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LABORATORY TESTING OF THERMAL INSULATION AND WEATHERCOATS DESIGNED FOR SHIPBOARD WEATHER DECK SERVICE

DEPARTMENT OF THE NAVY ★ NAVAL AIR ENGINEERING CENTER ★

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A continuing maintenance problem on aircraft carriers is the corrosion of catapult steam valves. Corrosion of the valves is caused by contact with sea water and other contaminants running down from the flight deck and penetrating thermal insulation around the valves. Previous research conducted by NAVAIRENGCEN/NAVSEC determined that thermal insulating weathercoats being used by the

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) fleet were ineffective. Consequently, NAVAIRENGCEN/NAVSEC initiated a program designed to determine more effective weathercoats and possibly alternate insulating systems for use on the catapult valves. The program was conducted by Ocean City Research Corporation under realistically simulated conditions at their laboratory site in Ocean City, New Jersey. The program rated twenty weathercoats on their resistance to sea water penetration; on their relative flammability; on their impact resistance; and on their stability in a simulated catapult environment. Also, five different types of blanket-wrap insulation were evaluated for stability in an environment simulating a weather deck exposure near the catapults. This report presents the results of the program.

I. INTRODUCTION

A continuing maintenance problem on aircraft carriers is the corrosion of catapult steam valves. Corrosion of the valves is caused by contact with sea water and other contaminants running down from the flight deck and penetrating thermal insulation around the valves. Previous research conducted by NAVAIRENGCEN/NAVSEC determined that thermal insulating weathercoats being used by the fleet were ineffective. Consequently, NAVAIRENGCEN/NAVSEC initiated a program designed to determine more effective weathercoats and possibly alternate insulating systems for use on the catapult valves. The program was conducted by Ocean City Research Corporation under realistically simulated conditions at their laboratory site in Ocean City, New Jersey. The program rated twenty weathercoats on their resistance to sea water penetration; on their relative flammability; on their impact resistance; and on their stability in a simulated catapult environment. Also, five different types of blanket-wrap insulation were evaluated for stability in an environment simulating a weather deck exposure near the catapults. This report presents the results of the program.

II. SUMMARY

The program identified four weathercoats (Vimasco WC-1FR, Childers CP-30, Birma I-C-571, and Dow Sylgard 170) which should provide increased protection in the catapult weather deck environment. Each of the four weathercoats exhibits good resistance to environment penetration and impact. All of the weathercoats are non-burning. The program also identified four blanket-type insulation wraps that are readily adaptable to the complex catapult valve shapes and will withstand characteristic temperatures. A recommendation has been made to evaluate in actual fleet service the thermal insulation and weathercoats identified as optimum in the program.

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V. LABORATORY TESTING OF THERMAL INSULATION AND WEATHERCOATS DESIGNED FOR SHIPBOARD WEATHER DECK SERVICE

A. INTRODUCTION. A continuing maintenance problem on aircraft carriers is the corrosion of catapult steam valves. Because of the Navy's awareness and concern over these problems, research is underway to determine effective anti-corrosive coatings for use over the low-alloy steel valves. Corrosion of the valves is caused by contact with sea water and other contaminants running down from the flight deck and penetrating thermal insulation around the valves. The high surface temperature of the valves accelerates corrosion significantly.

Although corrosion can be reduced by the use of a suitable anti-corrosive coating, it could also be reduced by preventing migration of the sea water and other contaminants through the thermal insulation. The current military specification on thermal insulation for naval ships (MIL-STD-769D) requires use of a suitable weathercoat (MIL-C-19565) on all insulated fittings in a weather deck environment. The primary purpose of the weathercoat is to prohibit environment penetration. Previous research conducted by NAVAIRENGCEN/NAVSEC screened five thermal insulation systems relative to their ability to prevent contact of the steel substrate with the typical flight deck environment. In these tests, weathercoats meeting MIL-C-19565 failed within three months.

In addition to controlling corrosion on the valves, there are other benefits to be derived by use of an effective weathercoat. When sea water penetrates the thermal insulation, it increases the thermal conductivity of the insulation, allowing greater heat loss. This results in higher exterior surface temperatures and higher compartment temperatures. Higher surface temperatures endanger personnel while higher compartment temperatures accelerate deterioration of protective coatings applied to bulkheading, decking and other exposed hardware in the compartment. High compartment temperatures also make poor working conditions for personnel. Effective weathercoating will reduce the occurrence of such conditions.

Even if effective weathercoating is accomplished over thermal insulation, some penetration by the environment must be anticipated in service. Therefore, a thermal insulation that resists environment penetration and/or retains its thermal barrier properties when contacted by a weather deck environment is also desirable. To date, the complex geometry of the catapult valves has constrained the choice of thermal insulation to blanket-type wraps that can be form-fitted on site. These blanket-type wraps are effective thermal barriers when kept dry. If exposed to a weather deck environment, however, some blanket-type wraps tend to actually absorb moisture by a wicking action. This results in reduced insulating effectiveness and provides a transport path for the environment to contact the valve surface. Insulation that can be form-fitted to complex valve shapes and reasonably resist a weather deck environment would help reduce the problems now plaguing the Navy.

NAVAIRENGCEN/NAVSEC initiated a program designed to determine more effective weathercoats and possibly alternate insulation systems for shipboard service. The weathercoats were rated on their resistance to sea water penetration; on their relative flammability; on their impact resistance; and on their stability in a simulated catapult environment. The following reports the results of the program.

B. EXPERIMENTAL APPROACH

1. LITERATURE SEARCH AND REVIEW. A literature search and review was conducted to define candidate weathercoats and thermal insulation for testing. The literature search included a review of qualified product lists, current manufacturer's data, and other available technical literature. Based on the literature search, twenty (20) weathercoats and five (5) alternate types of thermal insulation were selected. Selection of all candidates was based on their apparent serviceability in the catapult valve area. Criteria for selection included resistance to a weather deck environment, mechanical strength, relative flammability, ease of application to complex valve shapes, and relative cost.

2. PRELIMINARY SCREENING TESTS (WEATHERCOATS). After compilation of a final list of candidate weathercoats, preliminary screening tests were conducted to comparatively rate each weathercoat. The tests consisted of complete immersion beaker testing in sea water. Each weathercoat was applied to a steel panel and immersed in a beaker of sea water @ 100°F ± 5°F. The tests were conducted over one week. Electrical capacitance measurements were made each day to determine the rate of water absorption into each coating. Appendix A presents the theoretical basis for these measurements. Based on analysis of these results, ten (10) weathercoats were selected for additional screening tests.

3. ADDITIONAL SCREENING TESTS (WEATHERCOATS). The additional screening tests involved characterization of weathercoat performance at two different substrate temperatures, over fibrous glass lagging tape, and under simulated weather deck exposure. Figure 1 illustrates the typical test specimen configuration. The following summarizes the test conditions:

Coatings

10 weathercoats

Substrate Temperature

a. 100°F
b. 250°F

Test Environment (cyclic over 24 hours)

a. Sea Water Immersion - 2 hours (sea water contaminated with jet fuel, detergent used to clean flight decks, hydraulic fluid, and naval aircraft cleaning solution)

b. Semi-Open Marine Atmosphere - 22 hours

Duration of Tests

1 month

Data Acquisition

Electrical capacitance; daily for the first five (5) days in test and then every three (3) days for the remainder of the test.

The fibrous glass lagging tape was included to determine the relative value of the tape in preventing environment penetration. Two substrate temperatures were included to characterize failure as a function of temperature. The 100°F temperature was considered to be a reasonable service temperature under normal conditions. The 250°F temperature was estimated by NAVAIRENGCEN/NAVSEC to be the maximum service temperature encountered unless gross failure of the thermal insulation occurs. Higher service temperatures would have placed an unreasonable constraint on the choice of commercially-available weathercoats.

4. IMPACT TESTS (WEATHERCOATS). The resistance of all candidate weathercoats to impact was characterized on a comparative basis. Tests similar to ASTM D2794-69 were conducted. Briefly, a standard weight was dropped from prescribed distances on coated test panels until failure of the coating occurred. An impact coefficient was calculated by multiplying the standard weight times the drop distance required for failure. All coatings were tested three times to increase experimental accuracy.

5. FLAMMABILITY TESTS (WEATHERCOATS). All weathercoats selected for testing were subjected to flammability tests similar to ASTM D568. Briefly, each candidate weathercoat was applied to a 1" x 18" strip of fibrous glass lagging tape (MIL-C-20079). Gage marks were drawn across the strip, 3" from each end. The test strip was then hung vertically in a specially constructed heat cabinet and ignited from the lower end. A burning rate was calculated by measuring the charred area above the lower gage mark and the time required for the charring to occur. Phenomena such as melting and dripping of the weathercoat were recorded. If the weathercoat did not ignite after 15 seconds of flame application, it was recorded as non-burning. If the flame extinguished before reaching the upper gage mark, the weathercoat was reported as self-extinguishing.

6. LONG-TERM SIMULATED EXPOSURE TESTS (WEATHERCOATS). Four (4) weathercoats were selected for long-term testing based on the results of the previous tests (water penetration, impact, flammability). Figure 2 shows the test capsule used for this phase of the program. The test capsule simulated thermal insulation procedures specified under MIL-STD-769D. Each of four (4) test capsules was exposed in a test tank designed to simulate the catapult environment. Figure 3 is a picture of the experimental set-up. The simulated weather deck exposure was as follows:

a. 22 hours: semi-open marine atmosphere

b. 2 hours: spray with contaminated sea water identical to that in Phase B.3.

The test duration was three (3) months. Data acquisition included thermocouple measurements at different points in the thermal insulation blanket and electrical resistance measurements across a resistance wire exposed in each capsule. The resistance measurements were intended to detect corrosion. Appendix B describes these measurements in detail. The thermocouple measurements were designed to provide quantitative information on the decrease in thermal insulating properties caused by environment penetration. Reduction of the thermocouple data is described in the next section. After completion of the exposure tests, all of the steel cores were examined for corrosion.

7. SIMULATED EXPOSURE TESTS (THERMAL INSULATION). Simulated exposure tests were conducted to evaluate the five (5) alternate types of thermal insulation selected in Phase B.1. Test capsules identical to that shown in Figure 2 were made up for each system. The test capsules were also exposed to a test environment identical to that described in Phase B.6 for a duration of three months. Data acquisition, again, included thermocouple measurements at different points in the thermal insulation and resistance measurements across a resistance wire exposed in each capsule. The thermocouple measurements provided quantitative information enabling calculation of an approximate thermal conductivity factor for each insulation according to the following expression:

$$k = \frac{Q \ln (R_2 \div R_1)}{(T_1 - T_2) \pi D L}$$

where k = thermal conductivity

Q = heat input, measured by a wattmeter

R_2 = radius of steel core

R_1 = distance from O.D. of steel core to point of temperature measurement, T_2

L = length of test capsule

T_1 = surface temperature of steel core

T_2 = temperature at selected point in test capsule

D = diameter of test capsule

Thermal conductivity data was developed prior to exposure and periodically during the test exposure on each type of thermal insulation. After completion of the exposure tests, all steel cores were examined for corrosion.

C. RESULTS

1. SELECTION OF CANDIDATE WEATHERCOATS. Table I presents the twenty (20) weathercoats initially selected for screening. Selection of the weathercoats was based on review of available manufacturer's literature and the results of prior testing conducted by NAVAIRENGCEN/NAVSEC.

2. PRELIMINARY SCREENING TESTS (WEATHERCOATS). Table II presents the results of the preliminary screening tests intended to rate the relative ability of the candidate weathercoats to resist water penetration. The data represents the average depth to which sea water penetrated the weathercoat over 5 days. The depth of water absorption is expressed as a percentage of the original coating thickness.

3. ADDITIONAL SCREENING TESTS (WEATHERCOATS). Based on the results of the preliminary screening tests, ten (10) weathercoats were selected for further screening. The additional screening tests were longer in duration, at two temperatures, and simulated more closely the weather deck environment near the catapults.

Table III lists the weathercoats selected for additional testing. The first nine weathercoats listed in Table III were selected because they exhibited better resistance to water penetration than the remainder of the weathercoats included in the initial screening tests. The last coating was selected because it had looked favorable in previous tests conducted by NAVAIRENGCEN/NAVSEC.

Tables IV and V present the % water absorption for each weathercoat averaged over the 1-month test period. As is evident from Tables IV and V, this screening test proved to be too rigorous. All the weathercoats except Vimasco WC-1 @ 100°F were rapidly penetrated by water.

The performance of the Vimasco WC-1 coating in these tests presents an anomaly. In the preliminary 5-day immersion tests, Vimasco WC-1 did not perform as well as the other coatings. However, Vimasco WC-1 showed significantly better resistance to water penetration @ 100°F in these later tests. Final inspection of the test capsules confirmed this, showing that the Vimasco coating had, indeed, prevented corrosion of the copper core. Table VI summarizes the observations made during the final inspection.

The seemingly anomalous behavior of the Vimasco coating duplicates what has been observed in other tests conducted by NAVAIRENGCEN/NAVSEC. In tests designed to determine a suitable coating for a different application, Vimasco showed poor resistance to penetration by sea water when continuously immersed.[1] However, in tests consisting of a cyclic exposure to contaminated sea water, similar to that involved in these tests, Vimasco did not evidence significant deterioration over three months.[2] The exact reason for this apparent anomaly is not known, however, the different test solutions and/or test environments used in each of the screening tests might be the cause. Previous research[3] has shown that different water solutions can exhibit significantly different absorption rates. In the preliminary tests, the test solution was natural sea water @ 100°F. The coatings were continuously immersed over 5 days. In the later screening tests, the test solution consisted of natural sea water contaminated with JP-5 jet fuel, hydraulic fluid, and detergent. The coatings were immersed for only 2 hours a day in this test. The remainder of the time, the coatings were exposed to the atmosphere. Some of the other coatings (Foster 60-30, Foster 60-35, Eagle-Picher Stalastic, and Carey #830) showed a tendency to dissolve in the contaminated sea water, whereas they were relatively unaffected in sea water, by itself.

4. IMPACT TESTS (WEATHERCOATS). Figure 4 presents a bar graph summarizing the results of the impact tests. The first five weathercoats exhibited very high impact coefficients, exceeding the capacity of the impact tester. Impact coefficients of the remaining fifteen weathercoats were considerably lower than the first five. Of the first five weathercoats, three (Birma I-C-571, Childers CP-30 and Dow Sylgard 170) were included in the long-term exposure tests based on their performance in this test as well as the other tests.

5. FLAMMABILITY TESTS (WEATHERCOATS). Table VII summarizes the results of these tests. The rates of flame spread varied markedly depending on the coating system. Seven of the weathercoats were classified as non-burning by this test. Five of the weathercoats qualified as self-extinguishing. The remainder burned until completely consumed. Of the four weathercoats selected for long-term exposure testing, all were non-burning by this test.

[1] G. A. Gehring, Jr.; "Simulated Testing and Evaluation of Protective Coatings to Control Corrosion in Aircraft Carrier Launching and Recovery Equipment", Naval Air Engineering Center Report No. 7839. December, 1973.

[2] G. A. Gehring, Jr.; "Laboratory Evaluation of Protective Coatings Intended for Use Over Urethane Foam", Naval Air Engineering Center Report No. 7865, February, 1975.

[3] D. M. Brasher and A. H. Kingsbury; J. Appl. Chem., 4, 62 (1954).

6. LONG-TERM SIMULATED EXPOSURE TESTS (WEATHERCOATS AND THERMAL INSULATION). Table VIII presents the weathercoats selected for long-term simulated exposure testing. Selection of the weathercoats was based on the combined results of the flammability tests, the impact tests, and both of the screening tests for resistance to water absorption.

Table IX presents the thermal insulation selected for testing and describes particular characteristics. Selection of the candidate thermal insulation systems was based on the results of a literature review and prior testing conducted by NAVAIRENGCEN/NAVSEC. Previous testing evaluated five types of thermal insulation--premolded calcium silicate, premolded expanded perlite, ceramic fiber blanket, cellular glass, and amosite asbestos. Premolded calcium silicate and premolded expanded perlite exhibited good resistance to water penetration. The ceramic fiber blanket and amosite asbestos tended to absorb moisture. The cellular glass insulation was unable to withstand the high temperatures ($\approx$ 700°F) characteristic of catapult valve operation. It charred and cracked during the simulated exposure tests.

Blanket-type wraps are not approved by the current specification (MIL-STD-769D) covering thermal insulation procedures for hot piping in a weather deck environment. MIL-STD-769D specifies that for irregular fittings such as valves, premolded pipe insulation (calcium silicate) is to be broken into sections and then field fabricated around the fitting with adhesive cement. Adherence to this fabrication procedure has proven to be expecially difficult because of the complex shape and large size of the catapult valves. For the most part, the shipyards are currently using blanket-type wraps around the catapult valves in lieu of field-fabricated, premolded insulation. The blanket wrap insulation is considerably easier to work with. It does not possess the mechanical strength nor the resistance to water penetration as does the premolded insulation. However, the size and shape of the launch valves seems to constrain the practical choice of thermal insulation to blanket-wraps. Therefore, the literature review sought to identify five (5) different types of thermal insulation in the blanket-wrap category that would exhibit reasonable resistance to the typical catapult environment.

Table X lists the make-up of each test capsule (Figure 2) included in the exposure tests. It can be seen that by appropriate combination only eight test capsules were required to evaluate four weathercoats and the five types of insulation. For experimental control, the same weathercoat (Birma I-C-571), lagging, and finishing cement were used on each test capsule intended to evaluate the five types of thermal insulation. Conversely, the same insulation (Kaowool), finishing cement, and lagging were used on the test capsules evaluating each of the four weathercoats.

Three months of simulated exposure testing evidenced significant deterioration on only one insulation wrap (Eagle-Picher Mineral Fiber). Water penetrated the test capsule through a fault in the weathercoat (Birma I-C-571) and was absorbed into the insulation. The combination of heat and moisture significantly degraded the insulation material causing it to fuse and become embrittled. Correspondingly, the thermal conductivity of the insulation increased.

Table XI summarizes the thermal conductivity data gathered over the test period. As is evident, only the above mentioned insulation system exhibited any significant change. This data correlates excellently with visual observations.

Electrical resistance data gathered on the resistance wire probes installed in each test capsule showed no detectable changes, indicating corrosion was minimal. The absence of corrosion suggests the absence of significant water penetration. Again, this data correlates with visual inspection. In the test capsule where water had penetrated, the resistance probe was located in an area not exposed to the water.

Although the Birma I-C-571 weathercoat did fail on the above mentioned test capsule, it provided excellent protection on four other test capsules to which it had been applied. None of the other weathercoats evidenced any sign of deterioration.

Over 3 months, the simulated exposure tests failed to appreciably degrade or to distinguish meaningful differences for the 4 weathercoats tested and 4 of the 5 insulations tested. As already noted, previous testing conducted similarly over 3 months caused appreciable deterioration of weathercoats and insulation. Longer term testing is required if distinguishable differences in relative performance for these materials are to be further identified.

It is estimated, however, that 3 months of simulated exposure testing as conducted is equivalent to about 1 to 2 years service aboard ship. Therefore, it is reasonable to believe that any of the four weathercoats or the insulation materials, excepting the Eagle-Picher Mineral Wool, will provide adequate service. This assumes that insulation procedures would be consistent with the procedures followed in this program.

D. SUMMARY. The program has identified four weathercoats serviceable in the catapult weather deck environment. Three of the four weathercoats exhibited outstanding resistance to impact. All four were non-burning in the flammability test and reasonably resisted sea water penetration. Only one of the four weathercoats (Childers CP-30) has been qualified for shipboard service under the existing specification (MIL-C-19565).

From a cost standpoint (Table XII), three of the weathercoats are comparable on a per gallon basis. The Dow Sylgard coating is significantly more expensive per gallon. However, the recommended thickness of the Dow Sylgard is much less than the other weathercoats (about 1/10). Based on the results of this program, Dow Sylgard will perform equally as well as when applied at approximately 1/10 the thickness of the other coatings. In comparing the approximate cost to coat 100 $ft.^2$ of surface area, the Dow Sylgard coating is the lowest based on recommended thickness. All coatings were relatively easy to apply and should be readily adaptable for shipboard application.

The program determined four types of blanket wrap insulation that should provide adequate service if reasonably protected by a weathercoat. Performance of these insulation systems when exposed to moisture cannot be assessed without further testing. It is possible that some or all of the insulation materials will exhibit the same sort of deterioration as observed on the Eagle-Picher Mineral Fiber.

The results of the program tend to underscore the importance of the weathercoat as the first line of defense in preventing water penetration and subsequent corrosion of the catapult valves. Once water was able to penetrate the weathercoat in the one failure noted, it was readily absorbed and easily penetrated through to the insulation.

Meaningful design data obtained under realistically simulated conditions is now available to the design engineer. Existing specifications should be revised to incorporate more cost effective procedures where indicated by this program.

E. CONCLUSIONS

1. Vimasco WC-1FR, Childers CP-30, Birma I-C-571, and Dow Sylgard 170 are thermal insulation weathercoats which will adequately protect thermal insulation on catapult valves.

2. All of the above mentioned weathercoats exhibit good resistance to environment penetration and impact. All of the coatings are non-burning.

3. Babcock & Wilcox Kaowool, Pittsburgh-Corning Temp Mat, Carborundum Fiberfrax, and J. P. Stevens Aluminized Insulbatte are blanket-type insulation wraps that are readily adaptable to the complex catapult valve shapes and will withstand the characteristic temperatures ($\approx$ 700°F).

4. Blanket-type insulation wraps tend to absorb water. On the catapult valves, it is imperative that the blanket wraps be protected from the environment by the use of finishing cement (MIL-C-2861), lagging, (MIL-C-20079), and one of the above mentioned weathercoats.

5. Longer-term simulated exposure tests similar to those conducted in this program are required to distinguish meaningful differences among the weathercoats and thermal insulation mentioned above.

6. At this time, additional testing is not justified. The above mentioned systems should be evaluated in shipboard service to determine whether additional laboratory work is required.

F. RECOMMENDATIONS

1. Evaluate in actual fleet service the thermal insulation and weathercoats identified in this program as optimum.

TABLE I - CANDIDATE WEATHERCOATS INITIALLY SELECTED FOR TESTING

	Manufacturer/Trade Name	Generic Type
1.	Vimasco WC-1 FR	Polyvinyl-Acetate Emulsion
2.	Vimasco AC-7	Acrylic Polymer Emulsion
3.	Johns-Manville Insulkote ET	Bituminous Emulsion with Asbestos & Mineral Fiber Fillers
4.	Flintkote Thermalkote 100-15	*
5.	Howkote Insulation Seal	Bituminous Emulsion
6.	Birma Corp. Insul-coustic I-C-551 Vi-Ac Mastic	*
7.	Birma Corp. Insul-coustic I-C-571 M-O-H Mastic	*
8.	Foster Fire Resistive 60-30	Solvent-Based Mastic
9.	Foster Fire Resistive 60-35	Solvent-Based Mastic w/Aluminum Pigment
10.	Eagle-Picher Stalastic	Petroleum Asphalt w/Asbestos & Inert Fillers
11.	Eagle-Picher Insulseal	Asphalt Emulsion w/Asbestos & Inert Fillers
12.	Eagle-Picher Spray-Mastic	Asphalt Emulsion 2/Asbestos Fillers & Rust Inhibiting Agents
13.	Carey Insulation Seal #830	Asbestos Fibrated Bituminous Mastic
14.	Carey Thermotex B	Asphalt Emulsion W/Asbestos & Mineral Fibers
15.	Childers CP-30 Type II	*
16.	Childers CP-32 Type II	*
17.	Dyna-Therm Flamemastic 71A	*
18.	Dow Corning Sylgard 170	Silicone Rubber
19.	Resins Research RRC-FBIC-EXP	Epoxy-Based Mastic
20.	Products Research Corp. 1712	*

*Not available from manufacturer

TABLE II - AVERAGE % WATER ABSORPTION FOR EACH CANDIDATE WEATHERCOAT IMMERSED IN SEA WATER @ 100°F FOR 5 DAYS

	Coating	% Water Absorption
1.	Dow Sylgard 170	8%
2.	Childers CP-30	47%
3.	Eagle-Picher Stalastic	48%
4.	Childers CP-32	51%
5.	Foster 60-30 FR	53%
6.	Carey #830	64%
7.	Foster 60-35 FR	70%
8.	Birma I-C-571	70%
9.	Vimasco WC-1 FR	90%
10.	Vimasco AC-7	>99%
11.	Johns-Manville Insulkote	>99%
12.	Flintkote 100-15	>99%
13.	Howkote Insulation Seal	>99%
14.	Birma I-C-551	>99%
15.	Eagle-Picher Insulseal	>99%
16.	Eagle-Picher Spray-Mastic	>99%
17.	Carey Thermotex B	>99%
18.	Flamemastic 71A	>99%
19.	Resins Research FBIC-EXP-B1	>99%
20.	PRC 1712	>99%

TABLE III - WEATHERCOATS SELECTED FOR ADDITIONAL SCREENING TESTS

1. Birma Insul-coustic I-C-571
2. Foster 60-35 FR
3. Foster 60-30 FR
4. Childers CP-30
5. Eagle-Picher Stalastic
6. Carey Insulation Seal #830
7. Dow Sylgard 170A & B
8. Childers CP-32
9. Vimasco WC-1 FR
10. Resins Research RRC-FBIC-EXP

TABLE IV - AVERAGE % WATER ABSORPTION FOR SELECTED WEATHERCOATS OVER 30 DAYS IN SIMULATED CATAPULT ENVIRONMENT AT 100°F

	Coating	% Water Absorption
1.	Vimasco WC-1 FR	80%
2.	Resins Research FBIC-EXP-B1	>99%
3.	Dow Sylgard 170	>99%
4.	Birma I-C-571	>99%
5.	Foster 60-30 FR	>99%
6.	Foster 60-35 FR	>99%
7.	Eagle-Picher Stalastic	>99%
8.	Carey #830	>99%
9.	Childers CP-30	>99%
10.	Childers CP-32	>99%

TABLE V - AVERAGE % WATER ABSORPTION FOR SELECTED WEATHERCOATS OVER 30 DAYS IN SIMULATED CATAPULT ENVIRONMENT AT 250°F

	Coating	% Water Absorption
1.	Vimasco WC-1 FR	>99%
2.	Resins Research FBIC-EXP-B1	>99%
3.	Dow Sylgard 170	>99%
4.	Birma I-C-571	>99%
5.	Foster 60-30 FR	>99%
6.	Foster 60-35 FR	>99%
7.	Eagle-Picher Stalastic	>99%
8.	Carey #830	>99%
9.	Childers CP-30	>99%
10.	Childers CP-32	>99%

TABLE VI - VISUAL OBSERVATION OF TEST CAPSULES
AFTER ONE MONTH SIMULATED EXPOSURE

A. 100°F Exposure

Capsule #1. (Birma I-C-571)	Coating easy to remove. One side of fiberglass lagging cloth wet, the other dry, copper core corroded.
Capsule #2. (Foster 60-30)	Coating surface sticky, fiberglass lagging cloth wet, copper core corroded.
Capsule #3. (Foster 60-35)	Coating felt loose and was easy to remove, surface sticky, fiberglass lagging cloth wet, copper core corroded.
Capsule #4. (Eagle-Picher Stalastic)	Fiberglass lagging cloth wet, copper core corroded.
Capsule #5. (Carey #830)	Surface sticky, fiberglass lagging cloth wet, copper core corroded.
Capsule #6. (Childers CP-30)	Surface sticky, fiberglass lagging cloth wet, copper core corroded.
Capsule #7. (Childers CP-32)	Fiberglass lagging cloth damp, copper core corroded.
Capsule #8. (Dow Sylgard 170)	Coating surface slippery, fiberglass lagging cloth dry, copper core corroded.
Capsule #9. (Vimasco WC-1 FR)	Fiberglass cloth dry, copper uncorroded.
Capsule #10. (RRC-FBIC-EXP-B1)	Fiberglass cloth dry, coating difficult to remove, copper corroded.

TABLE VI (cont'd.)

B. 250°F Exposure

Capsule #1. (Birma I-C-571)	Fiberglass lagging cloth dry, coating burnt in middle and brittle, coating blistered on surface and throughout thickness, copper core corroded.
Capsule #2. (Foster 60-30)	Surface sticky, fiberglass lagging cloth wet, surface of coating blistered, copper core corroded.
Capsule #3. (Foster 60-35)	Coating burned in center, blisters on surface, brittle in center, fiberglass lagging cloth wet at one end and dry at the other, separation of coating layers in places, copper core corroded.
Capsule #4. (Eagle-Picher Stalastic)	Coating blistered, burned and brittle in center, fiberglass lagging cloth wet, copper core corroded.
Capsule #5. (Carey #830)	Surface sticky, fiberglass lagging cloth wet, copper core corroded.
Capsule #6. (Childers CP-30)	Center of coating looked burnt and coating was brittle in center, blistering in some areas, fiberglass lagging cloth wet, copper core corroded.
Capsule #7. (Childers CP-32)	Coating blistered, burn mark in center, fiberglass lagging cloth dry at one end and wet at the other, coating brittle in center, copper core corroded.
Capsule #8. (Dow Sylgard 170)	Fiberglass lagging cloth wet at one end and dry at the other end, copper core corroded.
Capsule #9. (Vimasco WC-1 FR)	Fiberglass lagging cloth dry, some disbondment between layers, copper core corroded.
Capsule #10. (RRC-FBIC-EXP-B1)	Coating looked burnt in middle, brittle, fiberglass lagging cloth dry, copper core corroded.

TABLE VII - RESULTS OF THE FLAMMABILITY TESTS

	Weathercoat	Burn Rate in/sec.	Comments
1.	Vimasco WC-1 FR	N/A	Non-Burning
2.	Vimasco AC-7	.083	Self-Extinguishing
3.	Johns-Manville Insulkote	.129	Self-Extinguishing
4.	Flintkote 100-15	.141	Drips
5.	Howkote Insulation Seal	.237	
6.	Birma I-C-551	.144	Self-Extinguishing
7.	Birma I-C-571	N/A	Non-Burning
8.	Foster 60-30 FR	.050	Self-Extinguishing
9.	Foster 60-35 FR	.074	
10.	Eagle-Picher Stalastic	.092	
11.	Eagle-Picher Insulseal	.102	
12.	Eagle-Picher Spray-Mastic	.118	Burns profusely
13.	Carey #830	.071	Burns profusely
14.	Carey Thermotex B	.083	Burns profusely
15.	Childers CP-30	N/A	Non-Burning
16.	Childers CP-32	N/A	Non-Burning
17.	Dyna-Therm Flamemastic 71-A	N/A	Non-Burning
18.	Dow Sylgard 170	N/A	Non-Burning
19.	Resins Research FBIC-EXP-B1	N/A	Self-Extinguishing
20.	Products Research Corp. 1712	N/A	Non-Burning

TABLE VIII - WEATHERCOATS SELECTED FOR LONG-TERM SIMULATED EXPOSURE TESTS (3-MONTHS)

1. Birma I-C-571
2. Childers CP-30
3. Vimasco WC-1 FR
4. Dow Sylgard 170

TABLE IX - THERMAL INSULATION SELECTED FOR SIMULATED EXPOSURE TESTING (3-MONTHS)

	Insulation	Characteristics
1.	Babcock & Wilcox Kaowool Blanket	Alumina-silica ceramic fiber blanket, rated up to 2300°F. Density = 8lb./ft.^{3}
2.	Eagle-Picher Mineral Fiber Blanket	Felted blanket made up of mineral fibers, rated up to 1400°F. Density = 8lb./ft.^{3}
3.	Pittsburgh Corning Temp-Mat	Glass fibers fabricated in mat form, rated up to 1200°F.
4.	Carborundum Fiberfrax Lo-Con Aluminized Blanket	Alumina-silica ceramic fiber blanket with a 2 mil aluminum foil backing, rated up to 2300°F. Density = 8lb./ft.^{3}
5.	J.P. Stevens Insulbatte Aluminized Blanket	Felted blanket made up of glass fibers with a 1 mil aluminum foil backing, rated up to 1200°F.

TABLE X - MAKE-UP OF TEST CAPSULES IN 3-MONTH SIMULATED EXPOSURE TEST

	Thermal Insulation	Finishing Cement	Lagging	Lagging Adhesive	Weathercoat
1.	Babcock & Wilcox Kaowool	Hydraulic-Setting Mineral Fiber (MIL-C-2861)	Fiberglass Cloth (MIL-C-20079)	Chlorinated Hydrocarbon (MIL-A-3316, CL1)	Birma I-C-571
2.	Eagle-Picher Mineral Fiber	"	"	"	"
3.	Pittsburgh Corning Temp-Mat	"	"	"	"
4.	Carborundum Fiber-frax	"	"	"	"
5.	J.P. Stevens Insulbatte	"	"	"	"
6.	Babcock & Wilcox Kaowool	"	"	"	Childers CP-30
7.	Babcock & Wilcox Kaowool	"	"	"	Vimasco WC-1 FR
8.	Babcock & Wilcox Kaowool	"	"	"	Dow Sylgard 170

TABLE XI - THERMAL CONDUCTIVITY FACTORS VS. TIME

DAYS IN TEST → Insulation	Weathercoat	INITIAL	5	6	14	21	28	35	42	45	52	68	75	82	89
B & W Kaowool	Vimasco WC-1	.305	.311	.286	.305	.320	.332	.320	.316	.335	.349	.325	.390	.382	.379
B & W Kaowool	Birma I-C-571	.299	.312	.283	.299	.307	.339	.320	.312	.328	.320	.315	.384	.365	.367
B & W Kaowool	Childers CP-30	.277	.304	.287	.299	.317	.353	.323	.314	.325	.325	.323	.380	.367	.366
B & W Kaowool	Dow Sylgard	.315	.311	.285	.295	.309	.332	.325	.312	.328	.336	.331	.374	.367	.363
PC Temp-Mat	Birma I-C-571	.275	.281	.273	.278	.301	.320	.304	.304	.313	.311	.311	.358	.356	.359
Stevens Insulbatte	Birma I-C-571	.279	.271	.240	.287	.282	.320	.306	.291	.302	.310	.297	.354	.340	.340
Carborundum Fiberfrax	Birma I-C-571	.271	.268	.254	.274	.278	.288	.290	.283	.325	.276	.298	.393	.343	.329
Eagle-Picher Mineral Wool	Birma I-C-571	.335	.343	.329	.343	.352	.434	.406	.658	.695	.687	.639	.888	.812	.837

TABLE XII - COST COMPARISON FOR OPTIMUM WEATHERCOATS

	Weathercoat	Recommended Coverage	Cost/Gal.	Cost/100ft.^{2} of Surface
1.	Birma I-C-571	1 gal/25ft.^{2}	\$ 7.45	\$ 29.80
2.	Childers CP-30	1 gal/25ft.^{2}	7.20	28.80
3.	Vimasco WC-FR	1 gal/25ft.^{2}	6.45	25.80
4.	Dow Sylgard 170	1 gal/250ft.^{2}	≈ 40.00	16.00

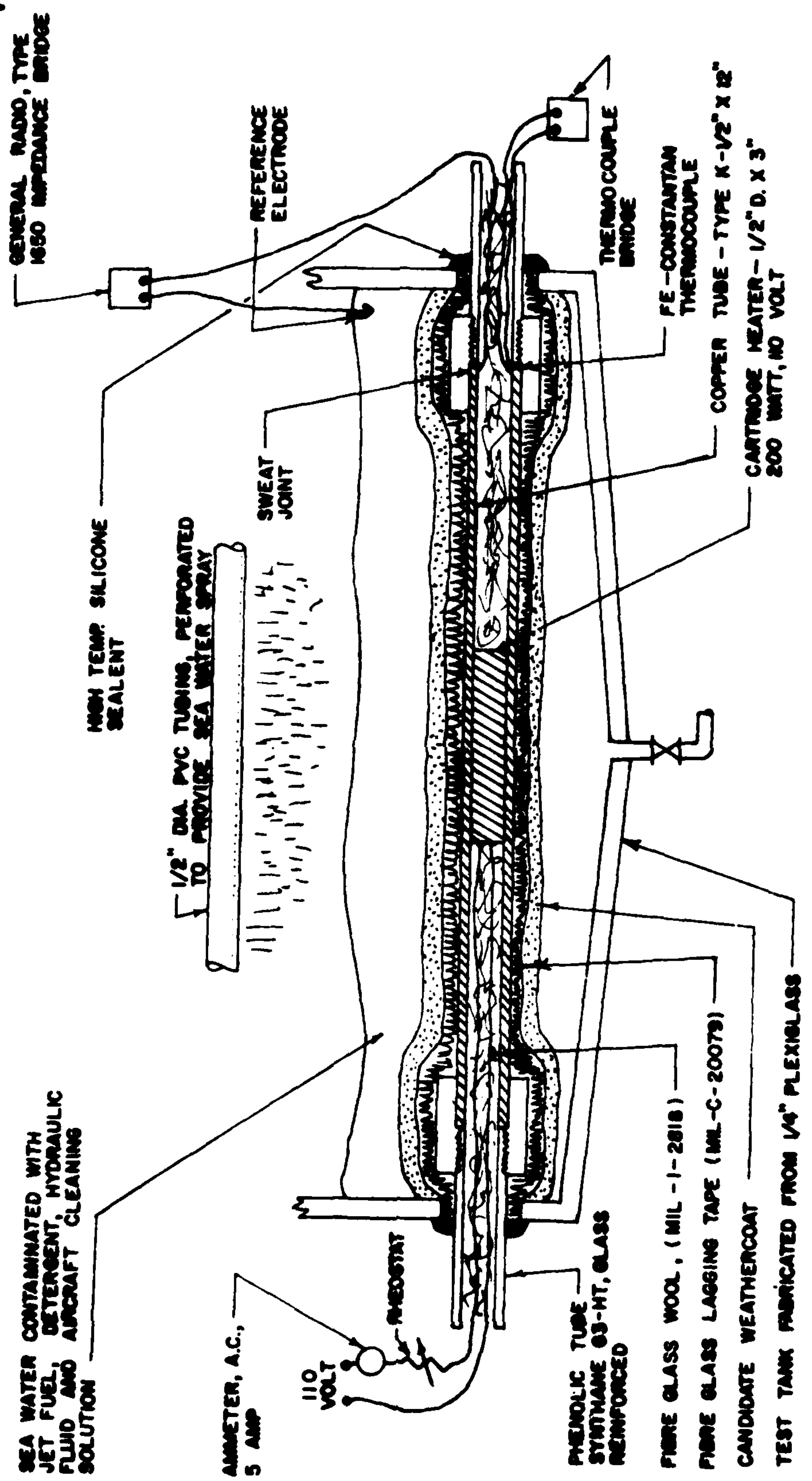

FIGURE 1 - TYPICAL TEST SPECIMEN FOR TESTING WEATHERCOATS

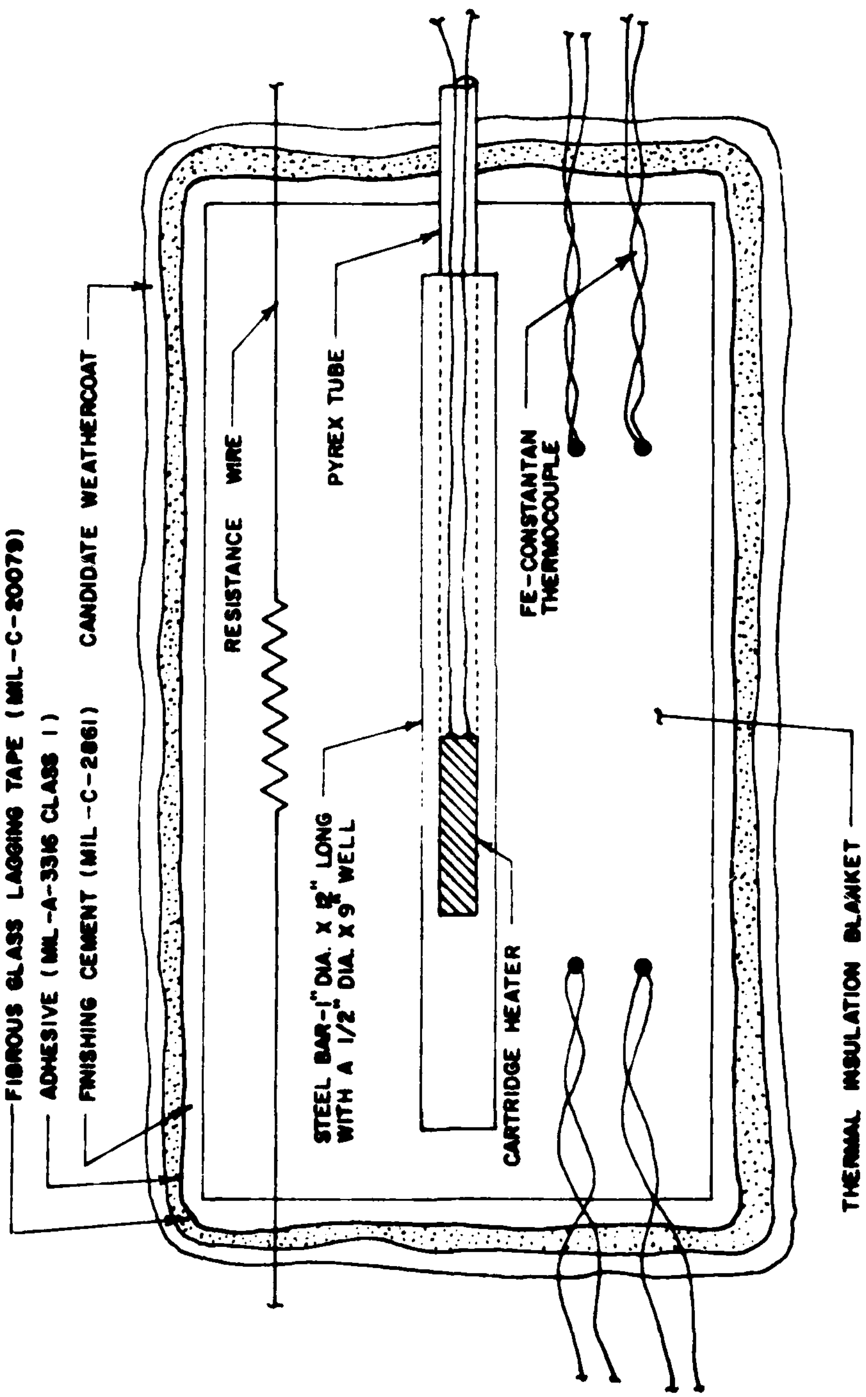

FIGURE 2 — TEST CAPSULE FOR LONG TERM SIMULATED EXPOSURE TESTS

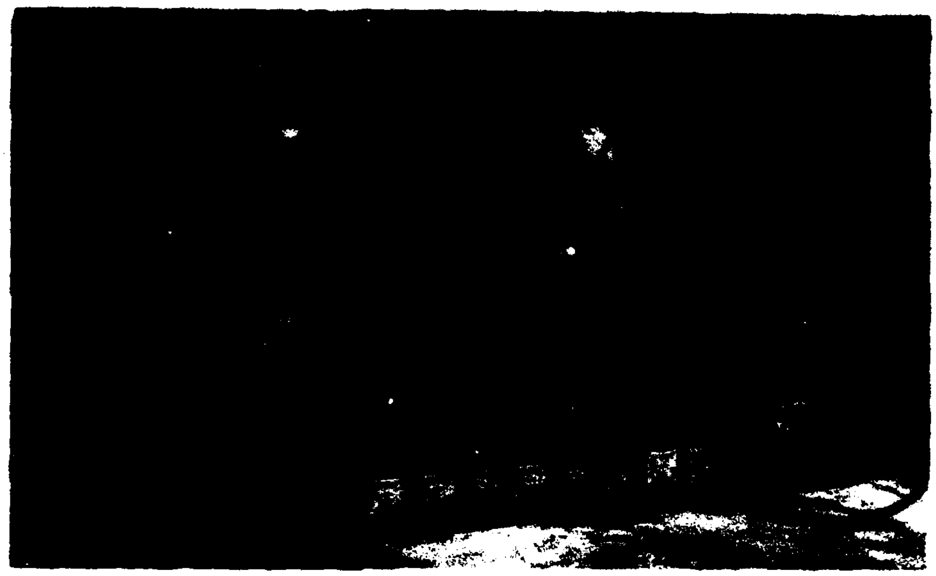

FIGURE 3 - Picture of Experimental Set-Up for
Simulated Exposure Tests

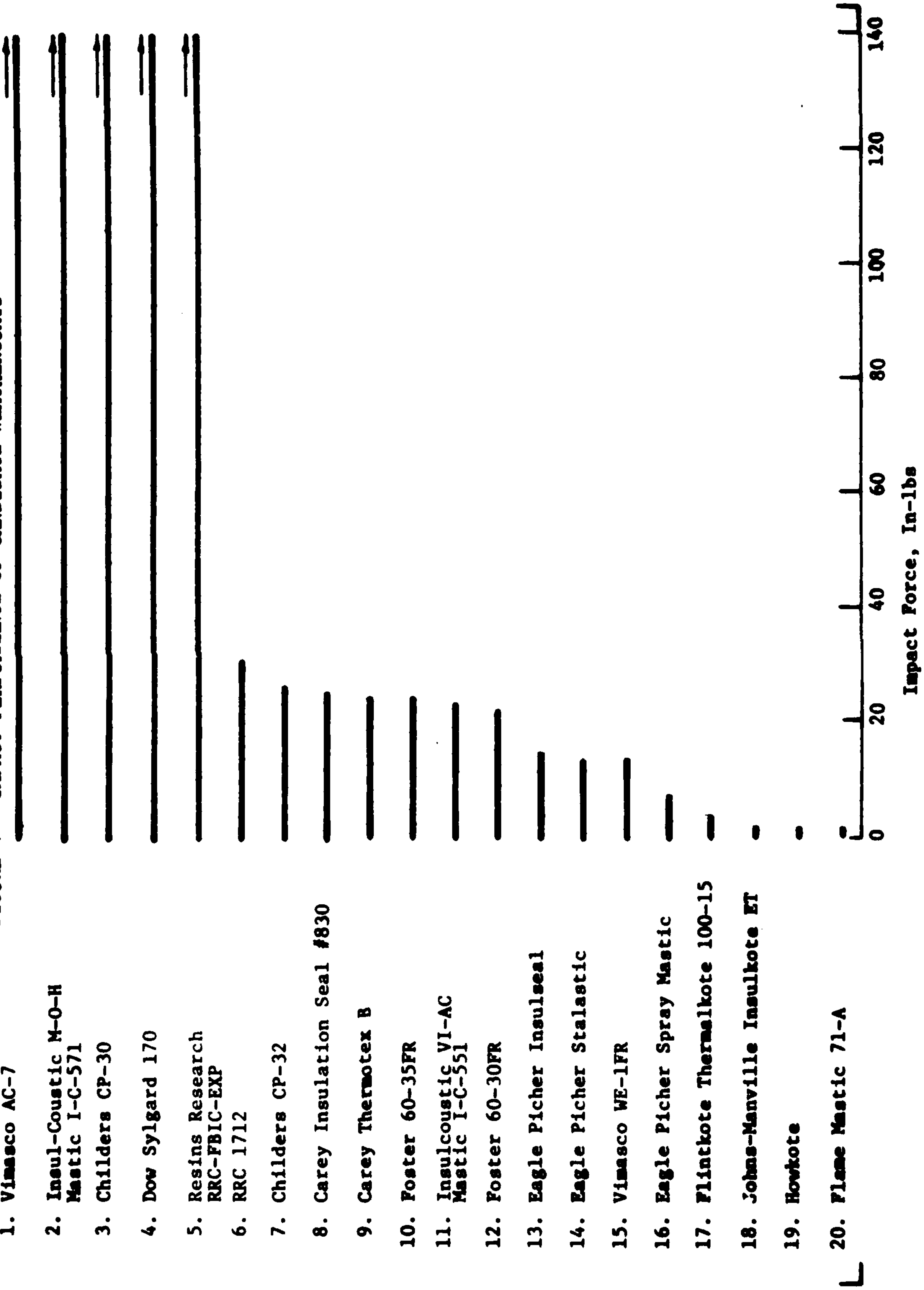

FIGURE 4 - IMPACT PERFORMANCE OF CANDIDATE WEATHERCOATS

APPENDIX A - Evaluation of Protective Coatings by Electrical Capacitance Measurements

In the past, electrical capacitance measurements have been used by several workers to evaluate protective coatings. Wormwell and Brasher[1] studied paint films and noted that capacitance values changed abruptly when the protective nature of paint deteriorated. Brasher and Kingsbury[2] compared values of water uptake by paint films calculated from capacitance measurements with gravimetric values. O'Brien[3] studied bituminous coatings utilizing capacitance measurements. More recently Leidheiser et al[4] used capacitance measurements to study polybutadiene coatings on steel.

The destructive effects of moisture and moisture transport in coatings has been documented at length in the literature. It is believed that deterioration of a coating immersed in an aqueous electrolyte is probably due to one or more of the following phenomena:

1. The absorption by the coating of the electrolyte in which it is immersed.

2. The physical break-down of the coating through the development of pores or small physical faults that allow the electrolyte to reach the substrate.

3. The underfilm penetration of moisture between coating and substrate, emanating from a coating fault that allows the electrolyte to reach the substrate.

4. Permeation of electrolyte through the coating leading to electrolyte accumulation at points where the coating is not tightly bonded to the substrate.

A direct measurement of the effect of moisture absorption into the coating, or loss of coating thickness through physical wear, can be obtained by the periodic measurement of the capacitance between the coated metallic sample and the electrolyte environment. Moisture absorption will radically lower the effective thickness of the coating to the depth of moisture absorption. A schematic model for this purpose is shown in Figure A-1. The reduced thickness of high dielectric coating increases the capacitance between the coated metallic coupon and the electrolyte. This in-

[1] F. Wormwell and D. M. Brasher; J. Iron Steel Inst., 164, 141 (1950).

[2] D. M. Brasher and A. H. Kingsbury; J. Appl. Chem., 4, 62 (1954).

[3] H. C. O'Brien; Ind. Eng. Chem., 58, 45 (1966).

[4] H. Leidheiser, Jr. and R. E. Touhsaent; Corrosion, 28, 435 (1972).

creased capacitance can be used as a basis for the calculation of electrolyte absorption. Periodic measurement determines a relationship between time and depth of moisture penetration. Extrapolation from these data then yields a basis for prediction of coating life as it may be limited by electrolyte absorption. Figures A-2 and A-3 present typical graphs of data acquired by such measurements.

The depth of water penetration into high dielectric coatings can be calcultaed from the following equation:

$$K = 11.3\ Ct \div A$$

where,

K = dielectric constant

C = capacitance (pf)

A = exposed surface area (cm^2)

t = effective coating thickness (cm)

then,

$$\%\ \text{water absorption} = \frac{t_o - t}{t_o}$$

where

t_o = initial coating thickness (cm)

Before exposing the coated test panel to the test environment, the dielectric constant, K, for the specific coating is determined by immersing the coated panel in mercury and measuring the electrical capacitance between the metal substrate and a reference electrode. Knowing the area and initial thickness of the coating, the dielectric constant for the coating can be calculated from the above equation. The decrease in effective thickness as water absorbs into a coating can be quantitatively determined by measuring the change in capacitance. Electrical capacitance data, then, can provide quantitative evidence of impending coating failure when there is no obvious change in the physical appearance of the coated sample.

Figure A-4 shows a typical test cell for making electrical capacitance measurements. The test panel is immersed in a beaker containing a low resistivity electrolyte. A reference electrode is positioned about 1 inch from the coated panel. Measurements are made at 3000 Hz using a General Radio Type 1650 Impedance bridge.

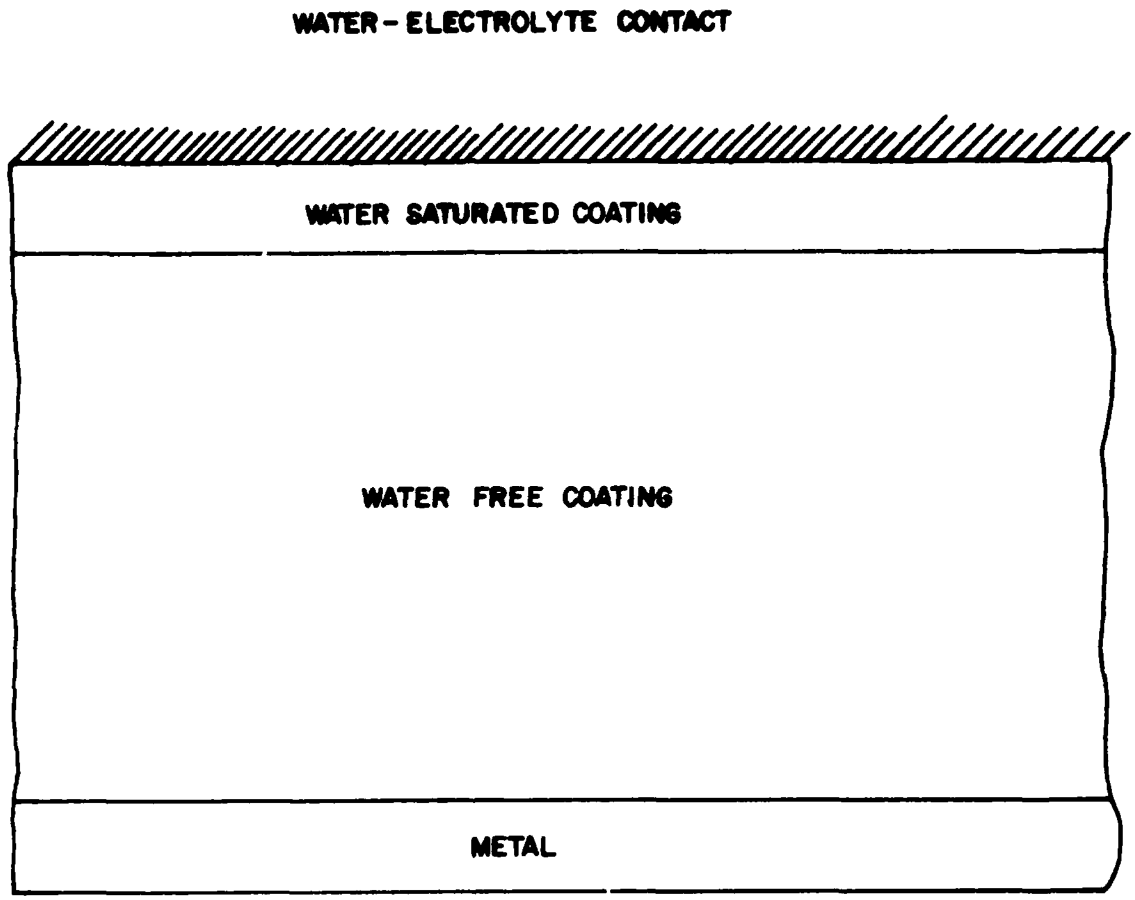

FIGURE A-1 - WATER PENETRATION MODEL CELL

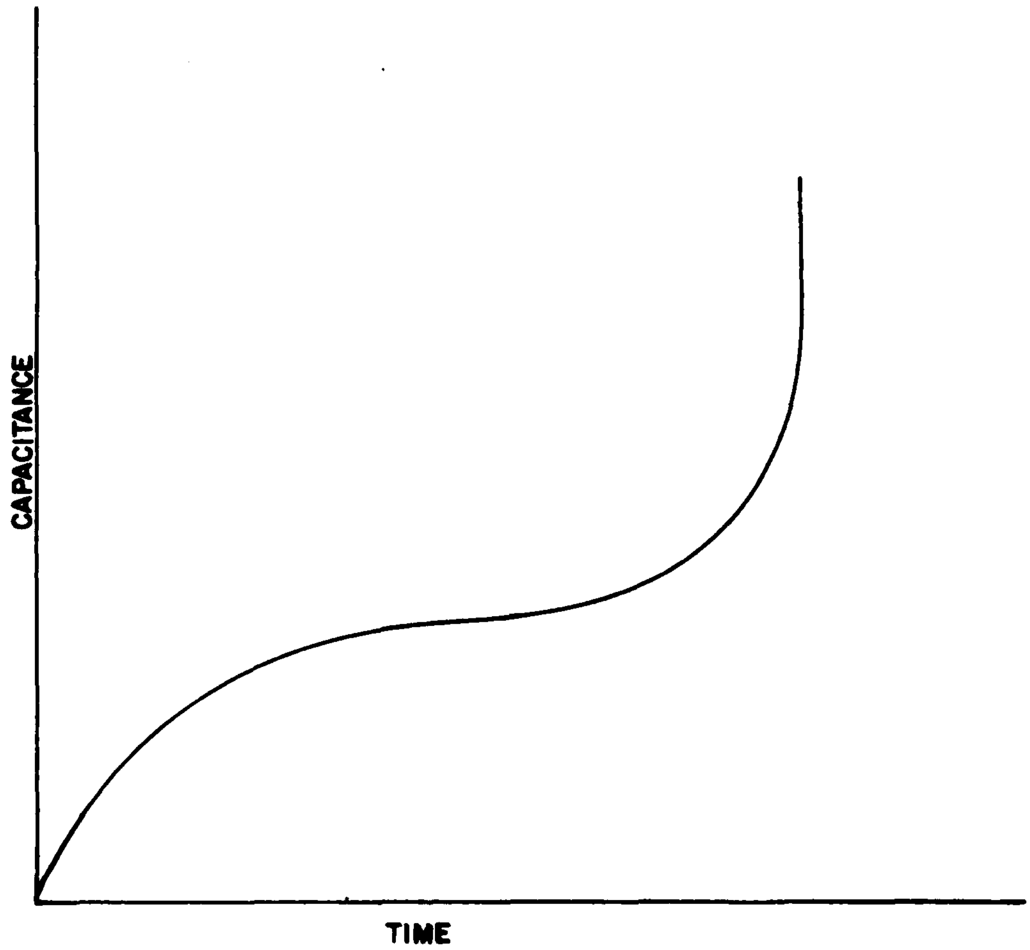

FIGURE A-2 – CAPACITANCE – TIME CURVE

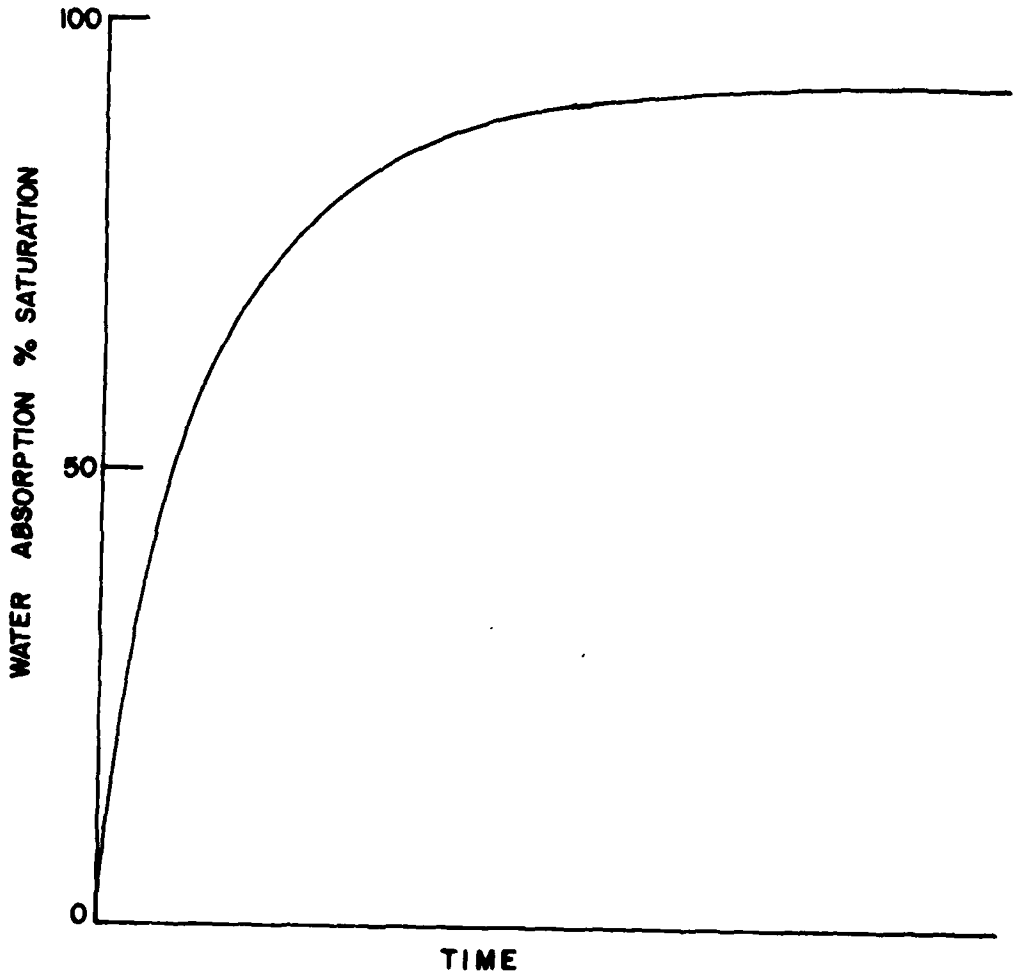

FIGURE A-3 - WATER ABSORPTION VERSUS TIME

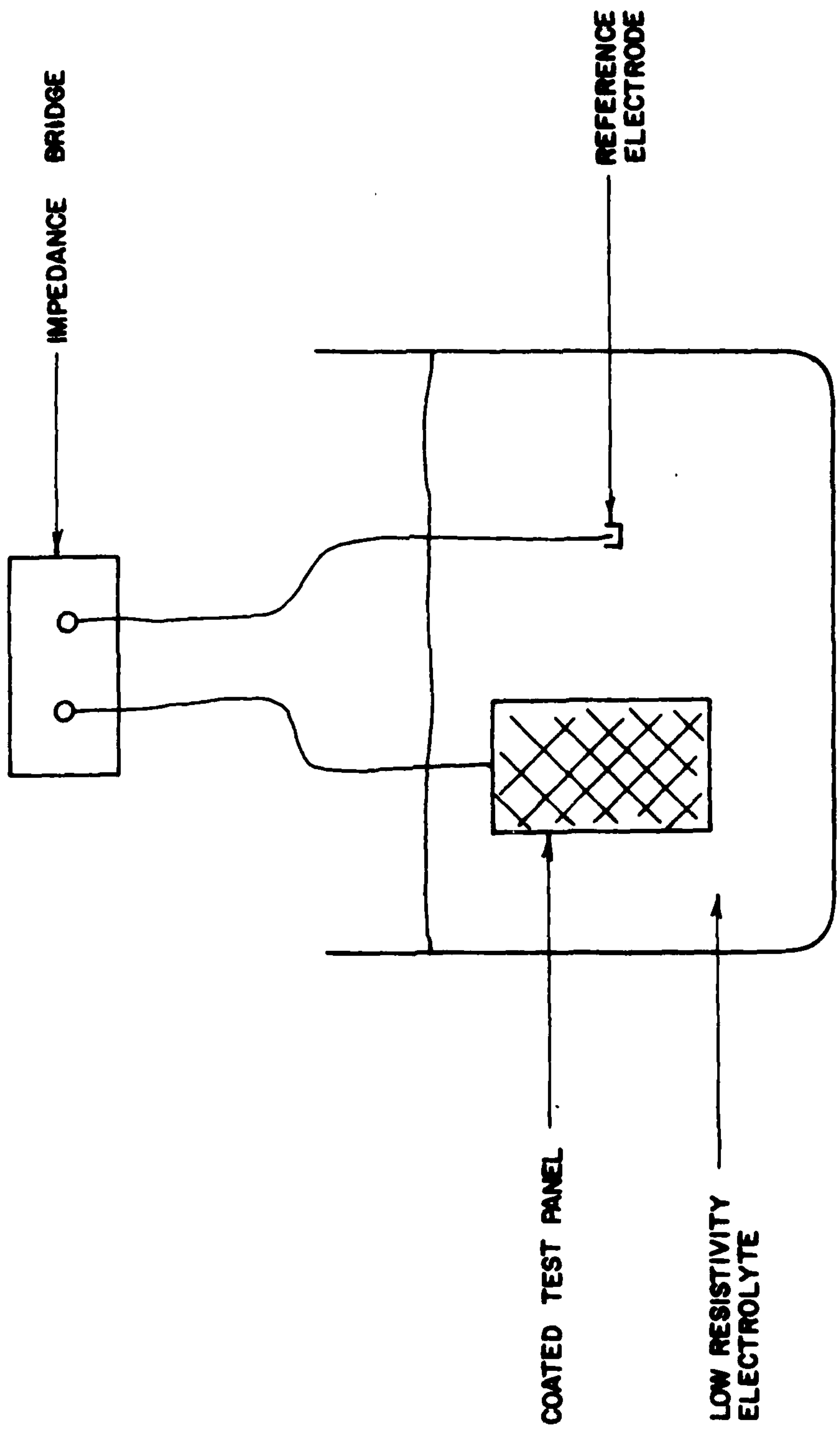

FIGURE A-4 - EXPERIMENTAL SET-UP FOR MAKING ELECTRICAL IMPEDANCE MEASUREMENTS.

APPENDIX B - Detection of Corrosion by Electrical Resistance Measurements

The electrical resistance corrosion probe is based on the principle that the electrical resistance of a metal wire is inversely proportional to its cross-sectional area. As the cross-sectional area of the metal wire is reduced by corrosion, the resistance of the wire increases.

A typical probe is shown in Figure B-1. It consists of an exposed wire portion and an internal reference wire section which is insulated from the environment of interest. The voltage drop across each portion caused by application of a small direct current is measured simultaneously with an X-Y recorder. Figure B-2 shows a typical circuit for making the measurements. Since the areas on the wire are adjacent, temperature effects are cancelled out. The resistance of the exposed wire area of the probe increases with respect to the reference portion as corrosion of the exposed wire of the probe occurs. Changes in the resistance of the exposed portion causes a change in the ratio of the voltage drops measured on the X-Y recorder. Figure B-3 shows typical experimental data.

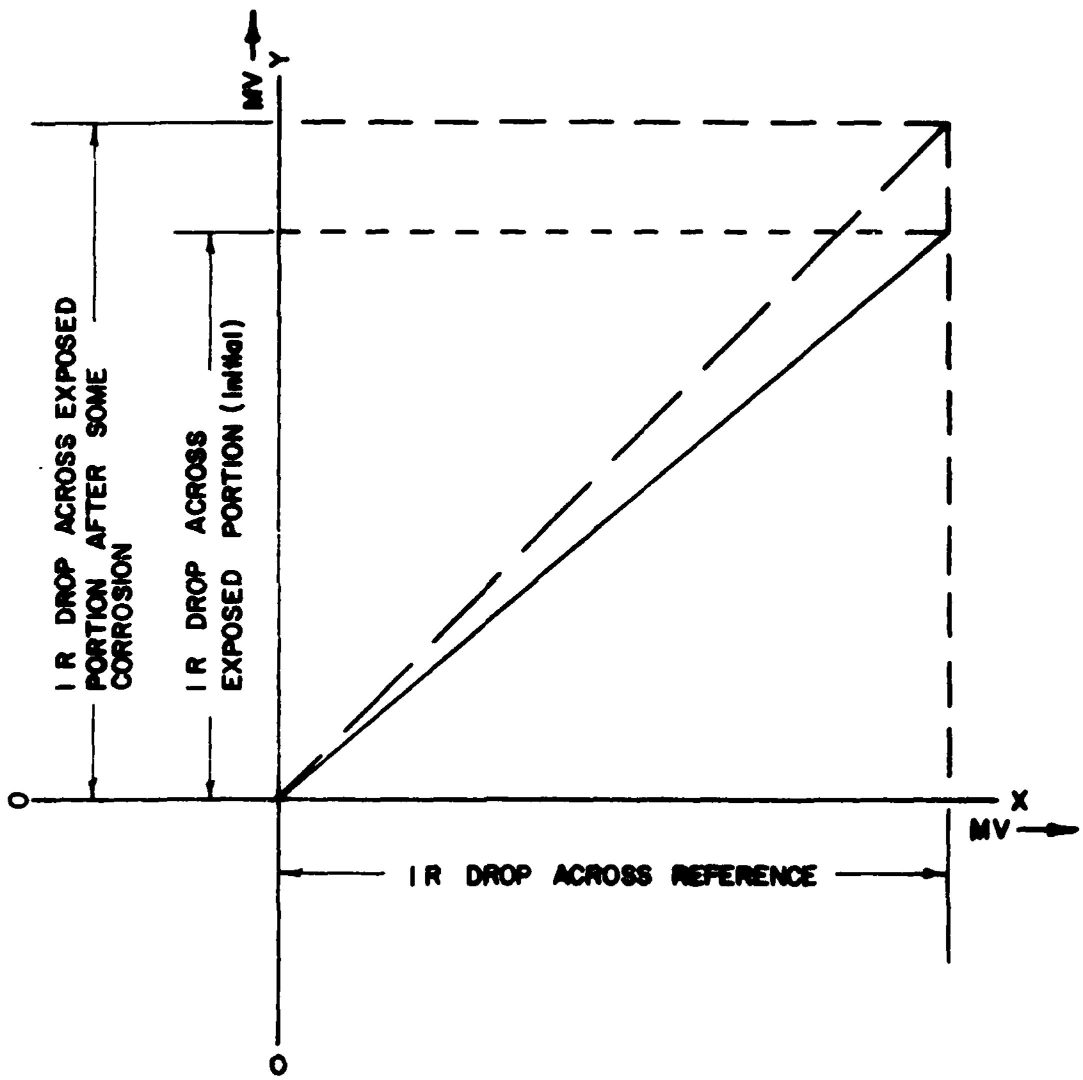

FIGURE B-3 — TYPICAL EXPERIMENTAL DATA

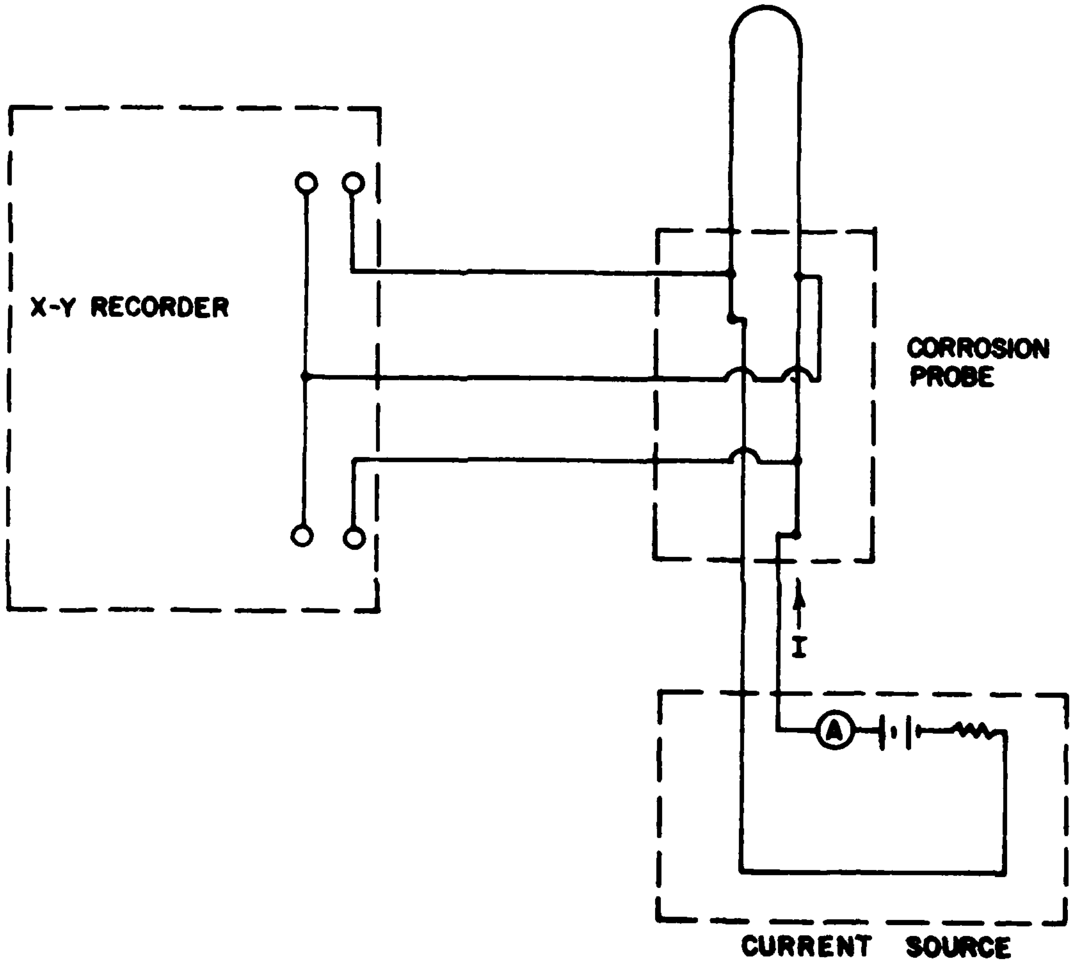

FIGURE B-2-CIRCUIT DIAGRAM FOR MAKING RESISTANCE MEASUREMENTS

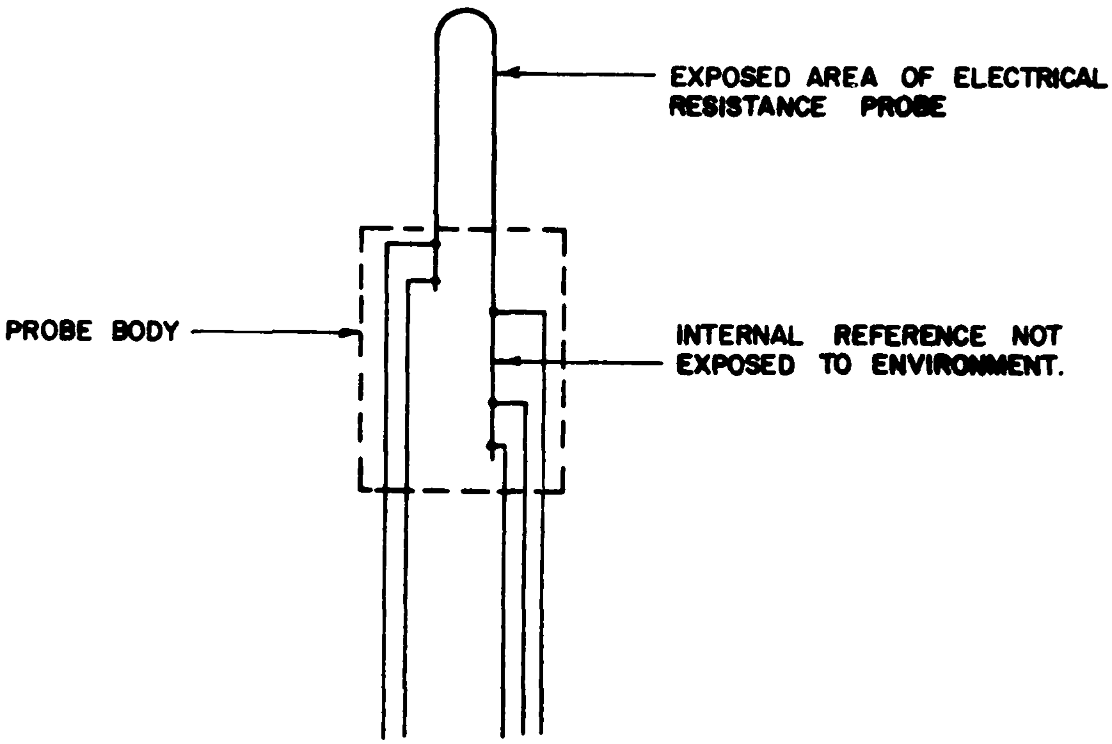

FIGURE B-1 — SCHEMATIC OF ELECTRICAL RESISTANCE CORROSION PROBE