U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-286 417

Materials for Oxygenated Wastewater Treatment Plant Construction

(U.S.) Bureau of Reclamation, Denver, CO

Prepared for

Municipal Environmetal Research Lab, Cincinnati, OH

Jul 78

DEPARTMENT OF DEFENSE
PLASTICS TECHNICAL EVALUATION CENTER
ARRADCOM, DOVER, N. J. 07801

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July 1978

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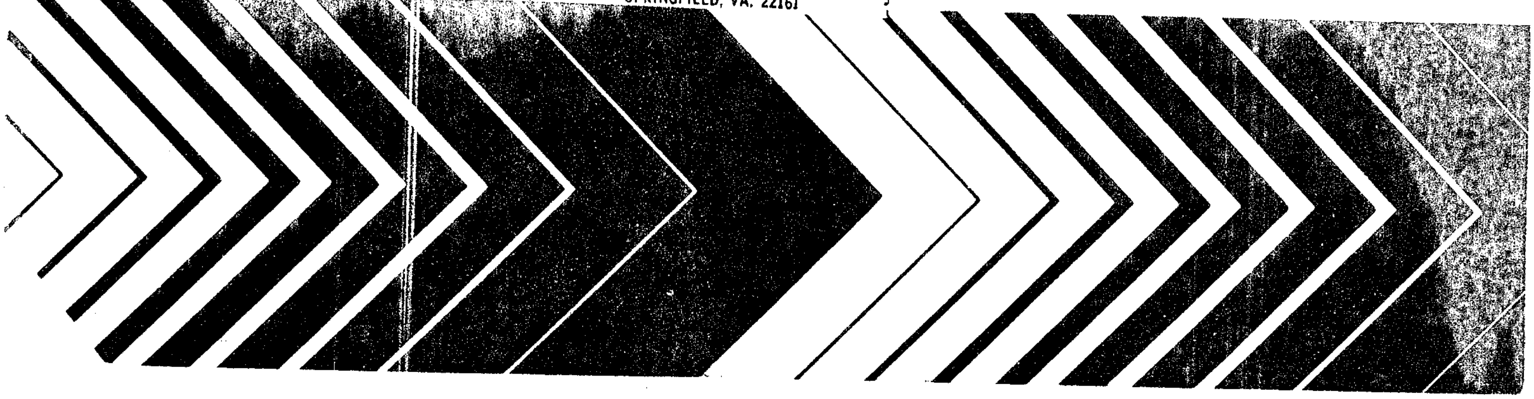

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-136	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE MATERIALS FOR OXYGENATED WASTEWATER TREATMENT PLANT CONSTRUCTION		5. REPORT DATE July 1978 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) H. K. Uyeda, B. V. Jones, T. E. Rutenbeck, and J. W. Kaakinen		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Division of General Research Engineering and Research Center Bureau of Reclamation Denver, Colorado 80225		10. PROGRAM ELEMENT NO. 1BC611 11. CONTRACT/GRANT NO. EPA-IAG-0187(D)
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Prepared in cooperation with the U.S. Department of Interior
Project Officer: James V. Basilico, U.S. EPA, Washington, D.C., (202) 426-3974

16. ABSTRACT

This research study was initiated to identify resistant materials for construction of wastewater treatment plants using the oxygen activated sludge process.

In this investigation, samples of a broad range of construction materials were exposed for periods up to 28 months in the aeration basins of three operating municipal wastewater treatment plants. All three plants were using oxygen-activated sludge processes during the exposure period. Materials exposed included metallics, portland cement concretes, protective coatings for steel and for concrete surfaces, sealers for joints in concrete, and plastic and rubber materials. An economic analysis was also conducted to evaluate the impact of materials recommendations generated by the exposure testing.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Activated sludge process *Corrosion prevention *Corrosion tests Sewage treatment Protective coatings Dissolved gases Oxygen	Materials Waste water	*Oxygen activated sludge Construction materials	13B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE A07-A01

EPA Form 2220-1 (9-73)

☆USGPO: 1978 — 757-140/1402 Region 5-11

EPA-600/2-78-136
July 1978

MATERIALS FOR OXYGENATED WASTEWATER TREATMENT PLANT CONSTRUCTION

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This study was conducted
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i.a

DISCLAIMER

FOREWORD

The Environmental Protection Agency was created because of increasing public and govenment concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the projects of that research; a most vital communications link between the researcher and the user community.

The recent use of high purity oxygen in the activated sludge process represents an important advance in wastewater treatment. This report evaluates materials of construction for use in high purity oxygen treatment plants and thus improves the application of oxygen technology in wastewater treatment.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

ABSTRACT

This research study was initiated to identify resistant materials for construction of wastewater treatment plants using the oxygen activated sludge process.

In this investigation, samples of a broad range of construction materials were exposed for periods up to 28 months in the aeration basins of three operating municipal wastewater treatment plants. All three plants were using oxygen-activated sludge processes during the exposure period. Materials exposed included metallics, portland cement concretes, protective coatings for steel and for concrete surfaces, sealers for joints in concrete, and plastic and rubber materials. An economic analysis was also conducted to evaluate the impact of materials recommendations generated by the exposure testing.

This report was submitted in fulfillment of Contract No. EPA-IAG-0187(D) by the Bureau of Reclamation under the sponsorship of the U.S. Environmental Proection Agency.

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ACKNOWLEDGMENTS

This study was directed by Mr. J. L. Kiewit, Head, Materials Science Section. Mr. L. O. Timblin, Jr., is Chief of the Applied Sciences Branch.

Specimens were prepared and tests were conducted by the following USBR personnel:

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Exposure racks were fabricated by Laboratory Shops personnel under the direction of Mr. R. E. Edlund, Superintendent.

We wish to acknowledge the cooperation of Mr. L. D. Hedenland, Manager, Sanitary Operations, Las Virgenes Water District, Calabasas, California; Mr. J. Lauderbaugh, Superintendent, Speedway Wastewater Treatment Plant, Indianapolis, Indiana; Mr. R. J. Gozikowski, Director, Wastewater Treatment Division, Department of Public Works, Fairfax County, Virginia; and Mr. B. Morrison, Manager, Westgate Wastewater Treatment Plant, Alexandria, Virginia; in providing their facilities for use as test sites. Messrs. Lauderbaugh and Morrison also provided the data on the exposure conditions for their respective plants. Mr. R. C. Brenner, U.S. Environmental Protection Agency, Cincinnati, Ohio, provided the data for the Tapia site.

The assistance of the developers of the oxygen processes used in the study, Cosmodyne Corporation, Torrance, California; Union Carbide Corporation, Linde Division, Tonawanda, New York; and Air Products and Chemicals, Inc., Allentown, Pennsylvania; is also appreciated.

The following individuals provided information and data used in evaluating the economic impact of the materials recommendations:

A. Holtz and J. Puntenney of the Denver Metropolitan Sewage District
J. D. Boyle of CH2M Hill
D. Waskiewicz and R. Spooner of Rodney Hunt Company
P. Heye of Henningson, Durham and Richardson, Inc.
F. French of ARMCO Steel Corporation

The assistance and cooperation of Mr. James V. Basilico, the EPA Project Officer, are greatly appreciated.

Special mention should be made of Dr. Alfred A. Bacher, retired from the Environmental Protection Agency, and Mr. L. M. Ellsperman, retired from the U.S. Bureau of Reclamation, whose original efforts initiated this study and who directed the majority of the work.

SECTION 1

INTRODUCTION

To cope with the ever-increasing quantities of wastewaters to be treated, considerable emphasis is now being placed on the use of new cost-effective advanced treatment processes. One such process is aeration with high purity oxygen in lieu of the traditionally used atmospheric air. The use of oxygen for aeration offers more efficient and complete oxygen absorption than obtainable using air. Greater efficiency and the consequent reduction in retention time will result in allowing existing facilities to increase their capacities or throughput rates without increasing physical plant size. This advantage notwithstanding, it was recognized that the use of the oxygen activiated sludge process may result in accelerated deterioration of materials normally used for construction of conventional wastewater treatment plants.

Thus, in an Environmental Protection Agency-sponsored study, the Bureau of Reclamation was charged with identifying resistant materials of construction suitable for use in plants using this advanced process. In this investigation, samples of a broad range of construction materials were exposed. Exposure periods were up to 28 months in the aeration basins of three operating municipal wastewater treatment plants. All were using oxygenated activated sludge processes. Materials exposed included metallics, portland cement concretes, protective coatings for steel and for concrete surfaces, sealers for joints in concrete, and plastic and rubber materials. The three test sites were the Tapia Water Reclamation Facility, Calabasas, California (site 1); the Speedway Wastewater Treatment Plant, Indianapolis, Indiana (site 2); and the Westgate Wastewater Treatment plant, Alexandria, Virginia (site 3). Each plant uses a different oxygen process and all three plants treat mostly domestic sewage.

An economic analysis was conducted to evaluate the impact of materials recommendations generated by the exposure testing on construction costs.

SECTION 2

CONCLUSIONS

Many variables require consideration in arriving at sound materials selection. These factors include mechanical requirements, reliability, maintenance considerations, wastewater chemistry, materials availability and ease of specification, and safety considerations. Because the multidisciplinary nature of these facets is not within or is only marginally within the scope of the authors' expertise, no effort has been made to recommend materials of construction for every component in oxygenated wastewater treatment plants. Rather, below is a list of materials which were shown to be resistant to this environment as indicated by this study. As applicable, the materials are listed in order of resistance (highest resistance first) or, in the case where more than one material displayed identical resistance, in alphabetical order.

1. Concretes. -

a. High-quality conventional concretes made with either Type II or Type V portland cement are suitable for oxygenated wastewater, secondary treatment tank construction. The selection of type of cement used should be based on the sulfate concentration of the particular wastewater. In plants where primary treatment does not remove all debris, either additional sacrificial thicknesses of concrete or a protective coating may be needed.

b. Significant reductions in strength occurred in the polymer-impregnated concrete. Nevertheless, strengths remained higher than for nonimpregnated concretes. Therefore, further long-term tests would be required to assess the performance of this material.

2. Steel embedded in concrete. - A 41-mm (1.6-inch) thick cover of dense, high-quality concrete provides excellent corrosion protection for embedded steel.

3. Alloys. -

a. The following alloys may be used unprotected in these environments. However, normal sound corrosion engineering principles should be followed, e.g., adverse bimetallic couples should not be exposed.

(1) Stainless steel, Type 201

(2) Stainless steel, Type 304
(3) Stainless steel, Type 316
(4) Sensitized stainless steel, Type 304
(5) Sensitized stainless steel, Type 316
(6) Deoxidized copper
(7) Austenitic cast iron

b. The following alloys should not be exposed unprotected in these environments. It should be recognized that addition of sacrificial thicknesses of gray cast iron is a form of corrosion protection widely practiced in the industry.

(1) Aluminum alloy 6061
(2) Gray cast iron
(3) Low alloy steel
(4) Mild steel

4. Plastics and rubbers. -

a. The lack of substantial difference in physical properties of polymers tested between tap water and wastewater exposures as well as between gas and liquor exposures, and the relative stability of polymers known to be sensitive to oxidation, indicates that the exposures encountered in this study do not represent a severe oxidation environment for higher polymers.

b. Selection of any of the tested products for use in wastewater treatment plants using oxygen for aeration should be made on the basis of established engineering properties dictated by the specific intended use. Products should be especially formulated for resistance to bacterial attack.

5. Protective coatings. -

a. For steel surfaces

(1) Phenolic-epoxy, proprietary, coating No. C-12
(2) Urethane, proprietary, coating No. C-9
(3) Coal-tar epoxy, MIL-P-23236, Type I, Class 2, coating No. C-4
(4) Phenolic, proprietary, coating No. C-8
(5) Vinyl resin, USBR VR-6, coating No. C-2
(6) Phenolic-epoxy, proprietary, coating No. C-16
(7) Urethane, proprietary, coating No. C-13
(8) Vinyl resin, USBR VR-3, coating No. C-1

b. For concrete surfaces

(1) Phenolic-epoxy, proprietary, coating No. C-12
(2) Urethane, proprietary, coating No. C-9
(3) Coal-tar epoxy, MIL-P-23236, Type I, Class 2, coating No. C-4

    (4) Phenolic-epoxy, proprietary, coating No. C-16
    (5) Urethane, proprietary, coating No. C-7

6. Sealers for concrete joints. -

   a. Silicone, one-component, low modulus, sealer No. S-4
   b. Polysulfide, two-component, Federal Specification TT-S-00227, sealer No. S-3

7. Added costs of the more durable materials, indicated for use by the results of this study, are negligible when compared to total construction costs.

SECTION 3

EXPOSURE CONDITIONS

Tapia Site

Samples were placed in the secondary treatment facility at the Tapia site which is a 9.1- by 36.0- by 4.6-m (30- by 118- by 15-foot) water depth spiral-flow aeration tank (figures 1, 2, and 3).

Nominal flow is 44.8 ℓ/s (1.0 Mgal/d) primary effluent plus 30 percent return activated sludge. High-purity oxygen is diffused into the mixed liquor from special submerged aeration diffusers along one side of the length of the tank.

Oxygen not dissolved or utilized in the mixed liquor is captured by an inflated polyvinyl chloride tent which covers and seals the tank. This oxygen, together with other gases, mainly carbon dioxide, a product of organic metabolism, is then recycled into the mixed liquor by an 850 ℓ/s (1.8 x 10^2 ft^3/min) centrifugal blower. The blower feeds the aeration diffusers along the opposite side of the tank to provide the principal aeration and the spiral-flow agitation of the mixed liquor.

Speedway and Westgate Sites

Samples were placed in secondary treatment oxygen contact tanks (figures 4, 5, and 6). In both these plants, high-purity oxygen is fed into the gaseous zone between the liquid surface and the tank cover under moderate pressure [approximately 17-kPa (2.5 lb/in^2)g]. A mechanical agitator with impellers at the liquid surface and at approximately one-half the liquid depth, diffuses the high-concentration oxygen atmosphere into the mixed liquor. (The impeller at the liquid surface resulted in splashing on the test specimens exposed in the gaseous phase.)

Typical characteristics of these systems during the sample exposure period are shown in table 1. (Essentially duplicate tables, as applicable, are provided to reflect both SI and English units.)

The Westgate site differs from the other two sites in that its primary treatment consists of only a bar screen for removal of large debris. The other two sites have complete primary treatment facilities.

Specimen Location

Test specimens were exposed in three zones (gaseous, interface, and liquor) of the covered aeration basins at each of three test sites.

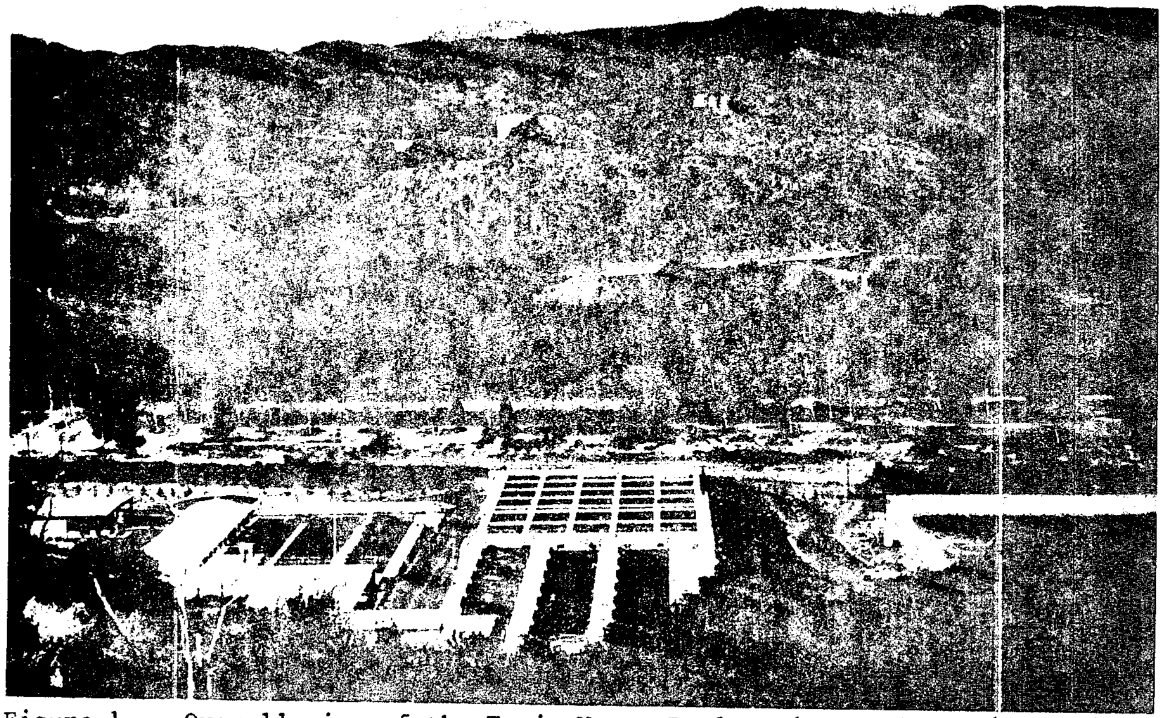

Figure 1. Overall view of the Tapia Water Reclamation Facility (site 1), Calabasas, California. Polyvinyl chloride tent covering the secondary tank in which exposures were made is shown in the left foreground.

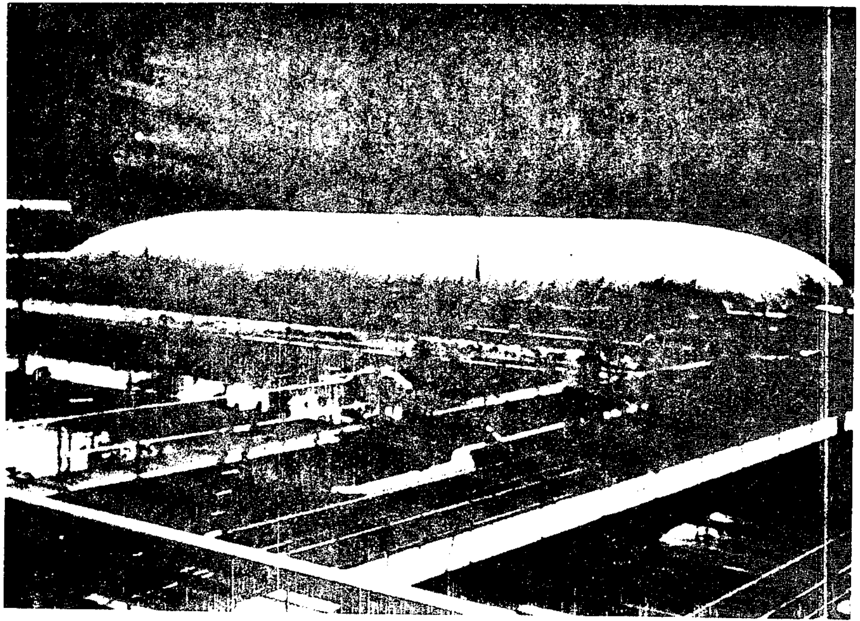

Figure 2. Closer view of the polyvinyl chloride tent at site 1.

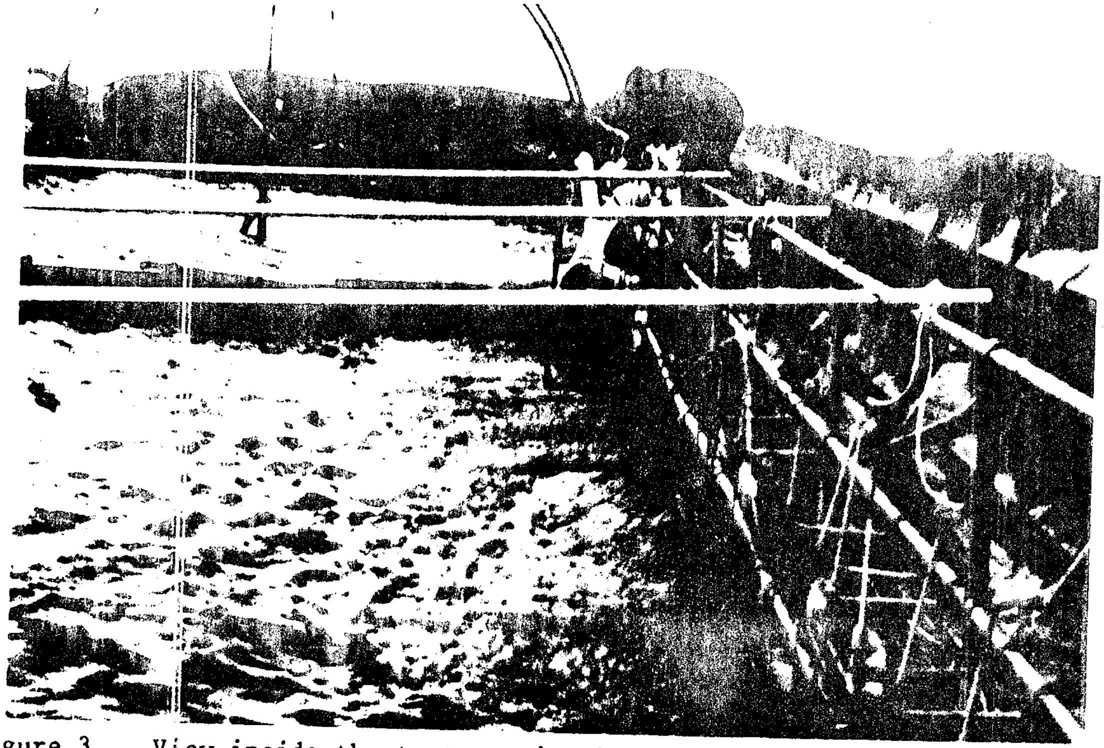

Figure 3. View inside the tent at site 1. Concrete cylinders exposed in the gas phase can be seen (right foreground) along the downstream end of the tank.

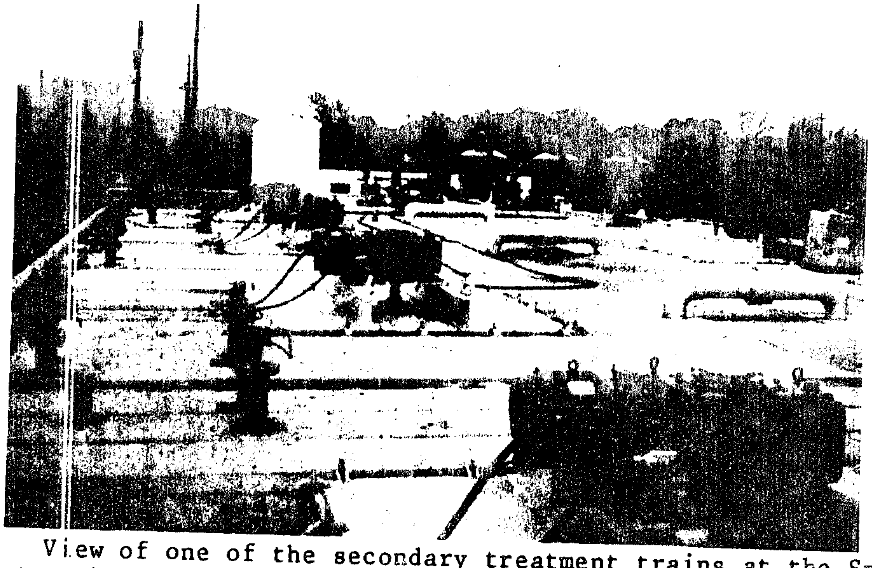

Figure 4. View of one of the secondary treatment trains at the Speedway plant (site 2). Covers for tanks are constructed of concrete.

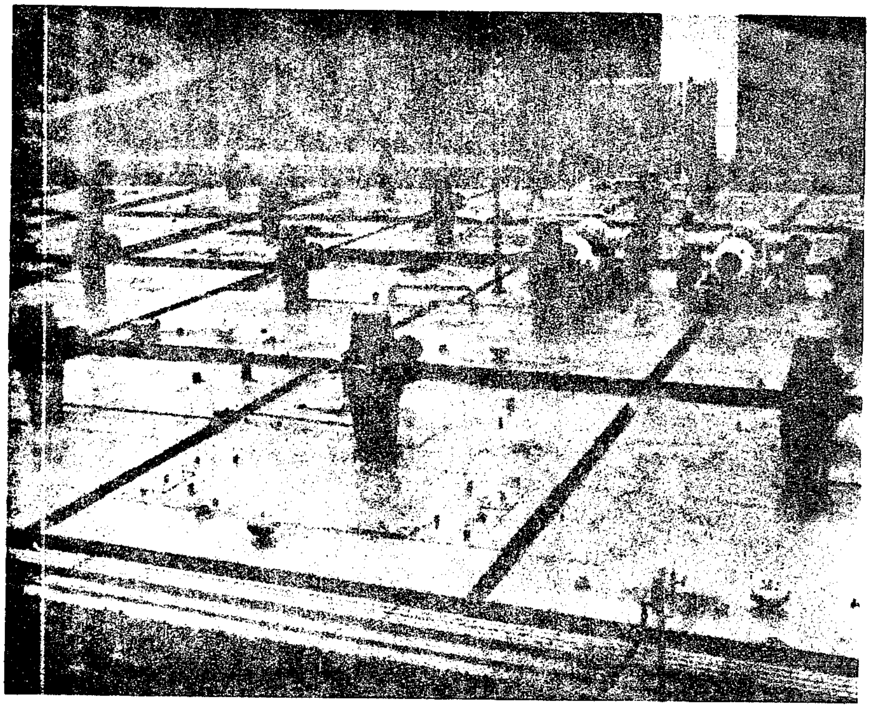

Figure 5. View of Westgate plant (site 3). Motors drive impellers located at the liquor surface and in the liquor. This plant utilizes steel covers.

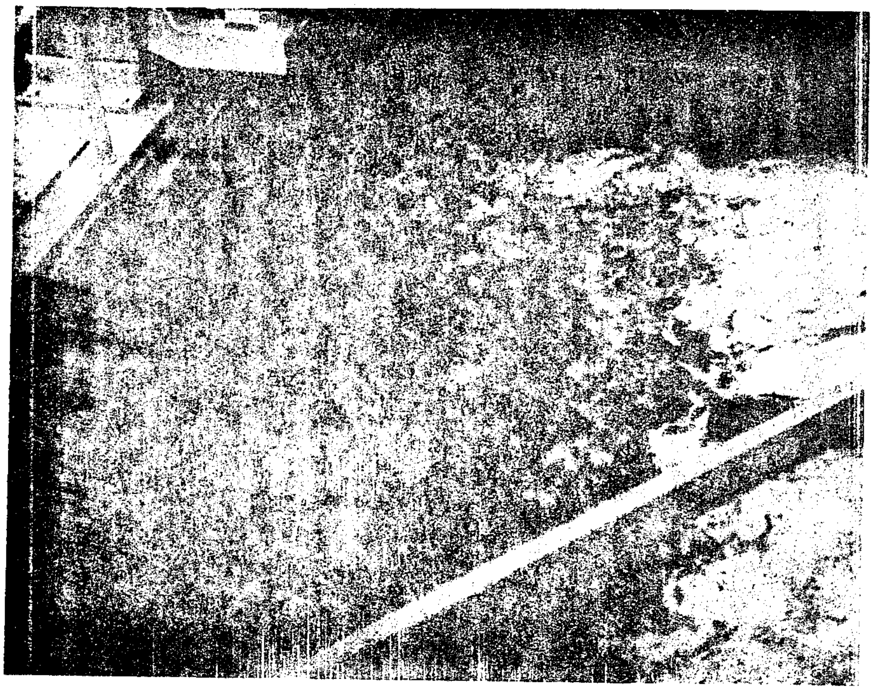

Figure 6. View of site 3 tank with cover removed to show splashing caused by the surface impeller. Test specimens were exposed to this splash zone effect.

TABLE 1. - TYPICAL MIXED LIQUOR SUSPENDED SOLIDS WASTEWATER ANALYSES

Property	Site*		
	No. 1	No. 2	No. 3
Conductivity (mho/cm)	1790	2081	1462
pH	7.4	7.0	6.0
Total suspended solids (mg/ℓ)	3700	2275	6044
Organic material, filterable (mg/ℓ)	-	516	328
Si O_2 (mg/ℓ)	11.0	36.5	38
Total dissolved solids (mg/ℓ)	840	816	1428
Cations and anions (mg/ℓ)			
Calcium	71.2	80	84.8
Magnesium	35.1	33.7	40.4
Sodium	133.0	150.0	48.3
Potassium	26.6	34.4	109.5
Carbonate	0.0	0.0	0.0
Bicarbonate	659.0	10.98	472.0
Sulfate	26.4	0.2	1.9
Chloride	144.0	7.4	78.1
Nitrate	4.96	-	-

* Site No. 1 - Tapia Water Reclamation Facility, Calabasas, California
Site No. 2 - Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site No. 3 - Westgate Wastewater Treatment Plant, Alexandria, Virginia

Racks for exposing the specimens at site 1 were fabricated of carbon steel; the racks were then hot-dip galvanized (figure 7). Racks used in sites 2 and 3 were constructed of stainless (Type 304) steel (figure 8).

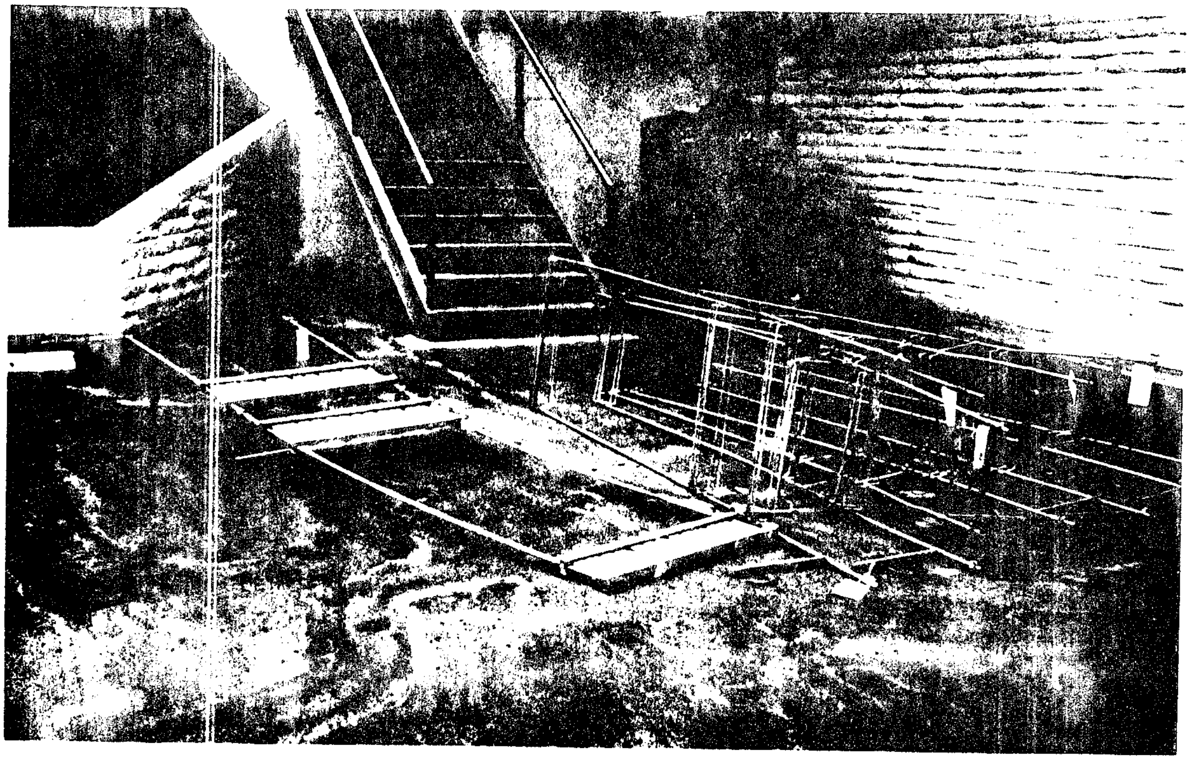

Figure 7. Typical rack used to expose test specimens at the Tapia plant.

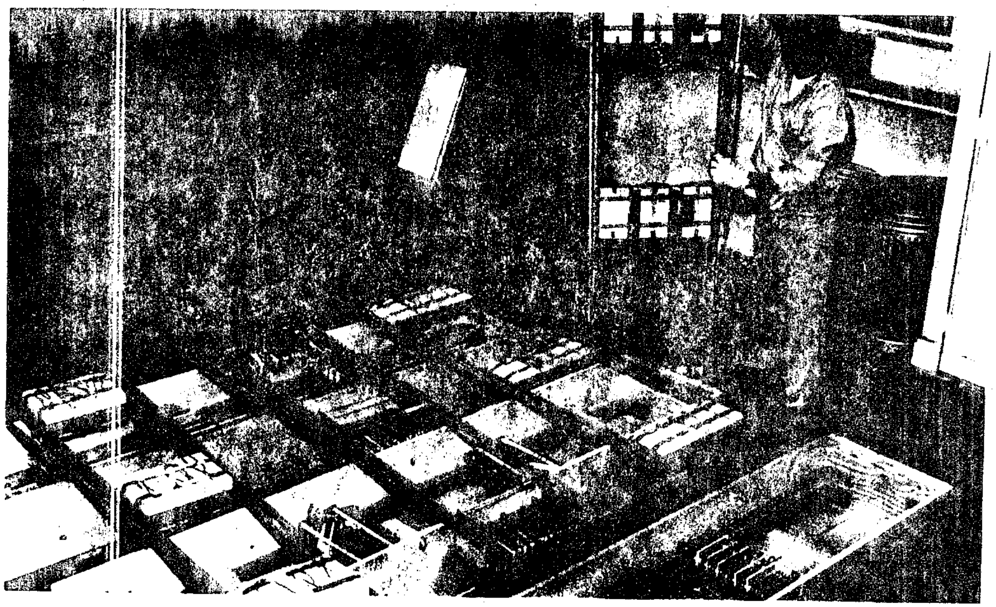

Figure 8. Racks for supporting test specimens at the Speedway plant. Similar but shorter racks were used at the Westgate plant.

SECTION 4

SPECIMEN INSTALLATION AND EXAMINATION

No modifications were necessary to enable the installation of the test specimens at site 1. Plant modifications were necessary at both sites 2 and 3 before the test specimens could be installed. The modifications consisted of removing existing covers from a portion of one of the reactor tanks and substituting a steel plate to support the specimen racks.

Initially, examinations were scheduled for 3-, 9-, and 18-month exposure periods. The actual examinations were performed in accordance with the schedule below:

Examination	Exposure time, months	
	Site 1	Sites 2 and 3
No. 1	3	3
No. 2	10	10
No. 3	-	20
Final	22	28

SECTION 5

EVALUATION PROCEDURES

Concrete

Three types of portland cement concrete were exposed: (1) Type II cement, (2) Type V cement, and (3) polymer-impregnated concrete (PIC) consisting of Type II cement concrete which was impregnated with the monomer, methyl methacrylate, and polymerized. Mix designs for the concretes are contained in the Appendix (Section 9).

Concretes were evaluated by (1) determination of compressive strength change, (2) determination of length change, and (3) visual examination for change in surface condition. Length determinations and visual examinations were conducted at the exposure locations. Compressive strength specimens were shipped to the Denver Laboratories for testing.

Compressive strength specimens were standard 76- by 150-mm (3.0- by 6.0-inch) cylinders. The length change cylinders (also 76- by 150-mm) were fitted with standard metal inserts for length measurements.

Steel Embedded in Concrete

Samples of concrete containing short sections of reinforcing steel were exposed to determine the effect of the test environments on the corrosion rate of the embedded steel. The reinforcing steel sections, 100 mm (4.0 inches) long by 19 mm (0.75 inch) diameter, were cast in 100- by 100- by 200-mm (4.0- by 4.0- by 8.0-inch) long concrete (Type II, Type V, and PIC) prisms, providing a concrete cover of 41 mm (1.6 inches) minimum over the steel. Copper lead wires were attached to the reinforcing steel prior to concrete placement to provide access for electrical tests.

Measurement of corrosion was accomplished by two nondestructive methods, including steel-to-electrolyte potential measurement and corrosion current determination.

Steel-to-electrolyte potential was referenced to copper-copper sulfate electrode (CSE). Magnitude of corrosion current was then determined only on those specimens showing a high negative (more negative than minus 0.30 volt) steel-to-electrolyte potential. The potential of uncorroded steel in concrete is in the range of minus 0.10 to minus 0.30 volt to CSE. When corrosion develops, the potential drops to that of corroding steel which is about minus 0.55 volt to CSE. Determination of corrosion current was by the polarization break method, devised by Swerdtfegar of the National Bureau of Standards, described in the Appendix.

The results of the nondestructive tests conducted at the exposure sites were compared to actual corrosion of the embedded steel as determined after removal of the concrete cover at the conclusion of the test.

Alloys

1. Unstressed specimens. - Circular coupons [56.7 mm (2.23 inches) in diameter] were exposed on standard corrosion test spools. All wrought alloy specimens were 1.6 mm (0.063 inch) thick and the coupons of cast alloys were 3.2 mm (0.13 inch) thick. Metals and alloys tested are identified in table 2 and mill test data appear in table 3. Test spools were fabricated of Type 316 stainless steel and individual coupons were insulated from the spool and from each other through use of teflon rod insulators and teflon spacers. Duplicate specimens of each alloy were exposed. Spacing between coupons was 13 mm (0.50 inch). The spacers also provided a crevice whereby concentration effects could be evaluated.

Sufficient replicate specimens were exposed such that duplicate specimens could be shipped to the Denver Laboratories for evaluation. Average corrosion rate was computed from weight loss data, and localized corrosion was determined through pit depth measurements. Procedures for preparation of coupons for exposure and cleaning of specimens after exposure are described in the Appendix.

2. Stressed specimens. - In addition to the unstressed circular coupons, stressed specimens of the wrought metals and alloys were also prepared. The stress specimens [200 by 13 by 1.6 mm (8.0 by 0.50 by 0.063 inch)] were bent over a 25-mm (1.0-inch) mandrel and retained in this position to provide plastic deformation as well as high tensile stresses.

Stressed specimens were evaluated by visual examination for cracking.

Rubber and Plastics

Materials selected for exposure are listed in table 4.

Twelve rubber materials were selected for exposure. Duplicate sets of dumbbell-shaped, tensile specimens were cut from each material in accordance with ASTM: D 412. Holes for mounting specimens on the racks were punched 13 mm (0.50 inch) from each end of the specimens. The specimens were then looped (end to end) and retained in this position to provide both stressed and unstressed areas during exposure.

The three flexible plastic sheeting materials were cut into duplicate 25-mm (1.0-inch) wide, parallel edge, tensile test strips in accordance with ASTM: D 882. These specimens were not looped since stress relaxation characteristics of the flexible plastic do not make this appropriate.

TABLE 2. - IDENTIFICATION - ALLOYS

Code No.	Coupon code	Alloy type	Specifications*
A-1	12	Gray cast iron	ASTM: A 48
A-2	7	Mild steel	AISI 1020
A-3	7-CT	Low alloy steel	ASTM: A 606
A-4	21-201	Stainless steel	AISI 201
A-5	18-304	Stainless steel	AISI 304
A-6	18-304S	Stainless steel, sensitized	AISI 304
A-7	19-316	Stainless steel	AISI 316
A-8	19-316S	Stainless steel, sensitized	AISI 316
A-9	13-1	Nickel cast iron	ASTM: A 436
A-10	41-103	Deoxidized copper	ASTM: B 152
A-11	43-6061	Aluminum	AA-6061

* ASTM - American Society for Testing and Materials
AISI - American Iron and Steel Institute
AA - Aluminum Association

TABLE 3a. MILL TEST DATA - ALLOYS
(metric units)

Alloy code No.	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11
Common identification	12	7	7-CT	21-201	18-304	18-304S	19-316	19-316S	13-1	41-103	43-6061
Material No.	-	-	659	75	656	656	657	657	557	665	-
Alloy name	Grey cast iron	Mild steel	Low alloy steel	201 stainless steel	304 stainless steel	304 stainless steel 1/	316 stainless steel	316 stainless steel 1/	Ni-Resist, Type I	Deoxidized copper	Aluminum alloy
Mill	-	-	U.S. Steel	Jorgensen	Fortuna	Fortuna	Ingersoll	Ingersoll	Standard Brass	Standard Brass	-
Heat No.	-	-	041534	-	360792	360792	41019	41019	13620	-	-
Chemical analysis (percent by weight)											
Carbon	-	-	0.10	≥0.15	0.05	0.05	0.07	0.07	2.70	-	-
Manganese	-	-	0.42	5.5-5.75	1.45	1.45	1.55	1.55	1.25	-	-
Phosphorus	-	-	0.10	-	0.026	0.026	0.018	0.018	-	-	-
Sulfur	-	-	0.019	-	0.009	0.009	0.003	0.003	-	-	-
Silicon	-	-	0.35	≥1.00	0.70	0.70	0.64	0.64	2.15	-	-
Nickel	-	-	0.11	3.5-5.5	9.10	9.10	13.15	13.15	15.75	-	-
Chromium	-	-	1.06	16.0-18.0	18.50	18.50	16.03	16.03	2.05	-	-
Molybdenum	-	-	-	-	-	-	2.40	2.60	-	-	-
Copper	-	-	0.30	-	-	-	0.13	0.13	6.24	99.90	-
Columbium	-	-	-	-	-	-	-	-	-	-	-
Titanium	-	-	-	-	-	-	-	-	-	-	-
Boron	-	-	-	-	-	-	-	-	-	0.02	-
Cobalt	-	-	-	-	-	-	0.10	0.10	-	-	-
Aluminum	-	-	-	-	-	-	-	-	-	-	-
Physical properties											
Tensile strength MPa	-	-	493.6	793.0	642.3	642.3	592.2	592.2	-	228.4	-
Yield strength MPa	-	-	381.2	276.6	343.2	343.2	266.1	266.1	-	68.9	-
Elongation Percent in 50 mm	-	-	31	-	-	-	-	-	-	-	-

1/ Sensitized.

TABLE 3b. MILL TEST DATA - ALLOYS
(English units)

Alloy code No.	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11
Coupon identification	12	7	7-CT	21-201	18-304	18-304S	19-316	19-316S	13-1	41-103	43-6061
Material No.	-	-	659	75	656	656	657	657	557	665	-
Alloy name	Gray cast iron	Mild steel	Low alloy steel	201 stainless steel	304 stainless steel	304 stainless steel 1/	316 stainless steel	316 stainless steel 1/	Ni-Resist, Type I	Deoxidized copper	Alumin alloy
Mill	-	-	U.S. Steel	Jorgenson	Fortuna	Fortuna	Ingersoll	Ingersoll	Standard Brass	Standard Brass	-
Heat No.	-	-	041534	-	360792	360792	41019	41019	13620	-	-
Chemical analysis (% by weight)											
Carbon	-	-	0.10	≥0.15	0.05	0.05	0.07	0.07	2.70	-	-
Manganese	-	-	0.42	5.5-5.75	1.45	1.45	1.55	1.55	1.25	-	-
Phosphorus	-	-	0.10	-	0.026	0.026	0.018	0.018	-	-	-
Sulfur	-	-	0.019	-	0.009	0.009	0.003	0.003	-	-	-
Silicon	-	-	0.35	≥1.00	0.70	0.70	0.64	0.64	2.15	-	-
Nickel	-	-	0.11	3.5-5.5	9.10	9.10	13.15	13.15	15.75	-	-
Chromium	-	-	1.06	16.0-18.0	18.50	18.50	16.03	16.03	2.05	-	-
Molybdenum	-	-	-	-	-	-	2.40	2.40	-	-	-
Copper	-	-	0.30	-	-	-	0.13	0.13	6.24	99.98	-
Columbium	-	-	-	-	-	-	-	-	-	-	-
Titanium	-	-	-	-	-	-	-	-	-	-	-
Boron	-	-	-	-	-	-	-	-	-	0.02	-
Cobalt	-	-	-	-	-	-	0.10	0.10	-	-	-
Aluminum	-	-	-	-	-	-	-	-	-	-	-
Physical properties											
Tensile strength (lb/in^2)	-	-	71,445	115,000	93,163	93,163	85,900	85,900	-	33,000	-
Yield strength (lb/in^2)	-	-	55,295	40,000	49,782	49,782	38,600	38,600	-	10,000	-
Elongation (% in 2 in.)	-	-	31	-	-	-	-	-	-	-	-

1/ Sensitized

TABLE 4. IDENTIFICATION - RUBBER AND PLASTIC MATERIALS

Rubber Sheeting

R-5	Neoprene - Gaco Western, Inc.
R-8	EPDM - Carlisle Tire and Rubber Company
R-17	Butyl - Carlisle Tire and Rubber Company
R-18	CSPE - Gaco Western, Inc.
R-25	Natural - Goodyear Tire and Rubber Company
R-27	Polyacrylate - Thiokol Chemical Corporation
R-29	Butyl - Gates Rubber Company
R-30	EPDM - Gates Rubber Company
R-31	Butyl-EPDM blend - Presstite Division, Interchemical Corporation
R-32	Silicone - Dow Corning Corporation
R-34	Nitrile Butadiene - B. F. Goodrich Chemical Company
R-532	Silicone - General Electric Company

Plastic Sheeting

B-6273	CSPE - Reeves Brothers, Inc.
B-6475	CPE - Goodyear Tire and Rubber Company
B-6514	PVC - Pantasote Plastics Company

Fabric Reinforced Flexible Sheeting

B-6386	Nylon reinforced CSPE - Burke Rubber Company
B-6399	Nylon reinforced EPDM - Firestone Coated Fabrics Company
B-6464	Nylon reinforced Butyl - Plymouth Rubber Company, Inc.
B-6467	Nylon reinforced CPE - Snyder Manufacturing Company
B-6468	Nylon reinforced CPE - Snyder Manufacturing Company

Rigid Polymers

RS-1	Epoxy-fiberglass - Shell Chemical Company
RS-2	Polyester-fiberglass - Atlas Chemical Industries, Inc.
RS-3	Vinyl-fiberglass - Dow Chemical Company
RS-4	RPM pipe - Johns-Manville Corporation
RS-5	HDPE - Hancor, Inc.

EPDM - Ethylene Propylene Diene Monomer
CSPE - Chlorosulfonated Polyethylene
CPE - Chlorinated Polyethylene
PVC - Polyvinyl Chloride
RPM - Reinforced Plastic Mortar
HDPE - High Density Polyethylene

The five, fabric-reinforced, flexible synthetic materials were cut into 76- by 100-mm (3.0- by 4.0-inch) specimens for hydrostatic pressure testing according to ASTM: D 751, diaphragm burst method.

These specimens were also exposed in a looped condition to provide both stressed and unstressed areas.

Four rigid, fiberglass-reinforced polymers were cut into 51- by 150-mm (2.0- by 6.0-inch) samples for exposure. Edges of the exposed specimens were sealed with epoxy cement to reduce possible wicking in the reinforcement. Upon removal from exposure, these were bisected and trimmed to produce 13- by 150-mm (0.50- by 6.0-inch) specimens for flexure testing in accordance with ASTM: D 790, Method I.

High-density, polyethylene drain tubing samples were cut into 100-mm (4.0-inch) long specimens for visual examination.

The rubber and plastic materials were visually inspected at the time of removal from the exposure environment and then shipped to the laboratory for testing. In the laboratory the specimens were photographed and washed. Vapor specimens were hand dried and placed in an atmosphere of 50 percent relative humidity and 23°C for a minimum of 3 hours before testing. Interface and liquor specimens were immersed in fresh water after washing and maintained wet until 2 minutes (maximum) before testing.

Protective Coatings

Initially, nine coating systems were selected for exposure. However, six additional materials were introduced during the course of the test. Some of these, as appropriate, were applied to both metal (mild steel) and concrete (cement mortar) substrates. Metal panels were 150 by 150 by 3.0 mm (6.0 by 6.0 by 0.13 inch) and the concrete panels were 150 by 150 by 25 mm (6.0 by 6.0 by 1.0 inch). The systems applied are shown in table 5.

Surface preparation of the steel panels was by sandblasting to white metal; whereas, the concrete specimens were lightly sandblasted and sack-rubbed with a portland cement-sand grout prior to coating.

Specific application data are contained in table 6.

The coating was scored in an X pattern on one 150- by 150-mm (6.0- by 6.0-inch) surface of each panel to determine effects of discontinuities. In addition to the 15 coating systems exposed on panels, the racks used to expose the test specimens at site 1 were hot dip galvanized to provide a test of this coating material.

Evaluation was accomplished by periodic visual observation at the test site, and visual examination in the Denver Laboratories at the end of the exposure.

TABLE 5. IDENTIFICATION - PROTECTIVE COATINGS SYSTEMS

Code No.	Generic type	Materials specifications	Manufacturer	Manufacturers designation	Tested on	
					Steel	Concrete
C-1	Vinyl resin	USBR VR-3	Ameron	Amercoat 33	X	X
C-2	Vinyl resin	USBR VR-6	Ameron	Amercoat 23	X	
C-3	Coal-tar enamel	AWWA C-203	Koppers Co.	Bitumastic 70B	X	X
C-4	Coal-tar epoxy	Mil-P-23236, Type I, Class 2	Porter Coatings	Tarset Standard	X	X
C-5	Butyl	-	U.S. Polymeric	PC-8152	X	X
C-6	Butyl	-	Enjay	6120	X	X
C-7	Urethane	-	Carboline	X 1304-146		X
C-8	Phenolic	-	Carboline	Phenoline 368WG	X	
C-9	Urethane	-	Crandalon	Crandalon	X	X
C-10*	Anodizing	-	CHN Anodizing	Anodized	X	
C-11**	Zinc	ASTM: A 123	Boyles Galvanizing	Hot-dip galvanize	X	
C-12*	Phenolic epoxy	-	Wisconsin Protective Coatings	Plasite 7122	X	X
C-13*	Urethane	-	Grove Specialties	Monopol GS-300	X	X
C-14*	Urethane	-	United Paint	Uni-Tile	X	X
C-15*	Urethane	-	Gaco Western	VWM-28		X
C-16*	Phenolic epoxy	-	Wisconsin Protective Coatings	Plasite 7155 HHB	X	X

* Exposed at sites 1 and 2 only.
** Exposed at site 1 only.

TABLE 6a. APPLICATION DATA - PROTECTIVE COATING SYSTEMS (metric units)

Code No.	Substrate	Application data	Application method	Total dry film thickness (mm)
C-1	Steel	Four coats	Brush	0.15
	Concrete	First coat thinned 1:1 with vinyl thinner + three coats	Brush	0.15
C-2	Steel	Primer + three body coats + two seal coats	Brush	0.25
C-3	Steel	Primer + one coat	Dip	2.54
	Concrete	Primer + one coat	Dip	2.54
C-4	Steel	Three coats	Brush	0.50
	Concrete	First coat thinned 1:1	Brush	0.50
C-5	Steel	Primer + two topcoats	Brush	0.38
	Concrete	Primer + two topcoats	Brush	0.38
C-6	Steel	Two coats	Brush	0.45
	Concrete	Two coats	Brush	0.45
C-7	Concrete	Primer + topcoat; topcoat thinned one pint/gallon of paint with 1:1 xylol/MEK mixture	Brush	0.50
C-8	Steel	Primer (thinned 1 pint/gallon with 2:1 xylol/MEK mixture) + two topcoats	Brush	0.50
C-9	Steel	Airless spray application by manufacturer	Spray	0.76
	Concrete	Airless spray application by manufacturer	Spray	0.76
C-10	Steel	Electrochemical application to galvanized panels by manufacturer	-	-
C-11	Steel	Hot-dip galvanized	Hot dip	0.07
C-12	Steel	Five coats	Brush	0.38
	Concrete	First coat (thinned 1:1 with manufacturer's thinner) + four coats	Brush	0.38
C-13	Steel	Three coats	Brush	0.88
	Concrete	Three coats	Brush	0.88
C-14	Steel	Primer + one topcoat	Brush	0.38
	Concrete	Primer + one topcoat	Brush	0.38
C-15	Concrete	One coat	Brush	0.38-0.50
C-16	Steel	Three coats	Brush	0.30
	Concrete	First coat (thinned 1:1 with manufacturer's thinner + two topcoats	Brush	0.30

TABLE 6b. APPLICATION DATA - PROTECTIVE COATING SYSTEMS (English units)

Code No.	Substrate	Application data	Application method	Total dry film thickness, (mils)
C-1	Steel	Four coats	Brush	6
	Concrete	First coat thinned 1:1 with vinyl thinner + three coats	Brush	6
C-2	Steel	Primer + three body coats + seal coat	Brush	10
C-3	Steel	Primer + one coat	Dip	100
	Concrete	Primer + one coat	Dip	100
C-4	Steel	Three coats	Brush	20
	Concrete	First coat thinned 1:1 with xylene	Brush	20
C-5	Steel	Primer + two topcoats	Brush	15
	Concrete	Primer + two topcoats	Brush	15
C-6	Steel	Two coats	Brush	18
	Concrete	Two coats	Brush	18
C-7	Concrete	Primer + topcoat; topcoat thinned 1 pint/gallon of paint with 1:1 xylol/MEK mixture	Brush	20
C-8	Steel	Primer (thinned 1 pint/gallon with 2:1 xylol/MEK mixture) + two topcoats	Brush	20
C-9	Steel	Airless spray application by manufacturer	Spray	30
	Concrete	Airless spray application by manufacturer	Spray	30
C-10	Steel	Electrochemical application to galvanized panels by manufacturer	-	-
C-11	Steel	Hot-dip galvanized	Hot dip	3
C-12	Steel	Five coats	Brush	15
	Concrete	First coat (thinned 1:1 with manufacturer's thinner) + four coats	Brush	15
C-13	Steel	Three coats	Brush	35
	Concrete	Three coats	Brush	35
C-14	Steel	Primer + one topcoat	Brush	15
	Concrete	Primer + one topcoat	Brush	15
C-15	Concrete	One coat	Brush	15-20
C-16	Steel	Three coats	Brush	12
	Concrete	First coat (thinned 1:1 with manufacturer's thinner) + two topcoats	Brush	12

Joint Sealers

Initially three synthetic rubber, joint sealing materials were exposed, a polysulfide, a polyurethane, and a silicone, all two-component sealers conforming to the physical test requirements of Federal Specification TT-S-227. During the course of the tests, two additional materials were exposed, a coal-tar extended polysulfide material conforming to USBR specifications and normally used for sealing contraction joints in concrete canal lining, and a single-component, low modulus silicone sealant. The sealers exposed are listed in table 7. These materials were cast in a 150- by 13- by 13-mm (6.0- by 0.50- by 0.50-inch) joint formed by two concrete (cement mortar) slabs.

Two specimens of each sealer were prepared for exposure in each zone. After curing, one specimen was extended 25 percent to a joint width of 16 mm (0.63 inch) and the other compressed 25 percent to 9.5-mm (0.38-inch) joint width.

Evaluation was accomplished by visual observation for adhesive or cohesive failure as well as for surface degradation.

TABLE 7. IDENTIFICATION - JOINT SEALERS

Code No.	Generic type	Manufacturer	Manufacturer's designation	No. of Components	Specifications
S-1	Silicone	General Electric Company	GE-1600	2	TT-S-227
S-2	Urethane	PRC Corporation	PRC No. 4 primer		
			PRC 270 sealant	2	TT-S-227
S-3	Polysulfide	W. R. Grace Company	2C primer	2	
			Hornflex L sealant	2	TT-S-227
S-4	Silicone	General Electric Company	GE-Silpruf	1	-
S-5	Coal-tar polysulfide	American Polytherm Company	TRP-409 primer	1	
			Poly-Seal E-4	2	USBR Class S canal sealer

SECTION 6

TEST RESULTS

Concrete

1. Compressive strength. - Compressive strength test results are shown in tables 8, 9, and 10.

a. Conventional concretes made using Types II and V cement show no loss of strength at any exposure site.

b. PIC specimens showed large variations in strength under most exposure conditions. For sites 2 and 3, all exposures resulted in loss of strength.

2. Length change. - Length change results are shown in tables 11, 12, and 13. Table 14 and figures 9, 10, and 11 show the effect of immersion in tap water on weight increase of the control specimens.

a. Conventional concretes made using Types II and V cement show no continuing tendency to increase in length. Increases in lengths were also well below the 0.2 percent generally accepted by the Bureau as indicative of impending failure from sulfate attack. (Complete failure by sulfate attack is considered to be 0.5 percent expansion.)

b. The effect of site exposures and laboratory immersion on the lengths of the PIC specimens are shown in figures 12, 13, and 14. The specimens continue to increase in length with duration of exposure. Although much less water is absorbed by the PIC specimens than the two conventional concretes, their increase in length after 22 and 28 months of exposure is of the same order of magnitude as the conventional concretes.

3. Surface conditions. - Generally, only minor changes in surface appearance have occurred at sites 1 and 2. At site 3, erosion of the surface was experienced as shown in figure 15.

a. Concrete made with Type V cement suffered the most severe erosion damage.

b. Less severe erosion damage was observed on concrete made using Type II cement.

c. PIC was only slightly altered in appearance by the erosion.

TABLE 8a. CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 1*
(metric units)

Concrete type	Nominal exposure time, mo.	Compressive strength (MPa) (average of duplicate specimens)				
		Site exposure			Laboratory exposure**	
		Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
Type II cement	0***				32.6	
(28 day strength -	3	41.6	38.3	38.6	34.1	39.0
31.0 MPa)	10	53.2	48.8	50.0	34.0	40.3
	22	51.6#	53.0#	49.1#	35.3	46.0
Type V cement	0***				31.9	
(28 day strength -	3	35.6	32.5	33.8	35.2	35.0
29.0 MPa)	10	46.5	46.0	45.5	40.3	41.4
	22	49.2##	48.8#	45.2#	36.1	42.2
Type II cement	0***				144.1	
polymer	3	123.0	127.8	127.1	151.8	139.1
impregnated###	10	115.4	132.9	83.4	132.9	99.9
	22	93.6#	130.0#	114.0#	142.2	114.9

* Tapia Water Reclamation Facility, Calabasas, California.

** E&R Center Laboratories, USBR, Denver, Colorado.

*** Concrete age when specimens first exposed: 3 months.

\# Based on four specimens.

\## Based on three specimens.

\### Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength.

TABLE 8b. CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 1*
(English units)

Concrete type	Nominal exposure time, mo.	Compressive strength (lb/in^2) (average of duplicate specimens)				
		Site exposure			Laboratory exposure**	
		Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
Type II cement (28 day strength - 4500 lb/in^2)	0***				4,730	
	3	6,040	5,560	5,600	4,950	5,650
	10	7,710	7,080	7,250	4,930	5,850
	22	7,490#	7,680#	7,120#	5,120	6,620
Type V cement (28 day strength - 4200 lb/in^2)	0***				4,620	
	3	5,160	4,720	4,900	5,110	5,080
	10	6,740	6,670	6,600	5,840	6,010
	22	7,140##	7,080#	6,550#	5,235	6,120
Type II cement polymer impregnated###	0***				20,900	
	3	17,840	18,530	18,440	22.010	20,170
	10	16,740	19,270	12,090	19,270	14,490
	22	13,580#	18,860#	16,530	20,620	16,660

* Tapia Water Reclamation Facility, Calabasas, California.

** E&R Center Laboratories, USBR, Denver, Colorado.

*** Concrete age when specimens first exposed: 3 months.

\# Based on four specimens.

\#\# Based on three specimens.

\#\#\# Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength.

TABLE 9a. CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 2*
(metric units)

Concrete type	Nominal exposure time, mo.	Compressive strength (MPa) (average of duplicate specimens) Site exposure Gas	Site exposure Interface	Site exposure Liquor	Laboratory exposure** 50 percent relative humidity, 73°F	Laboratory exposure** Denver tap water, room temperature
Type II cement (28 day strength - 31.0 MPa)	0***				26.8	
	10	42.9	39.9	45.1	34.5	41.0
	28	44.1#	40.4#	43.6#	38.3	45.3
Type V cement (28 day strength - 29.0 MPa)	0***				29.5	
	10	40.1	40.4	39.0	34.5	38.1
	28	39.2#	41.2#	42.4#	36.8	40.3
Type II cement polymer impregnated##	0***				138.5	
	10	103.1	115.6	106.0	126.7	108.0
	28	109.0#	102.7#	118.4#	107.4	77.5

* Speedway Wastewater Treatment Plant, Indianapolis, Indiana.

** E&R Center Laboratories, USBR, Denver, Colorado.

*** Concrete age when specimens first exposed: 8 months.

\# Based on length change specimen with inserts sawed off, results corrected to length/diameter - 2.0.

\## Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength.

TABLE 9b. CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 2*
(English units)

Concrete type	Nominal exposure time, mos.	Compressive strength (lb/in^2) (average of duplicate specimens)				
		Site exposure			Laboratory exposure**	
		Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
Type II cement (28 day strength - 4500 lb/in^2)	0***				3,890	
	10	6,220	5,780	6,540	5,000	5,950
	28	6,390#	5,860#	6,320	5,550	6,570
Type V cement (28 day strength - 4200 lb/in^2)	0***				4,280	
	10	5,820	5,860	5,660	5,000	5,530
	28	5,680#	5,960#	6,150#	5,340	5,840
Type II cement polymer impregnated##	0***				20,090	
	10	14,950	16,760	15,380	18,370	15,670
	28	15,810#	14,890#	17,170#	15,580	11,240

* Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
** E&R Center Laboratories, USBR, Denver, Colorado.
*** Concrete age when specimens first exposed: 8 months.
\# Based on length change specimen with inserts sawed off, results corrected to length/diameter - 2.0.
\## Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength.

TABLE 10a. - CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 3*
(metric units)

		Compressive strength (MPa) (average of duplicate specimens)				
		Site exposure			Laboratory exposure**	
Concrete type	Nominal exposure time, mo.	Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
Type II cement	0***				29.6	
(28 day strength -	10	41.2	41.8	38.2	31.0	38.45
31.0 MPa)	28	47.9	47.3	45.5	35.2	38.2
	28	45.9#	43.4#	46.1#		
Type V cement	0***				29.8	
(28 day strength -	10	42.7	40.4	41.3	32.5	37.5
29.0 MPa)	28	49.1	46.5	48.2	38.5	40.3
	28	49.4#	45.8#	44.7#		
Type II cement	0***				129.8	
polymer	10	116.0	129.2	92.2	118.6	74.5
impregnated##	28	119.9	81.6	89.3	121.7	110.6
	28	112.7#	115.5#	118.4#		

* Westgate Wastewater Treatment Plant, Alexandria, Virginia

** E&R Center Laboratories, USBR, Denver, Colorado.

*** Concrete age when specimens first exposed: 8 months.

\# Based on length change specimen with inserts sawed off, results corrected to length/diameter - 2.0.

\## Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength.

TABLE 10b. CONCRETE COMPRESSIVE STRENGTH TEST RESULTS - SITE 3*
(English units)

Concrete type	Nominal exposure time, mos.	Compressive strength (lb/in^2) (average of duplicate specimens)				
		Site exposure			Laboratory exposure**	
		Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
Type II cement (28 day strength - 4500 lb/in^2)	0***				4,300	
	10	5,980	6,060	5,540	4,500	5,580
	28	6,950	6,880	6,600	5,110	5,540
	28	6,660#	6,300#	6,680#		
Type V cement (28 day strength - 4200 lb/in^2)	0***				4,320	
	10	6.200	5,860	5,990	4,720	5,440
	28	7,120	6,750	6,990	5,590	5,850
	28	7,170#	6,640#	6,490#		
Type II cement polymer impregnated##	0***				18,820	
	10	16,830	18,740	13,370	17,200	10,810
	28	17,390	11,830	12,950	17,655	16,040
	28	16,340#	16,750#	17,170#		

* Westgate Wastewater Treatment Plant, Alexandria, Virginia

** E&R Center Laboratories, USBR, Denver, Colorado.

*** Concrete age when specimens first exposed: 8 months.

\# Based on length change specimens with inserts sawed off, results corrected to length/diameter - 2.0.

\#\# Strength before impregnation has little effect on final strength, and after impregnation, additional cure time does not increase strength.

TABLE 11. CONCRETE LENGTH CHANGE TEST RESULTS - SITE 1*

Concrete type**	Nominal exposure time, mo.	Length change, percent***				
		Site exposure			Laboratory exposure#	
		Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
II	3	0.043	0.056	##	-0.009	0.042
	10	0.050	0.070	0.098	-0.009	0.050
	22	0.022	0.048	0.056	-0.008	0.053
V	3	0.036	0.048	##	-0.009	0.035
	10	0.046	0.050	0.076	-0.004	0.037
	22	0.041	0.034	0.062	-0.005	0.040
P	3	0.006	0.016	##	-0.005	0.003
	10	0.031	0.036	0.037	0.003	0.021
	22	0.053	0.053	0.050	0.008	0.046

* Tapia Water Reclamation Facility, Calabasas, California.

** II - Concrete made using type II cement.
V - Concrete made using type V cement.
P - Polymer-impregnated concrete made using type II cement.

*** Percent gain (positive values) or loss (negative values) in length as compared to original length determined at time of exposure, average of three replicate specimens.

\# E&R Center Laboratories, USBR, Denver, Colorado.

\## Specimens could not be removed from exposure to determine their lengths after 3 months' exposure.

TABLE 12. CONCRETE LENGTH CHANGE TEST RESULTS - SITE 2*

Concrete type**	Nominal exposure time, mo.	Length change, percent***				
		Site exposure#			Laboratory## exposure###	
		Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
II	3	0.051	0.060	0.051	0.000	0.046
	10	0.059	0.066	0.056	-0.003	0.040
	20	0.068	0.061	0.056	-0.002	0.042
	28	0.068	0.079	0.054	-0.018	0.028
V	3	0.046	0.053	0.056	0.001	0.046
	10	0.056	0.047	0.057	-0.001	0.037
	20	0.063	0.043	0.053	-0.001	0.045
	28	0.074	0.054	0.063	-0.021	0.042
P	3	0.010	0.018	0.008	0.009	0.019
	10	0.028	0.027	0.013	0.010	0.021
	20	0.060	0.043	0.018	0.015	0.039
	28	0.078	0.067	0.034	0.012	0.047

* Speedway Wastewater Treatment Plant, Indianapolis, Indiana

** II - Concrete made using type II cement.
V - Concrete made using type V cement.
P - Polymer impregnated concrete made using type II cement.

*** Percent gain (positive values) or loss (negative values) in length as compared to original length determined at time of exposure.

\# Average of two replicate specimens.

\## E&R Center Laboratories, USBR, Denver, Colorado.

\### Average of three replicate specimens.

TABLE 13. CONCRETE LENGTH CHANGE TEST RESULTS - SITE 3*

Concrete type**	Nominal exposure time, mo.	Length change, percent***				
		Site exposure#			Laboratory## exposure###	
		Gas	Interface	Liquor	50 percent relative humidity, 73°F	Denver tap water, room temperature
II	3	0.059	0.055	0.055	0.001	0.045
	10	0.060	0.065	0.066	-0.003	0.042
	20	0.060	0.054	0.066	-0.007	0.046
	28	0.069	‡	0.076	-0.013	0.048
V	3	0.049	0.049	0.056	0.005	0.043
	10	0.053	0.044	0.057	-0.003	0.036
	20	0.053	‡	0.053	-0.009	0.052
	28	0.059	‡	0.063	-0.012	0.025
P	3	0.015	0.023	0.011	0.007	0.011
	10	0.029	0.031	0.028	0.017	0.030
	20	0.042	0.054	0.043	0.011	0.062
	28	0.076	0.081	0.068	0.005	0.070

* Westgate Wastewater Treatment Plant, Alexandria, Virginia

** II - Concrete made using type II cement.
V - Concrete made using type V cement.
P - Polymer-impregnated concrete made using type II cement.

*** Percent gain (positive values) or loss (negative values) in length as compared to original length determined at time of exposure.

\# Average of two replicate specimens.

\## E&R Center Laboratories, USBR, Denver, Colorado.

\### Average of three replicate specimens.

‡ Embedded metal inserts were loosened by exposure such that length determination could not be made.

TABLE 14. CONCRETE LENGTH CHANGE TEST RESULTS -LABORATORY* EXPOSURES

Concrete type**	Control specimens for site***	Nominal exposure time, mo.	Weight change#			
			50 percent humidity, 73°F		Denver tap water room temperature	
			Grams	Percent	Grams	Percent
II	1	3	-3.7	-0.24	57.7	3.80
		10	-1.0	-0.07	61.4	4.04
		22	2.3	0.15	62.5	4.12
	2	3	1.0	0.06	68.2	4.49
		10	3.0	0.19	71.4	4.70
		20	4.0	0.26	71.5	4.70
		28	7.7	0.50	73.7	4.85
	3	3	0.9	0.06	70.2	4.62
		10	2.6	0.17	73.6	4.84
		20	3.9	0.26	74.0	4.87
		28	7.3	0.48	76.0	5.00
V	1	3	-4.8	-0.32	57.0	3.70
		10	-2.6	-0.17	59.8	3.88
		22	1.3	0.08	61.3	3.97
	2	3	2.6	0.17	65.6	4.24
		10	4.7	0.31	66.6	4.31
		20	6.6	0.43	67.0	4.33
		28	10.0	0.66	69.0	4.46
	3	3	0.6	0.04	67.1	4.37
		10	2.6	0.17	69.2	4.51
		20	3.8	0.24	69.5	4.52
		28	7.3	0.48	71.8	4.68
P	1	3	-1.7	-0.11	11.3	0.71
		10	0.0	0.00	12.4	0.78
		22	2.4	0.14	18.1	1.14
	2	3	1.2	0.08	9.9	0.62
		10	1.9	0.12	17.4	1.10
		20	1.9	0.12	20.2	1.27
		28	3.8	0.24	23.2	1.46
	3	3	0.6	0.04	11.4	0.72
		10	1.4	0.09	15.0	0.94
		20	1.2	0.07	17.0	1.07
		28	4.0	0.25	20.7	1.30

* E&R Center Laboratories, USBR, Denver, Colorado.

** II - Concrete made using type II cement.
V - Concrete made using type V cement.
P - Polymer-impregnated concrete made using type II cement.

*** 1 - Tapia Water Reclamation Facility, Calabasas, California
2 - Speedway Wastewater Treatment Plant, Indianapolis, Indiana
3 - Westgate Wastewater Treatment Plant, Alexandria, Virginia

\# Gain (positive values) or loss (negative values) in grams and percent based on the original weight determined at time of exposure.

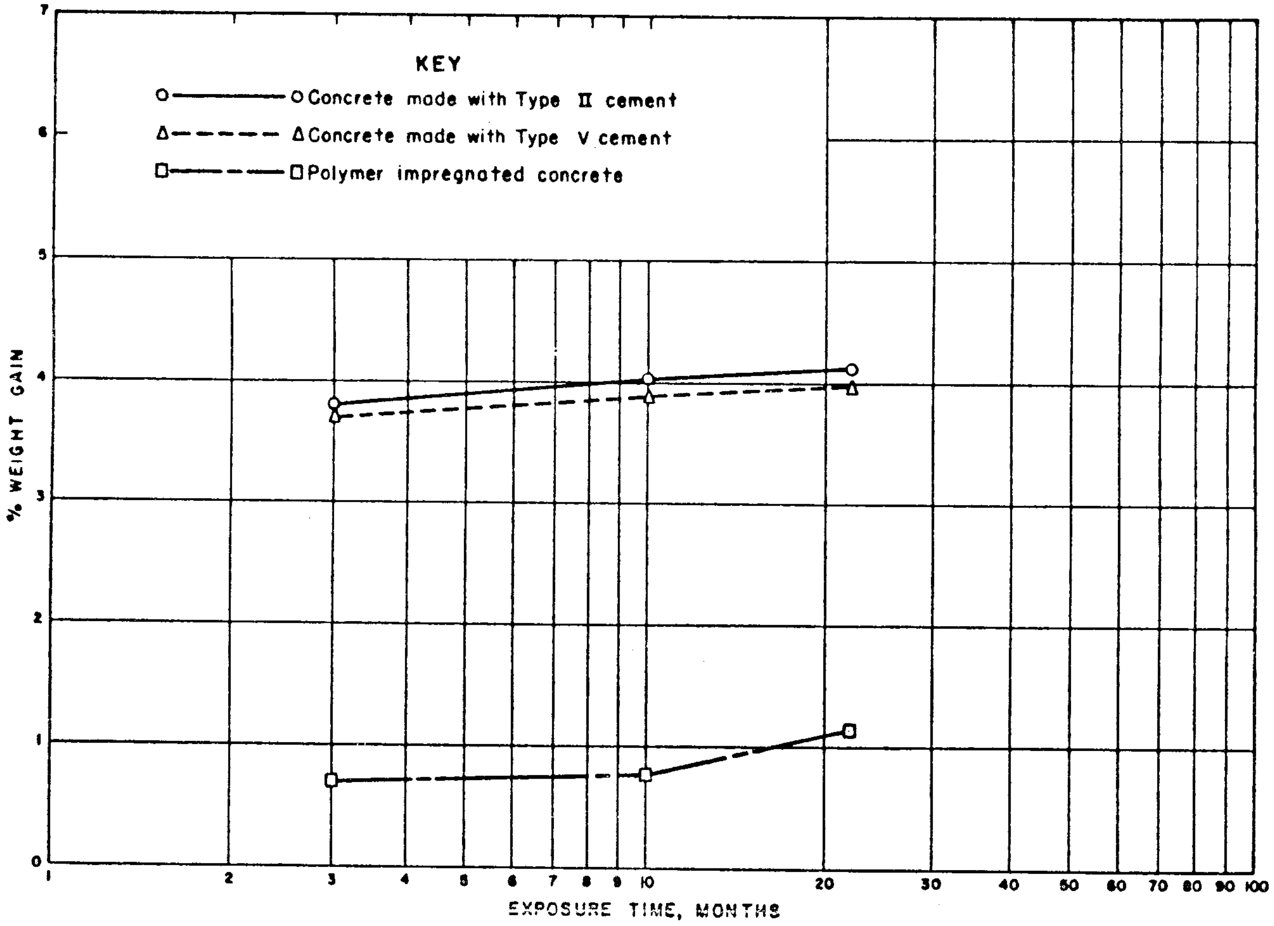

FIGURE 9. EFFECT OF IMMERSION IN DENVER TAP WATER ON ABSORPTION BY SITE I CONCRETE CONTROL SPECIMENS

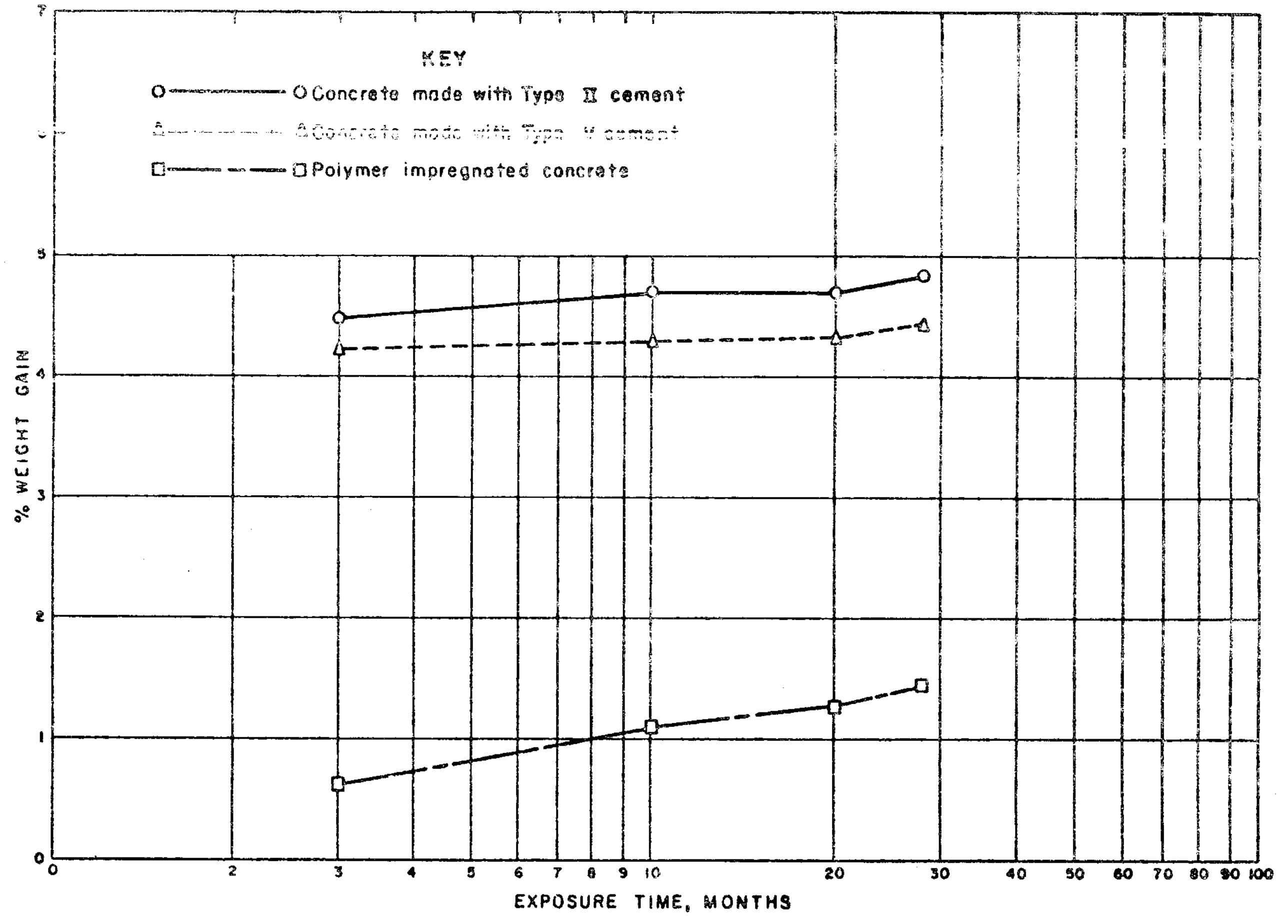

FIGURE 10. EFFECT OF IMMERSION IN DENVER TAP WATER ON ABSORPTION BY SITE 2 CONCRETE CONTROL SPECIMENS

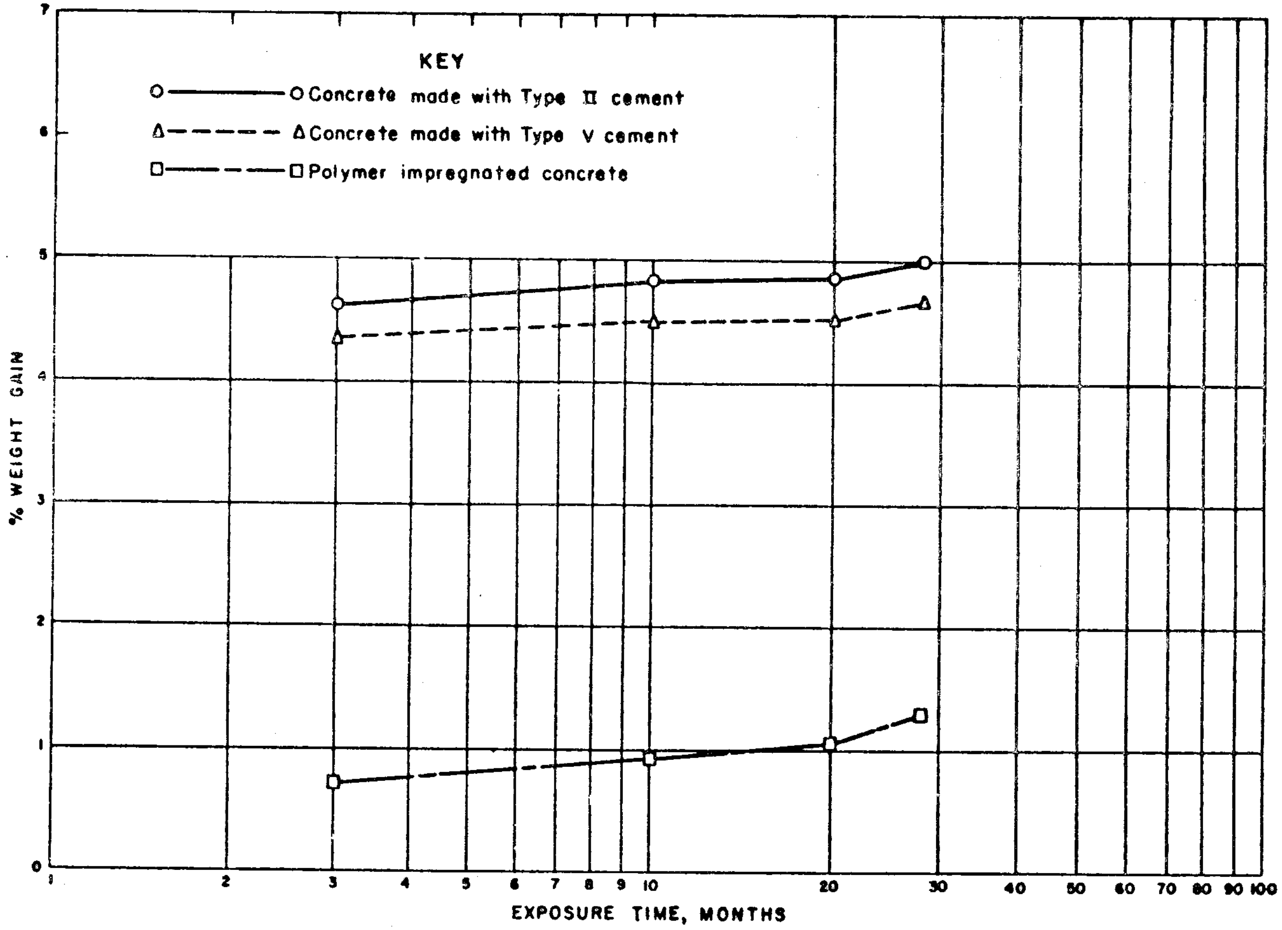

FIGURE 11. EFFECT OF IMMERSION IN DENVER TAP WATER ON ABSORPTION BY SITE 3 CONCRETE CONTROL SPECIMENS

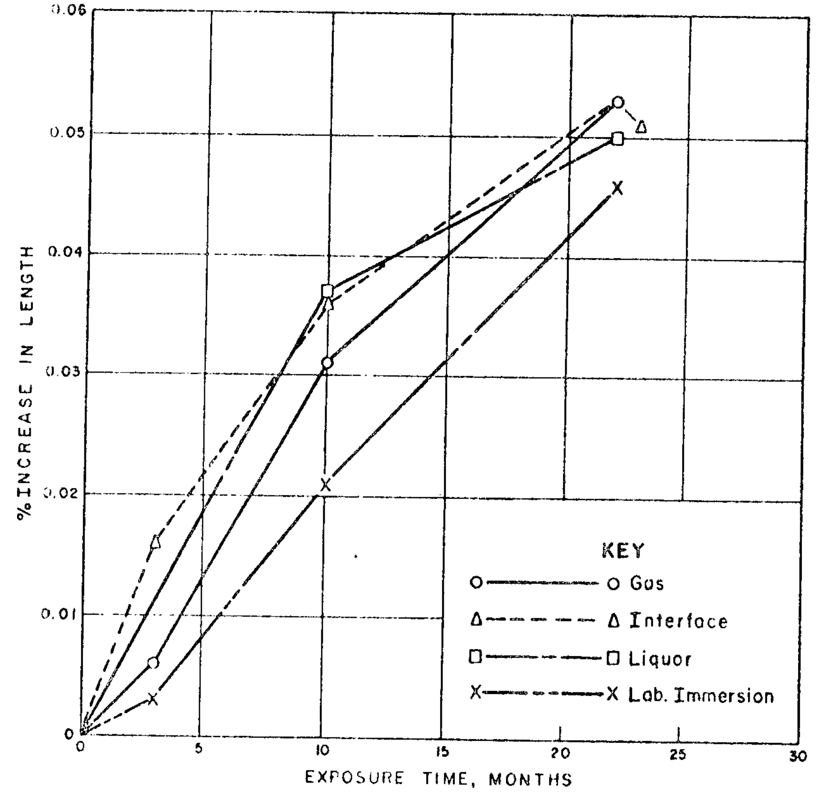

FIGURE 12. EFFECT OF SITE I EXPOSURE AND LABORATORY IMMERSION EXPOSURE ON LENGTH OF POLYMER IMPREGNATED CONCRETE

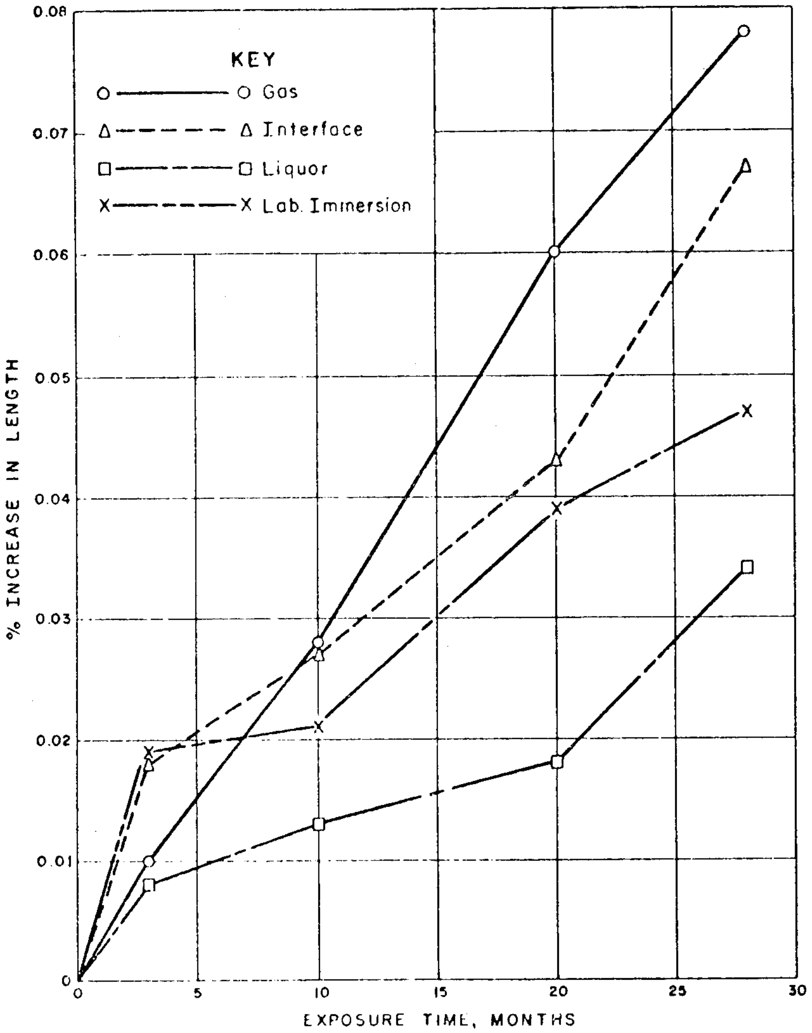

FIGURE 13. EFFECT OF SITE 2 EXPOSURES AND LABORATORY IMMERSION ON LENGTH OF POLYMER IMPREGNATED CONCRETE

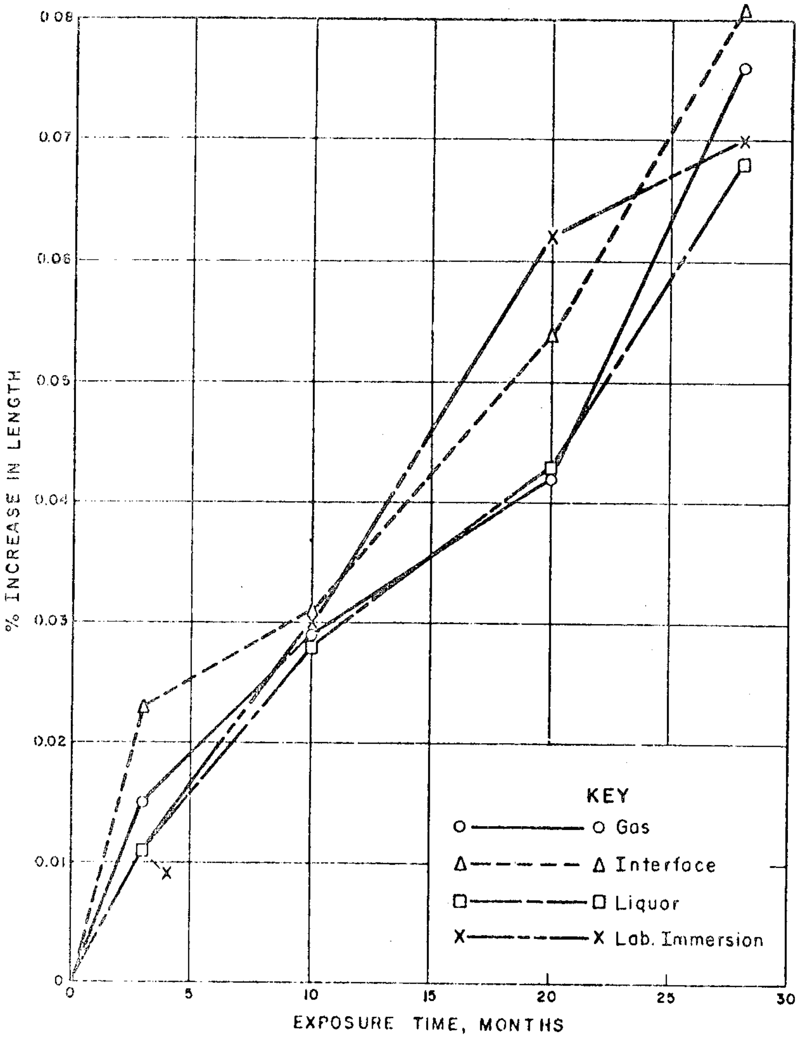

FIGURE 14 EFFECT OF SITE 3 EXPOSURES AND LABORATORY IMMERSION EXPOSURE ON LENGTH OF POLYMER IMPREGNATED CONCRETE

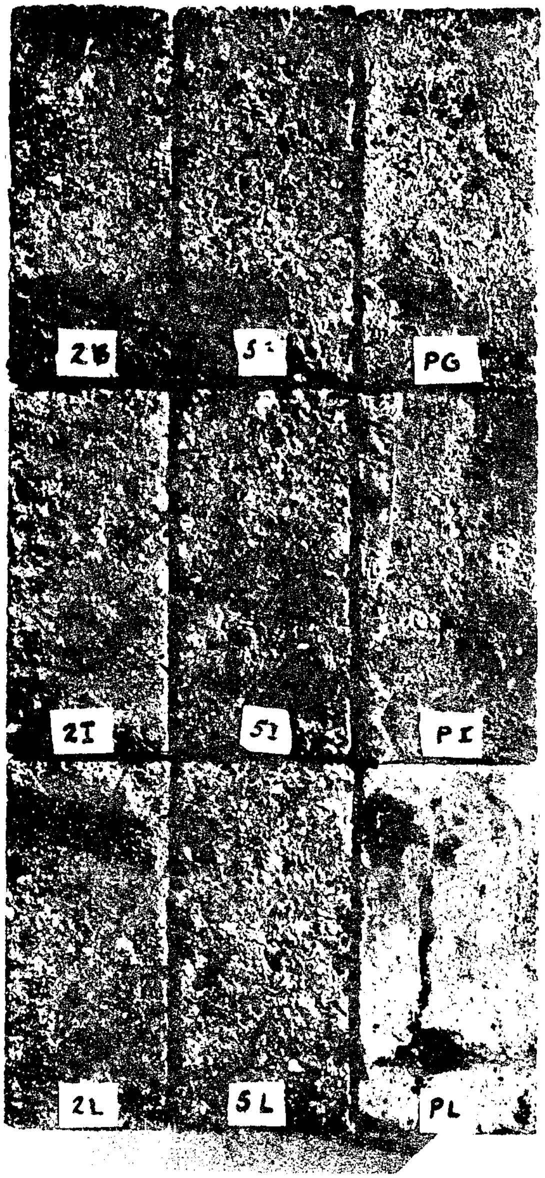

Figure 15. - Concrete prisms exposed at site 3 for 28 months depict the damage due to surface abrasion. Prefix of specimen code denotes concrete type, i.e., 2-Type II, 5-Type V, and P-PIC; suffix indicates exposure, i.e., G-gas, I-interface, L-liquor.

Steel Embedded in Concrete

These results are listed in tables 15, 16, and 17. The corrosion rates of steel embedded in concrete, as determined by steel-to-electrolyte potentials and polarization tests and as verified by visual examination of the steel after removal of the concrete cover at the end of the test, were found to be so low as to be insignificant.

Alloys

1. Unstressed specimens. - Average corrosion rate, maximum pit depth, and crevice corrosion results appear in tables 18, 19, and 20. The evaluation of the data has been summarized in table 21. Alloys were evaluated by assigning ratings based on their overall performance in all three exposure zones of all three test sites. The ratings were assigned in accordance with criteria shown in the table below:

Average corrosion rate (x)		Maximum pitting rate (y)		Rating
µm/yr	mils/yr	µm/yr	mils/yr	
$x<3$	$x<0.1$	$y<3$	$y<0.1$	1
$3 \le x<25$	$0.1 \le x<1.0$	$3 \le y<25$	$0.1 \le y<1.0$	2
$25 \le x<254$	$1.0 \le x<10.0$	$25 \le y<254$	$1.0 \le y<10.0$	3
$x \ge 254$	$x \ge 10.0$	$y \ge 254$	$y>10.0$	4

Figures 16 through 21 show typical corrosion of exposed specimens.

The alloys are rated as follows according to their performance in all three exposure zones at the three test sites:

a. Highly resistant (rating of 1.0)

   (1) Stainless steel, Type 201 (Alloy A-4)
   (2) Stainless steel, Type 304 (Alloy A-5)
   (3) Stainless steel, Type 316 (Alloy A-7)

b. Moderately resistant ($1.0 <$ rating ≤ 2.0)

   (1) Sensitized stainless steel, Type 304 (Alloy A-6)
   (2) Sensitized stainless steel, Type 316 (Alloy A-8)

c. Resistant ($2.0 <$ rating ≤ 3.0)

   (1) Nickel cast iron (Alloy A-9)
   (2) Deoxidized copper (Alloy A-10)

d. Nonresistant (rating > 3.0)

   (1) Gray cast iron (Alloy A-1)
   (2) Mild steel (Alloy A-2)

TABLE 15. TEST RESULTS - STEEL EMBEDDED IN CONCRETE - SITE 1*

Concrete type**	Nominal exposure time, mo	Steel-to-electrolyte potential*** volts			Corrosion rate # (grams/year) x 10^4		
		Gas	Interface	Liquor	Gas	Interface	Liquor
II	3	-0.11	-0.11	-0.25	-	-	-
	10	-0.06	-0.09	-0.05	-	-	-
	22	-0.26	-0.09	-0.30	-	-	-
V	3	-0.12	-0.08	-0.16	-	-	-
	10	-0.14	-0.02	-0.12	-	-	-
	22	-0.07	-0.12	-0.11	-	-	-
P	3	-0.11	-0.16	-0.11	-	-	-
	10	-0.39	-0.17	-0.22	42	-	-
	22	-0.41	-0.09	-0.09	116	-	-

* Tapia Water Reclamation Facility, Calabasas, California.

** II - Concrete made using type II cement.
V - Concrete made using type V cement.
P - Polymer-impregnated concrete made using type II cement.

*** Referenced to copper/copper-sulfate electrode.

\# As determined by polarization tests which were conducted only on those specimens exhibiting potentials more negative than -0.30 volt.

TABLE 16. TEST RESULTS - STEEL EMBEDDED IN CONCRETE - SITE 2*

Concrete type**	Nominal exposure time, mo	Steel-to-electrolyte potential*** volts			Corrosion rate # (grams/year) x 10^4		
		Gas	Interface	Liquor	Gas	Interface	Liquor
II	3	-0.54	-0.51	-0.44	133	277	242
	10	-0.11	-0.19	-0.36	-	-	236
	20	-0.08	-0.21	-0.20	-	-	-
	28	-0.05	-0.19	-0.14	-	-	-
V	3	-0.63	-0.50	-0.53	215	360	270
	10	-0.29	-0.13	-0.22	-	-	-
	20	-0.05	-0.20	-0.23	-	-	-
	28	-0.05	-0.11	-0.19			
P	3	-0.45	-0.54	-0.36	6	124	45
	10	-0.22	-0.40	-0.28	-	132	-
	20	-0.16	-0.26	-0.23	-	-	-
	28	-0.08	-0.26	-0.43	-	-	216

* Speedway Wastewater Treatment Plant, Indianapolis, Indiana.

** II - Concrete made using type II cement.
V - Concrete made using type V cement.
P - Polymer-impregnated concrete made using type II cement.

*** Referenced to copper/copper-sulfate electrode.

\# As determined by polarization tests which were conducted only on those specimens exhibiting potentials more negative than -0.30 volt.

TABLE 17. TEST RESULTS - STEEL EMBEDDED IN CONCRETE - SITE 3*

Concrete type**	Nominal exposure time, mo.	Steel-to-electrolyte potential*** volts			Corrosion rate # (grams/year) x 10^4		
		Gas	Interface	Liquor	Gas	Interface	Liquor
II	3	-0.49	-0.48	-0.49	103	36	103
	10	-0.42	-0.33	-0.41	100	45	97
	20	-0.20	-0.17	-0.27	-	-	-
	28	-0.28	-0.17	-0.27	-	-	-
V	3	-0.48	-0.46	-0.50	39	81	77
	10	-0.40	-0.39	-0.44	46	95	86
	20	-0.20	-0.18	-0.22	-	-	-
	28	-0.11	-0.10	-0.19	-	-	-
P	3	-0.50	-0.52	-0.52	14	6	6
	10	-0.32	-0.38	-0.36	10	84	96
	20	-0.19	-0.24	-0.23	-	-	-
	28	-0.20	-0.33	-0.47	-	87	186

* Westgate Wastewater Treatment Plant, Alexandria, Viriniga.

** II - Concrete made using type II cement.
V - Concrete made using type V cement.
P - Polymer-impregnated concrete made using type II cement.

*** Referenced to copper/copper-sulfate electrode.

\# As determined by polarization tests which were conducted only on those specimens exhibiting potentials more negative than -0.30 volt.

TABLE 18a. TEST RESULTS - ALLOYS - SITE 1 1/
(metric units)

Alloy 2/ code No.	Nominal exposure time (mo)	Average corrosion rate (µm/yr)			Maximum pitting rate (µm/yr)					
					Exposed surface			Crevice 3/		
		Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
A-1	3	66	89	109	711	356	432	<3	<3	<3
	10	69	41	51	366	152	152	<3	<3	<3
	22	140	30	69	401	89	122	124	51	15
A-2	3	107	109	112	914	508	610	<3	<3	<3
	10	145	53	58	762	152	213	853	Incipient	168
	22	152	86	114	251	130	201	142	71	104
A-3	3	91	86	46	1168	345	508	<3	<3	<3
	10	124	48	25	884	518	152	305	Incipient	137
	22	127	63	51	244	165	130	76	104	94
A-4	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	22	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-5	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	22	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-6	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	76	<3	<3	<3	<3	<3
	22	<3	<3	<3	229	<3	<3	<3	<3	<3
A-7	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	22	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-8	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	22	<3	<3	<3	91	<3	<3	<3	<3	<3
A-9	3	18	<3	28	254	305	152	<3	<3	<3
	10	23	41	36	259	168	305	<3	<3	<3
	22	46	30	56	124	114	117	<3	69	53
A-10	3	30	38	33	<3	<3	305	<3	<3	<3
	10	28	25	23	229	61	122	<3	<3	<3
	22	30	20	51	86	33	69	<3	<3	<3
A-11	3	8	119	130	1321	1829	2642	<3	<3	<3
	10	13	104	97	1006	1097	Perforated	Perforated	960	853
	22	20	33	66	Perforated	475	Perforated	Perforated	312	348

1/ Tapia Water Reclamation Facility, Calabasas, California
2/ See table 2 for alloy identification.
3/ Surface beneath teflon space.

TABLE 18b. TEST RESULTS - ALLOYS - SITE 1 1/

(English units)

Alloy 2/ code No.	Nominal exposure time (mo)	Average corrosion rate (mils/year)			Maximum pitting rate (mils/year)					
					Exposed surface			Crevice 3/		
		Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
A-1	3	2.6	3.5	4.3	28.0	14.0	17.0	< 0.1	< 0.1	< 0.1
	10	2.7	1.6	2.4	14.4	6.0	6.0	< 0.1	< 0.1	< 0.1
	22	5.5	1.2	2.7	15.8	3.5	4.8	4.9	2.0	0.6
A-2	3	4.2	4.3	4.4	36.0	20.0	24.0	< 0.1	< 0.1	< 0.1
	10	5.7	2.1	2.3	30.0	6.0	8.4	33.6	Incipient	6.6
	22	6.0	3.4	4.5	9.9	5.1	7.9	5.6	2.8	4.1
A-3	3	3.6	3.4	1.8	46.0	13.6	20.0	< 0.1	< 0.1	< 0.1
	10	4.9	1.9	1.0	34.8	20.4	6.0	12.0	Incipient	5.4
	22	5.0	2.5	2.0	9.6	6.5	5.1	3.0	4.1	3.7
A-4	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	22	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
A-5	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	22	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
A-6	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	10	<0.1	<0.1	<0.1	3.0	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	22	<0.1	<0.1	<0.1	9.0	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
A-7	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	22	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
A-8	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	22	<0.1	<0.1	<0.1	3.6	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
A-9	3	0.7	1.0	1.1	10.0	12.0	6.0	< 0.1	< 0.1	< 0.1
	10	0.9	1.6	1.4	10.2	6.6	12.0	< 0.1	< 0.1	< 0.1
	22	1.8	1.2	2.2	4.9	4.5	4.6	< 0.1	2.7	2.1
A-10	3	1.2	1.5	1.3	< 0.1	< 0.1	12.0	< 0.1	< 0.1	< 0.1
	10	1.1	1.0	0.9	9.0	2.4	4.8	< 0.1	< 0.1	< 0.1
	22	1.2	0.8	2.0	3.4	1.3	2.7	< 0.1	< 0.1	< 0.1
A-11	3	0.3	4.7	5.1	52.0	72.0	104.0	< 0.1	< 0.1	< 0.1
	10	0.5	4.1	3.8	39.6	43.2	Perforated	Perforated	37.8	33.6
	22	0.8	1.3	2.6	Perforated	18.7	Perforated	Perforated	12.3	13.7

1/ Tapia Water Reclamation Facility, Calabasas, California.
2/ See table 2 for alloy identification.
3/ Surface beneath teflon spacer.

TABLE 19a. TEST RESULTS - ALLOYS - SITE 2 1/

(metric units)

Alloy 2/ code No.	Nominal exposure time (mo)	Average corrosion rate (µm/yr)			Maximum pitting rate (µm/yr)					
					Exposed surface			Crevice 3/		
		Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
A-1	3	99	20	107	<3	<3	<3	<3	<3	<3
	10	99	112	244	396	396	1280	<3	<3	152
	28	58	168	221	81	345	386	180	<3	130
A-2	3	165	20	81	1016	965	762	<3	<3	<3
	10	69	46	97	762	747	457	198	168	366
	28	61	74	127	142	104	147	119	107	193
A-3	3	99	20	84	1880	254	610	<3	<3	<3
	10	97	74	163	533	457	549	213	107	<3
	28	48	74	97	180	Perforated	Perforated	175	51	<3
A-4	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	28	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-5	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	28	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-6	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	28	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-7	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	28	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-8	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	28	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-9	3	33	23	13	1067	1219	711	<3	1219	<3
	10	41	33	23	335	366	244	198	320	<3
	28	30	41	38	142	18	48	160	81	<3
A-10	3	5	10	33	<3	<3	<3	<3	<3	<3
	10	5	5	51	<3	<3	<3	<3	<3	<3
	28	3	15	33	168	8	48	<3	<3	<3
A-11	3	<3	<3	<3	<3	<3	1067	<3	<3	<3
	10	3	<3	10	1433	152	671	<3	<3	<3
	28	5	<3	48	Perforated	142	Perforated	15	201	<3

[1] Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
[2] See table 2 for alloy identification.
[3] Surface beneath teflon spacer.

TABLE 19b. TEST RESULTS - ALLOYS - SITE 2 1/
(English units)

Alloy 2/ code No.	Nominal exposure time (mo)	Average corrosion rate (mils/year)			Maximum pitting rate (mils/year)					
					Exposed surface			Crevice 3/		
		Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
A-1	3	3.9	0.8	4.2	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	10	3.9	4.4	9.6	15.6	15.6	50.4	<0.1	< 0.1	6.0
	28	2.3	6.6	8.7	3.2	13.6	15.2	7.1	< 0.1	5.1
A-2	3	6.5	0.8	3.2	40.0	38.0	30.0	<0.1	< 0.1	< 0.1
	10	2.7	1.8	3.3	30.0	29.4	13.0	7.8	6.6	14.4
	28	2.4	2.9	5.0	5.6	4.1	3.8	4.7	4.2	7.6
A-3	3	3.9	0.8	3.3	74.0	10.0	24.0	<0.1	< 0.1	< 0.1
	10	3.8	2.9	6.4	21.0	18.0	21.6	8.4	4.2	< 0.1
	28	1.9	2.9	3.8	7.1	Perforated	Perforated	6.9	2.0	< 0.1
A-4	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
A-5	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
A-6	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
A-7	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
A-8	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
A-9	3	1.3	0.9	0.5	42.0	48.0	28.0	<0.1	48.0	< 0.1
	10	1.6	1.3	0.9	13.2	14.4	9.6	7.8	12.6	< 0.1
	28	1.2	1.6	1.5	5.6	0.7	1.9	6.3	3.2	< 0.1
A-10	3	0.2	0.4	1.3	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	10	0.2	0.2	2.0	< 0.1	< 0.1	< 0.1	<0.1	< 0.1	< 0.1
	28	0.1	0.6	1.3	6.6	0.3	1.9	<0.1	< 0.1	< 0.1
A-11	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	42.0	<0.1	< 0.1	< 0.1
	10	0.1	<0.1	0.4	56.4	6.0	26.4	<0.1	< 0.1	< 0.1
	28	0.2	<0.1	1.9	Perforated	5.6	Perforated	0.6	7.9	< 0.1

1/ Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
2/ See table 2 for alloy identification.
3/ Surface beneath teflon spacer.

TABLE 20a. TEST RESULTS - ALLOYS - SITE 3 1/

(metric units)

Alloy 2/ code No.	Nominal exposure time (mo)	Average corrosion rate (µm/yr)			Maximum pitting rate (µm/yr)					
					Exposed surface			Crevice 3/		
		Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
A-1	3	18	86	69	<3	<3	<3	<3	<3	<3
	10	18	43	132	<3	<3	480	198	229	<3
	28	13	76	47	15	71	23	91	112	<3
A-2	3	33	118	76	610	457	305	<3	<3	<3
	10	36	36	94	183	366	198	335	351	<3
	28	25	81	33	48	257	61	160	173	53
A-3	3	30	107	71	457	305	559	<3	<3	<3
	10	30	38	69	152	91	381	262	213	122
	28	23	51	28	61	191	107	168	109	137
A-4	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	28	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-5	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	28	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-6	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	28	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-7	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	28	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-8	3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	10	<3	<3	<3	<3	<3	<3	<3	<3	<3
	28	<3	<3	<3	<3	<3	<3	<3	<3	<3
A-9	3	8	48	18	305	<3	<3	<3	<3	<3
	10	18	33	10	213	152	213	122	61	<3
	28	10	20	3	5	15	76	56	30	<3
A-10	3	8	18	23	<3	<3	<3	<3	<3	<3
	10	8	8	25	<3	<3	<3	<3	<3	<3
	28	8	20	18	48	79	<3	<3	<3	<3
A-11	3	3	3	<3	965	<3	<3	<3	<3	<3
	10	3	10	<3	671	914	579	335	198	229
	28	3	<3	<3	224	234	414	330	333	91

1/ Westgate Wastewater Treatment Plant, Alexandria, Virginia.
2/ See table 2 for alloy identification.
3/ Surface beneath teflon spacer.

TABLE 20b. TEST RESULTS - ALLOYS - SITE 3 1/

(English units)

Alloy 2/ code No.	Nominal exposure time (mo)	Average corrosion rate (mils/year)			Maximum pitting rate (mils/year)					
					Exposed surface			Crevice 3/		
		Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
A-1	3	0.7	3.4	2.7	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	10	0.7	1.7	5.2	< 0.1	< 0.1	19.2	7.8	9.0	<0.1
	28	0.5	3.0	1.6	0.6	2.8	0.9	3.6	4.4	<0.1
A-2	3	1.3	4.5	3.0	24.0	18.0	12.0	< 0.1	< 0.1	<0.1
	10	1.4	1.4	3.7	7.2	14.4	7.8	13.2	13.8	<0.1
	28	1.0	3.2	1.3	1.9	10.1	2.4	6.3	6.8	2.1
A-3	3	1.2	4.2	2.8	18.0	12.0	22.0	< 0.1	< 0.1	<0.1
	10	1.2	1.5	2.7	6.0	3.6	15.0	10.3	8.4	4.8
	28	0.9	2.0	1.1	2.4	7.5	4.2	6.6	4.3	3.4
A-4	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
A-5	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
A-6	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
A-7	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
A-8	3	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	10	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	28	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
A-9	3	0.3	1.9	0.7	12.0	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	10	0.7	1.3	0.4	8.4	6.0	8.4	4.8	2.4	<0.1
	28	0.4	0.8	0.1	0.2	0.6	3.0	2.2	1.2	<0.1
A-10	3	0.3	0.7	0.9	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	10	0.3	0.3	1.0	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	28	0.3	0.8	0.7	1.9	3.1	< 0.1	< 0.1	< 0.1	<0.1
A-11	3	0.1	0.1	<0.1	38.0	< 0.1	< 0.1	< 0.1	< 0.1	<0.1
	10	0.1	0.4	<0.1	26.4	36.0	22.8	13.2	7.8	9.0
	28	0.1	<0.1	<0.1	8.8	9.2	16.3	13.0	13.1	3.6

1/ Westgate Wastewater Treatment Plant, Alexandria, Virginia.
2/ See table 2 for alloy identification.
3/ Surface beneath teflon spacer.

TABLE 21. EVALUATION SUMMARY - ALLOYS - SITES 1, 2, AND 3

Alloy code No.	Site exposure	Performance rating 1/									Average
		Site 1 2/			Site 2 3/			Site 3 4/			
		3 mo	10 mo	22 mo	3 mo	10 mo	28 mo	3 mo	10 mo	28 mo	
A-1	Gas	4	4	4	3	4	2	2	3	3	3.0
	Interface	4	3	3	2	4	4	3	3	3	3.3
	Liquor	4	3	3	3	4	4	3	4	3	3.3
A-2	Gas	4	4	3	4	4	3	4	4	3	3.0
	Interface	4	3	3	4	4	3	4	4	4	3.3
	Liquor	4	3	3	4	4	3	4	3	3	3.0
A-3	Gas	4	4	3	4	4	3	4	4	3	3.0
	Interface	4	4	3	4	4	4	4	3	3	3.3
	Liquor	4	3	3	4	4	4	4	4	3	3.3
A-4	Gas	1	1	1	1	1	1	1	1	1	1.0
	Interface	1	1	1	1	1	1	1	1	1	1.0
	Liquor	1	1	1	1	1	1	1	1	1	1.0
A-5	Gas	1	1	1	1	1	1	1	1	1	1.0
	Interface	1	1	1	1	1	1	1	1	1	1.0
	Liquor	1	1	1	1	1	1	1	1	1	1.0
A-6	Gas	1	3	3	1	1	1	1	1	1	1.7
	Interface	1	1	1	1	1	1	1	1	1	1.0
	Liquor	1	1	1	1	1	1	1	1	1	1.0
A-7	Gas	1	1	1	1	1	1	1	1	1	1.0
	Interface	1	1	1	1	1	1	1	1	1	1.0
	Liquor	1	1	1	1	1	1	1	1	1	1.0
A-8	Gas	1	1	3	1	1	1	1	1	1	1.7
	Interface	1	1	1	1	1	1	1	1	1	1.0
	Liquor	1	1	1	1	1	1	1	1	1	1.0
A-9	Gas	4	4	3	4	4	3	4	3	3	3.0
	Interface	4	3	3	4	4	3	3	3	3	3.0
	Liquor	3	4	3	4	3	3	2	3	3	3.0
A-10	Gas	3	3	3	2	2	3	2	2	3	3.0
	Interface	3	3	3	2	2	2	2	2	3	2.7
	Liquor	4	3	3	3	3	3	2	3	2	2.7
A-11	Gas	4	4	4	1	4	4	4	4	4	4.0
	Interface	4	4	4	1	3	3	2	4	4	3.7
	Liquor	4	4	4	4	4	4	2	4	4	4.0

1/ Assigned as follows in accordance with average corrosion rate (x) and maximum pitting rate (y).

Average corrosion rate (x)		or	Maximum pitting rate (y)		Rating
µm/yr	mils/yr		µm/yr	mils/yr	
$x<3$	$x<0.1$		$y<3$	$y<0.1$	1
$3\le x<25$	$0.1\le x<1.0$		$3\le y<25$	$0.1\le y<1.0$	2
$25\le x<254$	$1.0\le x<10.0$		$25 \le v< 254$	$1.0\le y<10.0$	3
$x>254$	$x>10.0$		$y>254$	$y>10.0$	4

2/ Tapia Water Reclamation Facility, Calabasas, California.
3/ Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
4/ Westgate Watewater Treatment Plant, Alexandria, Virginia.
5/ Average of 22-month rating at site 1 and 28-month ratings at sites 2 and 3.

Figure 16. Sensitized Type 304 stainless steel specimen exposed in the gas zone at site 1 for 22 months. Note pitting due to sensitization.

Figure 17. Mild steel specimen exposed in the gas zone at site 2 for 28 months. Surface is deeply pitted.

Figure 18. Low alloy steel specimen exposed in the liquor at site 2 for 28 months. Specimen is perforated.

Figure 19. Aluminum alloy 6061 exposed in the gas zone at site 2 for 28 months. Sample is perforated.

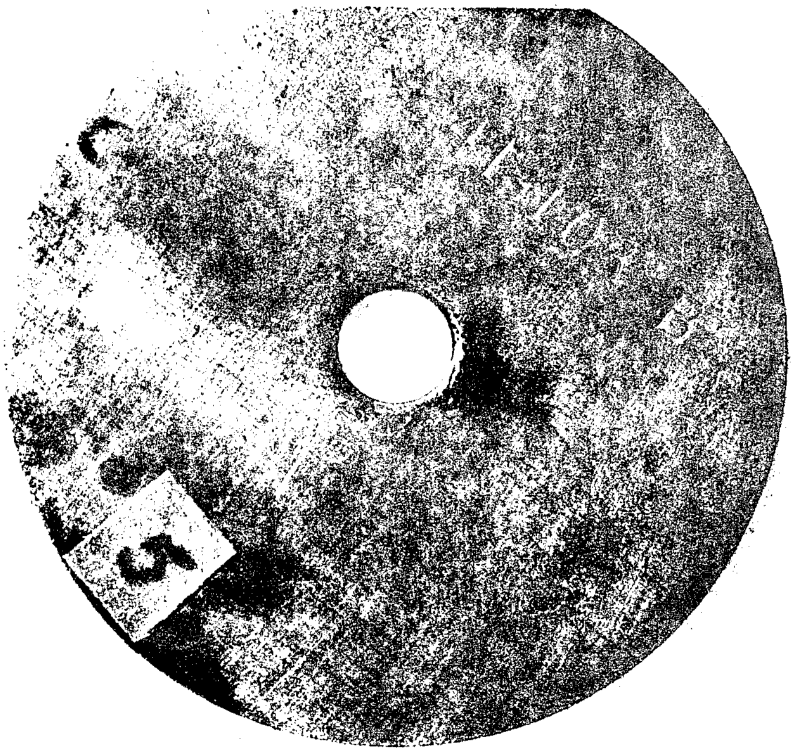

Figure 20. Copper specimen exposed in the gas zone at site 2 for 28 months. Sample is pitted in one localized area only.

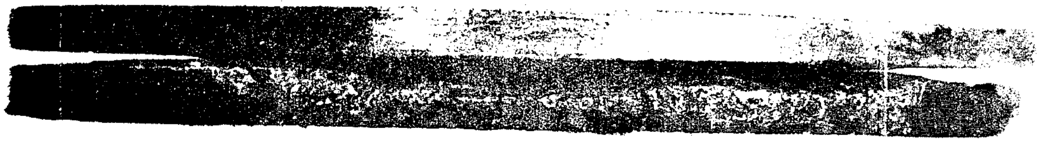

Figure 21. Edge view of gray cast iron coupons, unexposed (top) and exposed for 28 months in the gas-liquor interface at site 2. Thickness loss was caused by graphitization.

(3) Low alloy steel (Alloy A-3)
(4) Aluminum alloy (Alloy A-11)

2. Stressed specimens. - Table 22 shows the results of exposure of stressed alloy specimens. The split specimens are shown in figures 22 and 23. All stressed alloys performed satisfactorily in all exposures at the three test sites except:

a. Mild steel (Alloy A-2)
b. Low alloy steel (Alloy A-3)
c. Aluminum alloy (Alloy A-11)

Rubber and Plastics

1. Rubber Sheeting. - Physical property test results are shown in table 23. The effect of exposure on rubber materials is discussed below by rubber type:

a. Generally satisfactory

(1) Butyl. - Very slight strength loss. Slight shrinkage in one sample. Swelling and moderate strength loss at site 2 liquor/gas interface indicating contact with a petroleum product.

(2) Chlorosulfonated polyethylene. - Slight strength and elongation loss accompanied by slight hardening in all gaseous phases.

(3) Ethylene propylene diene monomer. - Spotty swelling with resulting moderate change in physical properties in the splash zone indicating some petroleum contact.

(4) Polyacrylate. - General moderate strength loss.

b. Satisfactory for limited use

(1) Natural. - Strength loss, softening, distortion, swelling from petroleum contact, initial ozone cracking, and indications of micro-organism attack. Use should be limited to applications in which high strength, high resiliency and resistance to fatigue, crack growth and tearing are essential, and exposure to oxygenated, bacteria-laden water, is minimal.

(2) Nitrile-butadiene. - General strength loss with slight elongation loss. Initial ozone cracking. Should not be used under conditions of combined stress and atmospheric or ozone exposure.

(3) Silicone. - Severe mechanical damage, caused by suspended solids and debris, observed in the splash zone. Discoloration of one product (R-32) accompanied by loss of strength and elongation loss. Should be formulated for bacteria resistance and limited to uses not subject to severe abrasive conditions.

TABLE 22. TEST RESULTS - STRESSED METALS - SITES 1, 2, AND 3*

Alloy**		Exposure			Test results
Code No.	Identification	Site No.	Phase	Period (months)	
2	Mild carbon steel, AISI 1020	2***	Liquor	28	Both specimens completely fractured
		3#	Interface	10	One specimen split; wearing indicative of abrasion
		3#	Interface	20	Both specimens split
3	Low alloy steel, USS Cor-Ten	3	Interface	28	One specimen split
11	Aluminum alloy, AA-6061	2	Liquor	10	One specimen split
			Liquor	20	Both specimends split; wearing indicative of abrasion

* Only those materials which split during the course of the exposure are listed. Since alloy No. 1, gray cast iron, and alloy No. 9, austenitic gray cast iron, are not subject to this test, only nine alloys were exposed.

** See table 2 for alloy identification.

*** Site 2 - Speedway Wastewater Treatment Plant, Indianapolis, Indiana.

\# Site 3 - Westgate Wastewater Treatment Plant, Alexandria, Virginia.

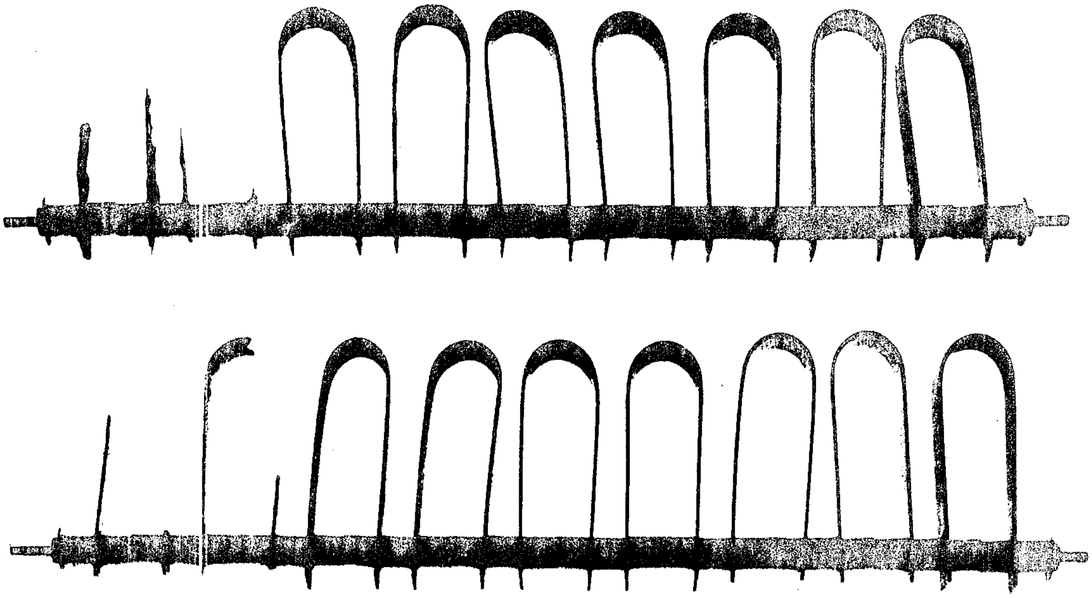

Figure 22. - Duplicate mild steel (top left) and aluminum alloy 6061 (bottom left) stressed specimens failed after 28 months' exposure in the liquor at site 2.

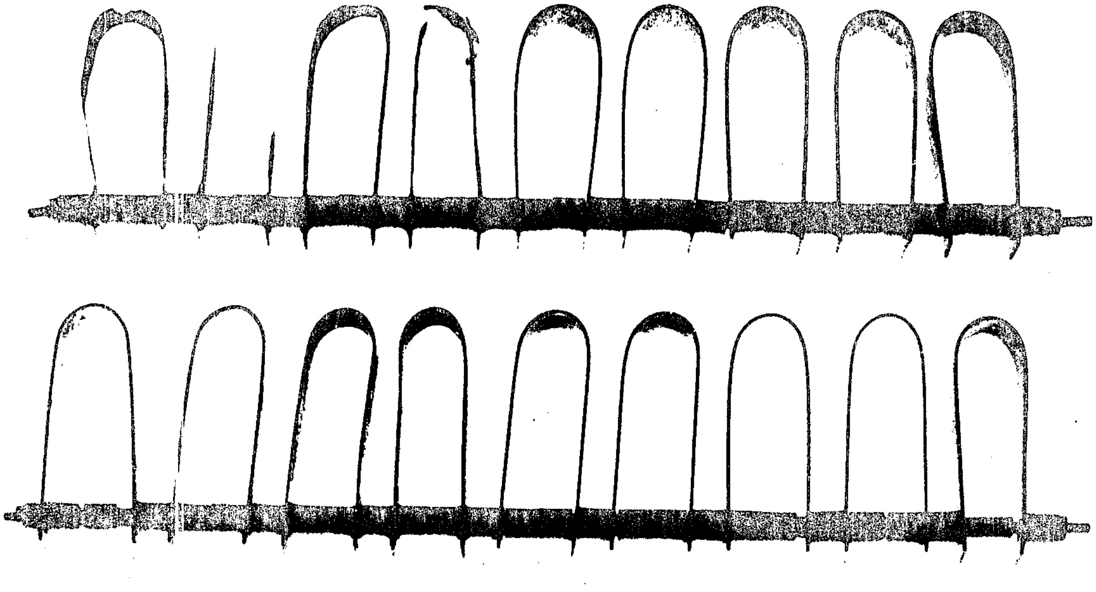

Figure 23. - Duplicate mild steel (first two samples, top row) and low alloy steel (second two samples, top row) stressed specimens failed after 28 months' exposure at the interface at site 3.

TABLE 23a. TEST RESULTS - RUBBER SHEETING - MATERIALS R-29, R-17, R-5
(metric units)

Material			R-29 Butyl - C			R-17 Butyl - C			R-5 Neoprene		
	Exposure										
Property	Exposure time, months	Site 1/	Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Tensile Strength MPa	0	4	14.8			10.1			16.5		
	3	1	14.9	14.5	14.3	10.1	10.4	9.9	16.5	16.9	17.1
		2	13.3	14.2	13.9	9.1	8.6	9.1	15.1	15.5	15.5
		3	13.1	14.2	14.2	9.2	8.6	9.7	13.5	14.7	14.8
	9	1	13.8	13.9	13.8	9.1	10.7	9.5	14.8	16.2	16.0
		2	14.5	13.3	14.5	9.6	9.1	9.6	16.2	15.3	15.7
		3	13.7	12.8	14.4	9.5	8.8	9.8	14.2	12.9	14.2
	28	1	12.8	13.2	13.3	9.4	9.8	9.8	12.7	13.1	14.0
		2	14.2	7.2	13.2	9.4	9.7	9.3	14.9	13.8	13.0
		3	11.8	12.2	14.4	8.1	8.6	9.5	11.0	11.7	13.0
		4	-	-	14.1	-	-	9.9	-	-	15.1
Elongation Percent	0	4	625			375			290		
	3	1	690	655	660	405	400	315	315	310	315
		2	640	645	645	390	340	360	290	300	300
		3	640	620	655	410	320	370	300	210	295
	9	1	580	620	610	385	375	380	285	300	280
		2	630	570	640	375	365	370	300	290	265
		3	610	565	630	335	340	350	270	235	250
	28	1	565	540	590	375	355	375	225	240	255
		2	590	380	610	390	340	385	270	240	240
		3	525	530	660	320	355	380	220	205	230
		4	-	-	630	-	-	390	-	-	270
Hardness Shore "A"	0	4	64			63			73		
	3	1	62	63	62	64	64	66	72	71	73
		2	63	62	63	65	64	64	72	72	70
		3	58	63	63	63	63	62	71	63	68
	9	1	63	62	64	64	64	66	73	70	72
		2	63	62	61	65	64	64	72	69	68
		3	62	61	62	64	64	64	73	72	69
	28	1	62	62	63	63	64	65	73	72	71
		2	62	50	61	66	64	64	73	68	70
		3	60	62	63	64	63	63	72	73	71
		4	-	-	64	-	-	64	-	-	74
Thickness Percent change	3	1	0.5	0.6	0.7	0.4	-0.7	-0.9	0.4	-0.2	0.0
		2	2.0	-1.5	-1.6	-2.1	0.2	-2.3	-1.5	-2.1	-2.3
		3	1.3	1.3	-1.4	-0.3	-0.8	-0.8	1.1	-1.8	4.4
	9	1	-0.3	0.8	0.5	-1.2	-1.2	-1.8	-0.8	0.3	-0.3
		2	0.2	2.1	3.3	-1.8	-1.4	2.1	-0.8	2.4	5.8
		3	0.2	1.5	-0.8	-2.2	-0.9	-1.9	-1.0	-0.2	2.2
	28	1	0.3	1.0	0.2	-1.2	-1.7	-0.9	-1.1	-1.5	-0.9
		2	0.3	9.9	0.8	-4.0	7.2	-1.6	-1.3	1.7	-0.1
		3	2.1	-0.6	-0.8	-1.1	-1.3	-1.9	0.2	-1.4	-1.3
		4	-	-	-0.1	-	-	-1.2	-	-	0.4

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado

TABLE 23a. TEST RESULTS - RUBBER SHEETING - MATERIALS R-29, R-17, R-5 (English units)

Material			R-29 Butyl - G			R-17 Butyl - C			R-5 Neoprene		
Exposure			Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/									
Tensile Strength lb/in²	0	4	2,160			1,470			2,400		
	3	1	2,175	2,110	2,080	1,470	1,515	1,450	2,400	2,400	2,485
		2	1,940	2,065	2,030	1,320	1,260	1,330	2,200	2,260	2,260
		3	1,910	2,060	2,060	1,340	1,260	1,420	1,960	2,140	2,160
	9	1	2,015	2,020	2,010	1,330	1,565	1,390	2,155	2,360	2,325
		2	2,115	1,940	2,105	1,400	1,324	1,405	2,360	2,220	2,280
		3	2,000	1,870	2,090	1,390	1,285	1,430	2,065	1,880	2,065
	28	1	1,865	1,915	1,940	1,375	1,435	1,435	1,845	1,900	2,035
		2	2,070	1,055	1,920	1,370	1,415	1,355	2,175	2,015	1,895
		3	1,725	1,770	2,100	1,180	1,255	1,385	1,600	1,700	1,895
		4	-	-	2,047	-	-	1,440	-	-	2,200
Elongation Percent	0	4	625			375			290		
	3	1	690	655	660	405	400	315	315	310	315
		2	640	645	645	390	340	360	290	300	300
		3	640	620	655	410	320	370	300	210	295
	9	1	580	620	610	385	375	380	285	300	280
		2	630	570	640	375	365	370	300	290	265
		3	610	565	630	335	340	350	270	235	250
	28	1	565	540	590	375	355	375	225	240	255
		2	590	380	610	390	340	385	270	240	240
		3	525	530	660	320	355	380	220	205	230
		4	-	-	630	-	-	390	-	-	270
Hardness Shore "A"	0	4	64			63			73		
	3	1	62	63	62	64	64	66	72	71	73
		2	63	62	63	65	64	64	72	72	70
		3	58	63	63	63	63	62	71	63	68
	9	1	63	62	64	64	64	66	73	70	72
		2	63	62	61	65	64	64	72	69	68
		3	62	61	62	64	64	64	73	72	69
	28	1	62	62	63	63	64	65	73	72	71
		2	62	50	61	66	64	64	73	68	70
		3	60	62	63	64	63	63	72	73	71
		4	-	-	64	-	-	64	-	-	74
Thickness Percent change	3	1	0.5	0.6	0.7	0.4	-0.7	-0.9	0.4	-0.2	0.0
		2	2.0	-1.5	-1.6	-2.1	0.2	-2.3	-1.5	-2.1	-2.3
		3	1.3	1.3	-1.4	-0.3	-0.8	-0.8	1.1	-1.8	4.4
	9	1	-0.3	0.8	0.5	-1.2	-1.2	-1.8	-0.8	0.3	-0.3
		2	0.2	2.1	3.3	-1.8	-1.4	2.1	-0.8	2.4	5.8
		3	0.2	1.5	-0.8	-2.2	-0.9	-1.9	-1.0	-0.2	2.2
	28	1	0.3	1.0	0.2	-1.2	-1.7	-0.9	-1.1	-1.5	-0.9
		2	0.3	9.9	0.8	-4.0	7.2	-1.6	-1.3	1.7	-0.1
		3	2.1	-0.6	-0.8	-1.1	-1.3	-1.9	0.2	-1.4	-1.3
		4	-	-	-0.1	-	-	-1.2	-	-	0.4

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado

TABLE 23b. TEST RESULTS - RUBBER SHEETING - MATERIALS R-30, R-8, R-32
(metric units)

Material			R-30 EPDM - G			R-8 EPDM - C			R-32 Silicone - D		
	Exposure		Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/									
Tensile Strength MPa	3	4	10.8			11.7			6.0		
	3	1	10.4	11.4	11.4	11.9	11.9	11.8	6.6	6.6	3.1
		2	9.8	9.3	10.3	10.2	11.1	11.2	5.7	4.6	5.6
		3	9.1	10.4	10.8	10.4	10.9	11.1	5.1	3.3	6.3
	9	1	10.1	11.4	10.1	11.2	11.7	11.2	6.9	5.9	4.4
		2	10.9	11.7	10.9	11.16	10.8	11.6	6.8	5.5	5.8
		3	10.8	9.8	10.5	11.4	11.5	12.0	5.5	4.7	6.5
	28	1	10.8	11.4	10.2	11.5	11.9	11.7	6.5	6.4	5.1
		2	11.0	8.7	10.8	11.6	10.2	11.5	8.2	2.6	5.7
		3	8.5	7.9	10.3	11.3	10.0	11.9	2.8	2.7	2.8
		4	-	-	11.4	-	-	11.7	-	-	6.9
Elongation, percent	0	4	660			440			180		
	3	1	670	680	650	475	440	425	160	160	130
		2	680	580	650	395	410	440	155	85	125
		3	580	600	660	420	410	430	135	45	150
	9	1	630	685	630	450	420	420	155	150	105
		2	680	605	620	400	385	425	140	140	120
		3	550	505	545	415	410	435	95	150	120
	28	1	615	575	540	440	430	400	135	140	80
		2	630	445	545	430	365	410	140	60	130
		3	410	370	485	390	370	400	45	50	110
		4	-	-	625	-	-	420	-	-	140
Hardness Shore "A"	0	4	68			66			74		
	3	1	65	68	66	66	66	66	71	71	70
		2	67	68	68	65	66	67	71	74	75
		3	66	73	66	66	68	68	73	74	72
	9	1	67	68	68	65	66	68	71	70	70
		2	66	66	69	68	68	68	74	70	72
		3	67	66	68	67	66	67	72	70	74
	28	1	67	67	68	66	65	67	71	72	71
		2	70	56	69	74	62	68	74	62	68
		3	66	66	70	67	66	69	75	71	71
		4	-	-	66	-	-	66	-	-	72
Thickness Percent Change	3	1	0.2	-0.6	-0.2	0.0	-1.2	-2.7	0.0	0.0	0.0
		2	-1.9	-1.9	-4.4	-0.6	0.2	-3.2	-0.3	1.6	-5.2
		3	0.2	-3.4	0.3	-0.7	-0.2	-0.8	-1.3	-0.3	-1.1
	9	1	-0.5	0.0	-1.2	-0.6	-1.4	-3.3	-1.0	-0.7	-0.8
		2	-1.2	1.2	1.8	-2.8	-1.9	0.1	-0.6	0.2	2.0
		3	-0.3	1.8	0.3	-0.3	3.5	-0.2	-0.4	-0.4	1.0
	28	1	-0.3	-0.5	-0.8	-0.1	-0.8	-2.0	-0.9	-0.6	-0.3
		2	-2.0	8.8	-0.6	-5.1	6.8	-1.3	-1.5	-0.3	0.1
		3	3.0	1.6	-0.4	0.6	3.2	0.2	-0.6	-0.8	1.4
		4	-	-	-0.8	-	-	-0.4	-	-	-0.8

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado

TABLE 23b. TEST RESULTS - RUBBER SHEETING - MATERIALS R-30, R-8, R-32
(English units)

Material			R-30 EPDM - G			R-8 EPDM - C			R-32 Silicone - D		
Exposure			Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/									
Tensile Strength lb/in²	0	4	1,570			1,700			880		
	3	1	1.515	1.665	1.660	1,740	1,735	1,715	970	975	450
		2	1,430	1,350	1,500	1,480	1,610	1,630	630	680	820
		3	1,330	1,520	1,580	1,520	1,590	1,610	750	480	920
	9	1	1,465	1,665	1,465	1,630	1,705	1,635	1,005	860	645
		2	1,585	1,710	1,595	1,620	1,575	1,685	990	800	850
		3	1,580	1,435	1,525	1,655	1,670	1,750	810	695	955
	28	1	1,570	1,665	1,480	1,670	1,730	1,700	955	930	745
		2	1,600	1,265	1,575	1,690	1,490	1,680	1,200	380	830
		3	1,245	1,155	1,505	1,640	1,460	1,735	410	405	420
		4	-	-	1,655	-	-	1,700	-	-	1,005
Elongation, percent	0	4	660			440			180		
	3	1	670	680	650	475	440	425	160	160	130
		2	680	580	650	395	410	440	155	85	125
		3	580	600	660	420	410	430	135	45	150
	9	1	630	685	630	450	420	420	155	150	105
		2	680	605	620	400	385	425	140	140	120
		3	550	505	545	415	410	435	95	150	120
	28	1	615	575	540	440	430	400	135	140	80
		2	630	445	545	430	365	410	140	60	130
		3	410	370	485	390	370	400	45	50	110
		4	-	-	625	-	-	420	-	-	140
Hardness Shore "A"	0	4	68			66			74		
	3	1	65	68	66	66	66	66	71	71	70
		2	67	68	68	65	66	67	71	74	75
		3	66	73	66	66	68	68	73	74	72
	9	1	67	68	68	65	66	68	71	70	70
		2	66	66	69	68	68	68	74	70	72
		3	67	66	68	67	66	67	72	70	74
	28	1	67	67	68	66	65	67	71	72	71
		2	70	56	69	74	62	68	74	62	68
		3	66	66	70	67	66	69	75	71	71
		4	-	-	66	-	-	66	-	-	72
Thickness Percent Change	3	1	0.2	-0.6	-0.2	0.0	-1.2	-2.7	0.0	0.0	0.0
		2	-1.9	-1.9	-4.4	-0.6	0.2	-3.2	-0.3	1.6	-5.2
		3	0.2	-3.4	0.3	-0.7	-0.2	-0.8	-1.3	-0.3	-1.1
	9	1	-0.5	0.0	-1.2	-0.6	-1.4	-3.3	-1.0	-0.7	-0.8
		2	-1.2	1.2	1.8	-2.8	-1.9	0.1	-0.6	0.2	2.0
		3	-0.3	1.8	0.3	-0.3	3.5	-0.2	-0.4	-0.4	1.0
	28	1	-0.3	-0.5	-0.8	-0.1	-0.8	-2.0	-0.9	-0.6	-0.3
		2	-2.0	8.8	-0.6	-5.1	6.8	-1.3	-1.5	-0.3	0.1
		3	3.0	1.6	-0.4	0.6	3.2	0.2	-0.6	-0.8	1.4
		4	-	-	-0.8	-	-	-0.4	-	-	-0.8

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado

TABLE 23c. TEST RESULTS - RUBBER SHEETING - MATERIALS R-532, R-25, R-34
(metric units)

Material			R-532 Silicone - G			R-25 Natural			R-34 NAR		
Property	Exposure: Exposure time, months	Exposure: Site 1/	Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Tensile Strength MPa	0	4	7.5			16.8			22.9		
	3	1	-	-	-	11.4	13.3	15.6	21.0	19.7	20.6
		2	6.5	7.4	7.6	10.5	13.8	13.3	17.5	17.8	19.6
		3	5.5	6.2	5.9	11.1	10.3	10.9	15.9	16.4	16.5
	9	1	-	-	-	10.8	13.9	13.3	16.7	18.4	19.7
		2	6.5	6.4	6.8	10.8	10.6	10.1	17.4	17.9	18.5
		3	5.7	5.0	6.8	11.2	10.3	11.1	17.1	16.1	16.9
	28	1	-	-	-	1.8	9.7	10.6	12.3	13.1	16.6
		2	6.6	6.7	6.8	8.6	2.9	8.1	16.2	16.3	16.0
		3	3.6	4.7	6.3	4.7	7.1	11.3	14.8	15.8	15.3
		4	-	-	7.2	-	-	8.5	-	-	15.1
Elongation Percent	0	4	570			615			515		
	3	1	-	-	-	610	625	650	540	620	500
		2	565	620	595	600	510	610	465	460	470
		3	430	495	430	620	590	580	430	430	430
	9	1	-	-	-	560	610	615	420	480	530
		2	480	505	520	590	565	575	445	445	440
		3	420	400	530	560	570	565	405	400	400
	28	1	-	-	-	270	440	505	335	360	385
		2	515	480	460	545	390	555	415	390	380
		3	280	340	450	450	530	560	315	370	330
		4	-	-	535	-	-	540	-	-	385
Hardness Shore "A"	0	4	52			49			66		
	3	1	-	-	-	49	50	52	66	66	64
		2	53	52	52	52	50	48	68	67	68
		3	60	54	57	52	49	50	71	66	67
	9	1	-	-	-	52	49	50	66	66	67
		2	53	51	54	52	50	48	68	68	68
		3	56	52	53	52	50	51	68	67	68
	28	1	-	-	-	51	50	50	67	66	67
		2	54	54	54	50	44	52	67	66	67
		3	56	54	56	51	51	51	67	68	68
		4	-	-	56	-	-	50	-	-	67
Thickness Percent change	3	1	-	-	-	0.0	1.4	0.8	-0.2	0.3	0.7
		2	1.0	2.9	1.8	-2.4	6.5	0.9	-1.8	-6.0	1.6
		3	1.4	1.7	5.2	0.2	0.2	2.8	0.0	-0.2	0.4
	9	1	-	-	-	-0.8	0.2	0.2	-0.6	-0.3	-0.4
		2	0.3	2.9	1.6	0.5	4.1	3.5	-0.2	0.4	0.5
		3	0.3	1.0	0.6	-0.8	1.3	0.0	-0.7	-0.2	-2.6
	28	1	-	-	-	-2.0	0.0	-1.0	0.2	-0.2	-0.3
		2	-2.6	3.9	1.3	-1.1	5.8	0.9	-0.4	0.6	-0.1
		3	-3.3	1.8	2.1	-0.9	1.8	0.0	-0.4	0.7	0.1
		4	-	-	2.3	-	-	4.7	-	-	1.4

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado.

TABLE 23c. TEST RESULTS - RUBBER SHEETING - MATERIALS R-532, R-25, R-34

(English units)

Material			R-532 Silicone - G			R-25 Natural			R-34 NAR		
Exposure			Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/									
Tensile Strength lb/in²	0	4	1,100			2,450			3,330		
	3	1	-	-	-	1,665	1,930	2,270	3,050	2,865	3,000
		2	945	1,000	1,105	1,530	2,010	1,940	2,540	2,590	2,850
		3	810	910	865	1,620	1,500	1,590	2,310	2,380	2,600
	9	1	-	-	-	1,575	2,020	1,940	2,435	2,670	2,870
		2	950	935	990	1,570	1,545	1,470	2,530	2,605	2,690
		3	835	730	995	1,630	1,500	1,620	2,490	2,345	2,465
	28	1	-	-	-	275	1,420	1,550	1,795	1,905	2,415
		2	970	980	990	1,250	435	1,175	2,350	2,370	2,330
		3	525	685	915	685	1,030	1,640	2,160	2,295	2,225
		4	-	-	1,055	-	-	1,235	-	-	2,195
Elongation Percent	0	4	570			615			515		
	3	1	-	-	-	610	625	650	540	620	500
		2	565	620	595	600	510	610	465	460	470
		3	430	495	430	620	590	580	430	430	430
	9	1	-	-	-	560	610	615	420	480	530
		2	480	505	520	590	565	575	445	445	440
		3	420	400	530	560	570	565	405	400	400
	28	1	-	-	-	270	440	505	335	360	385
		2	515	480	460	545	390	555	415	390	380
		3	280	340	450	450	530	560	315	370	330
		4	-	-	535	-	-	540	-	-	385
Hardness Shore "A"	0	4	52			49			66		
	3	1	-	-	-	49	50	52	66	66	64
		2	53	52	52	52	50	48	68	67	68
		3	60	54	57	52	49	50	71	66	67
	9	1	-	-	-	52	49	50	66	66	67
		2	53	51	54	52	50	48	68	68	68
		3	56	52	53	52	50	51	68	67	68
	28	1	-	-	-	51	50	50	67	66	67
		2	54	54	54	50	44	52	67	68	67
		3	56	54	56	51	51	51	67	68	68
		4	-	-	56	-	-	50	-	-	67
Thickness Percent change	3	1	-	-	-	0.0	1.4	0.8	-0.2	0.3	0.7
		2	1.0	2.9	1.8	-2.4	6.5	0.9	-1.8	-6.0	1.6
		3	1.4	1.7	5.2	0.2	0.2	2.8	0.0	-0.2	0.4
	9	1	-	-	-	-0.8	0.2	0.2	-0.6	-0.3	-0.4
		2	0.3	2.9	1.6	0.5	4.1	3.5	-0.2	0.4	0.5
		3	0.3	1.0	0.6	-0.8	1.3	0.0	-0.7	-0.2	-2.6
	28	1	-	-	-	-2.0	0.0	-1.0	0.2	-0.2	-0.3
		2	-2.6	3.9	1.3	-1.1	5.8	0.9	-0.4	0.6	-0.1
		3	-3.3	1.8	2.1	-0.9	1.8	0.0	-0.4	0.7	0.1
		4	-	-	2.3	-	-	4.7	-	-	1.4

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado

TABLE 23d. TEST RESULTS - RUBBER SHEETING - MATERIALS R-27, R-18, R-31
(metric units)

Material			R-27 Polyacrylate			R-18 CSPE			R-31 EPDM/Butyl[a]		
	Exposure										
Property	Exposure time, months	Site 1/	Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Tensile Strength MPa	0	4	13.9			10.4			0.9		
	3	1	14.8	7.5	12.2	9.1	10.7	10.4	0.9	0.9	1.1
		2	9.3	12.2	11.6	8.8	9.3	9.2	0.8	0.8	1.0
		3	7.0	7.3	13.0	9.2	9.6	11.1	1.0	0.8	0.9
	9	1	9.1	6.7	8.6	8.3	12.2	10.4	0.9	1.0	1.0
		2	11.9	8.1	8.2	9.2	11.3	11.2	0.9	0.8	1.0
		3	8.9	12.3	8.3	8.4	12.3	10.1	0.8	1.0	0.9
	28	1	10.6	11.6	12.3	9.4	11.2	11.9	1.1	1.2	1.1
		2	10.7	10.0	7.5	9.6	10.0	10.0	0.9	0.8	1.1
		3	13.0	6.8	14.0	7.1	10.0	11.9	1.0	1.1	0.9
		4	-	-	10.6	-	-	8.6	-	-	1.0
Elongation percent	0	4	125			465			200		
	3	1	135	95	110	475	470	440	215	245	245
		2	105	135	120	460	400	410	200	210	250
		3	105	100	160	455	425	450	235	240	230
	9	1	80	70	110	350	340	400	235	265	260
		2	130	110	105	430	390	370	280	265	220
		3	90	110	110	315	410	400	205	290	245
	28	1	95	110	100	330	355	370	230	235	260
		2	120	120	100	380	460	430	190	230	250
		3	130	80	120	290	400	410	250	260	260
		4	-	-	110	-	-	310	-	-	235
Hardness Shore "A"	0	4	74			68			-	-	-
	3	1	70	71	70	68	66	64	-	-	-
		2	72	72	72	69	68	68	-	-	-
		3	67	71	71	67	66	67	-	-	-
	9	1	74	72	72	74	69	68	-	-	-
		2	72	72	73	70	68	68	-	-	-
		3	71	70	71	72	68	67	-	-	-
	28	1	72	72	71	71	70	69	-	-	-
		2	71	70	71	71	67	68	-	-	-
		3	71	68	68	70	72	68	-	-	-
		4	-	-	72	-	-	63	-	-	-
Thickness Percent change	3	1	1.9	2.1	1.3	0.0	1.5	1.6	5.0	-18.2	-20.6
		2	-8.3	-4.4	-3.0	-0.6	1.3	1.5	-1.7	-8.0	-1.5
		3	-1.9	-2.2	-3.2	0.7	0.2	3.1	-6.6	-16.2	-12.0
	9	1	0.0	0.4	1.6	0.0	1.2	0.7	-5.7	-13.5	-14.9
		2	0.3	0.2	0.8	0.2	2.3	3.2	-9.0	-8.0	-1.0
		3	-2.7	-3.0	0.8	-0.8	0.3		-10.0	-31.0	-13.5
	28	1	0.5	1.1	1.1	-0.1	-0.1	-1.0	-0.7	-1.9	-5.3
		2	-1.8	-1.6	-2.3	-0.4	2.5	0.5	-11.4	-31.7	-24.8
		3	-3.2	-1.1	-2.5	-1.6	-0.4	-0.1	-28.7	-32.2	-31.2
		4	-	-	-0.4	-	-	13.4	-	-	0.8

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California.
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia.
Site 4: USBR Laboratories, Denver, Colorado.

[a] Closed cell expanded rubber.

TABLE 23d. TEST RESULTS - RUBBER SHEETING - MATERIALS R-27, R-18, R-31
(English units)

Material			R-27 Polyacrylate			R-18 CSPE			R-31 EPDM/Butyl*		
Exposure			Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/									
Tensile Strength lb/in^2	0	4	2,030			1,520			143		
	3	1	2,150	1,090	1,770	1,315	1,565	1,525	140	145	170
		2	1,350	1,770	1,690	1,280	1,350	1,340	135	120	150
		3	1,020	1,070	1,890	1,330	1,400	1,611	150	120	145
	9	1	1,320	985	1,255	1,215	1,755	1,520	140	155	155
		2	1,730	1,175	1,200	1,335	1,645	1,635	140	130	150
		3	1,295	1,790	1,210	1,230	1,785	1,465	120	155	140
	28	1	1,540	1,635	1,790	1,375	1,625	1,740	160	180	165
		2	1,565	1,460	1,085	1,395	1,445	1,460	140	120	165
		3	1,890	1,000	2,040	1,040	1,455	1,730	155	170	140
		4	-	-	1,535	-	-	1,260	-	-	150
Elongation Percent	0	4	125			465			200		
	3	1	135	95	110	475	470	440	215	245	245
		2	105	135	120	460	400	410	200	210	250
		3	105	100	160	455	425	450	235	240	230
	9	1	80	70	110	350	340	400	235	265	260
		2	130	110	105	430	390	370	280	265	220
		3	90	110	110	315	410	400	205	290	245
	28	1	95	110	100	330	355	370	230	235	260
		2	120	120	100	380	460	430	190	230	250
		3	130	80	120	290	400	410	250	260	260
		4	-	-	110	-	-	310	-	-	235
Hardness Shore "A"	0	4	74			68			-	-	-
	3	1	70	71	70	68	66	64	-	-	-
		2	72	72	72	69	68	68	-	-	-
		3	67	71	71	67	66	67	-	-	-
	9	1	74	72	72	74	69	68	-	-	-
		2	72	72	73	70	68	68	-	-	-
		3	71	70	71	72	68	67	-	-	-
	28	1	72	72	71	71	70	69	-	-	-
		2	71	70	71	71	67	68	-	-	-
		3	71	68	68	70	72	68	-	-	-
		4	-	-	72	-	-	63	-	-	-
Thickness Percent change	3	1	1.9	2.1	1.3	0.0	1.5	1.6	5.0	-18.2	-20.6
		2	-8.3	-4.4	-3.0	-0.6	1.3	1.5	-1.7	-8.0	-1.5
		3	-1.9	-2.2	-3.2	0.7	0.2	3.1	-6.6	-16.2	-12.0
	9	1	0.0	0.4	1.6	0.0	1.2	0.7	-5.7	-13.5	-14.9
		2	0.3	0.2	0.8	0.2	2.3	3.2	-9.0	-8.0	-1.0
		3	-2.7	-3.0	0.8	-0.8	0.3		-10.0	-31.0	-13.5
	28	1	0.5	1.1	1.1	-0.1	-0.1	-1.0	-0.7	-1.9	-5.3
		2	-1.8	-1.6	-2.3	-0.4	2.5	0.5	-11.4	-31.7	-24.8
		3	-3.2	-1.1	-2.5	-1.6	-0.4	-0.1	-28.7	-32.2	-31.2
		4	-	-	-0.4	-	-	13.4	-	-	0.8

* Closed cell expanded rubber

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado

2. Plastic sheeting. - These materials had generally satisfactory performance.

The chlorinated polyethylene exhibited initial swelling which stabilized during wet exposure and decreased when dried.

The initial stiffening of the polyvinyl chloride sheeting has continued throughout the exposure period. Elongation losses generally have been accompanied by strength increases, indicating loss of plasticizer rather than attack on the polymer. Limited thermo-gravimetric and infrared analysis also indicated plasticizer loss correlating with increased stiffness.

The chlorosulfonated polyethylene has shown continued stiffening. Minimum change in the control (Denver tap water) specimens indicates possible micro-organism attack.

Physical property test results are shown in table 24.

3. Fabric reinforced sheeting. - These materials had generally satisfactory performance.

No significant change occurred in the butyl. The ethylene propylene diene monomer materials had slightly lower wet strength. The chlorinated polyethylene materials have considerable swelling and slightly lower wet strength. One chlorinated polyethylene sample was severely abraded at the interface zone of the Westgate site. The chlorosulfonated polyethylene showed some increase in stiffness and moderate swelling. Physical property test results are shown in table 25.

4. Rigid polymers. - No significant change from the rather wide range of original test results has occurred.

No change was observed in the high-density polyethylene pipe specimens during visual examinations at the test sites and at the end of the exposure period. Hoop stiffness tests at the end of the exposure period also indicated no change in the physical properties.

Physical property test results for the rigid polymers are shown in table 26.

Protective Coatings

The results of protective coatings applied to steel surfaces are shown in tables 27 through 32. Tables 27, 28, and 29 show the results of coatings exposed on steel and tables 30, 31, and 32 exhibit the results of coatings applied to concrete. Typical defective and defect-free coated panels are shown in figures 24 and 30. The evaluation summary of coatings performance is shown in tables 33 and 34.

The coatings are rated as follows according to their overall performance in all three zones at the sites at which the coatings were exposed:

TABLE 24a. TEST RESULTS - PLASTIC SHEETING
(metric units)

Material			B-6515 PVC			B-6273 CSPE			B-6875 CPE		
Exposure			Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/									
Tensile Strength MPa	0	4	21.5			12.5			13.7		
	3	1	18.6	21.9	21.6	12.4	14.5	13.4	13.9	14.8	13.3
		2	15.8	-	19.5	10.9	13.4	14.4	12.8	12.1	14.7
		3	21.4	20.8	21.2	13.7	15.7	16.3	13.8	13.1	13.7
	9	1	22.7	24.9	23.7	14.2	15.8	14.8	14.3	14.3	14.0
		2	21.9	19.5	18.7	14.6	18.0	15.1	12.0	11.8	13.5
		3	20.7	20.2	21.0	18.3	17.7	17.4	9.9	8.9	13.3
	28	1	22.2	21.4	22.2	14.1	17.3	16.8	13.2	14.1	14.0
		2	21.4	27.2	17.7	16.0	19.2	17.8	13.6	11.2	11.7
		3	21.2	18.6	20.4	20.4	21.0	22.0	11.6	12.8	13.5
		4	-	-	22.0	-	-	14.8	-	-	13.5
Elongation, percent	0	4	300			215			300		
	3	1	265	330	290	230	245	265	340	330	310
		2	220	-	270	260	185	220	350	265	300
		3	270	250	325	205	210	220	320	300	295
	9	1	235	285	270	225	215	245	280	295	300
		2	230	220	170	190	180	200	270	215	290
		3	240	255	290	155	190	140	300	260	265
	28	1	255	225	247	202	149	183	225	276	312
		2	240	5	170	160	115	150	308	255	240
		3	225	210	280	125	128	132	255	278	305
		4	-	-	295	-	-	242	-	-	305
Thickness percent change	3	1	3.0	0.0	-4.0	1.5	2.1	1.7	6.2	11.8	7.5
		2	-1.4	-1.9	-1.4	-2.5	-1.8	-4.9	4.1	4.3	2.6
		3	-3.5	-1.0	-2.0	1.1	4.5	4.5	7.8	4.5	11.7
	9	1	-5.0	-6.1	-6.5	1.5	4.4	2.6	4.8	10.5	6.6
		2	-3.9	-1.0	-1.0	3.5	7.0	4.2	5.3	14.2	9.7
		3	0	-1.0	0	2.4	1.8	2.2	3.0	4.1	5.4
	28	1	-3.0	4.7	-4.3	1.0	2.1	2.0	7.2	7.2	-0.3
		2	-7.2	-5.8	-1.5	-0.6	4.0	1.8	-0.6	3.5	1.1
		3	-1.3	-3.0	0	1.0	1.7	1.8	-1.3	0	-0.4
		4	-	-	-5.3	-	-	2.7	-	-	6.5

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia.
Site 4: USBR Laboratories, Denver, Colorado.

TABLE 24b. TEST RESULTS - PLASTIC SHEETING
(English units)

Material			B-6414 PVC			B-6273 CSPE			B-6475 CPE		
Exposure			Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/									
Tensile Strength lb/in^2	0	4	3,130			1,820			1,990		
	3	1	2,700	3,185	3,140	1,800	2,110	1,950	2,020	2,160	1,940
		2	2,295	-	2,835	1,585	1,955	2,090	1,865	1,762	2,145
		3	3,110	3,030	3,075	2,000	2,280	2,375	2,010	1,910	1,994
	9	1	3,300	3,620	3,440	2,070	2,295	2,160	2,085	2,080	2,040
		2	3,180	2,840	2,715	2,125	2,620	2,195	1,870	1,720	1,960
		3	3,005	2,930	3,050	2,655	2,575	2,525	1,445	1,305	1,930
	28	1	3,224	3,110	3,222	2,058	2,510	2,442	1,923	2,046	2,040
		2	3,116	3,949	2,568	2,328	2,798	2,592	1,982	1,630	1,709
		3	3,075	2,704	2,960	2,964	3,050	3,202	1,686	1,804	1,966
		4	-	-	3,203	-	-	2,154	-	-	1,961
Elongation, percent	0	4	300			215			300		
	3	1	265	330	290	230	245	265	340	330	310
		2	220	-	270	260	185	220	350	265	300
		3	270	250	325	205	210	220	320	300	295
	9	1	235	285	270	225	215	245	280	295	300
		2	230	220	170	190	180	200	270	215	290
		3	240	255	290	155	190	140	300	260	265
	28	1	255	225	247	202	149	183	225	276	312
		2	240	5	170	160	115	150	308	255	248
		3	225	210	280	125	128	132	255	278	305
		4	-	-	295	-	-	242	-	-	305
Thickness Percent change	3	1	3.0	0.0	-4.0	1.5	2.1	1.7	6.2	11.8	7.5
		2	-1.4	-1.9	-1.4	-2.5	-1.8	-4.9	4.1	4.3	2.6
		3	-3.5	-1.0	-2.0	1.1	4.5	4.5	7.8	4.5	11.7
	9	1	-5.0	-6.1	-6.5	1.5	4.4	2.6	4.8	10.5	8.6
		2	-3.9	-1.0	-1.0	3.5	7.0	4.2	5.3	14.2	9.7
		3	0	-1.0	0	2.4	1.8	2.2	3.0	4.1	5.4
	28	1	-3.0	4.7	-4.3	1.0	2.1	2.0	7.2	7.2	-0.3
		2	-7.2	-5.8	-1.5	-0.6	4.0	1.8	-0.6	3.5	1.1
		3	-1.3	-3.0	0	1.0	1.7	1.8	-1.3	0	-0.4
		4	-	-	-5.3	-	-	2.7	-	-	6.5

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado

TABLE 25a. TEST RESULTS - FABRIC - REINFORCED FLEXIBLE SHEETING

(metric units)

Material			B-6464 Butyl Nylon reinforced			B-6399 EPDM Nylon reinforced			B-6467 CPE Nylon reinforced			B-6468 CPE Polyester reinforced			B-6386 CSPE Nylon reinforced		
Exposure			Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/															
Burst strength MPa	0	4	1.4			1.2			3.4			2.8			0.8		
	3	1	1.4	1.3	1.3	1.1	1.0	1.0	3.2	3.1	3.1	2.3	2.5	2.3	-	-	0.7
		2	1.3	1.4	1.4	1.1	1.1	1.1	3.0	3.0	3.0	2.6	2.6	2.6	-	-	0.8
		3	1.4	1.4	1.3	1.1	1.1	1.0	3.2	3.2	3.2	2.4	2.4	2.3	-	-	0.7
	9	1	1.5	1.3	1.4	1.2	1.1	1.1	2.7	3.3	3.3	2.8	2.4	2.5	-	-	-
		2	1.4	1.4	1.4	1.0	1.0	1.0	3.0	3.1	3.1	2.4	2.4	2.5	-	-	0.9
		3	1.4	1.3	1.4	0.9	1.0	1.1	2.6	3.2	3.3	2.3	2.6	2.4	-	-	1.0
	28	1	1.5	1.3	1.4	1.2	1.1	1.1	3.3	2.4	2.5	2.7	2.5	2.4	-	-	1.0
		2	1.4	1.3	1.4	1.1	1.0	1.2	2.3	2.6	2.8	2.6	2.5	2.4	-	-	1.1
		3	1.3	1.4	1.4	0.9	0.9	1.1	2.3	2.5	2.9	2.4	2.4	2.4	-	-	1.2
		4	-	-	1.4	-	-	1.0	-	-	3.1	-	-	2.6	-	-	0.8
Thickness percent change	3	1	-0.4	-0.3	0.3	0.6	0.1	0.4	5.9	8.4	7.1	9.2	11.3	11.3	-	-	5.3
		2	-1.7	-0.5	1.3	0.0	-0.9	0.4	4.5	2.0	2.8	7.6	6.3	6.6	-	-	8.5
		3	1.1	0.7	0.4	-0.8	1.5	3.7	5.5	6.1	7.2	9.4	7.4	11.5	-	-	10.0
	9	1	-0.8	0.2	0.0	-0.2	0.8	-2.0	1.3	11.1	11.8	13.4	20.3	20.0	-	-	-
		2	0.2	2.5	-0.1	-2.1	2.0	3.6	9.9	11.8	7.5	13.2	16.3	17.5	-	-	14.9
		3	-0.2	4.2	1.2	-0.2	-1.6	1.4	8.6	10.5	10.9	13.3	18.0	18.6	-	-	10.6
	28	1	-0.7	-1.2	-1.3	-1.8	-0.7	-1.0	6.8	6.2	1.8	2.6	5.4	2.7	-	-	4.1
		2	-1.0	1.8	-0.2	-4.7	0.7	0.5	7.1	8.6	8.0	8.4	7.7	7.1	-	-	9.0
		3	1.8	1.0	-0.2	-1.2	0.2	2.1	10.5	5.2	9.7	5.7	12.0	8.6	-	-	7.8
		4	-	-	0.0	-	-	4.8	-	-	16.4	-	-	20.9	-	-	8.6

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California.
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado.

TABLE 25b. TEST RESULTS - FABRIC - REINFORCED FLEXIBLE SHEETING

(English units)

Material			B-6464 Butyl Nylon reinforced			B-6399 EPDM Nylon reinforced			B-6467 CPE Nylon reinforced			B-6468 CPE Polyester reinforced			B-6386 CSPE Nylon reinforced		
Exposure			Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/															
Burst strength lb/in^2	0	4	215			180			505			415			125		
	3	1	210	200	200	165	150	150	470	460	455	340	370	340	-	-	115
		2	200	205	205	170	160	160	440	445	445	385	380	380	-	-	120
		3	205	210	200	165	160	155	470	470	470	350	355	340	-	-	110
	9	1	220	200	210	185	165	165	405	485	485	410	350	370	-	-	-
		2	210	205	205	150	150	150	440	455	460	360	360	370	-	-	135
		3	205	200	210	140	150	160	390	465	480	345	385	360	-	-	155
	28	1	225	200	205	180	160	155	480	350	365	395	365	360	-	-	150
		2	205	200	205	170	150	180	345	380	410	390	365	350	-	-	160
		3	200	205	205	140	135	165	345	375	435	355	360	350	-	-	175
		4	-	-	210	-	-	150	-	-	455	-	-	390	-	-	120
Thickness Percent change	3	1	-0.4	-0.3	0.3	0.6	0.1	0.4	5.9	8.4	7.1	9.2	11.3	11.3	-	-	5.3
		2	-1.7	-0.5	1.3	0.0	-0.9	0.4	4.5	2.0	2.8	7.6	6.3	6.6	-	-	8.5
		3	1.1	0.7	0.4	-0.8	1.5	3.7	5.5	6.1	7.2	9.4	7.4	11.5	-	-	10.0
	9	1	-0.8	0.2	0.0	-0.2	0.8	-2.0	1.3	11.1	11.8	13.4	20.3	20.0	-	-	-
		2	0.2	2.5	-0.1	-2.1	2.0	3.6	9.9	11.8	7.5	13.2	16.3	17.5	-	-	14.9
		3	-0.2	4.2	1.2	-0.2	-1.6	1.4	8.6	10.5	10.9	13.3	18.0	18.6	-	-	10.6
	28	1	-0.7	-1.2	-1.3	-1.8	-0.7	-1.0	6.8	6.2	1.8	2.6	5.4	2.7	-	-	4.1
		2	-1.0	1.8	-0.2	-4.7	0.7	0.5	7.1	8.6	8.0	8.4	7.7	7.1	-	-	9.0
		3	1.8	1.0	-0.2	-1.2	0.2	2.1	10.5	5.2	9.7	5.7	12.0	8.6	-	-	7.8
		4	-	-	0.0	-	-	4.8	-	-	16.4	-	-	20.9	-	-	8.6

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado

TABLE 26a. TEST RESULTS - RIGID POLYMERS
(metric units)

Material			RS-1 Epoxy			RS-2 Polyester			RS-3 Vinyl			RS-5 RPM		
	Exposure		Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/												
Flexural Strength, MPa	0	4	108.3			169.1			145.1			71.3		
	3	1	97.7	130.1	106.3	194.3	153.4	174.2	170.5	166.3	132.5	58.1	68.8	71.7
		2	120.5	115.2	110.7	134.1	142.6	140.3	98.8	123.0	102.4	52.3	45.4	48.0
		3	94.3	114.8	101.2	154.0	189.1	156.8	123.3	122.0	139.7	61.3	66.6	54.0
	9	1	111.6	107.9	123.4	177.7	166.6	178.4	111.9	96.0	133.3	74.3	80.7	97.2
		2	130.7	130.3	116.9	143.4	143.0	146.3	132.7	119.0	121.9	90.5	92.1	96.5
		3	119.2	113.5	103.0	174.2	164.5	135.6	115.6	115.0	112.7	97.1	72.7	82.7
	28	1	111.6	114.1	107.2	140.9	145.4	142.0	109.6	112.3	113.3	71.3	92.5	76.5
		2	112.6	118.8	94.4	140.9	184.7	162.6	134.3	142.0	145.2	80.9	92.8	79.8
		3	126.2	109.0	119.2	146.3	131.2	157.3	133.6	140.9	127.0	89.6	81.9	91.1
		4	-	-	105.4	-	-	148.2	-	-	102.2	-	-	80.9
Maximum Strain, percent	0	4	2.40			2.20			2.20			1.59		
	3	1	1.70	2.12	1.85	2.84	2.84	3.20	2.42	2.97	2.39	1.41	1.48	1.72
		2	1.90	1.88	1.71	2.27	2.47	2.29	1.46	2.24	1.98	1.56	1.20	1.20
		3	1.62	1.83	1.83	2.81	3.21	2.73	2.28	2.15	2.37	1.71	1.99	1.64
	9	1	1.94	1.84	2.20	2.58	3.17	2.92	1.75	1.54	2.20	1.67	1.83	2.10
		2	2.39	2.26	1.92	2.61	2.40	2.42	2.04	2.02	2.00	1.85	2.01	1.56
		3	2.35	1.88	1.86	2.58	2.68	2.48	1.88	1.77	1.86	2.02	1.72	2.07
	28	1	1.89	2.09	1.89	2.57	2.60	2.46	1.86	1.93	2.00	1.92	2.26	2.06
		2	1.90	1.96	1.51	2.45	2.78	2.72	2.24	2.53	2.52	1.78	1.96	2.32
		3	2.18	1.88	2.01	2.31	2.48	2.67	1.89	2.43	2.04	1.80	1.82	1.68
		4	-	-	1.92	-	-	2.56	-	-	1.76	-	-	1.86

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California.
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia.
Site 4: USBR Laboratories, Denver, Colorado.

TABLE 26b. TEST RESULTS - RIGID POLYMERS

(English units)

Material			RS-1 Epoxy			RS-2 Polyester			RS-3 Vinyl			RS-5 RPM		
	Exposure		Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor	Gas	Interface	Liquor
Property	Exposure time, months	Site 1/												
Flexural Strength, lb/in^2	0	4	15,710			24,530			21,050			10,350		
	3	1	14,180	18,870	15,430	28,190	22,260	25,270	24,730	24,120	19,220	8,430	9,990	10,400
		2	17,490	16,720	16,070	19,450	20,690	20,350	13,610	17,840	14,860	7,598	6,590	6,970
		3	13,680	16,660	14,690	22,350	27,440	22,750	17,890	17,700	20,270	8,900	9,660	7,846
	9	1	16,200	15,660	17,900	25,780	24,170	25,880	16,240	13,930	19,340	10,790	11,710	14,110
		2	18,960	18,900	16,960	20,800	20,750	21,230	19,260	17,260	17,690	13,130	13,360	14,000
		3	17,290	16,470	14,950	25,270	23,870	19,680	16,780	16,680	16,350	14,090	10,550	11,960
	28	1	16,200	16,560	15,550	20,450	21,090	20,600	15,900	16,300	16,440	10,350	13,430	11,100
		2	16,340	17,240	13,700	20,450	26,790	24,020	19,480	20,600	21,060	11,740	13,460	11,580
		3	18,310	15,810	17,290	21,220	19,040	22,820	19,390	20,450	18,430	13,000	11,890	13,220
		4	-	-	15,300	-	-	21,500	-	-	14,830	-	-	11,740
Maximum Strain, percent	0	4	2.40			2.20			2.20			1.59		
	3	1	1.70	2.12	1.85	2.84	2.84	3.20	2.42	2.97	2.39	1.41	1.48	1.72
		2	1.90	1.88	1.71	2.27	2.47	2.29	1.46	2.24	1.98	1.56	1.20	1.20
		3	1.62	1.83	1.83	2.81	3.21	2.73	2.28	2.15	2.37	1.71	1.99	1.64
	9	1	1.94	1.84	2.20	2.58	3.17	2.92	1.75	1.54	2.20	1.67	1.83	2.10
		2	2.39	2.26	1.92	2.61	2.40	2.42	2.04	2.02	2.00	1.85	2.01	1.56
		3	2.35	1.88	1.86	2.58	2.68	2.48	1.88	1.77	1.86	2.02	1.72	2.07
	28	1	1.89	2.09	1.89	2.57	2.60	2.46	1.86	1.93	2.00	1.92	2.26	2.06
		2	1.90	1.96	1.51	2.45	2.78	2.72	2.24	2.53	2.52	1.78	1.96	2.32
		3	2.18	1.88	2.01	2.31	2.48	2.67	1.89	2.43	2.04	1.80	1.82	1.68
		4	-	-	1.92	-	-	2.56	-	-	1.76	-	-	1.86

1/ Site 1: Tapia Water Reclamation Plant, Calabasas, California
Site 2: Speedway Wastewater Treatment Plant, Indianapolis, Indiana
Site 3: Westgate Wastewater Treatment Plant, Alexandria, Virginia
Site 4: USBR Laboratories, Denver, Colorado

TABLE 27. TEST RESULTS - PROTECTIVE COATINGS ON STEEL SURFACES - SITE 1*

Coating Film Defects***
Site 1 Exposure

Code No.**	Nominal exposure time, mo	Gas	Interface	Liquor
C-1	7	No defects	No defects	Slight pinhead blistering around score
	19	No defects	Pinhead blistering around score	Slight pinhead blistering around score
C-2	7	No defects	No defects	No defects
	19	No defects	No defects	No defects
C-3	7	Slight impact damage	Slight impact damage	No defects
	19	Slight impact damage	Alligator cracking, both sides	Slight alligator cracking
C-4	7	Thin area on edge with corrosion	No defects	No defects
	19	Thin area on edge with corrosion	No defects	No defects
C-5	7	Corrosion on unscored site, 1 percent	Pinhead blistering around score	Pinpoint blistering over 100 percent of area
	19	Corrosion over 100 percent of area	Corrosion over 100 percent of area	Pinpoint blistering over 100 percent of area
C-6	7	Corrosion on edge	No defects	One impacted area
	19	Corrosion on edge	Blisters with corrosion	Blisters with corrosion
C-8	7	One impacted area with rust	One impacted area	Two impacted areas
	19	One impacted area with rust	One impacted area	Two impacted areas
C-9	7	No defects	No defects	No defects
	19	No defects	No defects	No defects
C-11#	7	Few breaks in coating	Film deterioration	Film deterioration
	19	Few breaks in coating	Complete loss of film	Complete loss of film

* Site 1 - Tapia Water Reclamation Facility, Calabasas, California.
** See table 5 for coating identification
*** See figures 24 through 30 for typical examples of coating defects.
\# Exposure racks were coated with this material.

TABLE 28. TEST RESULTS - PROTECTIVE COATINGS ON STEEL SURFACES - SITE 2 1/
Coating Film Defects 3/
Site 2 Exposure

2/ Code No.	Nominal exposure time, months	Gas	Interface	Liquor
C-1	3	Blisters around score	No defects	No defects
	10	Blisters around score	Slight blistering around score	No defects
	20	Blisters around score	Slight blistering around score	One blister at score
	28	Blisters around score	Slight blistering around score	Pinpoint blistering
C-2	3	No defects	No defects	No defects
	10	No defects	Slight pinhead blistering	No defects
	20	No defects	Slight pinhead blistering	No defects
	28	No defects	Slight pinhead blistering	Mechanical damage
C-3	3	No defects	No defects	Mechanical damage
	10	No defects	Cracking on both sides	Mechanical damage
	20	No defects	Cracking on both sides	Mechanical damage
	28	Alligator cracking, both sides	Severe alligator cracking	Alligator cracking, both sides
C-4	3	No defects	No defects	No defects
	10	No defects	No defects	No defects
	20	No defects	No defects	No defects
	28	No defects	Slight alligator cracking	No defects
C-5	3	No defects	Some erosion of coating	No defects
	10	No defects	Pinhead blistering around score	Large blisters around score
	20	No defects	Pinhead blistering around score	Large blisters around score
	28	Large pinhead blisters, alligator cracking	Large pinhead blisters, alligator cracking	Large pinhead blisters, alligator cracking
C-6	3	No defects	No defects	No defects
	10	Pinhead blisters, both sides	No defects	Pinhead blistering around score
	20	Pinhead blisters, both sides	Blisters around score	Pinhead blistering around score
	28	Severe pinhead blistering, both sides	Large and pinpoint blisters	Film severely deteriorated
C-8	3	No defects	No defects	No defects
	10	No defects	No defects	No defects
	20	No defects	No defects	One chipped area by score
	28	Chipped on edges	No defects	One chipped area by score
C-9	3	No defects	No defects	No defects
	10	No defects	No defects	No defects
	20	No defects	No defects	No defects
	28	No defects	No defects	No defects
C-10	9	No defects	No defects	No defects
	17	Film completely deteriorated	Severe film deterioration	Severe film deterioration
C-12	3	No defects	No defects	No defects
	12	No defects	No defects	No defects
C-13	3	Pinhead blistering around score	Pinhead blistering around score	Pinhead blistering around score
	12	Large blisters around score	Pinhead blistering around score	Pinhead blistering around score
C-14	3	Blistering, both sides	Blistering, both sides	Blistering, both sides
	12	Blistering, both sides	Severe pinhead blistering	Blistering, both sides
C-16	3	Blistering, topcoat only	Blistering, topcoat only	Blistering, topcoat only
	12	Large blisters, topcoat only	Blistering, topcoat only	Blistering, topcoat only

1/ Site 2 - Speedway Wastewater Treatment Plant, Indianapolis, Indiana
2/ See Table 5 for coating identification
3/ See Figures 24 through 30 for typical examples of coating defects

TABLE 29. TEST RESULTS - PROTECTIVE COATINGS ON STEEL SURFACES - SITE 3 1/
Coating Film Defects 3/
Site 3 Exposure

2/ Code No.	Nominal exposure time, months	Gas	Interface	Liquor
C-1	3	Pinhead blisters around score	Pinhead blisters around score	No defects
	10	Pinhead blisters around score	Pinhead blisters around score	Pinhead blisters around score
	20	Pinhead blisters around score	4/	Pinhead blisters around score
	28	Pinhead blisters around score	Blistering, both sides	Pinhead blisters, both sides
C-2	3	No defects	No defects	No defects
	10	No defects	No defects	No defects
	20	No defects	4/	No defects
	28	No defects	No defects	No defects
C-3	3	No defects	Coating embrittled	Mechanical damage
	10	Alligator cracking, both sides	Alligator cracking, both sides	Mechanical damage
	20	Alligator cracking, both sides	4/	Mechanical damage
	28	Alligator cracking, both sides	Alligator cracking, both sides	Alligator cracking, both sides
C-4	3	No defects	No defects	No defects
	10	Pinhead blistering around score	No defects	Pinhead blisters around score
	20	Pinhead blistering around score	4/	Pinhead blisters around score
	28	Pinhead blistering around score	No defects	Pinhead blisters around score
C-5	3	Blistering around score	Some erosion of coating	Some erosion of coating
	10	Pinhead blisters, both sides	Pinhead blisters, both sides	Pinhead blisters around score
	20	Pinhead blisters, both sides	4/	Pinhead blisters around score
	28	Pinhead blisters, both sides	Pinhead blisters, both sides	Pinhead blisters, both sides
C-6	3	No defects	Some erosion of coating	Some erosion of coating
	10	Pinhead blisters, both sides	Pinhead blisters around score	Some erosion of coating
	20	Pinhead blisters, both sides	4/	Some erosion of coating
	28	Pinhead blisters, both sides	Pinhead blisters, both sides	Pinhead blisters, both sides
C-8	3	No defects	No defects	No defects
	10	Chipping around center hole	Slight cracking due to scoring	Chipping around center hole
	20	Chipping around center hole	4/	Chipping around center hole
	28	Chipping around center hole	Slight cracking due to scoring	Chipping around center hole
C-9	3	No defects	No defects	No defects
	10	No defects	No defects	No defects
	20	No defects	4/	No defects
	28	No defects	No defects	No defects
C-10	9	No defects	4/	No defects
	17	Film deteriorated	Film deteriorated	Film deteriorated
C-12	3	No defects	No defects	4/
	12	No defects	No defects	No defects
C-13	3	No defects	No defects	4/
	12	Pinhead blistering, both sides	Pinhead blisters, both sides	Pinhead blisters, both sides
C-14	3	No defects	Pinhead blisters, both sides	4/
	12	Severe pinhead blistering	Pinhead blisters, both sides	Pinhead blisters, both sides
C-16	3	Blistering, topcoat only	Blisters, topcoat only	4/
	12	Blistering, topcoat only	Blisters, topcoat only	Slight blistering, topcoat only

1/ Site 3 - Westgate Wastewater Treatment Plant, Alexandria, Virginia
2/ See Table 5 for coating identification
3/ See Figures 24 through 30 for typical examples of coating defects
4/ Sample could not be retrieved for evaluation during this inspection

TABLE 30. TEST RESULTS - PROTECTIVE COATINGS ON CONCRETE SURFACES - SITE 1*
Coating Film Defects***
Site 1 Exposure

Code No.**	Nominal exposure time, mo	Gas	Interface	Liquor
C-1	7	No defects	Pinhead blistering over 100 percent of surface	Pinhead blistering over 100 percent of surface
	19	No defects	Pinhead blistering over 100 percent of surface	Pinhead blistering over 100 percent of surface
C-3	7	Craters on scored side	Craters on scored side	Craters on scored side
	19	Craters on scored side	Alligator cracking, both sides	Slight alligator cracking
C-4	7	Slight pinhead blistering on scored side	Pinhead blistering, both sides	Pinhead blistering, both sides
	19	Slight pinhead blistering on scored side	Pinhead blistering both sides	Pinhead blistering, both sides
C-5	7	No defects	Blisters and flaking, 100 percent of area	Blisters and flaking, 100 percent of area
	19	No defects	Blisters and flaking, 100 percent of area	Blisters and flaking, 100 percent of area
C-6	7	Impacted area, unsored side	Pinhead blisters, 100 percent of area	Pinhead blisters, 100 percent of area
	19	Impacted area, unscored side	Flaking	Pinhead blisters, 100 percent of area
C-7	7	Slight cratering	Slight cratering, large pinhead blisters	Slight cratering, large pinhead blisters
	19	Slight cratering	Slight cratering, large pinhead blisters	Slight cratering, large pinhead blisters

* Site 1 - Tapia Water Reclamation Facility, Calabasas, California.
** See table 5 for coating identification
*** See figures 24 through 30 for typical examples of coating defects.

TABLE 31. TEST RESULTS - PROTECTIVE COATINGS ON CONCRETE SURFACES - SITE 2*
Coating Film Defects***
Site 2 Exposure

Code No.**	Nominal exposure time, mo	Gas	Interface	Liquor
C-1	3	No defects	No defects	No defects
	10	No defects	Pinhead blisters, both sides	No defects
	20	No defects	Pinhead blisters, both sides	Pinhead blisters abound score
	28	No defects	Large blisters	Pinpoint blisters, both sides
C-3	3	No defects	No defects	Mechanical damage
	10	Craters	Alligator cracking, both sides	Slight cratering
	20	Craters	Alligator cracking, both sides	Slight cratering
	28	Slight alligator cracking	Alligator cracking, both sides	Alligator cracking, both sides
C-4	3	No defects	No defects	No defects
	10	No defects	No defects	No defects
	20	No defects	No defects	No defects
	28	No defects	No defects	No defects
C-5	3	No defects	Some erosion of coating	General blistering
	10	Pinhead blisters, both sides	Pinhead blisters, both sides	Severe blistering, both sides
	20	Pinhead blisters, both sides	Severe blistering, both sides	Severe blistering, both sides
	28	Pinhead blisters, both sides	Blistering, alligator cracking	Severe blistering, both sides
C-6	3	No defects	No defects	No defects
	10	Severe blistering, both sides	Severe blistering, both sides	Large blisters around score
	20	Severe blistering, both sides	Severe blistering, both sides	Severe blistering, both sides
	28	Severe blistering, both sides	Severe blistering, both sides	Severe blistering, both sides
C-7	3	No defects	No defects	No defects
	10	No defects	No defects	No defects
	20	No defects	No defects	No defects
	28	No defects	No defects	No defects
C-9	3	No defects	No defects	No defects
	10	No defects	No defects	No defects
	20	No defects	No defects	No defects
	28	No defects	No defects	No defects
C-12	3	No defects	No defects	No defects
	10	No defects	No defects	No defects
C-13	3	No defects	No defects	Blisters, both sides
	12	Large blisters	Large blisters	Blisters, both sides
C-14	3	No defects	No defect	Blisters around score
	12	Pinhead blisters	Large and pinhead blisters	Large blisters, both sides
C-15	3	No defects	No defects	No defects
	12	Alligator cracking	Alligator cracking	Alliigator cracking
C-16	3	No defects	No defects	No defects
	12	Few blisters, topcoat only	Few blisters, topcoat only	Blisters, topcoat only

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* Site 2 - Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
** See table 5 for coating identification
*** See figure 24 through 30 for typical examples of coating defects.

TABLE 32. TEST RESULTS - PROTECTIVE COATINGS ON CONCRETE SURFACES - SITE 3 1/

Coating Film Defects 3/

Site 3 Exposure

2/ Code No.	Nominal exposure time, months	Gas	Interface	Liquor
C-1	3	No defects	No defects	No defects
	10	Pinhead blisters, both sides	Pinhead blisters, both sides	Pinhead blisters, both sides
	20	Pinhead blisters, both sides	4/	Pinhead blisters, both sides
	28	Pinhead blisters, both sides	Pinhead blisters, both sides	Pinhead blisters, both sides
C-3	3	No defects	Coating embrittled	Mechanical damage
	10	Alligator cracking, both sides	Alligator cracking, both sides	Mechanical damage
	20	Alligator cracking, both sides	4/	Alligator cracking, both sides
	28	Alligator cracking, both sides	Alligator cracking, both sides	Alligator cracking, both sides
C-4	3	No defects	No defects	No defects
	10	Pinhead blistering, both sides	No defects	Pinhead blisters around score
	20	Pinhead blistering, both sides	4/	Pinhead blisters around score
	28	Pinhead blistering, both sides	Pinpoint blisters, both sides	Pinhead blisters around score
C-5	3	No defects	Coating eroded	Coating eroded
	10	Pinhead blisters, both sides	Pinhead blisters, both sides	Pinhead blisters, both sides
	20	Pinhead blisters, both sides	4/	Pinhead blisters, both sides
	28	Pinhead blisters, both sides	Pinhead blisters, both sides	Pinhead blisters, both sides
C-6	3	No defects	Coating eroded	Coating eroded
	10	Pinhead blisters, both sides	Pinhead blisters, both sides	Pinhead blisters around score
	20	Pinhead blisters, both sides	4/	Pinhead blisters around score
	28	Pinhead blisters, both sides	Pinhead blisters, both sides	Pinhead blisters around score
C-7	3	No defects	No defects	No defects
	10	Cratering	Cratering	Cratering
	20	Cratering	4/	Cratering, one blister, unscored side
	28	Cratering	Cratering	Cratering, one blister, unscored side
C-9	3	No defects	No defects	No defects
	10	No defects	No defects	No defects
	20	No defects	4/	No defects
	28	No defects	No defects	No defects
C-12	3	No defects	No defects	4/
	12	No defects	No defects	No defects
C-13	3	No defects	No defects	4/
	12	Large blisters	Large blisters	Large blisters
C-14	3	No defects	No defects	4/
	12	Pinhead blisters, both sides	Pinhead blisters, both sides	Pinhead blisters, both sides
C-15	3	Slight abrasion damage	Blistering around score	4/
	12	Blisters, both sides	Blisters, both sides	Alligator cracking and blistering
C-16	3	Slight blistering, topcoat only	Slight blistering, topcoat only	4/
	12	Slight blistering, topcoat only	Slight blistering, topcoat only	Slight blistering, topcoat only

1/ Site 3 - Westgate Wastewater Treatment Plant, Alexandria, Virginia
2/ See Table 5 for coating identification
3/ See Figures 24 through 30 for typical examples of coating defects
4/ Sample could not be retrieved for evaluation during this inspection

Figure 24. Blistering of proprietary butyl coating (No. C-6) on steel (left) and concrete substrates.

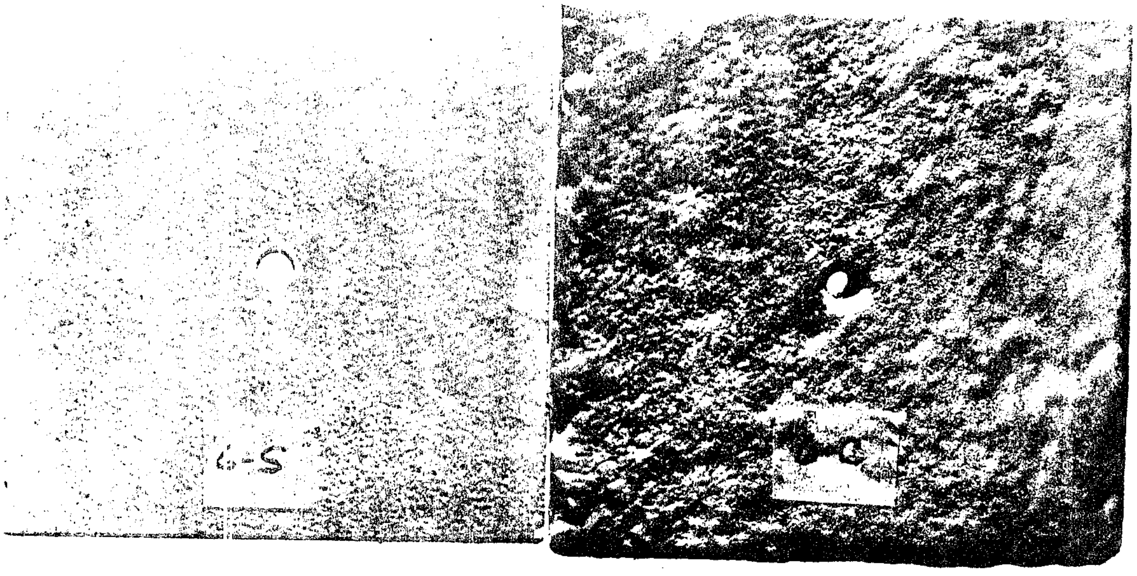

Figure 25. Defect-free proprietary urethane coating (No. C-9) on steel (left) and concrete substrates. Roughness is characteristic of application.

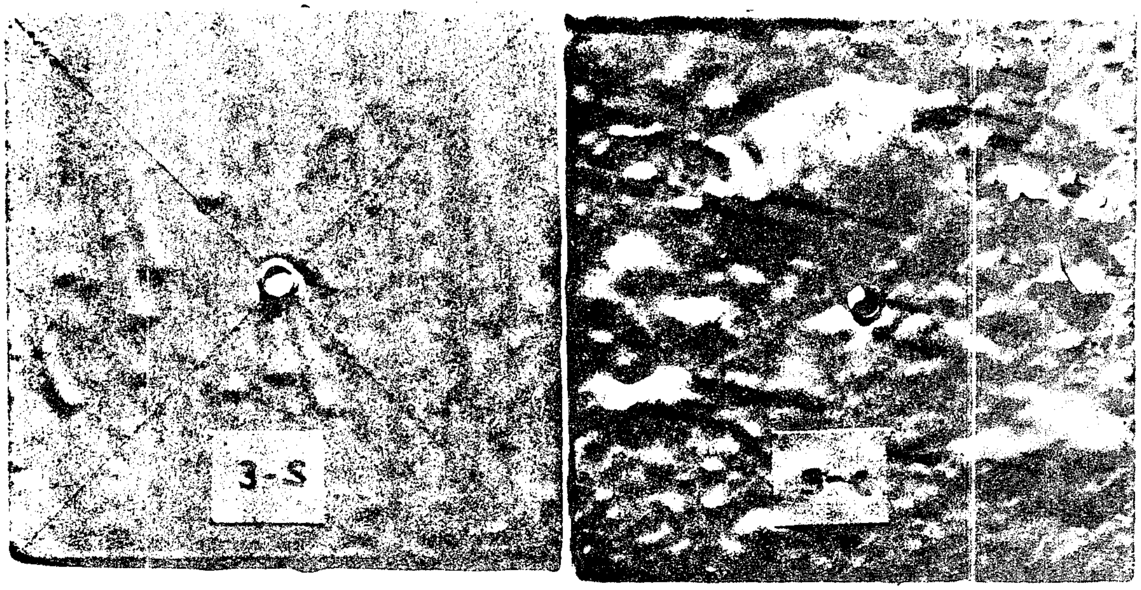

Figure 26. Blistering of proprietary, one-component urethane coating (No. C-13) on steel (left) and concrete substrates.

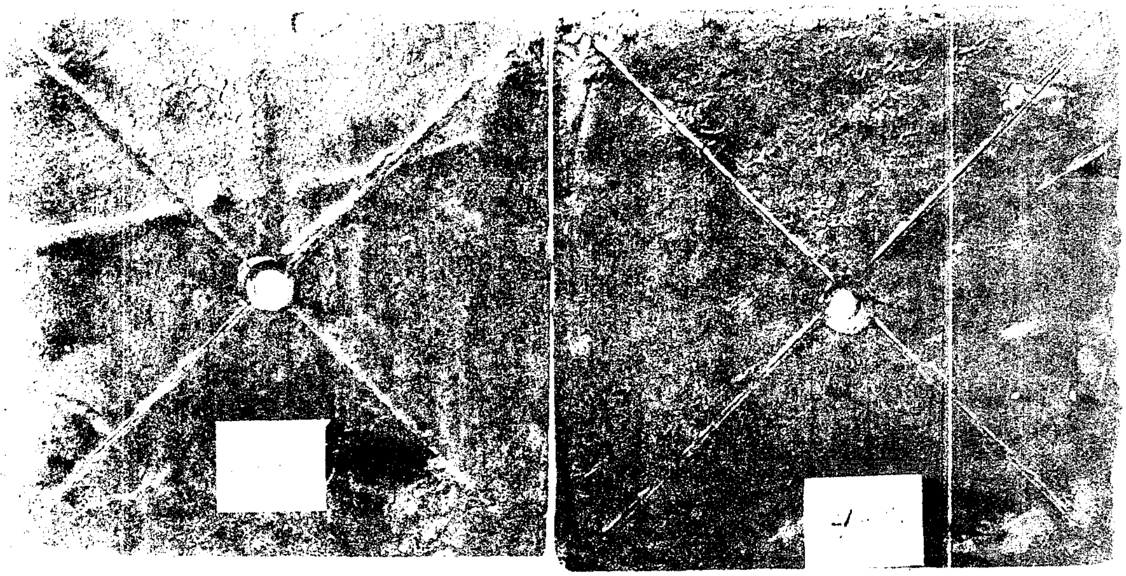

Figure 27. Cracking of coal-tar enamel coating (No. C-3) on steel (left) and on concrete substrates.

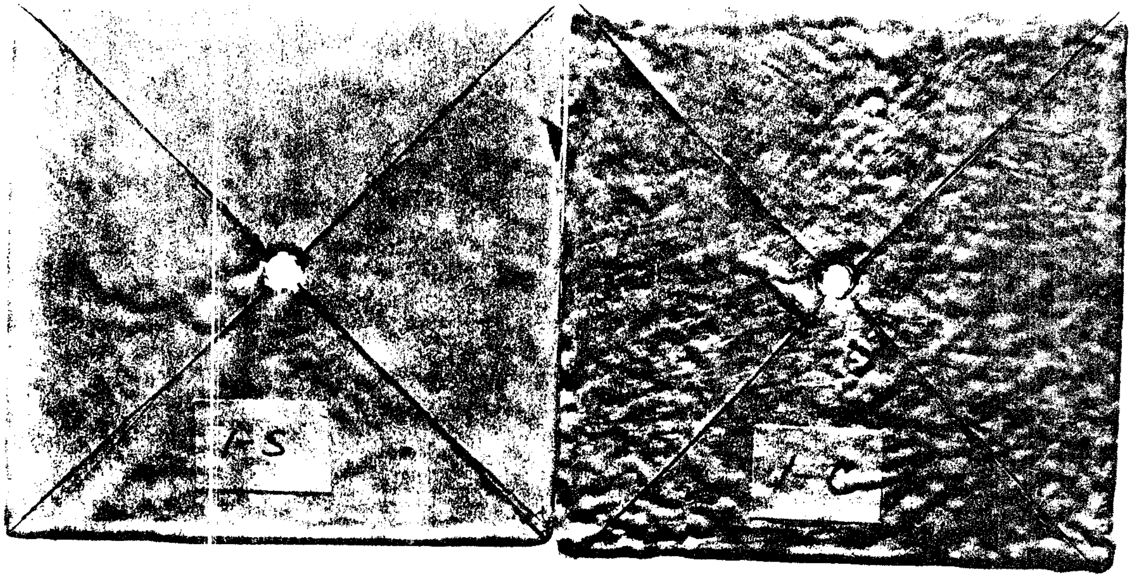

Figure 28. Defect-free phenolic-epoxy coating (No. C-12) on steel (left) and concrete substrates.

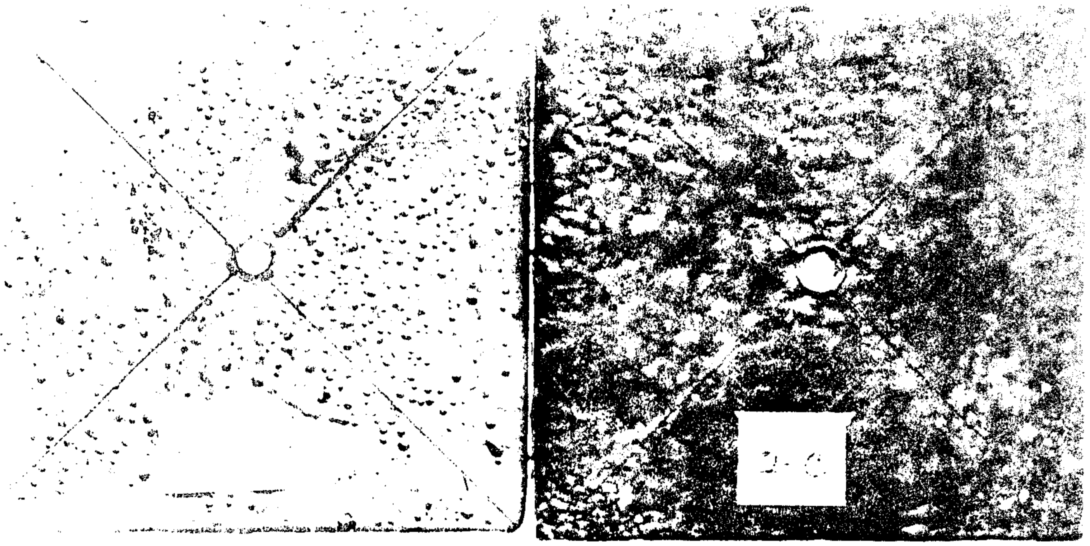

Figure 29. Severely blistered prorietary urethane coating (No. C-14) on steel (left) and concrete substrates.

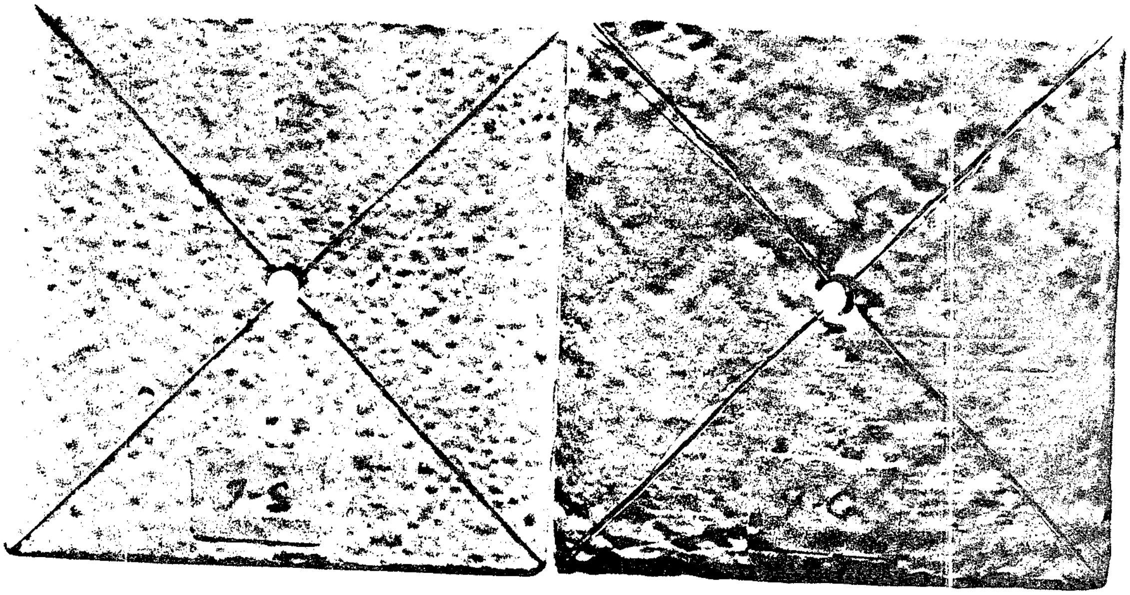

Figure 30. Blistering (topcoat only) of proprietary phenolic-epoxy coating (No. C-16) on steel (left) and concrete substrates.

TABLE 33. EVALUATION SUMMARY - PROTECTIVE COATINGS FOR STEEL SURFACES

Performance Rating 1/

Code No.	Site exposure	Site 1 2/		Site 2 3/							Site 3 4/							Average 5/	Highest 6/
		7 mos	19 mos	3 mos	9 mos	10 mos	12 mos	17 mos	20 mos	28 mos	3 mos	9 mos	10 mos	12 mos	17 mos	20 mos	28 mos		
C- 1	Gas	1	1	2	-	2	-	-	2	2	2	-	2	-	-	2	2	1.7	
	Interface	1	2	1	-	2	-	-	2	2	2	-	2	-	-	-	4	2.7	
	Liquor	2	2	1	-	1	-	-	2	3	2	-	2	-	-	2	4	3.0	3.0
C- 2	Gas	1	1	1	-	1	-	-	1	1	1	-	1	-	-	1	1	1.0	
	Interface	1	1	1	-	3	-	-	3	3	1	-	1	-	-	-	1	1.7	
	Liquor	1	1	1	-	1	-	-	1	2	1	-	1	-	-	1	1	1.3	1.7
C- 3	Gas	2	2	1	-	1	-	-	1	4	1	-	4	-	-	4	4	3.3	
	Interface	2	4	1	-	4	-	-	4	4	4	-	4	-	-	-	4	4.0	
	Liquor	2	4	2	-	2	-	-	2	4	2	-	2	-	-	2	4	4.0	4.0
C- 4	Gas	2	2	1	-	1	-	-	1	1	1	-	2	-	-	2	2	1.7	
	Interface	1	1	1	-	1	-	-	1	3	1	-	1	-	-	-	1	1.7	
	Liquor	1	1	1	-	1	-	-	1	1	1	-	2	-	-	2	2	1.3	1.7
C- 5	Gas	4	4	1	-	1	-	-	1	4	2	-	4	-	-	4	4	4.0	
	Interface	2	4	2	-	2	-	-	2	4	2	-	4	-	-	-	4	4.0	
	Liquor	4	4	1	-	2	-	-	2	4	2	-	2	-	-	2	4	4.0	4.0
C- 6	Gas	2	2	1	-	3	-	-	3	4	1	-	4	-	-	4	4	3.3	
	Interface	1	4	1	-	1	-	-	2	3	2	-	2	-	-	-	4	3.7	
	Liquor	2	4	1	-	2	-	-	2	4	2	-	2	-	-	2	4	4.0	4.0
C- 8	Gas	2	2	1	-	1	-	-	1	2	1	-	2	-	-	2	2	2.0	
	Interface	2	2	1	-	1	-	-	1	1	1	-	2	-	-	-	2	1.7	
	Liquor	2	2	1	-	1	-	-	2	2	1	-	2	-	-	2	2	2.0	2.0
C- 9	Gas	1	1	1	-	1	-	-	1	1	1	-	1	-	-	1	1	1.0	
	Interface	1	1	1	-	1	-	-	1	1	1	-	1	-	-	-	1	1.0	
	Liquor	1	1	1	-	1	-	-	1	1	1	-	1	-	-	1	1	1.0	1.0
C-10	Gas	-	-	-	1	-	-	4	-	-	-	1	-	-	4	-	-	4.0	
	Interface	-	-	-	1	-	-	4	-	-	-	-	-	-	4	-	-	4.0	
	Liquor	-	-	-	1	-	-	4	-	-	-	1	-	-	4	-	-	4.0	4.0
C-11	Gas	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.0	
	Interface	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	
	Liquor	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	4.0
C-12	Gas	-	-	1	-		1	-	-	-	1	-	-	1	-	-	-	1.0	
	Interface	-	-	1	-	-	1	-	-	-	1	-	-	1	-	-	-	1.0	
	Liquor	-	-	1	-	-	1	-	-	-	-	-	-	1	-	-	-	1.0	1.0
C-13	Gas	-	-	2	-	-	2	-	-	-	1	-	-	4	-	-	-	3.0	
	Interface	-	-	2	-	-	2	-	-	-	1	-	-	4	-	-	-	3.0	
	Liquor	-	-	2	-	-	2	-	-	-	-	-	-	4	-	-	-	3.0	3.0
C-14	Gas	-	-	4	-	-	4	-	-	-	1	-	-	4	-	-	-	4.0	
	Interface	-	-	4	-	-	4	-	-	-	4	-	-	4	-	-	-	4.0	
	Liquor	-	-	4	-	-	4	-	-	-	-	-	-	4	-	-	-	4.0	4.0
C-16	Gas	-	-	3	-	-	3	-	-	-	3	-	-	3	-	-	-	3.0	
	Interface	-	-	3	-	-	3	-	-	-	3	-	-	3	-	-	-	3.0	
	Liquor	-	-	3	-	-	3	-	-	-	-	-	-	3	-	-	-	3.0	3.0

1/ Assigned as follows:
1 - No defects
2 - Defects attributable to application, scoring, or mechanical damage
3 - Minor or few defects
4 - Severe defects

2/ Tapia Water Reclamation Facility, Calabasas, California

3/ Speedway Wastewater Treatment Plant, Indianapolis, Indiana

4/ Westgate Wastewater Treatment Plant, Alexandria, Virginia

5/ Average of ratings assigned after final evaluation at sites exposed

6/ Highest (numerical value) of average ratings for given coating

TABLE 34. EVALUATION SUMMARY - PROTECTIVE COATINGS FOR CONCRETE SURFACES
Performance Rating 1/

Code No.	Site exposure	Site 1 2/		Site 2 3/					Site 3 4/					Average 5/	Highest 6/
		7 mos	19 mos	3 mos	10 mos	12 mos	20 mos	28 mos	3 mos	10 mos	12 mos	20 mos	28 mos		
C- 1	Gas	1	1	1	1	-	1	1	1	4	-	4	4	2.0	
	Interface	4	4	1	4	-	4	4	1	4	-	-	4	4.0	
	Liquor	4	4	1	1	-	2	4	1	4	-	4	4	4.0	4.0
C- 3	Gas	2	2	1	2		2	3	1	4	-	4	4	3.0	
	Interface	2	4	1	4		4	4	3	4	-	-	4	4.0	
	Liquor	2	4	2	2		2	4	2	2	-	4	4	4.0	4.0
C- 4	Gas	2	2	1	1	-	1	1	1	4	-	4	4	2.3	
	Interface	4	4	1	1	-	1	1	1	1	-	-	4	3.0	
	Liquor	4	4	1	1	-	1	1	1	4	-	4	4	3.0	3.0
C- 5	Gas	1	1	1	4	-	4	4	1	4	-	4	4	3.0	
	Interface	4	4	2	4	-	4	4	2	4	-	-	4	4.0	
	Liquor	4	4	4	4	-	4	4	2	4	-	4	4	4.0	4.0
C- 6	Gas	2	2	1	4	-	4	4	1	4	-	4	4	3.3	
	Interface	4	4	1	4	-	4	4	2	4	-	-	4	4.0	
	Liquor	4	4	1	2	-	4	4	2	2	-	2	2	3.3	4.0
C- 7	Gas	2	2	1	1	-	1	1	1	2	-	2	2	1.7	
	Interface	4	4	1	1	-	1	1	1	2	-	-	2	2.3	
	Liquor	4	4	1	1	-	1	1	1	2	-	3	3	2.7	2.7
C- 9	Gas	-	-	1	1	-	1	1	1	1	-	1	1	1.0	
	Interface	-	-	1	1	-	1	1	1	1	-	-	1	1.0	
	Liquor	-	-	1	1	-	1	1	1	1	-	1	1	1.0	1.0
C-12	Gas	-	-	1	-	1	-	-	1	-	1	-	-	1.0	
	Interface	-	-	1	-	1	-	-	1	-	1	-	-	1.0	
	Liquor	-	-	1	-	1	-	-	-	-	1	-	-	1.0	1.0
C-13	Gas	-	-	1	-	1	-	-	1	-	4	-	-	2.5	
	Interface	-	-	1	-	1	-	-	1	-	4	-	-	2.5	
	Liquor	-	-	4	-	4	-	-	-	-	4	-	-	4.0	4.0
C-14	Gas	-	-	1	-	4	-	-	1	-	4	-	-	4.0	
	Interface	-	-	1	-	4	-	-	1	-	4	-	-	4.0	
	Liquor	-	-	4	-	4	-	-	-	-	4	-	-	4.0	4.0
C-15	Gas	-	-	1	-	4	-	-	2	-	4	-	-	4.0	
	Interface	-	-	1	-	4	-	-	2	-	4	-	-	4.0	
	Liquor	-	-	1	-	4	-	-	-	-	4	-	-	4.0	4.0
C-16	Gas	-	-	1	-	3	-	-	3	-	3	-	-	3.0	
	Interface	-	-	1	-	3	-	-	3	-	3	-	-	3.0	
	Liquor	-	-	1	-	3	-	-	-	-	3	-	-	3.0	3.0

1/ Assigned as follows:
1 - No defects
2 - Defects attributable to application, scoring, or mechanical damage
3 - Minor or few defects
4 - Severe defects

2/ Tapia Water Reclamation Facility, Calabasas, California

3/ Speedway Wastewater Treatment Plant, Indianapolis, Indiana

4/ Westgate Wastewater Treatment Plant, Alexandria, Virginia

5/ Average of ratings assigned after final evaluation at sites exposed

6/ Highest (numerical value) of average ratings for a given coating

No defects - Highly resistant - rating of 1.0
Defects attributed to application, scoring, or mechanical damage - Moderately resistant - 1.0 < rating ≤ 2.0
Minor or few defects - Resistant - 2.0 < rating ≤ 3.0
Severe defects - Nonresistant - rating > 3.0

Coatings exposed for only 12 months at just two of the three field test sites are preceded with an asterisk.

1. Coatings for steel surfaces. -

   a. Highly resistant

      (1) Urethane coating, proprietary (coating No. C-9)
      (2) *Phenolic-epoxy, proprietary (coating No. C-12)

   b. Moderately resistant

      (1) Vinyl resin, USBR VR-6 (coating No. C-2)
      (2) Coal-tar epoxy, MIL-P-23236, Type I, Class 2 (coating No. C-4)
      (3) Phenolic, proprietary (coating No. C-8)

   c. Resistant

      (1) Vinyl-resin, USBR VR-3 (coating No. C-1)
      (2) *Urethane, proprietary (coating No. C-13)
      (3) *Phenolic-epoxy, proprietary (coating No. C-16)

   d. Nonresistant

      (1) Coal-tar enamel, AWWA C203 (coating No. C-3)
      (2) Butyl, proprietary (coating No. C-5)
      (3) Butyl, Proprietary (coating No. C-6)
      (4) Coating for galvanized steel, proprietary (coating No. C-10)
      (5) Galvanized, ASTM: A 123 (coating No. C-11)
      (6) *Urethane, proprietary (coating No. C-14)

2. Coatings for concrete surfaces. -

   a. Highly resistant

      (1) Coating No. C-9
      (2) *Coating No. C-12

   b. Moderately resistant

      (1) None

c. Resistant

   (1) Urethane, proprietary (coating No. C-7)
   (2) Coating No. C-4
   (3) *Coating No. C-16

d. Nonresistant

   (1) Coating No. C-1
   (2) Coating No. C-3
   (3) Coating No. C-5
   (4) Coating No. C-6
   (5) *Coating No. C-13
   (6) *Coating No. C-14
   (7) *Urethane, proprietary (coating No. C-15)

Joint Sealers

The results of sealers for concrete joints are shown in tables 35, 36, and 37. Figure 31 shows typical defect-free and defective sealers. The evaluation summary for sealants appears in table 38.

The sealers are rated as follows according to their performance in all three exposure zones at the field sites.

Sealers exposed for 12 months only and at just two of the three field test sites are preceded with an asterisk.

No defects - Excellent - rating of 1.0
Surface defects only - Satisfactory - $1.0 \leq$ rating ≤ 2.0
Adhesive or cohesive failure - Unsatisfactory - rating > 2.0

1. Excellent. -

   a. *One-component, low modulus silicone (code No. S-4)

2. Satisfactory. -

   a. Two-component polysulfide (code No. S-3)

3. Unsatisfactory. -

   a. Two-component silicone (code No. S-1)
   b. Two-component urethane (code No. S-2)
   c. *Two-component, slow-set polysulfide (code No. S-5)

TABLE 35. TEST RESULTS - SEALERS FOR CONCRETE JOINTS - SITE 1*

Sealant Defects***

Site Exposure

Code No.**	Nominal exposure time, mo	Gas		Interface		Liquor	
		25 percent extension	25 percent compression	25 percent extension	25 percent compression	25 percent extension	25 percent compression
S-1	3	No defects	No defects	No defects	No defects	No defects	No defects
	10	No defects	No defects	No defects	No defects	No defects	No defects
	22	No defects	No defects	No defects	No defects	No defects	No defects
S-2	3	No defects	No defects	No defects	No defects	No defects	No defects
	10	No defects	No defects	75 percent bond failure	No defects	80 percent bond failure	No defects
	22	No defects	No defects	75 percent bond failure	No defects	100 percent bond failure	No defects
S-3	3	No defects	No defects	No defects	No defects	No defects	No defects
	10	Surface cracking	Surface cracking	Surface cracking	Surface cracking	Surface cracking	Surface cracking
	22	Surface cracking	Surface cracking	Surface cracking	Surface cracking	Surface cracking	Surface cracking

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* Site 1 - Tapia Water Reclamation Facility, Calabasas, Calfironia.

** See table 7 for sealer identification.

*** See figure 31 for typical examples of sealant defects.

TABLE 36. - TEST RESULTS - SEALERS FOR CONCRETE JOINTS - SITE 2*
Sealant Defects***
Site Exposure

Code No.**	Nominal exposure time, mo	Gas		Interface		Liquor	
		25 percent extension	25 percent compression	25 percent extension	25 percent compression	25 percent extension	25 percent compression
S-1	3	No defects	No defects	No defects	No defects	No defects	No defects
	10	No defects	No defects	100 percent bond failure	No defects	No defects	No defects
	20	No defects	No defects	100 percent bond failure	No defects	No defects	No defects
	28	10 percent bond failure	No defects	100 percent bond failure	No defects	No defects	No defects
S-2	3	100 percent bond failure	No defects	100 percent bond failure	No defects	100 percent bond failure	No defects
	10	100 percent bond failure	No defects	100 percent bond failure	No defects	100 percent bond failure	No defects
	20	100 percent bond failure	No defects	100 percent bond failure	No defects	100 percent bond failure	No defects
	28	100 percent bond failure	No defects	100 percent bond failure	No defects	100 percent bond failure	No defects
S-3	3	No defects	No defects	No defects	No defects	No defects	No defects
	10	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation
	20	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation
	28	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation
S-4	3	No defects	No defects	No defects	No defects	No defects	No defects
	12	No defects	No defects	No defects	No defects	No defects	No defects
S-5	3	No defects	No defects	No defects	No defects	No defects	No defects
	12	Surface cracking	Surface cracking	20 percent bond failure	Surface cracking	5 percent bond failure	Surface cracking

* Site 2 - Speedway Wastewater Treatment Plant, Indianapolis, Indiana.
** See table 7 for sealer identification.
*** See figure 31 for typical sealant defects.

TABLE 37. - TEST RESULTS - SEALERS FOR CONCRETE JOINTS - SITE 3*
Sealant Defects***
Site Exposure

		Gas		Interface		Liquor	
Code No.**	Nominal exposure time, mo	25 percent extension	25 percent compression	25 percent extension	25 percent compression	25 percent extension	25 percent compression
S-1	3	100 percent bond failure	No defects	100 percent bond failure	No defects	25 percent bond failure	No defects
	10	100 percent bond failure	No defects	100 percent bond failure	No defects	50 percent bond failure	No defects
	20	100 percent bond failure	No defects	100 percent bond failure	No defects	50 percent bond failure	No defects
	28	100 percent bond failure	No defects	100 percent bond failure	No defects	100 percent bond failure	No defects
S-2	3	100 percent bond failure	No defects	100 percent bond failure	No defects	100 percent cohesion failure	No defects
	10	100 percent bond failure	No defects	100 percent bond failure	No defects	100 percent cohesion failure	No defects
	20	100 percent bond failure	No defects	100 percent bond failure	No defects	100 percent cohesion failure	No defects
	28	100 percent bond failure	No defects	100 percent bond failure	No defects	100 percent cohesion failure	No defects
S-3	3	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation
	10	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation
	20	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degrada-
	28	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation	Surface degradation
S-4	3	No defects	No defects	No defects	No defects	#	#
	12	No defects	No defects	No defects	No defects	No defects	No defects
S-5	3	No defects	No defects	No defects	No defects	#	#
	12	Surface cracking	Surface cracking	Surface cracking	Surface cracking	Surface cracking	Surface cracking

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* Site 3 - Westgate Wastewater Treatment Plant, Alexandria, Virginia

** See table 7 for sealer identification.

*** See figure 31 for typical sealant defects.

\# Sample could not be retrieved for this inspection.

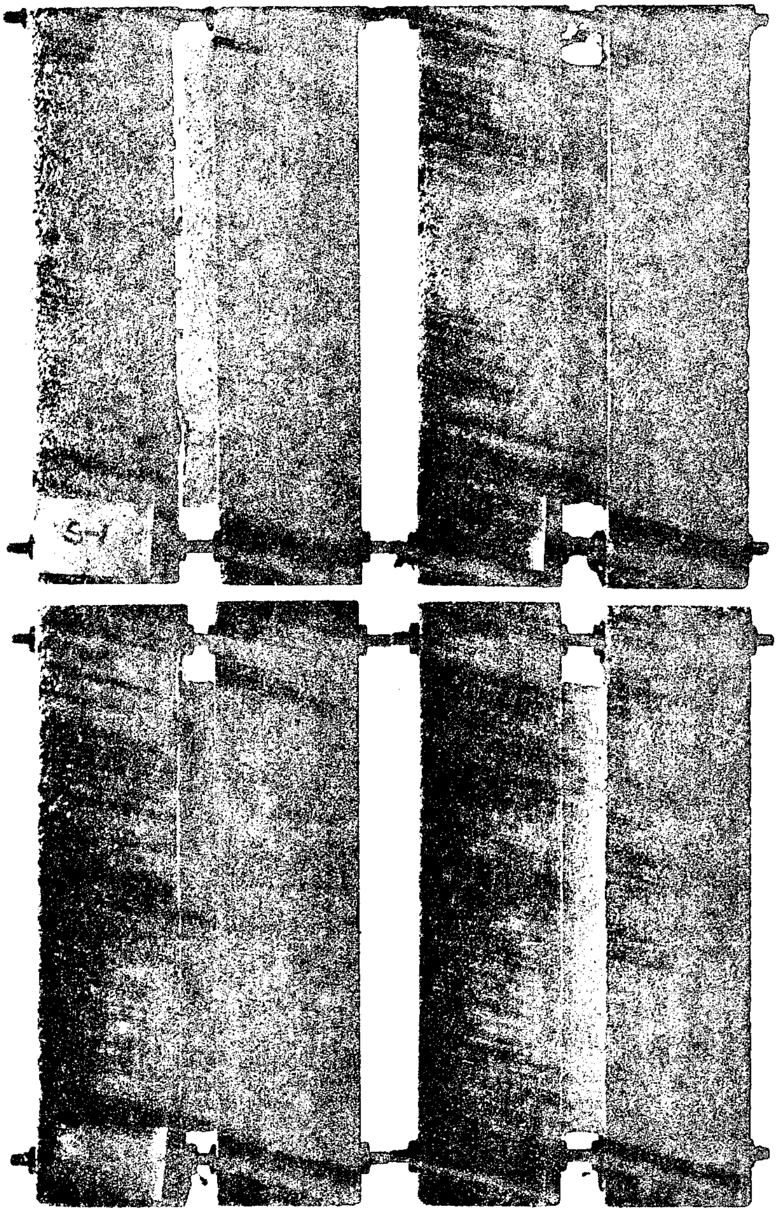


Figure 31. Typical joint sealer performance in these tests. S-1 is a two-component silicone sealant which has incurred bond failure, S-2 and S-3 show surface degradation of two-component polysulfide base material exposed in compressed (S-2) and stretched (S-3) condition and S-4 is intact one-component, low-modulus silicone.

TABLE 38. EVALUATION SUMMARY - SEALERS FOR CONCRETE JOINTS

Performance Rating 1/

Code No.	Site exposure	Stress type	Site 1 2/			Site 2 3/					Site 3 4/					Average 5/	Highest 6/
			3 mos	10 mos	22 mos	3 mos	10 mos	12 mos	20 mos	28 mos	3 mos	10 mos	12 mos	20 mos	28 mos		
S-1	Gas	Tension	1	1	1	1	1	-	1	3	3	3	-	3	3	2.3	
		Compression	1	1	1	1	1	-	1	1	1	1	-	1	1	1.0	
	Interface	Tension	1	1	1	1	3	-	3	3	3	3	-	3	3	2.3	
		Compression	1	1	1	1	1	-	1	1	1	1	-	1	1	1.0	
	Liquor	Tension	1	1	1	1	1	-	1	1	3	3	-	3	3	1.7	
		Compression	1	1	1	1	1	-	1	1	1	1	-	1	1	1.0	2.3
S-2	Gas	Tension	1	1	1	3	3	-	3	3	3	3	-	3	3	2.3	
		Compression	1	1	1	1	1	-	1	1	1	1	-	1	1	1.0	
	Interface	Tension	1	3	3	3	3	-	3	3	3	3	-	3	3	3.0	
		Compression	1	1	1	1	1	-	1	1	1	1	-	1	1	1.0	
	Liquor	Tension	1	3	3	3	3	-	3	3	3	3	-	3	3	3.0	
		Compression	1	1	1	1	1	-	1	1	1	1	-	1	1	1.0	3.0
S-3	**Gas**	**Tension**	1	2	2	1	2	-	2	2	2	2	-	2	2	2.0	
		Compression	1	2	2	1	2	-	2	2	2	2	-	2	2	2.0	
	Interface	**Tension**	1	2	2	1	2	-	2	2	2	2	-	2	2	2.0	
		Compression	1	2	2	1	2	-	2	2	2	2	-	2	2	2.0	
	Liquor	**Tension**	1	2	2	1	2	-	2	2	2	2	-	2	2	2.0	
		Compression	1	2	2	1	2	-	2	2	2	2	-	2	2	2.0	2.0
S-4	Gas	**Tension**	-	-	-	1	-	1	-	-	1	-	1	-	-	1.0	
		Compression	-	-	-	1	-	1	-	-	1	-	1	-	-	1.0	
	Interface	**Tension**	-	-	-	1	-	1	-	-	1	-	1	-	-	1.0	
		Compression	-	-	-	1	-	1	-	-	1	-	1	-	-	1.0	
	Liquor	**Tension**	-	-	-	1	-	1	-	-	-	-	1	-	-	1.0	
		Compression	-	-	-	1	-	1	-	-	-	-	1	-	-	1.0	1.0
S-5	Gas	**Tension**	-	-	-	1	-	2	-	-	1	-	2	-	-	2.0	
		Compression	-	-	-	1	-	2	-	-	1	-	2	-	-	2.0	
	Interface	**Tension**	-	-	-	1	-	3	-	-	1	-	2	-	-	2.5	
		Compression	-	-	-	1	-	2	-	-	1	-	2	-	-	2.0	
	Liquor	**Tension**	-	-	-	1	-	3	-	-	-	-	2	-	-	2.5	
		Compression	-	-	-	1	-	2	-	-	-	-	2	-	-	2.0	2.5

1/ Assigned as follows:
1 - No defects
2 - Surface defects
3 - Adhesive or cohesive failure

2/ Tapia Water Reclamation Facility, Calabasas, California

3/ Speedway Wastewater Treatment Plant, Indianapolis, Indiana

4/ Westgate Wastewater Treatment Plant, Alexandria, Virginia

5/ Average of ratings assigned after final evaluation of sites exposed

6/ Highest (numerical value) of average ratings for given sealer

SECTION 7

DISCUSSION OF TEST RESULTS

Concrete

1. Length change. - One established method of determining progression of deterioration of concrete exposed to a given environment is to monitor its change in volume with respect to exposure time. Whereas loss in volume of concrete is normally merely indicative of dehydration, an increase in volume can show not only increase in saturation with water but also effects of chemical and physical reactions.

The expansive effects of both freeze-thaw deterioration and sulfate attack are examples wherein concrete deterioration can be manifested by an increase in volume. These increases in volume are the result of internal pressures produced by the freezing of water in freeze-thaw deterioration and by chemical reaction in sulfate attack.

Small volume changes of concrete are difficult to determine accurately. Therefore, its length, a dimension which is easily and accurately measured, is monitored as a reflection of its volume.

In addition to lengths, weights were also determined for control specimens exposed in 50 percent relative humidity at 23°C and immersed in Denver tap water at room temperature in the laboratories. Weight change of concrete when exposed to these two laboratory control environments is merely the result of absorption or loss of water.

Many materials expand with an increase in moisture content. This characteristic is shown for the concrete specimens exposed to the two laboratory environments by comparing weight change and length change results. Whereas only slight changes in both length and weight have occurred in those specimens exposed in air, substantial increases in both weight and length have resulted for all specimens immersed in water.

It is interesting to note that in all three sets of control specimens (those for site 1, site 2, and site 3) concrete made with Type II cement is the most absorptive. Permeability to water is an indication of concrete quality and density; higher permeability corresponds to lower concrete quality and density. Concrete made with Type V cement is slightly less absorptive. The polymer-impregnated concrete is substantially less absorptive than the other two, although not completely impermeable to water. In polymer-impregnated concrete, the voids present before impregnation are, to some degree, filled with the polymer. Thus, there are fewer voids and, hence, less capacity for water to be absorbed.

The length change test results of samples exposed to site conditions are not so easily analyzed. The concrete specimens made from Type II and Type V cements increased in length initially in all three exposures (gas, liquid-gas interface, and liquor) at all three field sites. After this initial increase in length, which is undoubtedly the result of water absorption, the lengths of the specimens fluctuate, apparently due to the changing site conditions. Since no continuing tendency to increase in length is observed, it is concluded that field exposure has produced no detrimental effects to these two types of concrete. Additionally, the increases in lengths for these samples were well below the 0.2 percent generally accepted by the Bureau of Reclamation as indicative of impending concrete failure from sulfate attack. Complete failure in sulfate attack is considered to be 0.5 percent expansion. It is assumed that expansion caused by chemical or physical attack in an oxygenated wastewater environment can be judged by the same criteria.

It is evident that the PIC specimens in this study continue to increase in length with duration of exposure. In fact, although much less water is absorbed by the polymer-impregnated concrete than the other two concretes exposed in this study, its increase in length after 22 and 28 months of exposure is of the same magnitude as the other two concrete types. The expansion appears to be caused by moisture, as both wastewater and fresh water immersion result in continued increase in length of the same order of magnitude. There are at least two possible explanations for this continued length increase. First, since the voids in the polymer-impregnated concrete are plugged with the polymer, it simply may take longer for expansion to occur than it did in the conventional concretes. The expansion may then level off as it did for the conventional concretes. Because the specimens were ovendried prior to impregnation, the total expansion due to absorption may be greater than it was for conventional concrete. Secondly, moisture may have an adverse effect on polymer-impregnated concrete. If this were so, longer exposures should show continued expansion exceeding 0.2 percent. Further long-term exposure is needed to confirm or disprove this possibility.

2. Compressive strength. - The compressive strength cylinders were broken at a load rate of 14 000 kPa/min (2.0 x 10^3 lb/in^2min). At site 2, some of the compressive strength specimens came loose from the exposure rack and were irretrievable. It was therefore necessary to use the length change specimens, with metal inserts on each end to determine the 28-month compressive strength results. The ends were sawn off to remove the inserts and the shortened cylinders were tested. The results were corrected to equivalent results on cylinders with a length-to-diameter ratio of 2.0. As a check on the validity of this approach, the length change specimens were also tested for compressive strength at site 3 where the normal strength cylinders were also available. For concrete containing Type II and Type V cement, the strength results on the length change specimens were almost identical to the results on the compressive strength cylinders. This indicates that the 28-month values for site 2 are valid. The polymer-impregnated specimens at site 3 indicate variability in the 28-month strengths as determined by the two different sets of cylinders. This will be discussed later.

In all compressive strength computations except the 28-month results at sites 2 and 3, the nominal diameter was used to compute the area. For the 28-month results, the length and diameter of all specimens were measured. This was because surface erosion had become significant at site 3 and because of the variation in length of the specimens with inserts that were sawed.

Concrete made with Type II cement shows no strength loss at any exposure site. For example, at site 1 all strengths exceed the strength at the time the specimens were first exposed. At sites 2 and 3, the initial strengths (strength at the time the specimens were first exposed) are slightly lower than the 28-day strengths but this is not significant and is probably due to variability in fabrication of the test specimens. At both sites 2 and 3, concrete containing Type II cement gained strength beyond the 28-day strength under all test conditions. At all three sites, each exposure condition (gas, interface, and liquor) produced higher strengths than the 50 percent relative humidity laboratory control specimen exposure. This indicates that sufficient moisture was present to continue hydration of the cement in all three exposure conditions and that the composition of the wastewater does not alter the normal cement hydration processes. In fact, results at sites 1 and 3 indicate that the cure at the field site was superior to the cure of laboratory specimens submerged in tap water.

In general, exposure of concrete containing Type II cement resulted in strength increase with age at all three sites. The small decrease shown in a few cases is not significant considering the variability of concrete and considering the fact that all strength values exceed the 28-day strength. The exposure of the concrete made with Type II cement to oxygenated wastewater treatment plant conditions did not reduce the compressive strength but provided continued moist curing which increased strength.

Results on concrete made with Type V cement for all three sites were similar to those for concrete made with Type II cement. For all three sites, all exposures produced compressive strengths greater than the initial strengths. In general, all exposure conditions produced stronger concrete than the laboratory 50 percent relative humidity cure, indicating hydration of the cement is being continued by the presence of moisture. Again, results from sites 1 and 3 indicate that curing at the site produced stronger concrete than laboratory cure with specimens submerged in tap water. As with the Type II cement concrete, the Type V cement concrete, in general, showed an increase in compressive strength when exposed to various oxygenated wastewater treatment plant environments.

The polymer-impregnated concrete specimens showed large variations in strength under most exposure conditions, although all strength values exceeded the highest strengths for conventional concrete. For sites 2 and 3, all exposures produced strengths lower than the initial strength. At all three sites there are exposures showing a decrease in strength with length of exposure. There are also exposures at all three sites that show no consistent trend.

Results at site 3 at 28 months of exposure are especially significant. Two sets of specimens were tested at this exposure time. The first set was the specimens that had been fabricated for compressive strength testing. The second set was composed of length change specimens with the ends sawn off to remove the metal inserts. Results were corrected to a length-to-diameter ratio of 2.0. As mentioned previously, results on concrete made with Type II and Type V cement indicate that both sets of specimens gave similar results. For the polymer-impregnated specimens, however, this was not the case. In both the interface and the liquor exposures, there is a significant difference in the strengths of the two sets of specimens at 28 months of exposure. Thus, there is variability in strength of the polymer-impregnated specimens even when exposed under identical conditions. Since some of the compressive strengths of the polymer-impregnated concrete are significantly lower than the initial strengths, we must conclude that one of two possibilities caused this strength difference. Either the polymer-impregnated specimens are losing strength at different rates (even if in the same environment) or the specimens were not uniform in strength initially after polymerization. From the test results alone, it is not possible to prove which of these two possibilities caused the strength variations.

3. Surface erosion. - Generally, only minor changes in surface conditions have occurred at the Tapia and Speedway sites.

At the Westgate site, the most severe erosion occurred in the interface zone in the concrete fabricated with Type V cement. Less severe erosion was observed in all zones with the Type II specimens although noticeable change can be seen in the Type II vapor specimens. Good compressive strength and lack of significant volume change indicate that this is a surface condition. The polymer-impregnated concrete was only slightly altered in appearance. Results at 28 months of exposure were similar to those at 10 months with the erosion of the Type V and Type II cement concretes continuing.

As mentioned earlier, debris not trapped by the bar screen at the Westgate site were fed into the secondary treatment tank where the test specimens were exposed. These solids are removed in primary treatment at the other two sites. It is concluded that these solids inflicted the abrasion damage to the concrete cylinders. The fact that specimens in vapor exposure were also affected is explained by the turbulence of the liquor and water within the tank.

Steel Embedded in Concrete

Portland cement-mortar and -concrete coatings on steel derive their corrosion-inhibiting quality from formation of an insoluble, passivating, oxide film on the steel surface due to the highly alkaline environment. In addition, when voltage is imposed on a mortar- or concrete-coated steel surface, this film generates a counter-voltage (polarization) such that, within limits, no current will flow. This passivity and resistance to current flow developed by properly designed, dense, high-quality portland cement coating are sufficient to overcome the potential differences in virtually all naturally occurring fresh water and soil conditions. Environments high in concentration of chloride ions are the major exception. Therefore, the excellent performance of concrete in preventing corrosion of embedded steel in these tests was not surprising. The highest concentration of chloride observed was at site 1. At site 1 the chloride concentration was found to be 144 mg/ℓ. Seven hundred mg/ℓ chloride is the generally accepted threshold concentration above which passivity may be destroyed provided the chloride is accompanied by oxygen.

Alloys

1. Unstressed specimens. - The poor performance of aluminum, gray cast iron, and carbon steels in this test was anticipated.

Aluminum alloys are notorious for their susceptibility to pitting in high solids waters such as wastewater. Aluminum alloys derive their corrosion resistance from formation of a passive oxide film on their surfaces. Nearly all corrosion of aluminum results from deterioration of this passive film in localized areas resulting in pitting. Since aluminum has been found to pit deeply in conventional plants, it appears that the poor performance in these tests cannot be directly attributed to oxygenation.

Carbon steels have been found to pit in aerated, near-neutral waters. Corrosion in aqueous environments is basically an electrochemical reaction wherein electrons are released at the anode with metallic ions formed by oxidation going into solution. At the cathode, electrons are accepted and negative ions form. Action at the anode and cathode are interdependent, i.e., neither can proceed without the other. In the case of iron (steel) in water, iron goes into solution as ions and electrons are left behind in the metal at the anodic areas. These electrons travel through the steel to the cathode where they combine with hydrogen ions to form hydrogen gas. In neutral, slow-moving waters, the evolution of hydrogen gas at the cathode proceeds and accumulates as a layer of hydrogen on the metal. This layer decreases the cathodic reaction and thus the reaction is referred to as cathodic polarization. Therefore, corrosion proceeds very slowly in quiescent, deaerated waters. Dissolved oxygen in the water upsets the equilibrium condition established by cathodic polarization. The oxygen reacts with the accumulated hydrogen to form water. As the hydrogen is removed in this manner, corrosion is allowed to proceed. Dissolved oxygen concentration, therefore, controls the rate of corrosion of iron and steel in wastewater.

Corrosion of gray cast iron was by a process of selective dealloying commonly referred to as graphitization or graphitic corrosion. Cast iron consists mainly of iron and carbon with small amounts of silicon and manganese. The graphite is cathodic to iron, and thus an excellent cell exists. The iron is selectively dissolved leaving a porous mass of graphite, voids, and corrosion products.

Both copper and the austenitic cast iron suffered moderate uniform corrosion rates, less than 250 μm/yr (10 mil/yr). Sensitized 304 and 316 austenitic stainless steels were rated as only moderately resistant because of some minor pitting observed in the gas zone at one of the test sites. This pitting corroborates our past experiences as well as those of other investigators, in which sensitized austenitic stainless steels have been found to be susceptible to pitting. Sensitization is caused by heat treatment such as welding followed by slow cooling. The generally accepted theory for this phenomenon is that this treatment results in chromium carbide precipitation at the grain boundaries which in turn reacts galvanically with adjacent metal devoid of chromium. This phenomenon is known as intergranular corrosion.

As anticipated, the stainless steels, Types 201, 304, and 316, provided excellent resistance to these environments.

2. Stressed specimens. - Of the alloys exposed in the stressed condition, all passed this "go-no go" type of test <u>except</u> mild steel, low alloy steel, and aluminum. Since these materials also were found to be nonresistant when exposed as unstressed coupons, it is difficult to assess the effect of the stress. However, it was noted that all splitting occurred at the highly stressed, plastically deformed ends of the test specimens. Therefore, it appears that stress on these alloys in these environments does accelerate the rates of deterioration of these nonresistant materials.

Rubber and Plastics

Relatively little detrimental change has occurred in the rubber and plastic materials. Such changes that did occur were the result of specific environmental conditions which reacted somewhat differently, both in type and extent of reaction, with each polymer group. In addition to the different reaction of each basic polymer, behavior of specific products is greatly influenced by the variety of substances which are added to the compound, such as antioxidants, antiozonants, curing accelerators, cross linking agents, fungicides, reinforcing fillers, antibacterial agents, and extenders. For example, a material which might be a good antibacterial agent could adversely affect the oxidation rate of a polymer, or two manufacturers' products using the same polymer may perform differently as a result of the type or amounts of such additives.

The factors in the environment of this study which could be expected to influence the behavior of polymers are:

1. Oxidation (including ozone attack)
2. Biological attack
3. Water
4. Physical damage

Thermal degradation and photodegradation will not be considered to any extent because of the relatively cool operating temperatures and the absence of sunlight at the exposure sites.

1. Oxidation. - Since this study deals with oxygenated systems, it is important to know that oxygen is generally the most common factor in polymer degradation. All polymers react with oxygen at combustion temperatures and sunlight generally accelerates the process. Fortunately, with the absence of light and with the low temperatures encountered in this study (14° to 26°C), oxidation proceeds very slowly for most polymers. For example, the oxidation rate of linear polyethylene at 140°C is roughly 10 times the rate at 100°C. Furthermore, at 100°C,

oxygen uptake reaches a relatively early plateau. Measurement would be difficult at temperatures below 30°C since the rate of oxygen absorption is extremely slow. Even natural rubber absorbs oxygen very slowly at temperatures below 50°C.

Polymer selection is basic in reducing oxygen attack potential. Oxidation in polymers is a complicated process that involves chain reactions which result in the formation of unstable peroxy free radicals. Olefinic unsaturated hydrocarbon double bonds and other unsaturated functional groups present favorable sites for stabilization of these free radicals. Thus, silicone polymers (R-32 and -532) with their silica-oxygen molecular backbone are among the most stable toward oxidative degradation. Ethylene propylene diene monomer (R-8 and -30), which has residual unsaturation only in pendent side groups and not in the main chain, is very stable as is unbranched polyethylene. Branching generally decreases oxidation resistance. Butyl rubber (R-17 and -29), having its hydrocarbon chain interrupted by a relatively few double bonds, is also quite resistant to attack. Natural rubber (R-25) with its high chemical unsaturation (presence of double bonds) is among the most susceptible of polymers to oxidation. Nevertheless, natural rubber was included in this study since it is still widely used, especially in items such as water pipe gaskets.

Modification of polymer chains by addition of electrophilic side groups such as chlorine in neophrene rubber (R-5) has a protective influence on the double bond. This is generally more permanent protection than is reliance upon antioxidants, which are used up in the performance of their function. Where oxidation rates are very low, antioxidants may provide satisfactory protection.

The effect of ozone on polymers is similar to normal oxidation in that it attacks the double bond but the process is simpler since the attack is direct. An energetic reaction occurs as a result of the electrophilic character of ozone. Scission of the double bond occurs in a reaction between the electron-deficient terminal oxygen atom of the ozone molecule and the electrons of the double bond, ultimately resulting in the formation of polyperoxide and carbonyl compounds.

Unlike oxidation, in ozonation the thin film of the ozone reaction product (approximately 10^{-4} mm) is sufficient to restrict the access of ozone molecules to the underlying rubber if the rubber is unstrained. Therefore, unless rubber is strained (usually beyond 3 to 5 percent elongation), it appears not to have been affected by ozone and indeed suffers no significant damage. In the strained state, cracks appear which generally vary inversely in depth and directly in number to the degree of strain, with little change in the rubber between cracks.

As would be suspected the resistance of different rubber products to ozone attack is similar to their resistance to oxidation.

No unusual behavior of rubber or plastic products with regard to oxidation has been experienced in this study. The only attack of oxygen

(O_2 or O_3) that is significant is ozone cracking in the natural rubber (R-25) and in the nitrile-butadiene rubber (R-34). These two materials were highly sensitive to ozone. In tests conducted at the Bureau of Reclamation Laboratories, both materials developed cracking within 8 hours when exposed to an atmosphere of 0.5 ul/l ozone at 38°C. Initial ozone cracking could also be observed after 12 days in the laboratory atmosphere of less than 0.05 ul/l ozone and approximately 25°C.

It is significant that no difference in cracking was observed in any of the three zones nor was there any increase in cracking between the 3- and 9-month inspections. There was a difference in severity between sites corresponding to least delay (Tapia) and greatest delay (Westgate) in the time between stressing the specimens and installation at the sites. (It was necessary to stress the specimens prior to shipment.) Specimens of natural rubber stressed at the same time as the Westgate specimens and immersed in tap water at the Bureau of Reclamation Laboratories at the same time that the Westgate specimens were installed show nearly identical severity of ozone cracking at a 9-month inspection as the Westgate specimens, whereas specimens immersed immediately after stressing showed no evidence of cracking. Therefore, it is concluded that the cracking occurred before samples were installed at the test sites and not as a result of the oxygenated wastewater environment.

This environment does not represent a very severe oxidation environment insofar as higher polymers are concerned. This is evidenced by the lack of substantial difference in physical properties between the tap water and the wastewater specimens, as well as between specimens exposed in gas and liquor zones. It is also indicated by the relative stability after the 3-month exposure in the undamaged natural rubber and the nitrile-butadiene rubber which, among polymers selected for this study, are known to be the most sensitive to oxidation.

2. Biological attack. - Certain types of bacteria can utilize hydrocarbons, including rubber, as energy sources in their metabolism. Widespread deterioration of natural rubber water pipe joint gaskets in Europe has been reported to be the result of attack by two types of bacteria of the genus streptomyces. No deterioration of synthetic rubbers (other than polyisoprene) has been reported in Europe and no deterioration of natural rubber, widely used for pipe gaskets in the United States, has been reported. Accelerated soil micro-organism tests conducted by the Bureau of Reclamation on several rubber products (mainly butyl and ethylene propylene diene monomer) have shown no adverse effect after 10 years of exposure. It appears that rubber compounds most resistant to oxidation and ozone attack may possibly be the most resistant to attack by mico-organisms. Indeed, P. B. Dickenson, in the Rubber Journal (August 1965), opines that biological degradation of rubber must be preceded by an oxidation process that breaks the long hydrocarbon chain into shorter molecules which may then be consumed. In contradiction to this, some evidence of bacteria attack on the highly oxidation-resistant silicone rubbers has been reported and butyl rubber

may be affected by sulfate-reducing bacteria. The polyethylene family of polymers, including chlorinated (B-6475) and chlorosulfonated polyethylene (R-18), appears to be highly resistant to micro-organism attack, as is the polyvinyl chloride (PVC) resin, although plasticizers used in flexible PVC (B-6414) are commonly attacked with resultant stiffening of the material.

Results of these tests indicate some samples have suffered biological attack. One natural rubber (R-25) sample after 9 months of exposure in the mixed liquor at the Tapia site showed some sign of localized attack. Several small circles (3 to 6 mm in diameter) showed discoloration and pitting accompanied by deterioration to a depth of approximately 1 mm. Discoloration in one silicone rubber may also have resulted from micro-organism attack. The flexible PVC has shown some stiffening as well as some increase in yield strength indicating attack on the plasticizer. However, the increase in strength indicates no resin attack. During more than 10 years of USBR field experience with flexible PVC in canal lining, the relatively slow loss of plasticizer has caused no problems where protection from mechanical damage has been maintained. The plasticizer loss eventually produces a rigid PVC sheet. Rigid PVC has been used as a liner, but it is difficult to handle during installation, does not conform well to uneven subgrades, and in general is more labor-intensive than flexible PVC sheets.

3. Water attack. - Reaction of water with polymers merits serious study especially where continuous immersion is involved. In this study water reaction may have less potential for deterioration than micro-organism attack. The reason for this is the high availability of micro-organisms in the wastewater and because only materials known to be resistant to water attack were selected for exposure. However, for certain materials, water attack may be of primary significance. Although some studies have shown that in aerated water, immersion oxidation rates are reduced, other properties may be affected.

As in the case with oxidation, reaction of polymers with water may lead to chain scission (softening and decompositon) or to cross linking (hardening and brittleness). Previous USBR experience has shown embrittlement occurring in the polyacrylate (R-27) from water attack although at somewhat higher temperature than occurs in wastewater treatment plants. The polyacrylate, therefore, was closely observed for indications of water attack. Attack of water on polymers must be preceded by permeation of the water through the bulk of the polymer. This is usually accompanied by some evidence such as unusual softening or swelling which has not been observed in the polyacrylate. Further the changes in the physical properties of the polyacrylate although somewhat erratic appear to have stabilized.

4. Physical damage. - A wide variety of physical abuse has been encountered by samples exposed to the three sites in this study and at least as wide a range can be expected elsewhere. The principal damage

sustained has been tensile rupture of both silicone (R-32 and -532) specimens and a deep scratch in one reinforced chlorinated polyethylene (B-6468) and one reinforced butyl (B-6464), all at the interface of the Westgate plant.

5. Other damage. - Some unusual swelling of butyl and EPDM rubber samples occurred at the interface location at site 2. An oil spill was suspected by plant operators during the period in which swelling was encountered. In localities where problems of continuous contact with liquid hydrocarbons occur, the long-term effect of such exposure should be investigated.

Protective Coatings

To facilitate evaluation of the large number of coatings specimens exposed in this study, a numerical rating system was established to reflect performance. Performance of coatings after each exposure interval at each exposure zone at the three test sites was designated numerically as follows:

1. No defects.

2. Defects attributable to scoring of the protective coating film, such as blistering around the score only, or mechanically induced, such as by impact or abrasion.

3. Few or minor defects. A minor defect was defined as one which did not impair the protective effectiveness of the coating. Examples include blistering of the topcoat only and few, small blisters.

4. Severe defects. Severe defects include cracking and gross blistering.

Such a numerical rating system allows almost unlimited flexibility for mathematical manipulation and makes analysis of a large number of specimens exposed for various periods of time in three zones of three test sites manageable.

The performance of standard USBR immersion coatings, VR-3, VR-6, coal-tar enamel, and coal-tar epoxy, in these exposures was disappointing. Whereas these materials normally provide a minimum of 20 years of service, with minimal maintenance, when exposed to fresh water, defects appeared after only short exposure periods in these wastewater environments.

The VR-3 and, to a lesser degree, the VR-6 vinyl systems proved to be susceptible to blistering, the coal-tar enamel to pattern cracking, and the coal-tar epoxy to slight alligator cracking.

It is interesting to note, however, that of the coatings obtainable under standard specifications exposed, the coal-tar epoxy and the VR-6 proved to be most resistant.

The cracking of the coal-tar enamel coating which resulted in an overall evaluation in the nonresistant category is difficult to explain. This coating is projected to have a 50- to 100-year service life in Bureau applications. It is surmised that the highly oxidative nature of oxygenated wastewater resulted in scission of the coal-tar polymer chains. Heretofore, cracking of this enamel has been experienced only when exposed to cold temperature and to sunlight exposure.

Both coatings which received highly resistant ratings for steel also received highly resistant ratings when tested over concrete. These were the phenolic-epoxy and urethane coatings, both proprietary materials. At that point, similarity of performance over the two substrates ceased to exist. Whereas 8 of the 14 coatings applied to steel were rated resistant or higher, only 5 of the 10 coatings tested on concrete substrate achieved this rating. In addition, whereas three materials received a moderately resistant rating when applied to steel, none of the coatings tested on concrete achieved this rating. These comparisons indicate that concrete surfaces are more difficult to protect by coating.

Joint Sealers

Of the five joint sealers exposed, only one, the single component, low-modulus silicone sealant survived the test free of defect. Commonly used sealers for such applications, including the urethane and silicone, both two-component materials conforming to Federal Specifications TT-S-00227, failed to maintain bond to the concrete in these tests, whereas the two-component polysulfide material, also conforming to TT-S-00227, displayed surface distress but no adhesion or cohesion failure.

The continuous stress imposed on the sealants during these tests, i.e., 25 percent tensile and 25 percent compressive, is quite severe. Nevertheless, recognizing that Federal Specification TT-S-00227 requires materials resistant to a total joint movement of 50 percent and since the same stresses were applied to all sealants, the test should not be considered unfair.

These test results should not be used out of context, i.e., the stress imposed during these tests should be compared to stresses to be expected by the design of specific joints. However, since the single-component, low-modulus silicone material performed without defect when stressed to 25 percent extension and compression, one can safely assume that this sealer would perform well at lower stress levels also. Also, if such lower stress levels are anticipated, although the polysulfide material rated higher than either the two-component silicone or the urethane sealers, the selection of the latter materials is indicated because the silicone and urethane materials themselves were not attacked as were the polysulfide sealants.

SECTION 8

DISCUSSION OF ECONOMIC IMPACT

Some of the materials recommended for an oxygen activated-sludge plant, as indicated by the results of these tests, are more expensive than those ordinarily used in conventional activated-sludge plants. The costs of necessary materials substitutions and additional requirements were considered in order to evaluate the economic impact of the materials recommendations.

This study was limited to comparison of relative costs of materials exposed in those plant locations where elevated oxygen concentrations occur as a result of oxygen injection: in the aeration basins (mixed liquor tanks) and in piping, valves, etc., between aeration basin outlets and secondary clarifier inlets. Components in these locations include the concrete tanks and covers (if any) of the aeration basins and various flow channels; slide gates and sluice gates; waterstops and joint sealers; piping and valves; metal railings, probes, hardware, etc.; plus protective coatings as required for these surfaces. The corrosion potential in other plant locations would be essentially the same as in a conventional plant. Since special equipment for mixing and for generating and handling oxygen are not required in a conventional plant, costs for these items were not evaluated. Other cost differentials, such as for operating costs and capital costs due to the differences in processes (for example, aeration basin size) are not within the scope of this study.

The wide range of wastewater treatment plant designs made it impossible to determine a single set of traditionally used materials for either conventional or oxygen treatment plants. Obtaining general materials cost data applicable to either type of plant was also not feasible. However, by considering, in detail, the designs and materials specifications of two typical oxygen plants and the costs of using alternative materials, it was possible to obtain sufficient information to draw an overall conclusion in regard to economic impact; namely, that the additional costs of corrosion-resistant materials recommended for an oxygen plant are negligible as compared to total construction costs.

Chosen for economic evaluation were the Englewood-Littleton, Colorado plant and the new expansion of the Denver Metropolitan Sewage District plant, both currently under construction. The 880-ℓ/s (20-Mgal/d) Englewood-Littleton plant uses Food Machinery Corporation's (FMC) MAROX system and was designed by Henningson, Durham, and Richardson (HDR). The 3200-ℓ/s (73-Mgal/d) Denver Metro plant addition contains Union Carbide's UNOX system and was designed by CH2M-Hill.

These sewage districts and engineering design firms were contacted to obtain specific details concerning relevant components and materials of construction. Upon studying the designs, specifications, and some cost data for the two plants, it became apparent that the present materials recommendations would have the greatest economic impact on the costs of sluice or slide gates. However, it also developed that the installed costs of these gates and their differential costs among alternative materials were clearly insignificant as compared to the overall construction costs, which are dominated by costs of concrete structures. These two case studies are detailed below.

Case I: Englewood-Littleton Plant

In the Englewood-Littleton plant, all specified materials, with one exception, are in agreement with the present materials recommendations. This exception is that the slide gates are constructed of aluminum rather than of a more corrosion-resistant material. According to the project engineer for HDR, aluminum was chosen because it traditionally has been used for slide gates in conventional plants. HDR considered that specifying a more corrosion-resistant material was not necessary, although they were not aware of any corrosion data or operating experience with the MAROX system to substantiate their selection of aluminum. They based their choice upon past performance in conventional plants.

The costs of the aeration basin slide gates for the Englewood-Littleton plant were obtained from the local respresentative of ARMCO Steel Corporation, the manufacturer of these gates. ARMCO also supplied cost data for gates constructed of the recommended materials. A cost of coating with coal-tar epoxy [\$30/m^2 (\$3/ft^2) of surface installed, which may be conservatively high] was used to calculate costs for epoxy-coated carbon steel slide gates.

Results (table 39) indicate that the additional cost of using stainless steel as compared to aluminum is only \$12,600 for all 78 gates and is clearly insignificant in comparison to the total plant cost of just over \$20,000,000. These results also indicate that a savings would have been realized by using coal-tar epoxy coated mild steel slide gates as compared to the unprotected aluminum. However, the corrosion and abrasion resistance of material for construction of components exposed to severe abrasion and wear, e.g., gate seals and seal contact surfaces, should be considered since on these areas, protective coatings can be quickly worn away.

The above slide gates are for low-pressure applications. Higher heads [greater than 15 kPa (5 feet of water)] would require different designs of sluice gates and different materials such as cast iron. For example, the cost of an ARMCO 0.61- by 0.61-m (24- by 24-inch) cast iron sluice gate is \$1,750, and of a similar 1.5- by 0.76-m (60- by 30-inch) gate, \$4,900. Adding an epoxy-coal-tar coating would increase each of these prices by less than \$200. Again wear surfaces would require special consideration.

TABLE 39. COMPARISON OF COST* OF SLIDE GATES**

Material of construction/ protective coating	Cost				
	0.6 m x 0.6 m 1 gate	(24 in x 24 in) 30 gates	1.5 m x 0.7 m 1 gate	(60 in x 30 in) 48 gates	Total cost 78 gates
Carbon steel/coal-tar paint ***	$350	$10,500	$525	$25,200	$35,700
Carbon steel/galvanize***	370	11,100	625	30,000	41,100
Carbon steel/epoxy***	374	11,220	563	27,000	38,220
Aluminum/none	800	24,000	1,250	60,000	84,000
Stainless steel/none	900	27,000	1,450	69,600	96,.600

* Provided by Armco Steel Corporation. Comparisons between tables should not be made because of differences in accessories and gate applications.

** Required for aeration basins at Englewood-Littleton Sewage Treatment Plant.

*** Coating of all surfaces of these gates is not applicable. Wear surfaces should be constructed of corrosion and abrasion resistant materials.

Case II: Denver Metro Plant

In the Denver Metro plant addition, all materials in the covered aeration basins and piping to the secondary clarifiers are in agreement with present materials recommendations. Sluice gates are coal-tar epoxy coated cast iron. Waterstops and joint sealers consist of such recommended materials as neoprene rubber and polysulfide sealant, respectively. Concrete is the predominant material used in the aeration basins and represents the largest cost.

The costs of the cast iron sluice gates (complete installation including stems, hoists, anchor bolts, etc.) as supplied by their manufacturer, Rodney Hunt Company, are given in table 40. Also listed are prices which include the additional costs of epoxy coal-tar coating, assuming \$30/m^2 (\$3/ft^2) for coating materials and labor. Note that the relative cost of adding this coating is less than 1 percent of each gate price, but some surfaces of the gate may not be suitable for coating, e.g., high wear areas.

Prices for various sizes of fabricated slide gates of aluminum and stainless steel (table 41) were also obtained from the Rodney Hunt Company. Although these slide gates have the same opening as the sluice gates in table 40, they would probably not be serviceable at the Denver Metro plant because of the higher heads and other requirements. Note that these cost data agree with those in table 39; aluminum slide gates prices are less than 20 percent cheaper than those of stainless steel in these sizes.

A rough estimate of the installed costs of waterstops and joint sealers in the Denver Metro aeration basins was \$12,000. Variations in this value among various materials alternatives were found to be insignificant (installation is the largest portion of total waterstop or joint sealer cost) as compared to total capital cost. Total cost of the Denver Metro plant addition is about \$25,000,000.

TABLE 40. COMPARISON OF COSTS OF COATED AND UNCOATED CAST IRON SLUICE GATES*

Gate size	Unit cost		Number used	Total cost	
	Uncoated**	Coated***		Uncoated	Coated
48 inches by 48 inches	$5,176	$5,272	8	$ 41,408	$ 42,176
30 inches by 48 inches#	8,608	8,668	8	68,864	69,344
60 inches by 72 inches	8,545	8,725	1	8,545	8,725
42 inches diameter	5,536	5,594	10	55,360	55,940
TOTAL			27	$174,177	$176,185

* Used in the aeration basins of the Denver Metropolitan Sewage Treatment Plant.

** Provided by the Rodney Hunt Company. Prices for complete installation including stems, hoists, anchor bolts, etc. Comparisons between tables should not be made because of differences in accessories and gate applications.

*** Estimated assuming an added cost of $3 per square foot for a coal-tar epoxy coating. However, coating of all surfaces of these gates is not applicable. Wear surfaces should be constructed of corrosion and abrasion resistant materials.

\# Includes costs of a special electric operator.

TABLE 41. COMPARISON OF COSTS* OF SLIDE GATES CONSTRUCTED OF STAINLESS STEEL AND ALUMINUM

Gate size	Cost	
	Stainless steel	Aluminum
1.2 m by 1.2 m (48 in by 48 in)	$4,444	$3,508
0.7 m by 1.2 m (30 in by 48 in)**	7,779	7,059
5 m by 1.2 m (60 in by 48 in)	7,079	5,648
1.0 m diameter (42 in diameter)	4,778	4,018

* Provided by the Rodney Hunt Company. Comparisons between tables should not be made because of differences in accessories and gate applications.

** Includes cost of a special electric operator.

APPENDIX

Typical Concrete Mix Data

	Type II and polymer-impregnated	Type V
Cement, Laboratory No.	M-6400	M-5207
Aggregate source	Clear Creek 1/	Clear Creek 1/
Cement content, cement/concrete	977 kg/m^3 (549 lb/yd^3)	934 kg/m^3 (525 lb/yd^3)
Sand content, percent by volume of aggregate	42	42
Water-cement ratio by weight	0.51	0.51
Slump	76.2 mm (3.0 in.)	83.8 mm (3.3 in.)
Entrained air, percent	5.6	6.0
Total aggregate, aggregate/concrete	5319 kg/m^3 (2990 lb/yd^3)	5367 kg/m^3 (3017 lb/yd^3)

1/ A local aggregate deposit used in Bureau of Reclamation concrete testing programs.

Aggregate Gradation

Sand			Coarse aggregate	
No. sieve 2/	Opening (mm)	Percent retained	Size	Percent
Pan	-	5	4.76-9.53 mm (4-3/8 in.)	40
100	0.149	16	9.53-19.05 mm (3/8-3/4 in.)	60
50	0.297	24		
30	0.59	25		
16	1.19	15		
8	2.38	15		
Total		100		100

2/ U.S. Standard sieves.

Type II and Type V portland cement concrete specimens were cured for 14 days at 23°K (73.4°F) and 100 percent relative humidity. The specimens were then stored at 23°K (73.4°F) and 50 percent relative humidity until shipped to the test site for exposure.

Concrete-impregnation Procedure

Specimens prepared for impregnation were treated as follows:

1. Cure - 10 days at 100 percent RH, 23°K (73.4°F).
2. Dried in oven at 163°K (325°F) for 24 to 72 hours.
3. Cooled to room temperature for 24 hours.
4. Weighed to nearest 0.1 gram.
5. Specimens impregnated:
    a. Vacuum of 100 kPa (1 atmosphere) applied to impregnator for period 1/2 hour
    b. Impregnant, methyl methacrylate (MMA) monomer catalyzed with α, θ, butylazo isobutryonitrile, stirred for 1/2 hour
    c. Impregnant introduced into impregnator while vacuum was being maintained
    d. Vacuum released from impregnator and 376 kPa (40 $\mathrm{lb/in^2g}$) pressure applied using compressed air
    e. Pressure soaked in catalyzed monomer for 1 to 1-1/2 hours
    f. Pressure reduced to 100 kPa (atmospheric)

6. Polymerization of catalyzed monomer-impregnated specimens was accomplished by wrapping in foil and heating in oven to 75°C (167°F) for a period of 16 hours and allowed to cool to room temperature.

7. Specimens weighted to nearest 0.1 gram.

Percent loading was calculated for each specimen from the impregnated and dry weights. Average loading was 6.47 percent by weight.

Metals and Alloys

Corrosion coupons for the stressed and unstressed corrosion tests were procured from Corrosion Test Supplies Company, Baker, Louisiana. Data contained on certificates submitted are shown in table 1.

The circular unstressed and rectangular stressed corrosion specimens were prepared for exposure as follows:

1. Degreased in hot vapor degreaser using perchloroethylene solvent
2. Washed with grit soap until free of water breaks

3. Sensitized specimens (304 and 316 SS only) were then heated to 650°C (1200°F) for 1 hour and cooled slowly
4. Circular coupons weighed to nearest 0.1 milligram
5. Mount circular coupons on corrosion test spools
6. Stress rectangular specimens [bend over 25.4-mm (1-inch mandrel)]

Cleaning procedure following exposure was accomplished as follows:

1. Photograph
2. Wash carefully to remove all soluble material with soap
3. Chemical cleaning of respective specimens as shown below:

   Stainless steels: Washing with soap using a stiff-bristle brush and rubber stopper

   Cast iron, mild steel, low alloy steel, and austenitic cast iron: Immersion in hot caustic solution (20 percent sodium hydroxide with 200 grams of zinc dust added per liter), followed by washing with soap using a stiff-bristle brush and rubber stopper

   Copper: Immersion in 70 percent nitric acid solution followed by washing with soap using stiff-bristle brush and rubber stopper

4. Drying and weighing to nearest 0.1 milligram

Corrosion rate was calculated using the following formula:

$$\text{Corrosion rate} = \frac{(WL) \times (534)}{(D) \times (A) \times (T)}$$

where: Corrosion rate is in mils/year
D is the metal density in grams/cubic centimeter
A is the surface area of the coupon in square inches
T is the exposure time in hours, and
WL is the weight loss in milligrams

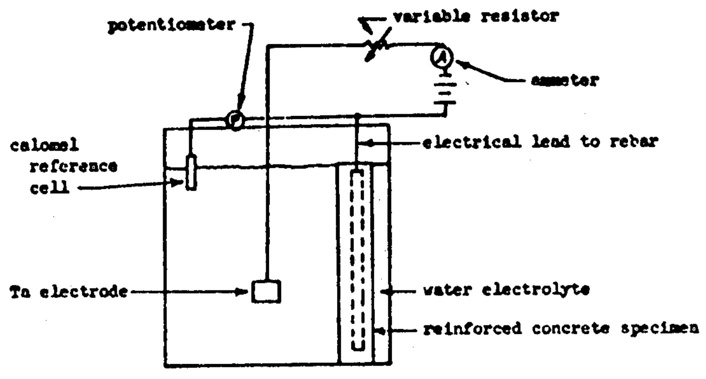
or: $$\text{Corrosion rate} = \frac{WL}{DAT}$$

where: Corrosion rate is in millimeters/year
D is the metal density in milligrams/mm^3
A is the surface area of the coupon in mm^2
T is the exposure time in years
WL is the weight loss in milligrams

Steel Reinforcement in Concrete

Polarization Break Method of Determining Corrosion Rates of Steel Reinforcement Embedded in Concrete

Sketch of test schemtic is shown below.



Polarization curve apparatus

Current is slowly increased by decreasing the resistance (variable resistor) until the impressed current is sufficient to overcome the anodic corrosion current. This point is determined by plotting the steel to electrolyte potential versus the log of the impressed current (E log I curve). The anodic current is the current at the break in the E log I curve. Similarly the cathodic corrosion current is determined by reversing the polarity of the cell. The corrosion current is then computed from the formula below:

$$I = \frac{Ia\ Ic}{Ia + Ic}$$

where: I is the corrosion current (amperes)
Ia is the anodic current (amperes)
Ic is the cathodic current (amperes)

The corrosion rate is then computed as follows:

$$W = F \times I \times t$$

where: W is the weight loss due to corrosion
F is Faraday's Number, 9.07 kg/ampere/yr (20 lb/ampere/yr) for steel
t is time (years)