



Research and Development Technical Report
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CORROSION RESISTANCE OF ELECTRONIC PARTS

Charles P. Lascaro

May 1972

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT ECOM-3576

CORROSION RESISTANCE OF ELECTRONIC PARTS

by

Charles P. Lascaro

Magnetics, Instrumentation & Interconnections Technical Area
US Army Electronics Technology and Devices Laboratory

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13. ABSTRACT One of the design objectives of military electronic equipments is to withstand the degradation of humid tropical exposures. Corrosion provides a significant contribution to the failure mechanisms that can occur. This study correlates various laboratory humidity and salt fog acceleration tests with actual field exposure studies of electronic parts in the Panamanian jungle and at marine shore sites. Significant corrosion failure mechanisms are described and correlation with the field is provided by comparing laboratory exposed parts with field results to determine field service life. Acceleration factors are then calculated. Results show good correlation between shore exposures and various salt-fog tests. Parts exposed in the jungle begin to show significant corrosion and fungus growth in three years, while shore conditions provide significant corrosion in two years. Laboratory humidity tests have acceleration factors of 4h field days per laboratory test, while salt fog tests provide acceleration factors of 36-42.			

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BACKGROUND

One of the design objectives of military electronic equipments is to withstand the degradation of humid tropical exposures. Many study programs and tropical field experiences have shown that jungle and marine localities possess environments which produce corrosive failure mechanisms which contribute to electronic part and/or assembly failures. For many years, laboratory tests, such as the Moisture Resistance Test, Method 106 of MIL-STD-202, have been used to determine the resistance of applied protective designs, coatings, and finishes to tropical atmospheres. The moisture resistance test, however, was developed for use over twenty years ago and, at that time, it appeared suitable for designs and materials in usage. Since then, tropical field experience in Southeast Asia and improvement of parts, materials, and processes made possible the achievement of extended field service lives, maintenance cycles, and reliability performance which needed to be reflected in more effective and correlated laboratory test cycles. Many predicted service lives of parts or assemblies must be based upon known acceleration factors of laboratory testing. Recently, a fungus test per Method 508 and a salt-fog test per Method 509 of MIL-STD-810 were added to equipment specifications to assure increased fungus and corrosion resistance of parts, materials, and processes. The continued use of such tests, however, must be based upon their ability to predict field service life in short term accelerated laboratory exposure tests.

Various studies have been made to expose selected electronic parts, such as resistors, capacitors, inductors, etc., to seashore and jungle sites at the Tropic Test Center, Panama Canal Zone, and to selected accelerated laboratory test cycles which included moderated salt-fog conditions. This report reviews the previous background data, and completes the analysis of the correlated data, with special emphasis on the identity of the corrosion failure mechanisms that can occur for the purpose of providing a basis for a prediction of environmental reliability and service life capabilities of the parts, and correlation between the various accelerated laboratory test procedures performed. A special analysis is conducted of reduced salt-fog concentration test procedures.

SUMMARY OF 1958 STUDY

Initial efforts to correlate laboratory tests with tropical exposure had been conducted in 1958.¹ Selected electronic parts had been exposed to jungle and seashore conditions at Galeta Point, Tropic Test Center, Panama Canal Zone, for periods up to eighteen months. Figure 1 shows a summary of the number of failures obtained for each type of part at each location. A comparison of the shore and shady jungle columns under the heading, "Field Results," shows a preponderance of failures occurring at the shore site, except for paper capacitors. Inasmuch as the average relative humidity is lower at the shore site due to the characteristics of this type of site, the larger number of failures could only be explained by an additional degradation factor which was salt vapour from the ocean.

Failure analysis of results in the field showed that lead wire corrosion was extensive with many open-lead wire failures occurring. End seal migration and case corrosion products were prevalent. Except for open-lead failures, corrosion was not a major factor in electronic failure rates that occurred.

As part of the study program, an attempt was made to duplicate these types of failures in the laboratory, using Method 106 of MIL-STD-202 and some modification thereof, including various adaptations of a salt spray test from ASTM B117-54T, with various percent salt solutions, as follows:

Accelerated Laboratory Test Procedure Variations

- I 20 cycles, Method 106.
- II 1, 3, 5, 7, 9, 11, 15, 17, 19 cycles of Method 106;
2, 4, 6, 8, 10, 12, 14, 16, 18, 20 of 20% Salt Spray.
- III 20 each of a 22-hour Method 106 cycle; plus each cycle including 2 hours of 5% Salt Spray.
- IV 18 cycles, Method 106; and 5th and 15th cycles 2 hours of 5% Salt Spray included.
- V 15 cycles Method 106; and, 1st, 4th, 8th, 11th, and 16th cycles 5% Salt Spray.
- VI 20 each 24-hour cycles of: 22 hours Method 106,
2 hours 3% Salt Spray.

Column 1 of Fig. 1 shows that except for composition potentiometers, twenty cycles of Method 106 failed to reproduce field failure rates or types. Most of the variations of Method 106, plus a salt spray condition, provided accelerated factor rates beyond that produced in the field for each site. Variation IV appeared to be close to results obtained at the shore site in the field.

Predicted service life was 1400 days for a shady jungle site and acceleration factor for one temperature-humidity laboratory test cycle was 70, depending upon part design. Estimated acceleration factors of Test Variation IV over the bench site ranged from 10 to 130. A life of 200 to 2600 days was calculated for four parts exposed at the shore site.

SUMMARY OF 1968 STUDY

In 1968, this work was continued on a newer family of subminiature parts.² Here again, eighteen selected parts were exposed at a jungle site and a seashore site for three years and these results compared to the following tests:

Accelerated Laboratory Test Cycling

1. 20 days, Method 106B, MIL-STD-202, Humidity Test.
2. 20 days, 1% Salt-Fog at +60°C.
3. 20 days, steady state Moisture Resistance at +90°C and 90% RH.
4. 20 days, 0.5% Salt-Fog at +50°C.

The units exposed in the field study were exposed with or without a polarizing potential. This potential is present in normal equipment operation and tends to accelerate certain corrosion processes. The absence of polarity simulates standby or storage conditions. The following parts were exposed:

<u>Abbreviated Code</u>	<u>Type Part</u>
CK	Ceramic Capacitor
CL	Fixed Tantalum Capacitor
CM	Mica Capacitor
CS	Solid Tantalum Capacitor
CT	Mylar Capacitor
MF	Metal Film Resistor
KC	Fixed Ceramic Capacitor
RC	Carbon Composition Resistor
RS	Variable Resistor
RL	Fixed Tin Oxide Resistor
RN	Film Resistor
RO	Fixed Carbon Resistor
RW	Wirewound Resistor
TA	Fixed Tantalum Capacitor
VC	Variable Ceramic Capacitor
VI	Inductor
VK	Fixed Ceramic Capacitor
WE	Fixed Inductor

For this report, only corrosion mechanism observations will be analyzed and compared with laboratory tests. Electrical data analysis will be continued and reported subsequently.

DATA PRESENTATION

1. During periodic field trips to Panama, observations were made of the corroded condition of the parts. These observations were accomplished after periods of exposure of 7, 24, 36 months. The data obtained at each of these times represent a time-related degradation level and, therefore, are eligible for use as a partial basis for rating each part's reliable service life capability in the field. Since these same parts were tested in the laboratory under two

humidity and two salt-fog tests, the data can also be used to estimate acceleration factors obtained for each test.

2. Based upon field observations and failure mechanism analysis, each corrosion failure mechanism obtained is hereby given, in addition to its contribution or significance to electronic part failure:

a. Lead wire corrosion (LC): Lead wires are normally plated or tinned copper wires. A few are copper-clad steels. Principal constituents are usually tin-lead or tin over copper, nickel-tin-magnesium, copper-silver, or nickel-copper. Corrosive atmospheres first tarnish coatings or platings and progressively attack the basis lead wire metals via pin hole or anodic corrosion processes. It is reasonable therefore, to grade extent of corrosion by the following code:

Rating

0	No corrosion	
X	Grey or tarnished plating	Fig. 2
XX	Grey leads plus black spots	Fig. 3
XXX	Grey, black and/or green encrustation	Fig. 4
- - - - - Failure Level - - - - -		
XXXX	Grey, black, green with necking	Fig. 5
XXXX(F)	Above corrosion with open leads	Fig. 6

Inasmuch as the part assemblies are subject to shock and vibration in the field, potential failure could occur at the XXX level or higher.

b. End seal migration (ESM): Applied circuit voltage polarities can cause migration of corrosion products over insulating end seals with resultant loss of insulation resistance and increase of wettability during condensation. A previous report on this subject³ established that lack of adequate filletting design of bushings (to prevent accumulation of contamination in inside corner designs) provided a corrosion failure mechanism which necked the leads adjacent to the part body and also deposited corrosion products over the surface of the insulated parts, thus shunting the resistance of the part (Fig. 7).

c. Solder corrosion (SC): Grey lead carbonate usually caused by residual flux contamination deposited by the part manufacturer. Lead-rich solder dips may also cause such corrosion products.

d. Silver migration (SM):⁴ Any silver platings or elements under conditions of direct current polarity and moisture will migrate through porous or filled plastic insulation and eventually cause short-circuit failure. Silver migration is usually invisible until catastrophic short-circuit failure occurs (Fig. 8).

e. Case corrosion (CC): Metallic cases can corrode and contribute to migrating corrosion products. Since cases usually carry identification, corrosion may mean loss of part identification (Fig. 9).

f. Plastic erosion (PE): Apparently, some plastic compositions are subject to chemical or fungus attack during tropical exposure. Salt exposures and voltage polarities accelerate this condition. Erosion may mean greying or dulling of surface with loss of identification, or deep erosions which bare part elements (Fig. 10).

g. Element corrosion (EC): Moisture absorption through protective coatings may cause corrosion of metallic end caps, terminal connections, ferrite rusting, contact corrosion, stress corrosion, plating corrosion; these increase part resistance or contribute to reduced performance (Fig. 11).

h. Electrolytic corrosion (ELC): Such corrosion may occur due to metallic couples of part elements within the part and can accelerate couple corrosion and catastrophic failures as open or short circuits, depending on the type of mechanism (Fig. 12).

i. Fungus growth (FG): The presence of fungus growth is considered a contributor of surface contaminants and corrosion electrolytes. The presence of fungus growth is also an indication that cleaning and maintenance of the assembly is due (Fig. 13).

3. The number of 18 part groups which exhibited significant occurrences of the above failure mechanisms after 7, 24, and 36-month exposures is shown in Fig. 14, 15, 16. Each test lot for each condition listed numbered 25. Figures 17, 18, 19 and 20 show the distribution of each failure mechanism with respect to location and exposure time. An indication of (F) beside any failure mechanism indicates that the part failed due to the mechanism alone.

4. The data and observations from the four accelerated laboratory tests are shown in Fig. 21. The calculation of equivalent field service life and acceleration factors are shown in Fig. 22 and 23. The data in Figure 22 shows the Equivalent Field Service Life, which each laboratory test cycle was capable of reproducing after 20 days of laboratory exposure. This was obtained by matching the terminal laboratory test result with each of three field test results at 10, 24, and 36 months. The acceleration factors in Fig. 23 were obtained by dividing each equivalent service life time in Fig. 22 by 20, since each laboratory test was conducted for that period.

DISCUSSION OF DATA

1. Failure Mechanisms: The failure mechanisms of electronic parts which were exposed in field tropical conditions and contributed to part degradation are as follows (listed in order of severity and showing the number of part groups which were susceptible):

	<u>Jungle</u>		<u>Shore</u>		<u>Total</u>
	<u>NP</u>	<u>P</u>	<u>NP</u>	<u>P</u>	
Lead Wire Corrosion	1	1	6	7	15
End Seal Migration	1	1	6	9	17
Plastic Erosion	2	2	4	4	12
Element Corrosion	2	3	3	4	12
Fungus Growth	8	6	4	5	23
Electrolytic Corrosion	2	3	3	4	12
Solder Corrosion	2	2	1	4	9
Silver Migration	1	2	0	2	5
Case Corrosion	1	1	1	1	4

The above numbers are the sum of each of 18 different type parts which exhibited failure mechanism effects as described to significantly affect electronic performance. All of these mechanisms were capable, in time, of contributing to catastrophic failures. Each of the above failure mechanisms could have been prevented by proper choice of materials and part design as follows:

- Lead Wire Corrosion: Use of two part pin-hole free plating of adequate thickness. Avoid couples, and poor filleting or end seal designs.
- End Seal Migration: Avoid or minimize corrosion of case or lead wire and right angle fillets design.
- Plastic Erosion: Use of inert and salt resistant plastics.
- Element Corrosion: Protect elements by adequate plating. Plastic coatings are not complete barriers to moisture entry.

Fungus Growth: Protect part surface from outside contaminants. Periodic maintenance at every one to two years may be necessary.

Electrolytic Corrosion: Avoid excessive couples in part design.

Solder Corrosion: Use approved fluxes, clean all residues, avoid lead-rich baths.

Silver Migration: Do not use silver electrodes in parts with filled or porous insulation where moisture may penetrate and direct current polarities may occur.

Case Corrosion: Provide adequate plating or coating protection for any metallic case.

2. Tropical Field Service Life: The progression of corrosion effect on the parts studied indicate that part failures can be expected to become significant factors in the operation of equipment assemblies as follows:

Jungle: 3 years
Shore: 2 years

3. Maintenance Field Life: To assure extended and continued service life in the field, maintenance is necessary to remove corrosion products and such contaminations as fungus growth. Maintenance periods should be selected to preclude the failures occurring in the next time period.

4. Acceleration Factors: By matching the results obtained in each laboratory test cycle and the corrosion results of parts exposed in the field, the following acceleration factors can be estimated:

Test	Jungle	Shore
Method 106, MIL-STD-202:	43.9	none
1% Salt Fog :	not significant	41.5
0.5% Salt Fog :	not significant	35.6
90°C Humidity :	50.1	none

Because the 90°C humidity test provided a large number of catastrophic failures not obtained in field testing, this test should not be considered for accelerated testing.² Its effectiveness, however, shows that temperature rate factors are profound and test temperatures should be raised as high as practical to increase degradation and acceleration factors. Method 106 provides no corrosion correlation with shore conditions and, inversely, neither of the salt-fog tests provide correlation with jungle degradation factors. On this basis, neither test should be substituted for the other. The 0.5% Salt-Fog

test provides some desirable mitigation of severe corrosive effects. It may be possible that as the salt content is lowered further and with higher temperature use, a workable combination test may eventually be obtained. Lead necking, end seal migration, and plastic erosion failures require salt contamination to produce these failures.

5. Comparison of Studies: A comparison of the two studies reveals the following approximate data:

	<u>Field Service Life</u> (days)	<u>Acceleration Factor</u> (field days/TH day)
<u>1958 Study</u>		
Jungle	11,000	Method 106 = 70
Shore	200 - 2600	TH SF Var. #IV = 10 - 130
<u>1968 Study</u>		
Jungle	880	Method 106 = 44
Shore	720 - 810	TH SF Var. = 36 - 42

Considering the approximations made in reaching the above data, it is considered that the two studies corroborate one another.

6. Long Term Effects: Certain degradative processes require long-term exposure and, therefore, are not correlated by short-term tests. These are element corrosion, fungal growth, and silver migration. Corrosive processes are usually not severe in humidity tests unless salt and direct current voltage stresses are present. The appearance of even slight corrosion in laboratory humidity tests should be a basis for failing a part and requiring improved finishes.

CONCLUSION

1. Failure Mechanisms: Electronic parts exposed to tropical environmental conditions are subject to failures because of the degradative influence of the following corrosion, erosion, and fungal effects:

- a. Lead Wire Corrosion
- b. End Seal Migration of Corrosion Products
- c. Plastic Erosion Due to Salt and Moisture Attack
- d. Element Corrosion Due to Moisture Ingress
- e. Fungal Growth and Surface and Plastic Degradation
- f. Electrolytic Corrosion Due to Galvanic Couples in the Parts
- g. Solder Corrosion Due to Flux Contaminants
- h. Silver Migration Due to Use of Silver and Porous or Filled Plastic Insulation
- i. Case Corrosion Due to Poor Finishes

Preventative techniques are recommended within this report and other referenced literature and most are within current state-of-the-art techniques. The

field service life and maintenance time recommended below are applicable to parts used in louvered cases open to outside contaminations. Protection by containing the assembly in sealed cases capable of maintaining dry clean internal conditions would extend service lives and minimize maintenance factors considerably.

2. Tropical Field Service and Maintenance Life: Terminal degradative corrosion effects can be expected during the following exposure periods. Maintenance procedures are recommended prior to irreversible corrosion or fungal growth effects:

	<u>Field Service Life</u>
Jungle	3 years
Shore	2 years

3. Acceleration Factors: Laboratory test conditions provide the acceleration shown in Paragraph 5 of Discussion of Data above. Method 106 provides no correlation with serious corrosive effects obtained at the shore or marine conditions. Salt-fog tests do provide correlation and significant acceleration. High temperature, high humidity tests are harsh and do not correlate well with field conditions. Salt fog testing is necessary for electronic assemblies, if corrosion prevention is required in tropical environments.

4. Long Term Degradative Effects: Accelerated laboratory testing, in periods of ten to twenty days, do not reproduce long-term failure types, such as element corrosion, fungal growth, silver migration, and severe lead wire corrosion with necking and/or open circuits.

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Dr. C. R. Southwell, Scientist in charge, Naval Corrosion Test Laboratory, NRL, Panama Canal Zone, for technical assistance in the field.

Part	Field Results			Acceleration Laboratory Test Results					
	Shore	Shady Jungle	Open Jungle	I	II	III	IV	V	VI
Resistor, Composition	3/10*	0/10	0/10	0/10	0/20	0/20	1/20	0/20	
Resistor, Hero-Carbon	2/10	1/10	2/10	0/10	20/20	20/20	10/20	10/20	10/20
Capacitor, Paper	5/20	12/20	0/20	0/20	10/20	7/20	3/20	5/20	
Capacitor, Glass	14/20	2/20	3/20	0/20	17/20	20/20	16/20	20/20	
Potentiometer, Composition	7/20	5/20	1/20	9/20					

Data Legend
* A/B: A = Number Failures, B = Number Tested

Data taken from Final Summary Report, Contract DA36-039-56-045, 8, "Laboratory Test Procedures for Predicting the Tropical Service Life of Electronic Components and Materials."

Fig. 1 - Summary of "Field Data" and "Acceleration Data"

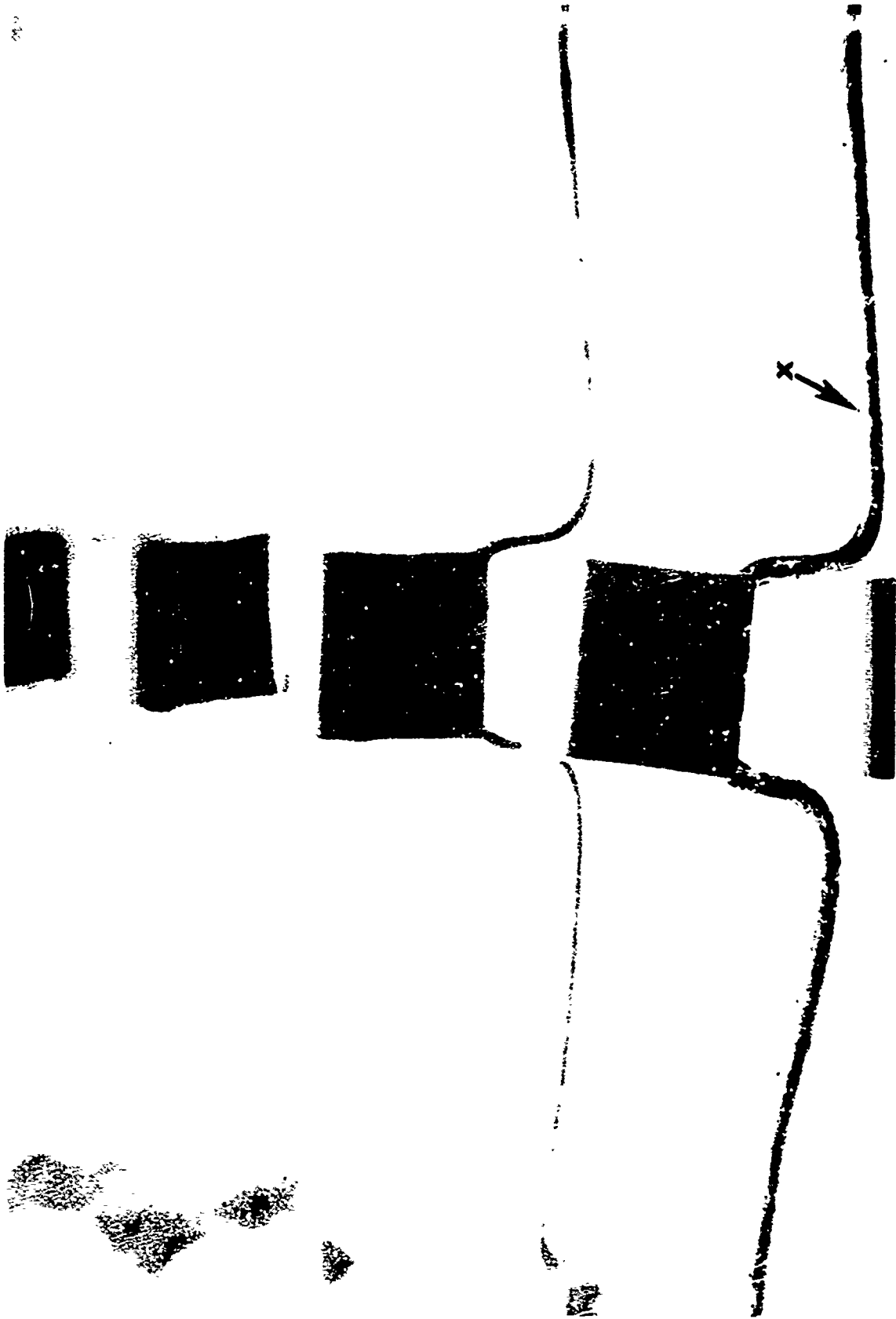


Figure 2
X = (··) or tarnished plating

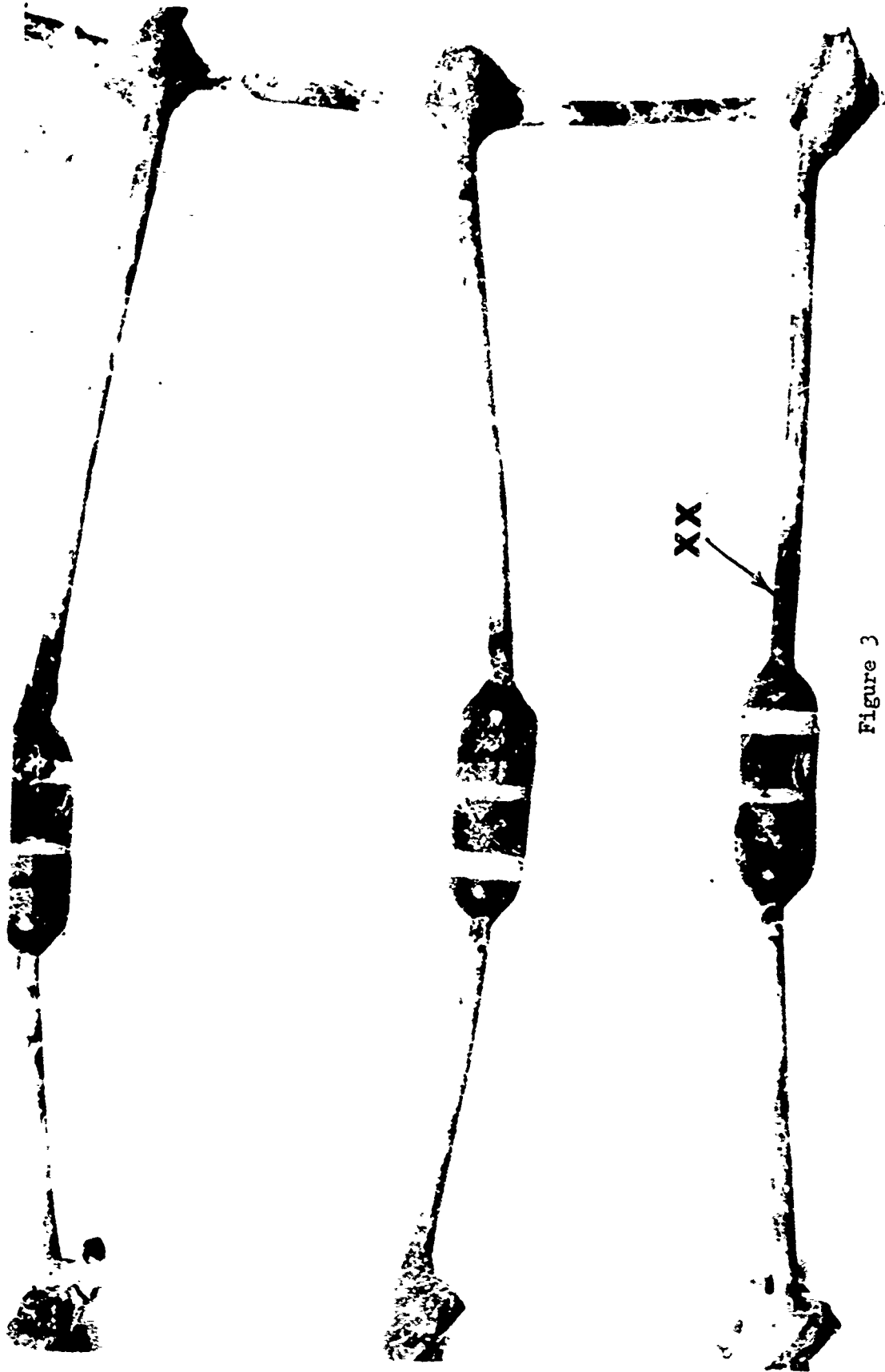


Figure 3

XX = Grey plus black spots

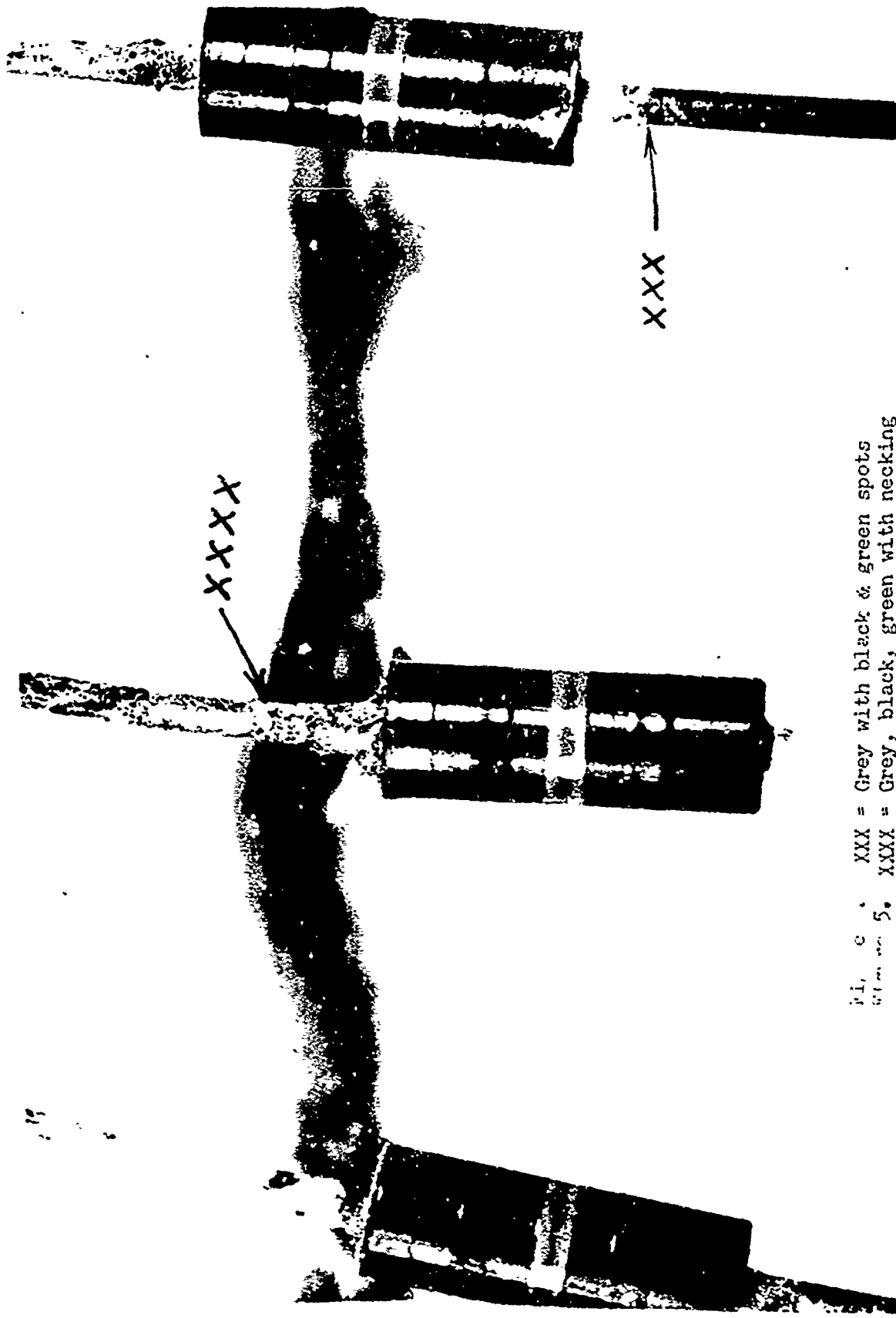


Fig. 5. XXX = Grey with black & green spots
XXXX = Grey, black, green with necking

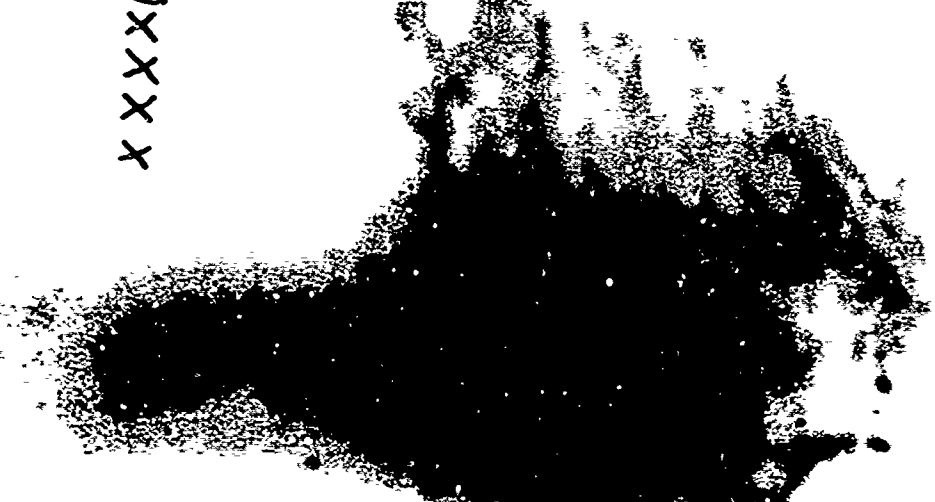
RN60C



RN00C

1002F

XXXX(F)



1002F

Figure 6

XXXX(F) Corrosion with open leads

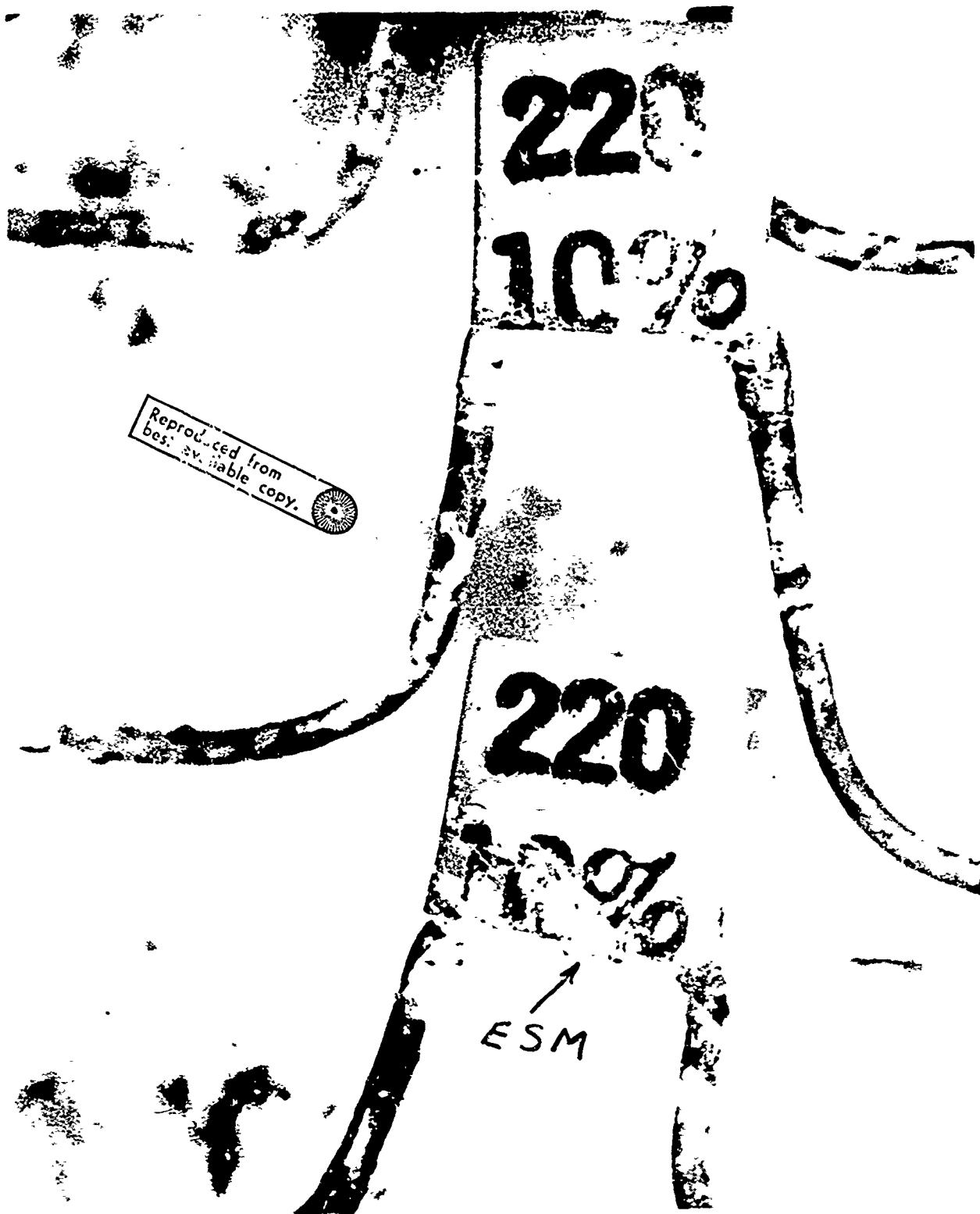
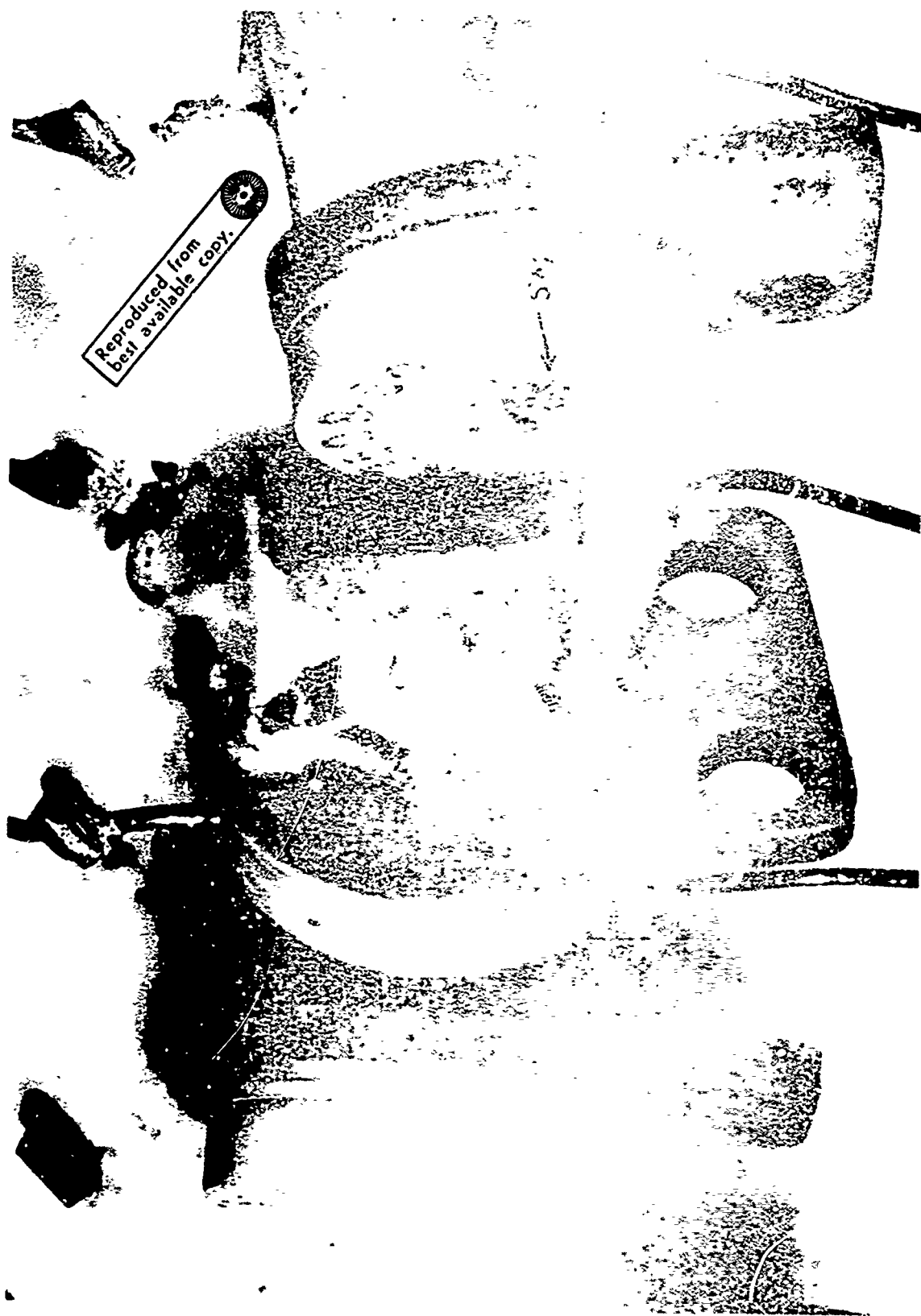


Figure 7

ESM = End Seal Migration



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Figure 8

SM = Silver migration

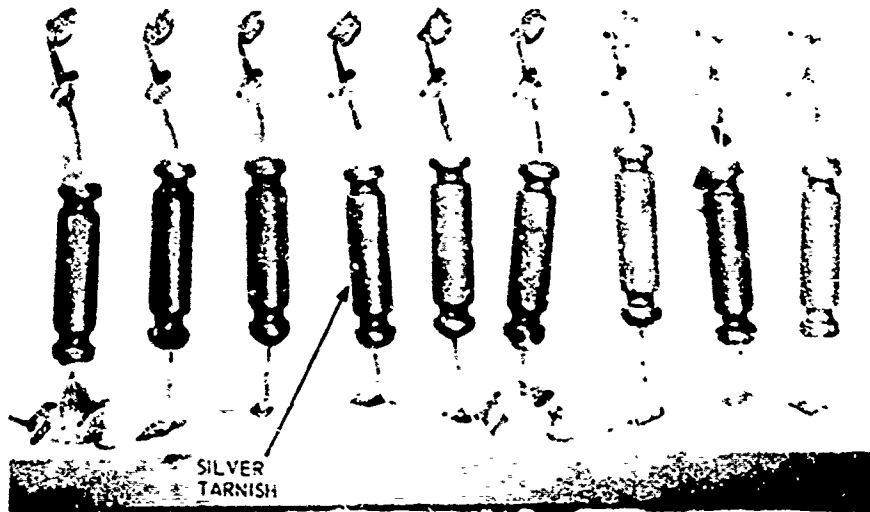


Figure 9

CC = Case corrosion



RESISTOR, CARBON FILM, BERN, ELEC-
TROLYTIC EROSION OF LEAD TERMINAL
AND PROTECTIVE PLASTIC

Figure 10
PE = Plastic erosion

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Figure 11

EC Element Corrosion

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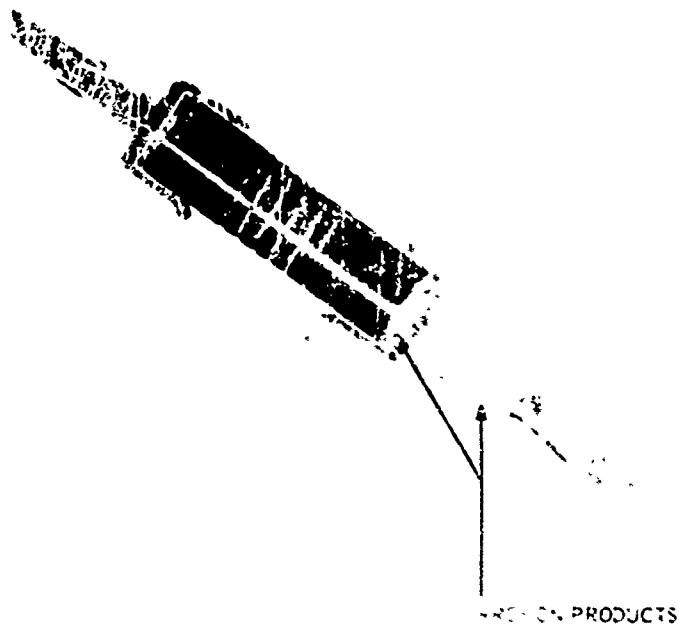
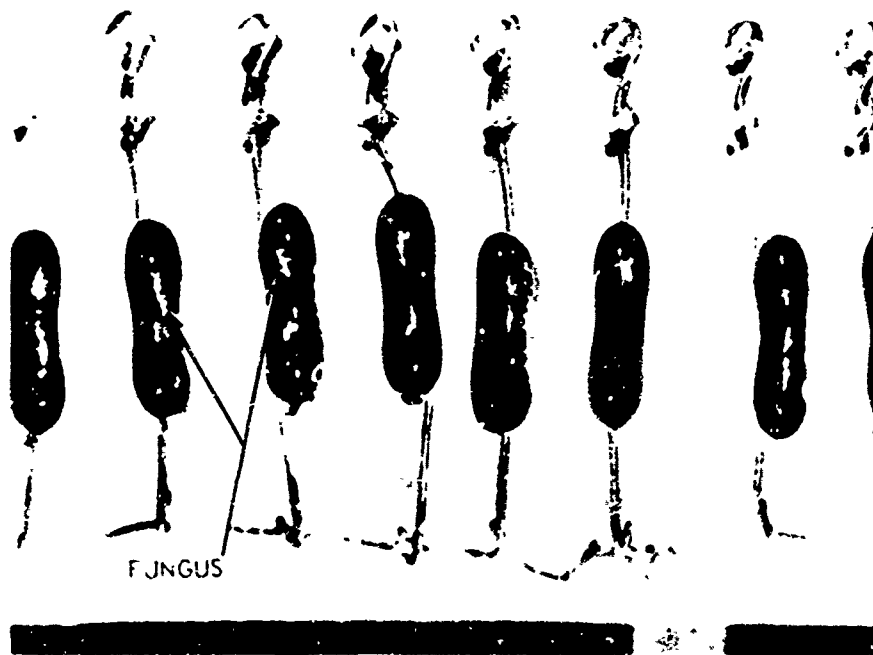


Figure 10

ELC = Electrolytic Cell



FUNGUS

Figure 13

FG = Fungus Growth

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Part	Tropical Field			
	Jungle		Shore	
	Non-Polar	Polar	Non-Polar	Polar
CK	0	0	X	XX
CL	0		X	
CM	0	0	X	XX
CS	0	0	X	XX
CT	0	0	X	X
MF	0	0	X	XX
KC	0	0	X	X
RC	0	0	XX	XXX
RS	0	0	0	0
RL	0		X	XX
RN	0	0	X	XXX
RO	0		X	X
RW	0	0	X, EC	XXX, EC
TA	0		X	XX
VC	0		0	0
VI	0		0	X
VK	0		0	0
WE	0	0	X	XX

*Failure Mechanism Code Explained in "Data Presentation," Par. 2.

Fig. 14 - Seven Months Field Corrosion Data.*

Part	Tropical Field			
	Jungle		Shore	
	Non-Polar	Polar	Non-Polar	Polar
CK	X	X	X	XXX(F)
CL	X, CC, ESM	X, CC, ESM	XX, ESM, CC	XX, ESM, CC
CM	0	0	XX, ESM	XX, ESM
CS	X	X	X, PE	XX, SC, PE
CT	0	0	XX	XXX, ESM
MF	X	X	XX, ESM	XXX, ESM
KC	0	0	XX	XX
RC	0	0	XX, SC, ESM	XXX, SC, ESM
RS	0	0	0	0
RL	0	0	XX	XXX
RN	0	0	XX, SC	XX, SC, ESM
RO	0	0	XX, ESM	XX, ESM
RW	0	0	X, EC	XX, EC, SC, PE
TA	0	0	XX	XXX
VC	0	0	X, PE	X, PE, ESM
VI	0	0	X, PE	XX, PE
VK	0	0	X	X
WE	0	0	X, ESM	XX, ESM

*Failure Mechanism Code Explained in "Data Presentation," Par. 2.

Fig. 15 - Twenty-Four Month Field Corrosion Data*

Part	Tropical Field			
	Jungle		Shore	
	Non-Polar	Polar	Non-Polar	Polar
CK	XXX	XXX	XXXX, PE	XXXX(F), PE
CL	O, FG, CC	O, FG, CC	XX, ESM, CC	XX, ESM, CC
CM	X, FG	X, FG, SM(F)	XX, FG	XX, ESM, SM(F), FG
CS	X, FG	X	XX, EC(F)	XX, ESM, SC(F)
CT	O	O	XX, PE, ESM	XXX, EX(F)
MF	X, FG	XX	XX	XX, ESM, PE
KC	O, PE	O, PE	XXX, ESM, SC	XX
RC	XX	XX, EC	FG, SC	XXXX, SC, ESM
RS	O	O	X, PE	FG, EC
RL	O	X	XXX, ELC	XX, PE, ESM(F), ELC
RN	X, SC, FG	X, SC, FG	XX, ESM	XXXX(F), EC(F)
RO	FG	O	XXX, ESM	XX, ESM
RW	O	O	XXX, FG	XXX, EC
TA	O, FG	O, FG	SC, FG	XXXX, FG
VC	SC, SM, FG	SC, SM, FG	FR, PE, FG	SM(F), SC, FG, EC
VI	EC, PE	O	XX	EX, CC, FG, PE
VK	O	O	XX	XX
WE	X, FG	XX, FG	XXX, ESM	XXXX, ESM, SC

*Failure Mechanism Code Explained in "Data Presentation," Par. 2.

Fig. 16 - Thirty-six Month Field Corrosion Data*

Exposure time - - - - -	7 months	24 months	36 months
<u>Mechanisms</u>			
Lead Corrosion (LC)	<u>Number of Part Groups Having Failures</u>		
O	18	14	8
X	0	4	4
XX	0	0	4
XXX	0	0	1
----- Failure Level -----			
XXXX	0	0	0
XXXX(F)	0	0	0

Fig. 17 - Lead Wire Corrosion at Jungle*

Exposure time - - - - -	7 months	24 months	36 months
<u>Mechanisms</u>			
Lead Corrosion (LC)	<u>Number of Part Groups Having Failures</u>		
O	3	14	0
X	4	4	1
XX	7	9	8
XXX	3	6	5
----- Failure Level -----			
XXXX	0	0	3
XXXX(F)	0	0	1

Fig. 18 - Lead Wire Corrosion at Shore*

*The above data shows that significant lead wire failures do not occur until after three years in the jungle and after two years at the shore.

Exposure Time - - - - -	7 months	24 months	36 months
<u>Failure Mechanism</u>	<u>Number of Part Groups with Failures at Jungle</u>		
ESM	0	1	0
SC	0	0	2
SM	0	0	2
CC	0	1	1
PE	0	0	2
EC	0	0	3
ELC	0	0	0
FG	0	0	6

Fig. 19 - Number of Jungle Failures

Exposure Time - - - - -	7 months	24 months	36 months
<u>Part</u>	<u>Number of Part Groups with Failures at Shore</u>		
ESM	0	9	9
SC	0	4	4
SM(F)	0	0	2
CC	0	1	1
PE	0	4	4
EC	1	1	4
ELC	0	0	1
FG	0	0	5

Fig. 20 - Number of Shore Failures

Part	Humidity Test Cycle 136	Salt Fog Test 60°C, 1% SF	Salt Fog Test 50°C, 0.5% SF	Humidity Test 90°C, 100% RH
CK		LC(F), PE	LC	LC
CL	LC, ESM	O	LC, CC	LC, CC
CM		LC, SM	O	PS
CS		LC(F), PE, EC	LC, PS, EC	PS, SC
CT		O	LC	O
MF	LC	LC(F), ESM	LC	LC, PS
KC	O	LC(F), ESM	LC	O
RC		LC, ESM		(
RS	O	LC, ESM		
HL	O	LC, ESM, Str Cr	LC	
RN		LC(F), PE	LC, SC	LC, EC
RO	LC	LC, ESM	LC, ESM	O
RW		LC, ESM, EC	LC	
TA	LC	LC	LC	EC
VC	CC, ESM	SM, EC		
VI	EC	LC(F), EC	LC, EC	SC, EC
VK	O	LC, SM	LC	LC, EC
WE		O	SC	O

Legend:

O = No failure mechanisms observed

Blank space = part was not tested

Str Cr = Stress Corrosion (not listed in text)

PS = Plastic Swelling

Fig. 21 - Failure Mechanisms Observed in Four Accelerated Laboratory Tests

Part	Laboratory Test Cycle			
	Method 106 HT	x 1% SF	0.5% SF	90°C, HT
CK		S 720	S 720	J 1080
CL	J 720	S 300	S 720	J 720
CM		S 1080	S 300	J 1080
CS		S 1080	S 1080	J 1080
CT		S 300	S 720	J 1080
MF	J 1080	S 720	S 720	J 1080
KC	J 720	S 1080	S 720	J 720
RC		S 720		J 720
RS	J 1080+	S 1080		
RL	J 720	S 720	S 720	
RN		S 1080	S 720	J 1080
RO	J 1080+	S 1080	S 720	J 1080
RW		S 1080	S 300	
TA	J 1080+	S 720	S 720	J 1080
VC	J 1080	S 720		
VI	J 1080	S 1080	S 720	J 1080
VK	J 720	S 1080	S 1080	J 1080
WE	J 300	S 300	S 720	J 1080

NOTES:

1. Jungle Data was compared to humidity tests (J)
2. Shore Data was compared to Salt Fog tests (S)
3. SF = Salt Fog
4. HT = Humidity Test

Fig. 22 - Field Service Life for Jungle (J) or Shore (S) Exposure in Days (Equivalent to 20 Days of Laboratory Tests)

(Equivalent Field Service Life / 20 Laboratory Test Cycles)

Part	106, MRT	1% SF	0.5% SF	90°C MRT
CK		S 36	S 36	J 54
CL	J 36	S 15	S 36	J 36
CM		S 54	S 15	J 54
CS		S 54	S 54	J 54
CT		S 15	S 36	J 54
MF	J 54	S 36	S 36	J 54
KC	J 36	S 54	S 36	J 36
RC		S 36		J 36
RS	J 54+	S 54		
RL	J 36	S 36	S 36	
RN		S 54	S 36	J 54
RO	J 54+	S 54	S 36	J 54
RW		S 54	S 15	
TA	J 54+	S 36	S 36	J 54
VC	J 54	S 36		
VI	J 54	S 54	S 36	J 54
VK	J 36	S 54	S 54	J 54
WE	J 15	S 15	S 36	J 54
Avg	43.9	41.5	35.6	50.1

* Acceleration Factor = Field Days per one lab day

Fig. 23 - Laboratory Test Cycles Acceleration Factors *