(12) LEVEL

DTNSRDC 79/042

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

ADA075353

INVESTIGATION OF ELECTROPLATED ELECTRICAL CONTACTS

by

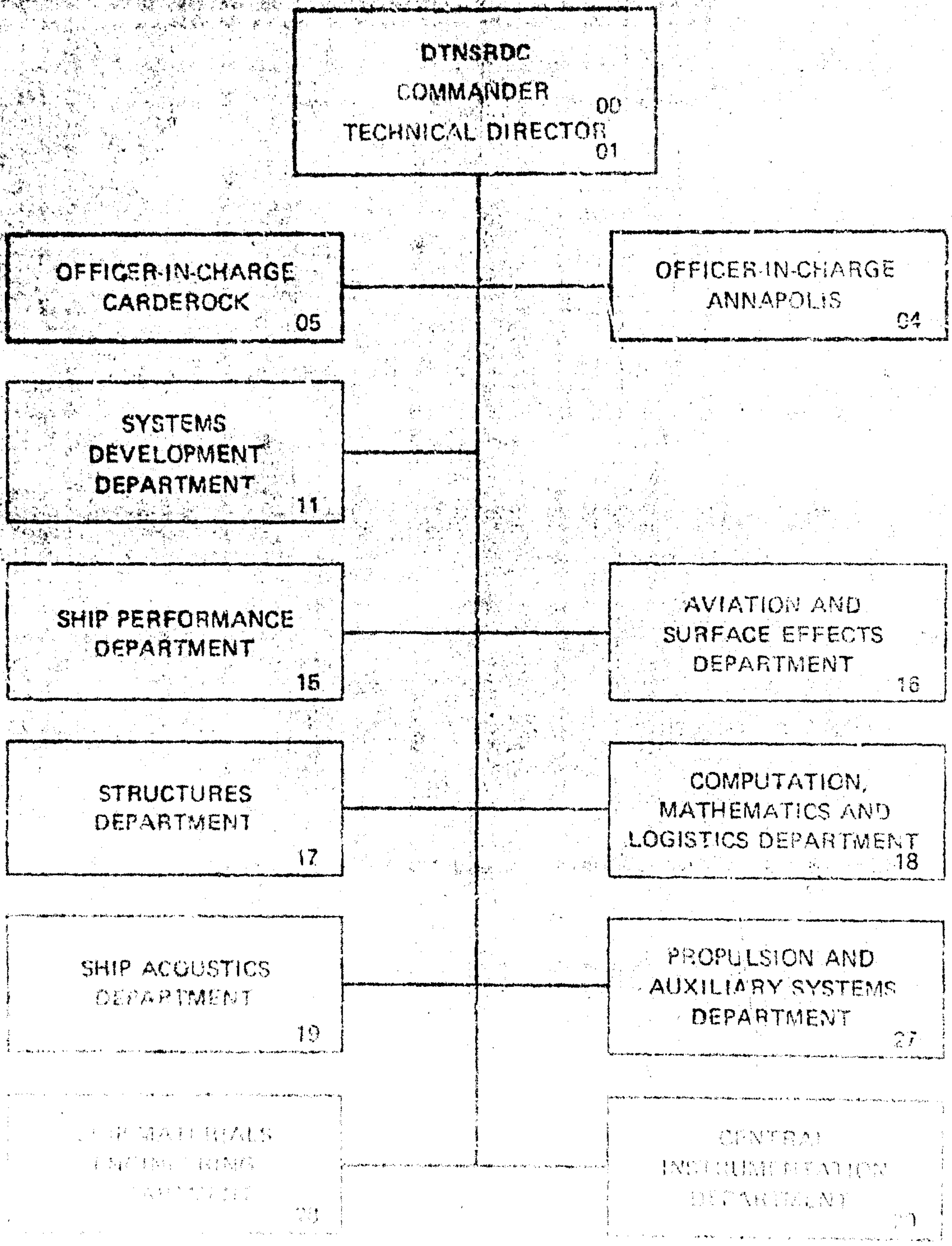
William H. Kohlmann

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

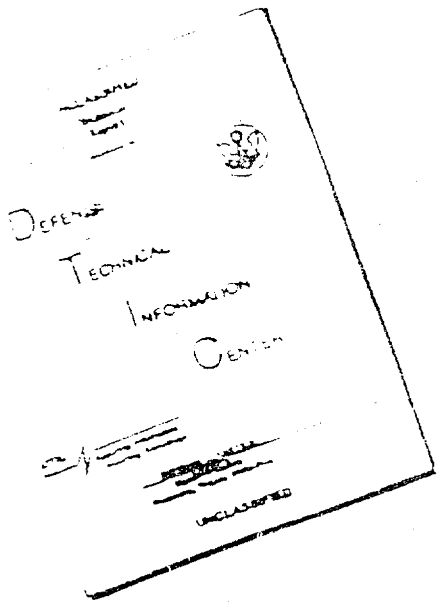
PROPULSION AND AUXILIARY SYSTEMS DEPARTMENT
RESEARCH AND DEVELOPMENT REPORT

...ED ELECTRICAL CONTACTS

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14 DTNSRDC-79/092 ✓	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 INVESTIGATION OF ELECTROPLATED ELECTRICAL CONTACTS		5. TYPE OF REPORT & PERIOD COVERED 9 Final Report, Oct [redacted] 65 - Oct [redacted] 78
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 William H./Kohlmann		8. CONTRACT OR GRANT NUMBER(s) 16 F61412 17
9. PERFORMING ORGANIZATION NAME AND ADDRESS David W. Taylor Naval Ship R&D Center Bethesda, MD 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Task Area ZF61-412-001 Program Element 62766N Work Unit 2773-106
11. CONTROLLING OFFICE NAME AND ADDRESS Director of Navy Laboratories (MAT 03L) Naval Material Command Washington, DC 20362	11	12. REPORT DATE Oct [redacted] 79
		13. NUMBER OF PAGES 53
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 55		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

DDC
RECEIVED
OCT 22 1979
B

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electrical Contacts	Contact Platings
Electrical Connectors	Marine Atmosphere
Component Failures	Salt Spray Atmosphere

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

The relative deterioration by marine atmospheres of noble metal platings for electric contacts has been determined in the interests of improving the reliability of electrical connections in the marine environment and of conserving precious metals. In cooperation with the Electronics Industry Association P-5.1 Committee on Electrical Contacts, this Center investigated

(Continued on reverse side)

(Block 20 continued)

the effects of marine and laboratory salt spray atmospheres on various contact platings in order to determine optimum platings; the emphasis was on platings with silver underplating. The work described includes establishment of experimental techniques, equipment development, a discussion of the marine exposure site at Ft. Tilden, New York, and the laboratory salt spray environment and procedures. The results with various platings show that the use of nickel as an underplating is very undesirable, but 30 millionths of an inch of gold over 100 millionths of an inch of silver is superior, and 30 millionths of an inch of gold over 100 millionths of an inch of copper is adequate in the marine environment. An examination of 4000 hours of laboratory salt spray exposure and 108,000 hours (11-1/2 years) of marine exposure indicates a corrosion acceleration factor ranging from 18 to 25 for gold-over-nickel plating systems.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

LIST OF ABBREVIATIONS

BTL	Bell Telephone Laboratory
EIA	Electronics Industries Association
IED	Independent Exploratory Development
MS	Military Standard
NASL	Naval Applied Science Laboratory

ABSTRACT

The relative deterioration by marine atmospheres of noble metal platings for electric contacts has been determined in the interests of improving the reliability of electrical connections in the marine environment and of conserving precious metals. In cooperation with the Electronics Industry Association P-5.1 Committee on Electrical Contacts, this Center investigated the effects of marine and laboratory salt spray atmospheres on various contact platings in order to determine optimum platings; the emphasis was on platings with silver underplating. The work described includes establishment of experimental techniques, equipment development, a discussion of the marine exposure site at Ft. Tilden, New York, and the laboratory salt spray environment and procedures. The results with various platings show that the use of nickel as an underplating is very undesirable, but 30 millionths of an inch of gold over 100 millionths of an inch of silver is superior, and 30 millionths of an inch of gold over 100 millionths of an inch of copper is adequate in the marine environment. An examination of 4000 hours of laboratory salt spray exposure and 108,000 hours (11-1/2 years) of marine exposure indicates a corrosion acceleration factor ranging from 18 to 25 for gold-over-nickel plating systems.

ADMINISTRATIVE INFORMATION

This work began as part of the in-house Independent Exploratory Development (IED) program conducted at the Naval Applied Science Laboratory (NASL) under IED-20. It was continued at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) under the IED* program and was performed under Work Unit 2773-106.

INTRODUCTION

Reliability studies had shown that the largest portion of failures in electrical and electronic circuits was due to electrical connectors. Physical size limitations in low-power circuits, which is the area of concern here, generally restrict the improvement of connectors to advances in

*Definitions of abbreviations used are given on page vi.

contact configurations, surfaces, and materials. Current improvements concentrate on the use of noble metals to electroplate electrical contacts, but the use of such metals is based on incomplete information on electrical performance and durability. Suitable materials having minimum thickness for reliable wear and low contact resistance, particularly at low-voltage levels, and capable of operation under both industrial and, especially, marine environments have not been firmly established.

Although commercial requirements may be met without the use of silver underplating, silver is tentatively considered necessary for inhibiting corrosion in marine atmospheres. Evidence is needed to demonstrate that the use of silver is indeed necessary for naval application.

For the above reasons, the Electronic Industries Association (EIA) P-5.1 Committee on Electrical Contacts, in which NASL participated, formulated a program for determining optimum contact platings. Both NASL and this Center conducted investigations on contact platings for naval application in a marine atmosphere.

APPROACH

ENVIRONMENTS

The Navy's interest in the electroplating of electrical contacts is unique in that the Navy operates in a corrosive marine environment. NASL, in cooperation with the Electronics Industry Association P-5.1 Committee on Electrical Contacts, formulated a program to determine optimum plating material for electrical contacts used in such an environment. This required the development of experimental techniques, equipment, and procedures that would be employed by all participating laboratories regardless of the environment with which each was concerned.

The EIA Committee established the following guidelines and objectives for its program:

1. confine attention to electroplatings of electrical contacts and not to geometry or contact life,

2. develop methodology to determine the efficacy of various types of platings, and

3. investigate exposure sites and their relationship to the application environments, namely,

a. industrial/urban,

b. sulphurous,

c. elevated temperature, and

d. marine.

In addition, NASL agreed to conduct an investigation of the effect of laboratory salt spray on the plating of electrical contacts. It was important to the study to select one type of basic metal for the contact, preferably from one manufacturer, and one geometry of contact. This would eliminate as many variables as possible from the experiment and facilitate correlation between cooperating laboratories. It was recognized that future investigations should be made into the effects of wear and the possible advantages of lubrication, but not until one or several good finishes for each environment had been established.

The studies of the effect of the marine corrosive environment and laboratory salt spray were initiated at NASL, using the techniques developed by Glowasky,* and continued at DTNSRDC. The environmental study into the effects of an industrial/urban atmosphere was assigned to Bell Telephone Laboratories, while the sulphurous atmosphere study was assigned to Burndy Research Division.

CONTACT SIZE AND PLATING

To keep the size of the program manageable - i.e., provide the maximum amount of statistically useful information with the minimum number of specimens - it was agreed to study the following five combinations of platings (nine thicknesses) on sizes 16 and 20 MIL-C-26636-type pin-and-socket contacts:

---

*Glowasky, A., "Investigation of Platings of Electrical Contacts," U.S. Naval Applied Science Laboratory Report IED 20 (8 Apr 1968).

Gold over Silver

1. Gold [$30X10^{-6}$ in. ($7.6X10^{-4}$ mm)]/Silver [$100X10^{-6}$ in. ($25.4X10^{-4}$ mm)]

2. Gold [$100X10^{-6}$ in. ($25.4X10^{-4}$ mm)]/Silver [$100X10^{-6}$ in. ($25.4X10^{-4}$ mm)]

3. Gold [$50X10^{-6}$ in. ($12.7X10^{-4}$ mm)]/Silver [$200X10^{-6}$ in. ($50.8X10^{-4}$ mm)]

Gold over Nickel

4. Gold [$30X10^{-6}$ in. ($7.6X10^{-4}$ mm)]/Nickel [$100X10^{-6}$ in. ($25.4X10^{-4}$ mm)]

5. Gold [$100X10^{-6}$ in. ($25.4X10^{-4}$ mm)]/Nickel [$100X10^{-6}$ in. ($25.4X10^{-4}$ mm)]

Gold over Copper

6. Gold [$30X10^{-6}$ in. ($7.6X10^{-4}$ mm)]/Copper [$100X10^{-6}$ in. ($25.4X10^{-4}$ mm)]

7. Gold [$100X10^{-6}$ in. ($25.4X10^{-4}$ mm)]/Copper [$100X10^{-6}$ in. ($25.4X10^{-4}$ mm)]

Rhodium over Bright Nickel

8. Rhodium [$20\text{-}30X10^{-6}$ in. ($5.1\text{-}7.6X10^{-4}$ mm)]/Bright Nickel [$100X10^{-6}$ in. ($25.4X10^{-4}$ mm)]

Rhodium over Silver

9. Rhodium [20-30X10^{-6} in. (5.1-7.6X10^{-4} mm)]/Silver [100X10^{-6} in. (25.4X10^{-4} mm)]

The Amphenol Corporation furnished a sufficient number of size No. 16 and No. 20 unplated pin-and-socket contacts manufactured from their leaded copper full-hard alloy 126. Nu-Line Industries plated all the contacts in accordance with the Bell Telephone Laboratories' (BTL) Specification WL-2250.101, Issue 8, for electroplated finishes.

CONTACT HANDLING

Upon receipt of all the electroplated contacts at NASL, no effort was made to clean them since they were to be handled in the same manner as would be electroplated contacts received from any contact manufacturer. Precautionary measures were taken, however, to avoid further contamination of the specimens. The electroplated contacts and related components were crimped and wired in a clean, controlled atmosphere by technicians using disposable vinyl examination gloves.

PROCEDURE

SAMPLE SELECTION

Approximately fourteen specimens were withdrawn from each size and type of electroplated contact for plating thickness measurements. The contacts were first measured with the Betascope using the Beta Ray method and then were sectioned for verification measurement with a toolmaker's microscope.

CRIMPING AND WIRING

Twenty plated contacts were allotted for each size and type of contact for each environment. Each pin-and-socket contact was crimped to two separate conductors (one was a current lead; the other, a voltage lead). A Buchanan MS3191-1 crimping tool with a MS3191-20A positioner was used for the two size No. 24 wires and a MS3191-16A positioner was used for the two size No. 22 wires to perform all the crimping of respective 2-wire conductors to each plated contact. The best combination of conductors was experimentally determined to be two No. 22 stranded wires for the size 16 contact and the two No. 24 stranded wires for the size No. 20 contact. Navy Type E, MIL-W-16878/4A, 7-strand, white Teflon insulated wire was used throughout. The opposite ends of the two wires emanating from each pin-and-socket contact were soldered into a 50-contact Amphenol connector (Part No. 57-20500). Ten such pin-and-socket contacts wired with 40 conductors were soldered to each Amphenol 50-contact connector.

CONTACT MATING

Ten of these contacts were mated only once prior to installation in the field environment; the remaining ten contacts were mated 100 times at a rate not exceeding one engagement every 5 min. This relatively long interval between engagements avoids possible overheating and relieves stresses of the contact surfaces. The mating of the contacts was accomplished by a specially designed reciprocating mechanism, as shown in Figure 1, which was automated to permit ten pin-and-socket contacts to be mated once every 5 min, with a mating cycle (insertion and withdrawal) lasting 10 sec.

CONTACT-RESISTANCE MEASURING CIRCUIT

Ten wired mated contacts were connected into a 10-position transfer switch, through which their resistances were measured with a Keithley Model 502A Milliohmeter. During cycling, resistance measurements were made on the contacts after every 25th cycle of engagement by utilizing a 4-wire contact-resistance measuring circuit.

Each group of ten wired pin-and-socket contacts was then mounted in a plastic fixture. These fixtures measured 2-3/4 in. (6.99 cm) wide, 2-1/2 in. (6.35 cm) high, and 4 in. (10.2 cm) long and were constructed of 1/4-in. (0.63-cm)-thick epoxy glass, assembled with stainless steel nonmagnetic screws. Thirty-six such fixture assemblies - 18 fixtures of size No. 20 contacts and 18 fixtures of size No. 16 contacts - were prepared for the nine different types of electroplated contacts. All 36 wired fixtures were mounted on a stainless steel stand measuring 15 in. (38.1 cm) wide, 19 in. (48.3 cm) long, and 12-5/8 in. (32.1 cm) high. The complete wired assembly, shown in Figure 2, was shock mounted on four layers of 1/4-in. (0.63-cm)-thick isomode pads. This was done to avoid mechanical disturbance of any films that would form in the contact area. The assembly was housed in a louvered aluminum shelter, 30 in. (76.2 cm) X 30 in. (76.2 cm) X 19 in. (48.3 cm), similar to a Stevenson Screen, mounted on a stainless steel terminal rack, as shown in Figure 3, in front of the exposure housing, and protected by an aluminum cover sealed to the base by a neoprene gasket. In addition, numbered electrolytic copper panels 1/2 in. (0.51 cm) X 1 in. (2.54 cm) X 1/32 in. (0.07 cm) thick, prepared by Bell Telephone Laboratories, were mounted alongside the stainless steel stand with glass thread as shown in Figure 3. These copper panels were removed at monthly intervals and returned to Bell Telephone Laboratories where the amount and types of tarnish films were analyzed. By exposing a set of these panels at the start of this study and measuring the tarnish rate, it is possible to compare the corrosiveness of the environment of this study with that of any other study, no matter when the study is started. This technique also permits the study of climatic variations from year to year.

Upon completion of the assembly, the entire shelter was transported to the marine field exposure site at Ft. Tilden, NY, and shock mounted on five layers of 1/4-in. (0.63-cm)-thick isomode pads, 2 ft above the ground, on a special supporting structure facing the ocean, without obstruction, approximately 300 ft (91.44 m) from the shoreline and 40 ft (12.2 m) above the mean low water (Figure 4).

Periodic resistance measurements were recorded on all 360 plated specimen contacts mounted within the modified Stevenson Screen enclosure at the marine site during the 11-1/2-yr exposure period.

After 17 months of exposure (January 1966 to June 1967) there was ample evidence of salt spray corrosion to components of the external supporting structure. However, no salt spray corrosion was noted within the

Stevenson Screen enclosure. It therefore appeared evident that the salt-laden atmosphere must have consisted of salt and moisture in such a particulate form and size as to have been prevented by the glass wool filter from entering the enclosure holding the specimens. These filters were replaced, therefore, with type 316 stainless steel wire screening (0.009-in. (0.23-mm)-diam wire, 18 x 18 mesh) which permitted a freer entry of the salt-laden marine atmosphere while preventing insects and other debris from entering the contact specimen area (Figure 5).

LABORATORY SALT SPRAY

A similar stainless steel stand was assembled with only 18 fixtures of ten wired contacts, each of size No. 20 contacts. For this type of plating, ten of these contacts were mated only once; the remaining ten contacts were mated 100 times. These contacts were wired identically to those installed at the exposure site at Ft. Tilden, NY.

The completed assembly was shock mounted on four layers of 1/4-in. (0.63-mm)-thick isomode pads placed on top a 1/4-in. (0.63-mm) stainless steel base and installed in a modified laboratory salt spray environment as shown in Figure 6.

This assembly of 180 plated contacts was then subjected to a salt spray fog (corrosion) utilizing a 5% salt solution, as outlined in method 101C of MIL-STD-202C. In order to utilize maximum corrosion time, the contacts were subjected to the salt spray fog corrosion for 64 hr, rinsed and washed in tap water for several hours, then dried for 24 hr, after which time contact resistance measurements were recorded. The electrical contacts were again submitted to the salt spray for corrosion for another 48 hr, rinsed and washed in tap water, dried, and then contact resistance measurements were recorded. This was accomplished over a 7-day period. The procedure was repeated continuously until the electrical contacts were subjected to a total of 4000 salt-spray-fog hours, with electrical contact resistances being recorded at the end of each salt spray corrosion period.

RESULTS

PLATING MEASUREMENTS

The unplated contacts furnished by Amphenol Corporation were plated by Nu-Line Industries. Results of these platings, shown in Table 1, indicate a wide variation in plating thickness for each plating requirement. These variations were recognized and tolerated because they were representative of plating state of the art. Uniformity of plating is difficult to control because of variations in plating solutions, temperatures, current density, cleanliness, and quantity of contacts involved.

WEAR PRECONDITIONING

The resistance measurements of the plated contacts which were preconditioned for 100 cycles showed only slight variation in contact resistance during the insertion and withdrawal matings. With only one exception, there was no significant difference in the average contact resistance of the contacts that were mated 100 times as opposed to those that were mated only once. The exception was that those contacts that were plated with rhodium over nickel and were mated 100 times showed an average contact resistance approximately 30% higher than the contacts that were mated only once.

MONITORING PANELS

The data on tarnish film thickness for the copper panels exposed at the Ft. Tilden exposure site is given in Table 2. The data should only be considered significant to the nearest 100Å. Film composition and thickness for these control panels were determined by the cathodic reduction method. It is known that corrosion films do not form at a uniform rate over the entire surface of the panel. However, in order to report an apparent thickness, one must assume uniformity of tarnish films. Thickness anomalies such as shown by panels 2 and 3 can occur and should not be of concern. There was no indication of sulphide tarnish films; this indicates a marine environment free of sulphide contamination.

TABLE 1 - THICKNESS MEASUREMENTS OF ELECTROPLATED ELECTRICAL CONTACTS

Lot	Plating	Thickness Measured by $[10^{-6}$ in. $(10^{-4}$ mm)]									
		Beta Scope*				Microsection					
						Gold			Silver		
P16S1G3	Gold $30X10^{-6}$ in. $(7.6X10^{-4}$ mm)** over Silver $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	Silver only	150 (38.1) 148 (37.6)	133 (33.8) 162 (41.1)	148 (37.6) -	39 (9.9) 43 (10.9)	33 (8.4) 29 (7.4)	32 (8.1) 37 (9.4)	145 (36.8) 158 (40.1)	156 (39.6) 153 (38.9)	162 (41.1) 155 (39.4)
S16S1G3	Gold $30X10^{-6}$ in. $(7.6X10^{-4}$ mm)** over Silver $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	Silver only	165 (41.9) 132 (33.5)	138 (35.1) 148 (37.6)	142 (36.1) -	25 (6.4) 32 (8.1)	26 (6.6) 28 (7.1)	29 (7.4) 26 (6.6)	119 (30.2) 142 (39.4)	149 (37.8) 133 (33.8)	137 (34.8) 137 (34.8)
P16S1G1	Gold $100X10^{-6}$ in. $(25.4X10^{-4}$ mm) over Silver $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	Microsection only				150 (38.1) 152 (38.6)	157 (39.9) 137 (34.8)	149 (37.8) 147 (37.3)	142 (36.1) 123 (31.2)	132 (33.5) 132 (33.5)	150 (38.1) 163 (41.4)
S16S1G1	Gold $100X10^{-6}$ in. $(25.4X10^{-4}$ mm) over Silver $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	Microsection only				116 (29.5) 106 (26.9)	108 (27.4) 111 (28.2)	120 (30.5) 117 (29.7)	118 (30.0) 138 (35.1)	131 (33.3) 151 (38.4)	113 (28.7) 109 (27.7)
P16S2G5	Gold $50X10^{-6}$ in. $(12.7X10^{-4}$ mm)** over Silver $200X10^{-6}$ in. $(50.8X10^{-4}$ mm)	Silver only	222 (56.4) 242 (61.5)	328 (83.3) 252 (64.0)	295 (74.9) -	62 (15.7) 64 (16.3)	71 (18.0) 56 (14.2)	68 (17.3) 69 (17.5)	397 (100.8) 394 (100.1)	374 (95.0) 479 (121.7)	465 (118.1) 453 (115.1)
S16S2G5	Gold $50X10^{-6}$ in. $(12.7X10^{-4}$ mm)** over Silver $200X10^{-6}$ in. $(50.8X10^{-4}$ mm)	Silver only	270 (68.6) 265 (67.3)	255 (64.8) 290 (73.7)	268 (68.1) -	45 (11.4) 50 (12.7)	53 (13.5) 43 (10.9)	56 (14.2) 54 (13.7)	352 (89.4) 373 (94.7)	466 (118.4) 339 (86.1)	460 (116.8) 363 (92.2)
						Gold			Nickel		
P16N1G3	Gold $30X10^{-6}$ in. $(12.7X10^{-4}$ mm) over Nickel $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	32 (8.1) 36 (9.1)	33 (8.4) 27 (6.9)	32 (8.1) 34 (8.6)	23 (5.8) 32 (8.1)	28 (7.1) 25 (6.4)	26 (6.6) 28 (7.1)	26 (6.6) 26 (6.6)	130 (33.0) 153 (38.9)	139 (35.3) 161 (40.9)	133 (33.8) 160 (40.6)
S16N1G3	Gold $30X10^{-6}$ in. $(7.6X10^{-4}$ mm) over Nickel $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	32 (8.1) 33 (8.4)	31 (7.9) 25 (6.4)	26 (6.6) 28 (7.1)	38 (9.7) 37 (9.4)	20 (5.1) 34 (8.6)	29 (7.4) 30 (7.6)	33 (8.4) 27 (6.9)	136 (34.5) 133 (33.8)	111 (28.2) 137 (34.8)	134 (34.0) 131 (33.3)
P16N1G1	Gold $100X10^{-6}$ in. $(25.4X10^{-4}$ mm) over Nickel $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	101 (25.7) 110 (27.9)	99 (25.1) 110 (27.9)	111 (28.2) 109 (27.7)	92 (23.4) 107 (27.2)	104 (26.4) 101 (25.7)	112 (28.4) 102 (25.9)	98 (24.9) 105 (26.7)	147 (37.3) 154 (38.4)	149 (37.8) 151 (38.4)	127 (32.3) 144 (36.6)

TABLE 1 (Continued)

S161N1G1	Gold 100X10^{-6} in. (25.4X10^{-4} mm) over Nickel 100X10^{-6} in. (25.4X10^{-4} mm)	102 (25.9) 116 (29.5)	118 (30.0) 118 (30.0)	127 (32.3) 97 (24.6)	105 (26.7) 103 (26.1)	101 (25.7) 111 (28.2)	123 (31.2) 126 (32.0)	119 (30.2) 109 (27.7)	118 (30.0) 130 (33.0)	152 (38.6) 139 (35.3)	145 (36.8) 147 (37.3)
						Gold			Copper		
P16C1G3	Gold 30X10^{-6} in. (7.6X10^{-4} mm) over Copper 100X10^{-6} in. (25.4X10^{-4} mm)	42 (10.7) 34 (8.6)	30 (7.6) 28 (7.1)	42 (10.7) 34 (8.6)	38 (9.7) 28 (7.1)	35 (8.9) 23 (5.8)	28 (7.1) 21 (5.3)	33 (8.4) 22 (5.6)	122 (31.0) 119 (30.2)	134 (34.0) 119 (30.2)	115 (29.2) 124 (31.5)
S16C1G3	Gold 30X10^{-6} in. (7.6X10^{-4} mm) over Copper 100X10^{-6} in. (25.4X10^{-4} mm)	32 (8.1) 38 (9.7)	33 (8.4) 33 (8.4)	26 (6.6) 38 (9.7)	32 (8.1) 34 (8.6)	30 (7.6) 31 (7.9)	20 (5.1) 29 (7.4)	37 (9.4) 23 (5.8)	115 (29.2) 120 (30.5)	126 (32.0) 110 (27.9)	108 (27.4) 109 (27.7)
P16C1G1	Gold 100X10^{-6} in. (25.4X10^{-4} mm) over Copper 100X10^{-6} in. (25.4X10^{-4} mm)	105 (26.7) 102 (25.9)	107 (27.2) 103 (26.1)	110 (27.9) 116 (29.5)	105 (26.7) 102 (25.9)	119 (30.2) 122 (31.0)	129 (32.8) 95 (24.1)	99 (25.1) 109 (27.7)	45 (11.4) 48 (12.2)	43 (10.9) 49 (12.4)	54 (13.7) 40 (10.2)
S16C1G1	Gold 100X10^{-6} in. (25.4X10^{-4} mm) over Copper 100X10^{-6} in. (25.4X10^{-4} mm)	100 (25.4) 40 (27.9)	102 (25.9) 108 (27.4)	114 (29.0) 113 (28.7)	113 (28.7) 103 (26.1)	102 (25.9) 118 (30.0)	101 (25.7) 108 (27.4)	104 (26.4) 88 (22.4)	116 (29.5) 115 (29.2)	129 (32.8) 111 (28.2)	113 (28.7) 116 (29.5)
						Rhodium			Nickel		
P16N1R2	Rhodium 20X10^{-6} in. (5.1X10^{-4} mm) over Nickel 100X10^{-6} in. (25.4X10^{-4} mm)	42 (10.7) 31 (7.9)	40 (10.2) 41 (10.4)	44 (11.2) 47 (11.9)	41 (10.4) 34 (8.6)	30 (7.6) 27 (6.9)	33 (8.4) 27 (6.9)	31 (7.9) 23 (5.8)	142 (36.1) 148 (37.6)	145 (36.8) 138 (35.1)	144 (36.6) 141 (35.8)
S16N1R2	Rhodium 20X10^{-6} in. (5.1X10^{-4} mm) over Nickel 100X10^{-6} in. (25.4X10^{-4} mm)	21 (5.3) 20 (5.1)	24 (6.1) 33 (8.4)	32 (8.1) 23 (5.8)	23 (5.8) 29 (7.4)	22 (5.6) 20 (5.1)	24 (6.1) 20 (5.1)	20 (5.1) 23 (5.8)	165 (41.9) 162 (41.1)	167 (42.) 134 (34.0)	142 (36.1) 140 (35.6)
						Rhodium			Silver		
P16S1R2	Rhodium 20X10^{-6} in. (5.1X10^{-4} mm) over Silver 100X10^{-6} in. (25.4X10^{-4} mm)	Microsection only				36 (9.1) 40 (10.2)	33 (8.4) 33 (8.4)	37 (9.4) 37 (9.4)	160 (40.6) 133 (33.8)	150 (38.1) 167 (42.4)	149 (37.8) 159 (40.4)
S16S1R2	Rhodium 20X10^{-6} in. (5.1X10^{-4} mm) over Silver 100X10^{-6} in. (25.4X10^{-4} mm)					36 (9.1) 33 (8.4)	43 (10.9) 34 (8.6)	38 (9.7) 44 (11.2)	145 (36.8) 151 (38.4)	152 (38.6) 134 (34.0)	130 (33.0) 136 (34.5)

*Instrument limits measurements to overlays only, except as otherwise noted.

**Gold omitted from specimens prepared for Beta Scope measurements.

TABLE 1 (Continued)

Lot	Plating	Thickness Measured by $[10^{-6}$ in. $(10^{-4}$ mm)]									
		Beta Scope*				Microsection					
						Gold			Silver		
P20S1G3	Gold $30X10^{-6}$ in. $(7.6X10^{-4}$ mm)** over Silver $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	Silver only	146 (37.1) 172 (43.7)	168 (42.7) 145 (36.8)	152 (38.6) -	41 (10.4) 41 (10.4)	43 (10.9) 46 (11.7)	40 (10.2) 44 (11.2)	216 (54.9) 228 (57.9)	230 (58.4) 232 (58.9)	197 (50.0) 252 (64.0)
S20S1G3	Gold $30X10^{-6}$ in. $(7.6X10^{-4}$ mm)** over Silver $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)		110 (27.9) 142 (36.1)	178 (45.2) 155 (39.4)	165 (41.9) -	26 (6.6) 21 (5.3)	28 (7.1) 19 (4.8)	35 (8.9) 21 (5.3)	170 (43.2) 170 (43.2)	187 (47.5) 171 (43.4)	157 (39.9) 168 (42.7)
P20S1G1	Gold $100X10^{-6}$ in. $(25.4X10^{-4}$ mm) over Silver $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	Microsection only				168 (42.7) 147 (37.3)	183 (46.5) 146 (37.1)	159 (40.4) 157 (40.4)	223 (56.6) 254 (64.5)	257 (65.3) 260 (66.0)	226 (57.4) 259 (65.8)
S20S1G1	Gold $100X10^{-6}$ in. $(25.4X10^{-4}$ mm) over Silver $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)					78 (19.8) 116 (29.5)	113 (28.7) 83 (21.1)	81 (20.6) 93 (23.6)	151 (38.4) 149 (37.8)	162 (41.1) 114 (29.0)	148 (37.6) 103 (26.1)
P20S2G5	Gold $50X10^{-6}$ in. $(12.7X10^{-4}$ mm)** over Silver $200X10^{-6}$ in. $(50.8X10^{-4}$ mm)	Silver only	232 (58.9) 242 (61.5)	227 (57.7) 270 (68.6)	248 (64.0) -	56 (14.2) 47 (11.9)	52 (13.2) 69 (17.5)	59 (15.0) 63 (16.0)	383 (97.3) 377 (94.7)	367 (93.2) 419 (106.4)	430 (109.2) 428 (108.7)
S20S2G5	Gold $50X10^{-6}$ in. $(12.7X10^{-4}$ mm)** over Silver $200X10^{-6}$ in. $(50.8X10^{-4}$ mm)		205 (52.1) 195 (49.5)	242 (61.5) 298 (75.7)	238 (60.5) -	47 (11.9) 45 (11.4)	46 (11.7) 47 (11.9)	47 (11.9) 40 (10.2)	454 (115.3) 363 (92.2)	447 (113.5) 377 (95.8)	422 (107.2) 384 (97.5)
						Gold			Nickel		
P20N1G3	Gold $30X10^{-6}$ in. $(7.6X10^{-4}$ mm) over Nickel $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	33 (8.4) 23 (5.8)	22 (5.6) 31 (7.9)	28 (7.1) 31 (7.9)	21 (5.3) 35 (8.9)	39 (9.9) 36 (9.1)	35 (8.9) 33 (8.4)	36 (9.1) 36 (9.1)	123 (31.2) 126 (32.0)	132 (33.5) 137 (34.8)	116 (29.5) 132 (33.5)
S20N1G3	Gold $30X10^{-6}$ in. $(7.6X10^{-4}$ mm) over Nickel $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	27 (6.9) 36 (9.1)	37 (9.4) 27 (6.9)	23 (5.8) 23 (5.8)	26 (6.6) 24 (6.1)	16 (4.1) 20 (5.1)	30 (7.6) 27 (6.9)	33 (8.4) 31 (7.9)	148 (37.6) 134 (34.0)	142 (36.1) 162 (41.1)	159 (40.1) 167 (42.4)
P20N1G1	Gold $100X10^{-6}$ in. $(25.4X10^{-4}$ mm over Nickel $100X10^{-6}$ in. $(25.4X10^{-4}$ mm)	97 (24.6) 86 (21.8)	96 (24.4) 112 (28.4)	107 (27.2) 93 (23.6)	102 (25.9) 94 (23.9)	113 (28.7) 122 (31.0)	120 (30.5) 113 (28.7)	105 (26.7) 117 (29.7)	152 (38.6) 154 (35.8)	158 (40.1) 144 (36.6)	141 (35.8) 151 (38.4)

TABLE 1 (Continued)

S20N1G1	Gold 100X10^{-6} in. (25.4X10^{-4} mm) over Nickel 100X10^{-6} in. (25.4X10^{-4} mm)	100 (25.4) 86 (21.8)	103 (26.1) 102 (25.9)	116 (29.5) 94 (23.9)	112 (28.4) 92 (23.4)	114 (29.0) 128 (32.5)	133 (33.8) 94 (23.9)	135 (34.3) 121 (30.7)	112 (28.4) 152 (38.6)	145 (36.8) 101 (25.7)	163 (41.4) 149 (37.8)
						Gold			Copper		
P20C1G3	Gold 30X10^{-6} in. (7.6X10^{-4} mm) over Copper 100X10^{-6} in. (25.4X10^{-4} mm)	32 (8.1) 27 (6.9)	32 (8.1) 28 (7.1)	25 (6.4) 27 (6.9)	32 (8.1) 34 (8.6)	38 (917) 36 (9.1)	46 (11.7) 30 (7.6)	43 (10.9) 29 (7.4)	120 (30.5) 123 (31.2)	127 (32.3) 122 (31.0)	131 (33.3) 126 (32.0)
S20C1G3	Gold 30X10^{-6} in. (7.6X10^{-4} mm) over Copper 100X10^{-6} in. (25.4X10^{-4} mm)	43 (10.9) 32 (8.1)	32 (8.1) 34 (8.6)	39 (9.9) 38 (9.7)	42 (10.7) 36 (9.1)	33 (8.4) 27 (6.9)	30 (7.6) [illegible] (7.6)	31 (7.9) 40 (10.2)	113 (28.7) 127 (32.3)	120 (30.5) 72 (18.3)	62 (15.7) 65 (16.5)
P20C1G1	Gold 100X10^{-6} in. (25.4X10^{-4} mm) over Copper 100X10^{-6} in. (25.4X10^{-4} mm)	117 (29.7) 103 (26.1)	92 (23.4) 110 (27.9)	116 (29.5) 96 (24.4)	102 (25.9) 96 (24.4)	108 (27.4) 119 (30.2)	[illegible] (31.2) 152 (38.6)	141 (35.8) 134 (34.0)	41 (10.4) 51 (13.0)	40 (10.2) 115 (29.2)	120 (30.5) 111 (28.2)
S20C1G1	Gold 100X10^{-6} in. (25.4X10^{-4} mm) over Copper 100X10^{-6} in. (25.4X10^{-4} mm)	125 (31.8) 97 (24.6)	98 (24.9) 101 (25.7)	92 (23.4) 93 (23.6)	111 (28.2) 101 (25.7)	101 (25.7) 107 (27.2)	92 (23.4) 108 (27.4)	102 (25.9) 126 (32.0)	127 (32.3) 111 (28.2)	122 (31.0) 119 (30.2)	120 (30.5) 126 (32.6)
						Rhodium			Nickel		
P20N1R2	Rhodium 20X10^{-6} in. (5.1X10^{-4} mm) over Nickel 100X10^{-6} in. (25.4X10^{-4} mm)	45 (11.4) 43 (10.9)	31 (7.9) 37 (9.4)	35 (8.9) 41 (10.4)	39 (9.9) 43 (10.9)	41 (10.4) 37 (9.4)	34 (8.6) 36 (9.1)	37 (9.4) 36 (9.1)	156 (39.6) 141 (35.8)	145 (36.8) 187 (47.5)	197 (50.0) 192 (48.8)
S20N1R2	Rhodium 20X10^{-6} in. (5.1X10^{-4} mm) over Nickel 100X10^{-6} in. (25.4X10^{-4} mm)	23 (5.8) 19 (4.8)	24 (6.1) 19 (4.8)	24 (6.1) 21 (5.3)	20 (5.1) 24 (6.1)	20 (5.1) 26 (6.6)	18 (4.6) 19 (4.8)	24 (6.1) 19 (4.8)	137 (34.8) 148 (37.6)	135 (34.3) 131 (33.3)	120 (30.5) 131 (33.3)
						Rhodium			Silver		
P20S1R2	Rhodium 20X10^{-6} in. (5.1X10^{-4} mm) over Silver 100X10^{-6} in. (25.4X10^{-4} mm)	Microsection only				31 (7.9) 38 (9.7)	34 (8.6) 41 (10.4)	48 (12.2) 38 (9.7)	131 (33.3) 138 (35.1)	136 (34.5) 129 (32.8)	138 (35.1) 141 (35.8)
S20S1R2	Rhodium 20X10^{-6} in. (5.1X10^{-4} mm) over Silver 100X10^{-6} in. (25.4X10^{-4} mm)					33 (8.4) 37 (9.4)	41 (10.4) 38 (9.7)	40 (10.2) 33 (8.4)	115 (29.2) 122 (31.0)	128 (32.5) 167 (42.4)	174 (44.2) 166 (42.2)

*Instrument limits measurements to overlays only, except as otherwise noted.

**Gold omitted from specimens prepared for Beta Scope measurements.

TABLE 2 - TARNISH FILM THICKNESS ON
COPPER CONTROL PANELS

Film Removal Date		Panel No.	Average Thickness (Angstroms) Cuprous Oxide	Cupric Oxide
2/8		1	173	0
3/10		2	625	60
4/11		3	565	118
5/12		4	520	107
6/9		5	577	149
7/7	1966	6	657	149
8/11		7	692	328
9/7		8	857	83
10/14		9	1695	113
11/16		10	1775	179
12/15		11	2363	0
2/15		12	2929	0
3/27		13	4427	0
4/20	1967	14	5630	0
5/18		15	5096	0
6/21		16	6138	0

MARINE EXPOSURE MEASUREMENTS

The data obtained at the Ft. Tilden site have been summarized in Tables 3 and 4. Seventeen months of seaside exposure (January 1966-June 1967) produced no appreciable change in contact resistance according to the measurements shown in these tables. Examination of the interior of the screened area showed no visual evidence of salt corrosion. Tests were then made by swabbing all interior surfaces with sterile cotton swabs wetted with distilled water. The swabs were chemically analyzed by means of a silver nitrate solution for the presence of sodium chloride. Results showed that there was no sodium chloride present within the screened enclosure. There was, however, ample visual evidence of salt spray corrosion to components of the external supporting structure. It was concluded that the salt-laden atmosphere consisted of salt and moisture in such particulate form and size that it had been prevented from entering the specimen enclosure by the glass wool filters shown in Figure 4. The glass wool filters were replaced with the stainless steel mesh screen filter shown in Figure 5 in order to permit the salt-laden marine atmosphere to come in contact with the plated specimen contacts. Prior to removing the glass wool filters from the Stevenson Screen enclosure in June 1967, there appeared to be only copper oxide corrosion of the small copper monitoring panels. After the glass wool filters were replaced with the stainless steel mesh screen filters, however, there was definite visual evidence of a green-colored (copper chloride) corrosion, indicating the presence of salt.

The data shown in Table 3A from the subsequent measurements made during the period from June 1967 to November 1967, reported* in April 1968, indicate a slight increase in resistance of the gold-over-nickel and rhodium-over-nickel plated specimens, while no significant change was noted in the gold-over-silver and gold-over-copper plated specimens as shown in Figure 7. Measurements made in August 1970 and June 1977 indicate an increase in resistance of the gold-over-nickel plating by one to

*Glowasky, A., "Investigation of Platings of Electrical Contacts," U.S. Naval Applied Science Laboratory Report IED 20 (8 Apr 1968).

TABLE 3 - CONTACT-RESISTANCE VALUES OF SIZE NO. 16 MIL-C-26636 PLATED CONTACTS

TABLE 3A - FOLLOWING INITIAL MATING

Plating Material	Date	1/11/66	6/9/66	2/15/67	7/31/67	11/29/67	8/10/70	6/2/77
	Temp [°F (°C)]	25 (-4)	68 (20)	51 (10)	78 (26)	33 (1)	80 (27)	70 (21)
		Resistance (mΩ)						
Gold 30×10^{-6} in. (7.6×10^{-4} mm)	Max	0.46	0.56	0.52	0.56	0.50	0.64	1.05
over	Min	0.24	0.28	0.26	0.27	0.23	0.29	0.30
Silver 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.32	0.38	0.36	0.37	0.34	0.43	0.46
Gold 100×10^{-6} in. (25.4×10^{-4} mm)	Max	0.42	0.48	0.46	0.48	0.45	0.58	0.47
over	Min	0.29	0.34	0.32	0.33	0.31	0.36	0.34
Silver 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.36	0.42	0.40	0.42	0.39	0.45	0.41
Gold 50×10^{-6} in. (12.7×10^{-4} mm)	Max	0.41	0.49	0.46	0.49	0.44	0.52	0.42
over	Min	0.27	0.32	0.30	0.31	0.29	0.32	0.31
Silver 200×10^{-6} in. (50.8×10^{-4} mm)	Avg	0.33	0.39	0.37	0.38	0.35	0.40	0.37
Gold 30×10^{-6} in. (7.6×10^{-4} mm)	Max	0.44	0.53	0.51	0.53	0.49	0.90	69.0
over	Min	0.30	0.35	0.33	0.34	0.32	0.36	0.35
Nickel 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.37	0.43	0.41	0.43	0.40	0.56	21.1
Gold 100×10^{-6} in. (25.4×10^{-4} mm)	Max	0.51	0.59	0.57	0.59	0.54	180.0	160.0
over	Min	0.25	0.29	0.28	0.29	0.27	0.42	0.38
Nickel 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.36	0.42	0.40	0.42	0.39	24.1	50.3
Gold 30×10^{-6} in. (7.6×10^{-4} mm)	Max	0.58	0.56	0.53	0.55	0.52	0.60	0.72
over	Min	0.27	0.32	0.30	0.31	0.29	0.32	0.31
Copper 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.39	0.41	0.39	0.40	0.37	0.42	0.42
Gold 100×10^{-6} in. (25.4×10^{-4} mm)	Max	0.40	0.48	0.45	0.47	0.43	1.75	2.30
over	Min	0.32	0.38	0.36	0.37	0.35	0.38	0.36
Copper 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.36	0.42	0.41	0.42	0.40	0.57	0.67
Rhodium 20×10^{-6} in. (5.1×10^{-4} mm)	Max	0.96	1.02	1.00	1.03	0.97	1.15	1.95
over	Min	0.49	0.55	0.54	0.55	0.51	0.61	0.55
Nickel 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.60	0.67	0.65	0.67	0.63	0.72	0.76
Rhodium 20×10^{-6} in. (5.1×10^{-4} mm)	Max	0.63	0.70	0.67	0.69	0.62	0.70	0.79
over	Min	0.37	0.41	0.40	0.42	0.40	0.43	0.42
Silver 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.46	0.52	0.50	0.51	0.48	0.54	0.56

TABLE 3 (Continued)

TABLE 3B - FOLLOWING 100 MATING CYCLES

Plating Material	Date	1/11/66	6/9/66	2/15/67	7/31/67	11/29/67	8/10/70	6/2/77
	Temp [°F (°C)]	25 (-4)	68 (20)	51 (10)	78 (26)	33 (1)	80 (27)	70 (21)
		Resistance (mΩ)						
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.41	0.52	0.50	0.52	0.48	0.55	0.51
over	Min	0.27	0.34	0.32	0.33	0.31	0.35	0.33
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.33	0.42	0.40	0.41	0.39	0.44	0.43
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.47	0.59	0.57	0.60	0.54	0.63	0.55
over	Min	0.25	0.32	0.30	0.31	0.29	0.33	0.32
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.35	0.44	0.42	0.43	0.40	0.46	0.42
Gold $50X10^{-6}$ in. ($12.7X10^{-4}$ mm)	Max	0.41	0.51	0.49	0.51	0.50	0.84	0.84
over	Min	0.23	0.29	0.28	0.29	0.24	0.30	0.28
Silver $200X10^{-6}$ in. ($50.8X10^{-4}$ mm)	Avg	0.30	0.38	0.36	0.38	0.36	0.45	0.40
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.48	0.57	0.56	0.58	0.55	100.0	125.0
over	Min	0.27	0.33	0.32	0.33	0.32	0.38	1.40
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.37	0.45	0.44	0.46	0.43	19.9	41.6
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.56	0.67	0.64	0.67	0.63	14.0	190.0
over	Min	0.24	0.30	0.28	0.29	0.29	0.46	0.57
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.39	0.47	0.45	0.47	0.45	1.94	53.9
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.39	0.48	0.45	0.48	0.43	0.51	0.44
over	Min	0.24	0.31	0.29	0.30	0.29	0.34	0.31
Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.32	0.39	0.37	0.39	0.36	0.42	0.38
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.44	0.52	0.50	0.53	0.48	0.56	0.52
over	Min	0.31	0.37	0.35	0.36	0.34	0.36	0.36
Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.37	0.44	0.42	0.44	0.40	0.45	0.42
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm)	Max	1.10	1.20	1.20	1.22	1.20	1.30	1.45
over	Min	0.56	0.64	0.63	0.65	0.62	0.66	0.62
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.78	0.87	0.86	0.89	0.85	0.92	0.92
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm)	Max	0.58	0.63	0.61	0.60	0.57	0.63	0.60
over	Min	0.28	0.33	0.33	0.34	0.33	0.36	0.35
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.42	0.50	0.48	0.49	0.47	0.52	0.51

TABLE 4 - CONTACT-RESISTANCE VALUES OF SIZE NO. 20 MIL-C-26636 PLATED CONTACTS

TABLE 4A - FOLLOWING INITIAL MATING

Plating Material	Date	1/11/66	6/9/66	2/15/67	7/31/67	11/29/67	8/10/70	6/2/77
	Temp [°F (°C)]	25 (-4)	68 (20)	51 (10)	78 (26)	33 (1)	80 (27)	70 (21)
		Resistance (mΩ)						
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.51	0.64	0.60	0.63	0.58	0.70	0.73
over	Min	0.38	0.46	0.44	0.45	0.42	0.50	0.56
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.44	0.54	0.52	0.54	0.51	0.58	0.62
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.60	0.67	0.64	0.67	0.62	0.76	0.78
over	Min	0.39	0.45	0.44	0.46	0.42	0.48	0.50
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.47	0.55	0.53	0.56	0.52	0.59	0.59
Gold $50X10^{-6}$ in. ($12.7X10^{-4}$ mm)	Max	0.48	0.60	0.57	0.61	0.56	0.64	0.69
over	Min	0.36	0.42	0.42	0.43	0.43	0.50	0.46
Silver $200X10^{-6}$ in. ($50.8X10^{-4}$ mm)	Avg	0.43	0.51	0.50	0.52	0.50	0.58	0.57
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.67	0.81	0.79	0.86	0.82	160.0	840.0
over	Min	0.48	0.56	0.55	0.58	0.54	0.73	0.70
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.56	0.65	0.64	0.68	0.65	25.9	168.8
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.64	0.74	0.72	0.76	0.71	23.5	130.0
over	Min	0.44	0.52	0.51	0.53	0.49	0.60	0.58
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.53	0.62	0.61	0.66	0.64	8.99	34.0
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.53	0.65	0.61	0.65	0.60	0.85	0.85
over	Min	0.38	0.44	0.43	0.45	0.41	0.53	0.54
Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.45	0.54	0.51	0.54	0.49	0.63	0.63
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.66	0.74	0.69	0.72	0.69	0.93	0.89
over	Min	0.40	0.47	0.45	0.48	0.44	0.50	0.47
Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.48	0.55	0.53	0.55	0.52	0.63	0.60
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm)	Max	1.10	1.12	1.15	1.20	1.13	42.0	340.0
over	Min	0.63	0.72	0.72	0.82	0.75	0.84	0.84
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.78	0.90	0.89	0.95	0.91	10.2	54.8
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm)	Max	0.71	0.80	0.77	0.82	0.84	1.15	1.85
over	Min	0.50	0.57	0.55	0.57	0.56	0.68	0.69
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.63	0.71	0.69	0.74	0.72	0.91	1.22

TABLE 4 (Continued)

TABLE 4B - FOLLOWING 100 MATING CYCLES

Plating Material	Date	1/11/66	6/9/66	2/15/67	7/31/67	11/29/67	8/10/70	6/2/77
	Temp [°F (°C)]	25 (-4)	68 (20)	51 (10)	78 (26)	33 (1)	80 (27)	70 (21)
		Resistance (mΩ)						
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.56	0.58	0.56	0.58	0.54	0.63	0.58
over	Min	0.35	0.44	0.43	0.45	0.41	0.47	0.46
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.42	0.51	0.49	0.51	0.48	0.55	0.52
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.58	0.72	0.69	0.72	0.67	0.76	0.69
over	Min	0.38	0.48	0.47	0.49	0.45	0.50	0.49
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.44	0.54	0.52	0.54	0.51	0.58	0.55
Gold $50X10^{-6}$ in. ($12.7X10^{-4}$ mm)	Max	0.48	0.60	0.57	0.60	0.56	0.63	0.57
over	Min	0.36	0.43	0.44	0.44	0.42	0.46	0.49
Silver $200X10^{-6}$ in. ($50.8X10^{-4}$ mm)	Avg	0.41	0.49	0.48	0.50	0.47	0.54	0.53
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.65	0.78	0.74	0.88	0.86	35.0	650.0
over	Min	0.41	0.50	0.48	0.51	0.47	0.70	0.64
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.53	0.64	0.61	0.66	0.63	5.86	191.6
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.62	0.74	0.72	0.76	0.74	38.0	380.0
over	Min	0.41	0.50	0.49	0.52	0.53	0.67	0.80
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.48	0.59	0.58	0.65	0.62	10.6	52.2
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.54	0.67	0.65	0.68	0.63	0.71	0.66
over	Min	0.37	0.45	0.43	0.46	0.42	0.48	0.48
Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.46	0.57	0.55	0.58	0.53	0.61	0.58
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.56	0.70	0.67	0.70	0.64	0.78	0.72
over	Min	0.44	0.54	0.52	0.55	0.50	0.56	0.54
Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.49	0.59	0.57	0.60	0.55	0.62	0.60
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm)	Max	1.50	1.66	1.65	1.78	1.72	13.0	210.0
over	Min	0.70	0.75	0.75	0.81	0.77	1.05	1.30
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	1.01	1.11	1.11	1.17	1.14	3.13	72.7
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm)	Max	1.10	1.16	1.17	1.15	2.35	4.70	5.30
over	Min	0.48	0.57	0.56	0.58	0.57	0.64	0.63
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.65	0.73	0.72	0.73	0.88	1.28	1.38

two orders of magnitude and a factor of five increase in the rhodium-over-nickel plating. There was still no significant change in the gold-over-silver and gold-over-copper specimens.

LABORATORY SALT SPRAY EXPOSURE MEASUREMENTS

The data shown in Tables 5A and 5B for the gold-over-silver plating, after 4000 hr of exposure to laboratory salt spray at NASL, indicates no significant change in the average contact resistance. The data for gold-over-nickel plating indicates an increase of two to three orders of magnitude in the average contact resistance. The data for gold-over-copper plating shows no significant increase in the average contact resistance. The data for rhodium-over-nickel plating shows an increase of three orders of magnitude in the average contact resistance. The data for rhodium-over-silver plating shows a slight increase in the average contact resistance.

ANALYSIS

MARINE VERSUS LABORATORY SALT SPRAY EXPOSURE

An analysis was performed on the average contact-resistance measurements made on all of the size No. 20 MIL-C-26636 contacts. Size No. 20 was the only size subjected to both the marine exposure of 11-1/2 yr (108,000 hr) and the laboratory 4000-hr salt spray exposure. The only contacts whose contact resistance showed any significant change during exposure were the nickel underplated and rhodium plated contacts, as shown in Tables 3 and 4 and Figure 7. In order to determine what the acceleration factor is between marine exposure and laboratory salt spray exposure for the plating systems that showed significant change in contact resistance, the laboratory salt spray curve was modified. A multiplication factor was applied to the time scale of the laboratory salt spray curve. This multiplication factor was selected to give a good fit of the laboratory salt spray exposure curve to the marine exposure curve.

GOLD-OVER-NICKEL PLATING

As shown in Figures 8a and 8b, multiplication factors of 25 and 28, respectively, were applied to the time scales of the laboratory salt spray measurements. The figures compare contact-resistance values in the marine and the laboratory environments for plated contacts subjected to initial mating only (Figure 8a) and to 100 cycles of insertion and withdrawal prior to exposure (Figure 8b). The contacts were size No. 20 plated with 30×10^{-6} in. (7.6×10^{-4} mm) gold over 100×10^{-6} in. (25.4×10^{-4} mm) nickel.

Figures 9a and 9b, which have multiplication factors of 21.5 and 18, respectively, for the time scales of the laboratory salt spray measurements, show contact-resistance values for size No. 20 contacts plated with 100×10^{-6} in. (25.4×10^{-4} mm) gold over 100×10^{-6} in. (25.4×10^{-4} mm) nickel.

RHODIUM-OVER-NICKEL PLATING

As shown in Figures 10a and 10b, multiplication factors of 71 and 66, respectively, were applied to the time scales of the laboratory salt spray measurements. The values shown are for contacts subjected to initial mating only (Figure 10a) and for 100 cycles of insertion and withdrawal prior to exposure (Figure 10b). The contacts were size No. 20 plated with 20×10^{-6} in. (5.1×10^{-4} mm) rhodium over 100×10^{-6} in. (25.4×10^{-4} mm) nickel.

RHODIUM-OVER-SILVER PLATING

As shown in Figures 11a and 11b, multiplication factors of 120 and 70, respectively, were applied to the time scales of laboratory salt spray measurements. The contacts were subjected to initial mating only (Figure 11a) and 100 cycles of insertion and withdrawal prior to exposure (Figure 11b). These size No. 20 contacts were plated with 20×10^{-6} in. (5.1×10^{-4} mm) over 100×10^{-6} in. (25.4×10^{-4} mm) silver.

TABLE 5 - CONTACT-RESISTANCE VALUES OF SIZE NO. 20 MIL-C-26636 PLATED CONTACTS DURING SALT SPRAY EVALUATION AT NASL

TABLE 5A - AS RECEIVED

Plating Material	Time (hr)	Initial	224	400	624	800	1008	1232	1408	1632	1808	2032
	Temp [°F (°C)]	80 (27)	80 (27)	80 (27)	80 (27)	79 (26)	81 (27)	83 (28)	80 (27)	80 (27)	82 (28)	81 (27)
		Resistance (mΩ)										
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm) over Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.74	0.73	0.74	0.72	0.73	0.72	0.72	0.71	0.72	0.72	0.72
	Min	0.54	0.54	0.55	0.55	0.56	0.54	0.54	0.54	0.56	0.55	0.55
	Avg	0.59	0.59	0.66	0.59	0.60	0.59	0.59	0.59	0.60	0.59	0.59
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm) over Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.62	0.61	0.63	0.62	0.62	0.61	0.62	0.61	0.62	0.62	0.62
	Min	0.48	0.48	0.49	0.49	0.50	0.48	0.48	0.48	0.49	0.50	0.49
	Avg	0.55	0.55	0.56	0.56	0.56	0.55	0.55	0.55	0.56	0.56	0.56
Gold $50X10^{-6}$ in. ($12.7X10^{-4}$ mm) over Silver $200X10^{-6}$ in. ($50.8X10^{-4}$ mm)	Max	0.69	0.68	0.70	0.68	0.68	0.67	0.67	0.67	0.68	0.68	0.67
	Min	0.50	0.48	0.50	0.50	0.50	0.49	0.50	0.50	0.50	0.51	0.50
	Avg	0.61	0.60	0.61	0.61	0.61	0.60	0.60	0.60	0.61	0.61	0.60
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm) over Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.71	1.20	2.34	14.0	32.0	30.0	60.0	66.0	68.0	72.0	76.0
	Min	0.53	0.63	0.69	0.70	0.75	0.91	1.20	1.30	2.10	2.40	2.45
	Avg	0.68	0.83	1.37	4.77	7.33	8.63	13.3	15.8	24.8	29.7	34.5
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm) over Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.77	0.93	1.10	3.70	12.5	10.0	17.5	19.5	20.0	36.0	44.0
	Min	0.58	0.62	0.64	0.64	0.64	0.63	0.64	0.68	0.70	0.70	0.76
	Avg	0.69	0.73	0.83	1.57	2.90	3.33	4.41	6.37	7.05	9.82	11.7
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm) over Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.70	0.70	0.71	0.81	0.81	0.81	0.81	0.81	0.80	0.81	0.81
	Min	0.56	0.56	0.56	0.58	0.60	0.58	0.60	0.60	0.64	0.63	0.64
	Avg	0.63	0.63	0.64	0.66	0.67	0.66	0.67	0.67	0.68	0.68	0.68
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm) over Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.80	0.77	0.79	0.77	0.77	0.76	0.76	0.75	0.77	0.75	0.77
	Min	0.51	0.50	0.52	0.51	0.52	0.51	0.53	0.53	0.56	0.56	0.55
	Avg	0.64	0.63	0.65	0.64	0.65	0.63	0.64	0.64	0.65	0.65	0.64
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm) over Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	1.15	1.35	7.65	33.0	60.0	68.0	120.0	160.0	420.0	440.0	510.0
	Min	0.84	0.90	1.05	1.10	1.15	1.10	1.15	1.20	1.60	1.60	1.60
	Avg	1.01	1.08	2.04	4.78	8.42	11.0	22.3	31.4	111.3	138.1	165.9
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm) over Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.92	0.83	0.83	1.10	4.0	8.0	16.5	18.0	18.0	15.0	15.5
	Min	0.58	0.58	0.58	0.60	0.60	0.60	0.60	0.60	0.61	0.61	0.61
	Avg	0.75	0.71	0.71	0.76	1.04	1.44	2.29	2.44	2.46	2.16	2.21

TABLE 5A (Continued)

Plating Material	Time (hr) / Temp [°F (°C)]	2192 / 81 (27)	2416 / 82 (28)	2592 / 81 (27)	2816 / 82 (28)	3040 / 81 (27)	3216 / 82 (28)	3440 / 85 (29)	3616 / 84 (29)	3792 / 85 (29)	4000 / 85 (29)
		Resistance (mΩ)									
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.71	0.71	0.71	0.71	0.71	0.73	0.74	0.73	0.74	0.73
over	Min	0.55	0.55	0.55	0.56	0.55	0.56	0.55	0.55	0.56	0.56
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.59	0.59	0.59	0.59	0.59	0.60	0.60	0.60	0.60	0.60
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.62	0.62	0.62	0.61	0.61	0.63	0.62	0.62	0.63	0.62
over	Min	0.49	0.50	0.49	0.50	0.49	0.49	0.49	0.49	0.50	0.49
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.56	0.56	0.56	0.57	0.56	0.56	0.56	0.56	0.57	0.56
Gold $50X10^{-6}$ in. ($12.7X10^{-4}$ mm)	Max	0.67	0.67	0.72	0.72	0.72	0.74	0.74	0.74	0.74	0.74
over	Min	0.50	0.50	0.50	0.51	0.50	0.50	0.50	0.50	0.50	0.50
Silver $200X10^{-6}$ in. ($50.8X10^{-4}$ mm)	Avg	0.60	0.60	0.61	0.62	0.63	0.64	0.64	0.64	0.64	0.64
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	79.0	94.0	95.0	98.0	195.0	256.0	272.0	282.0	290.0	315.0
over	Min	2.90	4.0	17.0	22.6	25.0	32.0	41.0	47.0	69.0	76.0
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	38.6	47.4	51.2	59.1	64.3	92.7	102.4	118.2	129.3	158.7
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	81.0	82.0	84.0	62.0	56.0	42.0	42.2	43.0	43.0	44.0
over	Min	0.76	0.76	0.80	0.88	0.88	0.88	0.88	0.89	0.89	0.88
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	15.8	19.4	20.2	18.0	17.7	15.9	16.0	18.1	17.8	19.1
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.80	0.81	0.81	0.82	0.80	0.81	0.80	0.80	0.81	0.80
over	Min	0.63	0.63	0.63	0.64	0.63	0.64	0.65	0.64	0.65	0.65
Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.68	0.68	0.68	0.69	0.68	0.69	0.68	0.68	0.69	0.68
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.75	0.75	0.75	0.76	0.75	0.77	0.77	0.77	0.78	0.77
over	Min	0.55	0.55	0.56	0.56	0.56	0.56	0.56	0.57	0.57	0.57
Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.64	0.64	0.64	0.65	0.64	0.65	0.65	0.65	0.65	0.65
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm)	Max	500.0	610.0	650.0	670.0	850.0	810.0	850.0	880.0	890.0	905.0
over	Min	1.90	2.55	2.90	2.90	2.90	2.95	4.30	53.0	98.0	108.0
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	172.8	251.2	266.9	390.9	473.3	485.0	519.3	539.9	580.7	594.3
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm)	Max	11.5	8.40	12.5	15.0	18.0	17.5	18.0	18.0	18.8	18.0
over	Min	0.62	0.62	0.62	0.65	0.64	0.64	0.64	0.76	0.65	0.65
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	1.81	1.50	1.94	2.21	2.51	2.46	2.49	2.50	2.55	2.51

TABLE 5 (Continued)

TABLE 5B – AFTER 100 MATING CYCLES

Plating Material	Time (hr) / Temp [°F (°C)]	Initial	224	400	624	800	1008	1232	1408	1632	1808	2032
		80 (27)	80 (27)	80 (27)	80 (27)	79 (26)	81 (27)	83 (28)	80 (27)	80 (27)	82 (28)	81 (27)
		Resistance (mΩ)										
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.70	0.66	0.76	0.80	0.84	0.85	0.90	0.89	0.90	0.90	0.90
over	Min	0.50	0.48	0.50	0.50	0.50	0.50	0.49	0.50	0.50	0.50	0.50
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.61	0.55	0.58	0.59	0.60	0.59	0.60	0.60	0.62	0.63	0.63
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.61	0.60	0.60	0.62	0.62	0.61	0.64	0.63	0.80	0.76	0.76
over	Min	0.41	0.40	0.40	0.44	0.45	0.43	0.44	0.44	0.44	0.43	0.43
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.51	0.51	0.51	0.53	0.54	0.52	0.53	0.52	0.56	0.54	0.54
Gold $50X10^{-6}$ in. ($12.7X10^{-4}$ mm)	Max	0.60	0.58	0.58	0.60	0.60	0.58	0.61	0.60	0.63	0.62	0.62
over	Min	0.44	0.42	0.42	0.43	0.44	0.42	0.44	0.42	0.46	0.45	0.44
Silver $200X10^{-6}$ in. ($50.8X10^{-4}$ mm)	Avg	0.52	0.50	0.50	0.51	0.52	0.50	0.52	0.51	0.54	0.53	0.53
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	1.25	1.70	21.5	30.0	34.0	32.0	35.0	38.0	42.0	44.0	105.0
over	Min	0.52	0.60	0.62	0.63	0.64	0.65	0.67	0.73	1.30	2.00	8.2
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.67	0.82	2.97	4.05	5.08	5.72	8.33	10.7	15.5	20.4	32.1
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.77	0.83	1.86	4.70	6.00	7.20	9.30	12.5	22.0	24.0	25.0
over	Min	0.57	0.56	0.59	0.60	0.62	0.61	0.62	0.62	0.65	0.67	0.68
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.66	0.68	0.86	1.20	1.35	1.53	2.29	2.80	5.01	5.23	6.29
Gold $30X10^{-6}$ in. ($7.6X10^{-4}$ mm)	Max	0.75	0.75	0.77	1.80	1.75	1.65	1.60	1.60	1.60	1.60	1.65
over	Min	0.55	0.54	0.56	0.57	0.58	0.55	0.58	0.57	0.61	0.60	0.60
Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.62	0.62	0.64	0.78	0.78	0.75	0.76	0.76	0.78	0.78	0.78
Gold $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Max	0.80	0.76	0.77	0.79	0.80	0.78	0.79	0.79	0.79	0.80	0.78
over	Min	0.51	0.52	0.53	0.53	0.54	0.52	0.54	0.53	0.54	0.54	0.53
Copper $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.63	0.62	0.63	0.63	0.64	0.63	0.64	0.63	0.65	0.65	0.64
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm)	Max	2.20	4.90	39.0	67.0	76.0	80.0	92.0	95.0	122.0	400.0	460.0
over	Min	1.05	1.00	1.10	1.30	1.35	1.35	1.70	3.05	17.0	22.0	26.5
Nickel $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	1.39	1.81	9.27	17.2	22.4	29.4	38.8	44.6	74.9	112.2	129.5
Rhodium $20X10^{-6}$ in. ($5.1X10^{-4}$ mm)	Max	0.89	1.25	1.50	1.50	1.55	1.50	1.50	1.58	1.40	1.45	1.45
over	Min	0.58	0.60	0.62	0.62	0.62	0.61	0.61	0.61	0.63	0.63	0.63
Silver $100X10^{-6}$ in. ($25.4X10^{-4}$ mm)	Avg	0.72	0.78	0.80	0.80	0.82	0.80	0.80	0.80	0.82	0.82	0.83

TABLE 5B (Continued)

Plating Material	Time (hr)	2192	2416	2592	2816	3040	3216	3440	3616	3792	4000
	Temp [°F (°C)]	81 (27)	82 (28)	81 (27)	82 (28)	81 (27)	82 (28)	85 (29)	84 (29)	85 (29)	85 (29)
		Resistance (mΩ)									
Gold 30×10^{-6} in. (7.6×10^{-4} mm)	Max	0.90	0.90	0.90	0.92	0.90	0.90	0.90	0.90	0.90	0.90
over	Min	0.50	0.50	0.50	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Silver 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.63	0.62	0.63	0.64	0.63	0.64	0.64	0.64	0.64	0.64
Gold 100×10^{-6} in. (25.4×10^{-4} mm)	Max	0.75	0.75	1.25	1.25	1.15	1.15	1.10	1.10	1.10	1.10
over	Min	0.43	0.43	0.43	0.44	0.43	0.44	0.43	0.44	0.44	0.44
Silver 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.54	0.54	0.61	0.61	0.61	0.60	0.59	0.60	0.60	0.59
Gold 50×10^{-6} in. (12.7×10^{-4} mm)	Max	0.61	0.61	0.62	0.62	0.62	0.63	0.63	0.63	0.64	0.63
over	Min	0.44	0.44	0.44	0.44	0.43	0.44	0.43	0.44	0.44	0.44
Silver 200×10^{-6} in. (50.8×10^{-4} mm)	Avg	0.53	0.53	0.54	0.54	0.53	0.54	0.54	0.54	0.55	0.54
Gold 30×10^{-6} in. (7.6×10^{-4} mm)	Max	105.0	115.0	122.0	150.0	155.0	160.0	175.0	540.0	650.0	695.0
over	Min	14.5	18.0	24.0	26.0	28.0	31.0	41.0	45.0	47.0	48.0
Nickel 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	34.3	47.7	56.1	63.7	74.2	79.6	88.8	141.3	173.6	211.6
Gold 100×10^{-6} in. (25.4×10^{-4} mm)	Max	25.5	30.0	30.0	31.0	31.0	29.0	35.0	38.0	38.0	38.0
over	Min	0.70	0.70	0.70	0.75	0.75	0.76	0.76	0.76	0.77	0.77
Nickel 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	7.40	8.94	8.95	9.33	9.53	9.96	13.2	13.6	13.6	14.6
Gold 30×10^{-6} in. (7.6×10^{-4} mm)	Max	1.65	1.75	1.55	1.60	1.60	1.55	1.55	1.55	1.55	1.55
over	Min	0.59	0.59	0.58	0.60	0.59	0.60	0.60	0.60	0.60	0.60
Copper 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.78	0.79	0.77	0.78	0.78	0.77	0.77	0.78	0.78	0.78
Gold 100×10^{-6} in. (25.4×10^{-4} mm)	Max	0.78	0.79	0.78	0.80	0.78	0.78	0.78	0.78	0.78	0.78
over	Min	0.53	0.53	0.54	0.54	0.54	0.54	0.53	0.54	0.54	0.54
Copper 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.64	0.64	0.64	0.65	0.64	0.64	0.64	0.64	0.64	0.64
Rhodium 20×10^{-6} in. (5.1×10^{-4} mm)	Max	500.0	570.0	620.0	840.0	900.0	920.0	965.0	1040.0	1060.0	1140.0
over	Min	30.0	36.0	36.0	36.0	36.0	38.0	39.0	39.0	40.0	40.0
Nickel 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	161.5	200.8	236.6	362.6	517.6	569.3	610.9	633.6	666.2	708.2
Rhodium 20×10^{-6} in. (5.1×10^{-4} mm)	Max	1.40	1.45	1.45	1.50	1.43	1.40	1.40	1.40	1.40	1.40
over	Min	0.63	0.64	0.63	0.64	0.63	0.64	0.63	0.64	0.64	0.64
Silver 100×10^{-6} in. (25.4×10^{-4} mm)	Avg	0.82	0.82	0.82	0.83	0.82	0.83	0.82	0.83	0.83	0.82

CONCLUSIONS

COPPER CORROSION MONITORING PANELS

The copper corrosion panels data obtained at Ft. Tilden, NY, showed no indication of atmospheric sulphide, but there was ample evidence of salt spray corrosion of the structure fittings. The site was deemed suitable for obtaining marine exposure corrosion data free of industrial atmospheric contamination.

STEVENSON SCREEN ENCLOSURE

The presence of salt spray corrosion within the Stevenson Screen enclosure with glass wool filters was investigated for the 17-month exposure period (to June 1967) by swabbing all interior surfaces with sterile cotton swabs wetted with distilled water. A chemical analysis was made of these swabs using a silver nitrate solution. The analysis showed no trace of salt. An analysis of the copper corrosion panels during this same period also indicated the absence of salt corrosion. However, when glass wool filters were replaced with stainless steel mesh screen filters, there was definite visual evidence of salt spray corrosion within the enclosure and evidence of green corrosion deposits on the copper corrosion panels. It was therefore concluded that chloride was present within the screened enclosure. It was also concluded that the salt and moisture in the atmosphere was of such particulate form and size as to be prevented from entering the specimen enclosure by the glass wool filters.

INSERTION-AND-WITHDRAWAL PRECONDITIONING

The 100 cycles of insertion-and-withdrawal preconditioning did not significantly affect the contact resistance of the gold-plated specimens.

MARINE EXPOSURE

The results of exposure of plated contacts at the Ft. Tilden, NY, marine environment have shown that there was no significant change in the resistances of the various plated contacts from the initial measurement to November 1967. This lack of any change occurred even though there was evidence of salt spray corrosion within the Stevenson Screen enclosure after the installation of the stainless steel mesh screen in June 1967. The measurements made in August 1970 and June 1977 indicate that nickel underplating is undesirable because of the relatively high increase in contact resistance in the contacts with gold-over-nickel and rhodium-over-nickel underplating. There was no significant increase in contact resistance in the gold-over-silver and gold-over-copper plated contacts. Therefore, while 30 millionths of an inch ($7.6\text{X}10^{-4}$ mm) of gold over 100 millionths of an inch ($25.4\text{X}10^{-4}$ mm) of silver is superior, 30 millionths of an inch ($7.6\text{X}10^{-4}$ mm) of gold over 100 millionths of an inch ($25.4\text{X}10^{-4}$ mm) of copper is adequate for naval applications in a marine atmosphere.

LABORATORY SALT SPRAY EXPOSURE

The results of exposure of plated contacts to 4000 hr of laboratory salt spray environment also showed no significant increase in contact resistance in the gold-over-silver and gold-over-copper plated contacts. Therefore, the same conclusion can be drawn that, while 30 millionths of an inch ($7.6\text{X}10^{-4}$ mm) of gold over 100 millionths of an inch ($25.4\text{X}10^{-4}$ mm) of silver is superior, 30 millionths of an inch ($7.6\text{X}10^{-4}$ mm) of gold over 100 millionths of an inch ($25.4\text{X}10^{-4}$ mm) of copper is adequate for the naval applications in a marine atmosphere. The results also indicate that nickel underplating is undesirable in a salt spray environment because of the relatively high increase in contact resistance in the contacts with gold-over-nickel and rhodium-over-nickel underplating.

PLATING THICKNESS

Conclusions as to the adequacy of the gold platings are made with due regard to the inherent variations in such platings produced by even the best current commercial practice. As Table 1 shows, there are overall variations in gold thicknesses ranging from about 80% above the nominal to 50% below the nominal 30 millionths of an inch ($7.6\text{X}10^{-4}$ mm). The conclusions as to the adequacy of platings are therefore conditional on the plating quality or porosity, as well as on the actual thickness as represented by the lower limit in the variation of plating thickness (Table 1).

LABORATORY SALT SPRAY ACCELERATED CORROSION

The results of fitting the average contact resistance curve for 4000 hr of laboratory salt spray exposure to the average contact resistance curve for 108,000 hr of marine exposure indicate that the laboratory salt spray gives apparent acceleration factors of 25 and 28 for 30 millionths of an inch of gold over 100 millionths of an inch of nickel plating. For 100 millionths of an inch of gold over 100 millionths of an inch of nickel, the acceleration factors are apparently 18 and 21.5. The acceleration factors for 20 millionths of an inch of rhodium over 100 millionths of an inch of nickel are apparently 70 and 66. The acceleration factors of 120 and 70 for rhodium over silver show a variance which makes it inconclusive as to whether these acceleration factors are valid or useful. The slight variance in the apparent acceleration factors for the gold-over-nickel plating systems may be accounted for by the preconditioning of 100 mating cycles (insertion and withdrawal) for one group of specimens as opposed to a single mating for the other group.

The contact resistance measurements made on contacts with gold-over-silver and gold-over-copper plating show a relatively small change for both the marine exposure and laboratory salt spray exposure. That small change in contact resistance indicates that there is no significant acceleration factor for the gold-over-silver and gold-over-copper plating systems using the laboratory salt spray exposure.

RECOMMENDATIONS

MIL-C-26636 CONTACT PLATING

In view of the adequate performance of the gold-over-copper plated contacts in a marine and laboratory salt spray environment, it is recommended that silver underplating no longer be required for naval applications. Under normal conditions of actual use, as represented by the repeated matings described in this investigation, the plating of 30 millionths of an inch ($7.6X10^{-4}$ mm) of gold over 100 millionths of an inch ($25.4X10^{-4}$ mm) of copper is recommended. However, it is also recommended that quality assurance provisions be incorporated in the contact specifications to insure that the actual thickness of the plating be held within the lower limit in variation of plating thickness shown in the report.

LABORATORY SALT SPRAY ACCELERATION FACTOR

An analysis of the results of exposure of the contacts to a marine environment and to laboratory salt spray Method 101.C of MIL-STD-202C indicates that the acceleration factor derived by curve fitting is consistent for the gold-over-nickel plating system. The poor performance of the nickel underplated contacts in both types of exposure indicates a possible continuing source of failure. It is therefore recommended that nickel underplating be avoided, where possible, for naval shipboard applications.

INVESTIGATION METHODS AND PROCEDURES

It is recommended that the methods and procedures adopted for this investigation be used as guidelines in the study of plating of electroplated electrical contacts subjected to industrial/urban, sulphurous, and elevated temperature environments so that the results of all investigations can be correlated.

In a marine environment where salt spray atmosphere corrosion is to be studied, it is recommended that a modified Stevenson Screen enclosure with type 316 stainless steel mesh screen filter be utilized in order to permit the passage of the salt-laden atmosphere to the plated specimens inside the enclosure.

ACKNOWLEDGMENTS

The work on this project at NASL was conducted by A. Glowasky until 1 December 1969. Technical assistance in planning the experiment was

rendered by R. G. Baker (Bell Telephone Laboratories), C. Stuart (Amphenol Corp.), A. Nash (Burndy Corp.), R. Tweed (Nu-Line Industries), and S. Weiss (Elco Corp.).

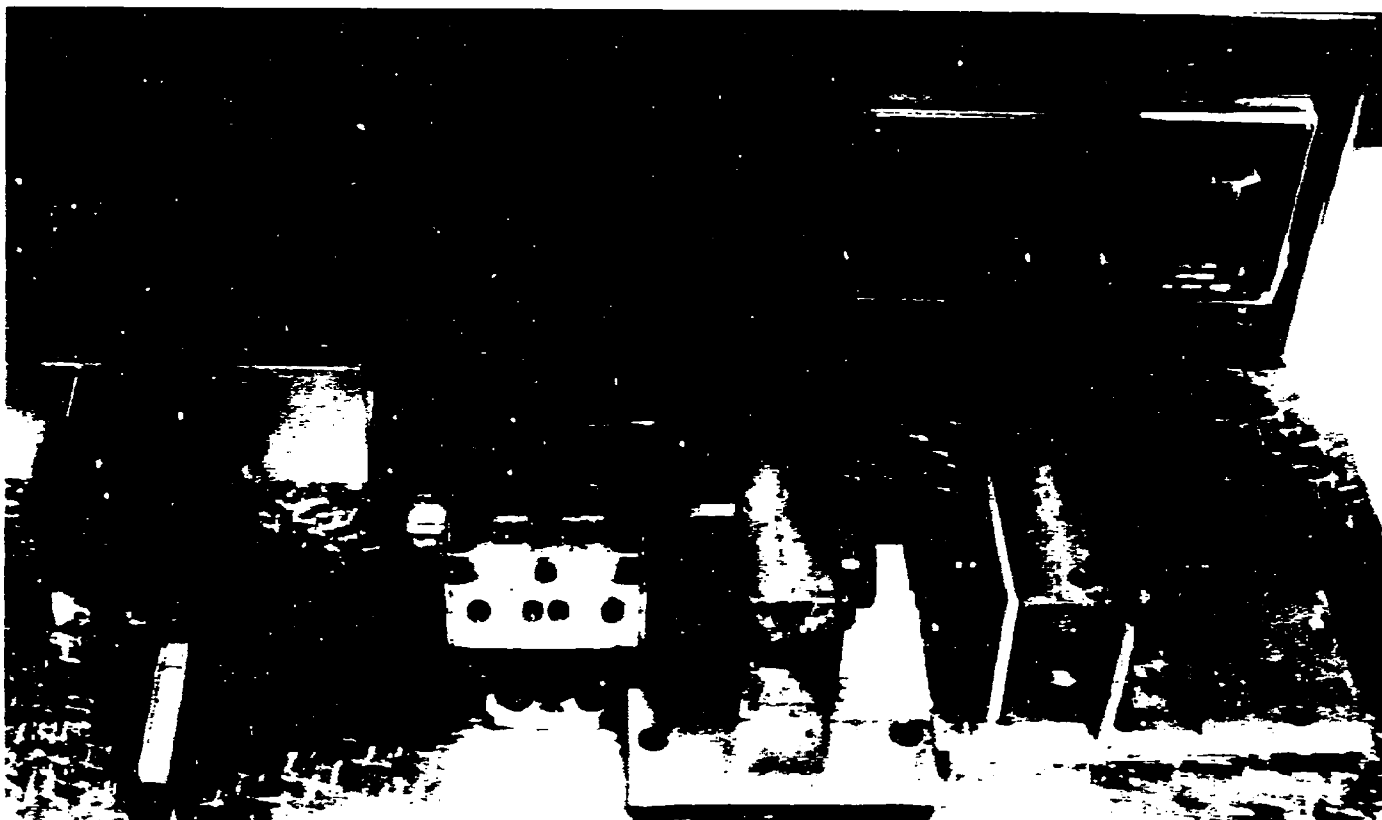


Figure 1 - Reciprocating Mechanism for Mating Ten Pin-and-Socket Contacts Once Every 5 Minutes
(Each Mating Lasts for 10 Seconds)

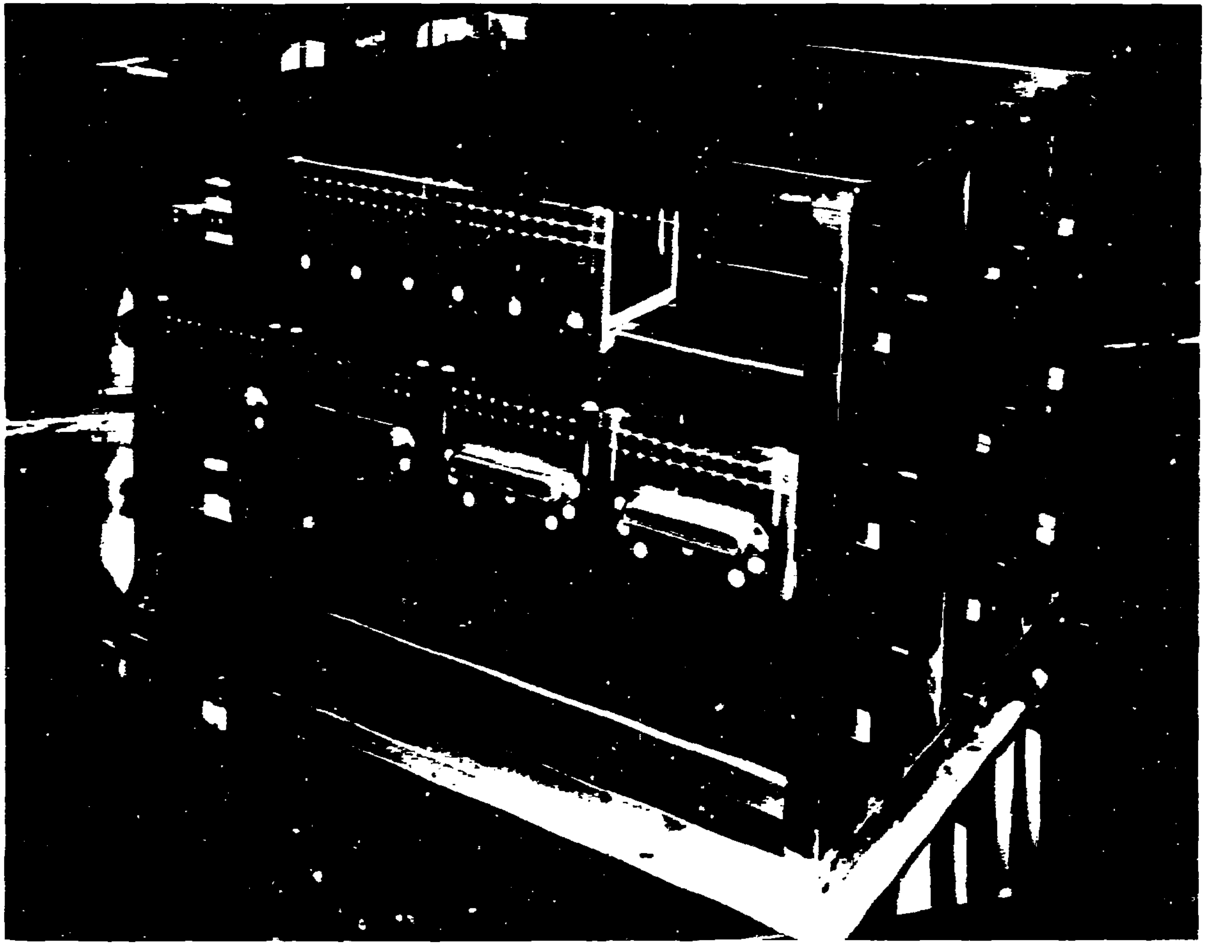


Figure 2 - Epoxy Glass Fixtures, Each Containing Ten Pin-and-Socket Contacts, Mounted on a Stainless Steel Stand

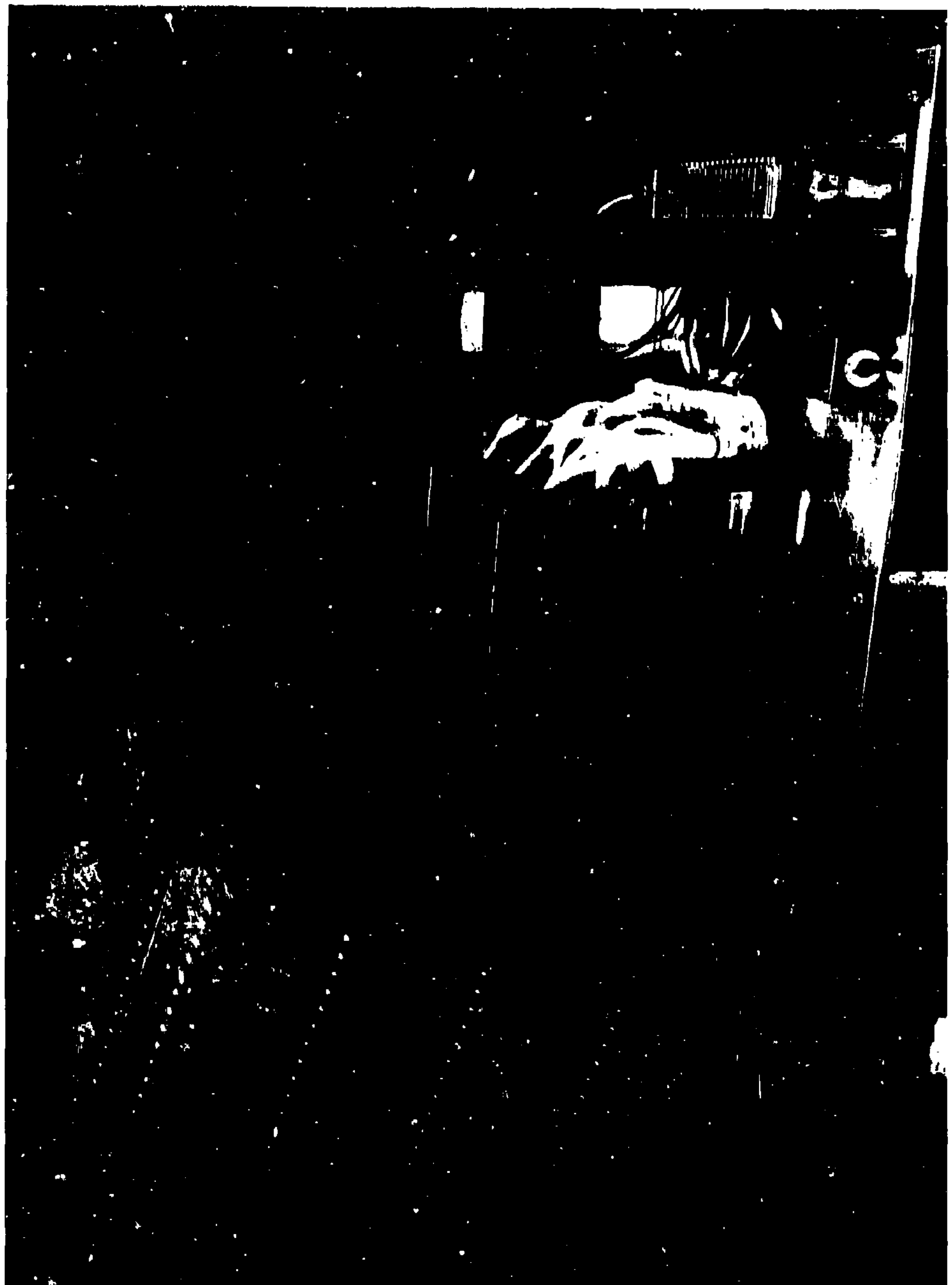


Figure 3 - Complete Wired Assembly with Keithley Model 502A Milliohmeter and 10-Position Swit

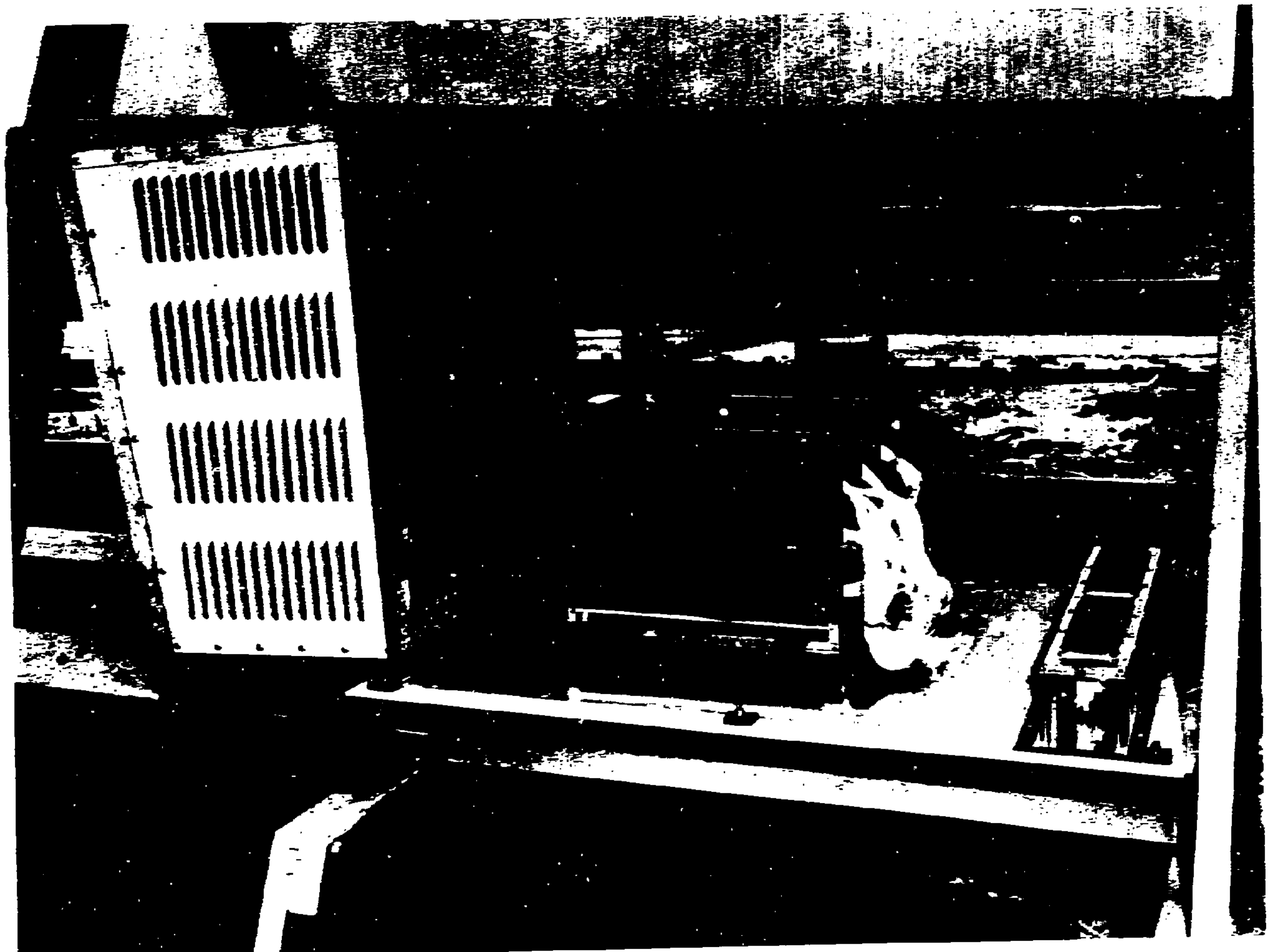


Figure 4 - Marine Environment Exposure Site at Ft. Tilden, New York, Showing Stevenson Screen (at Left) with Glass Wool Filter, and Stainless Steel Stand for Supporting Fired Assembly

Figure 5 - Stevenson Screen with Stainless Steel Mesh Screen Filter (see Figure 4)

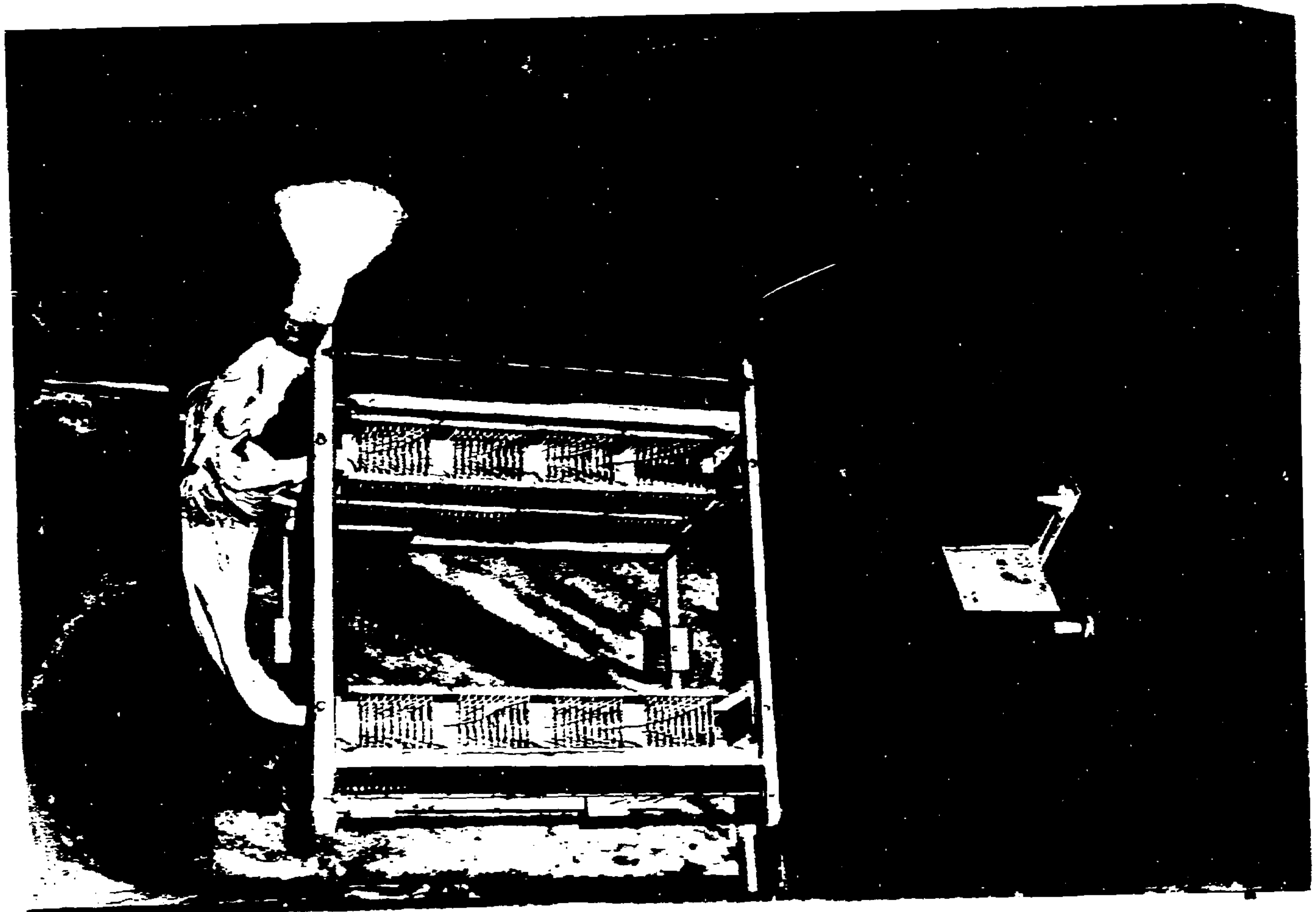


Figure 6 - Laboratory Salt Spray Exposure Environment (The Plated Contacts are Subjected to a 5% Solution Salt Spray Fog in the Tank)

Figure 7 - Average Contact Resistance Versus Time for No. 20 MIL-C-26636 Contacts Exposed in Marine Environment at Ft. Tilden after Initial Mating and after 100 Mating (Insertion-and-Withdrawal) Cycles

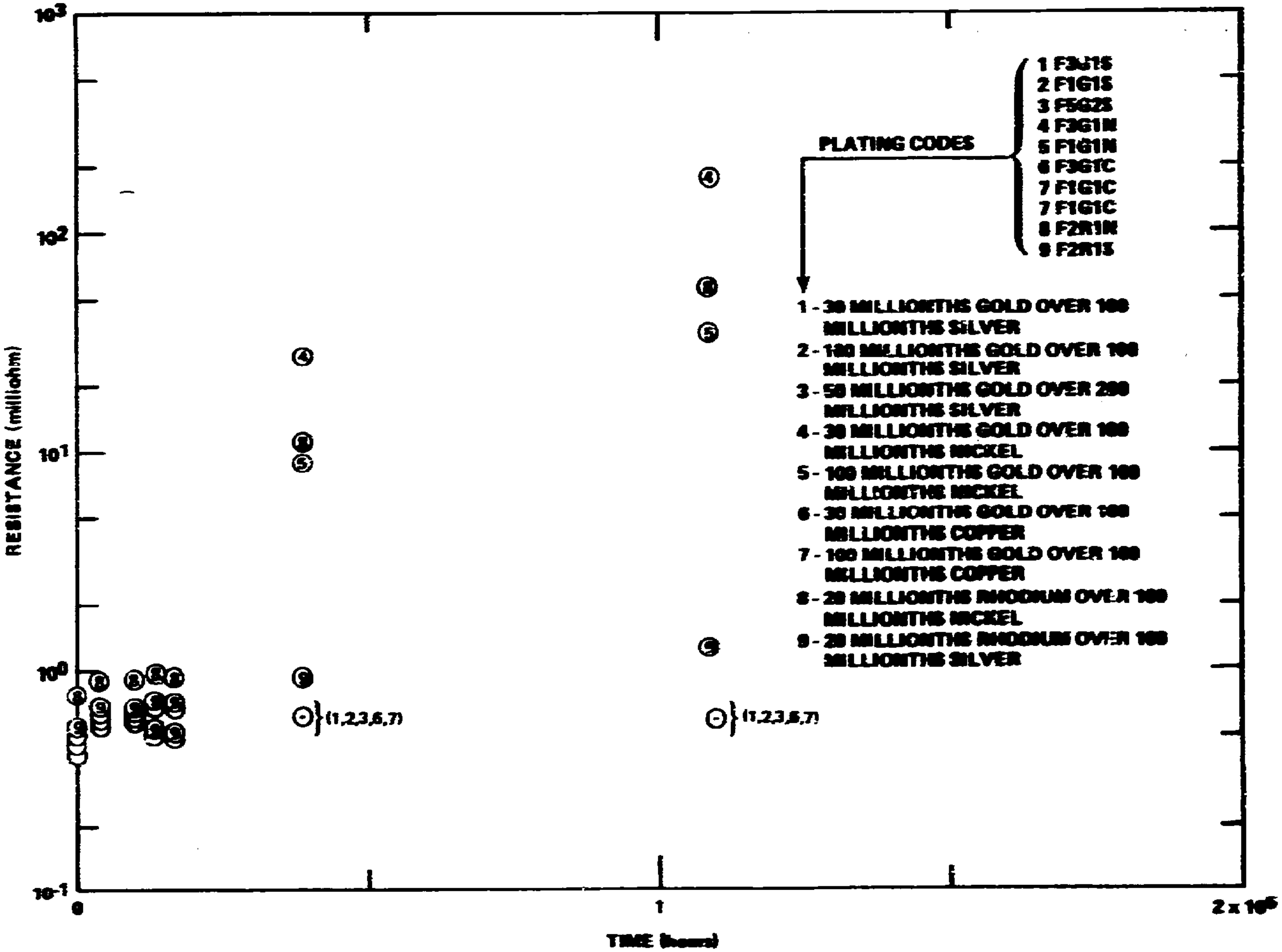


Figure 7a - After Initial Mating

Figure 7 (Continued)

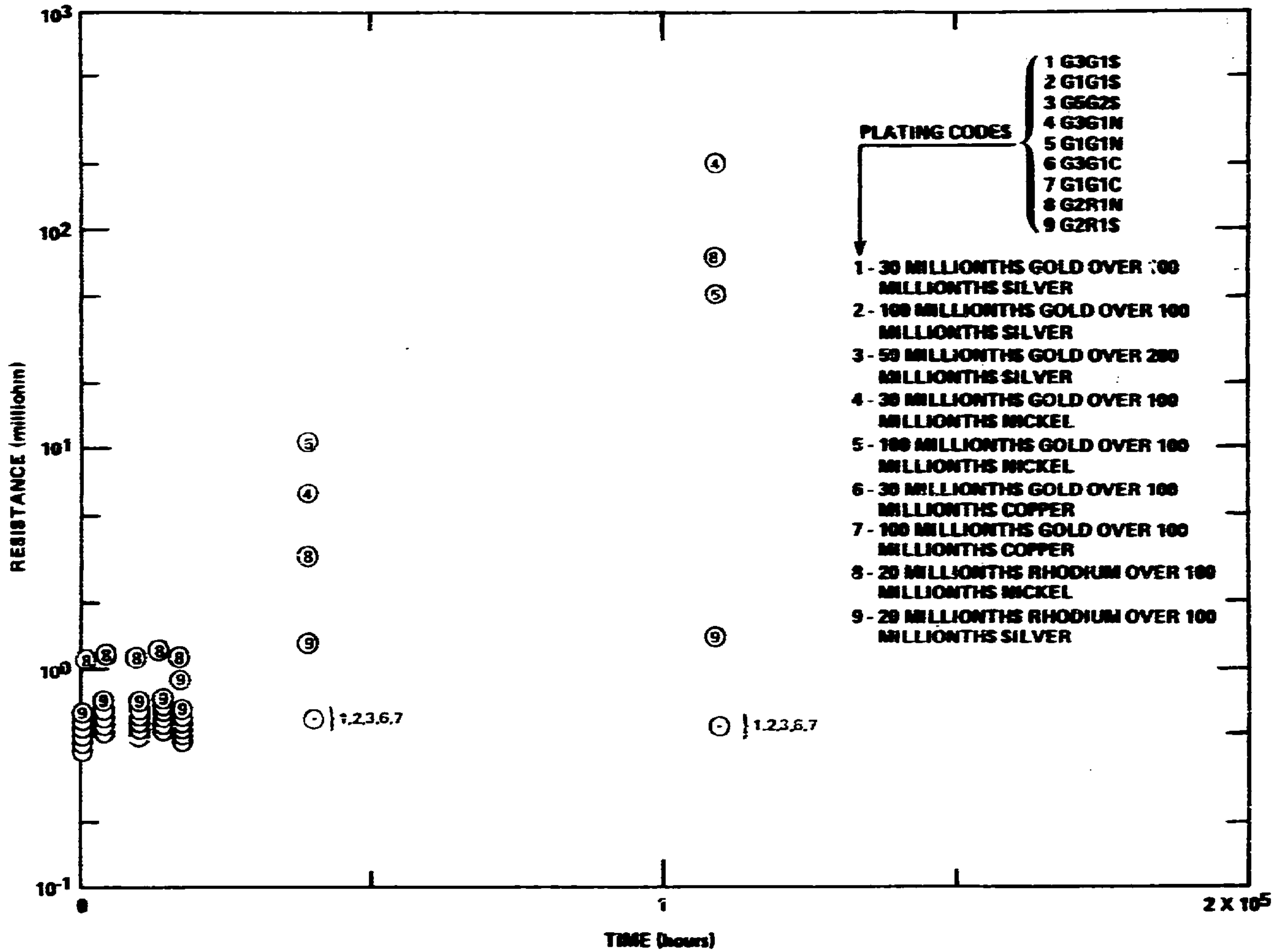


Figure 7b - After 100 Mating (Insertion-and-Withdrawal) Cycles

Figure 8 - Comparison of Marine and Laboratory Salt Spray Exposures of 30 Millionths Gold Over 100 Millionths Silver Plated Contacts after Initial Mating and after 100 Mating (Insertion-and-Withdrawal) Cycles

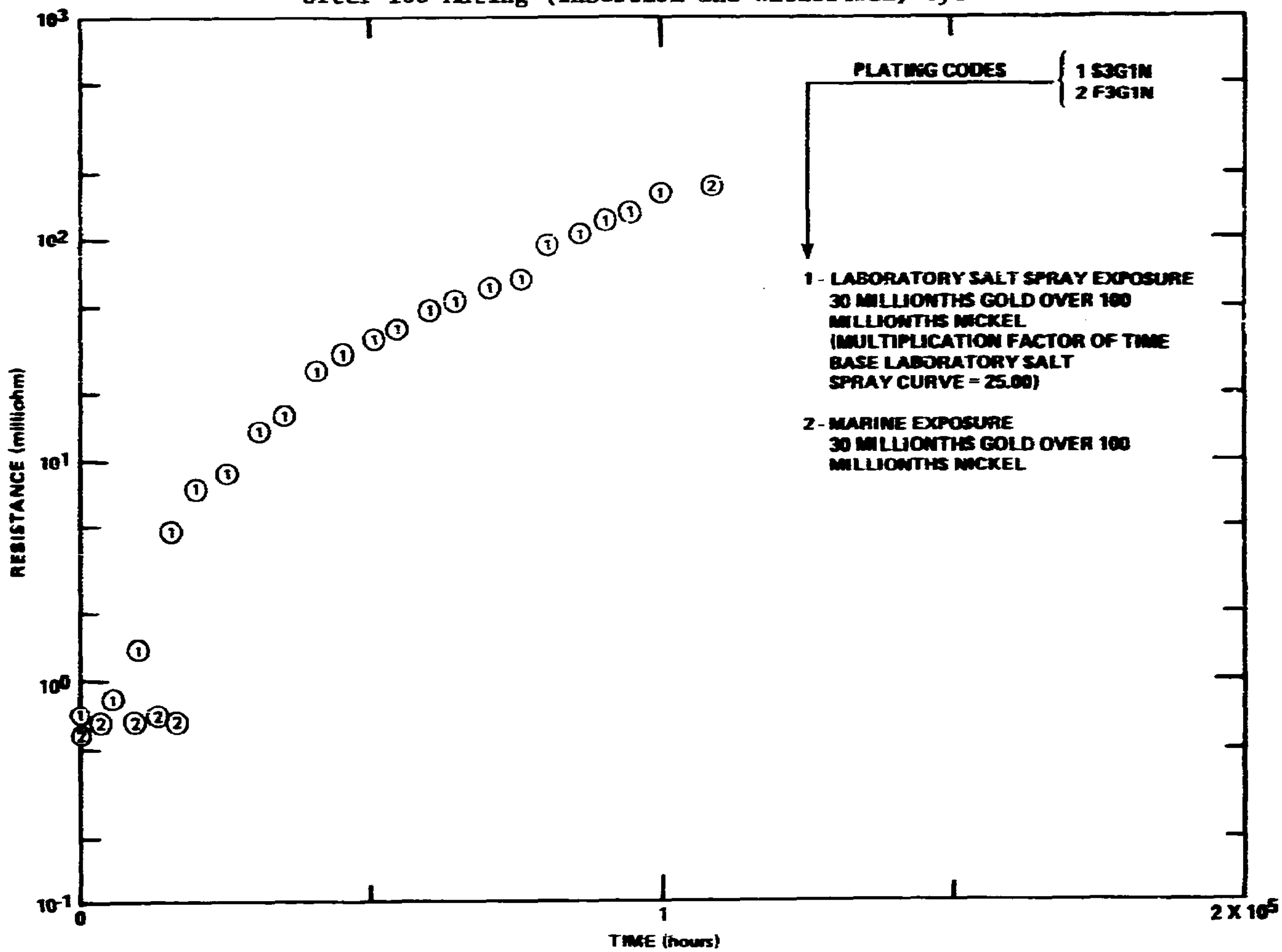


Figure 8a - After Initial Mating

Figure 8 (Continued)

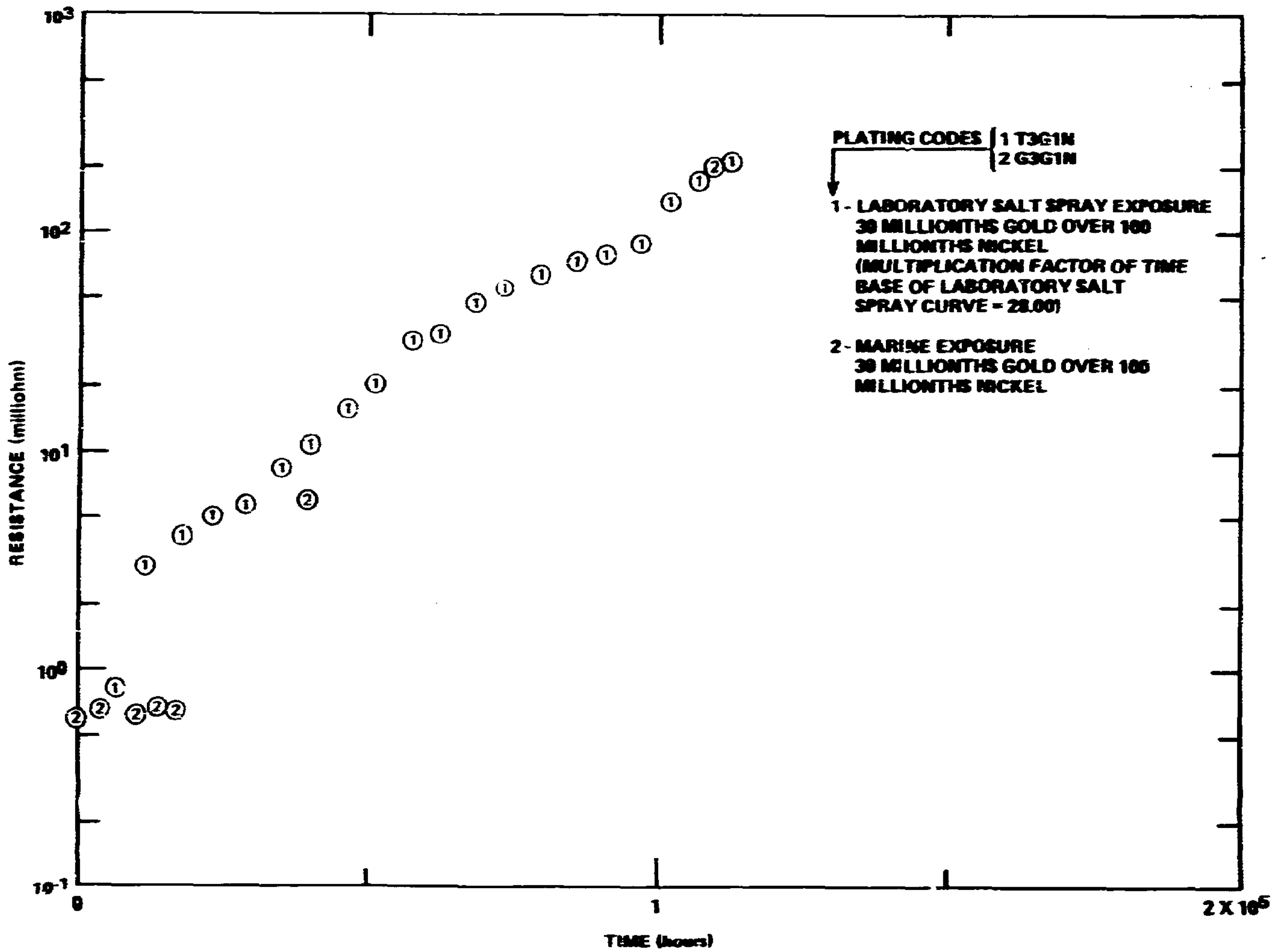


Figure 8b - After 100 Mating (Insertion-and-Withdrawal) Cycles

Figure 9 - Comparison of Marine and Laboratory Salt Spray Exposures of 100 Millionths Gold Over 100 Millionths Silver Plated Contacts after Initial Mating and after 100 Mating (Insertion-and-Withdrawal) Cycles

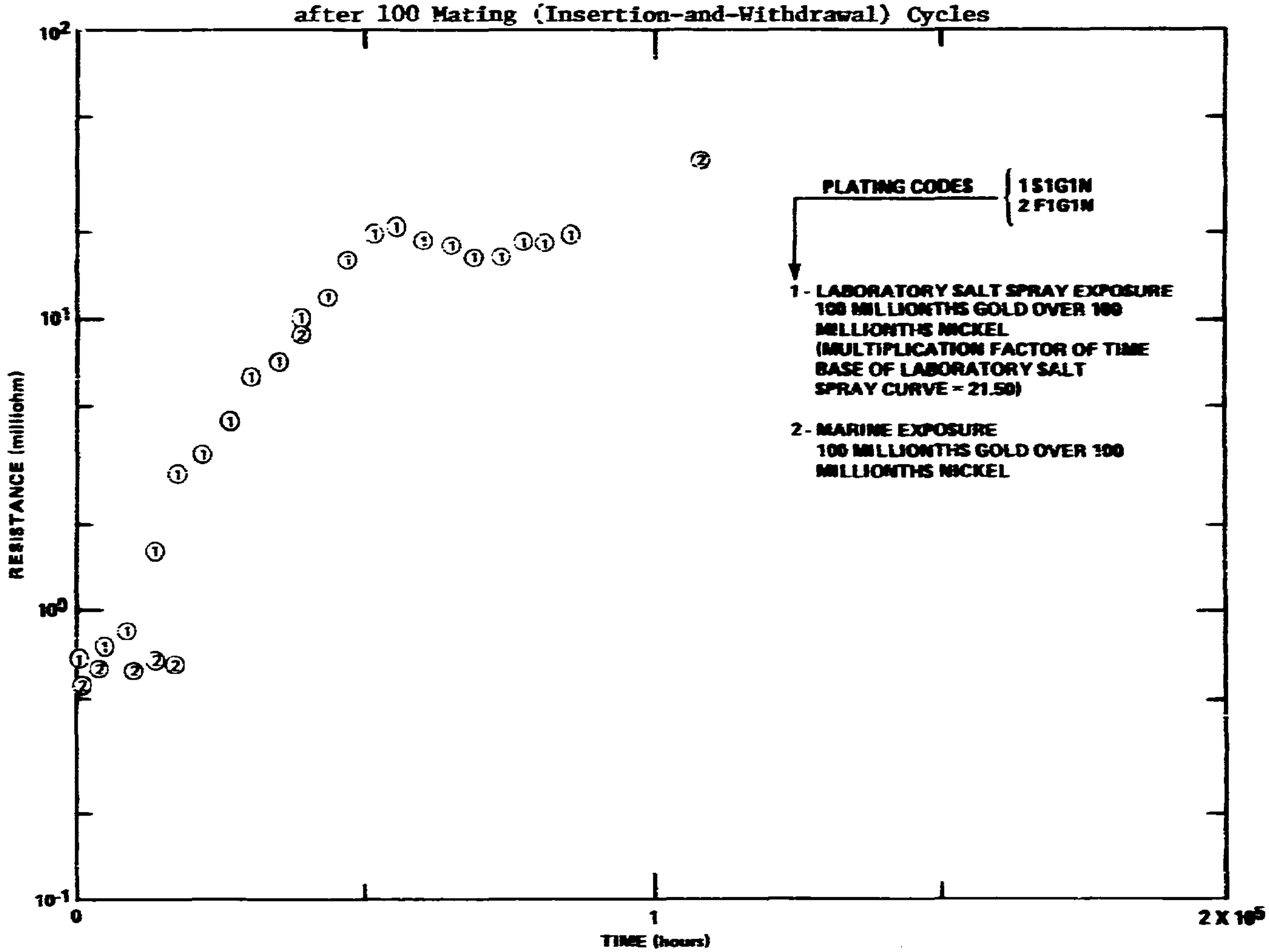


Figure 9a - After Initial Mating

Figure 9 (Continued)

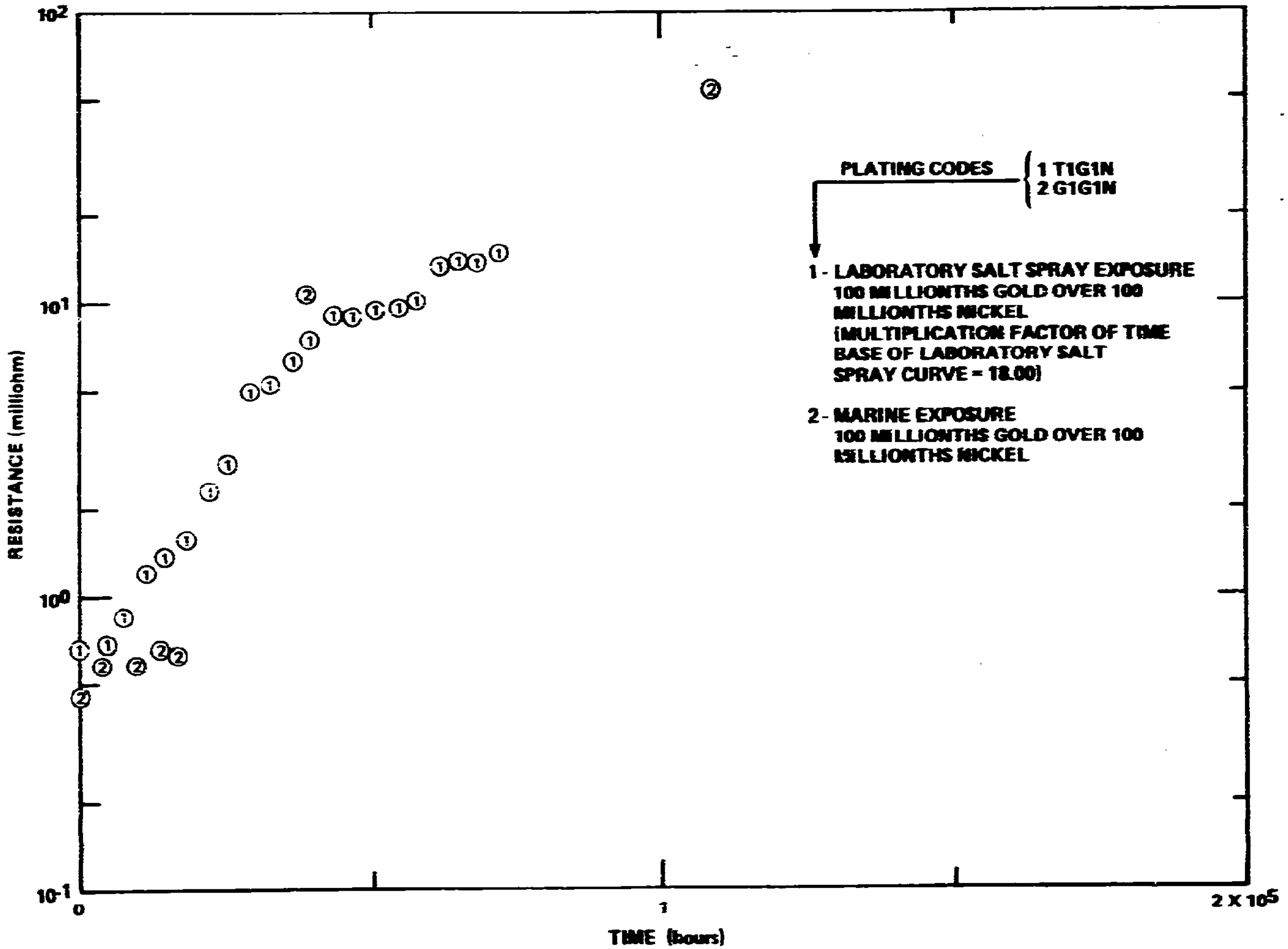


Figure 9b - After 100 Mating (Insertion-and-Withdrawal) Cycles

Figure 10 – Comparison of Marine and Laboratory Salt Spray Exposures of 20 Millionths Rhodium Over 100 Millionths Nickel Plated Contacts after Initial Mating and after 100 Mating (Insertion-and-Withdrawal) Cycles

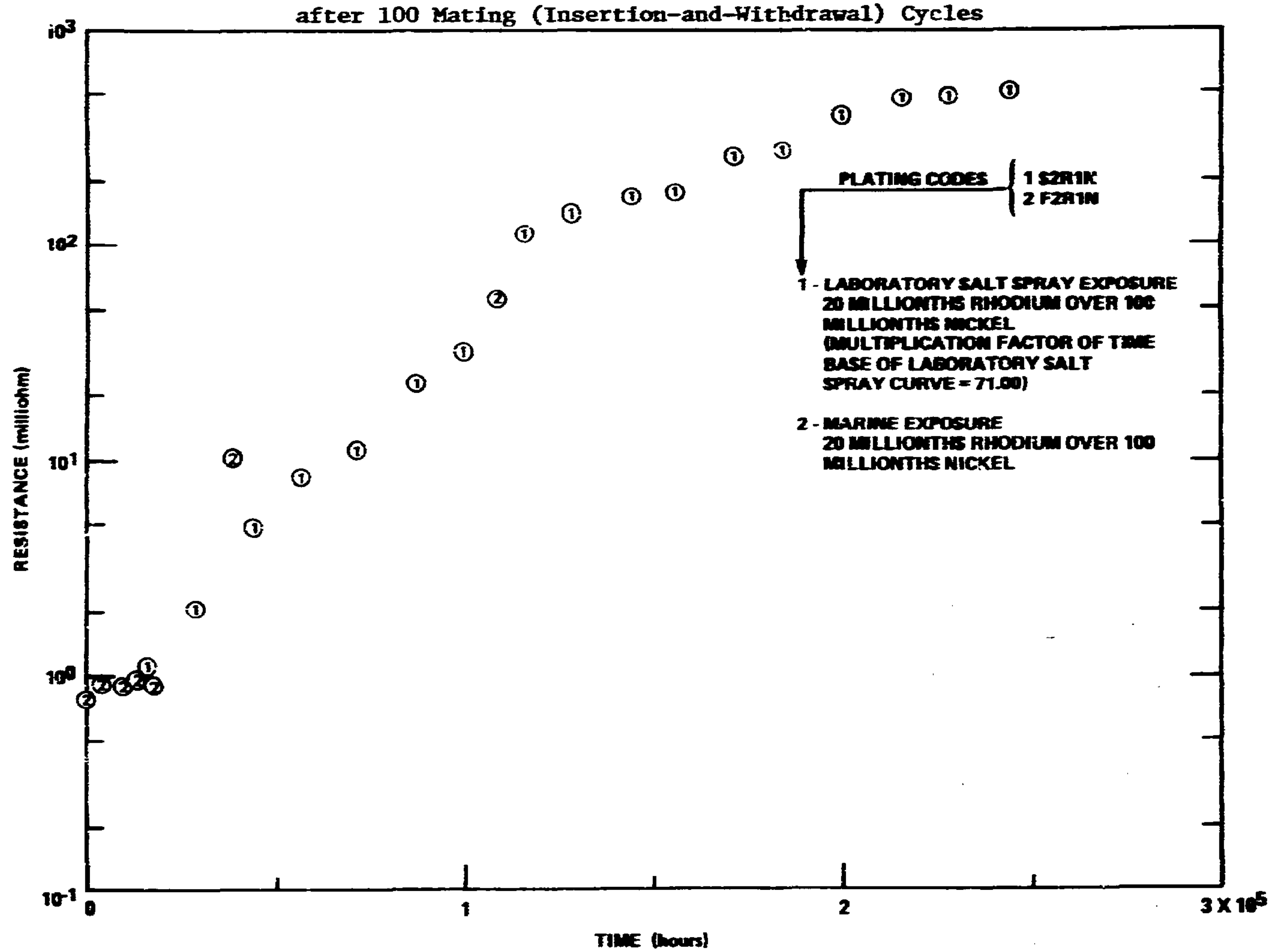


Figure 10a – After Initial Mating

Figure 10 (Continued)

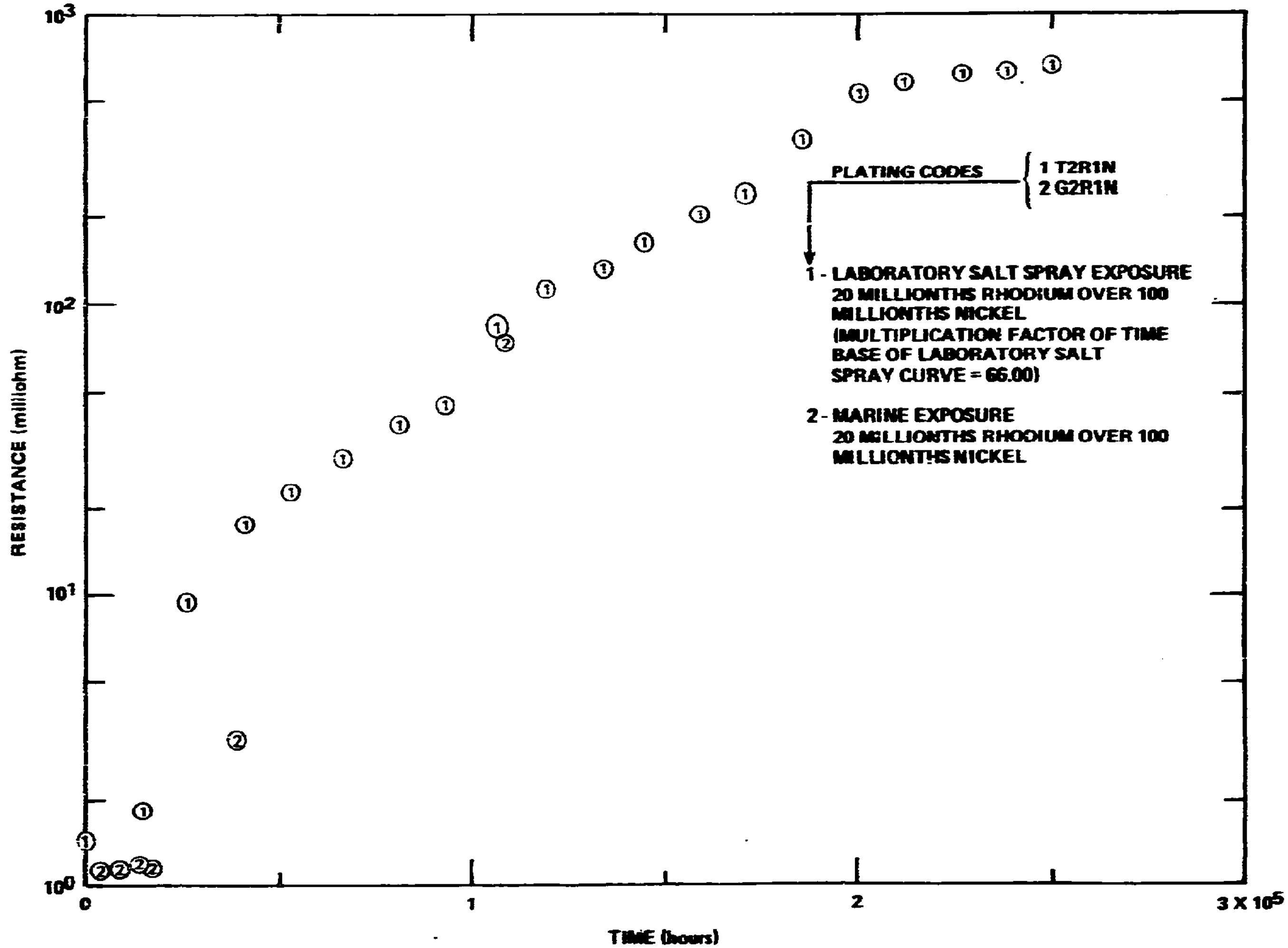


Figure 10b - After 100 Mating (Insertion-and-Withdrawal) Cycles

Figure 11 - Comparison of Marine and Laboratory Salt Spray Exposures of 20 Millionths Rhodium Over 100 Millionths Silver Plated Contacts after Initial Mating and after 100 Mating (Insertion-and-Withdrawal) Cycles

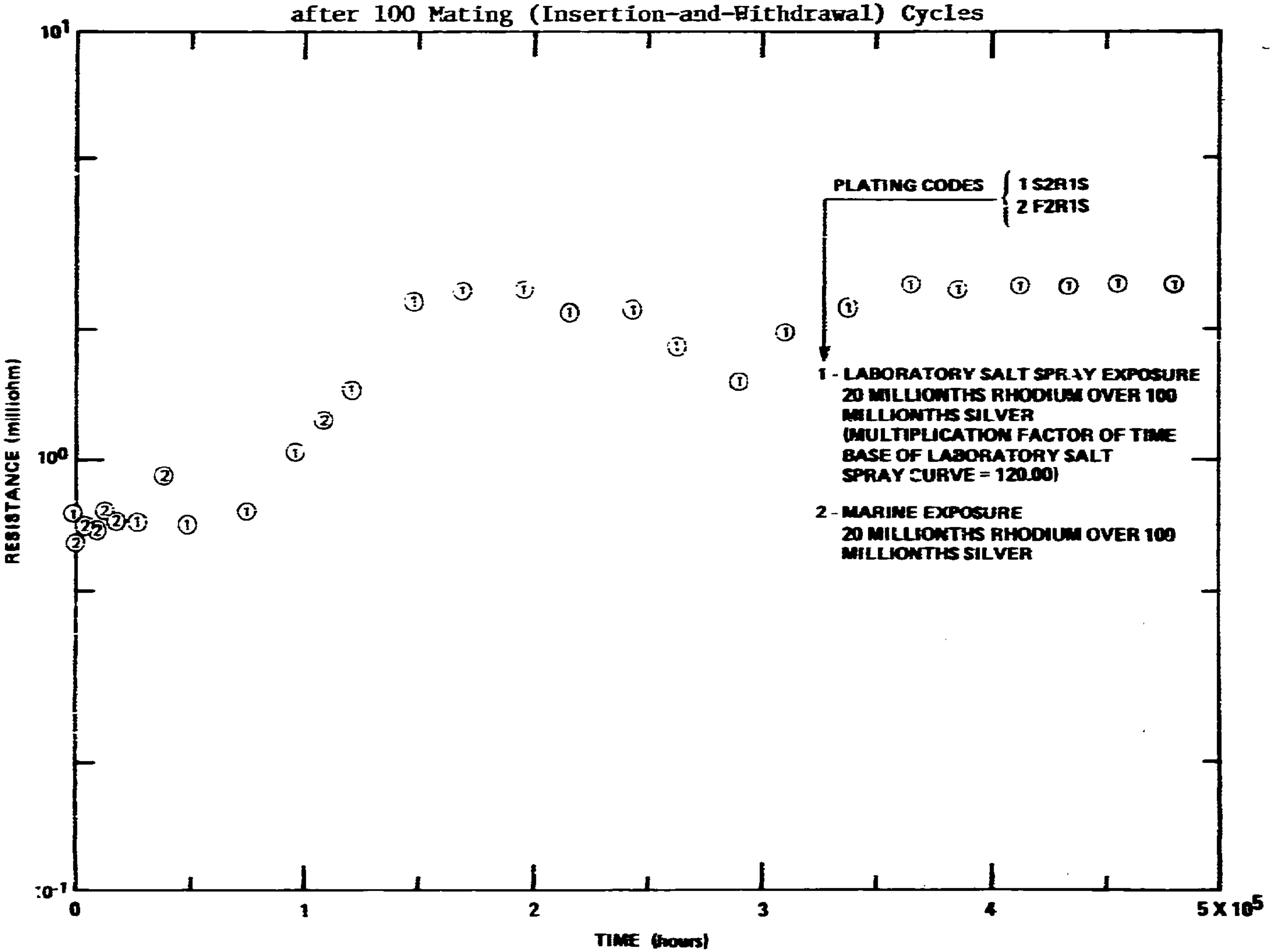


Figure 11a - After Initial Mating

Figure 11 (Continued)

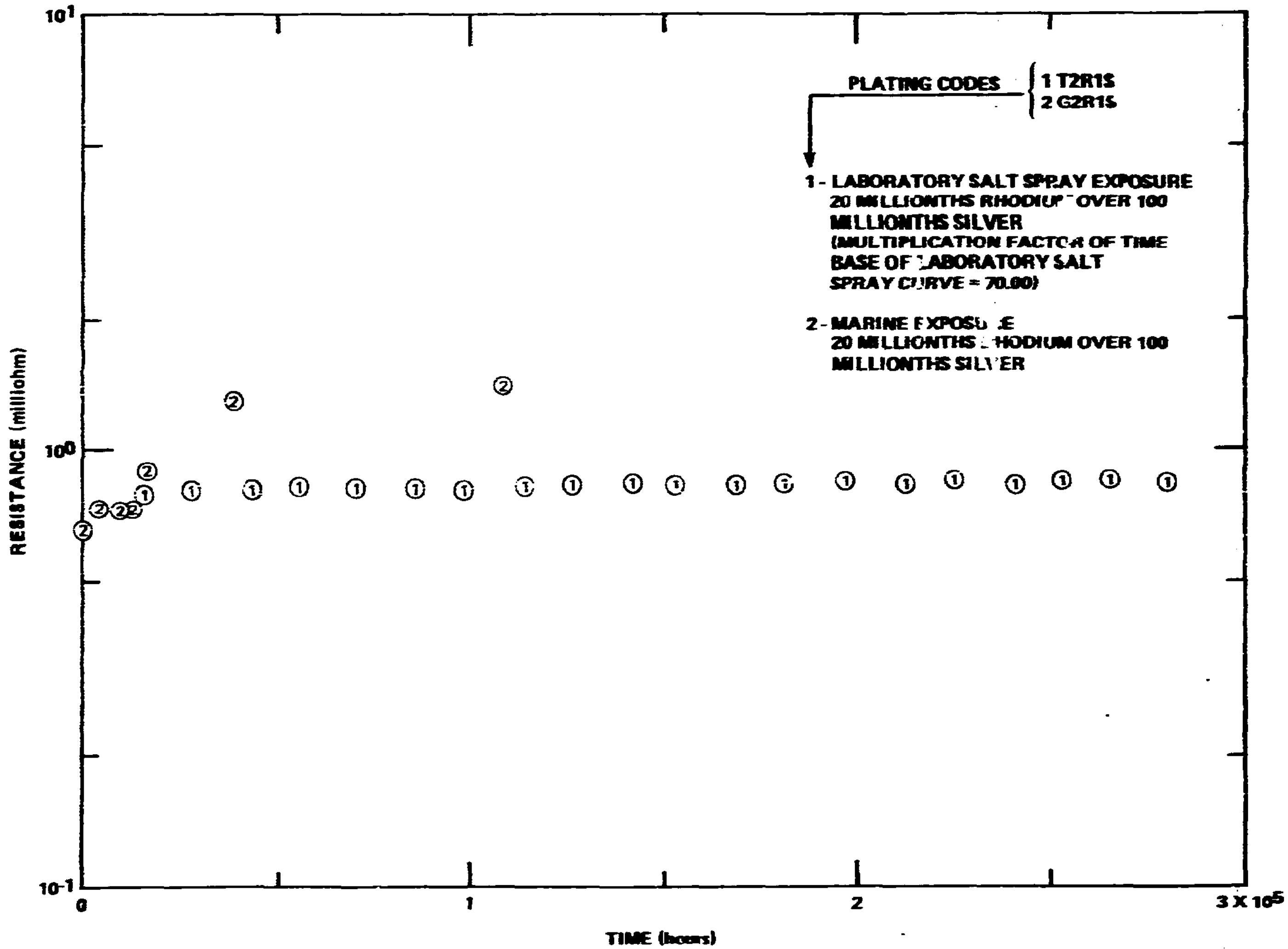


Figure 11b - After 100 Mating (Insertion-and-Withdrawal) Cycles

INITIAL DISTRIBUTION

Copies	
1	NAVELEX 50452/J. Kerr
2	NAVSEA 1 05R/A. Chaikin 1 543E/J. Regan
12	DDC
1	RADC/RBRAC I. L. Krulac
1	AMPHENOL CORP.
2	BELL TELEPHONE LABS 1 Dr. Morton Antler 1 Mr. Richard Baker

CENTER DISTRIBUTION

Copies	Code	Name
1	012	R. Allen
1	27	W. Dietz
10	2714	W. Kohlmann
10	5211.1	Rept Distribution
1	522.1	Uncl Library (C)
1	522.2	Uncl Library (A)

DTNSRDC ISSUES THREE TYPES OF REPORTS

1. DTNSRDC REPORTS, A FORMAL SERIES, CONTAIN INFORMATION OF PERMANENT TECHNICAL VALUE. THEY CARRY A CONSECUTIVE NUMERICAL IDENTIFICATION REGARDLESS OF THEIR CLASSIFICATION OR THE ORIGINATING DEPARTMENT.

2. DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, CONTAIN INFORMATION OF A PRELIMINARY, TEMPORARY, OR PROPRIETARY NATURE OR OF LIMITED INTEREST OR SIGNIFICANCE. THEY CARRY A DEPARTMENTAL ALPHANUMERICAL IDENTIFICATION.

3. TECHNICAL MEMORANDA, AN INFORMAL SERIES, CONTAIN TECHNICAL DOCUMENTATION OF LIMITED USE AND INTEREST. THEY ARE PRIMARILY WORKING PAPERS INTENDED FOR INTERNAL USE. THEY CARRY AN IDENTIFYING NUMBER WHICH INDICATES THEIR TYPE AND THE NUMERICAL CODE OF THE ORIGINATING DEPARTMENT. ANY DISTRIBUTION OUTSIDE DTNSRDC MUST BE APPROVED BY THE HEAD OF THE ORIGINATING DEPARTMENT ON A CASE-BY-CASE BASIS.