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HYDRO-JOHN ENGINEERING PROTOTYPE, THE DESIGN, DEVELOPMENT AND FABRICATION OF A WASTE MANAGEMENT AND WATER RECOVERY SYSTEM

Environmental Control Systems Branch
Crew Systems Division
NASA Manned Spacecraft Center
Houston, Texas

Contract Monitor: W. F. Reveley
Prepared Under Contract No. NAS 9-1301

by

R. W. Murray, F. Rudek, L. Cooper, R. Miller
General Electric Company
Missile and Space Division
Valley Forge Space Technology Center

OCTOBER 1964

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SECTION I
SUMMARY

The Hydro-John Waste Management System features psychological acceptability through unique and effective cleanliness and sanitation procedures. Manual manipulation of waste material or manual contact with the cleansing media is unnecessary with the Hydro-John concept, an advantage in zero gravity operations. The semi-automatic system is clean, simple to use, and is self-cleansing and sanitizing. It performs all the major functions required of a complete waste management system, i. e., collection and storage of human excrement and recovery of potable water, under conditions of both weightlessness and normal gravity.

The engineering prototype was evolved in several stages of development. Initially methods of fecal transportation and collection, i. e., slinger, augers and blenders, were tested with the pump-blender emerging as the superior method. An operational breadboard was then developed and tested and was the basis for the design of the fecal transportation element of the prototype system. Concurrently, laboratory tests of disinfectants, water potability, ammonia control, bacterial control, and flush water contamination were conducted. The test results along with previous waste management design experience were combined to form the foundation for design of the engineering prototype system.

The engineering prototype provides an effective and sanitary waste management system for a 4 man crew for a 14 day period. Also sufficient potable water is recovered from the biological wastes to equal the urine input to the system, thus contributing to a closed life support system. Cabin atmospheric gas flows are used to aid the transportation of metabolic wastes (solids and liquids) and for drying the cleansed areas of the body. Special container configurations are utilized to provide liquid positioning in zero gravity.

SECTION II

SYSTEM DESCRIPTION

1.0 Introduction

For future manned space flights, trade-offs of open versus closed or partially closed life support systems should result in a lower total vehicle weight and power requirement. Ideally for extended missions, most of man's waste products, e.g., urine, wash water, perspiration and respiration water, carbon dioxide, feces, refuse, etc., will be processed to extract usable products.

The Hydro-John concept makes a significant contribution to closed life support systems by providing for the reclamation of potable water from biological wastes and by providing an effective and sanitary waste management system. The system can be fully integrated with the man-vehicle complex, it has high crew acceptance and it provides effective sanitation. Specifically, the excreta is retained during the functional procedure, the body area is cleansed, the collection and transport equipments are cleansed and sanitized, and solid waste residue is treated and stored. The above is accomplished in a semi-automatic mode of operation.

The engineering prototype system developed under contract NAS 9-1301 was designed with zero gravity operational features. However, the still-pot was designed for visual monitoring. Thus the zero gravity design was somewhat compromised in this laboratory model since non-wettable surfaces could not be fully provided. Other performance factors were not compromised. The prototype design was not optimized since the component parts are greatly oversize and overweight.

Figure 2-1 illustrates the completed prototype.

2.0 Basic Concept

The basic Hydro-John concept is shown in the flow diagram of Figure 2-2. The feces enters the hopper and is carried by air flow (for zero gravity operation) through a transport tube to the pump-blender section. On command, the rectal area is cleansed with warmed flush water and dried with warmed air. The flush water (along with urine) mixes with the feces in the pump-blender. The resulting slurry is pumped into a still-pot. The water in the still-pot is boiled at reduced pressure and temperature; waste heat from the environmental control system provides the required evaporative heat. A space vacuum port vents non-condensables to provide pressure control. The resulting water vapor flow is divided so that the majority is condensed and filtered through activated charcoal for reuse as flush water. The smaller portion of the vapor is heated to approximately 1800°F and passed through a platinum catalyst in the presence of a small amount of oxygen. The water impurities are thereby oxidized. The water vapor is then condensed to yield potable water.

3.0 Design Parameters

The prototype Hydro-John system is designed to collect, transport, process and store the waste excreta and urine from 4 men during a 14 day simulated space vehicle mission. Also,

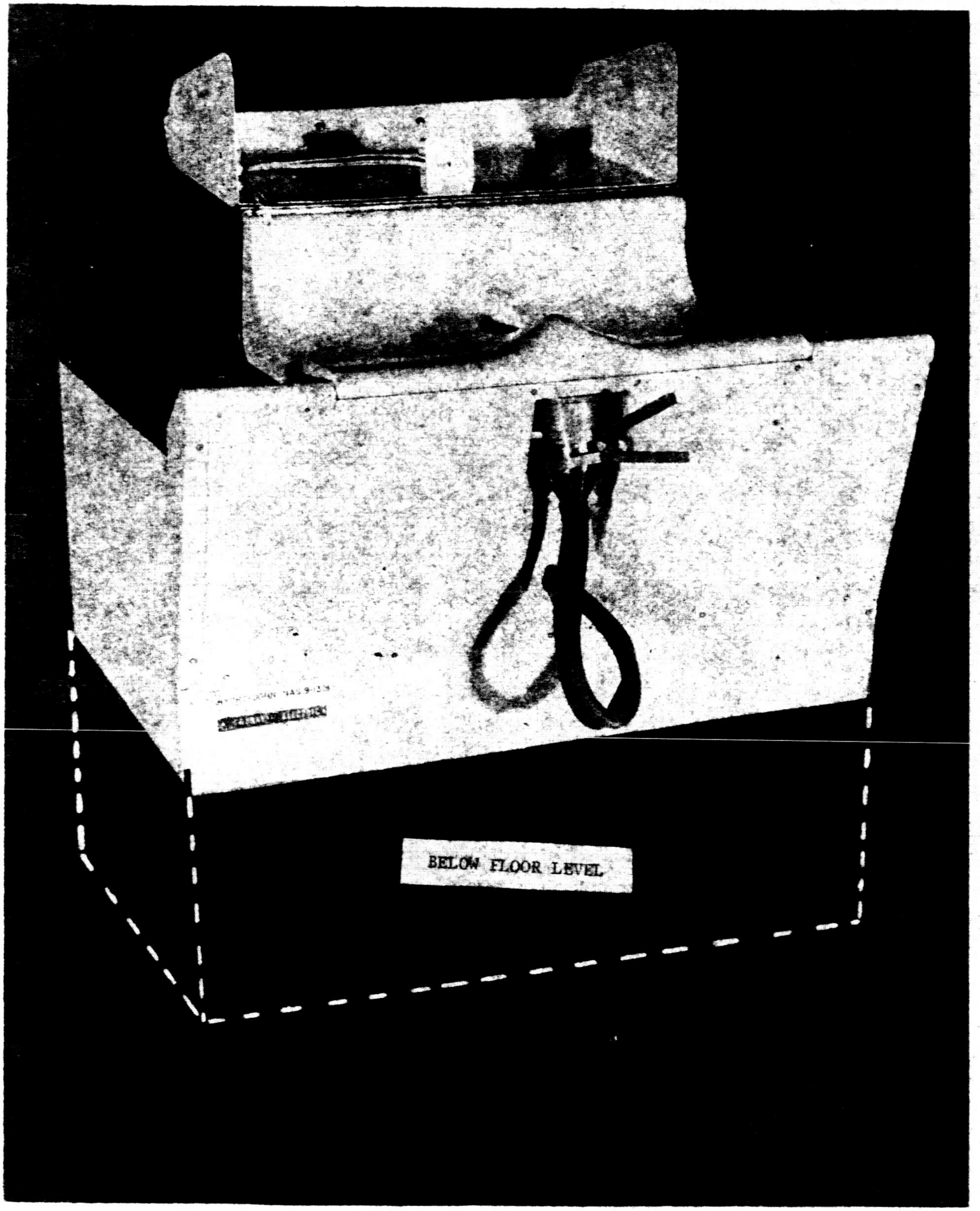


Figure 2-1. Hydro-John System Prototype

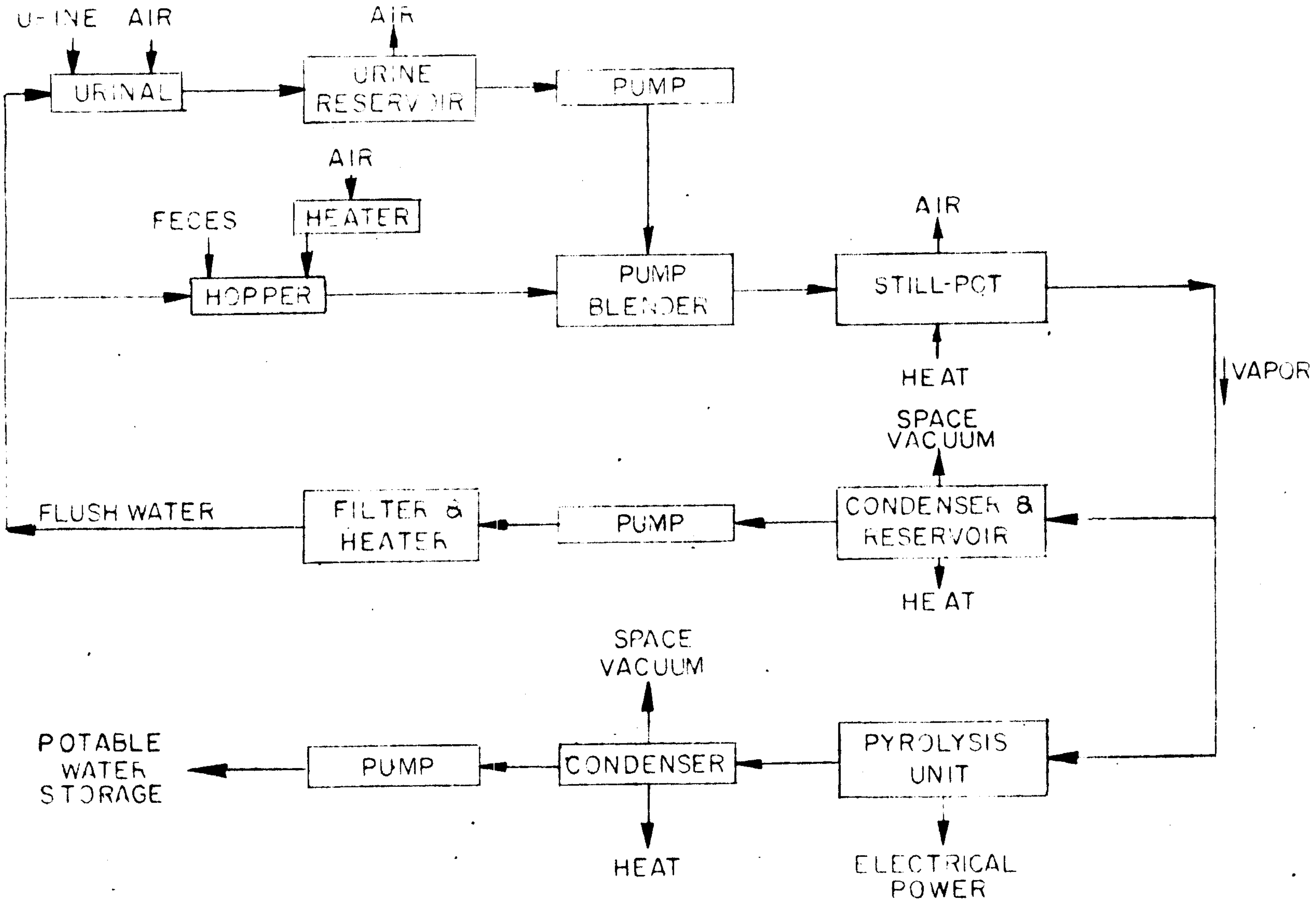


Figure 2-2. Hydro-John Waste Management System Block Diagram

the system is designed to reclaim approximately 12 pounds of potable water per day from the biological waste. The system will theoretically recover 99.6% of the water involved in the process as shown by the calculations in Table 3-1. The system is designed to the performance parameters shown in Table 2-1.

4.0 Major System Functions

Major functions provided by the prototype Hydro-John system are described below. Reference to the system schematic, Figure 2-3, will be helpful in following the discussion.

4.1 Feces and Urine Collection and Transfer

The feces is excreted while the man is seated on the hopper. A flow of atmospheric gas is used to convey the feces through the transport tube to the pump-blender during zero gravity conditions. This flow of air also prevents release of odors into the vehicle cabin. For micturition, the urinal seals around the penis; a flow of cabin air along with the initial liquid velocity conveys the urine to the urine reservoir. At ground check-out, gravity is the predominant transport force, the air flow essentially controlling odors and drying affected body areas. Since there will be at least 2 to 3 urinations between each defecation, urine is stored in the urine reservoir until a defecation occurs. It is then pumped into the pump-blender section to aid in the fecal-liquid blending process. This delay also alleviates the need of shutting down, i.e., pressurizing the still-pot at each urination and evacuating to resume boiling, with a consequent saving of vehicle atmosphere.

4.2 Feces and Urine Mixing and Storage

After urination and defecation, the subject depresses a push button switch and a series of automatic cycles are initiated.

4.2.1 A scheduled amount of stored urine and urinal flush water is pumped into the pump-blender while the pump-blender is rotated in a reverse (non-pumping) direction.

4.2.2 The reversed pump-blender allows little of the liquid to escape to the still-pot, thus aiding in the feces and liquid blending process.

4.2.3 The still-pot is also opened to the pump-blender at this time.

4.2.4 After about 5 seconds of reverse blending, the pump-blender is reverted to the normal pumping rotation, and the still-pot receives the slurry mixture.

4.2.5 Simultaneously with operation of the pump-blender, eight jets of flush water spray and cleanse the rectal area, while two jets tangential to the transport tube cleanse the tube walls. Approximately two liters of flush water are used.

4.2.6 After an additional 15 seconds, the cleanse and pump cycles stop and the still-pot is closed.

4.2.7 The urinal rinse push button switch is then actuated, while the urinal is still attached, cleansing the penis and urinal with flush water.

TABLE 2-1. PERFORMANCE PARAMETERS

Crew	4 Men
Mission	14 Days
Urine Input	3 Pounds per man day
Fecal Input	0.25 pounds per man day
Potable Water Collected	0.5 pounds per hour
Flush Water Collected	1.5 pounds per hour (recycled)
Flush Water Used	4 pounds per defecation flush 0.5 pounds per urination flush
Total Defecations	7 per day
Total Urinations	16 per day

WORST ANTICIPATED DAILY USE CYCLE

HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
DEFECATIONS	*	*	*				*				*				*				*					
URINATIONS	*	*	*	*	*	*	*	*	*	*	*		*		*		*		*			*		

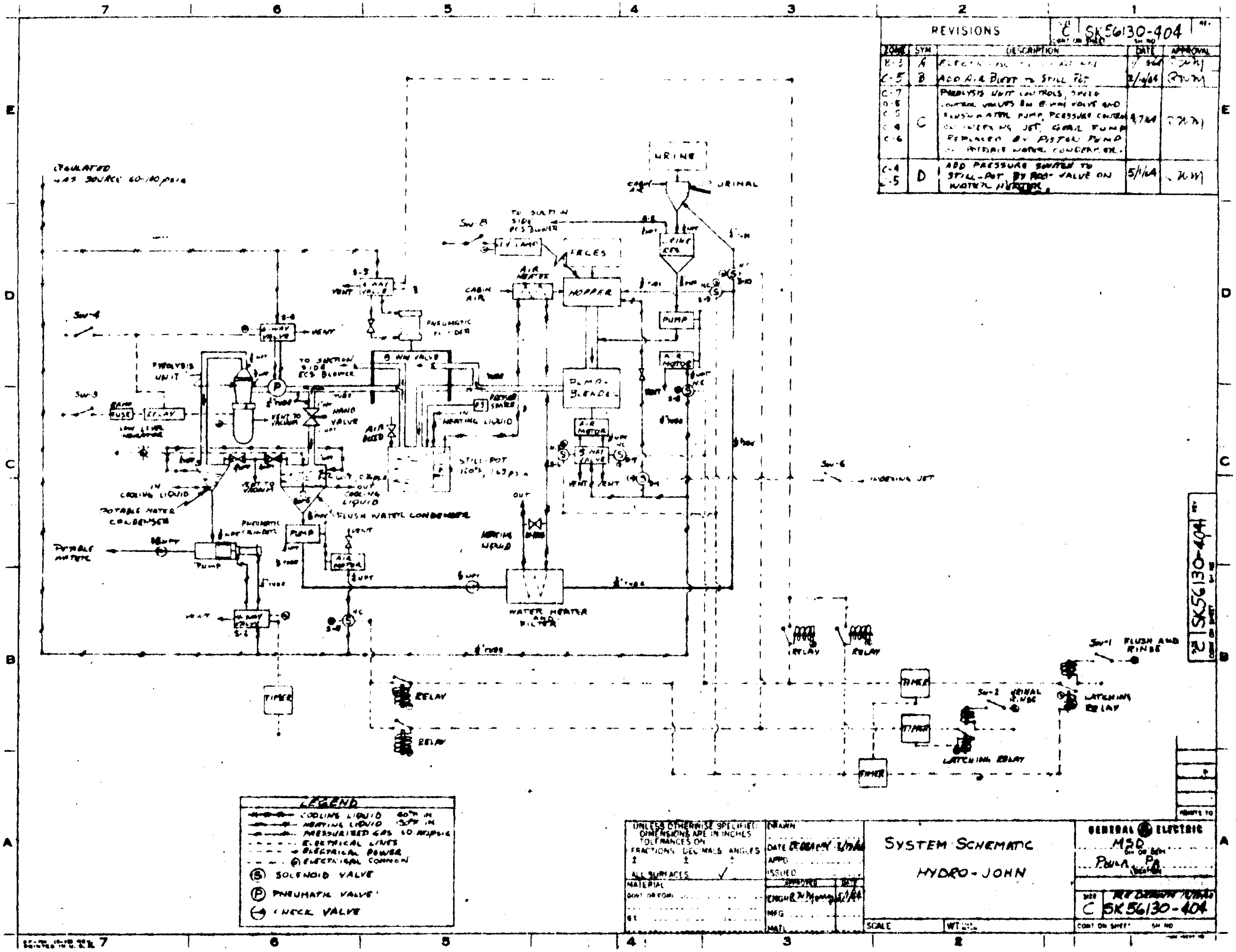


Figure 2-3. Hydro-John System Schematic

Consequently, all the feces is blended with first urine and then flush water and is pumped to the still-pot. The rectal area, penis, urinal, transport tube, and pump-blender are cleansed with flush water. This process leaves the man and the system clean and sanitary; the man does not use toilet tissue. The subject remains seated until the warmed air flow dries the rectal area, at which time the man rises (removing the urinal), dons his clothing, and resumes his duties.

4.3 Flush Water Recovery

Between each defecation, the slurry in the still-pot is subjected to a low pressure by venting non-condensables and a small amount of water vapor to space vacuum. The water content is evaporated from the slurry, by the addition of waste heat from a heating coil, thus leaving the solid residue in the still-pot. The water vapor flow from the still-pot is divided such that 1.5 pounds of water vapor per hour is diverted to the flush water condenser and 0.5 pounds per hour is diverted to the potable water recovery portion of the system, i.e., pyrolysis unit and condenser. No pumps are required to convey the water vapor from the still-pot to the condensers. The still-pot evaporates the water at approximately 120°F and 1.69 psia while the condensers operate at approximately 60°F and 0.26 psia. This pressure differential between the still-pot and condensers is sufficient to overcome the flow frictional losses for the given mass transfer, thus causing the vapor to flow from still-pot to condensers.

The flush water condenser is also used as the flush water reservoir. Consequently, water is pumped from the reservoir as required for the defecation and urination flush cycles. As the flush water is pumped from the reservoir, it is passed through an activated charcoal filter which removes organic odors and is warmed by a heating coil to provide an acceptable rectal cleansing spray. A small quantity of ammonia (generated in the still-pot) is dissolved in the flush water. Initially a maximum concentration of under 5000 ppm was deemed a reasonable ammonia concentration. This amount of dissolved ammonia was sufficient for disinfecting purposes. Thus, a separate disinfectant supply was not required; since the system was self-sterilizing. However, later tests indicated that some skin irritation was encountered from this ammonia concentration. Subsequently a chemical reagent ($CuSO_4$) was added which successfully controlled the ammonia concentration and bacterial growth.

4.4 Potable Water Recovery

The pyrolysis unit heats part of the water vapor from the still-pot to approximately 1800°F in the presence of a platinum catalyst. This action promotes the oxidation of water vapor impurities. The oxidized impurities are only slightly water soluble and condensable at the temperature and pressure of the condenser. Consequently, most of the impurities are removed from the system by the condenser vacuum vent leaving only potable water in the condenser. An air bleed in the still-pot adds approximately 30 standard cubic centimeters of air per minute to the water vapor flow. This small bleed provides the required oxygen for decomposition of the water impurities.

The potable water is removed from the condenser by a timed pump cycle. The water outlet is connected to the potable water storage reservoir of the simulated vehicle.

5.0 System/Vehicle Integration

The system is integrated into a simulated space vehicle such that several Hydro-John System functions rely on vehicle equipment (see Figure 2-3). This reliance on vehicle integration will permit a minimal power, weight and size for a flight optimized Hydro-John System. Thus the vehicle liquid heat transport medium, part of the environmental control system, is used to provide:

1. A heat source to the still-pot to evaporate the water from the fecal slurry.
2. A heat source to warm the flush water and the rectal drying air flow.
3. A heat sink to condense both the potable water and flush water.

The vehicle environmental control system also provides a suction for cabin air flow to transport the feces stool, urine, and flush water in a zero gravity environment. The vehicle environmental control system air filter is used to prevent odors from entering the cabin atmosphere.

SECTION III

SUBSYSTEM DESCRIPTION

1.0 Hopper

1.1 Seat

The hopper seat is designed to index the subject over the fecal transport tube opening, separate the gluteal fold, and provide a seal between the seat and the subject. See Figure 2-1. The initial form of the seat was cast in plaster from the rectal area of an 80th percentile subject. This cast was then used as the seat for a laboratory breadboard unit which was successfully used by men in the 5th to 90th percentile size range. See Figure 3-1.

The hopper seat is formed from fiberglas with a white gel coat surface to prevent any possible skin irritation from the fiberglas. Finally, several coats of white lacquer paint were sprayed on the seat surface.

1.2 Air Heater

The air heater consists of three spine finned aluminum heat exchanger tubes mounted in a fiberglas duct molded beneath the seat. See Figure 3-2. When the seated subject seals the transport tube opening, cabin air is drawn through the heat exchanger where the air is warmed by the space vehicle liquid heat transport loop. The warmed air enters the seat transport tube through eight small holes in the tube. See Figures 3-1 and 3-3. The air holes are angled so that all the air streams impinge on the rectal area and promote drying after the cleansing cycle. An air flow of 25 ft.^{3}/min. appears adequate for rapid drying and feces transport.

1.3 An ultraviolet lamp is mounted in the hopper cover to provide an effective germicidal protection for the seat area. The 4 watt General Electric lamp generates a predominant wavelength of 2537 Angstroms. When the hopper cover is lifted, a hermetically sealed limit switch is activated and shuts off the germicidal lamp.

1.4 Nozzles

The water nozzles and the air indexing nozzles are incorporated in an annular plexiglas section immediately below the seat. A common water manifold provides eight water jets which impinge on and cleanse the rectal area and two water jets tangential to the inner diameter to cleanse the transport tube. Also, a pressurized gas manifold provides two gas jets which impinge on the rectal area so that the subject may index himself over the center of the transport tube. The gas pressure to the indexing jet is initially adjusted to a comfortable flow.

2.0 Transport Tube

The three inch internal diameter transport tube is a type 304 stainless steel flanged tube, coated internally with an approximately 0.001 inch thick layer of baked Teflon. The

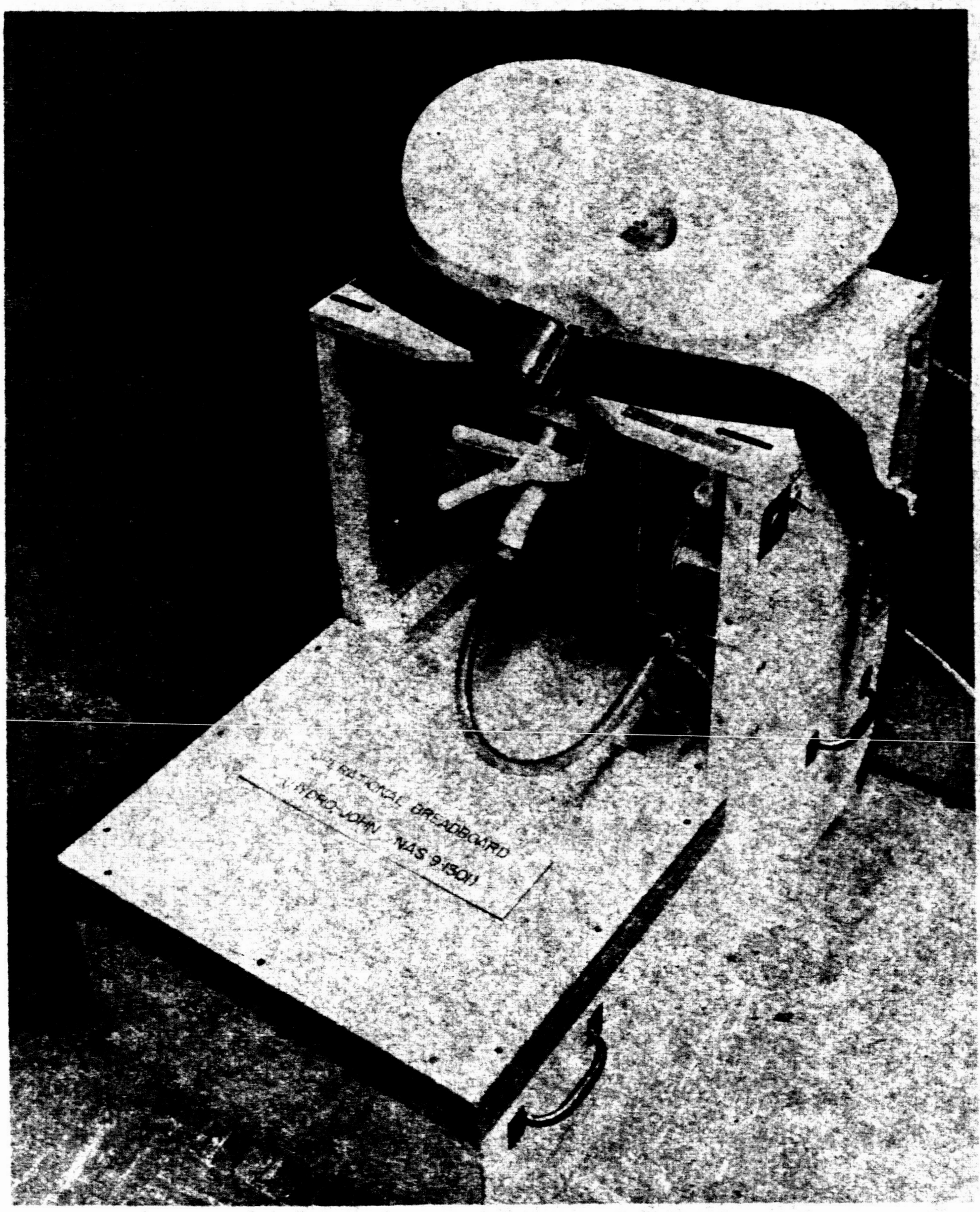


Figure 3-1. Operational Laboratory Breadboard

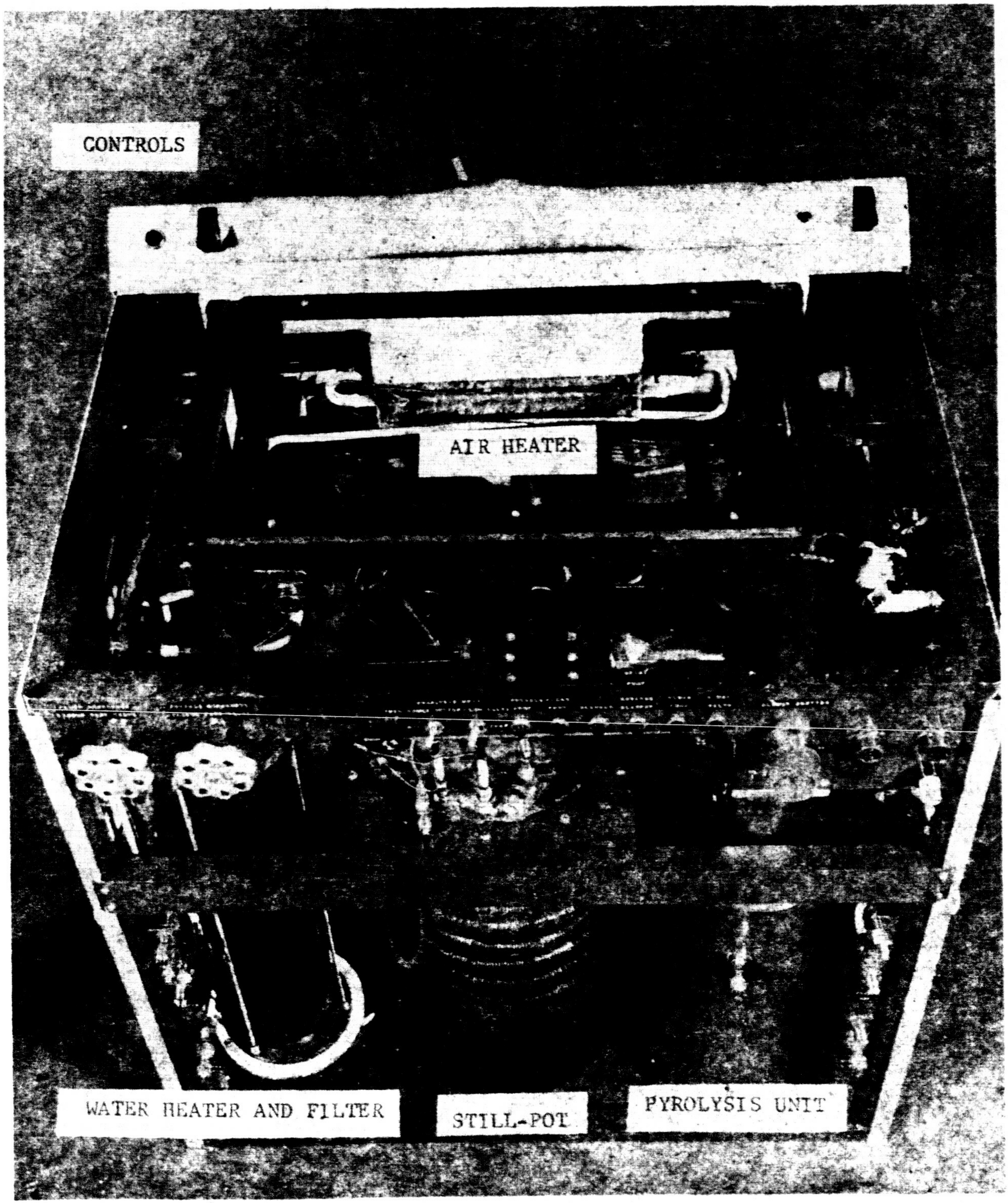


Figure 3-2. Engineering Prototype (Less Enclosure and Electronic Module)

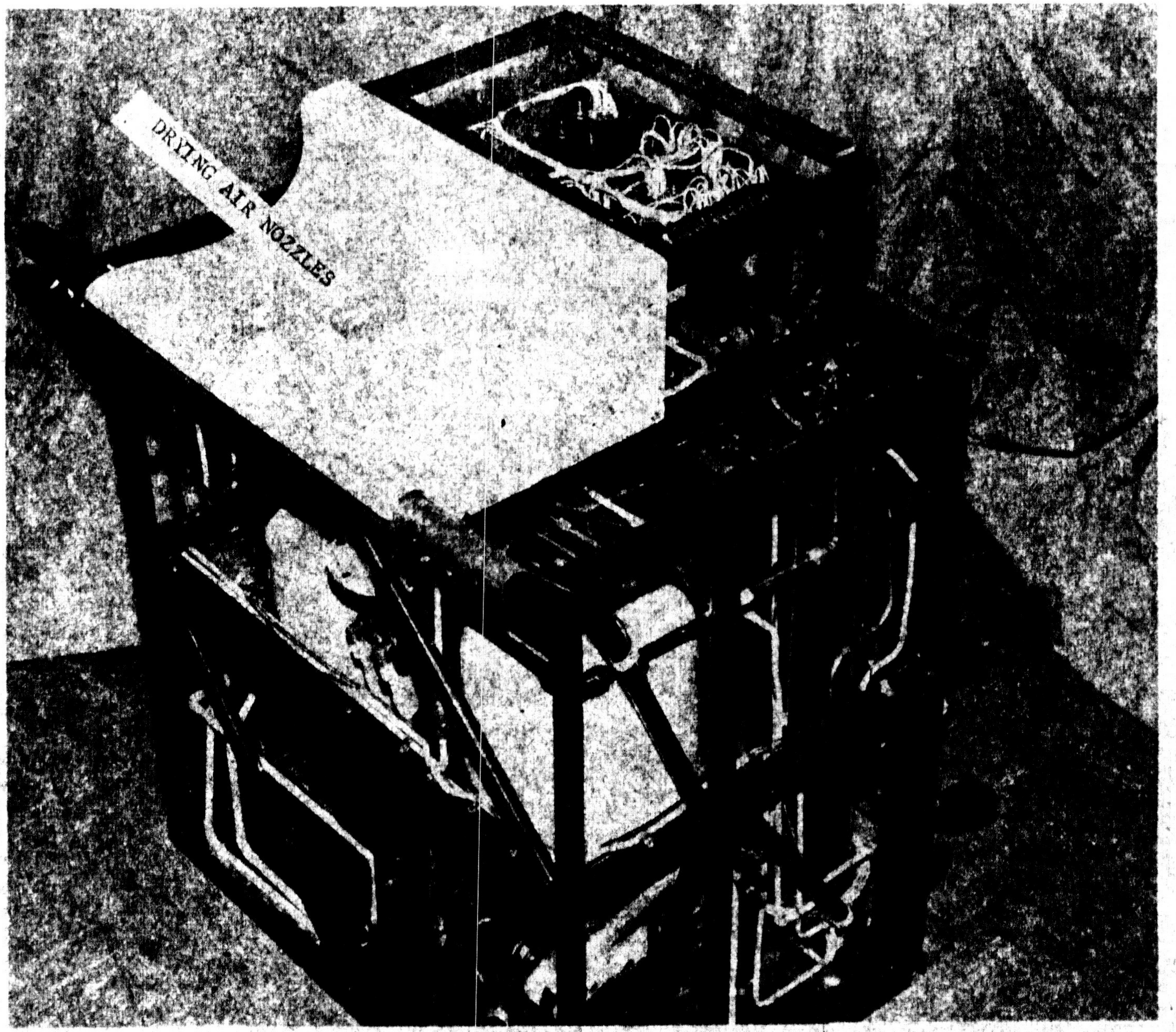


Figure 3-3. Engineering Prototype (Less Enclosure)

Teflon coat provides an essentially non-wettable surface which is easily cleaned by the water spray. At the base of the transport tube is a one inch diameter Teflon coated tube which is the outlet for the pump-blender section. See Figure 3-4.

3.0 Pump-Blender

The blender has four double edge blades, two blades sloping upward and two blades downward at approximately a 45 degree angle. See Figure 3-5. The blade edges are shaped so that as the blade cuts into the fecal solids, it also tends to pull the feces further into the blender. The blender blades are of type 304 stainless steel coated with approximately 0.001 inch thick baked Teflon film.

The pump consists of four vertical blades which, when rotated, centrifugally pump liquids. The rotor blades are of type 304 stainless steel coated with approximately 0.001 inch thick baked Teflon film. The pump and blender are mounted on a common shaft of type 304 stainless steel which is supported by two ball bearings.

A shaft seal isolates the bearings from the liquid being pumped. The bearings and seal are mounted in a plexiglas housing which also serves as the base for the pump-blender. See Figure 3-5.

3.1 Air Motor Drive

The pump-blender is driven by a direct coupled air motor. The pump-blender drive shaft is bored to a "D" shape and the shaft of the air motor is flattened and inserted into the pump-blender shaft. Thus a direct couple is accomplished without the need for shaft keyways and locking screws. The air motor is then mounted on the base of the pump-blender section. The air motor performance characteristics are given in Figure 3-6.

This 1.5 pound, Model 1AM, reversible air motor is manufactured by Gast Manufacturing Corp. and is equipped with an exhaust muffler.

4.0 Urinal

The urinal features an adjustable orifice and an internal water manifold with nozzles to cleanse the urinal and penis after micturition. See Figure 3-7. The urinal housing and water manifold are constructed of type 304 stainless steel and the removable cap and handles are constructed of anodized aluminum. Incorporated in each removable cap is a sliding seal to prevent water leakage, air vent holes to allow air to flow through the urinal (thus conveying the liquid in zero gravity), and a silicone rubber diaphragm. The diaphragm has a 3/4 inch diameter center hole which when stretched provides a larger hole over 1 1/2 inches in diameter. The diaphragm stretching action is accomplished by squeezing the handles which slide the cap over the urinal housing thus pulling and stretching the diaphragm over the housing. See Figure 3-7 and Figure 3-8. Releasing the handle tension permits the diaphragm to gently seal round the penis. The urinal cap with diaphragm and seal are removable so that each man may have his own diaphragm. Two flexible hoses are connected to the urinal; one provides a flow channel for the urine, flush water and air to the urine reservoir; the other line supplies the flush water to the urinal manifold.

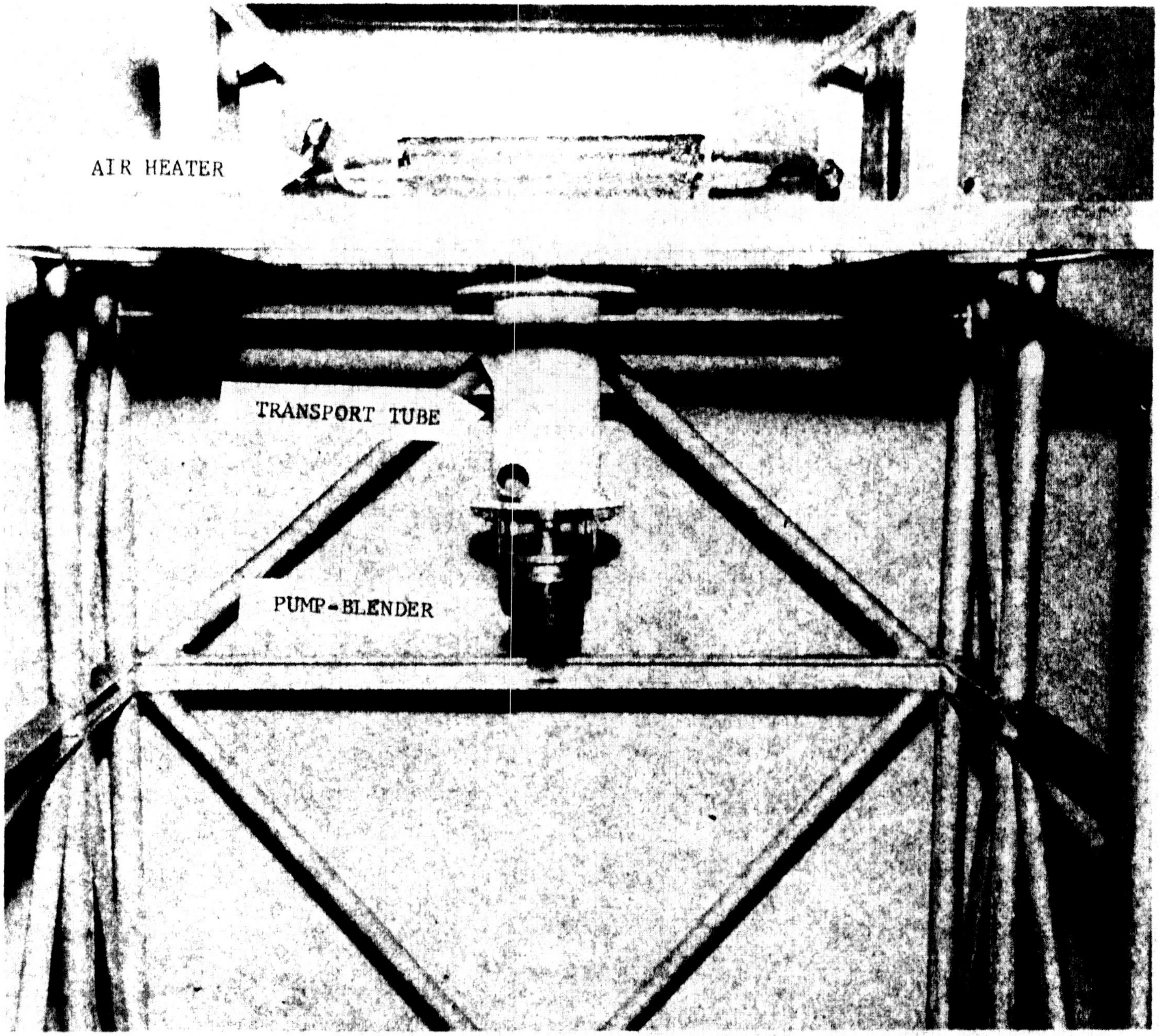


Figure 3-4. Engineering Prototype Structure (Rear View)

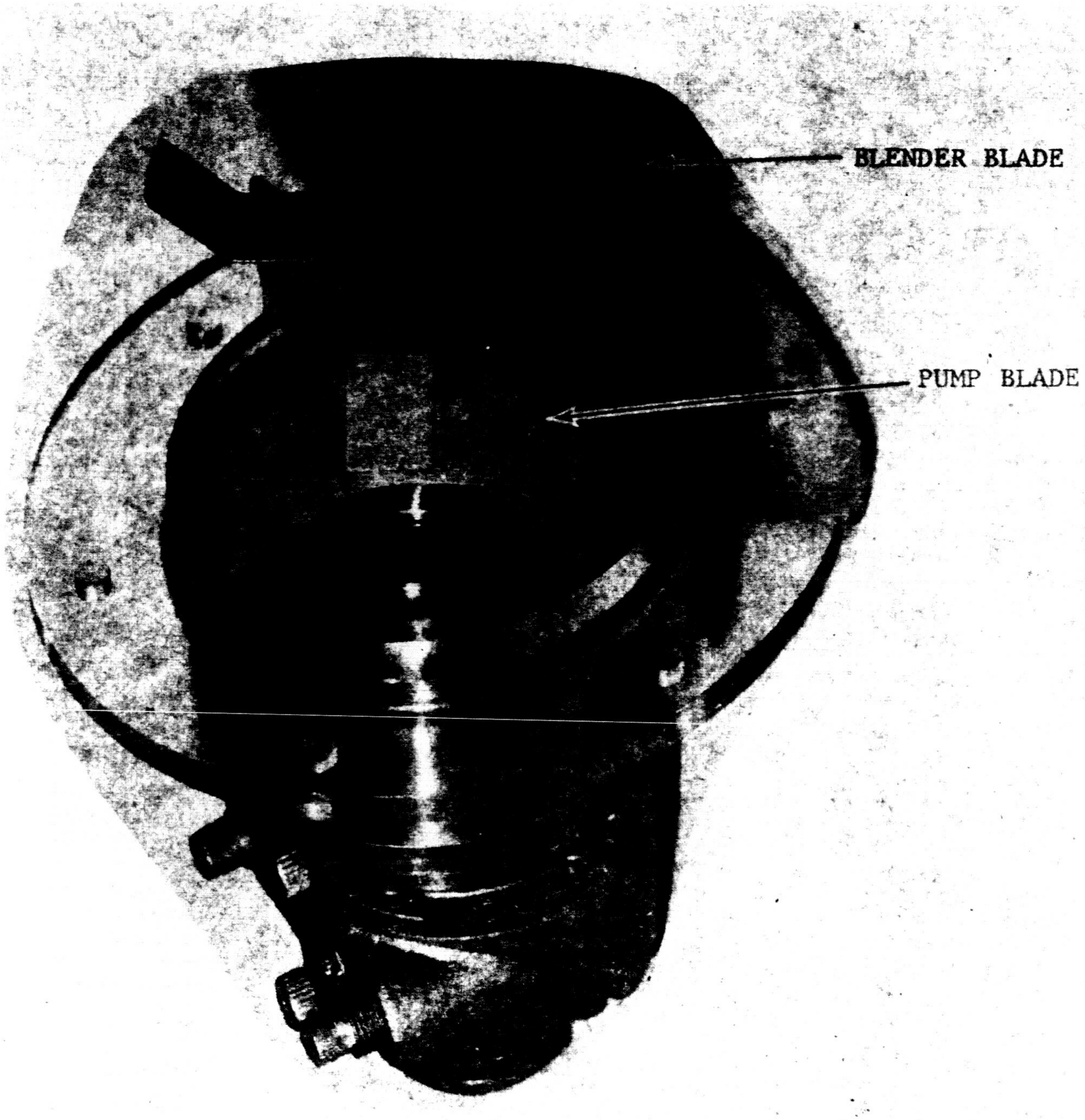
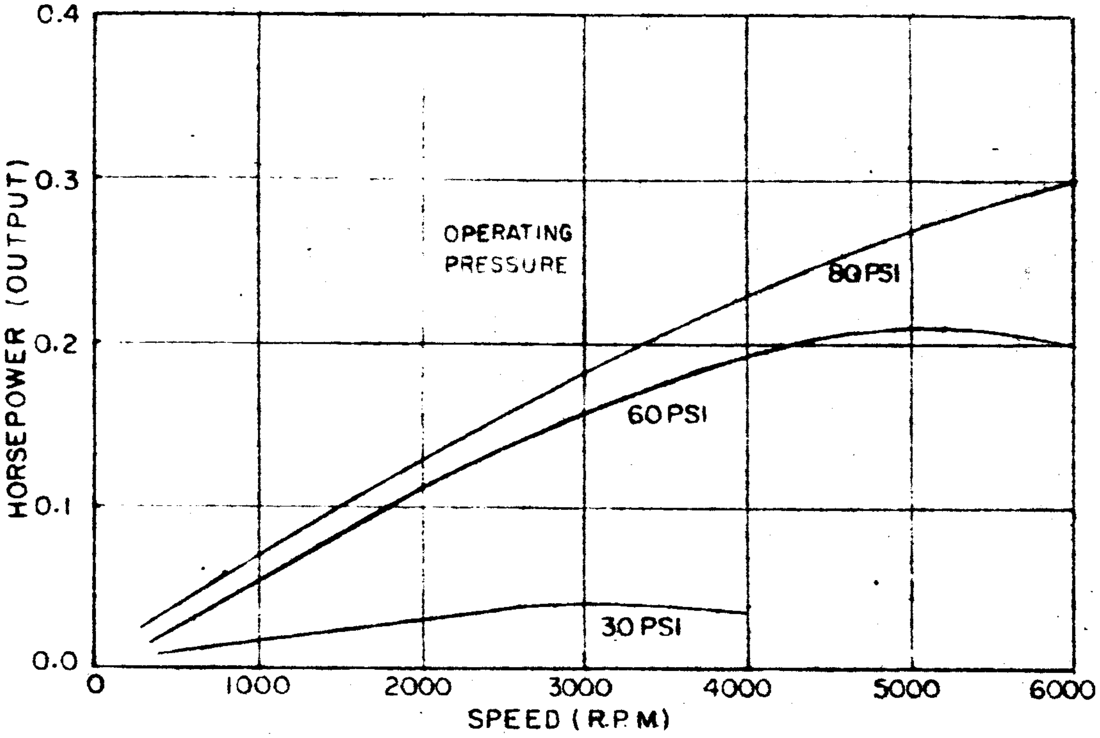


Figure 3-5. Pump-Blender



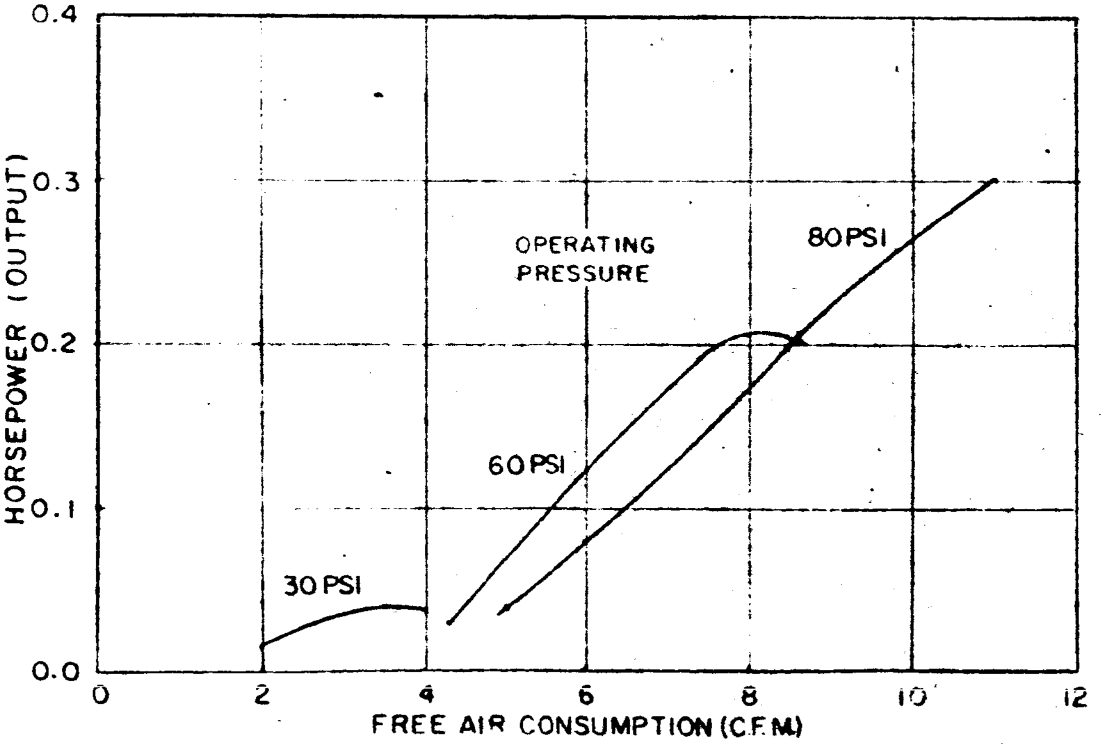


Figure 3-6. Air Motor Operational Characteristics (For Pump-Blender and Urine Pump)

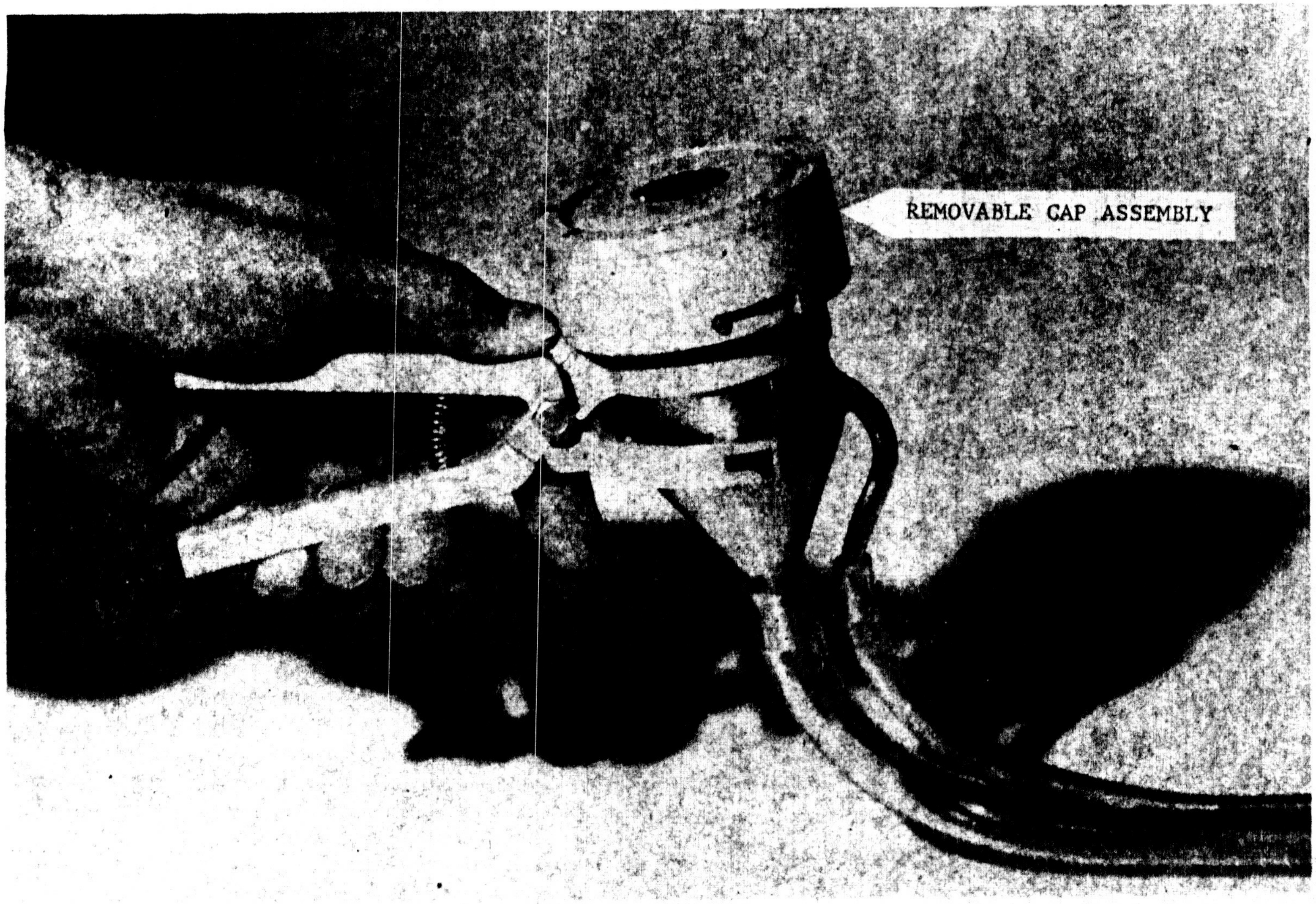


Figure 3-7. Urinal (Closed Position)

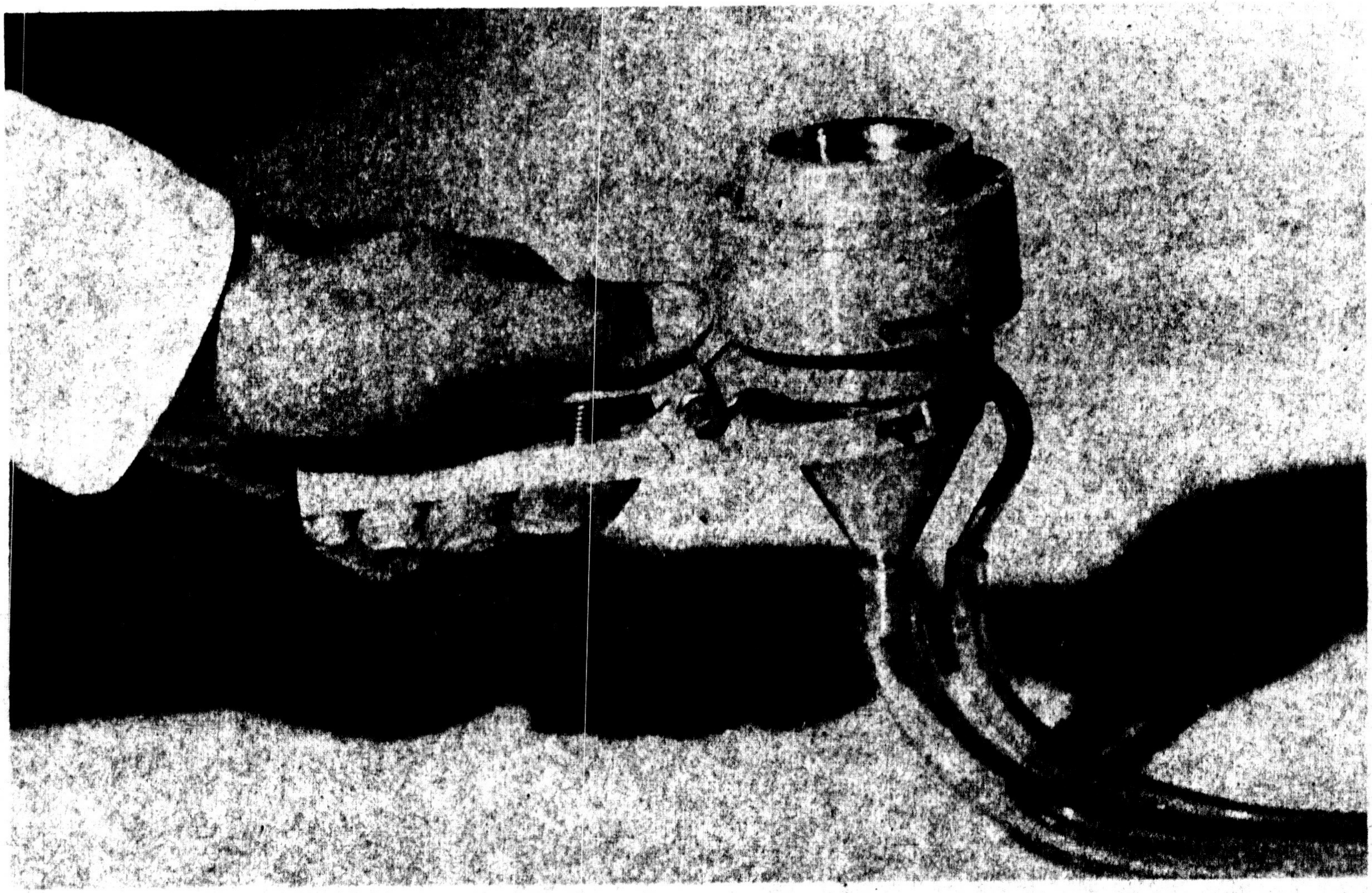


Figure 3-8. Urinal (Open Position)

5.0 Urine Reservoir

The urine, urinal flush water and transport air from the urinal enter through the top of the reservoir. The liquid adheres to the lower conical section of the reservoir while the air is separated and withdrawn from the top. See Figure 3-9. The reservoir has approximately 250 cubic inch volume. In zero gravity environments, the liquid should conform to a minimum energy configuration in the conical section of the reservoir as shown in Figure 3-10. The reservoir is constructed of type 304 stainless steel and is fabricated with a special furnace weld process. The base port of the reservoir is directly connected to a pump which removes the accumulated liquid (urine and flush water) during the initial part of the defecation flush cycle. See Figure 3-9.

5.1 Pump

The gear type pump is constructed of Delrin plastic and a stainless steel shafts. This model 3000 PN-2 pump manufactured by The Planet Products Corp. was modified with seals for internal vacuum service and a sprocket was mounted for chain drive. The pumps on the urine reservoir and flush water condenser are interchangeable. The operational characteristics of the pump are given in Figure 3-11.

6.0 8-Way Valve

The 8-way valve controls the fecal slurry flow to the still-pot, air flow through the still-pot, and water vapor flow from the still-pot. See Figure 3-12. The valve in the normal position permits the vapor from the still-pot to flow to the pyrolysis unit and flush water condenser. Also in this position the valve isolates the still-pot from the pump-blender and by-passes the air flow from the hopper. When the valve is activated during the flush cycle, the valve opens to the pump-blender so that the fecal slurry enters the still-pot. The activated valve also directs the air flow into the still-pot and out through another port in the 8-way valve, thus aiding the transportation of the slurry into the still-pot. The gas-liquid phases are separated by wettable surfaces, a porous Teflon barrier and a heating coil which vaporizes the liquid water. At the same time, both the pyrolysis unit and flush water condenser are isolated from the still-pot by the activated valve. The 8-way valve has large orifice ports for minimum flow restriction. Construction is such that a vacuum tight seal is provided when each port is closed.

The valve consists of a type 304 stainless steel gate which slides between Teflon seals. Each Teflon seal is pressed against the gate by an O-ring seal. See Figure 3-13. The valve housing is constructed of plexiglas with alodined aluminum brackets. The gate is activated by a Model AV-R Tom Thumb pneumatic cylinder with a 2 inch stroke. A gas pressure of 100 psig is required to activate the valve.

7.0 Still-Pot

The still-pot receives the fecal slurry from the pump-blender and supplies heat to vaporize the water. The resulting vapor flows to the pyrolysis unit and flush water condenser. The fecal and urine solids remain in the still-pot. The still-pot has an effective volume of over 1100 cubic inches. The still-pot is constructed with a cylindrical plexiglas

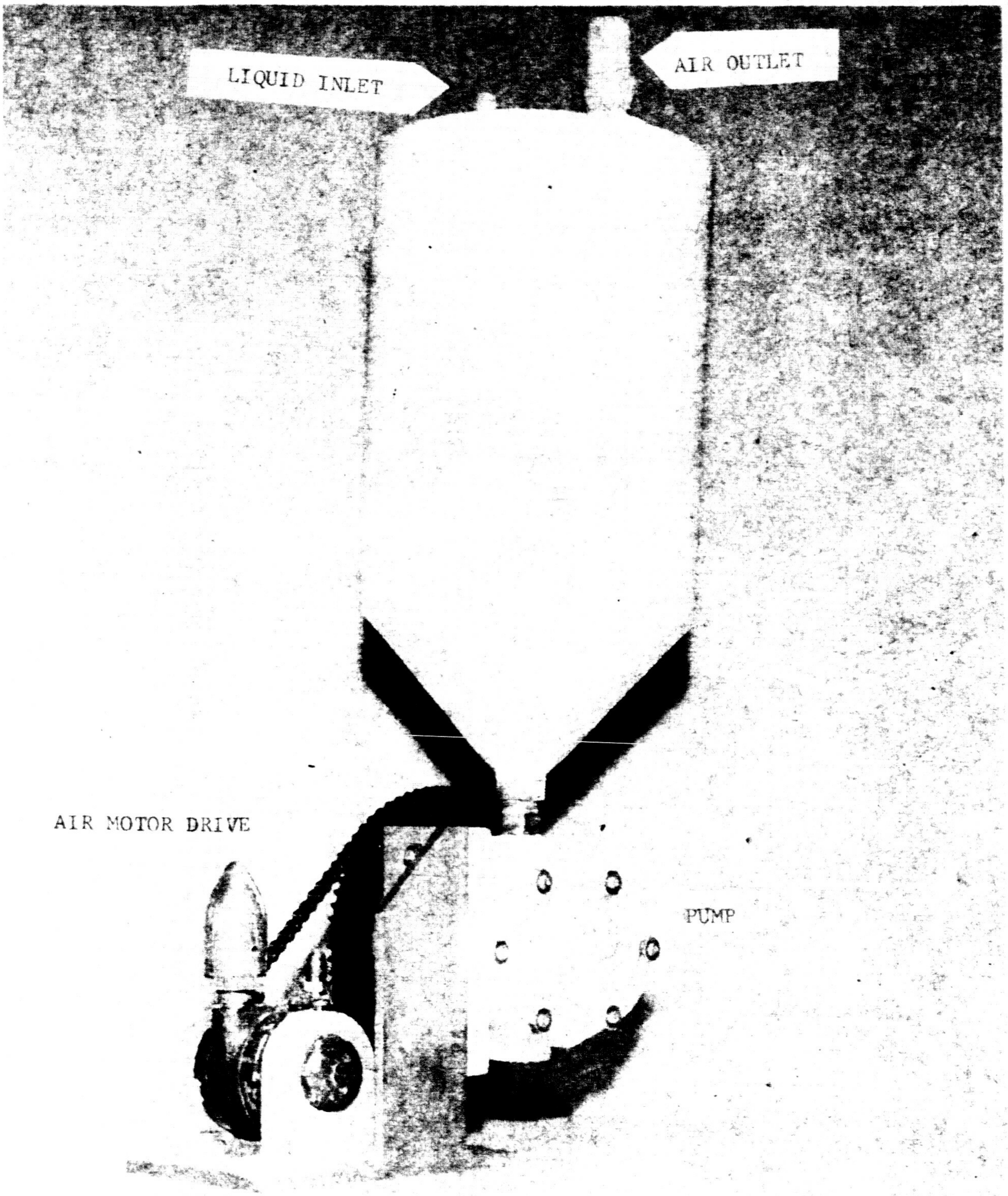


Figure 3-9. Urine Reservoir With Pump

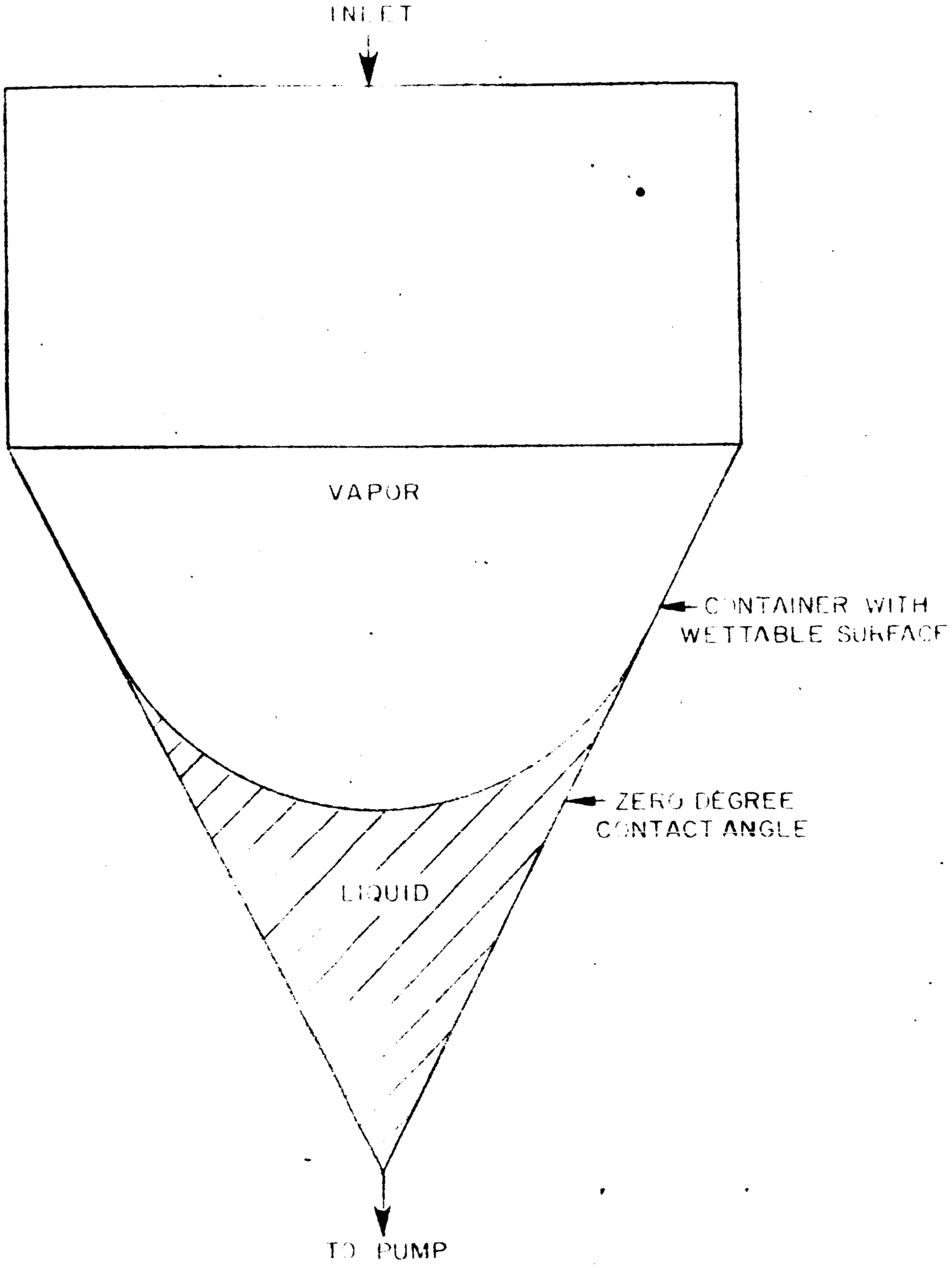


Figure 3-10. Minimum Energy Configuration for Conical Containers

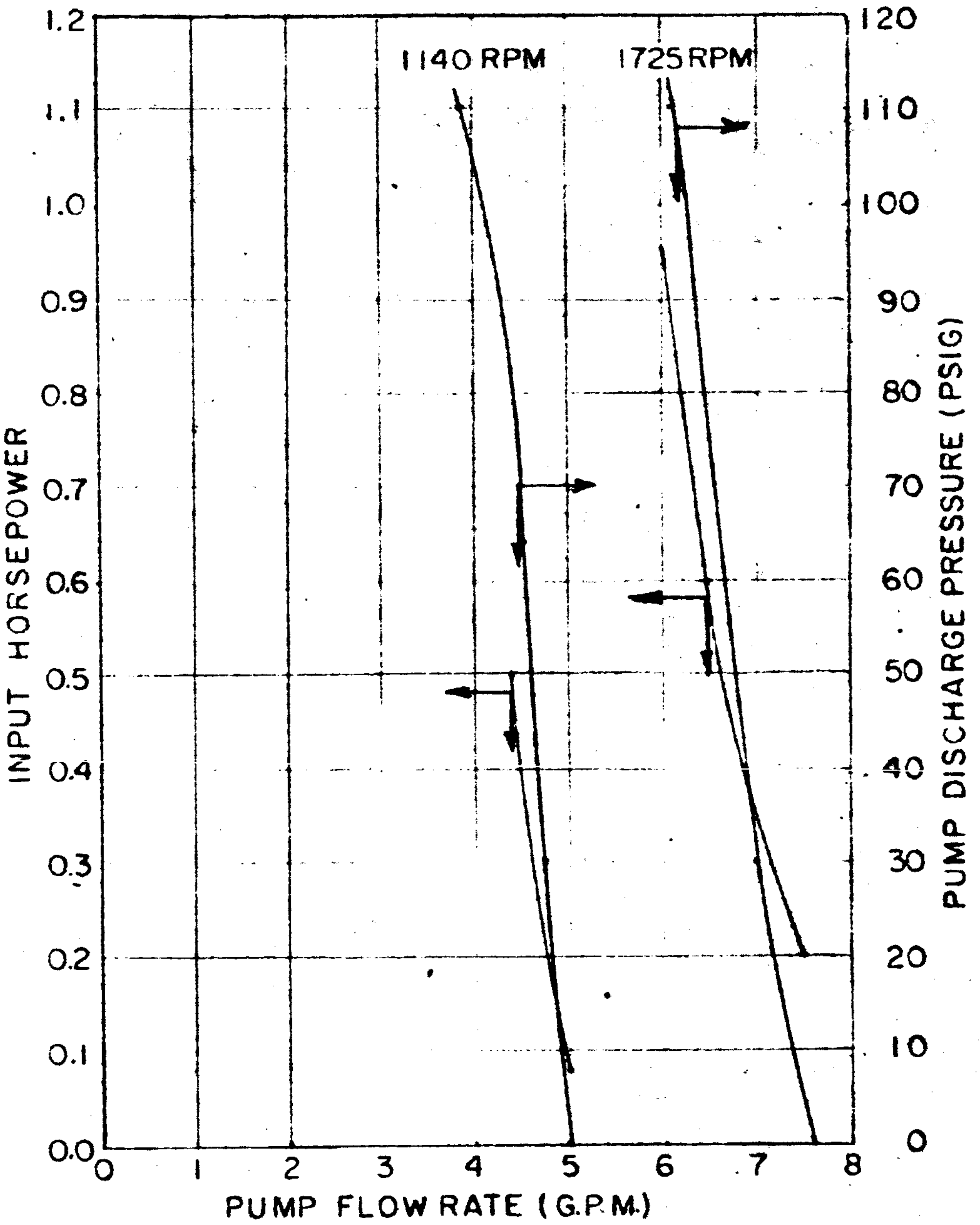


Figure 3-11. Pump Operational Characteristics (For Urine and Flush Water)

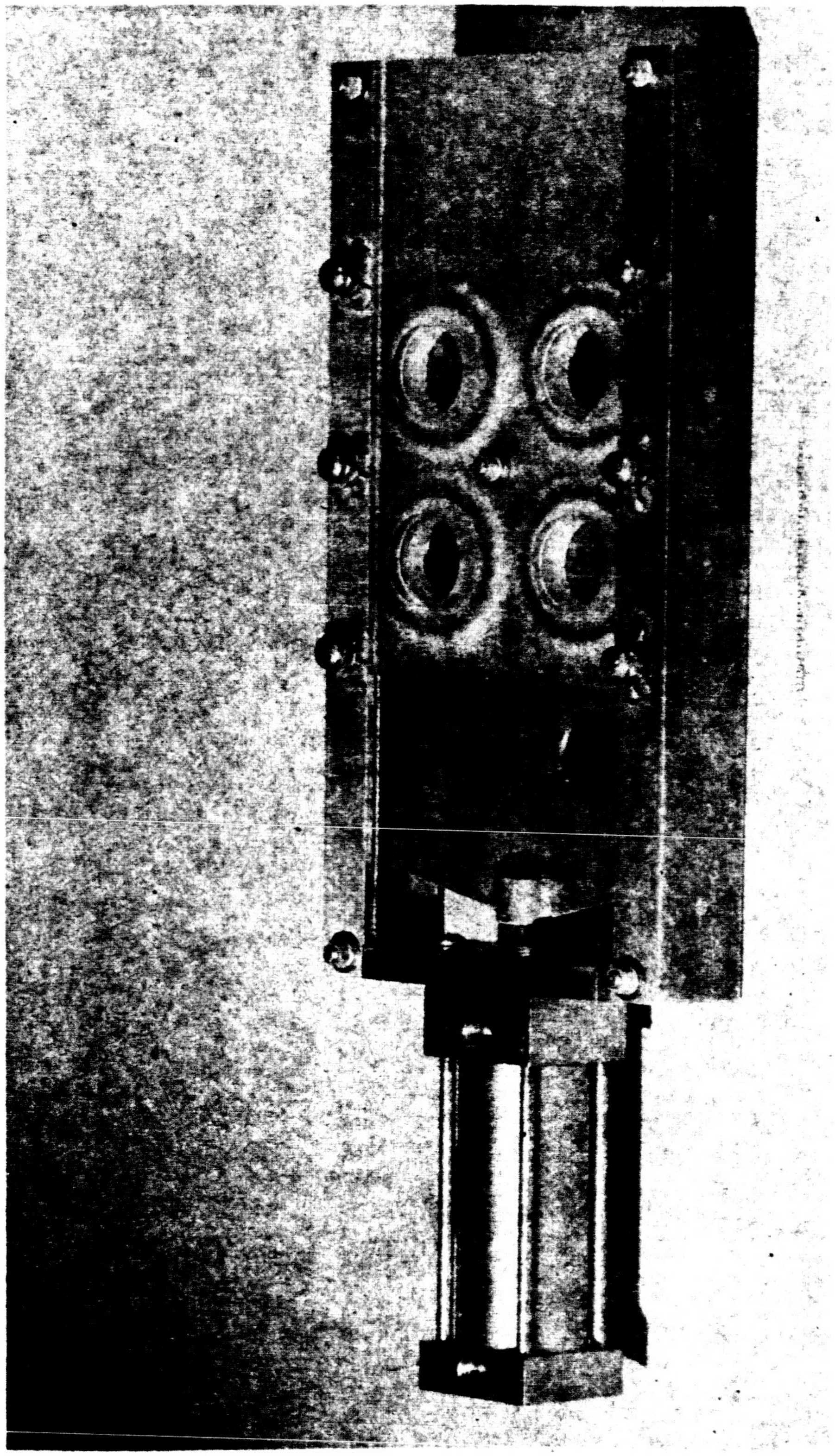


Figure 3-12. 8-Way Valve

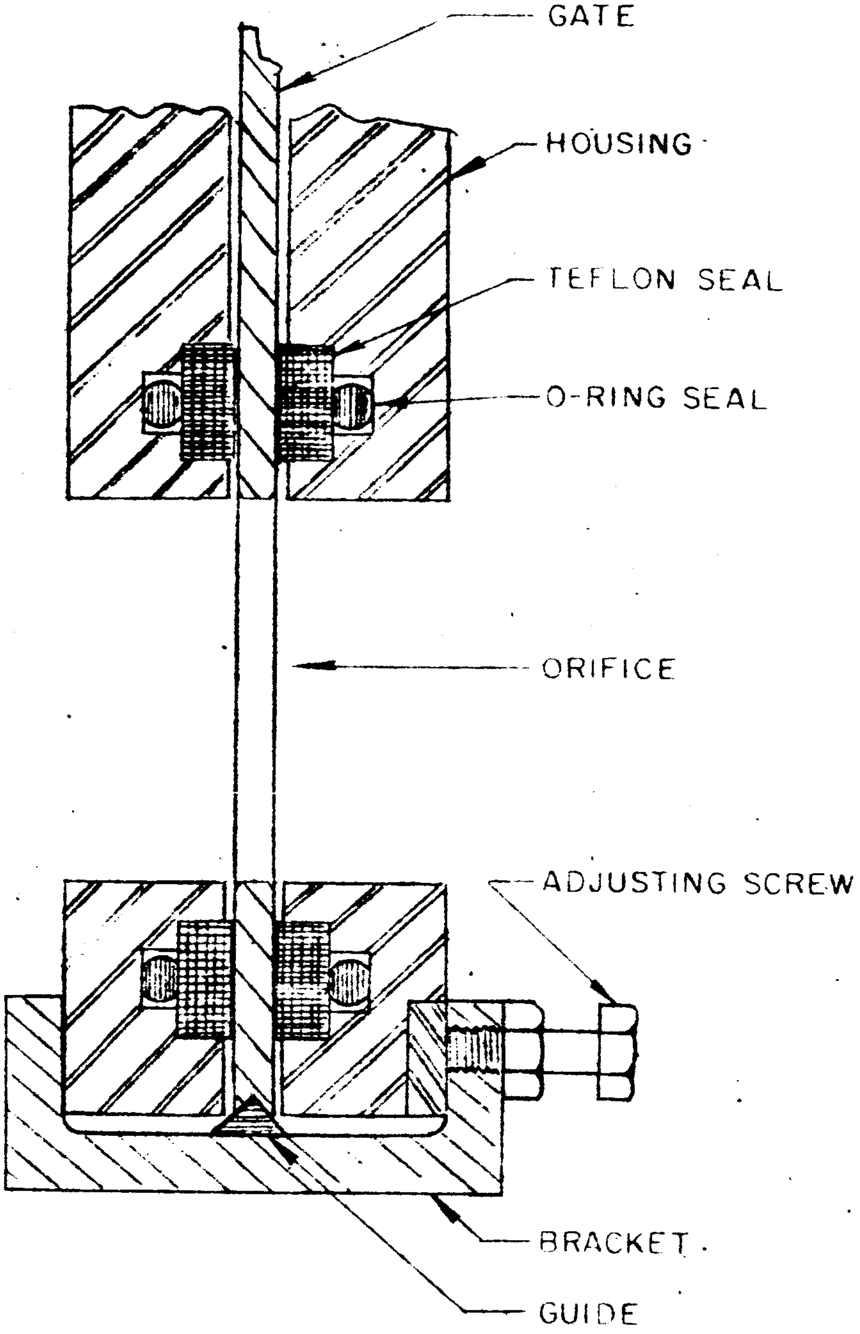


Figure 3-13. 8-Way Valve Sectional View

housing and removable top cover. Attached internally to the lid are a heating coil, a feces separator, and a liquid barrier. See Figure 3-14.

7.1 Heating Coil

The heating coil, all of type 304 stainless steel construction consists of a 1/4 inch outside diameter tube with one inch diameter fins furnace welded 8 per inch along the tube. The heating coil has approximately 20 square feet of heat exchange surface area.

7.2 Fecal Separator

The fecal separator consists of a perforated type 304 stainless steel cylinder through which the liquid portion of the slurry passes to contact the heating coil. The separator thus entraps the large fecal particles 0.156 inches or more in diameter and prevents them from curtailing the heat exchange efficiency of the heating coil. Fecal particles as large as 0.5 inches in diameter may be found leaving the pump-blender. The separator cylinder also provides a structural column to support the still-pot ends when the vessel is subjected to low internal pressure.

7.3 Liquid Barrier

The liquid barrier consists of a rigid porous Teflon membrane which permits the vapor from the still-pot to pass to the pyrolysis unit and flush water condenser but does not permit liquid to excape from the still-pot. However, during transient periods when ambient temperature liquids enter the still pot, a small portion of the vapor may condense after the barrier and form a pool of liquid on the far side of the membrane. After sufficient operation of the unit, the superheat of the vapor should re-evaporate this liquid. However, if some liquid were conveyed to the pyrolysis unit, it would be revaporized in the pyrolysis heat exchanger prior to entering the pyrolysis chamber. The condensation in the connecting line may also be minimized by the addition of insulation. The barrier should assure that contaminated liquids do not escape the still-pot and enter other parts of the system. A stainless steel wool sponge prior to the membrane should remove sufficient solids so that the membrane is not contaminated during the 14 day mission.

7.4 Air Bleed

A small air bleed of 30 cc per minute is metered into the top of the still-pot from the atmosphere through a needle valve. The oxygen in the air bleed is used to oxidize the water vapor impurities in the pyrolysis unit. In an actual vehicle with a pure oxygen (5 psia) atmosphere, only 6 cc per minute is required. This amounts to approximately 0.03 pound of oxygen per day. The vented gas is also saturated with water vapor, consequently approximately 0.188 pounds of water is lost per day.

8.0 Flow Control Valves

The water vapor flow from the still-pot is divided so that 1.5 pounds per hour flows to the flush water condenser and 0.5 pounds per hour flows to the pyrolysis unit. The vapor

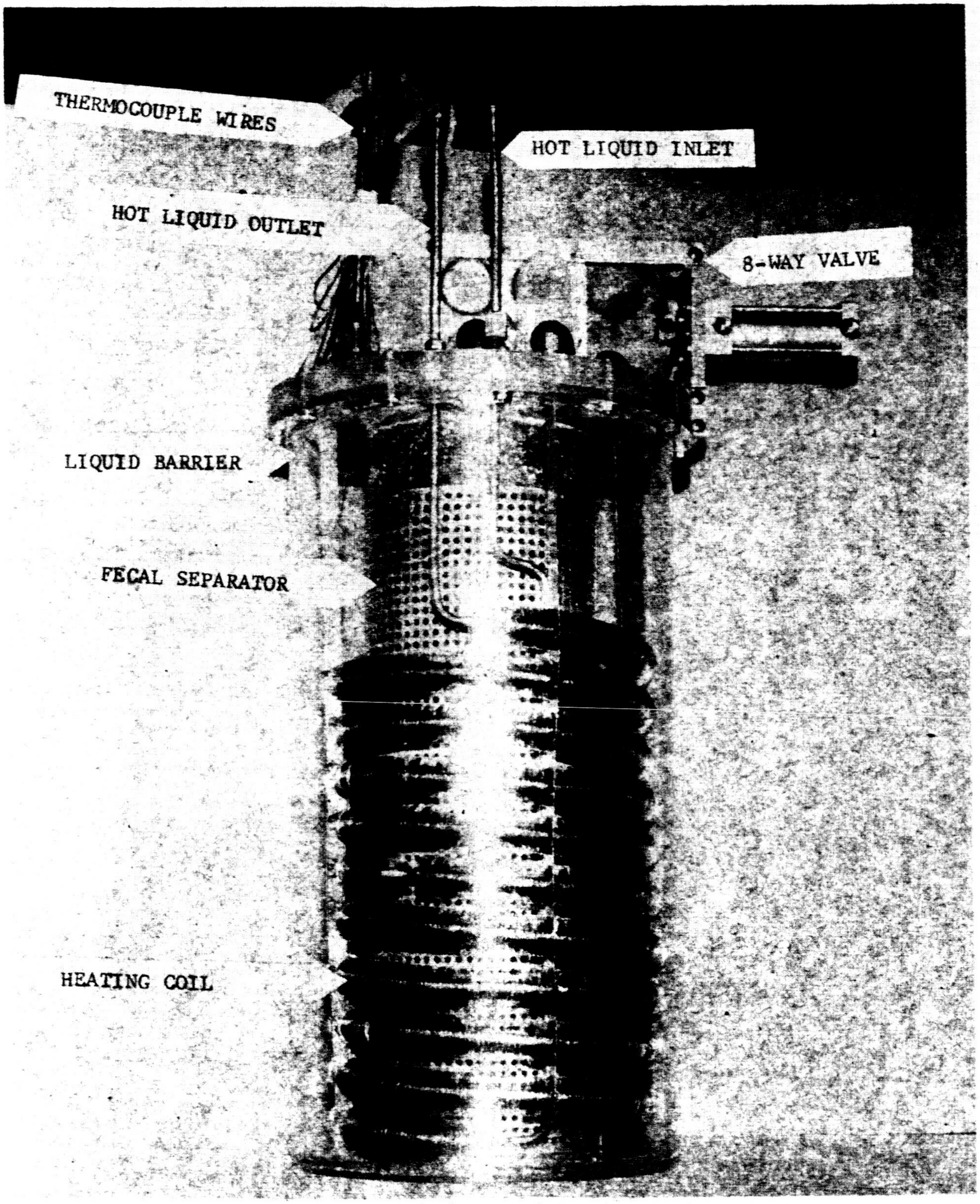


Figure 3-14. Still-Pot and 8-Way Valve

flow rate is controlled by the pressure differential between the vapor in the still-pot, and in the condensers, and by the pressure drop in the connecting lines and equipment.

The pyrolysis unit and potable water condenser induce more pressure drop to the vapor flow than does the flush water condenser. Consequently, a flow restriction assures the desired division of vapor flow. The flow restriction is a ball valve of Poly Vinyl Chloride construction having a 13/16 inch diameter orifice which is manually adjusted to provide the desired restriction.

9.0 Flush Water Condenser

The flush water condenser receives and condenses 1.5 pounds per hour of water vapor from the still-pot. The walls of the condenser are cooled by a flow of coolant liquid through a tube coil welded to the exterior of the condenser. The coolant removes thermal energy from the water vapor thus causing the vapor to condense. The condenser is constructed of type 304 stainless steel which is fabricated with stainless steel welds. See Figure 3-15. The condenser has an internal volume of over 370 cubic inches and is of a cylindrical shape with a flat top and conical base. The entire condenser is encased with a 1/2 inch layer of polyurethane insulation. In a zero gravity environment, the condensed water should conform to a minimum energy configuration in the conical section of the condenser so that the liquid may be drawn off by a pump connected to the apex of the cone.

9.1 Pump

The flush water pump removes water from the condenser; this liquid is forced through water nozzles for flushing the urinal and hopper. The pump is interchangeable with the urine reservoir pump. The pump is chain driven from an air motor model 2AM manufactured by the Gast Manufacturing Corp. The performance characteristics of the air motor are given in Figure 3-16 and the pump performance characteristics are given in Figure 3-11.

9.2 Level Indicator

A flush water level indicator is used to determine if sufficient water remains in the condenser to provide one flush. The indicator consists of a thermally activated switch which closes at approximately 80°F. When sufficient water remains in the condenser for one flush, the thermoswitch is submerged in the chilled 40-60°F water, thus the switch is open. As the water level drops during the next flush cycle, the thermoswitch is exposed to the incoming water vapor at 100-120°F. Thus the switch closes and a red light is energized, warning that sufficient water is not available for another flush. As more water condenses the water level rises and the thermoswitch opens, the red light is de-energized and another flush cycle may be initiated. The position of the thermoswitch is adjustable for different flush water levels. The level indicator is also usable in a zero gravity environment since the water is retained in nearly the same position as in normal gravity by the conical shape of the container.

10.0 Water Heater and Filter

The water from the condenser is pumped through the spray nozzles and into direct contact with the subject. Consequently, for maximum comfort and acceptability, the flush water

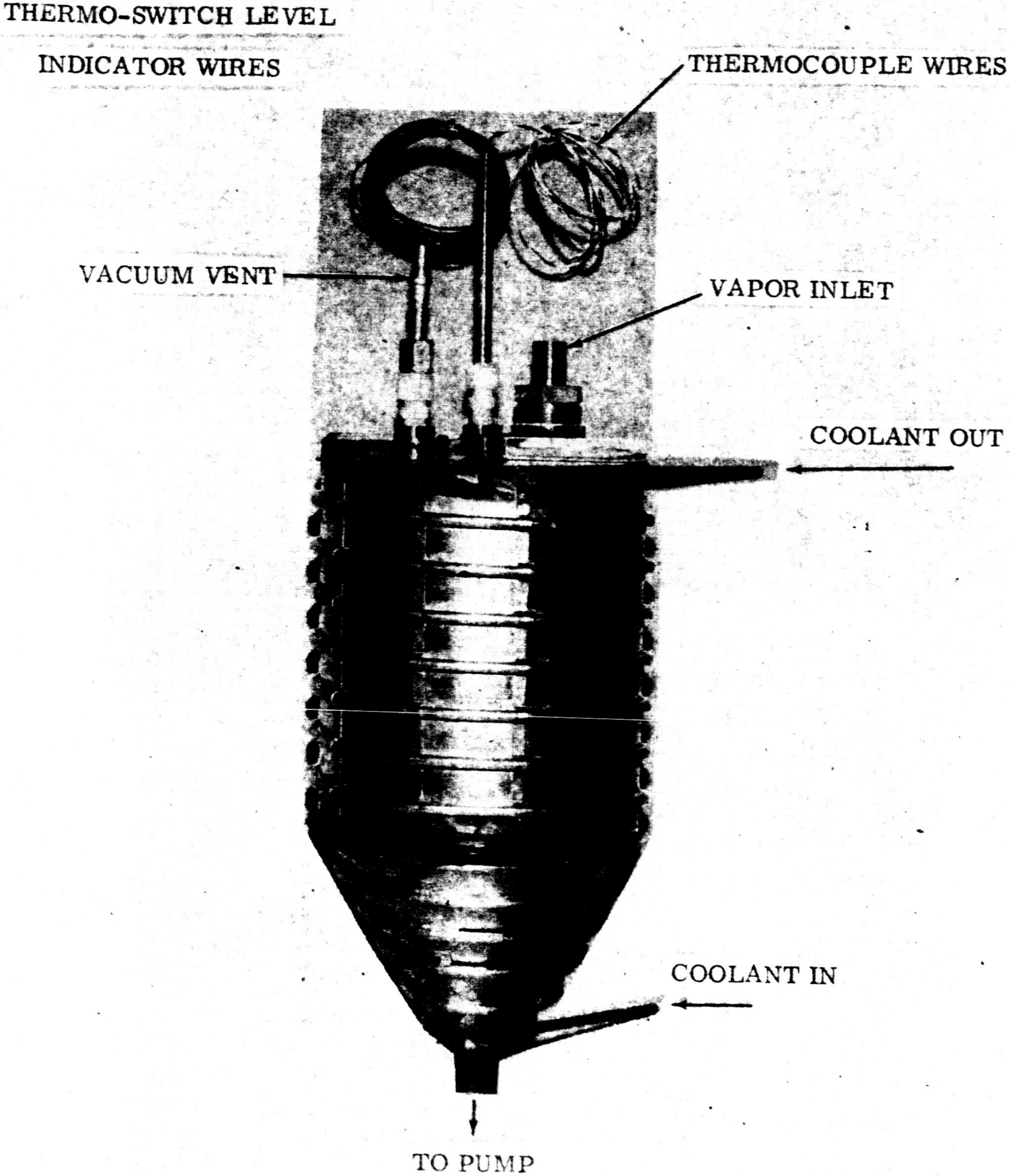


Figure 3-15. Flush Water Condenser

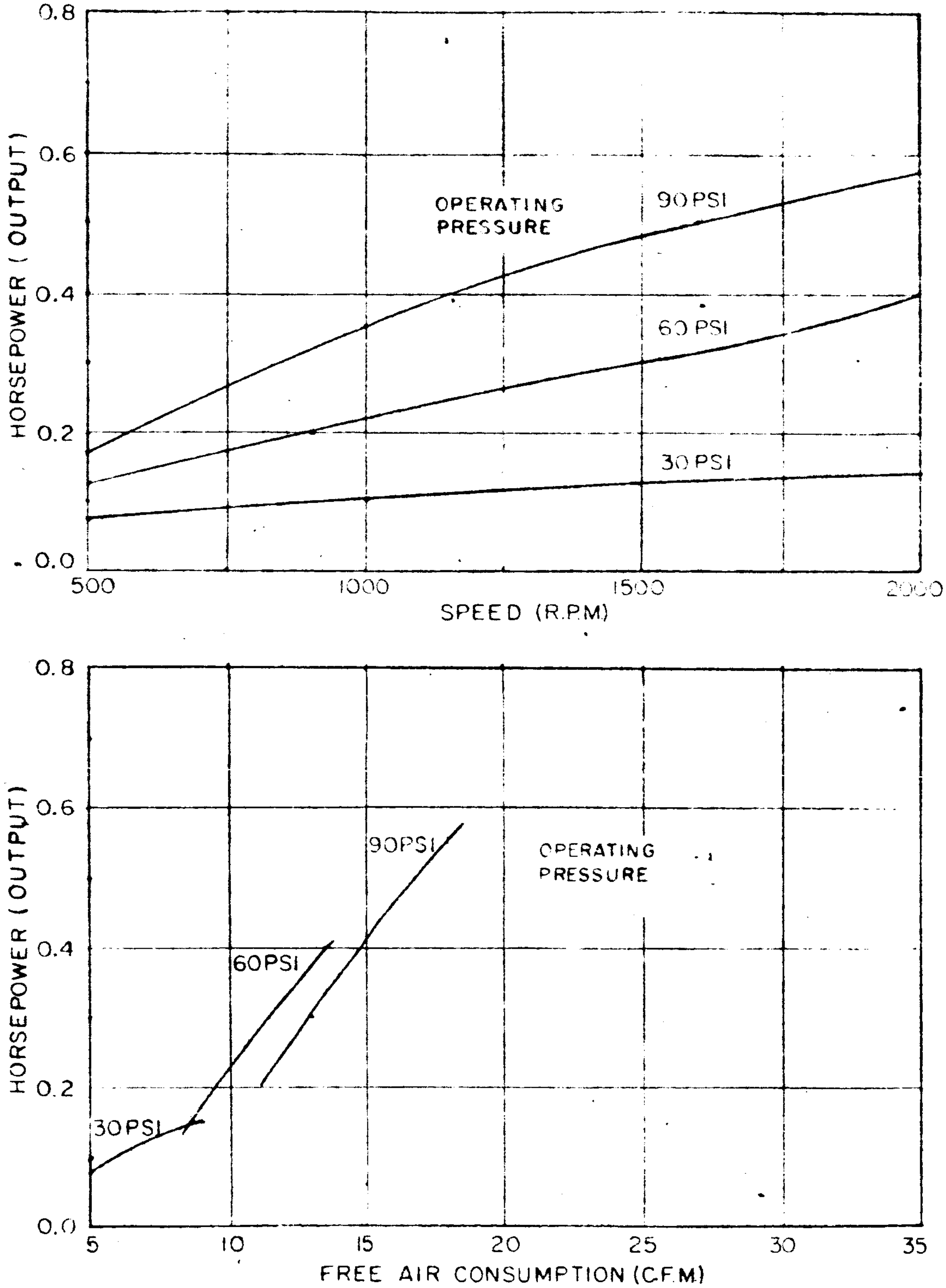


Figure 3-16. Air Motor Operational Characteristics (For Flush Water Pump)

is heated to about 100^{o}F. The heater coil is of type 304 stainless steel of similar construction as that of the heating coil in the still-pot. A small amount of organics are carried in the vapor from the still-pot to the flush water condenser. These organics are removed by filtration through activated charcoal which is contained in the water heater. The warm temperature of the filter inhibits the adsorption rate of the charcoal; however, sufficient material is available to negate the effect. Approximately 2 pounds of activated charcoal are contained in the filter. The heater and filter are contained in the same housing which is constructed of plexiglas with screens at each water flow port to prevent the fine charcoal granuals from escaping the filter housing. See Figure 3-2.

11.0 Pyrolysis Unit

Approximately 25% of the water vapor (0.5 lbs/hr) and a small amount of oxygen from the still-pot enters the pyrolysis unit where it is heated to approximately 1800^{o}F in the presence of a platinum catalyst. The water vapor impurities are thereby oxidized to non-condensables and removed from the system through a vacuum vent in the potable water condenser. The heated vapor leaving the pyrolysis chamber is in counter-flow heat exchange contact with the cooler incoming vapor, thus the vapor leaving the unit transfers heat to the vapor entering the unit. The heat exchange therefore reduces the energy lost in the exiting vapor flow and subsequently reduces the power required by the pyrolysis unit.

The heat exchanger is conservatively designed with an 81 percent effectiveness and a heat exchange surface area of 76 square inches. The overall heat transfer coefficient is 3 BTU hr-ft^2-F^o and the additional heat required by the vapor entering the pyrolysis chamber is reduced to 37 watts.

The present unit requires 7.5 amperes and 20 volts for a power requirement of 150 watts. The majority of the power is expended in radiation and conduction heat lost through the pyrolysis insulation jacket. The insulation jacket is a double wall annular shape which contains multi-layers of tantalum foil and "Fiberfrax" and is evacuated to less than 10 microns absolute pressure to prevent convection heat loss. See Figure 3-17 for the cut-away assembly drawing. The pyrolysis unit is constructed of a special type 310 stainless steel which provides great strength even at the elevated operating temperature. Internal parts are constructed of ceramic material which is used to encapsulate and isolate the pyrolysis chamber. A platinum wire heater provides the thermal energy and a platinum gauze provides the catalyst for the pyrolysis reaction. A chromel-alumel thermocouple is inserted in the pyrolysis chamber to monitor the operating temperature as shown in Figure 3-18. The overall power requirement for the unit may be reduced to 50 watts by a more sophisticated insulating jacket produced by Linde Co. and an additional vapor heat exchanger surface area. Of the 50 watts expended, 13 watts are for heat exchanger inefficiencies, and the remainder is for insulating jacket losses.

12.0 Potable Water Condenser

The potable water condenser receives and condenses 0.5 pounds per hour of water vapor from the pyrolysis unit. This condenser, although physically smaller, is of the same

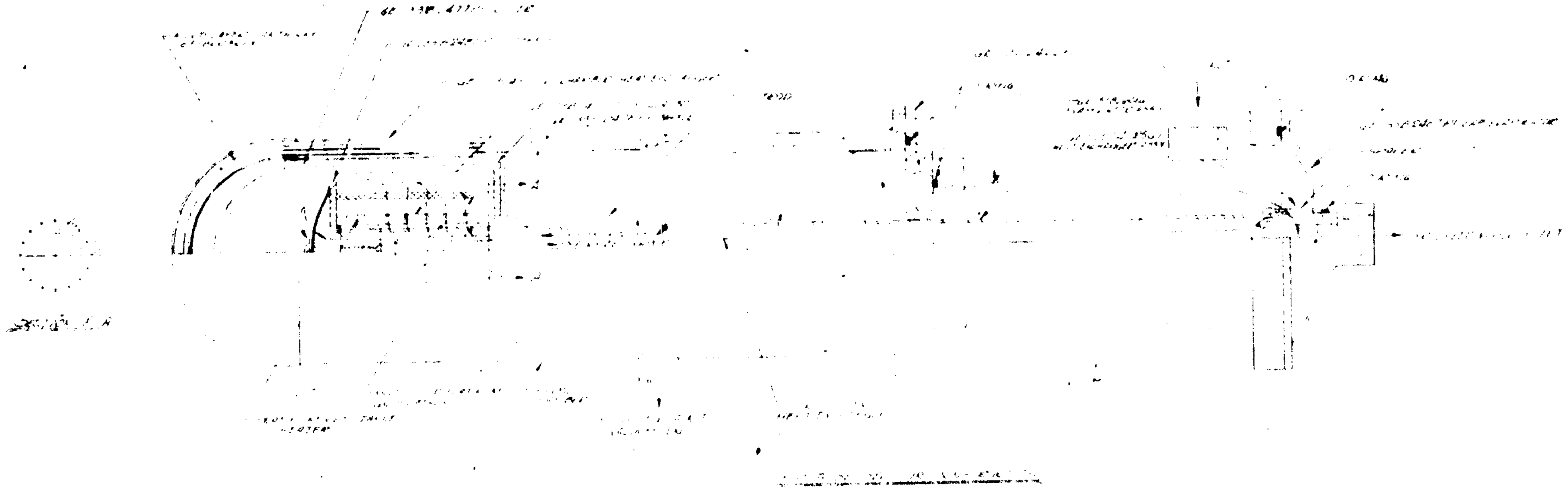


Figure 3-17. Urine Pyrolyzer Layout

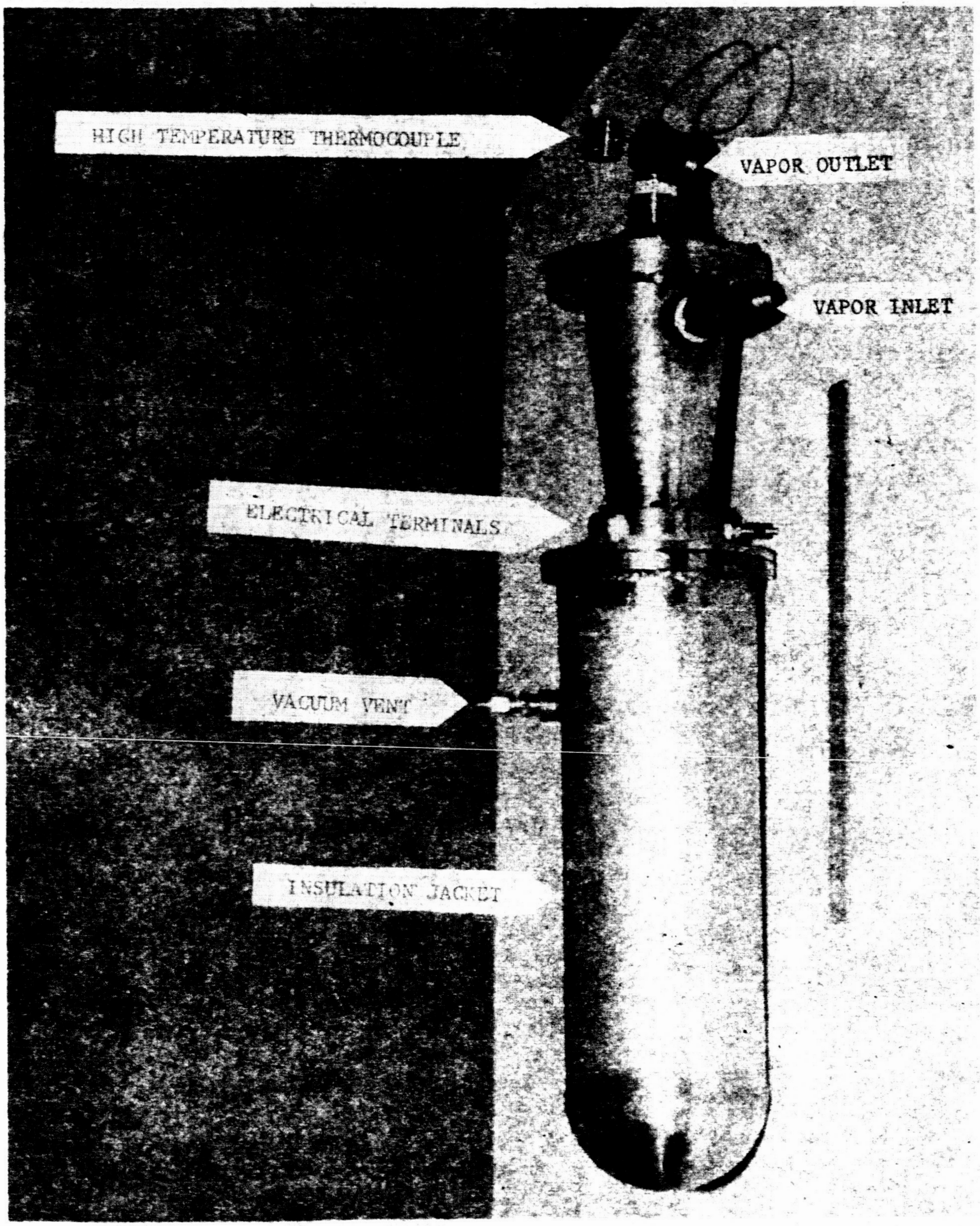


Figure 3-18. Pyrolysis Unit

construction as the flush water condenser. The condenser has an internal volume of over 25 cubic inches and is of a conical shape with a flat top. The entire condenser is encased with a 1/2 inch layer of polyurethane insulation. In a zero gravity environment the condenser water should conform to a minimum energy configuration in the conical section of the condenser so that the liquid may be drawn off by a pump connected to the apex of the cone. See Figure 3-19.

12.1 Potable Water Pump

The potable water pump removes water from the condenser four times an hour for storage in an external potable water storage container. The piston type pump is constructed of plexiglas with dual O-ring seals on the piston. The 1-5/8 inch diameter piston is powered by a model AV-R Tom Thumb pneumatic cylinder with a 2 inch stroke (same as used on the 8-way valve).

13.0 Controls

All controls are electrical or electro-pneumatic.

13.1 Control Panel

The main control module is easily removed from the rear of the structure as shown in Figure 3-20. On this panel are mounted:

a. Three Reset Timers, 2 for the flush cycle and 1 for the urinal rinse cycle.

b. One Continuous Timer, for the flush water pump cycle.

c. Four Relays, to isolate sections of the circuit which have dual functions.

d. Two Latching Relays to provide push button control of the flush and urinal rinse cycles.

e. A Ballast and Starter for the ultraviolet germicidal lamp.

All these controls are operated by 115 VAC, 60 cycle current.

13.2 Solenoid Valves

There are a total of ten solenoids activated valves in the system, all of which utilize 115 VAC, 60 cycle current.

a. One 5-Way Gas Valve for controlling the rotation and reverse rotation of the pump-blender air motor.

b. Two 4-Way Gas Valves for the operation of the 8-way valve pneumatic cylinder and the pyrolysis unit shut-off valve.

c. Two 3-Way Gas Valves for the operation of the pneumatic cylinder utilized on the potable water pump.

d. One 1/4 Inch Orifice 2-Way Gas Valve for the operation of the flush water pump air motor.

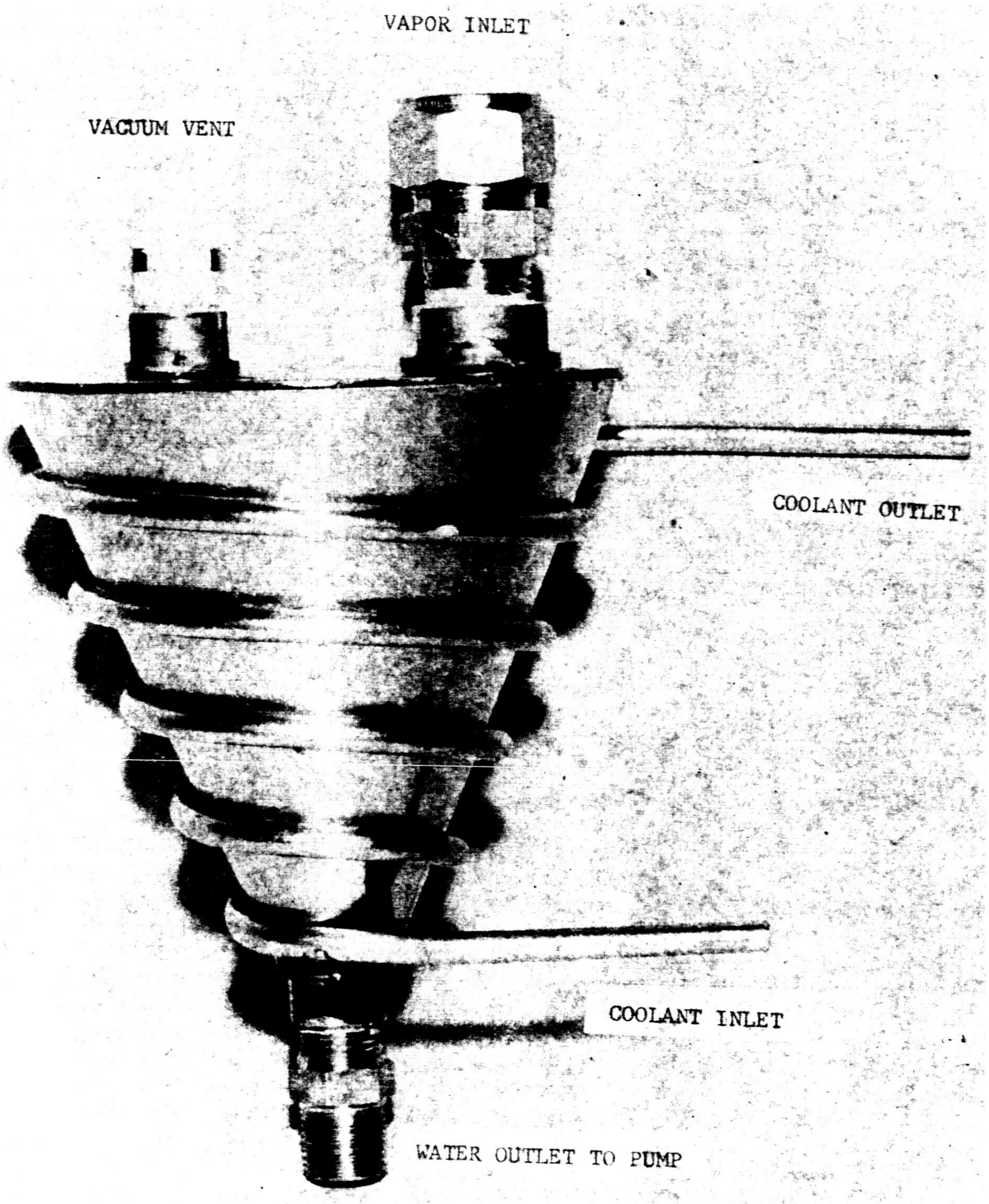


Figure 3-19. Potable Water Condenser

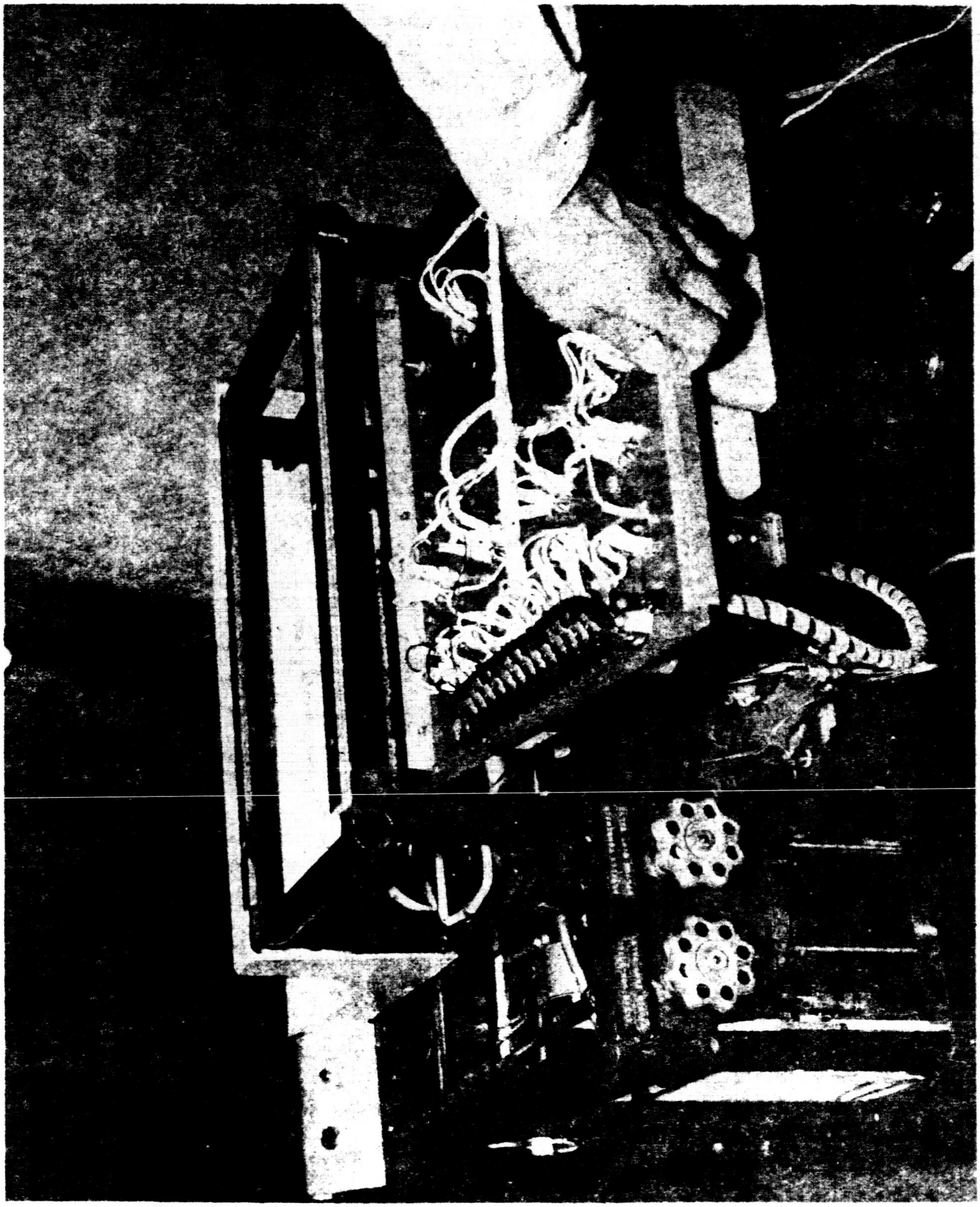


Figure 3-20. Electrical Control Module

e. Two 1/8 Inch Orifice 2-Way Gas Valves for the operation of the urine pump air motor and for the hopper indexing jet.

f. One 3/16 Inch Orifice 2-Way Water Valve for the flush water jets.

g. One 1/8 Inch Orifice 2-Way Water Valve for the urinal rinse water jets.

13.3 Pneumatic Valve

There is one pneumatically operated ball valve in the system. This valve is constructed of Poly Vinyl Chloride and is used as the shut-off valve for water vapor flow to the pyrolysis unit.

13.4 Manual Valves

There are seven manually operated valves in the system, all of which are used as flow controls.

a. Two Vacuum Vent control valves for the flush and potable condensers.

b. One Air Bleed valve for the control of air flow to the pyrolysis unit.

c. One Pressurized Gas Control valve for flow control of the indexing jet.

d. Two Speed Control for the 8-way valve and the flush water pump air motor.

e. One Heating Liquid Control for the water heater.

13.5 Check Valves

There are two check valves used to isolate the flush and potable water condensers. The check valves open when the water is removed but provide a vacuum tight seal when the pumps are not operating.

13.6 Pyrolysis Unit Controls

Once the temperature in the pyrolysis unit is established, only one control function is required. This control is to isolate the pyrolysis unit from the still-pot during flushing, or during a possible unit or system power failure. The unit is isolated by a remotely controlled pneumatically activated normally-closed valve. This valve is open between flushing operations. When flushing is initiated, this valve is closed isolating the pyrolysis unit until the pressure in the still-pot is again reduced; then a pressure switch closes, and the valve is opened. The power to the pyrolysis unit retains an electrical control relay in a closed position. If the power fails, the relay opens and de-energizes the valve thus isolating the pyrolysis unit. The isolation of the pyrolysis unit prevents vapor surges during flushing and insures that the potable water is not contaminated if a power failure occurs. Also a drop in the pyrolysis chamber temperature of 80 - 100°F (possibly caused by a vapor surge) is sufficient to lower the resistance of the platinum heating coil so that the 8 ampere protection fuse will melt, causing a power failure and the isolation of the pyrolysis unit. See Figure 3-21, (Schematic Electrical).

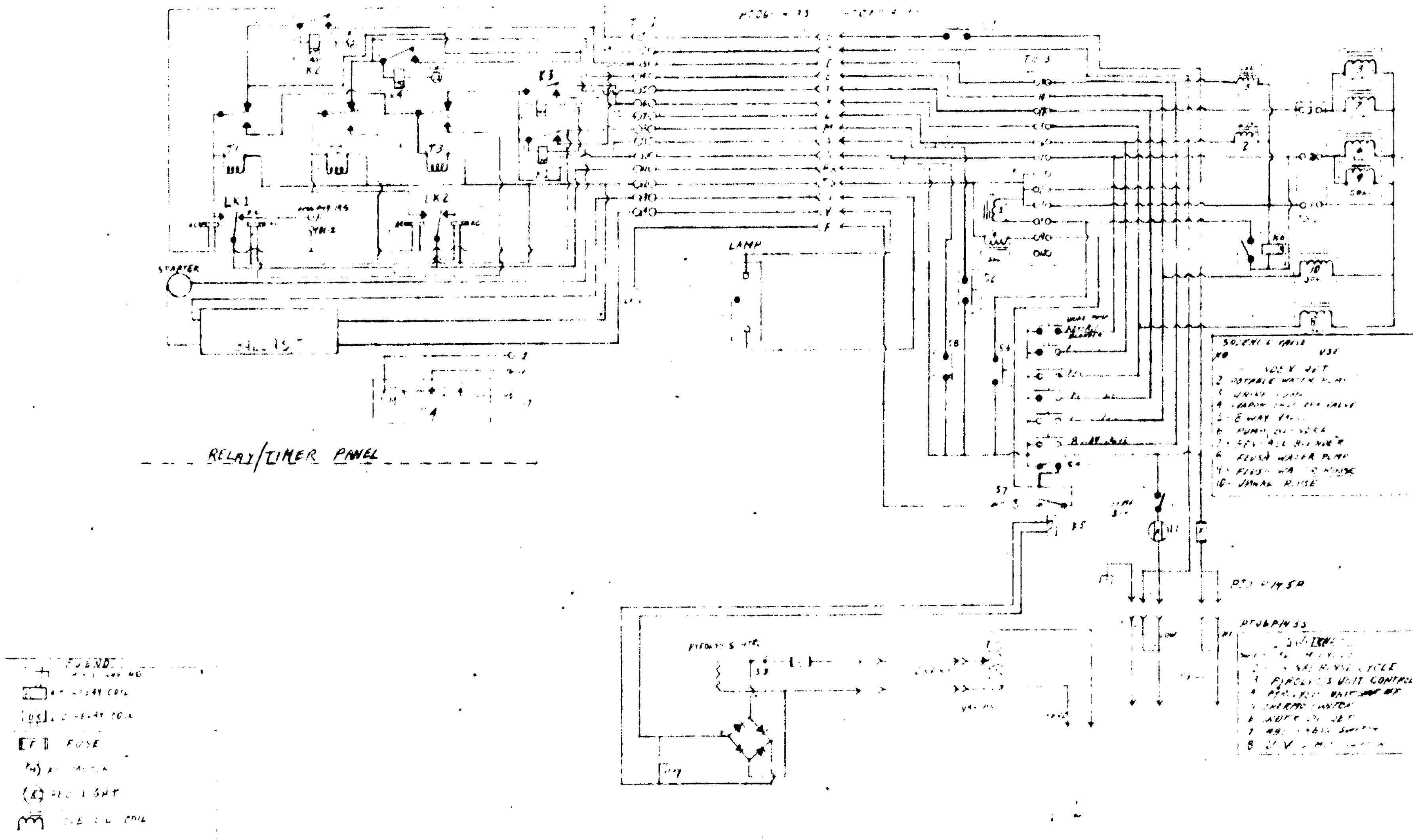


Figure 3-21. Hydro-John System Schematic

13.7 Electrical Controls

The electrical controls are standard push button and toggle type switches. The main controls are protected with switch guards to prevent accidental activation. See Figure 3-2.

14.0 Structure and Enclosure

The structure is fabricated of aluminum tubular and structural members welded into a rigid configuration. The exterior enclosure is constructed of anodized aluminum sheets, colored Textolite-aluminum panels, and anodized aluminum edgings. The hopper cover is constructed of aluminum, painted white, and is hinged from the rear of the hopper seat. The total enclosure is removable from the structure.

A step is mounted on the front of the unit to simulate the actual vehicle floor level. See Figure 3-22. The step is constructed of a painted aluminum frame of welded construction. Fastened atop the frame is a 28 inch wide by 24 inch long aluminum tread plate to provide a platform for ready laboratory use of the Hydro-John System. A large platform is required for convenience considerations, see Figure 3-23.

15.0 Weight and Power Break-Down

The weight and power break-down, Table 3-1, of the prototype system is not representative of a flight prototype system. It is a result of program objectives which were to provide a prototype system having the desired performance characteristic and incorporating zero gravity operating features. Minimum weight, volume and power were considered to be of secondary importance.

Significant reductions in weight and power are envisioned for a flight type prototype system as shown in Table 5-1.

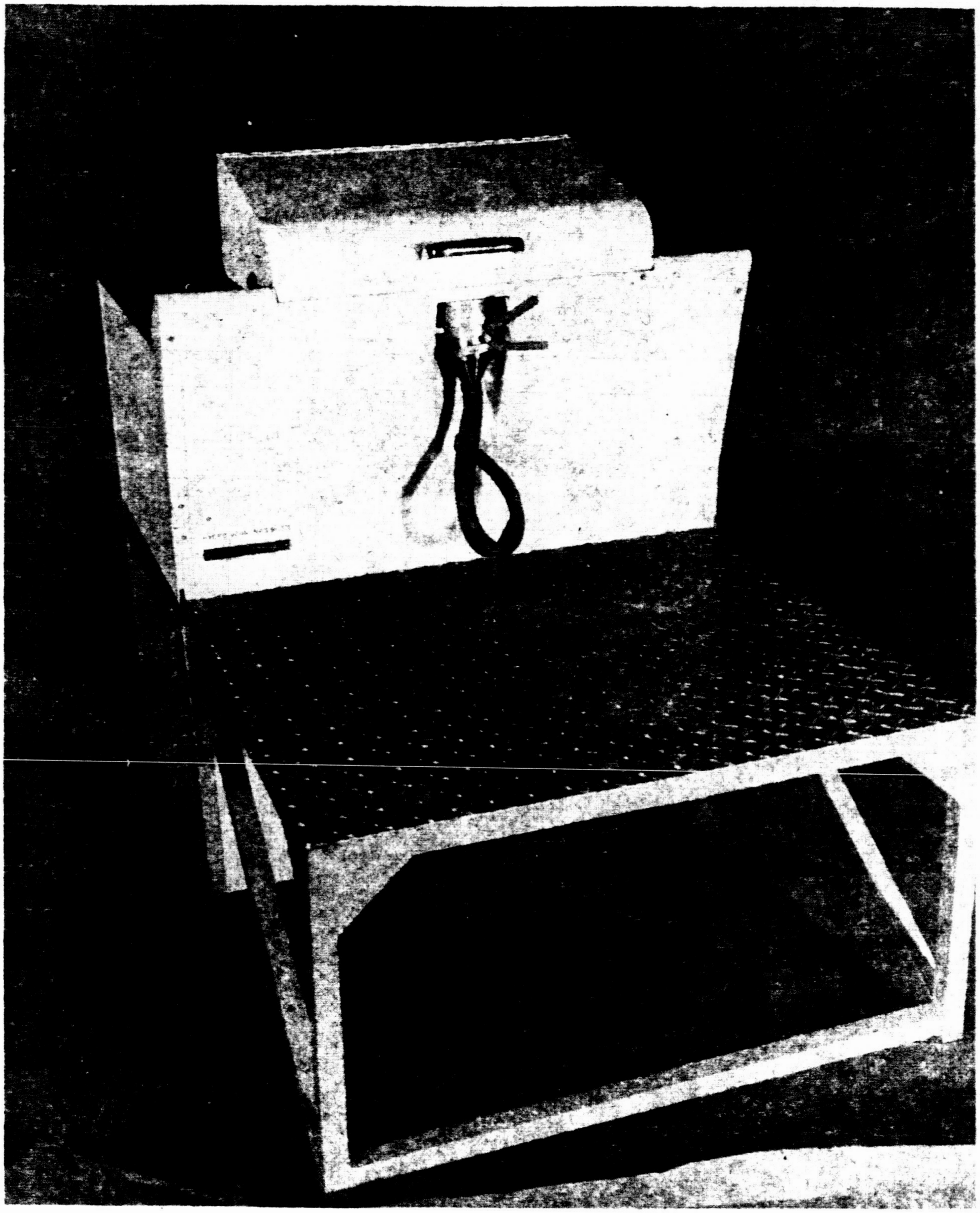
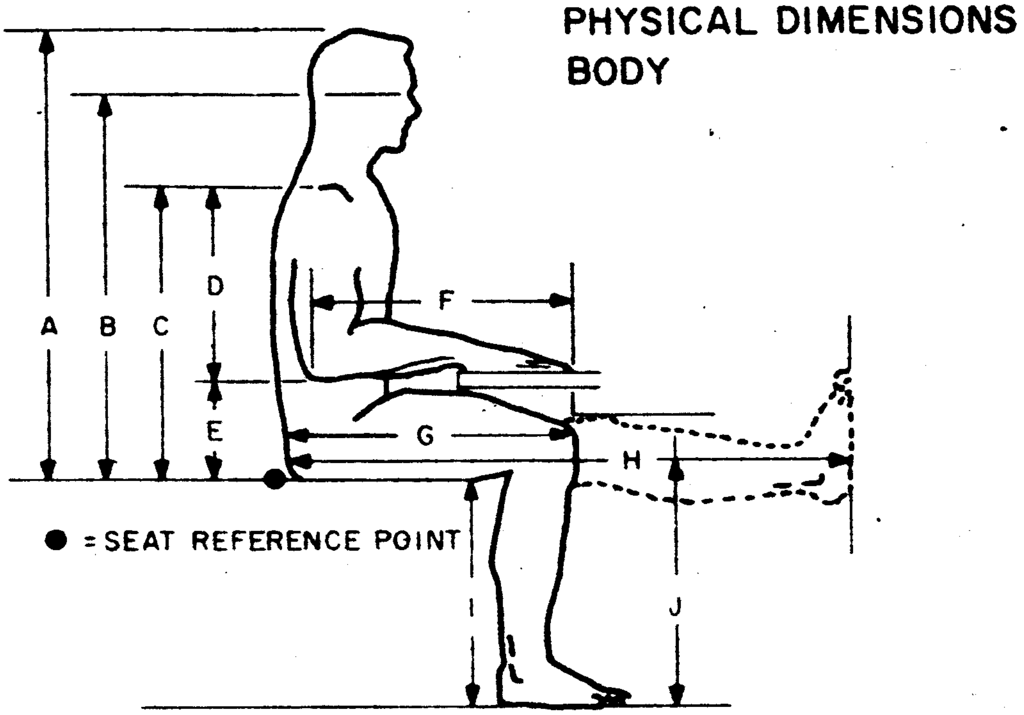


Figure 3-22. Engineering Prototype Unit


PHYSICAL DIMENSIONS
BODY

HUMAN SIZING DATA ON SEATED OPERATOR

KEY	BODY DIMENSIONS	DIMENSION IN INCHES BY PERCENTILES 5TH	50TH	95TH
A.	SITTING HEIGHT	33.8	36.0	38.0
B.	EYE HEIGHT	29.4	31.5	33.5
C.	SHOULDER HEIGHT	21.3	23.3	25.1
D.	SHOULDER-ELBOW LENGTH	13.2	14.3	15.4
E.	ELBOW REST HEIGHT	7.4	9.1	10.8
F.	FOREARM-HAND LENGTH (FINGERS EXTENDED)	17.6	18.9	20.2
G.	BUTTOCK-KNEE LENGTH	21.9	23.6	25.4
H.	BUTTOCK-LEG LENGTH	39.4	42.7	46.1
I.	UNDER-KNEE HEIGHT	15.7	17.0	18.2
J.	KNEE HEIGHT	20.0	21.7	23.3
	HIP BREADTH	12.7	13.9	15.4
	SHOULDER BREADTH	16.5	17.9	19.4

DATA FROM WADC TR 52-321

Figure 3-23. Human Sizing Data

TABLE 3-1. WEIGHT AND POWER DATA

QUANTITY	COMPONENT	DRY WEIGHT (lbs.)	POWER (Watts)	GAS FLOW (Atm. CFM)
1	Fiberglas Seat & Duct	5.0	--	--
1	Enclosure & Cover	15.0	--	--
1	Structure	25.0	--	--
1	Water Nozzles	1.0	--	--
1	Transport Tube	5.0	--	--
1	Pump Blender w/ Air Motor	4.0	--	10 for 20 sec
1	8-Way Valve w/ Cylinder	4.0	--	0.01 **
1	Still-Pot	26.0	--	--
1	Flush Water Condenser	10.0	--	--
1	Pump w/Air Motor	10.0	--	16 for 15 sec
1	Pyrolysis Unit	17.0	150.0 Continuous	--
1	Potable Water Condenser	4.0	--	--
1	Pump w/Cylinder	5.0	--	0.01 **
1	Urinal	2.0	--	--
1	Urine Reservoir	3.0	--	--
1	Pump w/Air Motor	7.0	--	10 for 5 sec
1	Water Filter & Heater	4.0	--	--
1	Air Heater	1.0	--	--
2	Check Valves	2.0	--	--
1	P. V. C. Pneumatic Valve	4.0	--	0.03 **
1	P. V. C. Hand Valve	1.0	--	--
1	Blender Control Valve	7.0	10.0	--
2	4-Way Solenoid Valves	2.0	20.0	--
2	3-Way Solenoid Valves	0.6	14.0	--
7	2-Way Solenoid Valves	3.5	56.0	--
7	Manual Valves	2.0	--	--
3	Reset Timers	6.0	10.5	--
1	Continuous Timer	1.0	5.0 Continuous	--
5	Relays	3.0	25.0	--
2	Latching Relays	1.5	8.0	--
1	U-V Lamp	0.2	4.0 Continuous	--
1	Ballast & Starter	1.0	5.0	--
1	Transistorized Relay Circuit	0.2	5.0	--
1	Misc. Fittings	5.0	--	--
1	Misc. Tubing	5.0	--	--
1	Misc. Hardware	2.0	--	--
		*195.0 lbs.		

* The weight will be reduced to approximately 60 pounds for a flight hardware unit.

** Per Actuation.

1. The average power requirement is approximately 175 watts.

2. The peak power requirement is approximately 260 watts for 20 seconds.

3. The average gas flow requirement is approximately 3.5 CFH.

4. The peak gas flow requirement is approximately 26 CFM for 15 seconds.

5. Air bleed loss thru vacuum vent:

$W_A = R\rho$

W_A = pounds air lost per day

R = bleed rate ft^3/day

ρ = gas density lbs/ft^3

R = 30 STD cc/min x 1440 min/day x $\frac{1}{28,200\ \text{cc}/\text{ft}^3}$ = 1.53 ft^3/day

ρ = 0.08 lbs/ft^3 for air at STP conditions

TABLE 3-1. (Cont'd)

Therefore $W_A = 1.53\ ft^3/day \times 0.08\ lbs/ft^3 = 0.123$ pounds air lost per day

6. Water vapor loss thru vacuum vent:

The water vapor saturates the exiting gas flow at the reduced pressure as a function of temperature. Assume that the dewpoint of the gas is 50°F for a water vapor partial pressure of 0.18 psia thus the gas partial pressure is 0.07 psia for a total pressure of 0.25 psia. The air flow rate R of 1.53 ft^3/day expands $\frac{14.7}{0.07}$ or 210 times as it enters the condenser. Consequently, the gas flow rate is 1.53 ft^3/day x 210 or approximately 320 ft^3/day. The density of the water vapor at the reduced pressure is approximately $\frac{1\ lb.}{1700\ ft^3}$

Therefore $W_W = 320\ ft^3/day \times lb/1700\ ft^3 = 0.188$ pounds water lost per day

7. Air loss during system flush:

During the seven daily system flushes, the air which fills the still-pot is lost when the still-pot pressure is reduced for boiling. The internal free volume of the still-pot is approximately 1100 cubic inches, consequently 1100 in^3 x 7 flushes or 7700 in^3 (4.46 ft^3) of air are lost per day. (Worst case).

$W_A = 4.46\ ft^3/day \times 0.08\ lb/ft^3 = 0.357$ pounds of air lost per day

Total Gas Losses	
	0.123 lb/day air
	0.188 lb/day water
	0.357 lb/day air
	0.660 lb/day

The overall water recovery efficiency of the 48 pounds of water processed per day is:

$$\frac{48 - 0.188\ \text{LOST}}{48} = 99.6\%\ \text{efficient}$$

SECTION IV

SYSTEM LABORATORY TEST PROCEDURE

The following procedure is presented as guideline for laboratory operation of the Hydro-John engineering prototype.

1.0 Auxiliary Test Equipment

Several items are required to simulate the integration of the Hydro-John System into a space vehicle design. (All items listed are usually readily available in projected vehicle designs. Consequently, little or no penalty will be paid for their use in an actual vehicle.)

1.1 A Hot Liquid Source is required to provide the heat necessary for evaporation of the liquid in the still-pot as well as to warm cleansing water and the drying air during the flush-dry cycle. An 8 gallon water bath at approximately 130°F will be suitable for this purpose. The bath may be heated by 1.5 KW electrical immersion heaters. Pumping at 0.5 GPM to the heat exchangers (by a positive displacement pump rated for a 50 psi pressure head) is required. A fluid differential pressure gage, 0-30 psia range is required to monitor the pressure drop through the system.

1.2 A Cold Liquid Source is required to cool the potable and flush water condensing units. A 40°F water process cooler rated at more than 3000 BTU/hr will be suitable for this purpose. The cooled water is pumped at 0.5 GPM to the heat exchangers by a positive displacement pump rated for a 50 psi pressure head. A fluid differential pressure gage, 0-30 psia range, is required to monitor the pressure drop through the system.

1.3 A Vacuum Pump is required to provide the low pressure for low temperature water boiling. A pump rated at 100 liters/per minute at 1000 microns absolute pressure is ample for this purpose. Also a cold trap is required in the vacuum suction line to prevent water vapor from entering the vacuum pump.

1.3.1 A Vacuum Pump of low capacity and 10 micron ultimate vacuum is required to maintain the pyrolysis chamber shell at an approximately adiabatic condition, and to prevent oxidation of the thermal reflectors.

1.4 A Suction Blower is required to pull air through the Hydro-John system to insure proper stool and water transportation and to provide a drying air stream after the flush cycle. Approximately 25 CFM at 6.5 inches water gage is required. Also a filter of activated charcoal is required in the air flow to provide odor removal. A simple filter housing of plexiglas may be fabricated in nearly any shop. If the Hydro-John system is integrated into a simulated vehicle environmental control system, the system ECS blower and odor control may be used for the above functions.

1.5 A Shop Air Source or pressurized environment gas is required to operate the air motors and pneumatic cylinders. The source should be regulated to 100 psig and provide a flow of at least 40 standard cubic feet per minute. A high pressure gas flowmeter, 0-28 SCFM, is required to monitor the gas flow to the air motors.

1.6 An Air Bleed to the still-pot provides the oxygen to the pyrolysis unit. A flow of 30 atmospheric cc of air per minute at ambient condition is metered into the system via a flowmeter.

1.7 Electrical Power Sources are required to operate the timers, solenoids, relays, etc. All power may be supplied by one standard 15 amp, 115V, 60 cycle 1 phase circuit except for the blower (if required) which may require a 200 volt, 3 phase, 400 cycle AC circuit. The 115 volt power can be reduced to the required pyrolysis unit voltage bv a transformer furnished with the Hydro-John System. A voltmeter and ammeter are required as support equipment for the pryolysis unit.

2.0 Instrumentation - The absolute pressure and temperature at various system stages will provide the bulk of empirical data for performance analysis. Consequently, 18 copper-constantan thermocouples in the 30 to 160°F range are required to monitor:

T_1	The flush water condenser - coolant water inlet
T_2	The flush water condenser - coolant water outlet
T_3	The flush water condenser - condensed liquid
T_4	The potable water condenser - coolant water inlet
T_5	The potable water condenser - coolant water outlet
T_6	The still-pot - heating water inlet
T_7	The still-pot - heating water outlet
T_8 & T_9	The still-pot - boiling slurry
T_{10}	The air heater - heating water inlet
T_{11}	The air heater - heating water outlet
T_{12}	The air heating - air outlet
T_{13}	The water heater - heating water inlet
T_{14}	The water heater - heating water outlet
T_{15}	The water heater - flush water
T_{16}	The distilled vapor prior to entering condensing chambers
T_{17}	The pyrolyzed vapor prior to entering condensing chamber
T_{18}	Referenced to ice water

A 1800°F chromel-alumel thermocouple T_H is required in the pyrolysis section to monitor performance. See Table 4-1 for conversion of millivolts output to temperature.

A 0-100 Micron Vacuum Gage is required to monitor shell pressure of the pyrolysis unit.

Also 3 laboratory type absolute pressure gages or 30 inch mercury manometers with water traps will be required to monitor:

TABLE 4-1.

CHROMEL vs. ALUMEL THERMOCOUPLE

Degrees Fahrenheit — Reference Junction 32° F.

°F	0	1	2	3	4	5	6	7	8	9
					Millivolts					
1200	26.98	27.01	27.03	27.06	27.08	27.10	27.12	27.15	27.17	27.20
1210	27.22	27.24	27.27	27.29	27.31	27.34	27.36	27.38	27.40	27.43
1220	27.45	27.48	27.50	27.52	27.55	27.57	27.59	27.62	27.64	27.66
1230	27.69	27.71	27.73	27.76	27.78	27.80	27.83	27.85	27.87	27.90
1240	27.92	27.94	27.97	27.99	28.01	28.04	28.06	28.08	28.11	28.13
1250	28.15	28.18	28.20	28.22	28.25	28.27	28.29	28.32	28.34	28.37
1260	28.39	28.41	28.44	28.46	28.48	28.50	28.53	28.55	28.58	28.60
1270	28.62	28.65	28.67	28.69	28.72	28.74	28.76	28.79	28.81	28.83
1280	28.86	28.88	28.90	28.93	28.95	28.97	29.00	29.02	29.04	29.07
1290	29.09	29.11	29.14	29.16	29.18	29.21	29.23	29.25	29.28	29.30
1300	29.32	29.35	29.37	29.39	29.42	29.44	29.46	29.49	29.51	29.53
1310	29.56	29.58	29.60	29.63	29.65	29.67	29.70	29.72	29.74	29.77
1320	29.79	29.81	29.84	29.86	29.88	29.91	29.93	29.95	29.97	30.00
1330	30.02	30.05	30.07	30.09	30.11	30.14	30.16	30.18	30.21	30.23
1340	30.25	30.28	30.30	30.32	30.35	30.37	30.39	30.42	30.44	30.46
1350	30.49	30.51	30.53	30.56	30.58	30.60	30.63	30.65	30.67	30.70
1360	30.72	30.74	30.77	30.79	30.81	30.83	30.85	30.88	30.90	80.93
1370	30.95	30.97	31.00	31.02	31.04	31.07	31.09	31.11	31.14	31.16
1380	31.18	31.21	31.23	31.25	31.28	31.30	31.32	31.34	31.37	31.39
1390	31.42	31.44	31.46	31.48	31.51	31.53	31.55	31.58	31.60	31.62
1400	31.65	31.67	31.69	31.72	31.74	31.76	31.78	31.81	31.83	31.85
1410	31.88	31.90	31.92	31.95	31.97	31.99	32.02	32.04	32.06	32.08
1420	32.11	32.13	32.15	32.18	32.20	32.22	32.25	32.27	32.29	32.31
1430	32.34	32.36	32.38	32.41	32.43	32.45	32.48	32.50	32.52	32.54
1440	32.57	32.59	32.61	32.64	32.66	32.68	32.70	32.73	32.75	32.77
1450	32.80	32.82	32.84	32.86	32.89	32.91	32.93	32.96	32.98	33.00
1460	33.02	33.05	33.07	33.09	33.12	33.14	33.16	33.18	33.21	33.23
1470	33.25	33.28	33.30	33.32	33.34	33.37	33.39	33.41	33.43	33.46
1480	33.48	33.50	33.53	33.55	33.57	33.59	[illegible]	33.64	33.66	33.69
1490	33.71	33.73	33.75	33.78	33.80	33.82	[illegible]	33.87	33.89	33.91
1500	33.93	33.96	33.98	34.00	34.03	34.05	34.07	34.09	34.12	34.14
1510	34.16	34.18	34.21	34.23	34.25	34.28	34.30	34.32	34.34	34.37
1520	34.39	34.41	34.43	34.46	34.48	34.50	34.53	34.55	34.57	34.59
1530	34.62	34.64	34.66	34.68	34.71	34.73	34.75	34.77	34.80	34.82
1540	34.84	34.87	34.89	34.91	34.93	34.96	34.98	35.00	35.02	35.05
1550	35.07	35.09	35.11	35.14	35.16	35.18	35.21	35.23	35.25	35.27
1560	35.29	35.32	35.34	35.36	35.39	35.41	35.43	35.45	35.48	35.50
1570	35.52	35.54	35.57	35.59	35.61	35.63	35.68	35.69	35.70	35.72
1580	35.75	35.77	35.79	35.81	35.84	35.86	35.88	35.90	35.93	35.95
1590	35.97	35.99	36.02	36.04	36.06	36.08	36.11	36.13	36.15	36.17
1600	36.19	36.22	36.24	36.26	36.29	36.31	36.33	36.35	36.37	36.40
1610	36.42	36.44	36.46	36.49	36.51	36.53	36.55	36.58	36.60	36.62
1620	36.64	36.67	36.69	36.71	36.73	36.76	36.78	36.80	36.82	36.84
1630	36.87	36.89	36.91	36.93	36.96	36.98	37.00	37.02	37.05	37.07
1640	37.09	37.11	37.14	37.16	37.18	37.20	37.23	37.25	37.27	37.29
1650	37.31	37.34	37.36	37.38	37.40	37.43	37.45	37.47	37.49	37.52
1660	37.54	37.56	37.58	37.60	37.63	37.65	37.67	37.69	37.72	37.74
1670	37.76	37.78	37.81	37.83	37.85	37.87	37.89	37.92	37.94	37.96
1680	37.98	38.01	38.03	38.05	38.07	38.09	38.12	38.14	38.16	38.18
1690	38.20	38.23	38.25	38.27	38.29	38.32	38.34	38.36	38.38	38.40
1700	38.43	38.45	38.47	38.49	38.51	38.54	38.56	38.58	38.60	38.62
1710	38.65	38.67	38.69	38.71	38.73	38.76	38.78	38.80	38.82	38.84
1720	39.87	38.89	38.91	38.93	38.95	38.98	39.00	39.02	39.04	39.06
1730	39.09	39.11	39.13	39.15	39.17	39.20	39.22	39.24	39.26	39.28
1740	39.31	39.33	39.35	39.37	39.39	39.42	39.44	39.46	39.48	39.50
1750	39.53	39.55	39.57	39.59	39.61	39.64	39.66	39.68	39.70	39.72
1760	33.75	39.77	39.79	39.81	39.83	39.86	39.88	39.90	39.92	39.94
1770	39.96	39.99	40.01	40.03	40.05	40.07	40.10	40.12	40.14	40.16
1780	40.18	40.20	40.23	40.25	40.27	40.29	40.31	40.34	40.36	40.38
1790	40.40	40.42	40.44	40.47	40.49	40.51	40.53	40.55	40.58	40.60

CHROMEL vs. ALUMEL THERMOCOUPLE

Degrees Fahrenheit — Reference Junction 32° F.

°F	0	1	2	3	4	5	6	7	8	9
					Millivolts					
1800	40.62	40.64	40.66	40.68	40.71	40.73	40.75	40.77	40.79	40.82
1810	40.84	40.86	40.88	40.90	40.92	40.95	40.97	40.99	41.01	41.03
1820	41.05	41.08	41.10	41.12	41.14	41.16	41.18	41.21	41.23	41.25
1830	41.27	41.29	41.31	41.34	41.36	41.38	41.40	41.42	41.45	41.47
1840	41.49	41.51	41.53	41.55	41.57	41.60	41.62	41.64	41.66	41.68
1850	41.70	41.73	41.75	41.77	41.79	41.81	41.83	41.85	41.88	41.90
1860	41.92	41.94	41.96	41.99	42.01	42.03	42.05	42.07	42.09	42.11
1870	42.14	42.16	42.18	42.20	42.22	42.24	42.26	42.29	42.31	42.33
1880	42.35	42.37	42.39	42.42	42.44	42.46	42.48	42.50	42.52	42.55
1890	42.57	42.59	42.61	42.63	42.65	42.67	42.69	42.72	42.74	42.76
1900	42.78	42.80	42.82	42.84	42.87	42.89	42.91	42.93	42.95	42.97
1910	42.99	43.01	43.04	43.06	43.08	43.10	43.12	43.14	43.17	43.19
1920	43.21	43.23	43.25	43.27	43.29	43.31	43.34	43.36	43.38	43.40
1930	43.42	43.44	43.47	43.49	43.51	43.53	43.55	43.57	43.59	43.61
1940	43.63	43.66	43.68	43.70	43.72	43.74	43.76	43.78	43.81	43.83
1950	43.85	43.87	43.89	43.91	43.93	43.95	43.98	44.00	44.02	44.04
1960	44.06	44.08	44.10	44.13	44.15	44.17	44.19	44.21	44.23	44.25
1970	44.27	44.30	44.32	44.34	44.36	44.38	44.40	44.42	44.44	44.47
1980	44.49	44.51	44.53	41.55	44.57	44.59	44.61	44.63	44.66	44.68
1990	44.70	44.72	44.74	44.76	44.79	44.80	44.82	44.85	44.87	44.89
2000	44.91	44.93	44.95	44.97	44.99	45.01	45.03	45.06	45.08	45.10
2010	45.12	45.14	45.16	45.18	45.20	45.22	45.24	45.27	45.29	45.31
2020	45.33	45.35	45.37	45.39	45.41	45.43	45.45	45.48	45.50	45.52
2030	45.54	45.56	45.59	45.60	45.62	45.64	45.66	45.69	45.71	45.73
2040	45.75	45.77	45.79	45.81	45.83	45.85	45.87	45.90	45.92	45.94
2050	45.96	45.98	46.00	46.02	46.04	46.06	46.08	46.11	46.13	46.15
2060	46.17	46.19	46.21	46.23	46.25	46.27	46.29	46.31	46.33	46.36
2070	46.38	46.40	46.42	46.44	46.46	46.48	46.50	46.52	46.54	46.56
2080	46.58	46.60	46.63	46.65	46.67	46.69	46.71	46.73	46.75	46.77
2090	46.79	46.81	46.83	46.85	46.87	46.90	46.92	46.94	46.96	46.98
2100	47.00	47.02	47.04	47.06	47.08	47.10	47.12	47.14	47.17	47.19
2110	47.21	47.23	47.25	47.27	47.29	47.31	47.33	47.35	47.37	47.39
2120	47.41	47.43	47.45	47.47	47.49	47.52	47.54	47.56	47.58	47.60
2130	47.62	47.64	47.66	47.68	47.70	47.72	47.74	47.76	47.78	47.80
2140	47.82	47.84	47.86	47.89	47.91	47.93	47.95	47.97	47.99	48.01
2150	48.03	48.05	48.07	49.09	48.11	48.13	48.15	48.17	48.19	48.21
2160	48.23	48.25	48.27	48.29	48.32	48.34	48.36	48.38	48.40	48.42
2170	48.44	48.46	48.48	48.50	48.52	48.54	48.56	48.58	48.60	48.62
2180	48.64	48.66	48.68	48.70	48.72	48.74	48.76	48.79	48.81	48.83
2190	48.85	48.87	48.89	48.91	48.93	48.95	48.97	48.99	49.01	49.03
2200	49.05	49.07	49.09	49.11	49.13	49.15	49.17	49.19	49.21	49.23
2210	[illegible]	49.27	49.29	49.31	49.33	49.35	49.37	49.39	49.41	49.43
2220	49.45	49.47	49.49	49.51	49.53	49.55	49.57	49.59	49.61	49.63
2230	49.65	49.67	49.69	49.71	49.73	49.76	49.78	49.80	49.82	49.84
2240	49.86	49.88	49.90	49.92	49.94	49.98	49.98	50.00	50.02	50.04
2250	50.06	50.08	50.10	50.12	50.14	50.16	50.18	50.20	50.22	50.24
2260	50.26	50.28	50.30	50.32	50.34	50.36	50.38	50.40	50.42	50.44
2270	50.46	50.48	50.50	50.52	50.54	50.56	50.57	50.59	50.61	50.63
2280	50.65	50.67	50.69	50.71	50.73	50.75	50.77	50.79	50.81	50.83
2290	50.85	50.87	50.89	50.91	50.93	50.95	50.97	50.99	51.01	51.03
2300	51.05	51.07	51.09	51.11	51.13	51.15	51.17	51.19	51.21	51.23
2310	51.25	51.27	51.29	51.31	51.33	51.35	51.37	51.39	51.41	51.43
2320	51.45	51.47	51.48	51.50	51.52	51.54	51.56	51.59	51.60	51.62
2330	51.64	51.66	51.68	51.70	51.72	51.74	51.76	51.78	51.80	51.82
2340	51.84	51.86	51.88	51.90	51.92	51.94	51.96	51.98	52.00	51.01
2350	[illegible]	52.05	52.07	52.09	52.11	52.13	52.15	52.17	52.19	52.21
2360	[illegible]	52.25	52.27	52.29	52.31	52.33	52.35	52.37	52.39	52.41
2370	52.42	52.44	52.46	52.48	52.50	52.52	52.54	52.56	52.58	[illegible]
2380	52.62	52.64	52.66	52.68	52.70	52.72	52.74	[illegible]	52.77	52.79
2390	52.81	52.83	52.85	52.87	52.89	52.91	52.93	52.95	52.97	52.99

P_1	The still-pot distillation absolute pressure
P_2	The flush water condenser absolute pressure
P_3	The potable water condenser absolute pressure

3.0 Test Preparation

Prior to actual use of the Hydro-John System several functions or operations must be performed. These operations must be carried out in order presented. See Figure 4-1.

3.1 Attach the interface connecting lines and cables to the fittings and attachments at the rear of the unit.

3.1.1 Attach the two 1/4 inch AN tube fittings from the hot liquid source to the bulkhead fittings identified with red tags.

3.1.2 Attach the two 1/4 inch AN tube fittings from the cold liquid source to the bulkhead fittings identified with black tags.

3.1.3 Attach the system vacuum pump to the 3/8 inch "Swagelok" tube fitting identified with a red tag "VENT COND. VACUUM." Assure that the condensers vent valves are closed.

3.1.4 Attach the pyrolysis shell vacuum pump to the 1/4 inch AN tube fitting identified by a red tag "VACUUM VENT PYROLYSIS SHELL."
NOTE: Provide a localized nitrogen atmosphere around the fitting during unsealing of the shell fitting cap. This is accomplished by spraying dry nitrogen at the fitting area.

3.1.5 Attach the blower air suction line to the 2 inch plastic fitting identified by a red tag "BLOWER SUCTION."

3.1.6 Attach the pressurized gas source to the 3/8 inch "Swagelok" tube fitting identified by a red tag "INLET HIGH PRESS. GAS."

3.1.7 Attach the 30 cc gas flowmeter to the 1/4 inch AN valved port on the top of the still-pot. The port is identified by a red tag "AIR BLEED VALVE."

3.1.8 Attach three manometers to the 1/4 inch AN tube fittings identified by yellow tags "PRESS. TAP POTABLE COND.", "PRESS. TAP FLUSH COND." and "PRESS. TAP STILL-POT."

3.1.9 Attach the external potable water reservoir to the 3/8 inch "Swagelok" bulkhead fitting identified by the yellow tag "OUTLET POTABLE WATER."

3.1.10 Assure that the pyrolysis unit power switch is OFF and the flow control valve is CLOSED.

3.1.11 Connect the electrical "quick couple" connectors with the main power to the 115 VAC plug and the line from the pyrolysis unit voltage regulator to the 20 VAC plug. Assure that the voltage regulator is set at zero.

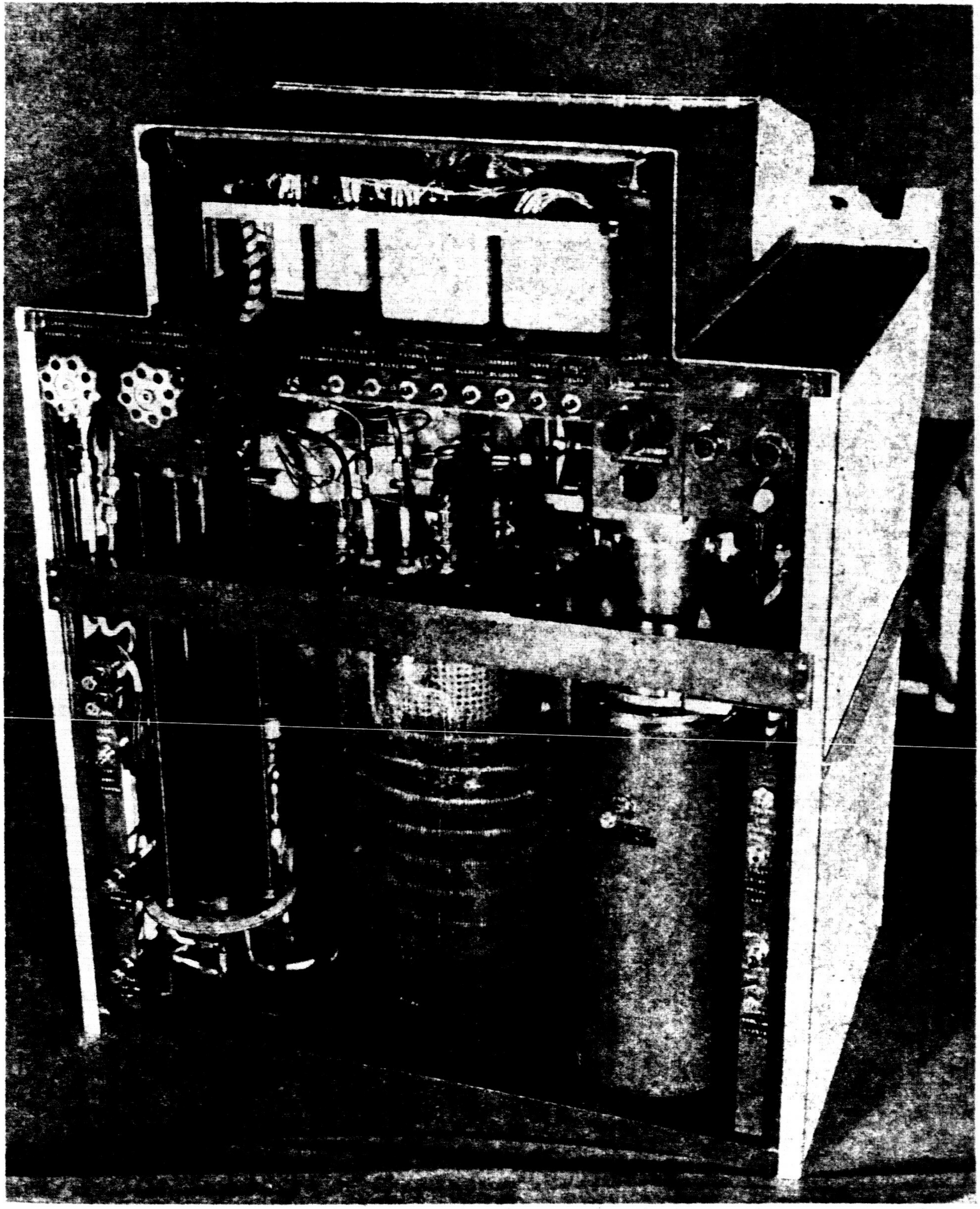


Figure 4-1. System/Vehicle Interface Connections

3.1.12 Attach the red tagged "HIGH TEMPERATURE THERMOCOUPLE" from the pyrolysis unit to a millivolt recorder by means of a special cable and plug connector.

3.1.13 Attach the seventeen thermocouples from the unit to a multi-point recorder. Also reference an additional thermocouple to an ice bath.

3.2 Turn on the vacuum pump to the pyrolysis shell. The vacuum pump pressure gage on the pyrolysis insulating shell should read 10 microns or lower before applying power to the pyrolysis unit. This low pressure in the shell must be maintained throughout the test and during heating and cooling of the pyrolysis unit.

3.3 Connect all electrical power lines. Turn on "PYROLYSIS UNIT POWER SWITCH" on rear control console. Power to the pyrolysis unit is maintained at a 7.5 amp current by the variable voltage regulator external to the unit. As the unit heats the heating coil electrical resistance increases so periodic increases in voltage are required until 20 volts at 7.5 amperes is attained. These values will correspond to an internal temperature of approximately 1800°F. Several hours are required to establish the high operating temperature. Monitor on thermocouple T_H.

3.4 Adjust the regulated gas source to 100 psig.

3.5 Turn on the air suction blower. Assure that the air filter is operational. (Not part of the Hydro-John System).

3.6 Partially fill the still-pot with 16 pounds of water (approximately 8 liters). This water is poured into the hopper with the 8-way valve manually activated to the open position. Also manually activate the pump-blender and check the speed with a stroboscope tachometer. The speed must exceed 3000 RPM.

3.7 Partially fill the urine reservoir with 2 pounds of water (approximately 1 liter). This is accomplished by pouring the water into the urinal.

3.8 Start the process cooler and the pump for the coolant liquid source. The process cooler should be maintained at the operational temperature during pre-test preparation.

3.9 Start the process heater and pump for the hot liquid source. The process heater should be maintained at operational temperature during pre-test preparation.

3.10 Turn on the vacuum pump, the system condensers, and open the red tagged "FLUSH CONDENSER VACUUM VENT VALVE" and the "POTABLE CONDENSER VACUUM VENT VALVE" approximately 1/4 turn. As the pressure is lowered to approximately 120 mm of Hg absolute pressure, the flow control valve is opened automatically.

3.11 Adjust the hot liquid source flow to 0.5 gallons per minute and 130°F per thermocouple T_6.

3.12 Adjust the cold liquid source flow to 0.5 gallons per minute and 40°F per thermocouple T_4.

3.13 As soon as thermocouples T_8 and T_9 register 120°F, adjust the pressure in the still-pot P_1 to 87.4 mm Hg (1.69 psia) by the condenser vacuum vent valves.

3.14 The pressure in the flush water condenser P_2 should read approximately 61 mm Hg while the potable water condenser P_3 should read approximately 36 mm Hg.

3.15 Allow the system to stabilize. Observe boiling in still-pot. To increase the boiling rate, the pressure P_1 may be lowered slightly.

3.16 Use simple approximation formula to derive flow rates to the potable and flush water condensers. Determined by the temperature difference.

$$T_5 - T_4 = \Delta T_A \text{ and } T_2 - T_1 = \Delta T_B$$

then $\frac{\Delta T}{4}$ = W pounds of water condensed per hour

or $\underline{\Delta T = 4W}$

Adjust the vapor flow control valve such that the boiling continues and $\Delta T_A = 2^{\circ}F$ and $\Delta T_B = 6^{\circ}F$. The total condenser coolant ΔT should approximately equal the still-pot hot liquid $\Delta T_C = T_6 - T_7$. $\Delta T_A + \Delta T_B \approx \Delta T_C \approx 8^{\circ}F$ for an evaporation rate of 2 lbs/hr. This water vapor flow is divided to 0.5 lbs/hr to the pyrolysis section and the potable water condenser and 1.5 lbs/hr to the flush water condenser.

NOTE: If heat transport liquids other than pure water are used for the coolant and heating fluids, the formula will vary inversely as the specific heat C_P of the liquid varies from 1.

Therefore:

$$\Delta T = \frac{4W}{C_P}$$

3.17 As soon as sufficient flush water is available in the flush water reservoir, the low level indicator light will be automatically de-energized and the system is ready for a "wet run" operational check-out without the man.

3.17.1 Cover the hopper opening with a sealed plexiglas lid and operate the Hydro-John System through one flush cycle by activating the red tagged "FLUSH" push button switch on the control console. Assure that the pump-blender, the urine pump, the flush water pump and the 8-way valve are operational. Also assure that the pyrolysis unit is isolated by momentarily disconnecting the 115 VAC connector plug. No noise should be heard from pneumatic activation since the normally closed valve should be closed. The speed of the 8-way valve is regulated to open very slowly.

3.17.2 When the system has returned to operational pressure again and sufficient water is available for flushing, another "wet run" is initiated using the hand as a seal over the hopper opening. The red tagged "INDEXING JET" is activated by a push button switch on the control console. The gas jet pressure may be manually adjusted to provide adequate pressure for physically sensing position. The "FLUSH" cycle is initiated with the subject's hand sensing the rate of suction, as the still-pot is opened, and the temperature of the water jets. If either is excessive, adjustment to the speed control on the 8-way valve and heating liquid by-pass thru the water heater should be made and the test repeated.

3.17.3 The subject's thumb is then inserted in the urinal and sealed by the diaphragm. The red tagged "URINAL RISE" push button switch on the control console is then activated with the thumb sensing water temperature and pressure.

3.17.4 After all "wet runs" prove satisfactory the system is ready for actual use. Permit time for all the water to be evaporated from the still-pot and stored in the flush water reservoir prior to initiating the maximum use schedule as depicted below.

4.0 Performance Test

4.1 Use Schedule

The following schedule is the maximum possible use cycle to which the system should be subjected.

USE SCHEDULE

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Defecations	*	*	*				*				*				*				*		7 per day			
Urinations	*	*	*	*	*	*	*	*	*	*	*		*		*		*		*			*	16 per day	

Normally, only four defecations will be excreted per day for a four man crew, however the system is designed for seven defecations. Notice that the system is designed for three defecations in the initial three hour period and the fourth defecation at the seventh hour. Note that in an actual normal use cycle that the defecation will be randomly scattered throughout the day.

However, for the performance test, within the limits of human regularity, there should be at least four defecation and three "wet run" flush wash cycles performed throughout each day at the given schedule.

The normal amount of excreta for men adhering to a normal diet is greater than that amount of excreta for men adhering to space flight type diet. The system is designed for 4 men excreting 4 ounces of feces per man day for a period of 14 days. Consequently, if men adhering to a normal diet use the system, only three men should use the system for the 14 day period or four men for a 10 day period. The amount of feces in the still-pot may be visually checked to determine how long the test may be continued.

4.2 Operation and Use

4.2.1 Assure that the regulated gas source is set at 100 psig.

4.2.2 Assure that the electrical power is "ON."

4.2.3 Assure that the flush water low level indicator light is not glowing. If the light is glowing this indicates that only sufficient water for one flush is remaining in the reservoir. Consequently, after this use, the remaining personnel should be warned to wait until the light is off prior to use. The system will generally require at least three hours to refill the reservoir to the use level.

4.2.4 Assure that the ultraviolet lamp is glowing. CAUTION: Do not look at the glowing ultraviolet lamp without protective glasses. The glass used in conventional eyeglasses affords adequate eye protection. However, care must be exercised that the ultraviolet energy does not enter the eyes from the side nor is reflected into the eyes from the back side of the glasses. The lamp is shut off automatically as the hopper protective cover is lifted.

4.2.5 Lift cover to expose hopper seat.

4.2.6 Assure that the suction blower is operating.

4.2.7 Remove trousers and underwear shorts.

4.2.8 Spread gluteal fold and sit in comfortable position on hopper seat.

4.2.9 Actuate the "INDEXING JET" switch and adjust physical position to center the rectal orifice directly over the seat opening.

4.2.10 Fasten seat belt.

4.2.11 Remove urinal from front of seat.

4.2.12 Squeeze the urinal handle to increase urinal orifice size, insert the penis, and release the handle to permit the urinal diaphragm to seal around the penis. Note that the urinal diaphragm cap is removable such that each man may have his own diaphragm for increased sanitization.

4.2.13 Urinate and defecate. Note that the subject normally should sit erect in the seat but may lean forward if desired to facilitate the defecation process.

4.2.14 Actuate the "FLUSH" switch to rinse the rectal area and flush the Hydro-John unit.

4.2.15 Actuate the "URINAL RINSE" switch to wash the urinal while the penis is still inserted in the urinal. This provides a rinse of the penis for added sanitation.

4.2.16 Remain seated to permit the circulating air flow to dry the rectal area and penis. Personal preference will dictate the drying period, however no discomfort was experienced by personnel who permitted the underclothing to absorb the small amount of liquid remaining on the rectal area.

4.2.17 Release the seat belt.

4.2.18 Replace the urinal under the seat front.

4.2.19 Rise from the seat. During a performance test, use toilet tissue to check the cleanliness of the rectal area. DO NOT PLACE TOILET TISSUE IN THE HYDRO-JOHN HOPPER.

4.2.20 Dress.

4.2.21 Replace cover over hopper seat.

4.2.22 Record significant data on cleanliness of rectal area, the fit of the seat, any discomfort experienced, etc.

5.0 System Shut Down

After the test plan is completed, the following operations must be used to shut-down the system in preparation for further testing.

5.1 Shut-off circulating pumps for heating and coolant water. The process cooler and immersion heaters may also be shut-off if further testing is not envisioned.

5.2 Turn-off vacuum pump to the condensing unit.

NOTE: The low pressure in the pyrolysis shell must be maintained below 10 microns until the pyrolysis unit temperature approaches room temperature.

5.3 Allow the still-pot and condensing units to bleed up to atmospheric pressure.

5.4 Add 8 fluid ounces of disinfectant (Weladyne) to the hopper and cover the hopper hole with a sealed plexiglas lid. Operate the Hydro-John system "FLUSH" switch through sufficient cycles to empty the flush water condenser and the urine reservoir.

5.5 Actuate the "POTABLE PUMP" switch to empty the potable water condenser.

5.6 Shut-off the regulated gas source and vent to atmospheric pressure.

5.7 Shut-off all electrical power except that to the pyrolysis unit shell vacuum pump. See 5.2.

5.8 Remove the still-pot from the unit by removing the mounting brackets and connecting lines.

5.9 Don protective garments such as rubber gloves and apron. Preferably the disassembly and cleaning of the still-pot should be performed in an open area of a well ventilated room.

5.10 Remove bolts from the still-pot lid and vertically lift-off the lid. The entire heating coil section is also attached to the lid thus leaving only the still-pot plexiglas shell.

5.11 Support the still-pot core a few inches above the shell and remove the center cap from the perforated cylinder. This is accomplished by removing three small screws from the perforated cylinder. The feces in the perforated cylinder is then dropped into the still-pot shell.

5.12 Shape a large funnel from heavy paper or plastic and insert it in the still-pot shell to catch the drippings from the core.

5.13 Wash the core with a low pressure water source and permit the drippings to fall into the still-pot shell.

5.14 Empty the still-pot shell.

5.15 Place a dilute disinfectant (Weladyne, Wescodyne, etc.) in the shell and replace the core.

5.16 Be sure that the entire still-pot volume is filled with the disinfectant solution and allow to soak.

5.17 Repeat steps 5.9 through 5.14.

5.18 If all the feces is not removed, add a dilute solution of sulfuric acid and potassium dichromate and allow to soak.

5.19 After the still-pot is sufficiently clean and disinfected, remove all liquids and allow the unit to dry.

5.20 Reassemble the cap into the perforated cylinder and reassemble the still-pot. Do not subject the still-pot to a low pressure unless the center perforated cylinder and cap are in place.

5.21 After several test runs of the unit it may be necessary to remove and replace a contaminated water barrier or stainless steel wool in the top interior of the still-pot. This is easily accomplished when the unit is disassembled by removing the plexiglas nut and plate inside the top of the perforated cylinder.

5.22 While the still-pot is removed from the unit, also remove and refill the activated charcoal flush water filter. Place only coarse charcoal granules in the filter and replace the filter paper which retains the granules in the unit.

5.23 Replace the filter and still-pot in preparation for further tests. Assure that all lines and connections are leak tight.

6.0 Usage In a 100% Oxygen Atmosphere

Prior to usage of the Hydro-John engineering prototype system in a pure oxygen atmosphere, two groups of components require servicing.

6.1 The electrical latching relays and adjustable timers must be sealed. These items were not sealed in order to permit easier timed cycle adjustment for the laboratory test phases.

6.2 The air motors, pneumatic cylinder, solenoids and connecting lines must be cleaned for oxygen service. Lubrication [illegible] provided by, oxygen atmosphere tolerant lubricants, i.e., phosphate ester type.

SECTION V

SYSTEM OPTIMIZATION

Commercially available components were used wherever possible; a conservative approach was taken throughout the system and individual component designs. This permitted, at minimum cost, the design and fabrication of a prototype system suitable for both demonstrating the feasibility of the Hydro-John concept and for obtaining, during laboratory testing, performance data and experience for continuing the further development of the concept.

An estimate, based on a review of the present design and experience gained during the program, has been made as to the degree of redesign required to optimize the present system design. This is noted in Table 5-1 which illustrates the weight and power reduction and the degree of alteration required to provide a four man 14 day flight type system.

TABLE 5-1. SYSTEM OPTIMIZATION

	Present System			Flight System*	
Component	Weight (Lbs.)	Electrical Power (Watts)	Degree Of Alternation**	Weight (Lbs.)	Electrical Power (Watts)
Seat and Enclosure	20	-	3	3	-
Structure	25	-	3	3	-
Pump-Blender w/Air Motor	10	Air Operated	2-4	3	Air Operated
8-Way Valve w/Clinder	4	Air Operated	2-4	2	Air Operated
Still-Pot	26	-	3	10	-
Flush Water Condenser	10	-	2	4	-
Flush Water Pump	10	Air Operated	4	2	150 Watts
Pyrolysis Unit	17	150	2	8	50 Watts (Continuous)
Potable Water Pump	5	Air Operated	2-4	1.5	Air Operated
Urinal and Urine Reservoir	5	-	2	3	-
Urine Pump	7	Air Operated	2-4	1.5	Air Operated
Water Filter & Heater	4	-	2	3	-
Air Heater	1	-	1	1	-
Control Valves	20.1	-	4	5	35 Watts
Manual Valves	2	-	4	2	-
Timers	7	-	4	2	20 Watts
U-V Lamp w/Controls	1.2	9 Watts	4	1	6 Watts (Continuous)
Misc. Hardware and Controls	16.7	28 Watts	4	3	20 Watts
	195.0			60 lbs.	

*1. The average power requirement will be approximately 75 watts.
2. The peak power requirement will be approximately 240 watts for 20 seconds.
3. The average gas flow requirement will be approximately 1.5 CFH.
4. The peak gas flow requirement will be approximately 10 CFM for 20 seconds.

** Degree of Alteration for Flight System
1. Unchanged
2. Minor redesign, e.g., light weight material
3. Major redesign
4. Replace with purchased flight hardware

*** See Table 3-1 for additional information on Present System

SECTION VI
CONCLUSIONS

The present engineering prototype was developed in several stages of experimentation with fecal transport methods, an operational breadboard, and a series of laboratory tests. Included were tests of disinfectants, water potability, ammonia control, bacterial control, and flush water contamination. These tests formed the basis for the design of the prototype system which is clean, simple to use, self-cleansing and self-sanitizing. The system provides for collection and storage of human excrement and the recovery of potable water under normal gravity conditions,plus the unit has design features which should permit use in zero gravity conditions. Significant improvement in these factors can be achieved. Redesign of the pryolysis unit, using a superinsulation jacket, and additional vapor heat exchange surface, will reduce the energy requirement from 300 watt hours to less than 100 watt hours per pound of potable water recovered. The overall average power will be reduced to less than 75 watts. Redesign of components and purchasing of flight type hardware will reduce the weight from 195 pounds to an estimated 60 pounds and reduce the volume from 12 cubic feet to less than 4.5 cubic feet, less solids storage.

The Hydro-John engineering prototype development was based on experimental data. Successful results were achieved in laboratory tests with a variety of subjects. Flight type prototype units using the developed principles will provide for future space missions an acceptable waste management and water recovery system, with moderate weight, volume and power requirements.

APPENDIX A

SYSTEM EVOLUTION

This section depicts and discusses the evolution of the system in the various stages of designs which, for convenience, coincide with the several program reporting periods. Since the system is fully described in previous sections of this report, the need and reason for certain specific items are readily evident. However, evolutionary changes are explored.

Figure A-1 illustrates the basic system concept at the start of the contract effort. The initial system concept, although unchanged in substance, has been modified in certain areas to provide a more sophisticated design.

First Report Period

The only system change made in the first reporting period was the placement of a by-pass circuit from the urinal to the still-pot. Thus only the required amount of potable water would be pyrolyzed. See Figure A-2.

Second Reporting Period

The major change to the system was the elimination of the fecal slurry filter and storage unit and the use of a common still-pot for both urine and flush water. Several vendors of filtration components were asked to evaluate present and future filter techniques for this application. Without exception, very large package sizes and weights were found to be required. Also filters tend to compromise the system by limiting the mission length to relatively short missions or by requiring objectionable changing of filters. The revised system transported the fecal slurry directly to the still-pot where the water is evaporated and reused. Also, the urine is mixed directly with the feces in the pump-blender, thus providing more liquid for mixing purposes. As a result of the above urine-fecal mixing, a portion of the evaporated water vapor from the still-pot is passed through the pyrolysis unit to produce the required potable water while the remainder (about 75%) of the vapor is condensed and reused for flush water. Other additions to the system were an air heater (to heat incoming air used for drying the rectal area after the cleanse cycle) and a disinfectant reservoir. Addition of distinfectants to the flush water was assumed to be a requirement at the outset of the program. However, data had not been accumulated from vendors and experimentation until this time. Consequently, the first insights as to disinfectant reservoir size and location were revealed in this period. See Figure A-3.

Third Reporting Period

Several minor system changes were made in this reporting period. Shown in Figure A-4.

1. A urine storage reservoir and pump were added such that the urine is accumulated until a defecation requires liquid for flush. The addition of these two components reduced the number of still-pot loadings to equal the number of defecations, a significant reduction (from about 16 to 7 loadings). Consequently, more liquid is available for the flushing operation, the still-pot operation is interrupted a minimal

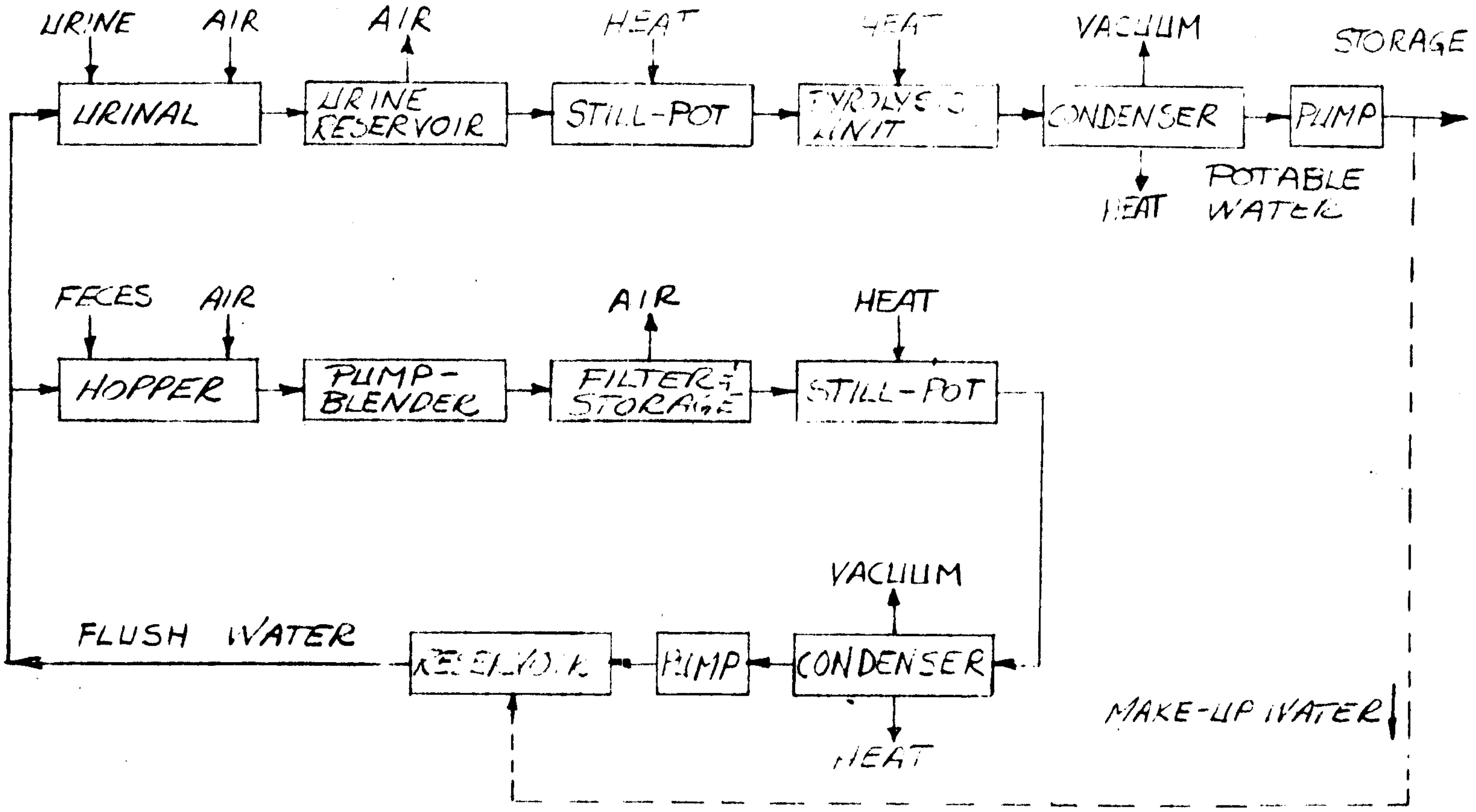


Figure A-1. Statement of Work Flow Diagram Initial Concept

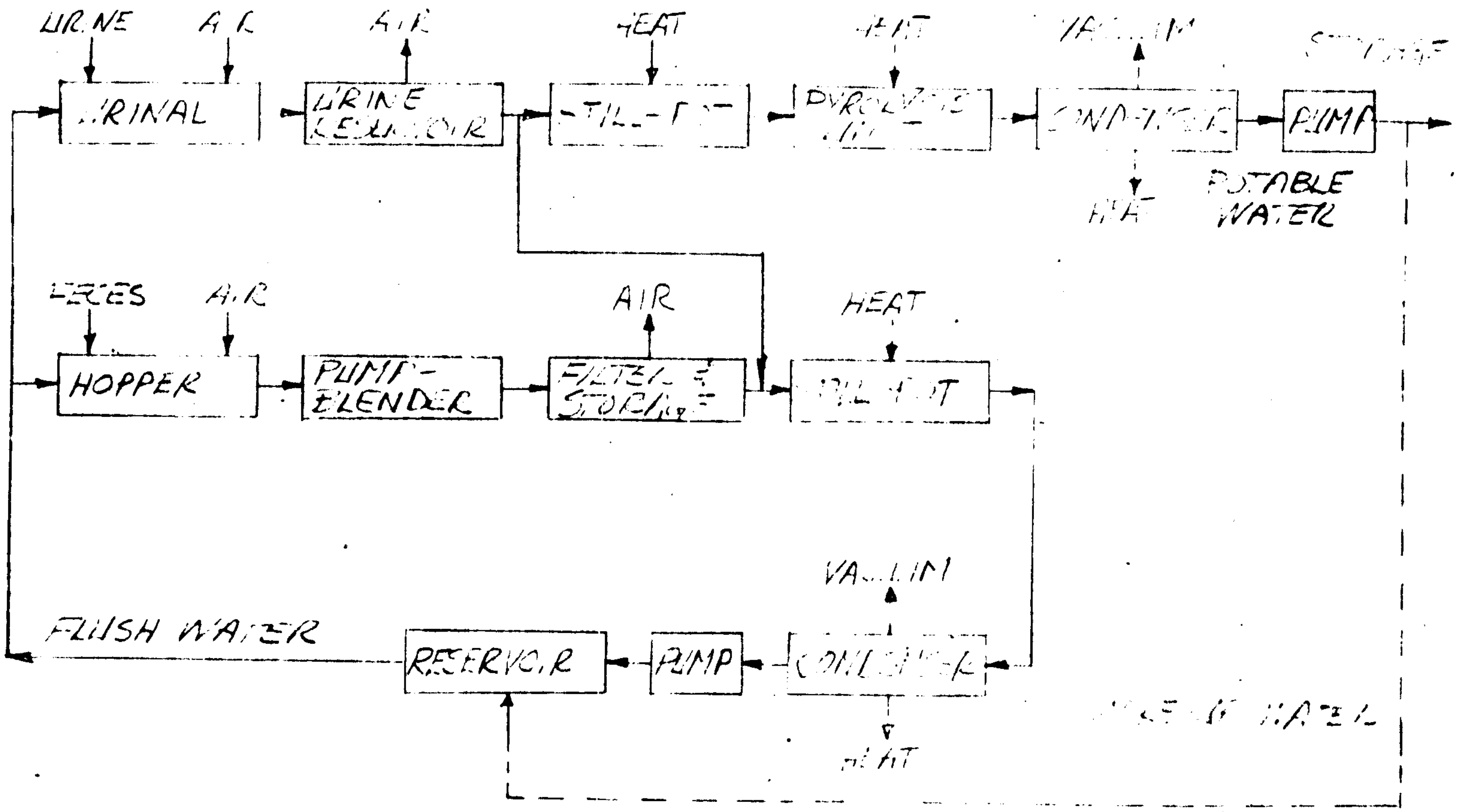


Figure A-2. First Period Flow Diagram

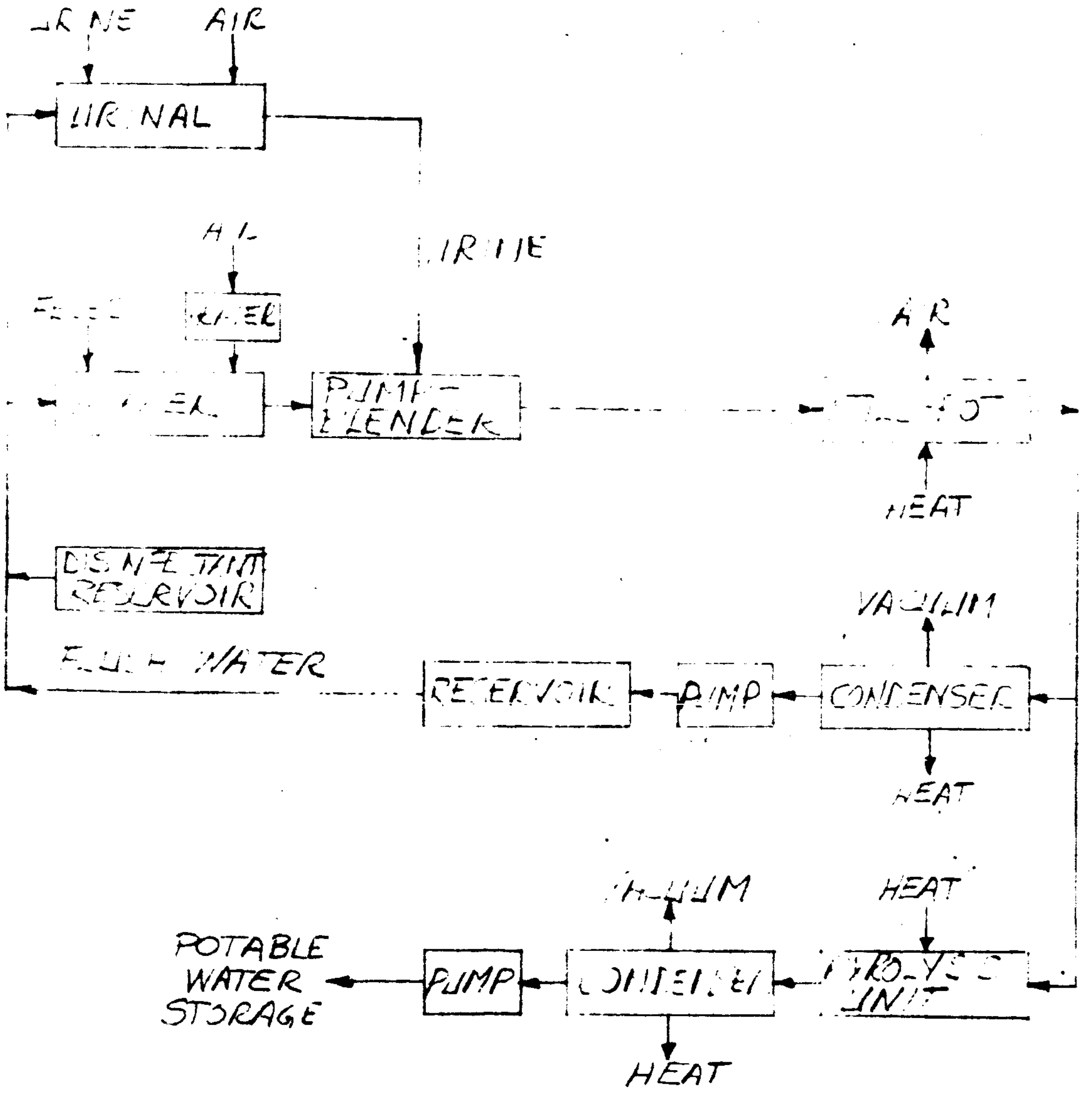


Figure A-3. Second Period Flow Diagram

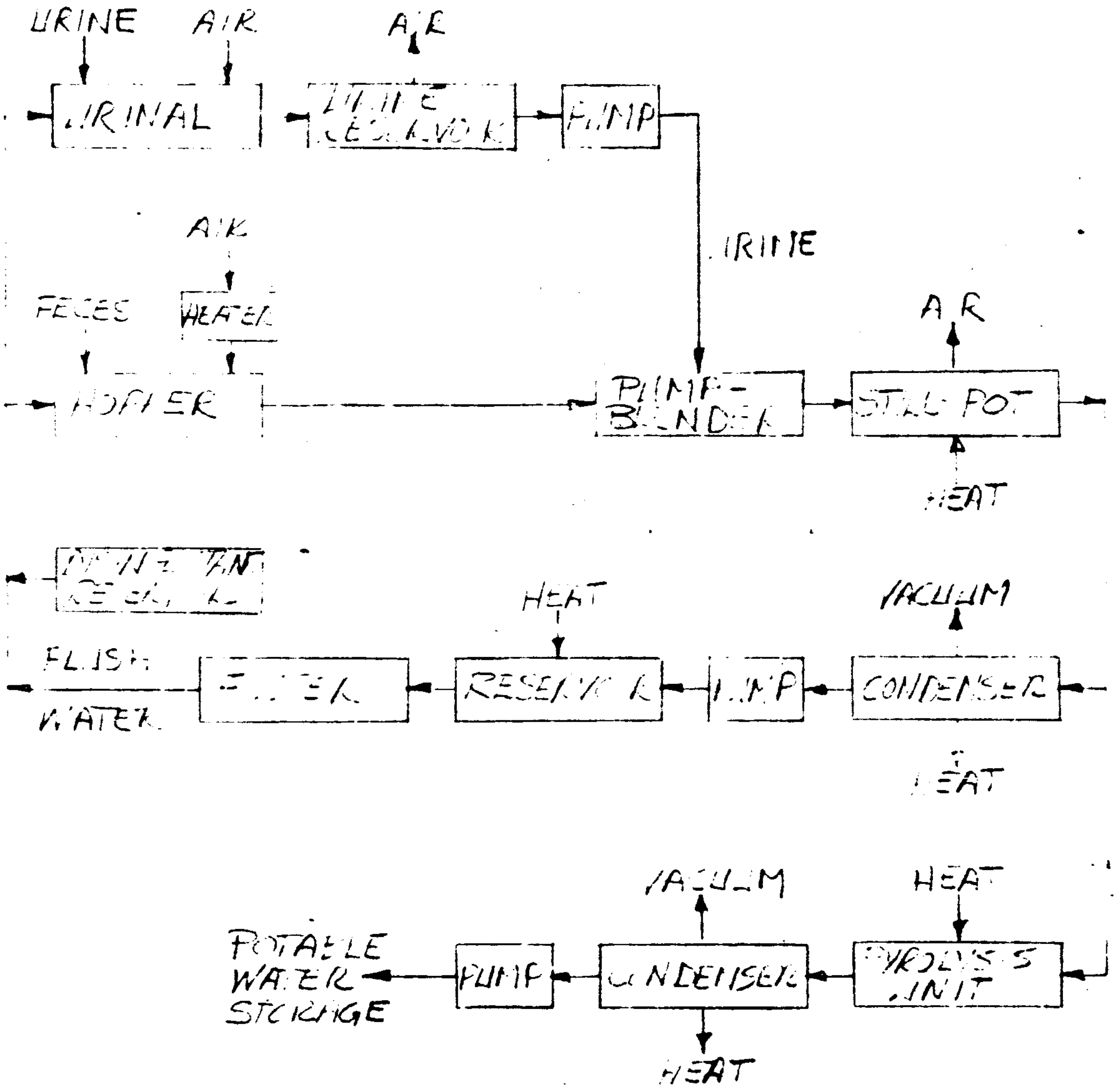


Figure A-4. Third Period Flow Diagram

number of times, and air loss through the still-pot condenser vacuum vents is reduced to a minimum.

2. A heating coil was added to the flush water reservoir to provide warmed cleansing water for spraying on the rectal area. Tests indicated that this addition was well received by users of the laboratory model.
3. An activated charcoal filter was added to the system to remove most of the organics from the flush water, thus reducing turbidity and odors.

Fourth Reporting Period

Two major components were removed from the system during this period. The flush water condenser and reservoir were designed as a single container in which the water was both condensed and stored. Also the disinfectant reservoir was eliminated since laboratory tests indicated that ammonia produced in the still-pot and dissolved in the flush water was sufficient to prevent viable bacteria from exiting in the flush water. This was later changed, see p. 14. Since the flush water condenser and reservoir were combined, heating coils were added to the filter to heat the flush water. See Figure A-5.

Also in the fourth report period, the packaging configuration was solidified by NASA to the "under the seat" package configuration.

Fifth Reporting Period

The fifth and final report period flow diagram is unchanged from the previous period and is also illustrated in Figure A-5.

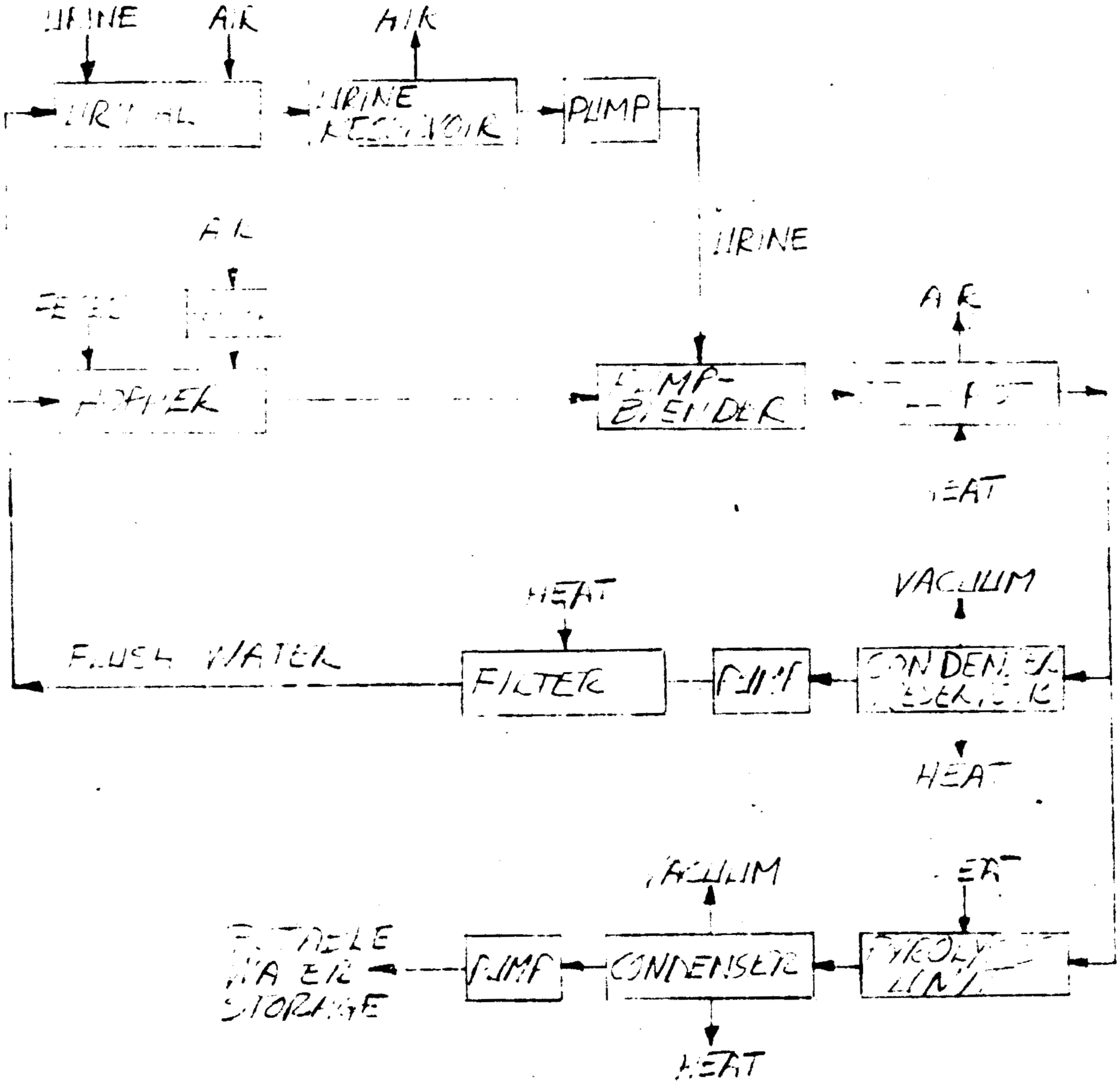


Figure A-5. Fourth Period Flow Diagram

APPENDIX B

DEVELOPMENT AND SYSTEM EVALUATION TEST PROGRAMS

Introduction

In support of the Hydro-John program, a series of development tests were initiated to provide data for substantiation of existing and contemplated flush water recycle/recovery system and process designs. In general, the test program was organized along the following lines:

1. Evaluation of bactericidal/bacteriostatic compounds to determine the material most suitable for the Hydro-John application.
2. Determine contaminant build-up in the flush water recycle stream and assess the impact of this build-up on overall system operation.
3. Substantiate pyrolysis unit designs and capabilities.

The tests were generally designed to attain specific objectives with other pertinent data evaluated as each became available. Subsequent tests were then formulated to further assess the implications of these additional findings.

Evaluation of Bactericides

Preliminary screening of bactericidal agents resulted in compilation of the following list of materials to be used during the test program.

1. Wescodyne (West Chemical Company)
2. Weladyne (West Chemical Company)
3. Zephiran Chloride (Winthrop Laboratories)
4. Silver Nitrate Solution
5. Copper Sulfate Solution

The materials listed were evaluated by simulating various portions of the flush water recycle/recovery process. Results of chemical and bacteriological analyses were used to determine the performance characteristics of each of these materials.

Tests Performed

Preliminary system designs emphasized liquid-solid separation by filtration with subsequent vacuum distillation of the filtrate. To reflect this mode of operation, 4 liters of water (with make-up as required) was processed through a typical flush water recycle operation consisting of the following steps:

1. Slurry with feces (1 man day equivalent)
2. Addition of bactericide
3. Filtration
4. Vacuum Distillation
5. Condensate recovery

This process was repeated through two complete cycles with Wescodyne added (2 cc initially, 4 cc for second cycle) as the bactericide.

Filtration of the fecal slurry was with a glass wool/No. 2 Whatman filter paper bed. Vacuum distillation was performed at 30 - 42°C and 30-50 mm Hg (absolute). One cycle was considered complete when 70 percent of the water (i.e., 2800 cc) was recovered. Water recovered following the second cycle had a strong odor and was contaminated with bacteria as evidenced by the summarized laboratory report from Betz Labs, Inc. tables B-1 and B-2. The chemical analyses shown indicate considerable organic contamination in the process sample. Comparison with a control sample (i.e., water and Wescodyne) indicate that chemical contamination was caused by the waste materials and was not a direct result of the chemical additives.

TABLE B-1

CHEMICAL ANALYSIS OF FLUSH WATER

Points Analyzed	Process Sample	Control Sample
Chloride, ppm	9.5	27
pH	9.4	--
Conductance, micromhos	80.0	210
C.O.D.	2105.0	250

TABLE B-2

BACTERIOLOGICAL ANALYSIS OF FLUSH WATER (PROCESS SAMPLE)

	(48 hrs. incubation)
Total No. of Bacteria/ml of Agar	11,600
Presumptive test (Coliform Group)	
Volume of Sample	
10.0 ml	5/5
1.0 ml	5/5
0.1 ml	5/5
Most Probable Number (M. P. N)*	524 +
Confirmatory Test	Positive
(E. M. B. Agar)	5/5
(Brillant Green Lactose Bile)	
0.01 ml	
Completed Test	
Lactose (positive)	
Gram-negative rods (present)	
Spores (absent)	
Presumptive Test (Streptococci Group)	
Volume of Sample	
10.0 ml	5/5
1.0 ml	5/5
0.1 ml	1/5

*Most Probable Number (M. P. N)

It is obvious from the bacteriological analysis that the quantities of Wescodyne added were not sufficient to provide positive bacterial control in the simulated flush water recycle process.

This preliminary evaluation coupled with a process design revision calling for evaporation of the water directly from the slurry of feces, urine, and water led to performance of a series of more sophisticated tests.

The first of these was a 25 day test of a laboratory system with periodic analyses of the recovered water performed to evaluate the recycle process. The general procedure followed during the test period was to blend feces (one man-day supply) with a portion of the flush water scheduled for use, to fill the still-pot and then to flush the mixture in with the remainder of the flush water bactericide mix. Urine was added in much the same manner. The still pot was operated continuously for a period of 25 days, with daily tests performed to determine degree of bacterial control achieved. Based upon manufacturers recommendations a solution of Weladyne was used as a bactericide during this test. The Weladyne has a phosphoric acid additive to provide increased stability over the Wescodyne previously used.

At the conclusion of the test period the material balance for the system was as follows:

Elapsed time, days	25
Feces input, man days	8
Urine input, liters	13.7
Water recycled, liters	15.3
Weladyne input, liters	0.396

To maintain the proper balance of materials a quantity of recovered water was discarded which was equal in volume to the urine added. All bacterial cultures obtained from the recovered water were negative, indicating positive bacterial control with the Weladyne.

Detailed chemical and bacteriological analyses were performed on samples of water recovered following the 14th and the 24th day of the test. At these points in the test the material processed was as follows:

Elapsed time, days	14	24
Feces input, man days	6	8
Urine input, liters	7.5	12.2
Water recycled, liters	11.0	14.8
Weladyne input, liters	0.245	0.390

Results of the analyses are summarized in Table B-3. These analyses were performed by the LaWall and Harrison Research Laboratories, an independent testing laboratory. Maintenance of bacterial control over the full test period is clearly shown by the analysis. Reason for the decrease in ammonia concentration is not known. However, the free ammonia concentration in water is susceptible to major change with temperature of, and pressure over, the water. At any rate the higher concentration is unacceptable because of the potential for skin irritation, the lower concentration may be marginal in that respect.

TABLE B-3.

CHEMICAL AND BACTERIOLOGICAL ANALYSIS FLUSH WATER RECOVERY CYCLE

	(14 days)	(24 days)
Total Solids, ppm	149	130
Dissolved Solids, ppm	142	127
Ash, ppm	88	*
Total Organics, ppm	61	*
Free Ammonia as NH_3, ppm	11,600	2,500
Phosphorous as P_2O_5, ppm	11	*
Total Iodine as I, ppm	1.48	*
*Analyses not performed		
Standard Plate Count, org./ml	3	5
Coliform Organisms	0	0
Strepticoccus Organisms	0	0

The water obtained following the 25th day was passed through the vapor pyrolysis unit and ultimately recovered as potable water. The analysis shown in Table B-3 is assumed to represent the quality of the raw water supply which was pyrolyzed. Results of the pyrolysis are shown in a later section of this report.

Continuation of the test program was performed in all glass systems running concurrently to further evaluate bactericides, and examine potential solutions to problems associated with ammonia build-up. The tests run in this series are identified by number, preceded by the letter G.

Tests G1-G3 were performed with mixtures of feces, urine and water as the raw materials. Weladyne, Wescodyne, and Zephiran Chloride were added to G1, G2, and G3 respectively. Daily samples were taken to determine ammonia concentrations and presence of bacteria in the recovered water. Figures B-1, B-2, and B-3 show the ammonia build-up with time for these runs. Table B-4 summarizes the quantities of material processed during the test period. It is noteworthy that bacteria was absent from the recycled flush water throughout the test duration.

TABLE B-4.

SUMMARY OF MATERIALS PROCESSED

Material Identification	Test Number G1	 G2	 G3
Elapsed time, days	26	25	23
Feces added, grams	631	631	380
Urine added, mls	3,271	3,711	2,391
Bactericide added, mls	64	64	61
Water recovered, mls	8,705	8,545	3,625

The build-up of ammonia appears to be a continuous process as noted in the ammonia concentration curves. Use of a small air bleed through the system reduced ammonia concentrations as expected. The mechanism behind this reduction is most likely the removal of

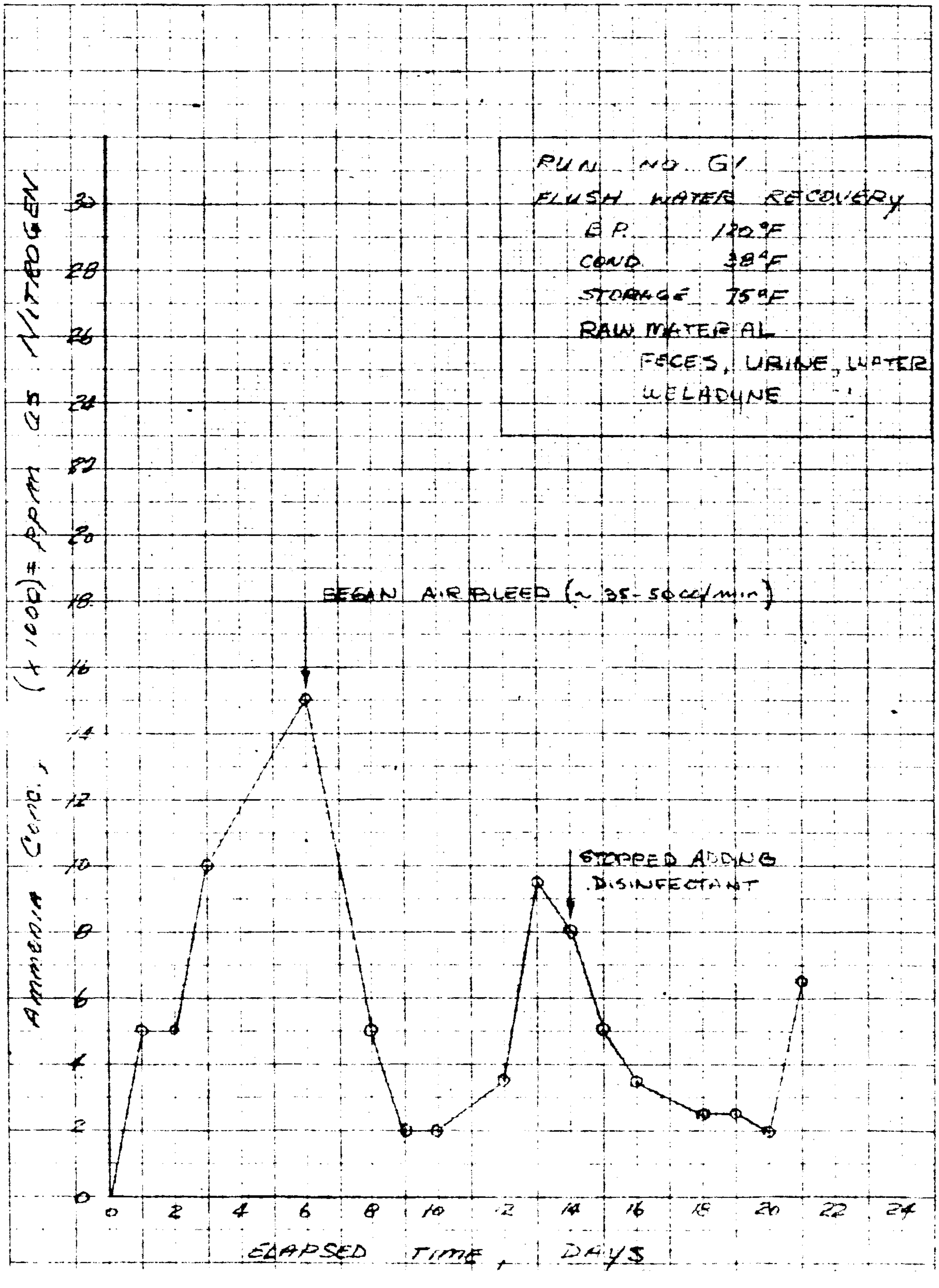


Figure B- Ammonia Build- in Recycled Flush Water

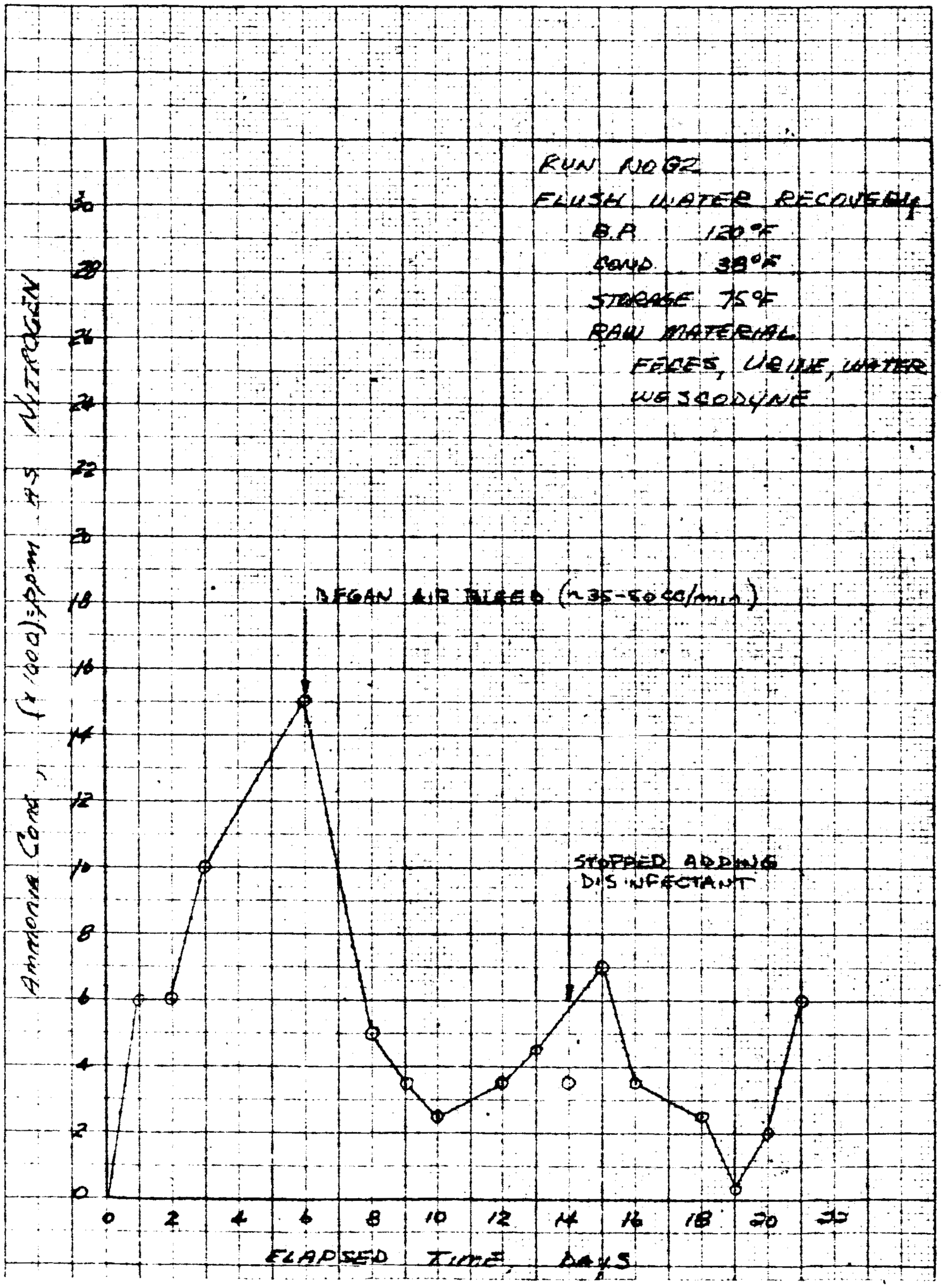


Figure B-2. Ammonia Build-up in Recycled Flush Water

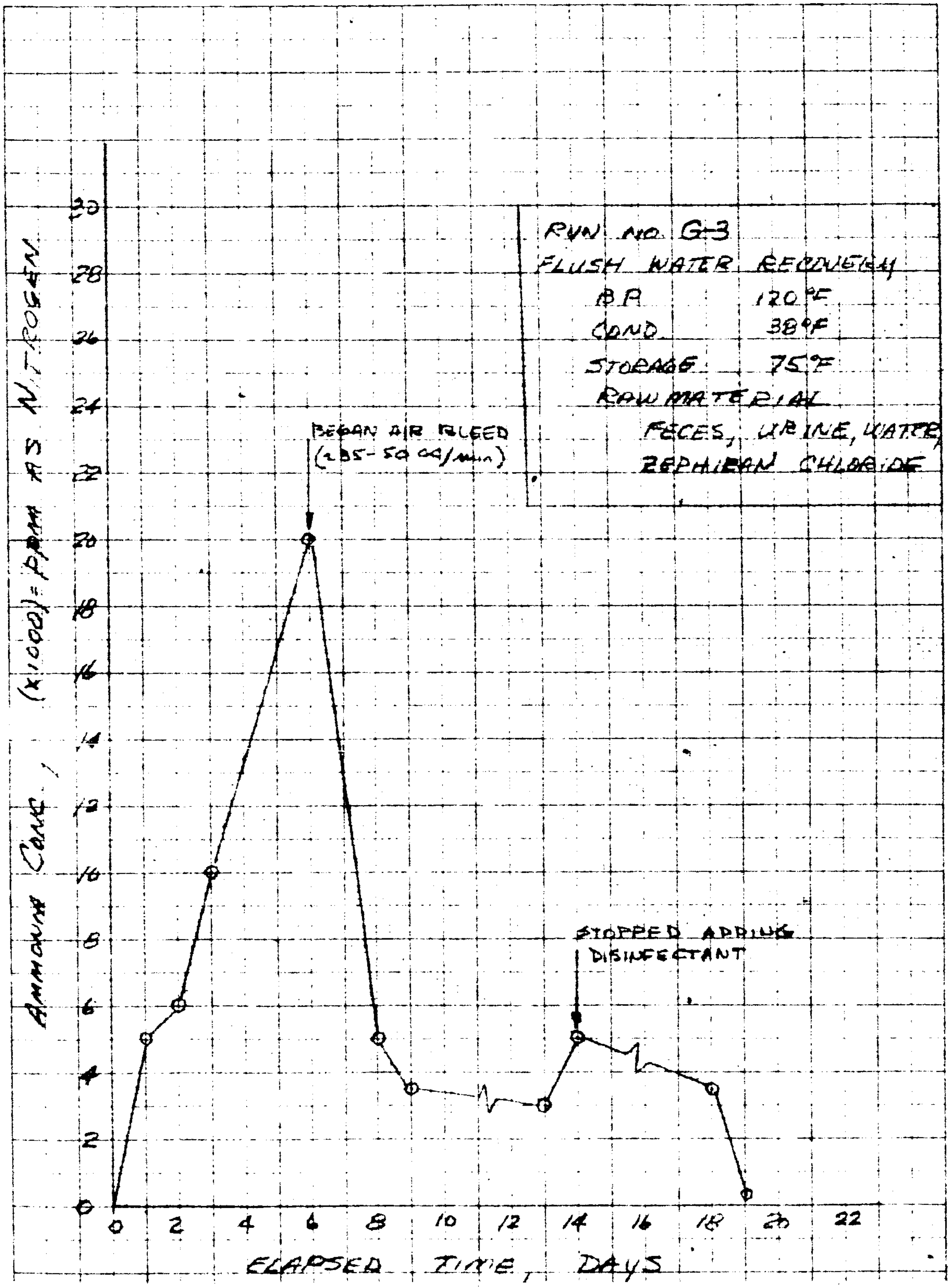


Figure B-3. Ammonia Build-up in Recycled Flush Water ammonia from over the liquid (hence reduction of partial pressure) with subsequent off-gassing of ammonia from the liquid. Choice of bactericide seemed to have no effect upon rate of build-up or eventual equilibrium point.

CONTAMINANT BUILD-UP

Tests G4, G5, and G6 were designed to aid in identification of the major source of ammonia. The raw materials added to each test system were feces and urine, feces and water, and urine and water. Wescodyne was the bactericide used in all three tests. An additional change in system operation was the reduction of boiling temperature (90°F) and pressure (0.75-1.5 inches mercury). As shown in Figure B-4 ammonia concentrations appeared to build up as before, addition of Wescodyne may have contributed to subsequent reduction of ammonia but test data at this point is inconclusive. Reduced temperature did not seem to have a major effect on quality of recovered water. Sampling of recovered water for bacteria showed no growth. The implication here is that ammonia concentration in recovered water is sufficient to provide bactericidal action.

Cursory examinations of metal salts as bactericidal additives was performed during short term (2-4 days) tests. Indications were that either copper sulfate or silver nitrate provide some degree of bacterial control and possess definite advantages in reducing ammonia evolution from urine-feces slurries, and urine-water mixtures. Ammonia concentrations were below 500 ppm for the short test durations. (It appears that the salts were successful in forming metal-ammonium complexes which tie up the ammonia and/or urea molecules.) Again, as with the previous tests, data was inconclusive because of the limited scope of the examination.

VAPOR PYROLYSIS

Initial tests reflecting the system concept whereby urine is kept separate from the feces transport/management system, processed a 2 liter sample of urine containing 50 cc of "recovered flush water through the vapor pyrolysis unit." Flush water used was obtained from the previous tests (Table B-2) to simulate flush water hold-up in the urine transport system. The catalyst temperature during pyrolysis was measured at 1200°C, with a still pot temperature of 47°C at 70 mm Hg (absolute). The water recovered during this test satisfied the U.S. Public Health Standards for chemical potability but showed positive results on presumptive tests for streptococci. The presence of bacteria was traced to a contaminated vent on the condensate collection tank. A duplicate run solved the bacteria problem, i.e., no bacteria were found in the analyzed sample. Table B-5 shows the chemical and the amended bacteriological report from Betz Labs, Inc.

A more stringent test of the pyrolysis unit operation was processing of a sample from the 25 day test (analysis of raw water shown in Table B-3, 24 days). This water was passed through the pyrolysis unit and the unit effluent collected and analyzed by Betz Labs. Inc. The water quality met USPH Standards for all points tested. The analysis is shown in Table B-6.

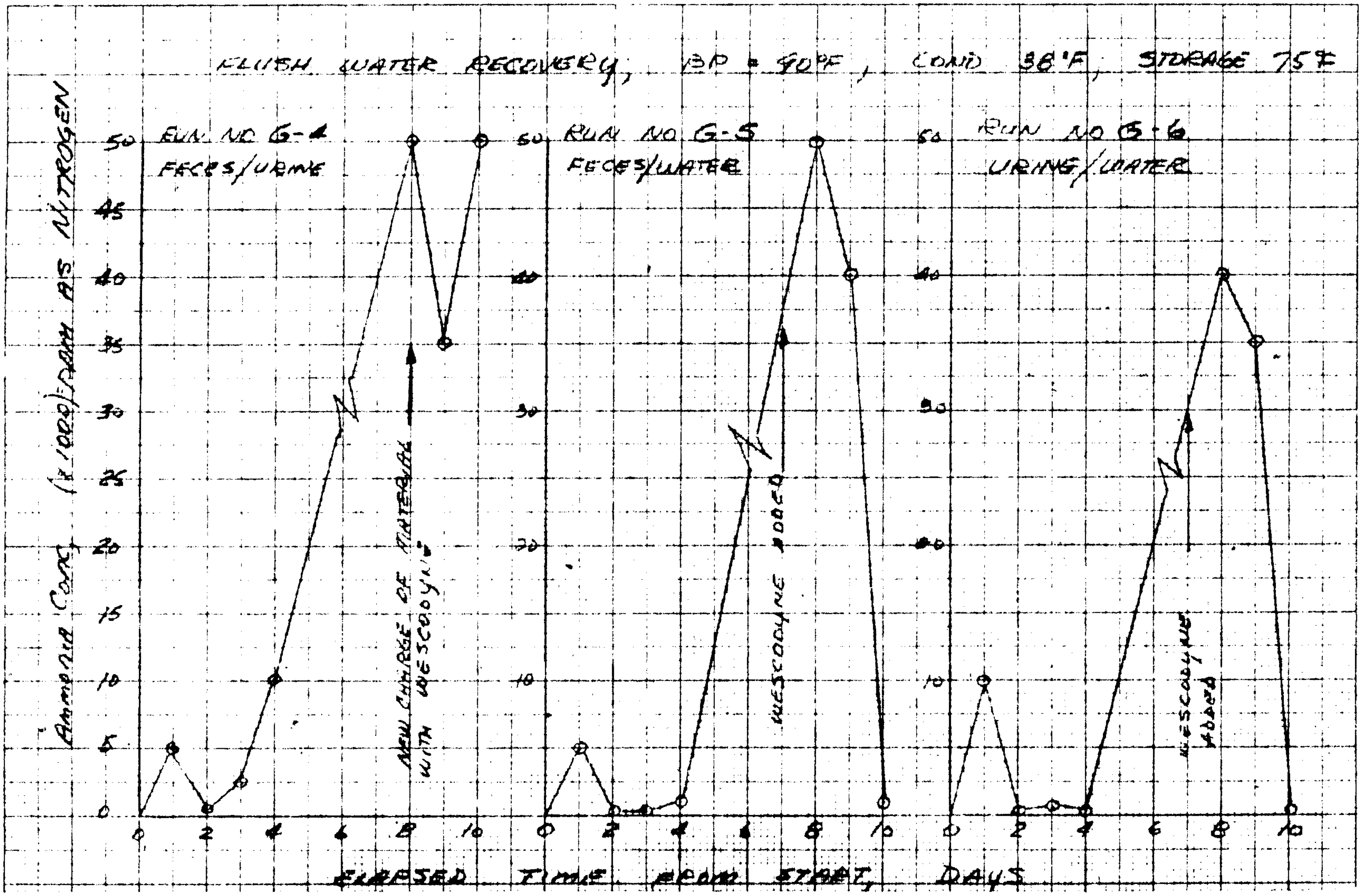


Figure B-4. Ammonia Build-up for Various Combinations of Waste Materials

TABLE B-5.

CHEMICAL AND BACTERIOLOGICAL ANALYSIS

Pyrolysis Sample (Urine and 50 cc Flush Water)

Ammonia, ppm	7.5
Carbon Dioxide, ppm	0.0
P. Alkalinity, ppm	16.0
M. Alkalinity, ppm	36.0
Chloride, ppm	2.0
Phosphate, Total, ppm	0.5
Phosphate, Ortho, ppm	0.5
PH	9.0
Conductance, 18°C, micromohos	40.0
(corrected), micromohos	3.5
Phenol, ppm	0.000
Nitrite, ppm	0.00
Nitrate, ppm	0.03
Odor	None
Color Units	1.0
Turbidity, ppm	0.5

		Period of Incubation	
Bacteriological		24 hours	48 hours
Total count per ml. at 24 hours		195	
Presumptive Tests, Coliform			
	10 ml.	0/5	0/5
	1 ml.		0/5
	0.1 ml.		0/5
	MPN	0	
Presumptive tests, Streptococci			
	10 ml.	0/5	0/5
	1 ml.		0/5
	0.1 ml.		0/5
	MPN	0	

TABLE B-6.

PYROLYZED SAMPLE

Ammonia, ppm	0.05
Alkalinity, ppm	0.0
Free Mineral Acid, ppm	2.0
Sulfate, ppm	0.4
Chloride, ppm	0.5
pH	3.8
Specific Conduct, Mmhos	55.0
Nitrite, ppm	0.1
Nitrate, ppm	0.0
Phenol, ppm	0.0
Odor	None
Color	---
Total Phosphate, ppm	1.3
Ortho Phosphate, ppm	1.3

The undetectable amounts of nitrate present indicate the high efficiency of ammonia oxidation in the pyrolysis chamber. The relatively low phosphates show the phosphoric acid stabilizer in the Weladyne does not add any particular problem to the water recovery cycle. The bacteriological analysis indicated the water sample to be potable. These tests provide strong evidence of the pyrolysis units' capability to satisfy overall process requirements.

System Evaluation

The design of the system was based on the results of the development test program and previously designed systems of a similar nature. When system fabrication was completed, a system evaluation test program was initiated to confirm the operational parameters. The evaluation tests were carried out as set forth in Section IV System Laboratory Test Procedure. The evaluation tests were conducted during a four week period, but several system alterations caused system shut-downs. Consequently, to provide the harshest test of the pyrolysis units' capability to produce potable water from metabolic wastes, a water sample was collected from the pyrolysis unit during the last test day. The water sample source was from a mixture of up to four week old feces and urine. The analysis was performed by an independent laboratory, Betz Laboratories, Inc. and the results are given in Table B-7.

TABLE B-7.

CHEMICAL AND BACTERIOLOGICAL ANALYSIS

PYROLYZED SAMPLE (From Evaluation Test)		
Chemical		
Ammonia, ppm	2.0	
Alkalinity, ppm	6.0	
pH	6.7	
Specific Conduct; Mmhos	2.5	
Nitrite, ppm	0.19	
Nitrate, ppm	0.0	
Phenol, ppb	0.0	
Odor	None	
Bacteriological	Period of Incubation	
	24 hours	48 hours
Total count per ml. at 24 hours	26	
Presumptive, Coliform		
10.0 ml.	0/5	0/5
1.0 ml.		0/5
0.1 ml.		0/5
MPN		0
Presumptive Tests, Streptococci		
10.0 ml.		0/5
1.0 ml.		0/5
0.1 ml.		0/5
MPN		0

From the several analysis points, the sample is adjusted potable in accordance with the standards established for the points by the U.S Public Health Service Drinking Water Standards. Thus the design concept of the pyrolysis unit is proven and the high quality of the recovered water is exemplified.

APPENDIX C

PARTS LIST

COMPONENT	PARTS DESCRIPTION	VENDOR NO. or GE DWG. NO.
Germicidal Lamp	U-V Lamp	GE G4T4/1
	Ballast	GE 58C827-60
	Starter	GE FS-5
	Hermetic Switch	Micro 1HS3
Hopper	Cover	Custom
	Seat	689E675
	Air and Water Nozzle	113C8503
	Air Heater	Custom
Pump-Blender	Assembly	103C4139
	Transport Tube	103C4140
	Blender Blade	113B2605
	Pump Blade Rotor	133B2606
	Shaft	133B2604
	Seal	Victor No. 65780
	Bearings	MRC No. 204-S
	Snap Ring	Waldes No. 5100-78
	Retainer	133B2603
	Motor Mount	133B2607
	Air Motor	Gast Mfg. Co. 1AM-NRV39
	Control Valve	Versa VXX4323
8-Way Valve	Assembly	825D213
	Gate	133B2492
	Housing	103C4134
	Manifold	133B2496
	Teflon Seals	133B2497
	O-Ring Seals	Parker 2-220
	Channel	133B2494
	Guide Rail	133B2495
	Bracket	133B2493
	Air Cylinder	Tom Thumb No. AV-R-1 1 1/8x2
	Control Valve	ASCO No. 834511
Still-Pot	Assembly	825D216
	Housing	103C4130
	Heating Coil	103C4147
	Separator	133B2755
	Top Cover	103C4128
	Nut	133B2498
	Sleeve	133B2624
	O-Ring Seal	Parker 2-272
	Cover	133B2491
	Fitting	133B2489
	O-Ring Seal	Parker No. 2-114
Flow Control Valve	Assembly	Jamesbury D88TT
Flush Water Condenser	Assembly	825D220
	Pump	Planet 3000PN-2
	Sprocket	Boston K2572
	Motor Mount	103C4144
	Air Motor	Gast Mfg. Co. 2AM-Fcc-1
	Sprocket	Boston K2548
	Chain	Boston No. 25
	Check Valve	Hoke 585
	Control Valve	Skinner RZDB2200
Pyrolysis Unit	Shut-Off Valve	Jamesbury D88TT-ST20
	Control Valve	ASCO No. 834511
	Assembly	SK56130-403
	Insulation Socket	103C4127
	Housing	113B2601
	Cap Housing	113B2487
	Flange Housing	103C2426

PARTS LIST (Continued)

COMPONENT	PARTS DESCRIPTION	VENDOR NO. or GE DWG. NO.
	Heat Exchanger	103C4125
	Ceramic Dome	133B2477
	Ceramic Spool	133B2479
	Ceramic Spacers	133B2478-80
	O-Ring Seal	Parker 2-118
	O-Ring Seal	Parker 2-140
	O-Ring Seal	Parker 2-154
	Condenser	103C4133
	Pump	Custom
	Control Valve	Skinner B3DA9150
	Air Cylinder	Tom Thumb No. AV-R-1 1/8 x 2
	Check Valve	Hoke 585
Water Filter & Heater	Assembly	103C4129
	Heating Coil	133B2774
	Cap	133B2773
	O-Ring Seal	Parker No. 2-240
	Housing	133C8502
	Fitting	133B2489
	O-Ring Seal	Parker No. 2-114
	Filter Paper	Fischer 9-873
	Filter Screen	133B2750
Urinal	Assembly	103C4141
	Housing	133B2609
	Handle	133B2613
	Sleeve	133B2610
	Cap	133B2611
	Retainer	133B2612
	Diaphragm	133B2614
	Seal	Victor No. 65780
Urine Reservoir	Assembly	103C4143
	Pump	Planet 3000 PN-2
	Sprocket	Boston K2572
	Motor Mount	103C4145
	Support	103C4144
	Air Motor	Gast Mfg. Co. 1AM-NRV39
	Sproket	Boston K2510
	Chain	Boston No. 25
	Control Valve	Skinner CZDA1092
Support Structure	Assembly	689E676
Enclosure		Custom
Electrical Control	Schematic	SK56130-418
	Hermetic Relay	Ohmite DOSHX-40T
	Latching Relay	Ohmite GPRLETRX-7T
	Reset Timer	Cramer 440P
	Continuous Timer	Industrial I4-116
Flush Water Level Indicator		Fenwals Inc. 67021-0
Flush Water Control Valve		ASCO 826230
Urinal Rinse Control Valve		ASCO 82626
Indexing Jet Control Valve		Skinner C2DA1092

APPENDIX D

PROBLEM AREAS

The Hydro-John System was evolved in several stages (See Appendix A) and the design was based on a series of development tests (See Appendix B). However, several system areas have exceeded power, weight and size expectations. Also, the reliability of the components has not been firmly established. In addition the chemical reaction between the urine and feces in the still-pot is not fully understood as far as gas production rates and subsequent gas removal are concerned. These problem areas are further discussed in the following sections.

Pyrolysis Unit Power Requirements

The power required for the pyrolysis unit has exceeded expectation due to increased thermal losses through the insulating jacket. The jacket is used to isolate the 1800°F pyrolysis chamber by use of an evacuated annulus of multi-layer tantalum foil thermal reflectors and Fiberfrax fibers. (See Section III-11.0) During operation of the unit, a vacuum pump is utilized to continuously maintain the jacket annulus at a low pressure. This is necessary to prevent convection currents in the enveloped annulus and to prevent oxidation of the thermal reflectors. However, a gradual degradation of the thermal reflector may result over several operation periods, thus more power will be consumed by the pyrolysis process.

Linde Company has proposed to fabricate a more sophisticated superinsulation jacket. This jacket with multi-layers of copper and quartz would be hermetically sealed at an ultra-low internal pressure with getters to remove trace molecules. The pyrolysis unit power requirement would thus be reduced from 150 watts to 50 watts by the superinsulation jacket and additional vapor heat exchange surface area. The unit is assured of at least two (2) years of operation at this low thermal leakage value.

Blender Blade Failure

The engineering prototype blender blade (See Section III-3.0) has always functioned properly in the limited number of operations during system check-out. However, one failure was encountered with a similar design (less Teflon coating) late in the laboratory breadboard test phase. This failure occurred when a quarter pound slug of dog food (used for feces simulation during demonstrations) adhered to the top of the blender blade and consequently rotated with the blade and was not blended. This failure was investigated and attributed to an abnormal slow rotation of the blade as a major cause. Also the flat surface of the slug and the sticking surface of the blade were possibly contributing factors. Failure of the prototype blender blade has not and should not occur. However, a canted blade surface would appear to offer some advantage over the present design.

Gas Generation in the Still-Pot

The mixing of the urine and feces in the still-pot results in the generation of ammonia and organic gases. These gases join with the vapor flow and dissolve in the reusable flush liquid when condensed. The majority of the organics are removed by an activated charcoal filter, however, only a small amount of the ammonia is removed by the process. Consequently, when the flush water is sprayed through the hopper nozzles during a flushing operation, small quantities of ammonia may escape from the solution and contaminate the cabin atmosphere. There is no provision in the prototype system to remove or control the ammonia which may be liberated to the cabin atmosphere. Additional studies and laboratory tests have shown that a chemical sorbent "Amberlyst" will provide control of the ammonia in the cabin air if it presents a problem.