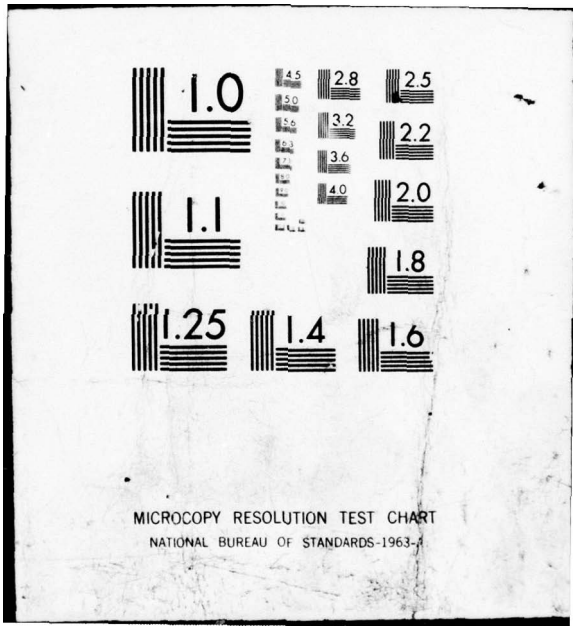
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FOREWORD

This report covers the work performed under Contract F04611-72-C-0062, "Storability Investigations of Water," performed by the Aerojet Liquid Rocket Company at Sacramento, California, and conducted under Air Force Project Task 305911 VD. The performance period covered from 1 October 1976 to 30 September 1977.

The program manager is Dr. S. D. Rosenberg; the project manager is Dr. E. M. Vander Wall. The experimental work was conducted by Dr. Vander Wall; R. L. Beegle, Jr., senior chemist; J. A. Cabeal, senior laboratory technician; and G. R. Janser, metallurgy specialist.

The program was administered under the direction of the Air Force Rocket Propulsion Laboratory, Mr. Oree Dyes, Project Engineer.

This report has been reviewed by the Information Office/DOZ and is releasable to the National Technical Information Service (NTSI). At NTIS it will be available to the general public including foreign nations.

This report is unclassified, and suitable for general public release.

Bernard R. Bornhorst,
Chief Strategic Systems Section

For the Commander

Edward E. Stein, Deputy Chief
Liquid Rocket Division

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this program is to gather data that will permit the Air Force to assess the long term storage characteristics of water, particularly with regard to formation of particulate matter, so that the feasibility of long-term storage of water for use as a transpiration coolant can be determined. Five metallic materials of construction are included in the program: 304 stainless steel, A-286 (aged) steel, 17-4 (aged) stainless steel,

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Abstract (cont.)

Inconel 718 (aged), 6Al-4V titanium (STA). Two types of water are used in the program; oxygen-saturated, deionized, filtered, and oxygen-free, deionized, filtered. Five-year storage tests have been initiated in 304 and 17-4 PH stainless steels, A-286 steel, Inconel 718, and 6Al-4V titanium (STA) containers using the filtered, deionized waters.

Evaluation of water and containers stored for forty-two months and forty-eight months has been completed. The data show that both oxygen-saturated and oxygen-free water can be stored in appropriate metal containers for the selected time periods without detrimental particulate matter formation or significant changes in the quality of the water. It is in excellent condition for transpiration coolant purposes.

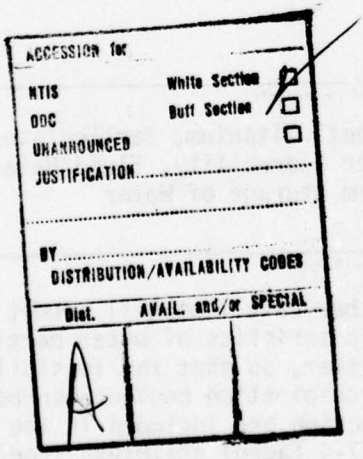


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SECTION I

INTRODUCTION

Inherent in the concept of transpiration-cooling is the requirement that the coolant remain free of particulate matter which may clog the passages of the cooling surface. The object of the "Storability Investigations of Water" program is to gather data that will permit the Air Force to assess the long term storage characteristics of water particularly with regard to formation of particulate matter. This report is the fourth annual progress report to document the experimental results from the forty-two month and forty-eight month storage tests of water in selected metal containers for the five year program being conducted under Contract F04611-72-C-0062.

The five metallic materials used for container material in the program are:

304 stainless steel
A-286 (aged) steel
17-4 PH (aged) stainless steel
Inconel 718 (aged)
6Al-4V Titanium (STA)

Two types of water are considered in the program:

oxygen-saturated, deionized, filtered water and
oxygen-free, deionized, filtered water

Three categories of tests are used for obtaining the data necessary for assessment of the storability of water. They are:

Water Characterization
Biological Characterization
Container Examination

The investigations which led to the selection of the candidate metallic materials for tankage for use in the five-year storage of waters are reported in AFRPL-TR-73-94 "STORABILITY INVESTIGATIONS OF WATER," VOLUME I: EXPERIMENTAL STUDIES, FINAL REPORT, Aerojet Liquid Rocket Company, Sacramento, California, December 1973. The results from the first year of storage are reported in AFRPL-TR-74-76 "STORABILITY INVESTIGATIONS OF WATER, LONG TERM STORAGE EVALUATION," FIRST ANNUAL REPORT, Aerojet Liquid Rocket Company, Sacramento, California, December 1974. The results from the second year of storage are reported in AFRPL-TR-75-62 "STORABILITY INVESTIGATIONS OF WATER, LONG TERM STORAGE EVALUATION," SECOND ANNUAL REPORT, Aerojet Liquid Rocket Company, Sacramento, California, December 1975. The results from the third year of storage are reported in AFRPL-TR-76-95 "STORABILITY INVESTIGATIONS OF WATER, LONG TERM STORAGE EVALUATION," THIRD ANNUAL REPORT, Aerojet Liquid Rocket Company, Sacramento, California, December 1976.

Introduction (cont.)

This annual report is presented in three sections: (1) Introduction, (2) Experimental Results and Discussions, and (3) Conclusions and Recommendations. In addition, there are two appendices provided for the convenience of the reader: Appendix A, Fabrication and Treatment Procedures for Water Containers which documents the history of the tanks; and Appendix B, Silting Index Measurement which describes a clogging tendency test.

SECTION II

EXPERIMENTAL RESULTS AND DISCUSSIONS

BACKGROUND INFORMATION

The purpose of the long-term storage tests is to demonstrate that water can be stored without formation of significant quantities of particulate matter and with insignificant corrosion of appropriate metal containers for time periods of at least five years in a controlled environment. The background information is presented for the convenience of the reader and documents the initial conditions of the selected containers and waters prior to the storage periods. The discussion is presented under the following headings: (1) Materials Selection, (2) Container Sterilization and Filling and (3) Storage Conditions.

A. MATERIALS SELECTION

1. Waters

Based on the data derived from the preceding experimental work (Reference 1) it was apparent that both oxygen-saturated and oxygen-free water were acceptable candidates for long-term storage tests. Further, the filtration of the water through a 0.22 micron pore size absolute filter was demonstrated to remove microorganisms effectively. Thus, the water used to fill the containers was passed through an activated charcoal bed to remove organic compounds and through two mixed-bed ion exchangers to obtain water that had an electrical resistance value of 1 megohm/cm or greater. The water was transferred through 0.22 micron filters into a 5 gallon stainless steel supply tank. To ensure the saturation of the water with oxygen, filtered oxygen was purged through the water in the supply tank for a minimum of 15 minutes. To obtain oxygen-free water, the water in the supply tank was heated to the boiling point of water for one hour while being purged with filtered, nitrogen obtained from the boil-off of liquid nitrogen. The tank was then pressurized with the filtered nitrogen, allowed to cool to ambient temperatures, and then repressurized with the filtered nitrogen. The outlet of the supply tank was fitted with a Twin 90 Filter* unit to assure the sterile characteristics of the water used to fill the storage containers.

2. Metals

The selection of the materials of construction for the long term storage test containers was based on the results of the laboratory investigations (Reference 1). The aluminum alloys were eliminated from

Ref. 1 E. M. Vander Wall, R. E. Anderson, G. R. Janser, Storability Investigations of Water, Volume I, Experimental Studies, AFRPL-TR-73-94, Contract F04611-72-C-0062 (December 1973).

* A 0.22 micron pore size, absolute filter pack available from Millipore Corporation, Bedford, MA.

A. Materials Selection (cont.)

consideration due to their introduction of insoluble corrosion products which are a source of particulate matter in the water. Because test results on the remainder of the seven candidate materials were not discriminatory, choice was made on the basis of selecting not more than one alloy from each class of material. The one class of material with more than one representative was the 18% chromium - 8% nickel austenitic stainless steels, i.e., 304L, 347 and Arde-form 301. Hence two of these materials were eliminated to provide the five materials required for container fabrication. The 304L stainless steel was selected due to its attractiveness as an expulsion bladder material. Hence, the selected materials are: 304L stainless steel, A-286, 17-4PH stainless steel, Inconel 718 and 6Al-4V titanium. During fabrication, some 304 stainless steel parts were incorporated into the 304L stainless steel containers and consequently the containers are identified as 304 stainless steel containers. The fabrication procedures, the heat treatment cycles, the cleaning procedures and the passivation procedures to which the containers were subjected are presented in Appendix A of this report.

B. CONTAINER STERILIZATION AND FILLING

Following the final rinsing with filtered, deionized water, and subsequent drying of the containers in a vacuum chamber, the containers were wrapped with reusable sterilization paper. The wrapped containers were then sterilized in an autoclave at 250°F with 15 psig steam for 30 minutes followed by a 30-minute drying period. The containers were then stored in the paper to maintain their sterile condition.

All the steps required to fill the containers with water were conducted in a sterile, laminar-flow bench. The tanks were removed from the wrapping paper in the laminar flow bench. The tanks were weighed empty; then weighed when filled completely with sterile water to determine the total volume of the tank. The water was drained out and the tank was rinsed once more with the sterile water. A sample of the rinse water was checked for pH, conductivity, and Silting Index (see Appendix B). If the values indicated that particulate matter and dissolved species were not present, the tank was considered ready for filling; if the values indicated that contaminants were present, the tank was rinsed until there was no evidence of contamination. A Silting Index value of 1 or less for the rinse water when using the filter with a cross-sectional area of 1.0 mm^2 was used as the criterion that no significant quantity of loose particulate matter remained in the containers.

Before the final filling with oxygen-saturated deionized water, the tank was purged with oxygen from a filtered supply. The tank was then filled with the water and a sample was withdrawn for pH, conductivity, and Silting Index measurements. The ullage was adjusted to the ten percent value by weighing the container and its contents; the ullage space was purged with the filtered oxygen; and the container was capped with a sterile, tapered plug made from the same material as the container. The plug was seated in

B. Container Sterilization and Filling (cont.)

the fill-tube by use of a hammer. The containers were filled with the oxygen-free, deionized water in an analogous manner except that filtered nitrogen was used instead of oxygen for purging and blanketing the container.

The final sealing of the containers was accomplished by GTA welding the fill-tube/plug interface. The welds were inspected visually for any apparent anomalies. None were found. Then the containers were labeled for the long-term storage test and placed in plastic bags.

The sampling plan for the long-term storage tests is to remove one container of each material with the two types of water for inspection and evaluation every six months for a period of five years. The contents will be characterized with respect to pH, conductivity, particulate content, and biological activity; and the containers themselves will be subjected to metallurgical examination if the other test data indicate that this is required.

C. STORAGE CONDITIONS

The storage area for the water containers is an air-conditioned room which is monitored continuously to document that the temperature is maintained at 70 $\pm$ 10°F and that the relative humidity is maintained at 50 $\pm$ 25 percent. The containers are stored in a closed metal cabinet to protect them from an accumulation of dust and the containers themselves are covered with plastic bags to prevent direct contact with foreign metal surfaces. The containers are visually examined on a weekly basis.

WATER CHARACTERIZATION

After six month intervals of storage at the conditions defined above ten containers are removed for evaluation. They consist of two containers of each selected material, one containing oxygen-free water and the other containing oxygen-saturated water.

A. PROCEDURES

After the initial six month storage period, the water containers were washed with deionized water and then placed in a sterile, laminar-flow bench for further handling to remove the stored water. The outlet of the container was rinsed repeatedly with filtered, deionized water to remove any contamiants and then briefly subjected to a torch flame to sterilize the exterior of the metal. After the subsequent six-month storage periods, the water containers were immersed in a 95% ethanol bath prior to placement in the sterile, laminar-flow bench; and then after removal from the bath and placement in the flow bench, the residual alcohol on the tank surface was removed by burning.

A. Procedures (cont.)

The outlet of the container was repeatedly exposed to a torch flame to assure a sterile condition. All the containers were opened in an identical manner. A sterile tubing cutter was used to sever the fill tube. For the six month, twelve month, and eighteen month storage periods, the water was expelled from the containers by inserting into the fill tube of the container a sterile stainless steel capillary tube through which filtered, gaseous nitrogen was passed while the container itself was inverted. The first several ml of water were used to flush the tube and were discarded. Subsequent samples of water were collected for measurement of pH, electrical conductivity, dissolved solids, particulate matter, flow behavior, and for characterization with regard to possible biological contamination. For the twenty four month storage period and subsequent six month storage periods special cannula were fabricated so that the water could be expelled from the container while it was maintained in its normal upright position. The cyclic insertion and withdrawal of the cannula for the various samples was avoided by controlling the nitrogen flow rate used to pressurize the container during the water expulsion.

The measurement of the pH was made using a standard pH meter with a calomel reference electrode and a glass indicator electrode. The electrical conductivity of the water was measured using a Balsbaugh Conductivity Meter, Model No. 900-.01T with a standard dip cell. The dissolved solids content of the water was determined by evaporating 200-300 ml samples of the water to dryness and weighing the residue. In addition, any particulate matter which collected on the 0.8μ filter of the flow behavior device was examined microscopically and sized. The flow behavior of the water was evaluated using a Silting Index Apparatus (see Appendix B for description) which permits filtration of the liquid through a known area (1.0 mm^2) at a constant pressure so that the flow decay due to the presence of particulate matter may be recorded as a function of time. The standard method of the test is described in ASTM F52-69. The data are reported as a silting index values; the greater the value, the greater the degree of contamination by small particulate matter.

B. DISCUSSION OF RESULTS

The data obtained from the tests are presented in Tables I to V. The data obtained during the initial loading of the containers as well as the data for the preceding six month storage intervals are included in the tabulation to facilitate comparison and identification of trends. The baseline data are labeled as initial and the data obtained after the storage periods are labeled as final.

The significant items to be noted from the data are as follows. First, the pH values of the waters change slightly during the storage periods. If the values are averaged one finds that for storage in 304 stainless steel containers the pH value increased 0.2 for the O_2-free water and 0.3 for the O_2-staturated water; for storage in A-286 containers the pH value did not change for O_2-free water but increased 0.20 for O_2-saturated water; for

TABLE I

DATA INDICATIVE OF THE STORABILITY OF WATER IN 304 STAINLESS STEEL CONTAINERS

Container Number	Exposure Period Months	Type of Water	Water Characterization										Particulate Matter Characteristics
			pH		Resistance megohm/cm		Silting Index		Total Solids Content, mg/l		Biological Activity		
			Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	
3	6	O_2-free	7.0	7.2	1.75	0.84	0.23	1.06	<1	6	-	X	3.2 x 1.6μ platelets
11	6	O_2-sat.	7.0	7.2	1.75	0.88	0.90	1.20	<1	<1	-	X	8 x 8μ platelets
5	12	O_2-free	7.0	7.1	1.80	0.83	0.13	0.68	<1	<1	-	-	1 x 4μ platelets
4	12	O_2-sat.	7.0	7.3	1.75	0.97	0.47	2.35	<1	<1	-	X	Mat of 3μ particles
6	18	O_2-free	7.0	7.3	1.90	1.02	0.29	0.99	<1	4.5	-	-	4x4μ Irregular Particles
1	18	O_2-sat.	6.6	7.2	1.75	0.81	0.22	0.90	<1	27	-	+	4x4μ Irregular Particles
2	24	O_2-free	7.0	6.9	1.80	0.99	0.35	0.44	<1	6	-	-	48x24μ Irregular Platelet
7	24	O_2-sat.	6.9	7.1	1.70	0.93	0.05	0.73	<1	2.5	-	+	32x16μ Irregular Platelets
10	30	O_2-free	7.0	7.2	2.00	1.15	0.09	2.03	<1	3.0	-	+	Many particles 8x8μ, dark orange coloration
8	30	O_2-sat.	7.0	7.3	1.75	0.95	0.90	1.73	<1	<1	-	+	~2μ Irregular particles
13	36	O_2-free	7.0	7.2	1.80	1.05	0.36	0.66	<1	2	-	-	Agglomerated 2-4μ particles
9	36	O_2-sat.	6.8	7.3	1.70	0.85	0.55	0.85	<1	7	-	+	~1μ irregular particles
14	42	O_2-free	7.0	7.1	1.85	0.95	0.30	1.60	<1	16	-	-	Many 1-2μ particles
12	42	O_2-sat.	6.8	6.8	1.80	0.73	0.60	0.75	<1	<1	-	+	Many 1-2μ particles
15	48	O_2-free	7.0	7.4	1.80	1.22	0.14	0.96	<1	11	-	-	Many 1-2μ particles
17	48	O_2-sat.	6.8	7.3	1.80	1.0	0.35	0.09	<1	<1	-	+	Mat of 1μ particles

TABLE II

DATA INDICATIVE OF THE STORABILITY OF WATER IN A-286 STAINLESS STEEL CONTAINERS

Container Number	Exposure Period months	Type of Water	Water Characterization: pH Initial	pH Final	Resistance megohm/cm Initial	Resistance megohm/cm Final	Silting Index Initial	Silting Index Final	Total Solids Content, mg/l Initial	Total Solids Content, mg/l Final	Biological Activity Initial	Biological Activity Final	Particulate Matter Characteristics
6	6	O_2-free	7.2	7.2	1.75	1.18	0	0.57	<1	<1	-	-	8 x 8μ platelets
13	6	O_2-sat.	7.0	7.2	1.80	0.97	0.54	1.11	<1	<1	-	X	3.6μ platelets
A-3	12	O_2-free	7.2	7.7	1.80	1.35	0	0.67	<1	<1	-	X	1 x 3μ platelets
19	12	O_2-sat.	6.9	6.7	1.80	1.08	0.46	0.65	<1	<1	-	-	3 x 3μ platelets
A-10F	18	O_2-free	7.2	6.4	1.75	1.04	0.00	0.06	<1	6	-	-	4x4μ Irregular Particles
A-2	18	O_2-sat.	7.0	6.8	1.80	1.17	0.73	0.24	<1	<1	-	+	8x4μ Irregular Particles
7	24	O_2-free	7.2	7.0	1.80	1.53	0.05	0.11	<1	4.5	-	+	7x7μ Irregular Platelets
4	24	O_2-sat.	6.7	7.1	1.80	1.26	0.43	0.16	<1	6.5	-	+	24x24μ Agglomerated Particle
A-20F	30	O_2-free	7.2	7.3	1.80	1.16	~0	0.45	<1	<1	-	-	2μ Irregular Particles
A-1	30	O_2-sat.	6.7	7.3	1.70	1.10	0.39	0.69	<1	<1	-	+	2μ Particles, very few observed
A-4	36	O_2-free	7.2	7.2	1.80	1.25	~0	0.35	<1	11.5	-	-	2μ Partilces
10	36	O_2-sat.	6.7	7.2	1.80	1.37	0.98	0.48	<1	2	-	+	2μ Particles and Agglomerates
A-5	42	O_2-free	7.0	7.1	1.95	1.05	0.04	0.86	<1	7	-	+	1 to 2μ particles and Agglomerates
14	42	O_2-sat.	6.8	7.0	1.70	0.88	0.42	0.14	<1	<1	-	+	Many 1 to 2μ particles
8	48	O_2-free	7.0	7.2	1.80	1.80	0.41	0.21	<1	<1	-	+	Many 1 to 2μ particles
15	48	O_2-sat.	6.7	6.8	1.80	1.45	1.09	0.17	<1	4.5	-	+	Mat of ~1μ particles

TABLE III

DATA INDICATIVE OF THE STORABILITY OF WATER IN 6Al-4V TITANIUM CONTAINERS

Container Number	Exposure Period Months	Type of Water	Water Characterization: pH Initial	pH Final	Resistance megohm/cm Initial	Resistance megohm/cm Final	Silting Index Initial	Silting Index Final	Total Solids Content, mg/l Initial	Total Solids Content, mg/l Final	Biological Activity Initial	Biological Activity Final	Particulate Matter Characteristics
2	6	O_2-free	7.0	7.4	1.90	0.84	0	0.69	<1	3.7	-	-	7.2 x 7.2μ + 5.4 x 5.4μ platelets
1	6	O_2-sat.	7.0	7.2	1.70	1.05	0.86	1.80	<1	1	-	-	3.6 x 3.6μ platelets
5	12	O_2-free	7.0	7.6	1.90	0.98	0.51	0.73	<1	<1	-	-	1 to 3μ particles, few 50μ agglomerates
3	12	O_2-sat.	7.0	7.5	1.65	0.82	0.10	1.17	<1	<1.	-	-	1 to 2μ particles agglomerated as a mat
7	18	O_2-free	7.0	6.6	1.95	0.75	0.00	0.00	<1	<1	-	-	2x2μ Irregular Particles
4	18	O_2-sat.	7.0	7.5	1.80	0.68	0.40	0.23	<1	11	-	-	4x4μ Agglomerates
8	24	O_2-free	7.0	6.5	1.80	0.75	0.49	0.94	<1	1	-	+	Mat of small particles
6	24	O_2-sat.	7.0	6.9	1.78	0.55	0.35	0.49	<1	<1	-	+	Agglomerated particles
11	30	O_2-free	7.0	6.9	1.85	1.05	0.05	0.46	<1	7.5	-	+	Irregular, Agglomerated Particles
9	30	O_2-sat.	7.0	7.1	1.79	1.10	0.38	0.62	<1	<1	-	+	Irregular, Agglomerated Particles
14	36	O_2-free	7.0	7.5	1.80	1.42	~0	0.39	<1	<1	-	-	Irregular, Agglomerated Particles
10	36	O_2-sat.	7.0	7.4	1.80	1.12	0.54	4.31	<1	<1	-	+	Irregular, Agglomerated Particles
15	42	O_2-free	7.0	7.0	1.90	0.96	0.37	0.65	<1	6	-	-	Agglomerated Particles
12	42	O_2-sat.	7.0	7.1	1.60	0.96	0.86	1.13	<1	8	-	+	Agglomerated Particles
17	48	O_2-free	7.0	7.2	1.80	1.30	0.32	1.10	<1	<1	-	-	Mat of small particles
13	48	O_2-sat.	7.0	7.4	1.70	1.13	0.28	0.86	<1	<1	-	+	Agglomerated particles

TABLE IV

DATA INDICATIVE OF THE STORABILITY OF WATER IN INCONEL 718 CONTAINERS

Container Number	Exposure Period Months	Type of Water	Water Characterization										Particulate Matter Characteristics
			pH		Resistance megohm/cm		Silting Index		Total Solids Content, mg/l		Biological Activity		
			Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	
1	6	O_2-free	7.0	7.6	1.70	0.58	0	0.42	<1	<1	-	-	1 to 2μ Particles agglomerated to 30μ
2	6	O_2-sat.	7.0	7.4	1.70	0.95	0.28	0.83	<1	4	-	-	1 to 2μ Particles agglomerated to 30μ
6	12	O_2-free	7.0	7.8	1.75	0.88	0	0.14	<1	<1	-	-	Mat of small particles, 18 agglomerates
4	12	O_2-sat.	7.0	7.3	1.80	0.98	0	0.59	<1	<1	-	X	1.3μ Particles, 50 x 90μ agglomerates
I-4	18	O_2-free	7.0	7.7	1.75	1.04	0.32	0.00	<1	5	-	-	2x2μ to 8x16μ Agglomerated irregular particles
I-1	18	O_2-sat.	7.0	7.5	1.75	0.88	0.56	0.35	<1	<1	-	-	2x2μ to 8x8μ Agglomerated irregular particles
I-2	24	O_2-free	7.0	7.3	1.80	1.00	0.15	0.11	<1	6	-	-	24x24μ Agglomerated particle
7	24	O_2-sat.	7.0	7.3	1.80	1.03	0.40	0.0	<1	3.5	-	-	48x112μ Agglomerated particle
I-5	30	O_2-free	7.0	7.2	1.80	1.09	~0	0.40	<1	5	-	-	Agglomerated 1-2μ particles
I-3	30	O_2-sat.	7.0	7.2	1.75	0.95	0.02	0.45	<1	11	-	-	Agglomerated 1-4μ particles
I-8	36	O_2-free	7.0	7.2	1.90	1.00	~0	~0	<1	5.5	-	-	Agglomerated 1-2μ particles
9	36	O_2-sat.	7.0	7.1	1.70	0.98	0.41	0.10	<1	5.5	-	-	Agglomerated 1-2μ particles
I-12	42	O_2-free	7.0	7.0	1.70	0.98	0.32	0.24	<1	4.0	-	-	Agglomerated 1-8μ particles
I-10	42	O_2-sat.	7.0	7.0	1.70	0.98	0.15	0.65	<1	2.0	-	-	Agglomerated 1-4μ particles
16	48	O_2-free	7.0	7.3	1.70	1.10	0	~0	<1	4.5	-	-	Agglomerated 1-4μ particles
I-13	48	O_2-sat.	7.0	7.4	1.70	0.95	0.33	0.04	<1	<1	-	-	Agglomerated 1-8μ particles

TABLE V

DATA INDICATIVE OF THE STORABILITY OF WATER IN 17-4 PH STAINLESS STEEL CONTAINERS

Container Number	Exposure Period Months	Type of Water	Water Characterization: pH Initial	pH Final	Resistance megohm/cm Initial	Resistance megohm/cm Final	Silting Index Initial	Silting Index Final	Total Solids Content, mg/l Initial	Total Solids Content, mg/l Final	Biological Activity Initial	Biological Activity Final	Particulate Matter Characteristics
P-11	6	O_2-free	7.0	7.4	1.80	0.82	0	0.66	<1	<1	-	-	1 to 4μ particles agglomerated to 200μ
P-1	6	O_2-sat.	7.0	7.1	1.75	0.98	0	0.42	<1	<1	-	-	1 to 4μ particles agglomerated to 300μ
P-12	12	O_2-free	7.0	7.9	2.00	1.02	0.27	0.49	<1	<1	-	X	Mat of indeterminate sized particles
P-2	12	O_2-sat.	6.7	7.6	1.80	0.70	0.03	0.62	<1	<1	-	X	3 to 14μ platelets
P-13	18	O_2-free	7.0	7.4	1.95	0.86	0.40	0.05	<1	2.5	-	-	Agglomerates Range from 2x8μ to 2x24μ
P-3	18	O_2-sat.	6.9	7.1	1.70	1.02	0.19	0.09	<1	5.5	-	+	Agglomerates Range from 8x8μ to 8x24μ
P-14	24	O_2-free	7.0	7.0	1.80	1.07	0.40	0.0	<1	1.5	-	-	4x10μ Irregular Platelet
P-4	24	O_2-sat.	6.8	7.2	1.80	1.12	0.14	0.0	<1	4.5	-	+	3.5 x 3.5μ agglomerated particles
P-15	30	O_2-free	7.0	6.8	1.80	0.78	0.25	0.17	<1	<1	-	-	Agglomerates of 1-2μ particles
P-5	30	O_2-sat.	6.8	6.9	1.80	0.80	0.20	0.39	<1	10	-	+	Agglomerates of 1-2μ particles
P-16	36	O_2-free	7.0	7.3	1.75	0.92	0.18	0.45	<1	<1	-	-	Agglomerates of 1-4μ particles
P-6	36	O_2-sat.	6.9	7.3	1.80	1.01	0.12	0.19	<1	<1	-	+	1-4μ particles
P-17	42	O_2-free	7.0	6.9	1.75	1.00	0.49	1.21	<1	<1	-	-	1-4μ particle and agglomerates
P-7	42	O_2-sat.	6.8	7.0	1.75	0.85	0.67	0.54	<1	<1	-	+	1-4μ particle and agglomerates
P-18	48	O_2-free	7.0	7.8	1.70	1.22	0.42	0.62	<1	<1	-	-	Mat of small particles
P-8	48	O_2-sat.	7.0	7.6	1.75	1.10	0.25	0.01	<1	<1	-	+	1-8μ particles and agglomerates

B. Discussion of Results (cont.)

storage in 6Al-4V titanium containers the pH value increased 0.1 for O_2-free water and 0.3 for O_2-saturated water; for storage in Inconel 718 containers the pH value increased 0.4 for O_2-free water and 0.3 for O_2-saturated water; and for storage in 17-4 PH containers the pH value increased 0.3 for O_2-free water and 0.4 for O_2-saturated water. Second, the resistance values of the waters have stabilized after the initial decrease in values due to an increase in concentration of ionic species, and the final resistance values still correspond to concentration levels which contain less than one part per million of dissolved metallic ions. Third, the Silting Index values indicate the presence of a slight amount of particulate matter in the size range of less than 5 microns in the water but the concentration levels are insignificant with regard to the quantities of particulate matter that are required to cause clogging in flow passages. In addition, the concentration level of particles in the less than 5 micron size is not increasing with increased periods of water storage. Fourth, There is apparently some increase in the total solids content of the waters as the storage period increases but the values are sufficiently low so that the quality of the water is not impaired. The level of detection in the method used corresponds to a mg/1ℓ. And fifth, the pH values, the resistance values, and the Silting Index values are not significantly different between the various storage periods.

The particulate matter that was collecting on the filters appeared to be that which adhered to the container walls during the cleaning, pickling, passivation, and flushing procedures prior to filling. In summation, the waters were all suitable for use in transpiration-coolant devices after periods of storage of the water for forty-eight months.

BIOLOGICAL CHARACTERIZATION

A. PROCEDURES

200 ml samples of the water taken from the storage containers were filtered through pre-sterilized filter pads which were transferred directly to sterilized Petri dishes containing suitable nutrients for direct colony counting after a suitable culturing period. The procedures are described in Standard Methods of Analysis of Water and Waste Water, American Public Health Association, 13th Edition (1971) and Biological Analysis of Water and Waste Water, AM 302, Millipore Corporation, Bedford, Mass. (1973). In addition, any biological organisms present were washed from the filter surfaces with a sterile buffer solution and placed directly in sterile nutrient solutions for culturing so that adequate samples are available for identifying the genus and the specific species of micro-organisms that might be present in the stored water. Based on the lag-period prior to growth of micro-organisms which have been observed earlier in the program (Reference 1), the tubes containing the nutrient solutions were incubated for periods up to one month.

B. DISCUSSION OF RESULTS

The results obtained by culturing samples from the water containers are presented in Tables I-V under the heading "Biological Activity". The lack of any indications of micro-organisms being present is denoted by a minus sign; if growth was indicated in either the culture tubes or on the filter pad, but not on both an "X" is used; and if growth was found in both the culture tube and on the filter pad a plus sign is used as an indication of the positive result.

After a month of incubation of the samples from the six month storage tests there was no indication of micro-organism growth on the presterilized filter pads. Slight growth was observed in the culture tubes containing washings from the 304 stainless steel containers and one of the A-286 containers. The number of micro-organisms present was extremely small as indicated by the negative results with the filter pads and the slight amount of growth in the culture tubes. There was no evidence that any biological growth occurred during the six-month storage period. The micro-organisms found were identified as an Aeromonas species.

After a month of incubation of the samples from the twelve month storage period, one of the culture tubes containing the washings from an Inconel 718 container exhibited growth, but the filter pad was negative. The micro-organisms present were identified as most likely being Pseudomonas aeruginosa. The filter pad used for the culturing the contents of both of the 17-4 pH containers, one of the 304 stainless steel containers, and one of the A-286 containers exhibited growth, but the corresponding culture tubes were all negative. The micro-organisms were identified as Pseudomonas species. Again there was no evidence that biological growth occurred during the twelve month storage period in any of the containers.

After a month of incubation of the samples from the eighteen month storage period, there was indication of micro-organism growth on the filter pads and in culture tubes containing samples from one of the 304 stainless steel containers, one of the A-286 containers, and one of the 17-4PH containers. The micro-organisms were identified as a Pseudomonas species. The number of organisms present was extremely small and there was no evidence that growth occurred during the eighteen month storage period.

After a month of incubation of the samples from the twenty-four month storage period, there were indications of micro-organism growth on the filter pads and in the culture tubes containing samples from one of the 304 stainless steel containers, both of the A-286 containers, both of the 6Al-4V titanium containers, and one of the 17-4PH containers. The micro-organisms were all of the same species and were identified as most likely being Pseudomonas teslosteroni based on the classifications used in the 8th edition of Bergey's

B. Discussion of Results (cont.)

"Manual of Determinative Bacteriology". In this edition, much of the former genus Aeromonas is now included in the genus Pseudomonas and therefore the micro-organisms observed in the two samples of the six month storage period may be the same species as those identified in samples from the twenty-four month storage period.

The number of organisms present in the samples from the twenty-four month storage period was extremely low, less than 100 per ml of water; and there was no evidence that growth occurred during the storage period. The fact that all the organisms are of the same species indicates that they were probably introduced during the fill procedure and the improved water removal procedure reduces the possibility of contamination during the sampling procedure.

After a month of incubation of the samples from the thirty month storage period, there were indications of micro-organisms present on the filter pads and in culture tubes containing samples from both of the 304 stainless steel containers, one of the A-286 containers, one of the 17-4 PH containers, and both of the 6Al-4V titanium containers. The number of micro-organisms present was small and there was no evidence that any growth occurred during the thirty-month storage period. The micro-organisms present were identified as a Pseudomonas species.

After a month of incubation of the samples from the thirty-six month storage period, there were indications of micro-organisms present on the filter pads and in the culture tubes containing samples from one of the 304 stainless steel containers, one of the A-286 containers, one of the 6Al-4V titanium containers and one of the 17-4 PH containers. The number of micro-organisms present was extremely small, less than 2 per ml, and they were identified as a Pseudomonas species.

After a month of incubation of the samples from the forty-two month storage period, there were indications of micro-organisms present on the filter pads and in culture tubes containing samples from one of the 304 stainless steel containers, both of the A-286 containers, one of the 6Al-4V titanium containers, and one of the 17-4 PH containers. The number of micro-organisms present was small and there was no evidence that any growth occurred during the forty-two month storage period. The micro-organisms present were identified as a Pseudomonas species.

After a month of incubation of the samples from the forty-eight month storage period, there were indications of micro-organisms present on the filter pads and in the culture tubes containing samples from one of the 304 stainless steel containers, both of the A-286 containers, one of the 6Al-4V titanium containers, and one of the 17-4 PH containers. The number of micro-organisms present was small and they were identified as Pseudomonas species.

B. Discussion of Results (cont.)

From the slight growth which was observed in the culture media, it can be inferred that the micro-organisms are in a weakened condition.

In summation, the biological testing has shown that there is no evidence for any biological growth during the storage periods even though a slight number of micro-organisms were introduced during the filling procedures.

CONTAINER EXAMINATION

A. PROCEDURES

After removal of the water from the containers by draining, they were vacuum dried for a day to insure sectioning in a dry condition. The containers were then photographed to document their general appearance. Sectioning of the containers to expose the internal surfaces was done by sawing without coolant to prevent contamination. Subsequent handling of the container halves was carefully performed to avoid touching the interior surfaces. The internal surfaces were then photographed to document their general appearance.

Further general examination at magnifications from 5 to 10X were conducted on all interior surfaces to define conditions found in the aforementioned visual examination and to reveal additional examination at magnifications to 40X. All welds were examined at 40X magnification. Representative discrepancies were photographed at magnifications adequate for defect definition. Those defects requiring further definition were examined metallographically to establish their cause and extent. Sections taken either through or immediately adjacent to the affected areas were mounted, polished, and examined. Photomicrographs were taken to document the condition. The contaminants or corrosion products capable of being sampled were identical in appearance to those chemically analyzed in the examination of the six and twelve month exposure tanks. Hence, additional analyses were not conducted. All interior surfaces were dye-penetrant inspected to determine whether any defects were undetected during the visual examinations. No additional indications of defects were found.

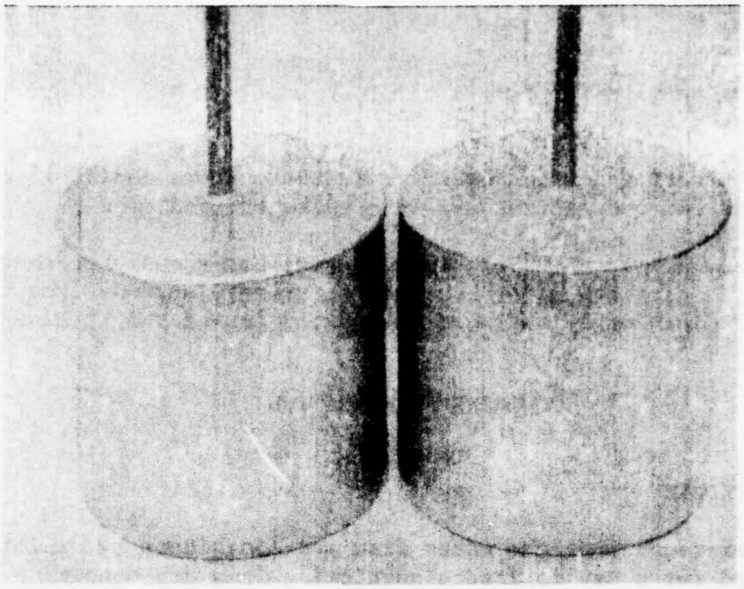
B. DISCUSSION OF RESULTS

The results of the container examinations are discussed under three headings: (1) General Visual Examination, (2) Metallographic and Chemical Analyses, and (3) Implications of the results of the Examinations.

1. General Visual Examination

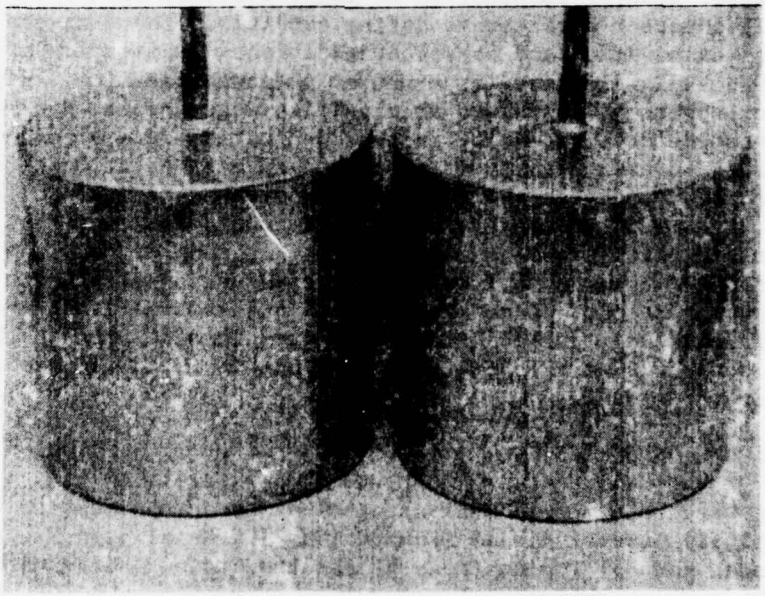
The external appearance of the containers is documented photographically in Figures 1 through 5. The internal appearance of the con-

42 MONTHS



NO. 12 NO. 14

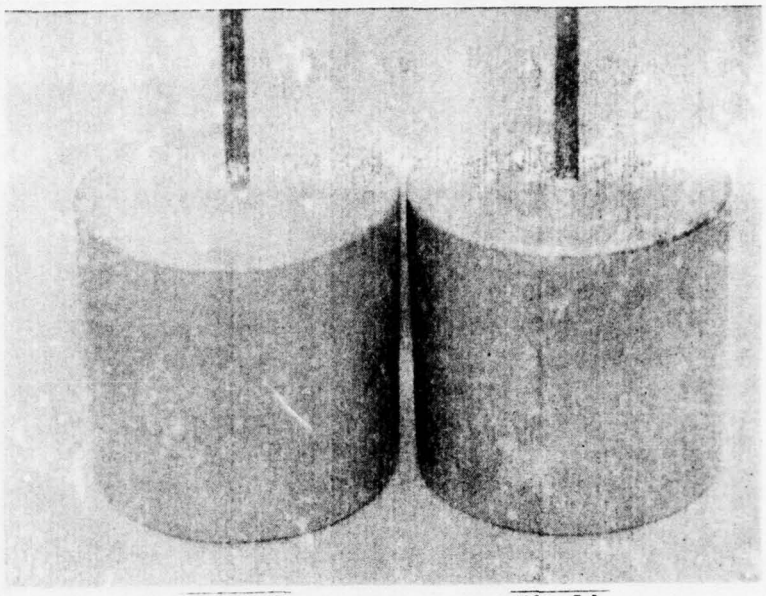
48 MONTHS



NO. 15 NO. 17

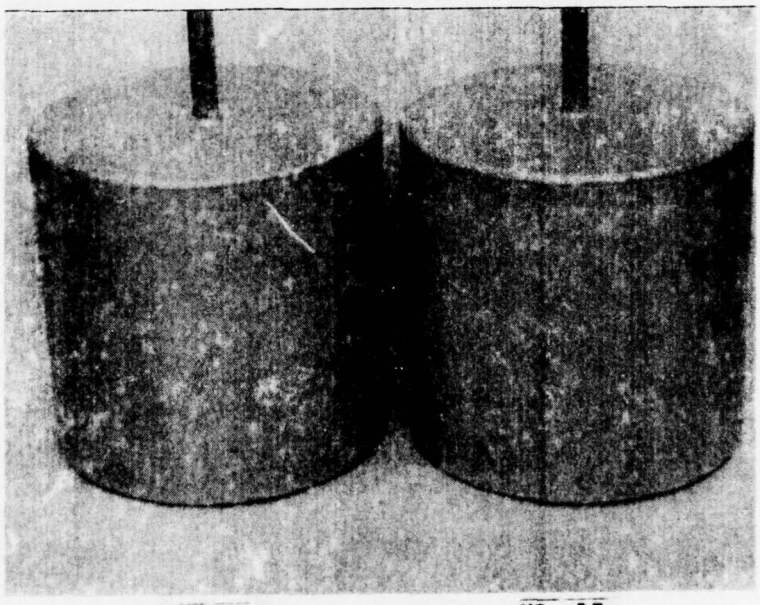
Figure 1. 304 Stainless Steel Containers, Magnification 1/3X

42 MONTHS



NO. A-5 NO. 14

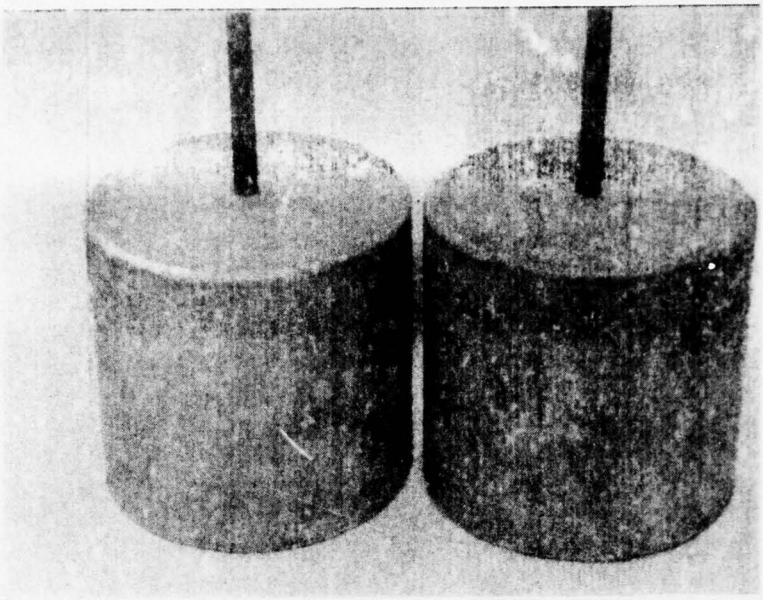
48 MONTHS



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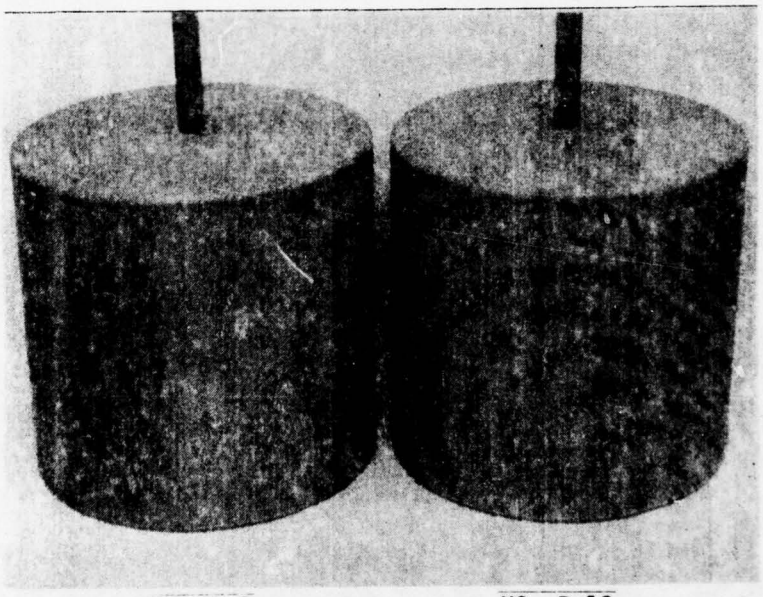
Figure 2. A-286 Containers, Magnification 1/3X

42 MONTHS



NO. P-7 NO. P-17

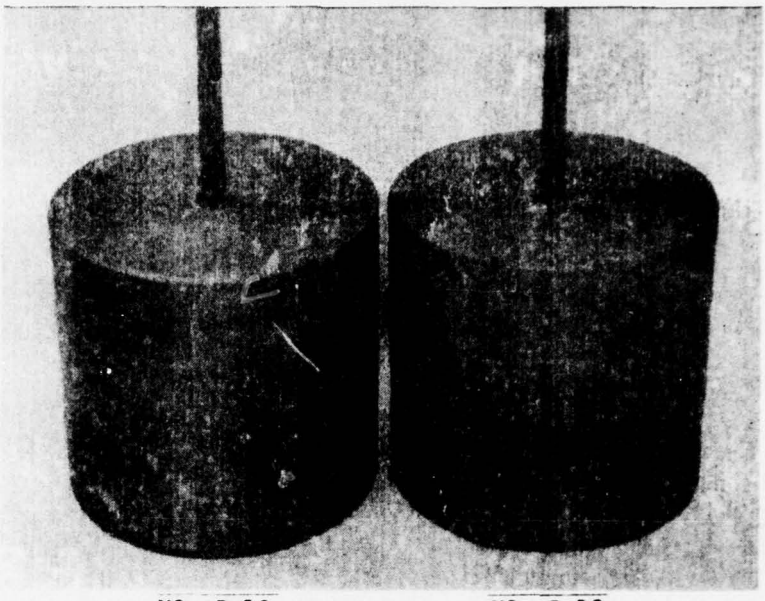
48 MONTHS



NO. P-8 NO. P-18

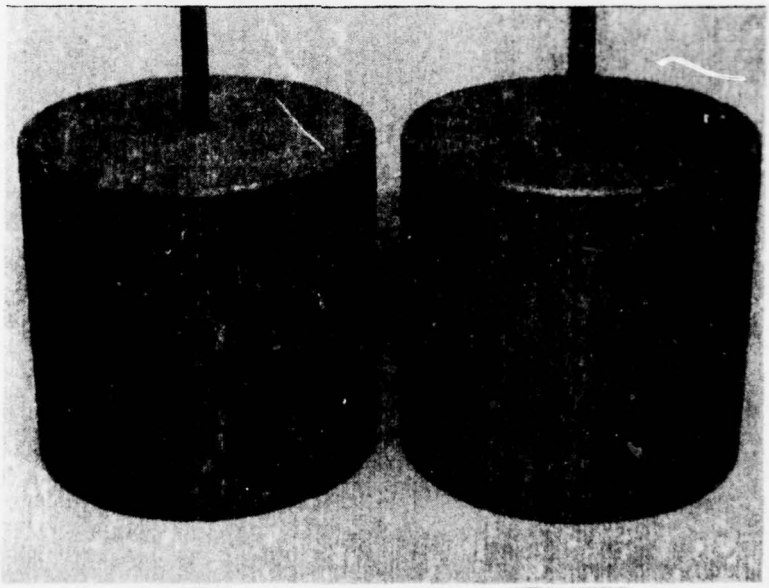
Figure 3. 17-4PH H-1025 Stainless Steel Containers, Magnification 1/3X

42 MONTHS



NO. I-10 NO. I-12

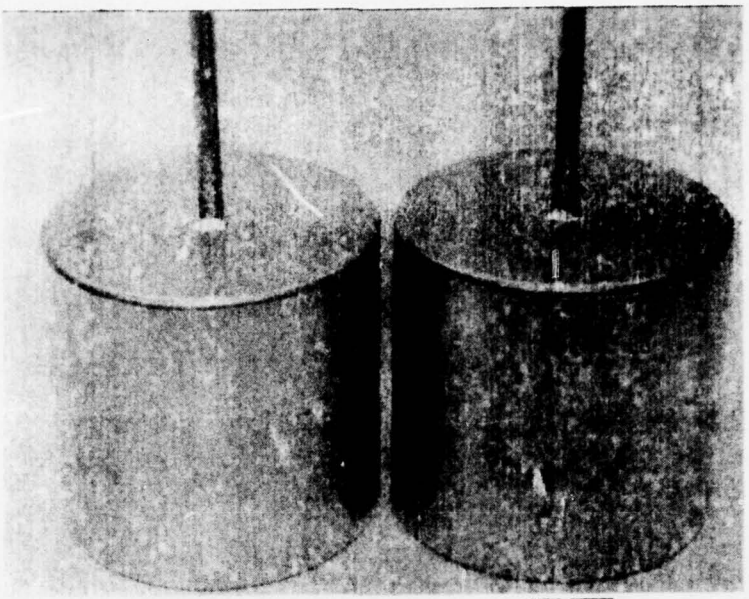
48 MONTHS



NO. 16 NO. I-13

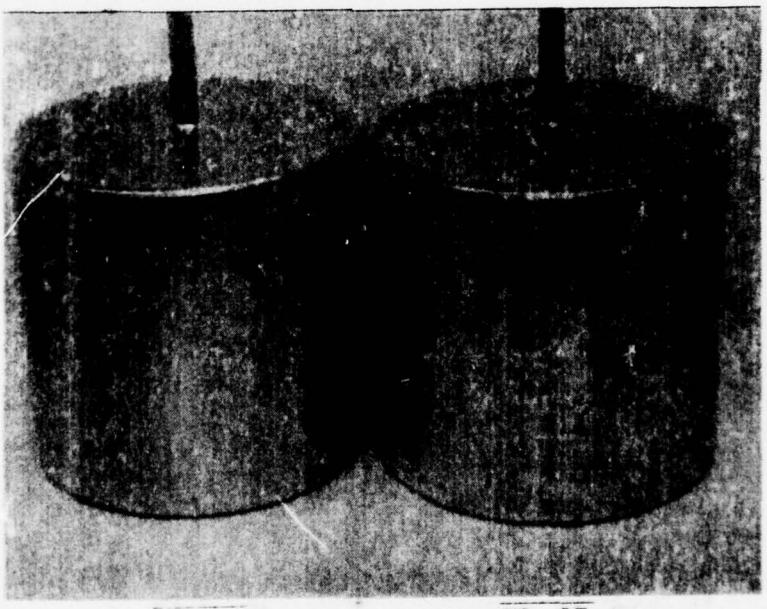
Figure 4. Inconel 718 Containers, Magnification 1/3X

42 MONTHS



NO. 12 NO. 15

48 MONTHS



NO. 13 NO. 17

Figure 5. 6Al-4V Titanium Containers, Magnification 1/3X

tainers is documented photographically in Figures 6 through 15. Examination of these surfaces without visual aids showed full penetration for the full length of all weldments. Other conditions resulting from fabrication and cleaning procedures were: (1) spots of organic contaminant, dull finish on interiors of 304 stainless steel containers and small oxide particles in the 304 stainless steel welds, (2) cracks in A-286 welds and etching of A-286 containers during pickling; (3) weld cracks, roughened surface from pickling, a tightly adherent smut, and a non 17-4 PH weld repair deposit on the 17-4 PH stainless steel containers; (4) a weld crack and a tightly adherent smut in the Inconel 718 containers; and (5) isolated areas of titanium oxide and localized staining from contamination present during heat treatment in the 6Al-4V titanium containers.

No significant differences were apparent between the six month, twelve month, eighteen month, twenty-four month, thirty month, thirty-six month, forty-two month and forty-eight month exposure containers, or between those holding the oxygen-free and oxygen-saturated water.

2. Metallographic Examination

A summary of the analyses performed on the container is presented in Table VI. The results of the macro- and micro examinations are shown in Figures 16 through 22. The results of the analyses are discussed below for each container material.

a. 304 Stainless Steel

The interior of the container exhibited a dull appearance relative to the exterior surfaces of the containers. This condition is attributable to inadequate hydrogen gas coverage in the container during the annealing process after welding. The aforementioned oxide particles in the welds and the spots of organic contaminants are shown in Figure 16.

b. A-286

Two weld shrinkage cracks were found in the containers. These cracks are similar to those found in the containers which were opened previously. Slight localized etching caused by pickling was found on all the containers interiors. A localized area of oxide remained in one tank after pickling. A typical crack and the unpickled oxide are shown in Figure 17. No evidence of corrosion resulting from the storage of water could be found.

c. 17-4 PH (H 1025) Stainless Steel

All of the containers exhibited the same conditions found in some of the previously examined containers; i.e., weld cracks

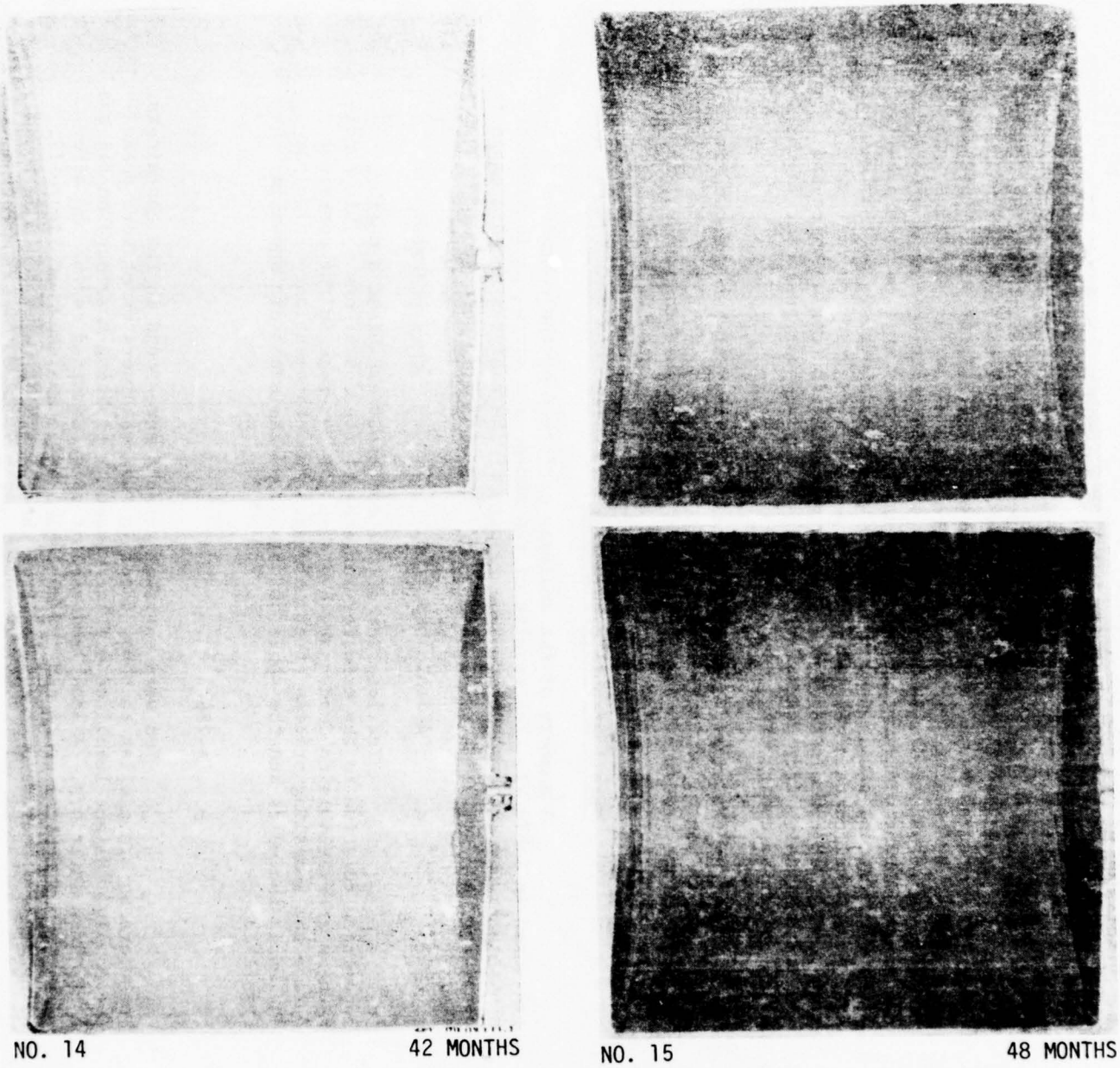
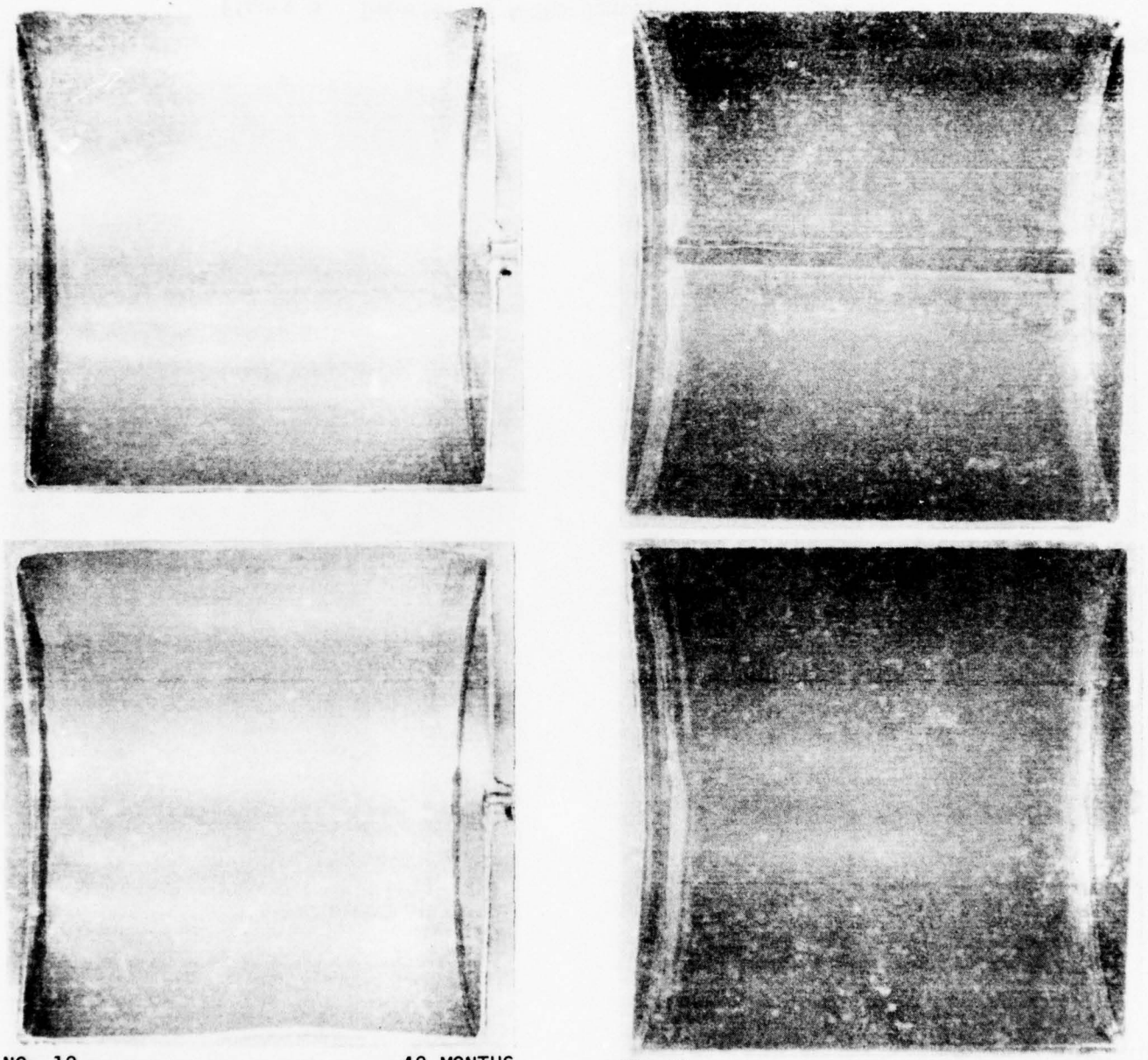


Figure 6. Interior of 304 Stainless Steel Containers after Exposure in Oxygen Free Water, Magnification 3/5X



NO. 12 42 MONTHS NO. 17 48 MONTHS

Figure 7. Interior of 304 Stainless Steel Containers after Exposure in Oxygen Saturated Water, Magnification 3/5X

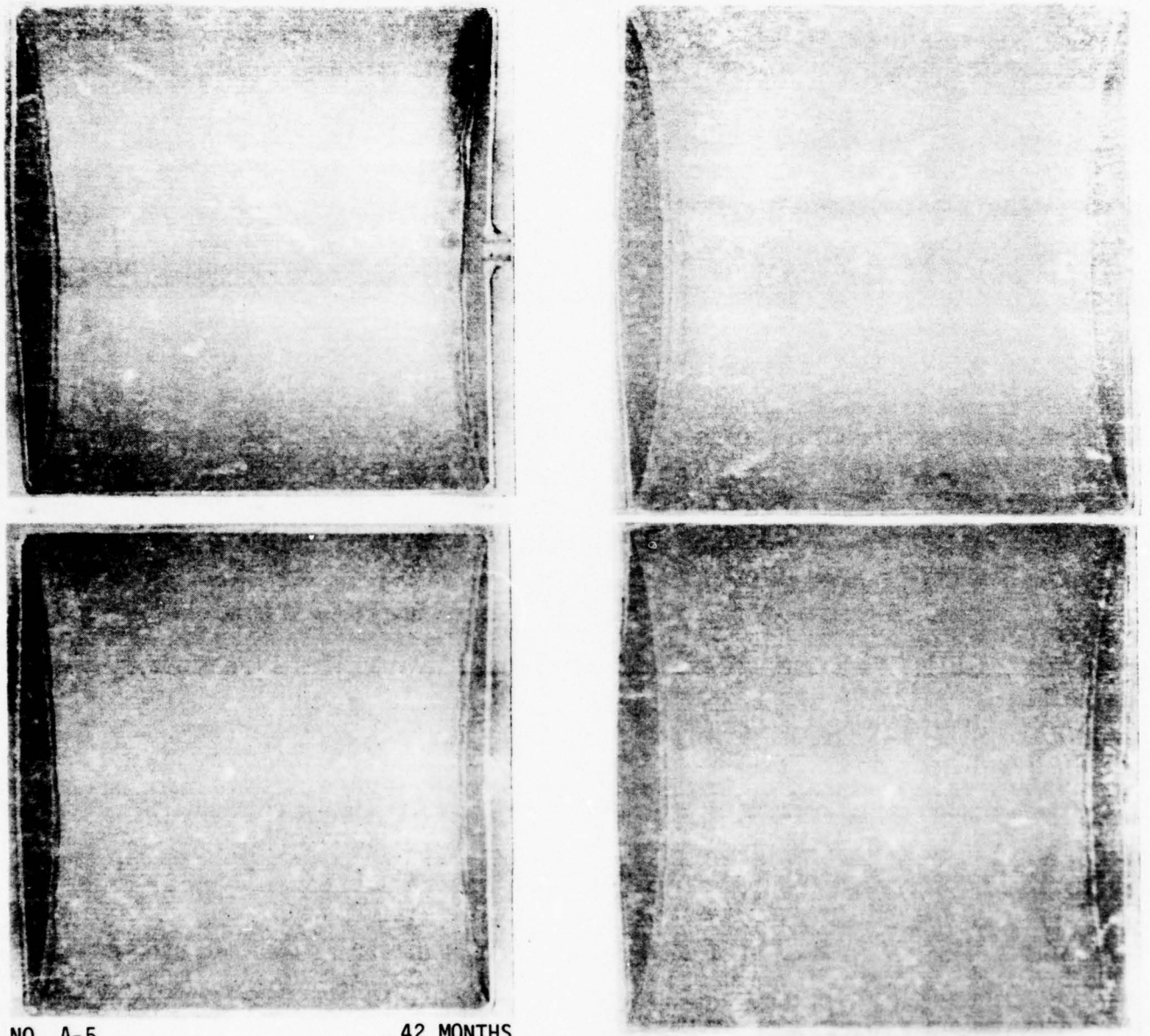
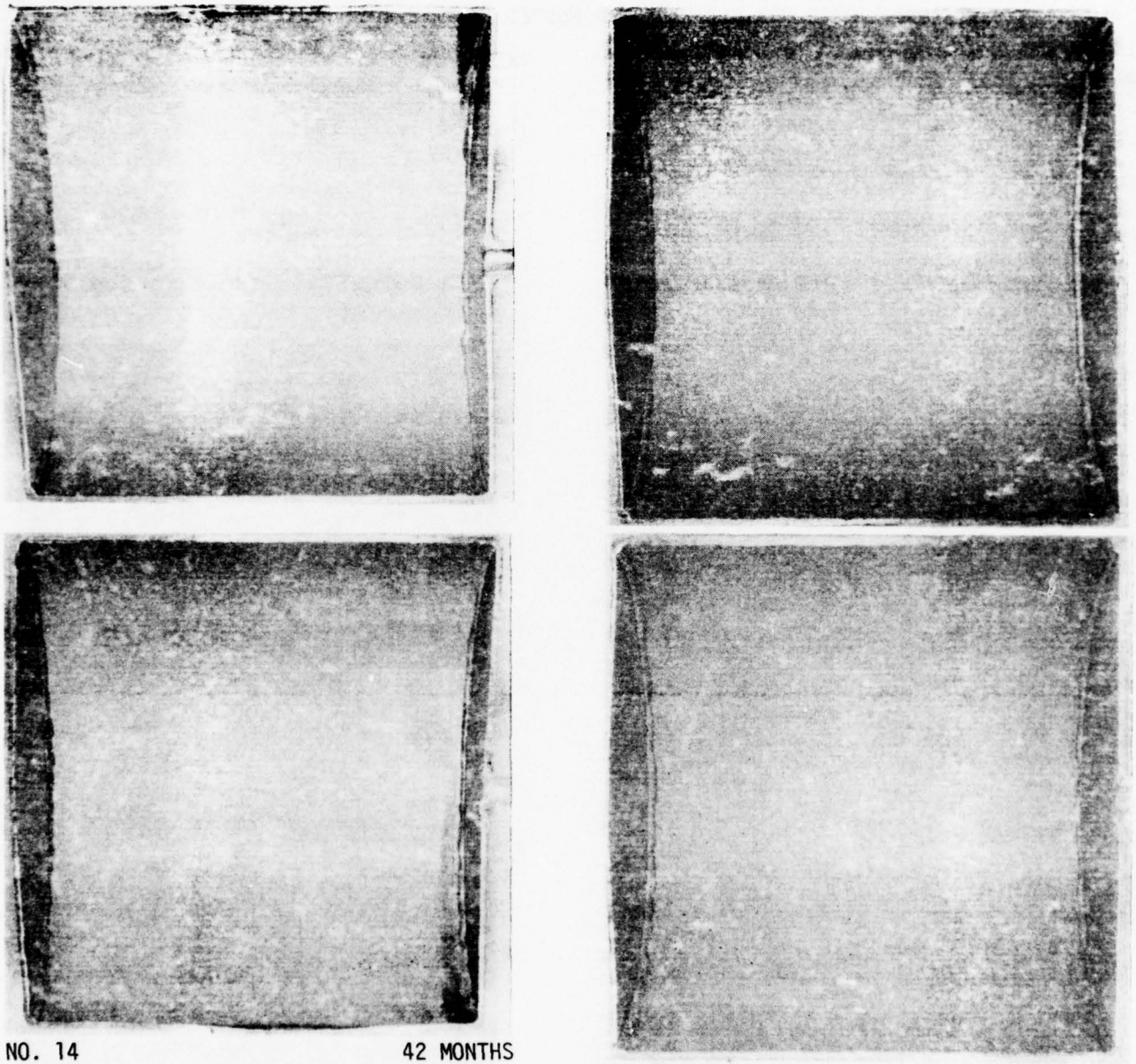


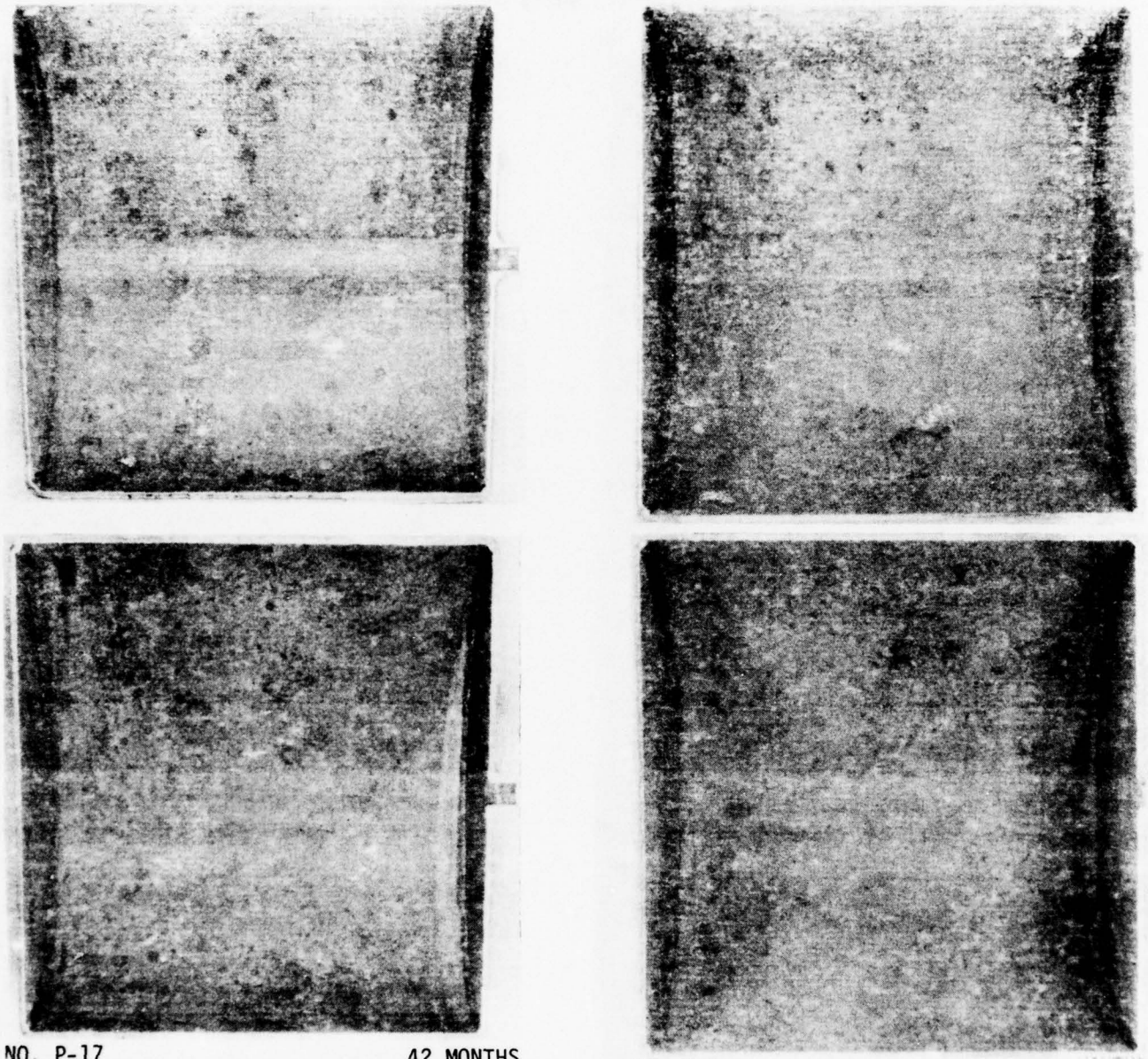
Figure 8. Interior of A-286 Containers after Exposure in Oxygen Free Water, Magnification 3/4X



NO. 14 42 MONTHS

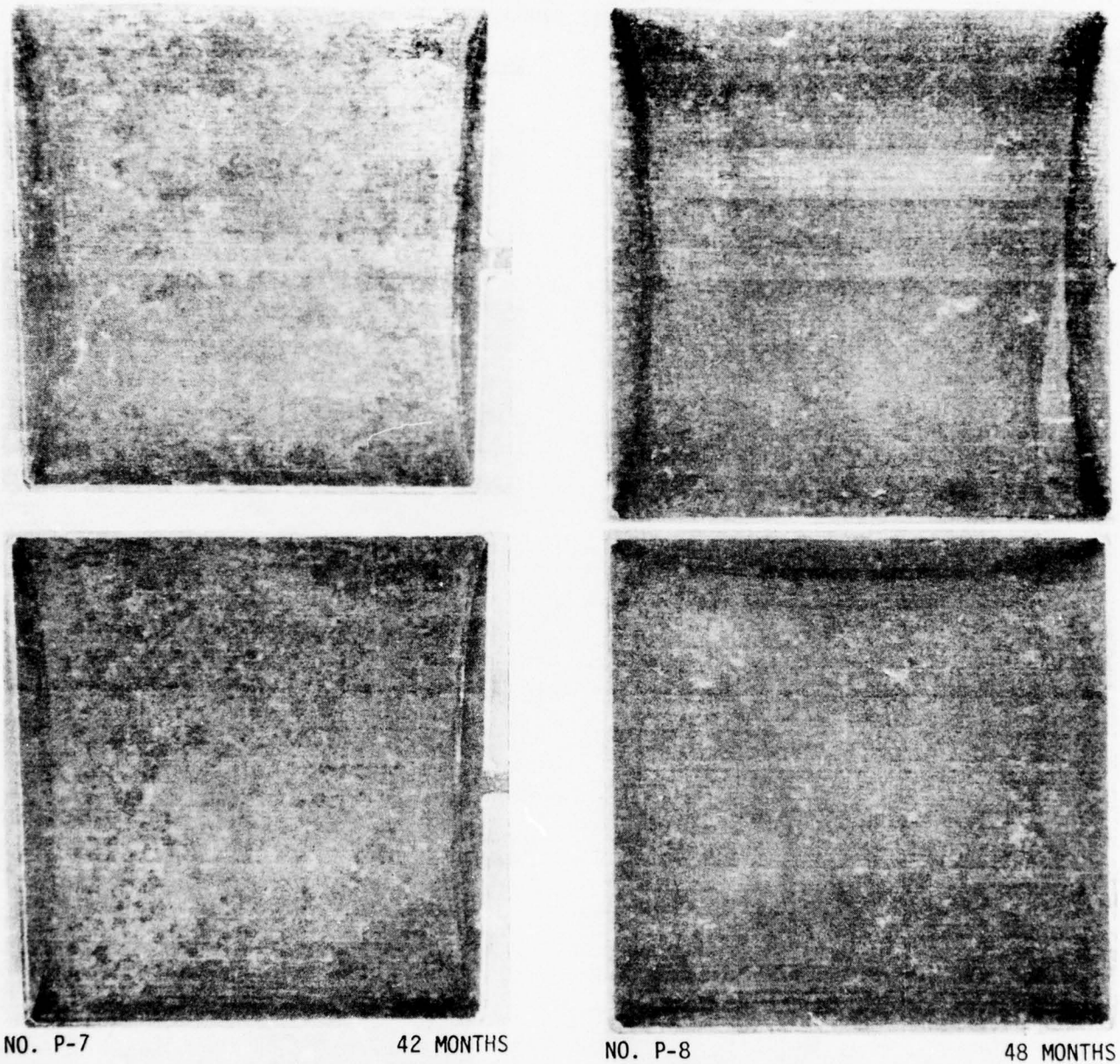
NO. 15 48 MONTHS

Figure 9. Interior of A-286 Containers after Exposure in Oxygen Saturated Water, Magnification 3/5X



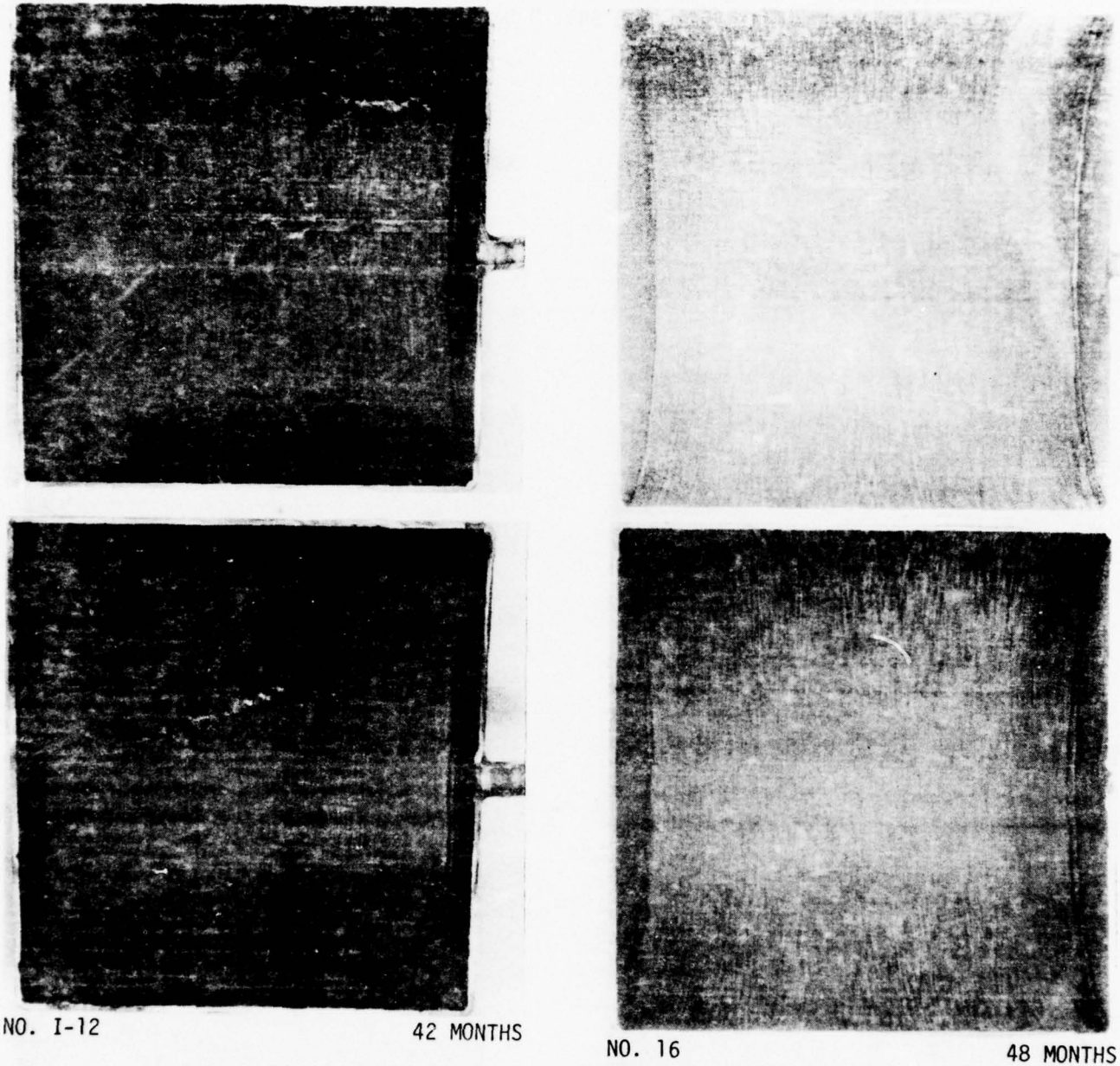
NO. P-17 42 MONTHS NO. P-18 48 MONTHS

Figure 10. Interior of 17-4PH H-1025 Stainless Steel Containers after Storage in Oxygen Free Water, Magnification 3/5X



NO. P-7 42 MONTHS NO. P-8 48 MONTHS

Figure 11. Interior of 17-4PH H-1025 Stainless Steel Containers after Exposure in Oxygen Saturated Water, Magnification 3/5X



NO. I-12 42 MONTHS

NO. 16 48 MONTHS

Figure 12. Interior of Inconel 718 Containers after Exposure in Oxygen Saturated Water, Magnification 3/5X

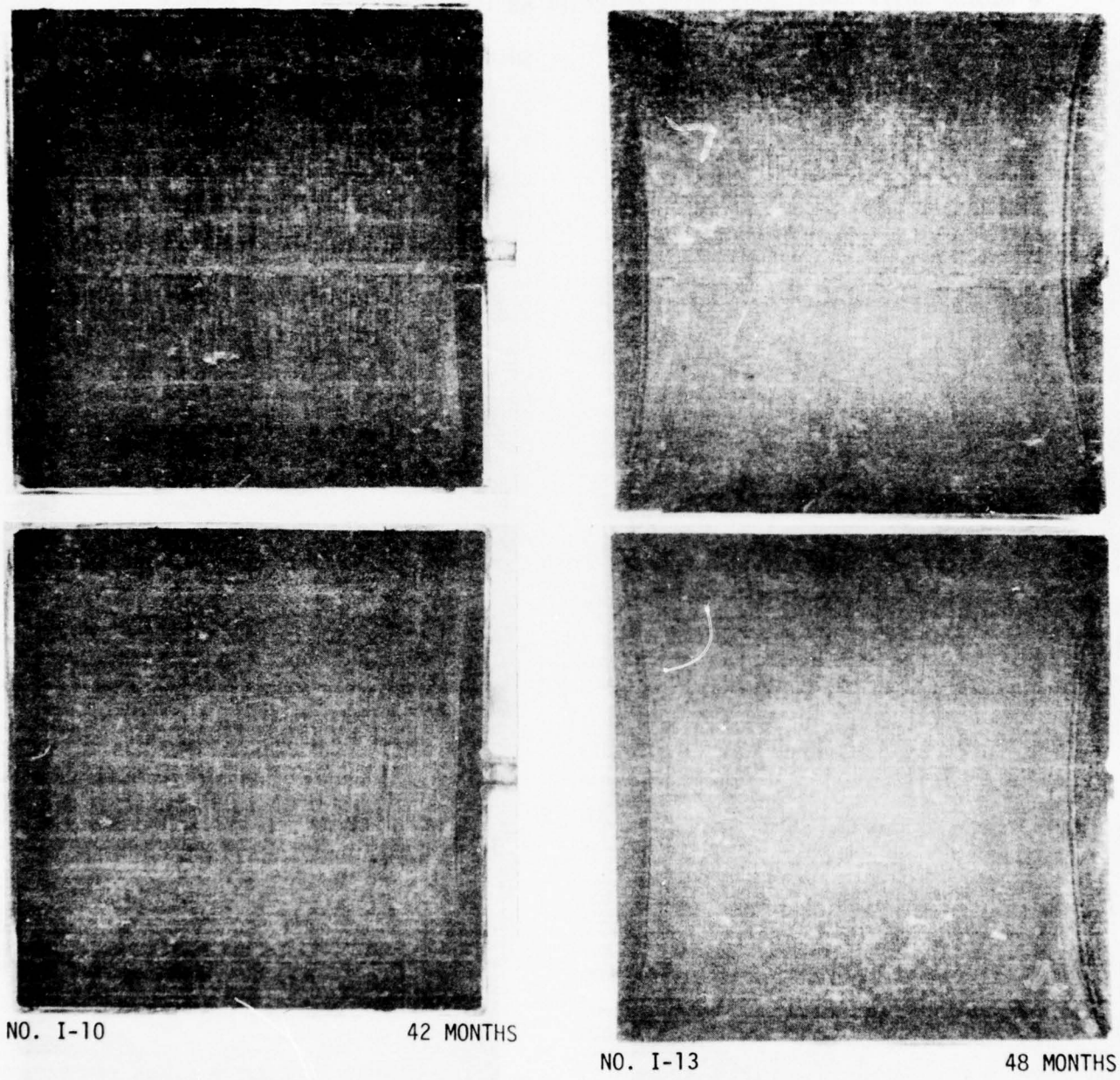


Figure 13. Interior of Inconel 718 Containers after Exposure in Oxygen Saturated Water, Magnification 3/5X

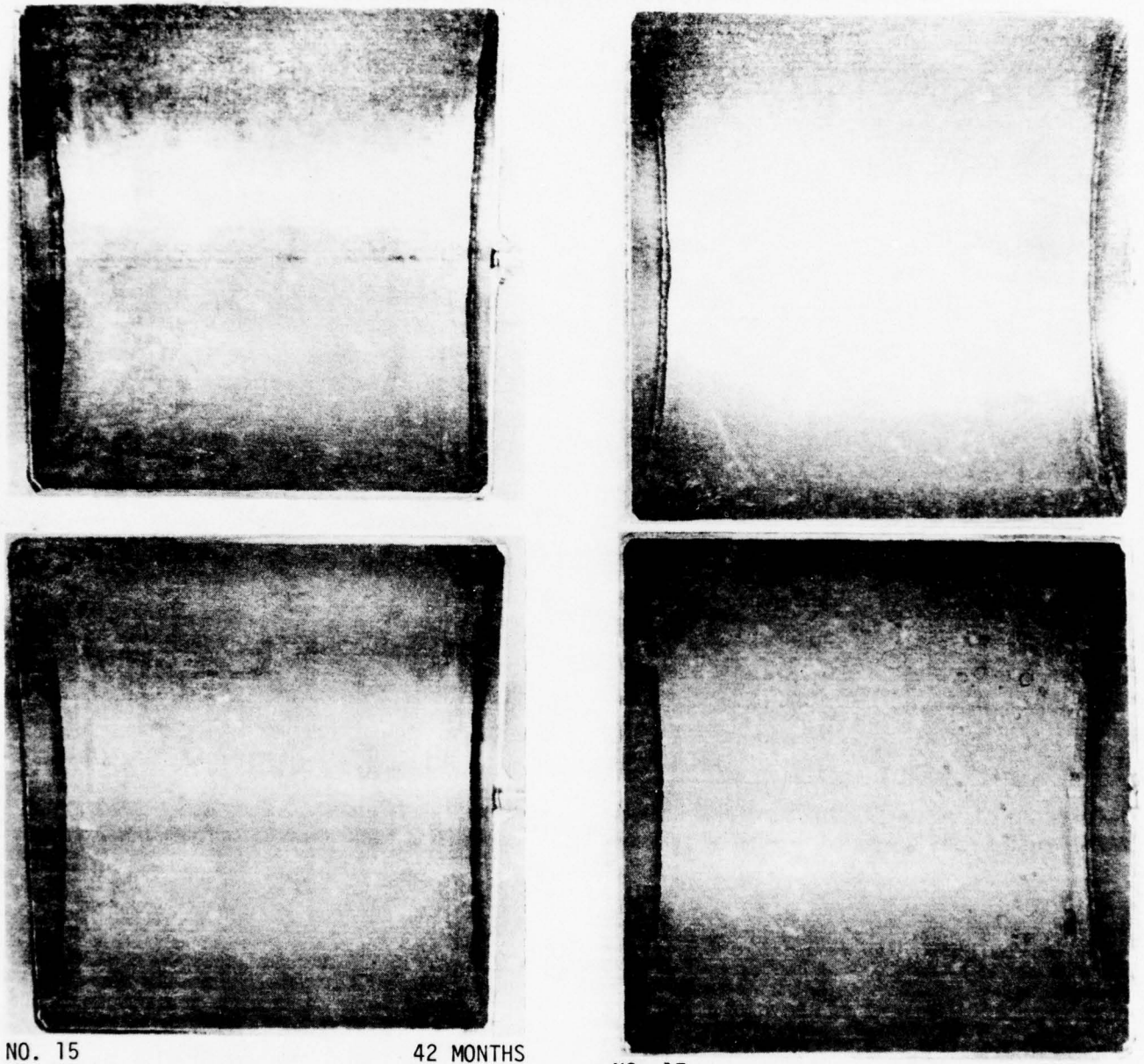


Figure 14. Interior of 6Al-4V Titanium Alloy Containers after Exposure to Oxygen Free Water, Magnification 3/5X

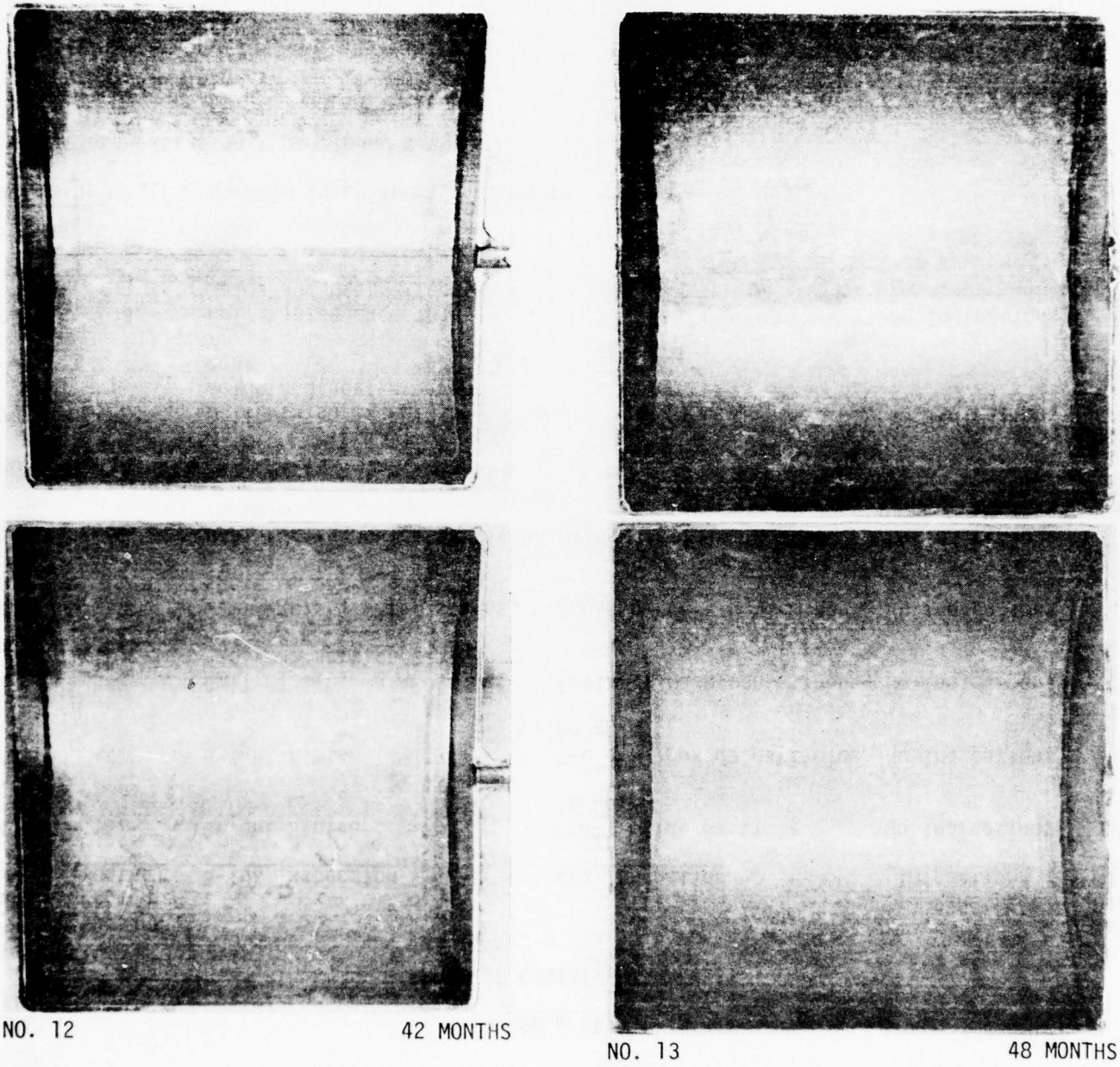


Figure 15. Interior of 6Al-4V Titanium Alloy Containers after Exposure in Oxygen Saturated Water, Magnification 3/5X

TABLE VI

SUMMARY OF CONTAINER ANALYSIS

Material	Tank Ident.	Exposure Period (Months)	5-10X Inspection	40X Inspection	Dye Penetrant Inspection*	Metallographic Documentation Macro	Micro
304 SS	12	42	Bright Finish	Small oxide particle in weld	No Indications	X	
304 SS	12W	42	Bright Finish	Two small oxide particles in weld	No Indications		
304 SS	14	42	Dull Finish, water stains, spots of dark contaminant	Spots of dark contaminant	No Indications	X	
304 SS	14W	42	Dull Finish, water stains, spots of dark contaminant	Spots of dark contaminant	No Indications		
304 SS	15	48	Dull Finish, oxide particle in weld	Oxide particle in weld	No Indications		
304 SS	15W	48	Dull Finish	-----	No Indications		
304 SS	17	48	Dull Finish except in welds and heat affected zone	-----	No Indications		
304 SS	17W	48	Dull Finish except in welds and heat affected zone	-----	No Indications		

W indicates the container half with weld in cylindrical portion.

*Dye penetrant indications excluding those found visually.

TABLE VI (cont.)

Material	Tank Ident.	Exposure Period (Months)	5-10X Inspection	40X Inspection	Dye Penetrant Inspection*	Metallographic Documentation	
						Macro	Micro
A-286	A-5	42	Dull Finish, slightly etched	--	No Indications		
A-286	A-5W	42	Dull Finish, slightly etched, unpickled oxide at top	One weld crack	No Indications		
A-286	14	42	Dull Finish, slightly etched, unpickled oxide at top	--	No Indications	X	X
A-286	14W	42	Dull Finish, slightly etched, unpickled oxide at top	One weld crack	No indications		
A-286	8	48	Dull Finish, slightly etched	--	No Indications		
A-286	8W	48	Dull Finish, slightly etched	--	No Indications		
A-286	15	48	Dull Finish, slightly etched	--	No Indications		
A-286	15W	48	Dull Finish, slightly etched	--	No indications		

TABLE VI (cont.)

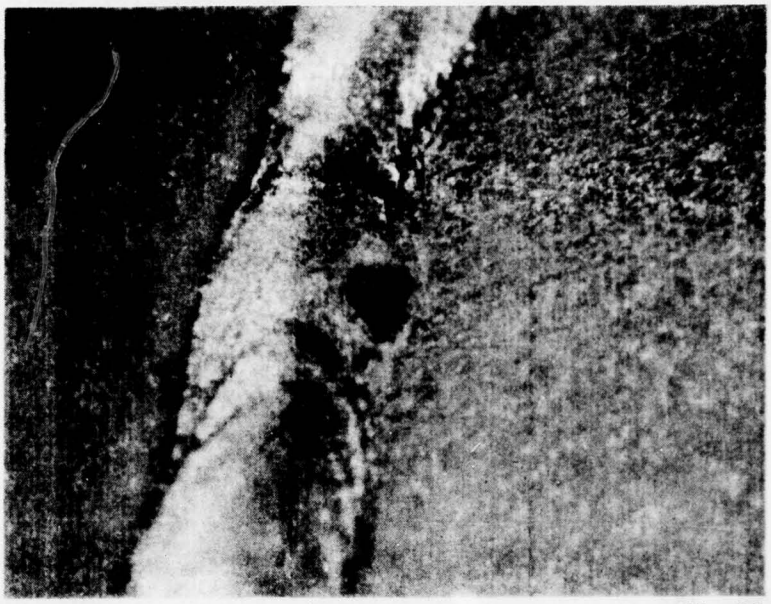
Material	Tank Ident.	Exposure Period (Months)	5-10X Inspection	40X Inspection	Dye Penetrant Inspection*	Metallographic Documentation Macro	Micro
Titanium 6Al-4V	12	42	Isolated oxides, stained areas from contamination prior to heat treatment	--	No Indications	X	
Titanium 6Al-4V	12W	42	Isolated oxides, stained areas from contamination prior to heat treatment	--	No Indications		
Titanium 6Al-4V	15	42	Isolated oxides, stained areas from contamination prior to heat treatment (including fingerprints)	--	No Indications	X	X
Titanium 6Al-4V	15W	42	Isolated oxides, stained areas from contamination prior to heat treatment	--	No Indications		
Titanium 6Al-4V	17	48	Isolated heavy oxides in weld, stained areas from contamination prior to heat treatment	--	No Indications	X	
Titanium 6Al-4V	17W	48	Isolated oxides in weld, stained areas from contamination prior to heat treatment	--	No Indications		
Titanium 6Al-4V	13	48	Lightly oxidized weld, lightly stained areas from stained areas from contamination prior to heat treatment	--	No Indications		
Titanium 6Al-4V	13W	48	Lightly oxidized weld, lightly stained areas from contamination prior to heat treatment	--	No Indications		

TABLE VI (cont.)

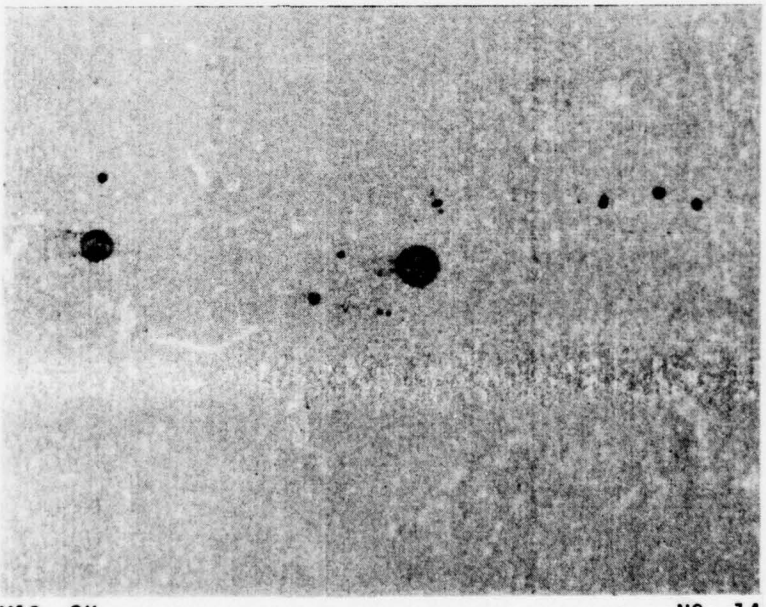
Material	Tank Ident.	Exposure Period (Months)	5-10X Inspection	40X Inspection	Dye Penetrant Inspection*	Metallographic Documentation	
						Macro	Micro
Inconel 718	I-10	42	Smut, localized attack from pickling at edge of weld	--	No Indications		
Inconel 718	I-10W	42	Smut, localized attack from pickling at edge of weld	--	No Indications		
Inconel 718	I-12	42	Smut, localized attack from pickling at edge of weld	--	No Indications		X
Inconel 718	I-12W	42	Smut, localized attack from pickling at edge of weld	--	No Indications		
Inconel 718	16	48	Smut, weld crack, localized attack from pickling at edge of weld	Weld Crack	No Indications		
Inconel 718	16W	48	Smut, localized attack from pickling at edge of weld	--	No Indications		
Inconel 718	I-13	48	Smut, localized attack from pickling at edge of weld	--	No Indications		
Inconel 718	I-13W	48	Smut, localized attack from pickling at edge of weld	--	No Indications		

TABLE VI (cont.)

Material	Tank Ident.	Exposure Period (Months)	5-10X Inspection	40X Inspection	Dye Penetrant Inspection*	Metallographic Documentation	
						Macro	Micro
17-4 PH SS	P-7	42	Smut, rough surface from scale removal during pickling	Weld Crack	No Indications		X
17-4 PH SS	P-7W	42	Smut, rough surface from scale removal. Non 17-4 PH weld deposit.	Weld crack	No Indications	X	X
17-4 PH SS	P-17	42	Smut, rough surface from scale removal	2 Weld Cracks	No Indications	X	X
17-4 PH SS	P-17W	42	Smut, rough surface from scale removal	--	No Indications		
17-4 PH SS	P-18	48	Smut, rough surface from scale removal	--	No Indications		
17-4 PH SS	P-18W	48	Smut, rough surface from scale removal, weld crack	Weld Crack	No Indications		
17-4 SS	P-8		Smut, rough surface from scale removal	--	No Indications		
17-4 SS	P-8W		Smut, rough surface from scale removal	--	No Indications		



MAG. 14X NO. 12

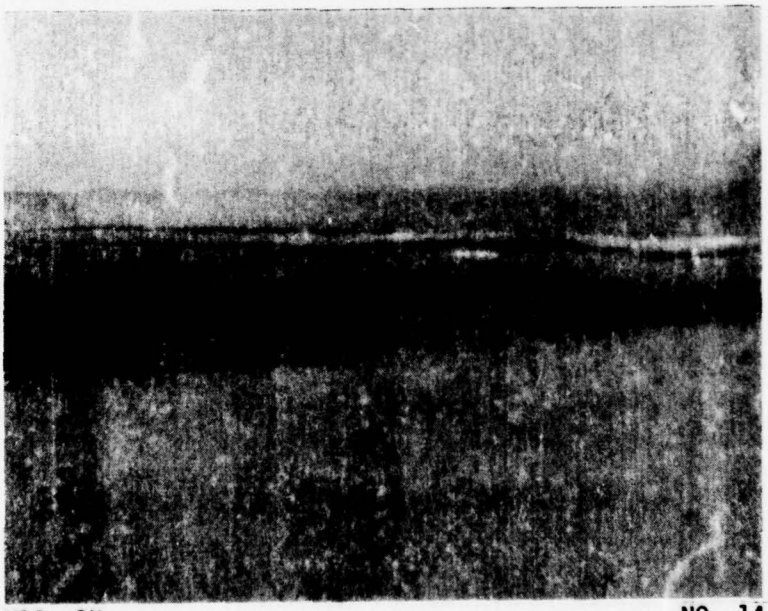


MAG. 8X NO. 14

Figure 16. High Temperature Oxide Particle in 304 Stainless Steel Weldment (TOP). Contaminant in 304 Stainless Steel Container (BOTTOM)

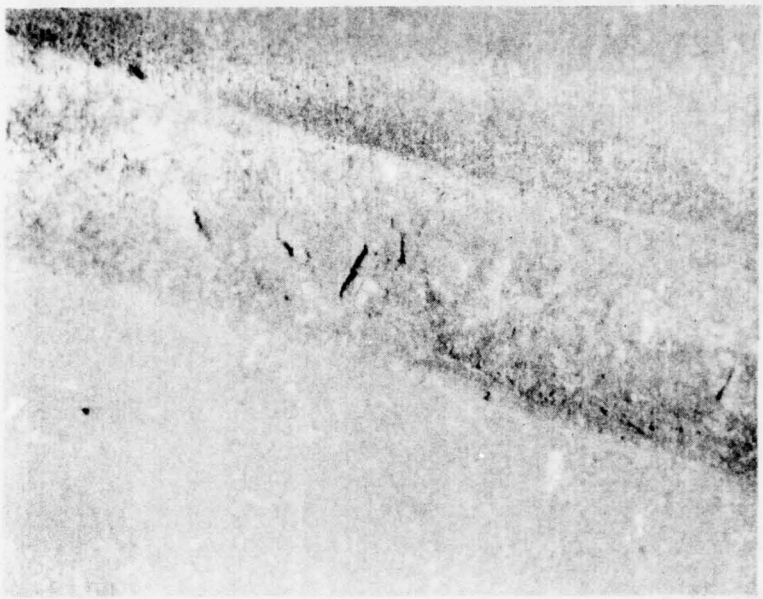


MAG. 14X NO. 14



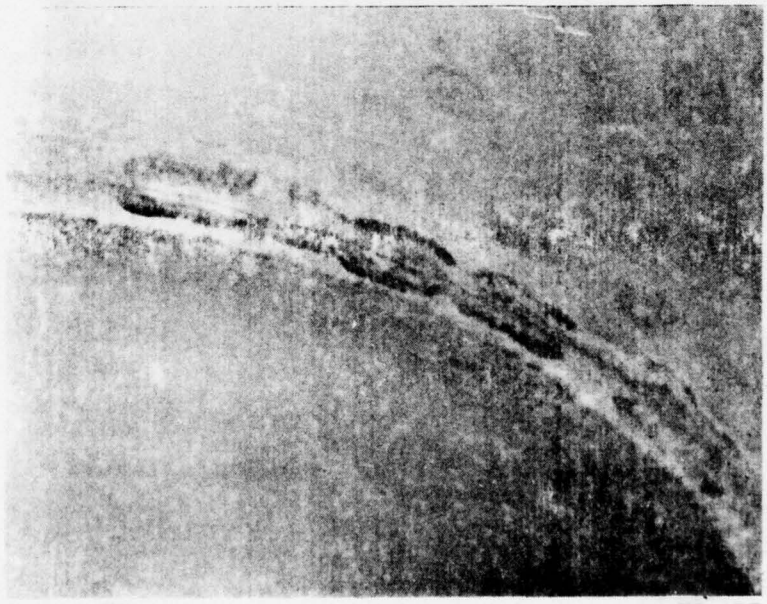
MAG. 3X NO. 14

Figure 17. Weld Crack in A-286 Container (TOP). Oxide Remaining After Pickling of A-286 Container



MAG. 1X NO. P-17

Figure 18. Crack in 17-4PH Stainless Steel Weldment



MAG. 1.5X NO. 17

Figure 19. Isolated Areas of Heavy Oxide on Titanium Weldment



MAG. 3X NO. 12



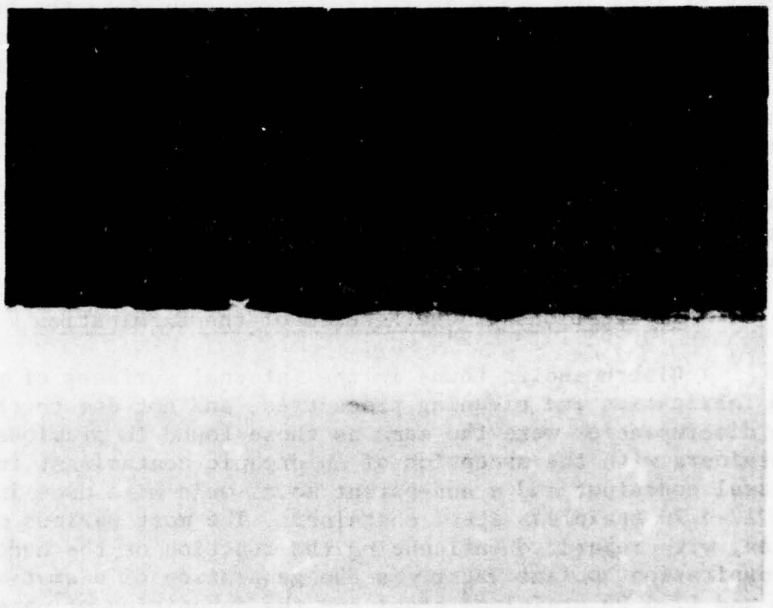
MAG. 1-3/4X NO. 15

Figure 20. Stained Areas on Titanium from Contaminants (Including Fingerprints) Present Prior to Heat Treatment



MAG. 250X

Figure 21. Localized Pickling Attack at Edge of Inconel 718 Weldment



MAG. 250X

Figure 22. Section Through Areas of Pickling Attack in Titanium Shown in Figure 20.

localized roughening of the surface due to scale removal during pickling and tightly adherent 17-4 PH stainless steel metallic particles. A non-parent metal weld wire was used in a weld repair of one container. No deleterious effects were found in the area of this discrepancy. A representative weld crack is shown in Figure 18. These cracks occurred during welding and, as the other anomalies, are not the result of the storage of water.

d. Inconel 718

As with the previously examined containers, examination of the interior surfaces at moderate magnification revealed a dark, porous area at the edge of all closure weldments. This condition is caused by selective attack during pickling. The entrapped oxides present because of inadequate inert-gas coverage during welding are removed by the pickling process as shown in the Figure 21 photomicrograph. All of the tanks displayed a tightly adherent smut as a result of the pickling procedure. No anomalies due to water storage were found.

e. 6Al-4V Titanium

All of the containers except one exhibited small isolated areas of titanium oxide in the interiors caused by the heat treatment (aging) and the areas were not removed during the pickling procedure (Figure 19). Examination of mottled areas at low magnifications revealed that these areas are primarily stains (see Figure 20). Portions of the stained surfaces contained crater-like areas outlined by knife-like corrosion. Metallographic examination of sections taken through these areas revealed no detectable depth to the corrosion effects associated with the stained areas as shown in the Figure 22 photomicrograph. This condition is attributed to inadequate cleaning of the container interiors prior to heat treatment. No effects attributable to the storage of water were found.

3. Implications of the Results of the Examination

Discrepancies found in the internal surfaces of the containers were due to fabrication and cleaning procedures, and not due to the stored water. The discrepancies were the same as those found in previously examined storage containers with the exception of an organic contaminant in a 304 stainless steel container and a non-parent metal weld wire used in a weld repair of a 17-4 PH stainless steel container. The most serious of these discrepancies, with regard to influencing the function of the containers for storing transpiration coolant water, is the generation of a smut on the Inconel 718 and 17-4 PH stainless steel and the deposition of parent metal granules on one of 17-4 PH stainless steel during pickling. However, neither of these irregularities have produced particles of sufficient size and

B. Discussion of Results (cont.)

quantity to degrade the functional quality of the water. The primary cause of these conditions is attributed to poor inert gas coverage on the container interiors during heat treatment and the resulting excessive oxidation. The presence of small amounts of oxide on the titanium alloy cannot be readily explained, becuase the containers were aged at 1000°F in air and the interiors were pickled for longer times than the exteriors from which all oxides were removed.

The presence of contaminants in the titanium alloy containers prior to heat treatment and the weld cracks found in the A-286 and 17-4PH stainless steel containers are attributable to inadequate process control on the part of the container supplier. In spite of the presence of the contaminants, the functional quality of this water was not impaired.

All discrepancies found on the internal surfaces of the containers were due to fabrication and cleaning procedures and not due to the presence of water in the containers.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The following conclusions are drawn from the forty-eight month storage evaluation program.

1. All five container materials, 304 and 17-4PH stainless steels, A-286, Inconel 718, and 6Al-4V titanium, are suitable for the storage of water for transpiration cooling purposes.

2. Both the oxygen-free and oxygen-saturated waters demonstrated favorable storability characteristics with regard to pH changes, ionic contamination as evidenced by electrical resistance measurements, and particulate formation as evidenced by Silting Index values and microscopic inspection of filters.

3. Based on the biological tests, there is no evidence that biological growth has occurred in the containers during storage periods up to forty-eight months.

4. Discrepancies in the containers such as cracks, smut and etched surfaces were produced during fabrication, cleaning, and passivation of the containers. Yet with adequate flushing prior to storage, the stored water is suitable for use as a transpiration coolant.

B. RECOMMENDATIONS

1. Long-term storage tests should be conducted with the selected waters in containers in which dissimilar metals are present to demonstrate which combinations of metallic materials can be used as suitable components in a transpiration coolant system.

2. The ease of fabrication, cleaning, and passivation of containers should be given proper priority in the selection and design of container materials for transpiration coolant devices.

3. Long-term storage tests should be conducted with the selected waters in containers which contain non-metallic materials which may be of use in the fabrication of transpiration coolant systems.

APPENDIX A

FABRICATION AND TREATMENT PROCEDURES FOR WATER CONTAINERS

FABRICATION AND TREATMENT PROCEDURES FOR WATER CONTAINERS

The fabrication procedures, the heat treatment cycles, the cleaning procedures, and the passivation procedures for the water containers prior to filling are presented below.

A. CONTAINER FABRICATION

Drawings of the long term storage container and its associated weld tooling are shown in Figures A-1, A-2, and A-3. The sequence of operations in the container fabrication is as follows:

1. Cylindrical Tube, -1

a. Fabricate -1 cylinder tube by rolling the sheared sheet stock into the desired diameter.

b. Weld the longitudinal joint using the automatic GTA* welding process. Full weld penetration must be obtained using gas backup for the welds.

c. Dye penetrant inspect welds then trim tubes to required length. No cracks allowed.

d. Machine tube ends for weld joint preparation.

e. Clean tubes and store in appropriate container while awaiting for next assembly.

2. Fill Tube, -2

a. Section fill tubes to 6 $\pm$ 0.12 in. lengths.

b. Deburr fill tube ends and inspect.

c. Clean fill tubes and then package individually and store for next assembly.

3. Tank Head, -3

a. Blank tank heads to the desired diameter by punching or sawing and then machining.

b. Machine weld joint preparation at outer edge as required.

c. Drill the fill tube hole to mate with the fill tube.

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*Gas Tungsten Arc

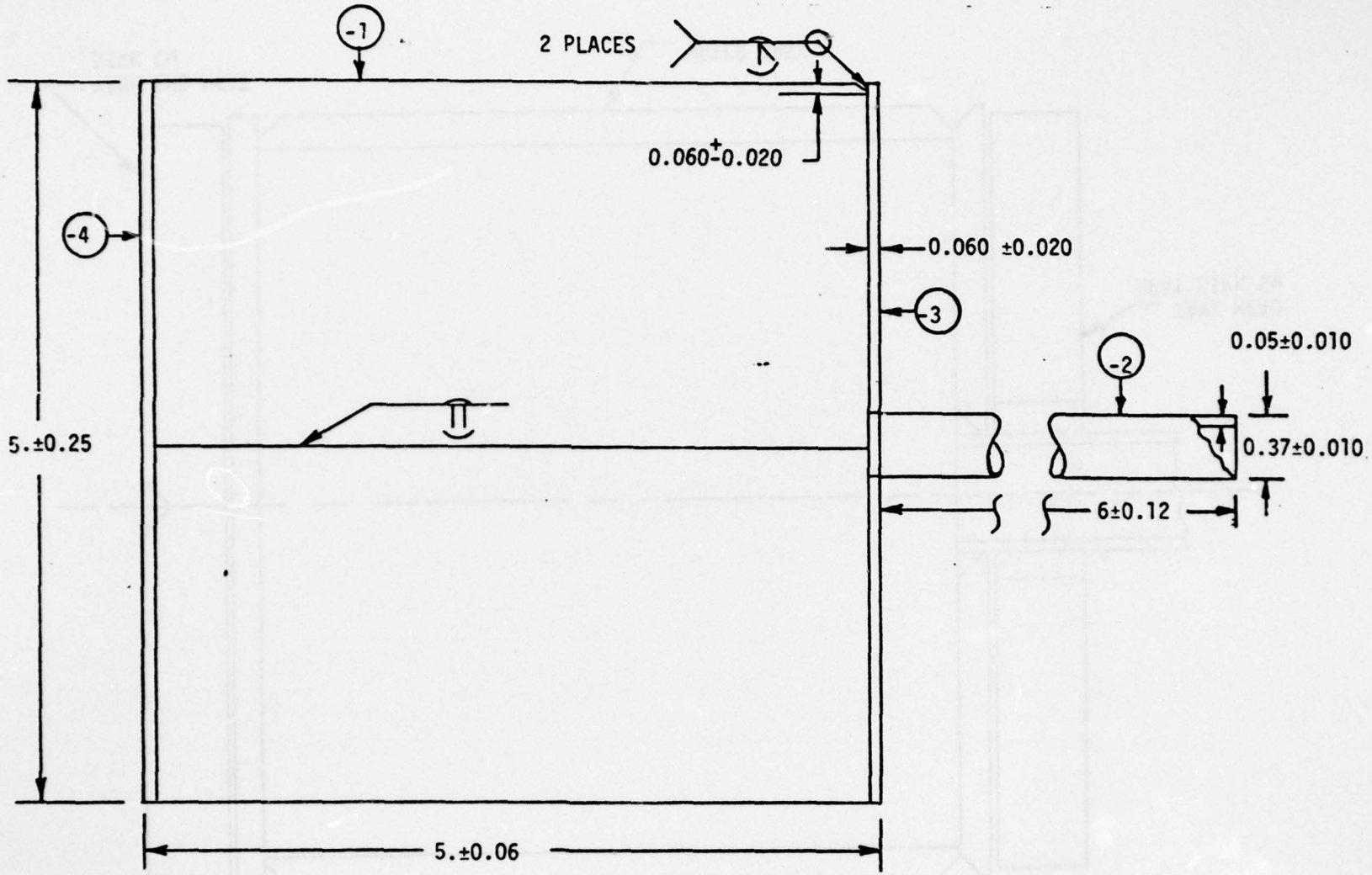


Figure A-1. Long Term Storage Container

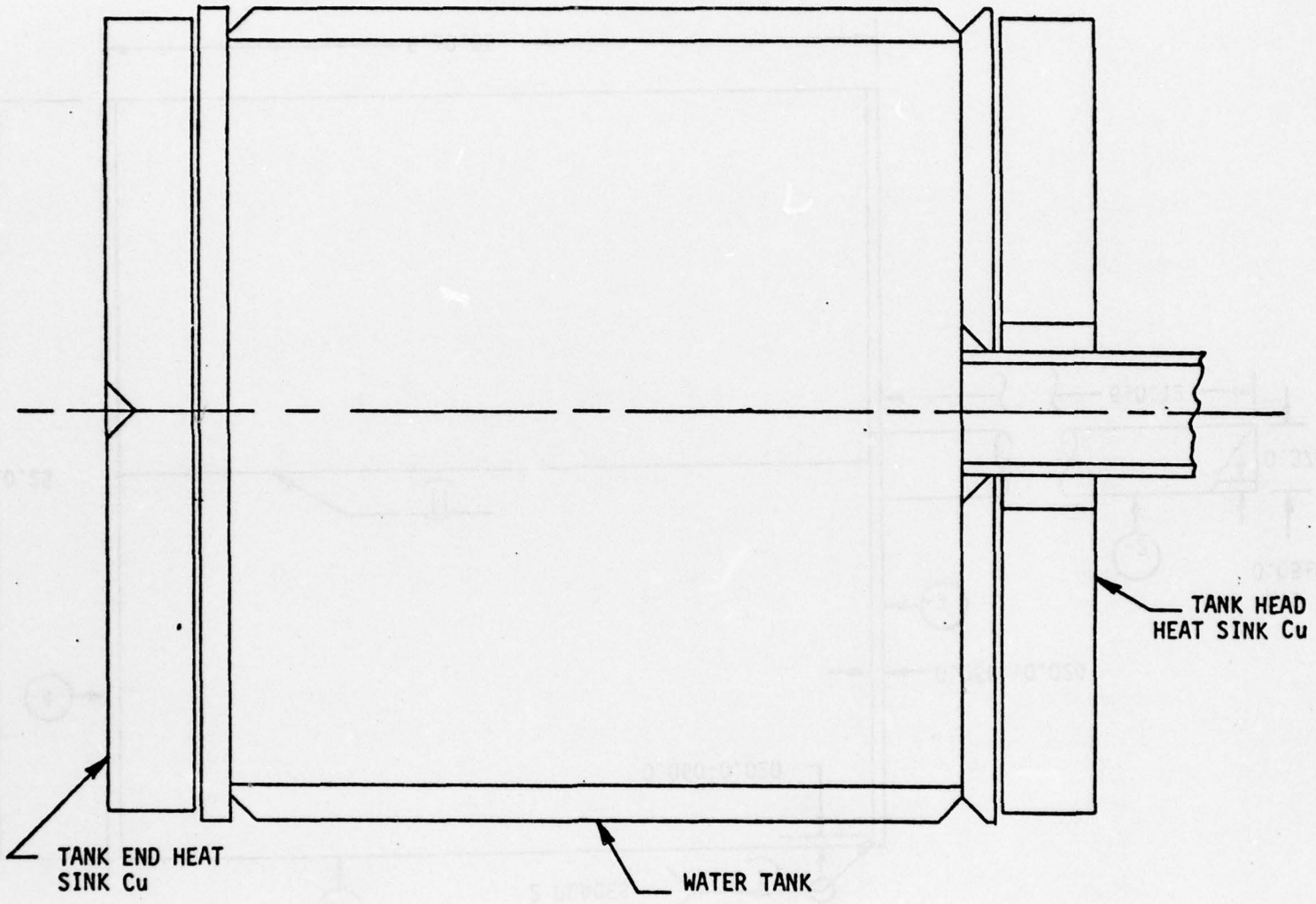


Figure A-2. Weld Tooling for Tank Closures

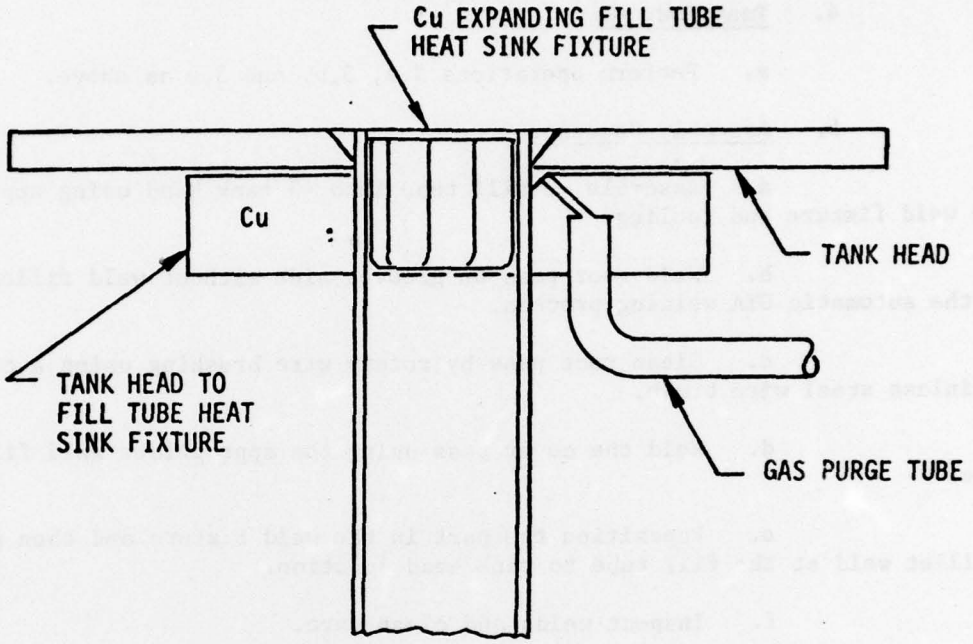


Figure A-3. Weld Tooling for Fill Tube to Tank Head Joint

A, Container Fabrication (cont.)

d. Counter bore the tank head on one side at the fill tube hole for weld joint preparation.

e. Inspect tank heads, clean and package.

4. Tank End, -4

a. Perform operations 3,a, 3,b, and 3,e as above.

5. Assembly Sequence

a. Assemble -2 fill tube into -3 tank head using appropriate weld fixture and tooling.

b. Weld root pass on grooves side without weld filler wire by the automatic GTA welding process.

c. Clean root pass by rotary wire brushing using a clean stainless steel wire brush.

d. Weld the cover pass using the appropriate weld filler wire.

e. Reposition the part in the weld fixture and then place a fillet weld at the fill tube to tank head junction.

f. Inspect welds and clean part.

g. Fixture tank head assembly with -1 tube for welding and purge tank with Ar or He.

h. Weld root pass without the use of weld filler wire. Full penetration must be obtained at the ID of the joint.

i. Dye penetrant inspect and clean root pass. No cracks allowed.

j. Fill weld groove using the appropriate weld filler wire.

k. Inspect and clean the inner tank surfaces.

l. Locate the tank end to the tank for welding, then purge the closed tank with Ar or He.

A, Container Fabrication (cont.)

m. Make the root pass without the use of weld filler wire to insure full penetration.

n. Clean root pass surface.

o. Inspect the internal weld penetration using a borescope. Full weld penetration is required.

p. Run weld cover pass using the appropriate weld filler wire.

q. Clean, inspect, and package unit for shipment.

Heat treatment of the containers was performed in an argon atmosphere and with one exception, as noted below, utilizing the thermal cycles listed in Table A-I.

Upon receipt of the tanks, the certifications were examined and it was found that some of the material used to fabricate the 304L stainless steel containers was actually 304 stainless steel. With the concurrence of the Air Force, the containers were subjected to a heat-treatment at 1925°F in hydrogen, followed by rapid cooling to preclude sensitization in the weld heat affected zone.

B. PREPARATIVE PROCEDURES

1. Container Cleaning and Passivation

All the containers were degreased by submerging and agitating the tanks three times in fresh isopropyl alcohol. The containers were then purged with dry, filtered nitrogen and placed in a vacuum chamber for final drying. The A-286, 17-4PH stainless steel, and Inconel 718 containers were then subjected to an alkaline descaling treatment for 60 minutes with Kelite No. 235 at a concentration level of 32 oz per gal at 190°F. The containers were then rinsed with water at 150°F for 2 to 5 minutes, followed by a rinse at ambient temperatures with deionized water for 2 to 5 minutes, then purged with dry, filtered nitrogen, and finally dried in a vacuum chamber.

The 304, A-286, and 17-4PH stainless steels and Inconel 718 were descaled in a pickling solution of 20% HNO_3, 5% HF, and 75% H_2O at 130°F for 30 minutes per immersion until the last traces of scale were removed as confirmed by examination with a borescope. Following the acid treatment, the tanks were flushed with tap water for 2 to 5 minutes, then flushed with deionized water for 2 to 5 minutes, then subjected to ultrasonic vibration in a water bath for 15 minutes, flushed with deionized water for 5 minutes, purged with dry, filtered nitrogen, and finally dried in a vacuum chamber.

TABLE A-I

HEAT TREATMENT PROCEDURES FOR WATER CONTAINERS

Material	Weld Wire Material	Heat Treatment	Surface Finish
304L Stainless Steel	-	-	Alkaline Clean, Pickle and Passivate
304L Stainless Steel	308L	-	Alkaline Clean, Pickle and Passivate
A-286	-	Solution Treat and Age - MIL-H-6875	Alkaline Clean, Pickle and Passivate
A-286	A-286	Solution Treat and Age - MIL-H-6875	Alkaline Clean, Pickle and Passivate
17-4 PH Stainless Steel	-	Age to H-1025 Condition - MIL-H-6875	Alkaline Clean, Pickle and Passivate
17-4 PH Stainless Steel	17-4	Solution Treat and Age to H-1025 Condition - MIL-H-6875	Alkaline Clean, Pickle and Passivate
Inconel 718	-	Age (1400 - 1200°F)	Alkaline Clean, Pickle and Passivate
Inconel 718	Inconel 718	Solution Treat (1950°F) and Age (1400-1200°F)	Alkaline Clean, Pickle and Passivate
6Al-4V-Titanium	6Al-4V Titanium	Age (1000°F - 4 Hours) - Weld-Stress Relieve (1000°F - 4 Hours)	Pickle

B, Preparative Procedures (cont.)

The 304 and A-286 stainless steels, and Inconel 718 were passivated with a 30% HNO_3/3% $Na_2Cr_2O_7$ aqueous solution at 130°F for 25 minutes, rinsed with tap water for 2 to 5 minutes, rinsed with deionized water for 2 to 5 minutes, subjected to ultrasonic vibration in water for 5 minutes, rinsed with deionized water for 2 to 5 minutes, purged with dry, filtered nitrogen, and dried in a vacuum chamber. The 17-4PH stainless steel received the same treatment with the exception of a 10 minute passivation time.

The 6Al-4V titanium was degreased in isopropyl alcohol as described previously for the other tankage and then descaled in a pickling solution of 33.2% HNO_3, 1.6% HF, and 65.2% water at 140°F for 3 minutes. The titanium containers were rinsed with 130°F tap water for 2 to 5 minutes, followed by a rinse in deionized water for 2 to 5 minutes, then subjected to ultrasonic vibration in water for 5 minutes, rinsed with deionized water for 2 to 5 minutes, purged with dry nitrogen, and then dried in a vacuum chamber.

2. Container Sterilization, Filling, and Sealing

Following the final rinsing with deionized water and the drying of the container in a vacuum chamber, the containers were wrapped with reusable sterilization paper. The wrapped containers were then sterilized in an autoclave at 250°F with 15 psig steam for 30 minutes followed by a 30-minute drying period. The containers were then stored in the paper to maintain their sterile condition.

All the steps required to fill the containers with water were conducted in the sterile laminar flow bench. The tanks were removed from the wrapping paper in the laminar flow bench. The tanks were weighed empty; then weighed when filled completely with sterile water to determine the total volume of the tank. The water was drained out and the tank was rinsed once more with the sterile water. A sample of the rinse water was checked for pH, conductivity, and Silting Index. If the values indicated that particulate matter and dissolved species were not present, the tank was considered ready for filling; if the values indicated that contaminants were present, the tank was rinsed until there was no evidence of contamination.

Before the final filling with oxygen-saturated deionized water, the tank was purged with oxygen from a filtered supply. The tank was then filled with the water and a sample was withdrawn for pH, conductivity, and Silting Index measurements. The ullage was adjusted to the ten percent value by weighing the container and its contents; the ullage space was purged with the filtered oxygen; and the container was capped with a sterile, tapered plug made from the same material as the container. The plug was seated in the fill-tube by use of a hammer. The containers were filled with the oxygen-free, deionized water in an analogous manner except that filtered nitrogen was used instead of oxygen for purging and blanketing the container.

B, Preparative Procedures (cont.)

The final sealing of the containers was accomplished by GTA welding the fill-tube/plug interface. The welds were inspected visually for any apparent anomalies. None were found. Then the containers were placed in plastic bags and labeled for the long-term storage tests.

The sampling plan for the long-term storage tests is to remove one container of each material with the two types of water for inspection and evaluation every six months for a period of five years. The contents will be characterized with respect to pH, conductivity, particulate content, and biological activity; and the containers themselves will be subjected to metallurgical examination if the other test data indicate that this is required.

APPENDIX B

SILTING INDEX MEASUREMENT

SILTING INDEX MEASUREMENT

In order to obtain a measurement of the clogging tendencies of the particulate matter which may be produced during the storage of water in the presence of metals and non-metals for prolonged periods of time, a flow test of the water samples through nominal 1 micron size pores was required. Due to the limited quantity of the water available for each sample, approximately 20 ml, the ASTM Method F 52-69, "Silting Index of Fluids for Processing Electron and Micro-electronic Devices", was selected as being appropriate for the program.

The method determines the silting or clogging tendency of a fluid containing fine particles and gelatinous materials suspended in the fluid. The fluid is filtered through a membrane filter having a uniform pore size of 0.8 micron at a constant differential pressure. Particles larger than 5 microns form an open network above the filter and do not affect the clogging tendency; particles smaller than 5 microns tend to block the flow passages of the filter and cause a decay in the flow rate. The rate of flow decay is expressed in terms of a Silting Index value; the greater the value, the greater the clogging tendency. A schematic diagram of the apparatus is shown in Figure B-1.

The total volume of fluid passed through the filter is 12 ml. The flow of the last 10 ml is timed incrementally as V_1 (1 ml), V_2 (5 ml), and V_3 (10 ml) with T_1, T_2, and T_3 the times required to flow the respective volumes. The Silting Index value is calculated from the equation:

$$S.I. = \frac{T_3 - 2T_2}{T_1}$$

The tests in the program were conducted with three silting heads, No. 1 with an effective area of 1.0 mm^2, No. 2 with an effective filter area of 4.3 mm^2, and No. 3 with an effective filter area of 18.5 mm^2. The procedure used in the tests was that prescribed in ASTM Method F52-69 except that samples were tested in triplicate only when sufficient sample was available. A photograph of the apparatus* used is shown in Figure B-2.

Water which had passed through the 0.22 micron pore size absolute filter and which was used in preparation of the tests, always produced a Silting Index value of less than 1 using the No. 1 silting head which has a cross-sectional area of 1 mm^2. The effect of particle size on the Silting Index was evaluated using latex spheres with a mean particle size of 1.25 microns with a range from 0.5 to 2.0 microns and puff ball spores with a size range from 3 to 4 microns. These data are presented for silting heads Nos. 1, 2, and 3 which have cross-sectional areas of 1 mm^2, 4.3 mm^2, and 18.5 mm^2, respectively, in Figures B-3 and B-4. The particle concentration is given in mg/l because the suspensions were prepared on a weight basis; the actual

*Available from Millipore Corp., Bedford, MA.

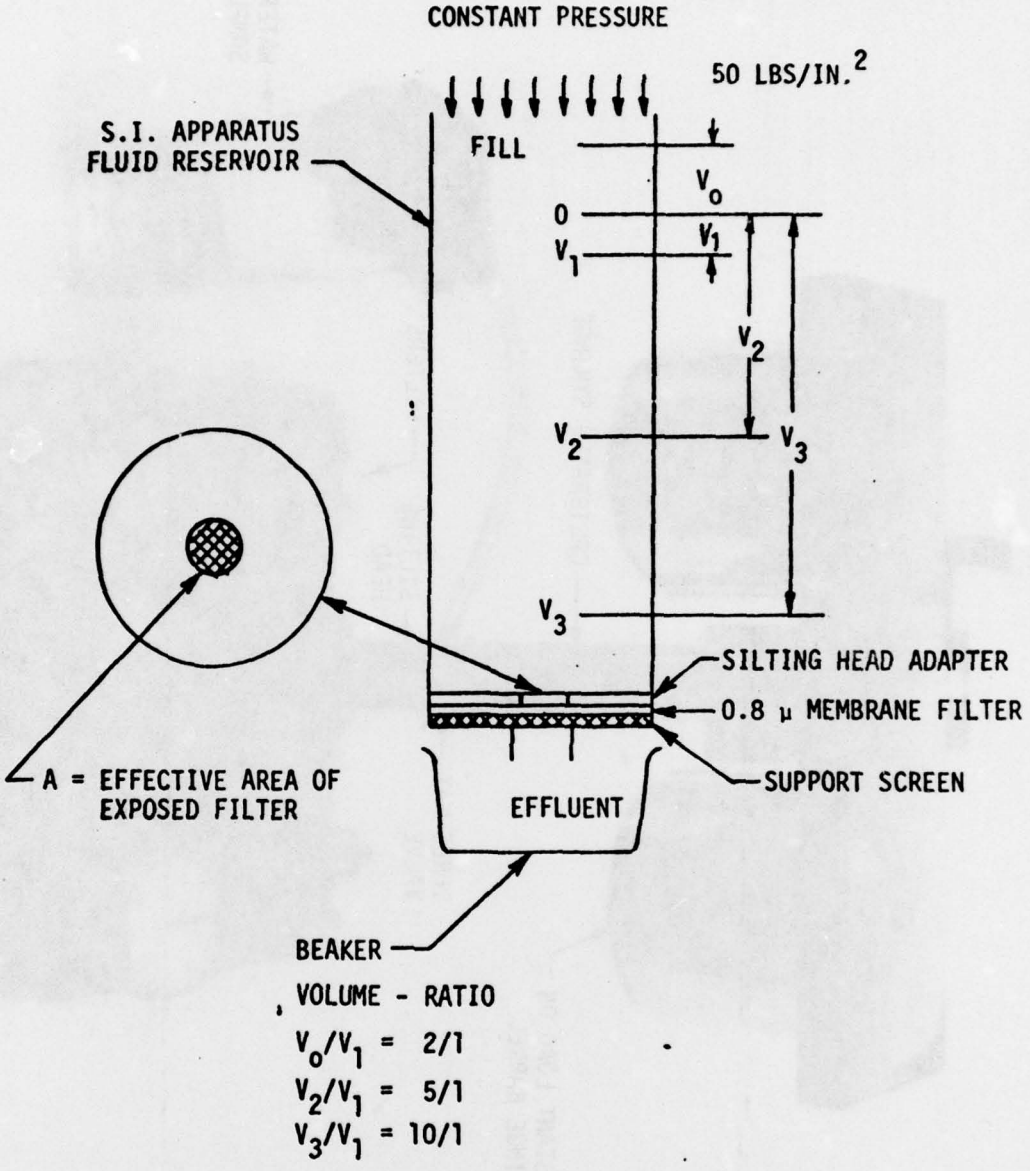


Figure B-1. Schematic of Silting Index Apparatus

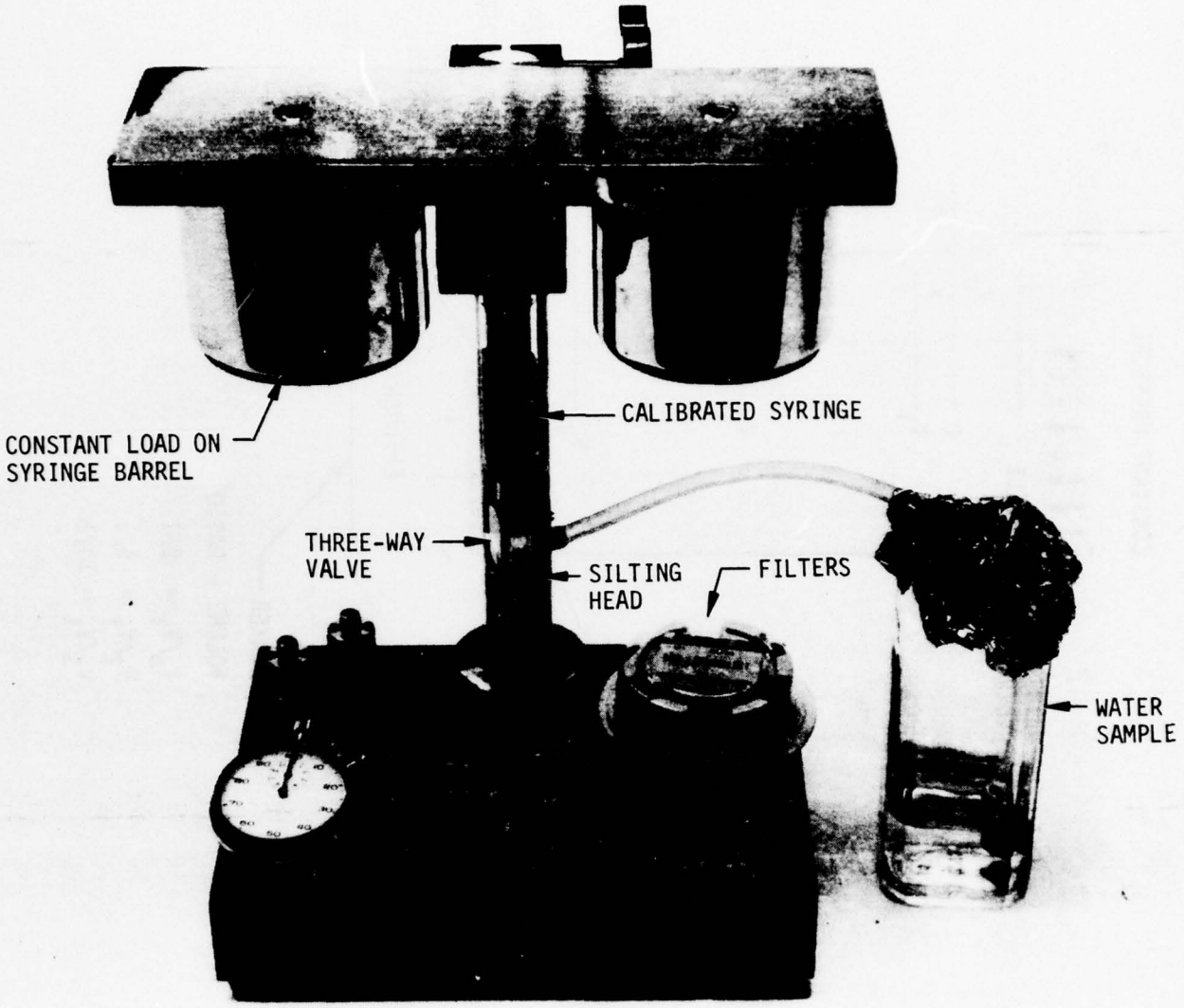


Figure B-2. Silting Index Apparatus

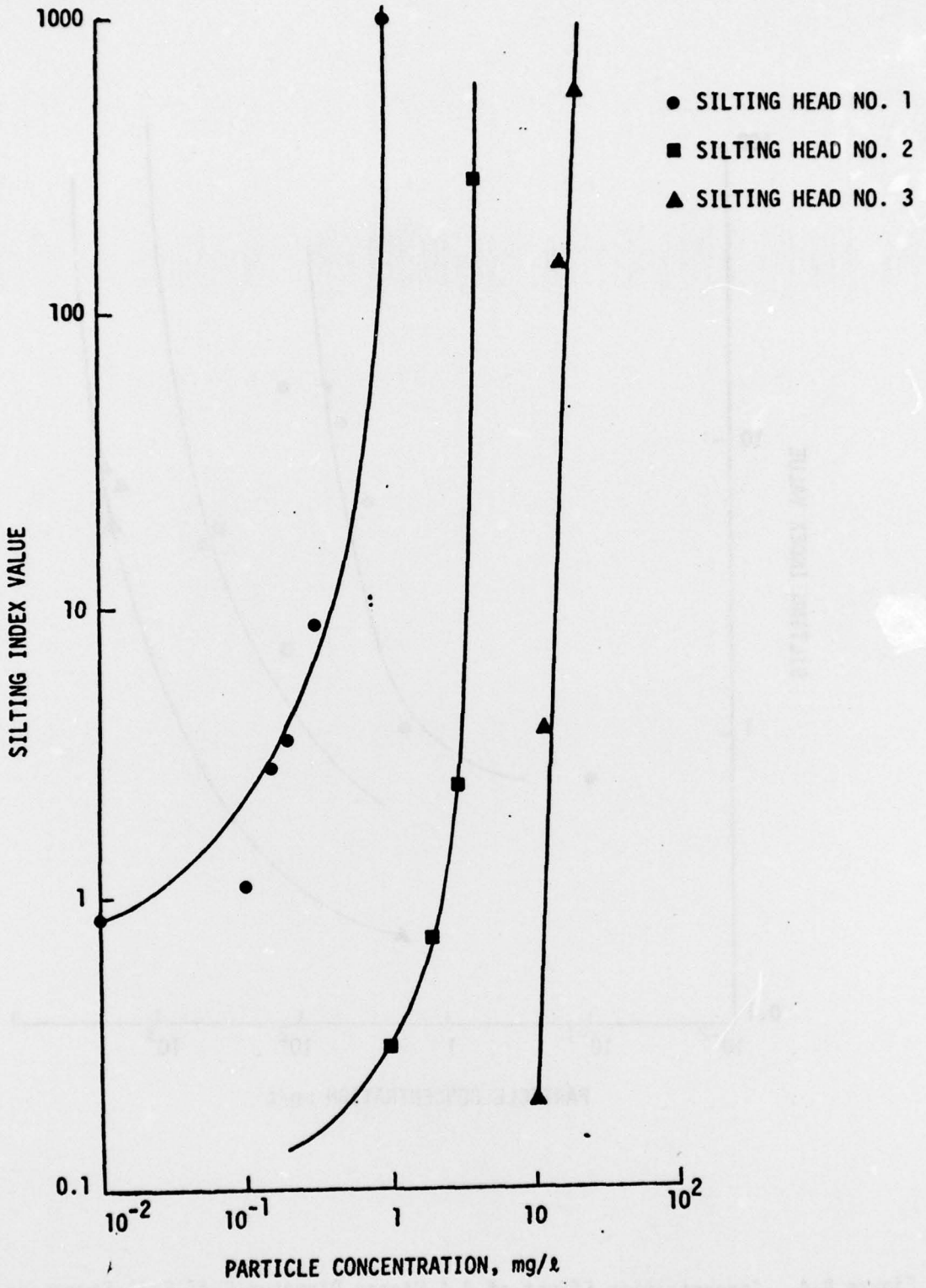


Figure B-3. Concentration Effect of 1.25 Micron Average Diameter Latex Particles on the Silting Index Values

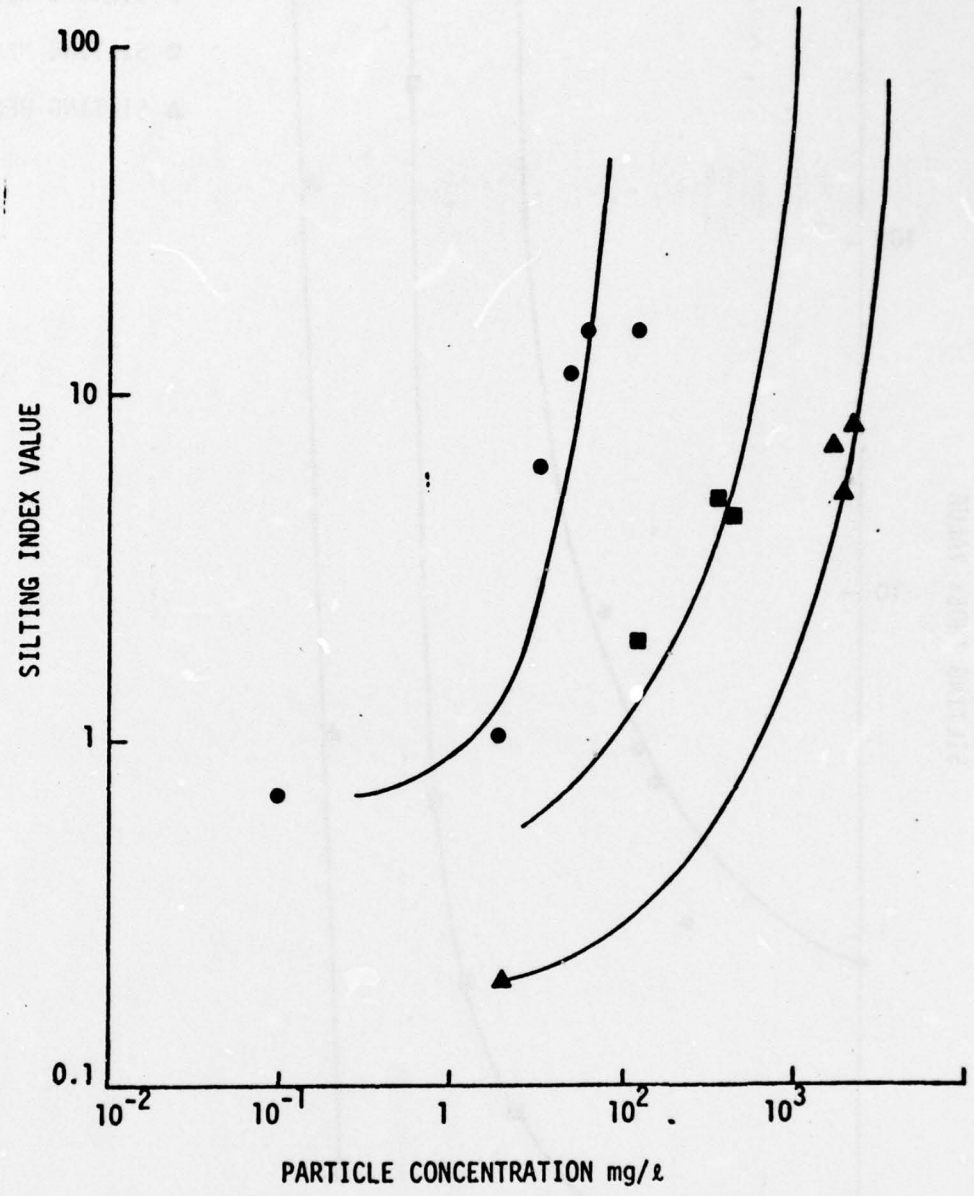


Figure B-4. Concentration Effect of 3-4 Micron Diameter Puff Ball Spores on the Silting Index Value

densities of the particles are comparable. The significant item to note from the comparison of the data is that the Silting Index values are comparable at concentration levels that differ by at least one order of magnitude, the smaller particle producing the higher Silting Index value.


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