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ADVANCE PROTOTYPE SILVER ION WATER BACTERICIDE SYSTEM

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CHEMTRIC, INC.

C H E M T R I C, I N C.

9330 WEST WILLIAM STREET

ROSEMONT, ILLINOIS 60018 • 312/671-2755

CHEMTRIC Final Report 3104

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Contract NAS 9-13718

Prepared by:

W. J. Jasionowski

E. T. Allen

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A Subsidiary of AMGLO Industries

FOREWORD

This report summarizes the results of the work performed by CHEMTRIC Incorporated under Contract NAS 9-13718 for an Advance Prototype Silver Ion Water Bactericide System. This program was sponsored by and performed for the Crew Systems Division of the NASA Lyndon B. Johnson Space Center, Houston, Texas 77058. Mr. J. C. Brady (EC3) was the designated Technical Monitor.

The work reported herein was started in September 1973 and completed in June 1974. Chief program personnel were Walter J. Jasionowski (Project Engineer) and Edward T. Allen (Project Chemist) under the direction of Robert A. Bambenek (Program Manager). Other personnel that made substantial contributions to this program are: Phillip P. Nuccio (Design Supervisor), Timothy G. Stadt (Design Engineer) and Andrew L. Murman (Technician). Mr. Charles Verostko of the NASA Johnson Space Center provided assistance by co-ordinating and supervising the analysis of water samples.

ABSTRACT

The design, fabrication, and testing of an Advance Prototype Silver Ion Water Bactericide System are described, along with the development of information to design a Silver Ion Generator for the Shuttle Orbiter. Preliminary tests were performed to verify suitability of components, to establish design data, and determine the effects of operating conditions.

An Advance Prototype Unit was designed and fabricated to treat anticipated fuel cell water. The unit is a single canister that contains a membrane-type prefilter and a silver-bromide contacting bed. A 7-day baseline simulated mission test was performed; the performance was satisfactory and the effluent water was within all specifications for potability. After random vibrations another 7-day simulated mission test was performed; the results indicate that simulated launch vibrations have no effects on the design and performance of the Advanced Prototype. The unit exhibited bactericidal activity against 10^9 (i.e., 10^4 cells/ml) Pseudomonas aeruginosa and or Type IIIa in 15 minutes or less.

Bench tests and accelerated breadboard tests were performed to define the characteristics of an upgraded model of the Advance Prototype Unit which would have 30 days of operating capability. A preliminary design of a Silver Ion Generator for the Shuttle Orbiter was also prepared.

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INTRODUCTION & SUMMARY

1.1 Background

All potable water available on the Space Shuttle Orbiter, except for that initially loaded preflight, will be supplied by fuel cells. The water will be used for consumption, personal hygene, and partial cooling by sublimation. During the past three years, under contracts NAS 9-12104 and NAS 9-12792, CHEMTRIC developed a Preliminary Flight Prototype system to treat "worst case" fuel cell water *,**. For this type of water the system required (1) a biological filter for removing particulates, (2) an activated charcoal and ion exchange resin canister for adsorbing organics and absorbing inorganic contaminants, (3) a silver chloride canister for dosing the stored water with approximately 1 ppm of silver ions to effect the spore forming bacteria, (4) a deionizer for removing the silver ion dose, since the U.S. Public Health Service does not recommend long-term ingestion of water containing more than 0.05 ppm silver ions, and (5) a silver bromide canister with a partial bypass for dosing the deionized product water with a residual of 0.05 ppm silver ions. Simulated mission tests demonstrated that the Preliminary Flight Prototype system does convert "worst case" fuel cell water to potable water, without any maintenance, and that silver ions are bactericidal against Pseudomonas aeruginosa and Type IIIa, the two bacteria which have been found in Apollo water systems.

With the advent of a baseline fuel cell water composition for the Shuttle Orbiter, it was concluded that only two components were necessary - namely, a prefilter and a silver halide contacting bed, since the "anticipated" fuel cell water's properties and ionic species were within the limits specified by the JSC Potable Water Standards. Under contract NAS 9-12792, extended tests verified that a 0.05 ppm silver ion dose in anticipated fuel cell water is bactericidal against Pseudomonas aeruginosa and Type IIIa bacteria. With this knowledge and information NASA JSC contracted CHEMTRIC to design, fabricate, and test an advance prototype silver ion water bactericide system suitable for use in the Shuttle Orbiter potable water system.

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* Hurley, T. L., and Bambenek, R. A., "Potable Water Bactericide Agent Development", NASA CR-115595, July 1972

** Jasionowski, W. J., and Allen E. T., "Preliminary Flight Prototype Potable Water Bactericide System," NASA CR-134135, October 1973

1.2 Objectives

The detail objectives of the program are delineated by the Task Description defined in Section 3.2 of the Statement of Work for Contract NAS 9-13718; they are described as follows.

Par 3.2.1 Advance Prototype Design

The design of an advance prototype silver ion water bactericide system shall be based on the results of the preliminary prototype system extended test program conducted under Contract NAS 9-12792. Preliminary tests shall be performed, as required, to demonstrate the suitability of the selected design concept, to optimize the ratio of silver bromide to activated carbon, to evaluate super saturation phenomena, and to investigate sterilization techniques before the final design is initiated. The advance prototype final design shall include the system design considerations for compatability with the Shuttle Orbiter potable water system - and shall emphasize hardware simplicity for program economy and incorporate the flight characteristics of minimum weight, low pressure drop, maintainability and compactness. Interface requirements, identifying all system constraints, also shall be established to facilitate incorporation of the silver ion water bactericide system into the Space Shuttle potable water system. In addition, a failure modes and effects analysis shall be performed in conjunction with the advanced prototype design.

Par 3.2.2 Advance Prototype Fabrication

An advance prototype of the silver ion water bactericide system shall be fabricated. All materials used in fabrication shall be compatible with the working fluid (fuel cell water) and spacecraft metallic and nonmetallic material requirements. The use of spacecraft incompatible nonmetallics may be considered for economic reasons, but NASA approval shall be required prior to final selection. Type 316 stainless steel shall be used in the fabrication of all major system components.

Par 3.2.3 Advance Prototype Testing

The advance prototype system shall be extensively tested with qualification-type rigor to demonstrate significant hardware maturity for maximum confidence of the Shuttle contractor and minimum program risk. All performance and design limits shall be demonstrated. The prototype system shall be assembled and exposed to the simulated Shuttle launch environment. Following the vibration exposure each component shall be inspected for structural failure, especially in weld areas. The advance prototype shall then be installed in a test stand and "life tested" under simulated Shuttle 7-day mission conditions. Test variables shall include water delivery rates, temperatures, pressure, storage times, water use rates and contamination. This test sequence (vibration exposure and "life test") shall be repeated as necessary to stress the system to the extent that relative design weaknesses of each component shall be uncovered.

A change in scope of work occurred after two 7-day simulated mission tests were performed with the Advance Prototype. In lieu of performing additional 7-day simulated mission tests, the efforts were redirected to collection of information on prefilters and the silver bromide contactor to upgrade the design of the Advance Prototype Unit for mission staytimes up to 30 days, with the constraint that the pressure drop shall not exceed 6900 N/sq m (1.0 psi) at a flow rate of 10.37 kg/hr (22.8 lb/hr). Development tests were performed and a preliminary design of a Silver Ion Generator was prepared.

1.3 Accomplishments

The work performed under Contract NAS 9-13718 yielded the following results and conclusions which are described in further detail on the pages listed in parentheses.

1.3.1 Preliminary Tests

A. A 7-day simulated mission test verified that the preselected filter (Pall Trinity Micro Corporation P/N MCY 4463UR) was satisfactory; it exhibited a pressure drop build-up < 3450 N/sq m (0.5 psi) with a 7-day anticipated particulate load. (p 2-1 to 2-4)

B. Contacting bed definition and optimization tests were performed. The results show that a bed composed of 4 parts activated charcoal to 1 part AgBr granules by volume saturated anticipated fuel cell water with AgBr at the flow rate of 5.63 kg/hr (12.4 lb/hr) and simultaneously maximized the quantity of activated charcoal. (p 2-3, & 2-5 to 2-10)

C. Operations of the AgBr contacting bed at elevated temperatures simulating fuel cell water exit temperature produced silver ion doses above the 0.1 ppm limit specified for potability. At 339°K (150°F) the silver ion content was approximately 0.75 ppm, and at 347°K (175°F) the silver ion content was approximately 1.14 ppm. (p 2-9 & 2-11)

D. Techniques for reducing the super dose which results from elevated temperature operations were investigated. Cooling, seeding, membrane filtration, and ion exchange were experimentally evaluated. Ion exchange was the only technique that reduced the silver ion content to 0.1 ppm. (p 2-9 & 2-12)

E. The effects of steam sterilizing were determined. A mock-up of the advanced prototype unit, when subjected to steam for 3 hrs at 394-408°K (250-275°F), lost less than 0.03% of the AgBr in the condensing steam. (p 2-12 to 2-14)

F. The effects of reduced pressure were investigated. No apparent effects were observed when a mock-up of the AgBr column was subjected to a vacuum of 2 mm Hg; upon rehydration the performance characteristics were the same as before (i.e., silver ion dosing, pressure drop, and effluent turbidity). (p 2-15)

1.3.2 Advance Prototype Design & Fabrication

A. Six design concepts were considered in a Failure Mode, Effects, and Criticality Analyses. The failure modes are: (1) external leakage, (2) internal leakage, (3) channeling, and (4) plugging. The maximum criticality of any possible failure is a level II. Single point failures may be corrected by selection of another canister. (p 3-1 to 3-4)

B. A Reliability Analysis indicates that the probability of no failures during a 7-day mission is 0.9997, and that the probability of no more than one failure is 0.9999... . (p 3-5 & 3-6)

C. On the basis of the FMEA, reliability, and the ground rule considerations for the Shuttle Orbiter, the concept "Parallel Canisters with External Selector Valve" was selected for development as the Advance Prototype. (p 3-6)

D. An Advance Prototype Unit was designed to treat up to 100 kg/day (220 lb/day) of anticipated fuel cell water for mission durations of 7 days. The unit is a single canister which incorporates a membrane-type prefilter and a AgBr contacting bed. (p 3-7 to 3-10)

E. The Advance Prototype Unit was fabricated from 316 stainless steel, except for the seals, prefilter, and the AgBr contacting bed. Brazing with stainless alloys and heli-arc welding was used to join various metallic parts used in the construction. The unit has an overall length of 19.4 cm (7.63 in), and an outside diameter of 9.0 cm (3.53 in); the packed and dry weight is 1.25 kg (2.75 lb). (p 3-10 & 3-11)

1.3.3 Advance Prototype Tests

A. A seven day baseline simulated mission test was performed with the Advance Prototype Unit. The performance of the unit was satisfactory; the effluent water was within all specifications for potability and the pressure drop did not exceed 6900 N/sq m (1.0 psi) at the flow rate of 5.63 kg/hr (12.4 lb/hr). (p 5-1 to 5-3)

B. Test results show that the bactericidal efficacy of the Advance Prototype Unit is as follows. (p 5-3, 5-6, 5-10 & 5-13)

(1) Bacillus subtilis spores (ca 200/ml) are excluded by the biological filter.

(2) The 0.08 ppm silver ion dose is bactericidal against $5 \pm 1 \times 10^4$ cells/ml of Pseudomonas aeruginosa and/or Type IIIa in 15 minutes or less.

(3) The 0.08 ppm silver ion dose is bactericidal against the infusion of 10^6 Pseudomonas aeruginosa and/or Type IIIa at either the hot or cold outlet valve.

C. Random vibration testing of the Advance Prototype Unit showed no detrimental effects. (p 5-8, 5-9 & 5-10)

D. A second seven-day simulated mission test was performed with the Advance Prototype Unit after random vibration. The performance of the unit was satisfactory except for pressure drop build-up on the seventh day of testing; it appears that the Bacillus subtilis spore population on the biological filter had multiplied geometrically, causing an increase in flow resistance. (p 5-8 to 5-14)

1.3.4 Shuttle Orbiter Development Tests

Development tests were performed to collect information to design a Silver Ion Generator (SIG) for the Shuttle Orbiter which will have 30 days of operating capability with given constraints. (p 6-1)

A. Four accelerated breadboard tests were performed simulating the particulate build-up of 30 days from anticipated fuel cell water. The results of these tests indicate the following. (p 6-2 to 6-11)

1. Three Advance Prototype Units as developed (see Section 3.6) connected in parallel will be required; or

2. Ten-inch long prefiltering elements will be required for a single unit design.

3. The membrane-type prefilters exhibit less pressure drop and produce an effluent with less turbidity than the depth-type prefilters.

4. The best prefilter for the SIG is the Pall Trinity Micro Corporation P/N AB1AR8A - on the basis of performance tests, plus the consideration that the media of this element contains no asbestos.

B. A silver bromide column with dimensions to suit the selected prefilter (Pall Trinity Micro Corporation P/N AB1AR8A) was assembled and tested. The column saturated anticipated fuel cell water at the flow rate of 10.37 kg/hr (22.8 lb/hr) and at minimum and maximum temperatures. At 285.8°K (55°F) the Ag^+ dose was 0.035 ppm, and at 296.9°K (75°F) the Ag^+ dose was 0.08 ppm. (p 6-11)

C. Two tests were conducted with bacteria to verify the bactericidal efficacy of 0.035 ppm silver ions in anticipated fuel cell water at 285.8°K (55°F). The results show that a 0.035 ppm silver ion dose killed $5 \pm 1 \times 10^4$/ml *Pseudomonas aeruginosa* and/or Type IIIa cells in 15 minutes or less. (p 6-12 to 6-14)

D. A preliminary design of the SIG recommended for the Shuttle Orbiter was prepared. The unit is a canister with a replaceable subassembly of a prefilter and silver bromide contacting bed. The SIG Unit's overall length is 30.5 cm (12 in) excluding the interface connectors, and its outside diameter is 10.17 cm (4 in); the unit will have a dry weight of 2.09 kg (4.61 lb). (p 6-14 to 6-17)

1.4 Recommendations

This report shows that the technology to develop a silver ion potable water bactericide system suitable for aerospace applications exists. It is recommended that a flight qualified system for the Shuttle Orbiter be developed.

SECTION 2

PRELIMINARY BENCH TESTS

The approach to develop and evaluate the Advance Prototype Silver Ion Water Bactericide System included initially performing a series of preliminary bench tests to verify and establish design data. Preliminary and optimization tests were performed to accomplish the following.

(1) Verify the suitability of the preselected filter.

(2) Determine the optimum ratio of AgBr granules to activated charcoals.

(3) Investigate elevated temperature effects.

(4) Evaluate desupersaturation techniques.

(5) Evaluate the effects of steam sterilization.

(6) Determine the effects of vacuum drying.

2.1 Filter Suitability Test

The performance and characteristics of the selected filter cartridge, Pall Trinity Micro Corporation's P/N MCY4463UR, was determined with particulates in anticipated fuel cell water. Figure 1 illustrates the test set-up; it was the same test bed that had been used under Contract NAS 9-12792, except for a new feed pump with higher capacity. A commercial housing was used in the testing.

A seven-day simulated mission test was performed with anticipated fuel cell water simulant and the various sized particulates. On each test day fuel cell water simulant was pumped into the filter at the maximum rate of 6.82 kg/hr (15 lb/hr) for 6 hours followed by 18 hours at one-half the maximum.

The anticipated fuel cell water simulant contained the following particles.

	Partical Size Range	Approximate Number of Particles per Liter	Concentration mg/l
a.	0 - 10 μ	200,000	0.560
b.	10 - 25 μ	2,000	0.089
c.	25 - 50 μ	400	0.146
d.	50 - 100 μ	200	0.560
e.	100 - 250 μ	20	0.873

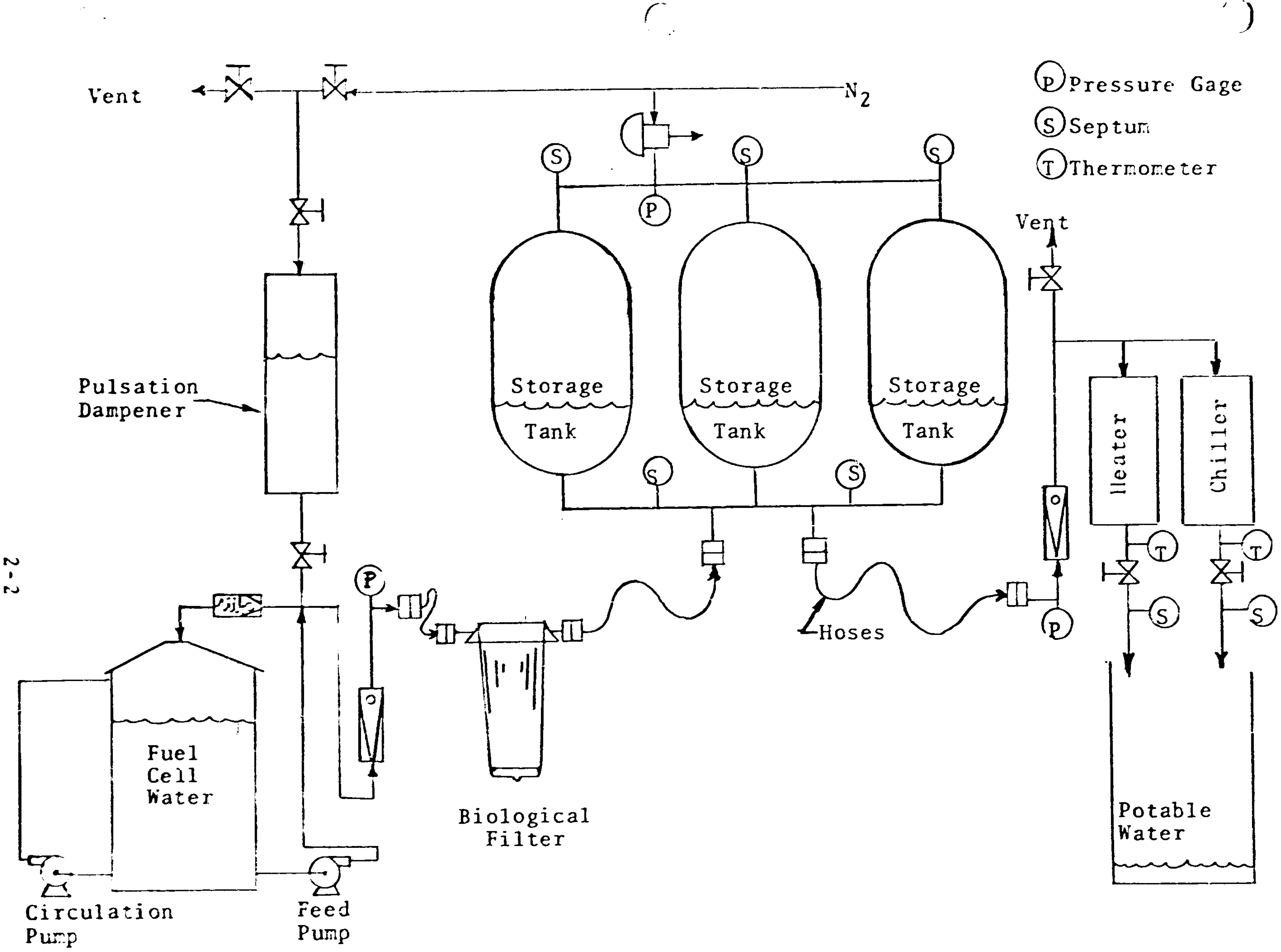


Figure 1 SCHEMATIC FOR FILTER BASELINE TEST

The particulate composition was prepared by utilizing selectively wet sieved (classified) Feldspar in the concentration designated. The classified particles were procured from the International Minerals & Chemical Corporation.

The "dirt" capacity as reported by the manufacturer is 10.9 grams. The "dirt" load for a seven-day mission is about 1.6 grams. Pressure drop data was collected before and after the 7 days to determine the actual pressure drop increase. As the graph on the following page shows, the increase was less than 3450 N/sq m (26mm Hg). Turbidity measurements, taken daily, proved the filter's effectiveness in removing the particulates. The filter was deemed acceptable.

2.2 AgBr-Activated Charcoal Bed Definition Tests

The silver halide colums developed under contracts NAS 9-12104 and NAS 9-12792 utilized contacting beds composed of 6 x 45 mesh silver salts (AgCl and/or AgBr) and glass beads 450 to 500 microns in diameter. The glass beads and silver salts were mixed in a ratio of 1.25 parts glass beads, to one part silver salt. The function of the glass beads was to separate the silver halide particles and prevent their reaggregation. CHEMTRIC recommended that activated charcoal be subsituted for the glass beads to reduce weight and provide some adsorption capacity for small quantities of organics.

NASA's "Space Shuttle Fluid Procurement and Use Control Specification", SE-S-0073A, was revised with respect to silver ion content. The potable water limit for silver ions was increased from 0.05 mg/liter to 0.1 mg/liter. This modification simplified silver ion dosing. The solubility of silver bromide at cabin temperatures 288.5-303.7^{o}K (60-80^{o}F) would limit the silver ion content to a range between 0.043 to 0.085 ppm and obviate the need for partial bypassing as employed in the Preliminary Flight Prototype System.

Bench tests were therefore performed with AgBr granules and activated charcoals (3 parts by weight Westvaco WV-G and 2 parts by weight Union Carbide Columbia LCJ) packed into a PVC tube which approximated the core dimensions of the filter cartridge (i.e., 2.0 cm in diameter and 12.7 cm long). The objective of these tests was to determine the ratio of AgBr granules to activated charcoal which saturated anticipated fuel cell water with silver ions at ambient temperatures and also maximized the amount of activated charcoal.

C H E M T R I C

2-4

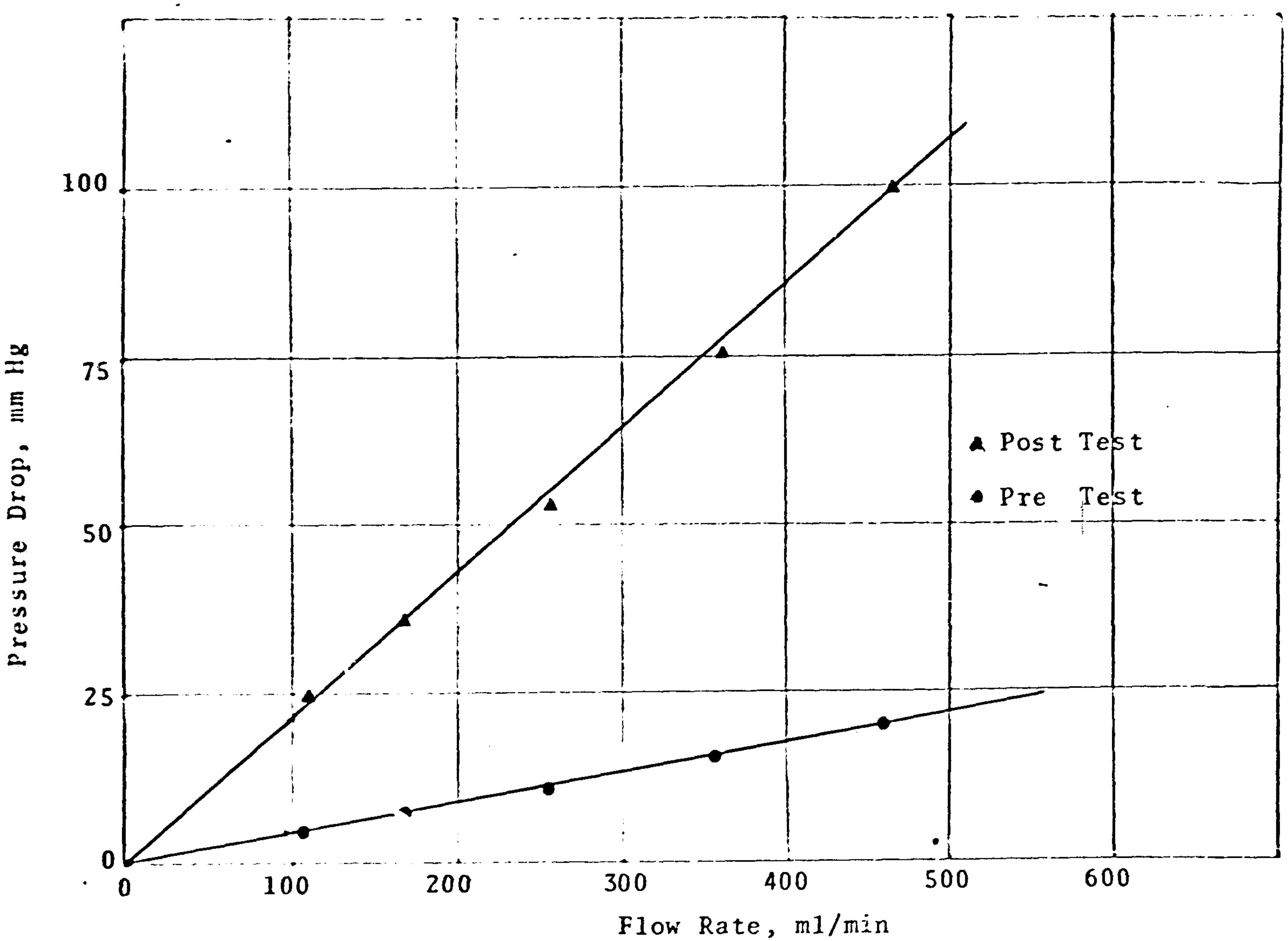


Figure 2 FLOW RESISTANCE OF MCY4463 UR FILTER

Figure 3 illustrates the test set-up that was used; a commercial housing and filter element were employed. The silver ion dosing cartridge (i.e., the PVC tube) was packed with 40 cm^3 of AgBr granules and activated charcoals. Experiments were performed with various ratios (e.g., 2:1, 3:1, or 4:1) of activated charcoals to AgBr granules (by volume), at various anticipated flow rates (e.g., 5.63 kg/hr, 6.82 kg/hr and/or 11.37 kg/hr). The performance of the silver ion dosing configuration was determined by measuring with atomic absorption the silver concentration of the effluent.

Table 1, which gives the results of these tests, shows that a ratio by volume of 4 parts activated charcoals to 1 part AgBr granules does in fact saturate the anticipated fuel cell water with silver ions at ambient temperatures while maximizing the volume of activated charcoals.

Table 1 RATIO TESTS

Test 1

Ratio:	1.7/1
	25 cc (29.2 g) Activated Charcoal
	15 cc (19.8 g) AgBr
Flow Rate:	5.63 kg/hr (12.4 lb/hr)
Ag^+ at 296°F(74°F):	80 - 85 ppb

Test 2

Ratio:	3/1
	30 cc (36.7 g) Activated Charcoal
	10 cc (15.0 g) AgBr
Flow Rate:	5.63 kg/hr (12.4 lb/hr)
Ag^+ at 296°F(74°F):	80 - 85 ppb

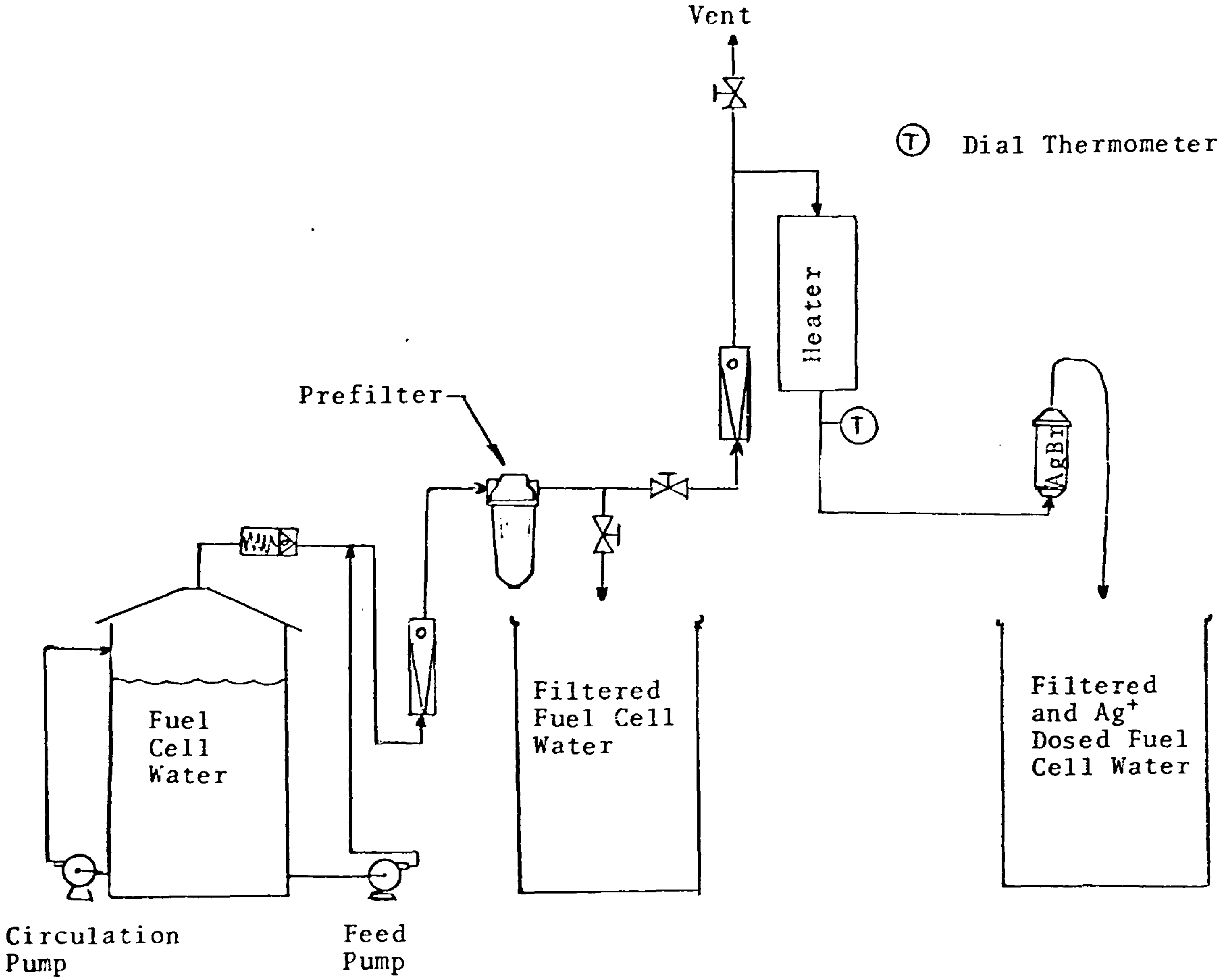


Figure 3 BENCH TEST SYSTEM

Table 1 (continued)

Test 3

Ratio:	4/1
	32 cc (40.2 g) Activated Charcoal
	8 cc (11.6 g) AgBr
Flow Rate:	5.63 kg/hr (12.4 lb/hr)
Ag^+ at 295°K(72°F):	80 - 85 ppb

Test 4

Ratio:	4.9/1
	34 cc (44 g) Activated Charcoal
	7 cc (10.2 g) AgBr
Flow Rate:	5.63 kg/hr (12.4 lb/hr)
Ag^+ at 296°K(74°F):	70 - 75 ppb

Test 5 (repeat of Test 3)

Ratio:	4/1
	32 cc (40.2 g) Activated Charcoal
	8 cc (11.6 g) AgBr
Flow Rate:	5.63 kg/hr (12.4 lb/hr)
Ag^+ at 296°K(74°F):	80 - 85 ppb

Test 6

Ratio:	4/1
	32 cc (40.2 g) Activated Charcoal
	8 cc (11.6 g) AgBr
Flow Rate:	11.37 kg/hr (25 lb/hr)
Ag^+ at 296°K(74°F):	25 - 30 ppb

Table 1 (concluded)

<u>Test 7</u>	
Ratio:	2/1
	26.5 cc (31.4 g) Activated Charcoal
	13.5 cc (18.1 g) AgBr
Flow Rate:	11.37 kg/hr (25 lb/hr)
Ag^+ at 296°K(74°F):	80 - 85 ppb
<u>Test 8</u>	
Ratio:	3/1
	30 cc (36.7 g) Activated Charcoal
	10 cc (15.0 g) AgBr
Flow Rate:	11.37 kg/hr (25 lb/hr)
Ag^+ at 296°K(74°F):	80 - 85 ppb
<u>Test 9</u>	
Ratio:	4/1
	32 cc (40.2 g) Activated Charcoal
	8 cc (11.6 g) AgBr
Flow Rate:	6.82 kg/hr (15 lb/hr)
Ag^+ at 296°K(74°F):	80 - 85 ppb
<u>Test 10</u>	
Ratio:	4.4/1
	31 cc (38.5 g) Activated Charcoal
	9 cc (13.3 g) AgBr
Flow Rate:	6.82 kg/hr (15 lb/hr)
Ag^+ at 296°K(74°F):	55 - 60 ppb

Also, pressure drop tests were conducted to determine the flow resistance created by the packed bed. As Figure 4 shows, determinations were made with different ratios of activated charcoal to AgBr and with slightly different volumes of the mixture. These slightly varied tests produced similar results of less than 3450 N/sq m (26 mm Hg) pressure drop at the anticipated flow rate of 6.83 kg/hr (113.5 ml/min).

2.3 Elevated Temperature Tests

For these tests, simulated fuel cell water was filtered, heated, and then passed through the 40 cc column of 4/1 ratio charcoal to AgBr. As expected, the solubility of the AgBr increased as the temperature of the water increased causing a supersaturated condition to occur; see Figure 5. The resultant silver-ion doses were as follows.

Temperature	Ag^+ Concentration
296°K (74°F)	80 - 85 ppb
339°K (150°F)	approx. 750 ppb
347°K (175°F)	approx. 1140 ppb

Ratio tests were conducted to determine if using a very small amount of AgBr at a water temperature of 347°K (175°F) would dose the water the Ag ions at a level less than 100 ppb. The rationale was to treat the water at 347°K (175°F), the fuel cell's water exit temperature, without further need of desupersaturation before ingestion. Two ratios by volume (i.e., 9 parts activated charcoal to 1 part silver bromide, and 20 to 1, respectively) were tested. At a flow rate of 11.37 kg/hr (25 lb/hr), the Ag^+ dosage was approximately 1150 ppb at 147°K (175°F) in both test cases. Since a 20 to 1 ratio allows only 2 cc of AgBr, further reductions were deemed impractical.

2.4 Desupersaturation Techniques

Since an upper limit of 100 ppb Ag exists for potability, desupersaturation techniques were evaluated. Four methods were studied - namely, cooling, recycling or seeding, filtering and ion exchange resins.

2.4.1 Cooling

Cooling to 277.4°K (40°F) samples collected at 339°K (150°F) and 347°K (175°F) with respective silver doses lowered the silver content level to approximately 320 ppb in both cases. Repeated tests showed duplicate results.

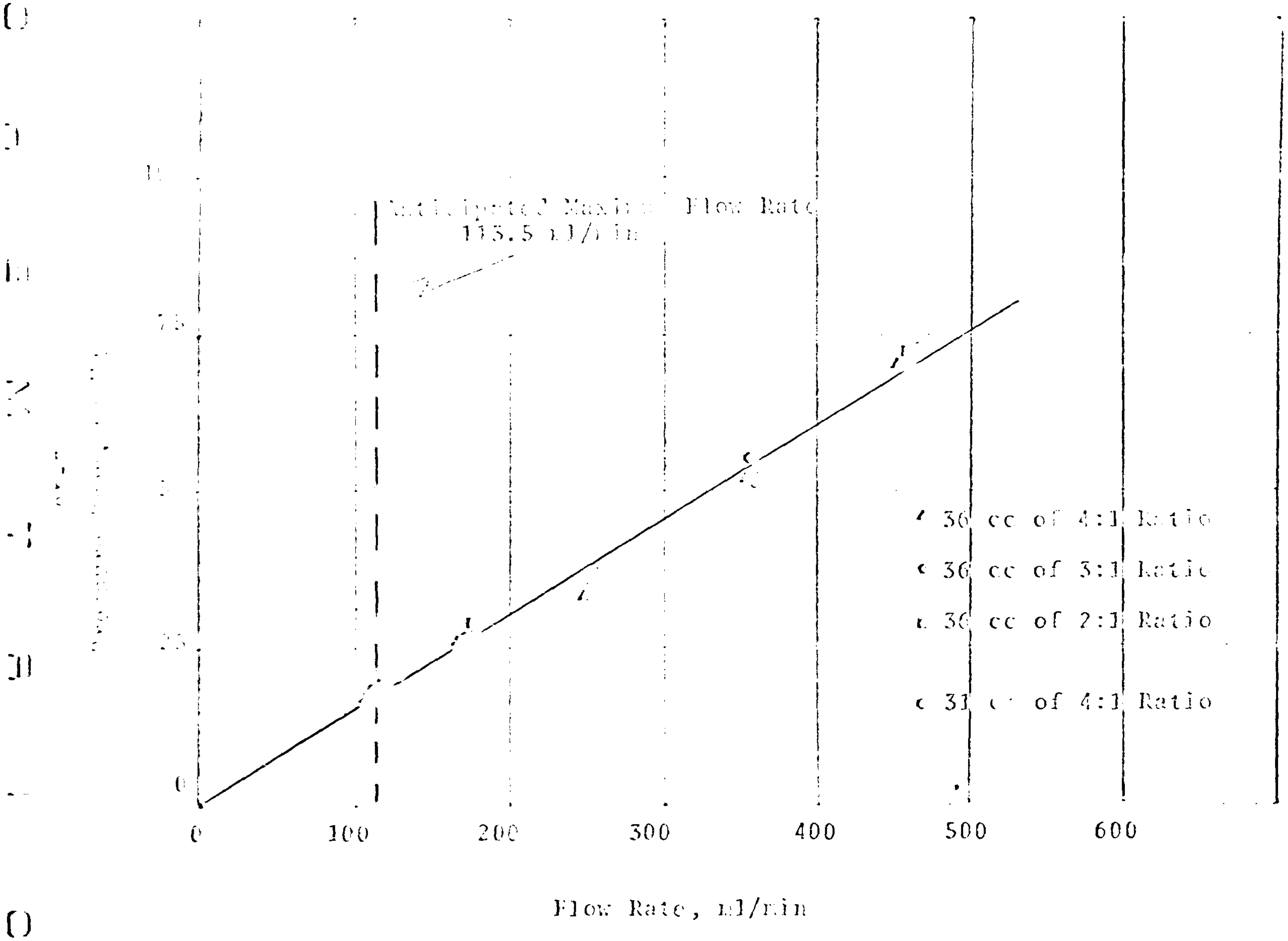
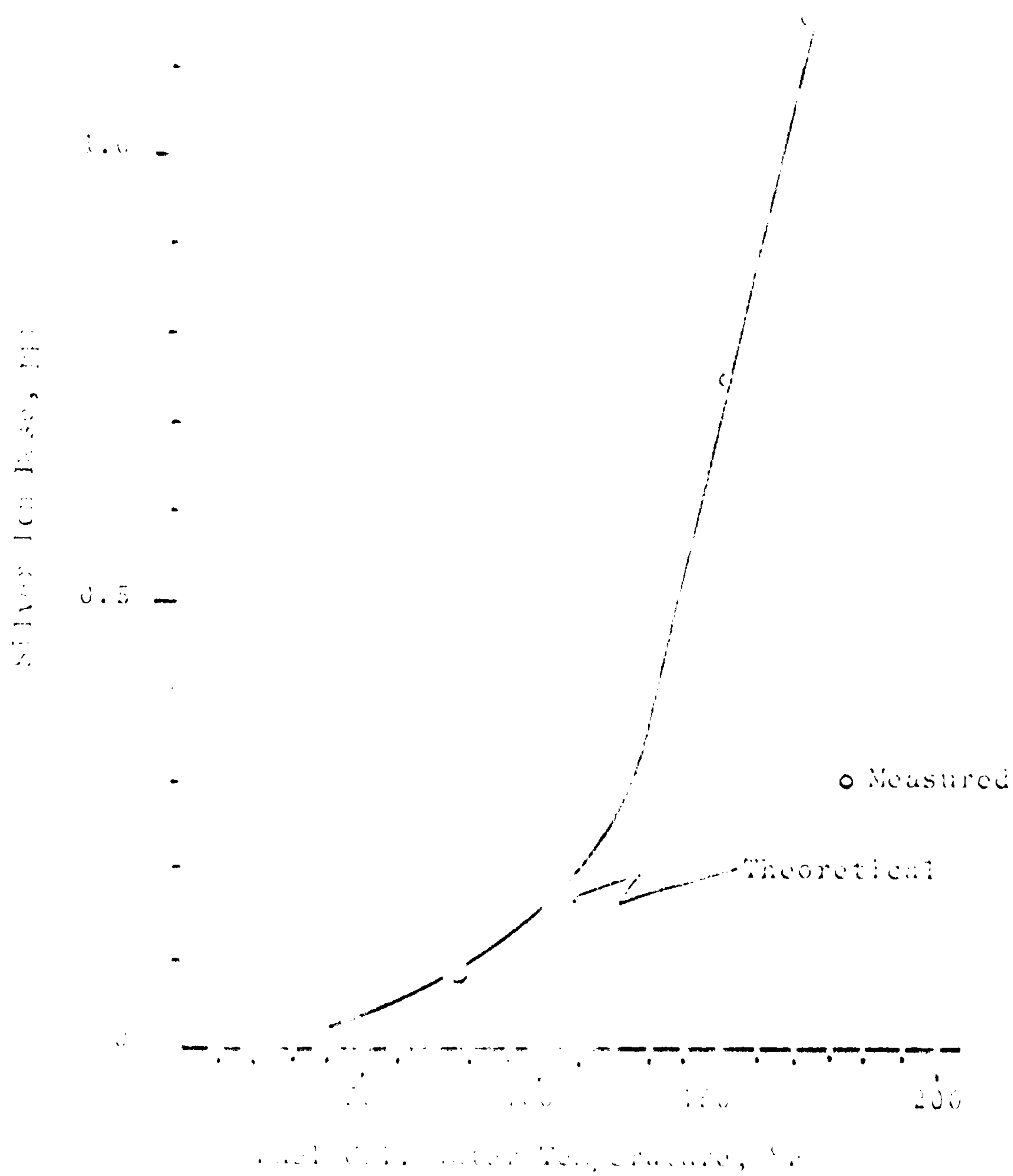


Figure 4 FLOW RESISTANCE OF PACKED CORE



0.5
200
Measured
Theoretical

2.4.2 Recycling or Seeding

Samples collected at 339°K (150°F) and 147°K (175°F) after cooling were recycled through the AgBr column at 296°K (74°F). This recycling or seeding lowered the Ag ion content in the effluent to approximately 300 ppb. Measurements taken after 3, 6, and 10 subsequent recycled passes showed no significant change from the 300 ppb level.

2.4.3 Filtration

The use of a membrane filter was also studied as a technique for the desupersaturation of Ag+ dosed water. Millipore filters of pore sizes 100 mμ, 50 mμ, and 25 mμ were used. This technique did not prove effective for reducing a supersaturated Ag+ dosage to the potability level of less than 100 ppb. This conclusion is based on the following test results:

at 347°K (175°F)	Ag+ dosage of 1140 ppb
cooled to 297°K (75°F)	Ag+ dosage of 330 ppb
Filtered at 297°K (75°F) 100mμ	Ag+ dosage of 300 ppb
50mμ	Ag+ dosage of 220 ppb
25mμ	Ag+ dosage of 220 ppb

2.4.4 Ion Exchange

Ion exchange resins were found to be effective. Samples of the 339°K (150°F) and 347°K (175°F) Ag+ dosed fuel cell water was passed through a mixed-bed, ion-exchange resin column with a volume of 450 ml. Using a flow rate of 6.82 kg/hr (15 lb/hr), both the 750 ppb and 1140 ppb level water was reduced to 10 ppb Ag+. A subsequent test at 11.37 kg/hr (25 lb/hr) flow rate on the similar samples proved just as effective in reducing the Ag+ content to <10 ppb.

2.5 Steam Sterilization Tests

Steam sterilization tests were conducted to determine the amount of AgBr which might be lost during a steam sterilization cycle of 394-408°K (250-275°F) for 3 hours. Figure 6 illustrates the test set-up that was used. A metallic commercial housing was employed and the core of the filter element was packed with the "optimum" ratio of activated charcoals to AgBr granules. Steam from an electric boiler heated up the test bed to 394-408°K (250-275°F) and maintain it at 394-408°K (250-275°F) for three (3) hours. The steam source was then shut-off and the test bed allowed to cool to ambient temperatures. The resultant condensate was drained and analyzed for pH, specific resistance, turbidity,

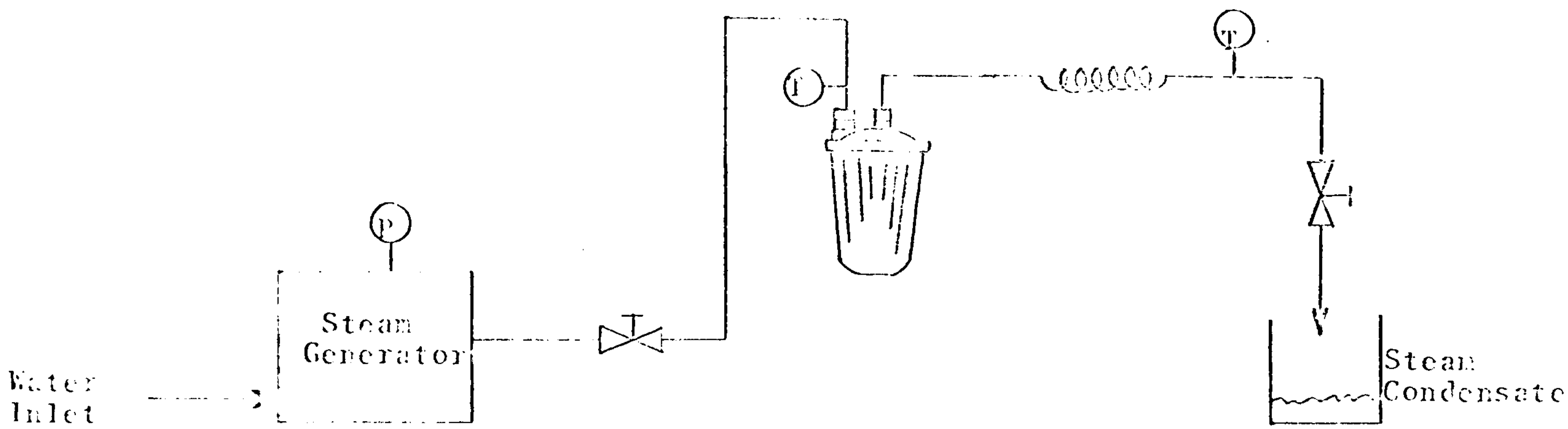


Figure 6 SCHEMATIC FOR STEAM STERILIZATION

COD, total solids, and silver concentration. The quantity of AgBr expended was then determined.

Four tests were conducted giving similar results. The amount of AgBr was diminished less than 0.03% by weight. These results were obtained by measuring the Ag ion concentration in the condensate by atomic absorption and converting the concentrations to mg AgBr. The results of these tests are summarized as follows.

Test No. 1 — 3 hrs at 394-408°K (250-275°F)

Ratio 4:1; 27.8g (28cc) charcoal: 9.2g (7cc)AgBr

	Volume	Ag+ Conc.
Steam Vent Condensate	1170 ml	Trace
Filter Housing Condensate	60 ml	1140 ppb

0.026% loss of AgBr by weight

Test No. 2 — 3 hrs at 394-408°K (250-275°F)

Ratio 4:1; 27.8g (28cc) charcoal: 9.2g (7cc)AgBr

	Volume	Ag+ Conc.
Steam Vent Condensate	1050 ml	Trace
Filter Housing Condensate	60 ml	1050 ppb

0.024% loss of AgBr by weight

Test No. 3 — 3 hrs at 394-408°K (250-275°F)

Ratio 4:1; 27.8g (28cc) charcoal: 9.2g (7cc)AgBr

	Volume	Ag+ Conc.
Steam Vent Condensate	1850 ml	Trace
Filter Housing Condensate	50 ml	1100 ppb

0.021% loss of AgBr by weight

Test No. 4 — 3 hrs at 394-408°K (250-275°F)

Ratio 4:1; 27.8g (28cc) charcoal: 9.2g (7cc)AgBr

	Volume	Ag+ Conc.
Steam Vent Condensate	1000 ml	Trace
Filter Housing Condensate	50 ml	1100 ppb

0.021% loss of AgBr by weight

2.6 Vacuum Tests

A series of three vacuum tests were performed to determine the effect of subjecting the packed core mixture of silver bromide and activated charcoals to an evacuated atmosphere. A wet packed core of silver bromide granules and activated charcoals was placed in a bell jar. The atmosphere in all three tests was then evacuated to a pressure of 2 mm Hg for at least one hour. The packed core was then reattached to a simulated fuel cell water source. Measurements taken before and after the reduced atmospheric condition showed no change. The effluent of the packed bed had a silver concentration of 80-85 ppb, and a turbidity of about 0.10 JTU during both pre-test and post-test readings. Also, the bed had no change in pressure drop as a result of the test.

ADVANCE PROTOTYPE UNIT DESIGN

An advance prototype silver ion water bactericide system was to be designed, fabricated, and tested under contract NAS 9-13718. The design was to be based upon the results of contract NAS 9-12792, and the results of the preliminary tests. The design was to emphasize hardware simplicity and include the flight characteristics of minimum weight, low pressure drop, maintainability, and compactness. The design must be compatible with the Shuttle Orbiter potable water system which has characteristics as follows:

a.	Water Supply	Fuel Cell
b.	Supply Flow Rate	5.63 kg/hr (12.4 lb/hr)max.
c.	Fuel Cell Exit Temp.	339-347°K (150-175°F)
d.	System Pressure	124,000-276,000 N/sq ma (18-40 psia)
e.	Water Delivery Flow Rate	Up to 27.2 kg/hr (60 lb/hr)
f.	Water Delivery Temperature	Hot 339 to 344°K (150-160°F) Cold 277.4-288.6°K (40 to 60°F)
g.	Water Delivery Pressure	207,000 N/sq md @ 22.7 kg/hr (30 psid @ 50 lb/hr)

After receipt of the contract, it was agreed that the advance prototype was to treat 626 kg (1377 lb) of anticipated fuel cell water per 7-day nominal mission, i.e., 89.3 kg/day (196.7 lb/day); in case of contingencies, it was decided that the unit would treat up to 100 kg/day (220 lb/day). During a review meeting on December 11, 1973 at NASA JSC, it was further agreed that the interface connectors were to be quick-connects and that the advance prototype would treat fuel cell water at cabin temperatures because the stored water would be at these temperatures.

3.1 Failure Modes & Effects Analyses (FMEA)

The failure modes and effects analyses presented in Appendix A represent the hypothesized failure modes, effects, and the criticality for six different design concepts. The objective of these analyses was to determine possible modes of failure, the effects of failure, and to provide the design criteria required to remove the susceptibility of such failures.

3.1.1 Procedure

An FMEA was completed for each design concept considered. The analyses was conducted to the part level.

The failure mode catagories used in the FMEA are defined below:

Category I Failure - A single failure which could cause loss of personnel.

Category II Failure - A single failure that could cause loss of subsystem function(s) essential to continuation of space operations and scientific investigation.

Category III Failure - A single failure which could not result in loss of primary or secondary mission objectives or adversely affect crew safety.

3.1.2 Example

Design Concept: Single Canister (No Valves)

Appendix Pages: A-1 and A-2

Failure Mode and Cause: External leak-seal or metal failure

Failure Effect on Performance: Water leaks into cabin

Failure Effect on Mission: High humidity, possible contamination and insufficient water.

Criticality: II

Detection Method: Visual, high humidity, and/or low quantity.

Crew Action Required: None possible

3.1.3 Results

Six design concepts were considered for analyses; they are as follows:

1. Single Canister
2. Replaceable Canister

3. Parallel Canisters with Integrated Selector Valves

4. Parallel Canisters with Selector and Check Valves

5. Series Connected Canisters with Isolation By-Pass Valves

6. Parallel Canisters with External Selector Valve

The failure modes are: (1) external leakage, (2) internal leakage, (3) channeling, and (4) plugging. It is assumed that tubing and valve housings have reliability of 1.0. If external leakage occurs water leaks into the cabin; the resultant effects are high humidity, possible contamination and reduced water supply. If internal leakage occurs water may bypass the membrane (biological) filter and the AgBr - Activated Charcoal Column; the resultant effects are the water may contain more solids, less silver ions, more organics, and possibly microorganisms. If channeling occurs, water may bypass AgBr - Activated Charcoal particles; the resultant effects are the water may contain less silver ions, more organics, and possibly microorganisms. If plugging occurs the water supply diminishes; the resultant effects are dehydration of the crew and loss of coolant. The maximum critically of any possible failure is a level II.

Concepts, 4, 5, and 6 are acceptable since single point failures may be corrected by selection of another canister.

The analyses further indicate the design of the Advance Prototype should minimize the failure modes. The probability for external leakage will be reduced by the use of welding and/or nickel-based stainless brazing alloys for joining, and a single removable seal of the "O" ring variety. Corrosion induced leakage, external or internal, will be minimized by material selection (316 SS), elimination of crevices, heat treatment, and passivation. A spring will be used to retard AgBr - Activated Charcoal bed shifting which can promote channeling; this restraint will reduce the probability of particle disintegration which could plug the outlet bed retainer (Pyrex wool).

A combination of stainless steel screens and Pyrex wool will be used as the AgBr - Activated Charcoal bed retainer. This arrangement provides "depth-type" filtration and is less prone to plugging than a "membrane-type" of retainer. The area of the "membrane filter" (i.e., the biological filter) used to protect the packed bed of AgBr - Activated Charcoal particles will be maximized to minimize plugging and pressure drop.

3.2 Component Failure Rates

The following failure rates were complied to predict expected failures of components and reliability. The failure rates for plumbing, valve housings, ducting, and structural members were assumed to be negligible. The failure rates utilized were based on information published in the "System Reliability Report", SSP Document Number A22 - Phase II A, Hamilton Standard Division of United Aircraft Corporation, June 4, 1971.

2 Way Selector Valve	Failure Rate (λ)
External Leakage	0.001×10^{-6}/hour
Metal Failure	0.400
2 Sliding O-rings	
Internal Leakage	
2 Sliding O-rings in series	0.020
	0.421×10^{-6}/hour

Canister	
External Leakage	
Metal failure	0.001×10^{-6}/hour
Static O-ring	0.055
Internal Leakage	
2 Static O-rings	0.110
2 Compression springs	0.040
Filter tears or cracks	0.200
Column channeling	0.400
Final Filter Plugs	0.160
	0.966×10^{-6}/hour

Check Valve	
External Leakage	
Metal failure	0.001×10^{-6}/hour
Static O-ring	0.055
Internal Leakage	
Poppet	0.116
Spring failure	0.020
	0.192×10^{-6}/hour

Isolation Valve with By-Pass

External Leakage	
Metal failure	0.001×10^{-6}/hour
2 Static O-rings	0.110
Internal Leakage	
2 Pairs of sliding O-rings in series	0.040
	0.151×10^{-6}/hour

3.3 Reliability

Utilizing the component failure rate information complied in Section 3.2, the expected failures and the reliability for a 7-day mission were calculated for design concepts 4, 5, and 6. Design concepts 4 and 6 are identical in these analyses.

3.3.1 Parallel Canisters with Integrated Selector & Check Valves and/or Parallel Canisters with External Selector Valve (Concepts 4 & 6)

3.3.1.1 Chance Failure Rate with 1st Canister

2-Way Selector Valve	=	0.0421×10^{-6}/hour
Canister	=	0.966
Check Valve	=	0.192
		1.579×10^{-6}/hour

3.3.1.2 Probability of No Failures During 7-Day Mission

$$R = e^{-1.58 \times 10^{-6} \times 24 \times 7} = e^{-265 \times 10^{-6}}$$

$$R = \frac{1}{e^{2.65 \times 10^{-4}}} = \frac{1}{1.000265} = 0.9997$$

3.3.1.3 Probability of No More Than One Failure

$$R = e^{-2t}(1 + 2t)$$

$$R = 0.9997\ (1 + 2.65 \times 10^{-4})$$

$$R = 0.9997\ (1.000265) = 0.9999....$$

3.3.2 Series Connected Canisters with Isolation/By-Pass Valves (Concept 5)

3.3.2.1 Chance Failure Rate with 1st Canister

1st Isolation Valve	=	0.151×10^{-6}/hour
Canister	=	0.966
2nd Isolation Valve	=	0.151
		1.268×10^{-6}/hour

3.3.2.2 Probability of No Failures During 7-Day Mission

$$R = e^{-1.27 \times 10^{-6} \times 24 \times 7} = e^{-213 \times 10^{-6}}$$

$$R = \frac{1}{e^{2.13 \times 10^{-4}}} = \frac{1}{1.000213} = 0.9997$$

3.3.2.3 Probability of No More Than One Failure

$$R = e^{-2t} (1 + 2t)$$

$$R = 0.9997 (1 + 2.13 \times 10^{-4})$$

$$R = 0.9997 (1.000213) = 0.9999....$$

3.3.3 Conclusions

On the basis of the FMEA and reliability, concepts 4, 5, and 6 are essentially equal. However, the ground rules for Shuttle indicate that concept 6, namely, "Parallel Canisters with External Selector Valve" is the preferred design and it was selected as the design to be developed as the Advance Prototype.

3.4 Safety

The design and performance deficiencies and category of failure were identified in Section 3.1, Failure Modes & Effects Analyses. There are no apparent mechanical safety hazards in the design. The interfacing quick-connects with double end shut-off provide reliable and safe hydraulic and mechanical connections. Maintenance (i.e., replacement and/or changing of an Advance Prototype Unit) on the ground or inflight is facilitated by the quick-connects.

Sterility requirements dictate no ground or inflight repair at the component level. The design of the flight unit should provide positive means to prevent canister disassembly.

3.5 Quality Assurance

The advance prototype unit is a unique chemical dosing apparatus and its performance is related to chemiophysical processes and the materials of construction. The unit was designed and fabricated in accordance to CHEMTRIC drawings and specifications. All specially fabricated parts were inspected and accepted at the manufacturing source. After receiving and inspection, the prefilter and the materials for the contacting bed were prepared, packed, and sterilized in accordance to procedures developed by CHEMTRIC. In the testing and evaluation of the advance prototype, standard methodology was utilized and certified chemical standards were employed in the calibration of instruments used to determine and verify performance characteristics. A quality assurance engineer was not employed to review, monitor or witness these tasks; these activities were performed by the program personnel.

The design emphasizes control of corrosion. The canister, V-band, bracket, springs, and the internal supporting parts were fabricated from 316 stainless steel. Brazing and welding were used to join elements; butt joints were used in lieu of lap-type unions. The unit was heat treated and annealed to minimize the potential for intergranular corrosion, and then passivated. Subsequent cleaning and decontamination procedures were performed, without the use of abrasives, to preserve the integrity of the passivated surfaces.

3.6 Design

Figures 7 and 8 show the Advance Prototype Unit that was developed under this program. As shown, the design is a single canister. It consists of a two piece housing fastened by a V-band clamp, a filter cartridge, and a contacting bed of silver bromide granules and activated charcoals. The design includes constraints for vibration by spring loading. Maintainability for re-use of the system is provided by quick connects in the head of the housing.

Fuel cell water enters the Advance Prototype Unit via an inlet port and is distributed by a manifold into the housing. The water then flows radially through the filtering element; the particulates and bacteria are excluded. The filtered water then flows axially through the silver bromide-activated charcoal column where the water is dosed with silver ions and

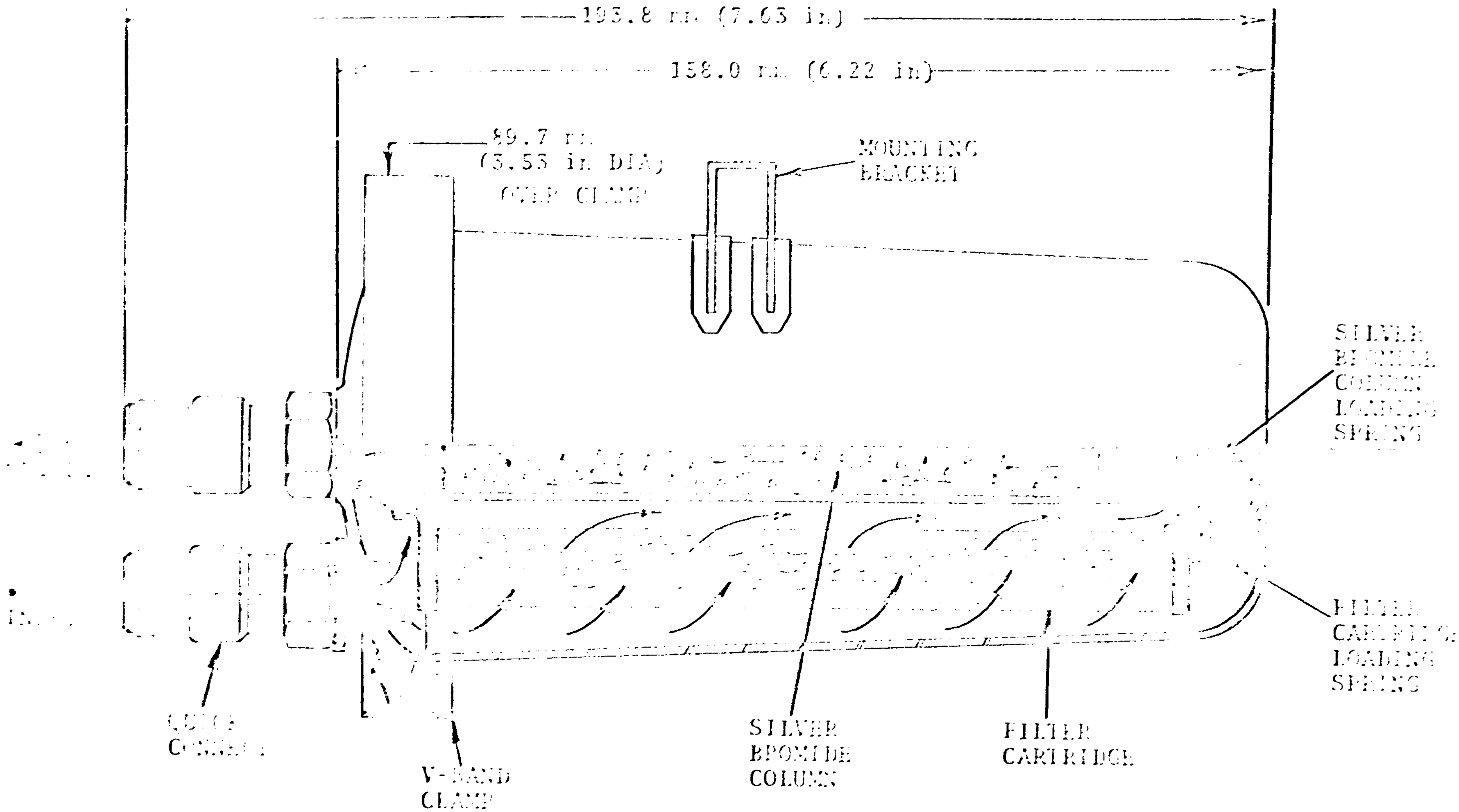


Figure 7 ADVANCE PROTOTYPE UNIT DESIGN

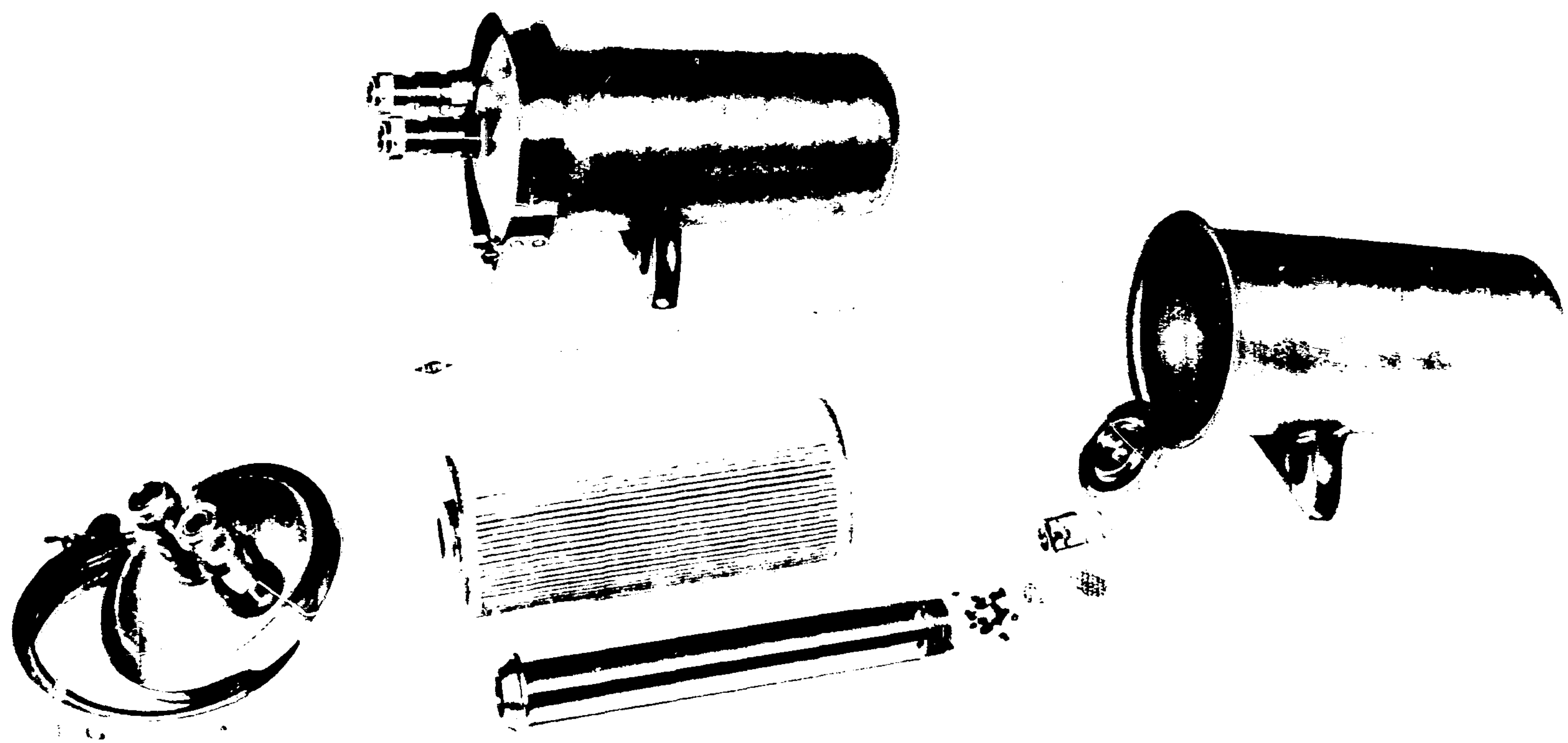


Figure 8 ADVANCE PROTOTYPE UNIT

small quantities of organics are adsorbed by the activated charcoals. Finally, the water flows axially out of the cartridge which contains the column of AgBr granules, through the outlet port, and into the storage tanks.

The filter cartridge (Pall Trinity Micro Corporation's MCY 4463CR) is 13.2 cm (5.25 in) long and has an outside diameter of 5.57 cm (2.1875 in). It has a pleated membrane-type filter area of 0.186 sq m (2.0 sq ft). The filtering element is rated for absolute retention of all particles 0.35 microns and larger and 98% of all particles as small as 0.15 microns. The filtering medium is a sheet of extremely fine inert inorganic fibers with an inert organic binder, melt-sealed to polypropylene end caps which are in turn melt-sealed to a perforated polypropylene internal support core; the differential pressure rating is 517,000 N/sq md (75 psid). At the anticipated maximum flow rate of 5.63 kg/hr (12.4 lb/hr), the ΔP across the filter cartridge is approximately 2070 N/sq m (0.3 psi). With a 7-day anticipated particulate load and at the maximum flow rate of 5.63 kg/hr, the pressure drop across the filter cartridge is approximately 3450 N/sq m (0.5 psi).

The silver-bromide activated-charcoal contacting column is contained within a cartridge; the diameter of the column is 17.2 mm (0.680 in) and the length is 129.4 mm (5.1 in). The column contents is composed of 24 cu cm (30.2 g) of activated charcoals and 6 cu cm (9.0 g) of AgBr granules, 12 x 45 mesh. At the anticipated maximum flow rate of 5.63 kg/hr (12.4 lb/hr), the pressure drop across the column is approximately 2070 N/sq m (0.3 psi). At cabin temperatures 288.7°K (60-80°F) and at a flow rate of 5.63 kg/hr the fuel cell water is passively dosed with 0.04-0.085 ppm of silver ion respectively. The activated charcoal is a mixture 2 parts by weight, 12 x 45 mesh, Union Carbide Columbia LCU and 3 parts by weight, 12 x 28 mesh, Westvaco Nuchar WV-G; the activated charcoal particles separate the silver bromide granules to prevent their reaggregation and adsorb small quantities of organics. At ambient temperature, the quantity of AgBr (9g) can theoretically dose up to 61,000 kg (134,000 lb) of fuel cell water.

The metal of construction is 316 stainless steel. All metal-to-metal joining was accomplished by brazing with AMS 4777, (a nickel-base, stainless-type alloy) or by heli-arc welding. After brazing or welding, the unit was heat treated to a fully stressed-relieved condition to maximize corrosion resistance, and then passivated.

3.7 Interface Requirements

The interface requirements for the Advance Prototype are as follows:

A. Mechanical
   1. Weight (packed and wet) - 1.25 kg (2.75 lb)
   2. Dimensions - 19.4 cm (7.63 in) x 9.0 cm (3.53 in)
   3. Two Fasteners - to be determined

B. Electrical - Class S Bonding

C. Thermal
   1. Minimum Temperature 277°K (40°F)
   2. Maximum Temperature 303°K (86°F)

D. Hydraulic - Two Quick-Connects with double end shut-off (Swagelock P/N 400-QC-200 DESO - 316 SS or Equivalent)

The Advance Prototype Unit is to be installed in the potable water system downstream of the fuel cells and upstream of the water storage tanks. A heat exchanger will be required to cool the fuel cell water; the influent water should be at a temperature of 294-297°K (70-75°F). If the influent fuel cell water is at the fuel cells exit temperature, 339-347°K (150-175°F), the water will be dosed with 0.75 to 1.1 ppm of silver ion and will not be within the silver ion concentration required (0.1 ppm max).

Maintenance of a flight unit is required on two levels; on the ground, to permit refurbishment of the system for the next flight, and in the vehicle, to provide reliable and safe hydraulic and mechanical connections. Quick-Connects with double end shut off were selected to make the connections and to minimize turn-around time. Utilization of Quick-Connects also permits in-flight maintenance to increase reliability or to extend mission capability with spare units.

TEST PROCEDURES & METHODS

4.1 Simulated Mission Test Definition

Two simulated mission tests (SMT), each seven days (168 hours) of continuous operation, were performed. The main characteristics were as follows.

1. Water Management Routine - A fixed water management routine, based on a typical crew duty cycle, was imposed on each SMT.

2. Fuel Cell Water Simulant - A fixed "anticipated" fuel cell water composition, based on data listed in paragraph 3.3.4 of the Statement of Work, was used in each SMT.

3. Pressurant Gas - Nitrogen was employed.

4. Baseline Water Sampling and Analysis - A basic routine of taking water samples for specific analyses was applied on each test day of each SMT; this routine was used for key performance characteristics as well as overall evaluation of the system.

5. Bacteria Challenges - A specific quantity of the bacteria designated for the Advance Prototype SMTs was introduced at specific locations on specified days of each SMT; the pattern of test day and challenge location was repeated in the SMTs as well as any sampling procedures instituted to support evaluation of the specific challenge.

Each of the above main SMT characteristics are described in detail in the following sub-sections. Wherever appropriate, supporting rationale is also presented.

4.1.1 Water Management Routine

On each test day the anticipated fuel cell water simulant was pumped into the Advance Prototype Unit at the nominal rate of 3.62 kg/hr (8.2 lb/hr) for 16 hours, 5 hours at the maximum rate of 6.82 kg/hr (15 lb/hr), and 3 hours at the minimum rate of 1.87 kg/hr (4.1 lb/hr). All product water was drained off during the last 4 hours at flow rates up to 27.3 kg/hr (60 lb/hr).

The nominal and maximum rates are based on Space Shuttle specification. The selection of 1/2 nominal rate as the minimum rate and the number of hours was somewhat arbitrary, but the available data did not permit a quantitative selection of a more accurate value.

The advantages of the above basic routines were as follows:

1. The use of three significantly different fuel cell water input flow rates provided a realistic test of the performance of the AgBr granule & activated charcoal cartridge; both are influenced by flow rate variations.

2. The selected rate combinations yielded a daily water quantity of 99.3 kg (218.5 lb), which is a close approximation of the nominal value of 89.5 kg/day (196.7 lb/day) and the maximum value of 100 kg/day (220 lb/day) as indicated by Rockwell International.

3. The selected product draw off sequence produced a 20-hour period during which static conditions prevailed in the plumbing downstream of the water storage tanks. This provided a rigorous test of silver's bactericidal action in segments of the system which are sensitive to bacterial infestation (e.g., draw-off outlets).

4. Extremes of bacteria-bactericide contact times were evaluated with the selected regimen, since FCW simulant would accumulate in the system over-night, yet during water draw-off, the contact times when the system was nearly empty were 15 minutes or less.

Water flow rates were monitored by flow meters with a rated accuracy of 1%. Input flow rates were set by manipulating the metering pump controls. Draw-off flow rates were a function of the water storage tank gas pressure and pressure drop caused by related plumbing. Water quantities were measured by (1) use of calibrated reservoirs, and (2) time and flow rate measurements. The use of calibrated reservoirs were the main measurement technique; however, the anticipated accuracy for such large reservoirs is 2%.

4.1.2 Fuel Cell Water Simulant

The Advance Prototype Unit processed anticipated fuel cell water; the same composition was used in each simulated mission test. The constituents composing the anticipated fuel cell water are listed in Table 2.

Table 2 ANTICIPATED FUEL CELL WATER COMPOSITION

1. Properties	Limits (Maximum Allowance)
a. pH	6.0 - 8.0 at 25°C (77°F)
b. Total Solids	20 ppm
c. Taste & Odor*	None at Threshold (Odor No. of 3)
d. Turbidity**	11 Units
d. Color, True***	15 Units
f. Total Organics	10 ppm

2. Particulate Size Range	No. of Particles per 500 ml Fluid
a. 0 - 10 microns	Unlimited
b. 10 - 25 microns	1000
c. 25 - 50 microns	200
d. 50 - 100 microns	100
e. 100 - 250 microns	10

3. Ionic Species	Maximum Allowable Concentration
a. Aluminum	For reference only
b. Cadmium	0.01 ppm
c. Chloride	1.0 ppm
d. Chromium (Hexavalent)	0.05 ppm
e. Copper	1.0 ppm
f. Iron	0.3 ppm
g. Lead	0.05 ppm
h. Magnesium	For reference only
i. Manganese	0.05 ppm
j. Mercury	0.005 ppm
k. Nickel	0.05 ppm
l. Potassium	For reference only
m. Selenium	0.05 ppm
n. Silica	For reference only
o. Silver	0.05 ppm
p. Ammonia	0.5 ppm

The contaminants listed were used at their respective concentration, but with some deviations.

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* Determined per the method described on page 304 of Standard Methods for the Examination of Water and Waste Water (12th Edition).

** Determined using the nephelometric turbidity procedure described in ASTM D1889.

*** Determined using the method described in para. 1.4 on page 127 of Standard Methods for the Examination of Water & Waste Water.

The tabulation contains silver. This element was omitted because it adversely affects the bacteria added to the fuel cell water simulant.

The particulate load could not be duplicated without microscopic counting. The particulate load, however was approximated by weighing-out classified Feldspar particles in size ranges listed. The anticipated fuel cell water contained the following particles.

	Particle Size Range	Approximate Number of Particles per Liter	Concentration mg/l
a.	0 - 10 μ	200,000	0.560
b.	10 - 25 μ	2,000	0.089
c.	25 - 50 μ	400	0.146
d.	50 - 100 μ	200	0.560
e.	100 - 250 μ	20	0.873

Bacteria added to the FCW simulant provided additional particles at the low end of the particle size spectrum - i.e., 10^5, 1 to 2 micron particles per 100 ml.

Sodium lauryl sulfate was used to simulate 10 ppm organics; at this concentration (10 ppm) sodium lauryl sulfate exhibits a threshold Odor No. = 1.2 and a threshold Taste No. = 1. The organic contaminants used under contract NAS 9-12792 were not used in these tests because at a 10 ppm concentration the resultant threshold odor and taste are greater than 3.

The FCW simulant was prepared each day by adding aliquots of concentrated solutions of the constituents to a fixed, measured quantity of deionized water of at least 1 megaohm purity; the quantity of simulant prepared each day was sufficiently large 113.5 l (30 gal) to accommodate reasonable contingencies. The constituents were compounded into one of five separate concentrated aqueous solutions as follows.

1. All cationic species except sodium and potassium as chloride salts.

2. All anionic species except chloride as sodium and potassium salts.

3. Feldspar particles.

4. Sodium lauryl sulfate.

5. Washed bacteria cells.

The dilution factor from the concentrate to the simulant was 1100, that is, the concentrate was 1100 times more concentrated than the simulant. By adding 100 ml of each concentrate (except the bacteria suspension), the concentrations specified for each constituent was attained. The composition of each daily batch of FCW simulant was monitored by total solids, pH, and conductivity measurements. The alkalinity provided by the dissolved species was also determined.

4.1.3 Baseline Water Sampling & Analysis

An important objective of the test program was the evaluation of performance with respect to time as well as overall system performance. To accomplish both types of evaluation, sampling and subsequent analysis of water at intermediate times was carried out in addition to final product water sampling and analysis. Such activity occurred uniformly in each SMT to insure a common basis of comparison.

4.1.3.1 Intermediate Sampling & Analysis

Samples were taken twice each day (3-4 hours and 20-21 hours after start-up) from the septum downstream of the AgBr granule-activated charcoal cartridge. All samples were taken aseptically. Two separate 500 ml quantity samples were taken at each time, thereby providing individual samples for chemical and bacteriologic analysis. Five ml of 1/10 normal sodium thiosulfate were added to the 500 ml biological sample immediately after sampling to arrest the bactericidal action of silver ions.

4.1.3.2 Final Product Water Sampling & Analysis

Sampling of the final product water was carried out at the end of each test day when the product water was being drained from the system. Grab samples were taken in the first, second, and third hours of hot and cold water draw-off for in-house analyses (primarily biological). Chemical analyses were performed on the accumulated product water each day.

The first 500 ml of product water was drained from the cold water outlet valve. Half of the sample was used for biological analyses while the remainder was used for silver analysis and key performance characteristics.

The second and third hour grab samples were used exclusively for biological analyses (plate counts). All grab samples were taken in sterile bottles directly from the hot and cold outlet valve.

Samples of product water were taken directly from the reservoir after all of the product water had been drained off.

Product water samples were shipped to NASA JSC for complete analysis. The analyses performed by the JSC included specific analyses for each constituent listed in the anticipated fuel cell water composition. This analysis corroborated CHEMTRIC's analyses, established a confidence level in the performance of system, and established compliance with potability requirements. The samples were identified by label as product water with the SMT number, test day, and date.

4.1.4 Bacteria Challenges

The Advance Prototype System was challenged with the test bacteria by the injection of specific quantities of viable bacteria cells/spores at specified locations on each test day. The pattern of challenges was identical in each SMT; the number of bacteria constituting each challenge was identical. The pattern was as follows:

Days 1 to 7

A bacteria suspension of *Bacillus subtilis* was added directly to the FCW simulant reservoir at the start of the test. Sufficient suspension was added to produce a cell/spore dose of 100 (minimum) per milliliter of simulant. Dosing the reservoir results in a continuous challenge to the filter element of the system. The stability of the bacteria dose was monitored by performing plate counts on the input water after 21 hours of operation. The effectiveness of the filter was determined by plate counts on (1) stored water samples after 4 and 20 hours of operation, and (2) potable water, hot and/or cold, after 20 and 22 hours of operation.

The additional pattern of challenges, sampling, and analysis was as follows.

Day 1

A suspension of *Pseudomonas aeruginosa* containing at least 10^9 bacteria was injected into septums located at the top of the storage tanks during the first hour of operation. Plate counts were performed on stored water samples after 4 and 21 hours of operation, and on potable water, hot and/or cold, after 20 and 22 hours of operation.

Day 2

A one (1) milliliter suspension of Pseudomonas aeruginosa with a cell dose $> 10^5$/ml was injected into the septum located at the hot water outlet. Dosing the water outlet challenged the efficacy of the AgBr dose residual. The stability of the bacteria dose was monitored by performing plate counts on 500 ml samples of hot water drawn-off 20 hours after injection.

Day 3

A one (1) milliliter suspension of Pseudomonas aeruginosa with a cell dose $> 10^5$/ml was injected into the septum located at the cold water outlet. Again, dosing the water inlet challenged the efficacy of the AgBr residual. The stability of the bacteria dose was again monitored by performing plate counts on 500 ml samples of cold water drawn-off 20 hours after injection.

Day 4

No additional challenges; sterilized hot and cold water outlets.

Day 5

A suspension of Type IIIa bacteria containing at least 10^9 cells was injected into septums located at the top of the storage tanks during the first hour of operation. Plate counts were performed on stored water samples after 4 and 21 hours of operation, and on potable water, hot and/or cold, after 20 and 22 hours of operation.

Day 6

A one milliliter suspension of Type IIIa bacteria with a cell dose $> 10^5$/ml was injected into the septum located at the hot water outlet. The dosing at the water outlet challenged the efficacy of the AgBr dose residual. The stability of the bacteria was monitored by performing plate counts on 500 ml samples of hot water drawn-off 20 hours after injection.

Day 7

A one (1) milliliter suspension of Type IIIa bacteria with a cell dose $> 10^5$/ml was injected into the septum located at the cold water outlet. The dose challenged the efficacy of the AgBr dose residual. The stability of the bacteria dose was monitored by performing plate counts on 500 ml samples of cold water drawn-off 20 hours after injection.

4.2 Chemical Analyses & Methods

This analytical effort was carried out in-house and at NASA JSC. Standard methodology was employed in all analyses.

The analytical methods employed at NASA JSC are described in detail in Document No. CSD-A-726 (Procedure Manual for Water Analysis). The procedures contained in the above manual are based on the procedures contained in the Standard Methods* text or on superior instrumental methods (e.g. atomic absorption).

The chemical analyses that were performed in-house used the following methodology.

(1) Specific Resistance

(a) Method - Standard Methods test; pages 323 - 327

(b) Instrument - YSI Model #31, Conductivity Bridge

(c) Accuracy - ± 1% in range of 2 ohms to 2 megaohms

(2) pH

(a) Method - Standard Methods text, pages 276 - 281

(b) Instrument - Corning Model 7 pH meter

(c) Accuracy - ± 0.05 pH (relative)

(3) Turbidity

(a) Method - Nephelometric as per insturment manufacturer's manual.

(b) Instrument - Hack Chemical Co., Model No. 2100 A laboratory turbidimeter.

(c) Accuracy - ± 2% of full scale

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* Standard Methods for the Examination of Water and Waste Water, 13th Ed., APHA, AWWA, WPCF, Washington, D.C. (1971)

(4) Total Solids

(a) Method - Gravimetric as per Standard Methods text, pages 535 - 541

(b) Instrument - None

(c) Accuracy - ± 5%

(5) Chloride

(a) Method - Titrimetric, mercuric nitrate method as per Standard Methods text, pages 95 - 99

(b) Insturment - None

(c) Accuracy - ± 4 ppm

(6) Silver

(a) Method - Atomic absorption

(b) Instrument - Perkin-Elmer Model 103, Atomic Absorption Spectrophotometer

(c) Accuracy - ± 4 ppm

(7) COD

(a) Method - Standard Methods text, pages 495 - 499

(b) Instrument - None

(c) Accuracy - ± 2 ppm

(8) Acidity

(a) Method - Standard Methods text, pages 50 - 52

(b) Instrument - None

(c) Accuracy - ± 1 ppm

(9) Alkalinity

(a) Method - Standard Methods text, pages 52 - 56

(b) Instrument - None

(c) Accuracy - ± 1 ppm

(10) True Color

(a) Method - Standard Methods text, pages 160 - 162

(b) Instrument - None

(c) Accuracy - ± 2%

4.3 Biological Analyses & Methods

The methodology for culturing the test bacteria, preparing bacteria challenges doses, and analyzing water are presented in the following discussions. Standard techniques were employed. The test bacteria were obtained as follows:

(1) Type IIIa from the National Center for Disease Control, Atlanta, Ga.

(2) *Pseudomonas aeruginosa* from the American Type Culture Collection - type #14502

(3) *Bacillus subtilis* from the American Type Culture Collection type #6633.

4.3.1 Culturing & Dose Preparation

The above cultures were transferred to appropriate media upon receipt. Sub-cultures of the initial transfers were made and after incubation, were refrigerated for future use.

The flavobacterium species and the *Pseudomonas* species were cultured on APT agar; the same medium was used in the analyses of water samples. The bacillus species were cultured on AK agar #2; as with the other bacteria species, the culturing medium was also used in the analyses of water processed in the SMT and dosed with the bacillus species. Periodic checks of culture purity were made by gram stain, spore stain, and streak plate preparation.

The same general procedure was followed in preparing the challenge doses of each of the three test bacteria. However, the bacillus species did require heat treatment to kill off vegatative cells and consequently some special treatment was required.

A correlation between viable cell count and suspension turbidity was established for each test species. This correlation was used subsequently to aid in determining the cell count in the test dose prior to injection into the system. The detailed procedures were as follows:

(1) Inocculate a Kolle flask containing 300 ml of the solid nutrient medium and incubate at 309°K (96.8°F) for 48 hours (120 hours for B. subtilis).

(2) Harvest the culture by teasing the agar surface with a wire loop in the presence of 25 ml sterile, phosphate-buffered saline (PBS).

(3) Transfer the suspension to a sterile, capped flask containing 25 ml PBS and a quantity of glass beads. The flask was agitated vigorously for 15 minutes.

(4) The above suspension was then decanted into a sterile, capped, centrifuge tube which in turn was centrifuged. The supernatant liquid was decanted off and the cells resuspended in 50 ml PBS and centrifuged again. The cells were then resuspended in 25 ml PBS.

(5) The final cell suspension was then submitted to serial, decade dilution using 10 ml aliquots. Plate counts (membrane filter technique) and turbidity readings were made on each of the dilutions. The correlation established between cell count and turbidity values were used in preparation of the challenge doses.

The correlation established above permitted estimation of the cell count in subsequently prepared suspensions withour incurring the delay (24 - 48 hours) inherent in plate counts. Subsequent suspensions were prepared by the above procedures up to step 4. An aliquot of the suspension was then subjected to selected dilutions; the turbidity of these dilutions was determined. From the turbidity, the cell count of the suspension was read from the correlation curve for that species.

Once the cell count of the final suspension was known, the challenge dose could be fixed accurately each time. The minimum challenge dose was 10^6 viable cells/spores.

The bacillus species was treated in an identical manner as above up to step 4. However, 8 Kolle flasks of this species were used and the final suspension resulting from step 4 was combined in a sterile flask. This combined suspension was immersed in a 343°K (158°F) water bath for 30 minutes after heat treatment; the combined suspension was submitted to plate counts (membrane filter). The serial dilutions used in the plate counts were submitted to turbidity measurements for reference purposes. The combined suspension served as the stock for all B. subtilis doses.

An aliquot of all challenge doses was submitted to plate count procedures on the day of injection to verify the estimated dose.

4.3.2 Quantitative Analysis

The assay method used for water analysis and for analysis of the cell suspensions was the membrane filter technique. The nutrient media used for culturing the test bacteria was also used in the assay. Sodium thiosulfate (1.0 ml of 0.1 N solution per 100 ml of water) was added to each sample as soon as possible after sampling to arrest the bactericidal action of silver.

The membrane filter method of assay is a standard procedure. The salient features of the subject application are as follows.

(1) Five hundred ml of sample were filtered.

(2) The filter disc was washed with three 100 ml aliquots of 0.001 N sodium thiosulfate, followed by washing with three 100 ml aliquots of APT broth. Filter discs used in cell suspension assays were washed with APT broth only.

(3) Standard filter disc holders were used (Millipore Catalog # XX11-047-00).

(4) Standard filter discs (47 mm diameter) were used; the pore size was 0.22 microns.

(5) The filter discs were placed (rolled) onto the surface of the appropriate agar medium; the petri dishes were sealed with plastic tape and incubated in a humidified atmosphere.

(6) The above plates were inspected for growth after 24 and 48 hours of incubation.

All water samples were assayed on the day that they were acquired.

ADVANCE PROTOTYPE UNIT TESTS

5.1 Test Apparatus

Figure 9 on the following page illustrates the test set-up used during mission testing of the Advance Prototype. The components and test stand procured and assembled under Contracts NAS 9-12104 and NAS 9-12792 were utilized and upgraded to include a steam generator, an additional storage tank, suitable insulation, fuel cell water simulant heater and thermostat, and a higher capacity feed pump. The Advance Prototype was mounted vertically to the test stand structure. The heater and chiller were located remotely to simulate installation in a vehicle.

The test system was cleaned and sterilized before each simulated mission test. This clean-up consisted of (1) filling the system with an aqueous solution of 50 ppm hypochlorite, (2) allowing the solution to remain one hour before draining, (3) flushing with 1 ppm silver dosed deionized water twice, and (4) filling the system with 0.080-0.085 ppm silver dosed deionized water which was allowed to stand one hour before final draining.

5.2 Advance Prototype Test No. 1

A seven-day (168-hour) simulated mission test was performed with the Advance Prototype. The objectives of the test were to establish baseline chemical performance and to determine the bacteriostatic/bactericidal efficacy of the Advance Prototype unit.

During both simulated mission tests, bacteria was injected to verify that silver ions are effective in killing bacteria, and the flow rates were varied to simulate the range of operating conditions. The bacteria were injected as follows:

Days 1 to 7 - Bacillus subtilis into the Simulant

Day 1 - P. aeruginosa into the storage tanks

Day 2 - P. aeruginosa into the hot water outlet

Day 3 - P. aeruginosa into the cold water outlet

Day 5 - Type IIIa into the storage tanks

Day 6 - Type IIIa into the hot water outlet

Day 7 - Type IIIa into the cold water outlet

The Advance Prototype Unit processed 100 kg/day (220 lb/day) of anticipated fuel cell water at ambient temperatures for seven days.

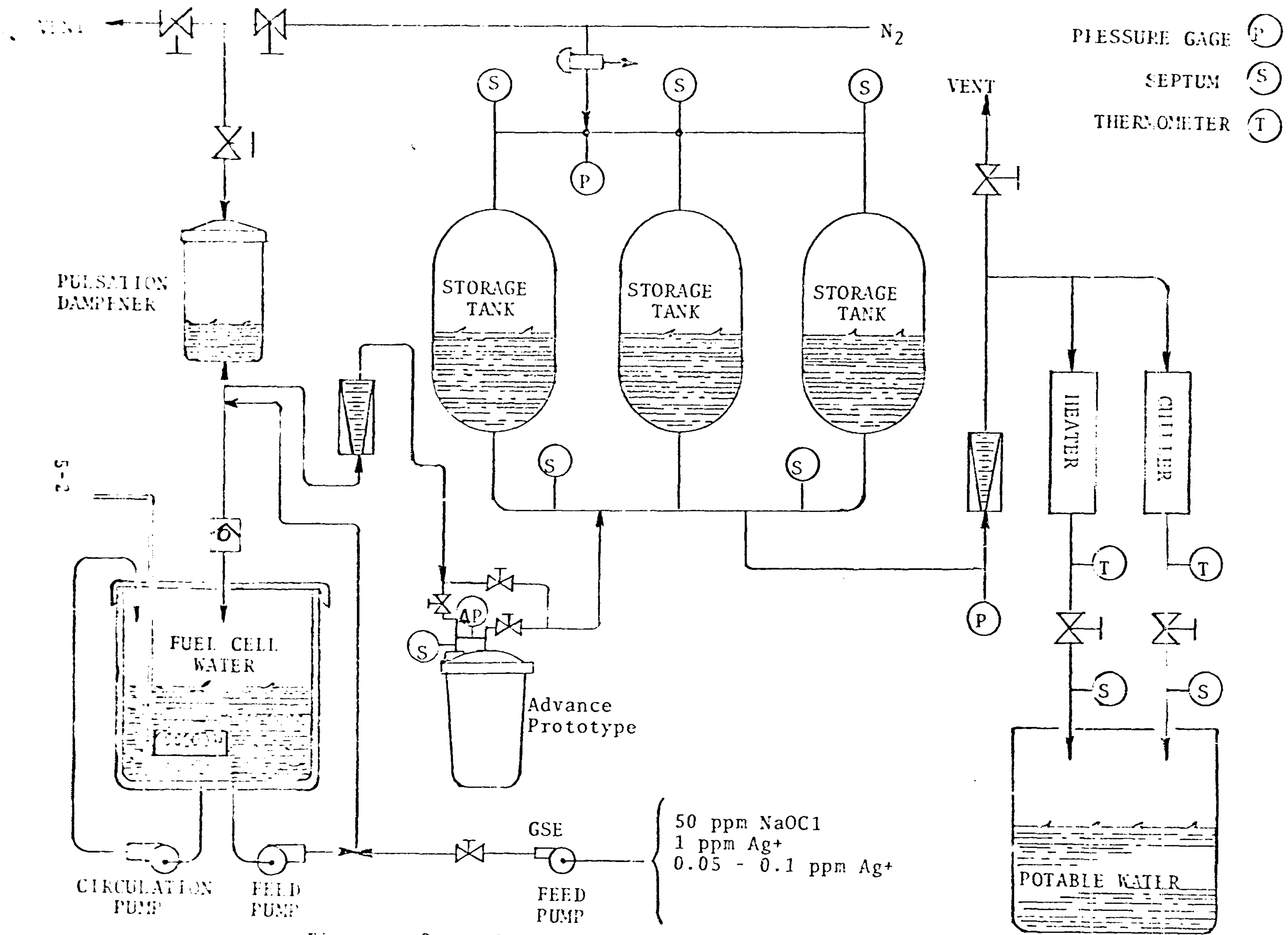

Figure 9 SCHEMATIC FOR SIMULATED MISSION TEST

Half of the treated water passed through a heater maintaining the water at 336-339°K (145-150°F) and the rest passed through a chiller maintaining the water at 278.5-281.9°K (42-48°F).

5.2.1 Advance Prototype Unit Preparation

After fabrication, the unit was cleaned and packed according to the conclusions of the bench tests. First, the cartridge core was packed with a mixed bed of activated charcoals and silver bromide in a ratio of 4 parts activated charcoal to 1 part silver bromide by volume. Then the cartridge core was assembled into the biological filter (Pall Trinity Micro Corporations MCY 4463UR), and the entire Unit was finally assembled.

5.2.2 Test No. 1 Results & Discussions

Table 3 lists the daily stream and water quality characteristics of Advance Prototype Test No. 1. The tabulated characteristics indicate that the system performed satisfactorily. The water quality was within all specifications. The silver ion dose was always approximately 0.08 ppm.

Table 4 lists the daily doses of bacteria injected and the plate counts of all samples collected. The tabulated data shows that the 0.08 ppm Ag^+ dose provides bactericidal activity against the infusion of 10^5/ml bacteria into the treated water, and that the biological filter excludes bacteria (spores) in the water before the silver bromide cartridge.

The operating pressure drop characteristics of the Advance Prototype Unit was determined before and after the seven day test. To obtain these characteristics, a mercury manometer, deionized water, and a rotameter were used. Figure 10 presents the results of these tests. These tests indicate that the flow resistance had increased slightly as expected following seven days of filtering particles and Bacillus subtilis spores; however, the pressure drop increased to only 5510 N/sq m (0.8 psi) at the designed flow rate of 94 ml/min (12.4 lbs/hr).

5.3 Random Vibration Testing

The Advance Prototype Unit was vibrated at the General Environments Corporation (formerly the Inland Testing Laboratories) in Morton Grove, Illinois. The vibration machine used for this work is the GEC Property No. ES-H-5090. This machine is capable of subjecting a fixtured load of 52.3 kg (115 pounds) to the random vibrations specified in paragraph 3.3.3 of the Statement of Work for this contract. The Lift-Off/Boost

Table 3 ADVANCE PROTOTYPE TEST No. 1

WATER QUALITY CHARACTERISTICS

Test Day No.	Sample Water	pH	ρ (Kohm-cm)	Ag+ Conc. (ppm)	True Color	Threshold No. Odor	Threshold No. Taste
1	Simulant	7.9	22.5	<0.01	10	2	2
	Stored 4th Hr	7.9	23	0.08	<5	1.4	1.6
	Stored 21st Hr	7.9	23	0.08	<5	1.4	1.6
	Product	7.9	23	0.08	<5	1.4	1.6
2	Simulant	7.8	80	<0.01	10	2	2
	Stored 4th Hr	7.8	78	0.08	<5	1.4	1.6
	Stored 21st Hr	7.8	78	0.08	<5	1.4	1.6
	Product	7.8	78	0.08	<5	1.4	1.6
3	Simulant	7.9	68	<0.01	10	2	2
	Stored 4th Hr	7.9	68	0.08	<5	2	2
	Stored 21st Hr	7.9	68	0.08	<5	2	2
	Product	7.9	68	0.08	<5	2	2
4	Simulant	7.3	70	<0.01	10	2	2
	Stored 4th Hr	7.3	70	0.08	<5	2	2
	Stored 21st Hr	7.3	70	0.08	<5	2	2
	Product	7.3	70	0.08	<5	2	2
5	Simulant	7.2	70	<0.01	10	2	2
	Stored 4th Hr	7.2	70	0.08	<5	2	2
	Stored 21st Hr	7.2	70	0.08	<5	2	2
	Product	7.2	70	0.08	<5	2	2
6	Simulant	7.9	66	<0.01	10	2	2
	Stored 4th Hr	7.9	66	0.08	<5	2	2
	Stored 21st Hr	7.9	66	0.08	<5	2	2
	Product	7.9	66	0.08	<5	2	2
7	Simulant	7.3	56	<0.01	10	2	2
	Stored 4th Hr	7.3	56	0.08	<5	2	2
	Stored 21st Hr	7.3	56	0.08	<5	2	2
	Product	7.3	56	0.08	<5	2	2

(continued on next page)

Table 3 (concluded)

Test Day No.	Sample Water	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)
1	Simulant	1.1	10	1.0	<1.0	1.0	37
	Stored 4th Hr	<0.10	<10	1.0	<1.0	<1.0	14
	Stored 21st Hr	<0.10	<10	1.0	<1.0	<1.0	23
	Product	<0.10	<10	1.0	<1.0	<1.0	17
2	Simulant	1.1	10	1.0	1.0	1.0	25
	Stored 4th Hr	<0.10	<10	1.0	1.0	<1.0	<1
	Stored 21st Hr	<0.10	<10	1.0	1.0	<1.0	10
	Product	<0.10	<10	1.0	1.0	<1.0	3
3	Simulant	1.1	10	1.0	1.0	1.0	39
	Stored 4th Hr	<0.10	10	1.0	1.0	<1.0	4
	Stored 21st Hr	<0.10	10	1.0	1.0	<1.0	6
	Product	<0.10	10	1.0	1.0	<1.0	12
4	Simulant	1.0	10	1.0	1.0	1.0	4
	Stored 4th Hr	<0.10	10	1.0	1.0	<1.0	9
	Stored 21st Hr	<0.10	10	1.0	1.0	<1.0	<1
	Product	<0.10	10	1.0	1.0	<1.0	<1
5	Simulant	1.0	10	1.0	1.0	1.0	10
	Stored 4th Hr	<0.10	10	1.0	1.0	<1.0	4
	Stored 21st Hr	<0.10	10	1.0	1.0	<1.0	3
	Product	<0.10	10	1.0	1.0	<1.0	9
6	Simulant	1.1	10	1.0	1.0	1.0	54
	Stored 4th Hr	<0.10	10	1.0	1.0	<1.0	4
	Stored 21st Hr	<0.10	10	1.0	1.0	<1.0	32
	Product	<0.10	10	1.0	1.0	<1.0	45
7	Simulant	1.1	10	1.0	1.0	1.0	19
	Stored 4th Hr	<0.10	10	1.0	1.0	<1.0	17
	Stored 21st Hr	<0.10	10	1.0	1.0	<1.0	7
	Product	<0.10	10	1.0	1.0	<1.0	19

Table 4 SUMMARY OF BACTERIOLOGIC ANALYSES FOR ADVANCE PROTOTYPE TEST No.1

	Dose(1)		Sample Points						
Test Day	Injection Point	Number & Specie	Simulant(2)	Stored Water Hr.	Stored Water Count	Hot O.V.(3) Hr.	Hot O.V.(3) Count	Cold O.V. Hr.	Cold O.V. Count
1	Simulant	$3\pm1\times10^{5}$ B.s.*	2×10^{2}/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
	Storage	$3\pm1\times10^{9}$ P.a**		21	<1/200ml	23	<1/200ml	24	<1/200ml
2	Simulant	$3\pm1\times10^{5}$ B.s.	2×10^{2}/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
	Hot O.V.	$3\pm1\times10^{5}$ P.a.		21	<1/200ml	23	<1/200ml	24	<1/200ml
3	Simulant	$3\pm1\times10^{5}$ B.s.	3×10^{2}/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
	Cold O.V.	$3\pm1\times10^{5}$ P.a.		21	<1/200ml	23	<1/200ml	24	<1/200ml
4	Simulant	$3\pm1\times10^{5}$ B.s.	2×10^{2}/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
5	Simulant	$3\pm1\times10^{5}$ B.s.	2×10^{2}/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
	Storage	$3\pm1\times10^{9}$ IIIa		21	<1/200ml	23	<1/200ml	24	<1/200ml
6	Simulant	$3\pm1\times10^{5}$ B.s.	2×10^{2}/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
	Hot O.V.	$3\pm1\times10^{5}$ IIIa		21	<1/200ml	23	<1/200ml	24	<1/200ml
7	Simulant	$3\pm1\times10^{5}$ B.s.	2×10^{2}/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
	Cold O.V.	$3\pm1\times10^{5}$ IIIa		21	<1/200ml	23	<1/200ml	24	<1/200ml

(1) All Doses injected during start-up, 1st hour.

(2) All simulant samples taken during 24th hour.

(3) O.V. = Outlet Valve

* *Bacillus subtilis*

** *Pseudomonas aeruginosa*

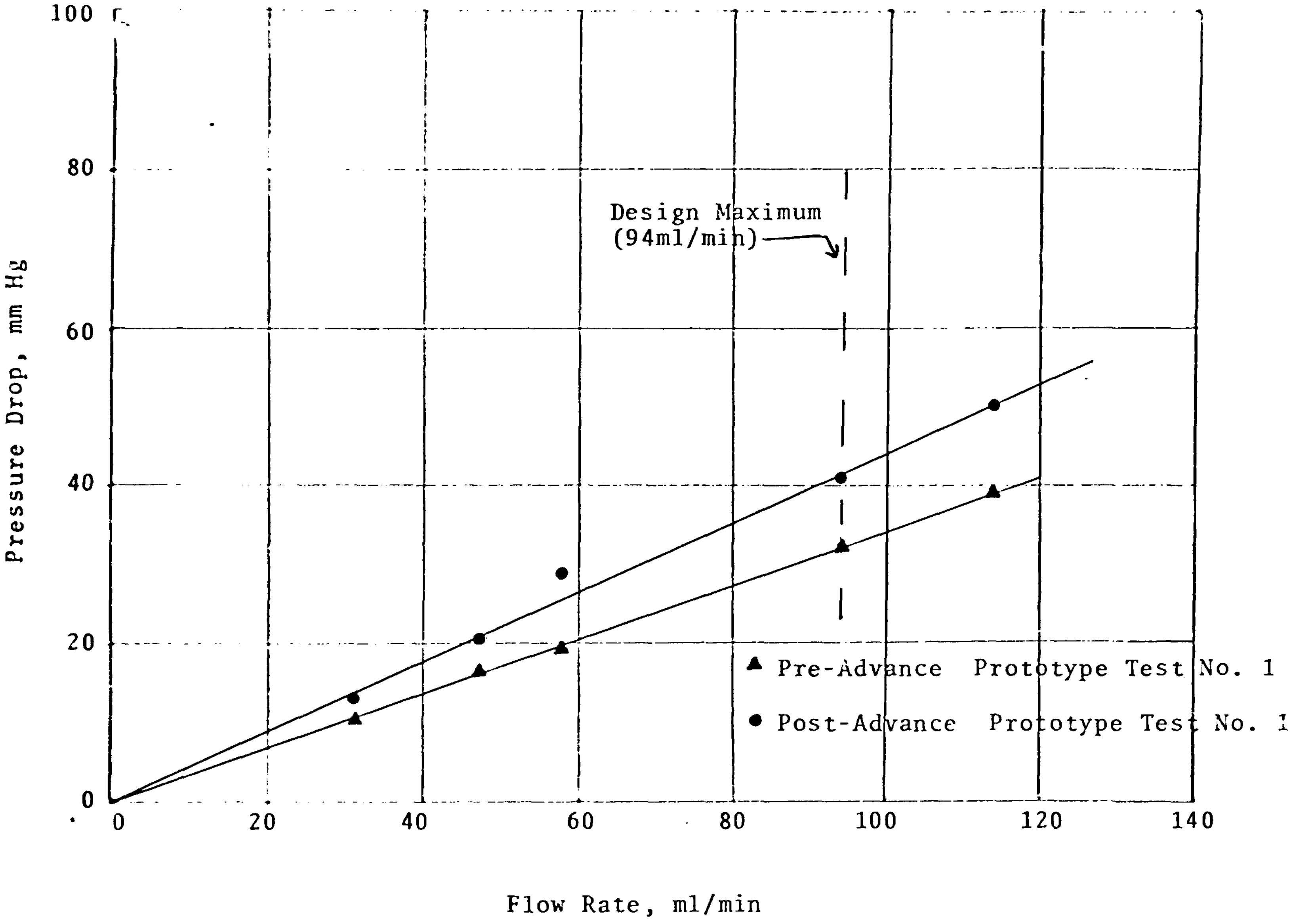

Figure 10 FLOW RESISTANCE OF ADVANCE PROTOTYPE UNIT

Random Vibration level was 2.5 minutes in each of 3 mutually perpendicular planes.

20 to 80 cps at 3 db/octave increase

80 to 180 cps at 0.06 G^2/cps

180 to 200 cps at 12 db/octave increase

200 to 400 cps at 0.1 G^2/cps

400 to 450 cps at -12 db/octave increase

450 to 2000 cps at 0.06 G^2/cps

The above vibration levels automatically provided a 6 "G" launch load (G in any direction) to satisfy the requisites of paragraph 3.3.1 of the Statement of Work.

5.3.1 External Examination

The Advance Prototype Unit, packed and sterilized, was secured to a vibration test fixture. The assembly was then subjected to the random vibrations as specified. Visual examination of the unit showed no apparent physical damage occurred. A copy of the General Environments test report is included as Appendix B in this report.

5.3.2 Flow Resistance - Hydraulic Examination

The operating pressure drop characteristics of the Advance Prototype Unit were determined before and after vibration. Measurements taken after vibration as illustrated in Figure 11 show only a slight decrease in flow resistance. Therefore, it was concluded that random vibration had caused no apparent hydraulic damage inside the Unit.

5.4 Advance Prototype Test No. 2

A seven-day simulated mission test was performed with the Advance Prototype Unit. The objectives of the test were to see if any chemical or bactericidal degradation occurred as a result of the random vibrations. The AP Unit processed 100 kg/day (220 lb/day) of anticipated fuel cell water at ambient temperatures for seven days as in Test No. 1. Bacterial injections, flow rates, and draw-off rates, were similar to those used in the first test.

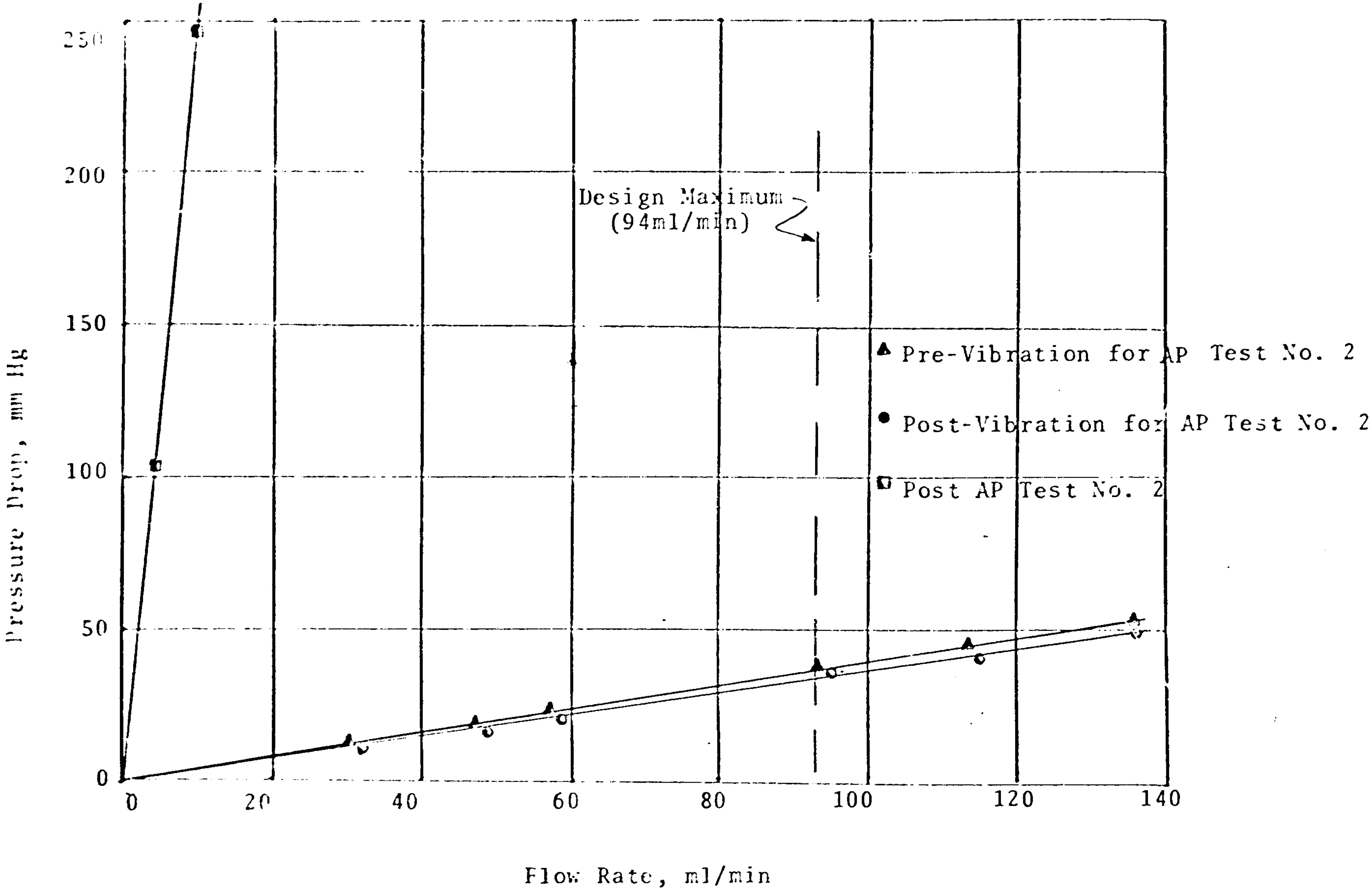

Figure 11 FLOW RESISTANCE OF ADVANCE PROTOTYPE UNIT

5.4.1 Refurbishment of the Advance Prototype

After completion of Advance Prototype Test No. 1, the unit was disassembled and the contents were unloaded. The canister and metallic parts were sanitized by soaking in an iodine solution (1% Mikroklene DF) for one hour, and then cleaned by washing in dilute detergent (Alconox), followed by multiple deionized water rinsings, and air drying.

All of the O-rings were replaced. The silver bromide cartridge was repacked with a "fresh" batch of AgBr - activated charcoal mixture and a new biological filter was installed. The unit was reassembled and steam sterilized at 394°K (250°F) for one hour in an autoclave.

5.4.2 Test No. 2 Results & Discussions

Table 5 lists the daily stream and water quality characteristics of Advance Prototype Test No. 2. The tabulated characteristics indicate that the system performed satisfactorily. The water quality was within all specifications. The silver ion dose was always at the 0.08 ppm level.

The AP system exhibited no chemical degradation due to the random vibration testing. Tabulated chemical analyses of this test indicate no significant change to that observed in Test No. 1.

Table 6 lists the daily doses of bacteria injected and the plated counts of all samples collected. The data shows that the 0.08 ppm Ag^+ dose provided bactericidal activity against the infusion of 10^6/ml bacteria into the treated water.

The operating pressure drop characteristics of the AP Unit were determined three times - namely, pre-vibration, post-vibration, and post-AP Test No. 2. To obtain these characteristics a differential mercury manometer, deionized water, and a rotameter were again used as in Test 1. Figure 11 presents the results of these tests.

The pre-vibration data was collected on the refurbished unit to establish a baseline for subsequent tests. Pressure drop measurements taken after vibration show only a slight decrease in flow resistance.

Table 5 ADVANCE PROTOTYPE TEST No. 2

WATER QUALITY CHARACTERISTICS

Test Day No.	Sample Water	pH	ρ (Kohm-cm)	Ag^+ Conc. (ppm)	True Color	Threshold Odor	No. Taste
1	Simulant	7.6	63	<0.01	10	2	2
	Stored 4th Hr	7.6	64	0.08	<5	1.4	1.6
	Stored 21st Hr	7.6	64	0.08	<5	1.4	1.6
	Product	7.6	64	0.08	<5	1.4	1.6
2	Simulant	7.9	46	<0.01	10	2	2
	Stored 4th Hr	7.9	46	0.08	<5	1.4	1.6
	Stored 21st Hr	7.9	46	0.08	<5	1.4	1.6
	Product	7.9	46	0.08	<5	1.4	1.6
3	Simulant	8.0	58	<0.01	10	2	2
	Stored 4th Hr	8.0	58	0.08	<5	1.4	2
	Stored 21st Hr	8.0	58	0.08	<5	1.4	2
	Product	8.0	58	0.08	<5	1.4	2
4	Simulant	7.9	48	<0.01	10	2	2
	Stored 4th Hr	7.9	48	0.08	<5	2	2
	Stored 21st Hr	7.9	48	0.08	<5	2	2
	Product	7.9	48	0.08	<5	2	2
5	Simulant	7.8	42	<0.01	10	2	2
	Stored 4th Hr	7.8	42	0.08	<5	2	2
	Stored 21st Hr	7.8	42	0.08	<5	2	2
	Product	7.8	42	0.08	<5	2	2
6	Simulant	7.7	29	<0.01	10	2	2
	Stored 4th Hr	7.7	29	0.08	<5	2	2
	Stored 21st Hr	7.7	29	0.08	<5	2	2
	Product	7.7	29	0.08	<5	2	2
7	Simulant	7.9	34	<0.01	10	2	2
	Stored 4th Hr	7.9	34	0.08	<5	2	2
	Stored 21st Hr	7.9	34	0.08	<5	2	2
	Product	7.9	34	0.08	<5	2	2

(continued on next page)

Table 5 (concluded)

Test Day No.	Sample Water	Tur-bidity (JTU's)	COD (ppm)	Cl⁻ (ppm)	Acidi-ty (ppm)	Alka-linity (ppm)	TS (ppm)
1	Simulant	1.0	10	1.0	<1.0	1.0	37
	Stored 4th Hr	0.12	<10	<1.0	<1.0	1.0	14
	Stored 21st Hr	0.10	<10	<1.0	<1.0	1.0	13
	Product	0.12	<10	<1.0	<1.0	1.0	7
2	Simulant	1.0	10	1.0	<1.0	1.0	35
	Stored 4th Hr	0.18	<10	<1.0	<1.0	1.0	11
	Stored 21st Hr	0.13	<10	<1.0	<1.0	1.0	10
	Product	0.13	<10	<1.0	<1.0	1.0	8
3	Simulant	1.0	10	1.1	<1.0	1.0	39
	Stored 4th Hr	0.20	<10	<1.0	<1.0	1.0	9
	Stored 21st Hr	0.16	<10	<1.0	<1.0	1.0	6
	Product	0.11	<10	<1.0	<1.0	1.0	12
4	Simulant	1.0	10	1.1	<1.0	1.0	34
	Stored 4th Hr	0.14	10	1.0	<1.0	1.0	9
	Stored 21st Hr	0.12	10	1.0	<1.0	1.0	10
	Product	0.12	10	1.0	<1.0	1.0	10
5	Simulant	1.1	10	1.0	<1.0	1.0	40
	Stored 4th Hr	0.11	10	1.0	1.0	1.0	8
	Stored 21st Hr	0.12	10	1.0	1.0	1.0	13
	Product	0.10	10	1.0	1.0	1.0	9
6	Simulant	1.2	10	1.0	<1.0	1.0	42
	Stored 4th Hr	0.12	10	1.0	1.0	<1.0	8
	Stored 21st Hr	0.11	10	1.0	1.0	<1.0	12
	Product	0.13	10	1.0	1.0	<1.0	15
7	Simulant	1.0	10	1.0	<1.0	1.0	41
	Stored 4th Hr	0.21	10	1.0	1.0	<1.0	[illegible]
	Stored 21st Hr	0.10	10	1.0	1.0	<1.0	[illegible]
	Product	0.14	10	1.0	1.0	<1.0	9

Table 6 SUMMARY OF BACTERIOLOGIC ANALYSES FOR ADVANCE PROTOTYPE TEST No. 2

Test Day	Dose(1) Injection Point	Number & Specie	Simulant(2)	Stored Water Hr.	Stored Water Count	Hot O.V.(3) Hr	Hot O.V.(3) Count	Cold O.V. Hr	Cold O.V. Count
1	Simulant Storage	$3\pm1\times10^5$Bs*	2×10^2/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
		$3\pm1\times10^9$Pa**		21	<1/200ml	23	<1/200ml	24	<1/200ml
2	Simulant Hot O.V.	$3\pm1\times10^5$Bs	3×10^2/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
		$3\pm1\times10^6$Pa		21	<1/200ml	23	<1/200ml	24	<1/200ml
3	Simulant Cold O.V.	$3\pm1\times10^5$Bs	2×10^2/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
		$3\pm1\times10^6$Pa		21	<1/200ml	23	<1/200ml	24	<1/200ml
4	Simulant	$3\pm1\times10^5$Bs	3×10^2/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
5	Simulant Storage	$3\pm1\times10^5$Bs	2×10^2/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
		$3\pm1\times10^9$IIIa		21	<1/200ml	23	<1/200ml	24	<1/200ml
6	Simulant Hot O.V.	$3\pm1\times10^5$Bs	2×10^2/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
		$3\pm1\times10^6$IIIa		21	<1/200ml	23	<1/200ml	24	<1/200ml
7	Simulant Cold O.V.	$3\pm1\times10^5$Bs	2×10^2/ml*	4	<1/200ml	22	<1/200ml	23	<1/200ml
		$3\pm1\times10^6$IIIa		21	<1/200ml	23	<1/200ml	24	<1/200ml

(1) All Doses injected during start-up, 1st hour.

(2) All simulant samples taken during 24th hour.

(3) O.V. = Outlet Valve

* Bacillus subtilis

** Pseudomonas aeruginosa

Following the seven-day Advance Prototype Test No. 2, a third set of data was collected. This set of measurements showed a large increase in flow resistance. This large increase had not been evidenced in AP Test No. 1 and was not due to the vibration in Test No. 2. Further and separate measurements indicated that the biological filter was the cause of the increase in pressure drop. It appears, that during the seventh test day, the Bacillus subtilis bacteria population on the biological filter had multiplied geometrically, causing an increase in flow resistance.

SHUTTLE ORBITER DEVELOPMENT TESTS

Efforts on this program were redirected when it was learned from Rockwell International that the requirements for a Silver Ion Generator (SIG) for the Shuttle Orbiter were extended to mission staytimes up to 30 days. The SIG shall also process up to 7950 pounds of anticipated fuel cell water per mission, and the pressure drop across the SIG shall not exceed 6900 N/sq m (1.0 psi) at a flow rate of 10.37 kg/hr (22.8 lb/hr). The Advance Prototype Unit has the theoretical capability of silver dosing up to 134,000 pounds of anticipated fuel cell water, but it will not withstand the particulate load of 30 days and yet be able to satisfy the requisite of less than 6900 N/sq m (1.0 psi) pressure drop at a flow rate of 10.37 kg/hr (22.8 lb/hr).

Utilization of high dirt capacity filter (wound-type) cartridges or larger sized area biological filters than previously tested, plus modification of the silver bromide cartridge were required to meet the 30-day design criteria. After screening several filters, CHEMTRIC performed four accelerated breadboard tests (1) to determine the pressure drop build-up of the four filters, each with a different particle size retention capability with 30 days of particulate load, and (2) to determine the performance and pressure drop across the modified activated charcoal silver bromide granule contacting bed as a function of the upstream filter's performance.

After performing the preliminary silver bromide bed definition tests and the accelerated breadboard tests, trade-offs were performed to select the most effective design for the Shuttle Orbiter SIG.

6.1 Silver Bromide Cartridge

After screening several in-depth and membrane-type filters by pressure drop measurements, four filters were selected for testing. The core size of these filters allowed modifications to be made within the silver bromide cartridge.

The internal diameter of the cartridge was increased to 2.2 cm (0.875 inches) since the core diameter of the selected depth-type prefilters was 2.7 cm (1-1/6 inches). The active length remained the same, 12.7 cm (5 inches). The particle size of both the activated charcoal and silver bromide granules was increased to 4 x 10 and 6 x 12 mesh, respectively, to allow particulated to pass through a packed column. The Pyrex wool was eliminated and was replaced by 30 to 50 mesh screens which will allow particulates to pass through, but retain the activated charcoal and silver bromide granules.

Two development tests were performed on contacting beds of different composition. A bed composed of 3 parts activated charcoal to 1 part AgBr dosed FCW simulant with 0.040 to 0.045 ppm silver ion at a flow rate of 10.37 kg/hr (22.8 lb/hr) at ambient temperature 294-297°K (70-75°F). A bed composed of 2 parts activated charcoal to one part AgBr produced saturation (i.e., 0.080-0.085 ppm Ag^+) under identical test conditions, and was the bed selected for accelerated breadboard testing.

6.2 Accelerated Breadboard Tests

During three accelerated breadboard tests 120.5 kg/day (265 lbs/day) of anticipated fuel cell water simulant were processed for three days at a rate of 10.36 kg/hr (22.8 lbs/hr). Test #4 used different conditions. The pressure drop across the prefilter and the silver bromide cartridge were measured periodically, and the silver ion dose and the turbidity of the effluent were determined. The simulant contained the following.

Particle Size Range	Approximate Number of Particles per Liter	Concentration mg/1
a. 0-10 μ	20,000	0.056
b. 10-25 μ	20,000	0.890
c. 25-50 μ	4,000	1.460
d. 50-100 μ	2,000	5.600
e. 100-250 μ	200	8.730

The table above shows that the particulate composition is one order of magnitude greated than that listed in Paragraph 3.3.4 of Contract NAS 9-13718, so that one day of accelerated testing simulated 10 days of nominal testing. A value of 20,000 particles per liter was arbitrarily selected for the 0-10 micron size range in accordance with existing data on Pratt & Whitney fuel cell water analyses.

6.2.1 Accelerated Breadboard Test No. 1

Prefilter: Serflico P/N C10A10S; 10 micron particle retention; 6.35 cm (2½ inch) OD; 25.4 cm (10 inches) long; depth type; weight - 240.6g (0.53 lb)

AgBr Cartridge: 12.7 cm (5inches) long; 2.22 cm (0.875 inches) OD; 6 x 12 mesh particles; 2 parts charcoal to 1 part AgBr by volume; support screens, one 30 mesh and one 20 mesh.

Prefilter Pressure Drop: Initial - 267 N/sq m (2 mm Hg); Maximum observed - 3257 N/sq m (24.4 mm Hg); Final - 1939 N/sq m (14.5 mm Hg); see Figure 12

AgBr Cartridge Pressure Drop: Initial - 1070 N/sq m (8 mm Hg); Maximum observed - 2167 N/sq m (16.2 mm Hg); Final - 1870 N/sq m (14 mm Hg); see Figure 13

Turbidity: Simulant - 1.1 JTU; Effluent - 0.28 to 0.54 JTU; average - 0.38 JTU

Silver Ion Dose: 0.075 to 0.085 ppm

6.2.2 Accelerated Breadboard Test No. 2

Prefilter: Pall Trinity Micro Corporation P/N MCY 1001 UX; retention, 100% of incident 0.8 micron particles, 99.9% of incident 0.45 micron particle and 98% of incident 0.25 micron particles; 7 cm (2-3/4 inches) OD; 24.45 cm (9-5/8 inches) long; 0.74 m^2 (8 ft^2) of membrane area; weight - 269.8g (0.59 lb)

AgBr Cartridge: 12.7 cm (5 inches) long; 2.22 cm (0.875 inches) OD; 6 x 12 mesh particles; 2 parts charcoal to 1 part AgBr by volume; support screens, one 50 mesh, one 30 mesh, and one 20 mesh.

Prefilter Pressure Drop: Initial - 793.5 N/sq m (6 mm Hg); Maximum observed - 1808 N/sq m (13.5 mm Hg); Final - 1090 N/sq m (8.2 mm Hg); see Figure 14.

AgBr Cartridge Pressdur Drop: Initial - 1359 N/sq m (10.2 mm Hg); Maximum observed - 2650 N/sq m (19.8 mm Hg); Final - 1560 N/sq m (11.7 mm Hg); see Figure 15

Turbidity: Simulant 1.1 JTU; Effluent - 0.05 to 0.20 JTU, average - 0.08 JTU

Silver Ion Dose: 0.080 to 0.085 ppm

6.2.3 Accelerated Breadboard Test No. 3

Prefilter: Pall Trinity Micro Corporation P/N AB1AR8A; retention, 100% of incident 0.2 micron particles; 7 cm (2-3/4 inches) OD; 24.45 cm (9-5/8 inches) long; 0.5 m^2 (5 ft^2) of membrane area; weight 349.6g (0.77 lb)

AgBr Cartridge: None utilized

6-4

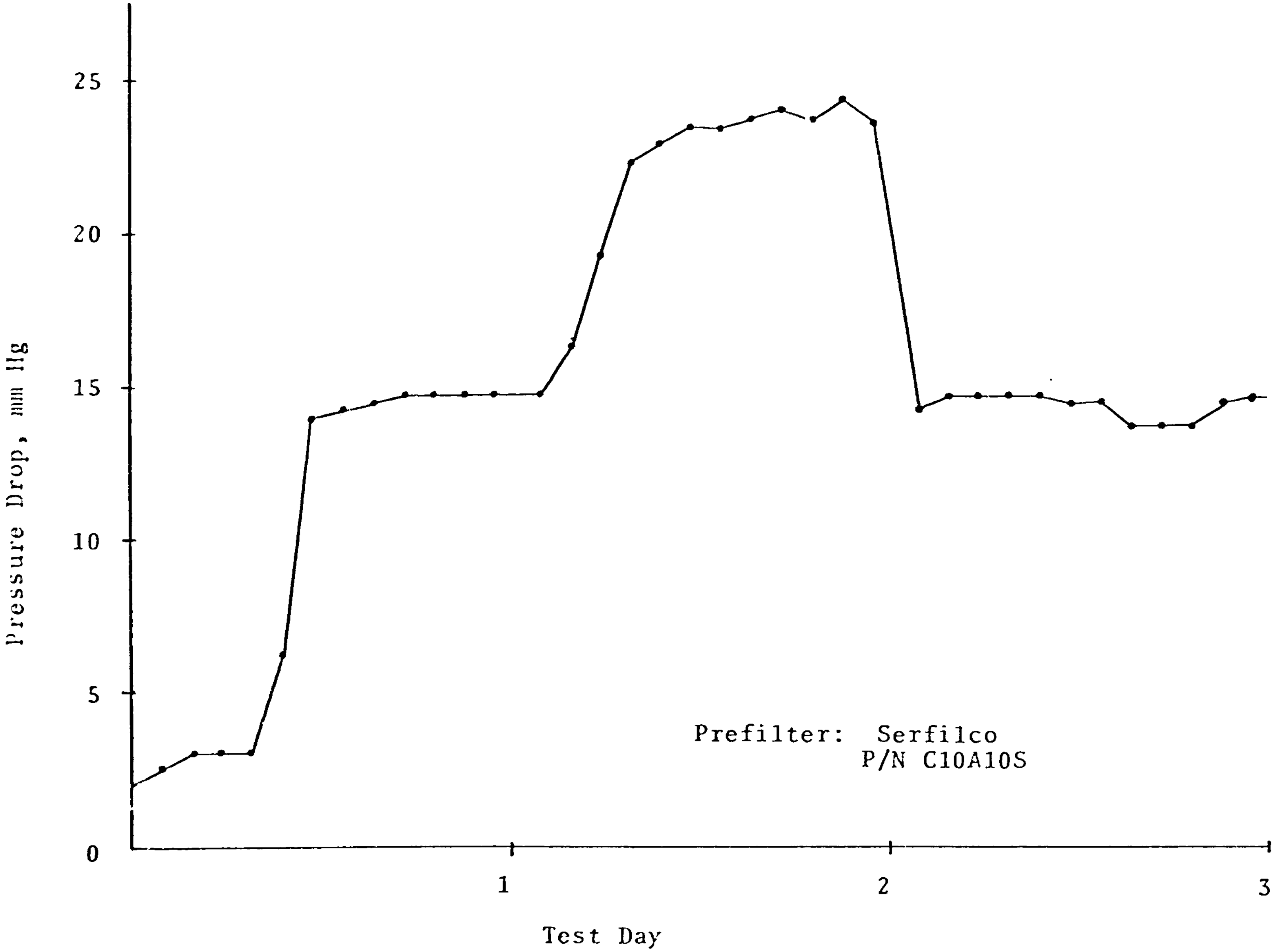

Figure 12 PRESSURE DROP OF PREFILTER VS TIME
ACCELERATED BREADBOARD TEST No. 1

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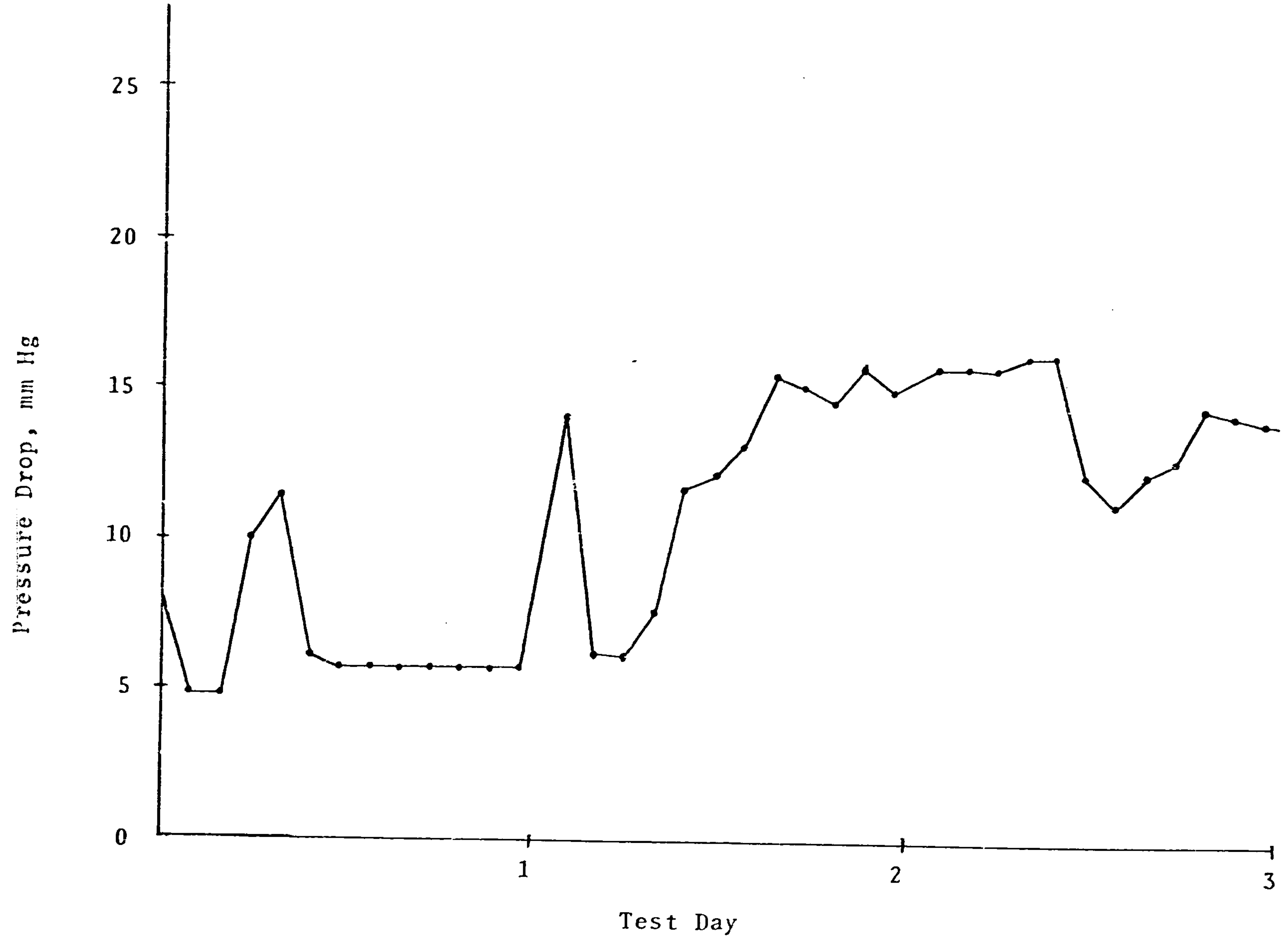

Figure 13 PRESSURE DROP OF AgBr CARTRIDGE VS TIME
ACCELERATED BREADBOARD TEST No. 1

C H E M T R I C

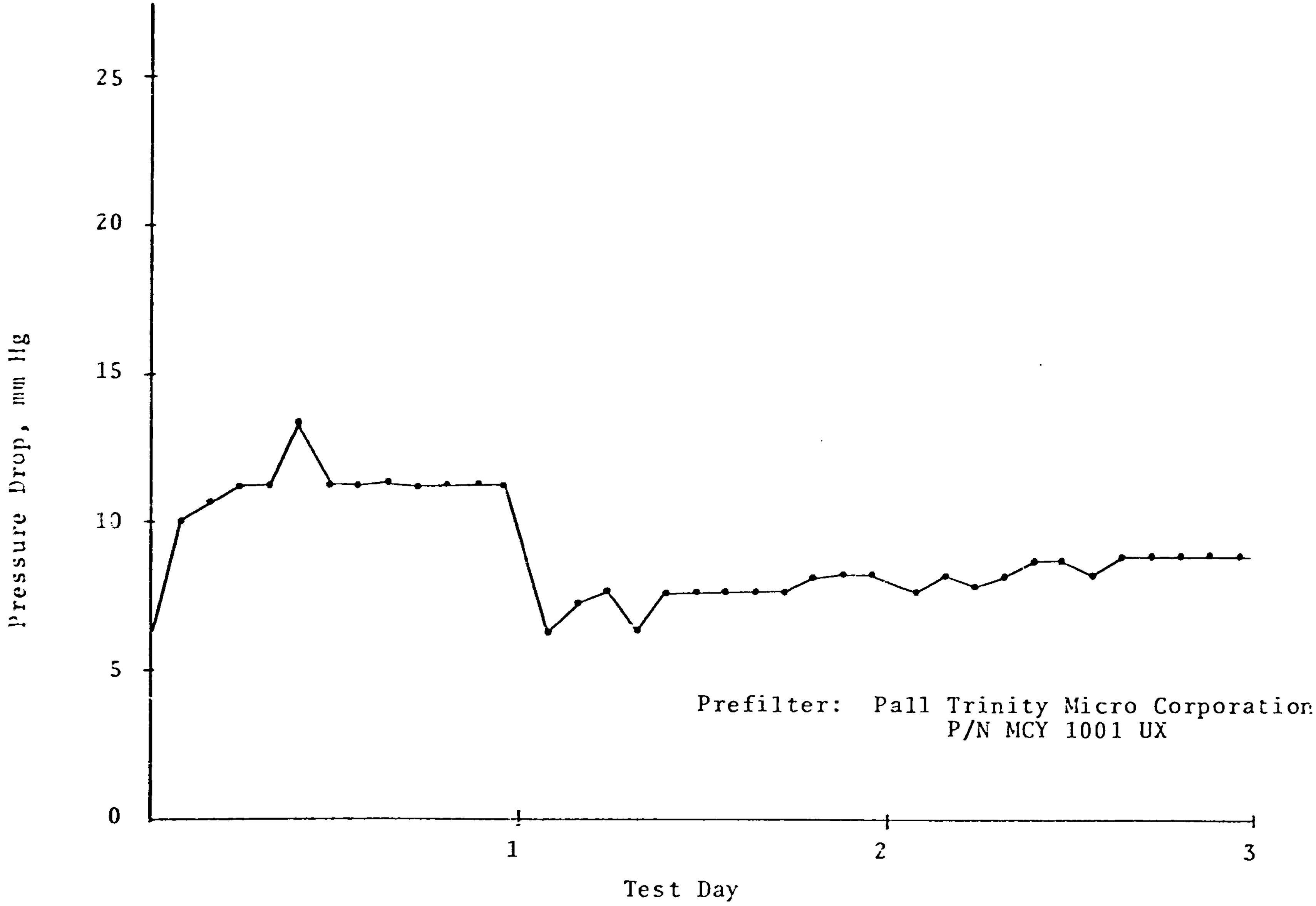

Figure 14 PRESSURE DROP OF PREFILTER VS TIME
ACCELERATED BREADBOARD TEST No. 2

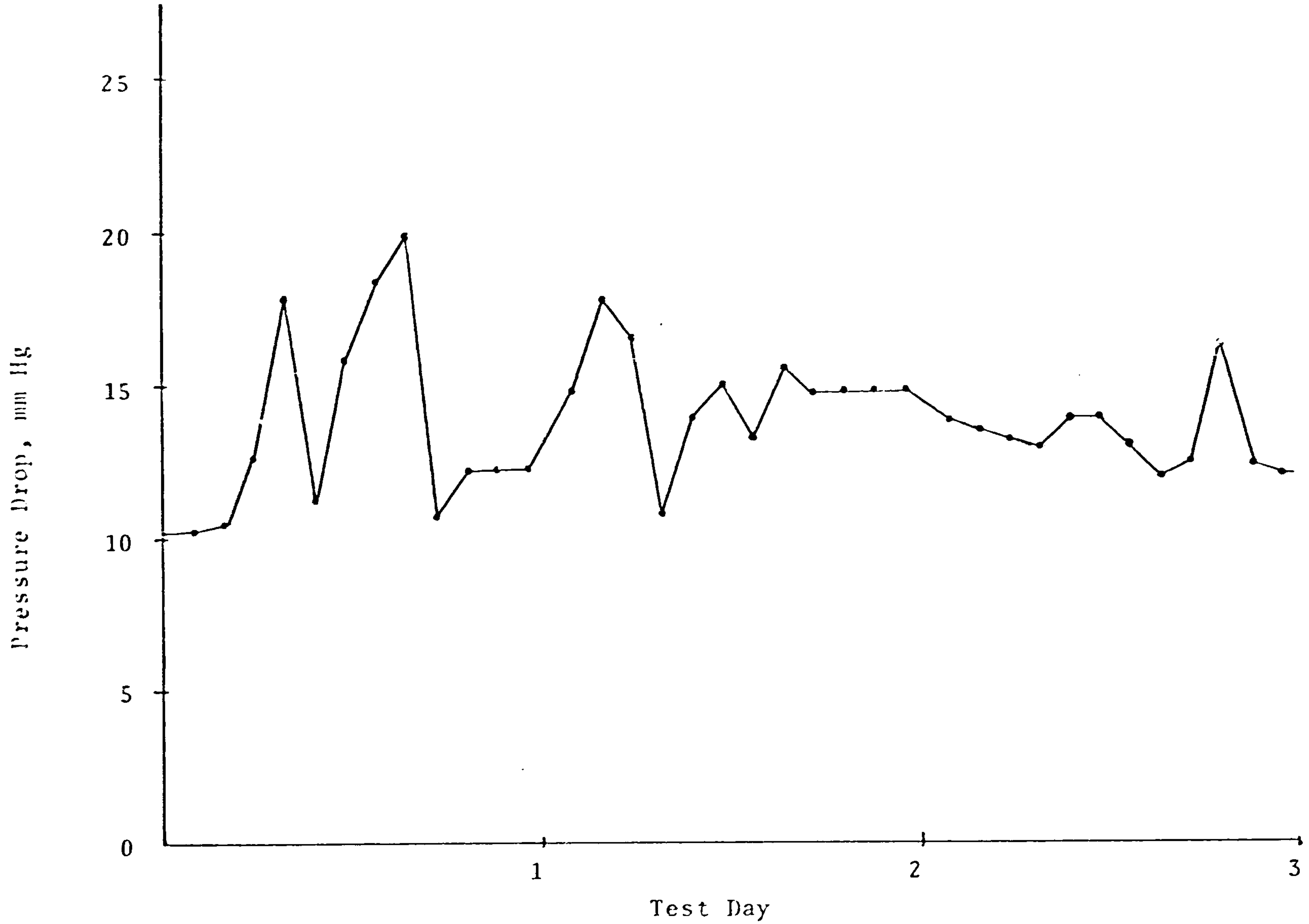

Figure 15 PRESSURE DROP OF AgBr CARTRIDGE VS TIME ACCELERATED BREADBOARD TEST No. 2

Prefilter Pressure Drop: Initial - 531 N/sq m (4 mm Hg); Maximum observed - 2008 N/sq m (15 mm Hg); Final - 1850 N/sq m (13.7 mm Hg); see Figure 16

Turbidity: Simulant 1.1 JTU; Effluent 0.04 to 0.08 JTU, average - 0.06 JTU

6.2.4 Accelerated Breadboard Test No. 4

During the forth accelerated breadboard test 132.5 pound per day of anticipate fuel cell water were processed for three days at a rate of 11.4 pounds per hour. This simulated the operation of two Advanced Prototype Units as developed under Contract NAS 9-13718 in parallel. The simulant contained the same particulate concentration (mg of particles per liter) as used in the three previous accelerated breadboard tests. This test is summarized as follows:

Prefilter: Pall Trinity Micro Corporation P/N MCY 4463 UR; retention, 100% of incident 0.35 micron particles; 5.4 cm (2-1/8 inch) OD; 13.33 cm (5-1.4 inches) long; 0.2 m^2 (2 ft^2) of membrane area; weight - 85.8 g (0.19 lb)

AgBr Cartridge: None utilized

Prefilter Pressure Drop: Initial - 2008 N/sq m (15 mm Hg); Maximum observed - 9867 N/sq m (74 mm Hg); Final - 8901 N/sq m (68 mm Hg); see Figure 17

Turbidity: Simulant 1.1 JTU; Effluent - 0.12 to 0.24 JTU; average - 0.11 JTU

6.2.5 Discussion of Results

The results of Accelerated Test No. 1 show that it is feasible to design a Silver Ion Generator which will allow particulates less than 10 microns to pass through the unit. The data indicates that reducing the length of the depth-type prefilter to 15.24 cm (6 inches) from 25.4 cm (10 inches) produces a SIG design which would exhibit pressure drops in excess of 6900 N/sq m (1 psi) at the flow rate of 10.36 kg/hr (22.8 lbs/hr). It appears that the depth-type prefilter does not provide any design advantages (i.e., geometry and weight) over the membrane type prefilters, and further testing with other size wound-type prefilters (5 and 1 micron retention) was not considered fruitful.

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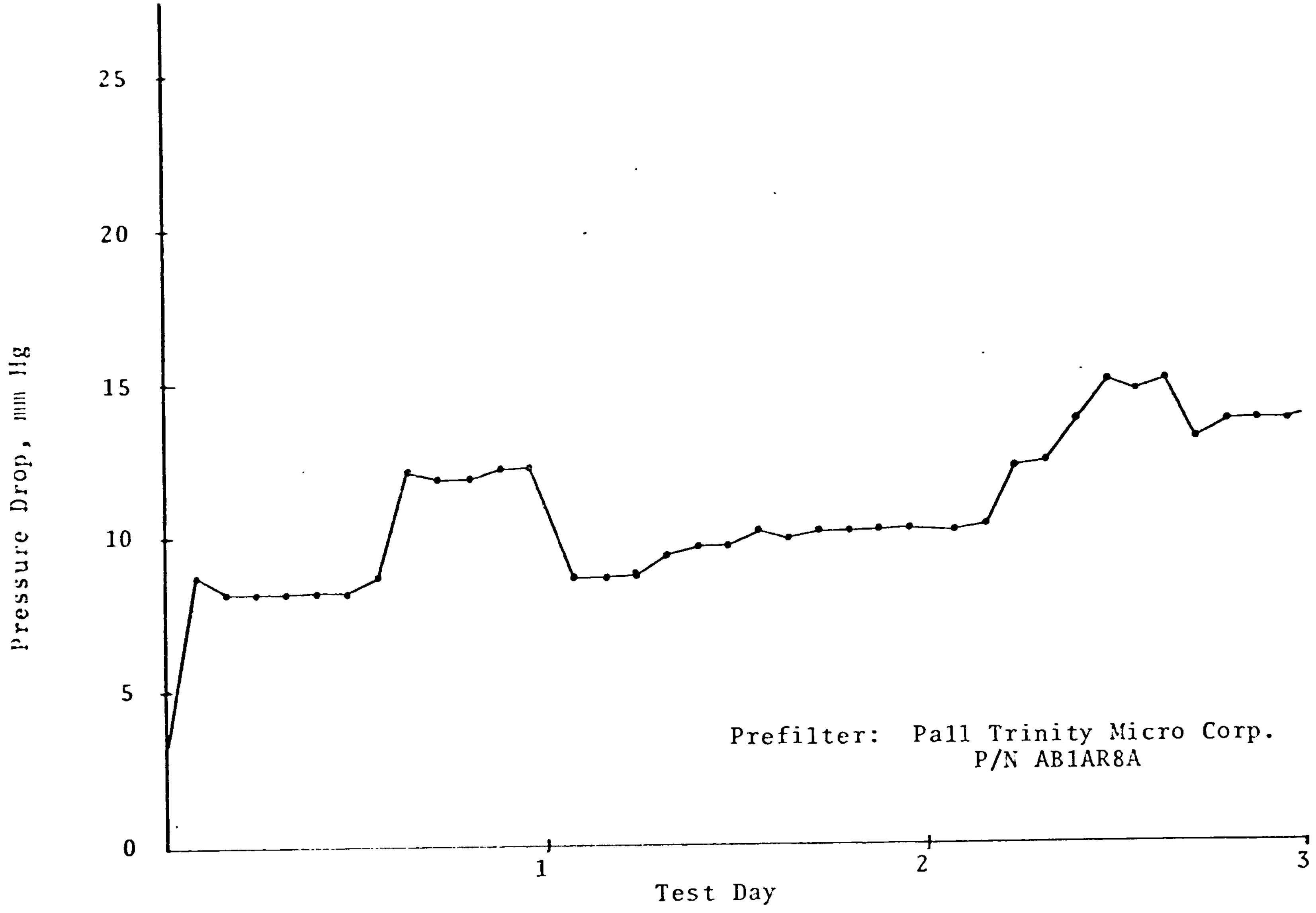


Figure 16 PRESSURE DROP OF PREFILTER VS TIME
ACCELERATED BREADBOARD TEST No. 3

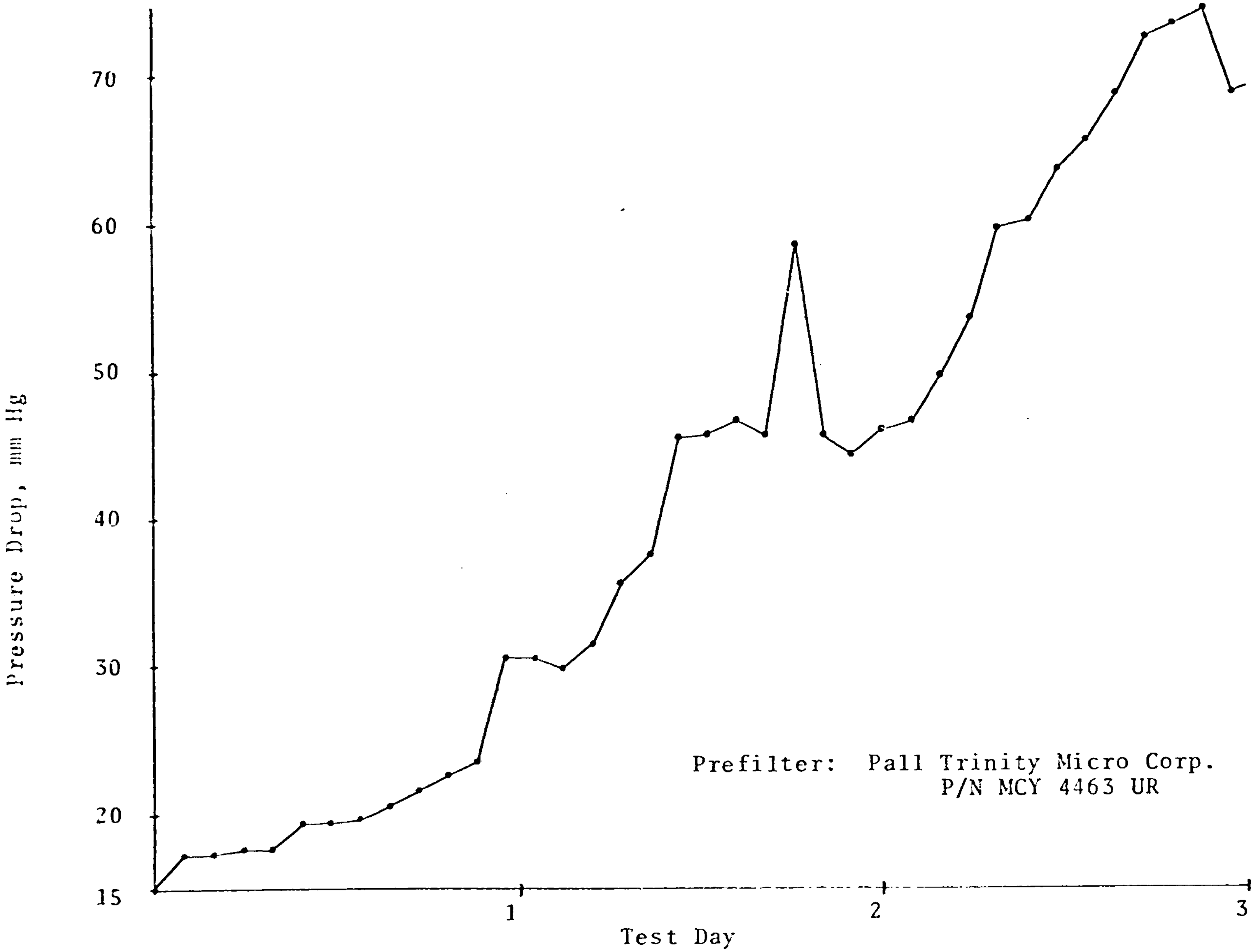


Figure 17 PRESSURE DROP OF PREFILTER VS TIME
ACCELERATED BREADBOARD TEST No.4

The results of Accelerated Tests No's 2 and 3 indicate that the 10-inch long membrane-type prefilters exhibit less pressure drop than a 25.4 cm (10-inch) wound-type prefilter, and produce a higher quality effluent (i.e., remove more turbidity and/or particulates). The turbidity data on Accelerated Tests No's 1 and 2 shows that the AgBr Cartridge (i.e., activated charcoal, and AgBr granules) is not a source of particules; during Test 1, the turbidity averaged 0.38 JTU, whereas, during Test 2, the turbidity averaged 0.08 JTU. It appears that the 6 x 12 mesh particles exhibit adequate attrition resistance durind hydrodynamic conditions.

CHEMTRIC concluded that Pall Trinity Micro Corporation's P/N AB1AR8A is the best prefilter for the SIG. In addition to low pressure drops and excellent particulate removal (effluent turbidity averaged 0.06 JTU), the filter media of this element contains no asbestos. At the present time there are no limits specified by USPH Standards on asbestos in drinking water, but the FDA specifies that medical fluids (e.g., medicines and intravenous solutions) contain no asbestos.

6.3 AgBr Cartridge Investigations

CHEMTRIC assembled a cartridge 2.86 cm (1-1/8 inches) in diameter x 23.5 cm (9-1/4 inches) in length to suit the core size of the AB1AR8A filter, that contained a contacting bed composed of 6 x 12 mesh AgBr particles, and 6 x 16 Westvaco Nuchar 503 activated charcoal. The charcoal and AgBr particles were mixed in a ratio of 1.25 parts charcoal to one part of AgBr. The column of AgBr and charcoal particles was supported at each end by a retaining subassembly composed of (1) a 20-mesh 316 SS screen, (2) a 3/16-inch thick pile of Pyrex wool, (3) a 30-mesh 316 SS screen, and (4) a 20-mesh 316 SS screen. At a flow rate of 10.36 kg/hr (22.8g lb/hr) this AgBr cartridge exhibited a pressure drop of 2877 N/sq m (0.417 psi).

At a temperature of 298°F (71°F) and at a flow rate of 10.36 kg/hr (22.8 lb/hr), the AgBr cartridge dosed anticipated fuel cell water with 0.08 ppm silver ions. At the minimum temperature of 285.8°K (55°F), and at flow rated of 1.05 kg/hr (2.3 lb/hr) and 10.36 kg/hr (22.8 lb/hr), the AgBr cartridge dosed anticipated fuel cell water with 0.035 ppm silver ions, respectively; this is saturation, the maximum dose attainable at 285.8°K (55°F) from AgBr solubility limits and in accordance with literature values.

6.4 Bactericidal Efficacy Tests

Figure 18 illustrates the test set-up used to verify the bactericidal efficacy of AgBr saturated fuel cell water at 285.8°K (55°F). Anticipated fuel water was chilled to 285.8°K (55°F) and then pumped through the AgBr column at 10.36 kg/hr (22.8 lb/hr). A 2 liter batch of silver dosed water (0.035 ppm) was maintained at 285.8°K (55°F) in a 3-neck flash and a viable suspension containing 10^8 cells of _Pseudomonas aeruginosa_ and/or Type IIIa was injected into the flask. After mixing (with a magnetic stirrer) the resultant concentration of microorganisms was approximately $5 \pm 1 \times 10^4$/ml.

Samples were withdrawn aseptically through a septum at the following times after bacteria injection and subjected to plate counts.

(a) 15 minutes

(b) 30 minutes

(c) 1 hour

(d) 2 hours

Table 7 summarizes the bacteriological test results. The tabulated data shows that a 0.035 ppm silver ion dose was bactericidal against $5 \pm 1 \times 10^4$/ml of _Pseudomonas aeruginosa_ and/or Type IIIa in 15 minutes or less. The test demonstrated that a 0.035 ppm silver ion dose is just as effective as a 0.05 ppm silver ion dose; both levels kill the bacteria.

Table 7 BACTERIOLOGICAL ANALYSES with 0.035 ppm Ag^+ DOSE

Test 1: Type IIIa

Injected Dose	Sample	Count
10^8 ($5 \pm 1 \times 10^4$/ml	15 min	<1/200 ml
	30 min	<1/200 ml
	1 hr	<1/200 ml
	2 hr	<1/200 ml

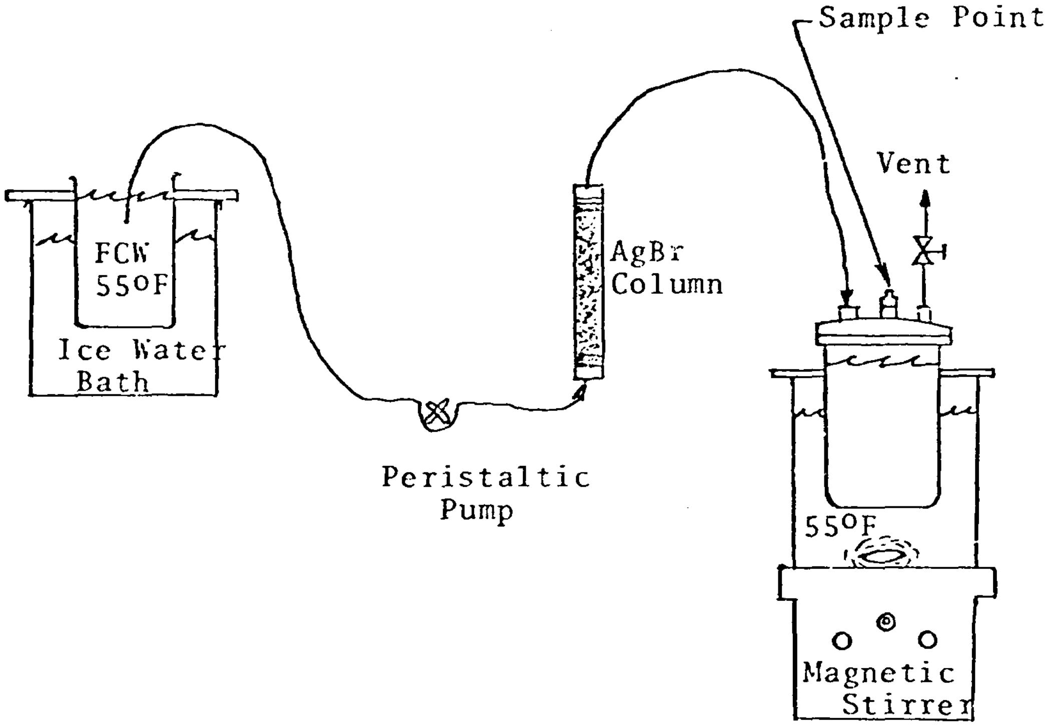


Figure 18 BACTERIOLOGICAL TEST SET-UP

Table 7 (concluded)

Test 2: *Pseudomonas aeruginosa*

Injected Dose	Sample	Count
10^8	15 min	<1/200 ml
($5\pm1x10^4$/ml)	30 min	<1/200 ml
	1 hr	<1/200 ml
	2 hr	<1/200 ml

6.5 Preliminary SIG Design

On the basis of the accelerated breadboard tests, the other development work, and trade-offs, CHEMTRIC prepared a preliminary SIG design.

The two drawings (6124-7402-1&2) illustrate the design of the Silver Ion Generator proposed for the Shuttle Orbiter. As shown, the design is a single canister. It consists of a two piece housing fastened by a V-band clamp, and contains a replaceable (expendable)element. The replaceable element is a subassembly of a filter cartridge and a column that holds the silver bromide-activated charcoal contacting bed. The design includes constraints for vibration by spring loading.

Fuel cell water enters the SIG via a 0.635 cm (1/4-inch) inlet port and is distributed by a manifold into the housing. The water flows radially through the filtering element and the particulates are excluded. The filtered water flows towards the base of the replaceable element, into the inlet manifold for the AgBr cartridge, and then axially through the silver-bromide, activated-charcoal bed. The water is dosed with silver ions, in accordance with the temperature and solubility limits of AgBr, and small quantities of organics are adsorbed by the activated charcoal. Finally, the water flows axially out of the AgBr cartridge, through the 0.95 cm (3/8-inch) outlet port, and into the storage tanks.

The filter cartridge (Pall Trinity Micro Corporation's P/N AB1AR8A) is 24.45 cm ((-5/8-inches) long and has an outside diameter of 7 cm (2-3/4-inches). It has a pleated membrane filter area of 0.5 m^2 (5.0 ft^2). The filtering element is rated for absolute retention of all particles 0.2 microns and larger. The filtering medium contains no asbestos and is a sheet of extremely fine inert inorganic fibers, with an inert organic binder melt-sealed to polypropylene end caps which are in turn melt-sealed to a perforated polypropylene internal support core and a perforated polypropylene outer jacket. The differential pressure

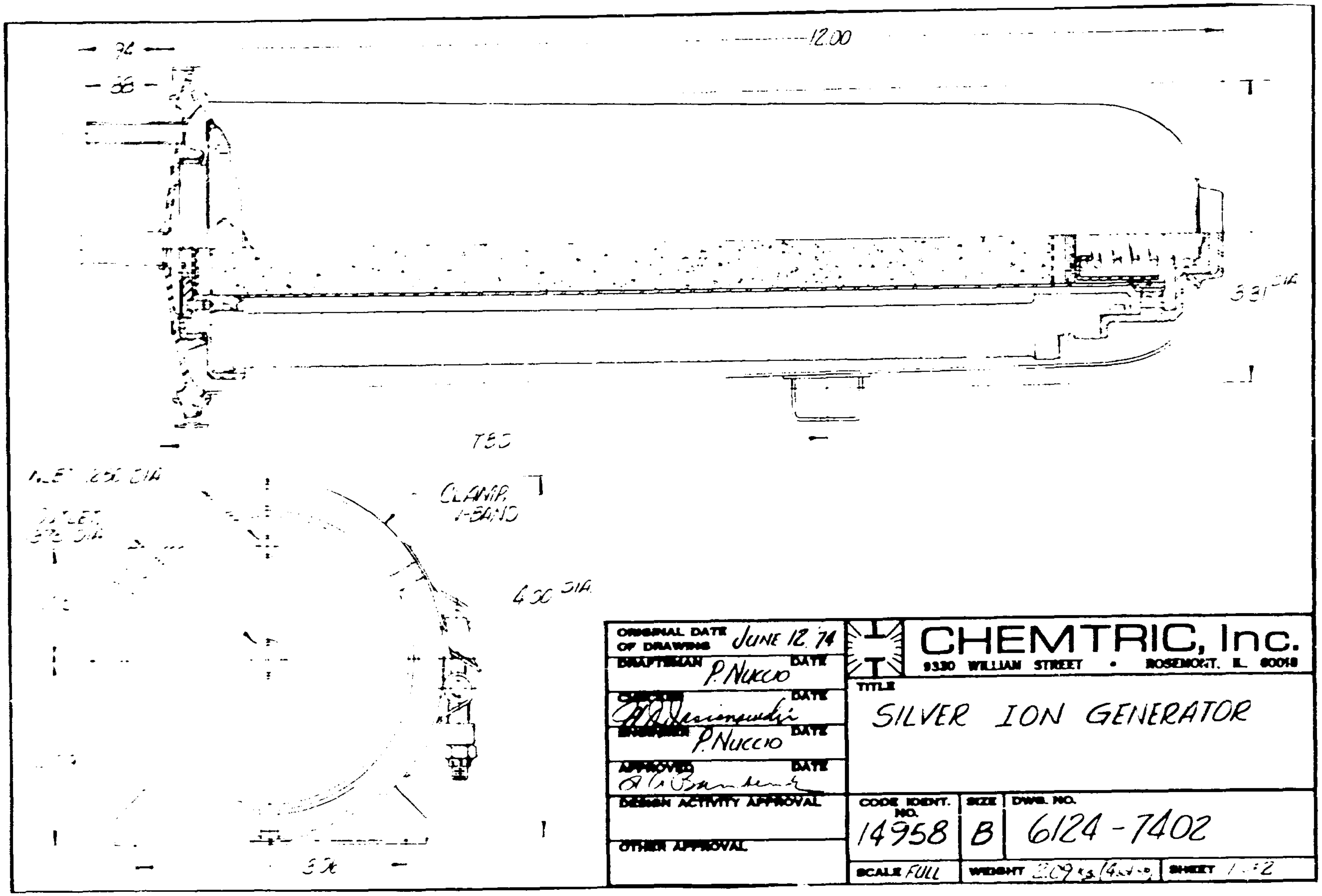
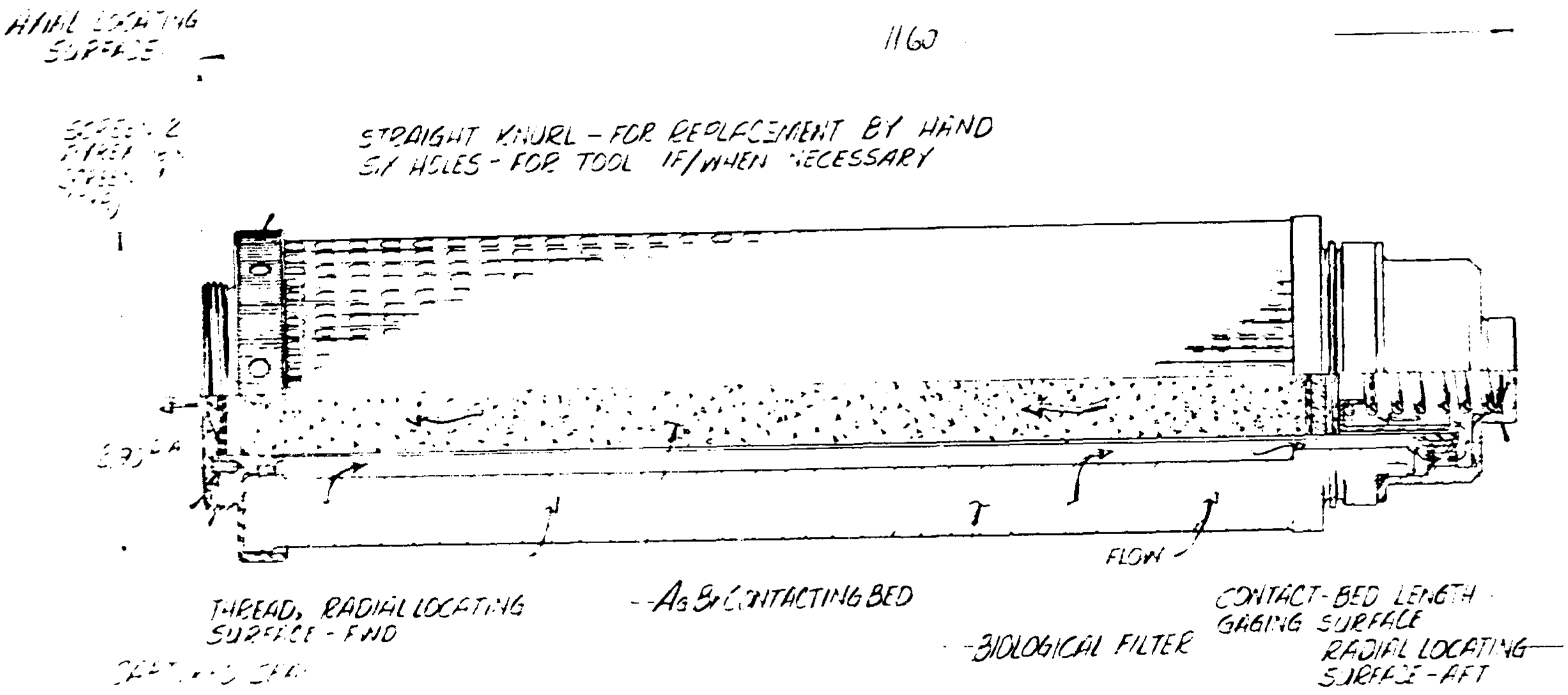


Figure 19 PRELIMINARY DESIGN - SILVER ION GENERATOR



FILTER-COLUMN ASSEMBLY

ORIGINAL DATE OF DRAWING	JUNE 12, '74
DRAFTSMAN	P. NUCCIO
CHECKED	[illegible signature]
ENGINEER	P. NUCCIO
APPROVED	
DESIGN ACTIVITY APPROVAL	
OTHER APPROVAL	

CHEMTRIC, Inc. 9330 WILLIAM STREET • ROSEMONT, IL 60018

TITLE: SILVER ION GENERATOR

CODE IDENT. NO.	SIZE	DWG. NO.
14958	B	6124 - 7402
SCALE FULL	WEIGHT 0.956 Kg (2.1 lb)	SHEET 2 OF 2

FIGURE 20 PRELIMINARY DESIGN SIG FILTER-COLUMN ASSEMBLY

rating is 517,500 N/sq md (75 psid). At the flow rate of 10.36 kg/hr (22.8 lb/hr), the pressure drop across a clean filtering element is approximately 552 N/sq m (0.08 psi). With a 30-day particulate load and at the flow rate of 10.36 kg/hr (22.8 lb/hr), the pressure drop across the filtering medium is approximately 2070 N/sq m (0.3 psi).

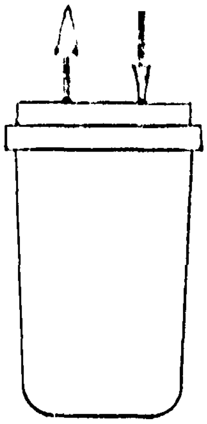
The silver bromide-activated charcoal contacting column is contained within a cartridge; the diameter of this column is 2.75 cm (1.08 inches) and the length is 25.08 cm (9-7/8-inches). The column is composed of 39 grams (0.086 lb) dry weight of 6 x 12 mesh AgBr particles, and 49 grams (0.108 lb) dry weight of 6 x 16 mesh Westvaco Nuchar 503 activated charcoal. At the flow rate of 10.36 kg/hr (22.8 lb/hr), the pressure drop across this column is approximately 3105 N/sq m (0.45 psi). At the minimum temperatures of 284.8°K (55°F) and the maximum temperature of 296.8°K (75°F), the fuel cell water will be passively dosed with 0.035 - 0.08 ppm silver ion respectively. The 39 grams of AgBr can theoretically dose up to 312,000 kg (695,0001b) of fuel cell water.

The metal of construction is 316 stainless steel. All metal-to-metal joining will be accomplished by heli-arc welding. After welding, the SIG will be heat treated to a fully stressed-relieved condition to maximize corrosion resistance, then passivated.

The interface connectors are 0.635 cm (1/4-inch) inlet and 0.95 cm (3/8-inch) outlet nipples. The overall dimensions of the SIG excluding the interface connectors are 30.5 cm (12.0 inches) long with an outside diameter over the clamp of 10.16 cm (4.0-inches). The unit packed (dry) weighs approximately 2.09 kg (4.61 lb). The replaceable element (dry) weighs approximately 0.96 kg (2.11 lb).

APPENDIX A

FAILURE MODES & EFFECTS ANALYSES



SINGLE CANISTER

Description

The single canister with no valve consists of the basic canister with the inlet and outlet lines rigidly attached to a plain canister cap. This concept represents the simplest case possible with the silver ion generator.

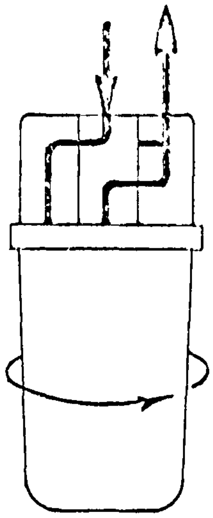
Conclusion

There is no corrective action possible if any failures occur. The maximum criticality of any possible failure is a level II.

SILVER ION WATER BACTERICIDE SYSTEM FAILURE MODES & EFFECTS ANALYSIS

Concept: Single Canister (No Valves)

Failure Mode and Cause	Failure Effect on Performance	Failure Effect on Mission	Criticality	Detection Method	Action Required	Time Required
External leak - seal or metal failure	Water leaks into cabin	High humidity, possible contamination, & insufficient water	II	Visual, hi humidity, and/or low quantity	NONE POSSIBLE WITH THIS CONCEPT	NA



REPLACEABLE CANISTER

Description

The replaceable canister consists of a filter cartridge and housing assembled with a special cap. The inlet and outlet lines are rigidly attached to this cap. By twisting the canister housing one is able to move a valve body and by-pass the inlet/outlet lines while disengaging the canister housing simultaneously. The reverse procedure holds for engagement of a replacement canister.

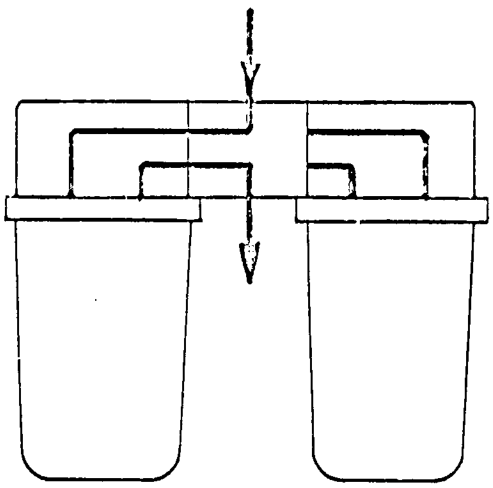
Conclusion

There is no corrective action possible if there is an internal leak in the valve/cap by-pass. The maximum criticality of this failure would be a level II.

SILVER ION WATER BACTERICIDE SYSTEM FAILURE MODE & EFFECTS ANALYSIS

Concept: Replaceable Canister (with Isolation/By-Pass Valve)

Failure Mode and Cause	Failure Effect on Performance	Failure Effect on Mission	Criticality	Detection Method	Action Required	Time Required
External leak in canister - seal or metal failure or improper assembly	Water leaks into cabin	High humidity, possible contamination, & insufficient water	II	Visual, hi humidity, and/or low quantity	Replace canister	Less than 1 minute
Internal leak in valve - seal or metal failure	Water by-passes bacteria filter and the AgBr and charcoal column	Water contains more solids, less silver ions, more organics and possibly microbes	II	Low ΔP & low silver ion conc.	NONE POSSIBLE WITH THIS CONCEPT	NA



PARALLEL CANISTERS WITH INTEGRATED SELECTOR VALVE

Description

This concept consists of two canisters attached to a common cap. The cap is a manifold that puts the two canisters in parallel hydrauically to each other through a common selector valve. The canister inlet and outlet lines are controlled simultaneously by a common body in the selector valve. The valve permits selection of an alternate canister while isolating a single point failure in the prime canister.

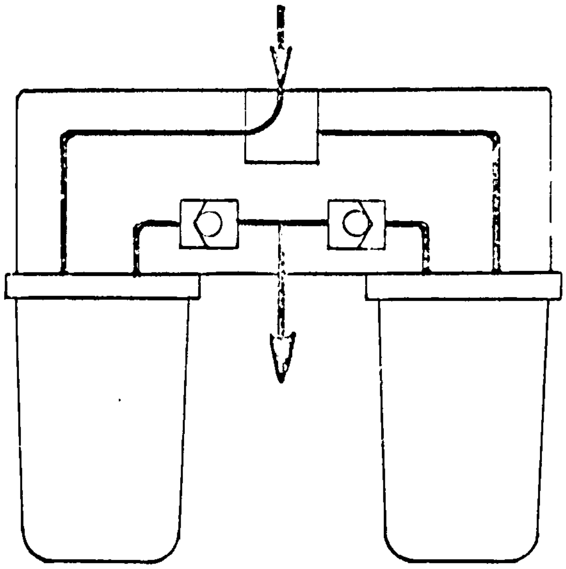
Conclusion

There is no corrective action possible ii the selector valve experiences an internal leak. The maximum criticality of this failure would be a level II.

SILVER ION WATER BACTERICIDE SYSTEM FAILURE MODES & EFFECTS ANALYSIS

Concept: Two Parallel Canisters With Integrated Selector Valves

Failure Mode and Cause	Failure Effect on Performance	Failure Effect on Mission	Criticality	Detection Method	Action Required	Time Required
External leak in canister - seal or metal failure	Water leaks into cabin	High humidity, possible contamination, & insufficient water	II	Visual, hi humidity, and/or low quantity	Select other canister	Less than 1 minute
Internal leak in canister - seal or metal failure	Part of the water by-passes bacteria filter and the AgBr and charcoal column	Water contains more solids, less silver ions, more organics and possibly microbes	II	low ΔP & low silver ion conc.	Select other canister	Less than 1 minute
Internal leak in Valves - seal or metal failure					NONE POSSIBLE WITH THIS CONCEPT	NA



PARALLEL CANISTERS WITH INTEGRATED SELECTOR & CHECK VALVES

Description

This concept consists of two canisters attached to a common cap. The cap is a manifold that puts the two canisters in parallel hydrauically to each other through a common selector valve and two check valves. The canister inlets are routed to the selector valve while each outlet is routed to its own check valve and then teed to a common outlet. The selector valve permits selection of an alternate canister while isolating a single point failure in the prime canister. The check valves prevent backflow from an operative canister to an inoperative one.

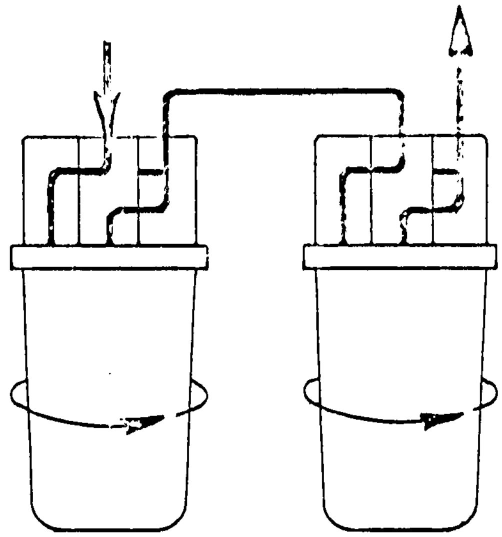
Conclusion

This concept is an acceptable design since there are no uncorrectable single point failure modes. The highest level of criticality for a correctable single point failure in this concept is a level II.

SILVER ION WATER BACTERICIDE SYSTEM FAILURE MODES & EFFECTS ANALYSIS

Concept: Two Parallel Canisters With Integral Selector & Check Valves

Failure Mode and Cause	Failure Effect on Performance	Failure Effect on Mission	Criticality	Detection Method	Action Required	Time Required
External leak in canister - seal or metal failure	Water leaks into cabin	High humidity, possible contamination, & insufficient water	II	Visual, hi humidity, and/or low quantity	Select other canister	Less than 1 minute
Internal leak in canister - seal or metal failure	Part of the water by-passes bacteria filter and the AgBr and charcoal column	Water contains more solids, less silver ions, more organics and possibly microbes	III	Low ΔP & low silver ion conc.	Select other canister	Less than 1 minute
Internal leak in selector valve - seal or metal failure	None - water flows through both canisters	None	None	Low ΔP	None	None
Plugging - filters or column	No water flow	Dehydration of crew, and no coolant	II	High ΔP and low quantity	Select other canister	Less than 1 minute
Channeling - particles shift	Water by-passes AgBr particles and charcoal	Water contains less Ag^+, more organics and possibly microbes	III	Low ΔP & low silver ion conc.	Select other canister	Less than 1 minute



SERIES CONNECTED CANISTERS WITH ISOLATION/BY-PASS VALVES

Description

This concept consists of two canisters independent of each other but plumbed in series. Each canister is basically a replaceable type with a special cap enabling rapid removal of the basic canister housing from the inlet and outlet lines simultaneously. By disengaging the canister from the lines, a by-pass is engaged and vice-versa for replacement. If one canister experiences a single point failure it can be isolated with the by-pass while still permitting full usage of the alternate.

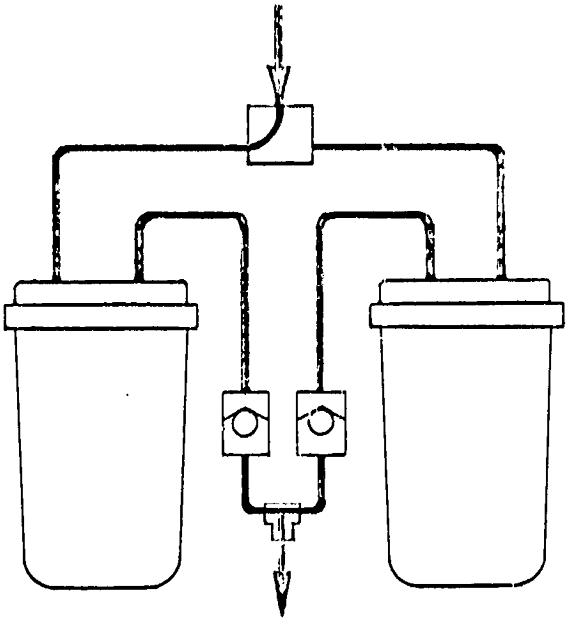
Conclusion

This concept is an acceptable design since there are no uncorrectable single point failure modes. The highest level of criticality for a correctable single point failure in this concept is a level II.

SILVER ION WATER BACTERICIDE SYSTEM FAILURE MODES & EFFECTS ANALYSIS

Concept: Two Series-Connected Canisters with Isolation/By-Pass Valves

Failure Mode and Cause	Failure Effect on Performance	Failure Effect on Mission	Criticality	Detection Method	Action Required	Time Required
External leak in canister - seal or metal failure or improper assembly	Water leaks into cabin	High humidity, possible contamination, & insufficient water	II	Visual, hi humidity, and/or low quantity	By-pass 1st and use 2nd canister	Less than 1 minute
Internal leak in canister - seal or metal failure	Part of the water by-passes bacteria filter and the AgBr and charcoal column	Water contains more solids, less silver ions, more organics and possibly microbes	III	Low ΔP & low silver ion conc.	By-pass 1st and use 2nd canister	Less than 1 minute
Internal leak in 1st head-seal or metal failure					By-pass 1st and use 2nd canister	Less than 1 minute
Plugging-filters or column	No water flow	Dehydration of crew, and no coolant	II	High ΔP and low quantity	By-pass 1st and use 2nd canister	Less than 1 minute
Channeling-particles shift	Water by-passes AgBr particles & charcoal	Water contains less Ag^+, more organics and possibly microbes	III	Low ΔP & low silver ion conc. canister	By-pass 1st and use 2nd	Less than 1 minute



PARALLEL CANISTERS WITH EXTERNAL SELECTOR VALVE

Description

This concept consists of two canisters independent of each other but with their inlets plumbed in parallel to a common selector valve. The valve permits selection of an alternate canister after a single point failure in the prime canister. The canister outlets are each plumbed to their own check valves and then teed together. The check valves prevent backflow from an operative canister into an in-operative one.

Conclusion

This concept is an acceptable design since there are no uncorrectable single point failure modes. The highest level of criticality for a correctable single point failure in this concept is a level II.

SILVER ION WATER BACTERICIDE SYSTEM FAILURE MODES & EFFECTS ANALYSIS

Concept: Two Parallel Canisters With External Selector & Check Valves

Failure Mode and Cause	Failure Effect on Performance	Failure Effect on Mission	Criticality	Detection Method	Action Required	Time Required
External leak in canister - seal or metal failure	Water leaks into cabin	High humidity, possible contamination, & insufficient water	II	Visual, hi humidity, and/or low quantity	Select other canister	Less than 1 minute
Internal leak in canister - seal or metal failure	Part of the water by-passes bacteria filter and the AgBr and charcoal column	Water contains more solids, less silver ions, more organics and possibly microbes	III	Low ΔP and low silver ion conc.	Select other canister	Less than 1 minute
Internal leak in selector valve - seal or metal failure	None - water flows through both canisters	None	None	Low ΔP	None	None
Plugging - filters or column	No water flow	Dehydration of crew, and no coolant	II	High ΔP and low quantity	Select other canister	Less than 1 minute
Channeling - particles shift	Water by-passes AgBr particles and charcoal	Water contains less Ag^+, more organics and possibly microbes	III	Low ΔP and low silver ion conc.	Select other canister	Less than 1 minute

APPENDIX B

RANDOM VIBRATION TEST REPORT

By

GENERAL ENVIRONMENTS CORPORATION

REPORT NO. 1467-11

DATE April 15, 1974

REPORT

ONE (1) CANISTER
ASSEMBLY

FOR

CHEMTRIC, INC.

GENERAL ENVIRONMENTS CORPORATION
7845 Nagle Avenue, Morton Grove, Illinois 60053

	PREPARED	CHECKED	APPROVED
BY	J. Schaffner	B. Loveless	B. Loveless
SIGNED	J. Schaffner	B. Loveless	B. Loveless
DATE	4-15-74		4-15-74

DATE April 15, 1974

PURPOSE OF TEST:

To determine the ability of the test sample to withstand the applied Random Vibration specified.

MANUFACTURER:

Chemtric, Inc.,
Under Contract NAS 9-13718

MANUFACTURER'S TYPE OR MODEL NO.:

One (1) Canister Assembly

DRAWING, SPECIFICATION OR EXHIBIT:

P.O. 02430

QUANTITY OF ITEMS TESTED:

One (1)

SECURITY CLASSIFICATION OF ITEMS:

Unclassified

DATE TEST COMPLETED:

April 12, 1974

TEST CONDUCTED BY: General Environments Corporation

DISPOSITION OF SPECIMENS:

Returned to Chemtric, Inc.

ABSTRACT:

None

REPORT NO. 1467-11

DATE April 15, 1974

DESCRIPTION OF TEST:

RANDOM VIBRATION TEST

Requirements:

The test sample shall satisfactorily withstand the applied vibration without exhibiting evidence of physical damage.

Test Procedure:

The test sample was secured to a fixture furnished by Chemtric, which, in turn was rigidly attached to the moving element of the vibration machine.

The sample was then subjected to 2.5 minutes of random vibration in each of three (3) mutually perpendicular axes. The bandwidth was limited to between 20 and 2000 Hz. with the spectral density as follows:

Frequency Range (Hz.)	Test Spectrum
20 to 80	+ 3dB/Oct
80 to 180	0.06 g^2/cps
180 to 200	+12 dB/oct
200 to 400	0.1 g^2/cps
400 to 450	-12 dB/oct
450 to 2000	0.06 g^2/cps

Overall G rms = 11.1

Description of Test Apparatus:

Vibration Machine, MB, Model 3600, S/N 101
Control Console, MB, Model T288, latest calibration date - Feb. 11, 1974, frequency of calibration 6 months.
Vibration Pick-Up, Endevco, Model 2213, S/N DA64, latest calibration date - Nov. 6, 1973, frequency of calibration 6 months.

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FORM NO. 108

DATE April 15, 1974

DESCRIPTION OF TEST:

RANDOM VIBRATION TEST (Cont'd)

Test Results:

Visual examination of the test specimen, limited to external surfaces, revealed no apparent evidence of physical damage.

The specimen was then returned to Chemtric, Inc. for further examination and final determination of results.

REPORT NO. 1467-11

FORM NO. 108