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WATER SYSTEM MICROBIAL CHECK VALVE DEVELOPMENT INTERIM REPORT

BY

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FEBRUARY 1978

PREPARED UNDER CONTRACT NO. NAS9-15079

BY

UMPQUA RESEARCH COMPANY

MYRTLE CREEK, OREGON

FOR

LYNDON B. JOHNSON SPACE CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

Development work on a device for the Space Shuttle that will prevent the transfer of viable microorganisms within water systems is described. The device serves as a check valve in that it prevents the transfer or cross-contamination of microorganisms from a nonpotable system into a potable water system when these systems are interconnected. In this regard, the function of the device is similar to that of the "air gap" found in conventional one-gravity systems. The device is essentially a bed of resin material impregnated with iodine . Basic design data for a variety of flow and temperature conditions are presented, together with results of challenging the beds with suspensions of seven microorganisms including aerobes, anaerobes, and spore formers.

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1.0 INTRODUCTION AND SUMMARY

1.1 Problem Definition. The Space Shuttle Orbiter has a number of systems that require water including the galley, bathing and personal hygiene, and evaporators/boilers. Because of design restraints, these systems are supplied with water from a single source - - - the potable water system. Design considerations favor the hard lining or cross-connection of the water source to the various using systems. The microbial contamination of the water within the using system cannot be precluded. During stagnant and backflow conditions, microbial back contamination of the potable water system is possible. The Microbial Check Valve (MCV) is a device that prevents this back contamination without introducing more than a modest pressure drop while allowing back flow equal to normal forward flow. In addition, the testing reported herein demonstrates that the MCV can replace the silver ion generator as a biocide dispensing device.

1.2 Microbial Check Valve (MCV) Unit. The MCV unit is a device that kills microorganisms with essentially 100% efficiency as contaminated water flows through the unit. The MCV cylinder, which fits in a 5 diam x 12.7 cm (2 diam x 5 in) envelope, is packed with a quaternary ammonium anion-exchange resin previously combined with triiodide complexes. The unit does not function as a filter as the dead organisms exit from the unit along with the product water. The iodine from the triiodide complex is supplied on demand and the iodine residual in the product stream is low. This results in extremely long useful life of the unit and a product water lacking in iodine taste.

The favorable characteristics which caused the MCV to be considered for space flight are the following:

1. Small volume and weight.

2. Highly effective in killing bacteria, fungi and viruses.
3. Low pressure drop.
4. Equally effective with flow in either direction.
5. Low iodine residual in product water.
6. Low cost.
7. Unlimited shelf storage life.
8. Long operational life.
9. Insensitivity to spacecraft operating conditions, i.e., pressure and temperature.
10. Resin can be replaced easily.
11. Simple interface.
12. No moving parts.
13. Requires no in-flight expendables.
14. Requires no electric power.

1.3 Previous Work. Under contract NAS9-11940 entitled "R & D in Spacecraft Water and Waste Management", an investigation of the basic MCV water disinfection system developed by Drs. Walter Lambert and Louis Fina at Kansas State University was conducted. This study was preliminary in nature and supported the definition of the capabilities of the technique and the application potential of the concept for spacecraft potable water disinfection. Since this time, the developers of the concept have obtained a U.S. patent for the development. (U.S. Patent #3,817,860 dated June 18, 1974.)

1.4 Current Work. The current effort was initiated in June 1976 to conduct developmental research and to develop a preprototype system for space flight. Based on very promising initial results the Shuttle Program Office adopted the system for use in the Shuttle potable water system. It replaced the silver ion generator which had previously been

baselined. The prime reason for the change was that qualification testing of the silver-ion generator indicated erratic performance and would have required additional expenditures for further development.

Major tasks in the current effort include:

a) preliminary design based on literature and Shuttle water system reviews.

b) pressure drop measurements

c) microbial challenges

d) preprototype unit design and fabrication

e) verification testing

f) prototype unit development

The experimental program was designed to determine operating parameters and limitations of the MCV concept based on Shuttle requirements by testing to failure. The effort included challenging the device with suspensions of the following microorganisms: Escherichia coli, Streptococcus faecalis, Staphylococcus aureus, Bacillus subtilis, Pseudomonas aeruginosa, Clostridium perfringens, and Aspergillus niger. The ability to kill these organisms at the following temperatures was verified: 275, 294 and 344 K (35, 70 and 160^{o}F).

The effects of other Shuttle requirements such as soaking the device with ethylene oxide, alcohol, autoclaving the device, and determining the effect of the device on water chemistry were also determined.

Sufficient information was developed to enable sizing the device for Shuttle applications. In general, it is concluded that the device will perform satisfactorily in its intended uses in the Shuttle potable water system.

2.0 MCV DESIGN REQUIREMENTS

2.1 MCV Interface Control Requirements. The latest revision of the interface control requirements for the MCV are listed below. These requirements are extracted from the Interface Control Document prepared by Rockwell International Corporation in November 1977.

2.1.1 OPERATING PRESSURE. The MCV shall operate as required with any water pressure from 4.5 to 36 psig.

2.1.2 PRESSURE DROP. The pressure drop across the MCV shall not, after being subjected to water in accordance with Table 2-1 for 7 days at an average flow rate of 15.5 lbs/hr, exceed 0.5 psi at a flow rate of 22.8 lbs/hour.

2.1.3 WATER TEMPERATURE. The temperature of the fuel cell water at the MCV interface will range from a minimum of $40^{o}F$ to a maximum of $200^{o}F$.

2.1.4 EXTERNAL LEAKAGE. External leakage shall not exceed 1×10^{-4} scc/sec He at 36 psig.

2.1.5 EFFLUENT. The MCV effluent shall conform to requirements of Table 2-1.

2.1.6 INSTALLATION. The MCV will be installed in the ECLSS Equipment Bay, as shown in V070-623200, and shall be compatible with the environments therein as defined in MF0004-014B.

2.1.7 ENVELOPE. The envelope of the MCV shall not exceed the dimensions shown in Figure 2-1.

2.1.8 PORTS. The inlet and outlet ports of the MCV shall be located as shown in Figure 2-1 and shall be designed to be compatible with quick disconnects as defined in MC276-0020B.

2.1.9 MATERIALS. The MCV materials shall be in accordance with MC999-0096D.

2.1.10 WEIGHT. The weight of the MCV shall not exceed 1.5 lbs.

2.1.11 APPLICABLE DOCUMENTS.

Rockwell International/Space Division

MC276-0020B Amendment C-04 22 August 1977	Disconnect, Fluid
MC999-0096D Amendment E-07 17 June 1977	Materials and Processes Control and Verification System for the Space Shuttle Program: Suppliers and Subcontractors
MF0004-014B Amendment C-05 28 February 1977	Environmental Requirements and Test Criteria for the Orbiter Vehicle
V070-623200 Revision A 28 September 1977	System Installation-Water Management, ECLSS Equipment Bay

TABLE 2-1

Simulated Fuel Cell Water Composition

Properties	Limits (Maximum Allowance)
a. pH	6.0 - 8 at 25 degrees C (77F)
b. Total Solids	20 ppm
c. Taste and Odor	None at Threshold (Odor No. of 3)
d. Turbidity	11 Units
e. Color, True	15 Units
f. Total Organics	10 ppm
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
100-250 microns	10
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
q. Zinc	5.0 ppm

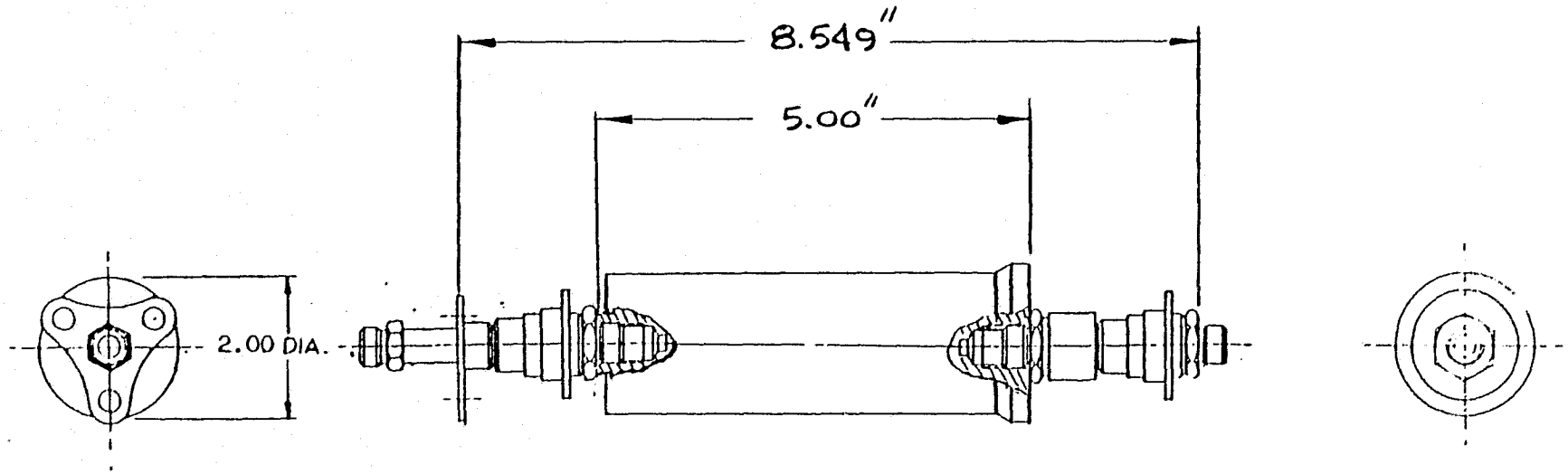


FIGURE 2-1
MICROBIAL CHECK VALVE ENVELOPE
AND INTERFACE CONNECTIONS

2.2 Other Information/Requirements. Other information and requirements that effect the MCV design are listed below.

Water Source:	Fuel Cells. Nominal flow = 5.4 kg/hr(12.0 lb/hr) Maximum flow = 10.0 kg/hr(22.0 lb/hr) Dissolved hydrogen = 82.7 kPa abs (12 psia) maximum 34.5 kPa abs (5 psia) nominal
Crew Size:	7 men
Mission Duration:	30 Days
Water Flow Rate to Galley:	0.45 kg/min (1.0 lb/min) maximum

Water Useage

Drinking & Food Preparation:	2.59 kg/man-day (5.70 lb/man-day)
Personal Hygiene:	1.16 kg/man-day (2.55 lb/man-day)
Total Water Useage:	3.74 kg/man-day (8.25 lb/man-day)
EMU Recharge:	5.4 kg (12 lb) per recharge, 2 recharges per mission, flow rate = 0.45 kg/min (1.0 lb/min)
Water Flow Rate (Use Port):	0.45 kg/min (1.0 lb/min)
Cold Water Temperature (Galley):	277±2.8 K (40±5^{o}F)
Hot Water Temperature:	344 K (160^{o}F) maximum
Pressure Drop:	13.8 kPa at 0.45 kg/min (2.0 psi at 1.0 lb/min)
Operational Design Life:	30 Days
Shelf Life:	maximize
Electrical Power:	120V/400 Hertz or 28V/DC

Shuttle Hardware Design Requirements

Temperature:	nominal 291-300 K (65-80^{o}F) range 275-311 K (35-100^{o}F)

Cabin Pressure:	nominal 101±1.4 kPa abs (14.7±0.2 psia) range 94 to 102 kPa abs (13.7 to 14.9 psia)
Water System Pressure:	range 55 to 117 kPa gage (8 to 17 psig) (cycles between limits during mission)
Ventilation:	range 0.46 - 1.2 M/min (15 -40 ft/min)
Acceleration:	range ±3.3 g in all attitudes
Random Vibration:	-60 min in each of the 3 mutual perpendicular axes

20-80 Hz	+9 dB/oct
80-250 Hz	0.3 g^2/Hz
250-320 Hz	-9 dB/oct
320-2000 Hz	0.15 g^2/Hz

Shock: Terminal peak sawtooth pulse of 11 ms in each mutually perpendicular axis.

+ X axis	0.0 g
- X axis	20 g
+ Y axis	6.8 g
- Y axis	6.8 g
+ Z axis	6.8 g
- Z axis	10.0 g

Salt fog & Humidity Soak: See MIL Std 810, Methods 507 and 508

3.0 PRESSURE DROP TESTS

3.1 Preliminary Tests. Flow/Pressure Drop studies were conducted in conformance with the conditions specified in the Program Plan. A 3.7 diam x 10 cm (1.5 diam x 4 in) bed was tested at 276, 297, 345 and 373 K (37,75,162 and 194^{o}F) and at room temperature after being autoclaved at 393 K (248^{o}F) for 15 minutes. In addition, two other bed diameters and bed depths were tested at room temperature yielding data for a total of 3 diameters and two depths. These data covered the flow ranges of interest for the proposed Shuttle missions, and provided enough information to size beds for any flow condition within these ranges.

The data were gathered using the apparatus shown in Figure 3-1. A volume of water was adjusted to a temperature near that of the test condition and placed in the reservoir. After flow had stabilized, the graduated cylinder was placed under the overflow and water was collected for a fixed period of time. Duplicate points were determined at each flow, and three to four flows were measured for each reported Flow/Pressure Drop curve.

The following beds were tested:

Diameter, cm	Depth, cm	Dry Weight, grams
1.5	5	11.0
1.5	10	21.1
2.54	5	28.4
2.54	10	52.6
3.7	5	62.3
3.7	10	124.8

The Flow/Pressure Drop data are shown on Figures 3-2, 3-3 and 3-4. Figures 3-2 and 3-3 show the effect of bed diameter at fixed depth at room temperature. Figure 3-4 shows the effect of temperature. Viscosity

(text continued on page 15)

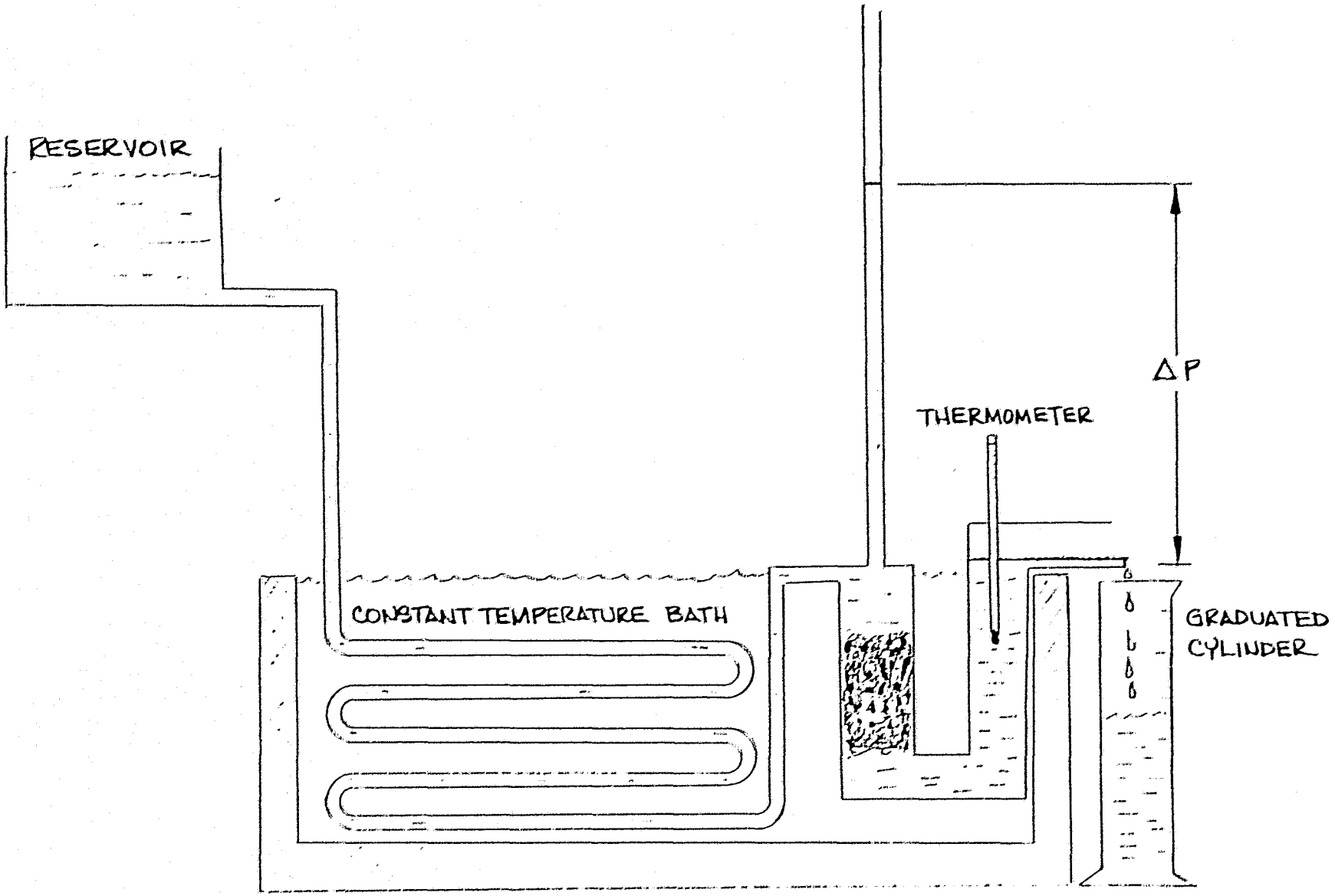


FIGURE 3-1
FLOW/ΔP TEST APPARATUS

FIGURE 3-2

FLOW/ΔP DATA FOR IODINATED RESIN AT VARIOUS BED DIAMETERS

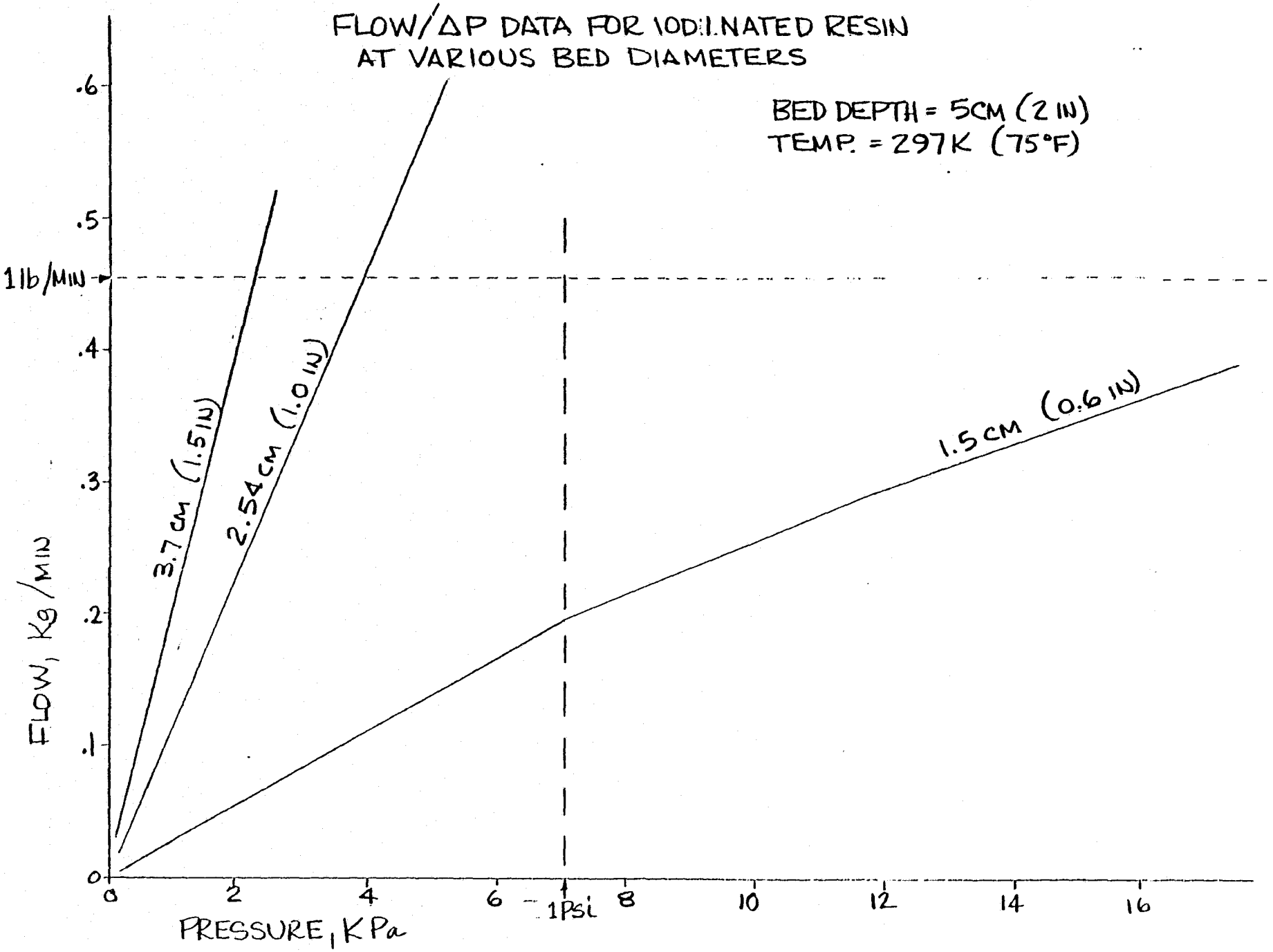


FIGURE 3-3
FLOW/ΔP DATA FOR IODINATED RESIN
AT VARIOUS BED DIAMETERS

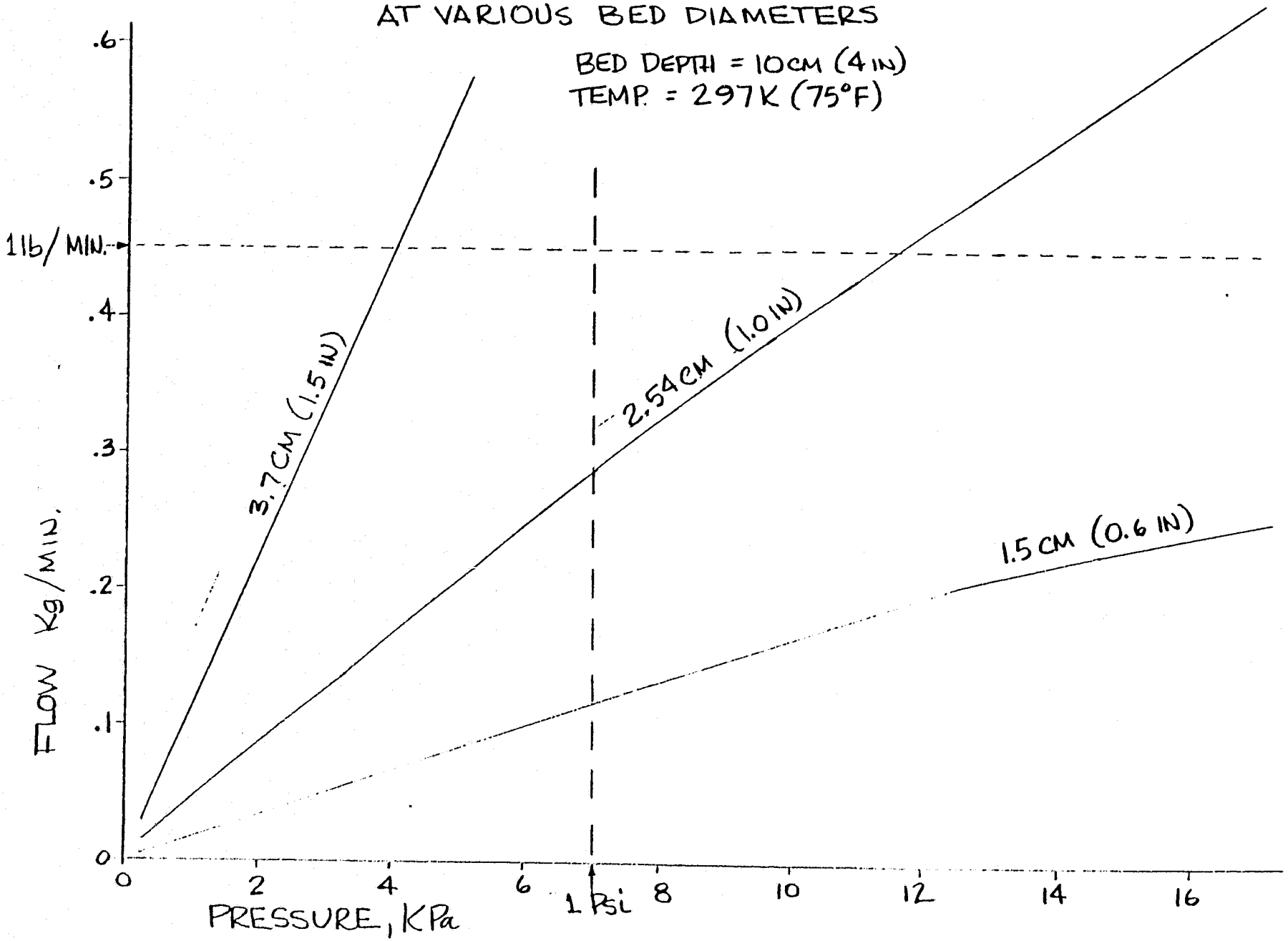
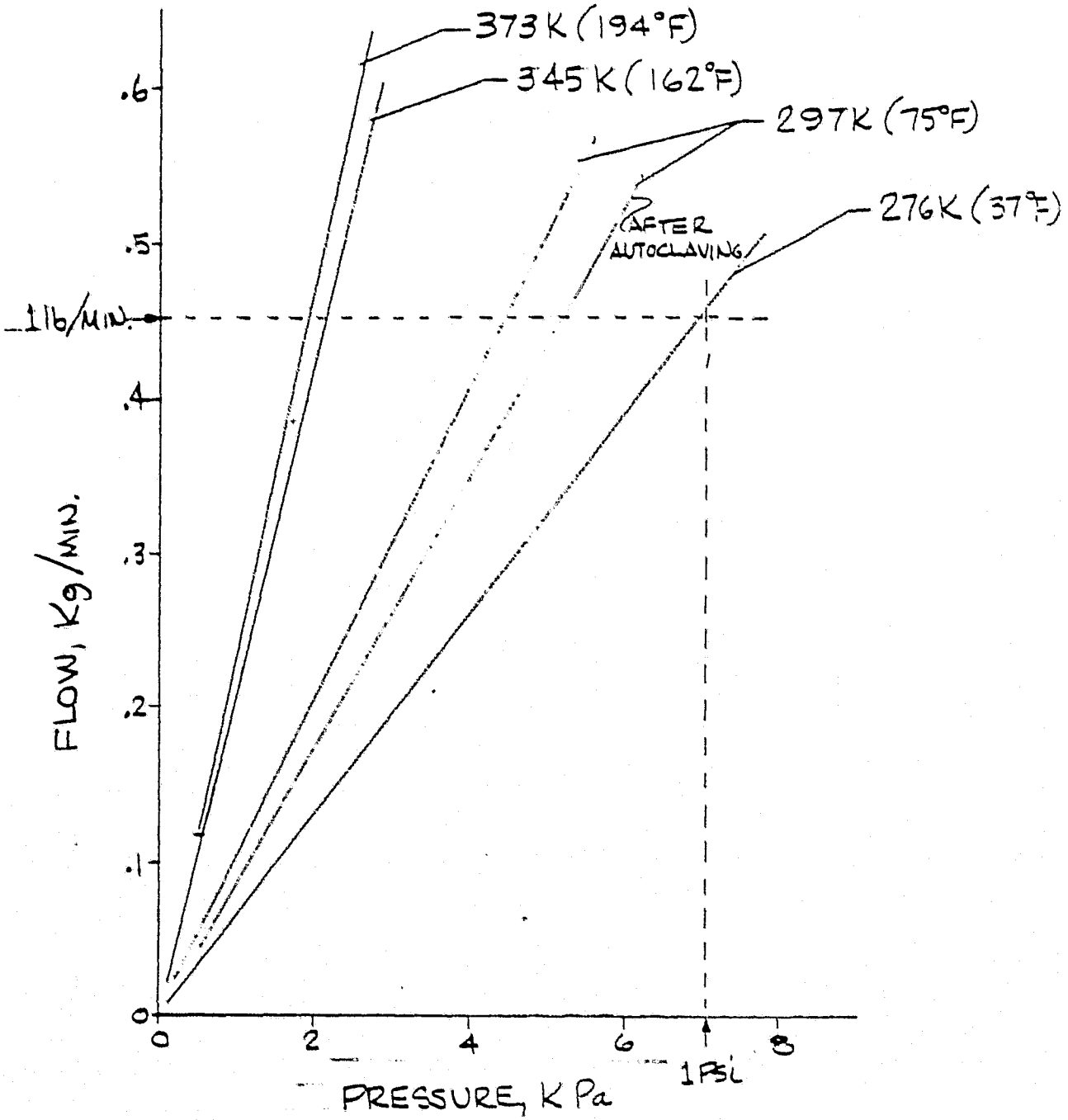


FIGURE 3-4
FLOW/ΔP DATA FOR IODINATED RESIN AT VARIOUS TEMPERATURES

BED DIAMETER = 3.7 CM (1.5 IN)
BED DEPTH = 10 CM (4 IN)



(continued from page 10)

is apparently the controlling factor, since the pressure drop decreases with increasing temperature at a given flow rate. In general, these preliminary data fell within the range predicted in the Program Plan.

In later tests with the preprototype unit, significantly higher pressure drops were observed than in the preliminary tests, because the resin bed in the preprototype unit is spring loaded which results in denser packing of the bed as explained in paragraph 3.2.

3.2 Preprototype Unit Tests. Subsequent to the microbial challenge tests (reported in Sections 3 and 4), off-the-shelf hardware was selected for the MCV preprototype unit, which resulted in a 4.4 diam x 10 cm (1.75 diam x 4 in) bed. The design is shown in Figure 3-5 and pressure drop data are plotted in Figure 3-6. Note that in Figure 3-6 the data are numbered in sequential order. In initial tests (1 through 5) the ΔP's indicate that the bed was at less than maximum packing density, but approached the maximum density line (design line) as testing proceeded (See points 5,6,7 and 8). When the flow was reversed, the initial test points (9,10 and 11) fell somewhat below the design line, but in continued testing the data moved back to the design line (12,13, 14 and 15).

In this preprototype unit, the resin bed was spring loaded to produce a force of 44.5 N (10 lb) on the resin and this resulted in gradual compaction of the bed to maximum density conditions, which produced a significantly higher pressure drop than was experienced in the preliminary tests. After compaction to the maximum density, the device had essentially the same pressure drop for flow in both the forward and reverse directions.

For the purpose of estimating pressure drop in differently sized beds, the following theoretical formula may be used:

$$\Delta P = 1.07 \frac{WL\mu}{d^2}$$

where: ΔP = pressure drop, psi

W = flow, lb/min

L = bed length, inch

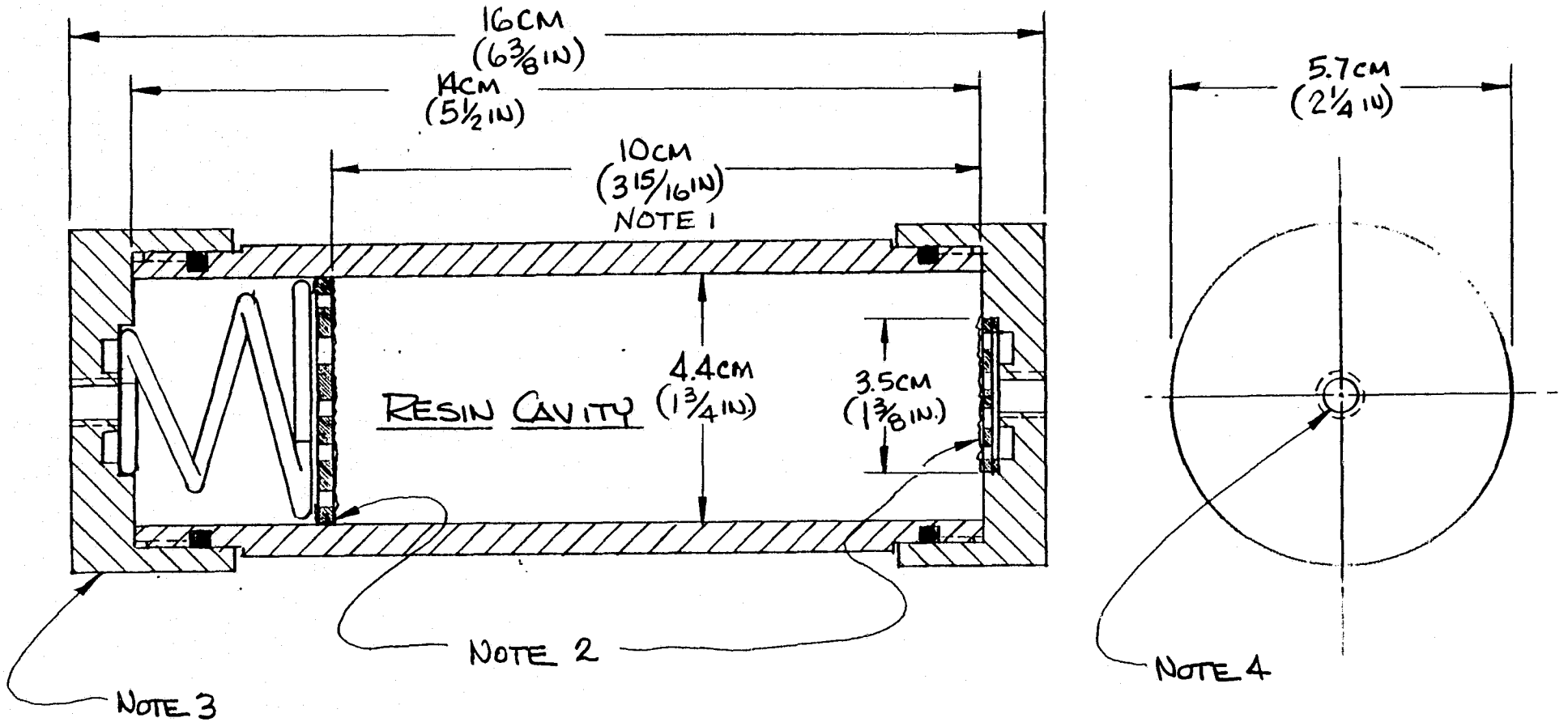
μ = water viscosity, centipoise

d = bed diameter, inch

3.3 Prototype Unit. The current design of the flight prototype MCV is shown in Figure 3-7. The unit has a bed size of 4.11 diam x 7.62 cm (1.65 diam x 3.0 in). The estimated pressure drop for this unit at a flow of 1 lb/min is:

$$\Delta P = 1.07 \frac{(1)\ (3.0)\ (1)}{(1.65)^2} = 1.18 \text{ psi} = 8.1 \text{ kPa}$$

(text continued on page 21)



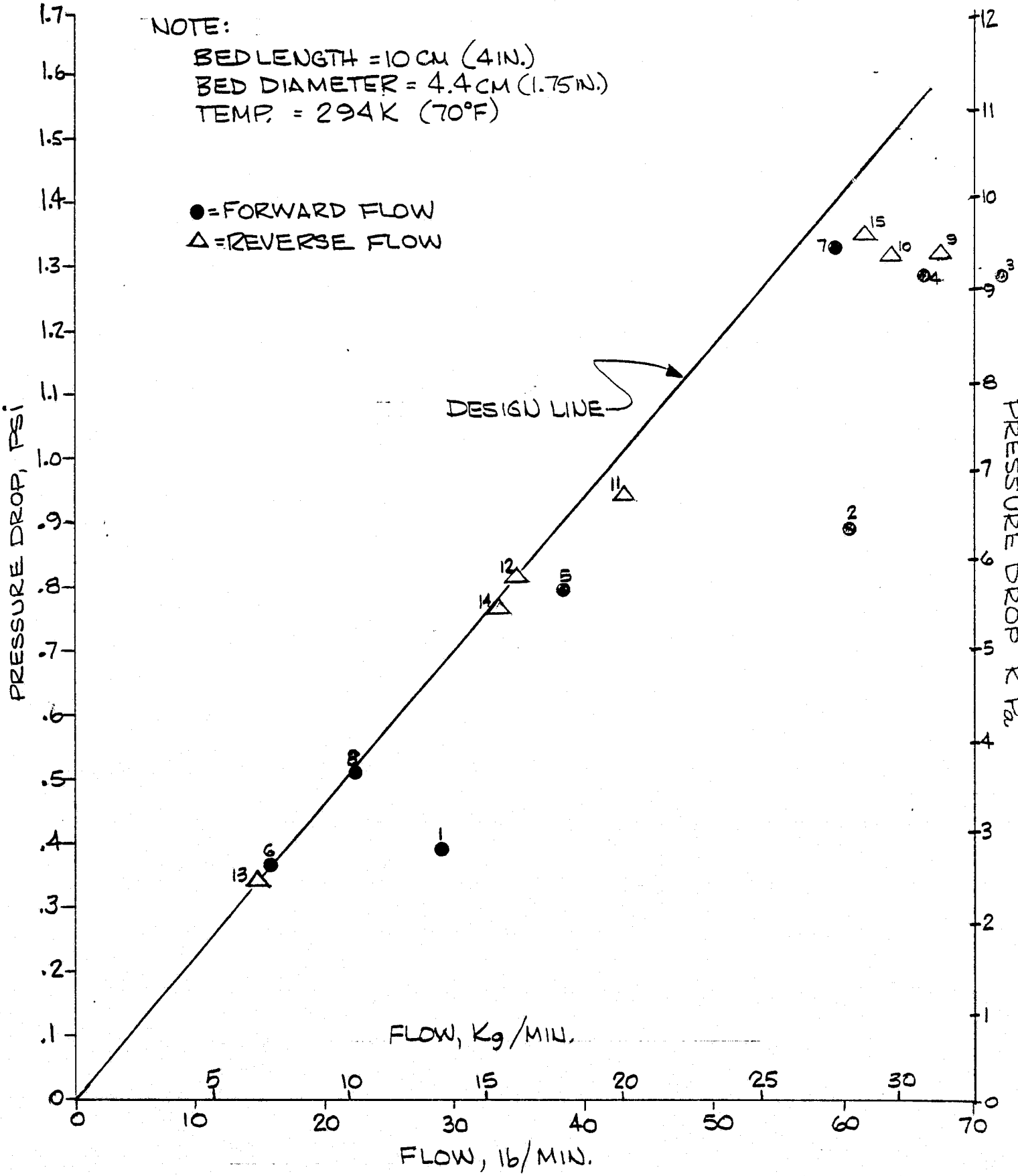
NOTES:

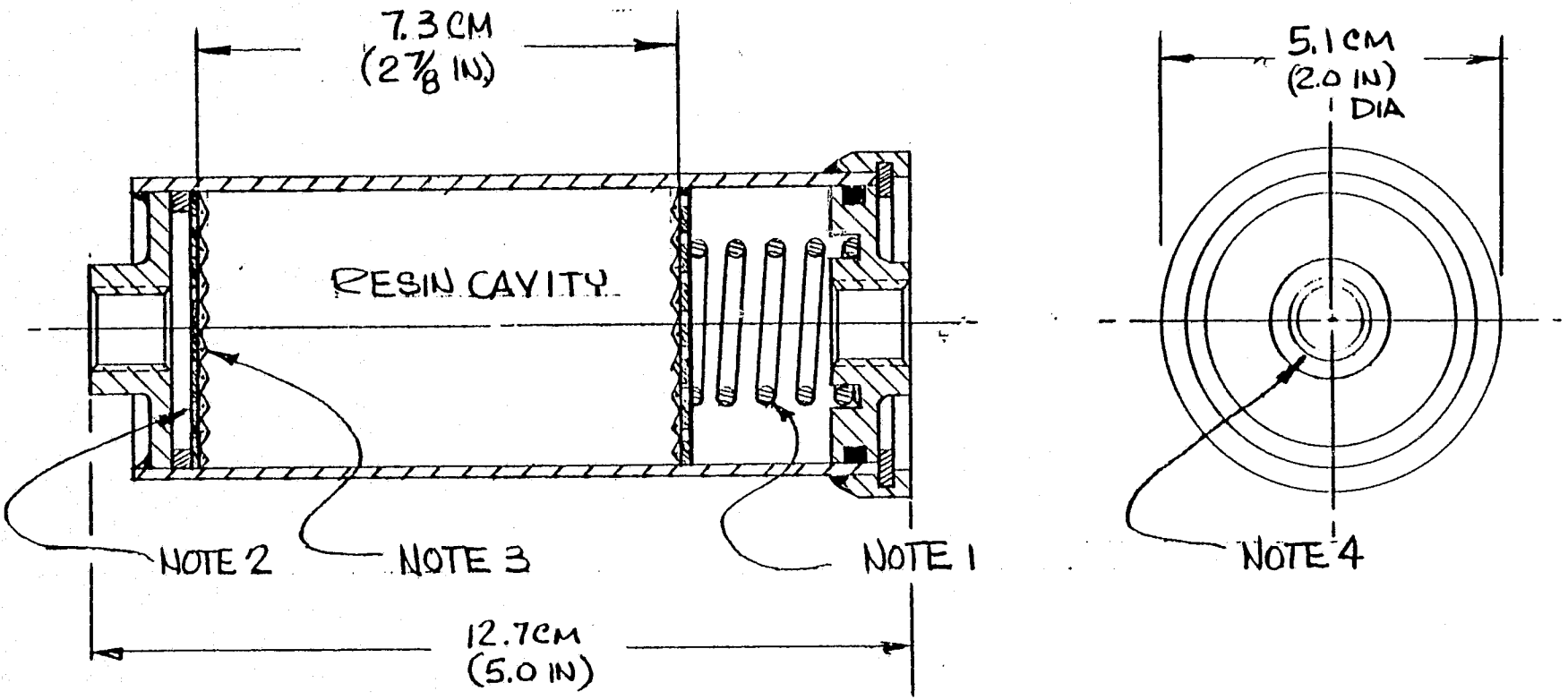
1. DIMENSION @ 4.55 Kg (10 lb) SPRING LOAD ON RESIN.
2. RESIN RETAINERS, PERFORATED DISCS COVERED WITH CRES CLOTH.
3. MAT'L : TYPE 304 CRES
4. 1/8" NPT, BOTH ENDS

FIGURE 3-5

MICROBIAL CHECK VALVE, PREPROTOTYPE

FIGURE 3-6
FLOW vs. PRESSURE DROP FOR THE MCV PROTOTYPE UNIT





NOTE:

1. COMPRESSION SPRING, TYPE 316 CRES, COMPRESSED LENGTH = 1.00 IN. DEFLECTED = 14.49 lb.
2. PERFORATED DISCS, BOTH ENDS
3. 100 MESH CRES SCREEN, MUST RETAIN 16 TO 50 MESH RESIN.
4. 1/4" AN THREAD (MS 33649-4), BOTH ENDS

FIGURE 3-7
MICROBIAL CHECK VALVE
PROTOTYPE

(continued from page 17)

4.0 MICROBIAL CHALLENGES

4.1 Overview. Preliminary design data were generated for the triiodide resin by first using small scale resin test beds in order to minimize the quantities of water and time involved in obtaining data. The first test set-up involved five small diameter (5mm) glass tubes, which were loaded with various amounts of resin ranging from zero to 10 cm in length. This set-up was used for running short-term tests of 24 hours duration or less. The second test set-up involved only a single 10 cm small diameter glass bed and a control bed, and was used for obtaining longer term data of up to 55 hours. In this series of tests the 10 cm bed was run to exhaustion.

After these small tests, a third large-scale stainless steel bed was successfully challenged with a quantity of water equivalent to twice the "worst case" Shuttle condition.

Microbial kill data were obtained for three different temperatures: 275, 294 and 344 k (35,70 and 160°F). Performance was also determined for certain potential Shuttle operational requirements including: exposing the resin to ethylene oxide sterilization; soaking the resin in alcohol; and autoclaving the resin. In addition, the effect of the resin on water chemistry was determined.

4.2 Microbial Species. The microbial challenges were made with individual suspensions of seven different representative microorganisms and a mixed suspension that contained all seven of the organisms. The organisms used represented types that had either previously been found in the water and wastewater systems of manned space flights and manned chamber tests or were considered to represent "worst case" possibilities. They included: Gram-positive rods, Gram-negative rods, obligate anaerobes, spore formers and Fungi. The actual microbial suspensions

used in the challenges are summarized in Table 4-1.

TABLE 4-1

MICROBIAL CHALLENGE SUSPENSIONS

SUSPENSIONS	ATCC	No. of Organisms Per Milliliter
1. Escherichia coli		10^6
2. Streptococcus faecalis		10^6
3. Staphylococcus aureus		10^6
4. Bacillus subtilis		10^6
5. Pseudomonas aeruginosa		10^6
6. Clostridium perfringens		10^6
7. Aspergillus niger		10^6
8. Mixture of all the above organisms in equal proportions.		10^4

A brief description of these organisms follows.

Escherichia coli - A widely distributed harmless intestinal parasitic bacteria found normally in the intestine of warm blooded animals and not adapted for life outside the intestine. Morphologically it is a gram-negative, non-spore-forming, facultatively anaerobic rod.

Streptococcus faecalis - Inhabits the intestine of man and animals and is quite tolerant of extremes in temperature and other unfavorable conditions. Morphologically it is a gram-positive non-spore-forming cocci.

Staphylococcus aureus - A ubiquitous pathogen found normally on the skin and mucous membranes of the animal body. It is responsible for suppurative conditions and internal abscesses in man. Morphologically it is a gram-positive non-spore-forming cocci.

Bacillus subtilis - A saprophytic soil bacteria commonly found in dust. Not commonly pathogenic. Morphologically it is a gram-positive, spore-forming-aerobe.

Pseudomonas aeruginosa - A bacteria found in soil and water or wherever organic material is decomposing. It is an occasional pathogen in man, causing and abetting a variety of infections. Morphologically it is a gram-negative, non-spore forming aerobic rod.

Clostridium perfringens - A normal inhabitant of the human intestine that is always present, although in small numbers. A human pathogen, it is responsible for gaseous gangrene and several other types of infections. Morphologically it is a gram-positive, strictly anaerobic spore-forming rod.

Aspergillus niger - A ubiquitous mold that is occasionally pathogenic to man. Its morphology is variable, depending upon the nature of the growth substrate.

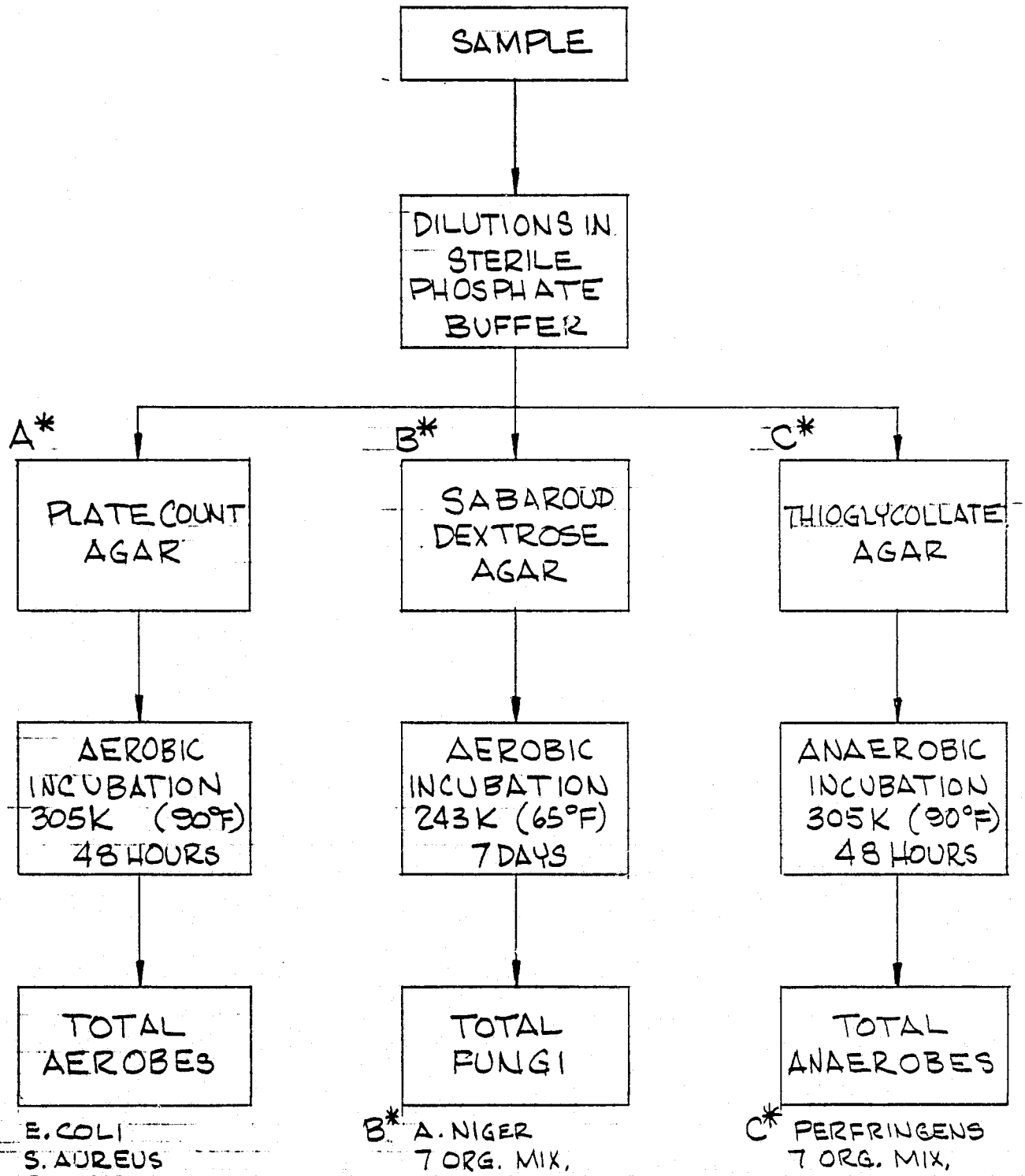
4.3 Microbiological Test Methods. The stock bacteria cultures used in the microbial check valve challenges were American Type Culture Collection cultures maintained in the appropriate media. A subculture was taken from the stock cultures and used as inoculum for the working cultures. Media was inoculated from the subculture, incubated for 18 to 24 hours and the cells harvested via centrifugation. After being harvested, the cells were washed in sterile buffered water and then in sterile, deionized water by centrifugation. The washed cells were then diluted in pasteurized deionized water to make up the challenge solution.

Bacteria concentrations were determined during the challenge by standard plate count procedures according to the 14th Edition of Standard Methods for the Examination of Water and Wastewater, 907.

Three basic enumeration procedures were used as illustrated in Figure 4-1.

For E. coli, S. aureus, B. subtilis, St. faecalis and

FIGURE 4-1
MICROBIOLOGICAL ENUMERATION PROCEDURE



P. aeruginosa, Method (A) was used to obtain the bacteria count. For A. niger Method (B) was used and for C. perfringens Method (C) was utilized.

For enumerating the organism mix, all 3 methods were used. The total microorganism count was obtained by summing the total aerobe and total anaerobe counts (the total fungi count was not added because the fungi are included in the total aerobe count).

In principle, plate count procedures involve serial dilutions of the sample, inoculation into growth media, incubation and enumeration. In theory each bacterium develops into a visible colony that can be counted. This count is multiplied by the dilution factor to obtain the bacterial concentration in the original sample.

4.4 Iodine Test Methods. The Iodine residual was monitored with the Leuco Crystal Violet Method as described in the 14th Edition of Standard Methods for the Examination of Water and Wastewater, 416 A. In principle, the test involves the hydrolysis of iodine and the production of hypoiodous acid by the addition of mercuric chloride to an aqueous iodine solution. Leuco Crystal Violet reacts with the hypoiodous acid for form crystal violet dye. The crystal violet is measured colorimetrically and the iodine concentration determined by comparison with known iodine solutions.

4.5 Water Chemistry Test Methods. The methods used for the physical and chemical analyses of water samples are summarized in Table 4-2. Detection limits are also listed.

TABLE 4-2

WATER CHEMISTRY ANALYTICAL METHODS

Parameter	Units	Detection Limit	Method[1]
pH	pH units	±0.01	EPA p.239
Sp. Conductance	μmho-cm^{-1}	1.	EPA p.275
Total Solids	mg/l	1.	EPA p.272
Volatile Solids	mg/l	1.	EPA p.272
Total Organic Carbon	mg/l	0.2	EPA p.236
Odor	T.O.N.	1.	EPA p.287
Turbidity	NTU	0.05	EPA p.295
Color, Apparent	CU	1.	EPA p.36
Cadmium	mg/l	0.005	EPA p.101
Chromium	mg/l	0.02	EPA p.105
Copper	mg/l	0.01	EPA p.108
Iron	mg/l	0.02	EPA p.110
Lead	mg/l	0.001	EPA p.112
Manganese	mg/l	0.01	EPA p.116
Mercury	mg/l	0.001	EPA p.118
Nickel	mg/l	0.02	EPA p.141
Selenium	mg/l	0.002	SM 150 A
Silver	mg/l	0.01	EPA p.146
Zinc	mg/l	0.005	EPA p.155

[1] EPA = Methods for the Chemical Analysis Water and Wastes, 1974
SM = Standard Methods for the Examination of Water and Wastewater, 14th Ed.

4.6 Distilled Water Suitability. The distilled water suitability test (D.W.S.T.), Standard Methods for the Examination of Water and Wastewater, 14th Ed., Section 905 B.2, was performed on the pasteurized, deionized water used to prepare the challenge suspensions and on the deionized water used in the dilution blanks. The results are summarized in Table 4-3. Both Water sources fell within acceptable limits of suitability for use in bacterial testing. The D.W.S.T. Ratio is the sample count divided by the control count and should be equal to 1.0±0.2.

TABLE 4-3

DISTILLED WATER SUITABILITY TEST RESULTS

DILUTION / SAMPLE	10^{-2}	10^{-3}	COUNT	D.W.S.T.* RATIO
CONTROL	TNC	40	3.6×10^4	
	TNC	37		
	TNC	31		
PASTEURIZED DEIONIZED WATER	TNC	41	3.6×10^4	1.00
	TNC	30		
	TNC	36		
DEIONIZED WATER	TNC	35	3.9×10^4	1.08
	TNC	39		
	TNC	43		

* The D.W.S.T Ratio is the sample count divided by the control count and should be equal to 1.0±0.2.

4.7 Scaling Factors. In the small scale tests, the resin bed cross sectional area, perpendicular to the direction of flow, was approximately $\frac{1}{70}$th of the full size prototype unit. Four different bed lengths were investigated: 1, 3, 6 and 10 cm (.39, 1.2, 2.4 and 3.9 in) in order to bracket the area of interest.

The large scale tests were run on a single bed with a cross sectional area of approximately 1/2 full size and 10 cm in length. The pertinent dimensional information and other important scaling factors for the test beds and the full size prototype unit are summarized in Figure 4-2 and discussed in the following paragraphs.

4.7.1 Mission Man-Day Equivalents. In order to facilitate a better understanding of the significance of the microbiological data as it applies to Shuttle missions, the actual throughput quantities achieved in the scaled down tests have been converted to mission man-day equivalents. A mission man-day for the full scale prototype unit is equivalent to a throughput of 3.74 kg (8.25 lb) of water, which is the projected average useage of water aboard Shuttle for drinking, food preparation and personal hygiene purposes. In scaling down the test beds, bed depth was defined as an independent variable, and the throughput that represents the equivalent of 1 mission man-day was considered to be proportional to the cross sectional area of the bed. Thus, for the scaled down beds, the throughput for 1 mission man-day equivalent is:

Small-scale beds:

$$\text{throughput} = 3.74 \frac{\text{kg}}{\text{mission man-day}} \quad \frac{0.20 \text{ cm}^2/\text{mission man-day equivalent}}{13.3 \text{ cm}^2/\text{mission man-day}}$$

$$= 0.0562 \text{ kg/mission man-day equivalent}$$

note: 0.20 cm^2 = cross sectional area of small beds
13.3 cm^2 = cross sectional area of prototype bed

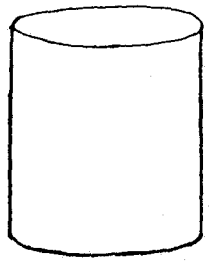
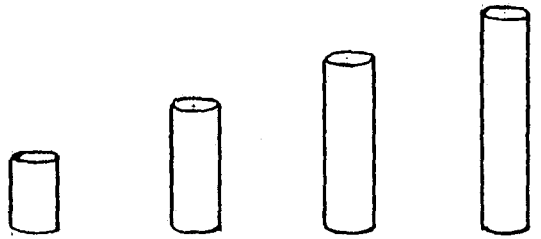
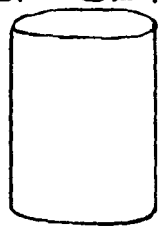
PARAMETER	UNITS	PROTOTYPE UNIT 	SMALL SCALE TEST BEDS 				LARGE SCALE TEST BED 
DIAMETER	CM	4.11	0.50	0.50	0.50	0.50	2.92
CROSS SECTIONAL AREA	CM^2	13.3	0.20	0.20	0.20	0.20	6.70
LENGTH	CM	7.62	1.0	3.0	6.0	10.0	10.0
VOLUME	CM^3	101.3	0.2	0.6	1.2	2.0	67.0
FLOW RATE	Kg/MIN.	0.454	0.009	0.009	0.009	0.009	0.454
RESIDENCE TIME (15% VOID VOLUME)	SEC	2.0	0.2	0.6	1.2	2.0	1.33
THROUGHPUT EQUIV. FOR 1 MISSION MAN-DAY	Kg	3.74	0.0562	0.0562	0.0562	0.0562	1.88
TEST TIME FOR 1 MISSION MAN-DAY EQUIV.	MIN.	8.24	6.24	6.24	6.24	6.24	4.14
MISSION MAN-DAY EQUIV. FOR 1 HOUR OF TEST TIME	MISSION MAN-DAY EQUIV./HOUR	7.28	9.62	9.62	9.62	9.62	14.5

FIGURE 4-2

SCALING FACTORS FOR RESIN BEDS

Large-scale beds:

$$\text{throughput} = 3.74 \frac{\text{kg}}{\text{mission man-day}} = \frac{6.70 \text{ cm}^2/\text{mission man-day equivalent}}{13.3 \text{ cm}^2/\text{mission man-day}}$$

$$= 1.88 \text{ kg/mission man-day equivalent}$$

4.7.2 Test Time. The test time to achieve 1 mission man-day equivalent is the amount of test time it takes to pass a quantity of water through the test bed that is equal to the throughput that represents 1 mission man-day equivalent. These values are calculated as follows:

4.7.2.1 Small-scale beds:

$$\text{Test Time} = \frac{0.0562 \text{ kg/mission man-day equivalent}}{0.009 \text{ kg/min}}$$

$$= 6.24 \text{ min/mission man-day equivalent}$$

4.7.2.2 Large-scale beds:

$$\text{Test Time} = \frac{1.88 \text{ kg/mission man-day equivalent}}{0.454 \text{ kg/min}}$$

$$= 4.14 \text{ min/mission man-day equivalent}$$

4.7.3 Test Time Conversion Factor. In order to convert test time to mission man-day equivalents the following conversion factors were used:

4.7.3.1 Small-scale beds:

$$\text{Conversion factor} = 60 \text{ min/hr} \div 6.24 \text{ min/mission man-day equivalent}$$

$$= 9.62 \text{ mission man-day equivalent/hr}$$

4.7.3.2 Large-scale beds:

$$\text{Conversion factor} = 60 \text{ min/hr} \div 4.15 \text{ min/mission man-day equivalent}$$

$$= 4.5 \text{ mission man-day equivalent/hr}$$

4.7.4 Residence Time. Residence time is the amount of time that the liquid flowing through the bed remains in the bed. Assuming continuity of flow, residence time is the bed void volume divided by the volume flow. The MCV resin has a 15% void volume, so residence time is calculated as follows:

4.7.4.1 Small-scale Beds:

$$\text{Residence Time} = 0.2\ \text{cm}^2(15\%)\ \ell\ \frac{1}{.009\frac{\text{kg}}{\text{min}}}\ 60\ \frac{\text{sec}}{\text{min}}\ 10^{-3}\ \frac{\text{kg}}{\text{cm}^3}$$

$$= 0.2\ \ell\ \text{sec}\ (\ell = \text{bed length in cm})$$

Bed Depth, Cm	1	3	6	10
Residence Time, Sec	0.2	0.6	1.2	2.0

4.7.4.2 Large-scale Beds:

$$\text{Residence Time} = 67\ \text{cm}^3(15\%)\ \frac{1}{0.454\ \frac{\text{kg}}{\text{min}}}\ 60\ \frac{\text{sec}}{\text{min}}\ 10^{-3}\ \frac{\text{kg}}{\text{cm}^2}$$

$$= 1.33\ \text{sec}$$

4.7.4.3 Prototype Unit:

$$\text{Residence Time} = 101.3\ \text{cm}^3(15\%)\ \frac{1}{0.454\ \frac{\text{kg}}{\text{min}}}\ 60\ \frac{\text{sec}}{\text{min}}\ 10^{-3}\ \frac{\text{kg}}{\text{cm}^2}$$

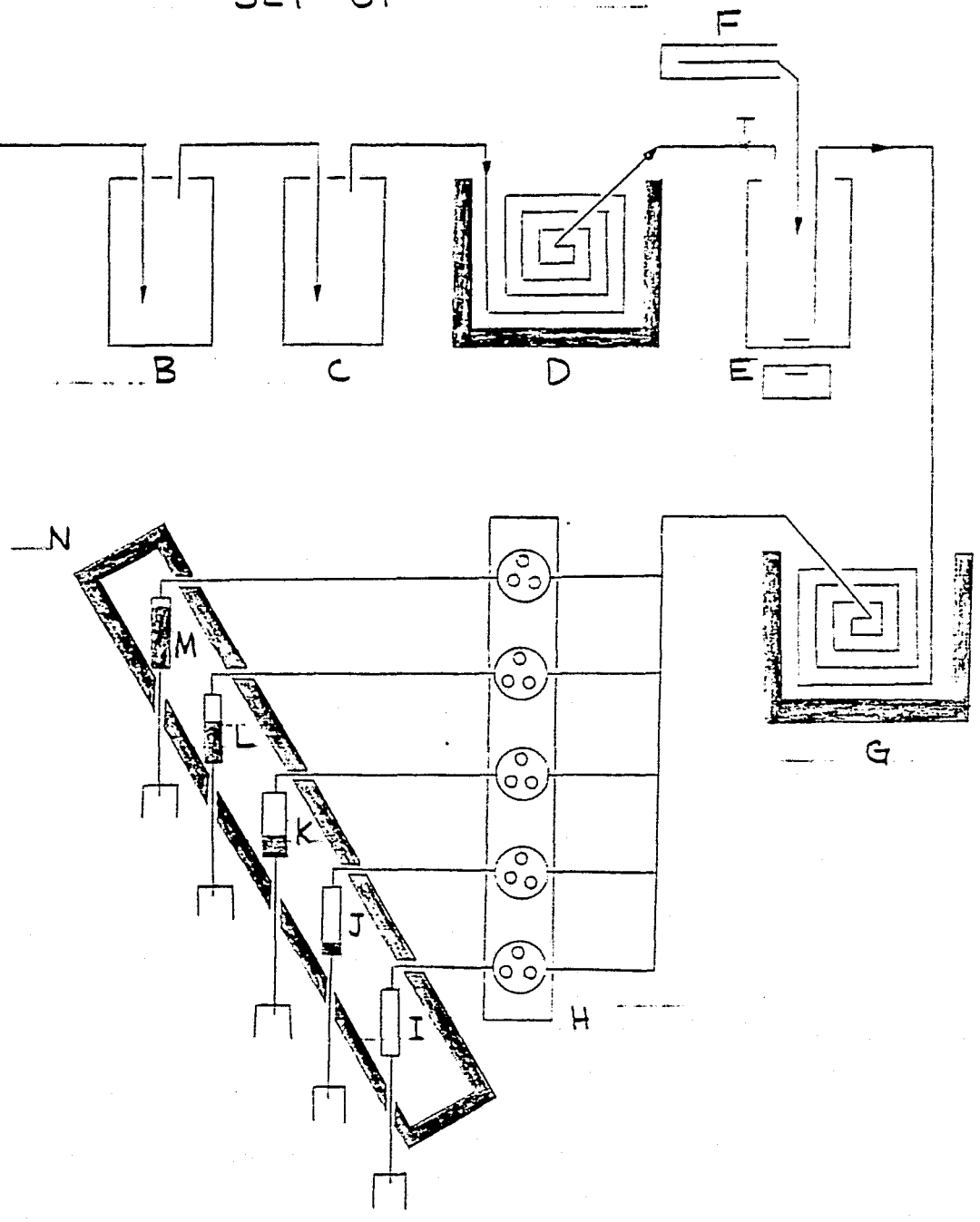
$$= 2.0\ \text{sec}$$

4.8 Small Scale Multi-bed Tests. A schematic drawing of the small scale multi-bed test set-up is presented in Figure 4-3. City tap water was fed through a deionization bed (B) into a glass-lined hot water heater (C). The water was pasteurized at 344 K (160°F) in the heater. The pasteurized, deionized water was gravity fed through Tygon heat exchange coils immersed in a controlled temperature water bath (D) into the influent suspension tank (E). Washed bacterial cells (F) were added to the influent suspension tank and mixed with a magnetic stir bar.

4.8.1 Challenges at 344 K (160°F). At 344 K (160°F) each of the 7 microbial species used in the challenges were killed immediately after their introduction to the system. It was concluded that these species will not survive at 344 K (160°F)

FIGURE 4-3

SMALL SCALE MULTI-BED TEST SET-UP



A. CITY WATER LINE
B. WATER DEIONIZATION BED
C. WATER STERILIZER
D. CONTROLLED TEMPERATURE WATER BATH WITH HEAT EXCHANGE COILS
E. BACTERIAL SUSPENSION TANK
F. WASHED BACTERIAL CELLS
G. CONTROLLED TEMPERATURE WATER BATH WITH HEAT EXCHANGE COILS
H. MULTI-HEAD POLYSTALTIC PUMP
I. CONTROL BED
J. 1CM RESIN BED
K. 3CM RESIN BED
L. 6CM RESIN BED
M. 10 CM RESIN BED
N. CONTROLLED TEMPERATURE WATER BATH

so no further testing was done at this temperature.

4.8.2 Challenges at 275 K(35°F). The challenge results for 275 K (35°F) are presented on an individual basis on the top half of Figures 4-4 through 4-11 and are summarized in Table 4-4.

Although a concentration of 10^4 organisms per ml is the maximum expected on the basis of previous flight experience, most of the challenges were conducted with concentrations of 10^5 and 10^6 organisms per ml in order to present "worst case" conditions in these "range finder" tests.

In the low temperature, 275 K(35°F), tests the resin did not perform as well as it did at ambient temperature, 294 K (70°F). This is thought to be due to one or more of the following reasons:

a) halogens are less effective biocidal agents at low temperature.

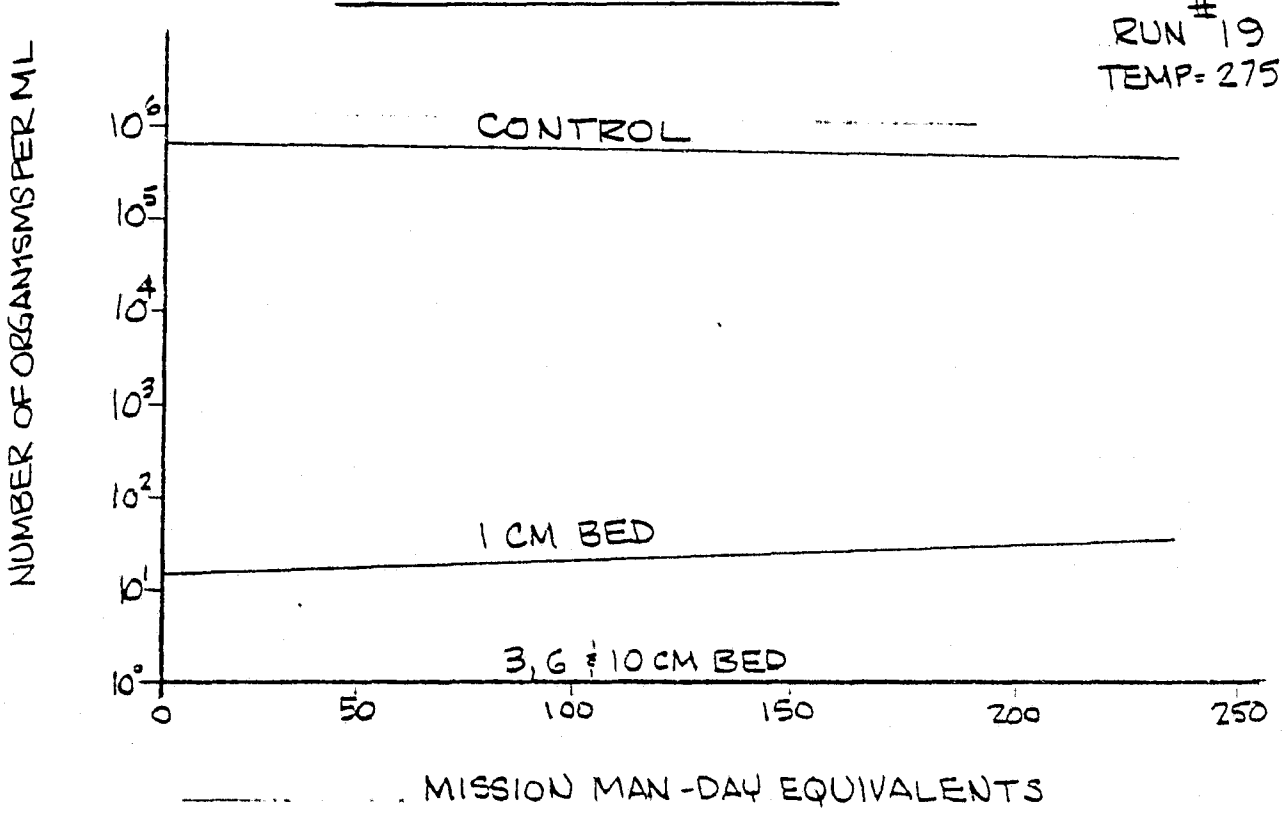
b) the residual iodine equilibrium is lower at low temperature.

c) more bacterial spores are present at lower temperature because spore vegatation is inhibited and spores are more resistant to iodine.

Immediate breakthrough occurred in 5 of the 8 challenges. This sounds bad until it is realized that in the worst case, involving the 6 and 10 cm (2.4 and 3.9 in) beds, the microbial concentration was reduced by a minimum of 10^3 organisms per ml. In the five tests where breakthrough occurred, the concentration of Staphylococcus aureus was reduced by 10^5, Aspergillus niger was reduced by 10^4 and the other three, Streptococcus faecalis, Pseudomonas aeruginosa and Clostridium perfringens were reduced by 10^3. In the challenges with the 7 organism mixture, reasonably

(text continued on page 43)

FIGURE 4-4
SMALL-SCALE TESTS
ESCHERICHIA COLI



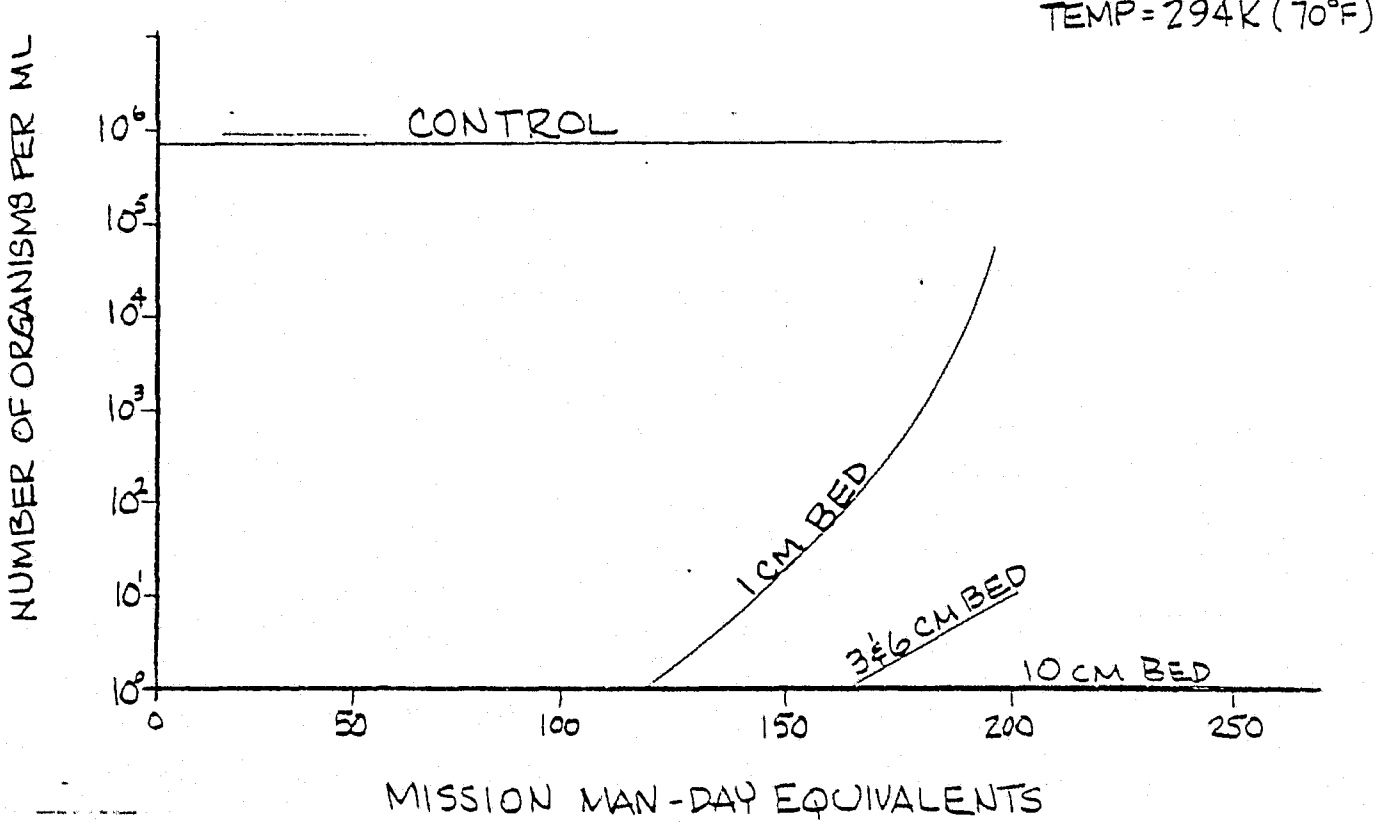
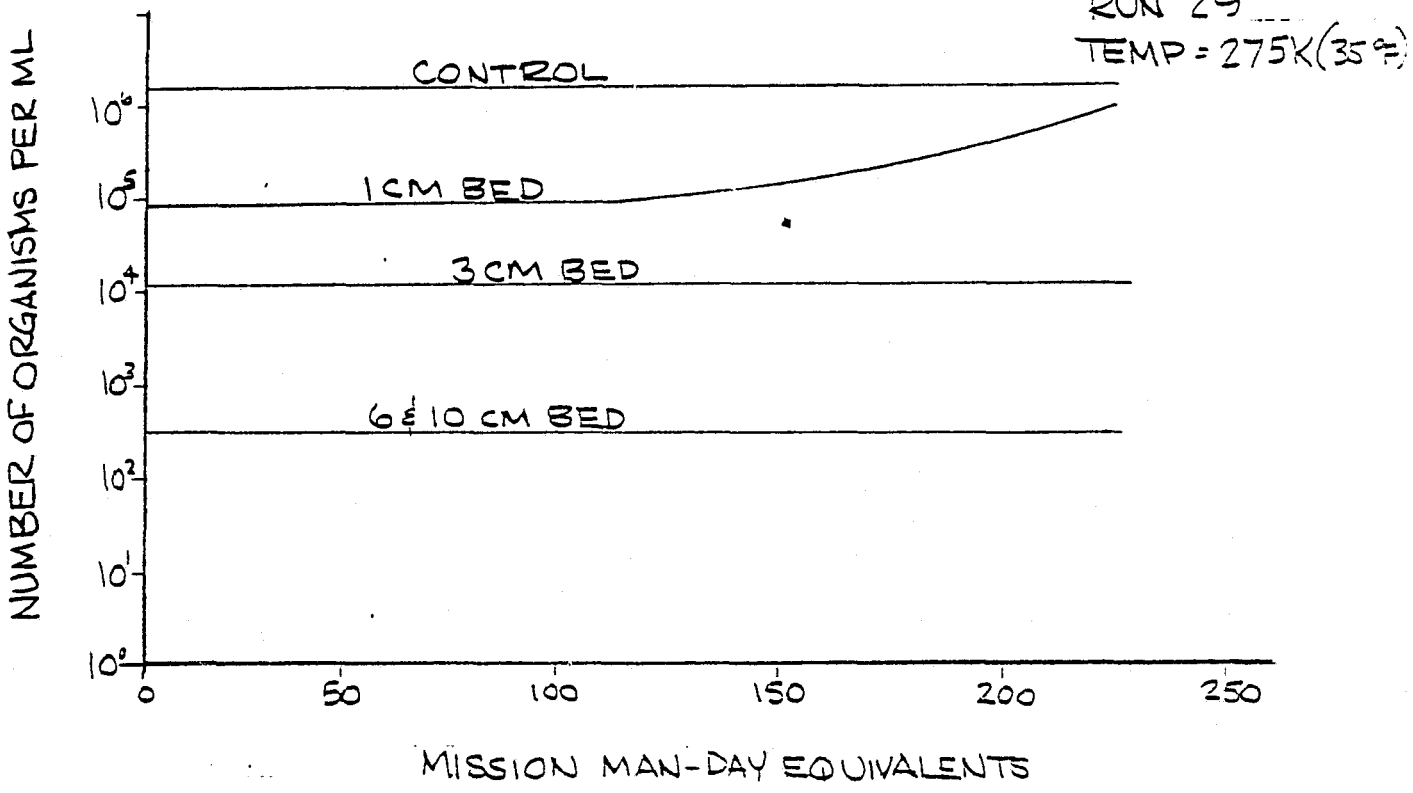


FIGURE 4-5
SMALL-SCALE TESTS
STREPTOCOCCUS FAECALIS



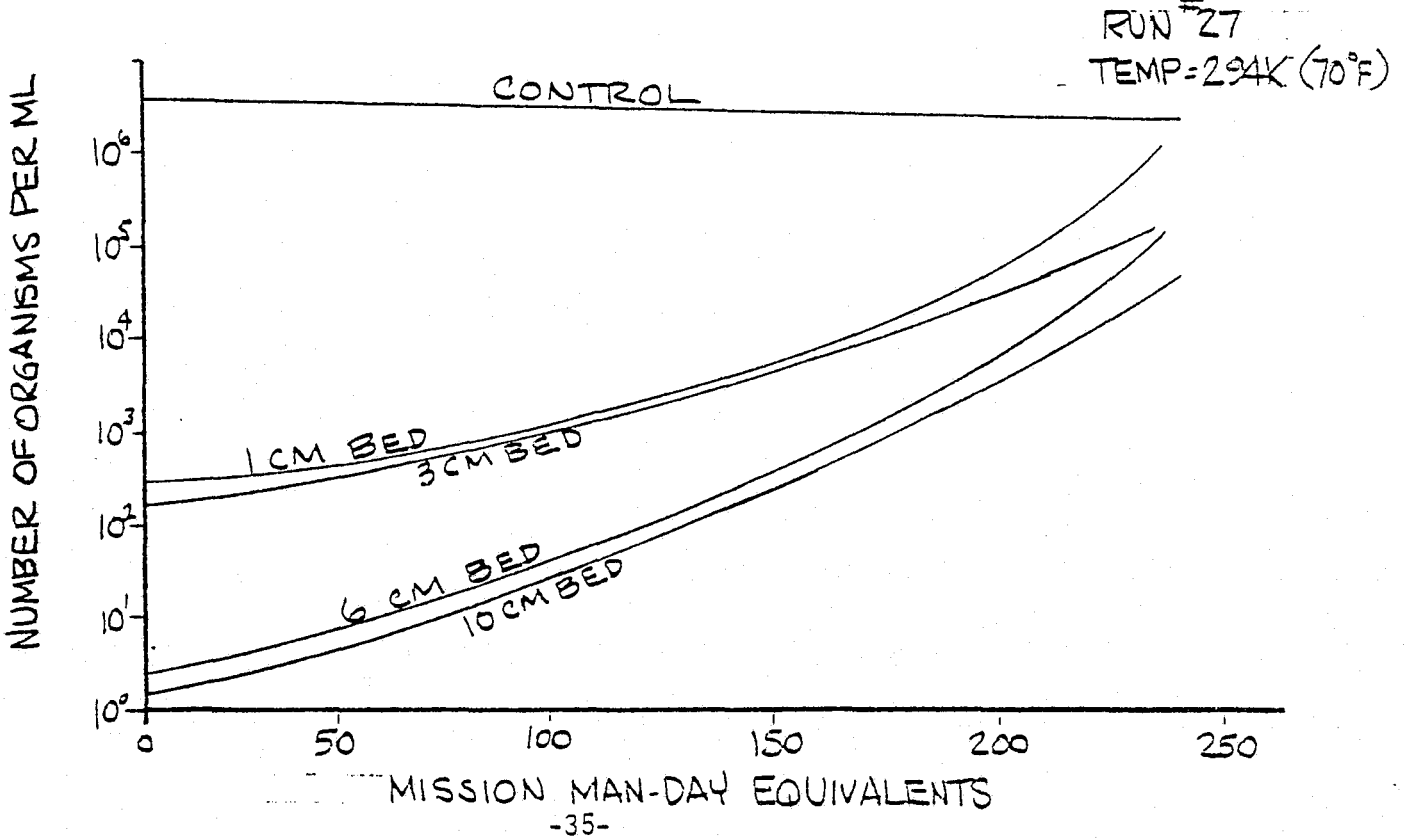
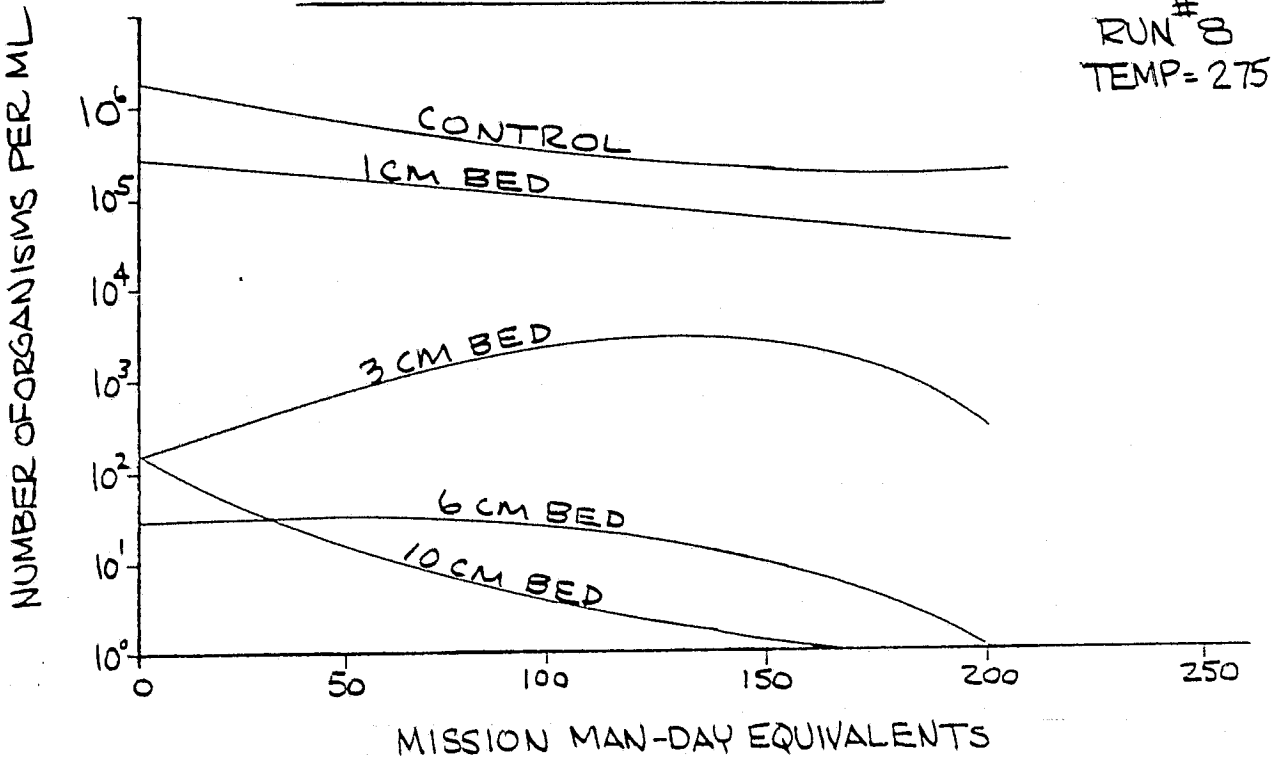


FIGURE 4-6
SMALL-SCALE TESTS
STAPHYLOCOCCUS AUREUS



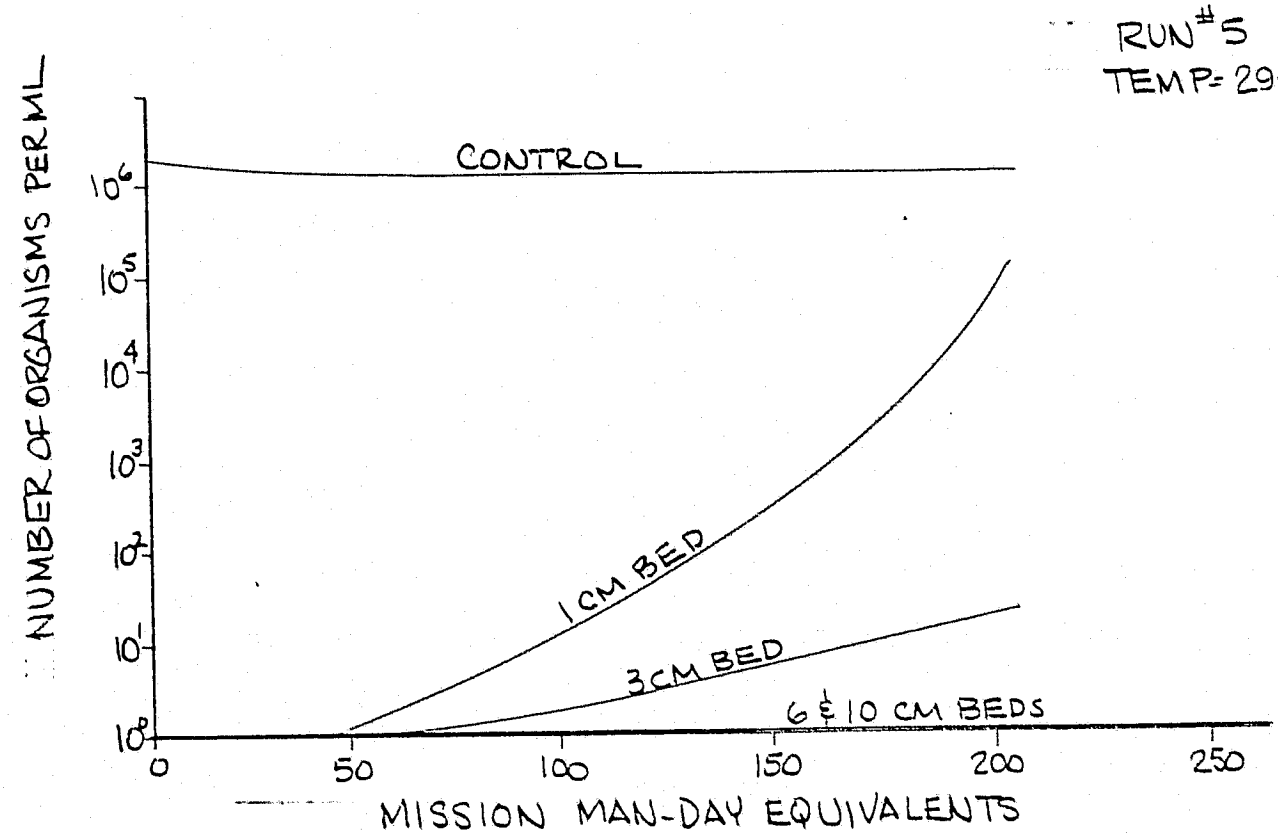
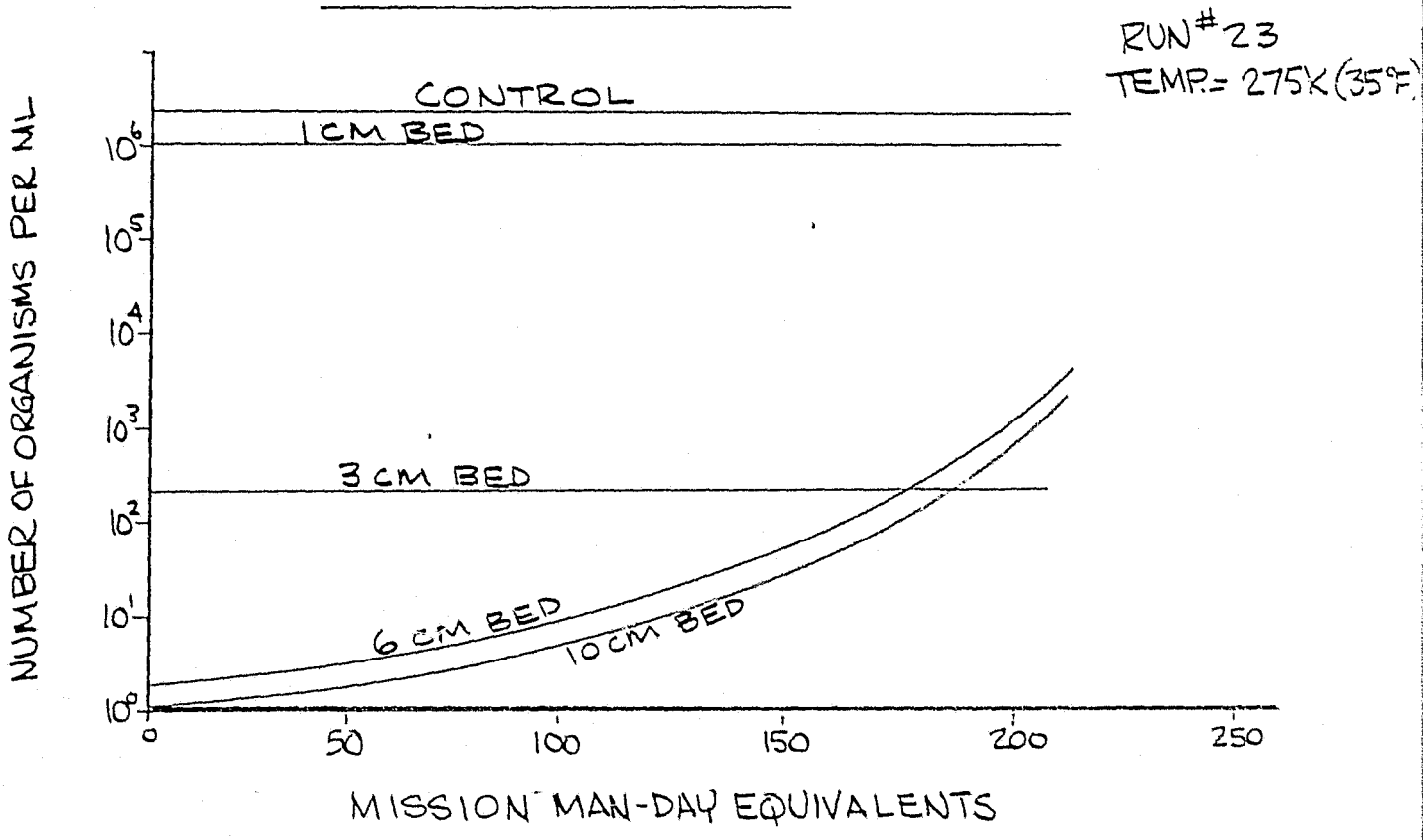


FIGURE 4-7
SMALL-SCALE TESTS
BACILLUS SUBTILIS



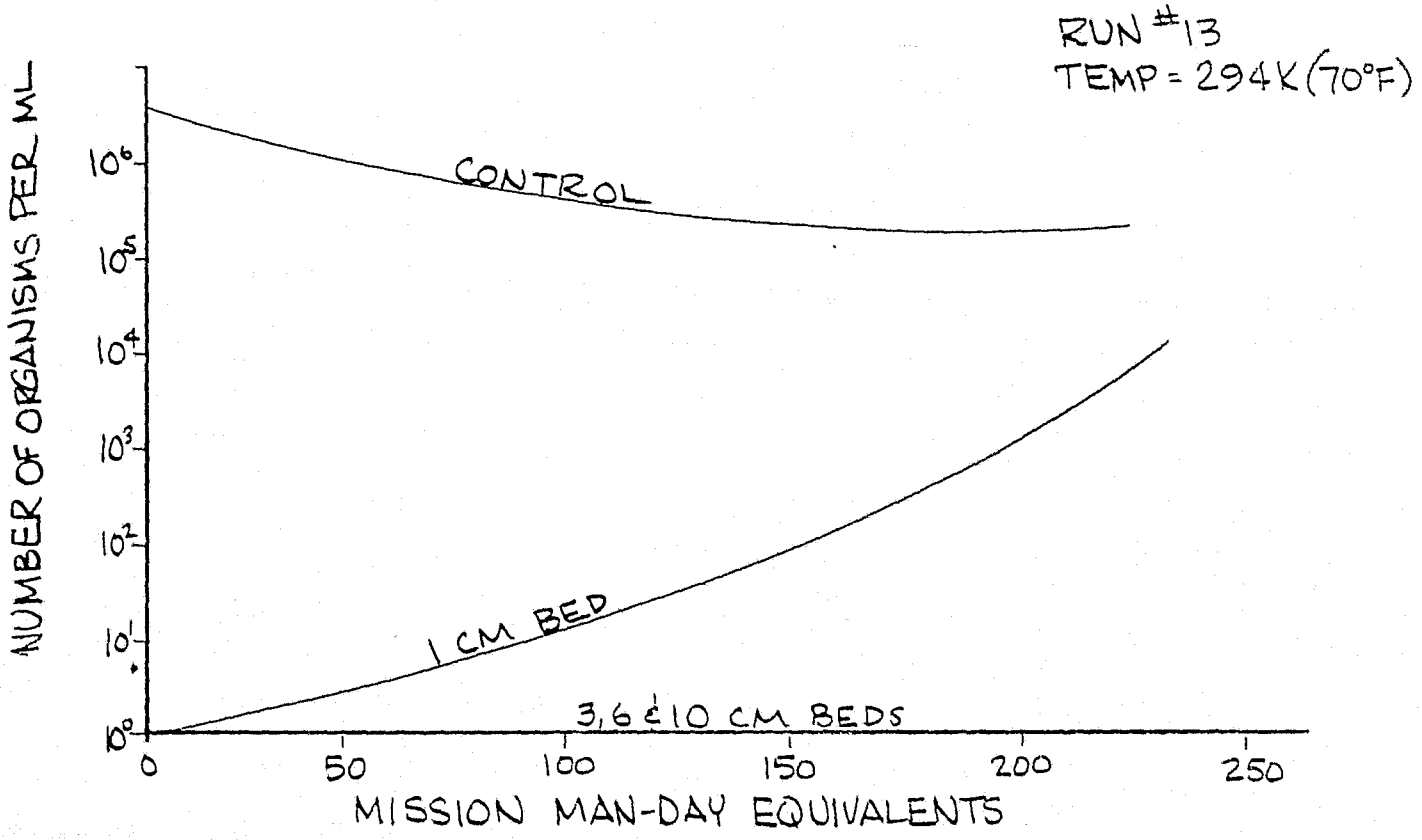
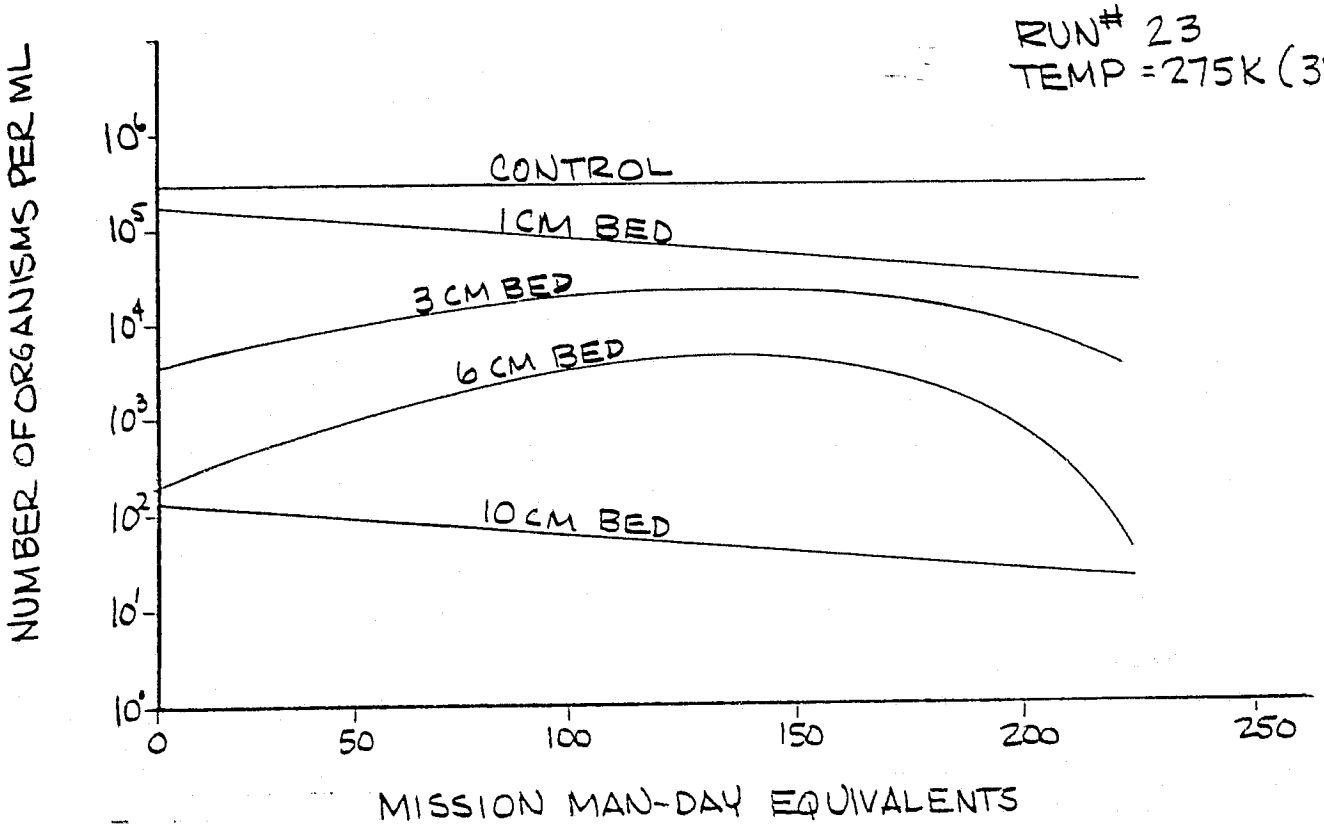


FIGURE 4-8
SMALL-SCALE TESTS
PSEUDOMONAS AERUGINOSA



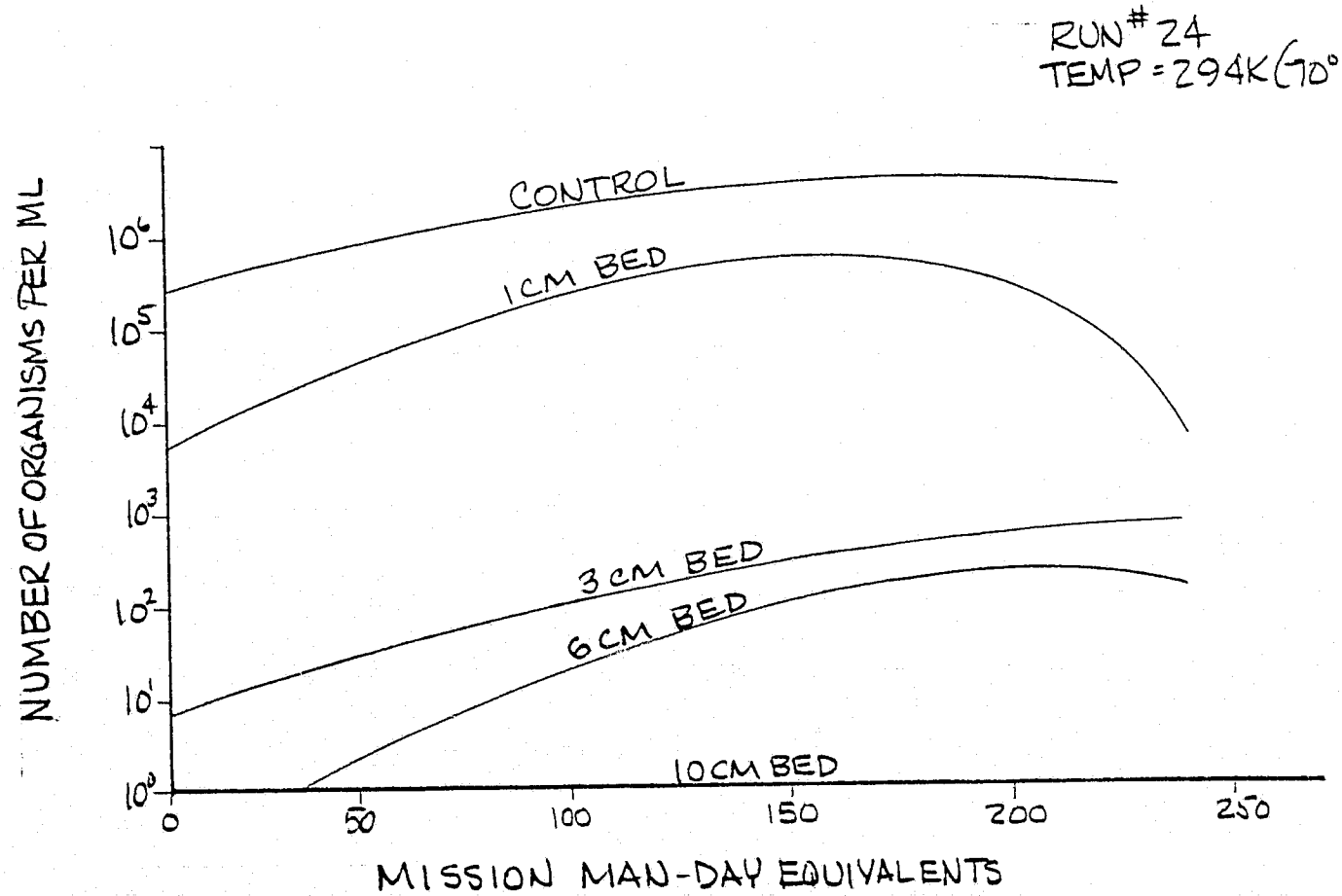
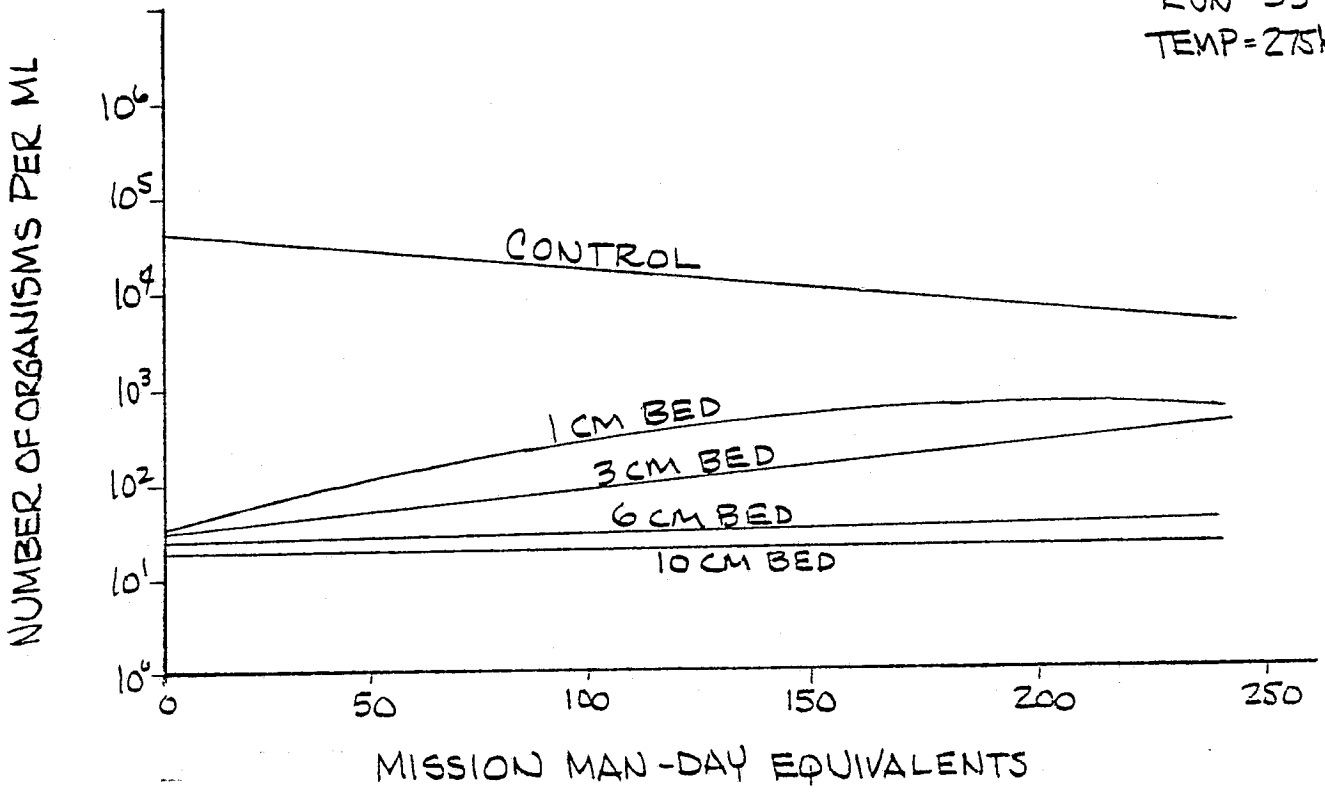


FIGURE 4-9
SMALL-SCALE TESTS
CLOSTRIDIUM PERFRINGENS

RUN #33
TEMP = 275K (35°F)



RUN #34
TEMP = 294K (70°F)

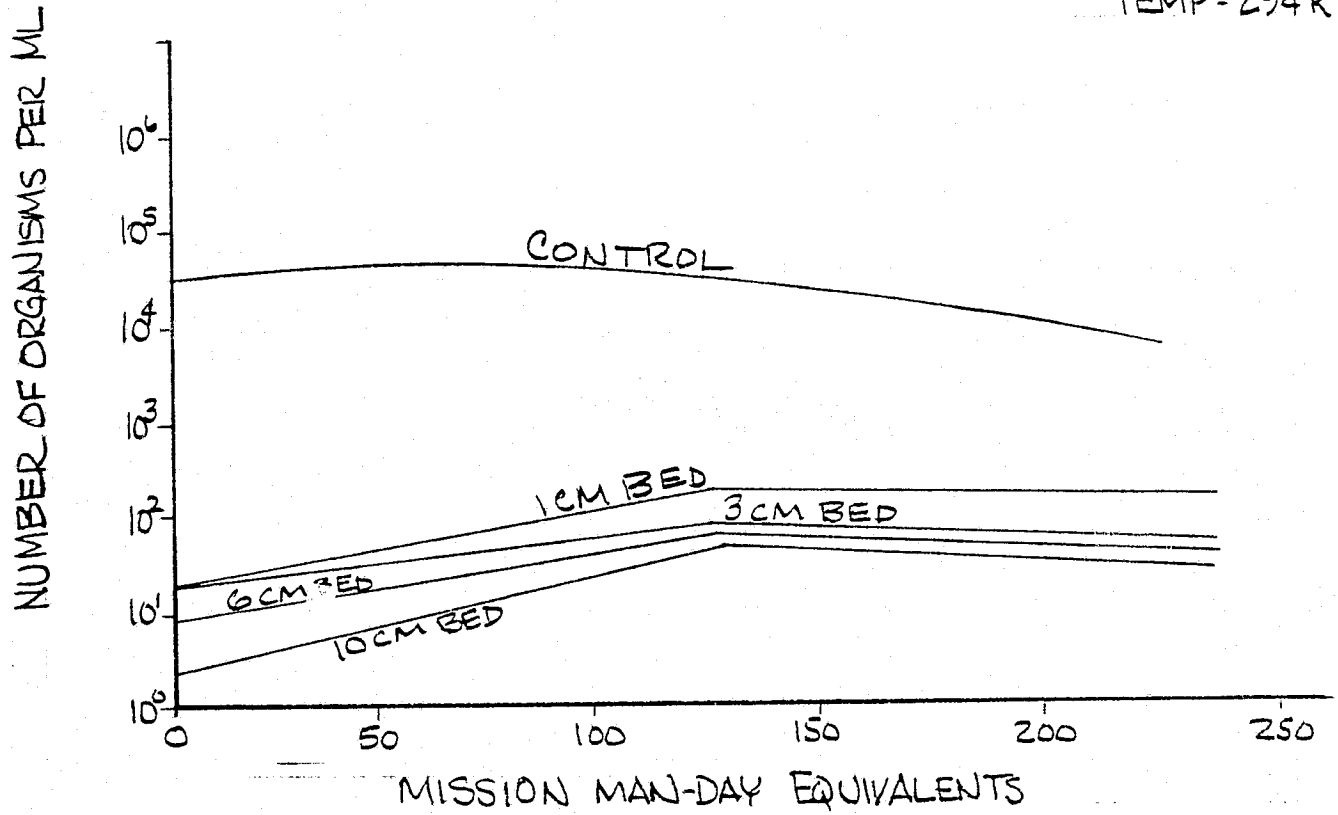
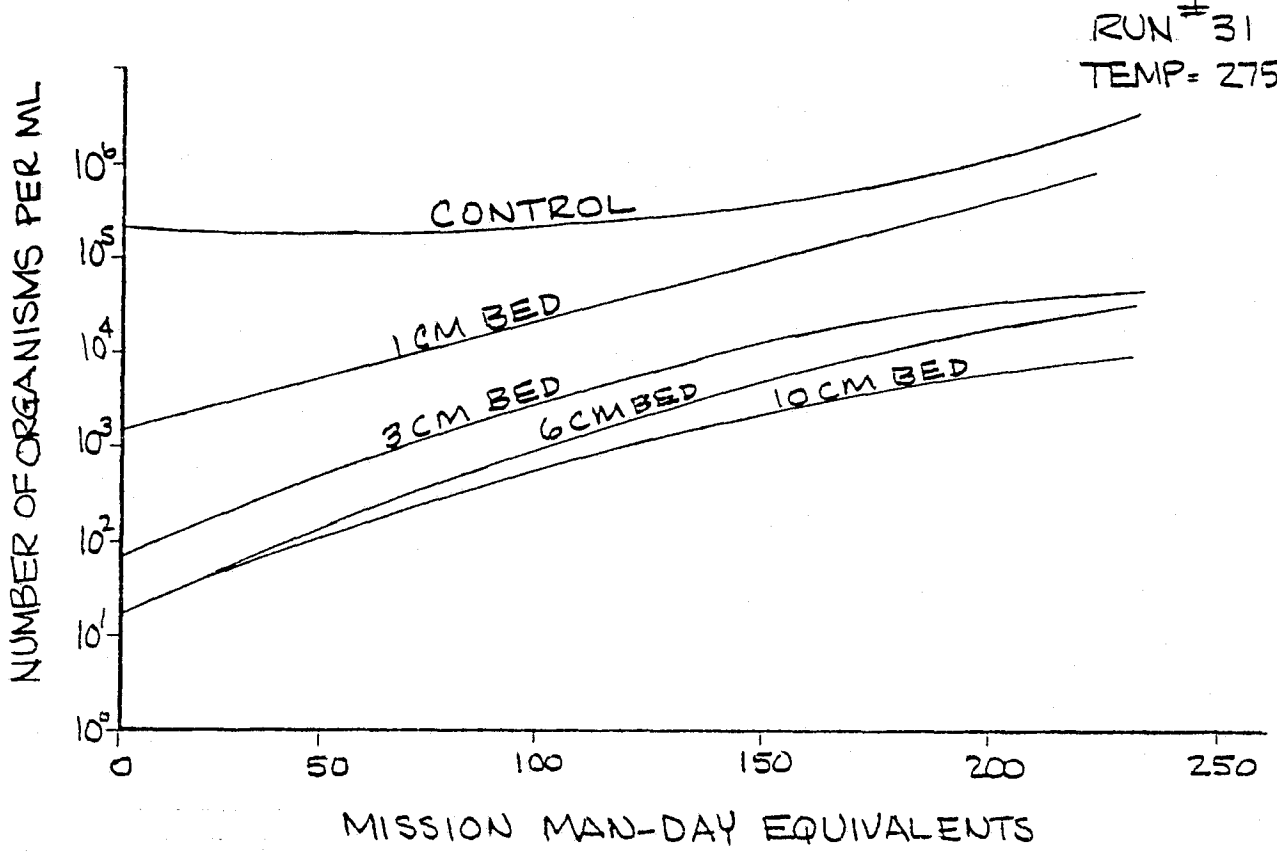


FIGURE 4-10
SMALL-SCALE TESTS
ASPERGILLUS NIGER



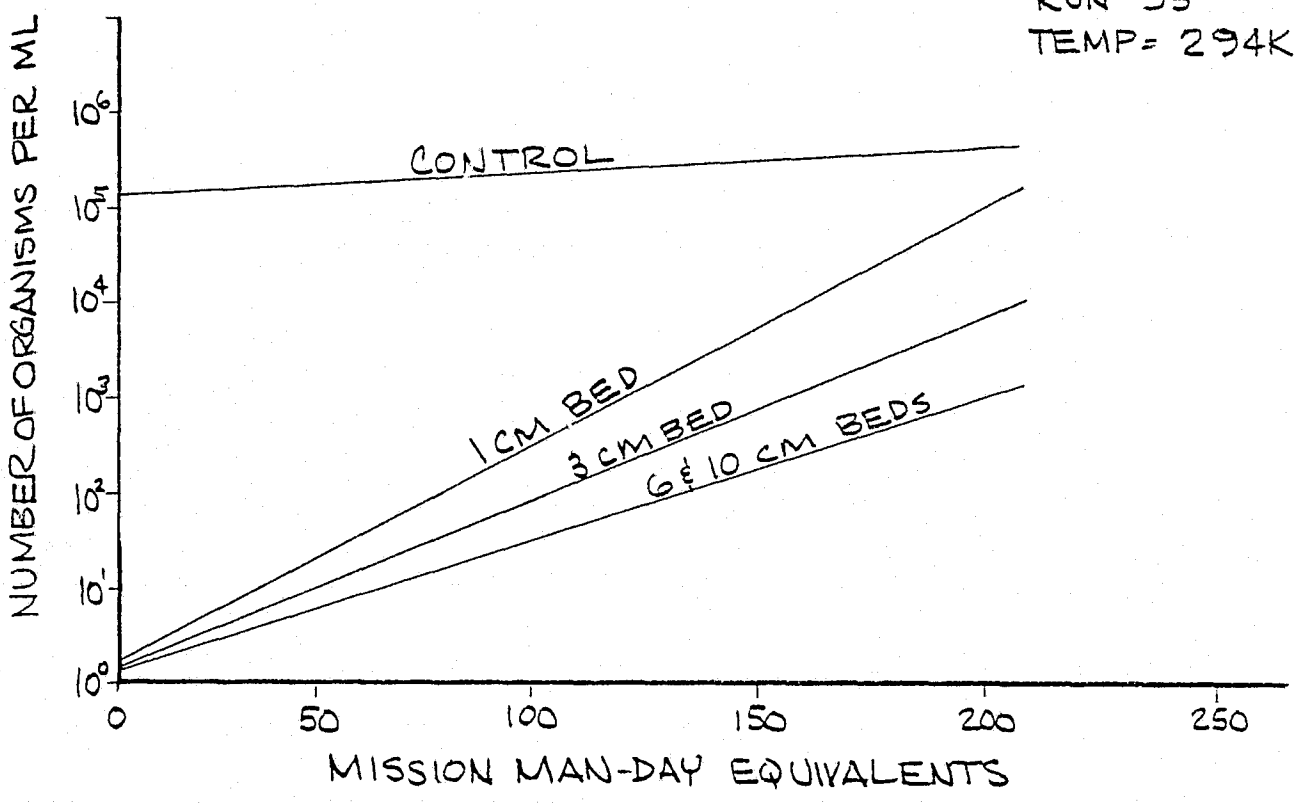
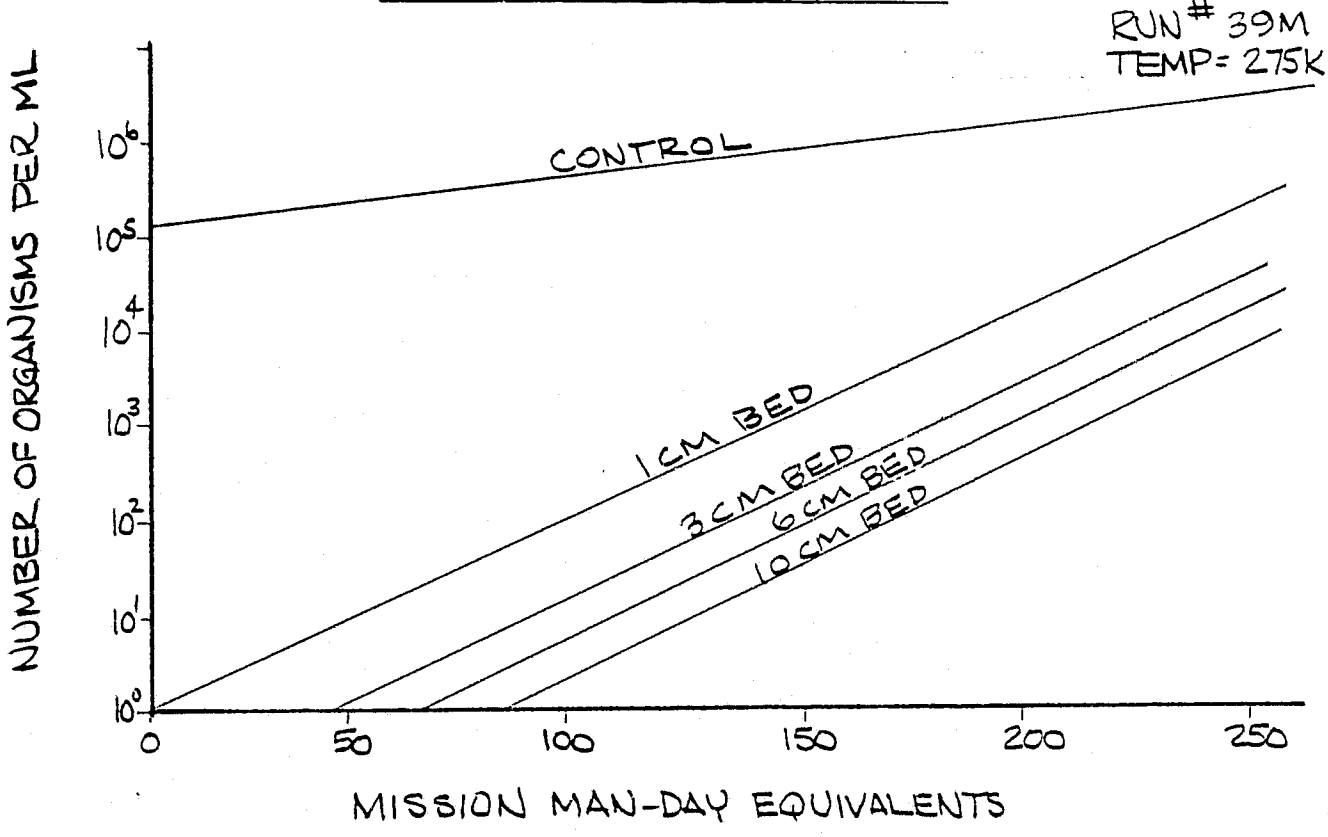
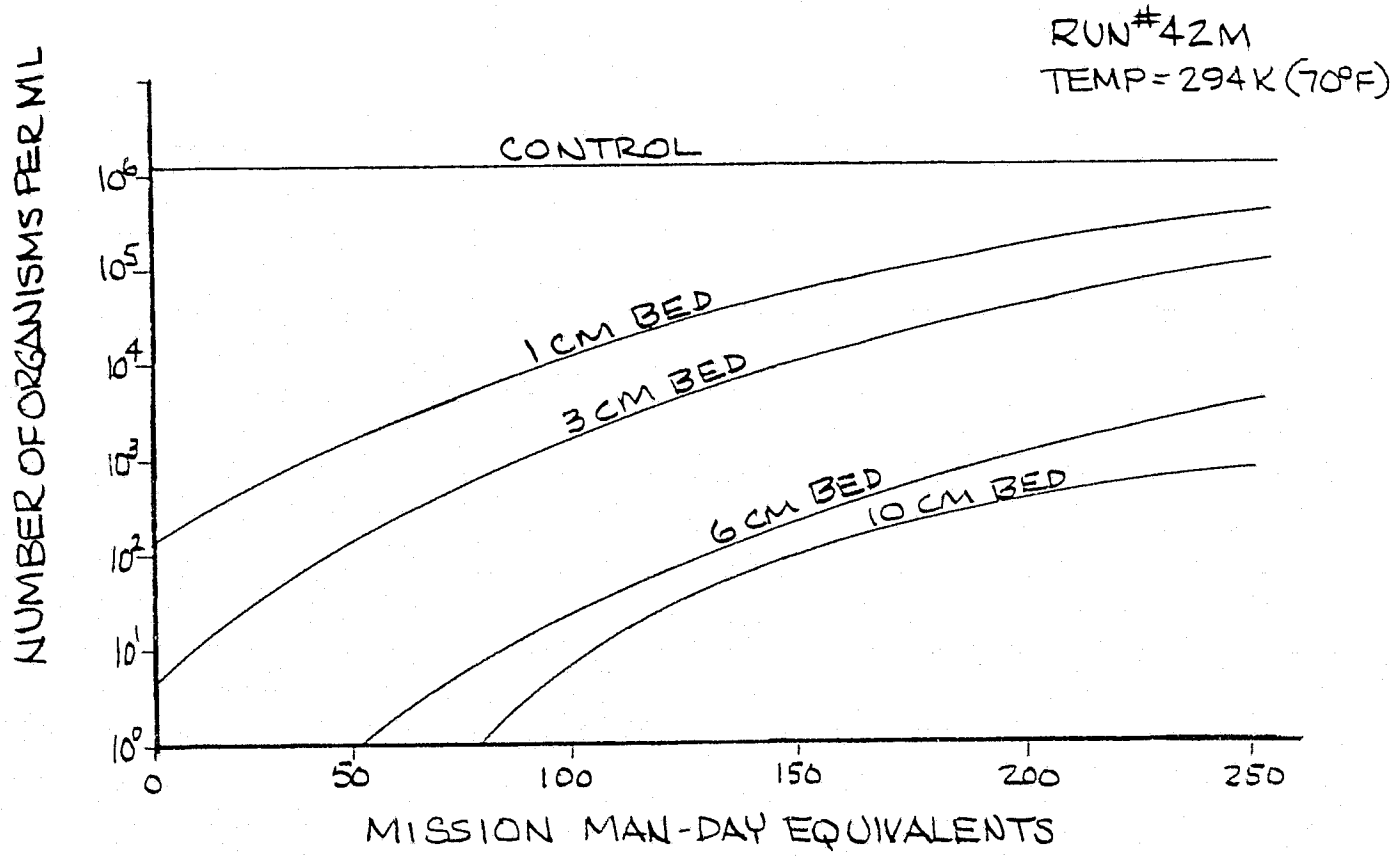


FIGURE 4-11
SMALL-SCALE TESTS
7 ORGANISM MIXTURE





CHALLENGE ORGANISMS	TEMP °F	MISSION MAN-DAY EQUIVALENTS AT BREAKTHROUGH[1] BED DEPTH				CONCENTRATION OF CHALLENGE ORGANISMS	REDUCTION IN THE NUMBER OF ORGANISMS AT BREAKTHROUGH BED DEPTH			
		1CM	3CM	6CM	10CM	NUMBER PER ML	1CM	3CM	6CM	10CM
ESCHERICHIA COLI	35	0	>235	>235	>235	10^6	10^5	10^5	10^5	10^5
	70	120	160	160	>200	10^6	10^5	10^5	10^5	10^5
STREPTOCOCCUS FAECALIS	35	0	0	0	0	10^6	10	10^2	10^3	10^3
	70	0	0	50	70	10^6	10^4	10^4	10^5	10^5
STAPHYLOCCUS AUREUS	35	0	0	0	0	10^6	10	10^4	10^4	10^5
	70	90	180	>200	>200	10^6	10^5	10^5	10^5	10^5
BACILLUS SUBTILIS	35	0	0	100	130	10^6	10^4	10^5	10^5	10^5
	70	90	>230	>230	>230	10^6	10^5	10^5	10^5	10^5
PSEUDOMONAS AERUGINOSA	35	0	0	0	0	10^5	2	10^2	10^3	10^3
	70	0	10	80	>240	10^6	10^2	10^5	10^5	10^5
CLOSTRIDIUM PERFRINGENS	35	0	0	0	0	10^4	10^3	10^3	10^3	10^3
	70	0	0	5	60	10^4	10^3	10^3	10^3	10^3
ASPERGILLUS NIGER	35	0	0	0	0	10^5	10^2	10^3	10^4	10^4
	70	30	45	60	60	10^5	10^4	10^4	10^4	10^4
7 ORGANISM MIXTURE (SEE FIG. 4-11)	35	40	90	110	130	10^5	10^4	10^4	10^4	10^4
	70	0	10	80	105	10^6	10^4	10^5	10^5	10^5
7 ORGANISM MIXTURE (SEE FIG 4-14)	70	50	>240	>240	>240	10^6	10^5	10^5	10^5	10^5

1 BREAKTHROUGH IS DEFINED AS 10 OR MORE. ORGANISMS PER ML

TABLE 4-4

SUMMARY OF SMALL-SCALE TEST RESULTS

(continued from page 33)

long lives were achieved for the 6 and 10 cm (2.4 and 3.9 in) beds with an input of 10^5 organisms per ml.

4.8.3 Challenges at 294 K(70^0F). In these ambient temperature tests the 6 and 10 cm (2.4 and 3.9 in) beds had reasonably long bed lives in the worst cases (see Table 4-4). Clostridium perfringens was the most resistant organism. Only a 10^3 reduction was achieved at breakthrough. Aspergillus niger, the next most resistant species, had a 10^4 reduction at breakthrough. The third most resistant organism was Streptococcus faecalis, which had a 10^5 reduction at breakthrough, as did all the other tests. In the challenges with the 7 organism mixture, reasonably long bed lives were achieved prior to breakthrough with an input of 10^6 organisms per ml. The individual challenges are presented in the bottom half of Figures 4-4 through 4-11 and are summarized in Table 4-4.

4.8.4 Challenge of Autoclaved Resin. Performance of the resin after autoclaving is shown in Figure 4-12. A 7 organism mixture was used with an input of about 10^5 organisms per ml. Breakthrough occurred in all beds sooner than it did in untreated resin beds (compare the curves in Figure 4-12 with those in the bottom of Figure 4-11 and those in Figure 4-14). It is concluded that autoclaving degrades resin performance by about 70%.

4.8.5 Challenge of Alcohol Soaked Resin. Performance of the resin after soaking in alcohol is shown in Figure 4-13. A 7 organism mixture was used with an input of 10^4 to 10^5 organisms per ml. Both the 1 and 3 cm beds broke through at 140 mission man-day equivalents. No breakthrough occurred in the 6 and 10 cm beds.

(text continued on page 46)

FIGURE 4-12

SMALL-SCALE TESTS

7 ORGANISM MIXTURE (AUTOCLAVED RESIN)

RUN #43 AC
TEMP = 294K (70°F)

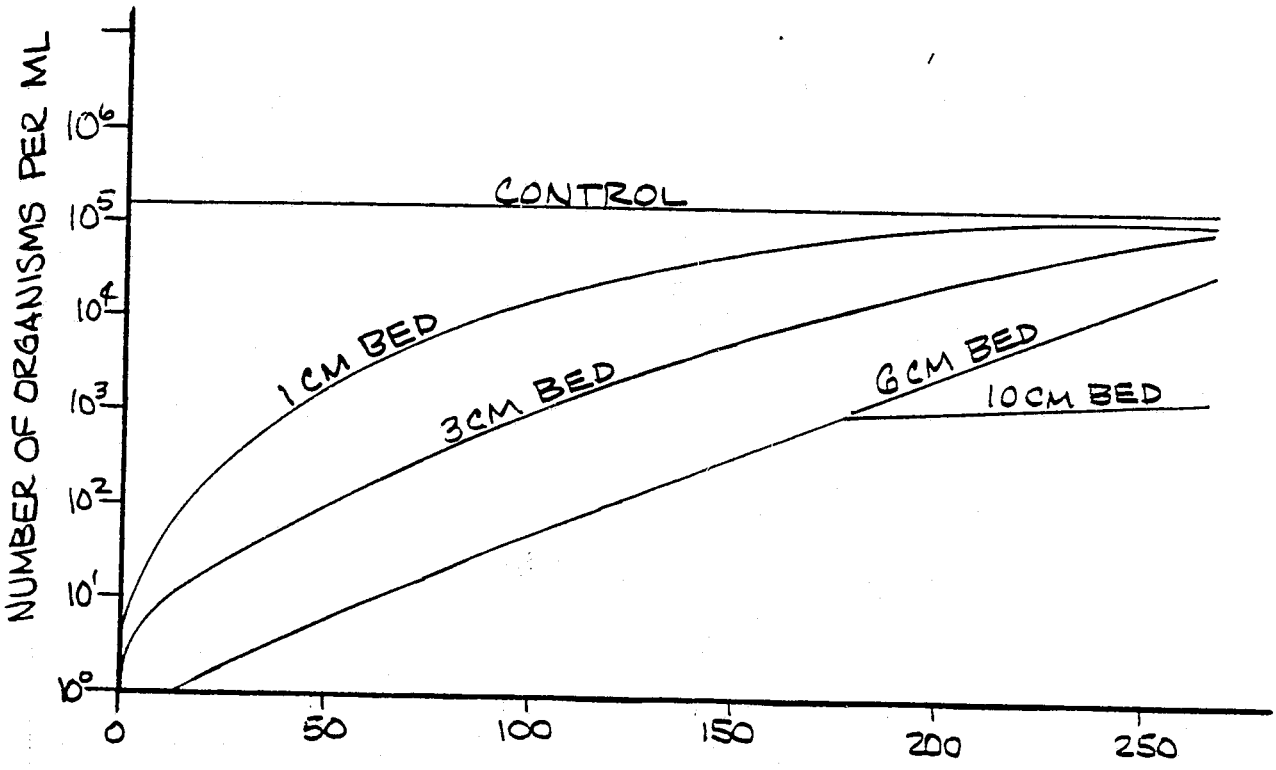
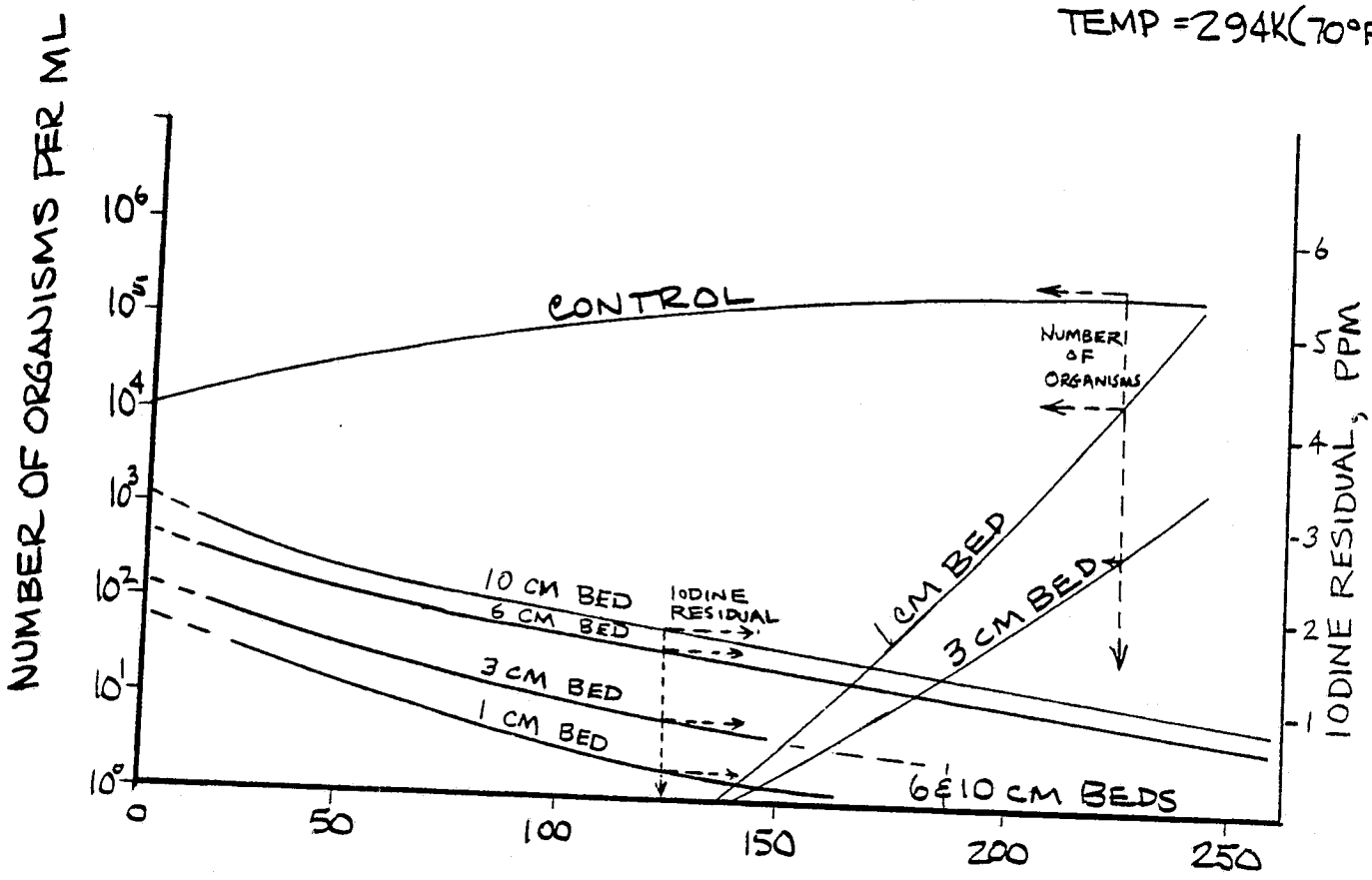


FIGURE 4-13
SMALL-SCALE TESTS
7 ORGANISM MIXTURE (ALCOHOL SOAKED RESIN)

RUN # 47
TEMP = 294K (70°F)



MISSION MAN-DAY EQUIVALENTS

(continued from page 43)

At first glance, when comparing this performance to Figure 4-11 (bottom) it might appear that alcohol soaking improved performance. However, it must be noted that the input concentration in Figure 4-11 (bottom) is 10^6 organism per ml, and that accounts for the earlier breakthroughs. Figure 4-13 is better compared to Figure 4-14, which in spite of inputs of 10^5 to 10^6 organisms per ml, no breakthrough occurred in the 3, 6 and 10 cm (1.2, 2.4 and 3.9 in) beds. Iodine residuals are also plotted in Figures 4-13 and 4-14 and are significantly lower for the alcohol soaked resins. This performance might have been predicted in that the alcohol recovered after washing the treated bed exhibited color indicating iodine washout.

It is concluded that an alcohol soak tends to decrease the resin's capability for killing microorganisms.

4.8.6 Challenge of Ethylene Oxide Sterilized Resin. Performance of the resin after sterilization in ethylene oxide is shown in Figure 4-15. A 7 organism mixture was used on a 10 cm bed with an input of 10^5 organisms per ml. Immediate breakthrough occurred. It appears that ethylene oxide sterilization produces a severe degradation in resin performance.

4.8.7 Iodine Residual. Iodine residual as a function of bed depth, temperature, throughput and microbial load was investigated and the results are plotted in Figures 4-16, 4-17 and 4-18. Bed depth did not seem to have a linear effect on iodine residual as might be expected. The 1 and 3 cm (.30 and 1.2 in) beds produced nearly identical residuals as did the 6 and 10 cm (2.4 and 3.9 in) beds. However, the residuals for the 6 and 10 cm beds were about 2½ times greater than those associated

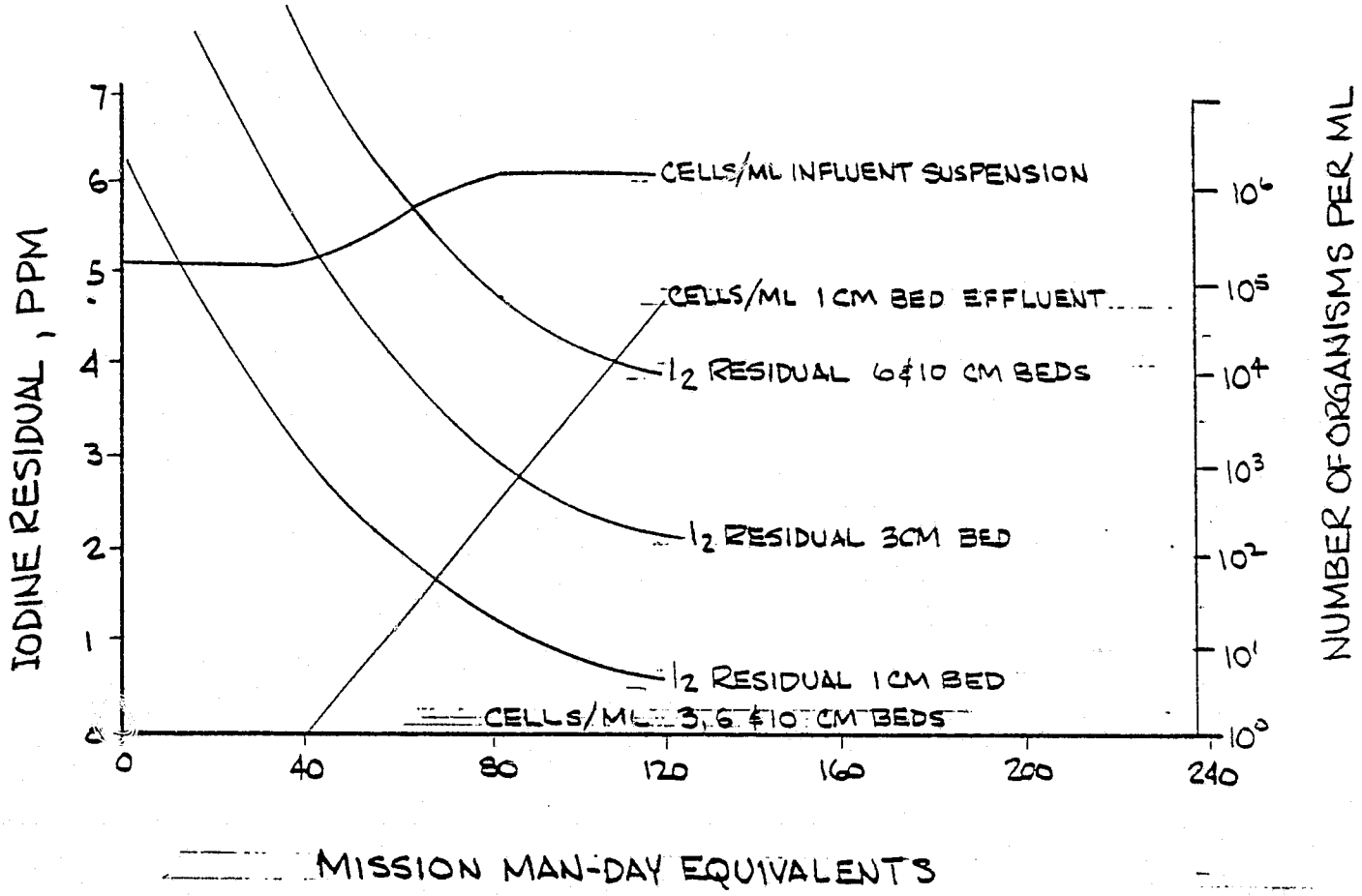
(text continued on page 52)

FIGURE 4-14

SMALL-SCALE TESTS

7 ORGANISM MIXTURE-IODINE RESIDUALS[1]

TEMP.= 294K (70°F)



1. NOTE THAT THE HIGH IODINE RESIDUALS ARE CAUSED BY THE DEMAND EFFECT OF THE CHALLENGE ORGANISMS (SEE PARAGRAPH 4.8.7.)

FIGURE 4-15

SMALL-SCALE TESTS
7 ORGANISM MIXTURE (ETHYLENE OXIDE STERILIZED RESIN)

RUN #48 ETO
TEMP = 294K (70°F)

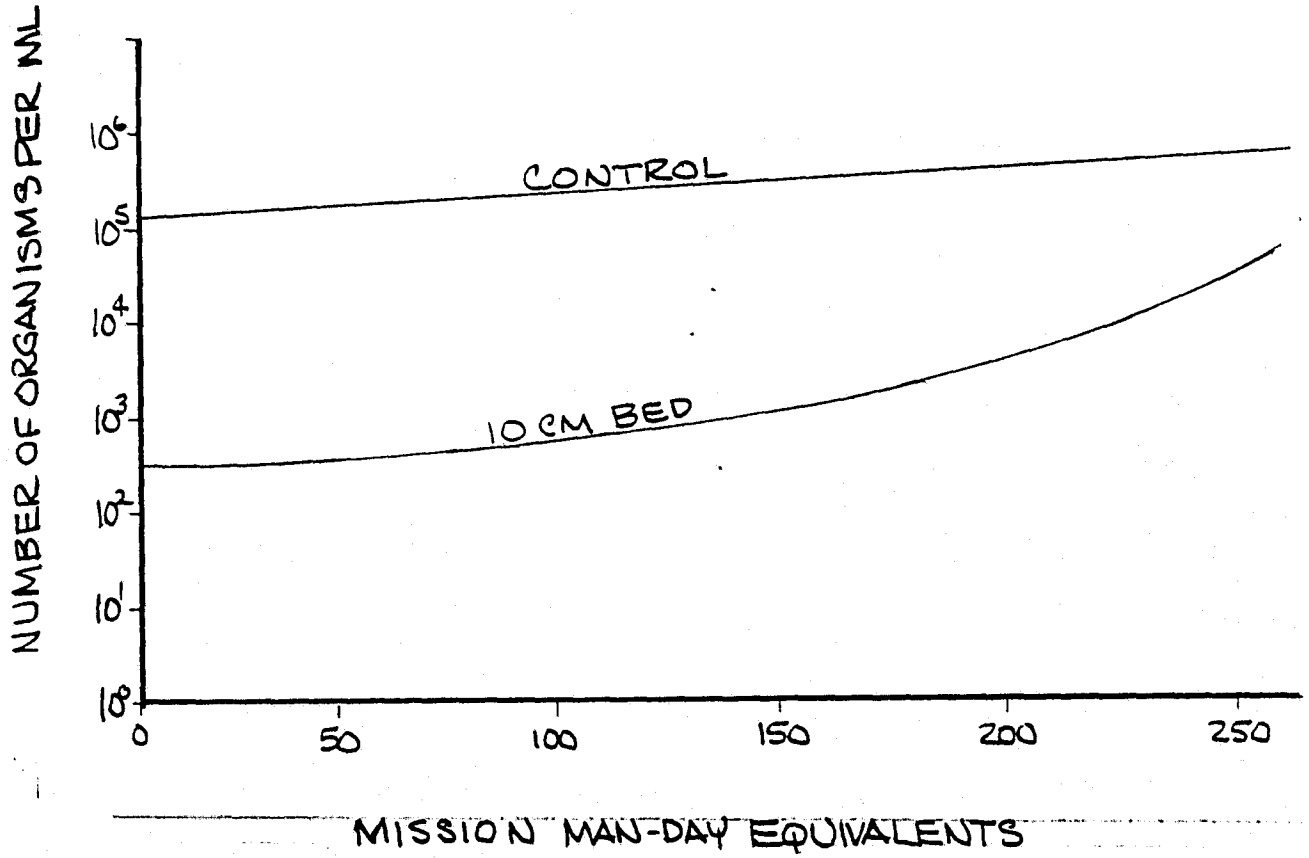


FIGURE 4-16

SMALL-SCALE TESTS

IODINE RESIDUAL vs. MISSION MAN-DAY EQUIVALENTS

(UNCHALLENGED TESTS)

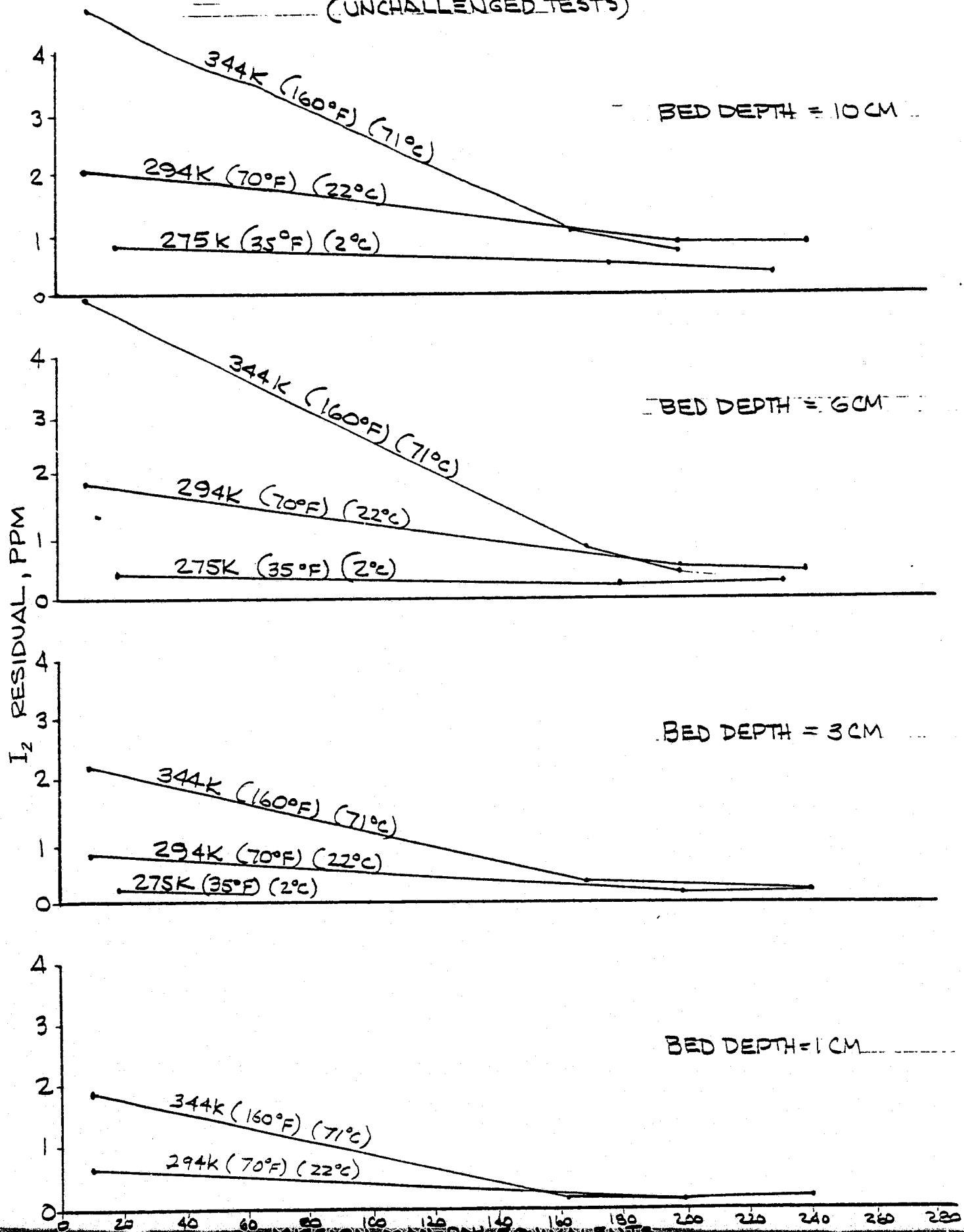
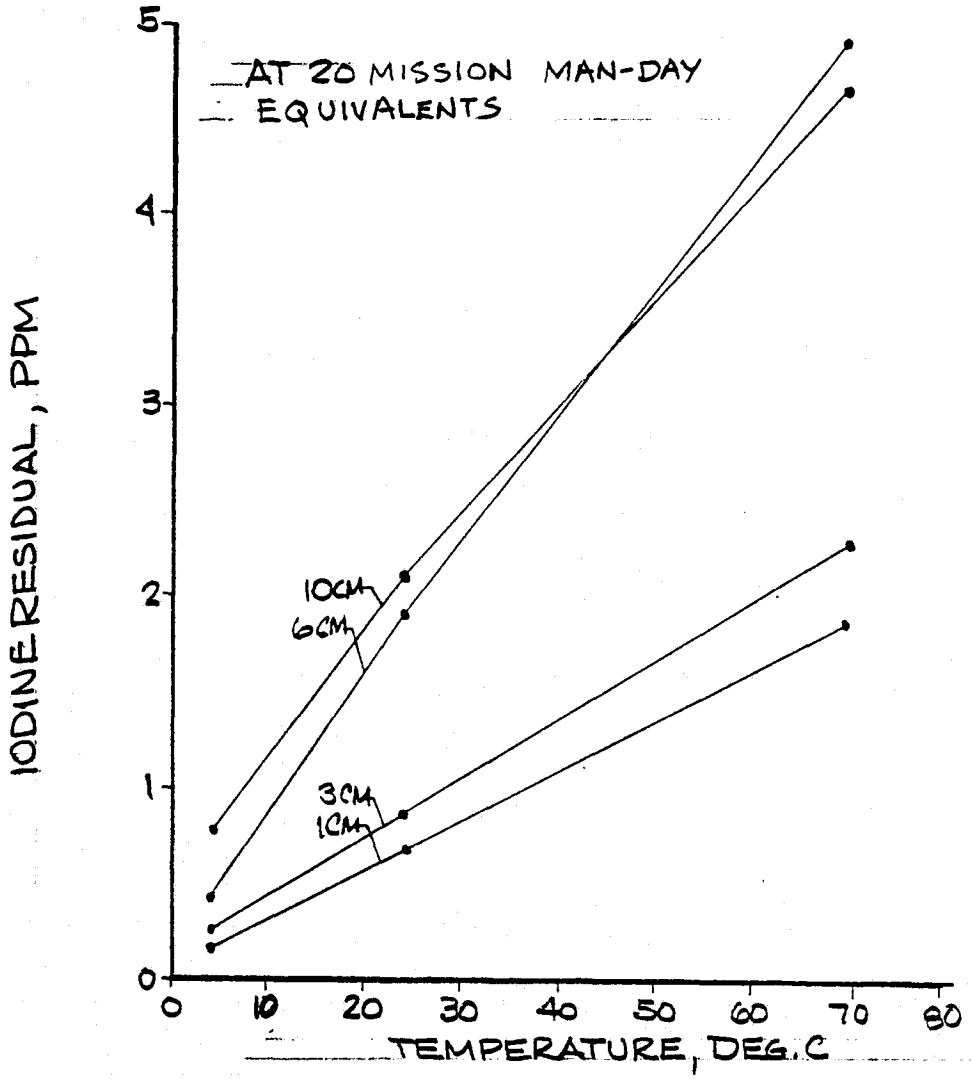


FIGURE 4-17

SMALL-SCALE TESTS
IODINE RESIDUAL vs. TEMPERATURE
(UNCHALLENGED TESTS)



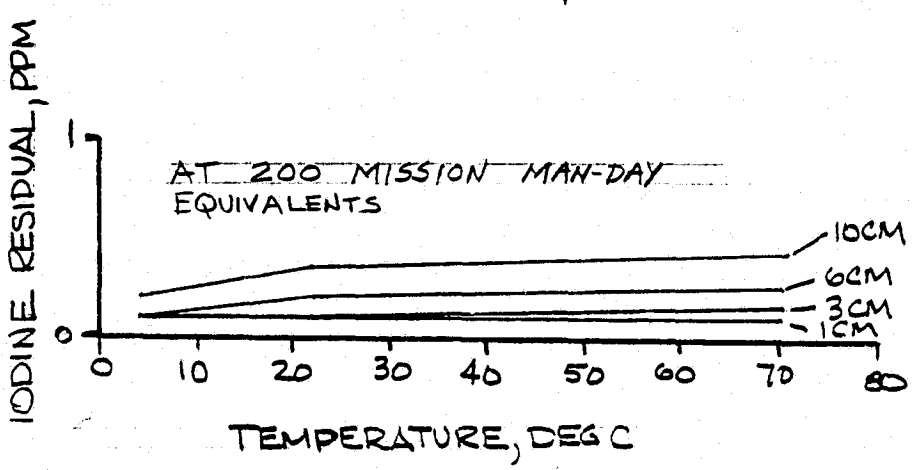
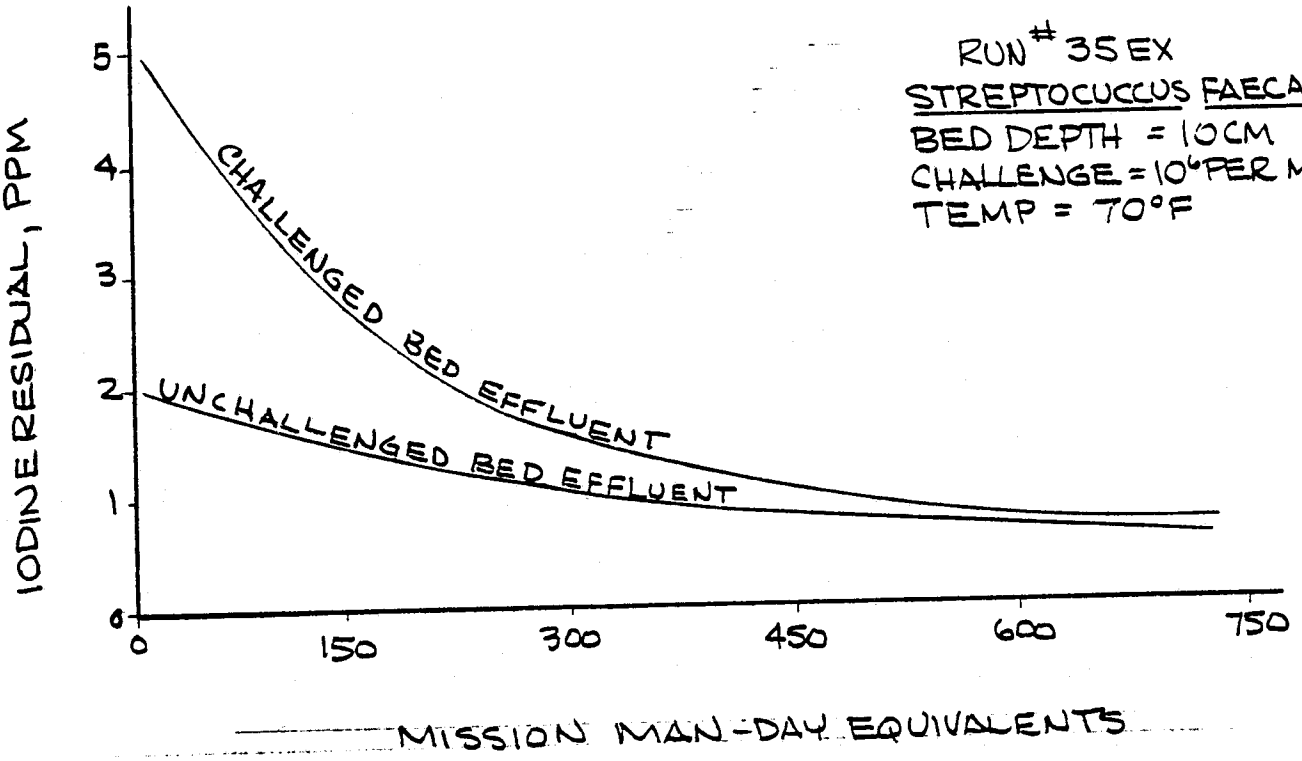
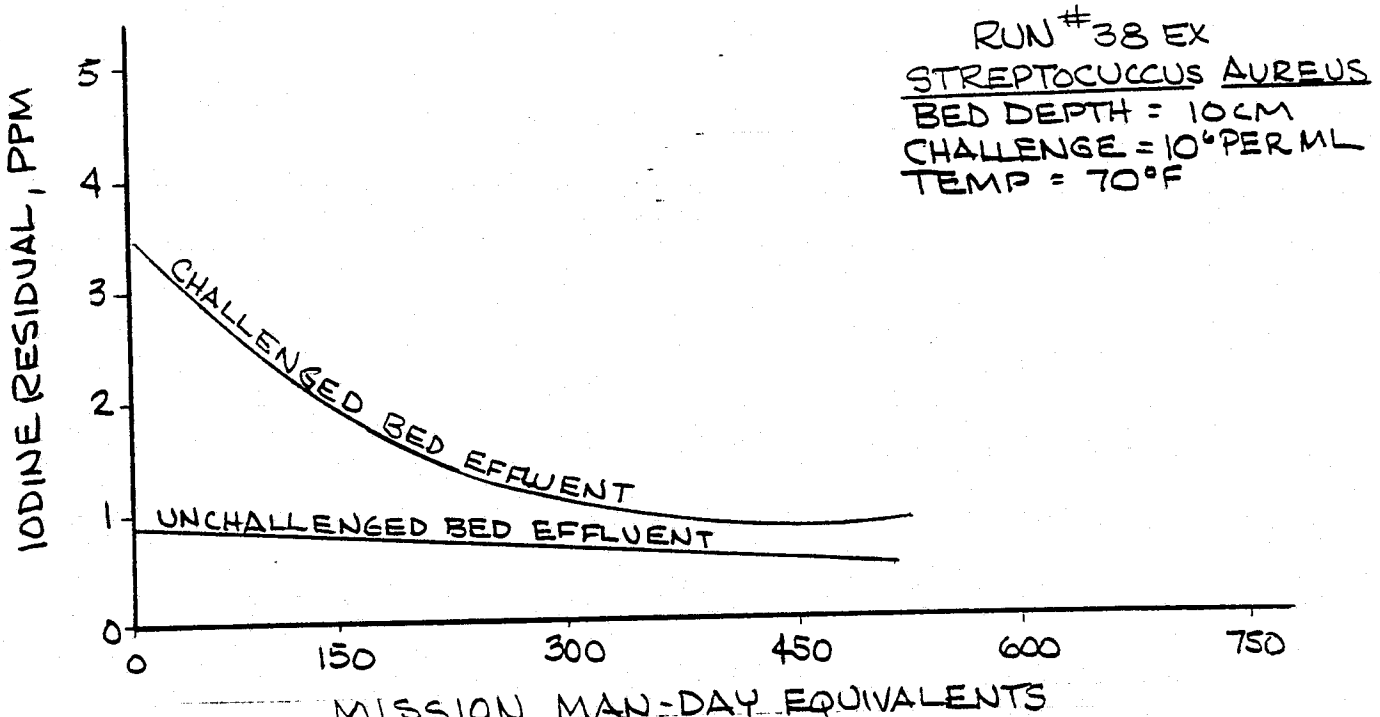


FIGURE 4-18

SMALL-SCALE TESTS IODINE RESIDUAL AS A FUNCTION OF MICROBIAL LOAD





(continued from page 46)

with the 1 and 3 cm beds.

Initially, temperature had a pronounced effect on the iodine residuals, as is best illustrated in Figure 4-17. However, after a throughput of 200 mission man-day equivalents, the effect of temperature was greatly diminished.

The relationship of iodine residual to microbial load is presented for two organisms in Figure 4-18. In both tests iodine residual was considerably higher in the effluent from the challenged bed than from the unchallenged bed. These results are interpreted to mean that microorganisms exert a demand effect on the iodine in the resin.

The results were obtained with the Leuco Crystal Violet method, which is sensitive to all oxidative forms of iodine. Parallel tests with starch, which is only sensitive to I_3^- were negative, indicating that the resin does not deliver I_3^- to the organisms on demand. Presumably, then it is I_2 that the bed delivers.

4.8.8 Discussion of Small-Scale Tests. Some idea of the importance of bed depth, which is theoretically proportional to residence time, can be obtained by further analyzing the data in Table 4-4. The number of mission man-day equivalents at breakthrough for the 6 cm (2.4 in) beds has been ratioed to that for the 10 cm (3.9 in) beds and tabulated in Table 4-5. This ratio is also equal to the ratio of throughputs at breakthrough. If residence time were the sole independent variable, then these ratios would all be in proportion to the bed sizes and equal to: $\frac{6\text{ cm}}{10\text{ cm}} = 0.6$. However, most of the ratios are greater than 0.6, which indicates

Table 4-5

COMPARISON OF 6 AND 10 CM BEDS

$$\text{Ratio} = \frac{\text{Mission Man-Day Equivalents at Breakthrough for 6cm Bed}}{\text{Mission Man-Day Equivalents at Breakthrough for 10cm Bed}}$$

TEST CULTURE	35°F	70°F
Escherichia coli	1.0	<.80
Streptococcus faecalis	1.0	.71
Staphylococcus aureus	1.0	1.0
Bacillus subtilis	.77	1.0
Pseudomonas aeruginosa	0	<.33
Clostridium perfringens	0	.08
Aspergillus niger	1.0	1.0
7 Organism Mixture	.83	.76
7 Organism Mixture	-	1.0

$$\text{Ratio} = \frac{\text{Iodine Residual from 6 cm Bed}}{\text{Iodine Residual from 10 cm Bed}}$$

THROUGHPUT	35°F	70°F
20 Mission Man-Day Equivalents	.58	1.0
200 Mission Man-Day Equivalents	.50	.6

that for these cases the smaller bed is doing a more effective job. In the case of Pseudomonas aeruginosa the additional resin contained in the 10 cm (3.9 in) bed produces a disproportionately higher effectiveness which suggests that residence time is critical and that the design residence time for the prototype unit should be at least equal to the 10 cm (3.9 in) bed.

In the case of Clostridium perfringens, the performance of the 6 and 10 cm (2.4 and 3.9 in) beds remained essentially flat during the 240 mission man-day test, while the effluent plate counts from the 10 cm (3.9 in) bed were about 1/2 the plate count levels of the 6 cm (2.4 in) bed. This also suggests that the design residence time should be at least equal to the 10 cm (3.9 in) bed.

In the two tests with the 7 Organism Mixture, the 6 cm (2.4 in) bed performed disproportionately better than its size indicating that it's residence time was adequate. It is interesting to note that the 7 Organism Mixture is less resistant than several of the pure cultures.

The ratio of iodine residuals for the 6 and 10 cm (2.4 and 3.9 in) beds is summarized at the bottom of Table 4-5 for both fresh resin (20 mission man-day equivalents) and used resin (200 mission man-day equivalents). The interesting point here is that the ratio of iodine residuals corresponds closely to the ratio of resin material indicating that residence time has a primary influence on iodine transfer under these conditions.

4.8.9 Summary of Small-Scale Test Results. The most significant results obtained in the small-scale tests were the following:

a. A temperature of 344 K(160°F) killed all of the 7 different microorganisms used in the challenges.

b. The MCV resin was less effective at low temperature 275 K (35°F) than at ambient temperature 294 K(70°F). That is, the resin had significantly shorter life at breakthrough in the low temperature tests. However, at both low and ambient temperature the minimum reduction achieved at breakthrough was 10^3 organism per ml.

c. Residence time should be at least 2 sec to insure an adequate kill for pure cultures of Pseudomonas aeruginosa and Clostridium perfringens. A residence time of 1.3 sec is adequate for pure cultures of the other 5 organisms and for the 7 organism mixture.

d. Autoclaving the resin reduces its performance by at least 70%.

e. Soaking the resin in alcohol removes iodine and significantly reduces its performance.

f. Sterilizing the resin with ethylene oxide severely reduces its performance.

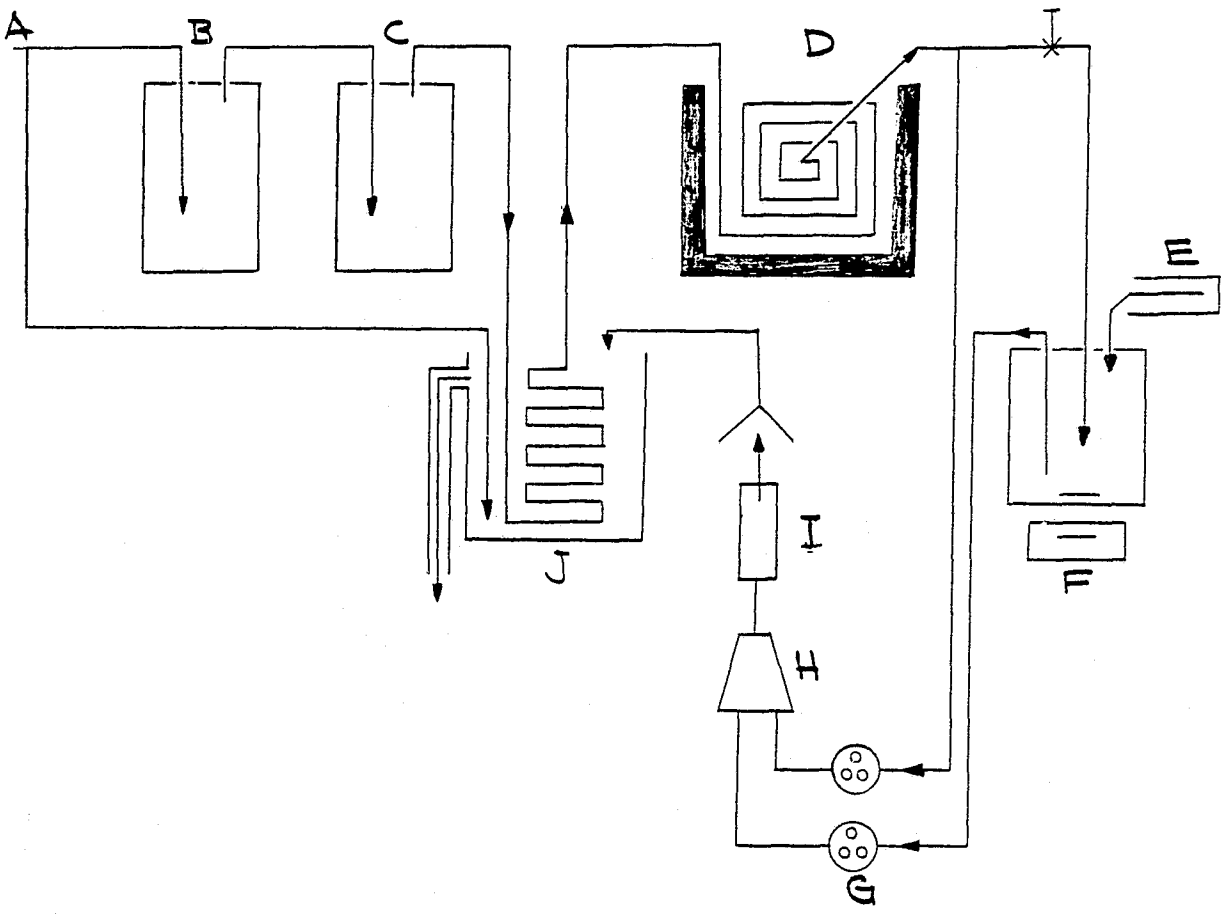
g. Iodine residual increases with microbial load.

h. Iodine residual increases with temperature.

i. Iodine residual decreases with throughput.

4.9 Large-Scale Tests. A schematic drawing of the large-scale test set-up is presented in Figure 4-19. City tap water (A) is fed through a water deionization bed (B) into a hot water heater (C) at 0.454 kg/min (1 lb/min). This gives an approximate residence time in the 150 kg (40 gal) hot water heater of 5 hours. Plate counts were taken to demonstrate counts of zero per ml in the water after a five hour residence time. From the hot water heater the pasteurized, deionized water was circulated through a running

FIGURE 4-19
LARGE SCALE TEST SET-UP



A. CITY WATER SUPPLY
B. WATER DEIONIZATION BED
C. HOT WATER HEATER
D. CONTROLLED TEMPERATURE WATER BATH WITH HEAT EXCHANGE COILS
E. WASHED BACTERIAL CELLS
F. INFLUENT SUSPENSION TANK WITH MAGNETIC STIR BAR
G. POLY STALTIC PUMP
H. MIXING CHAMBER
I. FULL SCALE RESIN BED
J. TAP WATER COOLING BATH WITH OVER FLOW TO DRAIN

cold water bath (I) and then through a controlled temperature water bath (D) before being pumped to a mixing chamber (H). In the mixing chamber the pasteurized, deionized water is mixed with a metered amount of washed bacterial cells pumped from the influent suspension tank (F) to give the target bacterial concentration. The influent plate count was taken at a sampling port immediately upstream of the resin bed. The effluent plate count was taken from the resin bed effluent. A 7 Organism mixture was used for all the large-scale tests.

4.9.1 Challenge at 257 K(35^{o}F). These results are presented in Figure 4-20. A minimum of 10^{2} reduction was achieved continuously for 660 mission man-day equivalents. However, breakthrough occurred at 10 mission man-day equivalents. The effluent plate counts ranged from 9 to 300 per ml, which was attributed to the three factors mentioned in paragraph 4.8.2.

4.9.2 Challenge at 294 K(70^{o}F). Two tests were performed and the data are presented in Figure 4-21. In both instances a 10^{4} reduction was achieved throughout the test periods of 375 and 827 mission man-day equivalents and all plate counts were well below 3 per ml.

4.9.3 Challenge at 344 K(160^{o}F). These results are presented in Figure 4-22. Both the influent and effluent plate counts were below 3 per ml throughout the 375 mission man-day test. Obviously the challenge organisms cannot survive this temperature.

4.9.4 Challenge of Autoclaved Resin. The results of challenging an autoclaved resin bed are shown in Figure 4-23. Only a 10^{3} reduction was achieved, and the effluent plate counts ranged from 0 to 300 per ml. This suggests a conclusion that autoclaving decreases the ability of the resin to kill microorganisms.

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FIGURE 4-20

LARGE SCALE TEST AT 275K (35°F)

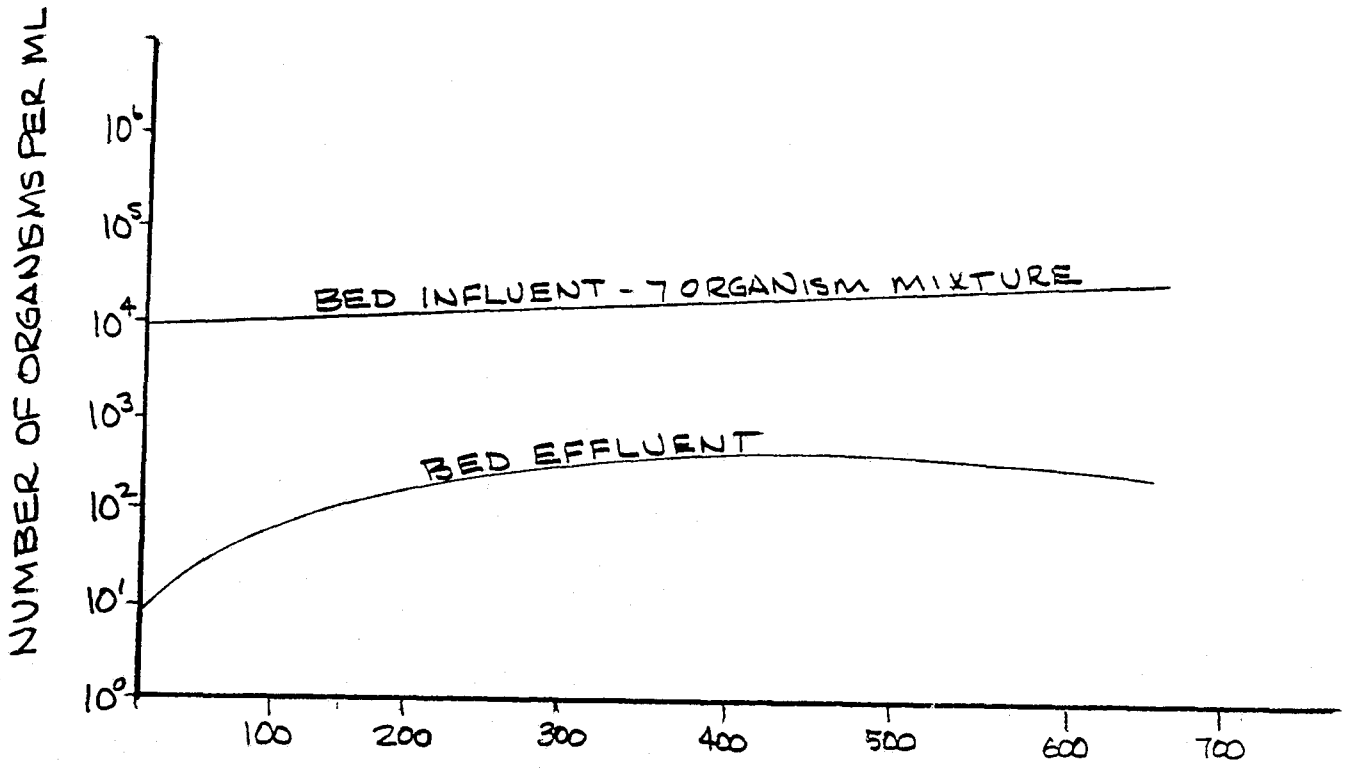
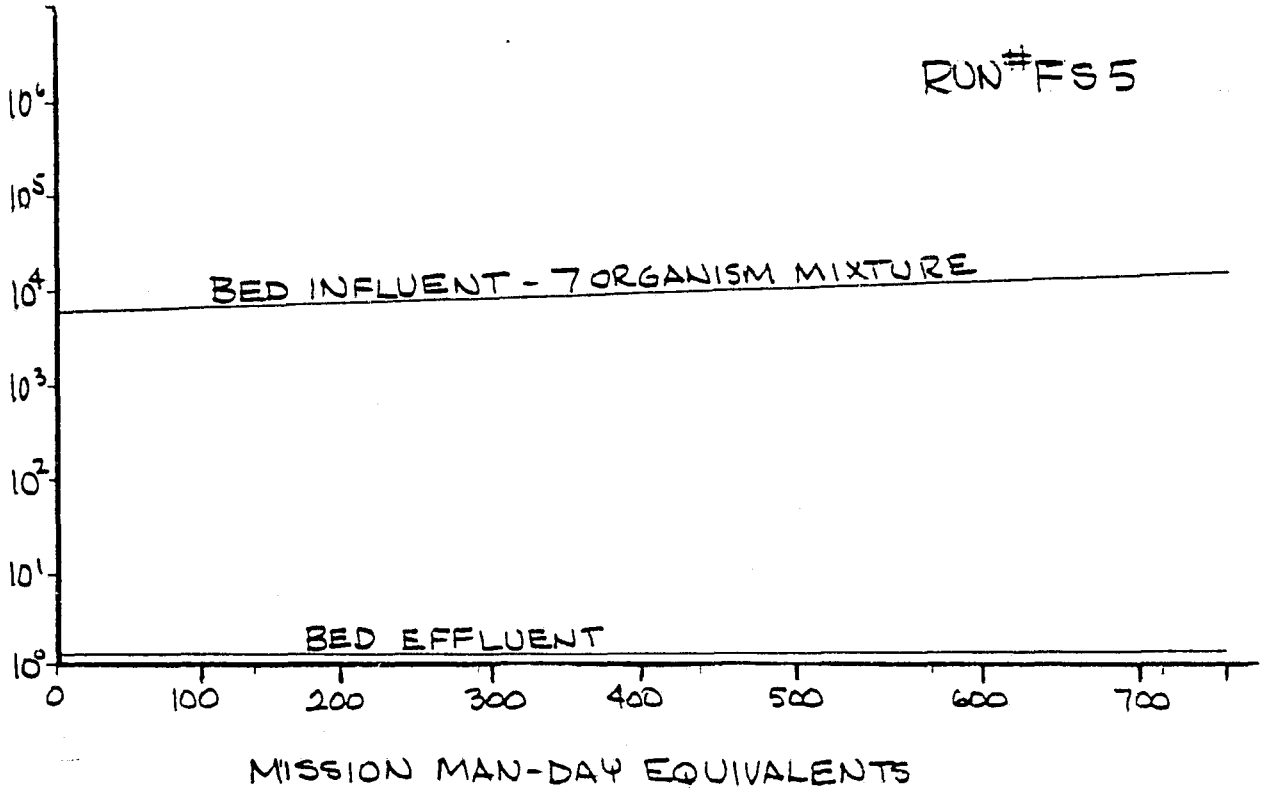


FIGURE 4-21
LARGE-SCALE TESTS AT 294K (70°F)



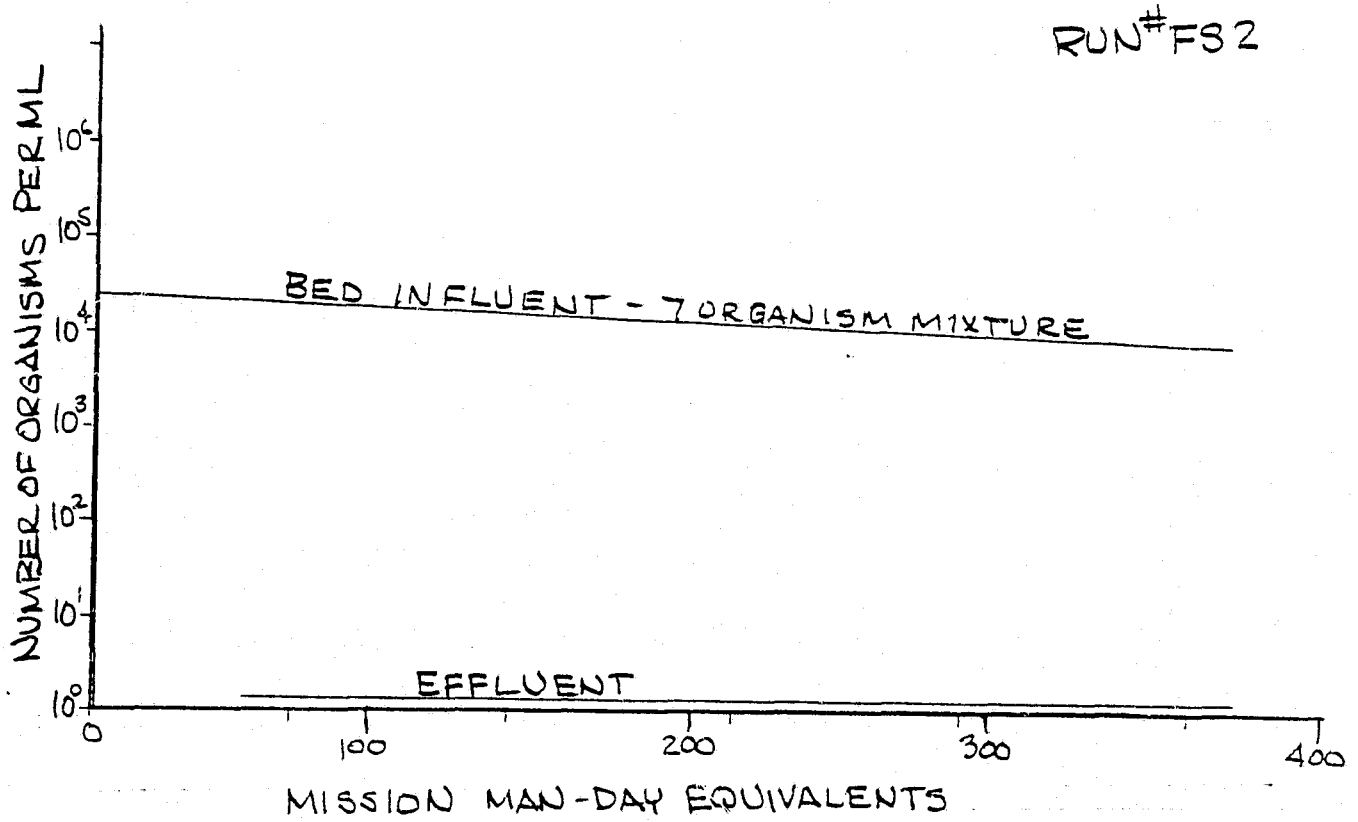


FIGURE 4-22
LARGE-SCALE TEST AT 344K (160°F)

RUN # FS 3
7 ORGANISM MIXTURE

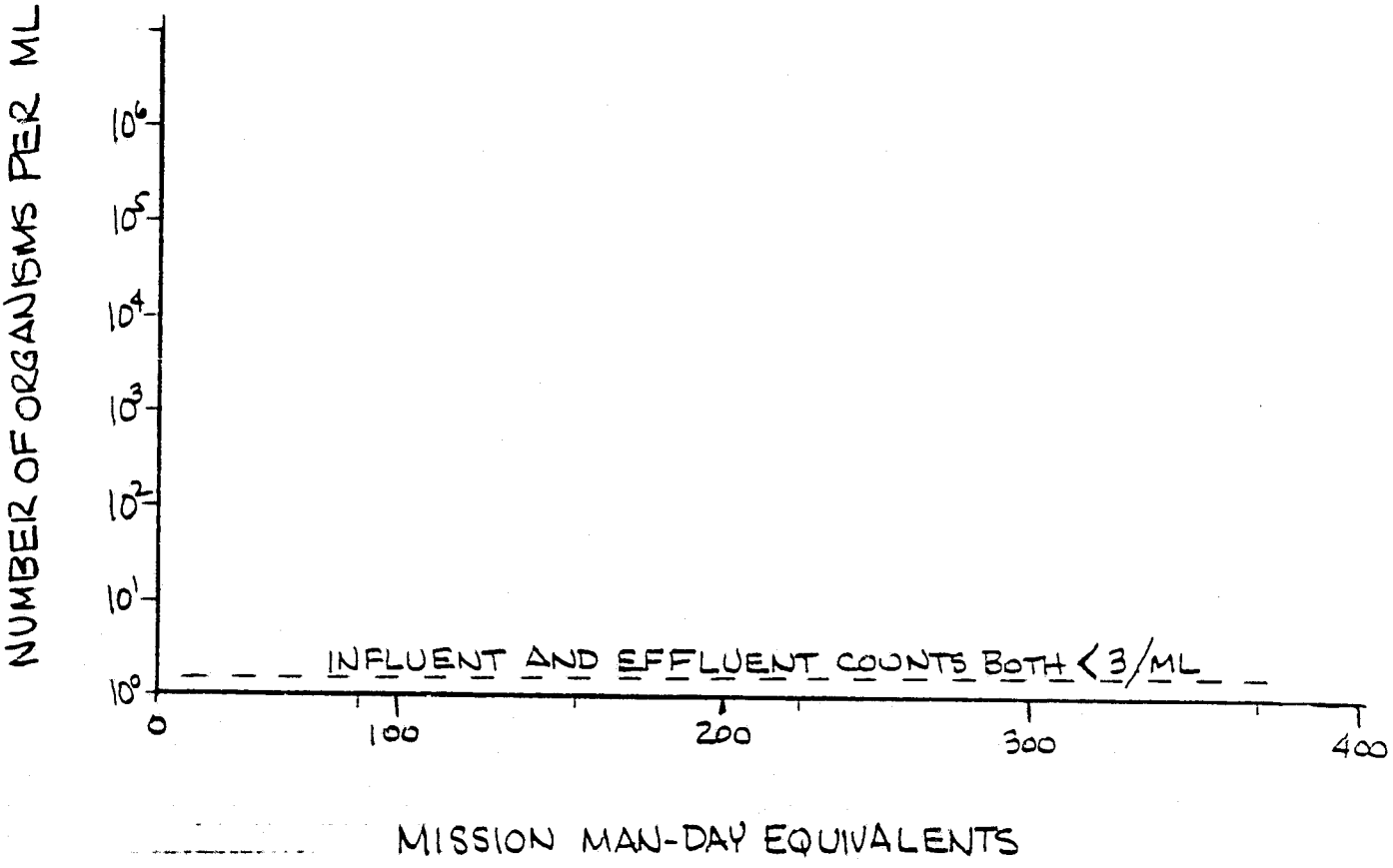
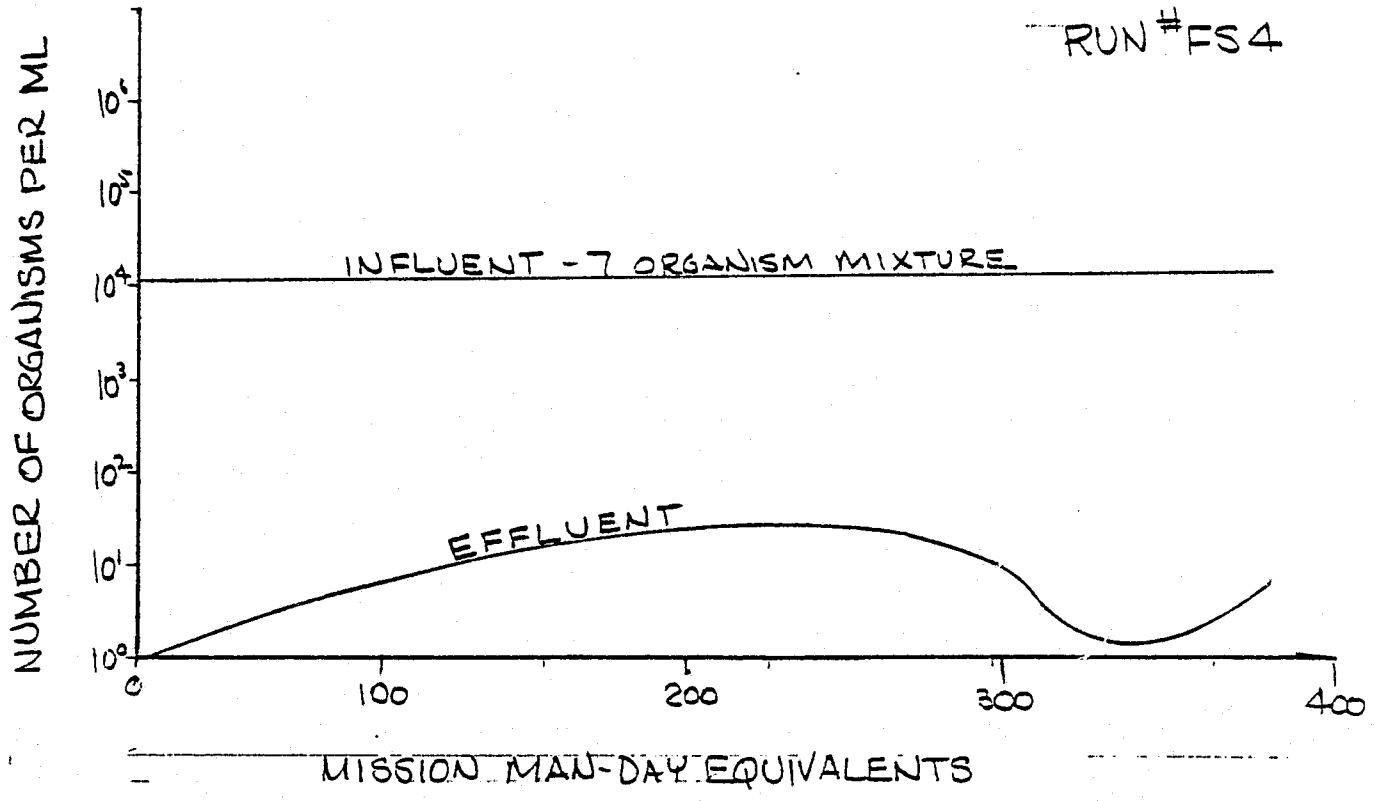


FIGURE 4-23
LARGE-SCALE TEST (AUTOCLAVED RESIN)



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4.9.5 Water Chemistry Effects. Influent and effluent water chemistry parameters were determined during the 294 and 344 K (70 and 160°F) microbial challenges in order to: (1) verify that the resins perform satisfactorily with typical fuel cell quality water and (2) to verify that the resins will not adversely effect water quality. Influent and effluent parameters for the 294 K (70°F) challenge (FS #2, see Figure 4-21, bottom) at 275 mission man-day equivalents and for the 344 K (160°F) challenge (FS #3, see Figure 4-22) at 290 mission man-day equivalents are presented in Table 4-6.

In general, the challenge water contained fewer trace contaminants than the maximum allowable concentrations in fuel cell water, so the resins were not challenged with the "worst case" situation. Based on total solids, the water was 30% for the 294 K (70°F) test and 45% for the 344 K (160°F) test as contaminated as maximum fuel cell water.

Examination of Table 4-6 indicates that the resin had a minuscule impact on the water quality parameters of interest. The only notable effects were the removal of iron and the lowering of pH to the 5.4 - 5.6 range.

4.9.6 Discussion of Large-Scale Tests. The large-scale tests were all conducted with a 7 Organism Mixture in a bed with approximately the same residence time but 56 times larger than the 6 cm (2.4 in) deep small-scale bed. In general, the large scale tests validated the small-scale tests and proved that a scale-up factor of 50 may be used with confidence.

TABLE 4-6

LARGE-SCALE TEST - INFLUENT AND

EFFLUENT WATER CHEMISTRY

		Run FS #2 at 275 Mission Man-Day Equivalents		Run FS #3 at 290 Mission Man-Day Equivalents	
	SOURCE	INF	EFF	INF	EFF
		294 K	294 K	344 K	344 K
	UNITS	(70°F)	(70°F)	(160°F)	(160°F)
pH	pH Units	6.0	5.6	7.0	5.4
SPECIFIC CONDUCTANCE	u mho/cm	1.2	2.1	4.0	4.0
TOTAL SOLIDS	mg/l	6.	2.	9.	16.
TOTAL ORGANIC CARBON	mg/l	0.97	0.89		
ODOR	TON	2.	2.	<1.	<1.
TURBIDITY	NTU	<0.1	<0.1	<0.1	<0.1
COLOR, APPARANT	CU	<1.	<1.	<1.	5
CADMIUM	mg/l	0.001	0.001	0.001	0.002
CHROMIUM	mg/l	<0.07	<0.07	<0.04	<0.04
COPPER	mg/l	<0.02	<0.02	<0.03	<0.03
IRON	mg/l	0.05	0.03	0.1	<0.04
LEAD	mg/l	0.007	0.008	<0.002	<0.002
MANGANESE	mg/l	<0.01	<0.01	<0.006	<0.006
MERCURY	mg/l	<0.001	<0.001	<0.001	<0.001
NICKEL	mg/l	<0.07	<0.07	<0.06	<0.06
SILVER	mg/l	<0.02	<0.02	<0.02	<0.02
ZINC	mg/l	0.007	0.007	0.008	0.01
SELENIUM	mg/l	0.001	0.002	<0.001	<0.001
VOLATILE SOLIDS	mg/l			3.	7.

4.9.7 Summary of Large-Scale Test Results. The most significant results obtained in the large-scale tests were the following:

a. The small-scale test results were confirmed.

b. A Scale-up factor of 50 is reasonable.

c. The MCV resin does not adversely effect water chemistry.

d. Typical fuel cell water does not adversely effect the MCV resin.

5.0 APPLICATION OF RESULTS

There are a number of possible MCV applications summarized in Table 5-1. For each application, the projected mission life is estimated assuming that the MCV prototype unit is used for that application. Other pertinent information is also tabulated including operating temperature, total throughput, flow rate, residence time, required life and factors of safety. Each application is discussed separately in the following paragraphs.

5.1 Total Water Used. Processing of the total water used by the crew for a 7 man-30 day Shuttle mission at ambient temperature conditions is the baseline application for the MCV. This amounts to 8.25 lb/man-day x 7 men x 30 day = 1733 lb. This is also equal to 210 mission man-days at 8.25 lb/man-day. Testing was curtailed on the large-scale test unit, without a breakthrough, after 826 mission man-day equivalents. The prototype unit then, would have a factor of safety on life of $\frac{826^{+}}{210}$ = 3.9^{+}. In addition, in this application the prototype has a factor of safety on residence time of 1.5, which would be expected to result in even greater life and also enable the unit to achieve higher microbial reductions.

5.2 EMU Recharge. In this application the prototype MCV has a factor of safety on life of 138^{+} and a factor of safety on residence time of 3.0.

5.3 EMU Recharge Projected. A projected design goal for EMU recharging is 12 lb/recharge x 120 recharges = 1440 lb at a flow of 1 lb/min. In this application the prototype MCV has a factor of safety on life of 4.7^{+} and a factor of safety on residence time of 1.5.

5.4 Galley Hot Water. Since no microbes survive at the operating temperature of 160^{o}F, the prototype MCV would have an infinite factor of safety in this application.

TABLE 5-1

CANDIDATE MCV APPLICATIONS

APPLICATION	MCV UNIT	OPERATING TEMP. ^{o}F	TOTAL THROUGH-PUT lb	FLOW RATE lb/min	RESIDENCE TIME sec	REQUIRED LIFE MISSION MAN-DAY EQUIV.	TESTED OR PROJECTED LIFE MISSION MAN-DAY EQUIV.	FACTOR OF SAFETY ON LIFE Projected Life / Required Life	FACTOR OF SAFETY ON RESIDENCE TIME
Test Data	Large Scale Test	35	1240	1	1.33	-	10	-	
Test Data	Large Scale Test	70	3420	1	1.33	-	826+	-	
Test Data	Large Scale Test	160	705	1	1.33	-		-	
Total Water Used	Prototype	70	1733	1	2.0	210	826+	3.9+	1.5
EMU Recharge	Prototype	70	50	½	4.0	6	826+	138+	3.0
EMU Recharge, Projected	Prototype	70	1440	1	2.0	175	826+	4.7+	1.5
Galley Hot Water	Prototype	160	690	-	-	-			-
Galley Chilled Water	Prototype	35	540	1	2.0	65.5	10	.15	1.5
Personal Hygiene	Prototype	70	536	1	2.0	65	826+	12.7+	1.5
Fuel Cell Production	Prototype	70	8640	.37	5.4	1047	826+	.79+	4.1

5.5 Galley Chilled Water. In this low temperature application the prototype MCV can not be expected to achieve more than a 10^2 reduction in microorganisms.

5.6 Personal Hygiene. In this application the prototype MCV has a factor of safety on life of 12.7^+ and a factor of safety on residence time of 1.5.

5.7 Fuel Cell Production. The prototype MCV might be able to process all of the fuel cell water, but the device has only been tested long enough to prove that it can process 79% of the projected amount. In this application the prototype MCV has a factor of safety on residence time of 4.1, which would be expected to result in greater life and also enable the achievement of higher microbial reductions.

6.0 MCV DESIGN CRITERIA

Based on the test data developed in this effort, a suggested list of MCV design criteria are presented in Table 6-1. The MCV prototype unit is listed for comparison.

TABLE 6-1

MCV DESIGN CRITERIA

BED PARAMETERS	DESIGN CRITERIA	MCV PROTOTYPE UNIT
Depth	>6 cm(2.4in)	7.6 cm(3.0in)
Depth to Diameter Ratio	>1.5	1.85
Residence Time	>1.33 sec	2.0 sec
Mission Man-Day Equivalents	<826	210

It should be emphasized that the microbial challenge procedure used in this program was extremely conservative because all test data were obtained with a continuous flow challenge of organisms which produced a total load on the device many times in excess of any anticipated operational conditions. Basically, the MCV is intended to prevent the back contamination of microorganisms should they be introduced at a point in the potable water system. Such contamination would be expected to occur only at infrequent intervals, if at all, and certainly never on a continuous flow basis corresponding to the challenge conditions.