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TECHNICAL REPORT ARPAD-TR-83006

COMPARISON OF EFFECTS OF NATURAL TROPIC ENVIRONMENT VERSUS CHAMBER EXPOSURE ON ARMY MATERIEL

AD-A142 817

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JUNE 1984

U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER
Technical Report ARPAD-TR-83006

2. GOVT ACCESSION NO.
[illegible]

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
COMPARISON OF EFFECTS OF NATURAL TROPIC ENVIRONMENT VERSUS CHAMBER EXPOSURE ON ARMY MATERIEL

5. TYPE OF REPORT & PERIOD COVERED
Final
August 1980 - November 1983

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
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8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
ARDC, LCWSL
Munitions Systems Div [DRSMC-LCU-SP(D)]
Dover, NJ 07801 (cont)

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
D.A. Project
4A762730AT42

11. CONTROLLING OFFICE NAME AND ADDRESS
ARDC, TSD
STINFO Div [DRSMC-TSS(D)]
Dover, NJ 07801

12. REPORT DATE
June 1984

13. NUMBER OF PAGES
129

14. MONITORING AGENCY NAME & ADDRESS (If different from Controlling Office)
ARDC, PAD
Fire Control and Small Caliber Armament Systems Div [DRSMC-QAF(D)]
Dover, NJ 07801

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)

18. SUPPLEMENTARY NOTES

Funding for this study was provided by the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia.

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

Degradation	Laboratory testing	Natural temperature/humidity
Correlation	Chamber testing	Induced temperature/humidity
Environment	Salt fog	Tropical environment exposure

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

Data were gathered for analysis and for comparison of natural tropical versus chamber environmental exposure effects on replicate samples of military materiel. Statistical analyses showed that correlations do exist for time to produce failure between natural and chamber tests but that they vary for different types of hardware. Increasing the severity of the environmental stress parameters is recommended to shorten chamber time to less than 28 days.

9. PERFORMING ORGANIZATION NAME AND ADDRESS (cont)

U.S. Army Research Office
Research Triangle Park, NC 27709

FOREWORD

This program was conducted as a joint effort of the U.S. Army Armament Research and Development Command (ARRADCOM) and the Tropic Test Center (TTC) in the Panama Canal Zone, Republic of Panama, and was funded by the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia. ARRADCOM participants included the Fire Control and Small Caliber Armament Systems Division and the Evaluation and Metrology Division, both of the Product Assurance Directorate (PAD); the Munitions Systems Division of the Large Caliber Weapon Systems Laboratories (LCWSL); the Materials and Manufacturing Technology Division of the Fire Control and Small Caliber Weapon Systems Laboratories (FSL); and the Test and Instrumentation Division of the Technical Support Directorate (TSD). The Fire Control and Small Caliber Armament Division of PAD was responsible for the overall management of the program.

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INTRODUCTION

This project was conducted to gather data for analysis and comparison of the effects of exposure of samples of Army materiel to the natural tropic environments versus exposure of identical materiel in laboratory test chambers. Uncertainty existed regarding whether laboratory tropic environment chamber testing of materiel was too severe for realistic service life evaluation. If that were so, then unwarranted over-design has caused unnecessary expenditures. However, it was also felt that an investigation could prove that laboratory testing may not be severe enough and materiel may degrade during storage or fail in actual usage in combat situations.

This three-year study involved a two-year exposure of selected test specimens in different natural tropic environments, followed by testing of replicate samples in laboratory chambers. The specimens were periodically inspected and evaluated for changes, degradation (types and rates), and failure. After definitive deterioration trends were observed at the natural tropic exposure test sites (oceanside, open field, and forest) and the data analyzed, a series of laboratory tests were conducted to determine the conditions that produced comparable changes, degradation (types and rates), and failure in the environmental chambers as those obtained in the natural environment. Correlations between the length of exposure in laboratory test chambers versus length of exposure in the field (tropics) were documented. Based upon these analyses and comparisons, new meaningful laboratory environmental chamber tests should evolve which will more accurately evaluate the effects of tropical exposure.

STUDY

Phase I--Exposure in the Tropics

The Product Assurance Directorate (PAD) of ARRADCOM obtained replicate samples of ten different items of surplus optical, mechanical, and electrical Army materiel (at least 60 of each item) for use in this program. The items obtained were:

- M3 binoculars
- M17 periscopes (plastic)
- M26 periscopes for M48 tank (glass)
- Laboratory photographic timers
- 1/20 hp electric motors (d.c.)
- Vacuum gages
- 150A ammeters (a.c.)
- Electromagnetic relays, 800 ohm
- Emergency light sets, 6 volts (d.c.)
- Helmet radio receivers, AN/PRR-6

ARRADCOM designed and constructed 25 aluminum and stainless steel ventilated storage cabinets and one open rack, all for assembly in five different test sites in the Tropic Test Center (TTC). A photograph of one of these cabinets installed in one of the sites in Panama is shown in figure 1. ARRADCOM also designed and constructed seven sets of test instrumentation for performance testing of the above 10 test items, first in the field and later in the laboratory.

A Test Program Request was prepared by ARRADCOM and sent to the U.S. Army Test and Evaluation Command, Aberdeen, MD, in March 1980, requesting the services of the Materiel Test Directorate of the TTC in erecting these exposure cabinets in five selected test sites, installing selected test specimens, and in performing periodic performance tests (fig. 2).

Test Plans

For each test specimen, a detailed test plan was prepared by ARRADCOM and coordinated with TTC. The test plan included:

1. The number of each item to be exposed at each test site

2. The exact manner of exposure, including method of mounting in the cabinets or on the rack, and orientations and type of protective cover, if any

3. Description of the test instrumentation to be used for each item

4. Test procedures to be used

5. Frequency of testing

6. Measurements and observations to be recorded

7. The environmental variables to be monitored; i.e., solar radiation, rainfall, temperature, dew point, wind velocity and direction, atmospheric salt aerosol concentration, and time and duration of condensation at each site

8. Disposal of item after completion of test

The five sites selected for these exposures were:

1. Fenced-in open clearing in Chiva Chiva, Pacific Ocean side (fig. 6)

2. Double canopy forest site in Chiva Chiva, Pacific Ocean side (fig. 3)

3. Fenced-in open clearing in Fort Sherman, Atlantic Ocean side

4. Triple canopy forest site in Fort Sherman, at Skunk Hollow (fig. 1)

5. Fenced-in open site on the beach at Fort Sherman (fig. 4)

A map of the Panama Canal Zone, showing the location of these sites, is shown in figure 5.

Twenty-five each of the 10 selected test items were shipped to TTC in July 1980, along with the test instrumentation designed and constructed by ARRADCOM.

Three of the ventilated cabinets were installed by TTC personnel in each of the above five sites during August and September 1980. Five of each test item were carefully observed and performance tested in the field. The results were entered on previously prepared data sheets. The items were than placed in predetermined locations in numbered exposure cabinets at each test site.

Monthly observations and performance tests were than made on nos 3, 4, and 5 of each item until failure of the item, or until the end of the field test program in November, 1982.

Completion of the initial performance testing for the five replicate samples of all 10 test items, and their emplacement in their designated cabinets in each test site, occurred between September 1980 and January 1981.

In addition to the three enclosed ventilated cabinets at each of the five sites, one open test rack was installed in the fenced-in open site at Chiva Chiva (fig. 6). On top of this rack, exposed to all of the environmental elements, were mounted three M3 binoculars, three M17 periscopes, three M26 periscopes, and three helmet radio receivers. No. 1 of each of these items was the "control" sample, while nos 2 and 3 of each item were performance tested monthly.

During the 2-year field exposure test period, three ARRADCOM personnel separately visited the TTC three times to observe the field testing at each of the sites. The field tests were performed by personnel of TTC monthly throughout this period.

It should be noted here, that due to an administrative misunderstanding between TTC and ARRADCOM, no monthly field testing was performed during the last 6 months of the field exposure (May through October 1982). However, it is believed that this did not seriously affect the results of this study, since final observations and performance tests were made on all items during the first week of November 1982, and most of the items that failed would already have done so before April 1982 (table 1).

Since none of the periscope optics or emergency light sets failed in the field, they were not considered for laboratory testing.

Graphs showing the actual cycling temperature and relative humidity at each test site in the TTC between September 1980 and October 1981 are shown in figures 7 through 10.

A graph showing the actual variations in aerosol salt concentration at the Fort Sherman coastal site between August 1980 and August 1982 is shown on figure 11.

Upon completion of all exposure tests on 8 November 1982, all results (data sheets) were forwarded to ARRADCOM, along with the test instrumentation. A listing of the monthly field observations and performance test measurements for each of the items at each of the test sites is available in the project file. This can be obtained by writing to Commander, U.S. Army Armament Research and Development Center, ATTN: DRSMC-QAF, Dover, NJ 07801.

Test Procedures

Procedures for performance testing were established, based on the functions of the specimen, the most likely vulnerability of the specimen (i.e., electrical wiring, drying, and cracking of materials such as rubber, etc.), and the most realistic means of testing under field conditions. Most importantly, the procedures were established to allow for a minimum of human error and method subjectivity (i.e., biasing). Thus, the results obtained are reproducible, given the same climatic conditions. Details of these test procedures are listed below. (Note: These same procedures were used for the chamber tests and in the field.)

Ammeter Test Procedure

1. The ammeter test fixture is set up with two 150-watt bulbs (fig. 12) and is connected to a source of 110-120 V a.c. power (either electric line or inverter).

2. A voltmeter, capable of reading between 100 V and 150 V a.c., is set up.

3. The ammeter to be tested is connected to the ammeter tester cord. The ammeter is placed on a nonconductive surface (cardboard, wood, etc.) with the dial facing the observer.

4. After the ammeter cord is plugged into the text fixture, one light bulb is unscrewed so that it will not light, and switch is turned on. This is the one-half load test. The meter is read and the voltage is measured across the light bulb socket nearest the observer. (An example of a reading is 37 amps, 113.6 volts.) This is recorded in the appropriate columns in the log book. The bulb is screwed back in so that both bulbs will light. This is the full load test. Again, the ammeter is read and voltage is measured across the light socket nearest the observer. An example of a full load reading is 73 amps, 112.8 volts. Full load readings are recorded in appropriate columns in the log book.

5. The source of power [110 V a.c. or inverter (INV)] is recorded in the log book.

6. Ammeter is visually examined, with particular attention given to moisture effects, salt corrosion, mildew, etc. and observations are recorded in log book.

Electromagnetic Relay Test Procedure

1. All necessary connections of the relay terminals (letter F) are made to conform with the wiring diagram shown in figure 13. Leads are connected to a 5-pin plug (letters A-E) compatible with the Alinco tester.

2. Relay to be tested is set, coil side down, on bench in front of Alinco tester and connector is plugged in (fig. 14).

3. Relay in the de-energized condition is tested by pushing black button on Alinco tester and turning blue knob to get meter to null. Needle moves in the direction in which knob is turned. Additional ohms may be added by pushing the black "ohms add" knob to get a null. When meter nulls, resistance in digital counter window is read. Reading is recorded in log book in "DE" column.

4. Relay is then tested in energized condition. (NOTE: Relay should be energized only once per test observation.) Relay is energized by pressing and holding red button. Button must not be released until test is completed. After red button is pressed, black button is pressed and the blue knob is turned to obtain a null of the meter. As before, it may be necessary to add ohms to obtain a null. When null is obtained, black button is released first; then red button is released. Resistance is read in digital counter window and is recorded. It is important that any ohms, added in reading, be included in the "E" column.

5. A visual examination is made of the relay, paying particular attention to salt deposits, corrosion, dampness, mildew, etc. and observations are recorded in the log book.

Vacuum Gage Test Procedure

1. Battery covers are removed from rear of each item.

2. Battery is installed in clip of first gage to be tested, with red (positive) end down.

3. Dummy load no. 1 is installed on octal connector at end of cord. [Note: The dummy load tester, figure 15, was made by removing the electroverter found within each vacuum gage (model TC-5, manufactured by Hastings-Raydist), and wiring it to an octal plug.] Two dummy loads, no. 1 and 2, were designed and fabricated to simulate the electrical signal outputs of two different vacuum loads. For preservation, each dummy load tester was set in silicone potting compound. The wiring diagram for the connections of the electroverter to the octal plug for this vacuum gage is illustrated in figure 16.

4. Knob on face of vacuum gage is turned to right to "set" position and is held while gage needle is zeroed with knob on left. If needle does not zero, battery is replaced. If needle still does not zero, "pegged" is entered in the "Set" column, and test is conducted with as near a zero setting as possible. If needle does zero, then O.K. is entered in "Set" column.

5. Immediately after zeroing, knob is turned to the right to the "on" position and dial is read. Increments are not the same over the dial. Between 100 and 200, dial increments are 10 per division; between 200 and 500, there are 50 per division; between 500 and 1000, there are 250 per division. Reading is recorded in log book.

6. Dummy load no. 1 is replaced with dummy load no. 2 and test is repeated. Readings are entered in log book. In each case, unit must be zeroed (or as nearly as possible) with dummy load in place immediately prior to taking reading.

7. After test is completed, battery and dummy load are removed. A thorough visual examination of the unit is conducted, with particular attention to mildew, blistering, corrosion, and moisture accumulation. Results are entered in log book.

Photographic Timer Test Procedure

1. Plug of timer is connected to 120 V a.c. power source (fig. 17). Timing function is checked and reset by momentarily starting timer and stopping it (pulling chain twice) to see if switch and timer motor function; then pulling ring to reset to zero. If timer does not run, NF (nonfunctional) is entered in log book. If the timer does not reset, then NR (not reset) is entered in log book.

2. All timers, when reset to zero, are started at 15-second (or other convenient) intervals. Each timer is stopped at exactly 3:00 minutes after its start. An entry is made in the log book regarding whether line power (110 V) or INV is used.

3. Difference between timer reading and 3:00 minutes (+ or -) is entered in log book. Differences of 1/2 second or less should be entered as "OK" since timer motor coasts approximately 1/2 second when turned off. Example: If timer reads 2:40, -20 seconds should be entered in log book. (Note: If an inverter is used, the timer may be 15-20 seconds slow). Deterioration is expected to show up as momentary or complete stalling.

4. A complete visual examination of the timer is made, with particular attention to mildew, rust, and other visible effects. Findings are recorded in log book.

Helmet Radio Receiver Test Procedure

1. Before test is begun, antennas are removed from both receiver and transmitter. This limits range to about 120 feet (fig. 18).

2. Battery is connected to radio and volume is turned on full to deactivate squelch. When noise is heard from speaker, switch is turned off to activate squelch and then volume is turned up to not more than three fourths maximum

volume with squelched operation. Radio should be predominately silent although occasional squelch-breaks may be heard. If radio continues to be noisy, then "NS" (no squelch) is entered in Squelch space on data sheet.

3. At a distance of about 72 feet, transmitter is keyed to "Tone." The tone should be heard in the speaker. If so, "O.K." is entered in Tone and Squelch spaces of data sheet. Then the transmitter is keyed to "Voice" and observer should blow or speak into microphone. If sound is heard, "O.K." is entered in Voice space on data sheet.

4. If no tone is heard in step 3, volume is turned up full to deactivate squelch and transmitter is keyed to "Tone" again. If tone is heard, "O.K." is entered in Tone space of data sheet and "NB" (no break) is entered in Squelch space. Transmitter should be keyed to Voice and observer should blow or speak into microphone. If sound is heard, "O.K." is entered in Voice space on data sheet.

Emergency Light Set Test Procedure

1. Positive lead of 6 V live battery is connected to red lead of light set. When negative battery lead is connected to positive lead of light set, lamp should light. A notation should be made on data sheet regarding whether or not lamp lights.

2. With live battery still connected, 110 V leads of light set are connected to 110 V a.c. power. Light should go out. If it does go out and no other effects are noted, "O.K." is entered in Relay space of data sheet. If relay chatters, "Noisy" is entered on data sheet. (Note: When inverter is used with a.c. power supply, relays tend to chatter much worse due to the non-sinusoidal waveform of the inverter output. Setting the inverter on "high" seems to help.)

3. Test button on light set is depressed several times, each time lighting up the lamp. If this occurs, "O.K." should be entered in Switch space of data sheet. (If light set fails, enter appropriate remark describing what happens.)

4. Live battery is disconnected with 110 V power still connected. Positive lead of dead battery is connected to red lead of light set. Black lead of ammeter is connected to black lead of light set. Red lead of ammeter is connected to negative post of dead battery. Charging rate from ammeter is read and entered in "C.R." space of data sheet. (Note: Charging rate will normally be around 0.2 to 2.0 amps. If relay is chattering, charging rate will be higher. This is apparently an electrochemical effect within the battery.)

5. Record all visual observations.

Fractional Horsepower d.c. Motor Test Procedure

1. One third of motor shaft is painted with white paint, or metallic tape should be fastened on one third of shaft so phototachometer is able to sense rotation of shaft.

2. All electrical wiring connections are made as illustrated in figure 19, except the ammeter-to-motor connection. This connection is essentially the "on-off" switch.

3. The d.c. power supply is set to 12 volts on 20 V scale of voltmeter.

4. Phototachometer is activated and let settle to zero while phototach light is shining on painted surface of motor shaft.

5. Motor is started by making ammeter-to-motor connection.

6. After motor has run for exactly 5 seconds, rpm of motor, current, and voltage are recorded. Tachometer readings should fall between 3000 and 4500 rpm.)

7. Visual observations are recorded for all motors tested.

M3 Binocular Resolution Test Procedure

1. Test target (fig. 20) is erected at an appropriate location.

2. Tripod with optical item test fixture is erected, approximately level, at a distance of 72 feet from target.

3. Binocular is installed on fixture in an inverted (upside down) position (fig. 21).

4. The following three steps are performed separately by two observers before binoculars are tested:

   a. Open sky is sighted through dioptometer with diopter setting at zero.

   b. Eyepiece setting is rotated until crosshairs are clearly in focus.

   c. Dioptometer is set on optical base fixture and sightings are made through dioptometer. Then forward ring on dioptometer is rotated until target is in focus.

Readings are taken with the dioptometer mounting block[1] "binocular" side down (against optical test fixture plate). Dioptometer is positioned against binocular left eyepiece (fig. 21). The target is sighted through the dioptometer and binocular left side simultaneously, being careful to avoid turning the dioptometer eyepiece adjustment. Moisture may be gently wiped from lenses, if necessary. Diopter of binocular eyepiece is turned until target is in focus. Diopter value of left binocular eyepiece is recorded. Process is repeated for the right diopter eyepiece of binocular, and resolution value is recorded. Resolution is recorded as the number of the smallest target elements that can be identified with three horizontal and three vertical bars (fig. 20).[2] These data are then converted to angle subtend (seconds) with the following formula:

$$\text{Arc tangent (sec)} = \frac{\text{distance (in.)}}{\text{line pair width (in.) x 3600 (deg in sec)}}$$

5. Record all visual observations.

M17 and M26 Periscope Resolution Test Procedure

1. Test target is erected at an appropriate location.

2. Tripod with optical item test fixture is erected, approximately level, at a distance of 72 feet from target.

3. Periscope is installed on fixture with mounting lugs down (fig. 21). Since fixture is only 1/4 inch wider than periscope, lateral centering is critical.

4. Sighting is made through left and right edges of periscope and fixture is turned until target is fully visible through both edges of periscope. Moisture may be wiped from optical surface if necessary.

5. The following three steps are performed separately by two observers before periscope is tested:

a. Open sky is sighted through dioptometer with diopter setting at zero.

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[1] Drawing for the optical base assembly and dioptometer mounting block is available in the project file.

[2] The binocular data were recorded in measurements of resolution with the Resolution Test Object RT-5-75 produced by the Graphic Arts Research Center, RIT, Rochester, NY, with assistance of the U.S. Naval Surface Weapons Center, Silver Spring, MD.

b. Eyepiece setting is rotated until crosshairs are clearly in focus.

c. Eyepiece setting is noted on data sheet.

6. The first two readings are taken with the dioptometer mounting block with "periscope middle" side down (against fixture plate). The first reading is "middle left" (ML) and the dioptometer is placed near the left edge of the periscope. Sighting is made through the dioptometer and the periscope at the target, being careful to avoid turning the eyepiece adjustment. The diopter setting (forward ring in dioptometer) is used to focus on target as sharply as possible. (The tripod may be adjusted slightly if field of view is not satisfactory.) Resolution is reported as the number of the smallest target elements that can be identified as three horizontal and three vertical bars. Then the dioptometer is removed and the diopter correction is read. Diopter corrections are reported to two decimal places. A reading is then taken in the lateral center of the periscope ("middle middle" or MM), and resolutions are recorded in the appropriate spaces in the log book. The use of any standard dioptometer is allowable, regardless of the diopter scale as long as it is used for the entire test.

7. The next three readings are taken with the "periscope high" side of the dioptometer mounting block down. Readings are taken as before except that they are identified as "high left" (HL), "high middle" (HM), and "high right" (HR). Readings are recorded in the appropriate spaces in the log book.

8. The above procedures are repeated by the second observer.

9. Visual observations are recorded for each periscope, with particular attention being paid to etching, discoloration, cracking, peeling of paint, corrosion, dirt, mildew, and any other visual effect that may be noted.

Failure Analysis

A preliminary analysis of the raw field data indicated that only five of the 10 items suffered significant deterioration or failure. These were the relays, vacuum gages, photographic timers, helmet radio receivers, and M3 binoculars. It was therefore decided that the laboratory chamber tests should only be performed on replicates of these five items. However, it was later determined that two of the items which held up the best in the field (the a.c. ammeters and the d.c. fractional hp motors) should be included to see if they would also hold up as well in the chamber tests.

Further analysis of the field data indicated that the primary causes of the deterioration or failures could be attributed to the cycling conditions of high temperature and high humidity in all of the sites. Also, the high concentration of aerosol salts at the oceanfront site in Fort Sherman caused significant salt deposits on the test specimens, with subsequent salt corrosion of the exposed metal surfaces and clogging of electrical contacts and switches. It was also noted that very little fungus growth was obtained on the test items and none of the failures obtained could be attributed to fungus. It was therefore decided that no laboratory fungus tests would be required. Hence, it was decided that the only types of laboratory chamber tests to be conducted were a cycling high temperature humidity test and a cycling sea water salt fog test.

For a determination of the actual causes of failure encountered in the field, the failed items were sent to the Evaluation and Metrology Division of PAD for tear-down and detailed analysis of the modes of failure. These data were recorded on fact sheets and are presented in table 1. After the failure analyses were completed, each of the disassembled items were identified and photographed. Typical examples are shown in figures 22 through 30.

A "0 to 10 deterioration rating scale" was devised which facilitated the analysis and future comparison of the field test results with the laboratory test results. The criteria for this rating scale is shown in table 2. The collated field test data were then evaluated and each entry was assigned an appropriate deterioration rating number.

Graphs depicting the rates of deterioration of all specimens at the different sites are provided in appendix A. The graphs reflect the relative degradation of each item, based on visual observations as well as performance test measurements. Each month, noticeably increased degradation occurred until, in many cases, the item failed. For each entry, a value of 0 (new) through 10 (failure) was assigned. This approach seemed to be the most logical in that each item started off new, was exposed for a duration of time during which it degraded gradually and finally failed. If the actual recorded numerical performance test data had been used for each of the items, the graphs would have shown, in some cases, no degradation or partial degradation occurring for the duration of the test, only to have a failure in the last entry, thus showing a horizontal line for all but the last date which would appear as a vertical line. It was more realistic, therefore, to show that over a period of time, the item was, in fact, degrading slowly. With a graph illustrating the combined effective rate of visually observed degradation and the numerical performance test data, the final outcome is shown to be the same, i.e., degradation rate-to-failure. Thus, the graphs in this report enable better comparison of field-to-laboratory degradation effects.

The graphs of binocular degradation illustrate only the measurements observed. Most of the binoculars tested in the field did not fail; however, when a binocular did fail, whether it was left or right side, the failure was indicated on the date at which the curve stops prior to November 1982. Since no measurement could be taken at the point of failure, the graph could not be drawn beyond the last date which the measurement was recordable prior to failure. Also, the graphs sometimes indicate that optical quality seems to improve after the item has degraded. This is due to the design of the binocular, namely the sealants and gaskets used in the manufacturing process. Due to the high humidity and the poor gaskets used, water vapor penetrated the internal volume and condensed on both the prism and lens surfaces. As the weather pattern cycled to drier conditions, the condensation on the inner optic surface evaporated. This cycling condition led to damage of the optics such as deterioration of the coatings and film of the glass due to impurities left behind after condensate evaporation. When this occurred, especially on the exposed rack at the Chiva Chiva open field site and in the laboratory, the binocular became void of any optic usefulness (i.e., its resolution badly deteriorated) and was considered failed. The trend of degradation, as shown in the graphs, indicates that the destructive process was apparent at all sites and would eventually have led to failure. However, due to the time constraints of the program, it was not possible to test these items beyond the time allowed.

Phase II--Laboratory Chamber Tests

Four replicate samples of each of the following seven items were selected for laboratory climatic chamber testing:

- a.c. ammeters
- electromagnetic relays
- vacuum gages
- photographic timers
- helmet radio receivers
- d.c. fractional hp motors
- M3 binoculars

Two climatic chambers located at ARRADCOM were selected for these tests. They were the temperature/humidity walk-in room 9 in the Test and Instrumentation Division, TSD, and the salt fog chamber (SCCH 22, manufactured by Singleton Corporation) in the Materials and Manufacturing Technology Division, FSL, (modified to perform a simulated sea water cycling concentration and cycling temperature/humidity test.

Cycling Temperature/Humidity Chamber Tests

The automatic cycling controls were set at 60°C (140°F) and 95% ± 5% R.H. for the high temperature portion of the cycle and at 30°C (86°F) and 95% ± 5% R.H. for the low temperature portion of the cycle, in accordance with Procedure III of Method 507.2 of Mil Standard 810D (fig. 31).

On 14 March 1983, four each of five test specimens were given ambient performance tests. Visual observations were made and they were then placed in the temperature/humidity chamber set to 40°C (104°F) with no humidity control to be subjected to a 48-hour drying period prior to start of the temperature/humidity cycling test. A fan shaft broke in the chamber before the dry-out was completed, and the test was aborted until after the malfunction was repaired. This repair was not completed until 31 March 1983. The temperature/humidity cycling test was restarted on 1 April 1983, at which time four each of the other two items were added to the program.

The number 2, 3 and 4 samples of each item were removed from the chamber weekly during the low temperature portion of the cycle for observation of deterioration and performance testing, and the results were recorded on appropriate data sheets. When specimens failed, they were taken to the PAD Evaluation and Metrology Division for tear-down and evaluation for mode of failure. The tear-down items were then identified and photographed.

All temperature/humidity chamber testing was completed by 15 June 1983. The results of all laboratory chamber tests were then collated with those of the tear-down failure analysis data. This comparison is shown in table 3.

The results were then evaluated and assigned degradation ratings in accordance with the criteria of table 2. The complete results of these temperature/humidity chamber tests are included in the project file.

Cycling Artificial Sea Water Salt Fog Test

Automatic cycling was controlled through a series of timers (AMF-Paragon Electric model 4003-OS) which were set at 23.9°C (75°F) and 29.5°C (85°F). Due to the limitations of the chamber in its ability to maintain the desired cycling conditions, the actual temperature parameters obtained were 22.3°C (72°F) and 27.3°C (81°F). The test procedure was in accordance with Procedure IV of method 509.2 of proposed revision D of Mil Std 810. (Note: Federal Std 151B, "Synthetic Sea-Water Spray Test," was considered as the test method; however, it was rejected because proposed Mil Std 810D was more representative of actual conditions.)

Samples were not washed between testing intervals as this would have affected the cumulative surface salt deposition effect of the salt fog. Temperature, humidity, and salt fog concentration were varied, however, due to chamber design restrictions; wind velocity could not be incorporated into this test. The test was terminated after 1344 hours (8 weeks) of test. This test procedure called for temperature/humidity cycling to simulate parameters associated with the tropical coastal marine environment. Further, based on TTC's meteorological data detailing graphically (fig. 11) the salt fallout rates at Fort Sherman coastal site, the concentration levels used in the salt fog chamber were comparably higher, to allow for accelerated results. Laboratory analysis was conducted on both the pre-fallout solution (prepared salt solution that was actually used in the test) and the fallout solution (collected by placing two funnels atop graduated cylinders on the floor of the chamber) for the salt fog chamber test. The analysis was conducted by the Energetics Material Division using a Dionex ion chromatograph model 14 and SP4100 computing integrator. The concentration level of chloride ions was 2400 mg/m^2/day. This concentration proved to be six times more severe than that of the Sherman Coastal site in Panama.

On 29 April 1983, four of each of the representative test specimens were given ambient performance tests, followed by overall visual observations. The specimens were then placed in the salt fog chamber to be cycled between 22.3°C (72°F)/85% R.H. and 27.3°C (81°F)/95% R.H. and between concentration levels of 120 mg/m^2/hour and 60 mg/m^2/hour over a 24-hour period (average 100 mg/m^2/hour), figures 32 and 33. The salts used to make up the solution were those which best simulated natural sea water (table 5).

As with the temperature humidity chamber tests, the no. 1 sample of each item was considered the control sample and was not performance-tested again until all of the other samples of the same item failed, or at the end of the test, if none failed. The no. 2, 3, and 4 samples of each item were removed from

Hollow sites, and comparing the salt fog test chamber results with results obtained at the Ft. Sherman coastal site.

The method used to perform the correlatability study of field versus laboratory chamber test results is described in the report, "Statistical Analysis of Field versus Laboratory Accelerated Life Test Data."[3]

The results of this correlation study are shown in figures 34 through 38.

Examination of the upper curve in a typical correlation study (i.e., field versus temperature/humidity chamber day curves for the photographic timers, figure 34 shows that if almost all of the timers had failed after being tested in the temperature/humidity chamber for 30 days, then almost all of the same type of timers would have failed in the field in approximately 910 days. The lower curve shows that almost none of the timers would have failed in the field in less than approximately 480 days. This shows that where items did not fail in the temperature/humidity chamber in 30 days, then most of the same types of items would have lasted for at least 480 days in the field.

It should be noted that the upper and lower curves show correlations having greater than 90% confidence levels. The additional correlation curves for the relay, vacuum gage, helmet radio receiver, and M3 binoculars are to be interpreted in the same manner as the photographic timers. It should be noted that only one correlation curve is provided for the binoculars. No differentiation was made between temperature/humidity chamber tests and salt fog chamber tests versus corresponding field areas. This was done because there were insufficient numbers of samples exposed in the Fort Sherman coastal site to compare with only four samples exposed in the salt fog chamber. Hence, this curve represents a composite of all failed binoculars exposed in the field versus all binoculars exposed in the chambers.

The center line is a point estimate having roughly a 50% confidence level. The point estimate is the best single estimate of the number of days an item would survive in the field, based on the number of days the item had survived in the chamber. Note: One should use the center line as an estimate only, because it is not an exact 50% confidence level; that is, it may be 48% or 54%, etc., depending on the specific point on the line to which one is referring. Also, it should be noted (from figures 34 through 38) that even when failure ratings 8 are used instead of 10, the correlation curves are almost identical. This fact further validates the correlation method used.

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[3] John Mardo and Paul Roediger, Technical and Automation, Information and Mathematics Division, Product Assurance Directorate, ARRADCOM, Dover, NJ (in press).

CONCLUSIONS

Based on a statistical analysis of the above results, it can be concluded that a correlation does exist between the number of days' exposure to produce failure in a climatic test chamber versus the corresponding number of days' exposure to produce similar failure in the tropics. The ratio of this relationship varies slightly for different types of military hardware (based on slopes of the curves).

Analysis of the correlation curves shown in figures 34 through 38 indicates that the type of failures obtained in military hardware exposed in various locations in the Panama Canal Zone can be duplicated in a much shorter time by exposure of replicates of these items in a cycling temperature/humidity test chamber for all inland sites and in a cycling salt fog test chamber for equipment exposed at a coastal site.

Due to the limited sample sizes utilized in both the field and in the laboratory test chambers, the correlation is not exact, but does have a rather high confidence level.

Analysis of the results indicates that it generally took too long in the test chambers to duplicate the types of failures obtained in the field. From a practical point of view, any single test in the laboratory which takes over four weeks to complete is too long. It is therefore concluded that chamber time should be shortened by increasing the severity of the test parameters.

RECOMMENDATIONS

Based on the positive results obtained in this research program, it is recommended that a follow-up study be initiated to determine whether an increase in the severity of test conditions (stress levels) will accelerate the laboratory test time without degrading correlatability. It is hoped that by the use of more extreme cycling temperature/humidity and salt fog laboratory test conditions, together with increased sample densities of items tested, valuable test time can be reduced and a greater degree of confidence in the correlatability between items tested in the field and in the laboratory can be provided. If such extreme (accelerated/aggravated) laboratory testing is successful, this could also serve as a baseline for improvements in the temperature/humidity and salt fog test procedures in subsequent revisions of Mil Std 810D.

Table 1. Summary of TTC exposure tests and failure analysis

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Electromagnetic Relay				
CC1	6 Jan 81	4 Nov 82	No meter reading	Moisture condensatior causing corrosion c terminals
CC2		4 Nov 82		
CC3		27 Jul 81		
CC4		4 Nov 82		
CC5		13 Apr 82		
CF1		4 Nov 82		
CF2		4 Nov 82		
CF3		19 Oct 81		
CF4		16 Nov 81		
CF5		13 Apr 82		
SO1	13 Jan 81	5 Nov 82		
SO2		5 Nov 82		
SO3		19 Nov 82		
SO4		7 Apr 81		
SO5		6 May 81		
SH1	14 Jan 81	8 Nov 82	Did NOT fail	
SH2			No meter reading	Moisture condensatior causing corrosion c terminals
SH3			Did NOT fail	
SH4			Did NOT fail	
SH5			Did NOT fail	
SC1	13 Jan 81	19 Jan 82	No meter reading	Salt corrosion of terminals causing shorting
SC2	13 Jan 81	19 Jan 82		
SC3		3 June 81		
SC4		19 Jan 82		
SC5		3 June 81		

Note: 21 relays failed (out of 25 exposed).

a.c. Ammeters and d.c. Motors

None of these items showed any sign of appreciable degradation.

Table 1. (cont)

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Vacuum Gage				
CC1	18 Oct 80	4 Nov 82	No meter reading possible	Humidity corrosion of wiring and circuitry
CC2	18 Oct 80	4 Nov 82	Did NOT fail	
CC3	1 Oct 80	15 Dec 81	No meter reading possible	
CC4		19 Oct 81	No meter reading possible	↓
CC5	↓	4 Nov 82	Did NOT fail	
SO1	7 Oct 80	5 Nov 82	Did NOT fail	
SO2		5 Nov 82	Did NOT fail	
SO3		16 Dec 81	Could not set meter	Humidity corrosion of wiring and circuitry
SO4				
SO5		↓	↓	↓
SC1		5 Nov 82	Did NOT fail	
SC2		5 Nov 82	Could not set meter	Humidity corrosion of wiring and circuitry Salt corrosion of octal plug.
SC3		16 Dec 81		
SC4				
SC5	↓	↓		↓
SH1	9 Oct 80	8 Nov 82		Humidity corrosion of wiring and circuitry
SH2		8 Nov 82		
SH3		19 Nov 81		
SH4		17 Dec 81		
SH5	↓	19 Nov 81		
CF1	16 Oct 80	4 Nov 82		
CF2		4 Nov 82		
CF3		15 Dec 81		
CF4				
CF5	↓	↓	↓	↓

Note: 20 vacuum gages fail_d (out of 25 exposed).

Table 1. (cont)

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Photographic Timers				
CC1	1 Oct 80	4 Nov 82	Hands did not turn. Reset ring stuck.	Corrosion on clock gear shafts prevented hands from moving. Corrosion on reset bracket prevented bracket from returning freely
CC2	↓	↓	Did NOT fail	
CC3	↓	↓	Switch stuck in "ON" position	Corrosion on switch chain and shaft caused switch to stay "ON."
CC4	↓	↓	Did NOT fail	
CC5	↓	↓	Did NOT fail	
CF1	1 March 81	16 Nov 81	Hands did not turn. Reset ring stuck.	Corrosion on clock gear shafts prevented hands from moving.
CF2	↓	19 Oct 81	Hands did not turn.	Corrosion on clock shafts and gears prevented hands from moving. Rust on hands and reset ring caused sticking.
CF3	↓	24 Aug 81	Hands slipped on shaft.	Warping and shifting of timer face caused slippage of second hand. Rust on reset ring.
SO1	7 Oct 80	14 Apr 82	Hands did not turn. Reset arm stuck.	Corrosion on hands and on clock gears and shaft prevented hands from moving. Reset arm very rusty.
SO2	↓	5 Nov 82	Did NOT fail	
SO3	↓	28 Jul 81	Hand stopped at 24 seconds.	Heavy corrosion on cloc shaft and gear mechanism. Rust between reset arm and bushing caused sluggish reset ting.

Table 1. (cont)

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Photographic Timers (cont)				
S04	7 Oct 80	5 Nov 82	Did NOT fail	
S05		16 Feb 82	Hands stuck.	Corrosion on clock shaft and gear mechanism. Rust on hands and reset ring.
SH1	9 Oct 80	8 Nov 82	Hands did not move.	Mildew and rust on clock face, hands, and reset ring. Also on clock motor shaft.
SH2			Hands did not move.	Mildew and rust on hands and clock gear mechanism.
SH3			Second hand stalled at 32 1/2 seconds. Second hand was bent and touching glass.	Corrosion on clock mechanism, especially on cam and shaft of second hand.
SH4			Second hand dragged against glass. 20 seconds slow.	Heavy corrosion on cam and shaft of second hand. Rust on reset arm prevented reset from returning freely.
SH5		21 Jul 81	22 seconds slow	Heavy corrosion on cam and shaft of second hand. Rust on hands and reset ring.
SC1	7 Oct 80	5 Nov 82	Did NOT fail	
SC2		19 Jan 82	Did not run	Rust on reset ring. Heavy rust buildup on clock shaft at motor; aluminum rotor badly rusted, causing motor to fail to run.
SC3		26 Aug 81	Would not stop after reset was activated.	Heavy corrosion between aluminum arm and brass bushing of reset mechanism prevented reset to function. Reset ring and shaft severely corroded.

Table 1. (cont)

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Photographic Timers (cont)				
SC4	7 Oct 80	20 Oct 81	Chain broke during test. Timer functioned OK. Item retired from further testing.	Rust caused switch chain to break at entrance to switch. Could not stop clock.
SC5	↓	26 Aug 81	Would not stop running.	Heavy rust between aluminum arm and brass bushing of reset mechanism . Reset ring severely corroded. Reset arm stuck.

Note: 16 timers failed (out of 23 exposed).

Table 1. (cont)

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Helmet Radio Receiver				
CC1	21 Jan 81	4 Nov 82	Did NOT fail	
CC2				
CC3				
CC4				
CC5	↓	↓		
SO1	13 Jan 81	5 Nov 82		
SO2				
SO3				
SO4				
SO5				
SC1				
SC2	↓	↓	↓	
SC3	27 Jan 81	22 Mar 82	No audibility	Salt corrosion
SC4	↓	5 Nov 82	Did NOT fail	
SC5	13 Jan 81	28 Jul 81	No audibility	Salt corrosion
SH1	14 Jan 81	8 Nov 82	Did NOT fail	
SH2				
SH3			↓	
SH4		4 Jun 81	No squelch	Moisture condensation, shorting circuitry
SH5	↓	8 Nov 82	Did NOT fail	
CO1	21 Jan 81	4 Nov 82	No audibility	Moisture condensation, shorting circuitry.
CO2			No audibility	↓
CO3			Did NOT fail	
CF1				
CF2				
CF3				
CF4				
CF5	↓	↓	↓	

Note: 5 radios failed (out of 28 exposed).

Table 1. (cont)

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
M3 Binoculars				
C01	19 Nov 80	8 Apr 81	Lens fogged	Gasket failure due to environmental stressing
C02	↓	4 May 81	↓	↓
C03	↓	↓	↓	↓
CC1	19 Oct 80	4 Nov 82	Did NOT fail	
CC2	↓	↓	↓	
CC3	1 Oct 80	↓	↓	
CC4	↓	↓	↓	
CC5	↓	↓	↓	
CF1	16 Oct 80	↓	↓	
CF2	↓	↓	↓	
CF3	31 Oct 80	↓	↓	
CF4	16 Oct 80	↓	↓	
CF5	16 Sep 80	↓	↓	
SH1	9 Oct 80	8 Nov 82	↓	
SH2	↓	↓	↓	
SH3	↓	21 Oct 81	Internal fogging on lenses	Gasket failure due to environmental stressing
SH4	↓	13 Mar 81	↓	↓
SH5	↓	8 Nov 82	Did NOT fail	
SC1	8 Oct 80	5 Nov 82	↓	
SC2	↓	↓	↓	
SC3	↓	↓	↓	
SC4	↓	↓	↓	
SC5	↓	↓	↓	
S01	7 Oct 80	5 Nov 82	Did NOT fail	
S02	↓	↓	↓	
S03	↓	↓	↓	
S04	↓	↓	↓	
S05	↓	19 Jan 82	Lens fogged	Gasket failure due to environmental stressing

Note: 6 binoculars failed (out of 28 exposed).

Table 2. Criteria for degradation rating

0 - New

1 - Like new; very few corrosion spots or salt deposits

2 - Few corrosion spots or salt deposits

3 - Few additional corrosion spots or salt deposits

4 - Additional corrosion spots or salt deposits

5 - Corrosion or salt deposits half as severe as at end of exposure

6 - Slightly more corrosion or salt deposits

7 - Fairly bad corrosion or salt deposits

8 - Badly corroded

9 - Very badly corroded, but functionally O.K.

10 - Failed functionally:

- a - Vacuum gage - Could not set to "0," i.e., pegged and/or could not obtain a meter reading with either load connected
- b - Radios - No audibility; i.e., no tone, squelch, or voice
- c - Relay - Excess resistance; open; or failed to energize
- d - Timer - No reset capability; loss of accuracy; stop/start mechanism nonoperative; min/sec hands did not rotate

Table 3. Summary of laboratory cycling high temperature/humidity chamber tests and failure analysis

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Electromagnetic Relays				
1	26 Apr 83	15 Jun 83	No readings on D.E. or Energized	Shorting of blades due to build-up of corrosion on blades due to high humidity
2		8 June 83	No reading on Energized	
3				
4	↓	↓	↓	↓

Note: All 4 relays failed.

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Vacuum Gages				
1	1 Apr 83	15 June 83	Did NOT fail	
2			Did NOT fail	
3			Slightly erratic	Electrical shorting due to moisture
4	↓	↓	No readings. No spring left in knob.	Operating switch failed due to corrosion on shaft and in switch.

Note: 2 vacuum gages failed.

a.c. Ammeters and d.c. Motors

None of these items showed any signs of appreciable degradation.

Table 3. (cont)

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Photographic Timers				
1	1 Apr 83	18 May 83	Could not stop second hand. Minute hand did not move. Could not reset.	Corrosion in clock switch prevented turning off timer clock. Corrosion on reset arm prevented arm from functioning.
2		8 Apr 83	Failed to start. Reset ring stuck open.	Moderate corrosion on clock motor drive shaft. Corrosion on aluminum reset shaft.
3			Failed to start.	Moderate corrosion noted on motor drive shaft clock.
4		11 May 83	Failed to start.	Considerable corrosion noted on all moving inside parts on clock mechanism.

Note: All 4 timers failed.

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Helmet Radio Receivers				
1	1 Apr 83	15 June 83	Did NOT fail.	
2		8 Apr 83	No tone. No voice. Squelch O.K.	O.K. after several dryouts until 15 Jun 83.
3		11 May 83	No tone. No voice.	Failure caused by accumulation of moisture on the inside electrical circuits.
4		4 May 83	No squelch. No tone. No voice.	Intermittent failures, since 4 May 83. Problem corrected itself after dryout; possibly caused by wetting of internal electrical circuits.

Note: 3 radios failed.

Table 3. (cont)

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
M3 Binoculars				
1	1 Apr 83	18 May 83	Couldn't see through either eyepiece	Breakdown of sealant around lens seals and film deposit on lenses and prisms
2	↓	4 May 83	Couldn't see through left eyepiece.	Same as above. Also, possible separation of lenses.
3	↓	16 Jun 83	Did NOT fail	
4	↓	11 May 83	Couldn't see through left eyepiece. Right eye cup cracked in 2 places.	Breakdown of sealant evident. Slight film on left prism. Possible separation of lenses.

Note: 3 binoculars failed.

Table 4. Summary of laboratory cycling salt fog chamber tests and failure analysis

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Electromagnetic Relays				
1	25 Apr 83	1 Jun 83	No reading; energized or de-energized	Salt buildup and corrosion of wiring and/or blades of relay
2	↓	18 May 83	↓	↓
3	↓	25 May 83	↓	↓
4	↓	1 Jun 83	↓	↓

Note: All 4 relays failed.

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Vacuum Gage				
1	21 Apr 83	21 Jun 83	Did NOT fail	
2	↓	25 May 83	Could not set to zero. Meter erratic.	Electrical shorting due to moisture and salt corrosion.
3	↓	21 Jun 83	Did NOT fail	
4	↓	↓	Did NOT fail	

Note: 1 vacuum gage failed.

a.c. Ammeters and d.c. Motors

None of these items showed any appreciable sign of degradation.

Table 4. (cont)

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Photographic Timer				
1	21 Apr 83	15 Jun 83	Did not reset. Stop/start chain did not function.	Corrosion on shaft of hands and on bushings of the reset mechanism. Corrosion on ring prevented ring and stop/start chain from functioning.
2				
3		25 May 83	Reset ring didn't work.	
4		4 May 83	Stop/start chain didn't function.	

Note: All 4 timers failed.

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
Helmet Radio Receiver				
1	22 Apr 83	21 Jun 83	Did NOT fail	
2		12 May 83	No audibility	Corrosion of circuitry
3		21 Jun 83	Did NOT fail	
4		12 May 83	No audibility	Corrosion of circuitry

Note: 2 radio receivers failed.

No.	Date test began	Date item failed or date test completed	Mode of failure	Reason for failure
M3 Binoculars				
1	29 Apr 83	5 May 83	Fogging of lenses	Gasket failure
2		24 May 83		
3		24 May 83		
4		19 May 83		

Note: All 4 binoculars failed.

Table 5. Chemical composition of simulated sea water*

Chemical Compound	Quantity (g)
$Mg\ Cl_2 - 6H_2O$	10.8087
$Ca\ Cl_2$	1.1382
KCL	0.7609
$Sr\ Cl_2 - 6H_2O$	0.0240
$Na_2\ SO_4$	4.0078
$Na\ HCO_3$	0.1955
Na Br	0.0866
Na F	0.0028
$H_3\ BO_3$	0.0254
Na Cl	23.8883
H_2O (distilled)	959.0862

* Composition for this artificial sea water taken from proposed Mil Std 810D, method 509.2.

Figure 1. Triple canopy jungle--Fort Sherman (Skunk Hollow)

Figure 2. Field examination of test specimens

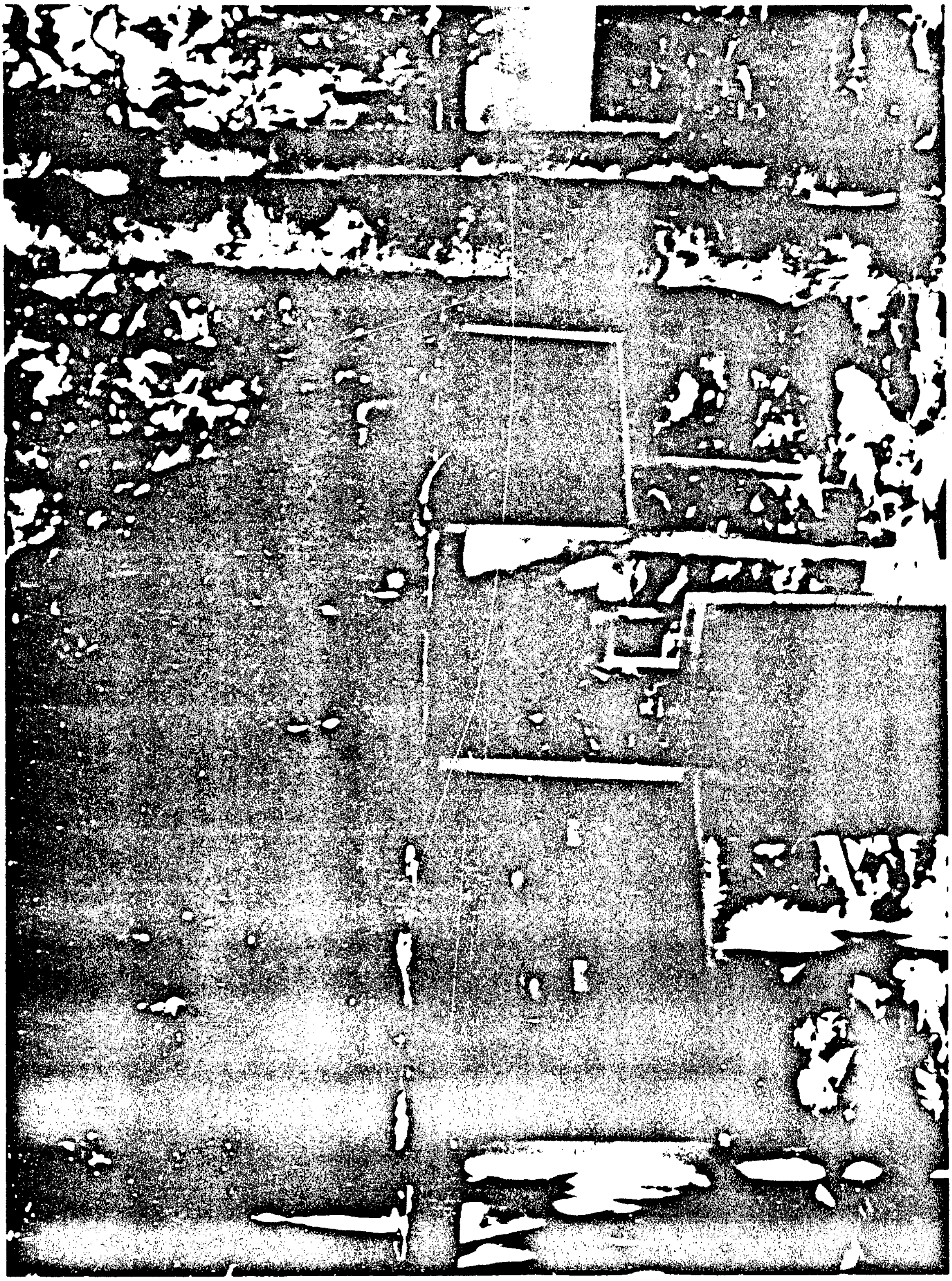


Figure 3. Double canopy jungle--Chiva Chiva forest

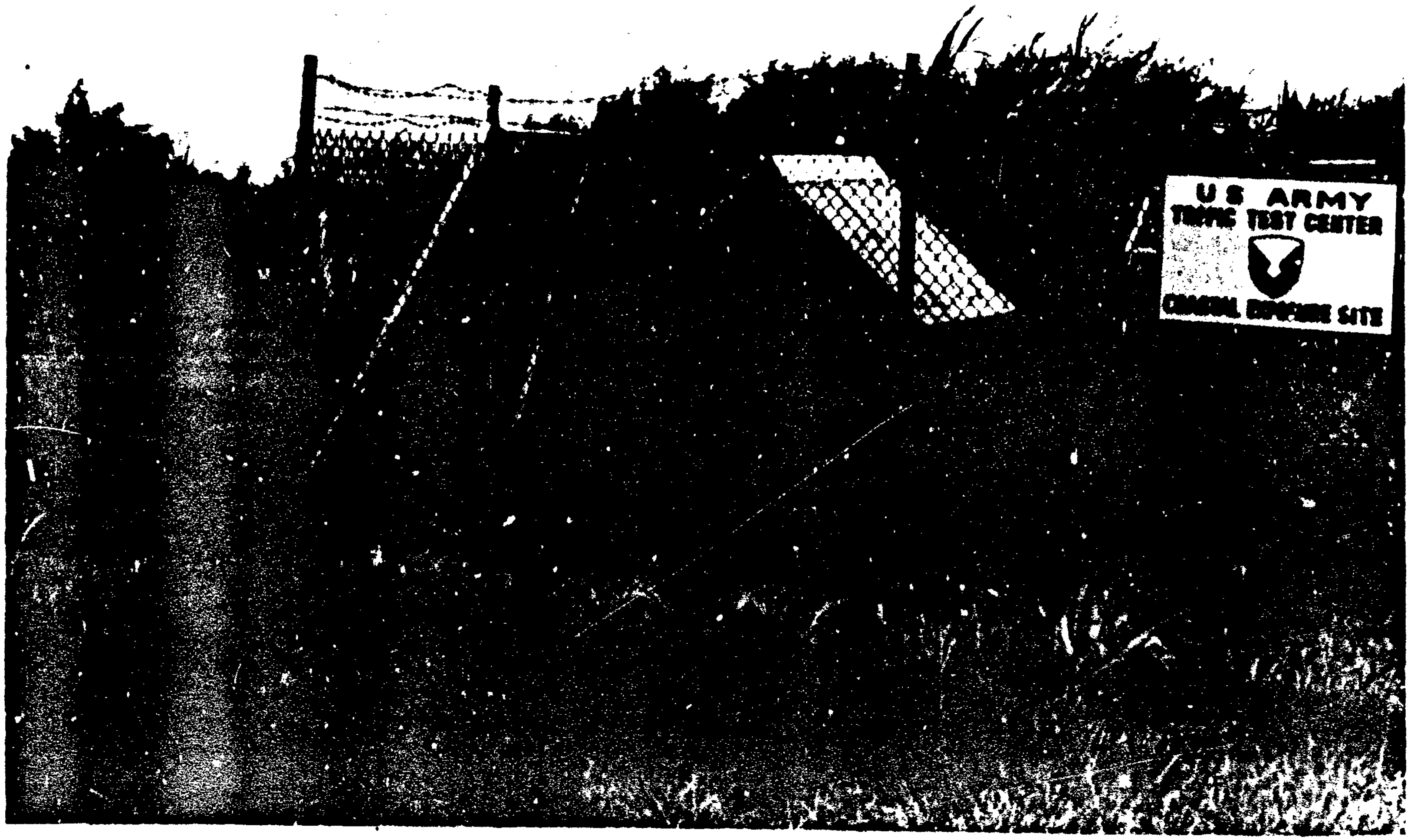


Figure 4. Coastal exposure site--Fort Sherman

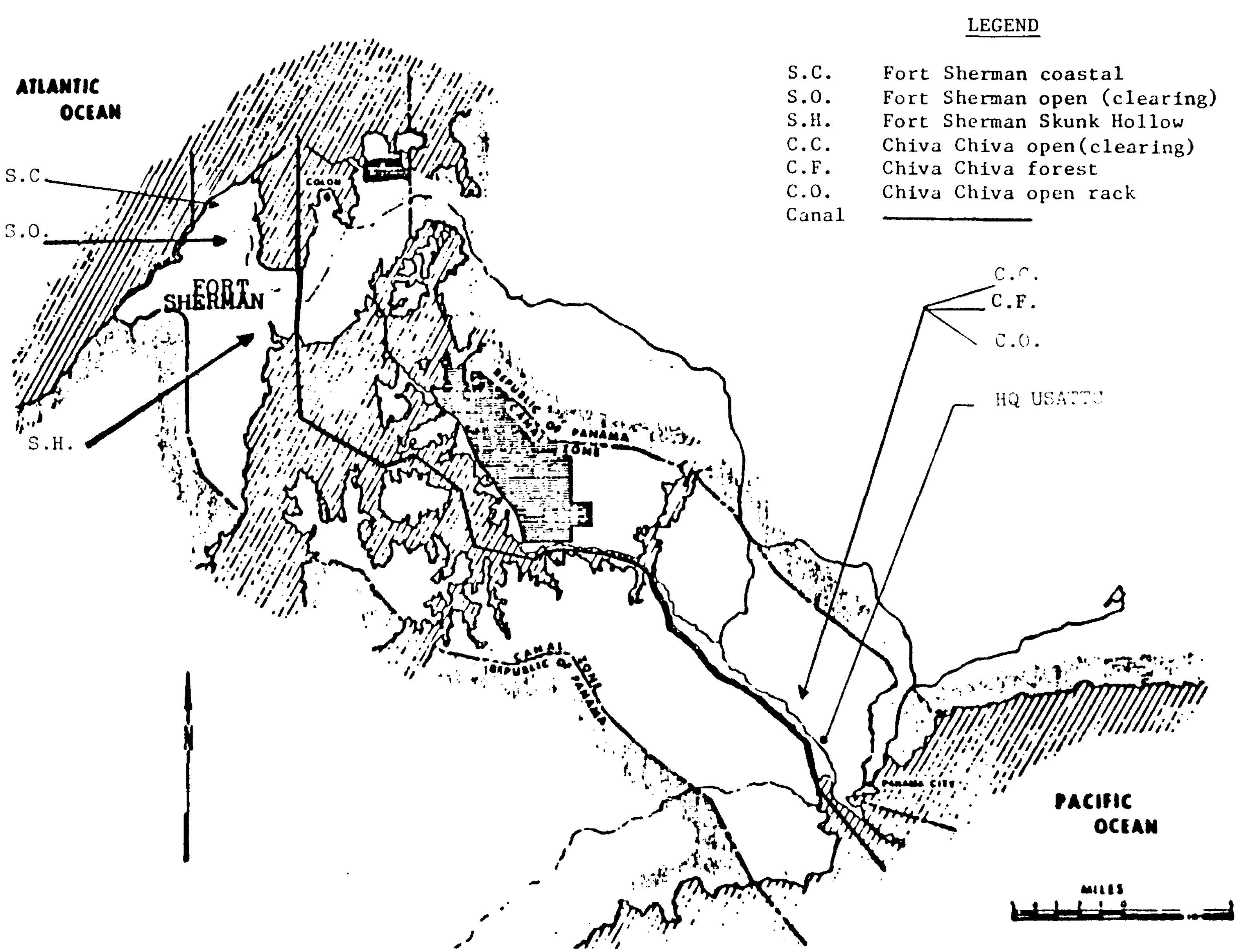


Figure 5. Map of Panama Canal Zone

Figure 6. Open test site--Chiva Chiva

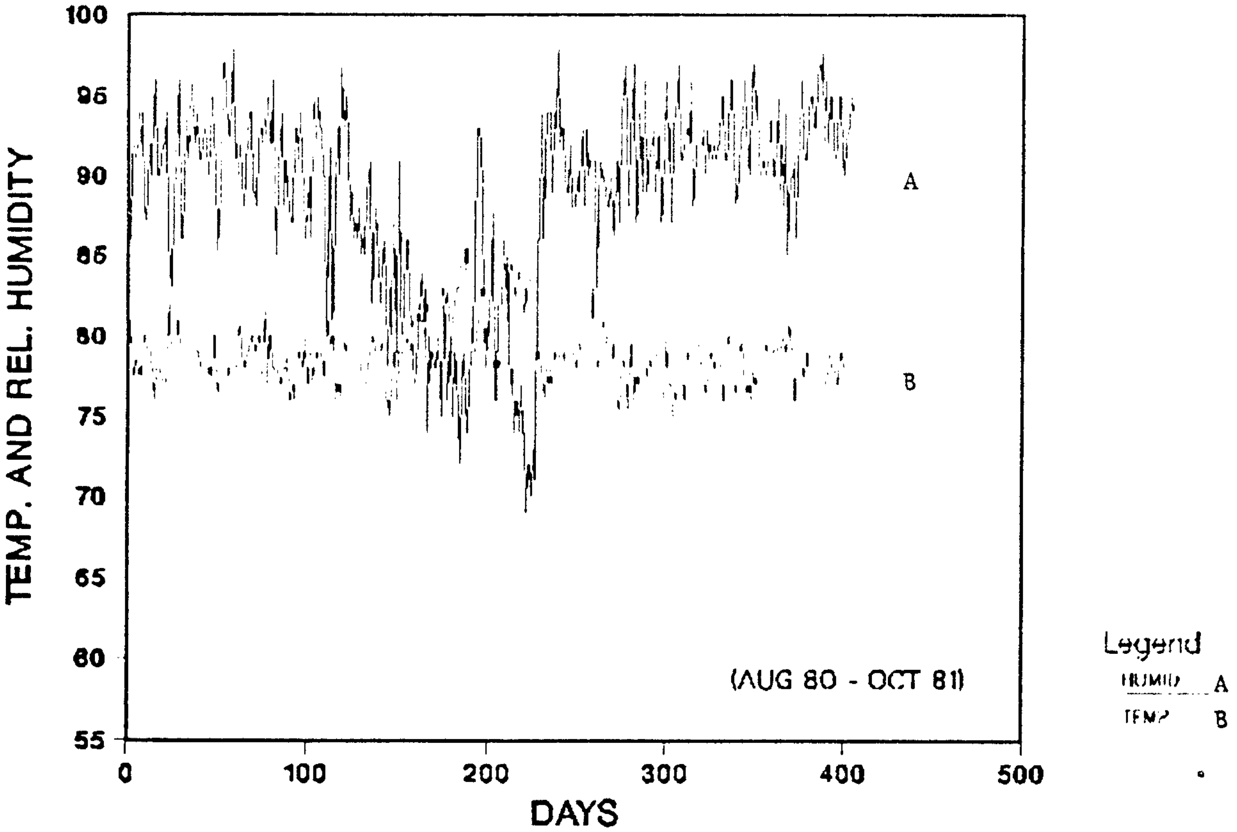


Figure 7. TTC weather data--Chiva Chiva forest

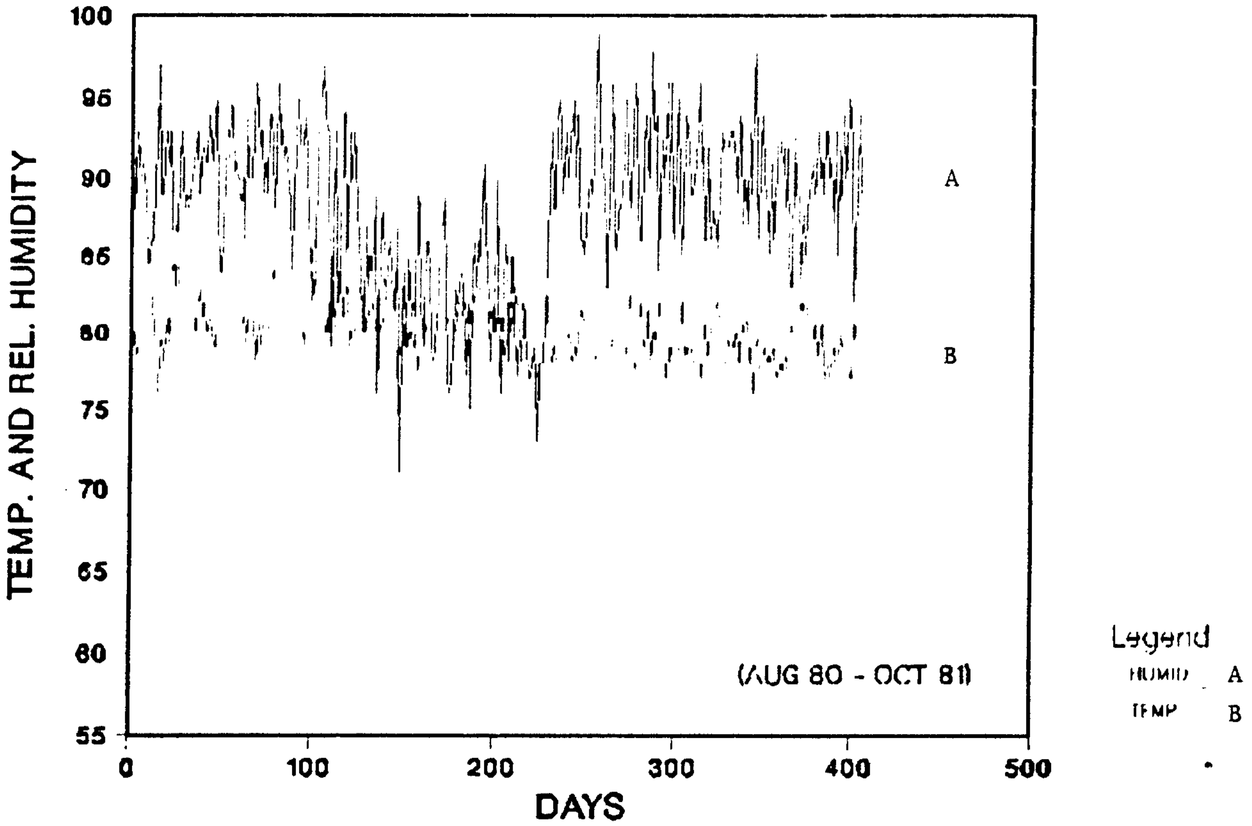


Figure 8. TTC weather data--Fort Sherman open sunfield

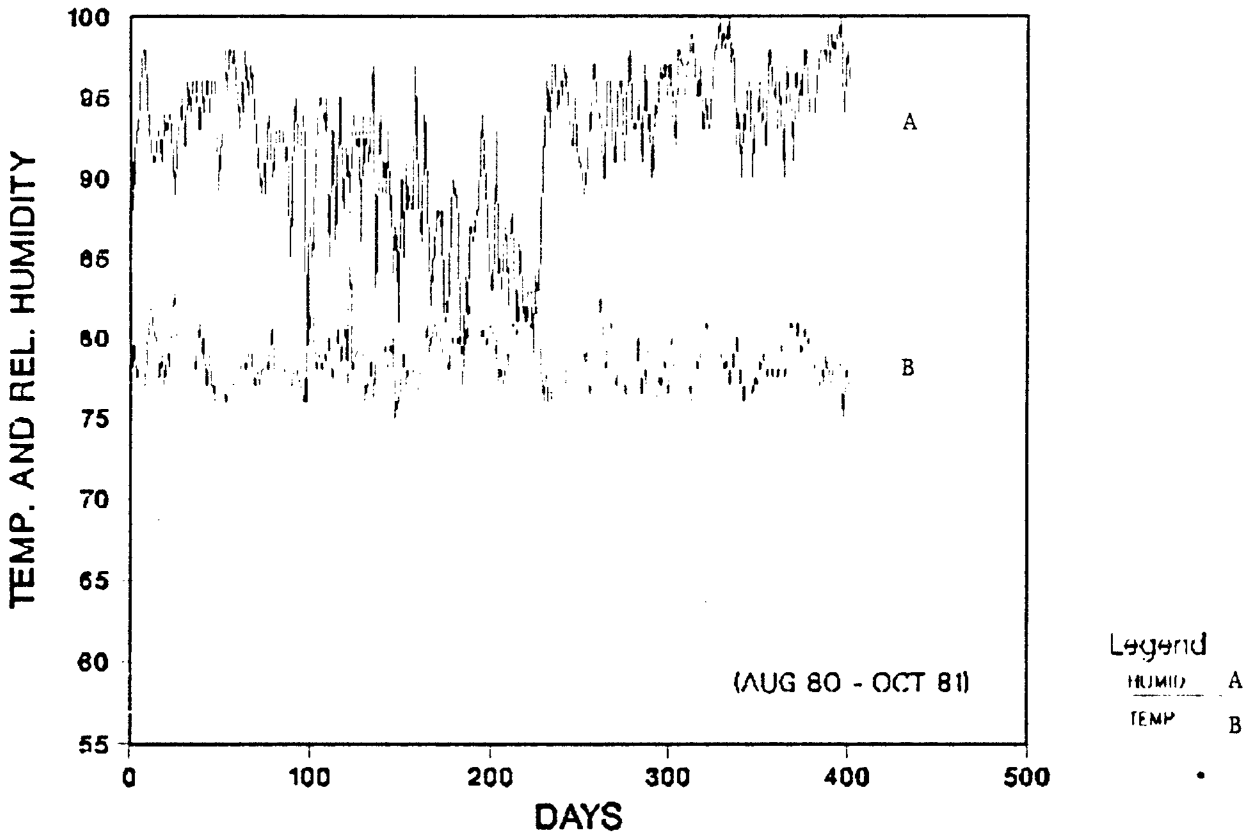


Figure 9. TTC weather data--Fort Sherman forest (Skunk Hollow)

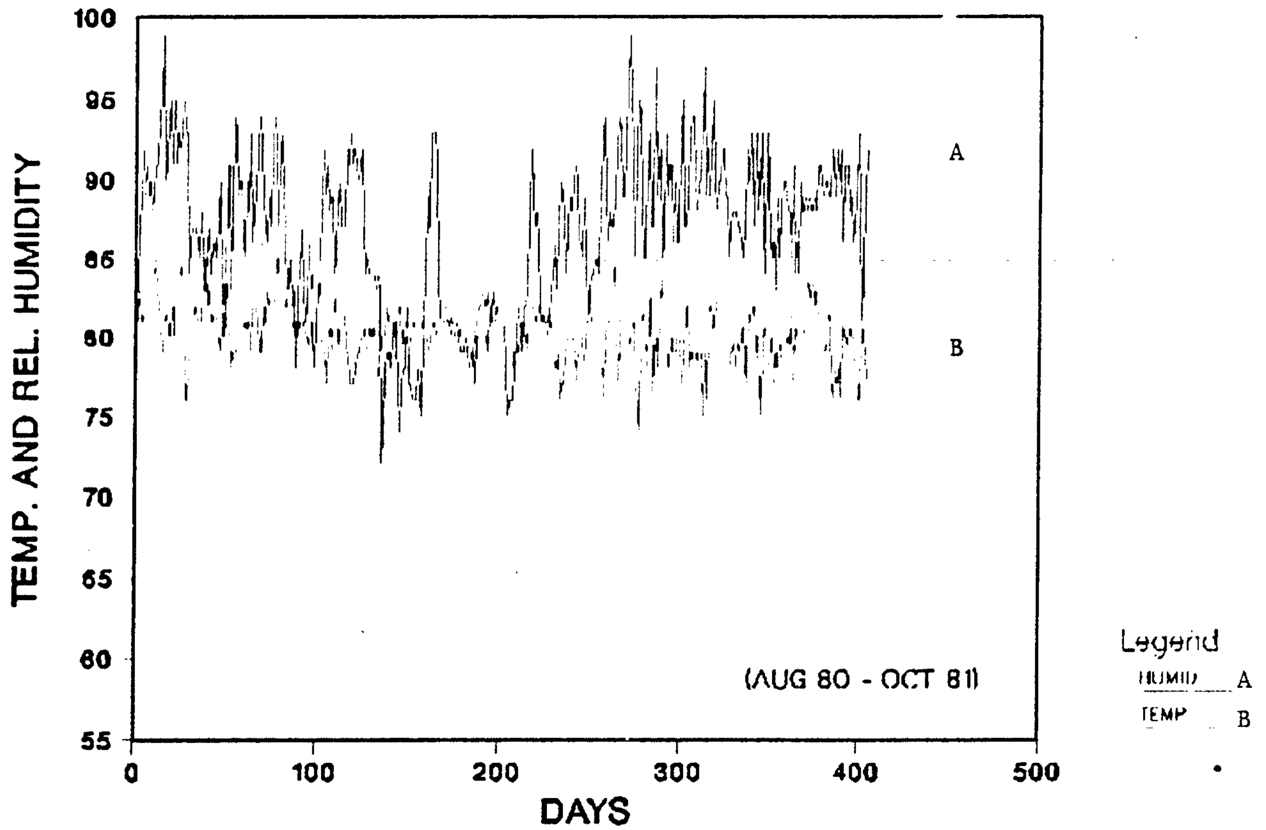


Figure 10. TTC weather data—Fort Sherman coastal

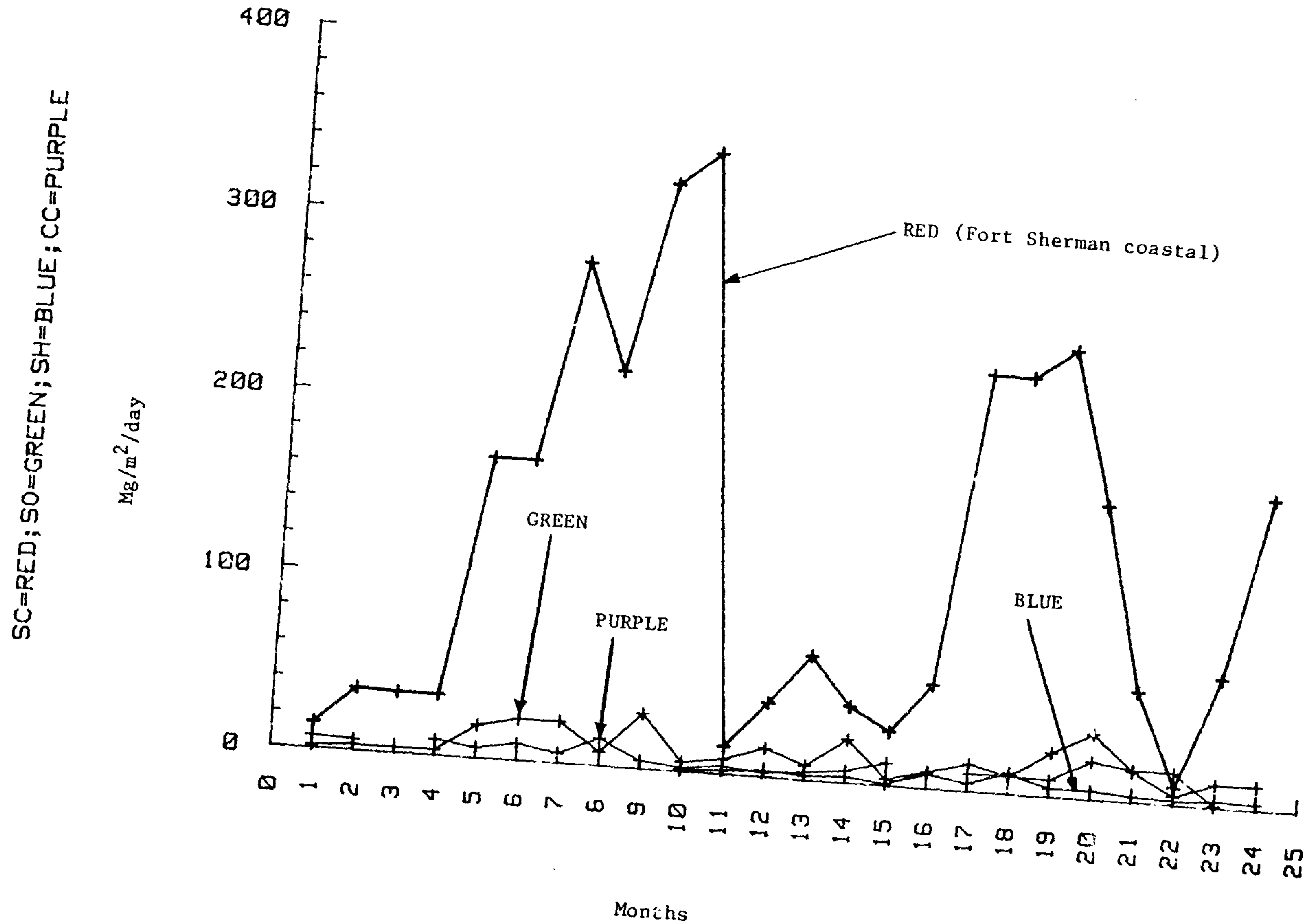


Figure 11. Salt candle data for August 1980 through August 1982

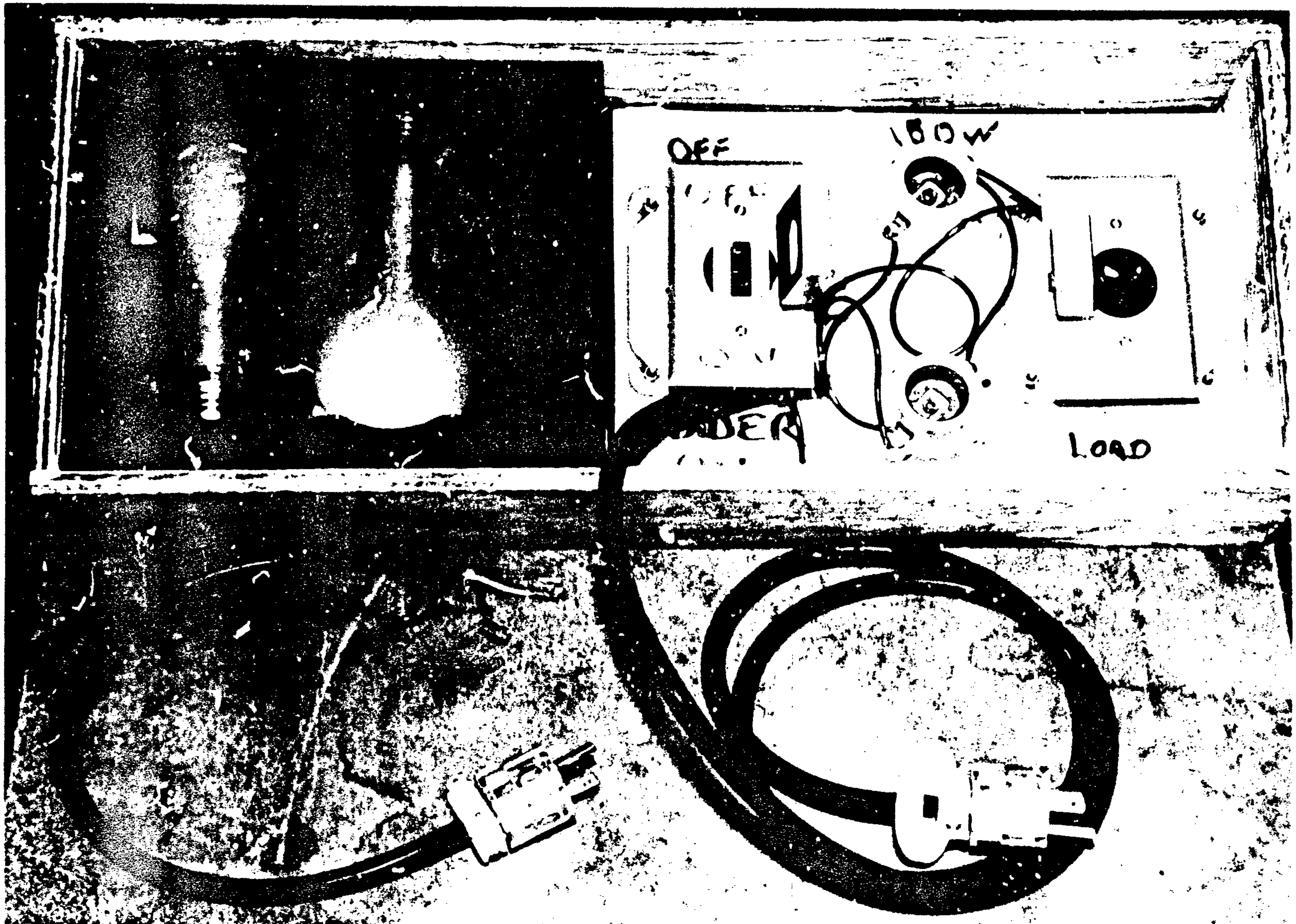


Figure 12. Test instrumentation for a.c. ammeter

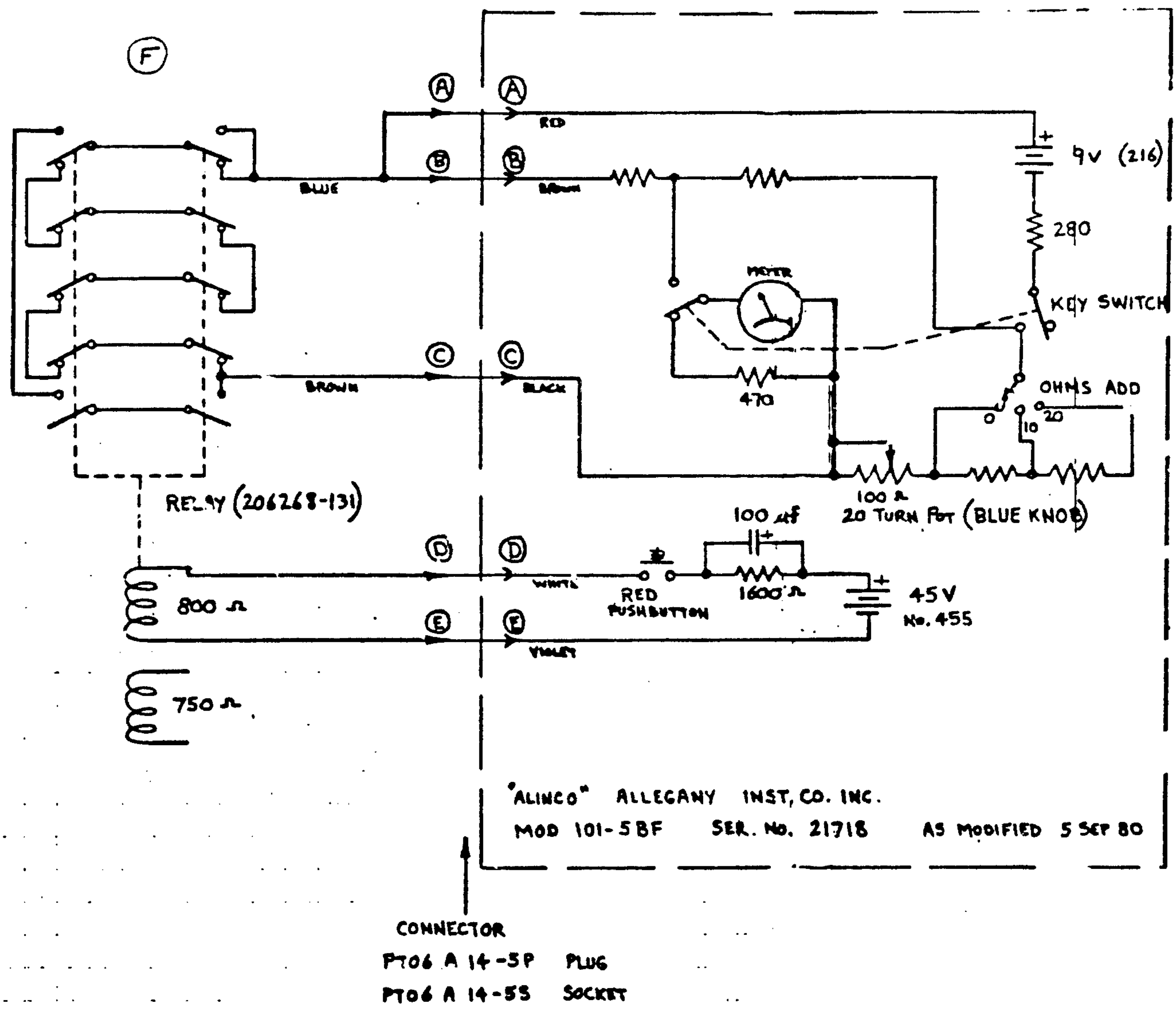


Figure 13. Wiring diagram for electromagnetic relay tester

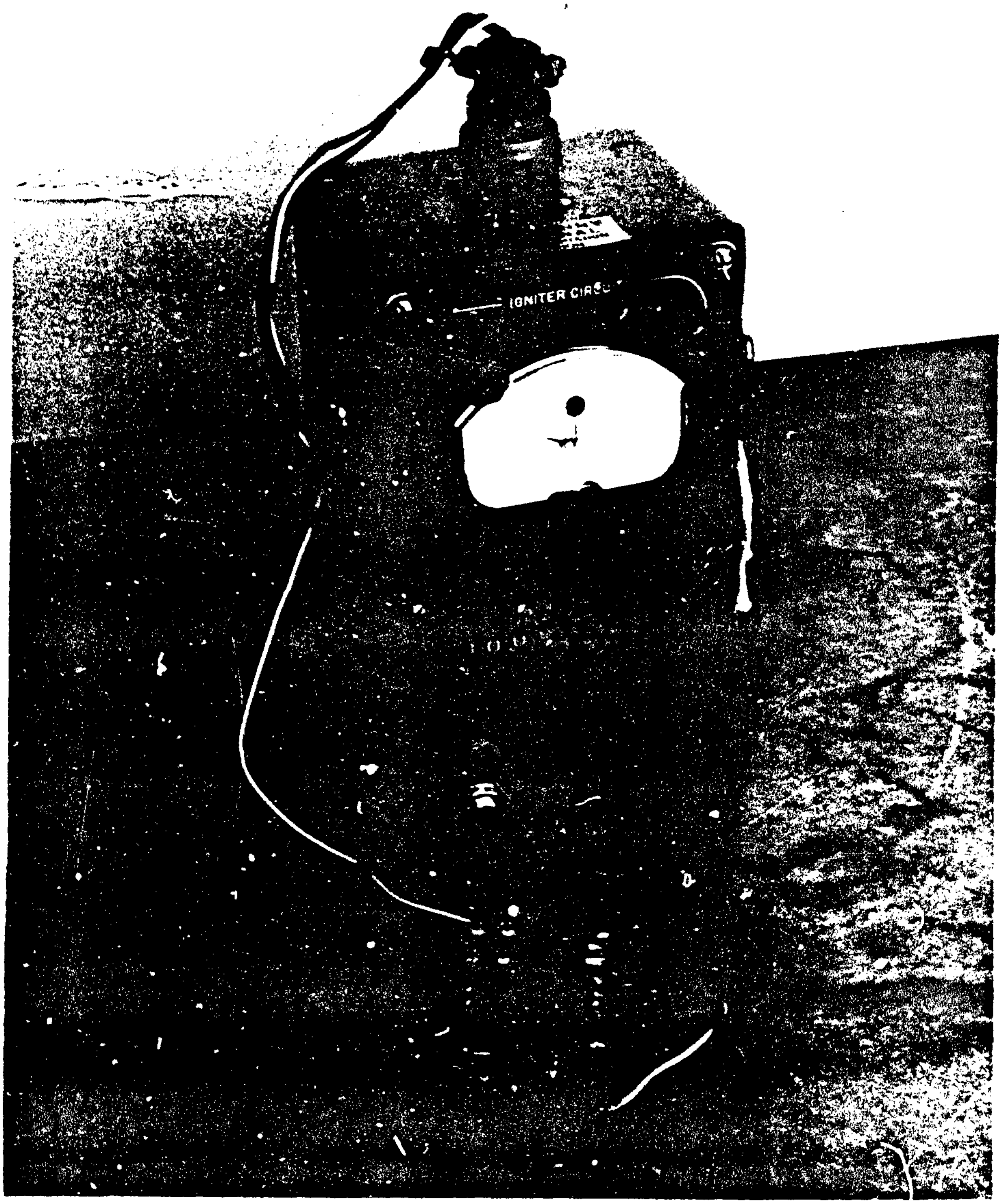


Figure 14. Test setup of electromagnetic relay and Alinco ohm tester

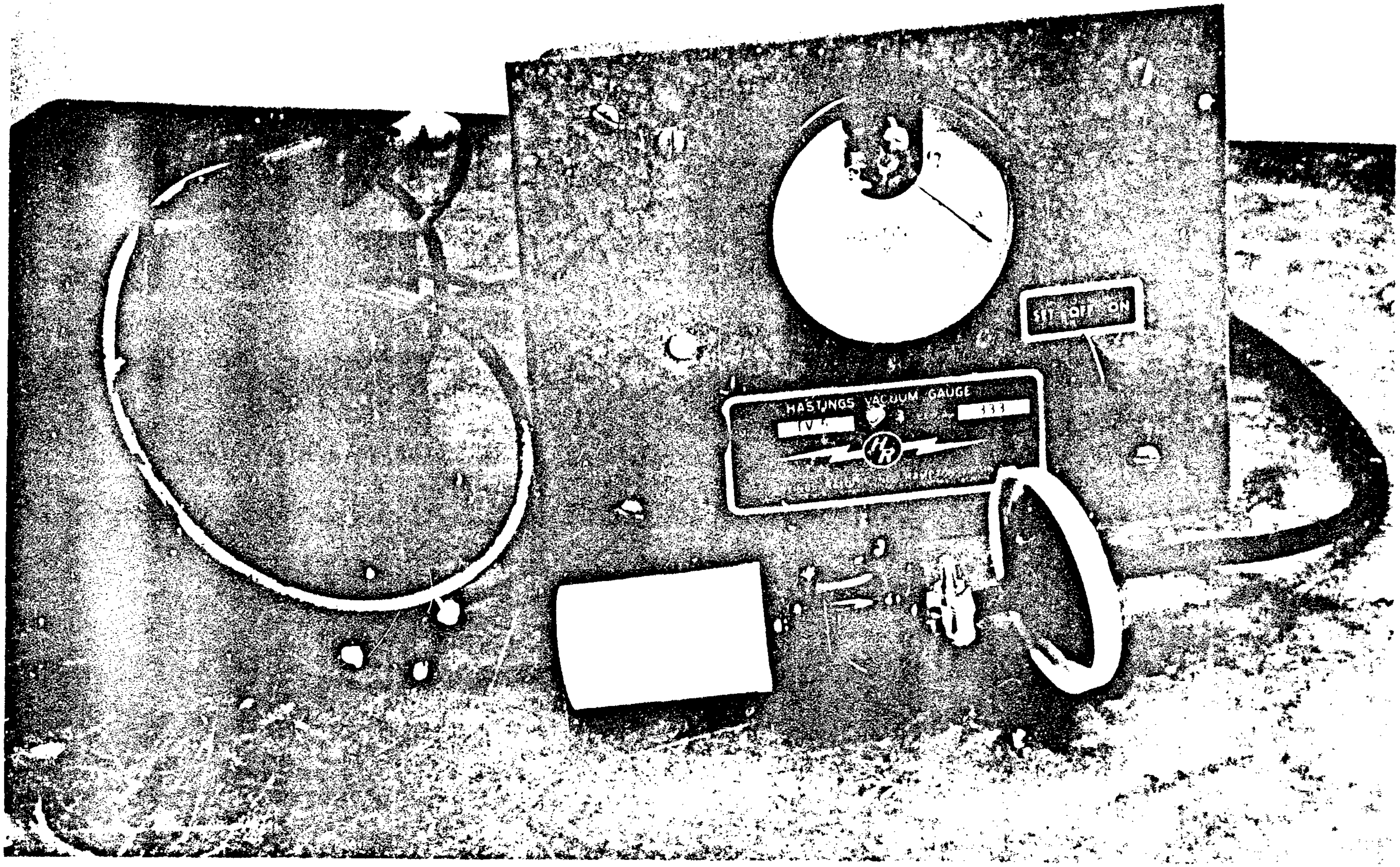
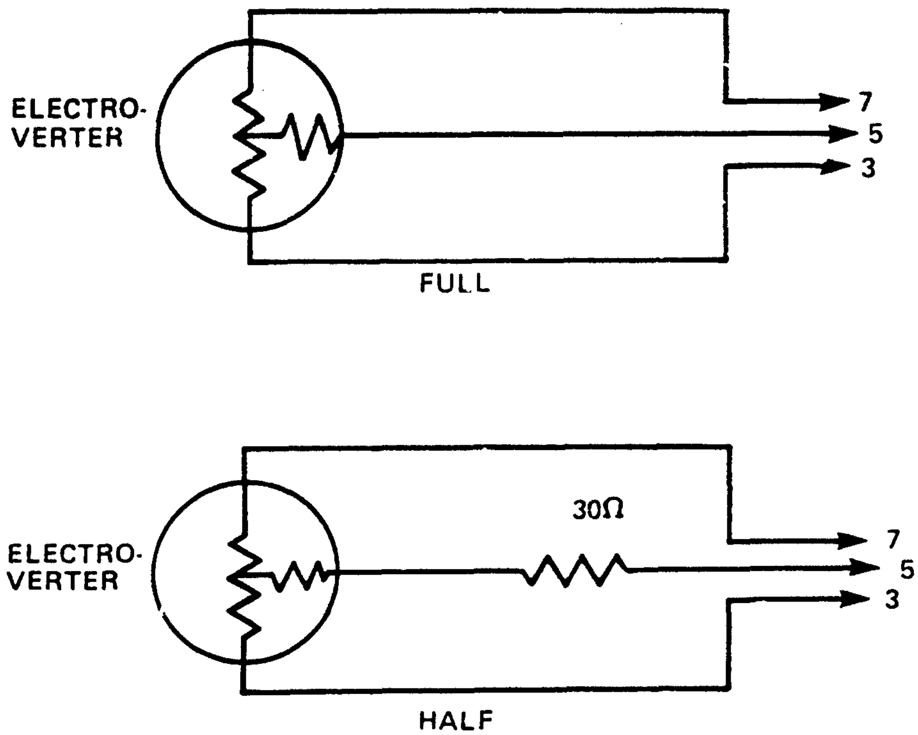


Figure 15. Test setup for vacuum gage, including dummy load tester and power supply



DUMMY LOAD TESTERS FULL AND HALF LOAD

Figure 16. Wiring diagram for vacuum gage dummy load tester

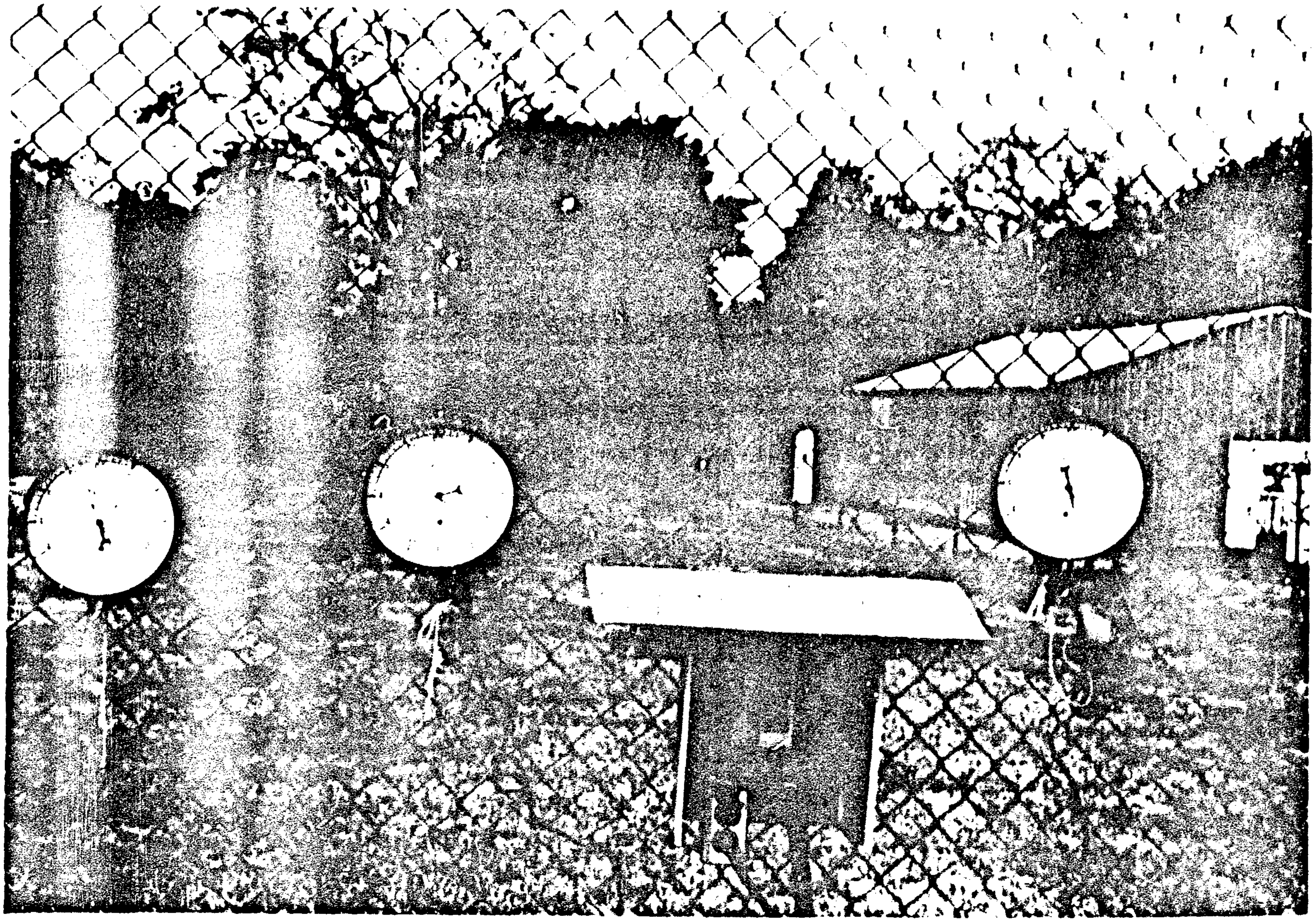


Figure 17. Test setup of photogr , uic timer--Chiva Chiva open clearing

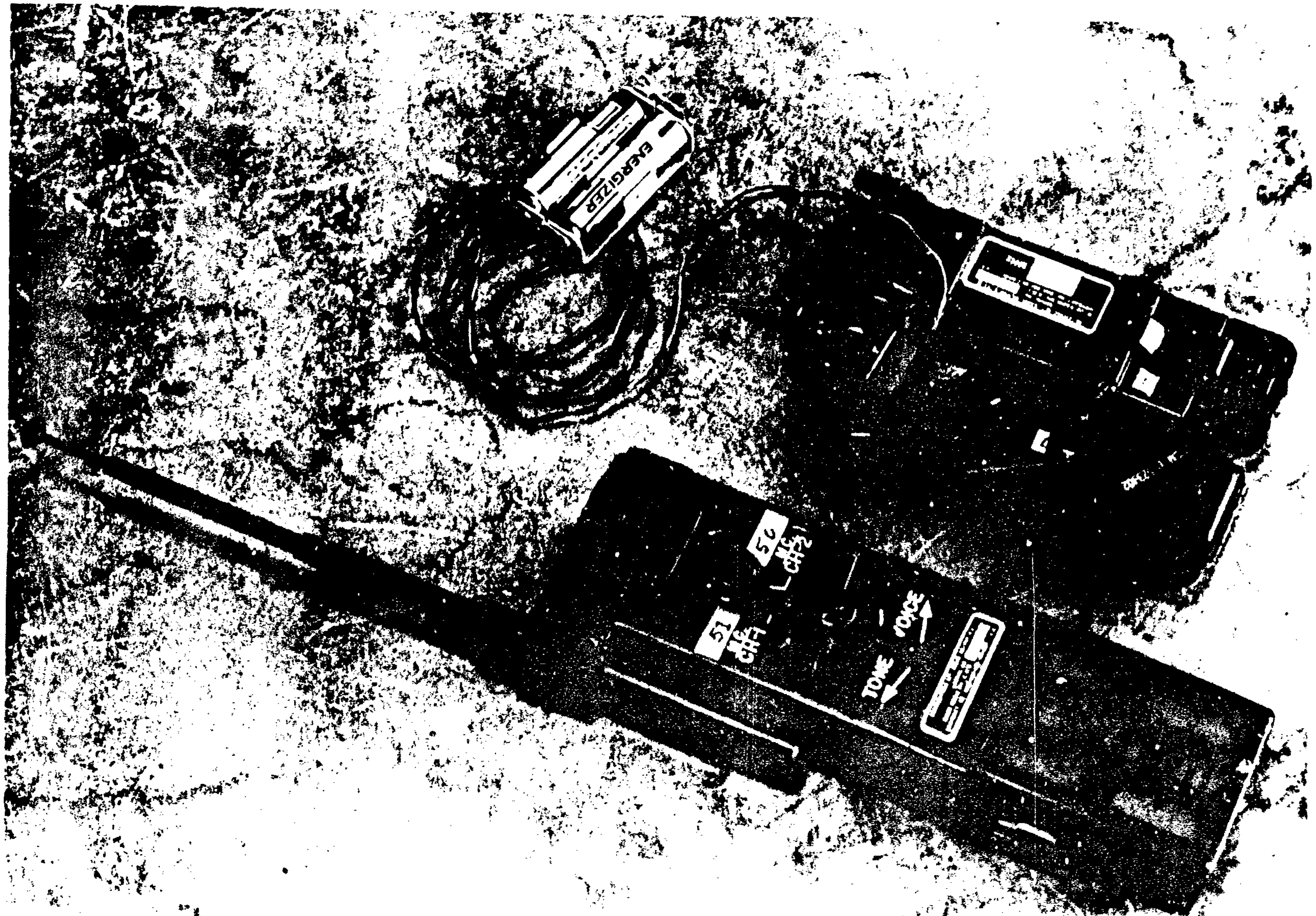


Figure 18. Test setup for helmet radio receiver, including transmitter

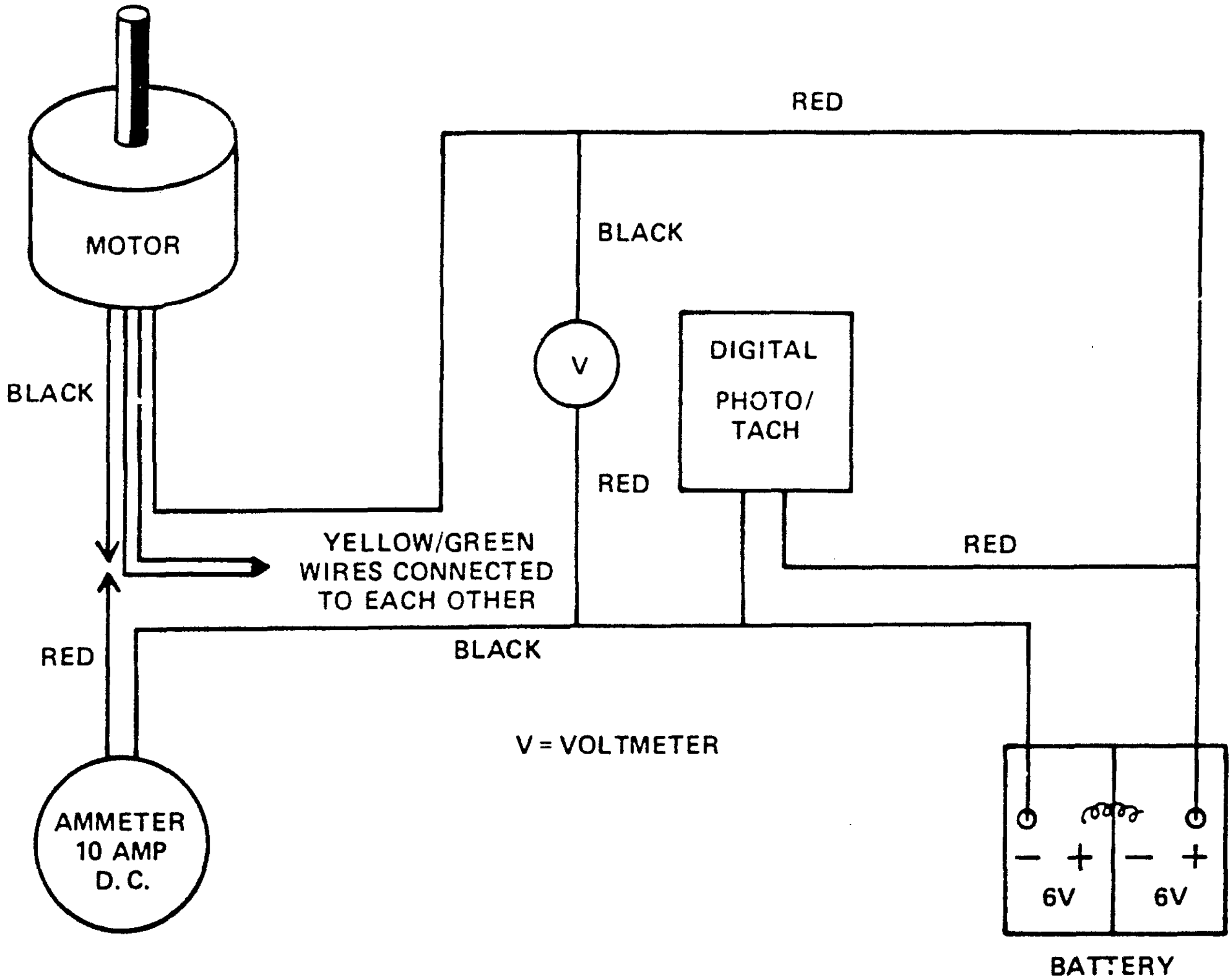


Figure 19. Wiring diagram for d.c. motor test setup

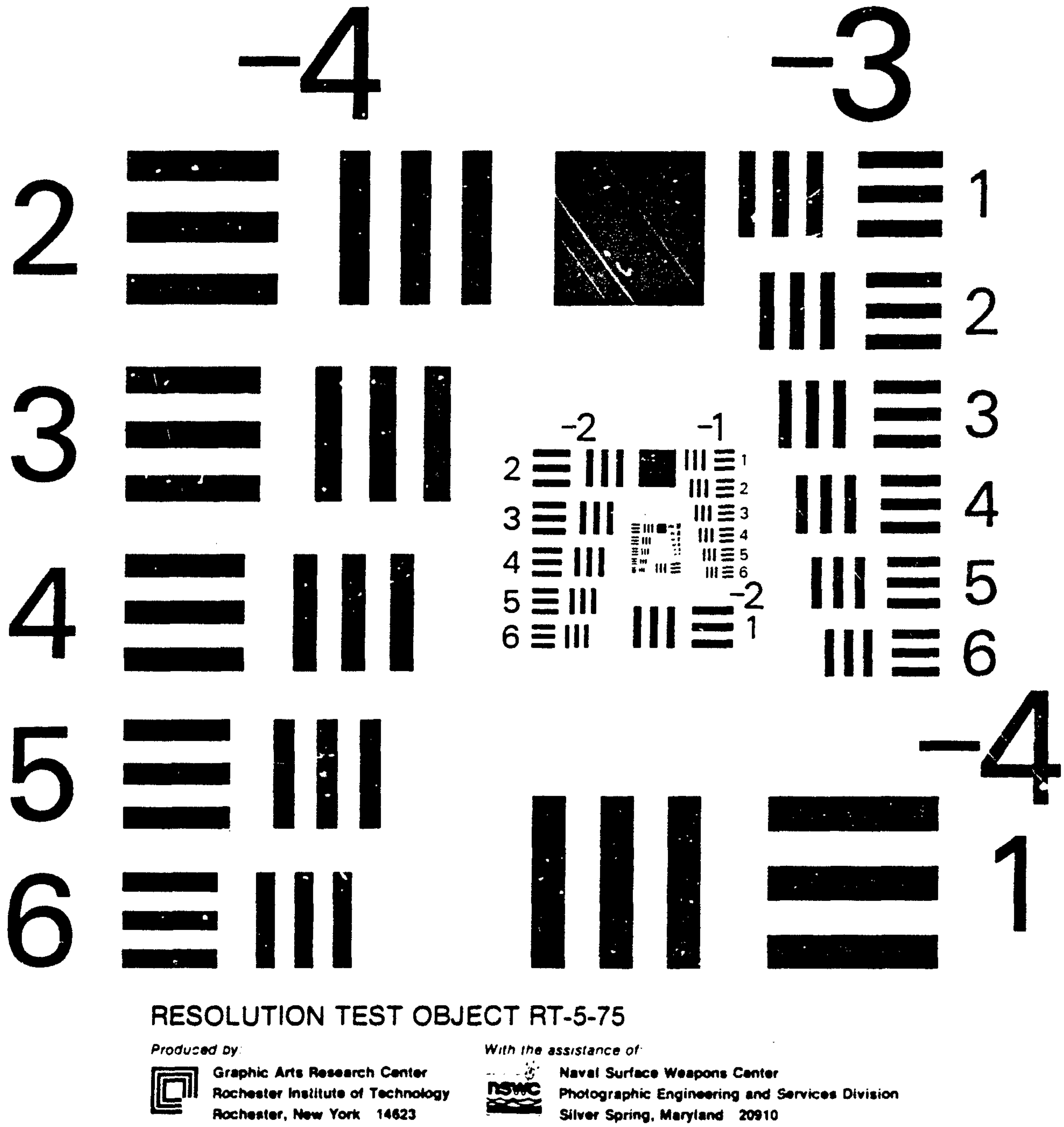


Figure 20. Resolution test target

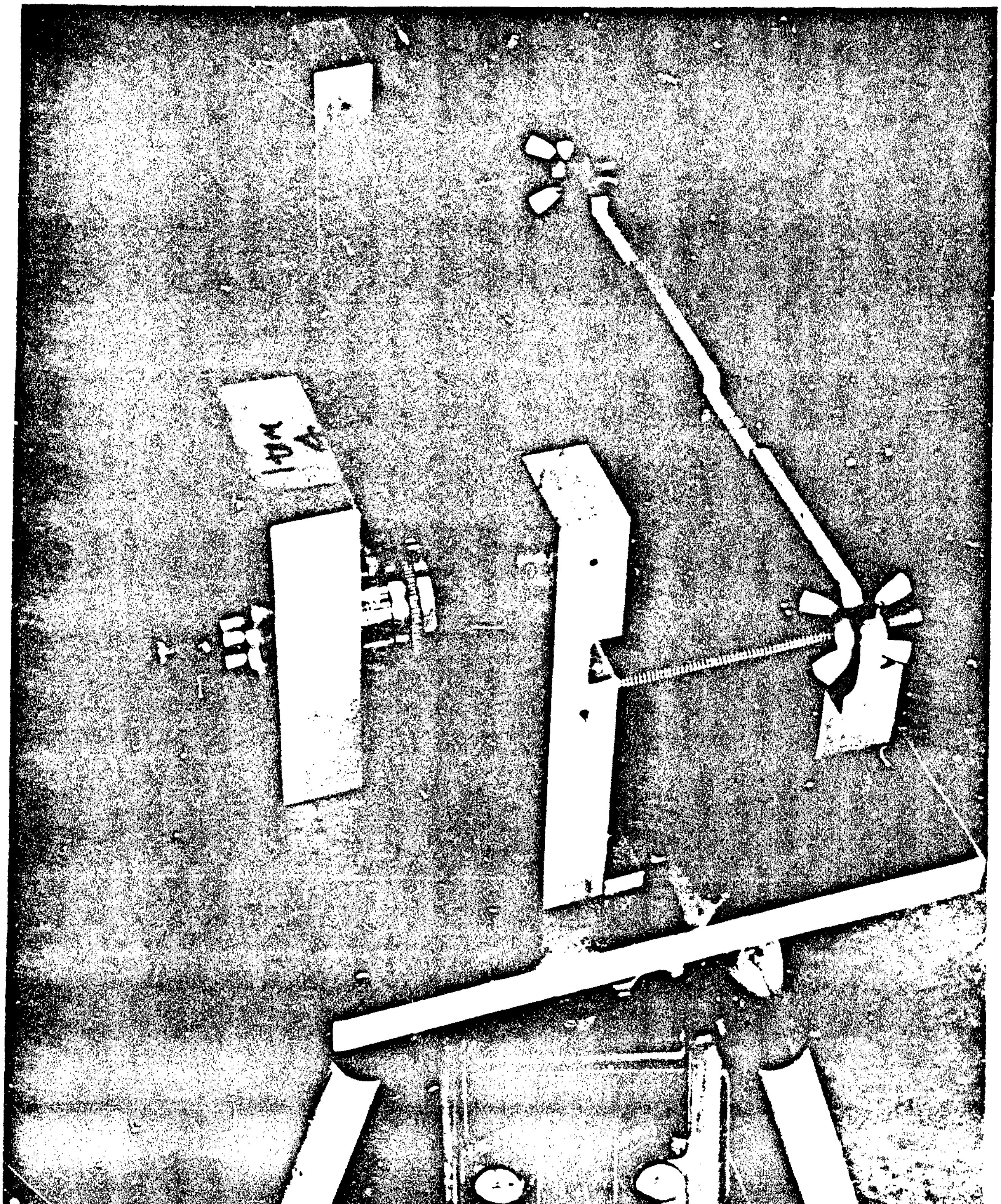


Figure 21. Test setup for optical resolution

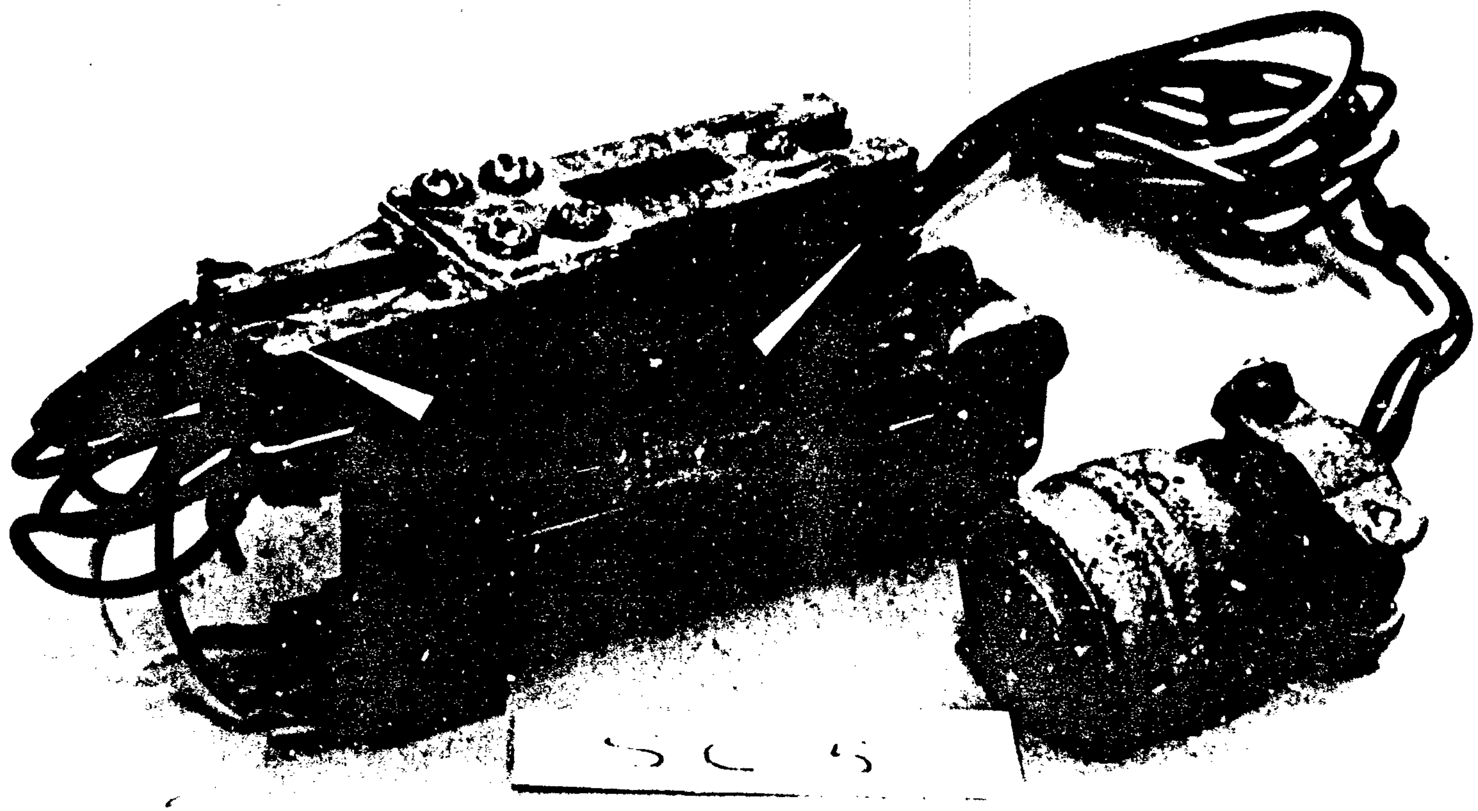


Figure 22. Condition of electromagnetic relay after test (representative photo)

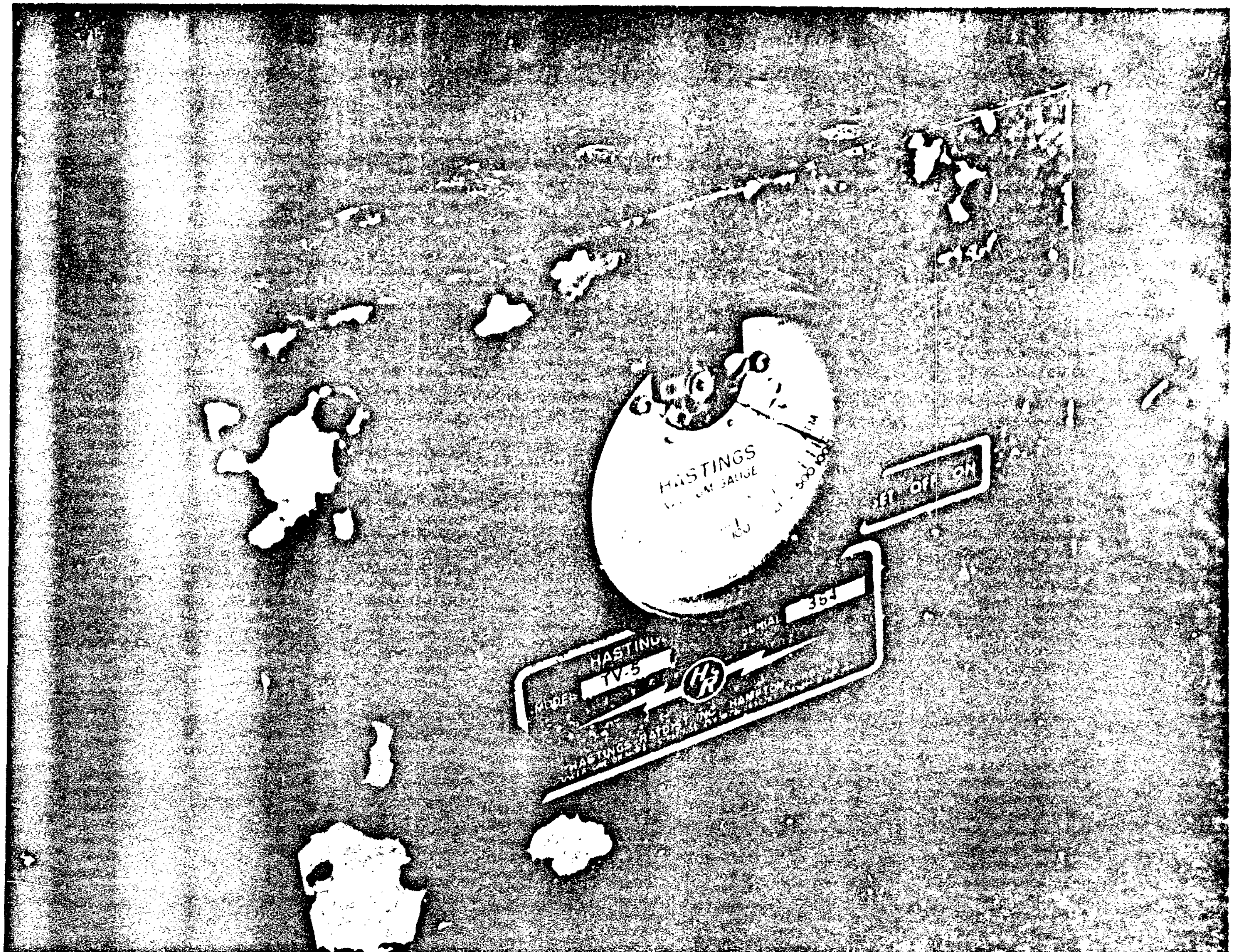


Figure 23. Vacuum gage showing corrosion of plug and painted surface--Fort Sherman coastal area

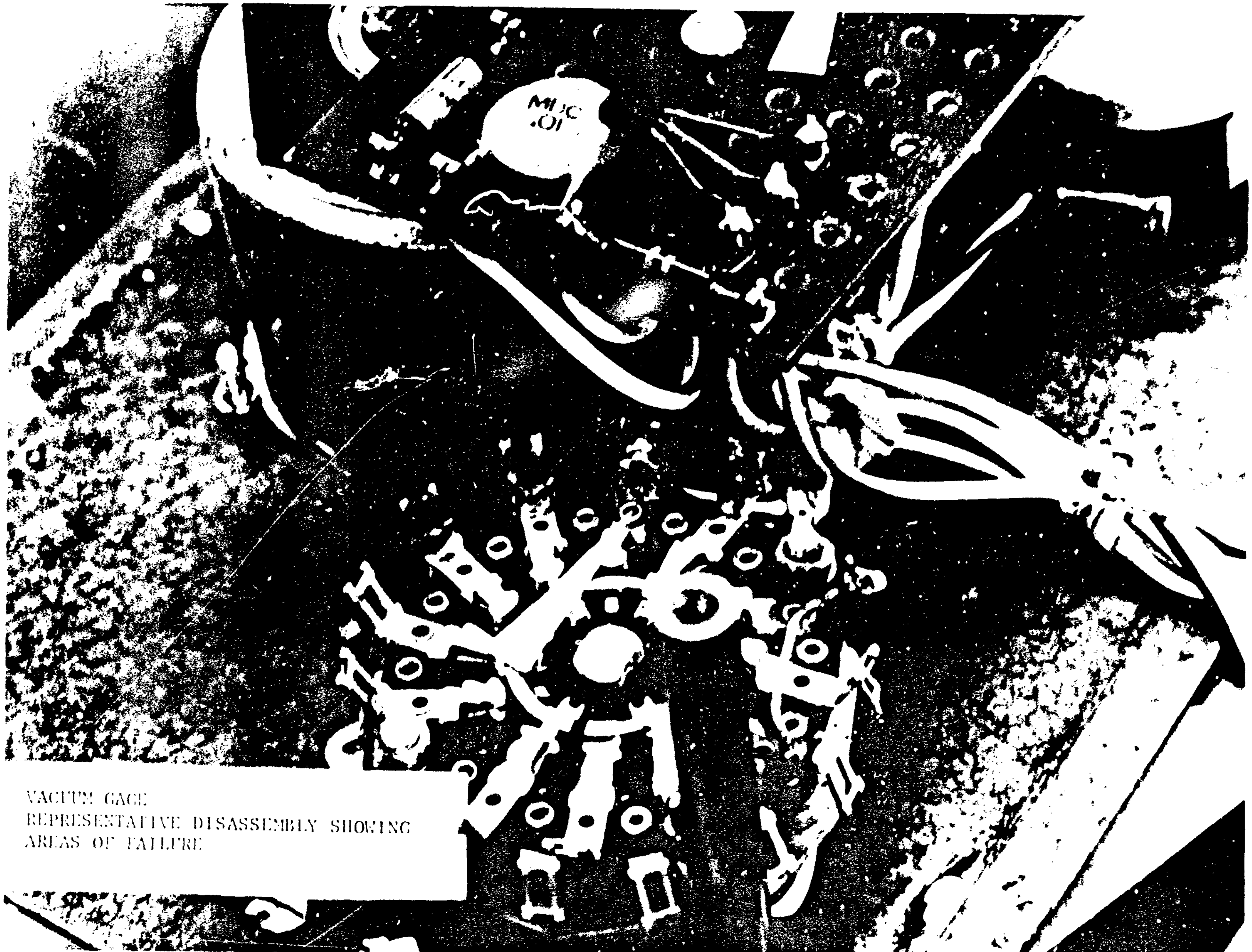


Figure 24. Vacuum gage disassembly

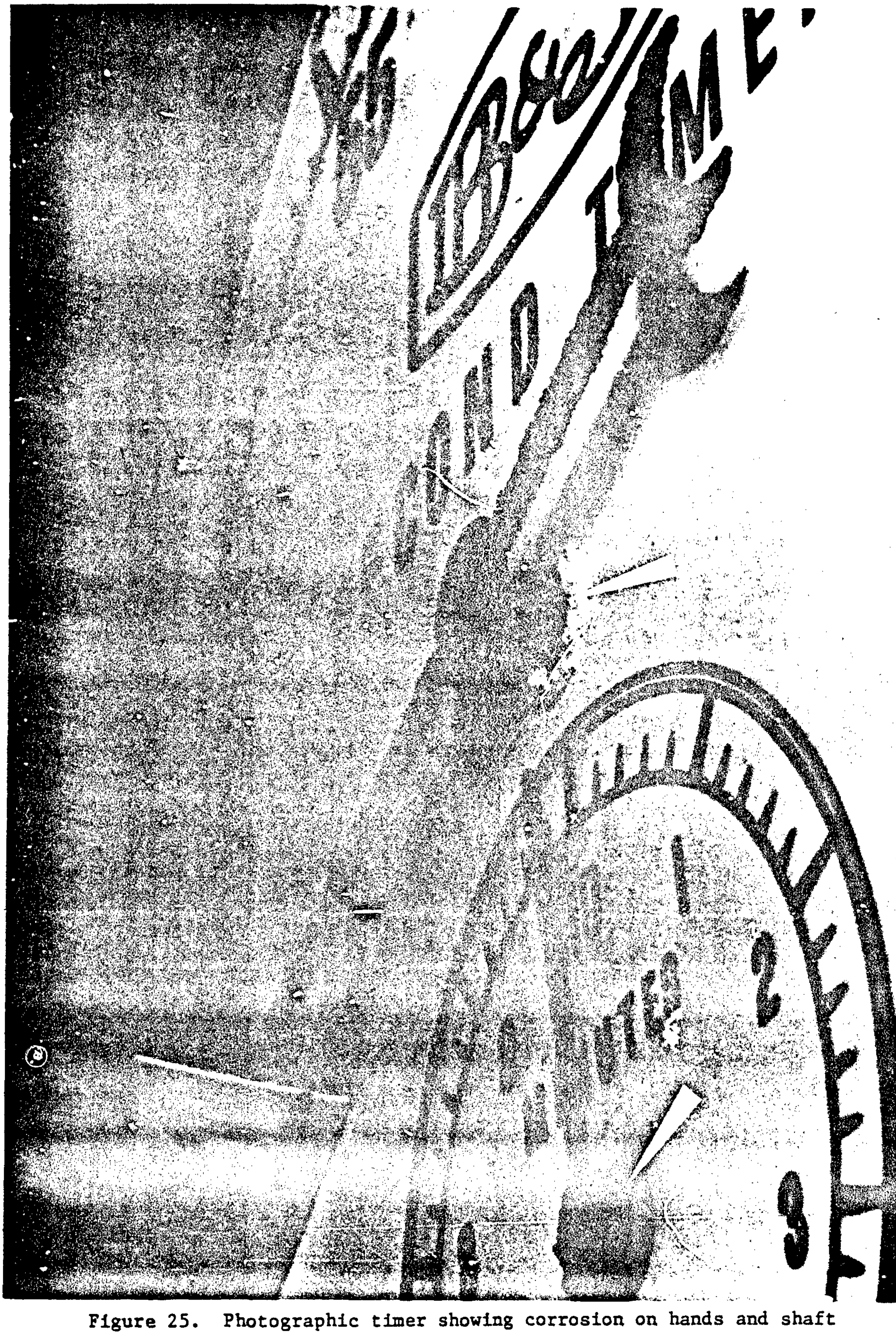


Figure 25. Photographic timer showing corrosion on hands and shaft

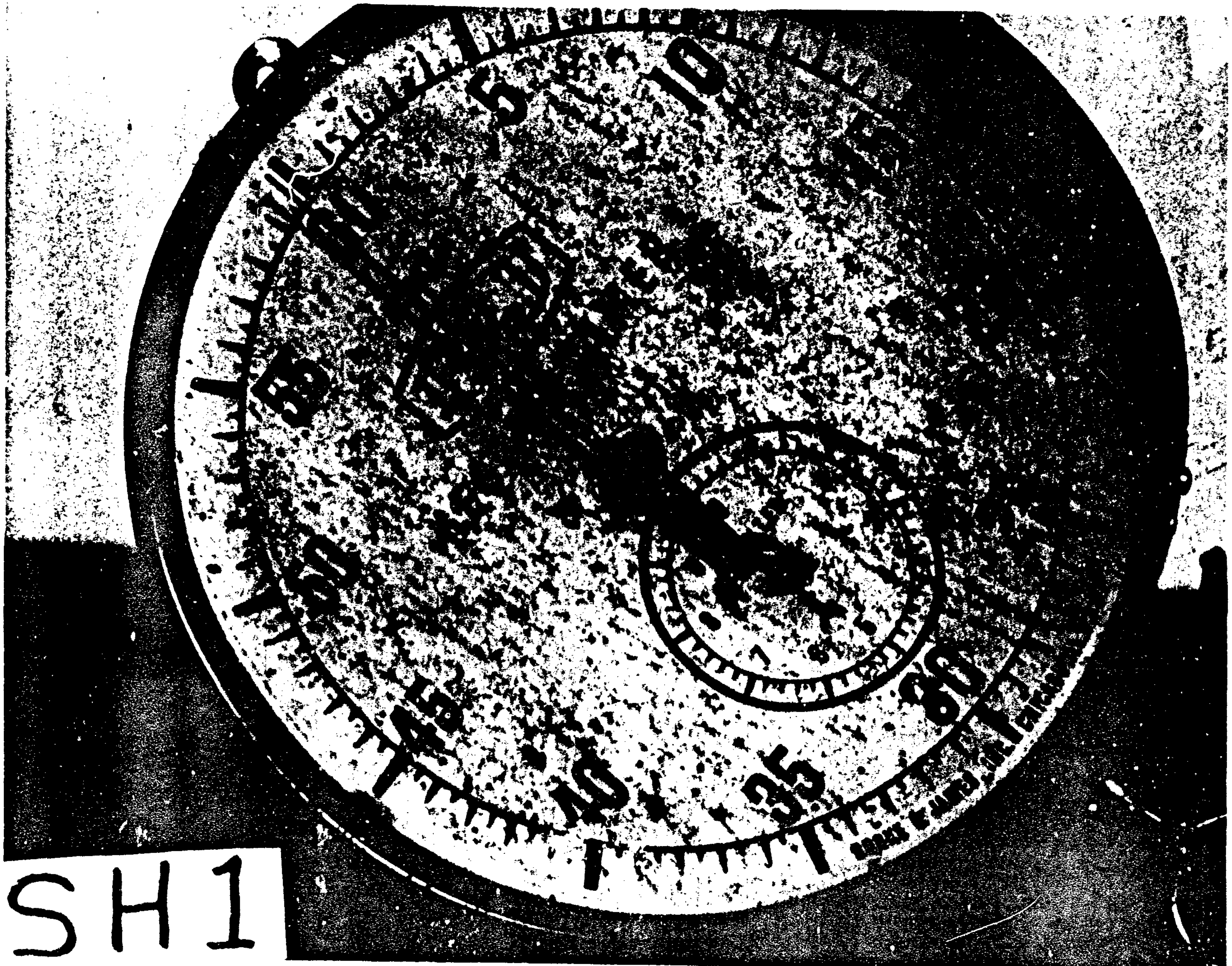


Figure 26. Photographic timer showing corrosion on shaft and fungal growth on paper face

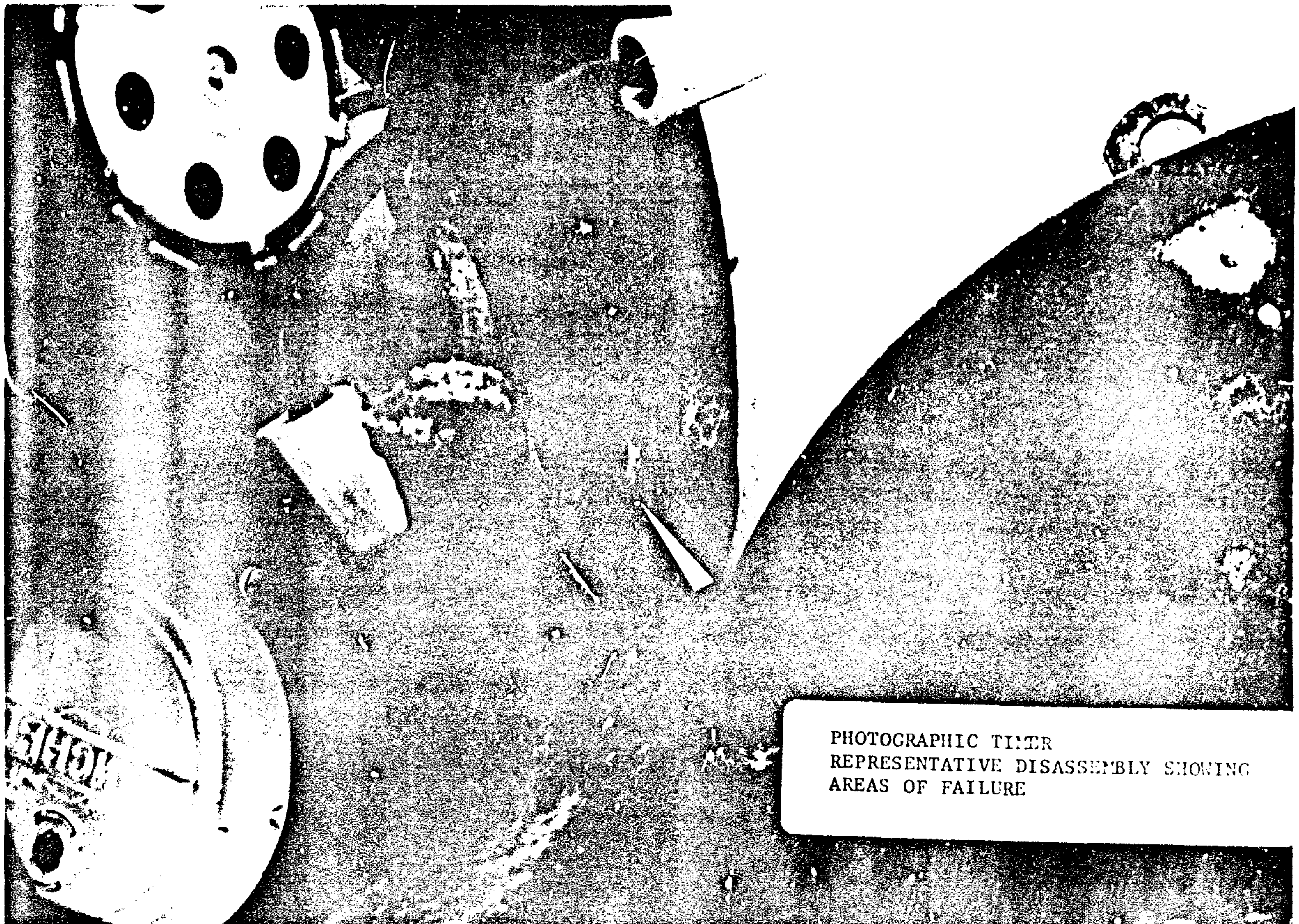


Figure 27. Timer disassembly

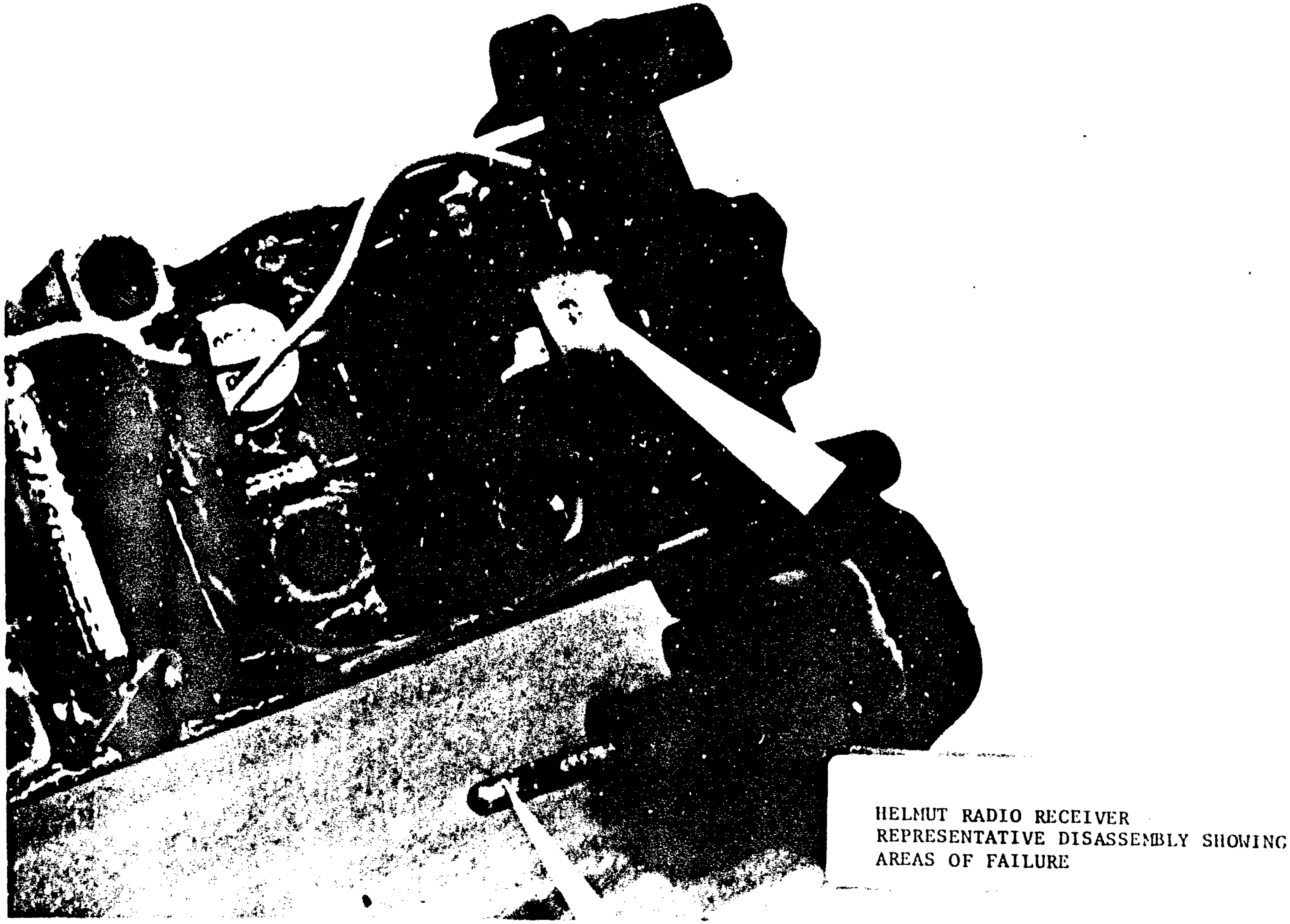


Figure 28, Radio disassembly

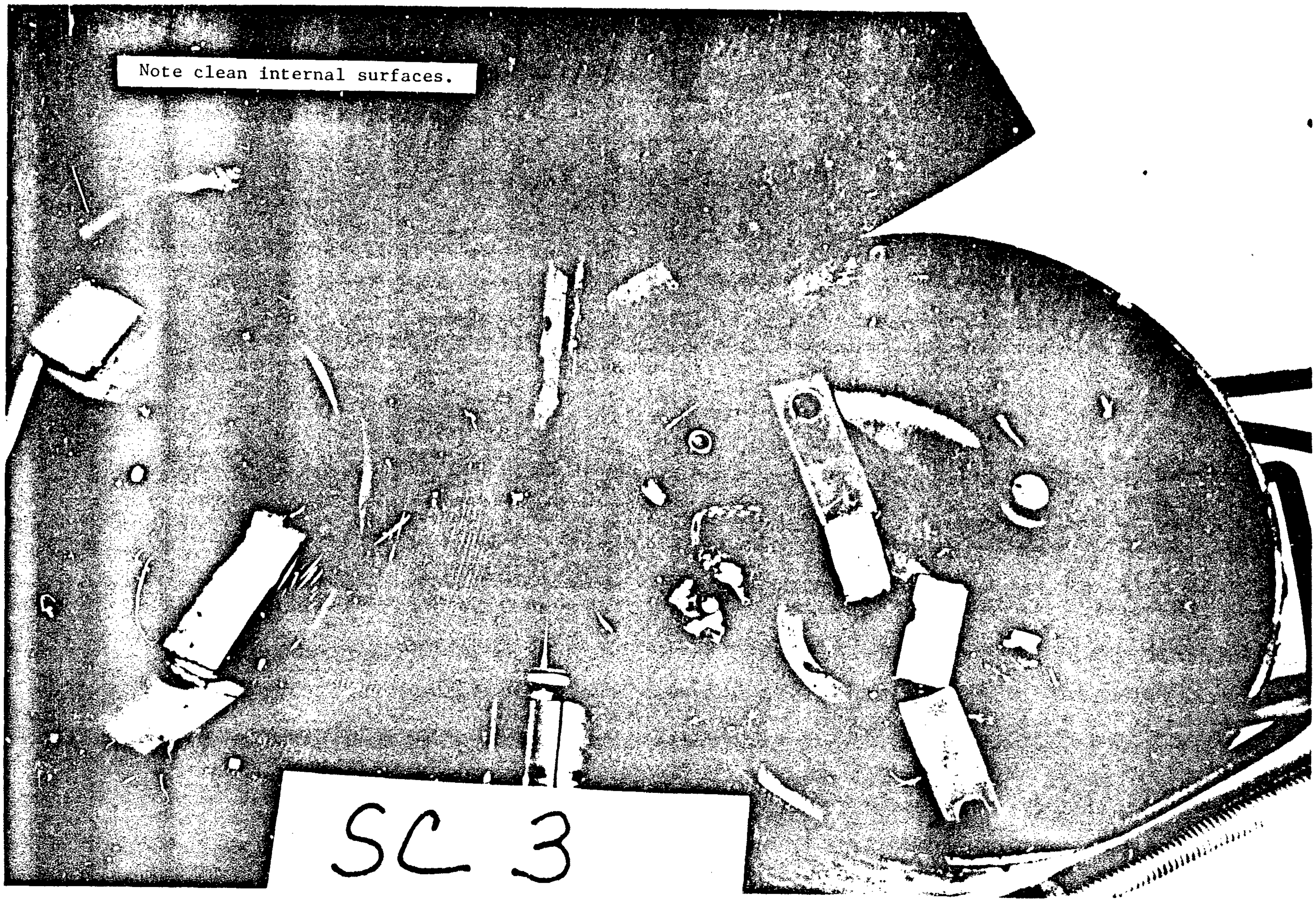


Figure 29. Disassembly of d.c. fractional horsepower motor

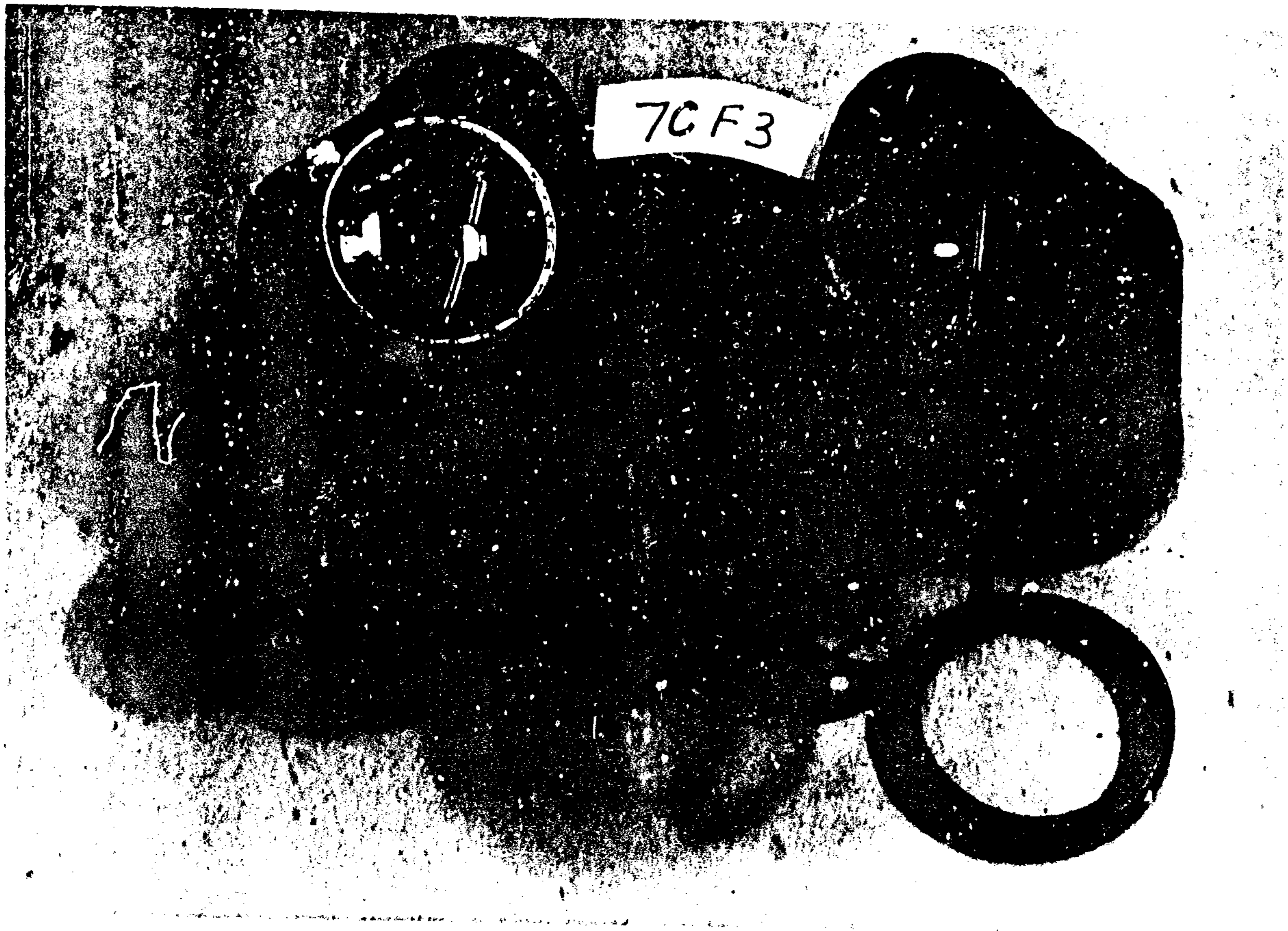


Figure 30. M3 binocular disassembly showing residue film on optics

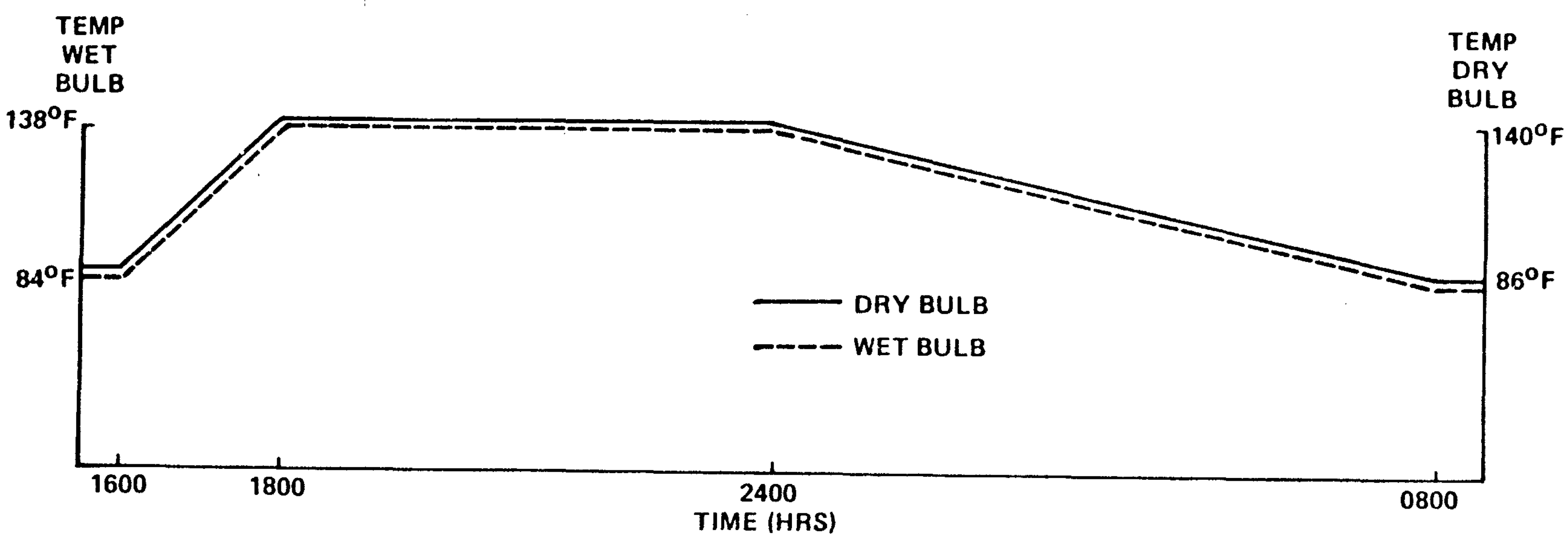
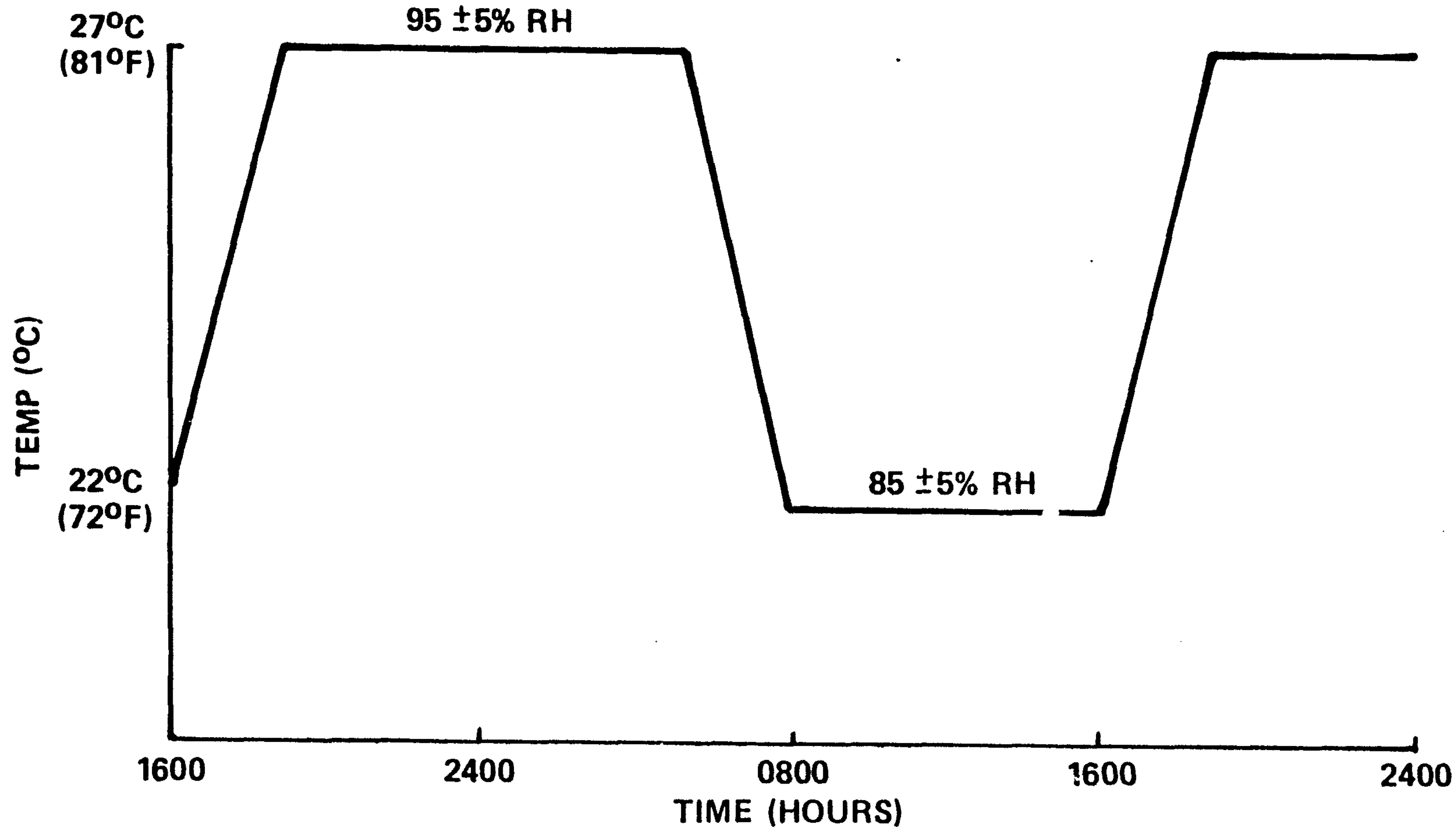


Figure 31. High temperature humidity chamber cycle



NOTE: AIR CIRCULATION WITHIN CHAMBER BY NATURAL CONVECTION ONLY

Figure 32. Salt fog chamber temperature humidity cycle

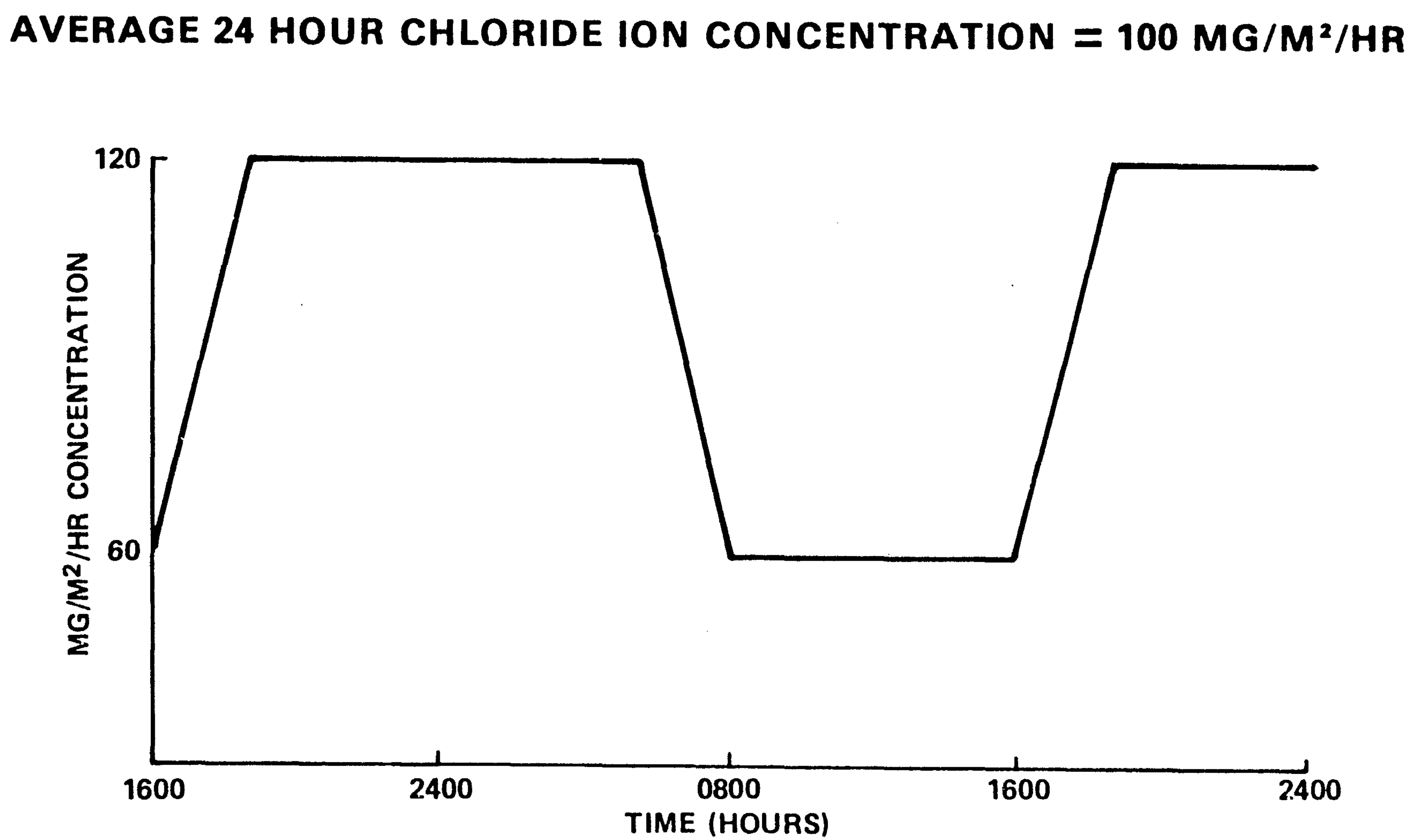
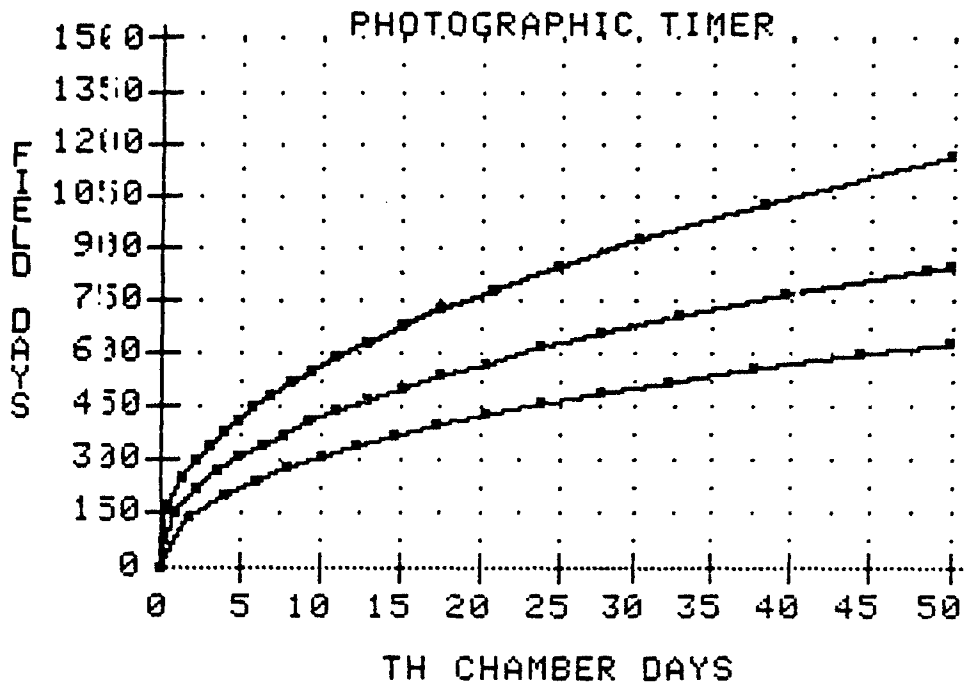
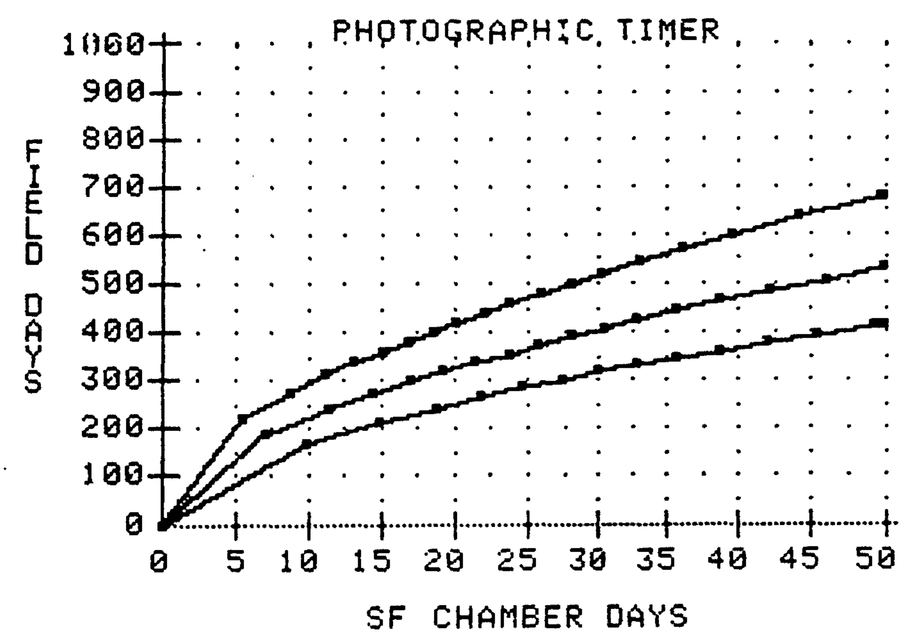


Figure 33. Salt fog chamber chloride ion concentration cycle

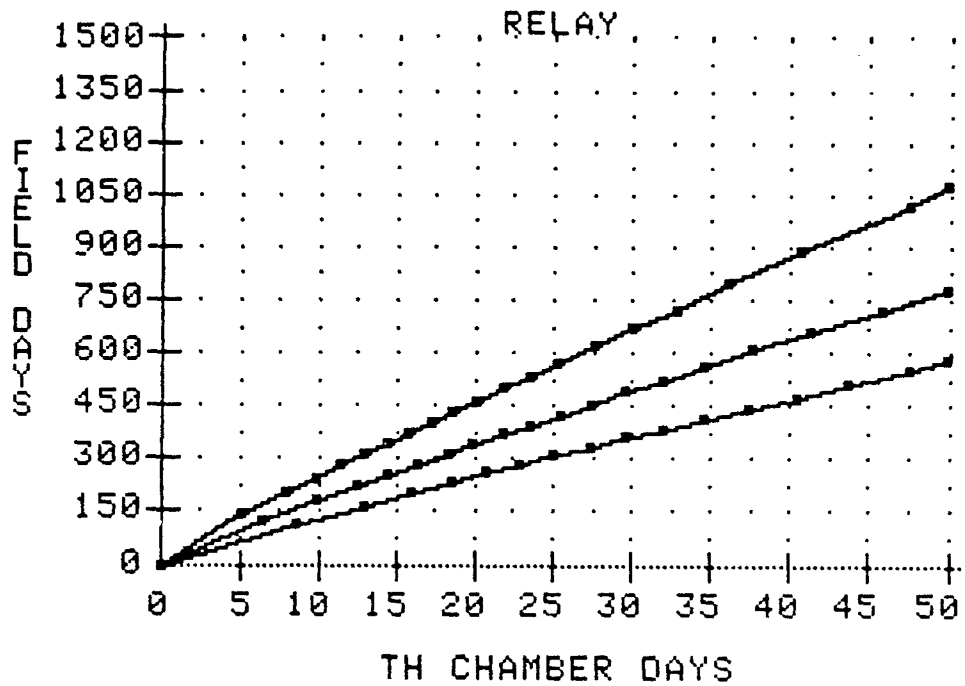


FIELD VERSUS TEMPERATURE/HUMIDITY CHAMBER

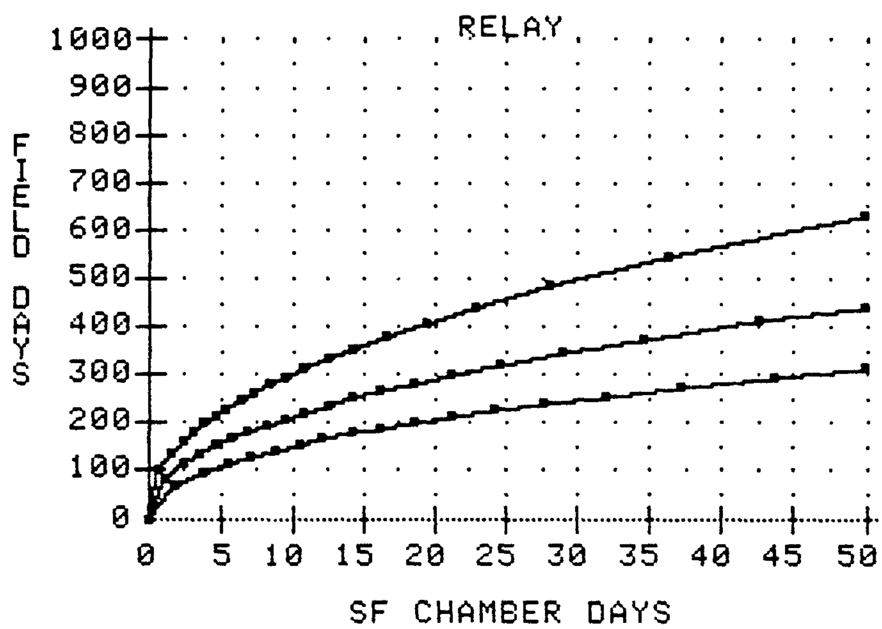


FIELD VERSUS SALT FOG CHAMBER

Figure 34. Correlation curves for photographic timers

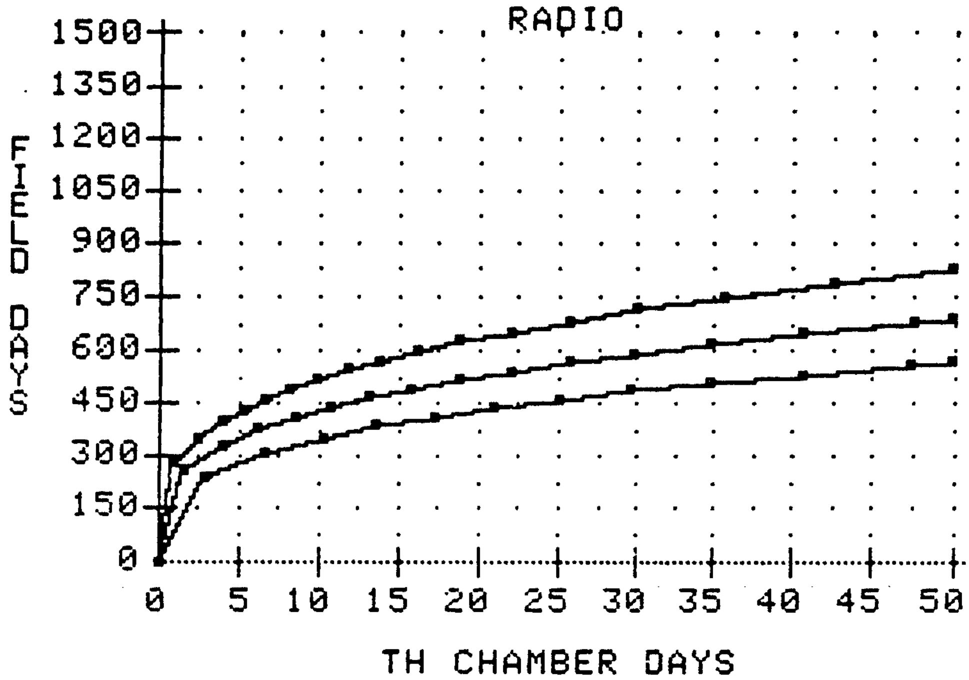


FIELD VERSUS TEMPERATURE/HUMIDITY CHAMBER

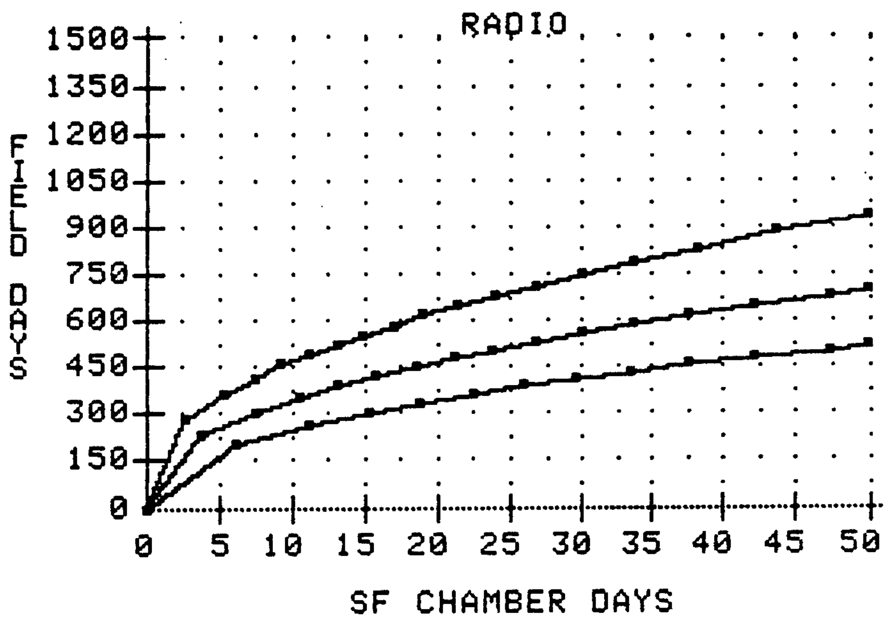


FIELD VERSUS SALT FOG CHAMBER

Figure 35. Correlation curves for relay

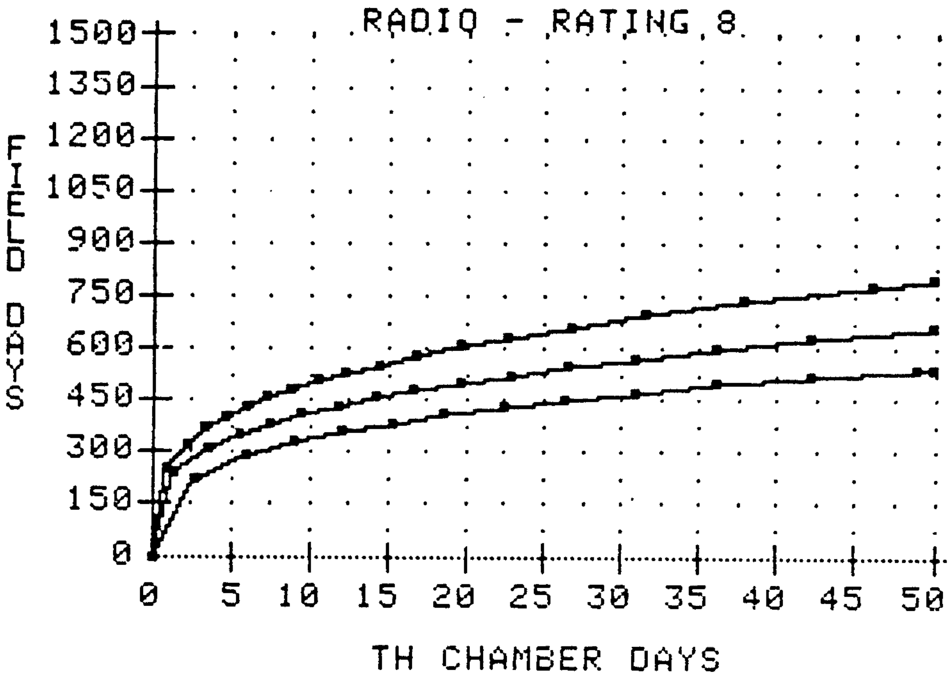


FIELD VERSUS TEMPERATURE/HUMIDITY CHAMBER

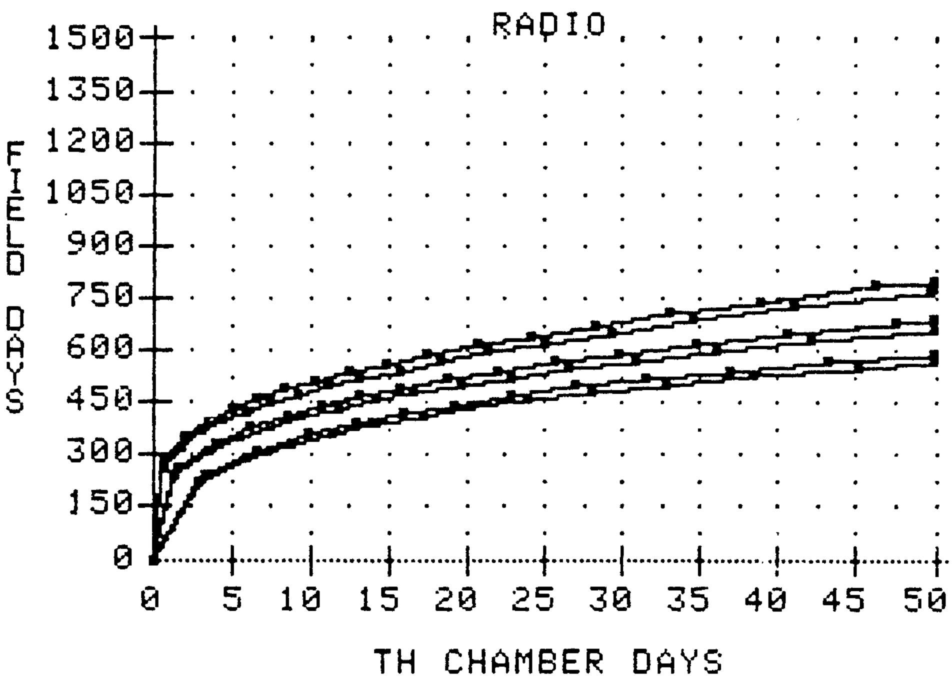


FIELD VERSUS SALT FOG CHAMBER

Figure 36. Correlation curves for helmet radio receiver

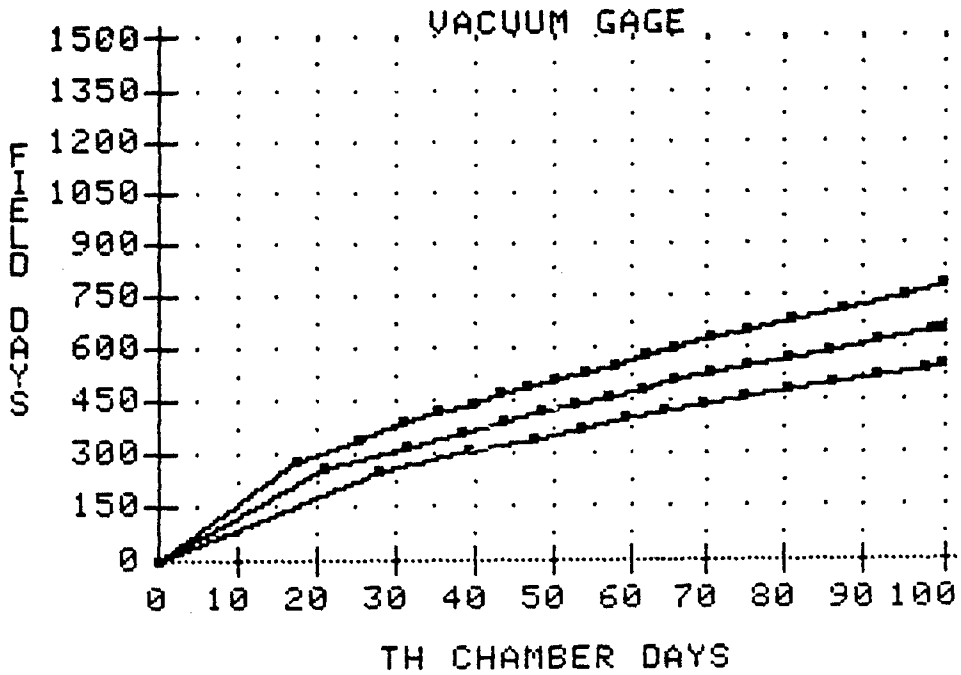


FIELD VERSUS TEMPERATURE/HUMIDITY CHAMBER

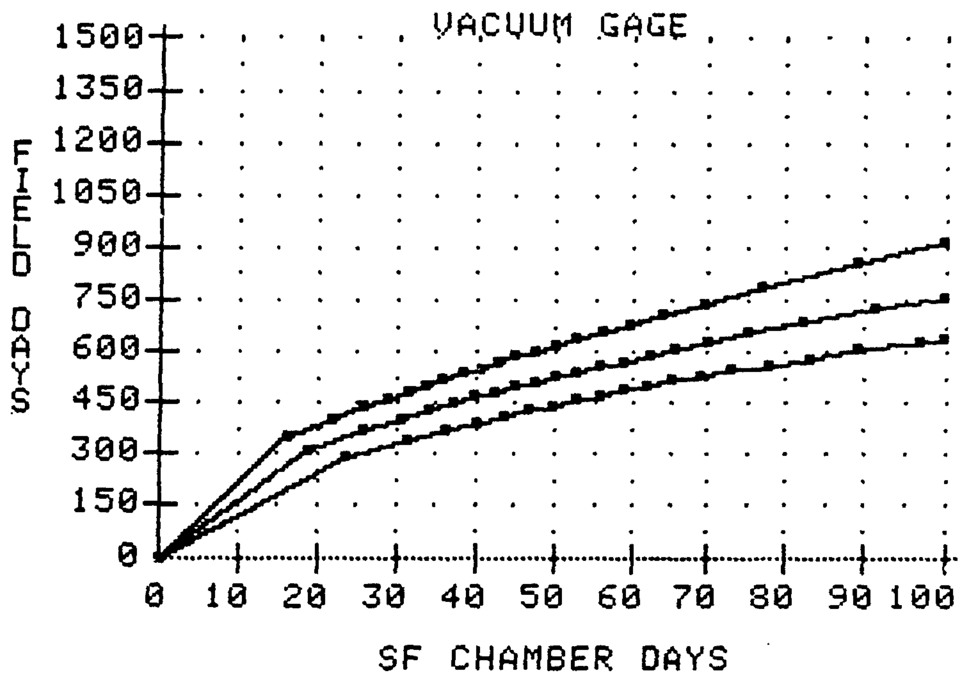


FIELD VERSUS TEMPERATURE/HUMIDITY CHAMBER--RATING 8 AND 10

Figure 36. (cont)

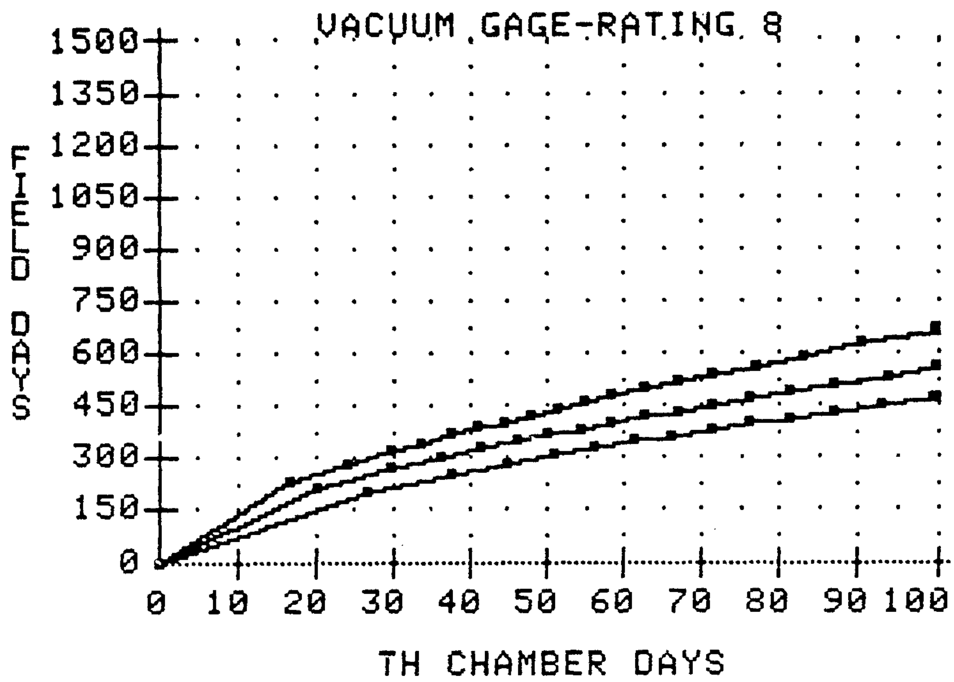


FIELD VERSUS TEMPERATURE/HUMIDITY CHAMBER

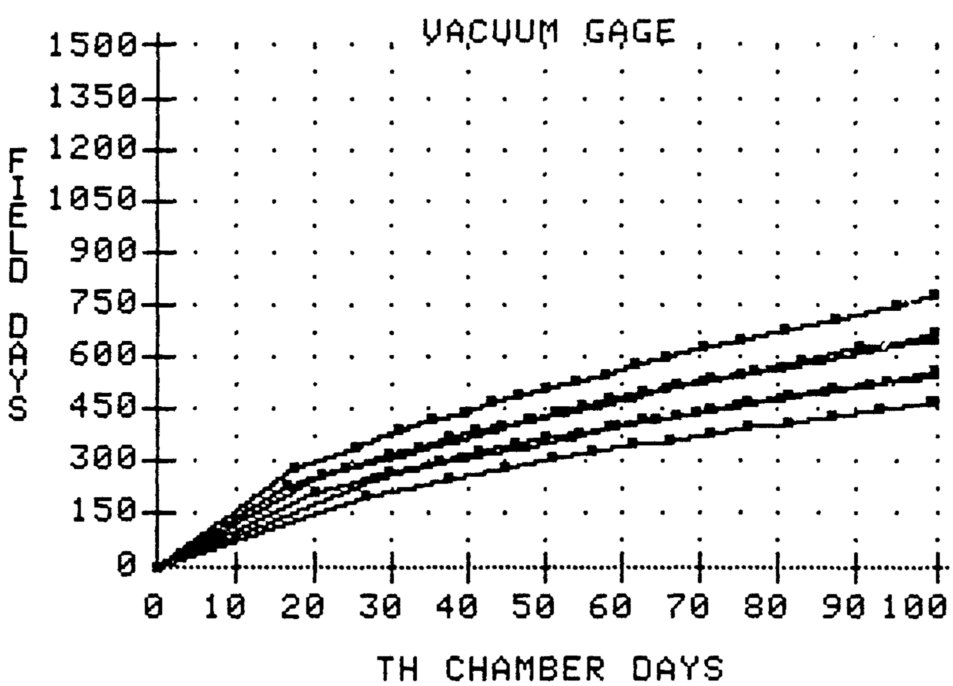


FIELD VERSUS SALT FOG CHAMBER

Figure 37. Correlation curves for vacuum gage



TEMPERATURE HUMIDITY CHAMBER



FIELD VERSUS TEMPERATURE/HUMIDITY CHAMBER--RATING 8 AND 10

Figure 37. (cont)

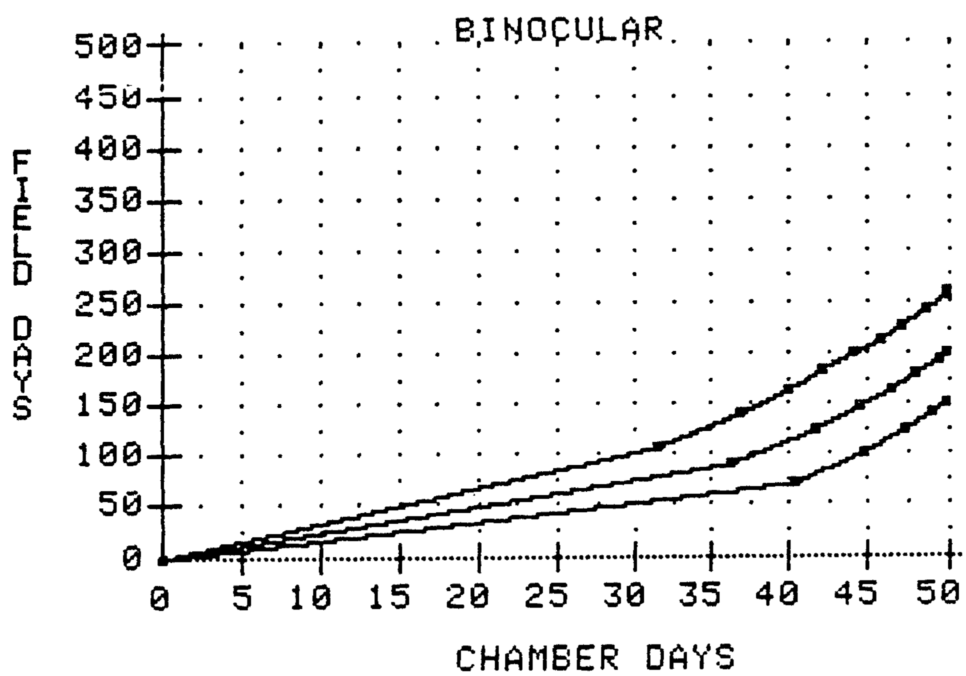
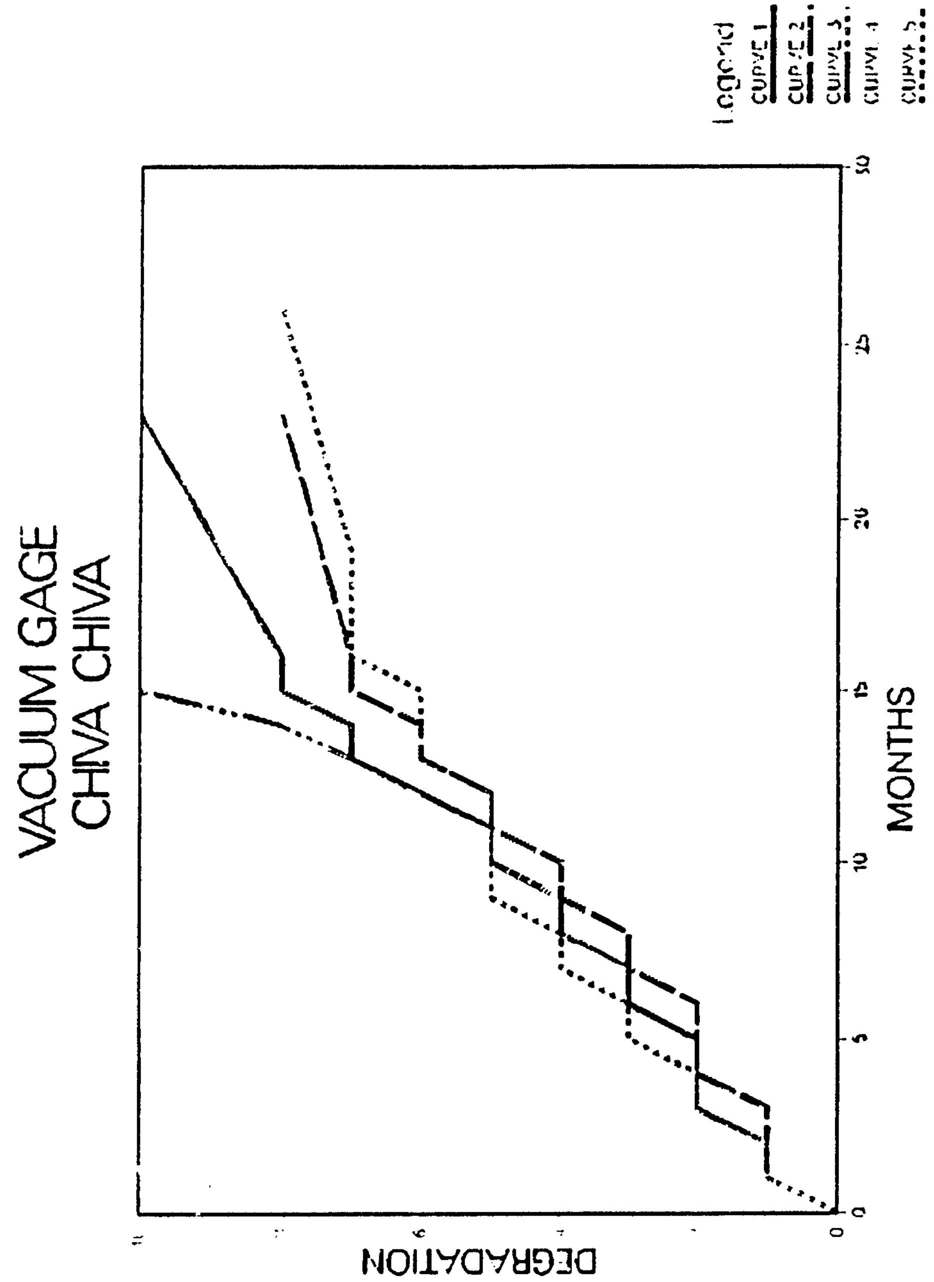


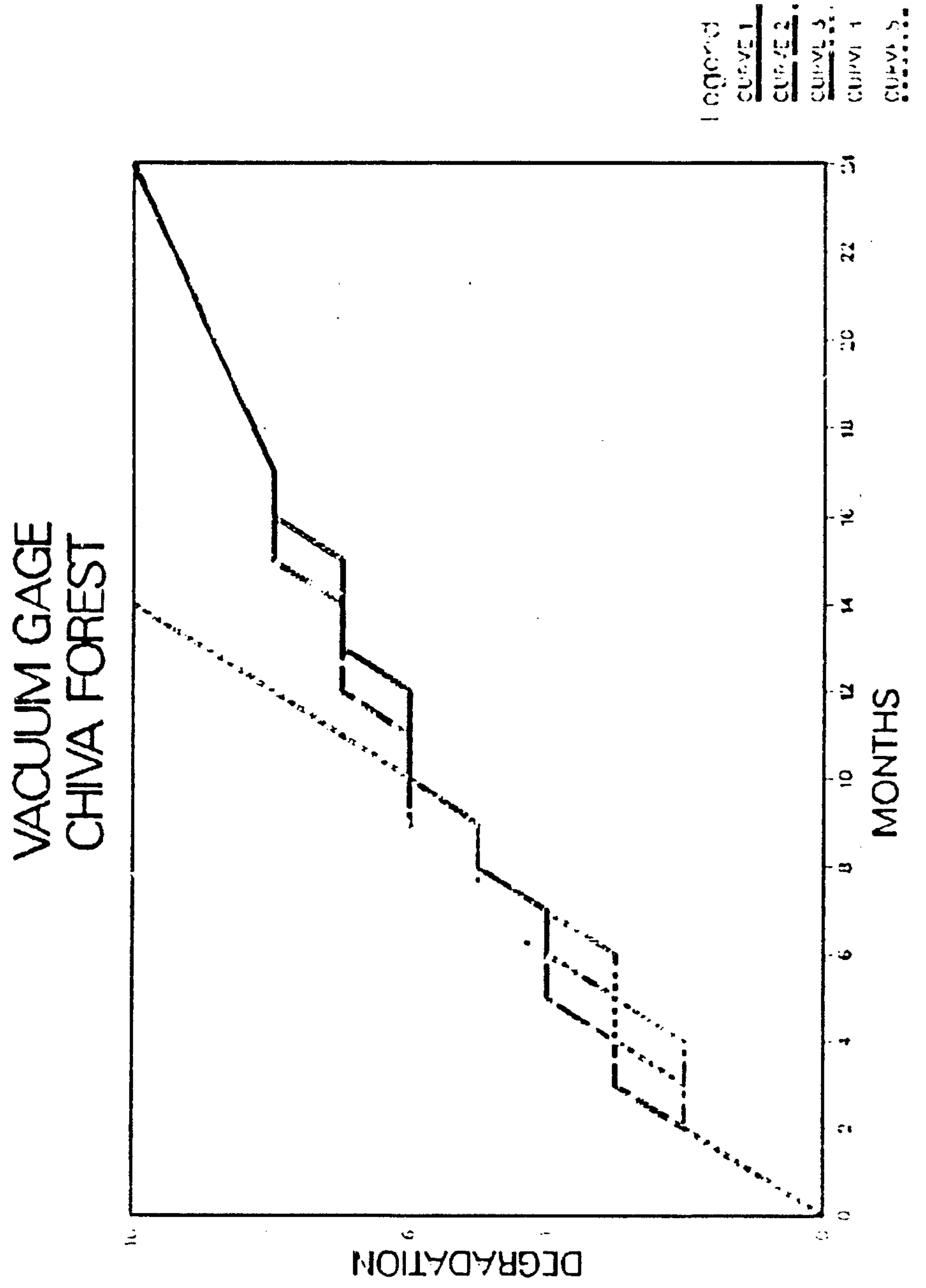
Figure 38. Correlation curves for binoculars: field versus chamber

APPENDIX A

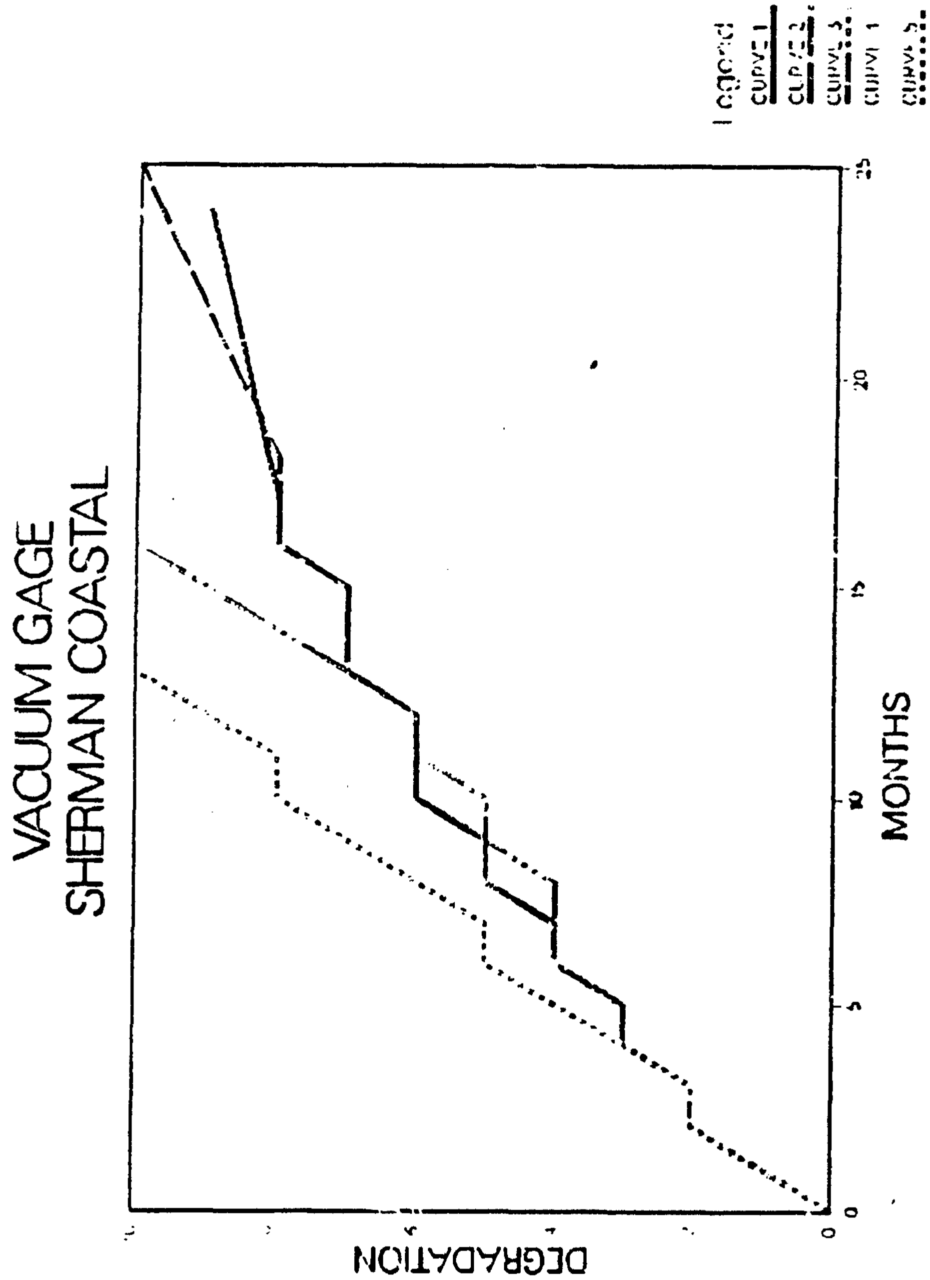
DEGRADATION CURVES OF THE EFFECTS OF
TEMPERATURE, HUMIDITY, AND SALT FOG
VERSUS MONTHS OF TTC EXPOSURES



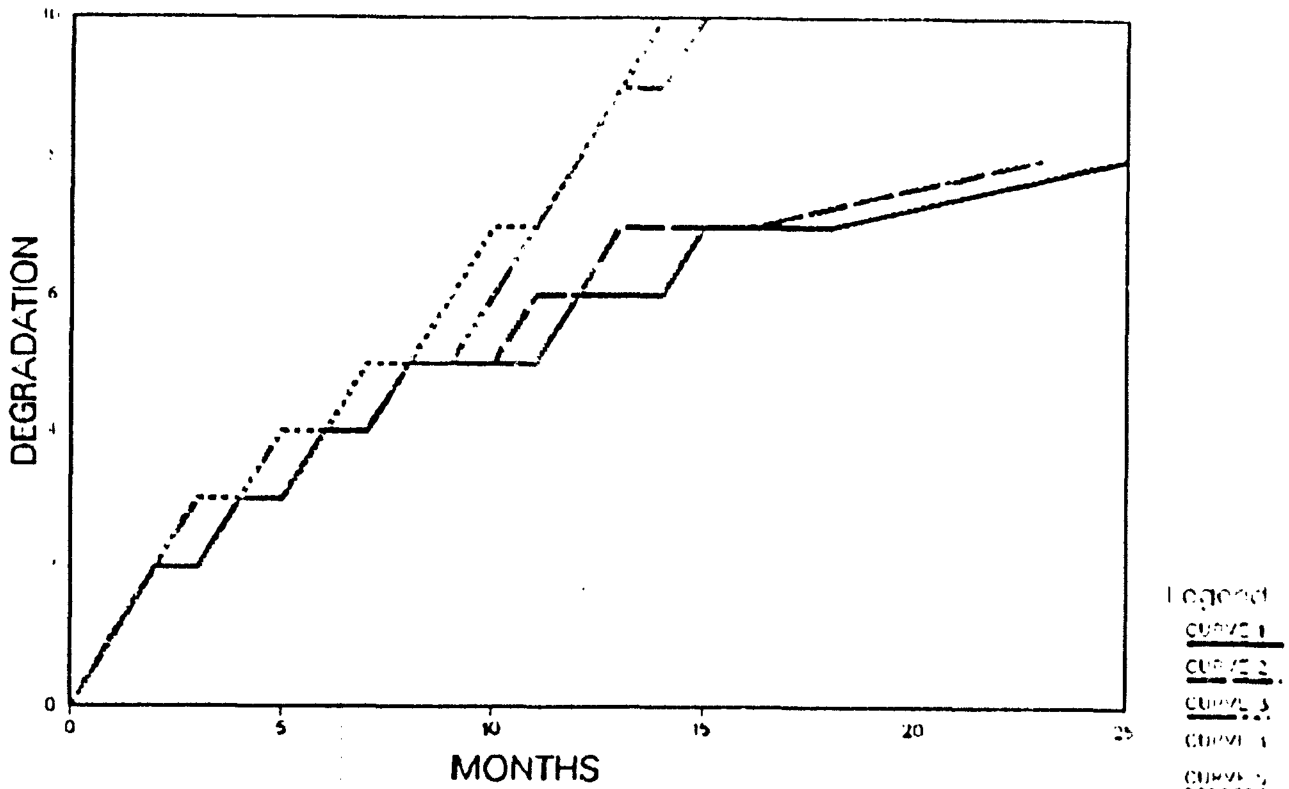
VACUUM GAGE
CHINA CHIVA
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
CURVE 5
MONTHS
DEGRADATION
0
5
10
15
20
25
30

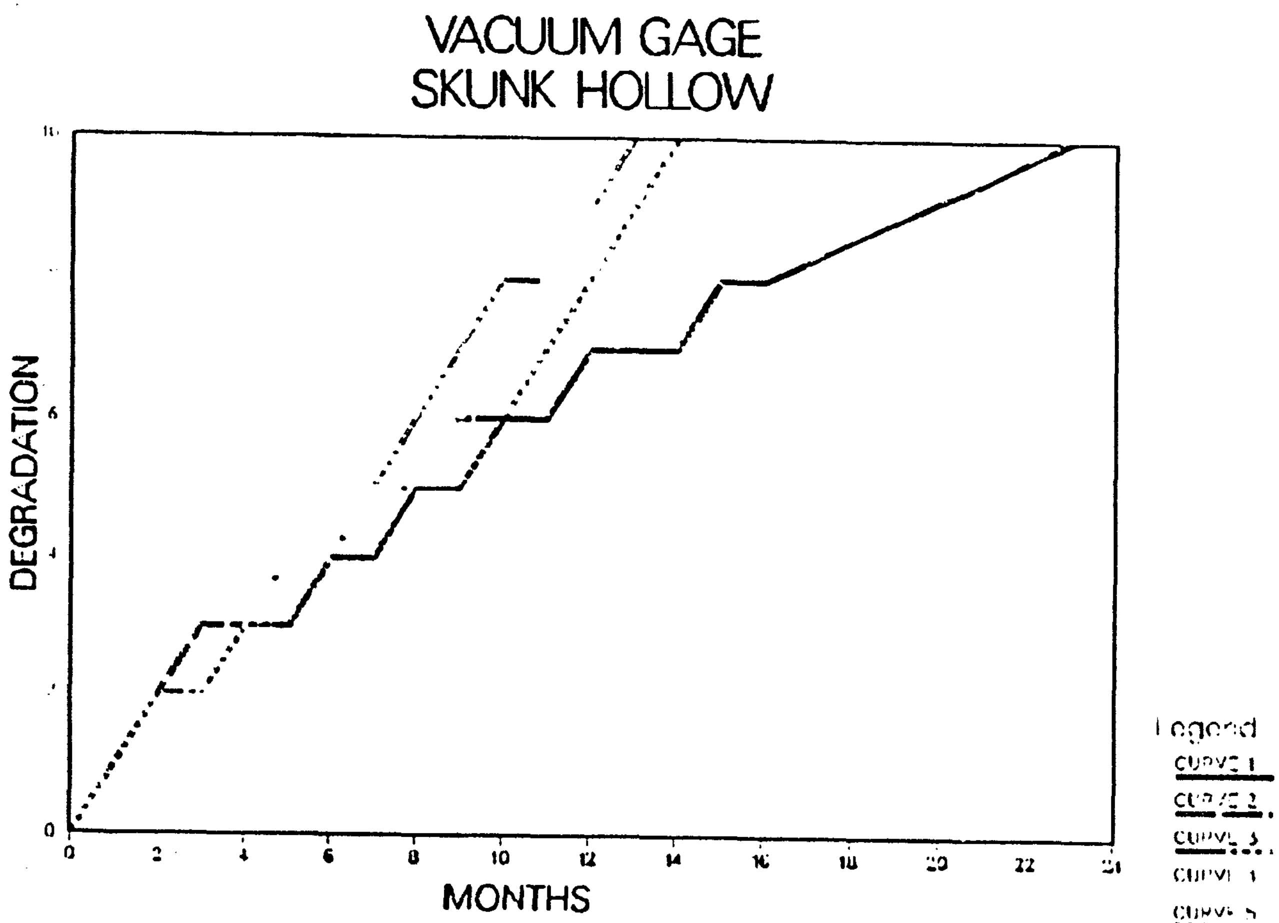


VACUUM GAGE
CHIVA FOREST
MONTHS
DEGRADATION
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
CURVE 5
0
2
4
6
8
10
12
14
16
18
20
22
24


VACUUM GAGE
SHERMAN COASTAL
DEGRADATION
MONTHS
0
5
10
15
20
25

VACUUM GAGE SHERMAN (OPEN)





VACUUM GAGE
SKUNK HOLLOW
DEGRADATION
MONTHS
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
CURVE 5

PHOTO TIMER
CHIVA CHIVA

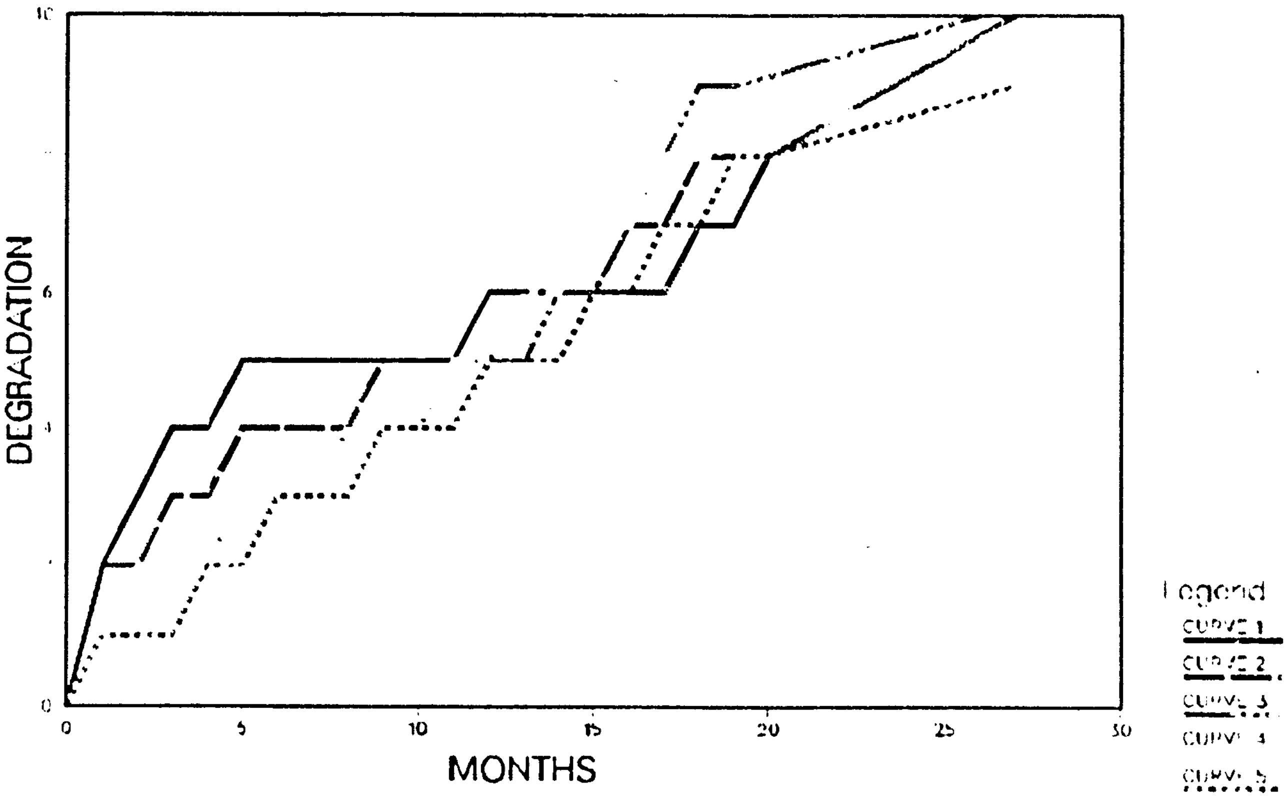
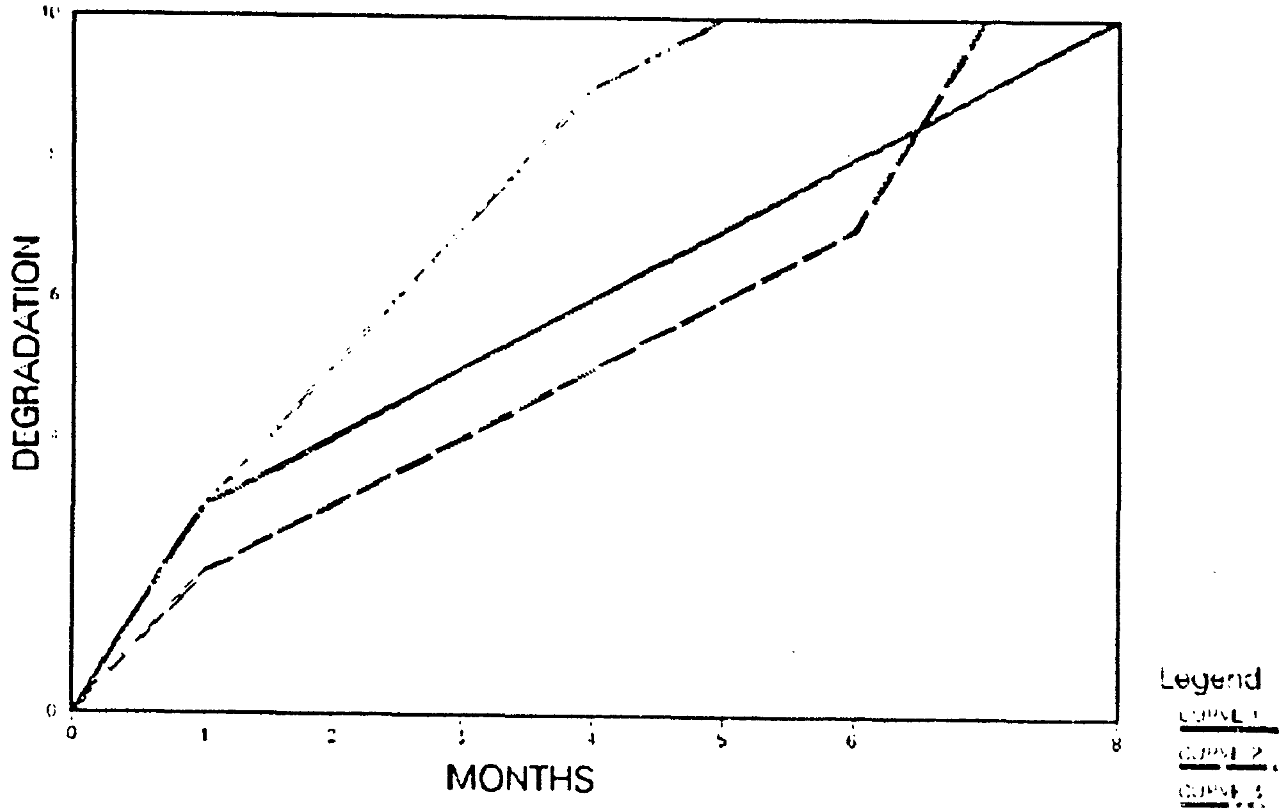


PHOTO TIMER
CHIVA FOREST



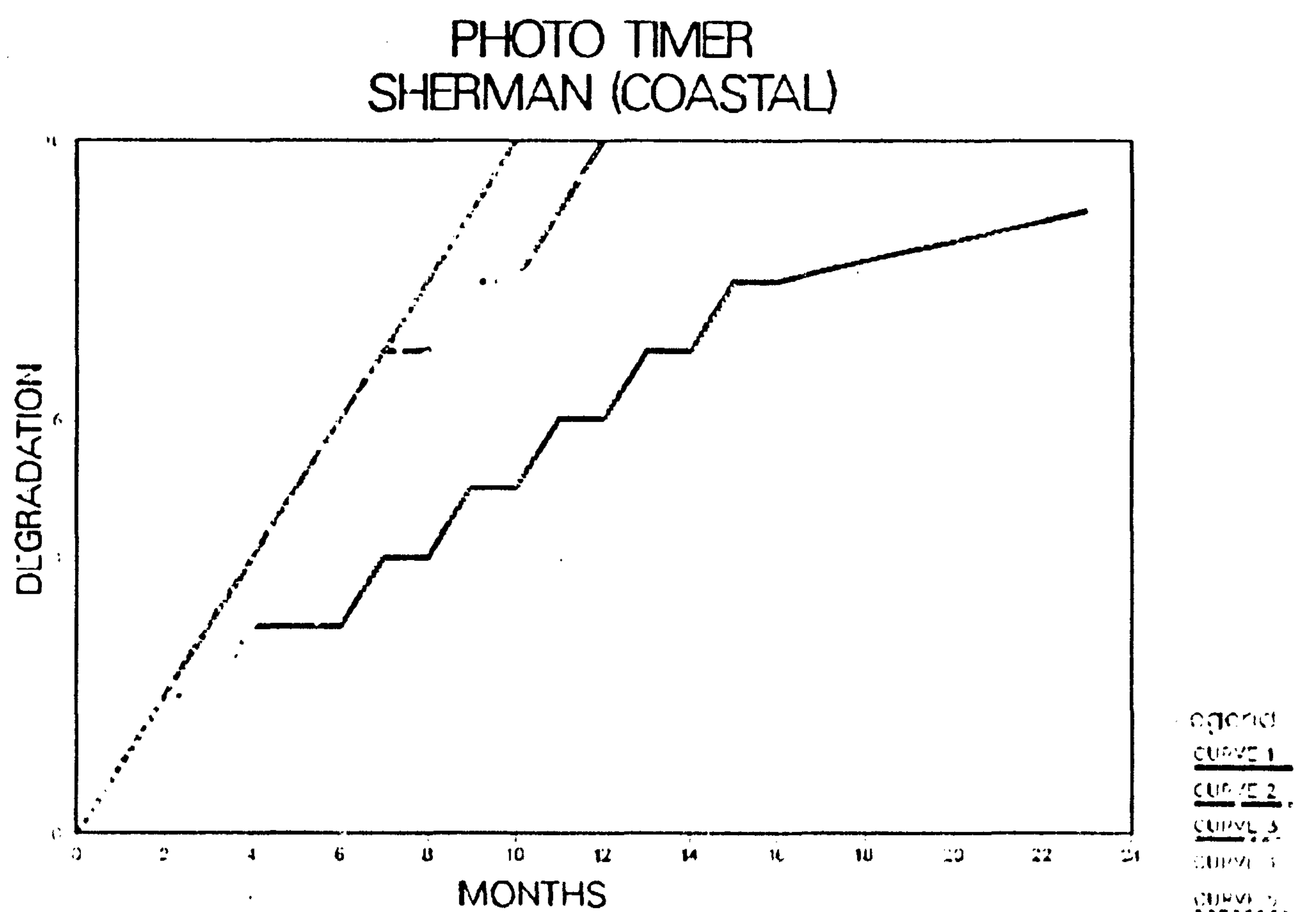


PHOTO TIMER
SHERMAN (COASTAL)
DEGRADATION
MONTHS
0
2
4
6
8
10
12
14
16
18
20
22
24
CURVE 1
CURVE 2
CURVE 3

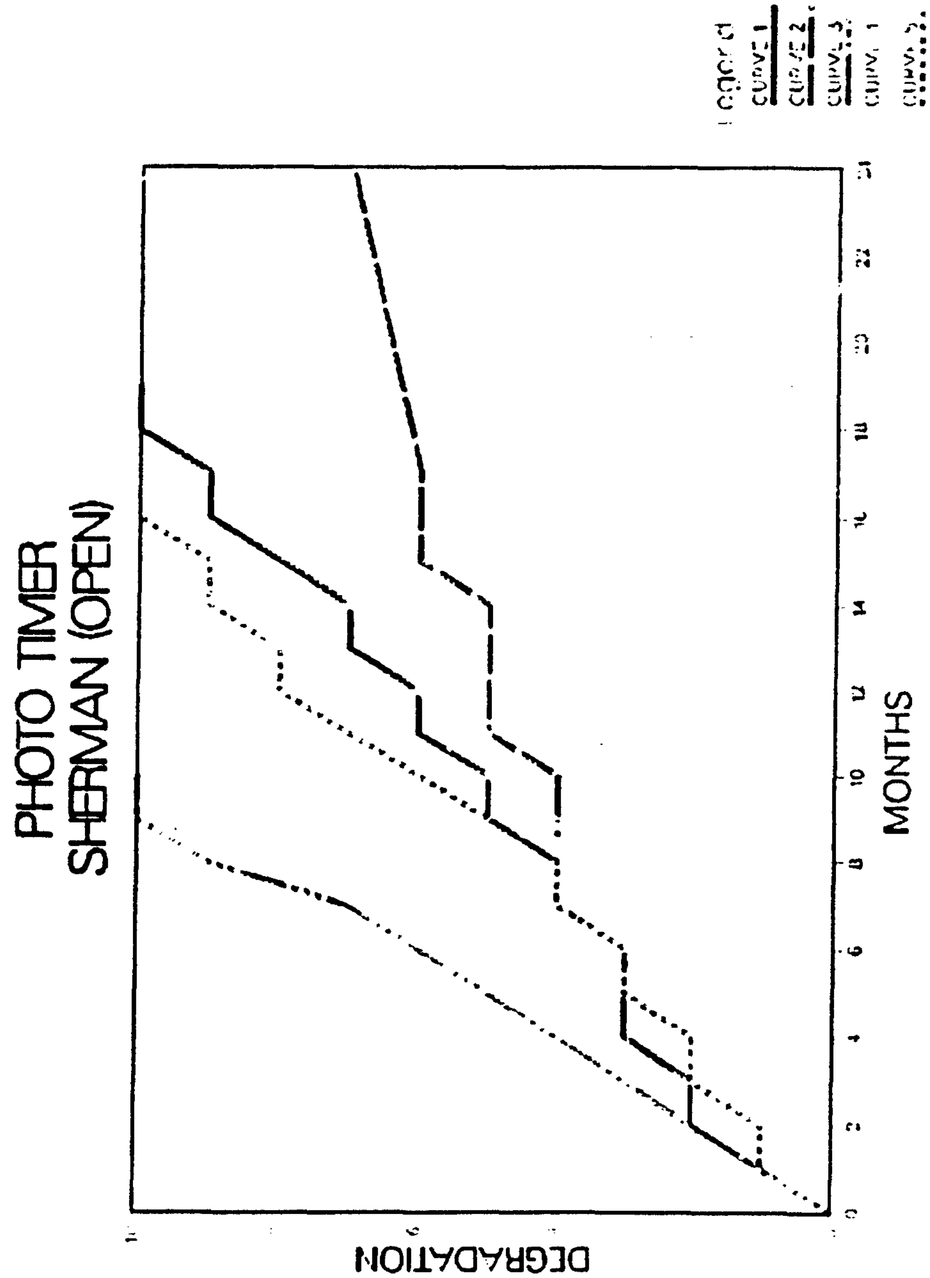


PHOTO TIMER
SHERMAN (OPEN)
MONTHS
DEGRADATION

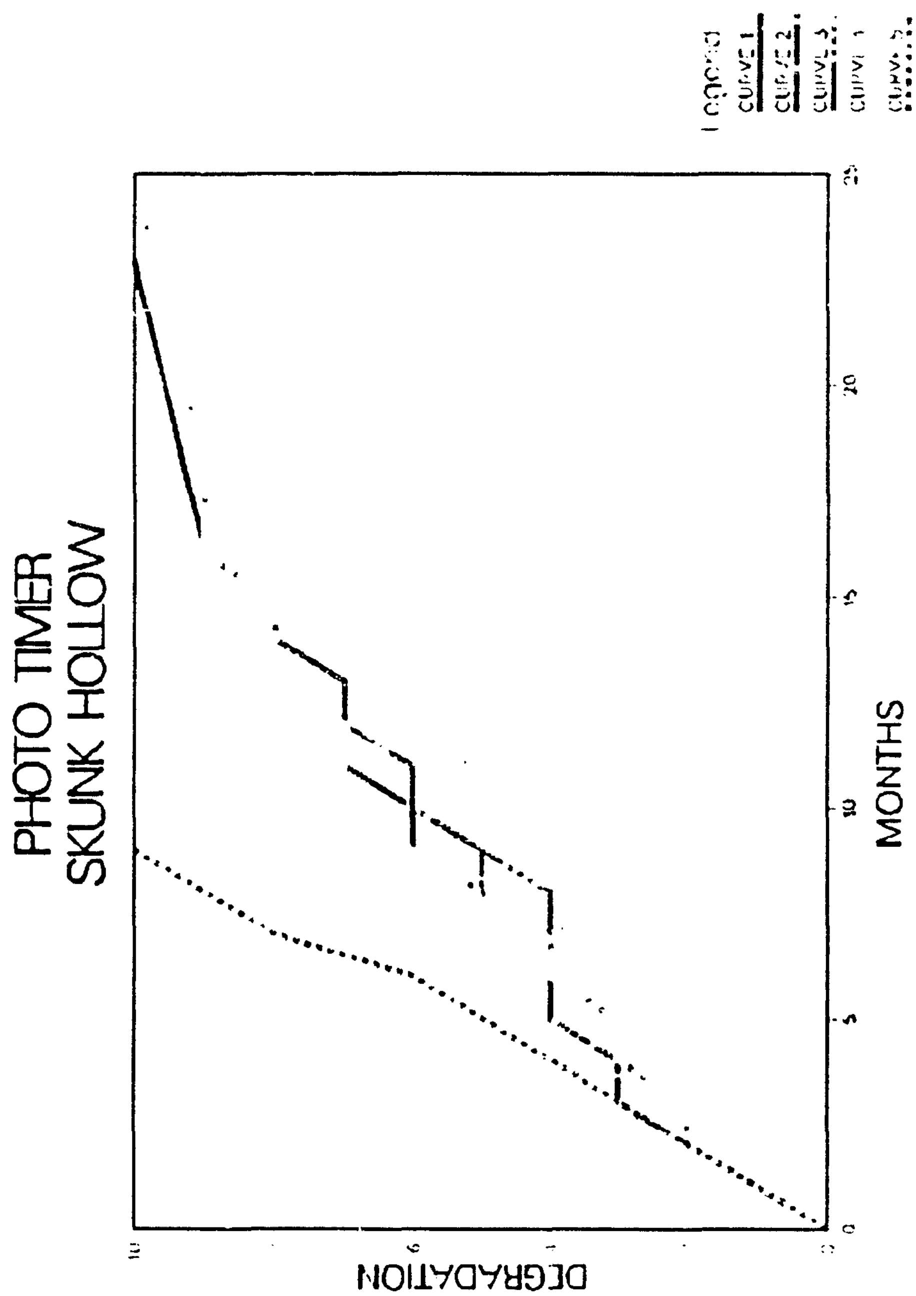
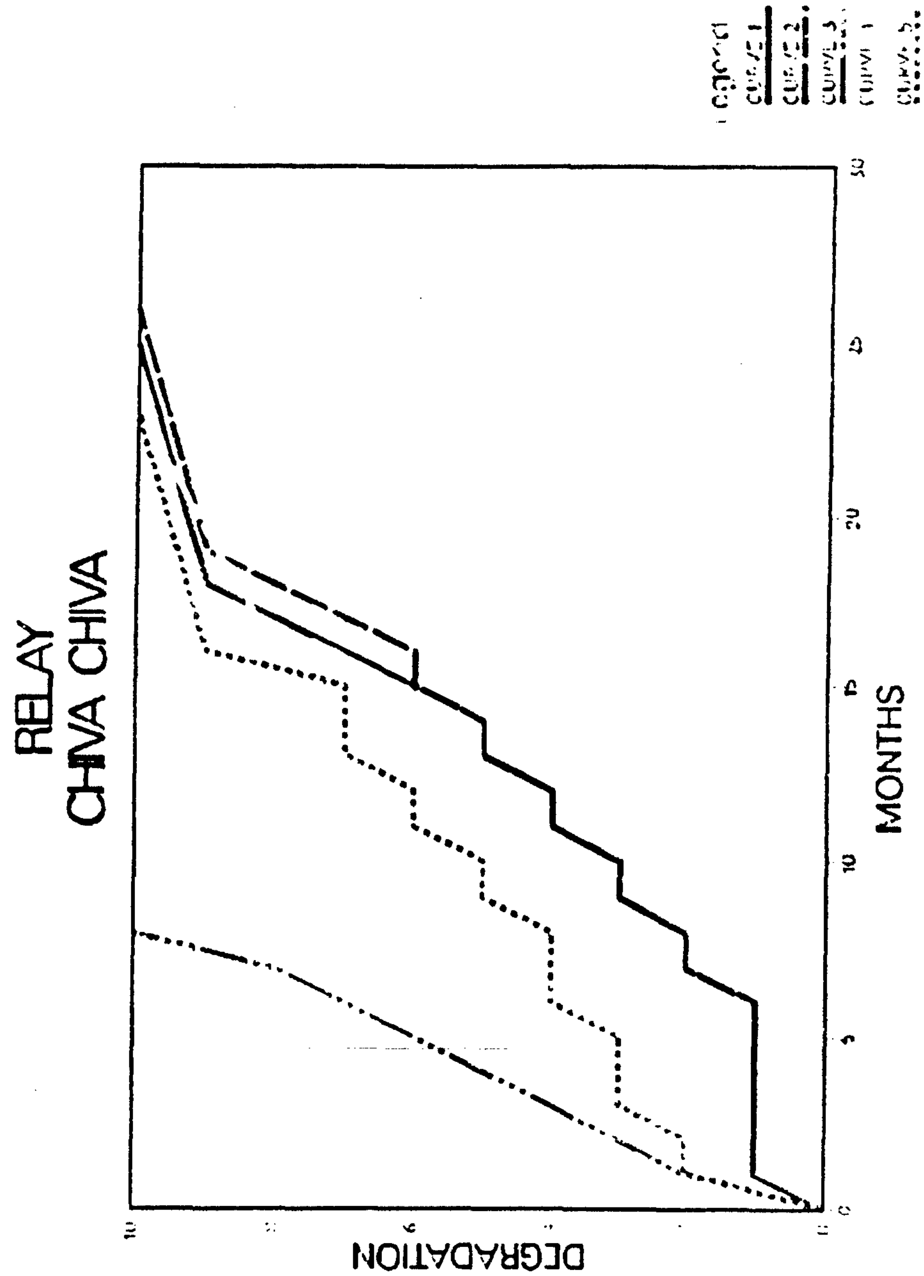
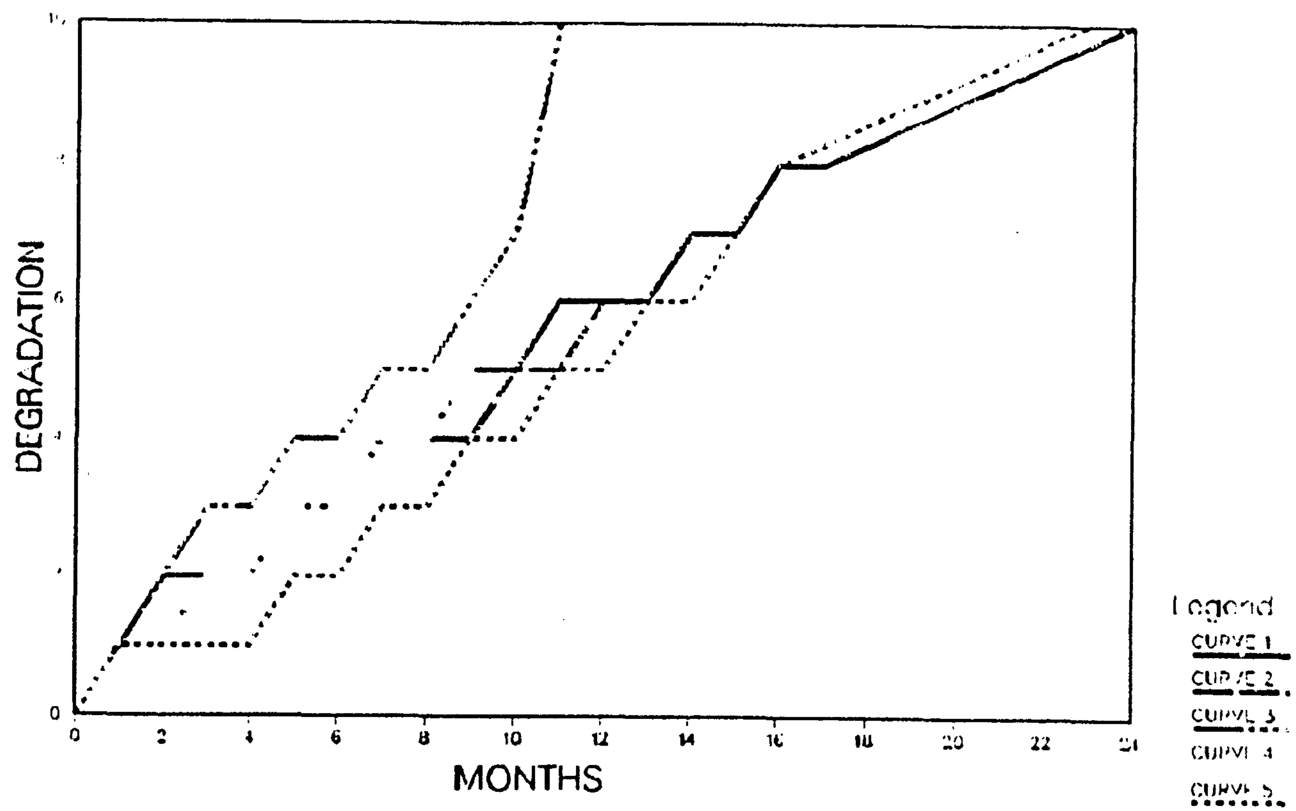
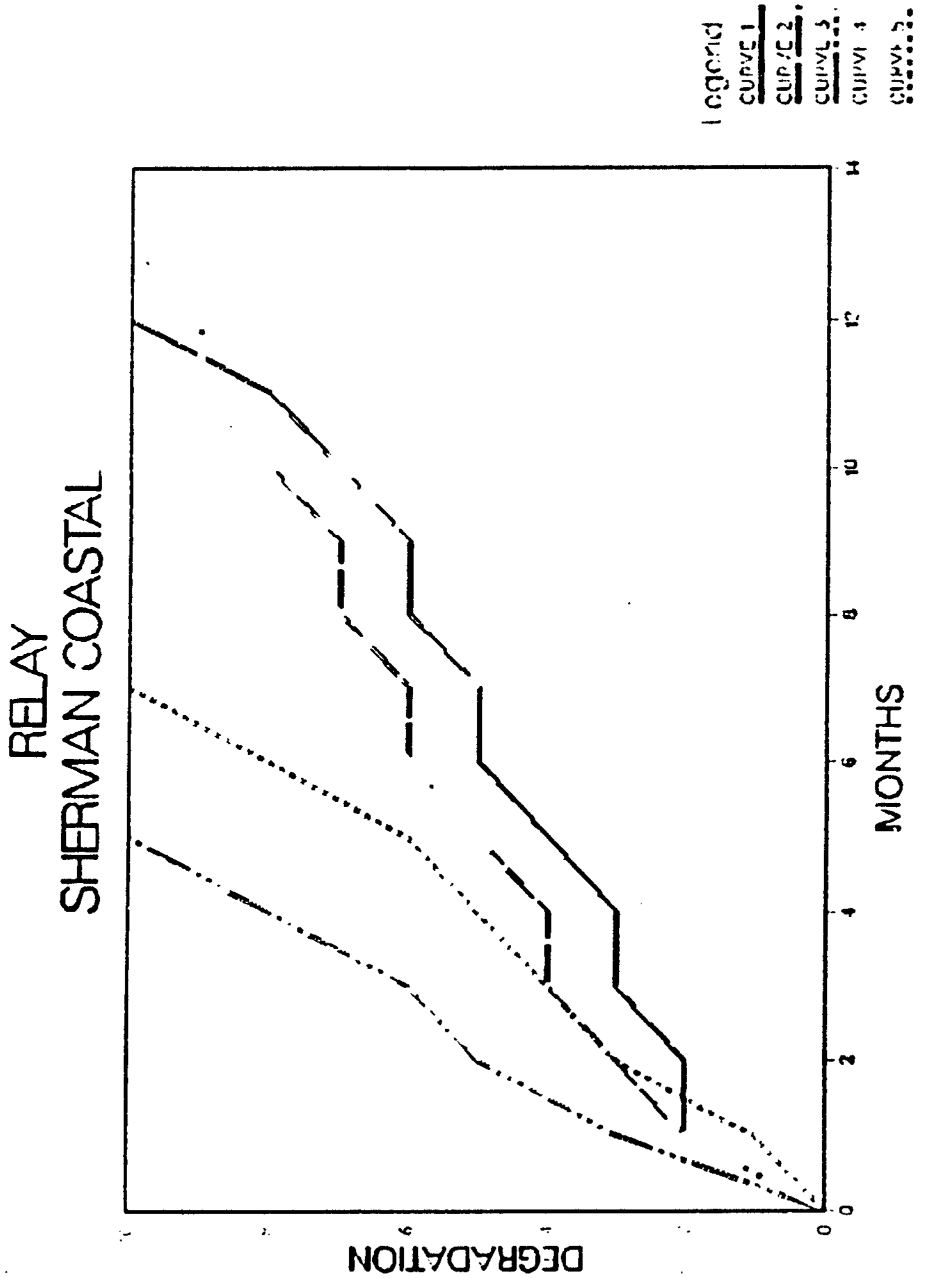


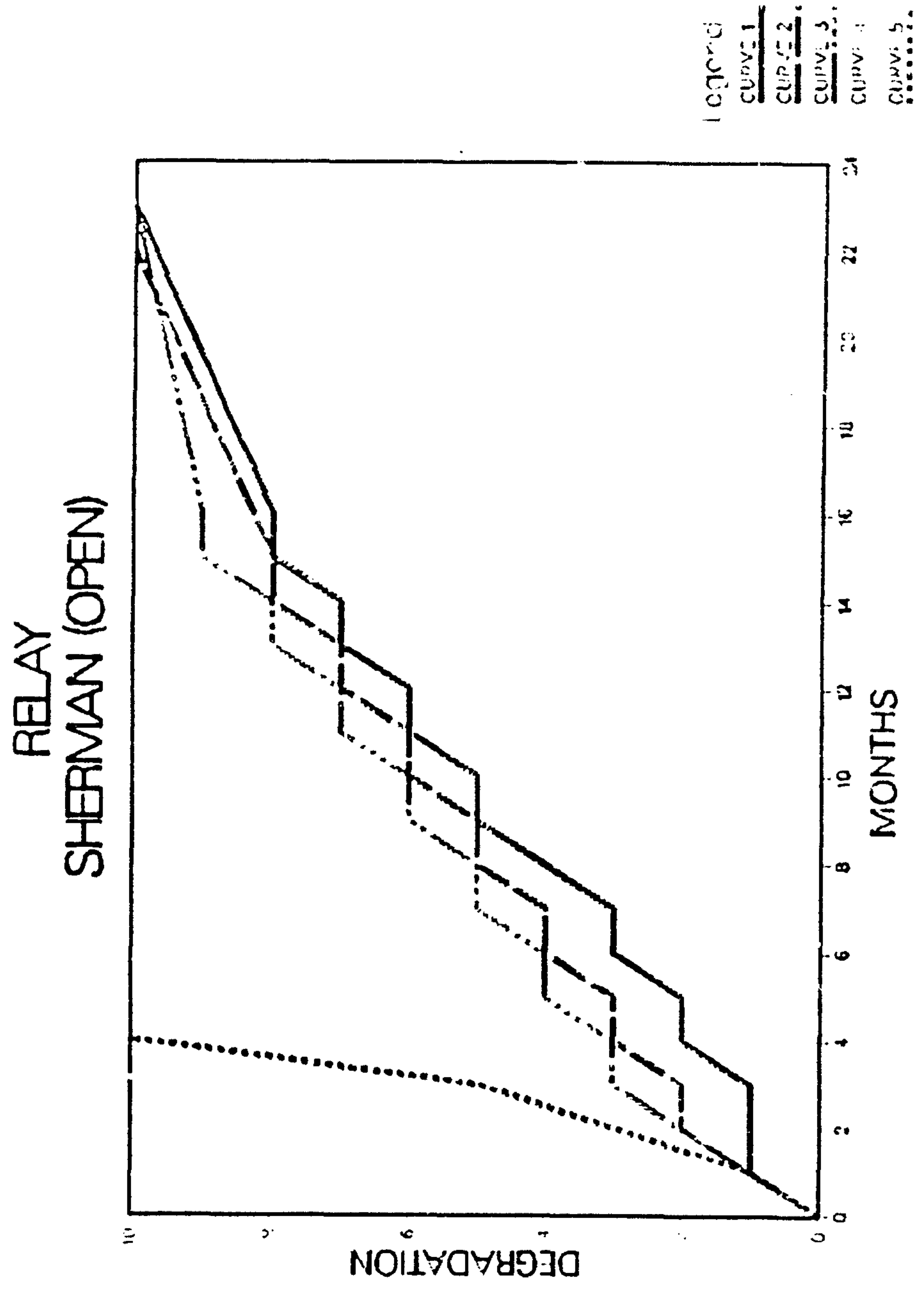
PHOTO TIMER
SKUNK HOLLOW
DEGRADATION
MONTHS
0
5
10
15
20
25
CURVE 1
CURVE 2
CURVE 3
CURVE 4
CURVE 5


RELAY
CHIVA CHIVA
MONTHS
DEGRADATION

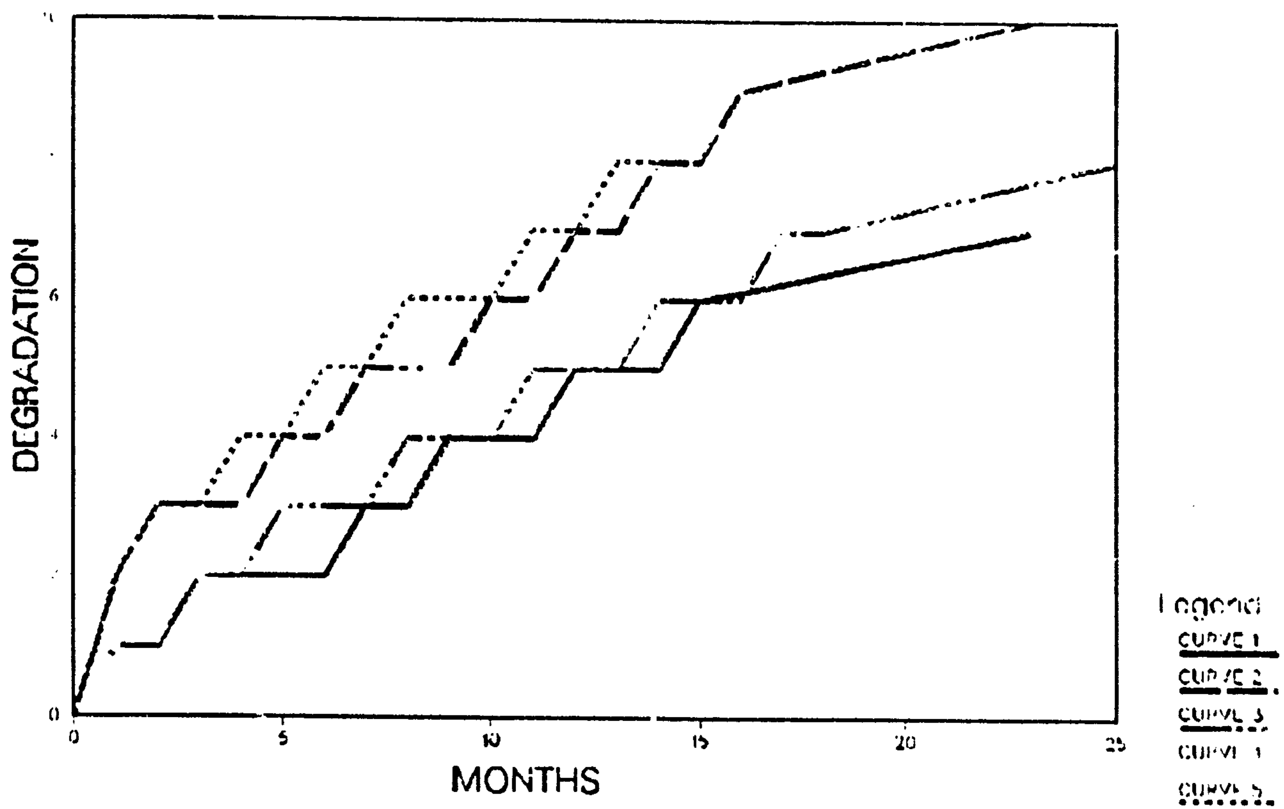
RELAY
CHIVA FOREST

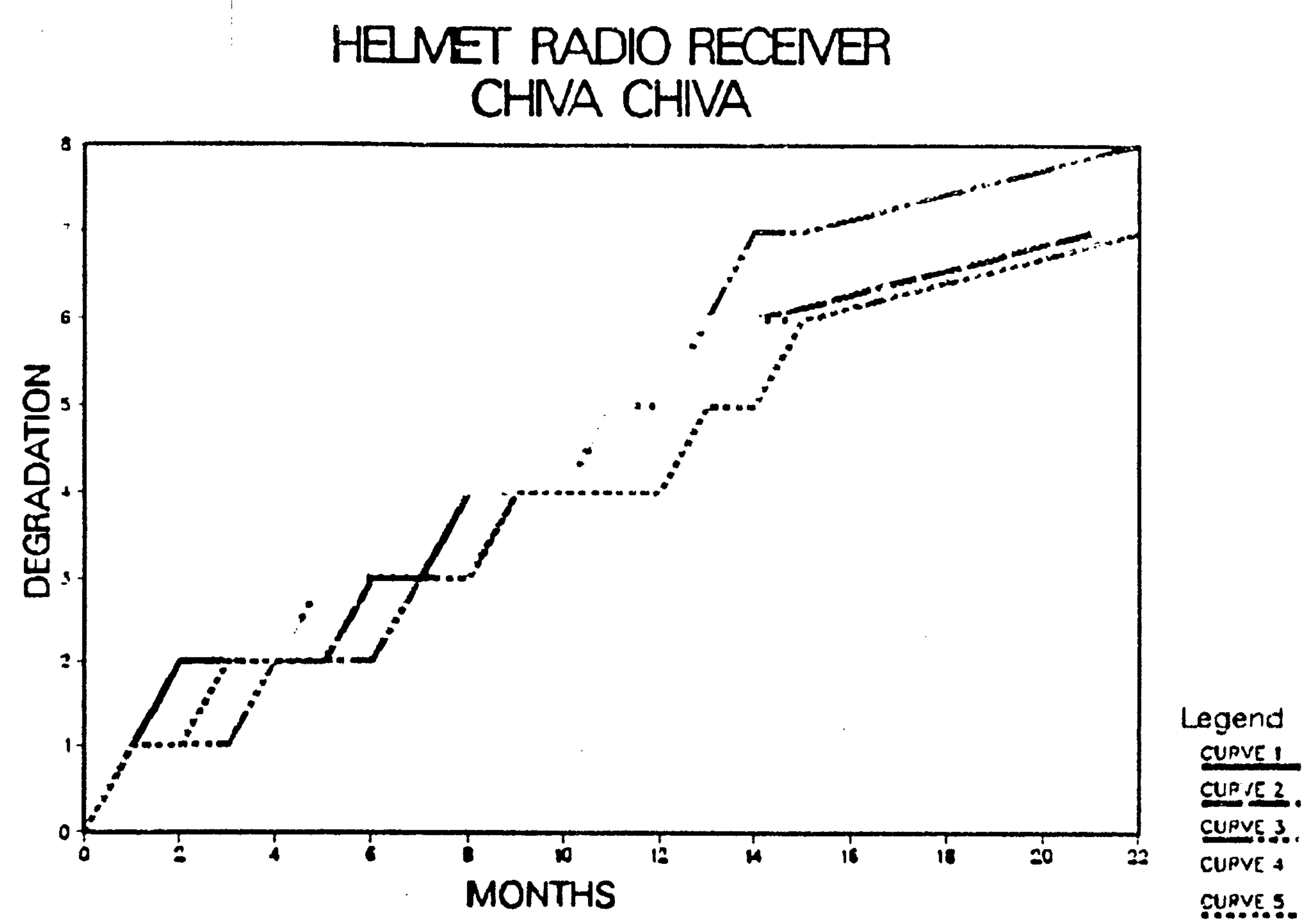



RELAY
SHERMAN COASTAL
DEGRADATION
MONTHS
0
2
4
6
8
10
12
14
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
CURVE 5

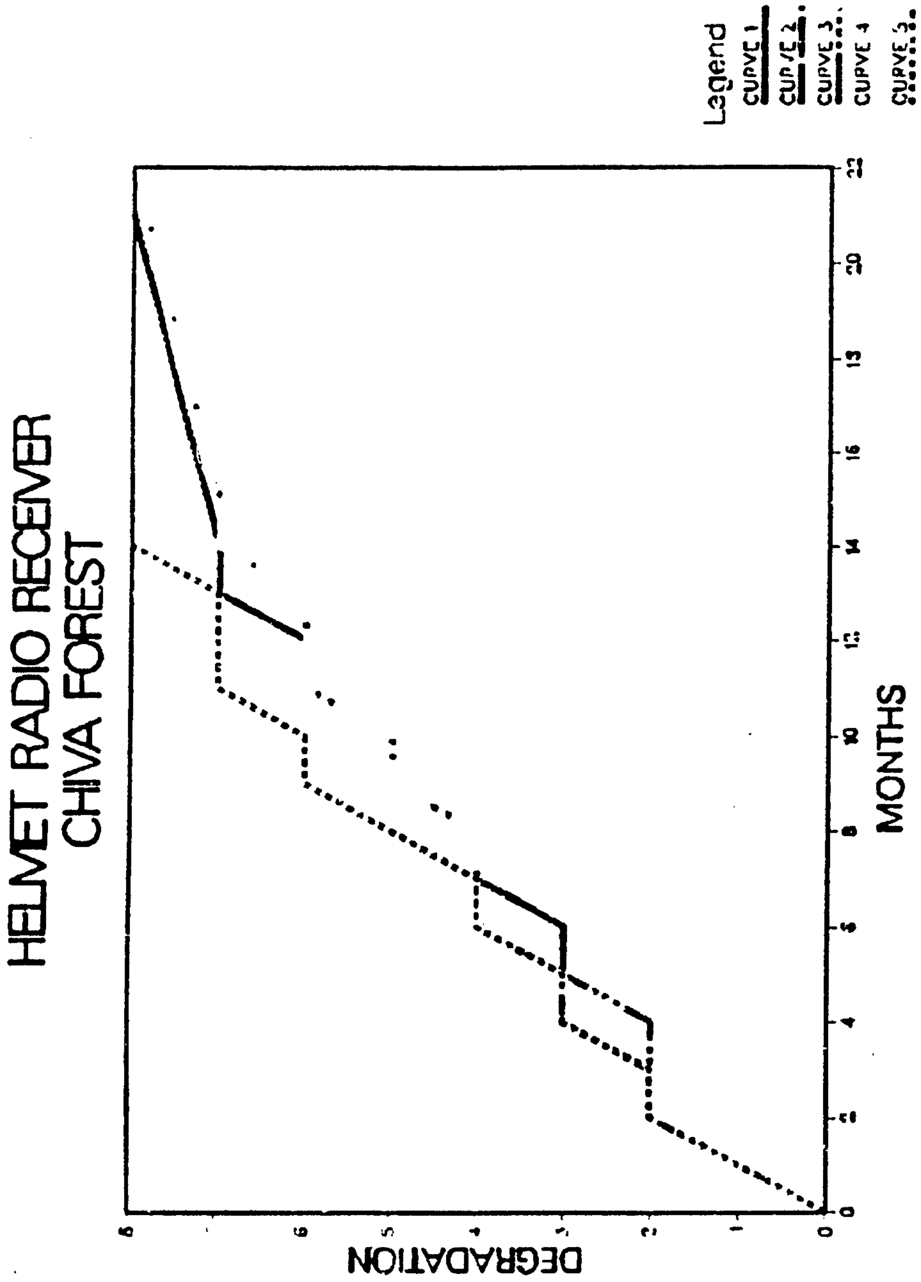

RELAY
SHERMAN (OPEN)
DEGRADATION
MONTHS
CURVE 1
CURVE 2
CURVE 3
CURVE 5

RELAY
SKUNK HOLLOW



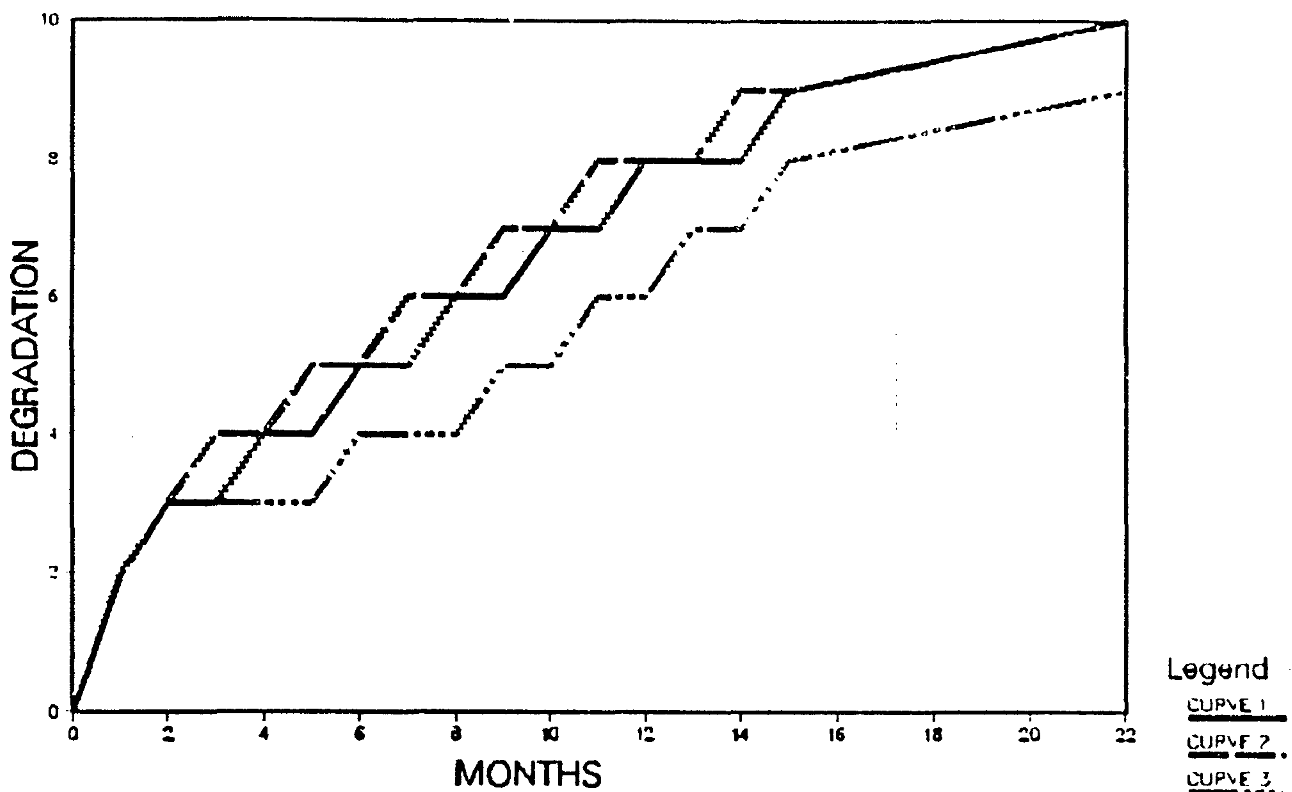


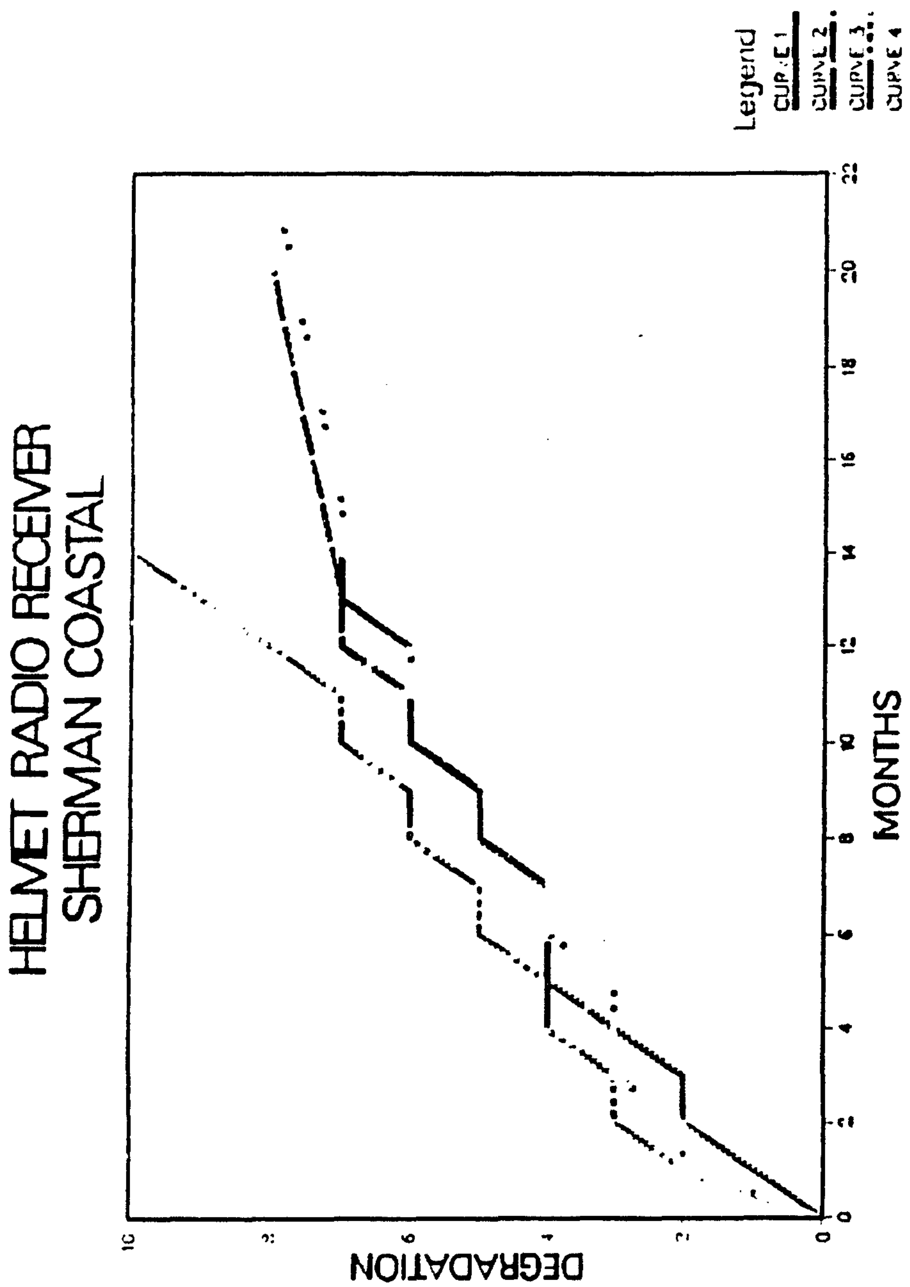
HELMET RADIO RECEIVER
CHIVA CHIVA
DEGRADATION
0
1
2
3
4
5
6
7
8
MONTHS
0
2
4
6
8
10
12
14
16
18
20
22
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
CURVE 5

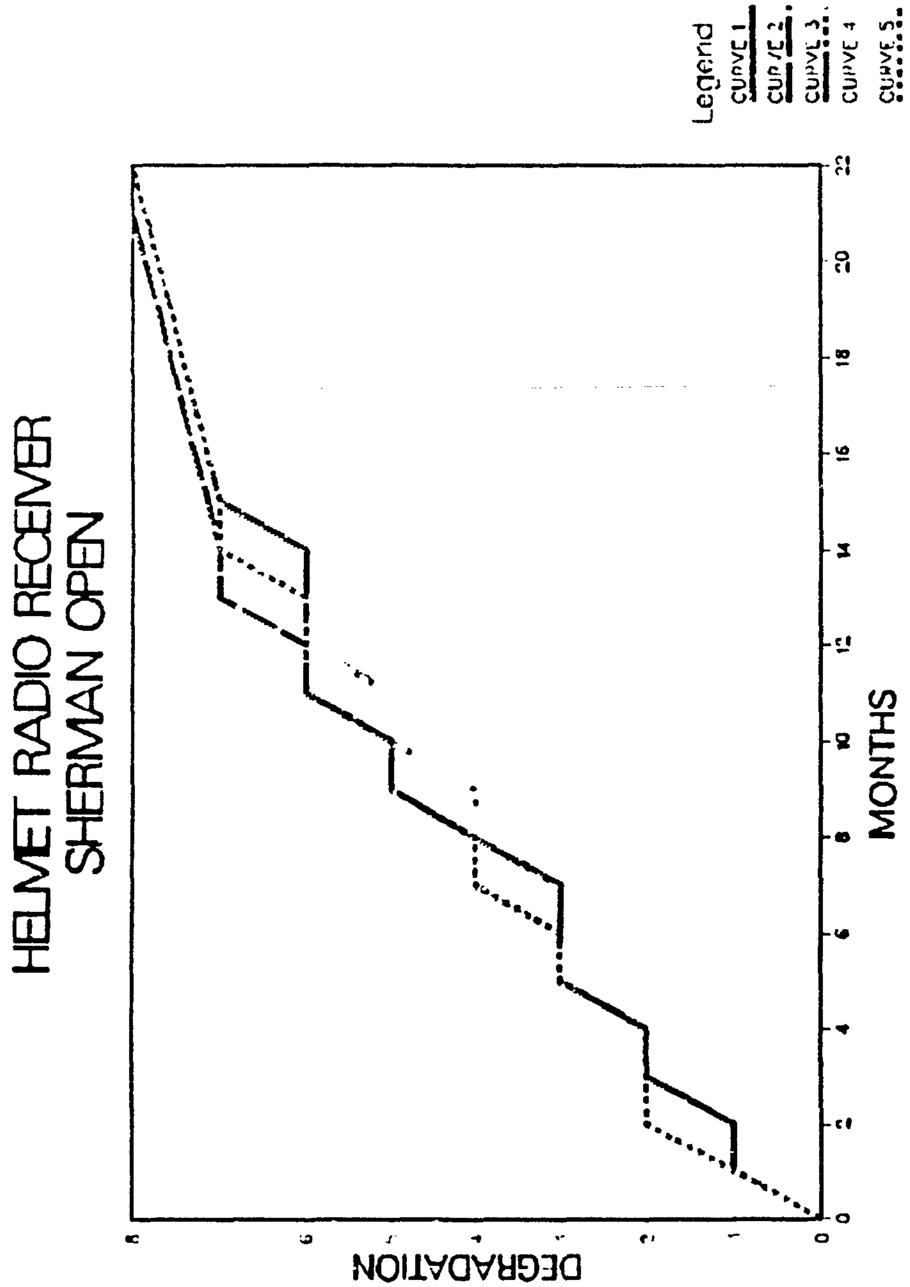


HELMET RADIO RECEIVER
CHIVA FOREST
DEGRADATION
MONTHS
0
2
4
6
8
10
12
14
16
18
20
22
1
3
5
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
CURVE 5

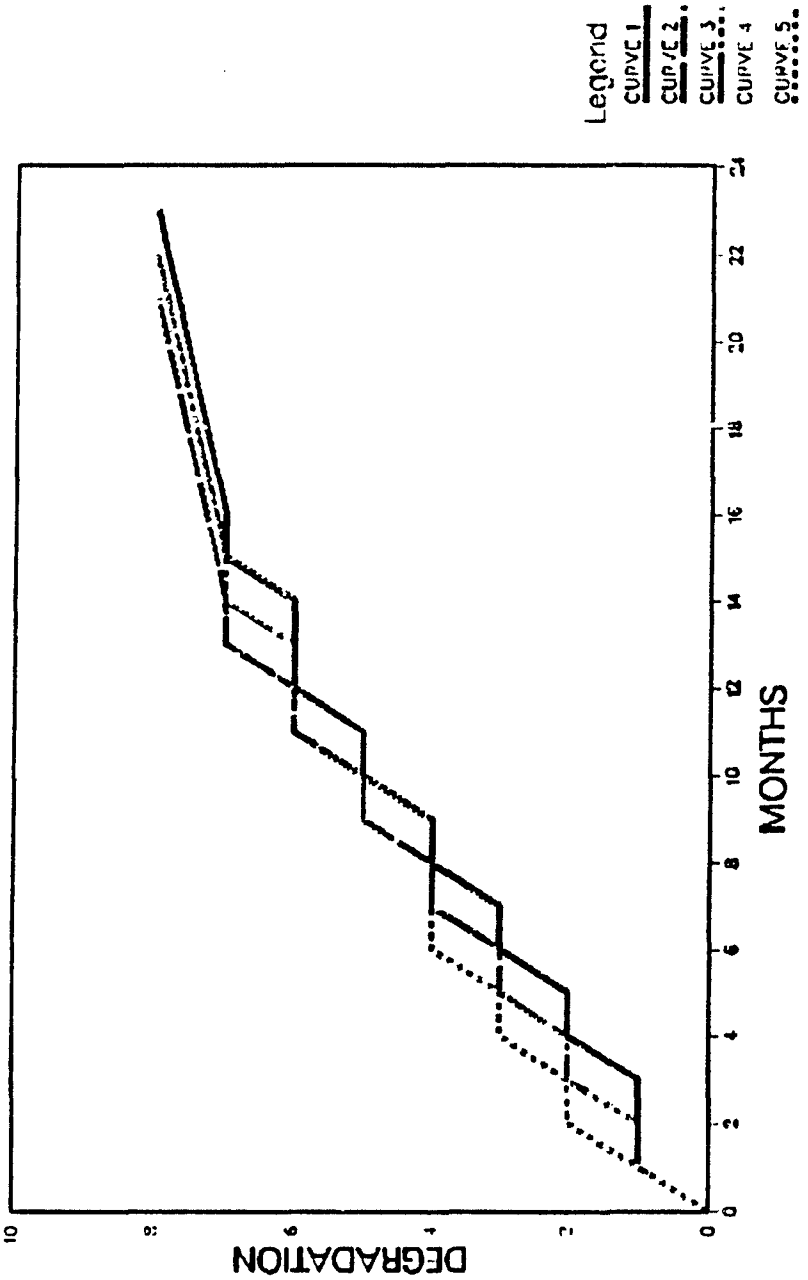
HELMET RADIO RECEIVER
CHIVA (OPEN)



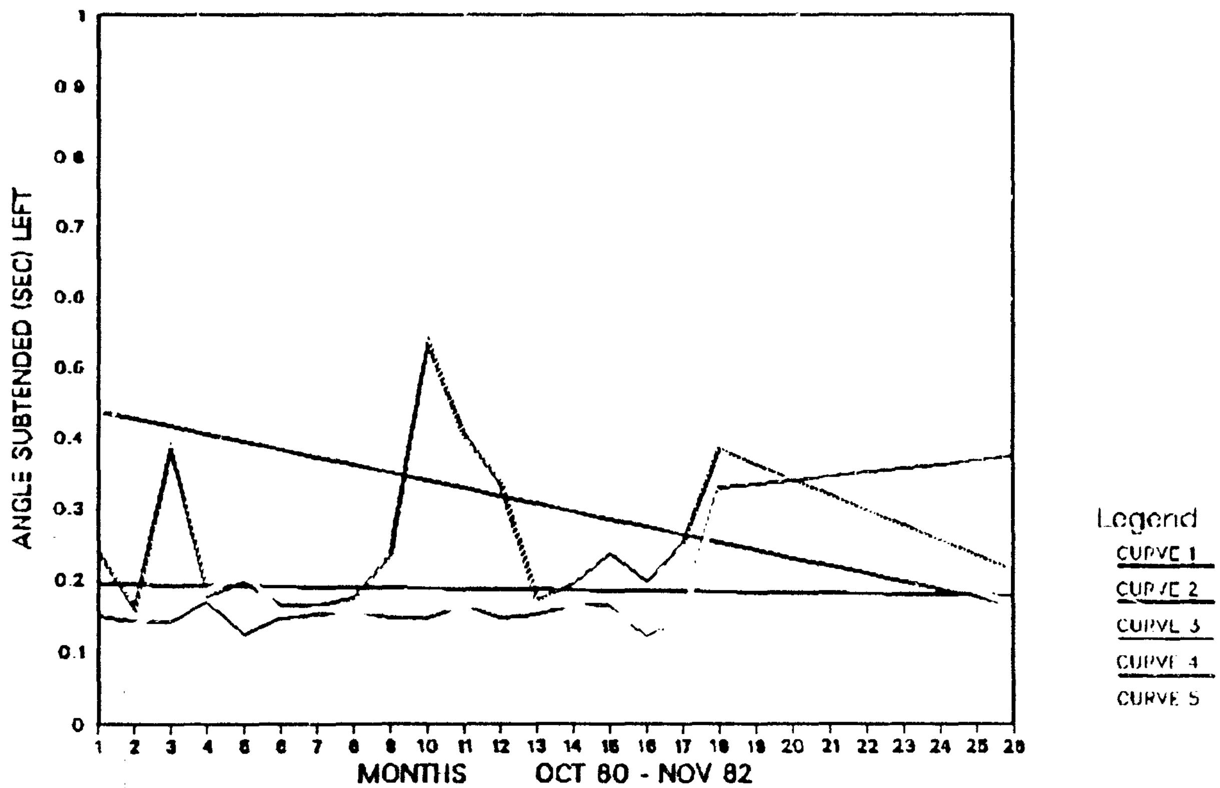

HELMET RADIO RECEIVER
SHERMAN COASTAL
DEGRADATION
MONTHS
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
0
2
4
6
8
10
12
14
16
18
20
22


HELMET RADIO RECEIVER
SHERMAN OPEN
DEGRADATION
MONTHS
0 2 4 6 8 10 12 14 16 18 20 22
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
CURVE 5

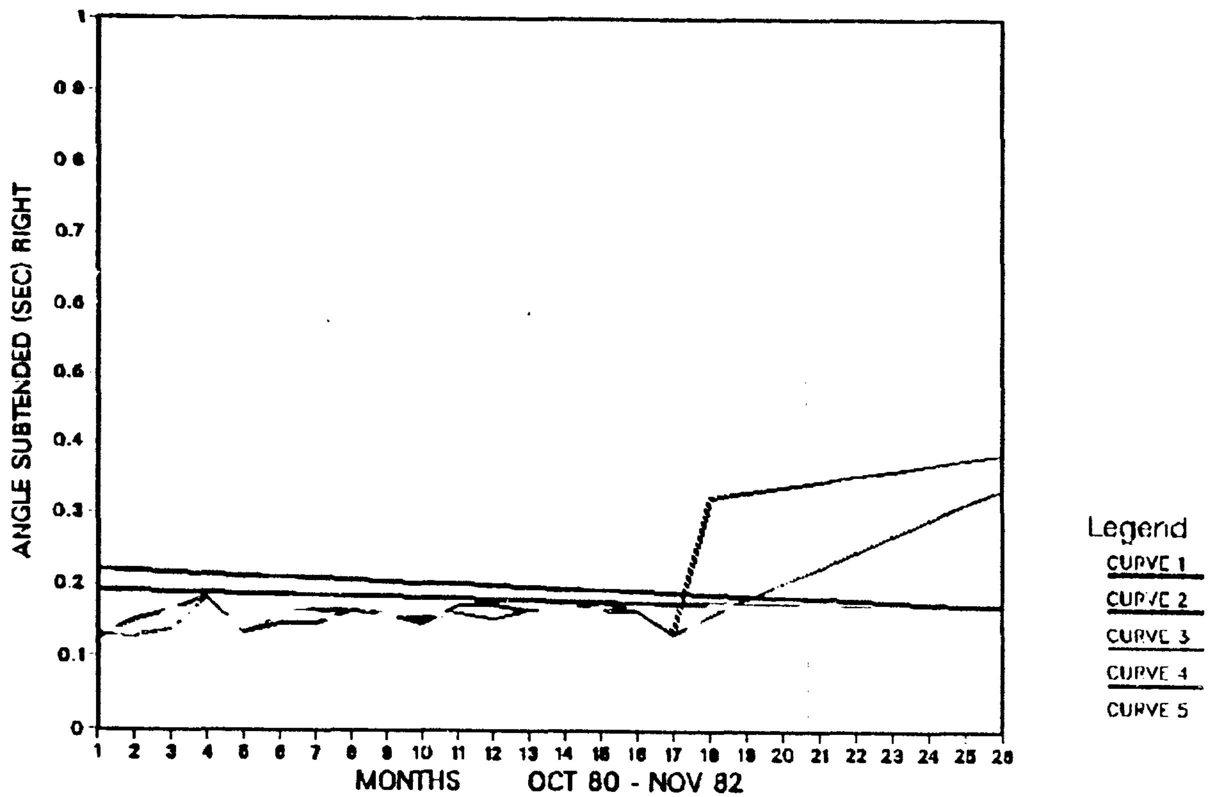
HELMET RADIO RECEIVER
SKUNK HOLLOW



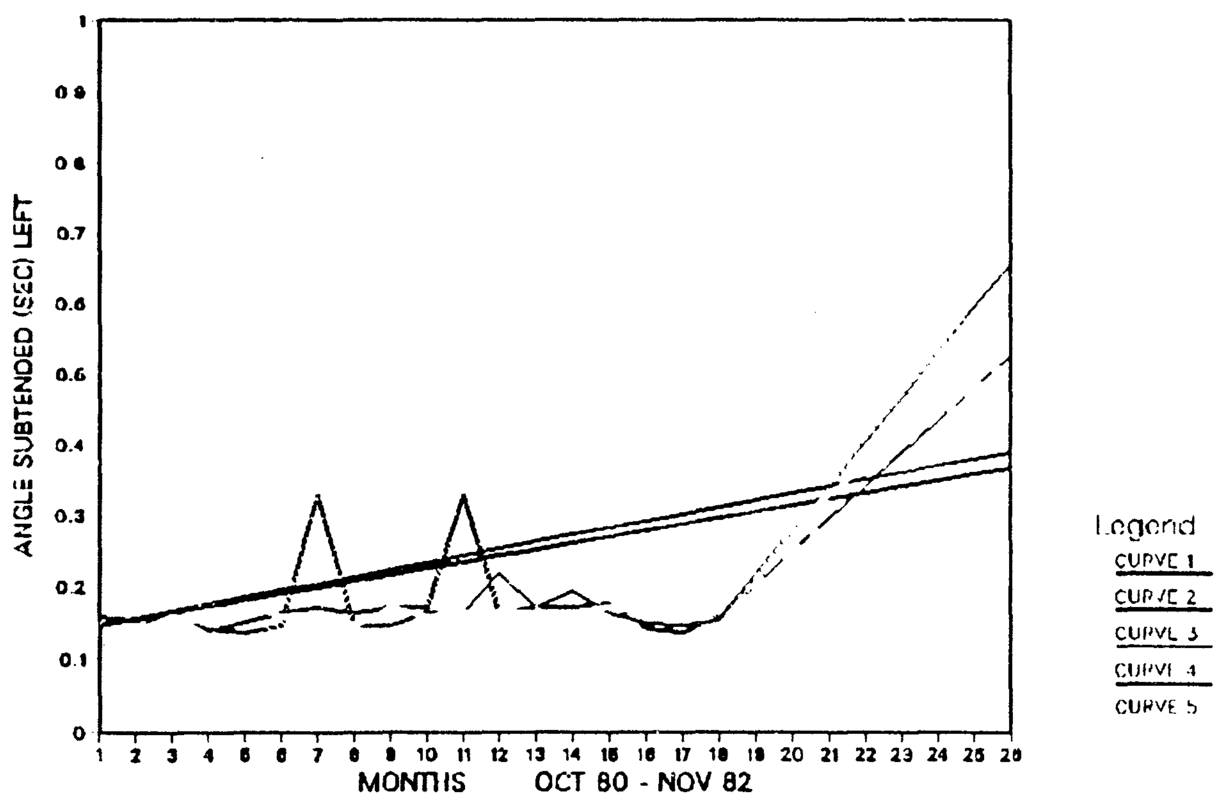
M-3 BINOCULARS
CHIVA CHIVA



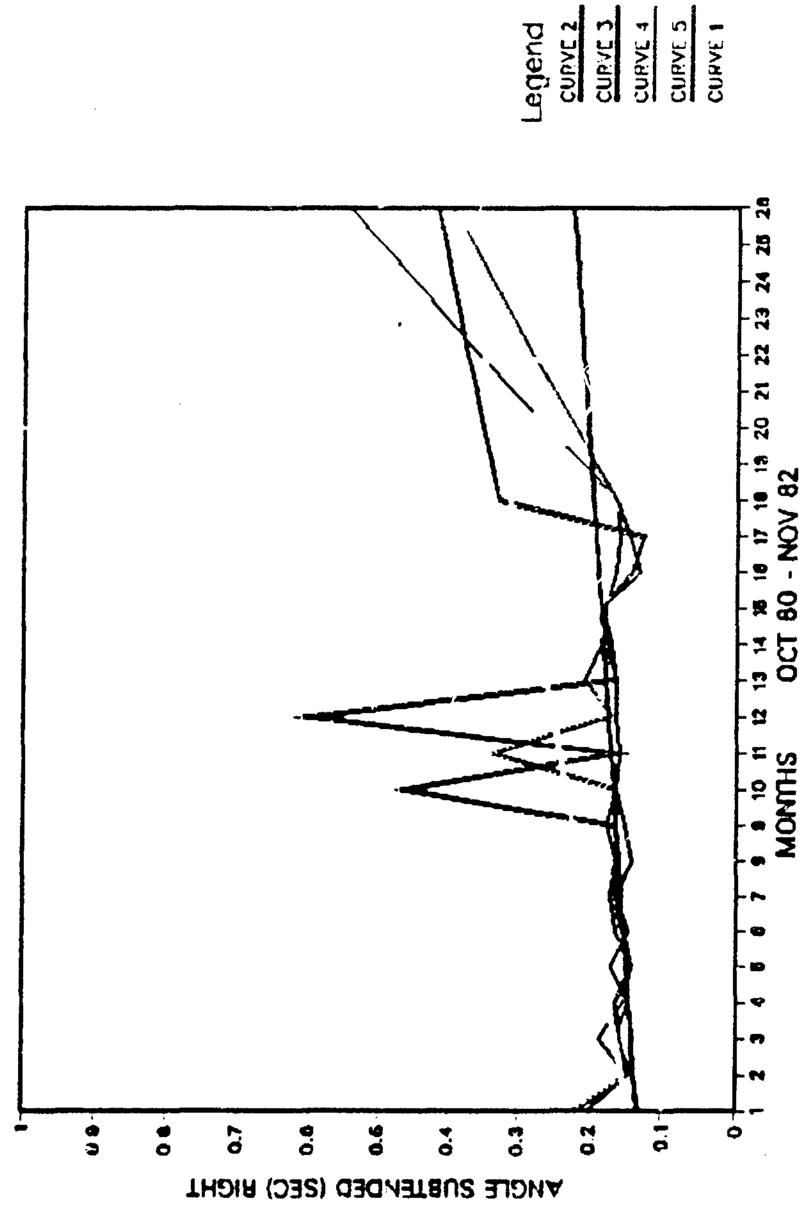
M-3 BINOCULARS
CHIVA CHIVA



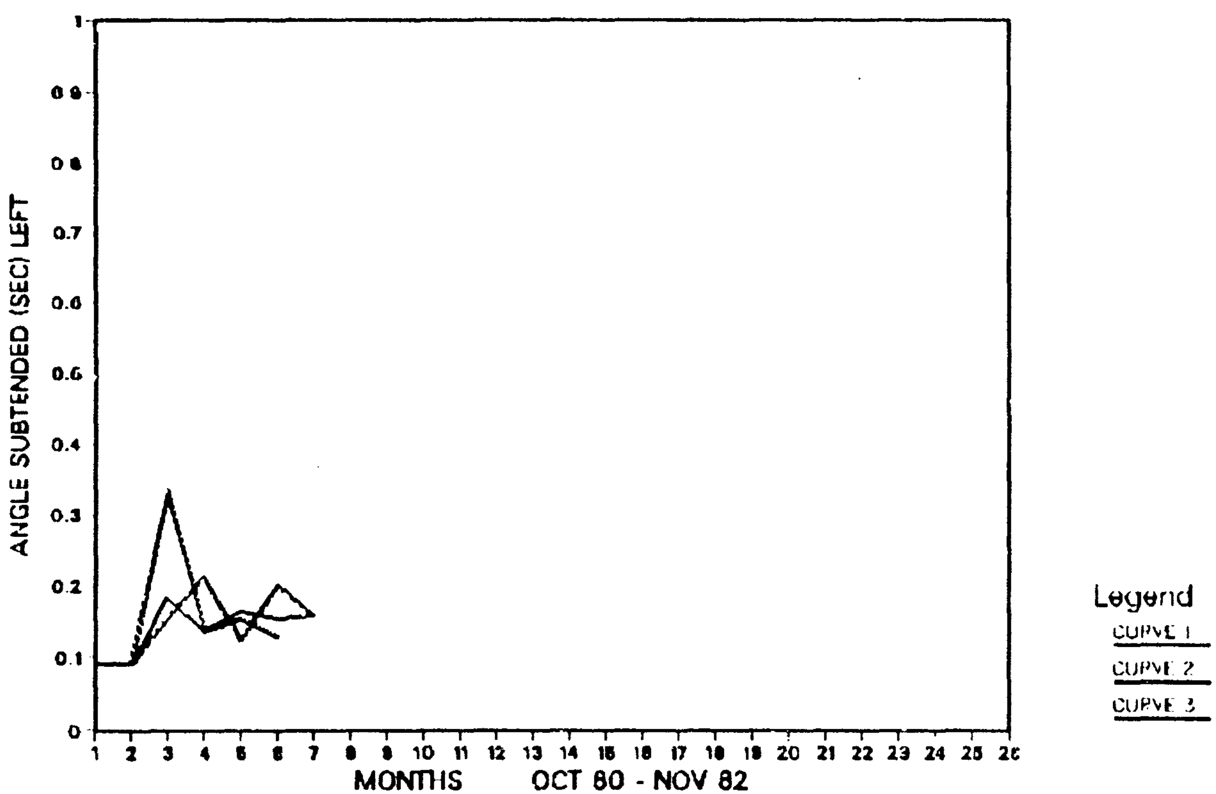
M-3 BINOCULARS
CHIVA FOREST



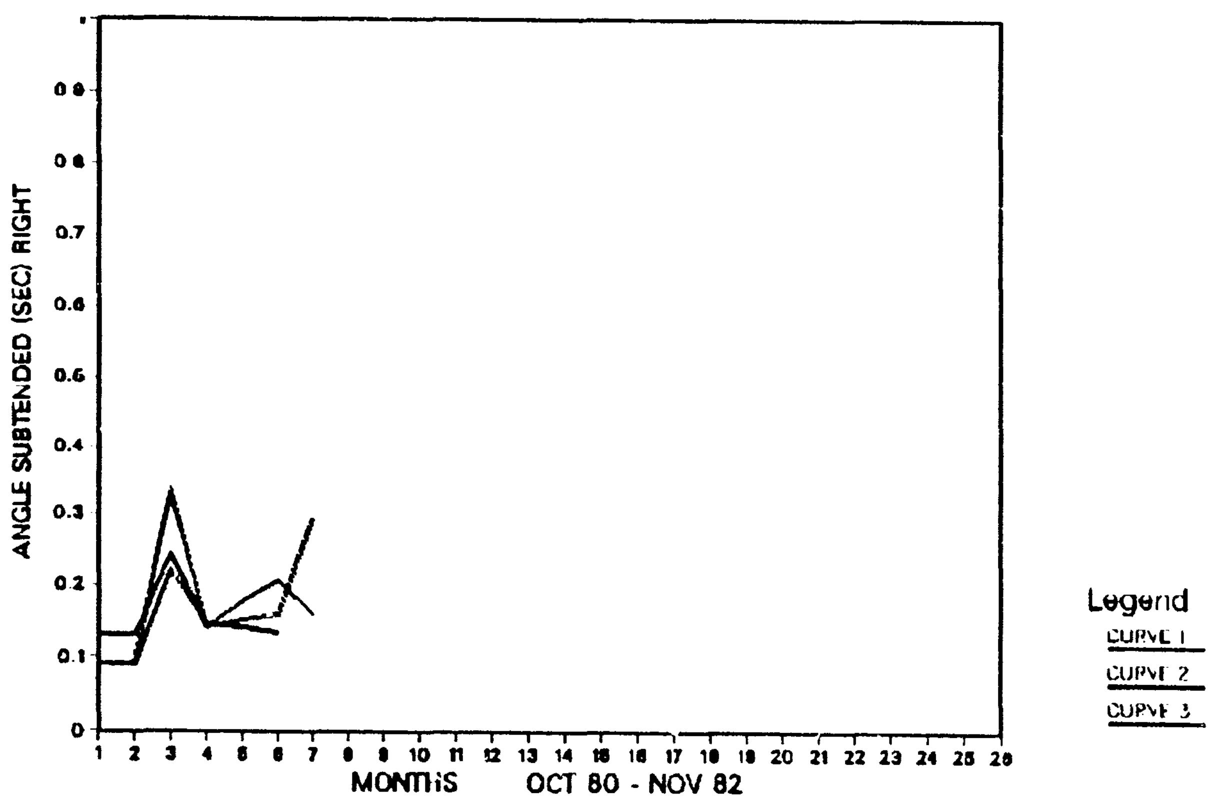
M-3 BINOCULARS
CHIVA FOREST

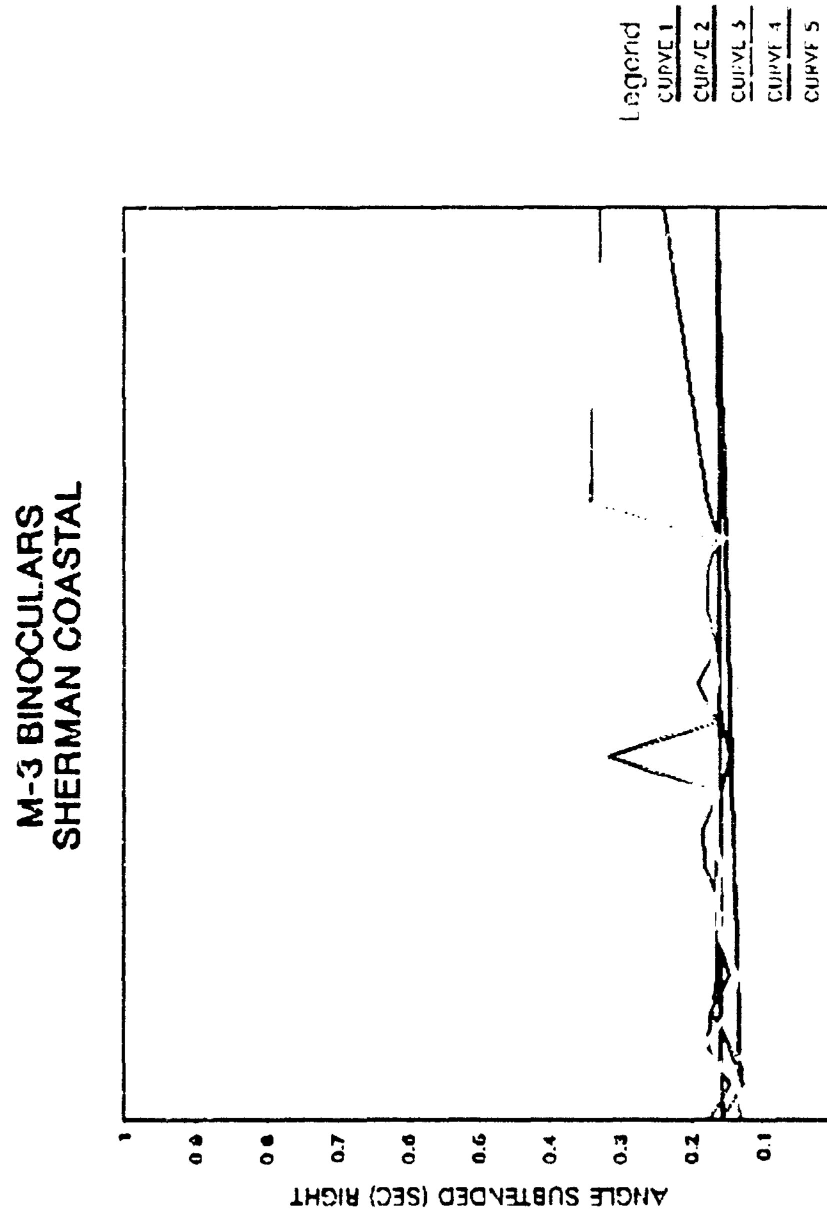


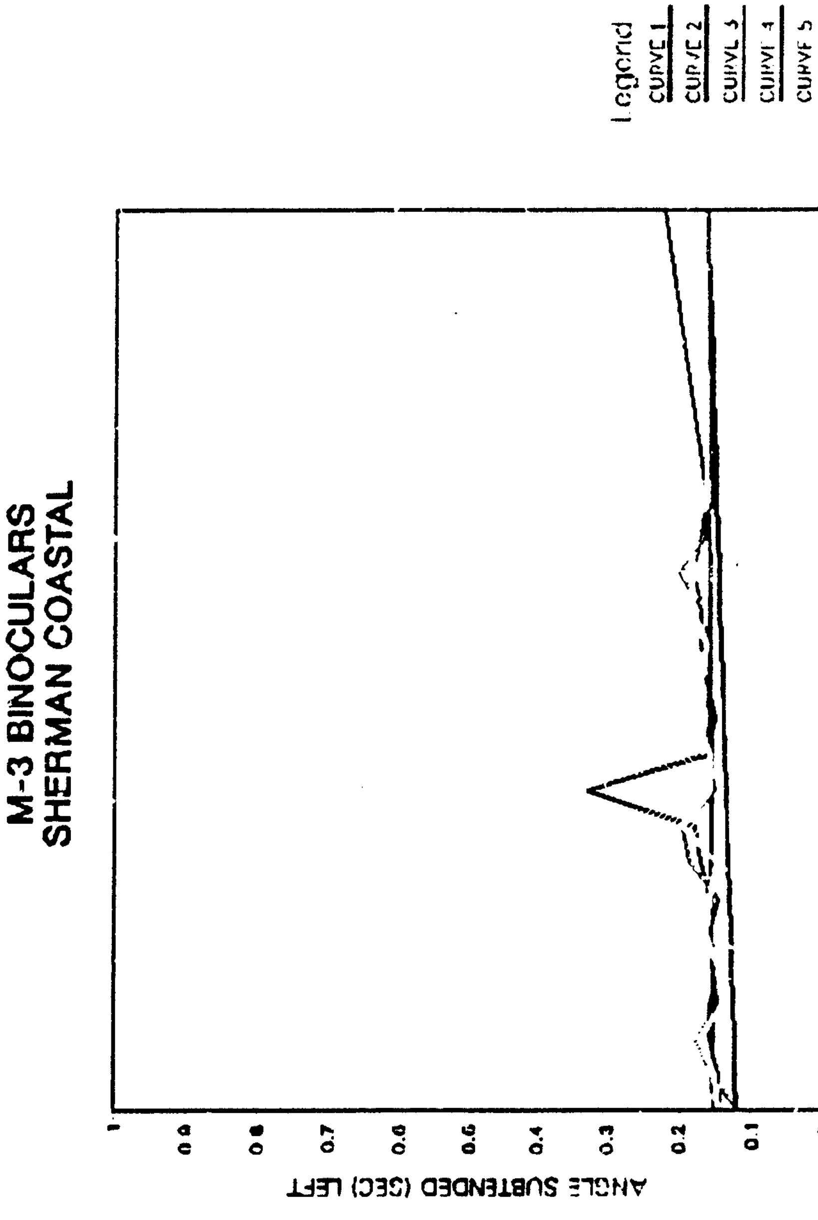
M-3 BINOCULARS
CHIVA OPEN



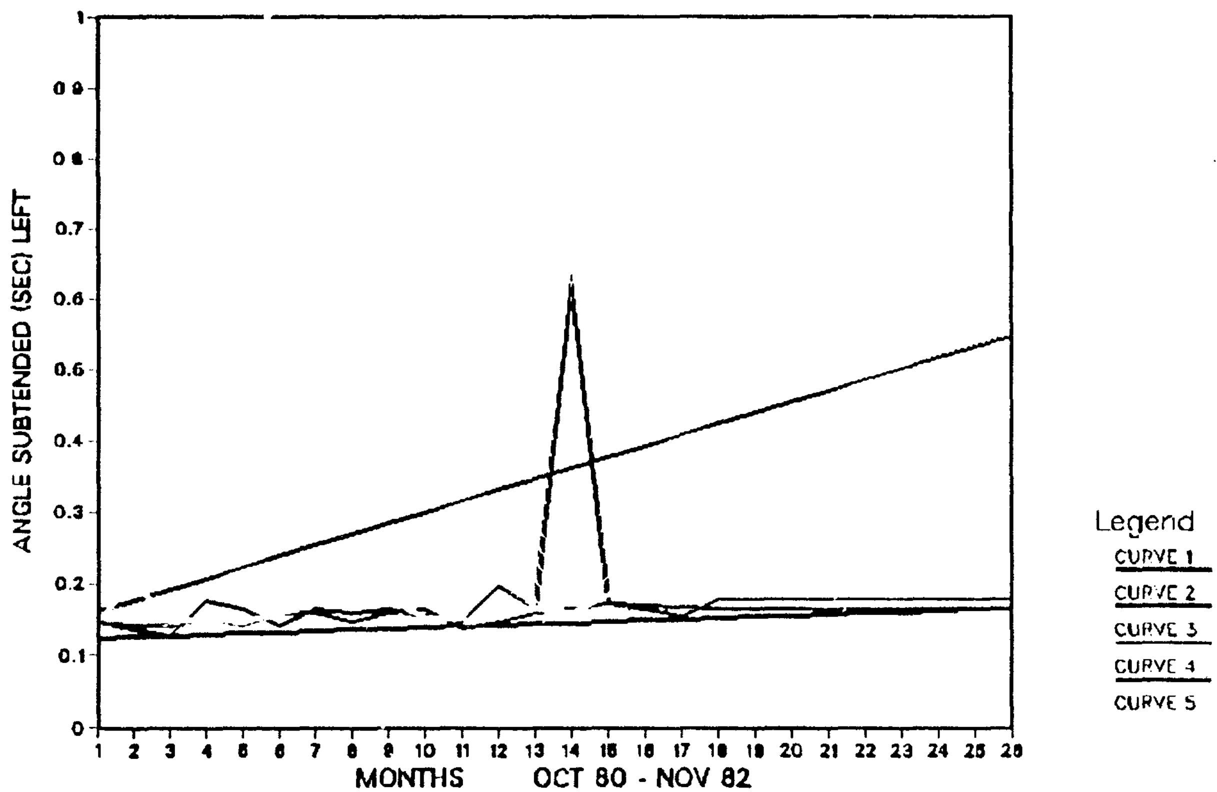
M-3 BINOCULARS
CHIVA OPEN



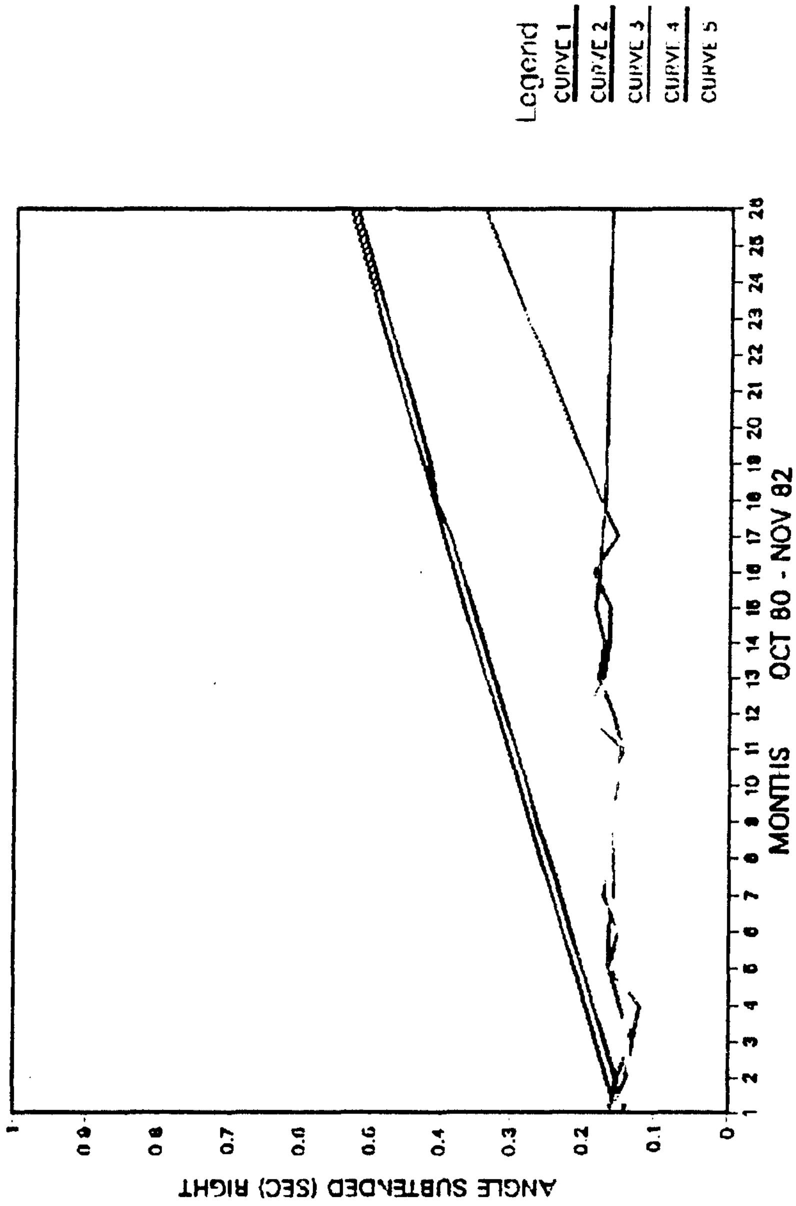

M-3 BINOCULARS
SHERMAN COASTAL
ANGLE SUBTENDED (SEC) RIGHT
MONTHS OCT 80 - NOV 82
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
CURVE 5


M-3 BINOCULARS
SHERMAN COASTAL
ANGLE SUBTENDED (SEC) LEFT
MONTHS OCT 80 - NOV 82
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
CURVE 5

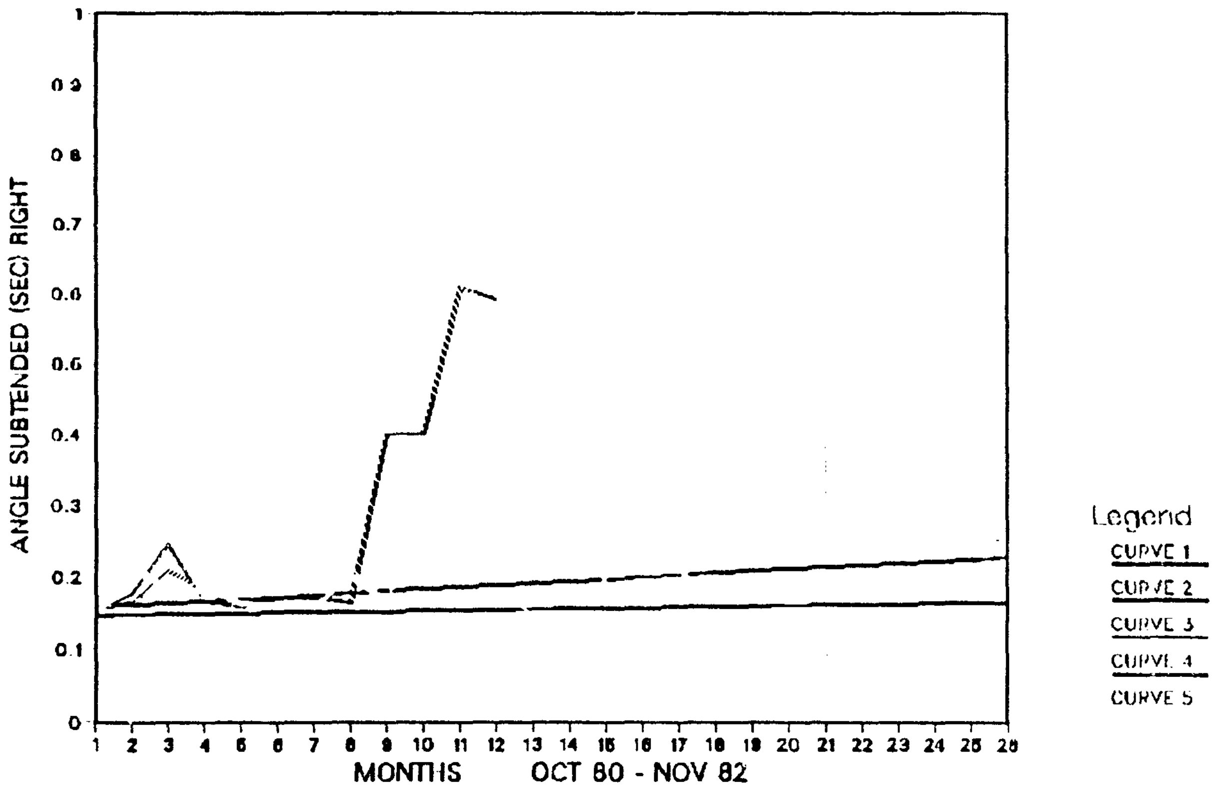
M-3 BINOCULARS
SHERMAN OPEN



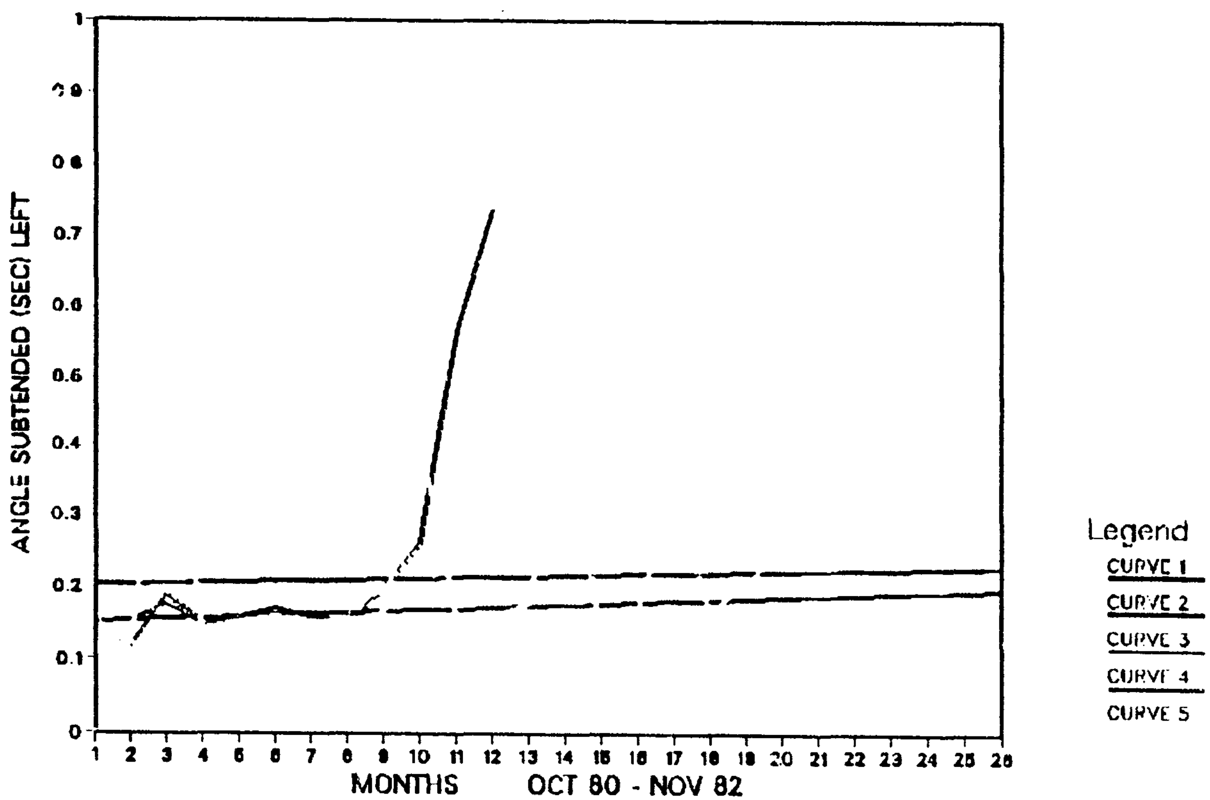
M-3 BINOCULARS
SHERMAN OPEN



M-3 BINOCULARS
SKUNK HOLLOW

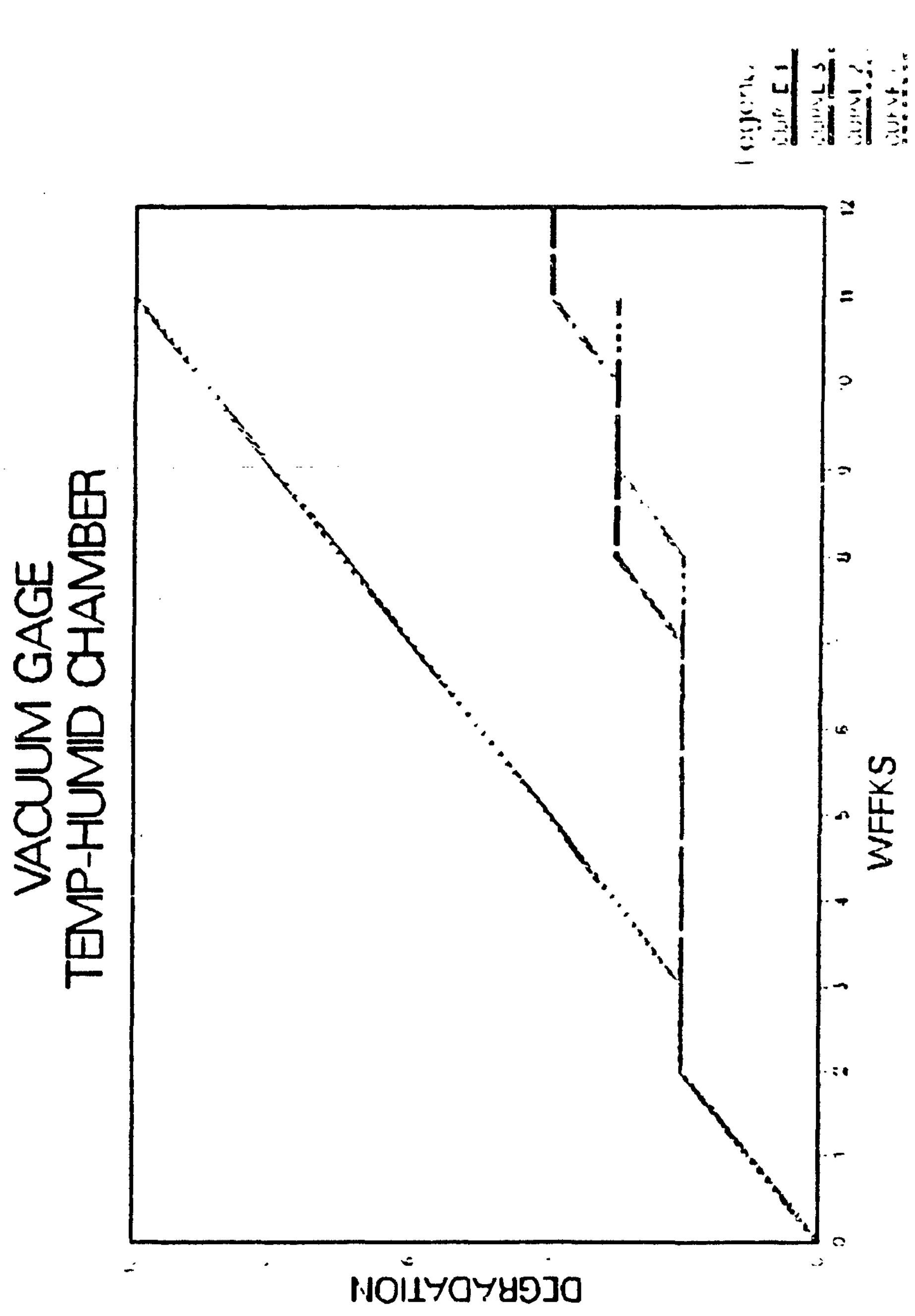


M-3 BINOCULARS
SKUNK HOLLOW



APPENDIX B

DEGRADATION CURVES OF THE EFFECTS OF TEMPERATURE/HUMIDITY LABORATORY CHAMBER EXPOSURES



VACUUM GAGE
TEMP-HUMID CHAMBER
WEEKS
DEGRADATION

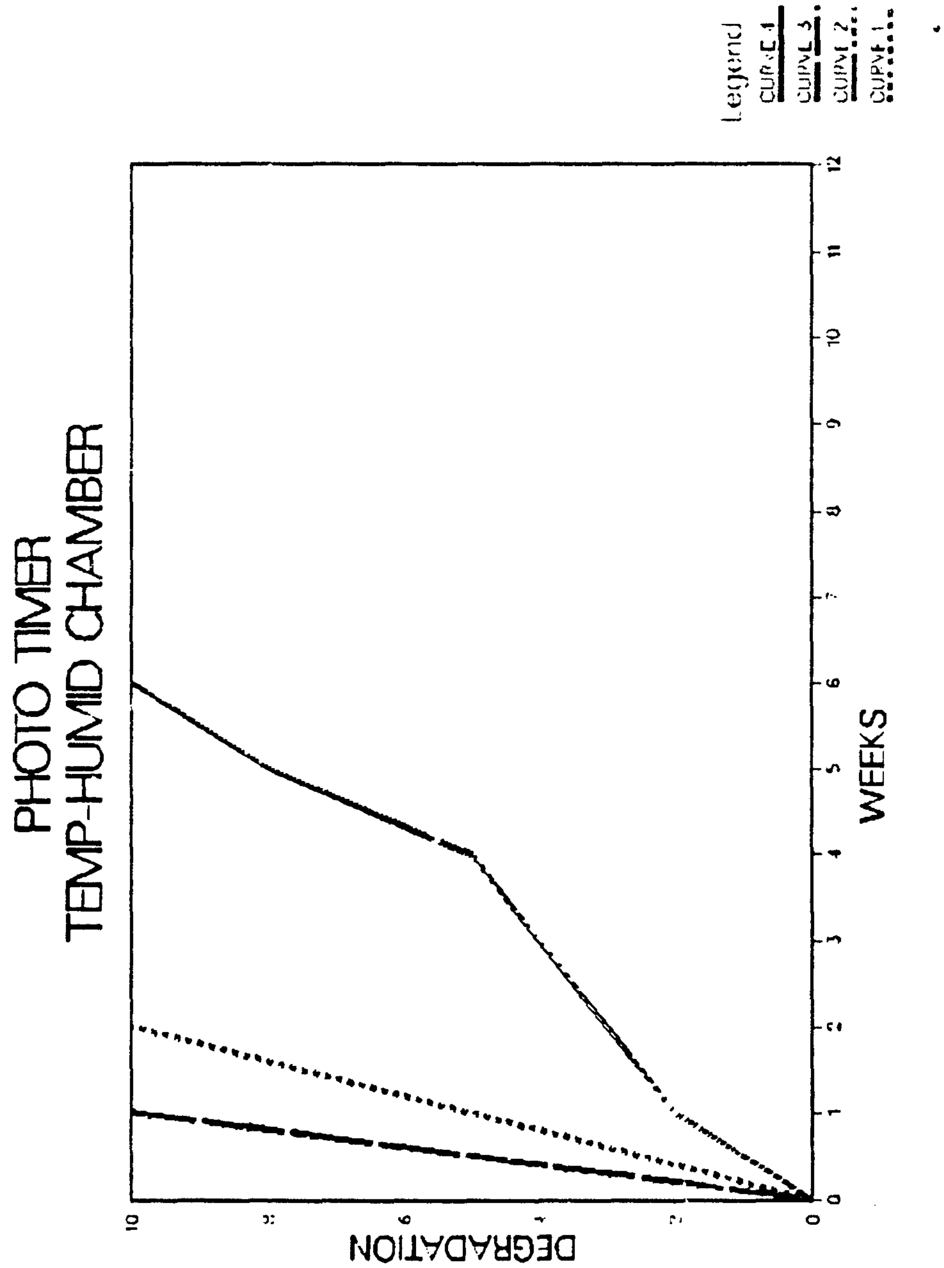
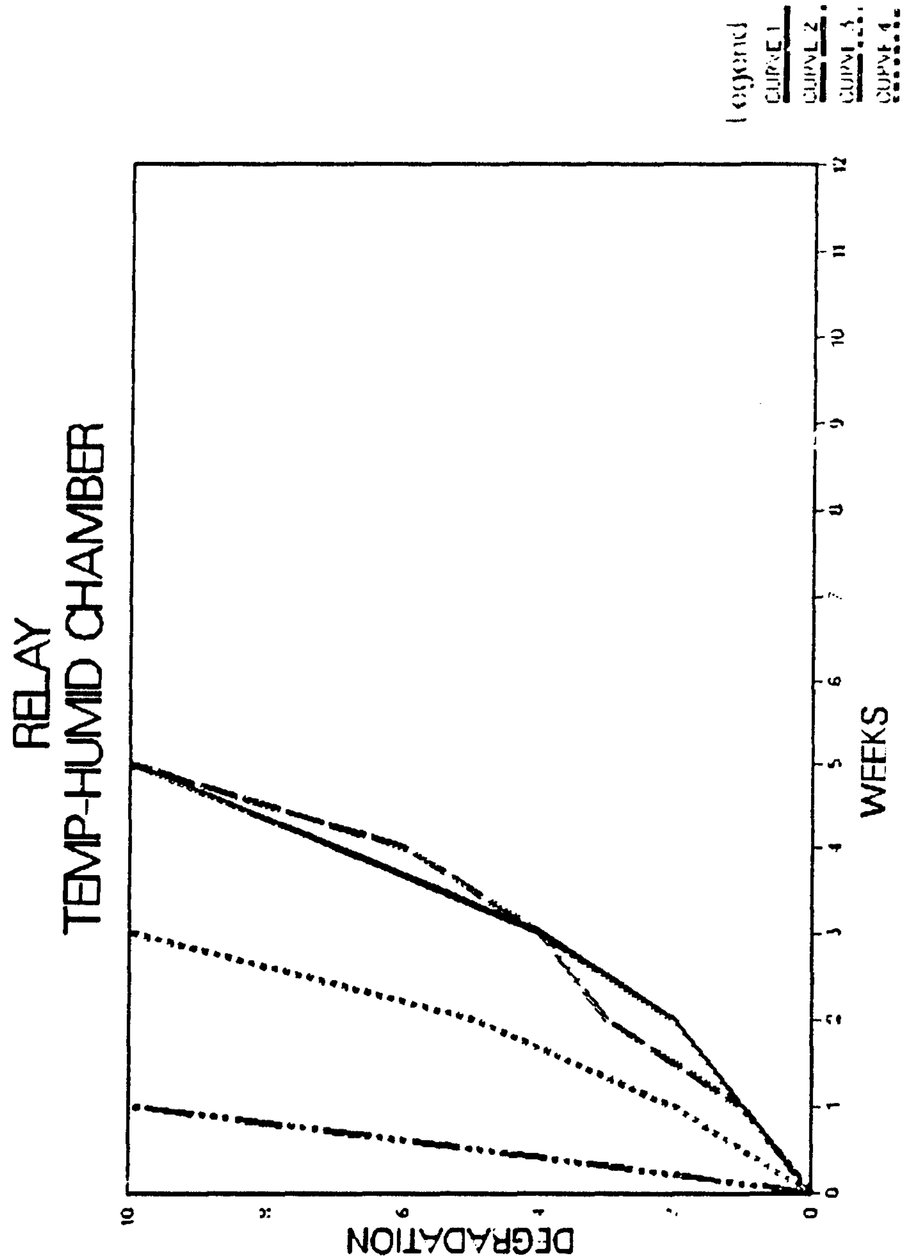
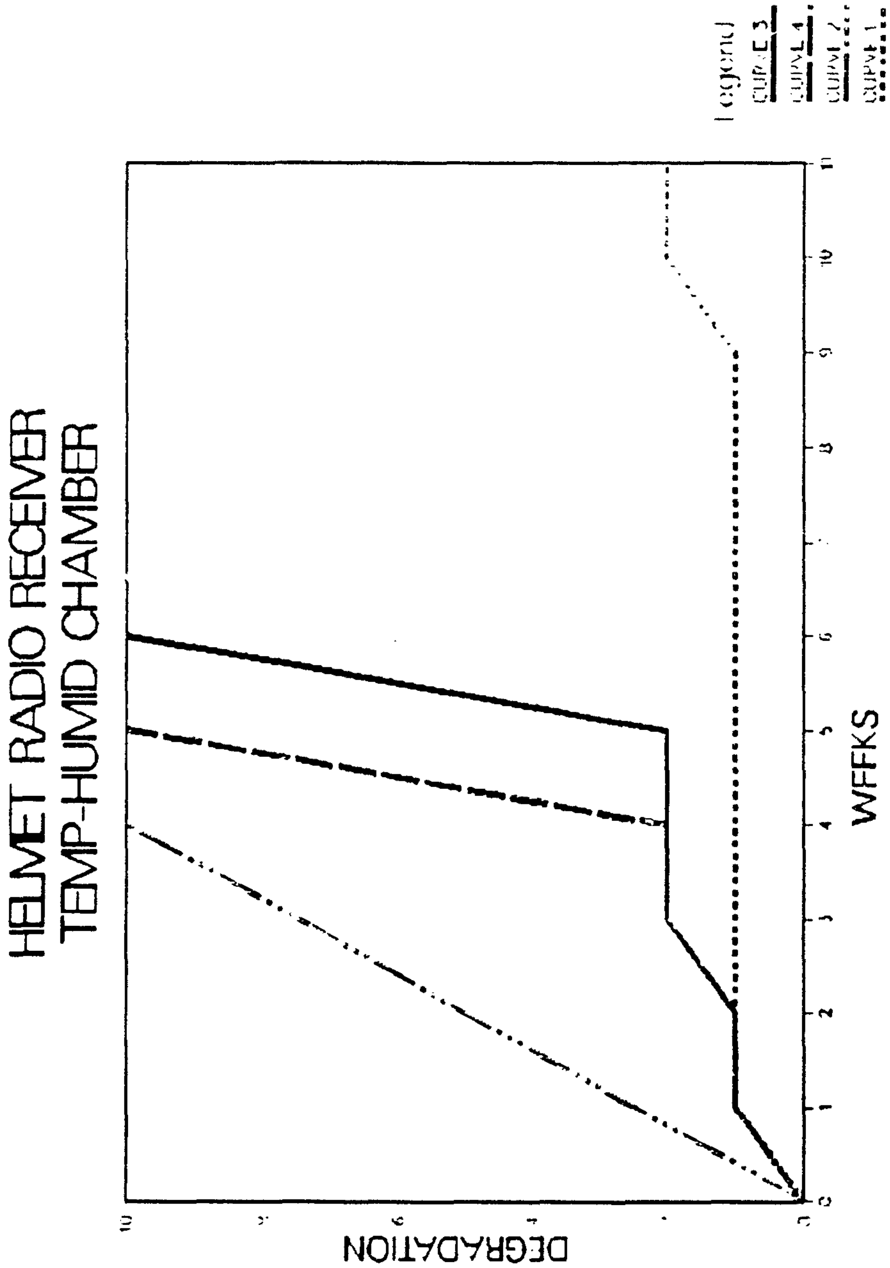
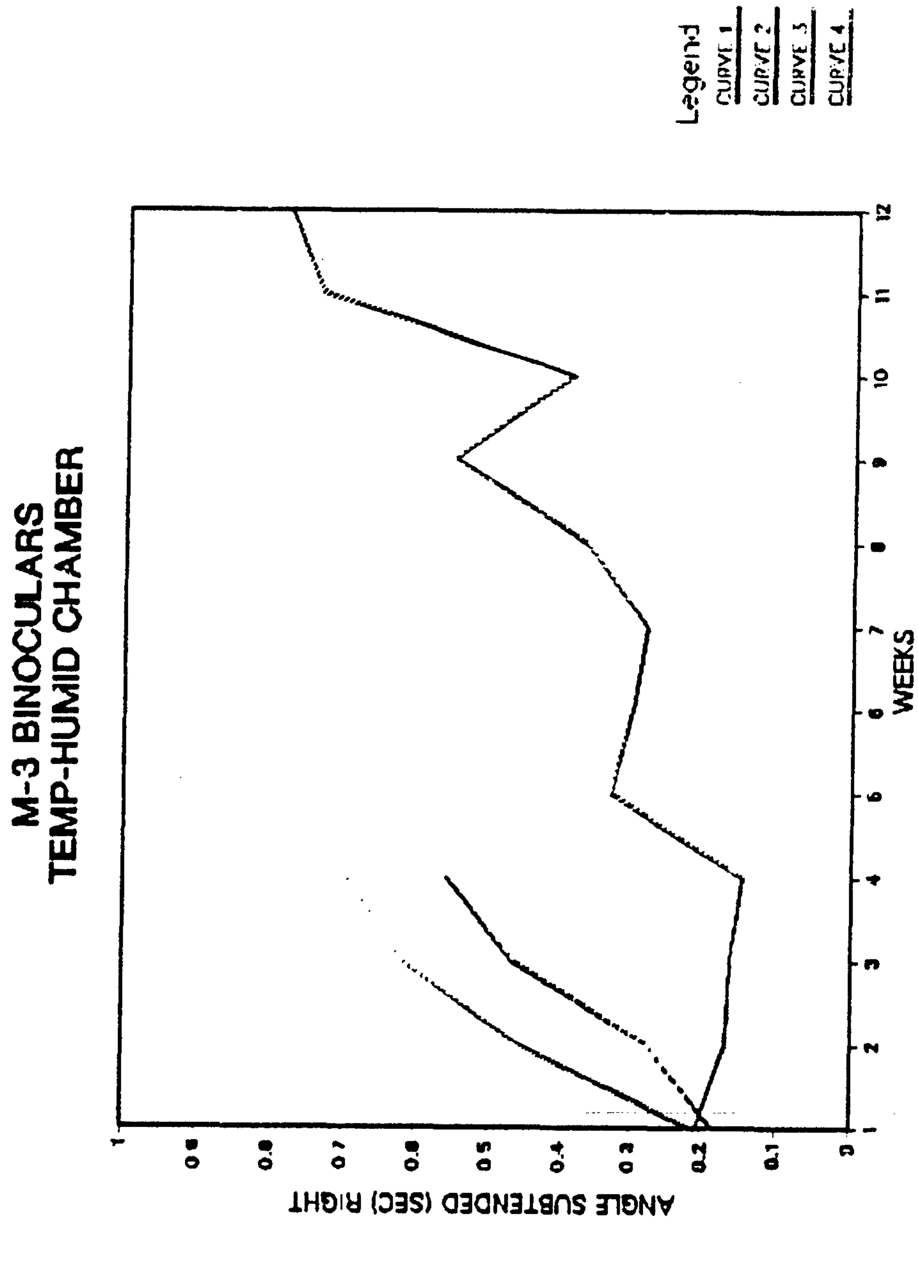


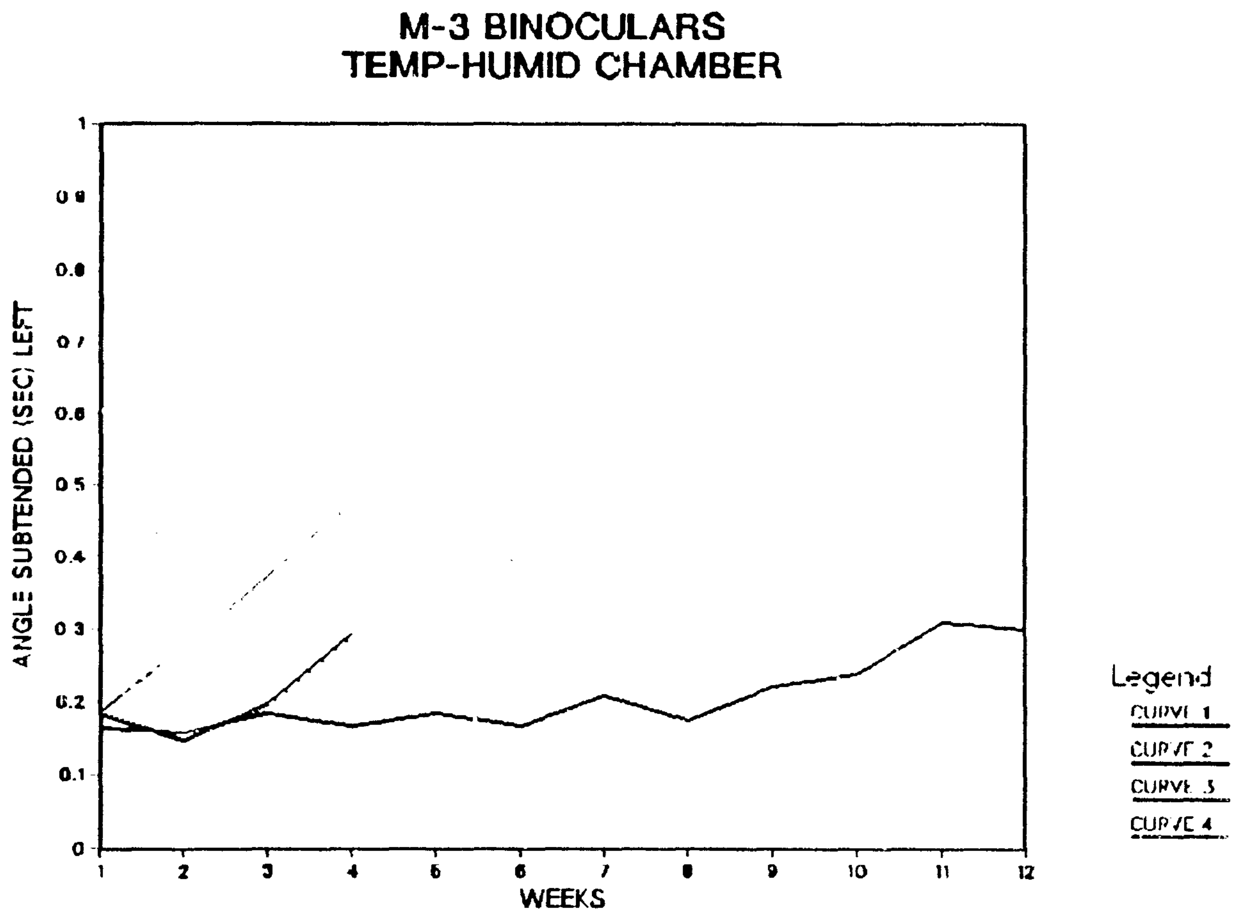
PHOTO TIMER
TEMP-HUMID CHAMBER
DEGRADATION
WEEKS
Legend
CURVE 4
CURVE 3
CURVE 2
CURVE 1


RELAY
TEMP-HUMID CHAMBER
DEGRADATION
WEEKS
0 1 2 3 4 5 6 7 8 9 10 11 12
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4


HELMET RADIO RECEIVER
TEMP-HUMID CHAMBER
DEGRADATION
WEEKS
Legend
CURVE 3
CURVE 4
CURVE 2
CURVE 1



M-3 BINOCULARS
TEMP-HUMID CHAMBER
ANGLE SUBTENDED (SEC) RIGHT
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1
2
3
4
5
6
7
8
9
10
11
12
WEEKS
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4


M-3 BINOCULARS
TEMP-HUMID CHAMBER
ANGLE SUBTENDED (SEC) LEFT
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
WEEKS
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4

APPENDIX C

DEGRADATION CURVES OF THE EFFECTS OF
SIMULATED SEA WATER SALT FOG
LABORATORY CHAMBER EXPOSURES

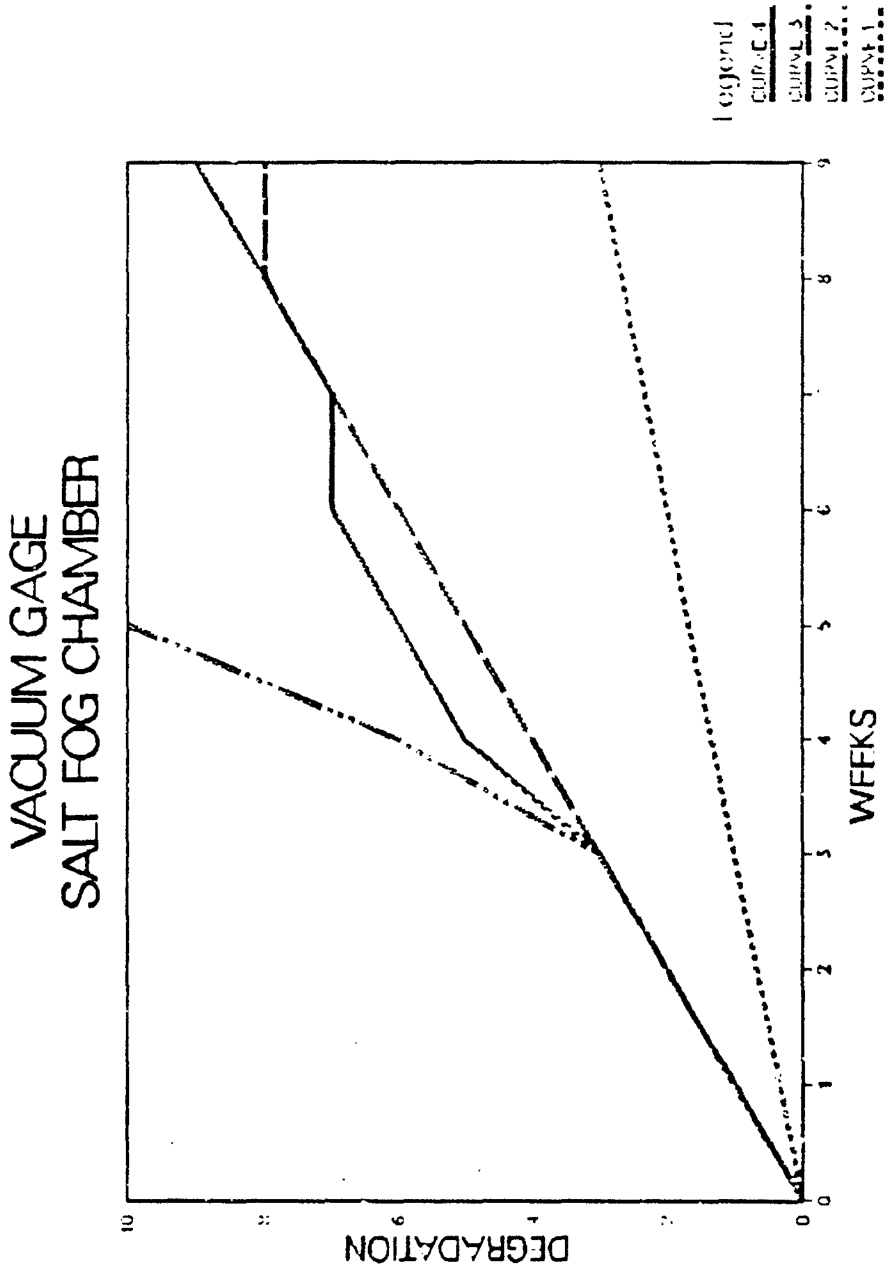
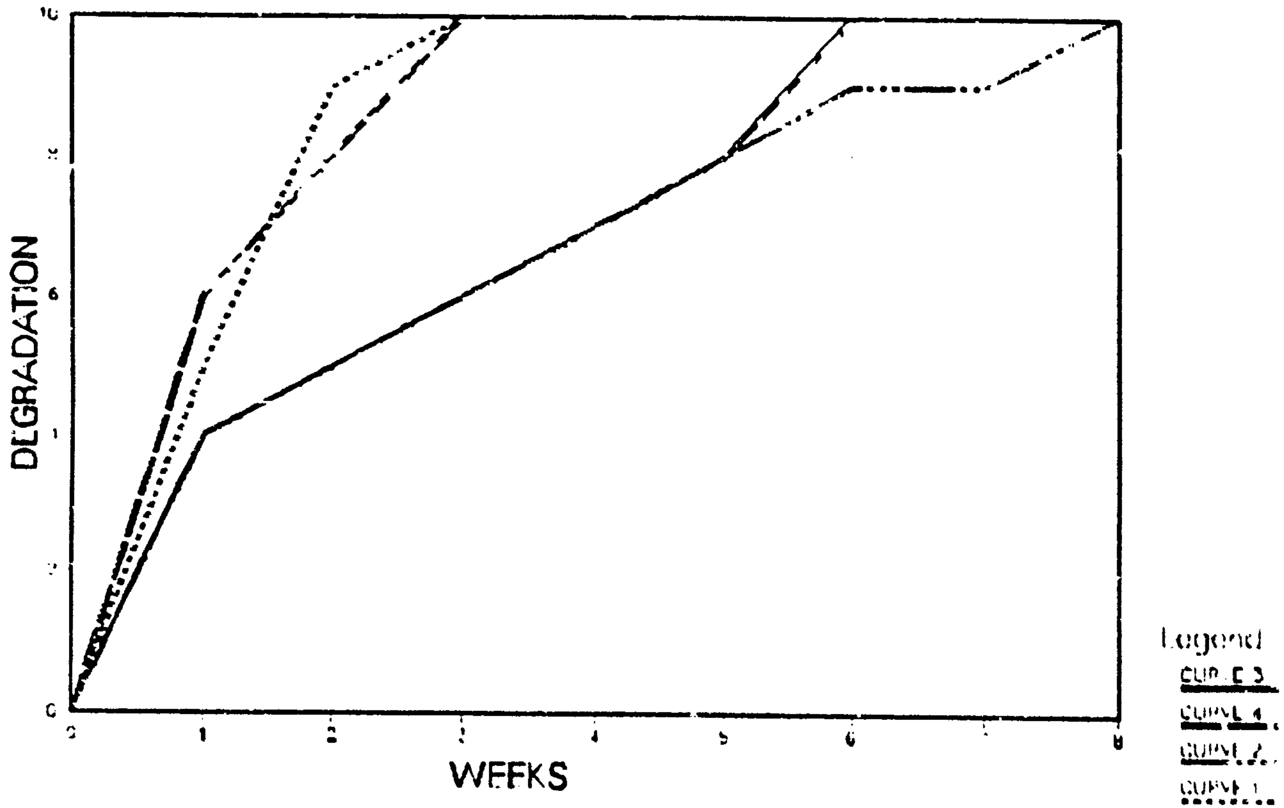
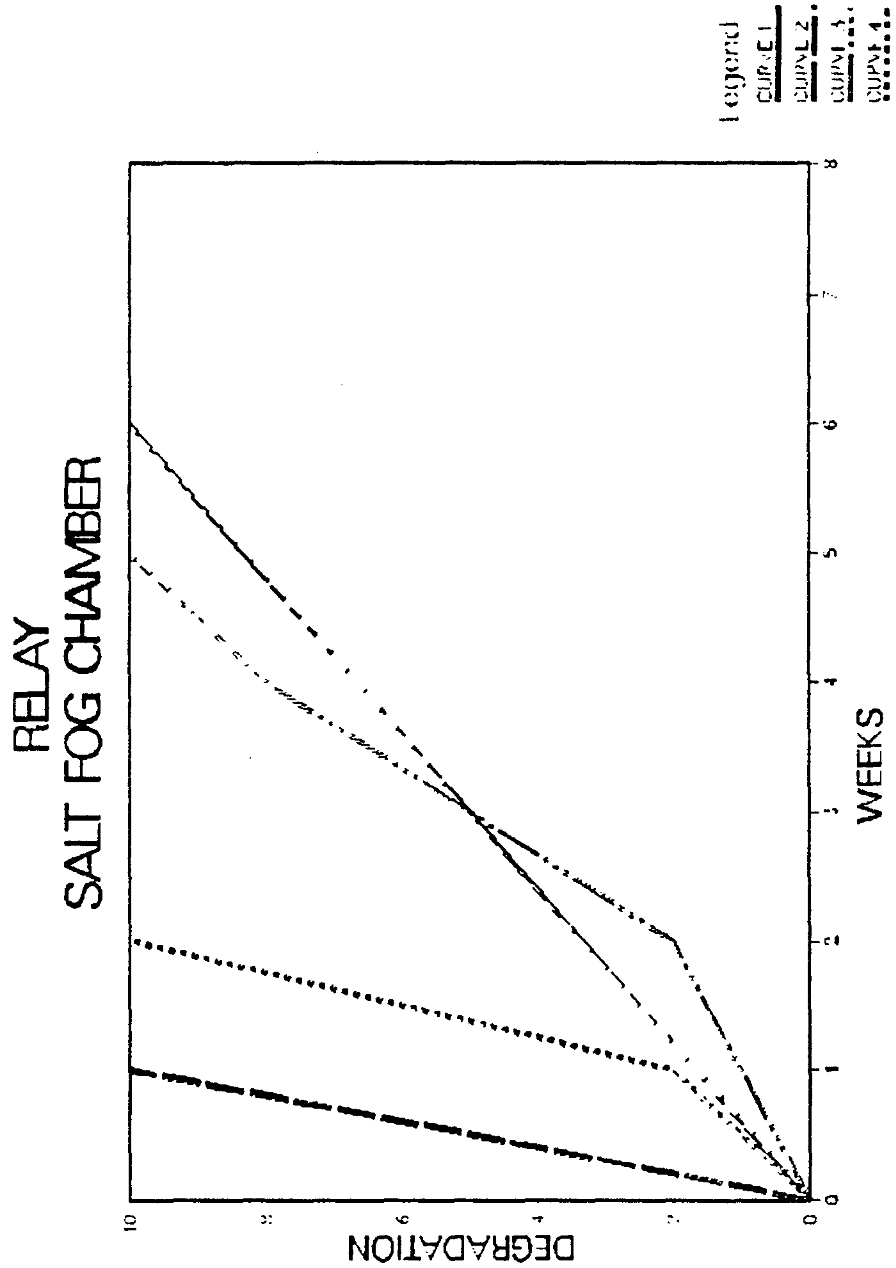
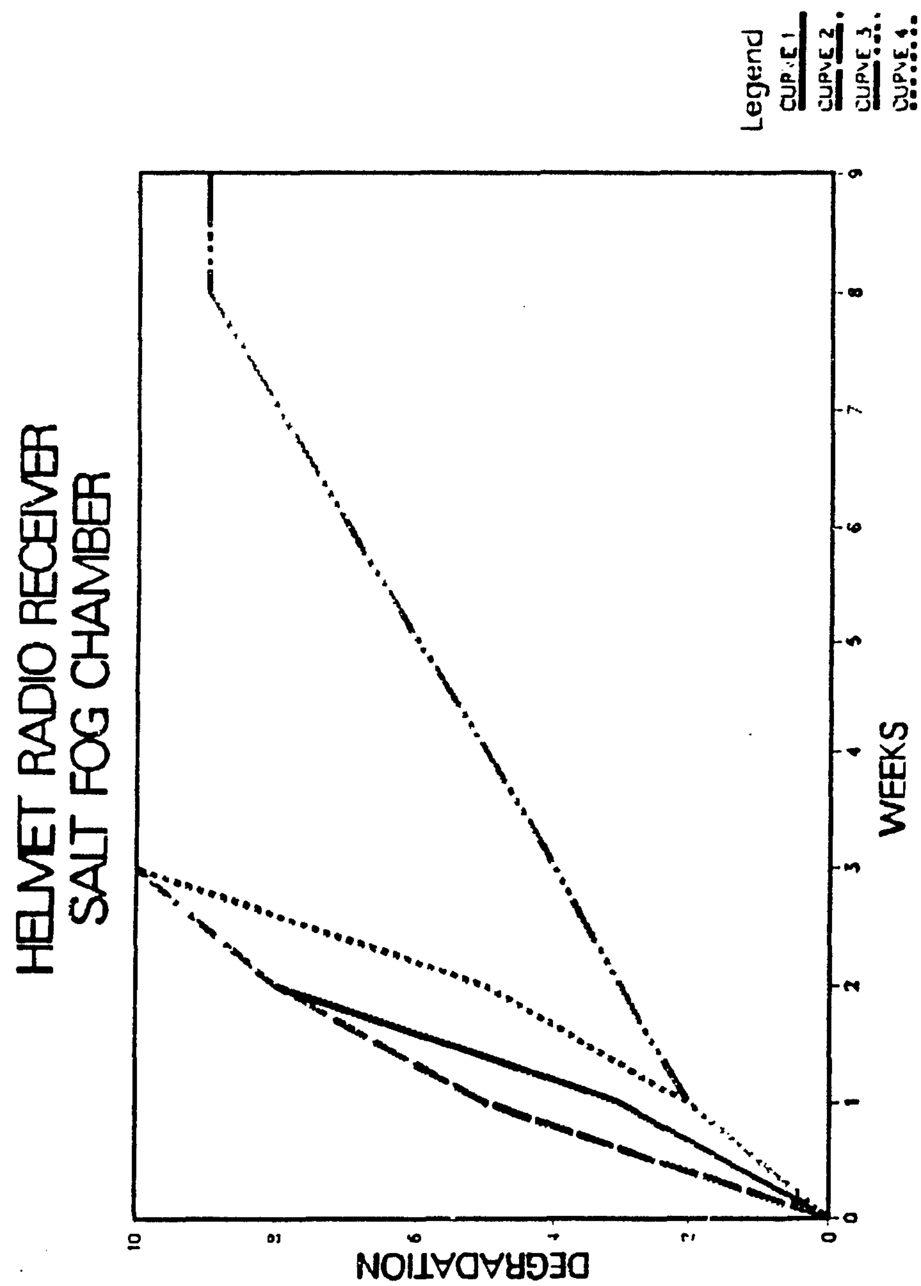

VACUUM GAGE
SALT FOG CHAMBER
DEGRADATION
WEEKS
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10

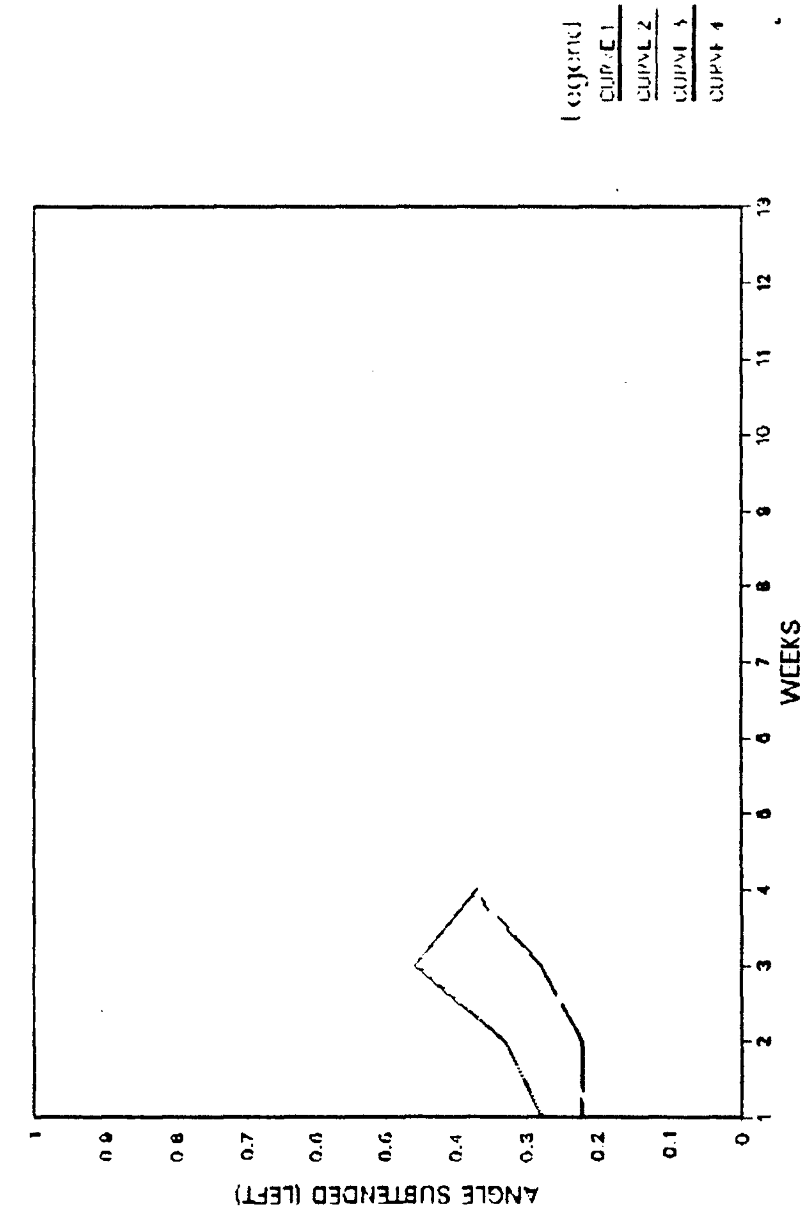
PHOTO TIMER
SALT FOG CHAMBER

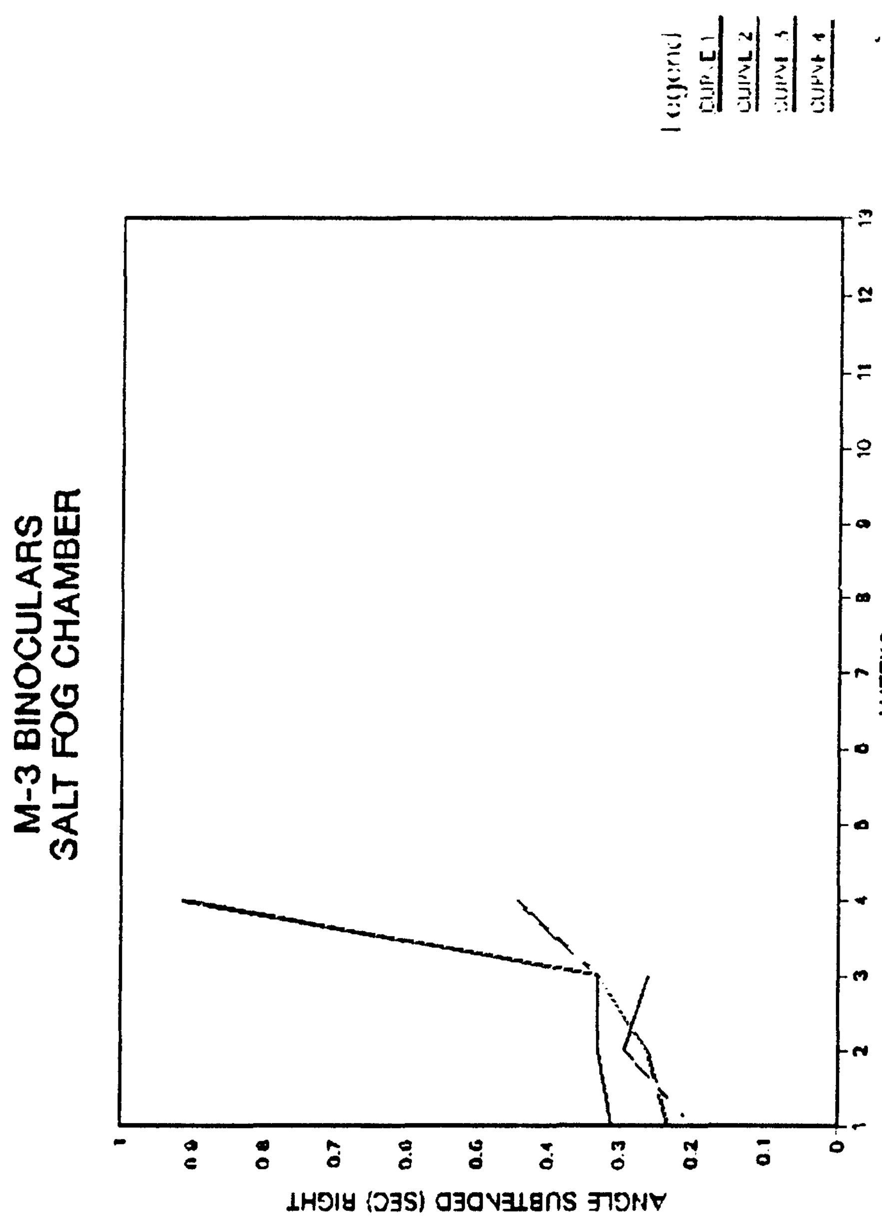



RELAY
SALT FOG CHAMBER
DEGRADATION
WEEKS
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
0
2
4
6
8
10
0
1
2
3
4
5
6
7
8


HELMET RADIO RECEIVER
SALT FOG CHAMBER
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4
DEGRADATION
WEEKS

M-3 BINOCULARS
SALT FOG CHAMBER




M-3 BINOCULARS
SALT FOG CHAMBER
ANGLE SUBTENDED (SEC) RIGHT
WEEKS
Legend
CURVE 1
CURVE 2
CURVE 3
CURVE 4

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