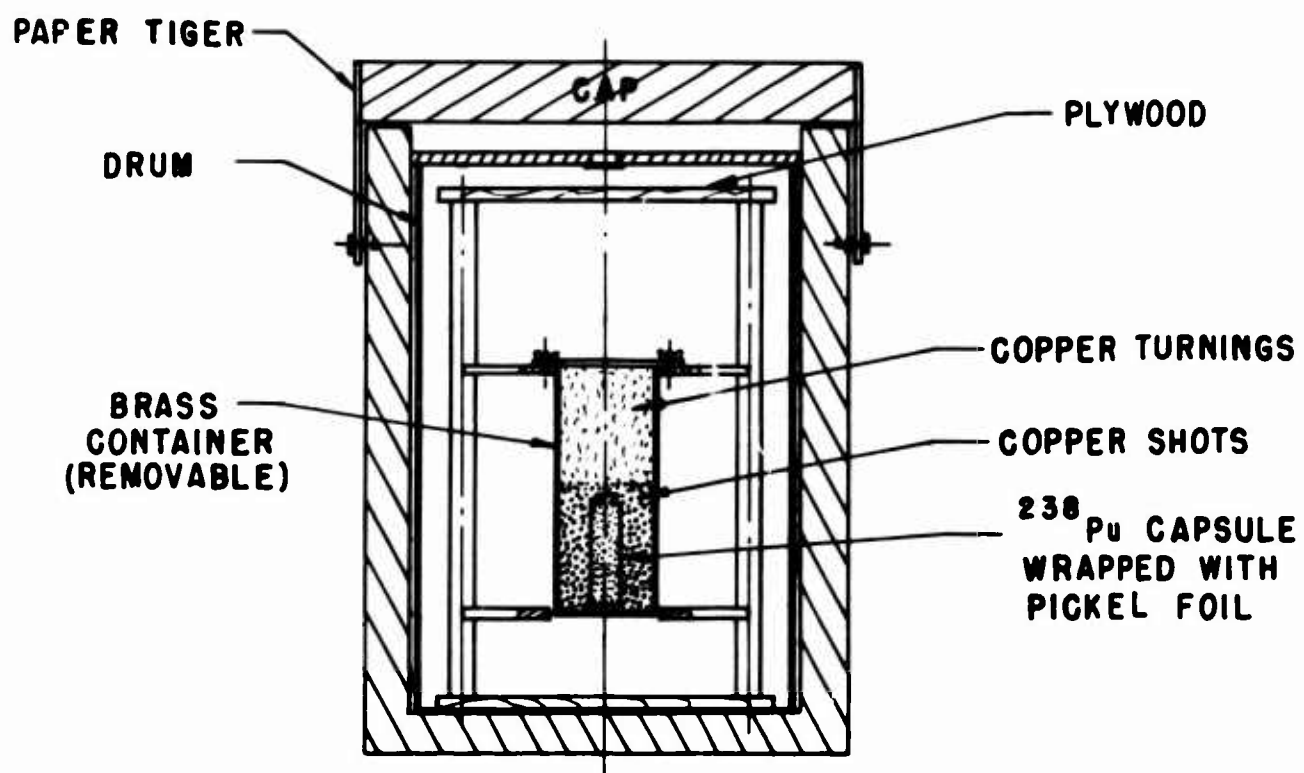


Figure 8 — Isotope Used for the Thermal Energy

The liner tube was fabricated from a tantalum-10% tungsten material. The wall thickness of the liner is 0.030 inch with an OD of 0.875 inch. The liner is 4.224 inches outside length with an internal length of 4.090 inches and is used to contain the fuel and to provide mechanical strength. (Plutonium-238, an alpha emitter, requires that a pressure vessel be used in this design to contain the resulting helium pressure buildup.) Caps were used to seal the liner. An outline drawing of a transport and storage container is shown in figure 9.

The clad tube was fabricated using Hastilloy-C and designed to act as an interface between the highly reactive refractory metal liner and the chemically corrosive environment. The wall thickness is 0.050 inch with an OD of 0.990 inch; the outside length is 4.438 inches. The capsule was sealed with caps.

Data derived using the stated dimensions and material (tantalum-10% tungsten) indicates 0.05% creep in 5 years at 1500 F since the stress builds linearly from zero to 22,000 psi during the 5 years and almost all the elongation occurs in the last year. MLM-1502, "The Compatibility of $^{238}\text{PuO}_2$ Microspheres with Refractory Metals and Alloys at 1000 C" indicated that a problem apparently does not exist with a 5 year lifetime for plutonium-238 dioxide microsphere-tantalum 10% tungsten (inner capsule) compatibility at temperatures up to 1500 F (ref 7).



NOT TO SCALE

Figure 9 — Radioisotope Storage and Transport Container Configuration

Table 2
ANALYTICAL RESULTS-RECLAIMED WATERS

[illegible]

Refractory metals/transition metals suffer from incompatibility when in contact at elevated temperatures; however, the diffusion coefficient allows a depth of penetration of about 5 mils in 5 years which is a slow enough rate for acceptability. Higher diffusion rates cannot be tolerated since the tantalum-10% tungsten liner will lose too much mechanical strength due to decreased wall thickness.

The 0.050 inch wall clad tube appears sufficient for 1500 F use if only air or inert gas environments are encountered. At 1500 F, Hastilloy-C exhibits good oxidation resistance. Air oxidation occurs to the extent of 2.3 mils in 1000 hours and 6.0 mils after 5000 hours at 1832 F. (ref 8). (Reference AEC Savannah River Publication DP-1105-1 and DP-1120-1, Savannah, Georgia.) Environmental control must be maintained. Should corrosive atmospheres or surroundings be encountered, the heat source would have to be located in a shell compatible with both the heat source and the corrosive ambient.

SECTION III RESULTS

CHEMICAL ANALYSIS

Twenty-one samples of recovered water (9 from Phase I and 12 from Phase II tests) were analyzed and the results are shown in tables II and III. All samples of recovered water were obtained during Phase I conformed with NAS (ref 8) and FWPCA (ref 9 and 10) standards for drinking water. The water produced during the first 18 days of the Phase II test was of excellent quality but from this date until the end of the test, the water produced showed contamination. The ammonia content, conductivity, pH, and odor showed a marked change beginning with sample Nr. FWPCA-7 collected on 11-10-69. The contamination of the system was the result of insufficient feed of the waste product to the evaporator causing a rise in temperature and the boil-over of ammonia before being detected. In both cases, ammonia would evaporate resulting in contamination of the system. After the evaporator was adjusted to the correct level, the system functioned satisfactorily. Although the system was known to be contaminated, operation was continued to gain information on system reliability and to evaluate the continuous use of the radioisotopes.

TABLE III
NITRITE-NITRATE ANALYSIS

The samples were delivered to the FWPCA on 5 Feb 70 and were analyzed on February 6 using a Technicon AutoAnalyzer®. The results were as follows:

<i>Sample Collected</i>	<i>NO₂/N, mg/liter</i>	<i>NO₃/N, mg/liter</i>	<i>Total NO₂-NO₃/N, mg/liter</i>
<i>1969</i>			
9/31	0.02	-	0.02
10/21	0.52	0.38	0.90
10/30	0.90	0.26	1.16
10/31	1.58	0.22	1.80
11/1	1.49	0.07	1.56
11/2	0.90	0.01	0.91
11/3	0.48	0.05	0.53
11/6	0.16	0.04	0.20
11/7	0.09	0.04	0.13
11/11	0.09	0.08	0.17

NOTE: Considering the fact that the samples were more than 2 months old at time of analysis, the amount of nitrite-nitrogen found indicates that this material was probably being removed from the catalyst.

MICROBIOLOGICAL ANALYSIS:

Forty-one samples of the recovered water were analyzed microbiologically using standard methods. Visual examination of the samples tested revealed no bacterial growth in thirty-seven of these samples. One sample contained an average count of 60 organisms/100 ml. Another contaminated sample exhibited bacterial growth with an average of 30 organisms/100 ml. The results of 39 samples analyzed microbiologically conform to the requirements of the NAS Ad Hoc Panel on Water Quality Standards (Sep 1967) which allows 10 organisms/ml. The contamination of the remaining two samples was due to septic techniques during sample collection.

Examination for nonviable cellular material revealed that no intact bacterial cells were present. Detailed methods used for the microbiological analysis and complete data covering the results have been presented elsewhere (Ref 11).

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

Potable bacteria-free drinking water was produced during continuous operation of 39 days (Phase I) and 18 days (Phase II). Failure to produce quality water continuously after the eighteen days in Phase II was the result of the timer or sensor failure which allowed the evaporator to overfill or go dry. This was the major problem during the entire test and the initial sensor failure resulted in contamination of the entire system. Although the system became contaminated the test was continued to obtain additional data on system operation. An acceptable and completely satisfactory sensor is not currently available to meet the requirements for this system, e.g. corrosive material, low pressure, weightlessness, minimum level differential, etc. The sight gauge incorporated with the evaporator also gave erroneous readings due to the requirement for operation of this gauge with the liquid and head pressure under vacuum. A sight gauge is unacceptable due to the weightlessness and vacuum environment.

Temperature during the evaporation of the waste product should never exceed 120 F and optimally should remain close to 100 F. The temperature and pressure in the evaporator contribute mostly to the satisfactory operation of the unit and the production of potable water. Unlike the evaporator, the catalytic oxidation unit temperature and pressure can vary considerably without affecting the potability of the water. Catalytic oxidation (240-280 F) of the vapors recovered from low temperature evaporation of waste products removes the odor and reduces the total organic carbon to an acceptable level. The catalytic oxidation of the vapor does not remove ammonia and if ammonia is boiled off, due to elevated temperature in the evaporator, it will contaminate the system and possibly poison the catalyst.

The radioisotopes show great promise to furnish thermal energy not only for water reclamation but also for various other life support systems. Operating temperatures can be controlled by the design of the heat source for the individual system. Actually the heat sources were the most reliable item of equipment of the complex system. Processes that have been previously abandoned because of the nonavailability of electrical energy to furnish the required heat should be reevaluated with consideration being given to the use of isotopes.

The process is a leading contender for future flight and bare base applications because the system design requires few moving parts and high quality water is continuously produced during extended tests. High temperature vapor pyrolysis and low temperature catalytic oxidation are rival approaches for future water reclamation systems and a detailed comparison evaluation should be accomplished. Future designs should also con-

sider incorporation of a vapor compressor with this system to obtain a self-contained unit. Research and development should continue to improve the membrane, catalyst and other components of the system. The design of the evaporator for aerospace application should be subjected to additional investigation and weightless testing for possible modifications. An AMRL research and development effort with the General American Research Division which will include a specific change in design of the evaporator is nearing completion.

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13. ABSTRACT Research conducted to obtain a process and system design for the recovery of potable drinking water from human waste during extensive space flights revealed that the most promising process required considerable thermal energy for satisfactory operation. The large consumption of electrical energy prohibits system acceptability when the energy drain is on the vehicle electrical supply system. To meet the need for thermal energy, radioisotopes were investigated and found to conform with the known requirements. The Air Force designed laboratory Vacuum Distillation-Vapor Filtered Catalytic Oxidation Water Recovery System, which uses electric energy, was redesigned to accept radioisotopes. Specific isotopes were designed for integration with the Air Force modified system. The review of previous research on water recovery systems, the design and development of the Air Force modified system, and detailed data on two (36 and 39 day) tests with the isotopes in place supplying the total thermal energy is presented in the report. The complex system is considered a technological breakthrough and for the first time, a radioisotope fueled system is programmed for a 90-day manned chamber test, recovering drinking water from human waste for consumption by four crewmen during the experiment.		

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