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# FINAL TECHNICAL REPORT FOR A WASTE MANAGEMENT SUBSYSTEM

NASA Contract No. NAS 1-2193

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# FOREWORD

This report was prepared by the MRD Division of the General American Transportation Corporation, Niles, Illinois, to summarize the work performed under Contract NAS 1-2193 for a life-support waste management subsystem. The work was monitored by Mr. C. H. Wilson of the Space Station Office at the NASA Langley Research Center.

Contract NAS 1-2193 was awarded on 19 July 1962, when MRD was the Mechanics Research Division of the American Machine and Foundry Company. On 1 September 1962 this Division was purchased by the General American Transportation Corporation, and renamed the MRD Division. All customer contracts, including NAS 1-2193, were included in the sale.

Contract NAS 1-2193 was amended three times after 19 July 1962. The first change covered the transfer of contract responsibility from AMF to GATC. The second amendment increased the scope of the contract to include the development of a flight prototype system for reclaiming potable water from urine. The third amendment increased the scope of the contract to include the development of an alternate drying unit for processing feces.

The work was performed by personnel within MRD's Environmental Systems Group. Mr. Jerry Rest, Design and Development Section, served as project engineer for this program. Mr. Jack D. Zeff, Supervisor of the Chemical and Biological Research Section, served as project supervisor. Mr. Thomas L. Hurley assisted Mr. Rest in the performance of all evaluation tests.

## ABSTRACT

This report summarizes the work performed under Contract NAS 1-2193 for the development, evaluation and delivery of a flight prototype waste management subsystem, as part of a life-support system for manned orbiting space stations. The subsystem provides for the collection, processing and storage of the urine and fecal wastes produced by three or four men for a period of at least 60 days without resupply. Feces are collected by pneumatic transfer techniques and then dried for storage in plastic bags. Two drying units were developed - one for recovery of fecal water and the second for overboard disposal of fecal water. Urine is also collected by pneumatic transfer techniques, and then separated from entrained gas before it is pumped to a bladder-type storage tank. The subsystem contains a vacuum distillation unit for recoverying potable water from urine. Thermoelectric techniques are used to pumping latent heat from the condenser to the evaporator. Also, the unit is provided with an internal condensate pump, and a self-contained purge pump so that water vapor is not lost overboard. A reliability analysis indicates that dynamic seals, thermoelectric junctions and vacuum disconnects must be designed for in-flight maintenance to achieve a high operational reliability. Tests have shown that the system can store processed fecal matter for at least 75 days; but additional testing is recommended. Future development work should be directed towards improving design reliability.

AUTHOR

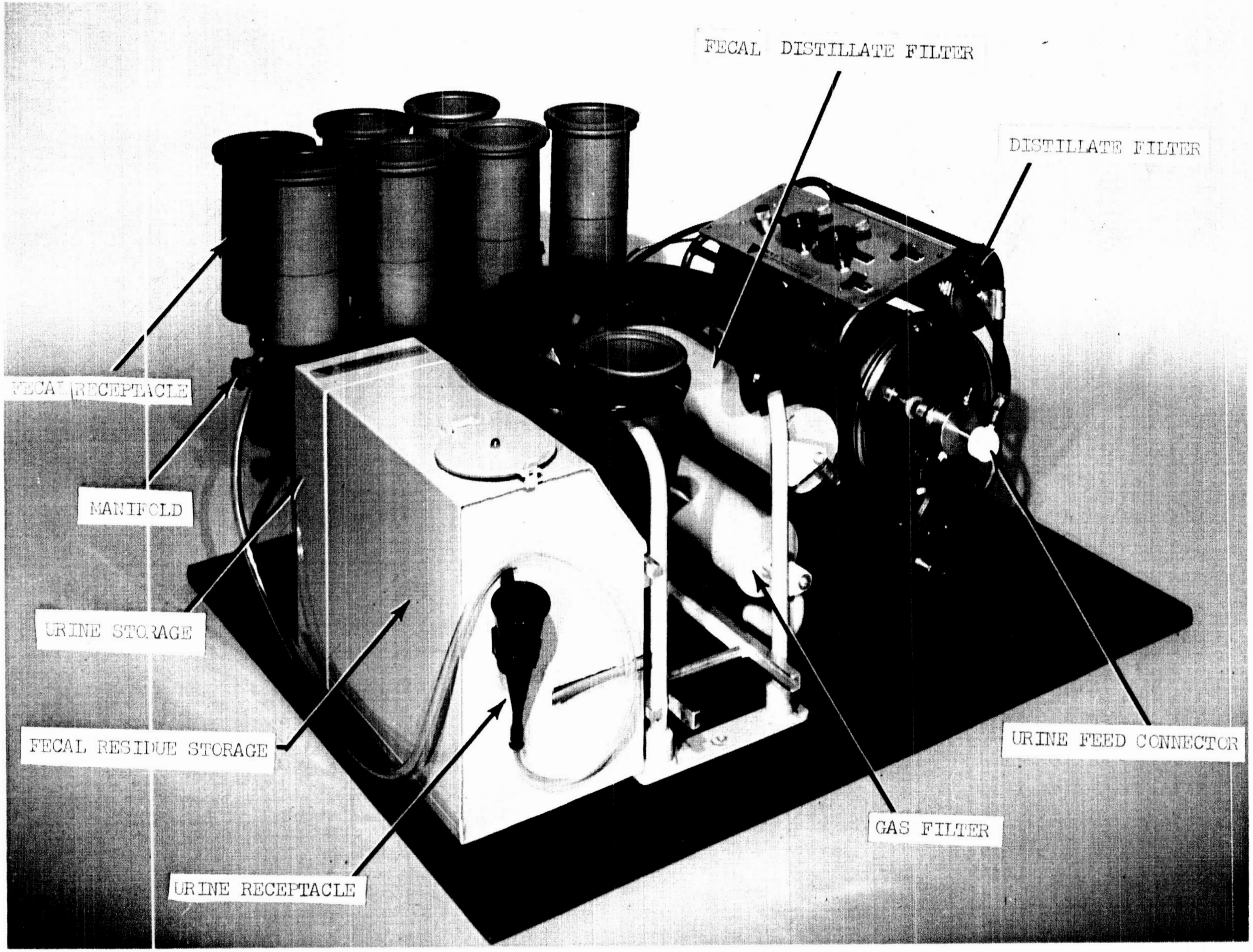

Figure 1 WASTE MANAGEMENT SUBSYSTEM

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## SECTION 1

## INTRODUCTION AND SUMMARY

This report summarizes the work accomplished on a program to analyze, design, fabricate, test, evaluate and furnish a waste management subsystem, as part of a life support system for manned orbiting space stations. It was originally specified that the subsystem shall provide for the collection, disposal and storage of human wastes. The program was extended at later dates to include (1) a thermoelectric distillation system to recover potable water from urine, and (2) a freeze drying unit as an alternate method of preserving fecal wastes.

It was specified that the waste management subsystem must provide for the separate management of urine and feces from a minimum of three men for a continuous period of at least 60 days. Also, the subsystem must be designed as flight prototype equipment and have minimum weight, volume and power penalties. In addition, the subsystem must be designed to operate at any acceleration level from zero to 1 "g" in a cabin environment of 7 to 15 psia (2.94 psi $O_2$ partial pressure), 70 to 80°F, and 40 to 60 percent relative humidity.

The following specific performance requirements were delineated for each major component of the subsystem:

### Waste Collection and Storage

Simultaneous collection of urine and feces must be provided with sufficient accommodation for the varied consistencies of fecal wastes, and for imbalances in the use cycle. A minimum of 85 percent water, containing particles of less than 50 microns, must be recovered from the feces, and the feces residue must be stored in a small volume. The collection and storage of the wastes must be done in a simple and sanitary manner with a minimum of handling and without bacterial contamination of the vehicle atmosphere.

## Urine Water Recovery

Urine is to be distilled at any rate up to 0.5 pounds per hour by thermoelectric transfer of heat from the condenser to the evaporator, with zero "g" capability being provided by centrifugal action. The total power demand of the unit must be less than 50 watts. Also, the unit is to include (1) a liner for removal of residue, (2) a self-contained vacuum pump, (3) a filter cartridge, and (4) a reclaimed water storage tank with a minimum capacity of 10 pounds.

## Alternate Freeze Drying Unit

An alternate method of fecal preservation is to be provided, and use the heat of cabin air and the vacuum of space for freeze drying of feces. The design of the dryer is to accommodate a crew of four men and provide heat exchange between the cabin air and the dryer. The dryer must be interchangeable with the original dryer which reclaims water from feces.

The waste management part of the subsystem, including the fecal water recovery and dryer unit was developed and tested initially. The fecal and urine collection were comfortable to use and easily maintained in a sanitary condition. The odor and bacteria control components proved effective and reliable. The water reclaimed from the feces was of better quality than anticipated, but the electrical energy demand for drying (330 watt-hours per man/day) was high. No evidence of bacterial action on the dried feces residue occurred after 75 days storage. Some odor was noted when the dried feces were transferred after drying to storage.

The thermoelectric urine water recovery system was developed subsequently. During development testing, some mechanical difficulties in the self-contained vacuum pump and the condensate pump were encountered and had to be corrected. The specified 0.5 pounds of urine per hour were processed with a direct yield of 91.6 percent. The quality of water recovered by this unit meets Public Health Standards. The thermoelectric modules required a direct current power input of 40 watts, while the drive motor required 20 watts of alternating current. The self-contained vacuum pump is of sufficient capacity to maintain condenser purge control.

The final extension to this contract was for the development of the alternate fecal freeze dryer unit. Preliminary testing of this unit found that sealing was adequate to maintain operating pressure below 3 mm Hga, and to minimize air loss (atmospheric pressure) to 0.003 pounds per drying.

From these tests it was concluded that (1) the collection equipment operated satisfactorily, (2) the urine collection technique is superior to previous techniques, (3) the recovery of fecal water requires too much electrical power, (4) dried feces can be stored in plastic bags for at least 75 days, (5) feces can be freeze dried by evacuation, (6) the average person uses an excessive amount of toilet tissue, (7) thermoelectric techniques require more power or larger heat transfer areas than vapor compression stills, and (8) a self-contained purge pump must have two stages for satisfactory operation with a vacuum distillation unit. A reliability analysis was performed to show that dynamic seals, thermoelectric junctions and quick-disconnects are the components most likely to fail during normal operation.

From results obtained it is recommended that the waste management subsystem, delivered to the NASA Langley Research Center, be subjected to additional tests. The objectives of these tests should be more detailed data on water recovery performance and storability of dried feces.

More development work is not recommended at this time, unless it is directed towards the improvement of subsystem reliability. A water recovery unit for a flight subsystem should (1) use waste heat or vapor compression, (2) be provided with internally located purge and bag vacuum pumps, (3) be provided with a urine metering pump, and (4) use Teflon coated or Teflon slipper seals.

## SECTION 2

## DESIGN CONSIDERATIONS

The basis for designing the waste collection, the water recovery, the waste storage, and the fecal drying units of the waste management subsystem are discussed in this section.

### 2.1 Fecal Accommodation

The volumes of the fecal collection, the fecal water recovery, and the fecal residue storage components are all dependent upon the quantity of feces output per man-day. The amount can vary from 0.2 pounds to over one pound per man-day depending upon diet, environment and well-being of an individual crew member. On a low residue diet, an average man in good health will probably excrete about 0.2 pounds of feces per day. For design purposes, MRD selected a value of 0.3 pounds per man-day.

### 2.1.1 Collection

The chosen concept of pneumatic control of the feces after defecation was first tested in a waste collection unit developed by MRD under Contract AF 33(616)-6132 (1)*. A follow-on program for waste collection verified the principle of pneumatic control (2). Both of these programs specified that the feces were to be used for further processing, and only temporary storage was needed. The containers developed in both programs were not designed for fecal water removal nor for feces drying; therefore, it was necessary to develop a new collector. It was concluded that the feces and free water could be retained by a porous plastic liner, within a rigid container, that would permit gas to pass through during defecation, but would not allow the fecal solids and liquids to pass

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* Numbers in parenthesis refer to references listed in Section 6.

through. During drying, the vapors from the feces would also pass through the permeable liner leaving the solid residue behind.

The displacement volume of 0.3 pounds of feces is less than 10 cubic inches. An individual feces collector must be substantially larger than this to accommodate a collection bag and toilet paper. Cursory experiments were performed to show that a collection bag will occupy about one cubic inch, and used toilet paper will occupy a volume less than two cubic inches. The minimum total volume of a feces collector should therefore be about 13 cubic inches. This is a relatively small volume; a container with this volume would either be too short or too small in diameter. It was decided, therefore, to design a 4-inch diameter by 8-inch long container to facilitate insertion of a collection bag and also provide sufficient height for the maximum length feces anticipated.

### 2.1.2 Water Recovery

Approximately 75 percent of the feces weight is water. Therefore, the water available from this source is about 0.15 pounds per man-day when a controlled, low residue diet is used.

Feces contain a large number of malodorous compounds with high vapor pressures, and also a great number of microorganisms. Previous research conducted by MRD (3) has shown that there is high carry-over of odor and bacteria when feces are distilled from either the liquid or the frozen state. Distillation processes with odor removal processes that can be employed are the following:

A. Multieffect distillation

B. Catalytic vapor phase oxidation

C. Vapor or liquid phase absorption

D. Liquid phase oxidation

The advantages of *multieffect distillation* are efficient utilization of input energy and positive separation of high vapor pressure from low vapor pressure constituents. The disadvantages are the lower yield of water and the greater weight and volume of the processing system. These disadvantages can be partly overcome if the total effects are reduced to two, and if vapor or liquid adsorption is used either between the effects or after the second effect. Further reduction in weight and power is possible if the second effect is the urine water recovery system.

*Catalytic oxidation* removes odor-causing compounds by allowing the water vaporized from the feces to contact a heated platinum screen. The compounds such as mercaptans, indole, and skatole are oxidized to innocuous sulfates, nitrates, water and carbon dioxide. The main disadvantage of this catalytic oxidation method is that a large amount of power (approximately 0.6 watt-hour per ml of water recovered) is needed to heat and maintain the catalyst at an operating temperature of 1000°C or greater. Present oxidation techniques also use cabin gas for the source of oxygen. If external vacuum is used to reduce pressure within the still, unused oxygen and the nitrogen would be lost overboard. If a vacuum pump is used, a greater size pump and more power are necessary to remove the excess oxygen and the nitrogen.

The odorous constituents can be removed in the distilling of the water from feces by adsorbing these contaminants on activated carbon. The adsorption can be done either in the vapor or liquid state. The advantage of *vapor adsorption* is that a high degree of contact between the vapor and the carbon is possible. The disadvantage of the technique is that the temperature of the carbon will have to be maintained above the boiling temperature so that condensing does not take place within the carbon. Electrical heating of the carbon would therefore be needed, unless waste heat is available for this purpose.

In liquid phase adsorption, odor adsorption of the contaminants in the condensate will require more contact time, since there is less surface contact between the adsorbent and the contaminant. This should not present a problem because of the small quantity of fecal water to be recovered per day; also the temperature of the carbon does not have to be higher than the saturation temperature. The amount of adsorbent required per unit volume of recovered water is dependent upon the end use and the quality of the water. The weight penalty of the system will have to include the weight of adsorbent to be carried on the mission.

Liquid phase oxidation removes odoriferous compounds in the fecal water by means of a chemical or biological oxidizing agent. Chemical agents which can be used are the persulfates, dichromates, and permanganates. Their advantage is that they not only oxidize the contaminants to less noxious compounds but they are also strong disinfectants. The disadvantage in using these oxidizers is that they require a high degree of mixing to be effective. Therefore special mixing apparatus would be required if this technique was used to disinfect feces.

None of the preceding methods of odor removal has been evaluated to any extent for use in fecal water recovery. It appeared that the most practical means of odor removal, as indicated in previous water recovery work carried on by MRD, is the double-effect distillation method combined with liquid phase adsorption. Experimental verification of this method of fecal water recovery was therefore required.

The experimental program was designed to study the following variables of fecal water distillation:

A. Quality of recovered water

B. Stability of residue after distillation to determine storability at ambient conditions

C. Processing time

D. Sterilization technique(s)

E. Adsorption cartridge design and contents

F. Operating pressure and temperature

G. Approximate power and insulation requirements.

### 2.1.2.1 Low Pressure Tests

Recovery of water from feces at atmospheric and reduced pressures was performed in a 3-neck, 1000-milliliter filter flask. When reduced pressures were used, a dry ice-acetone trap was placed in the line to the vacuum pump to collect any water that failed to condense in the filter flask.

A thermometer and manometer were connected to the 3-neck flask and the temperatures of the mantles were read by means of thermocouples. A schematic diagram of the apparatus is shown as Figure 2.

Using random samples of feces collected from a number of individuals, duplicate distillations were run at 760 mm, 300 mm, and 100 mm absolute pressures. The average weight of feces used per run was approximately 100 grams. In each run, the feces were transferred to the flask and the contents of the flask were heated to the boiling point using both heating mantles. The power inputs of the mantles were controlled by use of Variac transformers.

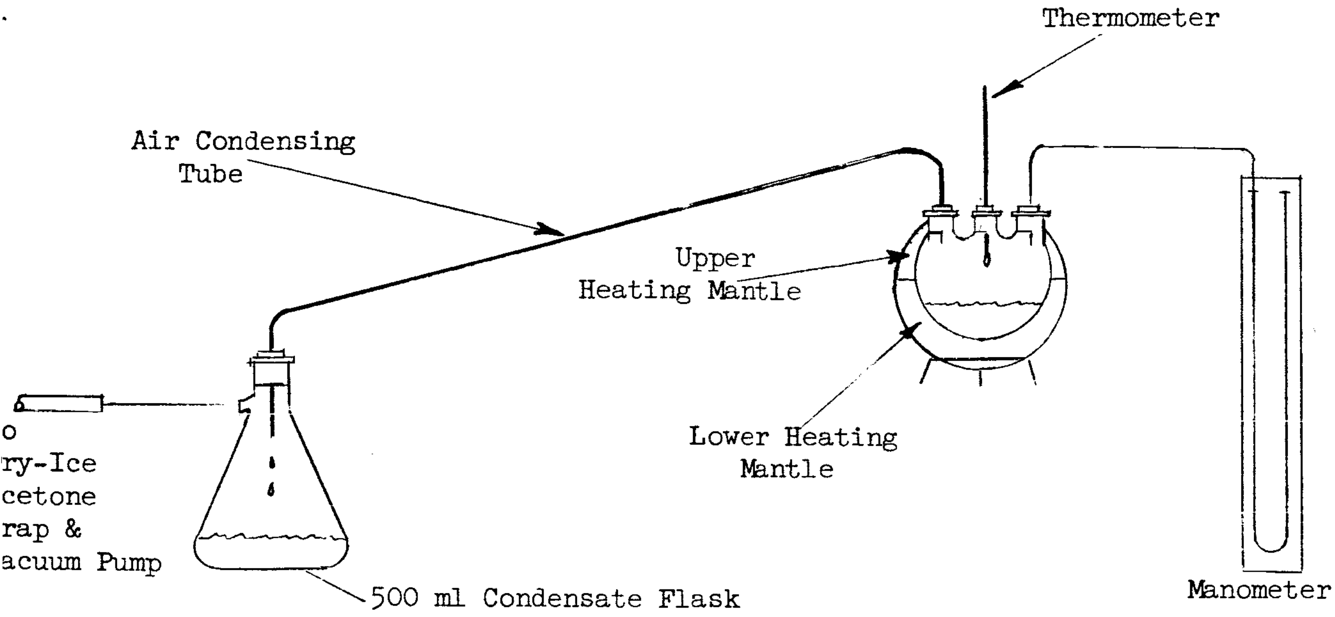


Figure 2 LOW PRESSURE DISTILLATION APPARATUS

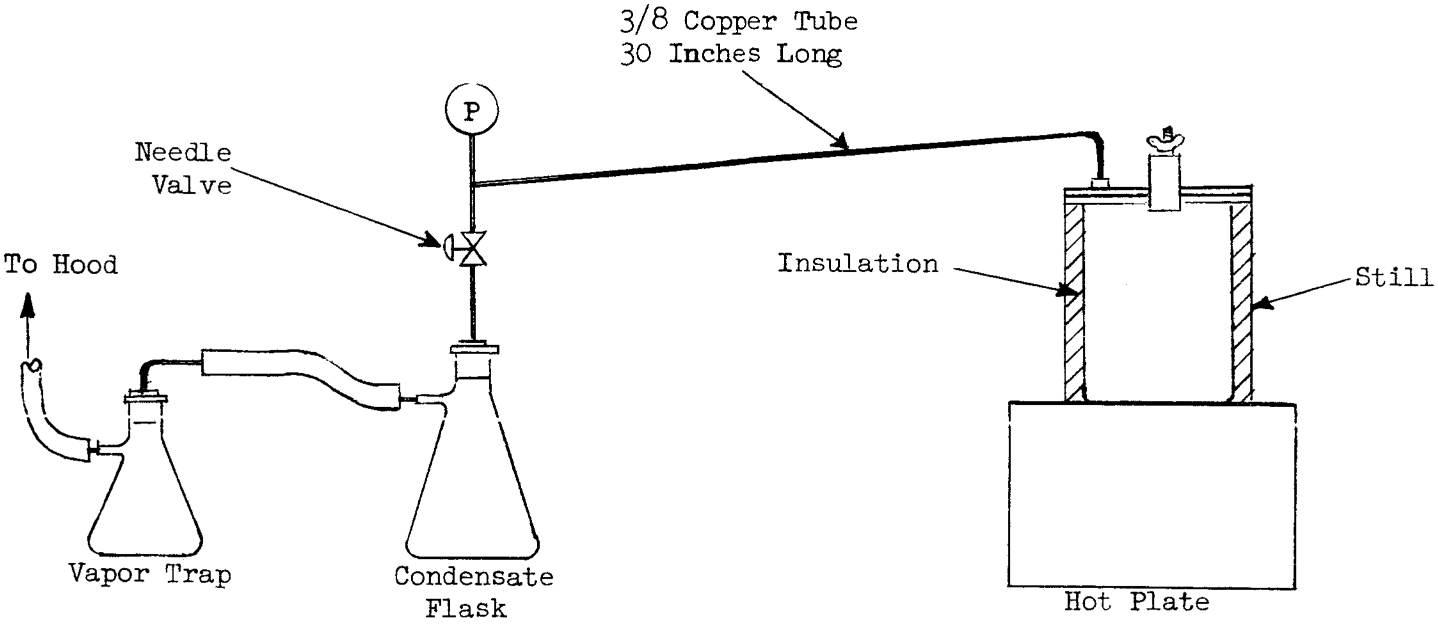


Figure 3 HIGH PRESSURE DISTILLATION APPARATUS

In all runs, it was observed that no undue frothing or foaming occurred. The distillate was found to be turbid, highly odiferous, and had some color in all cases. Almost 100 percent yield of the available water in the feces was obtained in each run. The time required for atmospheric distillation was less than the time required for the reduced pressure distillations.

The cloudy, odorous distillate from each run was passed through a 2-inch long by 5/8-inch diameter column of "Hydrodarco" (Infilco) activated carbon to determine the effect of carbon filtration on the water. The odor of the waters, after passing through the carbon, were noticeably reduced and only a slight odor remained. The filtration also reduced color slightly and improved clarity. A tabulation of experimental conditions and results are presented in Table 1. As indicated, the quality of water varied with each run to a considerable extent even when process conditions were the same. There appeared to be no consistency of results regarding total solids or ammonia nitrogen; there was only consistency in pH, odor, and the negative presence of coliform bacteria.

The residue after distillation was placed in sealed containers and stored at room temperature (70 to 90°F). The residue was divided into two parts with one part being stored with 3 grams of silica gel and one part without the gel. As shown in Table 1, all samples were evaluated after three weeks storage and were found to have no evidence of bacterial action such as a large increase in odor or gas build-up. Apparently the silica gel maintained the residue at a lower odor level than the residue without the gel.

### 2.1.2.2 High Pressure Tests

The seventh run was conducted at 2 atmospheres absolute pressure by distilling the feces in a bronze, asphalt-analysis still. As shown in Figure 3,

|  | EXPERIMENT NO. |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 1 | 6 | 2 | 4 | 3 | 5 | 7 |
| **PROCESS** |  |  |  |  |  |  |  |
| Wt. of Feces (Gm) | 80.2 | 104.2 | 88.2 | 107.5 | 125.5 | 78.3 | 180.5 |
| P mm Hg | 760 | 760 | 100 | 100 | 300 | 300 | 1520 |
| T °F | 212-257 | 212-248 | 131-147 | 133-178 | 167-212 | 171-234 | 350-450 |
| Yield Water Wt. Gm | 57.1 | 69.6 | 56.0 | 73.1 | 88.5 | 51.0 | 142.5 |
| % | 71.2 | 64.2 | 63.0 | 68.1 | 70.4 | 65.0 | 79.0 |
| Reclaim Time Hrs. | 7.5 | 6.5 | 11.5 | 16 | 11 | 13.5 | 26.5 |
| Residue Yield Wt. Gm. | 23.1 | 34.6 | 32.2 | 34.5 | 37.0 | 27.3 | 38.0 |
| % | 28.8 | 33.2 | 36.5 | 32.1 | 29.5 | 34.9 | 21.0 |
| Power Input Average Watts | 65 | 65 | 30 | 30 | 40 | 45 | -- |
| Total Energy Watts-hrs. | 487 | 423 | 345 | 480 | 440 | 608 | -- |
| Energy Wt. $H_2O$ W-H/Gm | 8.54 | 6.09 | 6.17 | 6.55 | 4.97 | 11.9 | -- |
| **WATER QUALITY** |  |  |  |  |  |  |  |
| After C Filtration |  |  |  |  |  |  |  |
| pH | 8.5 | 8.2 | 8.2 | 8.5 | 8.0 | 8.2 | 7.5 |
| Color | Yel-Br | Dk Br | Sl Yel Br | Sl Yel Br | Sl Yel Br | Sl Yel Br | Yel Br |
| Odor | Sl | Sl | Sl | Sl | Sl | Sl | Sl |
| Clarity | Clear | Clear | Clear | Clear | Clear | Clear | Clear |
| Coliform | Neg | Neg | Neg | Neg | Neg | Neg | Neg |
| $NH_3$ N ppm | 500 | 1550 | 240 | 1030 | 1100 | 480 | 3050 |
| Total Solids ppm | 195 | 249 | 5100 | 2010 | 2030 | 172 | 6550 |
| **RESIDUE QUALITY** |  |  |  |  |  |  |  |
| W/O Desiccant Stability | Sl. Gas | No Gas | No Gas | No Gas | No Gas | No Gas | No Gas |
| Odor | Str. Pung | Str. Pung | Str. Pung | Str. Pung | Pung | Pung | Sl Arom |
| W Desiccant Stability | No Gas | No Gas | No Gas | No Gas | No Gas | No Gas | No Gas |
| Odor | Pung | Sl Pung | Pung | Pung | Sl Pung | Sl Pung | Sl Arom |

TABLE 1 RESULTS OF FECAL DISTILLATION TESTS

the vapor from the still was condensed by air cooling in a 30-inch length of 3/8-inch diameter copper tube. A needle valve at the end of the copper tube was used to control distillation pressure. The condensate was collected in a filter flask connected to a secondary condenser flask submerged in a dry-ice, acetone bath. Heating was provided by a thermostatically controlled hot plate, and the upper sections of the still were insulated with fiberglass to minimize refluxing.

A larger amount of feces was used in this distillation than in the others, because the still had a large cover and was easy to load. The still was lined with aluminum foil so that the residue could be easily removed. As indicated in Table 1, the time of distillation was 26.5 hours; which was a longer time than any of the others. The amount of power required for the distillation could not be estimated, because only a small part of the hot plate surface was in contact with the still.

The temperature of distillation varied from 350° to 450°F with the higher temperatures occurring at the latter part of the cycle. During the early stages, the distillate was clear and colorless, although highly odiferous. The distillate in the late stages turned brown and viscous, indicating some destructive distillation. The overall quality of the distillate indicated more contamination than the previous runs as seen by total solids and ammonia nitrogen content.

The residue from this distillation was different from the previous residues in that the odor was more aromatic and not pungent, and that it was more brittle and ash-like in appearance.

### 2.1.2.3 Conclusions

From the results of the experimental study it was found that the quality of water was poor in all cases. The quality of water recovered at atmospheric pressure or lower was not affected to any significant degree by process conditions. Also, the quality of the residue was unaffected. The water distilled at 2 atmospheres absolute, however, was more contaminated. The available water in all cases was almost totally recovered.

The residue in all cases showed very little change or deterioration after being stored in sealed containers for three weeks or more. Silica gel added to the residue appeared to decrease the odor of the stored residue in most cases.

The reclaimed water even after passing through activated carbon was highly contaminated and will require further distillation and other treatment before it will be suitable for washing or drinking.

The study therefore found that a minimum of two effects are required for fecal water distillation. The study also indicated that the feces residue can be stored at 70 to 90°F for 3 to 4 weeks without the occurrence of marked bacterial action.

### 2.1.3 Freeze Drying

The drying of feces without recovery of the fecal water can be accomplished by freeze drying if outside vacuum is used. The sensible heat of the cabin can be employed to provide the latent heat of vaporization. The vapor vented overboard can be sterilized without the use of electrical energy if a sterilizing filter is provided. The same porous plastic liners used for fecal water recovery can be used for freeze drying. The loss of vehicle atmosphere must be kept at a minimum during initial venting; this can be achieved by displacing the vehicle gas back to the cabin prior to outside venting by the use of a hand pump or by the use of a deep well cover which acts as a piston. The gas that is returned to the vehicle must be passed through a deodorizing and sterilization unit.

Freeze drying of an average one man-day load of feces using a water recovery type fecal container and plastic liner resulted in the drying of the feces within 36 hours at an ambient temperature of 75°F and at an internal pressure of 3 mm Hga.

### 2.1.4 Storage

Dehydrated feces occupy about one-half their original volume. When packaged with toilet paper and compacted by hand, the bulk volume is less than 8 cubic inches. The total storage volume required for 190 man-days is, therefore, less than 1440 cubic inches.

## 2.2 Urine Accommodation

It was specified that the waste management system must provide the equipment necessary to (1) collect urine from three men, (2) temporarily store up to 10 pounds of urine, (3) recover potable water from urine at any rate up to 0.5 pounds per hour, and (5) store up to 10 pounds of potable water. Urine output varies with diet, activity and environmental conditions such as temperature and relative humidity. At the specified ambient temperature range of 70 to 80°F and relative humidity range of 40 to 60 percent, the average daily output of a sedentary male on a normal diet will range from 550 to 1900 milliliters (4) (5). The average quantity of urine anticipated each day is 1200 grams per man (6). The water recovery unit therefore, must be capable of operating each day at maximum capacity for a period of 7 to 24 hours, with an average use rate of 16 hours per day.

### 2.2.1 Urine Collection

An average, adult male can discharge up to 500 milliliters of urine in a single micturition. Previous systems provided for the collection of urine in a weightless state by directly transferring the urine into a collection container while the penis was held in contact with the container inlet (7,8). The urine was then manually transferred to a storage container by collapsing the flexible collection container. These techniques are satisfactory, provided the penis receptacle can be maintained in a sterile condition and the crew are able to perform the manual operations required. For this program it was decided to develop a urine collection system that does not have these disadvantages.

Aircraft-type relief tubes have proven to be acceptable for flight vehicles; they do not require contact between the penis and the funnel shaped inlet. The pneumatic force created by gas flow through the tube prevents back-flow of urine, so the same technique should prove satisfactory for operation in a weightless state. In a manned space station, however, cabin gas must be drawn through the relief tube by a blower instead of an overboard vent. Also, a urine separator must be provided.

The blower provided for pneumatic collection of feces can also be used for drawing cabin gas through the relief tube and a water separator. The gas flow rate required for operation in a weightless state can not be calculated until the frequency and amplitude of vehicle disturbances are known. However, past experience has shown that for odor control it is advisable to have a flow rate of at least 5 cubic feet per minute through the fecal collector. It was decided therefore to provide the waste management system with an available blower that could draw a total flow rate of 10 cubic feet per minute at 0.5 atmospheres against a static pressure of at least 4-inches water gauge.

Sponge and membrane type liquid-gas separators have been developed for operation in a weightless state. These types are not considered to be satisfactory for a urine separator because urine solids would accumulate on the sponge or

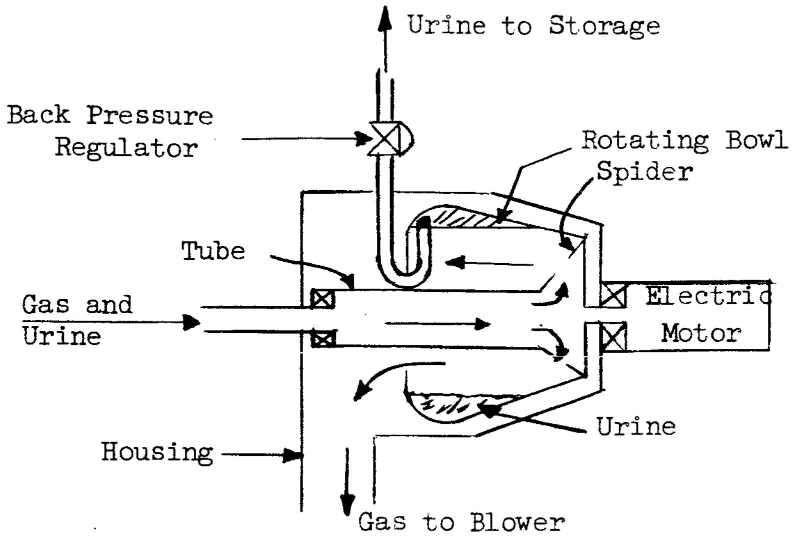


Figure 4 URINE SEPARATOR CONCEPT

membrane and thereby reduce the separators effectiveness. Therefore, it was decided to develop a centrifugal separator that is provided with an impact tube for pumping urine into a temporary storage container. The figure above illustrates this technique.

As shown, an electric motor is required to rotate the tube, spider and bowl within a rigid housing. Gas and urine passed into the unit are forced to assume a vortex flow pattern so that urine will be centrifugally separated and forced against the inner wall of the bowl. Viscous drag forces tend to keep the urine rotating with the bowl so that a stationary impact tube can be used to "pump" urine out of the separator. Since an impact tube is capable of developing higher static pressures with liquids than with gases, the back-pressure regulator can be set to (1) close when the bowl has been emptied, and (2) prevent back-flow of urine from a pressurized urine storage container. Capillary action can be used to hold urine in the impact tube so that gas is not forced into the storage container during the next operation.

Several design calculations were necessary to size the urine separator components; namely, the bowl diameter and electric motor requirements. An electric motor operating at a rotational speed of 3450 rpm was selected, because the power input specified was 115 volt, 60 cycle, single phase. Also, it was assumed that the bowl could be driven directly by this motor. If the rotational speed of the urine at the impact tube inlet is equal to the bowl speed, the following relationship indicates the maximum static pressure attainable with a given bowl diameter.

$$p = \frac{\rho}{2g} (\omega \pi d)^2$$

where

$p$ = static pressure, $lb/ft^2$

$\rho$ = urine density, 63.6 $lb/ft^3$

$\omega$ = rotational speed, 3450 rev/min

$d$ = diameter, feet

$g$ = 32.2 $ft/sec^2$

From this relationship it can be shown that a five-inch diameter bowl could develop a static pressure as high as 39 psi. A high static pressure is not required because the urine only has to be transferred to a storage tank, from there it is to be drawn into a vacuum distillation unit. On the other hand, the actual pressure developed will be much less than the theoretical, because the urine velocity in the region of the impact tube will be significantly less than the surface speed of the bowl in that region; the balance of viscous drag forces is such that the average impact velocity should be at least one-half the surface velocity of the bowl. It was decided to use a five-inch diameter bowl so that a static pressure near 10 psi would be achieved and a relatively insensitive back-pressure regulator could be used.

The power required to drive the urine separator bowl is determined primarily by the drag effect of the impact tube, when it is fully immersed in urine. The following equation shows that power varies as the cube of urine velocity past the tube.

$$P = \frac{C \rho A\ v^3}{7200\ g}$$

where

$P$ = power, ft-lb/min

$C$ = drag coefficient

$\rho$ = urine density, 63.6 $\text{lb/ft}^3$

$A$ = drag area of tube, $\text{ft}^2$

$v$ = urine velocity, ft/min

$g$ = 32.2 $\text{ft/sec}^2$

It was assumed that the drag coefficient would be near a value of 1.0, and that the urine velocity would be near one-half the tangential speed of the bowl in the vicinity of the impact tube. The power equation then reduces to the following:

$$P = 31.5 \times 10^6\ A, \text{ ft-lb/min}$$

or

$$P \cong 1000\ A, \text{ horsepower}$$

The urine separator should not require a power input of more than 15 to 20 watts, to be practical for a manned space station. From the power relationship it can be seen that the drag area must be very small to keep the power requirement down at this level. It was decided, therefore, that the exact design could not be determined completely by analysis, experimental data was needed. The bowl diameter was then fixed at 5 inches, and the impact tube design left for determination later in the program. Two electric motors were ordered from the Diehl Manufacturing

Company — one rated at 1/100 horsepower and second rated at 1/250 horsepower. If these motors proved to be inadequate, it would be necessary to reduce the static pressure requirement imposed by MRD and operate the separator at a lower speed.

### 2.2.2 Water Recovery

It was specified that the water recovery system shall utilize thermoelectric devices for vacuum distilling water from urine at any rate up to 0.5 pounds per hour. Also, it was specified that centrifugal action shall be employed to operate at any g level from zero to one-g. In addition, the power input to the thermoelectric devices shall be 30 watts or less, and the total power input shall be less than 40 watts. It was also specified that the unit shall be provided with a (1) filter cartridge, (2) self-contained purge pump, (3) self-contained condensate pump, and (4) removable liners for collection and disposal of urine residue.

It was desired to achieve nucleate boiling with this system, as in the compression distillation system developed by MRD under Contract NAS 1-1225, so that the vaporization process would be fairly stable and relatively insensitive to changes in feed and ambient temperatures. From past experience, it was known that with a 5-mil thick cast vinyl liner, one square foot of heat transfer area would be required to achieve a vaporization rate of 0.5 pounds per hour. Also, it was known that the temperature difference across the liner and the vaporization film must be near 10°F, and all other temperature differences would be insignificant. The thermoelectric devices must, therefore, be designed to transfer at least 600 Btu per hour against a 10°F temperature difference with a power consumption of 30 watts or less.

Centrifugal action was to be employed to separate water vapor from the urine. A cylindrical bowl was therefore selected to serve as the evaporator so that by rotating the bowl around its longitudinal axis, urine could be retained within the bowl in which vaporization occurred. A bag-shaped vinyl liner could then be used to facilitate the periodic removal of urine residue. The outer surface of this bowl could also serve as the condensation surface, like the compression distillation units developed by MRD. In this system, however, the bowl must be of double-wall construction so that thermoelectric devices in the annular space can "pump" heat from the condensation surface to the back-side of the vinyl liner. This approach was selected because it provides a very compact design. This assembly was then designed to fit within another rotating bowl which serves as a condenser shell. No insulation was provided because the system will operate satisfactorily at a temperature less than 10°F above any ambient temperature in the range of 40 to 120°F.

The minimum internal diameter recommended for the evaporator is six inches — with smaller diameters, flashing and/or foaming could cause vapor entrainment of urine. The bowl length required to provide one square foot of vaporization surface is then 7.65 inches.

The Jepson Thermoelectric Corporation was contracted to design, develop and build the thermoelectric modules specified by MRD. The results of their work is summarized in Section 3.3 on page 37.

It was specified that the unit must be furnished with a vacuum pump for purging the condenser, instead of an overboard connection with a purge control valve like MRD had furnished on previous vacuum distillation systems. From past experience it was known that the purge rate can be less than one percent of the water vapor flow rate. With a condenser temperature of 80°F, the maximum purge rate required is then approximately 90 cubic inches per minute.

It was then decided to provide one electric motor for (1) rotating the bowl assembly, (2) operating the condensate pump, and (3) driving the purge pump. Since the desired bowl speed was approximately 60 rpm, it was decided to select the same speed for the purge and condensate pumps. A two-piston purge pump was then designed so that the torque requirements would be minimized. The displacement rate provided was 114 cubic inches per minute, so that a pumping rate of at least 90 cubic inches per minute would be achieved. From past experience, it was known that the maximum electrical power required to operate this pump could be estimated from the following relationship:

$$P = 100\ (v_d)^{0.75},\ \text{watts}$$

where

$P$ = electric motor input, watts

$v_d$ = displacement rate, $ft^3/min$.

For $v_d$ equal to 114 cubic inches, the electric power demand for operating the purge pump should be less than 13 watts. A 15 watt motor was purchased to perform this function as well as rotate the bowls and operate the condensate pump.

### 2.2.3 Residue Storage

In reclaiming water from urine, residue and plastic evaporator liners will accumulate during a mission and must be stored. Since the waste management subsystem was designed before the urine water recovery extension to the program was included, no storage allowance for residue and plastic liners is provided. Future subsystems will require 0.8 cubic feet storage for wet residue storage or 0.5

cubic feet dry residue storage for a 180 man day mission. The evaporator liner occupancy for 180 man days is about 0.3 cubic feet (based upon the use of one liner per day).

## 2.3 Odor and Microorganism Control

Odors and microorganisms can emanate from the fecal collection unit, the urine collection unit, the fecal and urine water recovery units, and the fecal and urine residue storage units. Provisions must be made for preventing these contaminants from entering the vehicle atmosphere. The control of the odor and biological contaminants can be achieved by providing suitable components in the vehicles atmospheric control system to accommodate the contaminants from the waste management subsystem as well as from other sources. The alternative method is to provide separate components to specifically control the waste management subsystem contaminants. The latter case of separate components was specified for this program.

### 2.3.1 Fecal Collection

A slight negative pressure within the fecal collector will prevent the contaminants from entering the atmosphere. Negative pressure can be attained by connecting the container to the suction side of a blower. The odors and microorganisms drawn into the blower are then removed or neutralized before the gas is returned to the vehicle atmosphere.

Odors are removed either by catalytic oxidation or by activated carbon or by a combination of both. Odor control was employed effectively by the sole use of activated carbon in a previously developed MRD waste collection system. The system, a modified chemical toilet, was developed for use in the Martin-Marietta

Lunar Landing Simulator. The collected fecal matter was preserved by thermoelectric cooling instead of chemical disinfecting. Odor control was achieved by drawing the cabin gas into the fecal collector and then through two, 1-pound canisters of activated carbon connected in series. This system was used by three men for missions of three days or longer without exhaustion of the two pounds of activated carbon. From this experience, the initial design of the subsystem incorporated activated carbon for odor control without the use of catalytic oxidation.

Microorganism control can be effected by wet or dry thermal destruction, by micro filtration, by ultraviolet radiation, and by chemical disinfection. The thermal and radiation methods require electrical power, while the disinfecting method requires additional weight for chemicals. Microfiltration appeared to be the simplest and most positive method; therefore, it was selected for this system.

### 2.3.2 Fecal Storage

Water is removed from the feces either by distillation or freeze drying. After water removal, bacteriostasis occurs and odor and gas propagation is prevented as long as the fecal residue remains in a dry state. To accomplish this, the storage container for the fecal residue must be sealed and the atmosphere in the storage container maintained in as dry as state as possible.

### 2.3.3 Urine Collection

The control of odor and any microorganisms evolving from the voiding of urine can be accomplished by the use of slight negative pressure in the collection container. The odors and bacteria can be removed in a similar manner as the contaminants from feces by filtration and adsorption. The pneumatic and contaminant control components can be common for urine and fecal collection.

### 2.3.4 Urine Residue Storage

The residue from urine distillation contains approximately 37 percent water. The residue should be dried before storing to prevent the growth of bacteria and the evolvement of odors. The residue can be dried by exposing the residue to outside vacuum at the end of the distillation. Drying can be done in the thermoelectric still or can be done in one of the freeze-dry fecal containers. The former method is most convenient since handling of the wet residue is not necessary.

# SECTION 3

## DETAIL DESIGN

The waste management subsystem consists of subassemblies for (1) waste collection, (2) fecal water recovery, (3) urine water recovery, (4) fecal freeze drying, (5) residue storage and (6) microorganisms and odor control. The assembly drawing of the designed subsystem (without urine recovery) is shown in Figure 5.

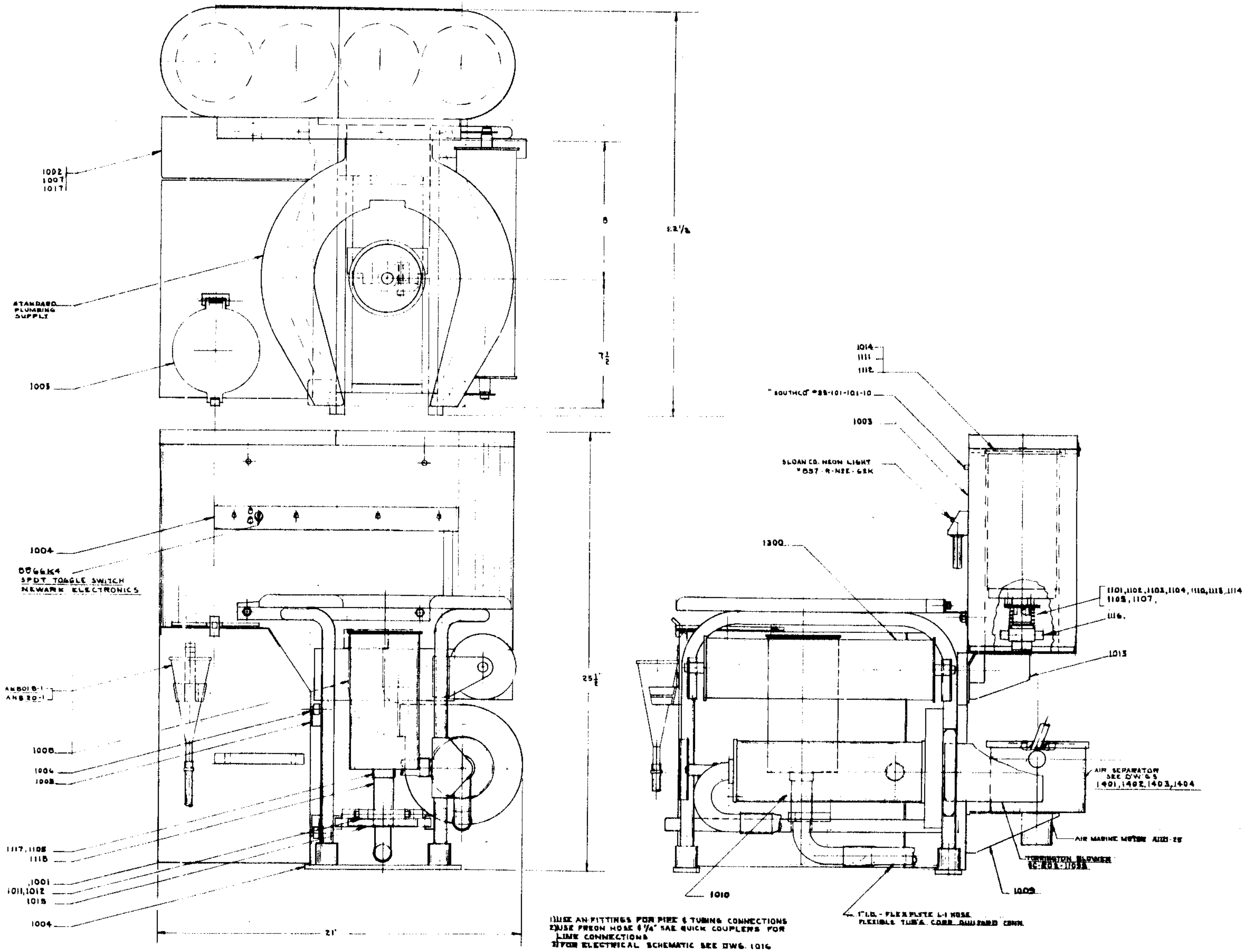
### 3.1 Waste Collection Unit

The waste collection components consist of a conventional toilet seat, a fecal waste collector, and the urine collector.

### 3.1.1 Fecal Collection

The fecal collector is a cylindrical receptacle approximately four inches in diameter by eight inches long. It is constructed from aluminum alloy, and Emarlon-coated for corrosion protection and prevention of odor adsorption. A 5/8-inch diameter, bayonet-type connector is located in the bottom of each receptacle. The inlet side of this penetration is protected by a 10-mesh, Emarlon-coated screen.

Two types of fecal collection receptacles were designed, as shown in Figures 6 and 7 — one for fecal water recovery and the other for freeze drying of the feces. The overall dimensions are the same for each, but the covers and connectors differ. The cover on the receptacle for water recovery has a flat inner surface and a gasket seal. The cover on the freeze dry receptacle is a deep, well-type cover, for maximum cabin gas displacement, and has an "O" ring seal for high vacuum use.



1) USE AN FITTINGS FOR PIPE & TUBING CONNECTIONS
2) USE FREON HOSE & 1/4" SAE QUICK COUPLERS FOR LINE CONNECTIONS
3) FOR ELECTRICAL SCHEMATIC SEE DWG. 1016

Figure 5 ASSEMBLY DRAWING OF WASTE MANAGEMENT SUBSYSTEM (URINE WATER RECOVERY UNIT NOT SHOWN)

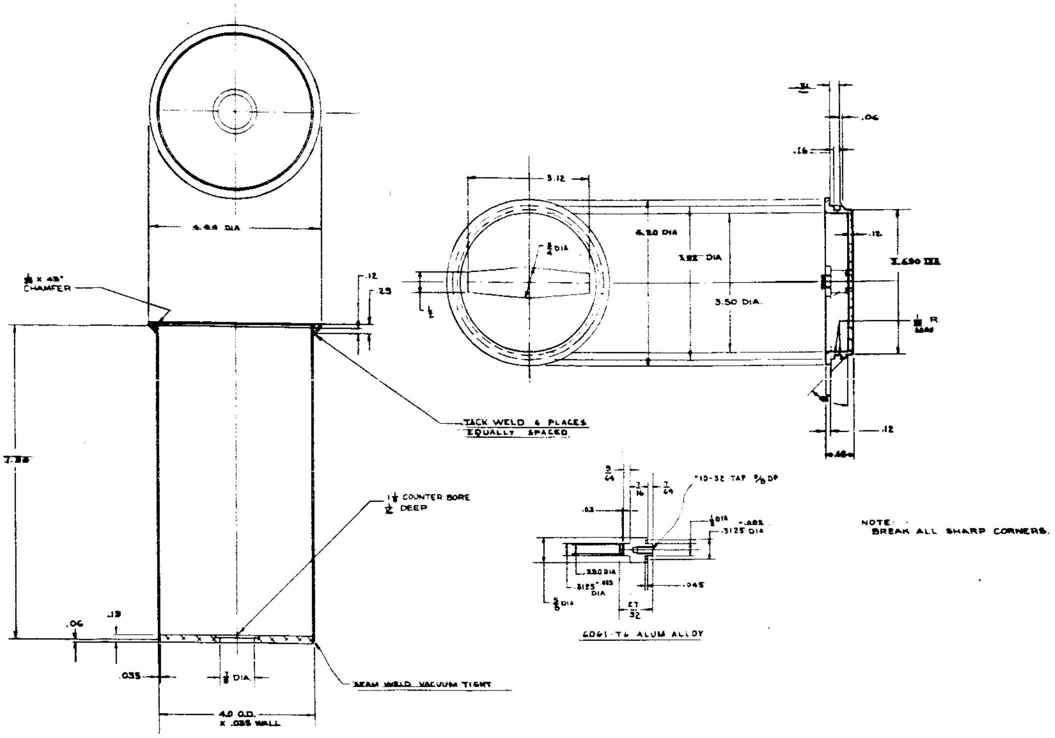


Figure 6 ASSEMBLY DRAWING OF WATER-RECOVERY TYPE FECAL COLLECTOR

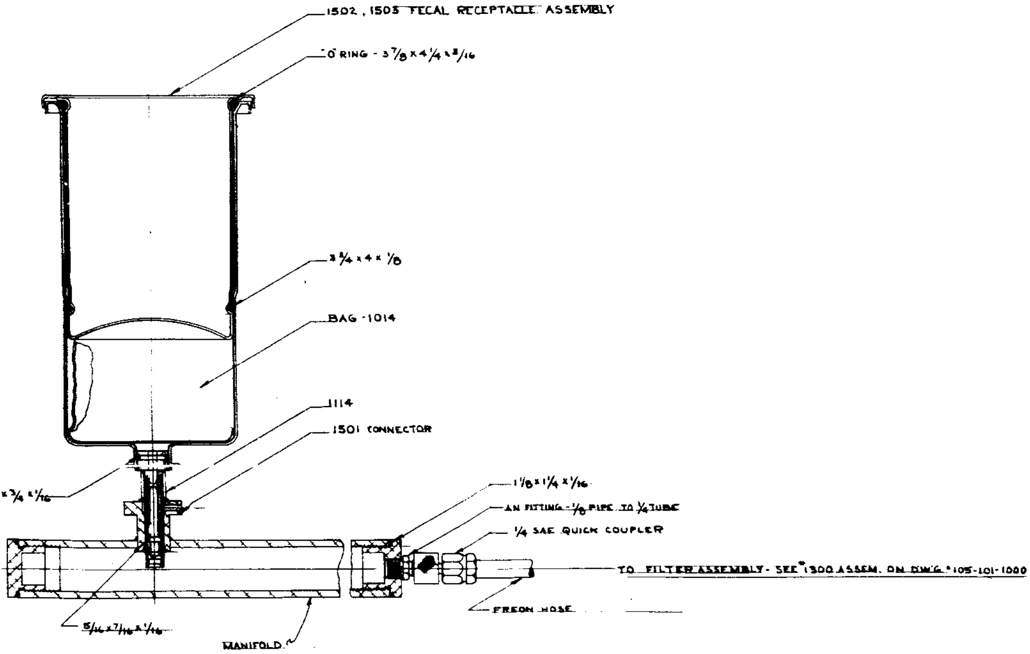


Figure 7 ASSEMBLY DRAWING OF FREEZE-DRY TYPE FECAL COLLECTOR

The plastic liner fits both receptacles. A 10-mil thick, low density polyethylene film is used to form the upper portion of this liner, while a 10-mil thick, porous polyethylene film (see Figure 8) is used to form the lower portion. The porous polyethylene has an average pore size of 10 microns, and is treated for water repellency. The material is manufactured by ESB-Reeves Corporation, Glenside, Pennsylvania and is identified as "Mipor" Product No. 14PN-R. The low density polyethylene provides strength for stretching the liner over the top of the receptacle. The porous polyethylene allows gas to pass through for liquid, solid, and odor control.

Either of the fecal collection receptacles can be mounted in place and connected to the pneumatic control system by inserting the connector on the bottom of the receptacle into a mating connector mounted within the connecting block (see Figure 5). This block is mounted on a slide for horizontal adjustment of the receptacle and for easy connection of the receptacle. The fecal receptacle can be adjusted vertically by loosening a set screw and moving the connector either up or down in the block.

The gas mover used to pneumatically control the collection of feces and urine, and to control odors is a centrifugal blower, Torrington Manufacturing Company Model SC-502-11098. This blower is capable of delivering 20 cubic feet per minute of gas against a static pressure of 6.3 inches of water when the inlet gas density is 0.075 pounds per cubic foot, and it is driven by a 60 cycle, series-type electric motor.

The schematic diagram showing the integration of the fecal collector with the odor control, pneumatic control and urine collection components is shown in Figure 9.

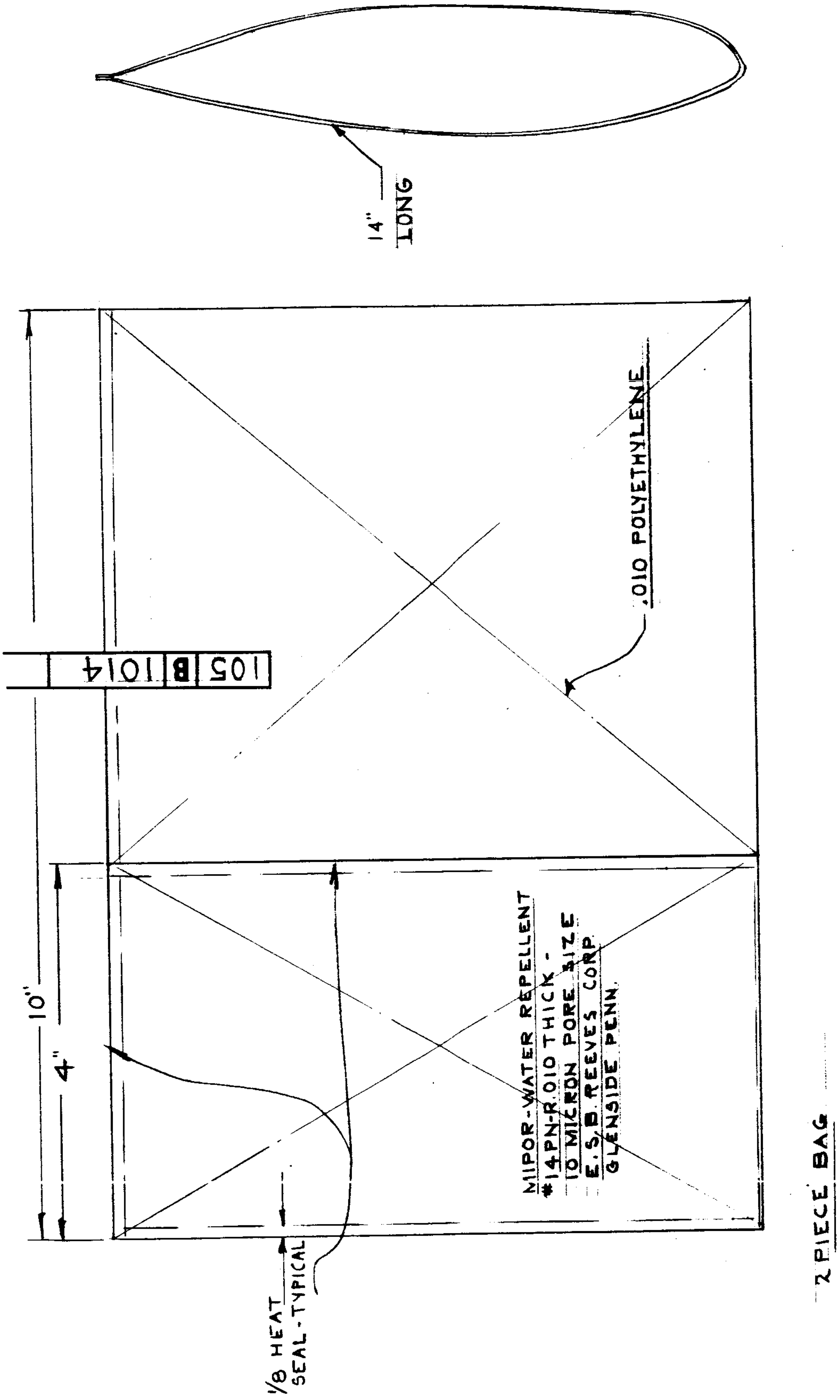


Figure 8 PLASTIC LINER FOR FECAL COLLECTION

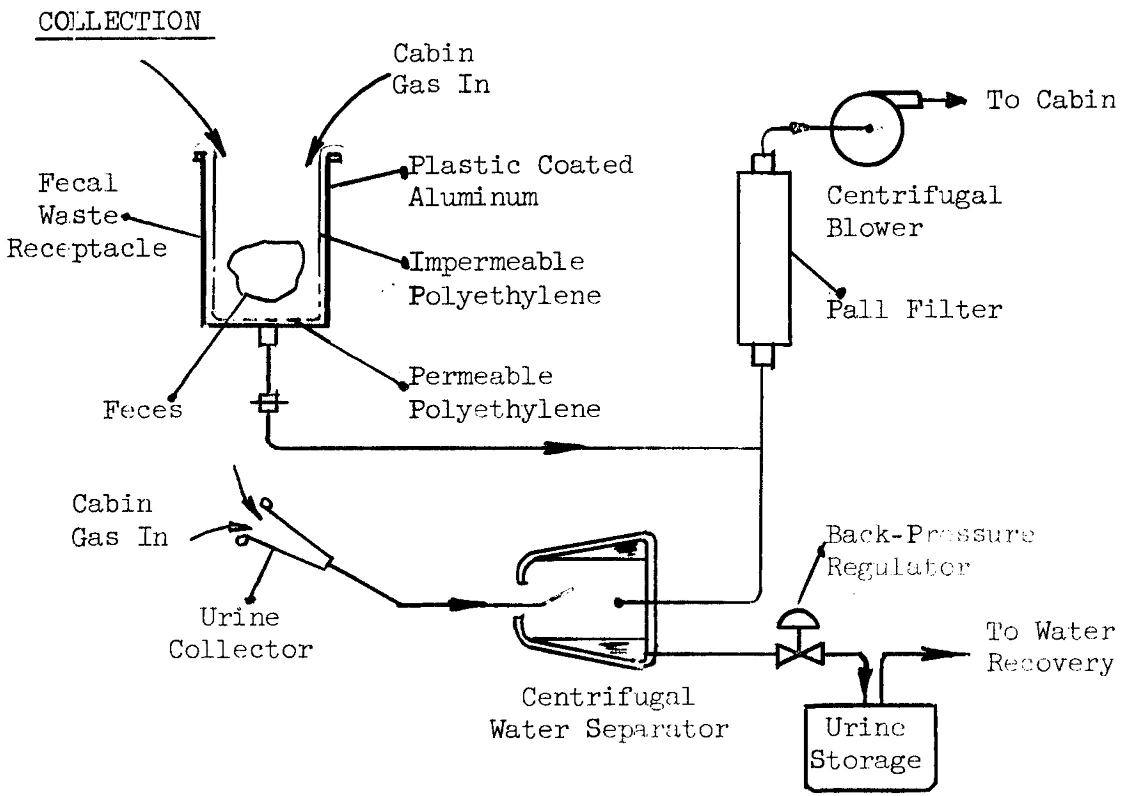


Figure 9 SCHEMATIC DIAGRAM OF WASTE COLLECTION SUBSYSTEM

### 3.1.2 Urine Collection

As shown in Figure 9, the urine collection system consists of a collector, a centrifugal separator and a storage tank. An available relief tube (Air Associates Model AN 8018-1) was selected for the urine collector. This unit is connected to the inlet side of the separator by means of a 3/8-inch diameter Tygon tube. Gas is drawn through the collector and separator by the centrifugal blower, which is also used for feces collection.

Urine is separated from the gas by centrifugal action. Figure 10 shows that an electric motor is provided with the separator to rotate a cylindrical bowl and inlet guide cone. The cone is supported by means of a bearing at the inlet end, and a spider attached to the motor shaft. The rotating cone induces the entering mixture to assume a vortex flow pattern, so that urine leaving the cone will be centrifuged against the inside wall of the rotating bowl. The gas continues through the bowl toward the blower connection. Viscous forces cause the urine to rotate with bowl so that the impact tube can be used to develop the static pressure desired. The back-pressure regulator is set at 5 pounds per square inch so that gas will not be forced into the storage tank when the separator bowl is empty.

Gas leaving the separator is combined with the gas drawn through the fecal receptacle, and then passed through a Pall Micropore filter before entering the suction side of the blower. This filter contains activated charcoal for removal of odors, and a 0.15 micron filter for removal of any particulate matter such as bacteria.

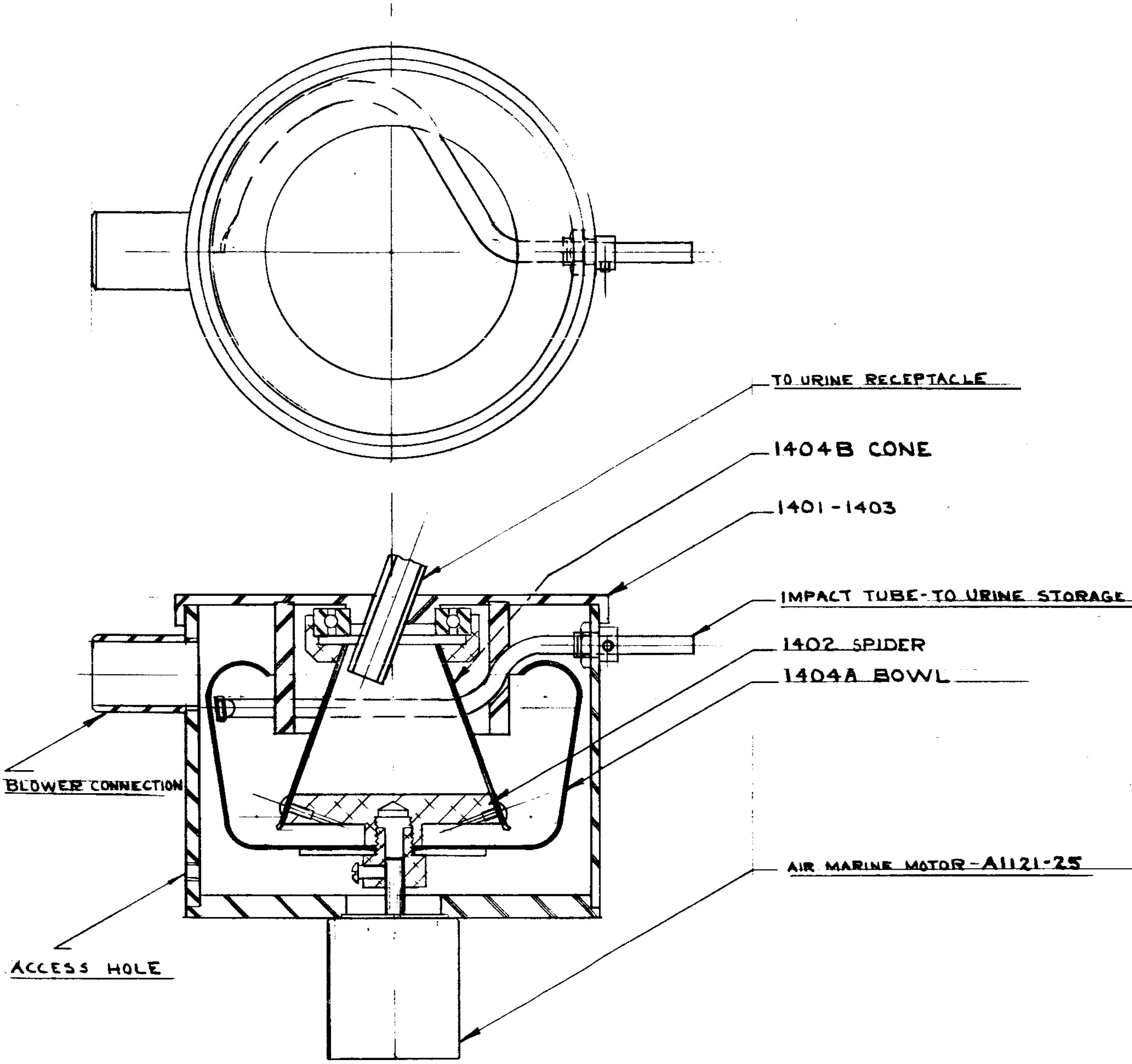


Figure 10 ASSEMBLY DRAWING OF CENTRIFUGAL SEPARATOR

## 3.2 Fecal Water Recovery Unit

Distillation of water from the feces is accomplished by (1) closing the plastic liner, (2) capping the receptacle, (3) disconnecting the receptacle from the pneumatic control system, and (4) placing the receptacle in one of four heater wells located behind the seat. When the fecal collector is placed in the heater well it is directly mated with the vapor line connector. Upon closing of the well cover, the bottom of the collector is pressed against a hot plate containing a 30-watt electric heater thermostatically controlled to maintain a temperature of 220°F. The heater circuit is actuated by a spring-loaded pin which closes a microswitch when the well cover is closed. The water distills at a pressure slightly above the pressure of the evaporator in the thermoelectric distillation unit. The evolved vapor is condensed by gas cooling and then passed through a Pall filter for deodorization and sterilization. The water is then combined with urine before entering the thermoelectric still.

## 3.3 Urine Water Recovery Unit

The assembly drawing of the thermoelectric distillation unit is shown in Figure 11. The unit is mounted on its side so that all of the cylindrical wall of the evaporator is wetted when the unit is operated with gravity acting downward.

Important features of the system are the following:

A. The thermoelectric modules are installed in the hollow wall of the evaporator bowl for direct and efficient pumping of heat from the condenser to the evaporator.

B. Self-contained vacuum purge pump - no loss of cabin gas overboard.

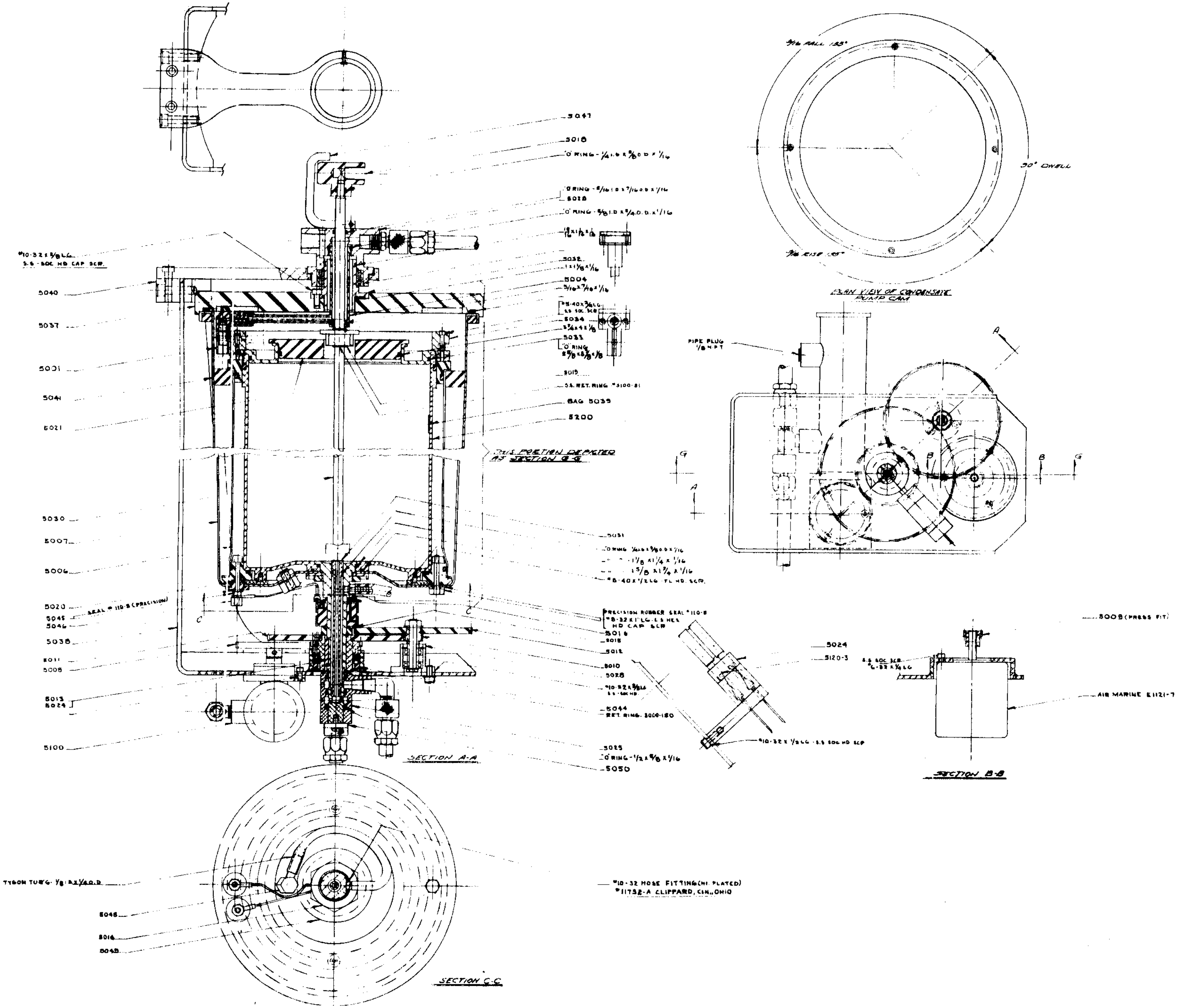


Figure 11 ASSEMBLY DRAWING OF WATER RECOVERY UNIT

C. Self-contained condensate pump which continuously pumps distillate from the condenser to storage through an adsorption-filtration cartridge.

The distillation unit is comprised of two concentric, cylindrical bowls that both rotate at a speed of 60 rpm. The inner bowl serves as the evaporator while the outer blwo is the condenser shell. Thermoelectric modules are located in the double-wall evaporator bowl and are energized by direct current through an external slip-ring.

Subcontractor, Jepson Thermoelectrics, Inc., determined that a coefficient of performance of 6 or more was obtainable across a module consisting of 15 couples with a $\Delta T$ of 10°F, $T_c$ being 80°F and $T_H$ being 90°F. A photograph of the Jepson test module is shown in Figure 12. As shown, an electrical heater was used to provide heat to the cold side or simulated condenser side. Tabulation of C.O.P.'s for various current and power input is shown in Table 2.

From these results, it was concluded that a total of 36 modules (each containing 15 couples) connected in a series was needed to evaporate and condense the required one-half pound of water per hour. The design was resolved such that the evaporator had a dodecagonal perimeter with 3 modules mounted on each side. The method of mounting of the modules is shown in the evaporator assembly drawing in Figure 13.

The evaporator bowl is lined with 5-mil thick cast vinyl bag and it contains a 4-inch diameter handhole for periodic removal of the bag and urine residue. The removable handhole and condenser covers are transparent so that the liquids in both the evaporator and condenser can be observed during

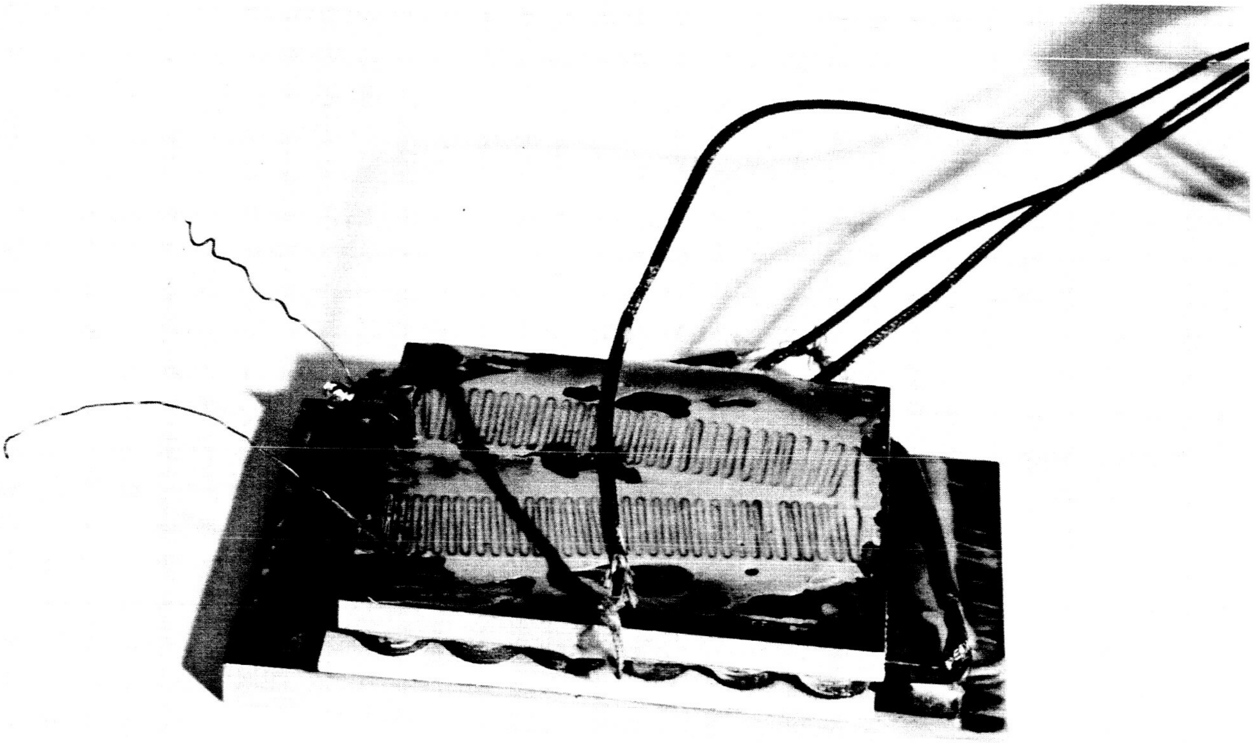


Figure 12 PHOTOGRAPH OF THERMOELECTRIC TEST MODULE

Table 2 RESULTS OF THERMOELECTRIC MODULE TESTS

| Electric Input To Module | | | Electrical Input to Heater (Energy Pumped) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| I (Amps) | E (Volts) | P (Watts) | I (Amps) | E (Volts) | P (Watts) | C.O.P. | $T_1$ (°F) | $T_2$ (°F) | $T_3$ (°F) |
| 3.0 | 0.115 | 0.345 | 0.290 | 7.4 | 2.15 | 6.24 | 80 | 90 | 90 |
| 4.0 | 0.13 | 0.52 | 0.385 | 9.8 | 3.77 | 7.25 | 80 | 90 | 90 |
| 4.5 | 0.14 | 0.63 | 0.425 | 10.7 | 4.55 | 7.22 | 80 | 90 | 90 |
| 5.0 | 0.15 | 0.75 | 0.430 | 11.0 | 4.73 | 6.31 | 80 | 90 | 90 |
| 5.5 | 0.165 | 0.908 | 0.470 | 12.0 | 5.77 | 6.22 | 80 | 90 | 90 |
| 6.0 | 0.18 | 1.08 | 0.500 | 12.9 | 6.45 | 5.96 | 80 | 90 | 90.5 |

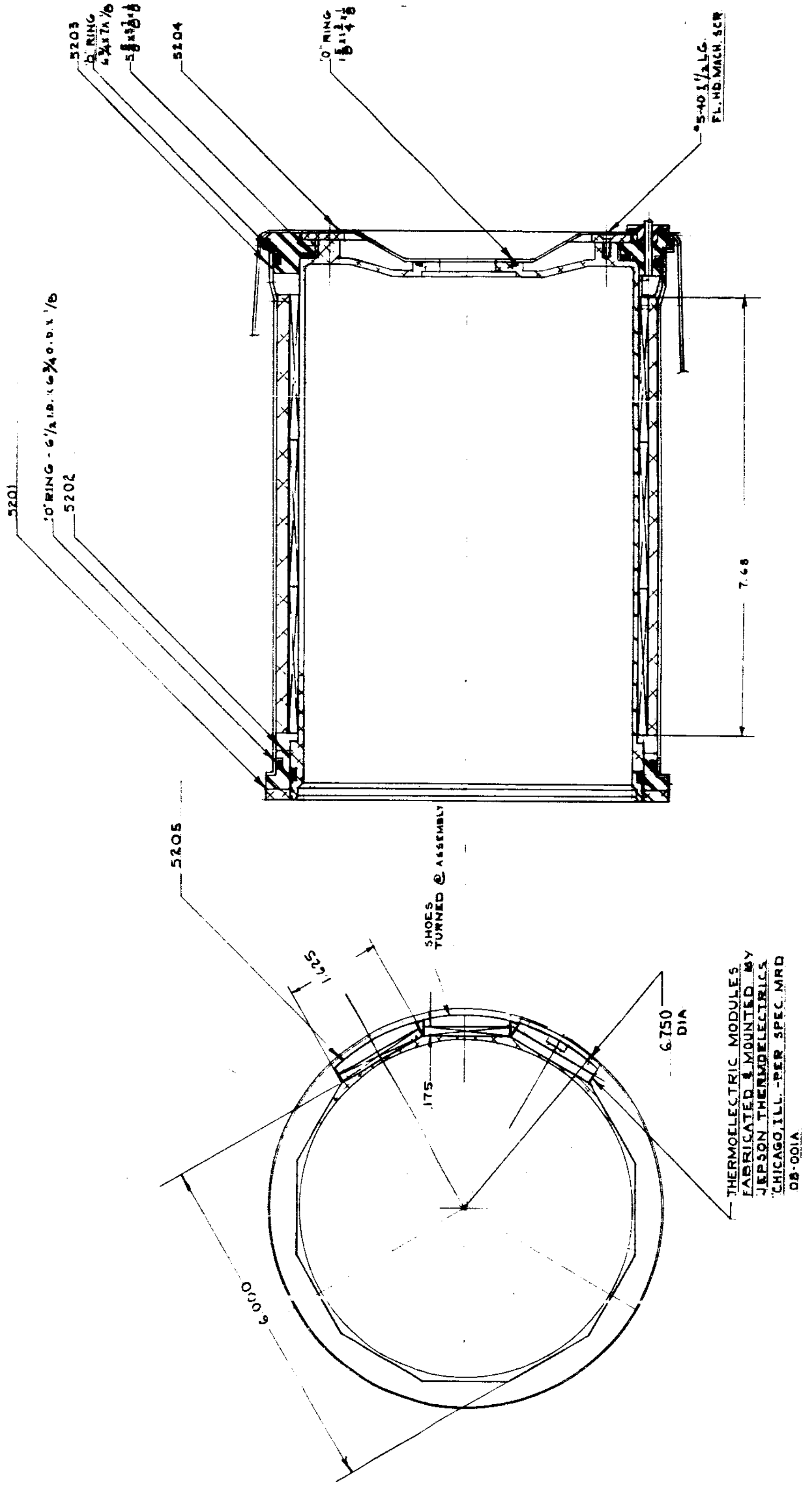


Figure 13 EVAPORATOR ASSEMBLY DRAWING

operation. The distillation unit rotates about its axis on two sealed ball bearings, and is driven by a 15-watt induction motor.

The evaporator bowl provides an effective heat transfer area of about 1 square foot. This is the minimum area recommended to distill the 0.5 pounds of water per hour with nucleate boiling. The particular L/D ratio (7/6) of this bowl provides for a foaming heat of more than 2 inches. This is also considered to be a minimum design value, so a tubular vapor duct fabricated from stainless steel screening material is provided as an extra protection against liquid entrainment. Waste water drawn into the system, through a micrometer type needle valve and the stationary feed tube, is introduced at the end of evaporator bowl opposite the vapor outlet. An internal valve is provided at the vapor outlet. This valve is sized to maintain vapor velocities at less than 100 feet per second.

Vapor forced out of the evaporator, because of its higher saturation pressure, will enter the condenser and flow along the cold side of the evaporator bowl, where it condenses and centrifuged against the inner wall of the condenser shell. Noncondensable gases aid the vapor transport because the condenser purge outlet is located at the end of the bowl opposite the vapor inlet.

An internal condensate pump is shown in the condenser. This is a barrel-type, cam-actuated, piston pump designed to transfer one pound of water per hour against a back pressure of 20 psia. The pump does not rotate with the bowl, so it will operate satisfactorily under both weightless conditions and with gravity acting downward.

Evacuation of the system and purge control is accomplished by means of the external piston-type pump, which has a displacement of 1 cubic-inch. This pump is designed to operate at 40 cycles per minute through a gear train from the motor. With this arrangement no gases will be lost overboard during normal operation. The gases should be vented through a cartridge of activated carbon to prevent odors from contaminating the cabin atmosphere. In an actual flight situation this venting can be directly to the odor control section of the vehicle environmental control system.

The distillation unit is mounted in a tubular frame with a control panel mounted on the top side. The panel contains a motor switch, blower motor switch fuses, urine feed valve, bag vacuum valve and condenser purge valve. Flexible hoses are provided for waste water feed, potable water, and vacuum connections. Easy access to the rear of the panel is provided when the bowl is removed.

After distillation the distillate is pumped from the condenser continuously by the cam-actuated piston pump through a Pall Filter to the potable water storage tank. As described in detail in Section 3.6, the water is passed through a 0.015 micron filter for bacteria removal and through activated carbon for organic trace removal before entering the 10-pound storage tank.

The box dimensions of the complete system are less than 11 x 13-1/2 x 20 inches. The estimated design weight is about 25 pounds. The estimated a.c. power required is 15 watts, while the d.c. input power required is designed to range from 20 to 50 watts, depending upon the exact performance of the thermoelectric modules.

## 3.4 Fecal Freeze Drier

As shown in Figure 14, the assembly drawing of the freeze dryer assembly the dryer consists of two, one-inch diameter aluminum manifolds. Each manifold has four plunger-type connectors for attaching the fecal collection containers. Both the containers and the manifold are Emarlon-coated onboth sides for

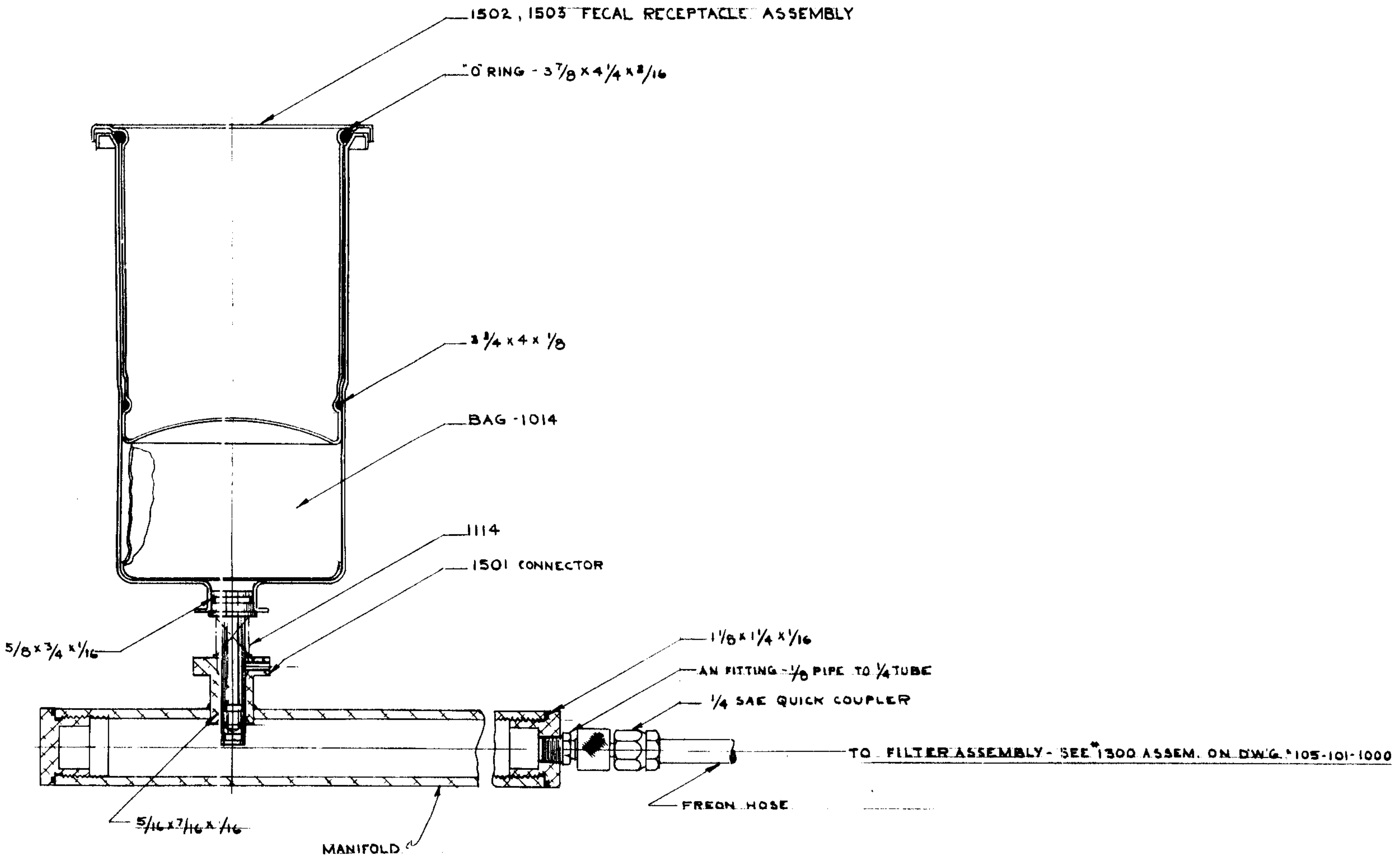


Figure 14 ASSEMBLY DRAWING OF FREEZE DRIER UNIT

corrosion resistance. The fecal collection containers are spun in one piece from the 5052-H34 aluminum alloy.

The piston-type cover on the fecal collection container is used to displace a major portion of the cabin gas in the container prior to freeze drying.

A Pall MSC 1001 CW Ultipor 0.15 Filter with a 2.5 ft$^2$ area sterilizes the vapor passing out of the fecal containers to outside vacuum.

### 3.5 Residue Storage Unit

The storage of dried feces residue and toilet paper enclosed in the porous polyethylene liner and sealed in polyethylene "Baggettes" are placed in the 13-5/8 x 12-1/4 x 8-3/4 inch, Emarlon-coated aluminum container. The assembly drawing of the container is shown in Figure 15. The volume of the container is 1400 in$^3$, sized for 180 man-days of fecal residue. The container does not accommodate urine residue, since this container was designed and fabricated before the thermoelectric distillation unit was added to the subsystem.

The fecal residue is placed in the container by opening the spring latched door. When filled, the container is readily replaced since it rides on nylon rollers in aluminum guides.

### 3.6 Microorganism and Odor Control

Pall Ultipor 0.15 micron filters with activated carbon are used for (1) removing odor and microorganisms from cabin gas that is circulated through the waste collection unit for feces and odor control, (2) removing trace contaminants from water recovered from feces, (3) removing trace contaminants from water recovered from urine, and (4) removing microorganisms and particulates from vapors and gases vented overboard.

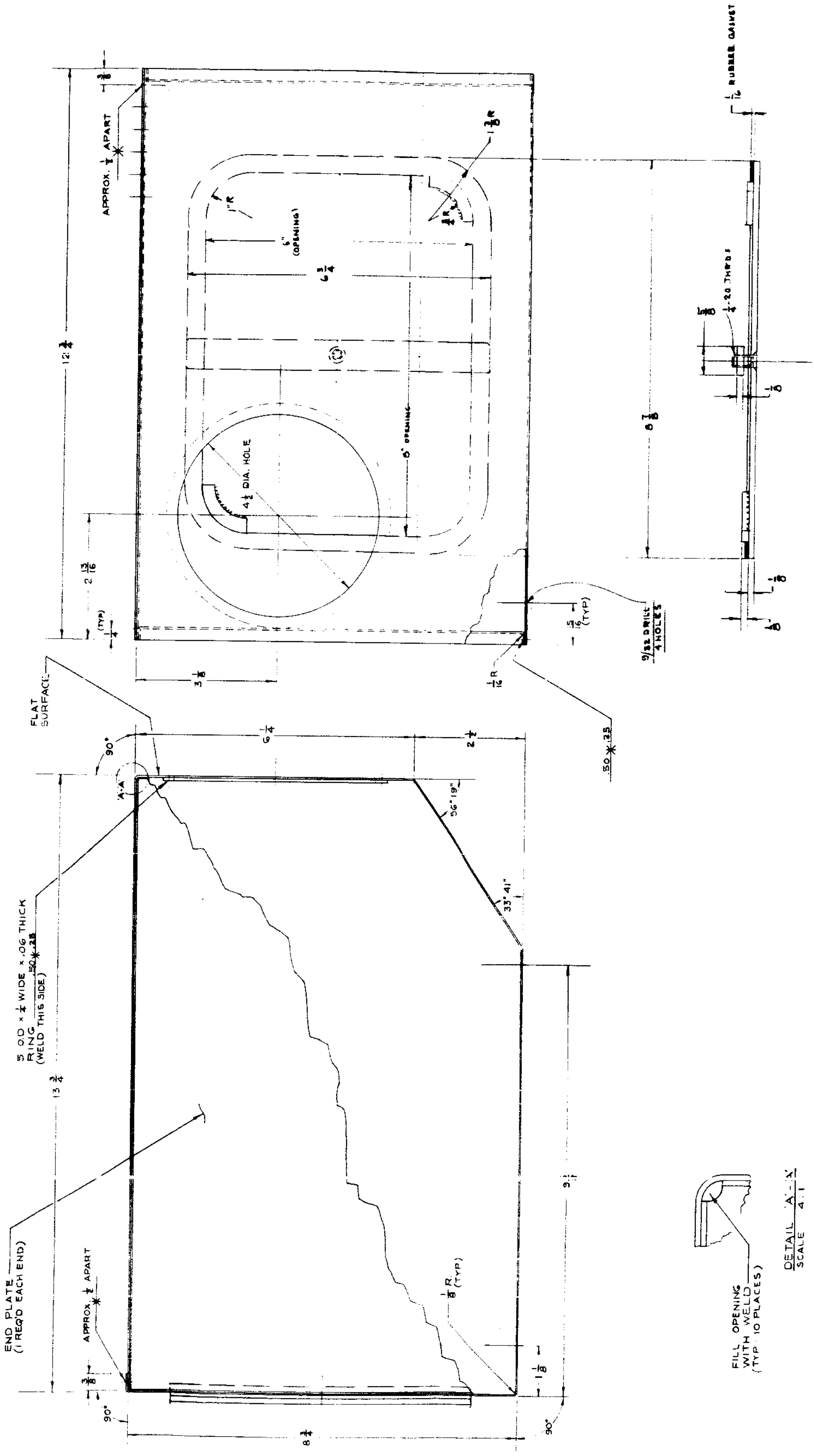


Figure 15 ASSEMBLY DRAWING OF FECAL RESIDUE STORAGE CONTAINER

The Ultipor filter as shown in Figure 16 contains a filter medium consisting of a rigid substrate, a filter paper coated with inorganic fibers and other particules to reduce the effective pore size of the filter (9). These particles are bonded to the substrate and to each other with epoxy resin. The filter contains high voids volume, usually in excess of 90 percent and also has high permeability.

As shown in Figure 16 the cartridge contains 30 cubic inches of activated carbon in the annular space between the Ultipor filter and the outer perforated cylinder. The total weight of the cartridge is one pound, 2-1/2 ounces.

The filter is presently manufactured in three different pore sizes. The removal effectiveness of each size for water and air are shown below.

Ultipor Grades*

| Grade | 98% Removal Rating (microns) | 100% Removal (microns) | Test Method |
|---|---|---|---|
| | In Water | | |
| Ultipor .9 | 0.45 | 3.0 | Glass Beads and carbonyl iron |
| Ultipor .15 | 0.15 | 0.35 | Bacteria |
| Ultipor .02 | 0.02 | 0.08 | Viruses |
| | In Air | | |
| Ultipor .9 | .008 | .08 | Finely ground dye |
| Ultipor .15 | .001 | .015 | Electron Microscope |
| Ultipor .02 | .0005 | .003 | Analysis of Effluent |

The Ultipor 0.15 filter has also been tested by the Pall Corporation for removal of the following bacteria from water with the results as shown below (10).

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* The Ultipor .02 filter was not available at the time the subsystem was being developed.

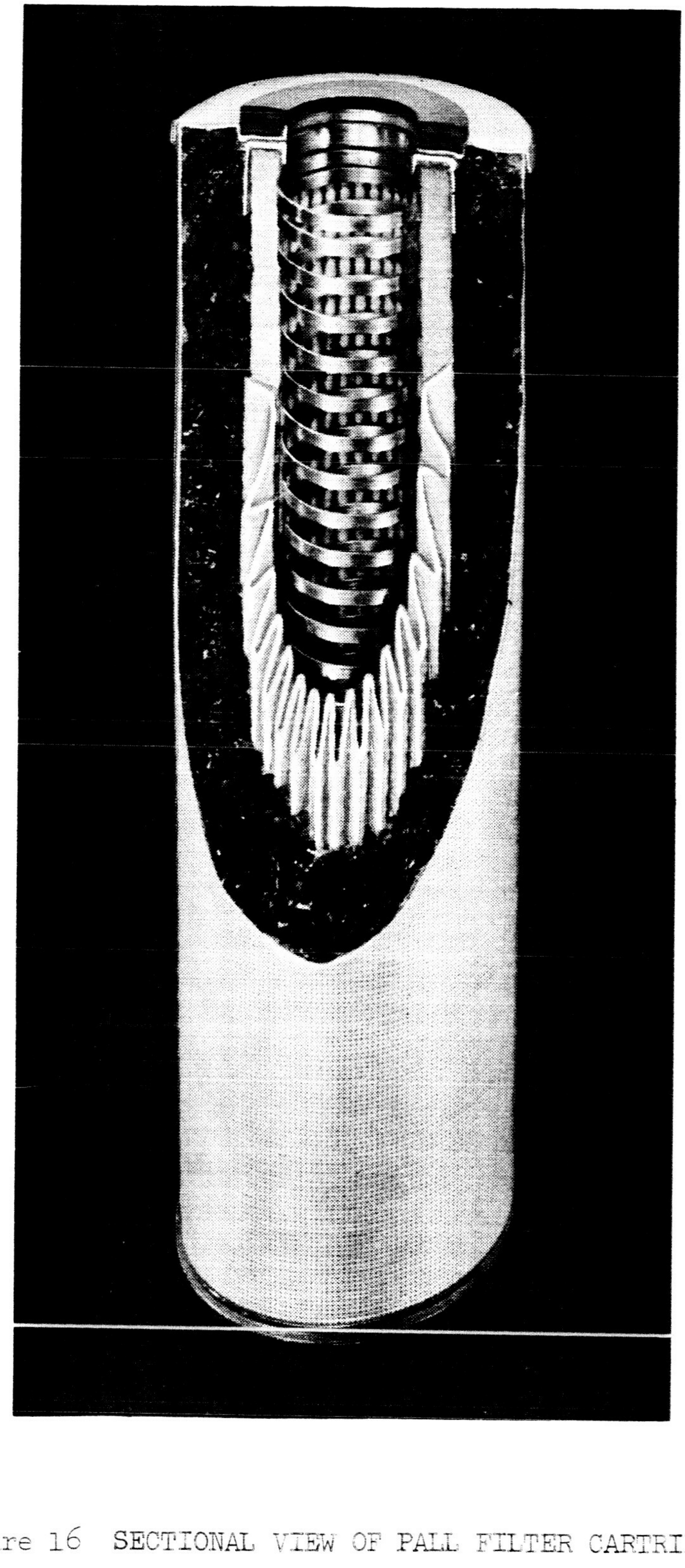

Figure 16 SECTIONAL VIEW OF PALL FILTER CARTRIDGE

| Organism | Size (microns) | Upstream (bacteria/liter) | Downstream (bacteria/liter) |
|---|---|---|---|
| Escherichia coli | 0.5x1-3 | 487,000 | 0 |
| Staphylococcus aureus Var. 80/81 | 0.8-1 | 535,400 | 0 |
| Shigella dysenteriae | 0.4-0.6x1-3 | 583,200 | 0 |
| Streptococcus pyogenes | 0.6-1 | 493,000 | 0 |
| Diplococcus pneumoniae | 0.5-1.25 | 621,200 | 0 |
| Vibrio comma | 0.3-0.6x1-5 | 557,100 | 0 |
| Salmonella typhosa | 0.6-0.7x2-3 | 493,500 | 0 |
| Mycobacterium turberculosis | 0.3-0.6x0.5-4 | 518,000 | 0 |

Tests have also been run at Fort Detrick, Maryland, National Institutes of Health, Bethesda, Maryland, as well as Pall Corporation Laboratories for removal of E. coli, Serratia marcescens, Bacillus subtilis, Pseudomonas, Flavobacterium and other microorganisms from fluids. All have consistently obtained 100% removal of all test organisms.

Pall has also tested the efficiency of Ultipor 0.15 for the removal of microorganisms from jet fuel and, as the data below indicates, 100% removal of all the organisms was obtained:

1. Contaminated JP-4 fuel with E. coli added.
2. Jet fuel from a commercial aircraft with E. coli added.
3. Jet fuel from a commercial aircraft.
4. JP-4 fuel containing naturally occurring contaminants.

| Sample No. | Upstream (organisms/liter) | Downstream (organisms/liter) |
|---|---|---|
| 1 | 14,000,000,000,000 | 0 |
| 2 | 21,000,000,000 | 0 |
| 3 | 5,000 | 0 |
| 4 | 330,000,000 | 0 |

Ultipor .9 filters are being tested for air sterilization in "germ free" enclosures at Walter Reed Hospital and National Institutes of Health. Ultipor .9 and Ultipor .15 filter elements were tested by Research Laboratories, Lockheed Missiles and Space Company, Palo Alto, California; they concluded that the high flow rates with minimum pressure drop is another feature which adds to the successful operation of the sterilization unit.

The Ultipor .15 filter will effectively remove viruses from a gaseous menstruum. The Ultipor .02 filter will quantitatively remove 100% of the adeno viruses (80 millimicrons) from liquids, and will remove viruses of 20 millimicrons with 98% efficiency.

The minimum dirt capacity of the Ultipor 0.15 filter per MIL-F-25762 is 43 grams according to the Pall Corporation. The maximum pressure drop across the cartridge is 0.8 psi at 20 scfm when using air and 8 psi at 2.5 gpm when using water, if the air and water are reasonably clean. The pressure drops across the cartridges in the subsystem will be less than the specified maximums since the flows will be less. Performance aspects of the filter were measured during the testing phase as described in Section 4.

# SECTION 4

## TEST AND EVALUATION RESULTS

The assembled subsystem with the freeze dryer unit is shown in Figure 17. The waste management assembly with the freeze dryer unit weighs 46 pounds (without the thermoelectric distillation unit and the fecal water recovery unit). The thermoelectric distillation unit weighs 36 pounds, and the fecal water recovery unit weighs 21 pounds. A summary of weight and power penalty data is shown in Table 3.

After fabrication and assembly, the major components were evaluated in regard to performance to determine if they met the specified criteria of design. Modifications were undertaken when necessary to correct performance deficiencies. Reliability analyses are presented where component failure data analysis are available and when actual failures occurred during testing.

### 4.1 Feces and Urine Collection

Performance of the feces collection unit designed for fecal water recovery and the feces collection unit designed for freeze drying operated as intended. The pressure drop across the Pall Filter was approximately 1 inch w.g. and 0.8 inch w.g. across the "Mipor" porous polyethylene liner. The air flow through the fecal collection system was approximately 20 cfm at atmospheric pressure. Collection units were used to collect 60 man-days of feces. The collection units were used on a random basis by 8 subjects. All subjects found the fecal collection unit easy to use after the initial orientation. No complaints of discomfort were made and no operational difficulties were encountered.

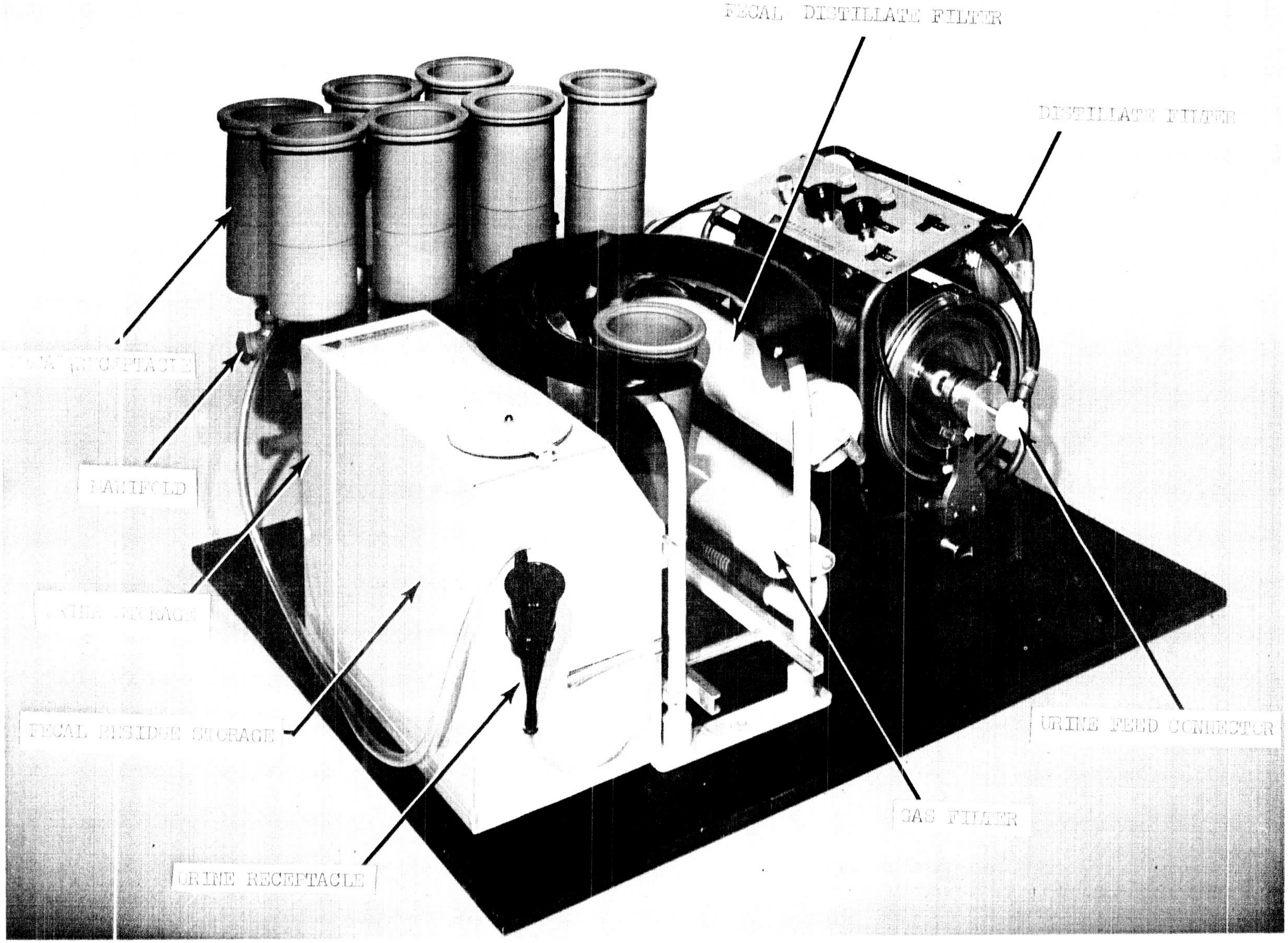

Figure 17 ASSEMBLED SUBSYSTEM WITH FECAL FREEZE DRYER
(FECAL WATER RECOVERY UNIT NOT SHOWN)

Table 3 WASTE MANAGEMENT SUBSYSTEM
WEIGHT AND POWER PENALTY DATA

| | |
|---|---|
| **Waste Collection and Storage (With Fecal Freeze Dryer)** | |
| Weight - Fixed | 46 pounds |
| Variable | 10 gm per M/D (Plastic Liners & Storage Bags)<br>5 gm per M/D (Silica gel added to residue)<br>1 lb-2 1/2 oz. Pall Cartridge per 60 M/D or more |
| Power Consumption | |
| Blower - Peak | 80 watts |
| Continuous | 0 |
| Centrifugal Urine Air Separator Peak | 12 watts |
| Continuous | 0 |
| **Fecal $H_2O$ Recovery** | |
| Weight - Fixed | 21 pounds |
| Variable | 1 lb-2 1/2 oz Pall Cartridge per 60 M/D or more |
| Power Consumption | |
| Heaters - Peak | 120 watts |
| Continuous | 0-120 |
| **Urine $H_2O$ Recovery** | |
| Weight - Fixed | 36 pounds |
| Variable | 31 gm per M/D plastic evaporator liner<br>1 lb-2 1/2 oz. Pall Cartridge (life unknown) |
| Power Consumption | |
| Thermoelectric Modules | 40 watts continuous (Operation not optimized) |
| Motor | 20 watts continuous |

Training in fitting the plastic liner around the top edge of the fecal collection container, removing the liner and sealing, and the capping and insertion of the container into either the freeze dryer or electric dryer manifolds was needed.

Sealing of the plastic liner after defecation, and the transfer of the dried fecal residue to storage necessitated handling. Other handling of the fecal wastes was not required.

Odor was not detected during collection of feces nor when closing and sealing of the plastic liner. Odor was noticeable after both freeze drying and after electrical drying when transferring the dried residue to the storage container.

The volume of both types of fecal containers were found to be adequate in all tests. The porous polyethylene liner retained fecal wastes in all forms without evidence of leakage.

The Emarlon coating on the inside of the fecal containers was not attacked or corroded by any of the products of defecation or by the distillation or freeze drying processes.

Urine collection was tested with and without defecation. The urine was collected in a positive manner without odor emanation and sealing of the penis to the receptacle was not needed. Room air drawn in with the urine was separated efficiently by the urine-air centrifugal separator. It was found that excessive vibration of the separator occurred if the centrifuge bowl was rotated at 3100 rpm. Reduction of vibration to a satisfactory level was achieved when the rotation was reduced to 750 rpm.

No discomfort was noted when voiding urine, even though urine was drawn into the separator by venting the separator to the suction of the centrifugal blower. A vacuum of 10 inches water was provided at the penis receptacle. Urine was not retained in the Tygon tube unless the tube was looped to form a suction head more than 10 inches; greater.

The impact tube in the urine separator pumped the urine into the storage tank without the inclusion of air. Some urine remained in the separator bowl and the blow could be flushed and cleaned only by subsequent urination. The addition of a disinfecting agent in liquid form via the penis receptacle will prevent breakdown of any urine compounds remaining in the lines and separator. Addition of the disinfectant can be achieved by the use of a positive displacement dispenser of plastic squeeze container.

## 4.2 Fecal Water Recovery

The water from feces is reclaimed by vacuum distillation and air-cooled condensation. The distillate passes through a Pall Filter for deodorization and sterilization prior to being combined with urine in the thermoelectric distillation unit.

After defecation, the porous polyethylene liner is closed and the fecal container is capped. The container is then placed in one of the four heater wells. Upon insertion, the hot plate electrical heater at the bottom of the well is actuated and the container is connected to the vapor line leading to the Pall Filter and to the thermoelectric distillation unit.

A filter flask cooled by a dry-ice, acetone mixture was substituted for the thermoelectric distillation unit during testing to collect and measure the water recovered. As selected during the design study, 30-watt, thermostatically controlled heaters were used in each hot plate. The heaters maintained the plates at a temperature in the range of 230 to 240°F; they were "on" approximately 50% of the time. It was found that to dry the average quantity of feces, the time required was 22 hours. The total energy consumption during this period was approximately 330 watt-hours per container.

The quality of the reclaimed water collected in the dry-ice trap was found to be good. Only a slight odor remained, and the water was clear and colorless. One gallon of this water was sent to the Electric Boat Division of the General Dynamics Corporation for evaluation in a fecal water recovery system being developed for the Langley Research Center. Their analysis of the water before recovery is shown in Table 4.

Water was reclaimed from 60 man-days of feces. The same Pall filter was used to filter the fecal water during this period. During the filter's use, there was no evidence of decrease in filter effectiveness. When the filter was removed six months after initial installation, the outside, perforated-aluminum screen was found to have been almost completely corroded. As shown in Figure 18, the stainless-steel end plates, the membrane filter, and the aluminum inlet tube were not corroded. A new filter is shown along side the corroded filter. Filters with stainless-steel, perforated screens should be developed for future waste management subsystems.

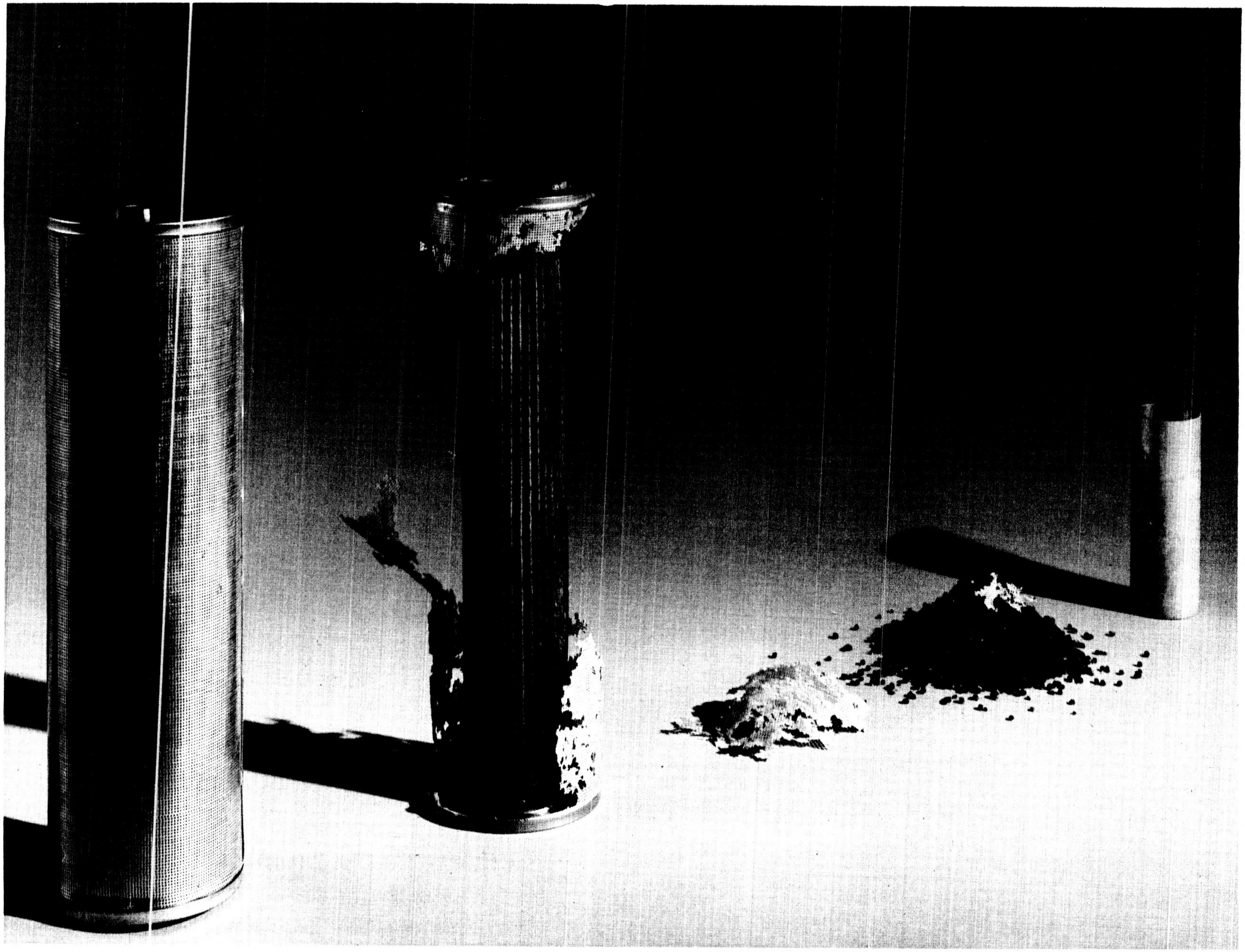

Figure 18 NEW AND CORRODED PALL FILTERS

Table 4 ANALYSIS OF FECAL WATER (FILTERED)

| | Sample | Original Fecal Water |
|---|---|---|
| | Volume (ml) | -- |
| | Conductivity (micromhos/cm) | 500 |
| | pH | 9.0 |
| | $NH_4^+$ | Positive |
| | $Cl^-$ | Negative |
| | $SO_4^{--}$ | |
| Organoleptic Tests | Appearance | Clear |
| | Odor | Slightly unpleasant |
| | Color | None |
| | Chemical Oxygen Demand (ppm) | 185 |
| | Coliform Bacteria | Negative |
| | Total Solids (ppm) | 45 |

## 4.3 Urine Water Recovery

Upon assembly of the thermoelectric distillation unit, the unit was tested initially with tap water, and then with urine. A number of minor faults were found in the initial checkout. They are listed as follows along with corrections performed.

### 4.3.1 Checkout Tests

Vacuum pump - Initial tests showed that the self-contained vacuum pump could not evacuate the condenser to the desired operating pressure (50 mm Hga or less); the pump could only attain 15 mm Hga when pumping dry air. It was also found that the pump had excessive friction when operated at a speed of 60 cycles per minute. Consequently, modifications were made to the pump to increase the compression ratio and to reduce friction, with some sacrifice in capacity.

The pump originally consisted of two cylinders connected in parallel; one pump was provided for reducing pressure within the unit, and the other pump was provided for reducing the pressure between the plastic liner and the evaporator wall. Since the pump was found to be inadequate for evacuating the system to operation pressure, the two pumps were then connected in series to increase the compression ratio. A laboratory-type vacuum pump was then used to evacuate the space between the vacuum liner and the evaporator wall. Also, the operating speed was reduced to 40 cycles per minute to decrease the power requirements. These changes provided the pump with an ultimate vacuum limit of less than 5 mm Hga, with dry air. With water in the thermoelectric unit, the pump could then evacuate the unit to saturation pressure in about one hour, and hold this pressure during normal operation.

Condensate Pump - Initially the condensate pump failed to remove recovered water from the condenser. The pump was designed to draw in condensate on the suction stroke through an opening in the cylinder wall. This opening apparently did not provide for the escape of any entrapped vapor. The pump was then modified to provide a large annular escape opening at the bottom of the suction stroke.

The friction between the pin attached to the piston and the barrel cam was found to be high. Friction was reduced to a satisfactory level when the pin was replaced by a miniature ball bearing, which rides in the barrel cam.

With these changes the pump operated at the minimum rated capacity of 0.5 pounds of water per hour, and with a sufficient compression ratio to overcome the pressure difference between internal operating pressure of approximately 37 mm Hga and atmospheric pressure.

Sealing of Modules - The end plates with "O" ring seals designed to seal the thermoelectric modules from water and urine vapor failed due to lack of sufficient rigidity of the evaporator and condenser walls. To remedy the inefficient sealing, the thermoelectric modules were encapsulated in Dow Corning Silicone Rubber "Silastic" RTV 501. This grade proved not to be completely waterproof and some electrical shorting of the modules occurred. A more impermeable grade (Dow Corning "Silastic" 502) was then used as a replacement, it proved effective in preventing in-leakage and also provided a sanitary seal.

Cover on Evaporator Bowl - The acrylic cover on the evaporator bowl was found to flex with the pressure difference between the evaporator and the condenser. The flexing was extensive enough to break the "O" ring seal between the cover and the evaporator bowl. Urine then leaked from the evaporator to the condenser and contaminated the recovered water. A new cover was then fabricated with the thickness increased from 1/8-inch to 5/8-inch; further flexing and leakage was prevented.

Entrainment Screen - The original design included a 20-mesh, cylindrical, stainless-steel screen extending through the center of the evaporator bowl. The screen was attached to the exit port from the evaporator leading to the condenser and was designed to entrap any liquid particles that were passed over with the water vapor.

During testing it was found that water quality was not altered by the use of this screen and the screen was eliminated from the unit.

The 15-watt, Air Marine motor used to rotate the evaporator and condenser bowls and to drive the vacuum pump operated at rated power consumption when the internal pressure of the unit was above 100 mm Hga. When the pressure was reduced to operating pressure, 20 watts of power were required to sustain operation due to the greater pressure difference on the rotary seals. A larger motor was not procurred because the 15-watt motor appeared to be capable of handling this load. Also, Teflon slippers were procurred for installation over the "O" ring seals, at a later date.

### 4.3.2 Performance Tests

Testing of the thermoelectric distillation unit included the determination of performance capabilities of the unit. Time was not sufficient for optimizing performance variables such as (1) temperature difference between evaporator and condenser, (2) urine level in the evaporator, and (3) rate of urine feed in the evaporator. The current input to the thermoelectric modules was maintained at 5 amperes, which according to the tests conducted by Jepson Thermoelectrics, (see Section 3.3) will pump 4.73 watts or 16.1 Btu per hour for a 15-couple module. The 36 modules between the evaporator and condenser should then pump 580 Btu's per hour, more heat transfer than required for evaporating and condensing the required 1/2 pound of water per hour. The amperage and voltage across the modules were not varied to determine the effect on performance. The main objective of these tests were to ascertain a nominal recovery rate, coefficient of performance, recovery efficiency and quality of the recovered water.

Rhe results obtained for the final test of seven hours is shown in Table 5. As summarized, the average recovery rate of the run was 225 ml per hour. The amount of water recovered was 91.6 percent of the starting urine and the average C.O.P. was 3.8. Higher energy efficiencies could have been achieved at lower rates of water recovery.

As shown in Table 5, the quality of the water before filtration shows a total solids content of 190 ppm, considerably less than the maximum 500 ppm specified in the Public Health Drinking Water Standards 1961. The $NH_3$ as N and the aluminum contents of the water are high. From previous tests on compression distillation system, the $NH_3$ content from this distillation is of the same order of magnitude as obtained by compression distillation. Satisfactory removal of $NH_3$ content is obtained by use of the Pall Filter with activated carbon. The aluminum content is higher by an order of magnitude than that of water reclaimed by compression distillation. Aluminum corrosion must occur in the condenser or in the discharge lines or pump and an investigation to determine the source is needed to reduce the contamination.

### 4.4 Fecal Freeze Drying

The fecal freeze drying assembly was tested to determine drying time and loss of gas per each drying cycle.

The drying manifold was connected to a 2 cfm vacuum pump with a dry-ice and acetone condensate trap. When a covered fecal collection container was connected to the drying manifold, approximately 800 milliliters of air at atmospheric pressure (0.0021 lb) was pumped from the container. Freeze drying commenced when the internal pressure was less than 3 mm Hga. The internal

Table 5 RESULTS OF THERMOELECTRIC DISTILLATION TESTS

| | |
|---|---|
| Test Duration | 7 hours |
| Quantity of Urine Used | 1680 ml |
| Quantity of Water Recovered | 1574 ml |
| Average Water Recovery Rate | 225 ml/hour |
| Water Reclaimed from Starting Urine | 91.6% |
| Condenser Pressure (average) | 37 mm Hga |
| Evaporator Pressure (average) | 42 mm Hga |
| DC Voltage Across Modules | 8.0 |
| Amperage Across Modules | 5.0 |
| DC Power Across Modules | 40.0 watts |
| Coefficient of Performance (COP) | 3.8 |
| Water Quality<br>(Before Filtration) | |
| Specific Conductance | 122 micromhos/cm |
| pH | 8.0 |
| Total Solids | 190 ppm |
| $NH_3$ as N | 18.8 ppm |
| Al | 38.5 ppm |
| Cl | 2.0 ppm |

pressure during drying reached equilibrium at 2 mm Hga. Druing was completed in approximately 40 hours. The in-leakage of air was approximately 10 ml per hour (atmospheric pressure). Loss of air during the frying cycle was then 400 ml or 0.001 pounds.

Latent heat for drying of the feces was provided from ambient air at 80°F, without the aid of forced convection. The drying time can be reduced with the use of air movement across the outside of the fecal containers.

## 4.5 Residue Storage

After collection of dried fecal residue for 60 man-days, the 1400 $in^3$ storage container was half full, indicating that the container was being filled at one and one-half times the anticipated rate. This greater demand of storage volume is attributed to more toilet paper being used than the expected 1.1 $in^3$ per defecation (see Sections 2.1.1 and 2.1.4). The volume of the residue can be reduced to the design volume by the controlled use of toilet paper.

There was no evidence of corrosion of the Emarlon coating within the container.

## 4.6 Microorganism Control

The effectiveness of the Pall Filters for sterilizing (1) the air returned to the ambient, (2) the reclaimed fecal water, and (3) the vapors and gases removed in freeze drying was determined by bio-assay. Also, the ability of the fecal water recovery system to kill a specific culture was ascertained. An examination of dried feces after a specific storage period was also made.

### 4.6.1 Waste Collection

To determine the effectiveness of the Pall Filter for removing bacteria from the air used for odor control and for drawing the feces into the porous polyethylene bag in the fecal collection container, a Millipore xx30 Swinny Hypodermic Adapter with a Millipore 0.80 filter was used to sample the effluent gases. By sampling the gases at this point, any bacteria passing through the Pall filter are trapped in the filter. However, bacterial spores which are smaller than 0.80 could pass through the Millipore filter. The Millipore apparatus was placed in the stream of effluent gases during defecation. The flow rate through the filter was 4.3 cubic feet per minute, (which amounts to 18% of all gases handled by the Pall filter. The test was performed 5 times.

### Results

No bacteria were recovered by the filter. Aerobic and anoerobic media were used to initiate growth. No growth was obtained in either media in all test runs.

### 4.6.2 Waste Storage

Three dried feces samples, the residue of fecal water reclamation, were examined after 75 days of storage. Initially, the samples were tested for presence of coliform bacteria. The testing was carried out in three steps as follows:

A. Presumptive Test

Growth and gas production in lactose broth within 24 hours at 35°C.

B. Confirmatory Test

Gas production in brilliant green bile broth and development of typical coliform colonies on easin methylene blue agar within 48 hours at 35°C.

C. Completed Test

This test is carried out when the confirmatory test is positive. It consists of a gram stain and a lactose fermentation test.

The above series of tests demonstrate the various physiological and morphological characteristics of coliform bacteria. If the sample tested is positive in each test, the sample definitely contains coliform bacteria. These tests do not identify the species involved but only the general group that is the coliform group.

The condition of the fecal material made sterile sampling quite difficult. The material was contained in a plastic bag which had been distorted by the distillation, and the material was dry and quite hard and brittle. Steps were taken to reduce outside contamination. A completely sterile technique was not possible since flaming could not be employed.

The results of the tests were:

A. Presumptive Test

Gas was formed in all three samples within the 24 hour period. This is a positive presumptive test.

B. Confirmatory Test

Gas was not formed in brilliant green bile broth and there was no growth on eosin methylene blue agar. This is a negative confirmatory test.

C. Completed Test

The organisms in all three samples were found to be gram positive.

The data obtained above showed that no coliform bacteria survived processing and storage.

Tests were run to determine the nature of the surviving bacteria. These tests included:

A. Microscopic Examination
  a. Wet preparation
  b. Stained preparations.
B. Growth in aerobic and anaerobic media

The samples were arbitrarily labeled, A,B,C for identification.

Microscopic Examination

A. Nonmotile, large slender rods, gram positive, nonspore forming
B. Same as A
C. Highly motile, large rods, gram positive with spores.

### Aerobic and Anaerobic

A. Rapid growth in anaerobic media at room temperature (25° to 30°C). No growth on agar plates.

B. Same as A.

C. No growth in anaerobic media at room temperature; heavy growth on agar plates.

Samples A and B were one or more species of Lactobaccilus. Sample C was one or more species of Baccilus.

The identifications were made by comparing the above data with the description of these genera in Bergey's Manual of Determinative Bacteriology, (11). Species of these genera are not normally pathogenic and are the usual fecal contaminants. It should be noted that some species of Lactobaccili are thermophilic (12) and that most probably the spores and not the vegetative cells of the Baccilus species involved survived.

### 4.6.3 Fecal Water Recovery

Snythetic feces (75% water and 25% dehydrated dog food) was used as a growth media to determine the effectiveness of the fecal water recovery system to kill a specific coliform bacteria. A 150 gram quantity of the synthetic feces was sterilized by autoclaving and then innoculated with Escherichia intermedia at a viable cell count level of $10^4$ to $10^9$ cells per gram. This bacterial strain was chosen over Escherichia coli because of its superior growth rate and rate of fermentation. Control tests were performed to determine the effects, if any, that the dog food might have on the cultures. The result of plate counts, growth rate, fermentation rate studies showed that the dog food has a minimal effect. Plate counts obtained from dog food cultures were less. and two percent lower than similar cultures without dog food.

No bacteria survived the fecal water recovery process since growth was not evident in lactose broth even after four days.

### 4.6.4 Freeze Drying

Water condensed in a dry-ice and acetone trap, from the freeze drying of a one man-day batch of feces, after passing through the Pall filter was tested for coliform bactieria. The test was negative, since there was no evidence of growth in lactose broth.

## 4.7 Environmental Tests

The waste management subsystem was designed to the capable of re-start and satisfactory operation subsequent to complete cabin decompression and subsequent to temperature extremes of 0°F and 150°F. To verify the achievement of these design requirements, the subsystem was exposed to these conditions in a 10 cubic-foot environmental chamber at MRD, and then tested for re-start capability. The environmental exposure tests were conducted as follows:

### A. Low Temperature (0°F)

The subsystem assemblies were placed in the chamber and cooled to 0°F. After 45 minutes of exposure to 0°F, the assemblies were removed from the chamber - and tested after their temperature reached 70°F.

### B. High Temperature (150°F)

The subsystem assemblies were placed in the chamber and heated to 150°F. After 30 minutes of exposure to 150°F, the assemblies were removed from the chamber - and tested after their temperature reached 80°F.

### C. Low Pressure (0.2 mm Hga)

The subsystem assemblies were placed in the chamber and subjected to an ambient pressure of 0.2 mm Hga, for 30 minutes. The assemblies were then removed from the chamber and tested.

The subsystem assemblies were all capable of satisfactory operation after exposure to the adverse environmental conditions. Adiitional tests showed that the fecal dryers would not operate satisfactorily at 0°F; the manifold seals leaked at 0°F, but they resealed after warming to 70°F.

## 4.8 Reliability Analysis

Obviously, quantitative failure data could not be determined during this program. The waste management subsystem, however, can be analyzed using generic data to estimate the design failure-rate, and indicate which components should be considered for redesign or in-flight replacement to achieve a desired operational reliability.

The waste management subsystem contains components that will have failure-rates possibly as high as 100 failures per million hours, and as low as 0.001 failures per million hours. For this analysis it is necessary to consider only those components that are predicted to have failure-rates on the order of 1 to 100 failures per million hours. The analysis can be simplified further by using order-of-magnitude estimates; that is 1, 10 or 100 failures per million hours. The failure-rate (FR) estimated on this basis is presented in Table 6.

Table 6 FAILURE RATE ANALYSIS

| Item Description | FR x $10^6$ Hours |
|---|---|
| Fecal Collection, Drying and Storage | |
| Centrifugal Blower and Motor | 10 |
| Gas Filter Seals (2) | 2 |
| Gas Line Connections (2) | 2 |
| Fecal Receptacle Connections (9) | 9 |
| Dryer Manifold Disconnects (8) | 80 |
| Dryer Evacuation Line Connections (5) | 5 |
| Vent Filter Seals (2) | 2 |
| Storage Purge Line Connections (2) | 2 |
| Sub-Assembly Total | 112 |
| Urine Collection and Storage | |
| Urinal-Separator Hose Connections (2) | 2 |
| Separator Bowl Bearing | 1 |
| Separator Motor | 10 |
| Urine Line Connections (4) | 4 |
| Urine Check Valve | 10 |
| Urine Storage Tank Bladder | 1 |
| Separator - Filter Hose Connections (2) | 2 |
| Sub-Assembly Total | 30 |
| Water Recovery and Storage | |
| Urine Feed Line Connections (4) | 4 |
| Urine Feed Tube "O" rings, static (3) | 3 |
| Thermoelectric Junctions (2160) | 216 |
| Module Seals, static (4) | 4 |
| Slip-Ring Connectors, (2) | 20 |
| Bowl Bearings (3) | 3 |
| Condenser Seal, dynamic (1) | 100 |
| Condenser Seals, static (3) | 3 |
| Condensate Pump Seal | 100 |
| Condensate Pump Bearing | 10 |
| Condensate Check Valve | 10 |
| Condensate Line Connections (4) | 4 |
| Condensate Filter Seals (2) | 2 |
| Condensate Storage Bladder | 1 |
| Bag Vacuum Seals, static (3) | 3 |
| Bag Vacuum Seals, dynamic (1) | 100 |
| Bag Vacuum Line Connections (4) | 4 |
| Purge Line Connections (6) | 6 |
| Purge Line Seals, dynamic (2) | 200 |
| Purge Pump Seals, static (4) | 4 |
| Purge Pump Seals, dynamic (3) | 300 |
| Purge Pump Check Valves (2) | 20 |
| Pump-Filter Line Connections (2) | 2 |
| Drive Mechanism Bearings (4) | 4 |
| Drive Motor | 10 |
| Sub-Assembly Total | 1133 |
| Sub-System Total | 1275 |

From this analysis it is apparent that dynamic seals are considered to be the most unreliable single items in the complete subsystem. This was found to be true during the program when these seals had to be changed several times. If Teflon slippers are added to these seals it may be possible to reduce the design failure-rate for the complete system to less than 500 failures per million hours.

The thermoelectric junctions are considered to be the second weakest link in the subsystem, primarily because there are a large number required (2160). Junction failures were not experienced during the development program, but they should be anticipated on a flight vehicle.

The third weakest link is considered to be the "O" ring disconnects on the fecal dryer manifold. The number of fecal dryer connections could be reduced to improve the reliability in this area.

In conclusion, it must be stated that this analysis serves to indicate only the weakest links in the subsystem, and not the opearational failure-rates anticipated. Periodic maintenance and emergency repair procedures will be necessary on long duration applications, to achieve the desired reliability goals.

# SECTION 5

# CONCLUSIONS AND RECOMMENDATIONS

The waste management subsystem analyzed, designed, fabricated, tested and evaluated under this program was delivered to the NASA Langley Research Center in October 1963. This subsystem was provided with the equipment necessary to collect, process and store human waste products on manned orbiting space stations. The following conclusions and recommendations are based upon the results obtained during the performance of this work.

## 5.1 Conclusions

A. The fecal and urine collection equipment operated as required, as evidenced by the satisfactory performance achieved during use for 60 man-days. During these tests is was determined that (1) the collectors are comfortable and easy to use, (2) the Pall filter prevents contamination of the surrounding atmosphere by odors and bacteria, and (3) manual operations are suitable for transferring the collected fecal matter to the processing equipment.

B. The urine collection technique developed under this program is superior to previous systems because it is not necessary to contact the penis to the urinal during micturation.

C. Potable water can be recovered from feces by means of double distillation and adsorption filtration; however, the initial distillation process requires an excessive amount of energy. The fecal water recovery unit developed for this program required 330 watt-hours of electrical energy to recover the water contained in a one man-day quantity of feces.

D. Dried feces can be stored in plastic bags for at least 75 days, without contaminating the surrounding atmosphere. Tests showed that no bacterial decomposition occurs under normal environmental conditions. Some bacteria spores that do survive have been identified.

E. Feces can be vacuum dried in a sealed container without the application of electrical energy or direct heating. The freeze drying unit developed for this program contains eight drying stations for fecal containers, exposed to ambient conditions. Each container can dry a one man-day quantity of feces in 40 hours or less, with an average loss of atmospheric air equal to 0.003 pounds per man-day.

F. The average individual uses an excessive amount of toilet tissue for each defacation. At the beginning of this program it was predicted that the average person would use 1.1 cubic inches of tissue. During a 60 man-day test it was concluded that an average person uses at least 3 times this amount of tissue.

G. Thermoelectric techniques can be used to vacuum distill potable water from urine. The unit developed under this program recovered 0.5 pounds of water per hour with an electrical power input of 40 watts to the thermoelectric modules. The electrical energy required per pound of water is significantly higher than for compression distillation systems previously developed by MRD. Apparently, with available thermoelectric materials, it is necessary to provide more heat transfer area than for an equivalent capacity vapor compression still, if the specific energy requirements are to be comparable.

H. Self-contained purge and condensate pumps are desirable features on a vacuum distillation unit because they minimize control problems and improve system reliability. The condensate pump must be designed to avoid cavitation problems, and the purge pump must contain two stages if it is the positive displacement type.

I. Development tests and a reliability analysis has shown that dynamic seals will have the highest component failure rate. The second weakest link in the system is the thermoelectric material junctions; the water recovery unit developed has 2160 junctions in series. The third weakest link is the eight quick-disconnects provided for connecting the freeze dryer containers to a vacuum manifold.

## 5.2 Recommendations

The waste management subsystem should be subjected to an extensive testing program so that more detailed data will be available for the development of a flight subsystem. These tests should be directed towards the determination of (1) water recovery performance as a function of power input, and (2) fecal residue storability for long periods of time under various environmental conditions. The determination of quantitative reliability data is also desirable, but not possible with one subsystem in a reasonable period of time.

More development work is not recommended at this time, unless it is directed towards the improvement of subsystem reliability. To improve reliability, a flight subsystem should incorporate the following features.

A. Waste heat or vapor compression should be used to vacuum distill potable water from urine.

B. The purge pump and a bag vacuum pump provided with the water recovery unit should be internally contained to reduce the number of dynamic seals required.

C. Urine should be fed to the water recovery unit through a variable capacity metering pump, instead of a metering valve.

D. All dynamic seals should be Teflon coated or provided with Teflon slippers.

E. The freeze dryer assembly should be simplified and the drying time reduced to less than 24 hours.

## SECTION 6

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# APPENDIX A

## OPERATING INSTRUCTIONS

The GATC Model MRD 1210 Waste Management Subsystem is a flight prototype model designed for evaluation in a testing laboratory and/or life-support system simulator. The following operating instructions are, therefore, written for such application.

As described previously in this report, two different systems have been developed for processing feces for storage: (1) a freeze-dry method in which overboard vacuum is utilized for removing the fecal water, and (2) a direct heat application system in which the fecal water is distilled and recovered.

Since the subsystem is shipped with the freeze-dry arrangement installed, operation of this system will be discussed first.

### 1.1 Installation

The system is mounted on a wooden base plate (see Figures A1 and A2). If the system is installed in a simulator, it can be moved into the aisle for performing routine maintenance.

Three lines must be connected to the subsystem, namely (1) a vacuum line to the fecal water distillate filter, (2) a second vacuum line to the bag vacuum valve on the panel of the water recovery unit, and (3) a water line to the discharge end of the potable water storage tank. The two hoses furnished with the system are for vacuum connections. These lines must be flexible if the system is to be moved out into the aisle for servicing.

For initial tests it is recommended that condenser pressure, bag vacuum, and manifold pressure in the freeze-dry unit be sensed and displayed. Mercury

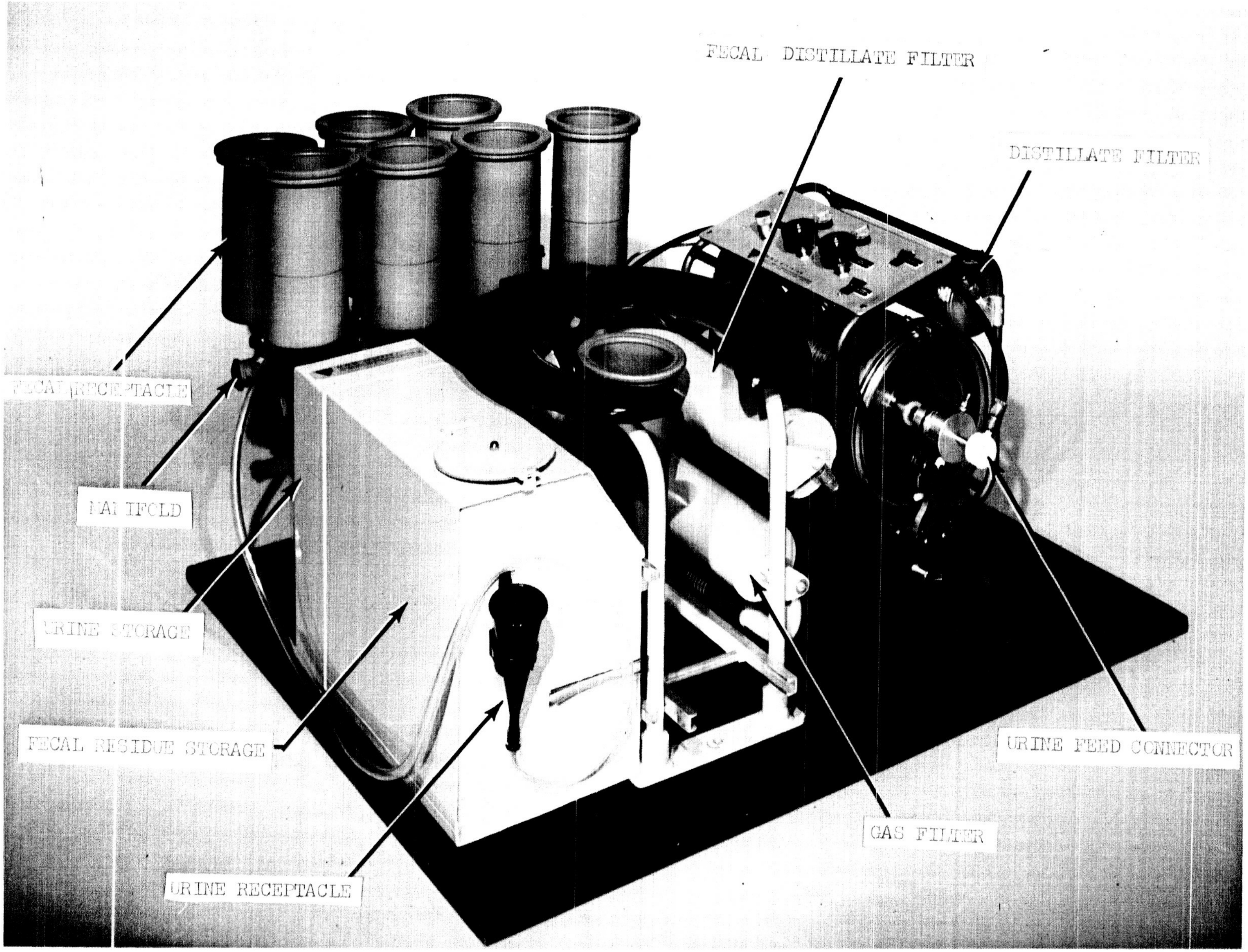


Figure A1 WASTE MANAGEMENT SUBSYSTEM

Figure A2 VIEW OF CONTROL PANEL

manometers are well suited for this application because the pressure range of interest is 1 to 100 mm Hg absolute. Extra connections are provided in the freeze-dry manifold and upper bearing support of the water recovery unit for sensing these pressures. For sensing bag vacuum a manometer can be placed in the line.

In addition, a corrosion resistant dial vacuum gauge, with a range of 0 to 30 in Hg, should be placed in the condenser pressure line. Any significant leak in the water recovery system which would exceed the pump-down capacity of the small built-in vacuum pump would then be quickly detected by the fluctuations of this gauge. Two vacuum pumps should be used to operate the system. A 2 cfm CENCO Megavac vacuum pump, or equivalent, is suitable for the freeze-dry system. A 0.35 cfm CENCO Hyvac vacuum pump, or equivalent, is suitable for bag vacuum control. A single pump may be used for both vacuum systems provided the capacity of the pump will maintain a minimum bag vacuum of 2 mm Hg.

When operating the system with vacuum pumps, it is necessary to place a moisture freeze-out trap in the line between the pump and the freeze-dry unit-otherwise moisture will condense in the pump oil. A standard filter flask in a vacuum Dewar flask can be used for this purpose, with a mixture of dry—ice and acetone as the heat sink.

Two flexible power cords are provided for power connections; one to a 115-volt, 60-cycle source and the other to a D.C. power supply for operation of the thermoelectric unit in the water recovery system.

## 1.2 Calibration Procedure for Urine Feed to Water Recovery System

To obtain the maximum COP for the water recovery system, it is essential that the urine be fed in at a uniform rate. The unit has been designed to recover

0.5 lb of water per hour at a minimum COP of 6. Allowing approximately 10 percent for residue and purge losses, the rate of feed should be four milliliters per minute.

If the micrometer valve is used for laboratory evaluation of the system, the urine supply should be contained in a one-liter graduate or equivalent in order to visually establish the proper rate of flow.

## 1.3 Operation of Water Recovery System

To prepare the water recovery system for use, the following operations must be performed in the order shown:

1. Start the bag vacuum pump; vacuum should not exceed 2 mm Hg absolute.
2. Close urine feed valve.
3. Turn "On" D.C. power supply and adjust voltage to obtain 5-ampere output.
4. Turn "On" the "Potable Water" switch; bowl will begin to rotate and built-in vacuum pump will begin evacuation of condenser. Approximately 1 hour and 15 minutes is required to bring the condenser down to operating pressure of 33 mm Hg absolute.
5. When condenser pressure has reached 33 mm Hg, open the urine feed valve.

## 1.4 Preparation and Use of Waste Collection Unit

To prepare the collector for use, the deep well cover is removed (see Figure A3) from the fecal collection receptacle into the mating connector located on a horizontally adjustable slide at the base of the toilet (see Figure A4).

The receptacle can also be adjusted vertically by loosening a clamp screw and moving the connector up or down.

The composite plastic liner is then placed in the container and the open end stretched over the top of the receptacle.

The "Toilet" switch is then turned on actuating the blower and urine separator. The toilet is then ready for use.

When using the toilet, the occupant holds the urine receptacle in position for voiding of urine.

After defecation, the open end of the plastic liner is closed and tied by means of a plastic-coated wire. The fecal receptacle is then capped with the deep-well cover and placed in the freeze-dry manifold by inserting the connector at the bottom of the receptacle into the mating connector of the manifold. During these operations, the blower must be kept on to insure no contamination escapes into the cabin air.

At the completion of the drying cycle, the fecal receptacle assembly is removed from the manifold and the bag containing the dehydrated feces is deposited in another polyethylene plastic bag. This bag provides an additional seal and contains 5 grams of silica gel to maintain dehydration of the feces during storage.

The bag is then sealed similarly to the fecal bag and placed in the storage container.

### 1.5 Installation of Fecal Water Recovery Drying Rack

To replace the freeze-dry rack with the fecal water recovery drying rack, proceed as follows:

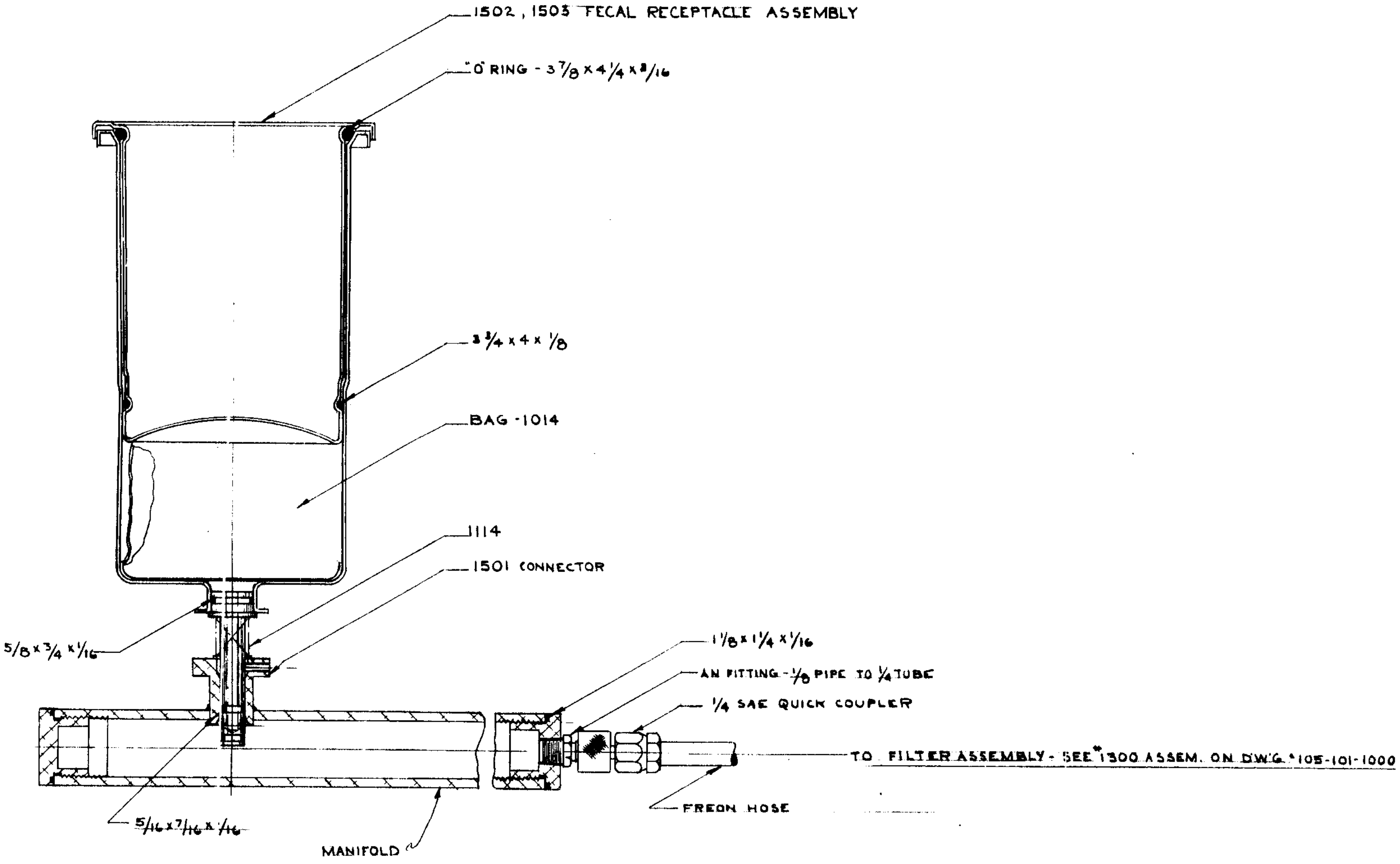


Figure A3 FECAL RECEPTACLE ASSEMBLY - (FREEZE-DRY SYSTEM)

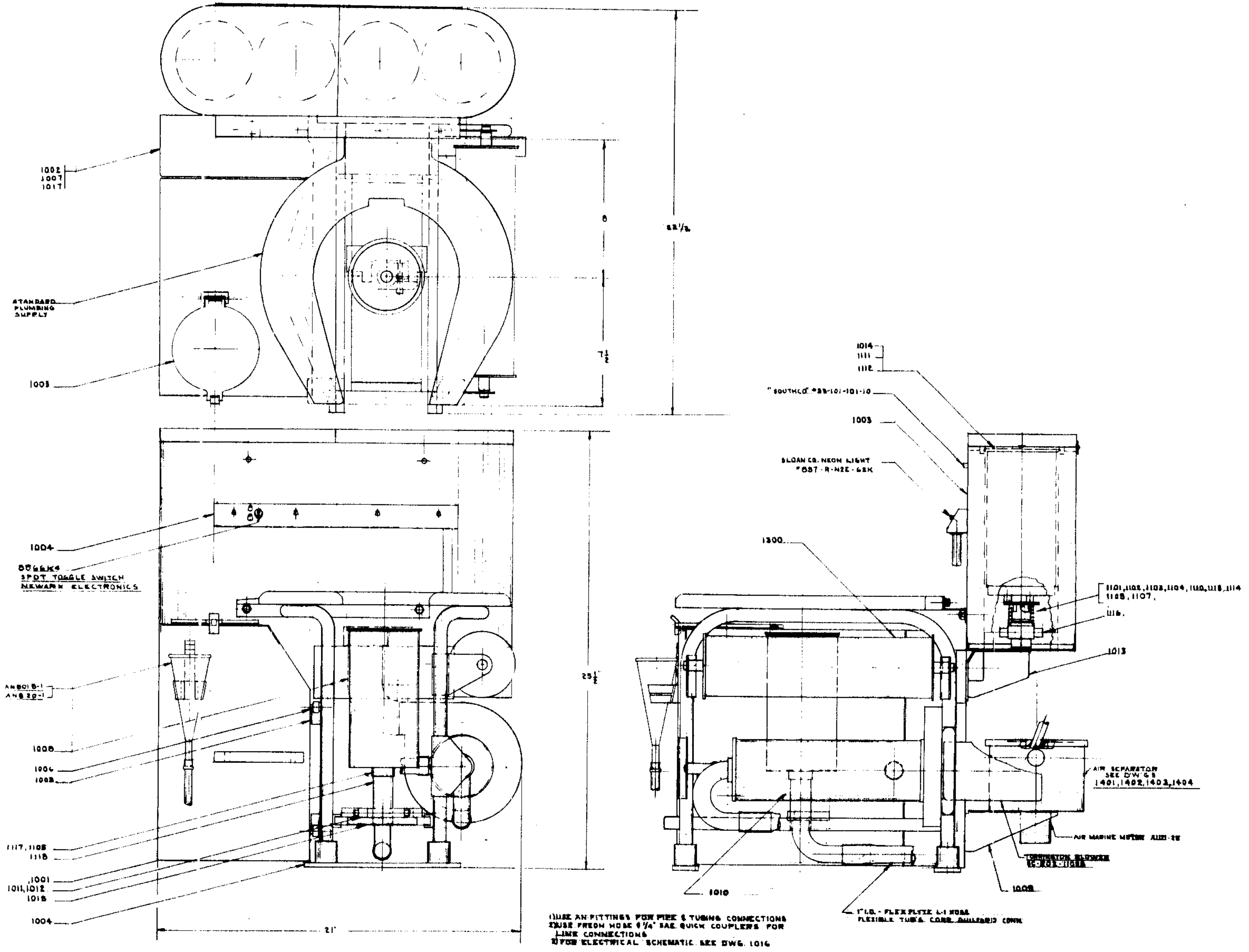


Figure A4 TOILET ASSEMBLY WITH FECAL WATER RECOVERY RACK INSTALLED

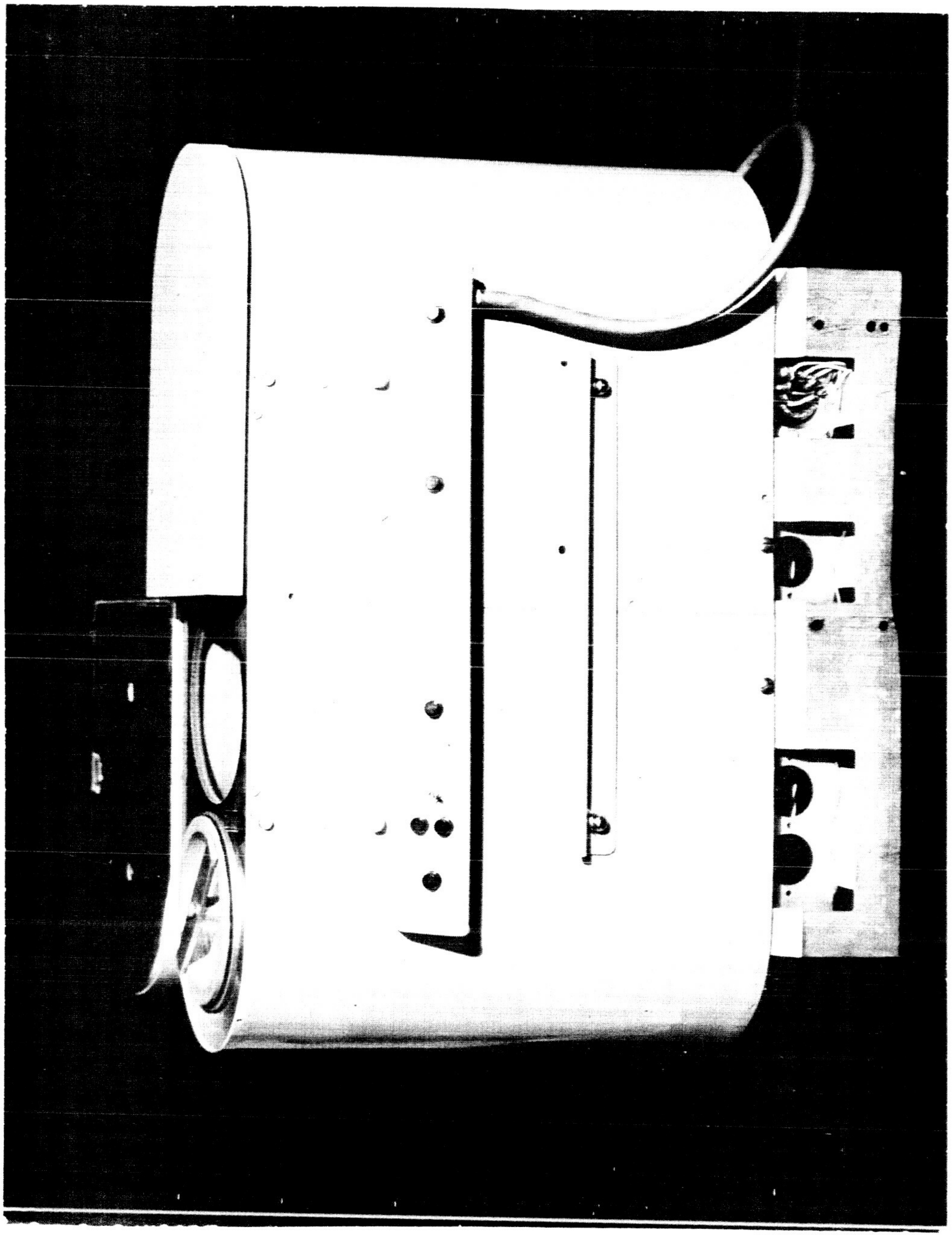


Figure A5 DRYING RACK - FECAL WATER RECOVERY SYSTEM

1. Disconnect vacuum pump to fecal water distillate filter.
2. Disconnect manometer gauge.
3. Remove fecal containers.
4. Disconnect amphenol connectors to air separator, blower and 110-volt source.
5. Disconnect hose to filter.
6. Remove four screws holding rack to tubular support frame and remove rack.

Install fecal water recovery drying rack as follows:

1. Remove support bracket from rack and fasten to rear of toilet seat (see Figures A4 and A5).
2. Attach rack to tubular frame with same four screws as used on the freeze-dry rack.
3. Secure support bracket to rack.
4. Make electrical connections to air separator, blower and 110-volt power source at water recovery unit.
5. Connect filter hose to rack.
6. Connect outlet hose from fecal water filter to tee at urine connector on panel of water recovery unit.

### 1.5.1 Operation of Fecal Water Drying Rack

The operation of the fecal water drying rack is similar to that of the freeze-dry rack with the following exceptions.

1. A miniature, double-throw, toggle switch located on the indicating panel on the drying rack alternately operates the blower and heaters for minimum peak wattage. "Toilet" switch on water recovery panel remains on at all times.

2. Fecal receptacles are placed into heater wells in the rack. When cover is closed micro-switch is actuated supplying power to heater. A neon light comes on indicating heater in operation.
3. The fecal container becomes hot in operation. To remove, a glove, or other protective means should be used and containers opened only when cool.
4. Fecal receptacles have a shallow cover and different connector at base. To use with toilet, remove freeze-dry receptacle adapter from mating connector on toilet slide. Re-position fecal receptacle is necessary.

# APPENDIX B

## MAINTENANCE INSTRUCTIONS

The GATC Model MRD 1210 Waste Management Subsystem was developed to provide for the collection, disposal and storage of human occupant wastes and to also provide for the recovery of potable water from urine. The system is capable of managing the waste products of three men for at least 60 days. Preventive maintenance is required during this period and should be performed every 48 hours, when the bag is changed in the water recovery system. Every 30 days the Water Recovery System should be disassembled, and inspected for corrosion and wear, and every 60 days a similar inspection performed on the toilet and accessories.

### 1.1 Forty-four Hour Maintenance

#### 1.1.1 Evaporator Bag

Once every 48 hours, the water recovery system should be shut down to change the evaporator bag. To change bag, proceed as follows: (Refer to Figures A1, B1 and B2)

1. Loosen retainer at top of bowl and remove urine feed connector.
2. Disconnect hoses (2) to filter and condenser pressure gauge from upper bearing support.
3. Remove retaining washer from rear of bowl and slip off rotary seal connector.
4. Remove screws from support arm and remove bowl assembly. Remove key from stem (see Figure B3).
5. Remove cover clamps (2).
6. Rotate upper bearing support and line up condensate pump with access opening in barrel cam surface. These parts are visible through the transparent cover.

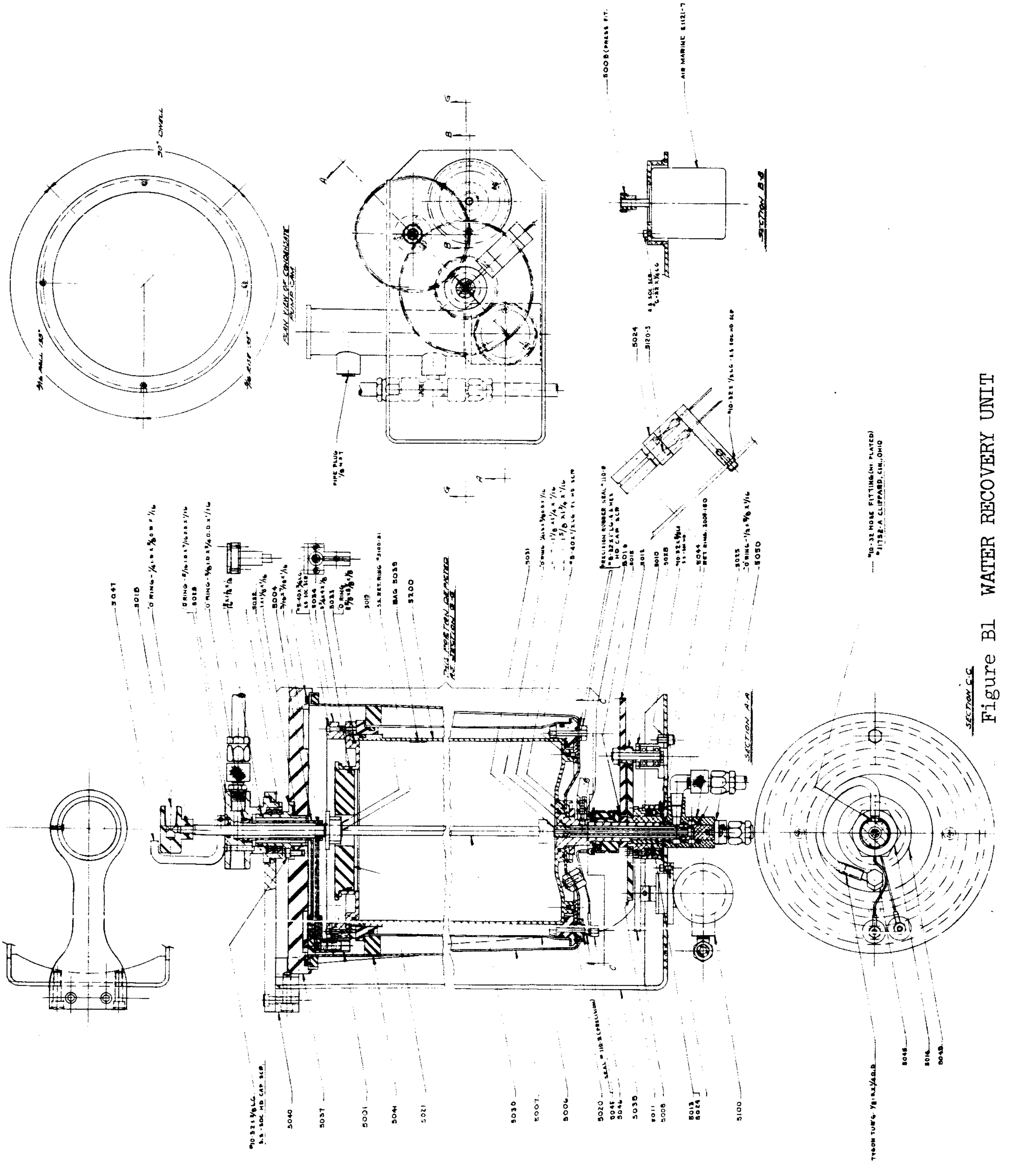


Figure B1 WATER RECOVERY UNIT

MRD DIVISION
GENERAL AMERICAN TRANSPORTATION CORPORATION

Figure B2 BOWL ASSEMBLY

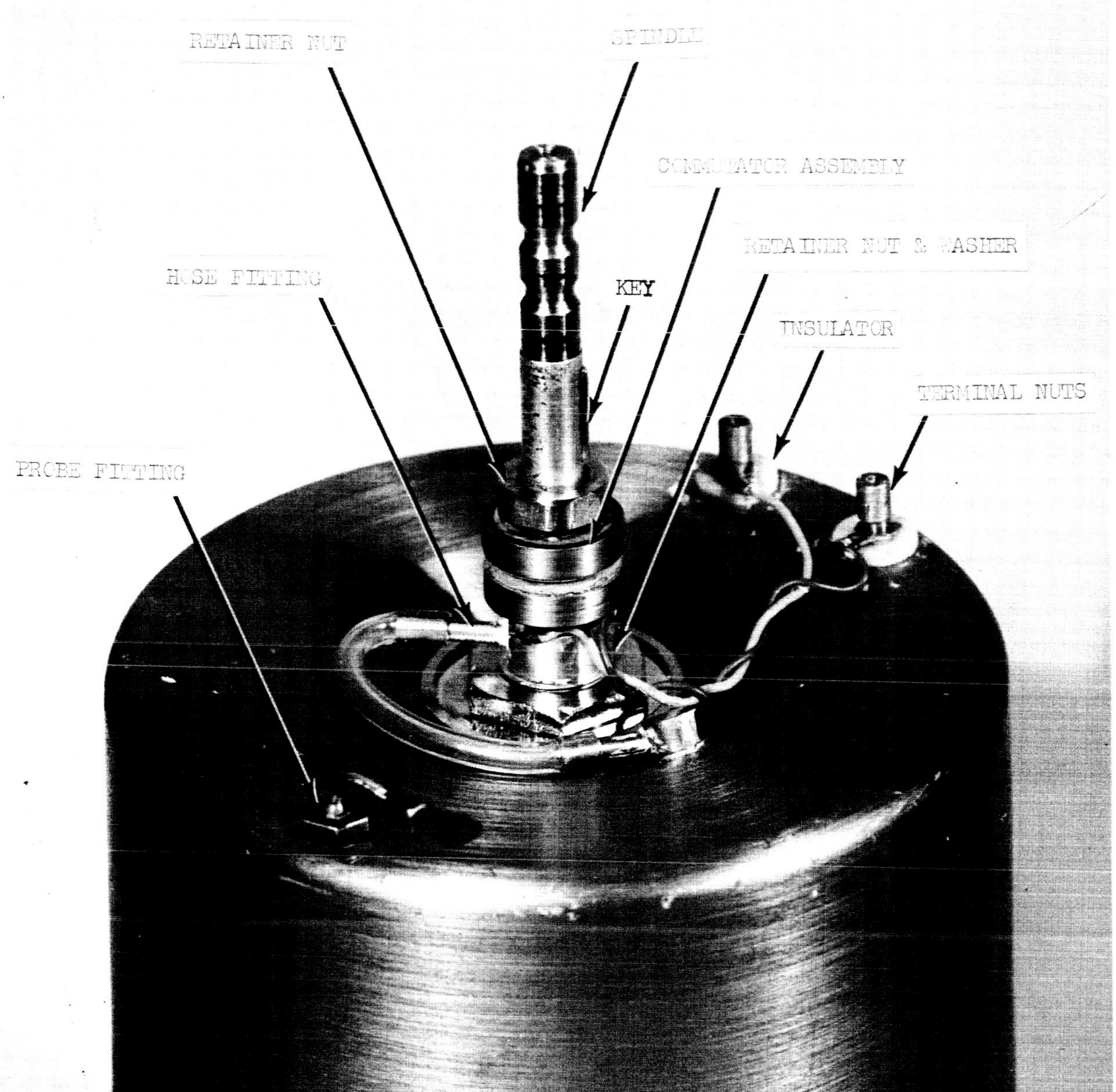


Figure B3 VIEW OF SPINDLE END OF BOWL ASSEMBLY

7. Remove cover, complete with bearing support, condensate pump, and urine feed tube (see Figure B4).
8. Remove evaporator cap. Bag is now accessible.
9. Replace bag.

(NOTE: In reassembling bowl to support frame, commutator brushes must be retracted to enable insertion of bowl stem in bowl drive gear. Key must be in place on stem.)

### 1.1.2 Inspection and Lubrication of Upper Bearing Assembly Condensate Pump Assembly and Rotary Seals (Figure B5)

To disassemble upper bearing assembly and condensate pump, grasp bearing support and rotate arm of condensate pump assembly in a counter-clockwise direction.

Remove upper bearing support and inspect ball bearings and "O" ring seal. Clean "O" ring and lubricate with a small quantity of silicone grease.

Remove condensate piston and inspect miniature ball bearing and "O" ring. (NOTE: Bearing is a light push fit on shaft and can easily be removed and replaced).

## 1.2 Thirty Day Maintenance

### 1.2.1 Water Recovery System

In addition to performing the forty-eight hour maintenance procedure, the evaporator bowl and outer bowl should be disassembled and thoroughly inspected.

Disassembly is performed as follows: (See Figure B6)

1. Remove terminal nuts at base of bowl assembly and remove wires, spacers, and insulators.

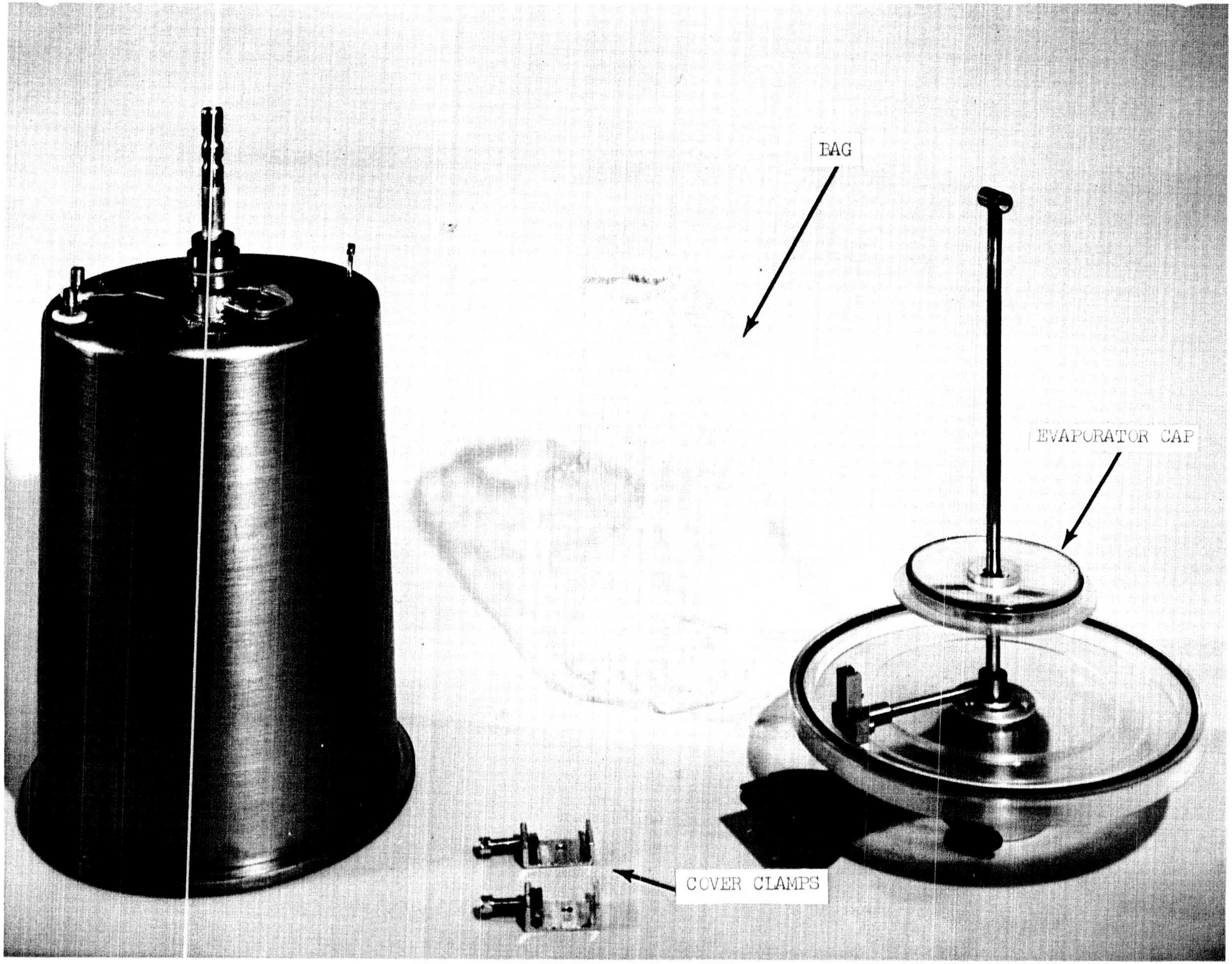


Figure B4 BOWL DISASSEMBLED FOR BAG REPLACEMENT

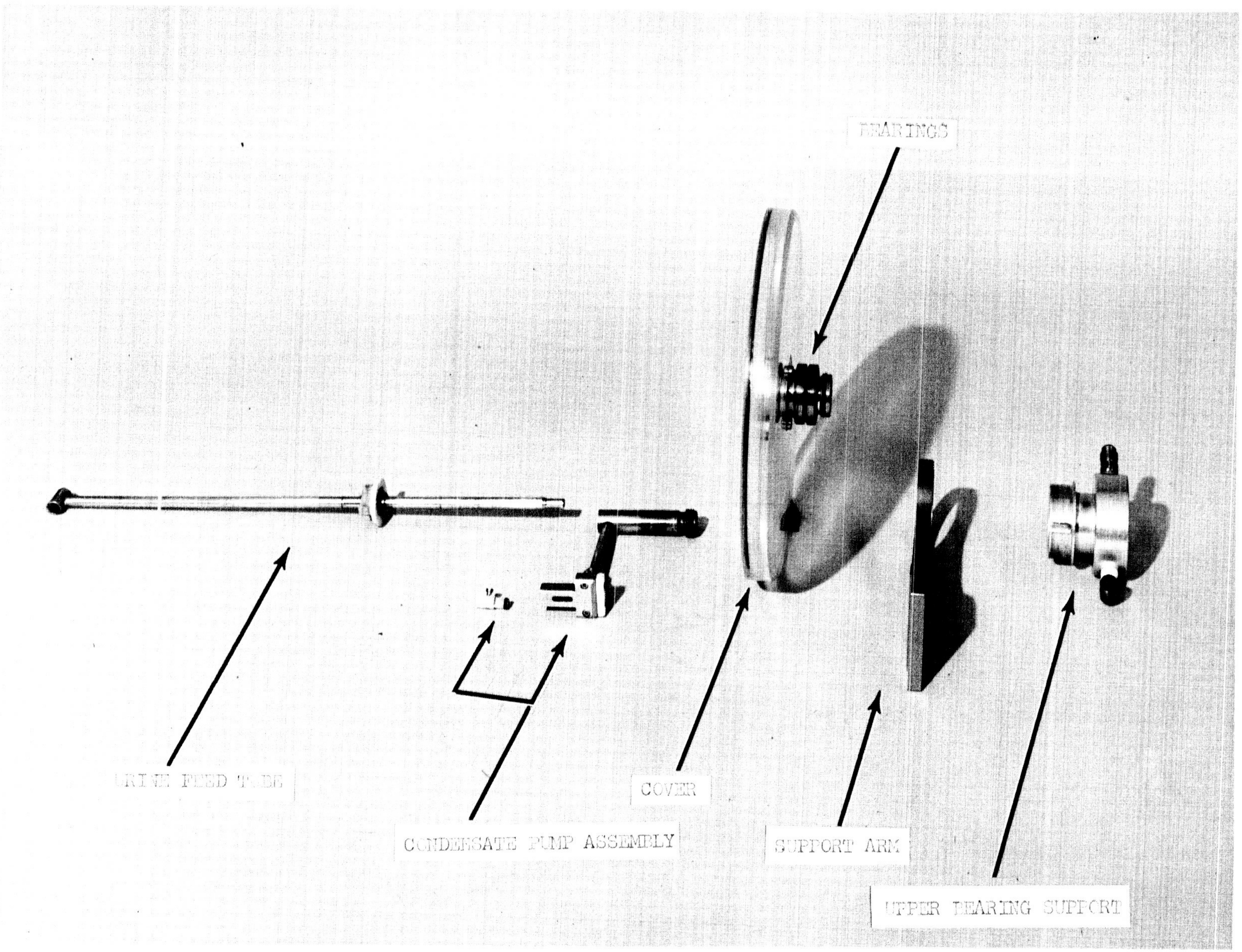


Figure B5 DISASSEMBLY OF UPPER BEARING SUPPORT AND CONDENSATE PUMP

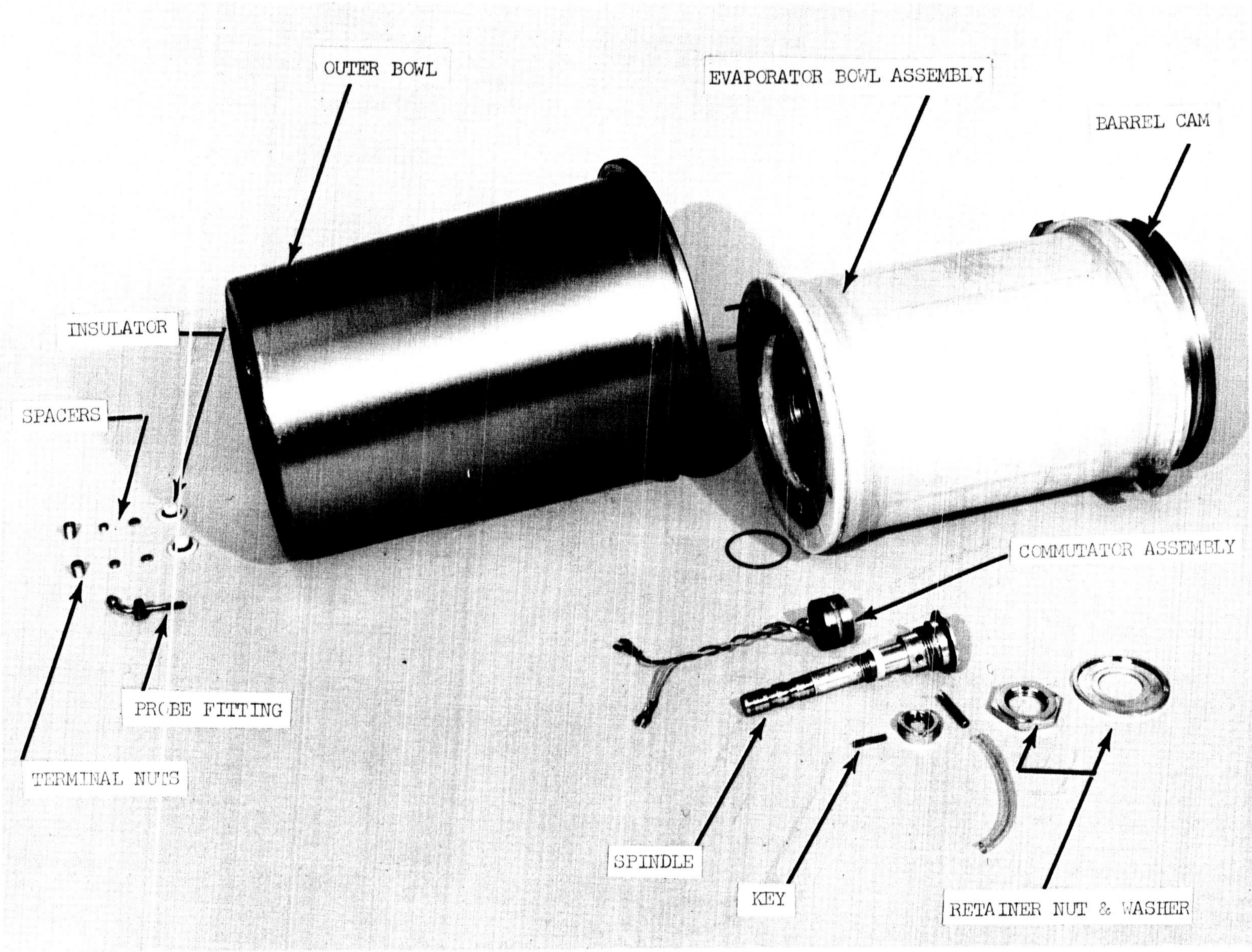


Figure B6 DISASSEMBLY OF EVAPORATOR BOWL AND OUTER BOWL

2. Unscrew probe screw.
3. Remove commutator and insulator spacer by unscrewing retaining nut.
4. Remove Tygon hose fitting in stem.
5. Unscrew large hexagon nut and remove washer. Stem and bowls are now separable.

Upon disassembly wash the bowl in a mild detergent and inspect for corrosion. Check the barrel cam for wear and replace all "O" rings and Tygon tubing.

In addition, check all gears for wear and ball bearing on hub of bowl drive gear. Lubricate where required.

### 1.2.2 Vacuum Pump Assembly (See Figure B11)

To inspect and service vacuum pump, disassemble as follows:

1. Remove gear from driven shaft and remove pump from bowl support frame.
2. Remove acorn retaining nut and shoulder screw #5109. Pistons and inner check valve housing can now be removed.
3. Detach sleeve from check valve housing.
4. Remove retaining rings and check valves.
5. Remove driven shaft and ball bearing assembly.

Inspect all parts for wear. Replace all "O" rings and worn parts and reassemble. Lubricate "O" rings with a small quantity of silicone grease.

Check pump operation. Pump should pull vacuum of 5 mm Hg absolute with ambient air.

## 1.3 Sixty Day Maintenance

At the end of sixty days of operation all components of the Waste Management Subsystem should be thoroughly cleaned and inspected as follows:

1. Water Recovery System as described in 1.1.
2. Air-separator - check bearing in separator cover. See Figure B7.
3. Urine storage bladder.
4. Condensate storage bladder.
5. Filter assemblies. See Figures B8 and B9. Disassemble, clean and disinfect. Replace all filters.
6. Freeze-dry manifold. See Figure B10. Remove end caps and clean and disinfect unit. Remove connectors and inspect. Replace all "O" rings.
7. Fecal water recovery rack. See Figures A3 and A4. Remove base of rack. Remove end plates on manifold and clean and disinfect unit. Remove thermostat and connector wires to terminal block and unscrew heater assemblies. Replace thermostats and all "O" rings. Set thermostats at 230-240°F.
8. Check brushes of blower motor.
9. Clean all flexible hoses.

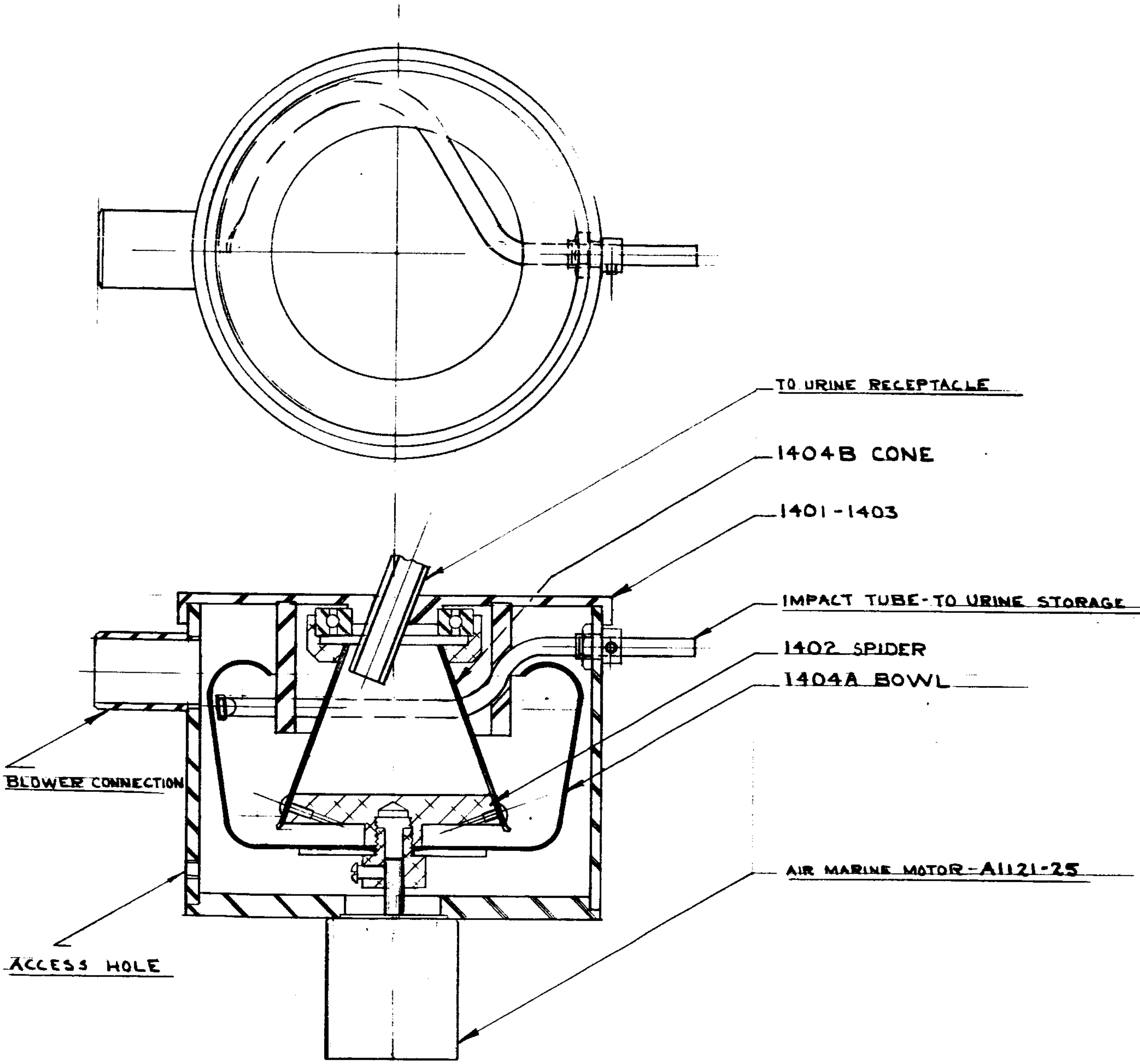
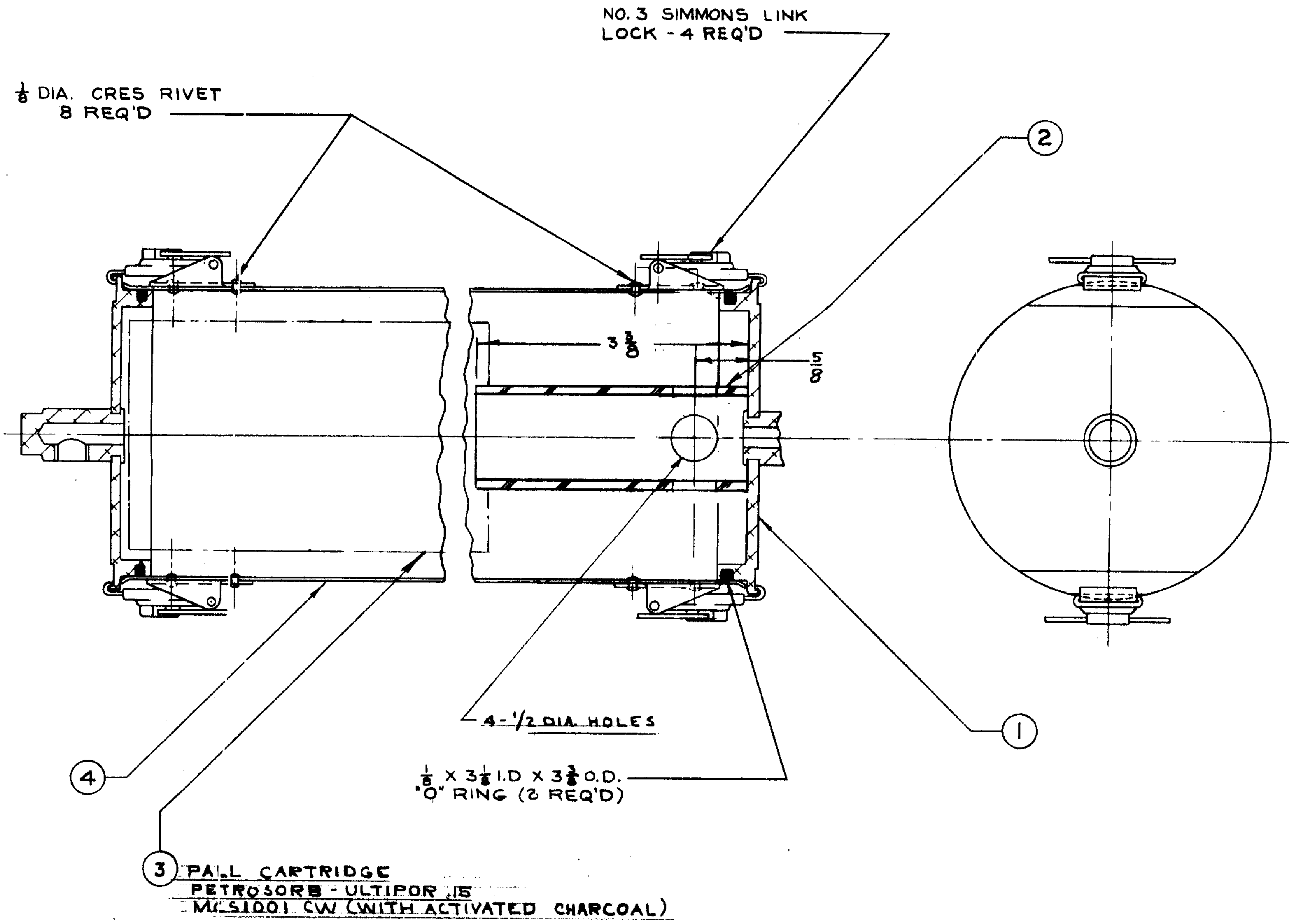


Figure B7 AIR-URINE SEPARATOR



NOTE:
CLEAN AND
CLEAR ANODIZE

Figure B8 WATER DISTILLATE FILTER ASSEMBLIES

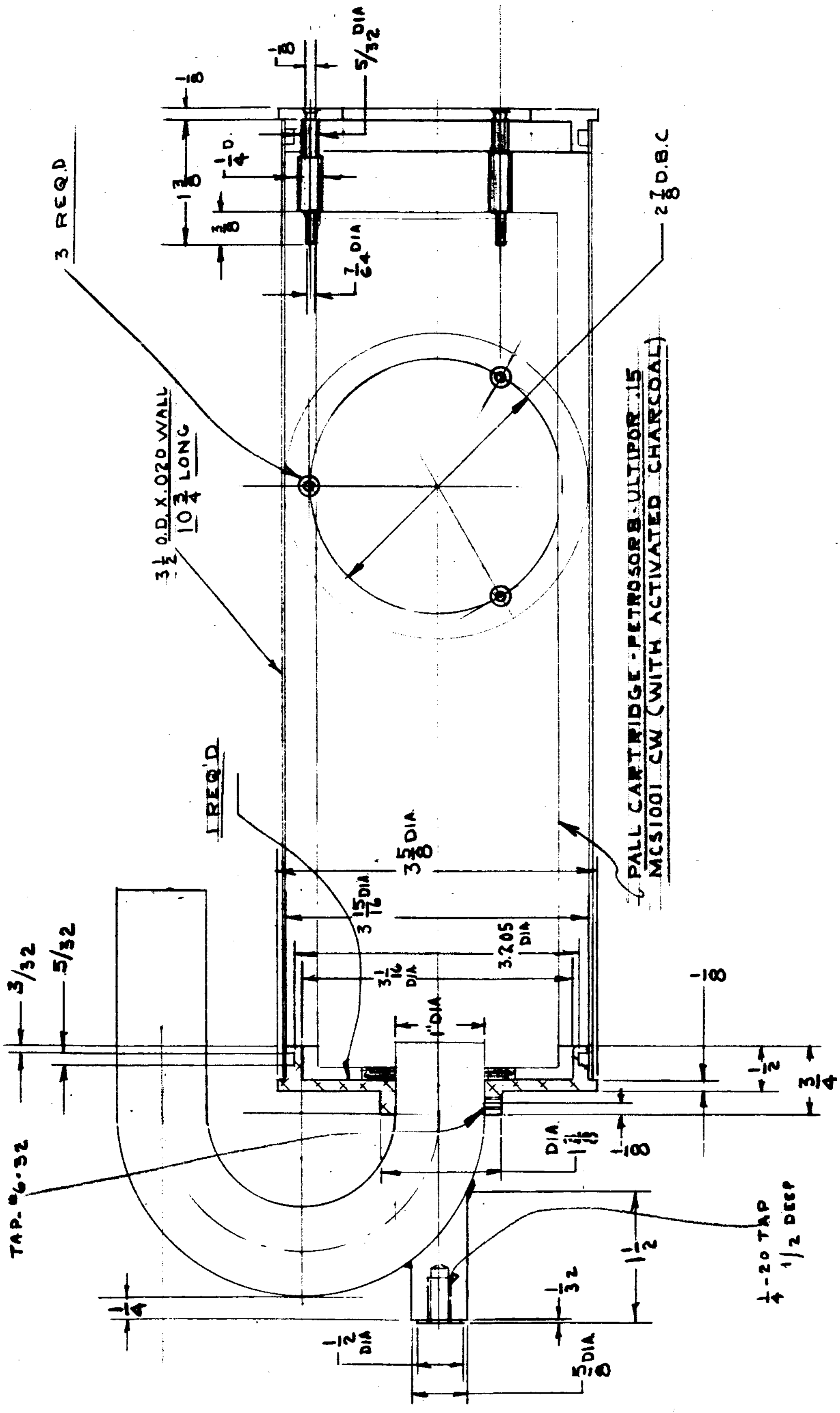


Figure B9 GAS FILTER ASSEMBLY

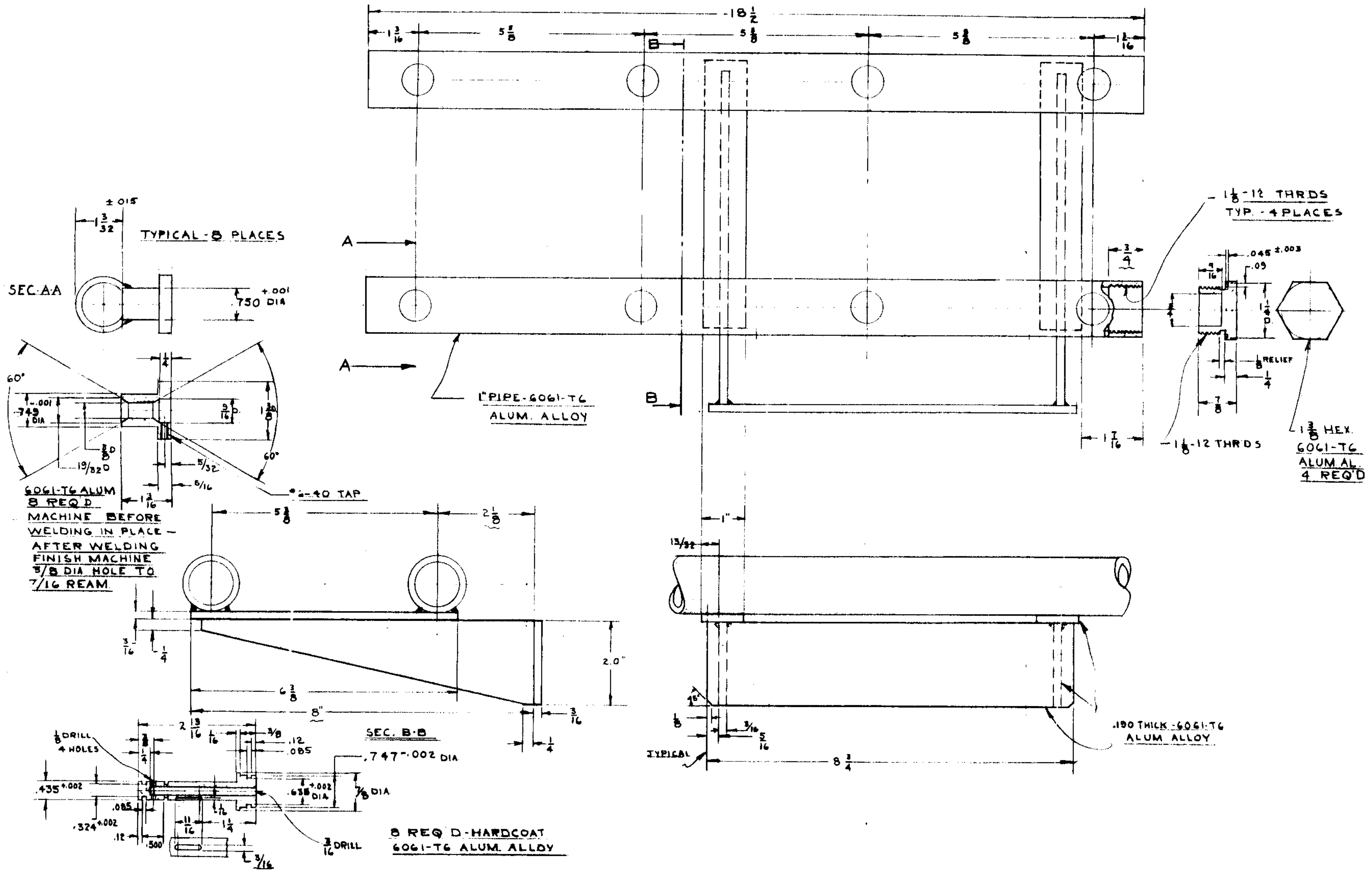
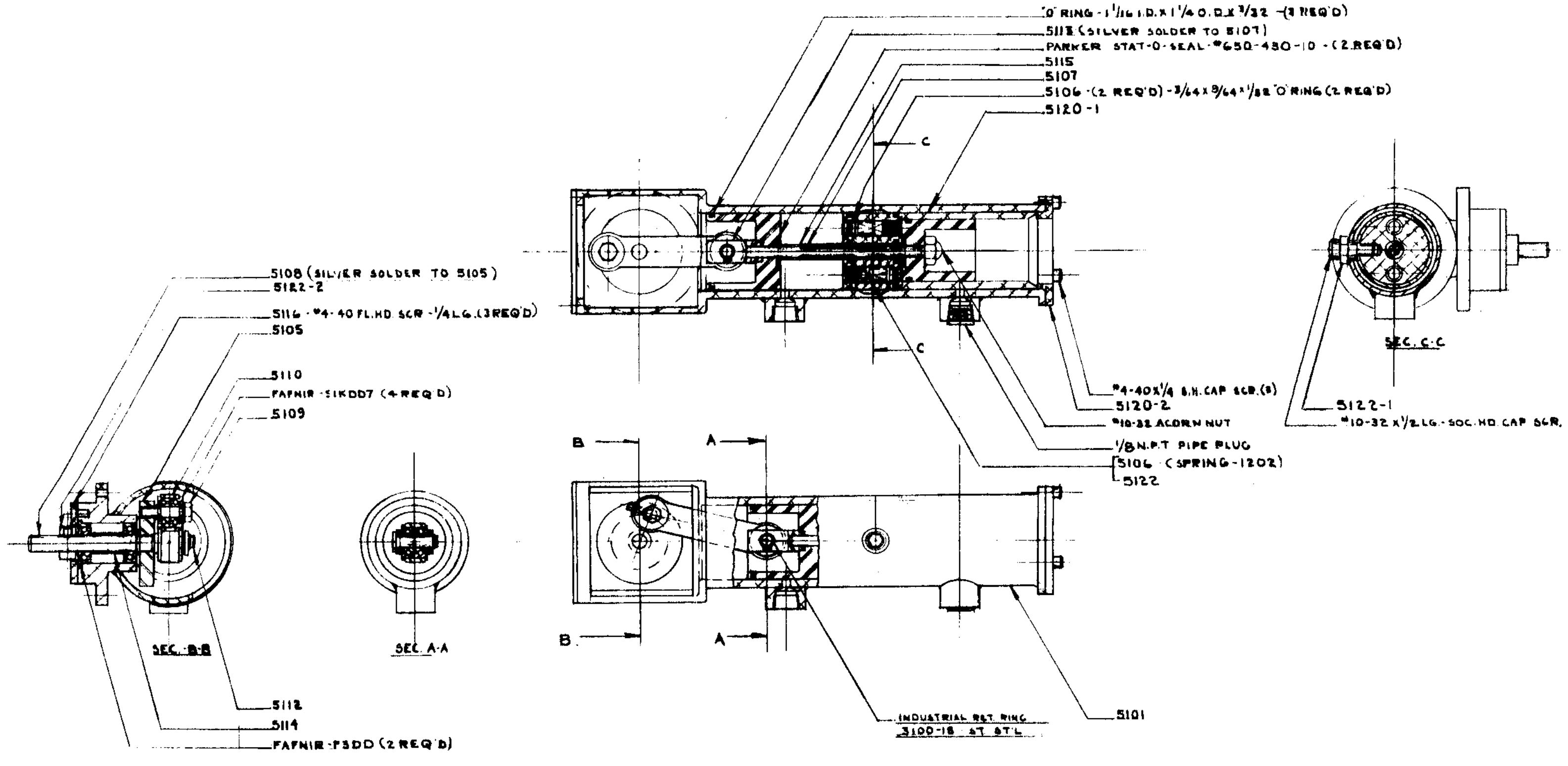


Figure B10 DETAILS-FREEZE-DRY MANIFOLD



NOTE:
ALL SCREWS STAINLESS ST'L

Figure B11 VACUUM PUMP ASSEMBLY