

WADC TECHNICAL REPORT 52-99

RESEARCH INVESTIGATION OF PROTECTIVE COATINGS FOR MAGNESIUM

*H. D. Childers
K. B. Niles
A. G. Valles*

Northrop Aircraft, Inc.

November 1952

*Materials Laboratory
Contract No. AF 33(038)-23273
RDO No. 601-298*

**Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio**

McGregor & Werner, Inc.
Dayton, O. 150, 4 Feb. 53

FOREWORD

This report was prepared by Northrop Aircraft, Inc. in conformance with Contract No. AF33(038)-23273, and includes all performance data and pertinent test results obtained during the twelve-month span of the project. This work was initiated under Research and Development Order No. 601-298, "Development of Protective Coatings for Magnesium," and was administered by the Materials Laboratory, Wright Air Development Center, with Capt Harold W. Lasch acting as project engineer.

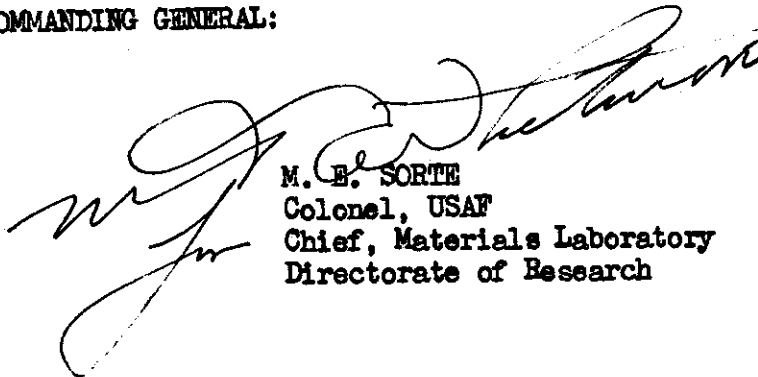
ABSTRACT

Numerous proprietary and developmental organic coatings are screened for relative corrosion protection of magnesium sheet alloy, with respect to a current Government specification system. Superior primers and systems are more fully evaluated for mechanical properties as well as corrosion protection. It was found that air-dry vinyl systems offer optimum protection, considering the systems tested. Developmental data and discussions of magnesium corrosion inhibitors and galvanic cell test methods are included in the report.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:



M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Directorate of Research

TABLE OF CONTENTS

1.	INTRODUCTION	1
2.	TEST METHODS	2
2.1	Corrosion Testing	2
2.2	Film Properties	3
2.3	Fuel Resistance	4
2.4	Water Resistance	4
2.5	Hydraulic Fluid Resistance	4
2.6	Electrochemical Tests	4
2.7	Notes	6
3.	TEST RESULTS	7
3.1	Part 1 - Screening Tests	7
	TABLE 1 VINYLs AND MODIFIED VINYLs	7
	TABLE 2 ALKYD AND MODIFIED ALKYD FINISHES.....	11
	TABLE 3 ACRYLIC AND MODIFIED ACRYLIC FINISHES	13
	TABLE 4 MISCELLANEOUS VEHICLES	14
	TABLE 5 HAE REFRACTORY COATING	16
3.2	Part 2 - Evaluation Tests	17
	TABLE 6 - EVALUATION TEST RESULTS	18
3.3	Part 3 - Electrochemical Test Data	19
	TABLE 7 MAGNESIUM CORROSION INHIBITORS	19
	Figures 1 - 8 Galvanic Cell Test Data	20 - 27
4.	DISCUSSION	28
5.	ACKNOWLEDGMENT	31
6.	BIBLIOGRAPHY	31
7.	APPENDIX I	33

Contrails

	Page
FIGURE 1 PLOT OF CURRENT VERSUS TIME IN GALVANIC CELL	20
FIGURE 2 PLOT OF CURRENT VERSUS TIME IN GALVANIC CELL	21
FIGURE 3 PLOT OF CURRENT VERSUS TIME IN GALVANIC CELL	22
FIGURE 4 POLARIZATION CURVES FOR UNTREATED MAGNESIUM VS. ALCLAD 24ST ALUMINUM	23
FIGURE 5 POLARIZATION CURVES FOR UNTREATED MAGNESIUM VS. 24 ST ALCLAD ALUMINUM	24
FIGURE 6 POLARIZATION CURVES FOR UNTREATED MAGNESIUM VS. 24 ST ALUMINUM	25
FIGURE 7 POLARIZATION CURVES FOR UNTREATED MAGNESIUM VS. 24 ST ALCLAD ALUMINUM	26
FIGURE 8 POLARIZATION CURVES FOR UNTREATED MAGNESIUM VS. 24 ST ALCLAD ALUMINUM	27
FIGURE 9 STANDARD DISSIMILAR METAL TEST PANEL	33
FIGURE 10 INHIBITION STUDY	34
FIGURE 11 HUMIDITY CABINET	35
FIGURE 12 SALT SPRAY CABINET	36
FIGURE 13 OUTDOOR EXPOSURE RACK	37

Contrails

PROTECTIVE COATINGS FOR MAGNESIUM1. INTRODUCTION

- 1.1 The aircraft designer is continually searching for stronger and lighter structural materials. Too frequently he must pay a penalty for the more desirable materials. That penalty may be in availability, in processing, fabrication or forming problems, or in service factors such as fatigue resistance or corrosion susceptibility.
- 1.2 Magnesium and its alloys offer considerable promise to the designer because of outstanding strength to weight ratios. The raw material source for magnesium is virtually inexhaustible, and processing and fabrication problems have been minimized by development work of the past few years. One of the primary factors delaying the wide use of magnesium for aircraft structural parts is its corrosion susceptibility. Since modern aircraft are subjected to wide extremes of environmental conditions and magnesium is inherently a highly active metal in the presence of water or other corroding media, a durable and practical protective finish is essential.
- 1.3 This project was initiated to investigate and consolidate reported data on the efficiency of magnesium protection offered by existing or newly developed organic finishes. It was hoped that general conclusions could be derived that would contribute to the development of a finish system to enable the use of magnesium alloys to be used in aircraft design without concern as to corrosion. Obviously, such a comprehensive program of evaluating corrosion protective properties must be limited by a number of simplifying assumptions since the correlation of accelerated aging tests and service life is highly opinionated and subject to many variables.
- 1.4 Since magnesium exhibits a highly electronegative potential with respect to hydrogen in the so-called galvanic series, it is susceptible to corrosion or solution in water. The corrosion products formed apparently show little tendency to passivate or inhibit this solvent action. As corrosion progresses, small areas on the magnesium surface begin to show differing electromotive potentials with respect to each other, and galvanic currents flow which accelerate the corrosion or solution of the anodic (more electronegative) surfaces. In many cases, high galvanic currents may flow initially due to surface impurity inclusions, attachment of other more cathodic metals to the magnesium surface, or to other causes such as solution concentrations, oxygenation, etc.
- 1.5 Two fundamental approaches to magnesium corrosion protection become apparent: (1), surround the magnesium with an impermeable film to completely exclude water, and (2), to include certain soluble or polarizing materials in the protective film such that when water does penetrate, polarization phenomena take place and galvanic or corrosion currents are held to a minimum by the increased effective internal cell resistance. It is believed that the more efficient and practical magnesium coatings should incorporate some measure of each of these two protective mechanisms.
- 1.6 Before these two fundamental mechanisms can be translated into a successful magnesium finish, consideration must be given to the essential film

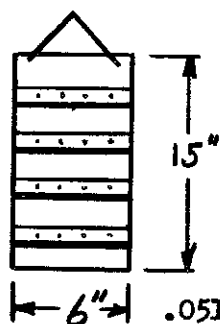
properties. These properties include: (1) electrical insulation, either by dielectric mechanisms or by apparent polarization phenomena, (2) alkali resistance, required by the highly alkaline hydrolysis of magnesium, and (3) adhesion, which is a prime factor of the coating durability. For specific coatings, other properties may be of greater or lesser importance, such as flexibility, hardness, ultra-violet radiation resistance, water resistance, etc. It is apparent that relative evaluations of coatings must consider all pertinent properties and screening tests and their evaluations must be judged accordingly.

- 1.7 As an aid in the development of this project, a "prior art" search was made including a survey of opinions and products of many of the leading paint and resin manufacturers and corrosion experts. While the response to the circulated questionnaire was quite cooperative, it was apparent that a wealth of information is available for ferrous metals, but surprisingly little work has been done on corrosion mechanisms and protective measures for the lighter metals, particularly magnesium. The survey results themselves were useful in indication fields of further study, and many of the ideas generated have been reflected in products and discussion presented in the body of this report.
- 1.8 This report represents an attempt to tabulate the observed performance properties of many proprietary and experimental magnesium coatings and to present some developmental data that may be of value for future work in this field.

2. TEST METHODS

2.1 Corrosion Testing

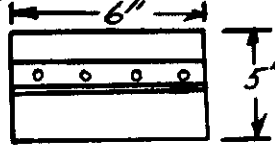
- 2.1.1 From a laboratory viewpoint, accelerated aging tests are highly desirable because they produce results in a relatively short time. However, real benefit can be derived from accelerated tests only if they closely simulate the service exposure conditions or if they contribute better understanding of the aging (or corrosion) mechanisms. Since magnesium is chemically so highly electronegative, it has been assumed that corrosion is primarily a function of galvanic current flowing either between electrically dissimilar portions of the metal surface or between couples set up by attachment of a more noble metal. The primary test method relied upon for screening and evaluation testing of magnesium finishes has been the standard salt spray corrosion test cabinet because the accelerated corrosion so obtained can be considered a major function of galvanic potentials. Salt spray corrosion test panels were standardized in the following form:



Formed angles of dissimilar metal were attached with 56S aluminum alloy rivets after painting the magnesium panel.

.051 magnesium FS-1h panel (Dow #7 dichromate pre-paint treatment, unless otherwise specified).

- 2.1.2 The edges of the test panel were given a spray coat of the test finish just prior to spraying the panel surface, and were not otherwise protected, either by deburring (rounding) or by waxing. The panels were suspended vertically, and the dissimilar metal angles consisted of 24S-T3Al, top and bottom, cadmium plated steel, and 75S-T6Al, in most cases. The angles were varied in some tests to determine effects with other metals such as copper or Type 302 stainless steel. The overall corrosion evaluation was affected very little by these variances, although 302 stainless normally caused the greatest attack, with 24S aluminum and copper being nearly as severe.
- 2.1.3 Since some finishes may be more affected by the high chloride ion content of the salt spray than others, the salt spray evaluation must be tempered, in marginal cases, by other test methods. Accelerated outdoor weathering exposure was used for this purpose, with small painted panels of magnesium alloy prepared with a 24S-T3 formed angle attached as shown below.



- 2.1.4 These panels were mounted 45° from the horizontal, facing south on an outdoor stand, and natural sea water sprayed daily on the panels. This method accelerated galvanic corrosion while exposing the finish to the deteriorating effects of sunlight and condensing moisture. However, the benefits of the method could not be fully utilized because of time limitations.

2.2 Film Properties

- 2.2.1 Sunlight and weathering effects were simulated by Atlas Twin-Arc Weatherometer exposure. This test primarily shows the dependence of the film protection on volatile, soluble, or oxidizable components.
- 2.2.2 Humidity effects were tested in a standard humidity cabinet maintaining 95% \pm 5% Relative Humidity at 100°F. Films with hygroscopic tendencies allow film softening, blistering, and corrosion.
- 2.2.3 Flexibility was determined by bending a panel, (.051 x 3 x 5) coated with the test finish, over a 0.50 diameter mandrel. The panel was bent 180° at room temperature and after aging at 200°F for 48 hours. Rupture of the film on the tension side was considered to be failure primarily in flexibility, while rupture on the compression side of the bend was considered primarily due to adhesion failure.
- 2.2.4 Adhesion was not determined quantitatively, but on a relative basis. Fingernail and knife scratching and peeling were observed. For more critical determinations, parallel lines approximately 1/16 inch apart were scribed on the paint surface to form a grid.

Four lines in each direction were normally sufficient. When adhesion was poor, the squares of paint would flake off during the scribing. The ease with which the squares part from the panel is a fairly critical measure of adhesion, if some consideration is made of the degree of cohesion of a particular finish.

2.3 Fuel Resistance

2.3.1 Specimen panels, .051 x 3 x 5, coated with the test finishes were immersed in jet engine fuel (JP-4) for four hours at an approximate temperature of 70°F. (This fuel is a hydrocarbon mixture with approximately 15% aromatics). The panels were visually rated on the basis of film softening, loss of adhesion, blistering, and appearance changes.

2.4 Water Resistance

2.4.1 Specimen panels, .051 x 3 x 5, coated with the test finishes were immersed in tap water at room temperature for 24 hours. The panels were visually rated on the basis of film softening, loss of adhesion, blistering, and appearance changes.

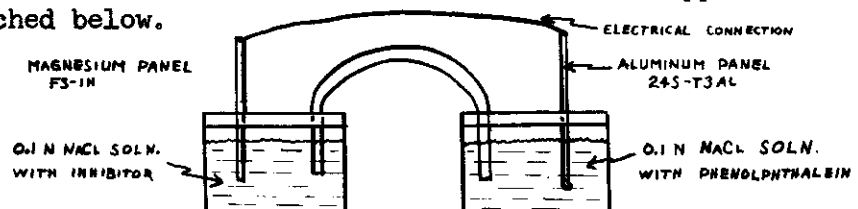
2.5 Hydraulic Fluid Resistance

2.5.1 Specimen panels, .051 x 3 x 5, coated with the test finishes were immersed in mineral oil hydraulic fluid (Spec. MIL-O-5606) at room temperature for 24 hours. The panels were visually rated on the basis of film softening, loss of adhesion, blistering, and appearance changes.

2.6 Electrochemical Tests

2.6.1 Three fundamental test methods were used in the study of pigment inhibition and ion permeability.

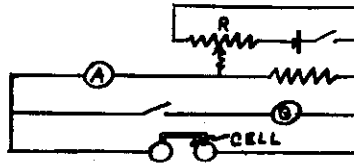
2.6.1.1 Simple evaluations of corrosion inhibiting properties of pigments and soluble additives were made with an apparatus as sketched below.



Additives were placed in the anode or cathode solution, as desired, to form a saturated solution. Corrosion inhibition evaluation was based upon actual corrosion of the anode (magnesium) and by observation of side effects such as gas evolution or pH change at the cathode.

2.6.1.2 The change of corrosion current with time for a particular finish was measured by use of a zero-resistance ammeter circuit so that the deterioration of the film could be evaluated by the flow of galvanic current under simulated short-circuit conditions. The apparatus was

in accordance with the sketch below.



By adjusting the resistance, the potential differential between anode and cathode compartments of the cell was reduced to zero, so that the current measured at A was a function of the effective internal resistance of the cell only. This condition simulates a corrosion test panel where the dissimilar metal is riveted or fastened directly to the magnesium with essentially zero contact resistance.

This test method interposes the condition of immersion in the electrolyte, which is normally not true for corrosion specimens in accelerated aging test. However, the permeability of a coating to ion conduction can be easily observed, and, of particular interest, the change in current with time on rupturing of a finish (such as a scratch or puncture) can be plotted accurately.

It is presumed that this "inhibition curve" demonstrates the effectiveness of a finish additive in combating moisture permeation or film rupture effects.

The particular apparatus used was capable of measuring currents as low as 0.01 microamperes. For ease of handling and improved control of test conditions, all data were obtained by use of the isolated half-cells. For this reason, the limiting current in the cell at short circuit may have been restricted by the increased internal resistance due to the agar gel conducting bridge. This influence was not considered to be too significant, since relative effects and curve shapes were the primary interest.

- 2.6.1.3 Cell potentials vs. cell current were plotted for magnesium-aluminum cells to evaluate polarization phenomena of various inhibiting pigments. Unpainted electrodes were used in the same cell apparatus as described above for the zero external resistance current measurements. Anode and cathode potentials were measured with reference to a calomel half-cell, and absolute values converted to hydrogen electrode reference. Using the zero-resistance ammeter circuit to vary the cell current from zero (open-circuit) to maximum (short-circuit), potentials of each electrode were measured in an external, potentiometer-bridges balanced, zero current circuit. Plots were made of potential vs. current for various additives to cathode, anode, or both, to graphically demonstrate the polarization or depolarization effectiveness of the additive.

- 2.6.2 Some of the inhibitors studied under methods (1) and (3) above were milled into an experimental alkali resistant modified alkyd resin and evaluated as a paint film. Panel test results reported for Northrop - source finishes are of this nature. The resin used was known to be permeable to conducting ions when pigmented, as evidenced in preliminary testing by method (2) above. These finishes offered excellent opportunity to evaluate films dependent primarily upon inhibitive properties for protection.

2.7 Notes

- 2.7.1 All finish evaluations reported herein were conducted on magnesium alloy FS-IH. Most of the panels were fabricated from .051 sheet stock, although some corrosion test panels were made from .040 sheet. The corrosion performance of these two thicknesses appeared to be identical.
- 2.7.2 All evaluation finishes were applied by spray technique, with the finish thinned and handled in accordance with the vendor's recommendations. No control could be exercised by this contractor over the vendor application spray technique or equipment; however, Northrop application involved use of the DeVilbiss Touch-up Spray Gun for screening tests, and the American Brake Shoe Gun, Model S-70, for evaluation tests of screened materials. Both guns were operated at 35 lbs. air pressure.

3. TEST RESULTS

3.1

Part 1 - Screening Tests

- 3.1.1 Commercial and experimental primers and finishes were screened for corrosion protection of magnesium by 120 hour exposure to salt fog in a standard salt spray cabinet (Industrial Filter and Pump Mfg. Co., Type CA3). Salt concentration was 20% and the temperature was controlled at $98 \pm 2^{\circ}\text{F}$.
- 3.1.2 The test results are presented in tabular form for more convenient reference. Each panel tested is listed by panel number. The numbering system has no particular significance except as an aid to laboratory personnel in maintaining records.
- 3.1.3 The source (or manufacturer) of each finish is given by number only. The identification of a number with a particular vendor or manufacturer is given on a Finish Key list furnished as a separate appendix to this report.
- 3.1.4 Finishes are pigmented and air dried unless otherwise stated.
- 3.1.5 Evaluation ratings are from 1 (very poor, failure) to 10 (excellent).

TABLE 1

VINYLs AND MODIFIED VINYLs

PANEL NO.	SOURCE (MFG.)	NO. OF COATS INCLUD PRIMER	NO. OF FINISHES E.G. PRIMER-TOP COAT ETC.	OVER-ALL FINISH SYSTEM THICK.	EVALUATION (SALT SPRAY, 120 HRS.)			REMARKS
					COR-ROSION RESIST-ANCE	ADHE-SION	BLIST-ERING	
8 (S.C.S.)		3	2	.0015	3	9	9	Specification Control System
9 (S.C.S.)		3	2	.0015	5	9	9	Specification Control System Suspended Horizontally
1	1	1	1		3	5	5	
2	1	2	2	.0020	5	5	7	
3	1	2	2	.0020	5	5	7	Panel scratched between angles
4	13	2	1	.0020	5	7	9	
5	13	2	1	.0020	5	7	9	Panel scratched between angles
10	13	2	1	.0010	8	9	7	Pigment modified #4
11	13	2	1	.0010	6	8	8	#10, except phosphate pre-paint treatment
12	13	2	1	.0015	4	7	8	#10, no pre-paint
13	19	2	1	.0015	7	7	8	
14	19	2	1	.0020	6	6	8	#13, phosphate pre-paint
15	19	2	1	.0030	6	6	8	#13, no pre-paint
21	1	2	2	.0050	6	7	8	
22	1	2	2	.0020	6	7	8	
29	11	2	1	.0020	6	8	8	No pre-paint
30	11	2	1	.0020	6	8	8	#29, Dow #7 pre-paint

TABLE 1 (Cont'd.)

VINYLS AND MODIFIED VINYLs

PANEL NO.	SOURCE (MFG.)	NO. OF COATS INCL. PRIMER	NO. OF FINISHES E.G. PRIMER-TOP COAT ETC.	OVER-ALL FINISH SYSTEM THICK	EVALUATION (SALT SPRAY, 120 HRS)			REMARKS
					COR-ROSION RESISTANCE	ADHE-SION	BLIST-ERING	
31	11	2	1	.0015	6	8	8	Special pre-paint treatment
35	11	2	1	.0015	3	8	8	Vapor-blast clean. no pre-paint
43	9	1	1	.0005	5	6	9	Scratched to bare metal. Coating baked at 300°F for 20 min.
44	9	1	1	.0015	4	4	5	#43, no pre-paint
45	9	1	1	.0005	3	4	4	No pre-paint. Coating baked at 350°F for 30 min.
46	9	1	1	.0010	4	5	9	#45, Dow #7 pre-paint. Coating baked at 350°F for 30 min.
47	9	2	2	.0010	4	4	9	No pre-paint, top coat baked 30 min at 350°F.
48	9	2	2	.0005	4	10	10	No pre-paint, top coat baked 30 min. at 350°F.
49	9	2	2	.0010	5	7	8	No pre-paint, top coat baked 30 min. at 350°F.
50	11	2	1	.0025	8	8	9	Dow #7 pre-paint
51	11	2	1	.0035	8	10	9	Dow #7 pre-paint
52	11	2	1	.0030	6	8	8	Dow #7 pre-paint
53	13	2	1	.0015	4	5	4	Special vendor pre-paint
54	13	2	1	---	5	4	8	Special vendor pre-paint
55	13	2	1	.0010	5	4	8	Special vendor pre-paint
56	13	2	1	---	5	5	8	Special vendor pre-paint
60	11	2	1	.0025	8	10	9	Dow #7 pre-paint
61	11	2	1	.0030	8	10	9	Dow #7 pre-paint
62	22	2	1	.0005	4	5	8	Dow #7 pre-paint
63	22	2	1	.0005	4	5	8	Dow #7 pre-paint
64	22	2	2	.0015	7	8	8	Dow #7 pre-paint
65	22	2	2	.0015	7	8	8	Dow #7 pre-paint
70	11	2	1	.0035	7	6	8	Dow #7 pre-paint
71	11	2	1	---	9	10	8	Dow #7 pre-paint
72	11	2	1	---	10	9	9	Dow #7 pre-paint
73	11	2	1	---	8	8	5	Vapor Blast pre-paint
78	11	2	1	---	10	8	9	Dow #7 pre-paint
79	2	2	2	.0025	6	8	8	Chrome pickle pre-paint
80	2	2	2	.0025	8	8	8	AN-M-12A Type 1 chromate pre-paint
81	2	2	2	.0050	5	8	8	AN-M-12A Type 1 chromate pre-paint, top coat baked 30 min. at 200°F, then 15 min. at 350°F.
82	2	2	2	.0025	5	8	8	AN-M-12A Type 1 chromate pre-paint
83	11	2	1	---	9	4	8	Dow #7 pre-paint
84	11	2	1	---	10	5	8	Dow #7 pre-paint
85	13	1	1	.0010	5	7	8	Dow #7 pre-paint

Contrails

TABLE 1 (Cont'd)

VINYLs AND MODIFIED VINYLs

PANEL NO.	SOURCE (MFG.)	NO. OF COATS INCLUD. PRIMER	NO. OF FINISHES E.G. PRIMER-TOP COAT ETC.	OVER-ALL FINISH SYSTEM THICK.	EVALUATION (SALT SPRAY, 120 HRS)			REMARKS
					CORROSION RESISTANCE	ADHESION	BLISTERING	
86	13	2	1	.0015	6	7	8	Dow #7 pre-paint
87	13	3	1	.0020	6	7	8	Dow #7 pre-paint
91	11	2	1	—	6	7	8	Dow #7 pre-paint
92	11	2	1	—	9	7	8	Dow #7 pre-paint
93	11	2	1	.0010	6	7	8	Dow #7 pre-paint, clear resin
94	11	2	1	.0025	8	8	8	Dow #7 pre-paint, clear resin
100	4	2	2	—	8	7	6	Dow #7 pre-paint
101	4	2	2	—	8	7	6	Dow #7 pre-paint
102	22	2	1	—	7	5	6	Dow #7 pre-paint
103	22	2	1	—	7	5	6	Dow #7 pre-paint
104	22	2	2	—	7	2	2	Dow #7 pre-paint
105	22	2	2	—	7	2	2	Dow #7 pre-paint
106	11	2	1	—	8	5	7	Dow #7 pre-paint
107	11	2	1	—	7	8	9	Dow #7 pre-paint
108	11	2	1	—	6	5	9	Dow #7 pre-paint
109	11	2	1	—	9	5	9	Dow #7 pre-paint
110	11	2	1	—	9	5	9	Dow #7 pre-paint
136	11	2	1	.0015	8	6	7	Dow #7 pre-paint
137	20	1	1	.0005	6	8	7	Stainless steel pigment. Phosphoric Acid etching.
138	20	1	1	.0005	6	8	7	Stainless steel pigment, and phosphoric acid etching, Dow #7 pre-paint
139	20	1	1	.0005	6	8	7	Stainless steel pigment, Dow #7 pre-paint
155	11	3	2	—	9	8	8	Dow #7 pre-paint
156	11	2	1	—	3	2	2	Dow #7 pre-paint
158	11	2	1	—	9	8	9	Dow #7 pre-paint
179	11	2	1	.0020	9	8	9	Dow #7 pre-paint
181	1	3	2	.0010	9	7	9	Dow #7 pre-paint
182	11	2	2	.0030	8	8	6	Dow #7 pre-paint
183	11	3	2	.0010	9	9	9	Dow #7 pre-paint
184	11	2	1	.0020	5	8	8	Dow #7 pre-paint
185	11	2	1	.0025	9	9	9	Dow #7 pre-paint
190	10	2	1	.0020	5	8	8	Dow #7 pre-paint
191	10	2	1	.0020	7	7	8	Dow #7 pre-paint
192	10	2	1	.0020	5	8	8	Dow #7 pre-paint
193	11	2	1	.0020	8	10	9	Dow #7 pre-paint
194	11	3	2	.0020	8	8	3	No pre-paint
195	11	2	1	.0025	9	8	8	Dow #7 pre-paint
198	2	2	1	.0010	9	4	3	Dow #7 pre-paint
199	2	3	2	.0010	9	4	3	Dow #7 pre-paint
200	2	3	2	.0010	4	8	2	Dow #7 pre-paint

WADC TR 52-99

TABLE 1 (Cont'd.)

VINYLS AND MODIFIED VINYL

PANEL NO.	SOURCE (MFG.)	NO. OF COATS INCL. PRIMER	NO. OF FINISHES E.G. PRIMER-TOP COAT ETC.	OVER-ALL FINISH SYSTEM THICK.	EVALUATION (SALT SPRAY, 120 HRS)			REMARKS
					CORROSION RESISTANCE	ADHESION	BLISTERING	
201	2	3	3	.0005	8	8	4	Dow #7 pre-paint
202	2	3	3	.0005	5	9	2	No pre-paint
203	2	3	3	.0010	8	8	3	Dow #7 pre-paint
204	2	3	3	.0010	5	8	2	No pre-paint
206	11	2	1	.0020	8	8	8	Dow #7 pre-paint
207	11	2	1	.0020	4	8	8	Dow #7 pre-paint, resin modified to withstand lubricants
208	11	2	1	.0020	6	8	8	Dow #1 pre-paint
209	10	2	1	.0020	10	10	8	Dow #7 pre-paint
210	10	2	1	.0035	9	9	8	Dow #7 pre-paint
211	10	2	1	.0030	9	8	8	Dow #7 pre-paint
212	10	2	1	.0015	9	3	6	Dow #7 pre-paint
213	10	2	2	.0030	9	5	9	Dow #7 pre-paint
214	10	2	1	.0030	9	5	6	Dow #7 pre-paint
215	10	2	2	.0025	9	3	6	Dow #7 pre-paint
216	10	2	1	.0035	8	8	6	Dow #7 pre-paint
217	10	1	1	.0035	8	8	6	Dow #7 pre-paint
218	10	2	2	.0035	10	10	9	Dow #7 pre-paint
219	10	2	2	.0035	9	8	8	Dow #7 pre-paint
500	13	1	1	—	6	4	8	Dow #15 & Dow #7 pre-paint
501	13	1	1	—	6	4	8	Dow #15 & Dow #7 Pre-paint
502	13	1	1	—	5	4	8	Dow #7 pre-paint
503	13	1	1	—	5	4	8	Dow #7 pre-paint
520	13	1	1	.0010	6	7	8	Dow #7 pre-paint
521	13	1	1	.0015	6	7	8	Dow #7 pre-paint
522	13	1	1	.0010	6	7	8	Dow #15 & Dow #7 pre-paint
523	13	1	1	.0015	7	7	8	Dow #15 & Dow #7 pre-paint
524	13	1	1	.0010	6	7	6	Dow #7 pre-paint
525	13	1	1	.0010	7	7	6	Dow #7 pre-paint
526	13	1	1	.0010	7	7	6	Dow #15 & Dow #7 pre-paint
527	13	1	1	.0010	6	7	6	Dow #15 & Dow #7 pre-paint
532	13	2	1	.0010	4	7	7	Dow #7 pre-paint, clear resin
533	13	2	1	.0005	4	7	7	Dow #15 pre-paint, clear resin
534	13	2	1	.0010	4	7	7	Dow #15 & Dow #7 pre-paint, clear resin

TABLE 2

ALKYD AND MODIFIED ALKYD FINISHES

PANEL NO.	SOURCE (MFG)	NO. OF COATS INCL. PRIMER	NO. OF FINISHES E.G. PRIMER-TO-PRIMER COAT ETC.	OVER-ALL FINISH SYSTEM THICK.	EVALUATION (SALT SPRAY, 120 HRS)			REMARKS
					COR-ROSION RESIST-ANCE	ADHE-SION	BLIST-ERING	
S.C.S	3	2	2	.0015	3	9	9	Specification Control System
6	19	3	2	.0020	2	9	9	MIL-E-5557, Enamel over Northrop Seal Primer
18	17	2	1	.0020	8	8	8	Dow #7 pre-paint
19	17	2	1	.0025	4	7	6	Phosphate pre-paint
32	11	2	1	.015	3	8	6	No pre-paint
33	11	2	1	.0010	4	8	7	No pre-paint
34	11	2	1	.0030	2	8	6	Specially treated magnesium
36	11	2	1	.0030	4	8	6	Vapor blasted magnesium
88	17	1	1	.0010	4	5	7	Dow #7 pre-paint
89	17	2	1	.0010	4	5	7	Dow #7 pre-paint
90	17	3	1	.0010	4	5	7	Dow #7 pre-paint
134	23	2	1	.0010	5	5	8	No pre-paint
135	23	2	1	.0020	8	5	8	Dow #7 pre-paint
147	23	2	1	.0010	7	5	9	Dow #7 pre-paint
148	23	2	1	.0010	8	5	9	Dow #7 pre-paint
149	23	2	1	.0005	4	3	7	No pre-paint
150	23	2	1	.0005	6	5	7	Dow #7 pre-paint
151	23	2	1	.0020	6	8	7	No pre-paint
152	23	2	1	.0025	8	8	7	Dow #7 pre-paint
153	23	2	1	.0020	5	6	7	No pre-paint
154	23	2	1	.0020	9	7	8	Dow #7 pre-paint
159	23	2	1	.0020	4	5	7	No pre-paint
160	23	2	1	.0010	5	5	7	Dow #7 pre-paint
161	23	2	1	.0010	5	5	6	Organic pre-paint
162	23	2	1	.0020	5	3	6	No pre-paint
163	23	2	1	.0020	6	5	7	Dow #7 pre-paint
164	23	2	1	.0020	5	5	6	Organic pre-paint
165	23	2	1	.0020	5	5	5	No pre-paint
166	23	2	1	.0025	9	8	8	Dow #7 pre-paint
167	23	2	1	.0010	4	3	6	Dow #7 pre-paint
168	23	2	1	.0025	3	3	6	No pre-paint
169	7	3	3	.0025	8	9	9	Dow #7 pre-paint
170	7	3	3	.0025	8	9	9	Dow #7 pre-paint
171	23	2	1	.0015	6	7	8	Dow #7 pre-paint
172	23	2	1	.0015	5	6	8	No pre-paint
173	23	2	1	.0020	6	8	8	Dow #7 pre-paint
176	23	2	1	.0015	5	7	7	Dow #7 pre-paint
177	23	2	1	.0030	8	7	7	Dow #7 pre-paint
178	23	2	1	.0030	6	7	7	Dow #7 pre-paint
186	23	2	1	.0015	5	4	5	Dow #7 pre-paint
187	23	2	1	.0015	5	8	7	Dow #7 pre-paint

TABLE 2 (Cont'd)

ALKYD AND MODIFIED FINISHES

PANEL NO.	SOURCE (MFG.)	NO. OF COATS INCLD PRIMER	NO. OF FINISHES E.G. PRIMER-TOP COAT ETC.	OVER-ALL FINISH SYSTEM THICK.	EVALUATION (SALT SPRAY, 120 HRS)			REMARKS
					COR-ROSION RESIST-ANCE	ADHE-SION	BLIST-ERING	
196	23	2	1	.0020	6	7	8	Dow #7 pre-paint
197	23	2	1	.0020	8	8	8	Dow #7 pre-paint
205	13	2	1	—	3	8	8	Dow #7 pre-paint
220	25	2	1	.0025	8	8	8	Dow #7 pre-paint
221	25	2	1	.0015	4	8	8	Dow #7 pre-paint
222	25	2	1	.0025	8	4	8	Dow #7 pre-paint
508	13	1	2	.0005	3	7	8	Dow #7 pre-paint, clear resin
509	13	1	2	.0005	3	7	8	Duplicate of #508
510	13	1	2	.0005	4	7	8	Dow #15 and Dow #7 pre-paint, clear resin
511	13	1	2	.0005	4	7	8	Duplicate of #508
512	12	2	3	.0025	2	7	7	Dow #7 pre-paint
513	13	2	3	.0035	2	7	7	Duplicate of #512
514	13	2	3	.0010	2	7	6	Dow #15 and Dow #7 pre-paint
515	13	2	3	.0030	2	7	6	Duplicate of #514
541	13	2	1	.0005	5	7	6	Dow #7 pre-paint, clear resin
542	13	2	1	.0005	4	7	6	Dow #15 pre-paint, clear resin
543	13	2	1	.0005	4	7	6	Dow #15 and Dow #7 pre-paint, clear resin

TABLE 3

ACRYLIC AND MODIFIED ACRYLIC FINISHES

PANEL NO.	SOURCE (MFG.)	NO. OF COATS INCLUD. PRIMER	NO. OF FINISHES E.G. PRIMER-TOP COAT ETC.	OVER-ALL FINISH SYSTEM THICK	EVALUATION (SALT SPRAY, 120 HRS)			REMARKS
					COR-ROSION RESISTANCE	ADHE-SION	BLIST-ERING	
S.C.S.		3	2	.0015	3	9	9	Special Control System
20	5	2	2	.0025	8	8	8	Dow #7 pre-paint; 10 days cure time
23	5	2	2	.0020	4	6	3	#20, no pre-paint; 3 days cure time
24	5	3	3	.0025	5	8	4	No pre-paint; 10 days cure time
25	5	3	2	.0030	3	6	3	No pre-paint; 10 days cure time
26	5	2	2	.0035	3	6	3	No pre-paint; 10 days cure time, clear resin
27	5	4	3	.0055	3	6	3	No pre-paint; 10 days cure time
28	5	2	2	.0030	3	6	3	No pre-paint; 10 days cure time
74	5	3	3	.0060	8	4	8	No pre-paint
75	5	3	3	.0085	8	7	8	#74, Dow #7 pre-paint
76	5	3	3	.0060	9	8	9	Dow #7 pre-paint
77	5	3	3	.0085	8	7	9	Dow #7 pre-paint
95	5	3	3	.0055	9	7	8	Dow #7 pre-paint
96	5	3	3	.0055	10	8	9	Dow #7 pre-paint
97	5	3	3	.0060	10	8	9	Dow #7 pre-paint
98	5	3	3	.0070	10	8	9	Dow #7 pre-paint
99	5	3	3	.0070	9	9	9	Dow #7 pre-paint
127	5	3	3	.0030	9	7	9	Dow #7 pre-paint
128	5	3	3	.0030	8	7	8	Dow #7 pre-paint
129	5	3	3	.0040	9	7	9	Dow #7 pre-paint
130	5	3	3	.0025	5	5	8	Dow #7 pre-paint
131	5	3	3	.0025	9	8	9	Dow #7 pre-paint
132	5	2	2	.0040	8	8	7	Dow #7 pre-paint
133	5	2	2	.0025	8	8	7	Dow #7 pre-paint
140	5	2	2	.0025	5	7	8	Dow #7 pre-paint
141	5	2	2	.0025	7	7	8	Dow #7 pre-paint
142	5	2	1	.0020	5	7	8	Dow #7 pre-paint
143	5	2	2	.0030	9	8	9	Dow #7 pre-paint
144	5	2	2	.0025	8	9	9	Dow #7 pre-paint

TABLE 4 (Cont'd)

EPON FINISHES

PANEL NO.	SOURCE (MFG.)	NO. OF COATS INCLUD. PRIMER	NO. OF FINISHES E.G. PRIM-ER-TOP COAT ETC.	OVER-ALL FINISH SYSTEM THICK.	EVALUATION (SALT SPRAY, 120 HRS)			REMARKS
					COR-ROSION RESIST-ANCE	ADHE-SION	BLIST-ERING	
37	9	1	1	.0010	7	10	10	Dow #7 pre-paint, panel scratched clear resin baked 45 min. at 400°F.
38	9	1	1	.0015	4	5	7	#37, no pre-paint clear resin, baked 45 min. at 400°F.
39	9	1	1	.0010	6	8	9	Clear resin, baked 45 min. at 400°F.
40	9	1	1	.0005	7	4	6	#59, no pre-paint No pre-paint, Zinc Chrom. Primer baked at 400°F for 45 min.
41	9	2	2	.0010	5	8	8	under Epon Clear resin top coat, Wash primer under Epon clear resin top coat, baked at 400°F for 45 min.
42	9	2	2	.0015	6	9	10	resin top coat, baked at 400°F for 45 min. No Dow #7
66	9	2	1	—	5	8	10	Dow #7 pre-paint, baked coating #66, different pigment-vehicle ratio, baked coating
67	9	2	1	—	5	8	10	#66, different pigment-vehicle ratio, baked coating
68	9	2	1	—	5	8	10	#66, different pigment-vehicle ratio, baked coating
69	9	2	1	—	4	8	9	Dow #7 pre-paint, Aluminum pig-ment, baked coating
57	18	2	1	.0005	4	4	6	Dow #7 pre-paint No pre-paint Special pre-paint by vendor
58	18	2	1	.0010	4	4	6	
59	18	2	1	.0010	5	5	6	
535	13	2	1	.0010	4	5	6	Dow #7 pre-paint, clear resin
536	13	2	1	.0015	3	5	6	Dow #15 pre-paint, clear resin
537	13	2	1	.0010	4	5	6	Dow #7 and Dow #15 pre-paint clear resin

(NOTE: STYRENEATED ALKIDS LISTED UNDER ALKID AND MODIFIED ALKID FINISHES.)

STYRENE FINISHES

METALINE FINISHES

PANEL NO.	SOURCE (MFG.)	NO. OF COATS E.G. PRIM-ER-TOP COAT ETC.	OVER-ALL FINISH SYSTEM THICK.	EVALUATION			REMARKS
				OVER-COR-ROSION RESIST-ANCE	ADHE-SION	BLIST-ERING	
125		21	1	.0005	2	8	No pre-paint, baked clear resin
126		21	1	.0005	4	8	Dow #7 pre-paint, baked clear resin
180		19	1	.0005	8	9	Dow #7 pre-paint, clear resin
188		15	2	---	6	9	Dow #7 pre-paint, baked clear resin
189		15	1	---	7	9	Dow #7 pre-paint, baked clear resin
111	3	1	1	---	2	10	Low temperature fired ceramic. No pre-paint
112	3	1	1	---	2	10	Low temperature fired ceramic. No pre-paint
CHLORINATED RUBBER FINISHES							
16	8	2	1	.0015	6	7	Dow #7 pre-paint
17	8	2	1	.0015	6	7	Phosphate pre-paint
174	12	2	1	.0020	3	4	Dow #7 pre-paint
175	12	2	1	---	1	4	No pre-paint
516	13	2	1	.0020	5	7	Dow #7 pre-paint, clear resin
517	13	2	1	.0015	5	7	Dow #7 pre-paint, clear resin
518	13	2	1	.0020	4	7	Dow #7 and Dow #15 pre-paint, clear resin
519	13	2	1	.0015	4	7	Dow #7 and Dow #15 pre-paint, clear resin
538	13	2	1	.0015	4	8	Dow #7 pre-paint, clear resin
539	13	2	1	.0010	2	8	Dow #15 and Dow #7 pre-paint, clear resin
540	13	2	1	.0015	2	8	Dow #15 and Dow #7 pre-paint, clear resin

MISCELLANEOUS VEHICLES

TABLE 4

TABLE 5

HAE REFRACTORY COATING

COATING*	PRE-PAINT TREATMENT	CORROSION PROTECTION	BLISTERING	ADHESION
A	HAE	6	9	10
A	HAE	8	9	10
A	Dow #7	2	9	8
A	Dow #7	2	9	8
B	HAE	7	7	10
B	HAE	8	9	10
B	Dow #7	8	7	6
B	Dow #7	7	7	6
H	HAE	8	9	10
H	HAE	7	9	10
H	Dow #7	9	8	9
H	Dow #7	9	8	9
Northrop Seal Primer	HAE	7	9	10
Northrop Seal Primer	HAE	6	9	10
None	HAE & Sil- icone Lub- ricant	5	-	-
None	HAE & Sil- icone Lub- ricant	5	-	-
None	Wax over HAE	7	-	-

*Code letters refer to finishes listed in Table VI.

Part 2 - Evaluation Tests

3.2

- 3.2.1 Finishes and finish systems subjected to over-all evaluation testing were selected primarily on the basis of performance in the preceding Screening Tests. However salt spray performance was not a rigid requirement since it was desirable to subject as many promising finishes as possible to the full evaluation program.
- 3.2.2 The test results are listed in tabular form, and each finish or finish system is identified by a code letter. The source and full description of each finish is contained in a separate appendix to this report. Note that all evaluated finishes with the exception of the Specification Control system, were of the air-dry vinyl type: primer, top-coat, or both (see Discussion, Section 4).
- 3.2.3 The numerical rating system simply defines the degree of performance from 1 (very poor or complete failure) to 10 (excellent or no effect).

TABLE 6

EVALUATION TEST RESULTS

FINISH SYSTEM	120 HRS. SALT SPRAY OVERALL THICK.: .0020		250 HRS. SALT SPRAY EXPOSURE THICKNESS .0020		TOP-COAT PERFORMANCE 250 HOURS SALT SPRAY MIL-L-7178 MFGS. RECOM- LACQUER ON MENDED TOP MAG. PRIMER COAT OVERALL THICK.: .0025 THICK.: .0025				150 HRS. IN HUMIDITY CABINET		AFTER 24 HRS. 250 HRS. WEATHER-OMETER		AFTER 24 HRS. IN HYDRAULIC OIL		AFTER 4 HRS. IN JP-4 FUEL		FLEX AT NORMAL TEMP. BENT OVER 1/2" MANDREL		FLEX AFTER AGING FOR 48 HRS. AT 200°F. BENT OVER 1/2" MANDREL		OUT-SIDE WEATHERING 14 DAYS	
	Corrosion	Adhesion	Corrosion	Adhesion	Corrosion	Adhesion	Corrosion	Adhesion	Immediately	15 Minutes	16 Hours				One Hour	24 Hours	Compression	Tension	Compression	Tension	Corrosion	Adhesion
A	2	8	1	8	1	8	None	None	4-5	4-5	8	10	10	10	5	7	3	9	2	9	5	5
B	7-8	6	5-7	5	8	5	None	None	5	5	8	10	10	10	5	9	1	7	1	1	7-8	7
C	7	6	2-3	8	7	8	None	None	3	4	7	10	10	10	8	10	1	7	1	1	6-8	7
D	7-8	8	5	8	4-7	5-8	None	None	4	4-5	10	10	10	10	9	10	1	8	1	8	7	8
E	8-9	8	2-6	8	5	9	7	8	7	7	10	10	10	9	6	9	1	7	1	4	6	9
F	9	9	9	9	7	8	9	9	5	5	10	10	10	10	10	10	1	4	1	1	8	9
G	8	8	4-5	7	7	7	6-7	7	7	8	10	10	10	7	6	6	1	6	1	5	6-7	8
H	9	9	7-8	9	6-8	6	7-9	8	7	7	10	10	10	10	7	8	10	10	1	8	7-8	9
J	8	8	6-8	8	7-9	8	None	None	7-8	8	8	10	10	10	10	10	3	8	2	10	8	7-9
K	9	10	4	7	8	6	9	8	7	7	10	10	10	10	9	9	8	7	1	1	8	10
L	6-7	7	1	7	7	6	7	7	7-8	8	10	10	10	10	8	8	1	1	1	1	6-7	7

Part 3 - Electrochemical Test Data

3.3

3.3.1 The test results presented here have not been used directly in the evaluation of proprietary finishes; however, the trends and basic data have been useful in promoting better understanding of the corrosion mechanisms and aided in the more accurate finish evaluation. See Discussion, Section 4.

TABLE 7

MAGNESIUM CORROSION INHIBITORS

Compound	Rating (Anode Inhibition)	Remarks*
Barium Sulfide	8	Excellent inhibition. Mills well.
Cadmium Sulfide	5	
Calcium Sulfide	7	Very good inhibition. Mills well with vehicle.
Sodium Sulfide	8+	Excellent inhibition. May be too water soluble for effective formulations.
Zinc Sulfide	7	
Barium Potassium Chromate	5+	
Strontium Chromate	6+	
Zinc Chromate	6	
Basic Zinc Chromate	4	
Titanium Dioxide	1	Very poor inhibition. Specimen appearance worse than control.
Zinc Oxide	1	Not so severe as TiO_2 , but apparently no inhibition.
Sodium Aluminate	5	
Sodium Arsenite	6	
Sodium Fluoride	7+	Water solubility may be detrimental.
Sodium Pyro-phosphate	7	
"Chromic Phosphate"	6	New proprietary pigment reported as containing trivalent cation. Inhibition fair. Mills well.
Hydroquinone	7+	
8-Hydroxyquinoline	7+	Very good inhibition. Soluble in vehicle. Appears to retard drying.

*Inhibition remarks apply only to performance in the immersion cell.

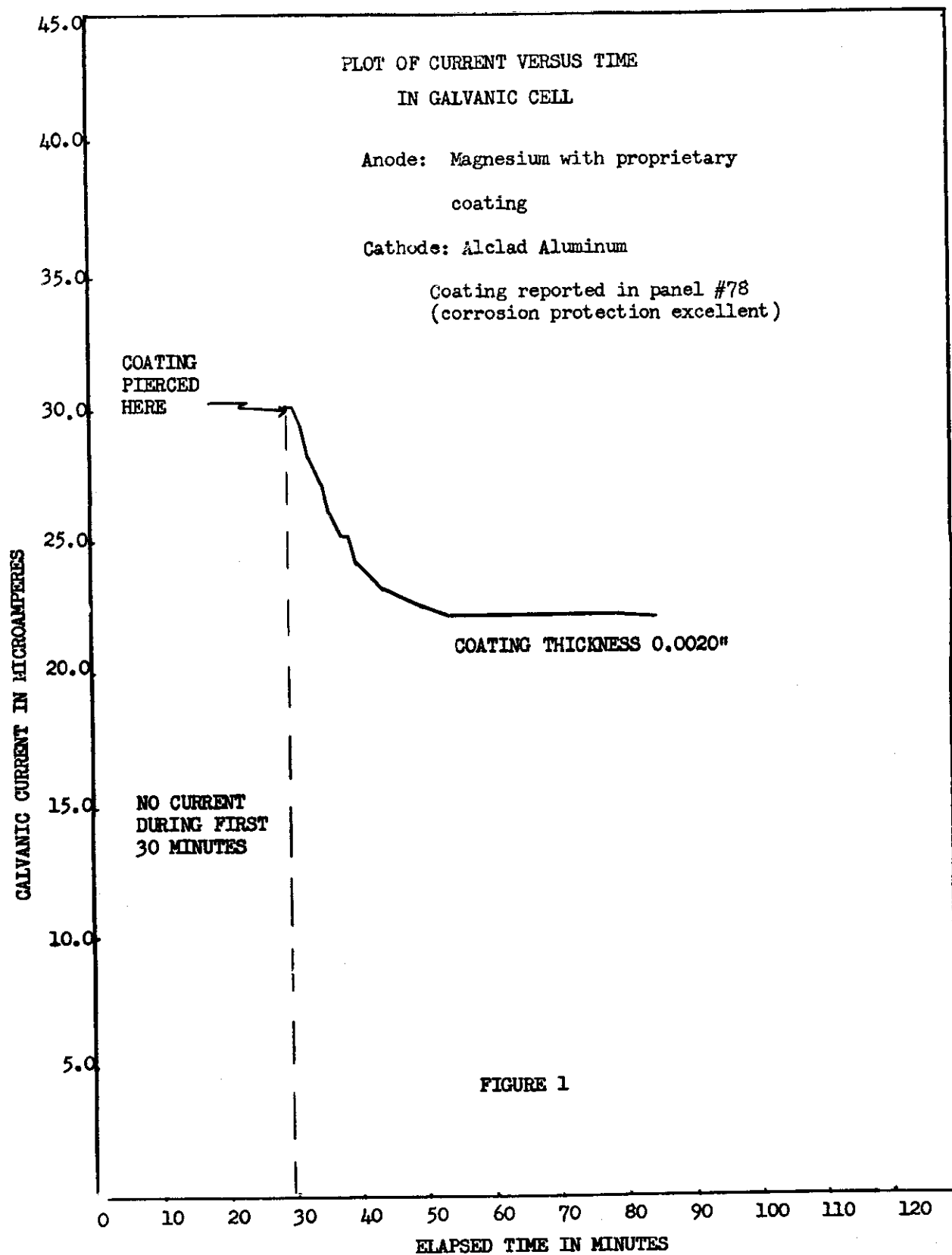
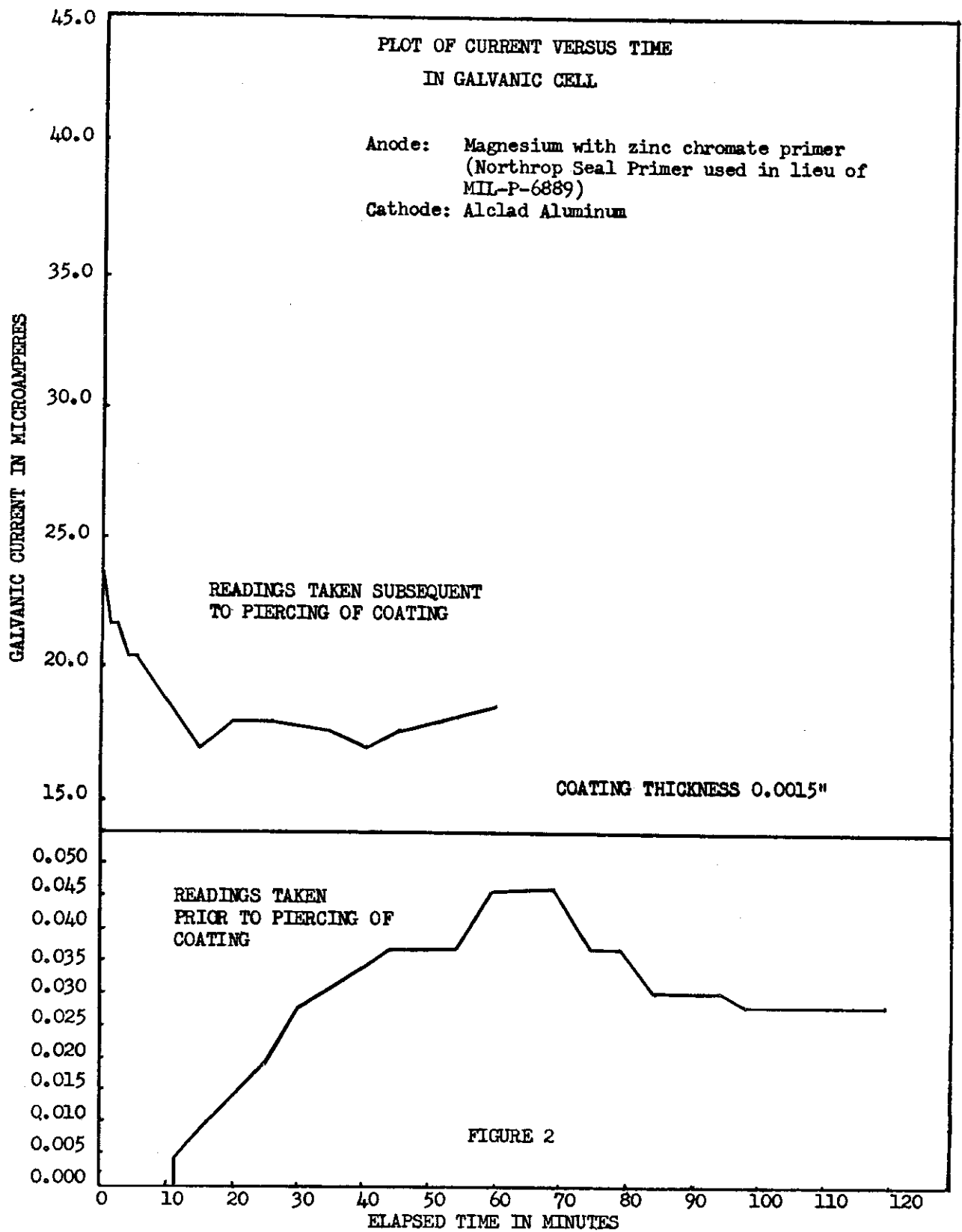
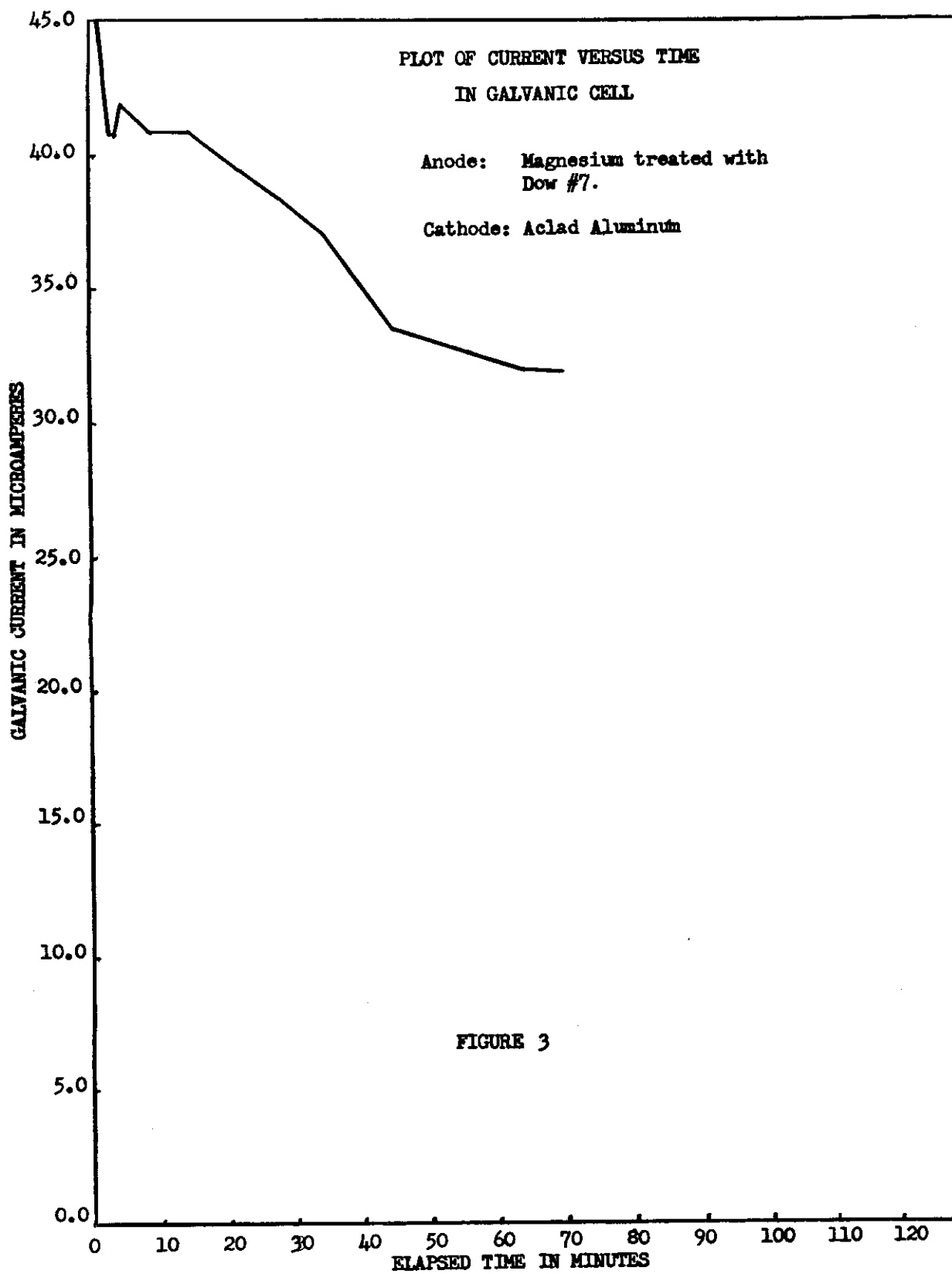


FIGURE 1





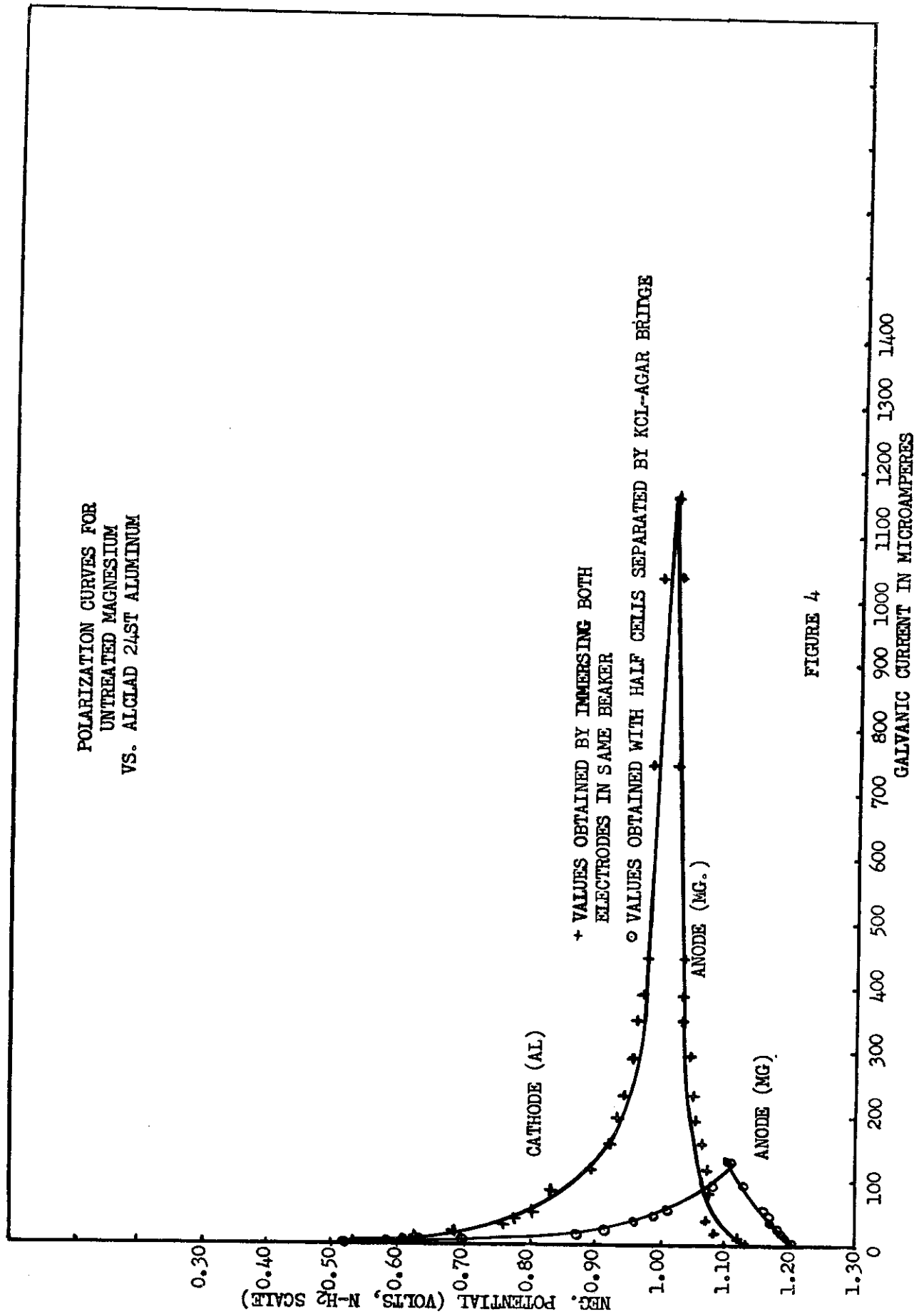


FIGURE 4

POLARIZATION CURVES FOR UNTREATED
MAGNESIUM VS. 24 ST ALCLAD ALUMINUM

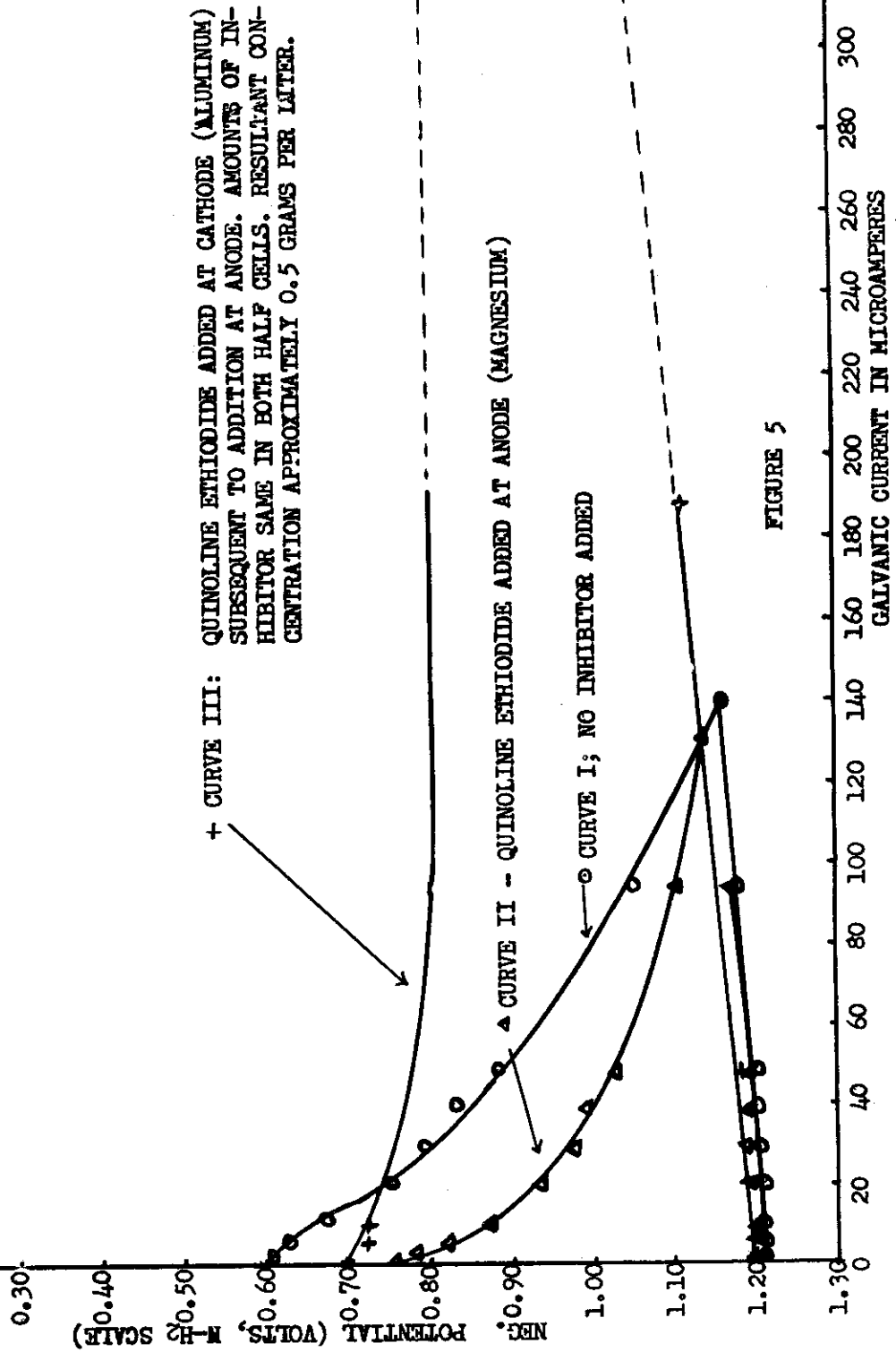
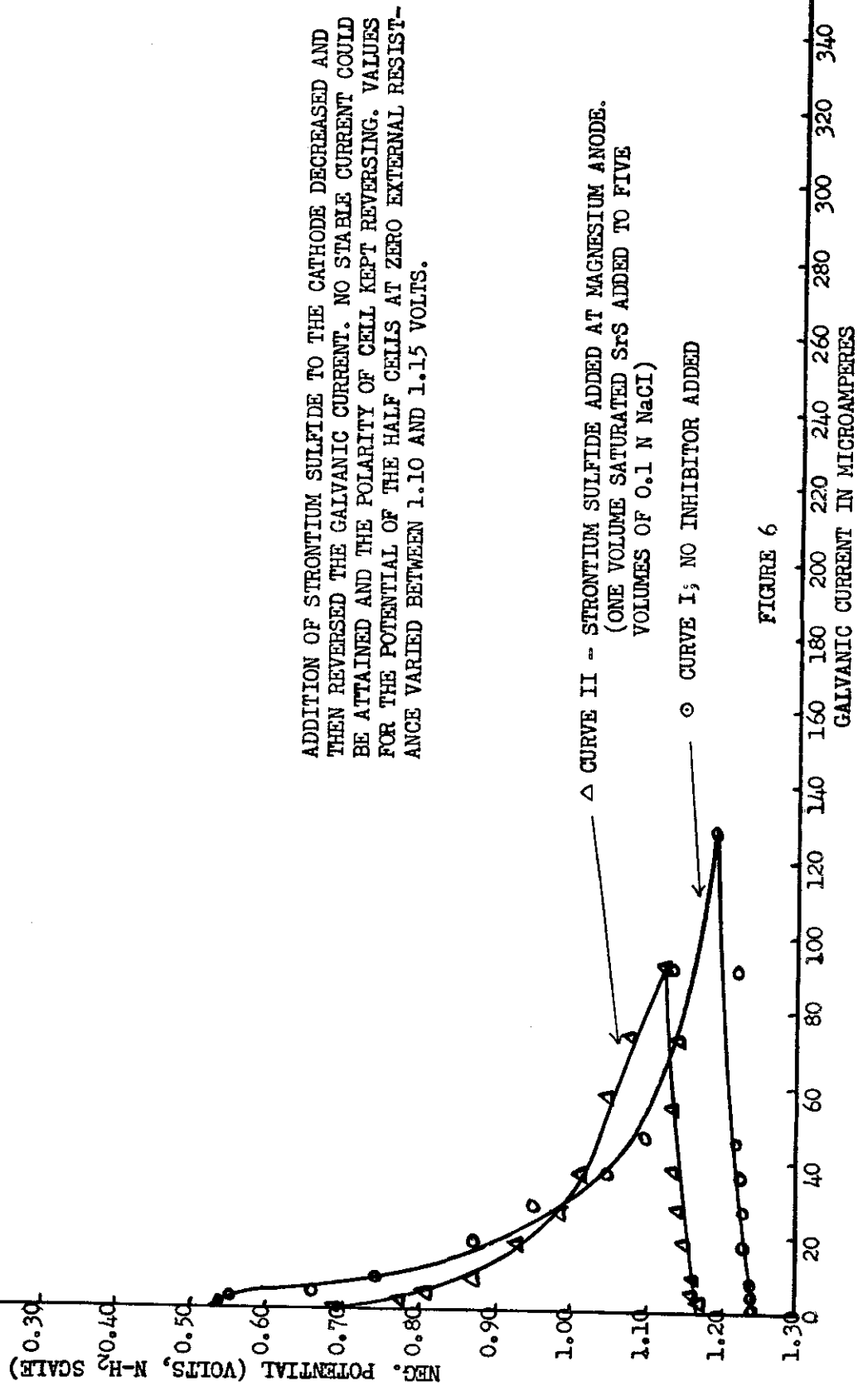


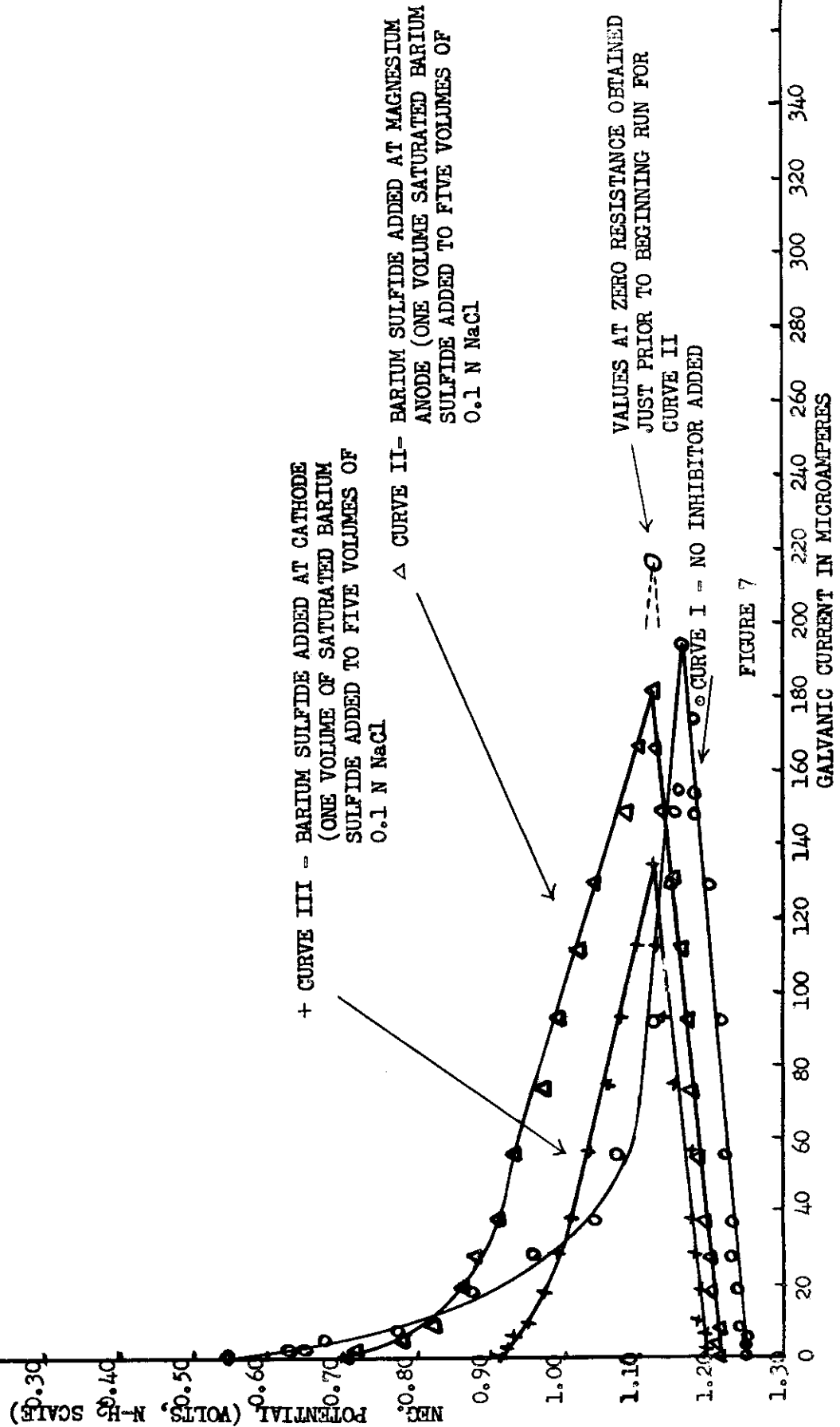
FIGURE 5

POLARIZATION CURVES FOR UNTREATED
MAGNESIUM VS. 24 ST ALUMINUM



ADDITION OF STRONTIUM SULFIDE TO THE CATHODE DECREASED AND THEN REVERSED THE GALVANIC CURRENT. NO STABLE CURRENT COULD BE ATTAINED AND THE POLARITY OF CELL KEPT REVERSING. VALUES FOR THE POTENTIAL OF THE HALF CELLS AT ZERO EXTERNAL RESISTANCE VARIED BETWEEN 1.10 AND 1.15 VOLTS.

POLARIZATION CURVES FOR UNTREATED
MAGNESIUM VS. 24 ST ALCLAD ALUMINUM



POLARIZATION CURVES FOR UNTREATED
MAGNESIUM VS. 24 ST ALCLAD ALUMINUM

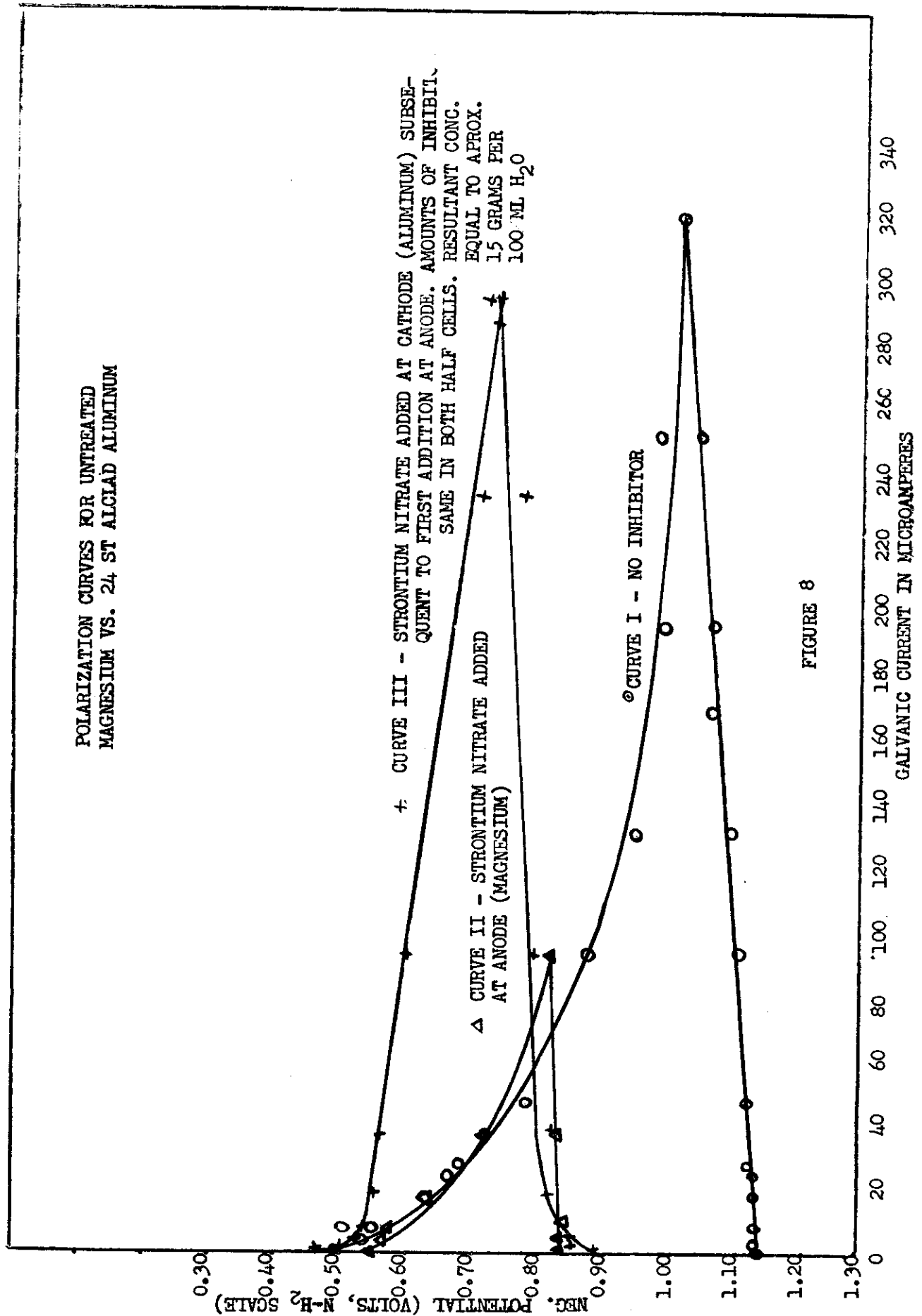


FIGURE 8

4. DISCUSSION:

- 4.1 The criteria listed in Test Results for the evaluation of the more satisfactory finishes are believed to be those of primary interest in the determination of a satisfactory finish. The numerical rating system was established to allow fine gradients from "good" to "bad" and was based upon average expected results, or upon performance of the Specification system, depending on the particular test. Since the ratings are all relative, simple addition of the ratings for the various exposure conditons of interest will allow selection of the most satisfactory finish.
- 4.2 An analysis of the results of the screening tests leads to several interesting generalizations. One is that the corrosion protection offered by baked films is not significantly better than that of the air-dry films. Since the adhesion of baked films was normally better than that of the air-dry, the inference is that adhesion (and related properties) is not in itself a significant factor for magnesium protection. This thought is substantiated by the lack of correlation of adhesion with corrosion protection of the air-dry films. However, for a particular type of finish, e.g. a chromate pigmented vinyl, adhesion is a factor of corrosion resistance.
- 4.3 Another interesting generalization is that superior protection has not been achieved with any of the clear finishes tested, although ion conduction tests by the electrochemical method showed no measurable permeation. This fact allows the presumption that, for a non-perfect film, which is the condition of virtually all production painted assemblies, an inhibiting pigment is essential for superior performance.
- 4.4 It is noted that the large majority of the more satisfactory primers and finish systems tested are of the so-called vinyl type, meaning that the paint resin is primarily polyvinyl chloride or a copolymer of vinyl chloride-vinyl acetate. Since most of the finishes tested are proprietary, precise formulations have not been disclosed. However, it is known that virtually all of the "vinyls" are modified by oils and by other resins such as melamine, phenolic, and alkyd. The "vinyls" were selected by most commercial finish suppliers as the most probable magnesium finish presumably because of the inherent low permeability, and modifications were for the purpose of enhancing film properties such as adhesion, flexibility, etc.
- 4.5 At the beginning of the project, the theory was advanced that the more satisfactory magnesium finishes would be those having the lower acid numbers, i.e. showing less tendency to react with alkaline solutions. The reasoning was that in the normal imperfect film, water would permeate to the magnesium surface and cause some hydrolysis with consequent release of hydroxyl ions. If the finish were high in acid number, the alkaline solution so formed would react with the film and cause loss of adhesion and protective properties, resulting eventually in severe corrosion. In line with this presumption, the majority of finishes supplied

for this test project were low in acid number (5 or below). However, low acid number cannot be specified as an independent variable or an essential property. Obviously, if the finish is sufficiently impermeable and water resistant, and no breaks exist in the film, virtually no corrosion will occur and alkaline resistance (and low acid number) is not necessary. In the case of most imperfect organic films, some corrosion will occur initially, and alkaline resistance is essential, and consequently low acid numbers are probably also essential. This is particularly true if the acid number is measure of the free carboxyl groups in the resin or modifying oils. This theory has been neither proved nor disproved by the test results of this project; however, the contention that alkaline reactivity is detrimental to magnesium finish is reasonable and substantiates this contractor's observation that paints and primers developed for neutral or acid hydrolyzing metals are unsuitable for magnesium.

- 4.6 The study of pre-paint treatments was not a specified part of this project. However, some test panels were given treatment other than the specified dichromate (Dow #7) or left bare for the purpose of furthering the understanding of primer compatibility. Some interesting phenomena have been observed. For example, a drop of distilled water placed on a fresh, mechanically cleaned magnesium surface will quickly (within minutes) reach an equilibrium pH of approximately 9.5-10. If the surface is given a Dow #7 treatment, the hydrolysis pH will be approximately 8.0 - 8.5. For several different phosphate and sulfur-bearing chemical surface conversion treatments, the degree of paint adhesion appeared to be a function of this hydrolysis pH. The time required for finish evaluations did not permit further verification of this phenomenon or refinement of laboratory techniques.
- 4.7 Almost without exception, Dow #7 pre-paint treatment gave superior results for the finishes tested, over the use of untreated surfaces or other experimental treatments. Note that several panels treated with the new Frankford Arsenal HAE coating were tested. This treatment produced excellent primer adhesion, superior to any other treatment attempted. As a function of adhesion, the corrosion protection of a good finish was improved, although it appeared that the protection was still primarily dependent upon the primer properties, i.e. the HAE treatment did not offer significant corrosion protection in itself. This is a reasonable observation since it is known that the dichromate surface allows the release of soluble inhibiting ions, and some measure of the galvanic protection is due to these ions. It is improbable that such release occurs with the HAE coating.
- 4.8 It is entirely possible that the HAE coating would be quite beneficial in applications where mechanical protection of the magnesium surface is essential. As previously stated, this test project was directed on the assumption that galvanic corrosion reduction was the primary goal, and corrosion tests were such that inhibition was essential to superior performance.
- 4.9 It was noted that the HAE magnesium coating was brittle and would flake readily when the panel was bent. However, the same is true of the Dow #7 dichromate surface when subjected to flexibility tests without a paint

finish (bending of a .040 or .051 panel over a 0.50 diameter mandrel at room temperature). Some experimentation with a coating involving the formation of a magnesium organic complex on the panel surface shows that it is possible to produce a coating that will withstand this bend test. Further investigation into the effect of pre-paint coating brittleness should be beneficial.

- 4.10 With the exception of one acrylic-type finish and the specification control system (alkyd primer, enamel top-coat), all finishes subjected to evaluation testing consisted of air-dry vinyl primers. In most cases, top-coats were also of the vinyl or modified vinyl type. Since baked finishes did not show any significant improvement in protection over the air-dry types and are not desirable for air-frame use from a production viewpoint, it was not felt that evaluation of baked finishes in the final phase of this project would be beneficial. However, future work on the evaluation of baked finishes might be desirable because the improved mechanical properties may be of value in special applications, particularly for equipment items. The selection of vinyl-type finishes was simply because of their superior performance in screening tests.
- 4.11 The outdoor weathering test employed for this project showed remarkable changes in results for exposure at different seasons. Exposure of the specification control system for the three months - December, January and February - did not produce significant corrosion, although representative vinyl systems showed some blistering. Considerably more severe results were obtained for two weeks exposure beginning in March than for the entire three months preceding. For both periods, the exposure was accelerated by daily spray application of natural sea water. This difference probably demonstrates the significance of exposure at different conditions of solar radiation and temperature, since the accelerated two-week period had average maximum temperatures of approximately 10°F. greater than during the preceding three months. It was also interesting to note that the relative standing of the various finishes were more closely aligned with salt spray ratings during the rapid corrosion than during the slow three month period.
- 4.12 The studies of galvanic cell action and the resulting plots submitted in the "Test Results" section of this report were primarily for the purpose of gaining further insight into the mechanisms of galvanic corrosion and polarization effects. The results obtained were not used directly in the formulation of the evaluated finishes, although more accurate evaluations were possible knowing the nature of the galvanic action. For the plots of cell current vs. half-cell potential, the shape of the curves are not of critical importance as far as determining effectiveness of a particular inhibitor. Of more significant interest is the increase or decrease of limiting short-circuit current with the addition of a polarizing or depolarizing material in the cell compartments.
- 4.13 The electrochemical techniques utilized in a preliminary manner in this project should be quite useful in further development work for magnesium coating formulations. As stated in the galvanic cell test method, some application of the galvanic cell test data was attempted

by Northrop laboratory personnel with promising results in that a permeable vehicle film, by addition of inhibitors, was made to protect magnesium almost as well as the much less permeable vinyl film with conventional zinc chromate pigment. While Northrop will continue some study on this mechanism of galvanic corrosion protection, it is hoped that the curves presented herein and the brief discussion given will generate further interest in the industry for this type of research.

5. ACKNOWLEDGEMENT

This project was aided by the splendid cooperation of many paint and resin firms in submitting sample finishes. Among the many contributors, the following technical personnel were especially helpful and their efforts and advice are gratefully acknowledged.

Mr. H. Acker	General Paint
Mr. N. Bassett	India Paint and Lacquer Co.
Mr. G. Canet	India Paint and Lacquer Co.
Mr. B. Martin	Ferro-Martin Co.
Mr. C. Shepherd	Ferro-Martin Co.
Mr. C. Spessard	Bakelite Div., Union Carbide and Carbide Corp.
Mr. F. Stewart	Custom Coatings Co.
Mr. C. West	United States Industrial Chemicals

6. BIBLIOGRAPHY

BOOKS

- (1) Blalock Grover C. Principles of Electrical Engineering, Second Edition, McGraw-Hill Book Co., Inc., New York and London, 1936.
- (2) Evans, Ulick R. Metallic Corrosion Passivity and Protection, Longmans, Green and Co., New York, 1948.
- (3) Glasstone S. Introduction to Electrochemistry, First Edition, Van Nostrand Company Inc., New York, 1942.
- (4) Harned, Herbert S. and Owen Benton D. The Physical Chemistry of Electrolytic Solutions, Second Edition, Reinhold Publishing Corp. New York, 1950.
- (5) Hodgman, Charles D. Handbook of Chemistry and Physics, 32nd Edition, Chemical Rubber Publishing Co., Cleveland, Ohio, 1950.
- (6) Latimer Wendell M. and Hildebrand Joel H., Reference Book of Inorganic Chemistry, Revised Edition, the Macmillan Company, 1941.
- (7) MacDougall Frank H., Physical Chemistry, Revised Edition, The Macmillan Company, New York, 1943.
- (8) Mattiello, Joseph J. Protective and Decorative Coatings, Volume I to V, Fourth Printing, John Wiley & Sons, Inc., New York; Chapman and Hall, London, 1947.

BOOKS (Cont'd)

- (9) Modern Plastics Encyclopedia Plastics Catalogue Corporation, New York, 1948.
- (10) Perry, John H. Chemical Engineers Handbook, Third Edition, McGraw-Hill Book Company, Inc., New York, Toronto, and London, 1950.
- (11) Shreve, Norris R. The Chemical Process Industries, First Edition, McGraw-Hill Book Company, Inc., New York and London, 1945.
- (12) Uhlig, Herbert H. The Corrosion Handbook, John Wiley & Sons, Inc., New York. Chapman & Hall, Ltd., London, 1948.

PERIODICALS

- (13) British intelligence Objectives Subcommittee, Manufacture of Anti-Fouling Paints in Germany and Related Matters.
- (14) Holler H.D. Studies of Galvanic Couples, Journal of the Electrochemical Society, Volume 97, No. 9, Part I and II, pp. 271-282; No. 12 Part III, pp. 453-461, Sept., Dec., 1950.
- (15) Mears R. B. and Brown R. H. Causes of Corrosion Currents, Ind. and Eng. Chem. Volume 33, August 1941, P 1001.
- (16) Regan J. E. and Silverstein M.S. Kinetics of Corrosion of Magnesium in Moist Air, Frankford Arsenal Report No. R 981, Nov., 1950.
- (17) Reinhart, Fred M. Corrosion Factors in Design, Product Engineering Volume 22, No. 7, July, 1951, pp. 101-107.
- (18) Segrave, J. E. H. Anticorrosive Coatings for Magnesium, Naval Research Laboratory. Report No. G-3393, Washington, December 7, 1948.
- (19) U. S. National Advisory Committee for Aeronautics, 1926 Annual Report, pp. 451, 453, 454.
- (20) Whiting, L. R. Some Recent Developments In Synthetic Resins for Protective Coatings, American Paint Journal, April 19, 1948.

Contrails

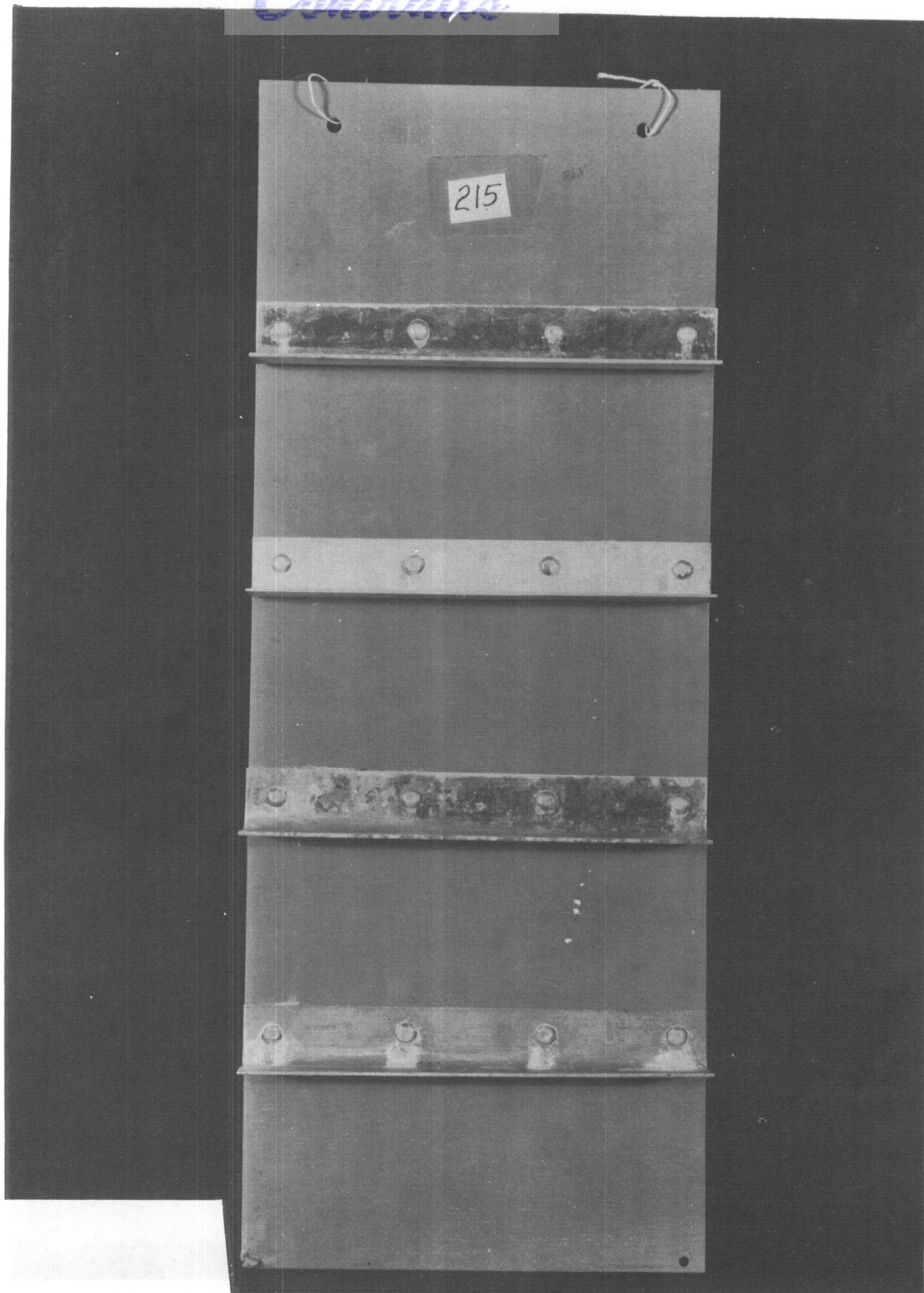


FIGURE 9 STANDARD DISSIMILAR METAL TEST PANEL

WADC TR 52-99

33

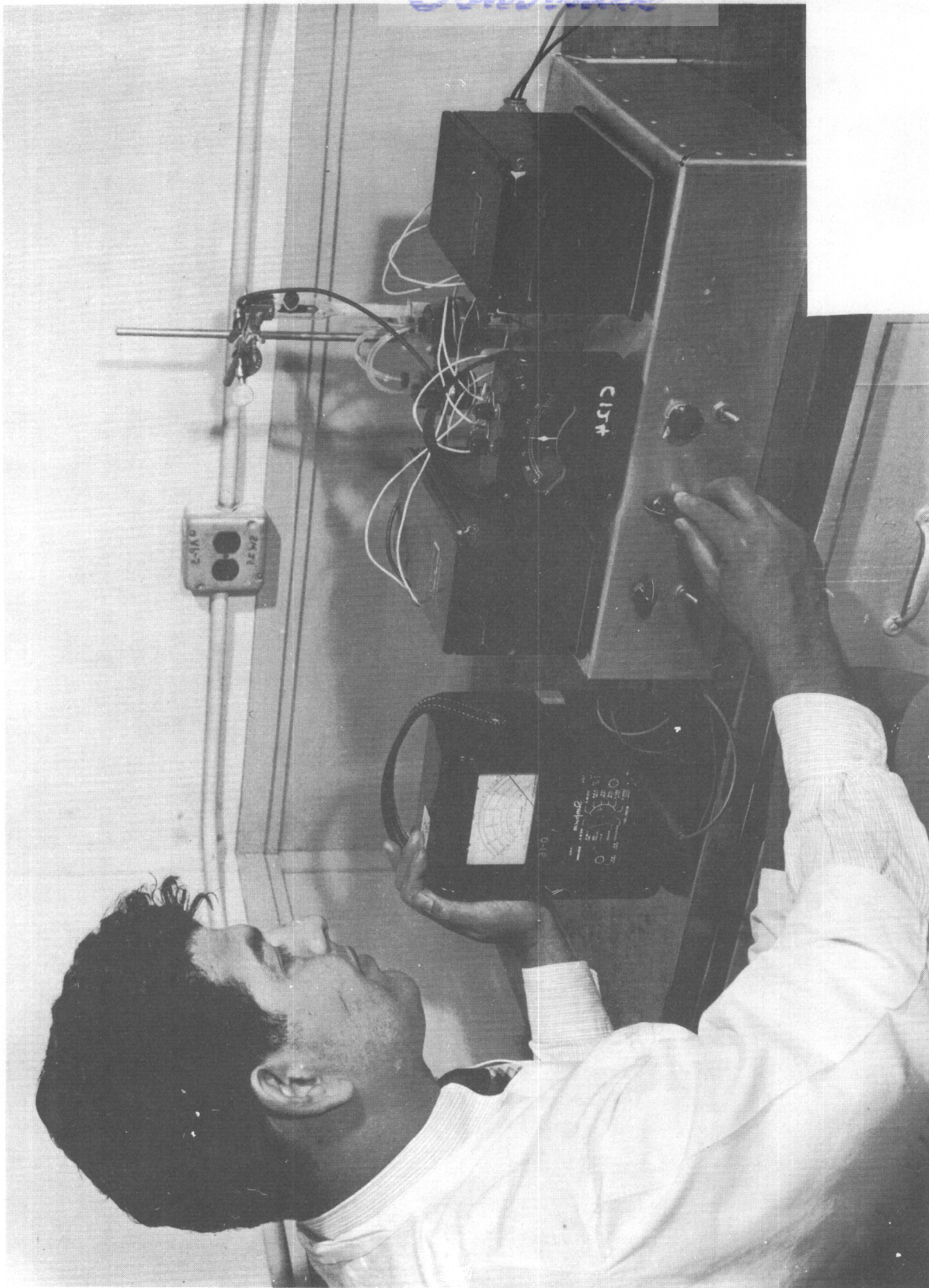


FIGURE 10 INHIBITION STUDY



FIGURE 11 HUMIDITY CABINET

WADC TR 52-99



FIGURE 12 SALT SPRAY CABINET

WADC TR 52-99

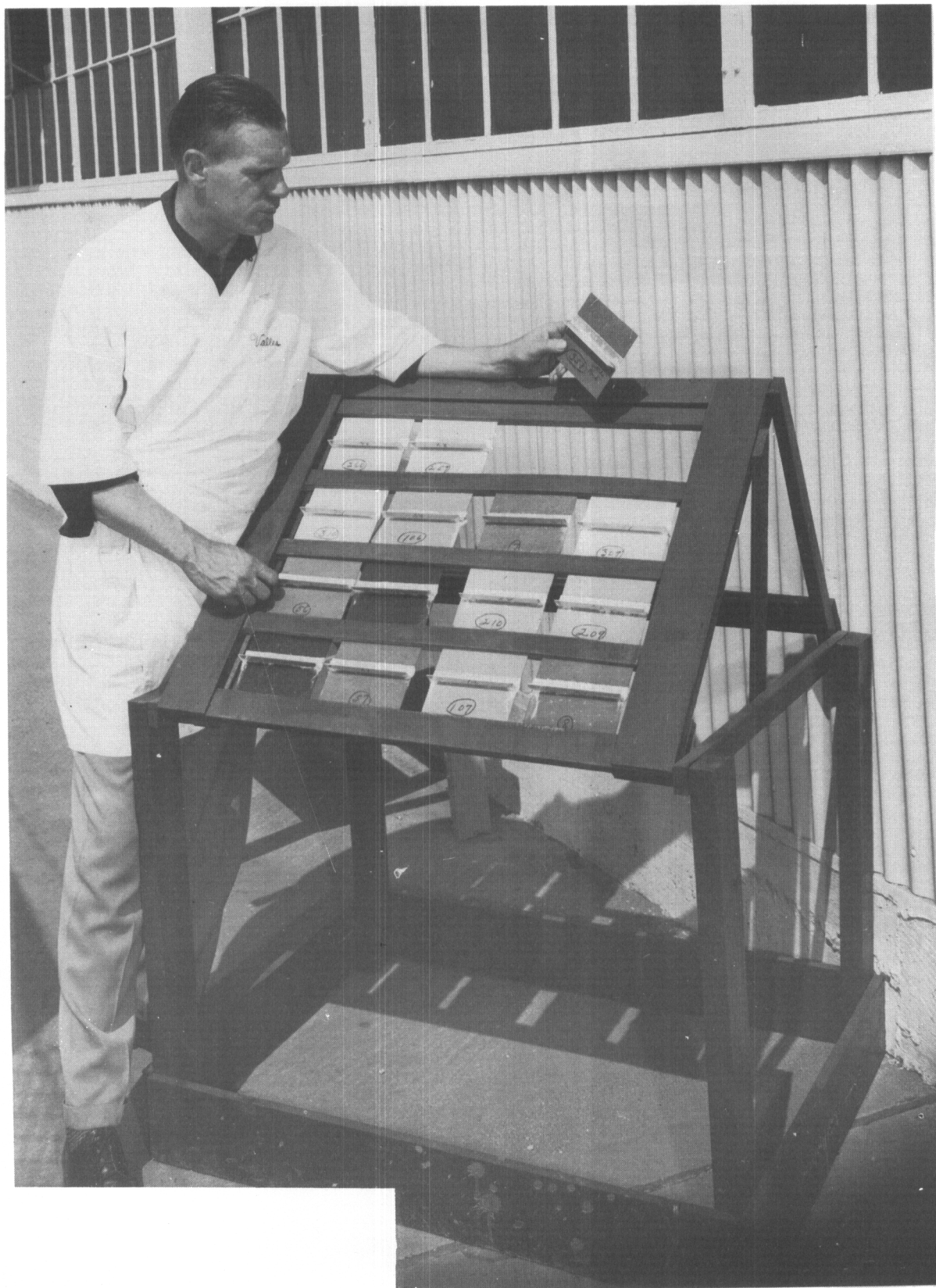


FIGURE 13 OUTDOOR EXPOSURE RACK

WADC TR 52-99

37