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PHILADELPHIA, PENNSYLVANIA

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AERONAUTICAL MATERIALS LABORATORY

REPORT NO. NAEC-AML-2436

DATE 11 MAY 1966

DEVELOPMENT OF AN ENVIRONMENTAL WET TEST CHAMBER FOR
SIMULATING CARRIER DECK AND OTHER CORROSIVE ENVIRONMENTS

PROBLEM ASSIGNMENT NO. 12-87 UNDER
BUREAU OF NAVAL WEAPONS WEPTASK
RRMA 03 013/200 1/FO20 03 01

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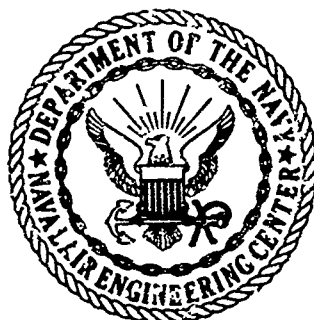
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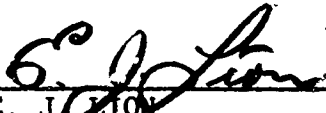
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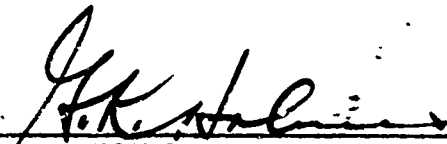
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ABSTRACT

An environmental wet test chamber was designed, developed and evaluated to simulate the wet environments of either coastal, industrial or shipboard sites. It provides an accelerated test procedure whereby results can be obtained in a matter of hours as compared to the days and weeks presently required in some commonly used environmental chambers. The unit permits the simultaneous testing of nine specimens and has proven its reliability in providing repeatable and reproducible patterns of corrosion. Specimens can be removed for examination or replacement without interrupting the operation of the unit, or disturbing the environment, or other specimens. The unit can be assembled from readily available, relatively inexpensive items, at a material cost not exceeding \$100.00.

5. Environment Stability - It should be possible to remove specimens for examination or replacement without interrupting the operation of the unit, disturbing the existing environment or other specimens.

II. EXPERIMENTAL PROCEDURES AND RESULTS

A. List of Components

The unit as shown in Plate 1 is composed of the following parts:

1. The test chamber consists of a glass jar twelve inches in diameter by twelve inches high.
2. A spray nozzle, employing two standard, glass eye droppers which are mounted in an acrylic holder as shown in Plate 1. It is important that the small diameters of the tubes be brought together as shown to effect proper spray pattern. Numerous commercial spray nozzles were tried but the fine orifices often clogged, especially when salt solutions were used. In addition they were fabricated, at least in part of metals, posing separate corrosion problems.
3. A tripod stand, made of acrylic plastic, which is a 4" dia. disc mounted on three narrow legs. It supports and positions the spray nozzle in the center of the chamber, eight inches from the bottom.
4. A specimen holder, Plate 2, which consists of an 8 oz. glass jar with the bottom removed. The 2-5/16" O.D. jar lid gasket was removed and a 1 1/2" diameter hole was cut through the center of the lid.
5. A water jacket, shown with specimen holder in Plate 2, was formed by shaping the bottom of a 125 milliliter aluminum beaker to fit the neck of the jar.
6. A turntable, fabricated from acrylic plastic is 9" in diameter by 3/8" thick. It is provided with nine evenly spaced 2-3/8" diameter x 1/4" deep sockets or wells, with center lines 1-7/16" from edge, which accommodates the mounted specimens. The bottoms of the wells are provided with a 1-7/8" diameter hole. A 1/4" diameter center shaft couples the turntable to a drive motor.
7. Drive Motor - 110VAC, 60 cycle; gear ratio = 9800:1; rpm = 1/3; output rotation = CW; 1/4" drive shaft with 1-1/8" exposed for coupling.
8. A motor housing was fabricated of 1/8" acrylic to protect the motor from vapors escaping from the chamber.
9. Air supply from the laboratory compressed air line was filtered and passed through a flowrator before entering the spray nozzle.

10. Flex frame support rods were used to suspend the motor and turntable over the glass jar chamber

B. Test Specimens - Preparation and Cleaning

The specimens (Plate 3) used in the evaluation of the unit were:

1. 1020 steel, cold rolled conforming to specification MIL-S-7952, measuring 2-1/8" diameter x 1/16" thick, which were surface ground on one side (test surface).

2. Dissimilar metal specimens which consisted of two magnesium discs, one, 2-1/8" dia. x 1/16" thick, and the other 1" dia. x 1/8" thick, fastened together with a steel screw. The purpose of the larger disc was to provide proper fit in the specimen holder mount. The magnesium conformed to specification AZ31, H-24 and the screw was an AN510, flat head, from which the cadmium plating had been stripped. All specimen test surfaces were hand polished with 240 grit aluminum oxide cloth to a surface finish of 10-20 microinches, immediately prior to testing.

The specimens were cleaned by scrubbing with surgical gauze wetted with hot mineral spirits (TT-T-291), followed by dipping in hot mineral spirits, then in boiling 95% methanol, and finally in boiling absolute methanol. They were stored in a desiccator until ready to be used. The magnesium specimens were in the disassembled state during the surface preparation and cleaning operations.

C. Assembly and Operation

The preliminary investigational work was done with the unit assembled as shown in Plate 4. The significant feature of this set-up was the plastic baffle located about 3" from the specimen. Approximately one liter of the corrodent was placed in the flask and the spray was started with the filtered air from the laboratory air supply metered at one cfm. The resultant fog filled the chamber. Fifty milliliters of cold water (35°F) was put into the aluminum sleeve which was placed in the specimen jar in contact with the back of the specimen in order to effect condensation on the face of the specimen.

The specimens were exposed to the test environment for a period of one hour after which the spray and the turntable motor were turned off. The entire turntable rig, with the specimens still in place, was removed from the chamber and placed on a laboratory table allowing the specimens to dry at ambient conditions of $73 \pm 3^\circ\text{F}$ and $50 \pm 5\%$ r.h. for a period of three hours, after which they were examined. Moderate overall rust formed on all nine test samples.

The next test set up was identical with the first except that the dissimilar metal specimens (magnesium disc-steel screw) were substituted for the steel. The results of this test were unsatisfactory since none

of the specimens displayed galvanic corrosion, although they were exposed for several hours. However, when the acrylic baffle was removed, moderately heavy galvanic corrosion was evident around the screw head within fifteen minutes. Subsequent tests were conducted to test the reliability of the system without a baffle. These tests indicated that further modifications were necessary since the moisture deposit on the specimen was too heavy and lacked uniformity. Numerous baffle designs in various positions were tried but these attempts were negative as they provided too little or too much moisture to the test specimens. The problem was resolved by omitting the baffle and mounting the spray nozzle on a tripod stand, which was positioned in the chamber so that the nozzle was centered about eight inches from the bottom of the chamber. The spray pattern was directed toward the bottom of the chamber. Also it was noted that the cold water jacket could be omitted because it permitted an excessive water droplet deposit on the specimens. Subsequent tests were conducted with these modifications. The changes were adopted since they provided a moderate, uniform water droplet accumulation on the specimens.

D. Environments

After the establishment of a satisfactory test procedure, consideration was given to the types of environments that would be maintained in the chamber.

For the first environment, a fog was created by spraying distilled water into the chamber. The blank steel specimens used in the test displayed a moderate and uniform corrosion pattern at the end of the cycle consisting of 1 hour fog exposure and 3 hours drying. The next step was to simulate an industrial atmosphere. Here, in addition to a high humidity problem there are corrosive products of combustion such as smokestack gases to consider.

In order to simulate this condition, diesel fuel contained in a Cleveland open flash cup was ignited and permitted to burn freely. The smoke and combustion products were pulled into the chamber via a blower and duct system where they were mixed with the water spray (Plate 5). This environment was more severe than that produced by distilled water fog alone as evidenced by more pronounced pitting and discoloration of both the steel blank and the dissimilar metal specimens, shown in Plates 6 and 9.

To carry the development further, it was thought that a refinement could be made whereby the cumbersome soot-producing apparatus required to produce and deliver the combustion products to the chamber could be eliminated. Inasmuch as SO_2 is a combustion product of fuels it was decided that sulfurous acid (8.5% assay as SO_2) could be added in the proportion of 2 milliliters of acid to a liter of water. A low acid concentration was selected in order to prevent the indiscriminate corrosion of all metal specimens. The results of these tests indicated by the

similarity of the corrosion patterns, that the sulfurous acid could be substituted for the burning diesel fuel. Results are illustrated in Plates 6 and 9 where corrosion patterns are comparable.

Simulation of a coastal atmosphere, was accomplished by using natural sea water spray in the chamber. The sea water was obtained from Atlantic City, New Jersey. The results of this test are shown on the blanks illustrated in Plates 7 and 10 whereby the corrosive effects of salt water are evident. This can be more readily seen on the dissimilar metal specimen in Plate 12 where the galvanic action produced a heavy deposit of magnesium oxide at the peripheral edge of the magnesium disc in contact with the steel.

The inclusion of shipboard type environments was one of the main objectives of this investigation. Here again, in addition to sea spray mist, the smoke stack gases are present. This condition was simulated by employing the diesel fuel burner and associated gear (Plate 5) that was used previously. The smoke and the natural sea water spray, delivered simultaneously in the chamber, resulted in a combination of dense fog and smoke. The results of exposure to this environment demonstrated the effect of combining the two corrodents, manifested by a heavier corrosion pattern and overall discoloration of the test specimens (Plates 7 and 10).

A simplification of the test was desired, therefore another test was scheduled in which the sulfurous acid, as used previously in the distilled water spray, would be added to the natural sea water being sprayed, thus replacing the smoke producing apparatus. In this test the advantage of using the acid was demonstrated, for the results of this test, illustrated in Plates 7 and 10, depicted a similarity in corrosion intensity and pattern between the two lower blanks.

It was thought that natural sea water, obtained at different times, and from various sources, would vary in salt concentration and contents. It also was considered likely that it may contain contaminants. To eliminate these variables a synthetic sea water was made up of salts that comprise about 95% of the ingredients of natural sea water.

The synthetic sea water consisted of:

NaCl	50.0 grams
MgCl ₂ · 6H ₂ O	22.0 grams
CaCl ₂ · 2H ₂ O	3.2 grams
Na ₂ SO ₄	8.0 grams

added to one thousand milliliters of distilled water.

In order to determine the feasibility of substituting synthetic sea water for natural sea water another series of tests were conducted in which the natural sea water was replaced by the synthetic sea water.

A critical comparison of the specimens exposed to the natural sea water environments with those exposed to the synthetic sea water environments showed that with the latter the corrosion appeared to be more severe but the difference was insignificant. This demonstrated the feasibility of using synthetic sea water in tests simulating coastal or shipboard atmospheres. The specimens referred to are shown in Plates 7, 8, 10 and 11.

To determine the performance of corrosion preventive compounds in the wet test chamber, two compounds were formulated. One, a light oil with 10% inhibitor, identified as sample A, was formulated to produce an oil film with a thickness of 0.06 mils and sample B an inhibited petrolatum selected to effect a soft, non-draining film with a thickness of 2 mils.

The specimens, both 1020 steel and the dissimilar metal specimens (magnesium and steel), were abraded and cleaned as described previously. They were immersed singly and suspended in the material for a period of one minute then withdrawn at a rate of four inches per minute. A Fisher-Payne dip coater was used in this operation. Materials and specimens were at a temperature of $72 \pm 3^{\circ}\text{F}$ at the time of coating. Immediately after coating they were placed in a horizontal position on a level plate and conditioned at $72 \pm 3^{\circ}\text{F}$ and 40 to 50% relative humidity, in a dust-free atmosphere, for a period of 16 to 18 hours. Stainless steel hooks were used throughout the cleaning and coating operations. The coated specimens then were exposed in the wet test chamber to each of the environments to which the blank specimens had been exposed previously. The comparative results are shown in Plates 6 and 11 inclusive.

To demonstrate the versatility of the unit and further determine its suitability, additional corrodents were included, viz. 5% and 20% NaCl solutions. These were selected because they are used in the standard salt spray units and variations were effected here too by adding the diesel fuel combustion products or sulfurous acid. Plates 13 to 16 inclusive show the results of these tests.

All of the tests conducted in the wet test chamber showed sample A to be unsatisfactory as a corrosion preventive compound while sample B was satisfactory; the reason being that the film thickness and the percentage of corrosion inhibitor were less for the sample A material than they were for sample B.

To show the corrosion gradations obtainable on steel specimens exposed in the wet test chamber, other compounds were formulated and tested. The inhibitor concentrations used in the light oil formulations were: (a) 35% inhibitor, providing a film thickness of 0.27 mil,

identified as sample C; (b) 50% inhibitor, film thickness of 0.50 mil, identified as sample D; and (c) 60% inhibitor with a film thickness of approximately 0.80 mil, identified as sample E.

They were applied to 1020 steel discs and exposed in the wet test chamber to the synthetic sea water /SO₂ environment. The exposure cycle, identical to that used in all the previous tests, consisted of one hour exposure and a three hour drying period. The results of the tests, shown in Plates 17 to 19 inclusive, show a corresponding increase in protection with the increase of corrosion inhibitor. Specifically, sample C displays a moderately heavy corrosion pattern, sample D a somewhat similar pattern but corrosion not as intense, while E displays very light, scattered rust spotting on each of the six discs.

E. Comparative Tests

Since the JAN-H-792 humidity cabinet and the salt spray cabinet are widely used in the evaluation of materials, a comparison of the results obtained from them with those obtained from the wet test chamber was made.

For this phase light oils, as used in the previous tests, were applied to 1020 steel test panels. The formulations of the oils were altered, as described later, to provide a reasonable test time. The coated panels were then exposed in either of the cabinets as follows:

Salt Spray tests:

Two light oils were used here. One, identified as sample G, contained 50% inhibitor, while the other, sample H, contained 75% inhibitor. The sample G material was applied to ten steel test panels and exposed in the salt spray cabinet. Subsequently, another set coated with sample H material was exposed in the same environment. This sequence was repeated over a period of three months until twelve separate sets, six for each oil, had been tested.

During the exposure periods observations were made twice daily. Failure time of a given specimen, was recorded as the time in hours when three or more distinct rust spots were observed. The area within 1/4" of the periphery was not included in the evaluation. A test was terminated when a minimum of seven panels in a set failed. The test sets were started in the cabinet at irregular intervals so that none of the sets, coated with identical materials, ran concurrently. Charts were drawn up whereby the failure time of each panel could be determined as well as the failure time amongst sets. They are represented in Plates 24 to 27 inclusive. A comparison of the results revealed a lack of correlation amongst sets, and the failure times of members of a set usually failed to coincide. Also almost all the specimens displayed corrosion patterns that were not uniform, usually appearing in the form of random corrosion, and/or pitting and rust streaking.

In still another test, steel discs as used in the wet test chamber tests, were coated with a light oil containing 60% inhibitor (identified as sample E) and suspended in the 5% NaCl solution salt spray cabinet until failure occurred. The results of this test too showed the specimens failed at different times, and as shown in Plate 20, the specimens were rust streaked and spotted and the patterns were not uniform.

Six steel panels were then coated with sample A and exposed in the 5% NaCl salt spray cabinet. The purpose of this test was to provide additional comparative information since sample A was one of the materials used in the evaluation of the wet test chamber. The specimens from this test, shown in Plate 21, exhibited random rust spots, pitting and streaking.

Humidity Cabinet Tests

For this test steel panels were coated with the sample A material. They were exposed in the JAN-H-792 humidity cabinet and during this period daily observations were made. The first failure occurred in 14 days. The 31st day, two more specimens failed followed by another failure on the 32nd day. The test was terminated on the 35th day, with a total result, depicted in Plate 22, of four failures with two passing. Again, as noted in the salt spray tests, where failure occurred it was characterized as random rust streaking, spotting or pitting.

In still another test, steel discs were coated with a light oil containing 1% exhibitor and exposed in the humidity cabinet. This material, identified as sample F, was used to provide comparative results in a relatively short exposure time. The specimens, shown in Plate 23, displayed non-uniform corrosion patterns.

III. CONCLUSIONS

A. Based on the results of this investigation, it is concluded that the Wet Test Chamber and the associated test methods described in this report are suitable for evaluating the protective qualities of corrosion preventive compounds.

B. Further, it is concluded that the Wet Test Chamber fulfills the objective of this investigation by providing:

1. Reproducibility: Numerous tests demonstrated that reproducible, repeatable, and uniform results are obtainable in the Wet Test Chamber.

2. Versatility: The facility with which each of the controlled fog atmospheres was established and maintained demonstrated the versatility of the unit.

3. Short Test Time: A short test time (total of 4 hours) was found suitable for the evaluation of the corrosion preventive compounds used in this investigation.

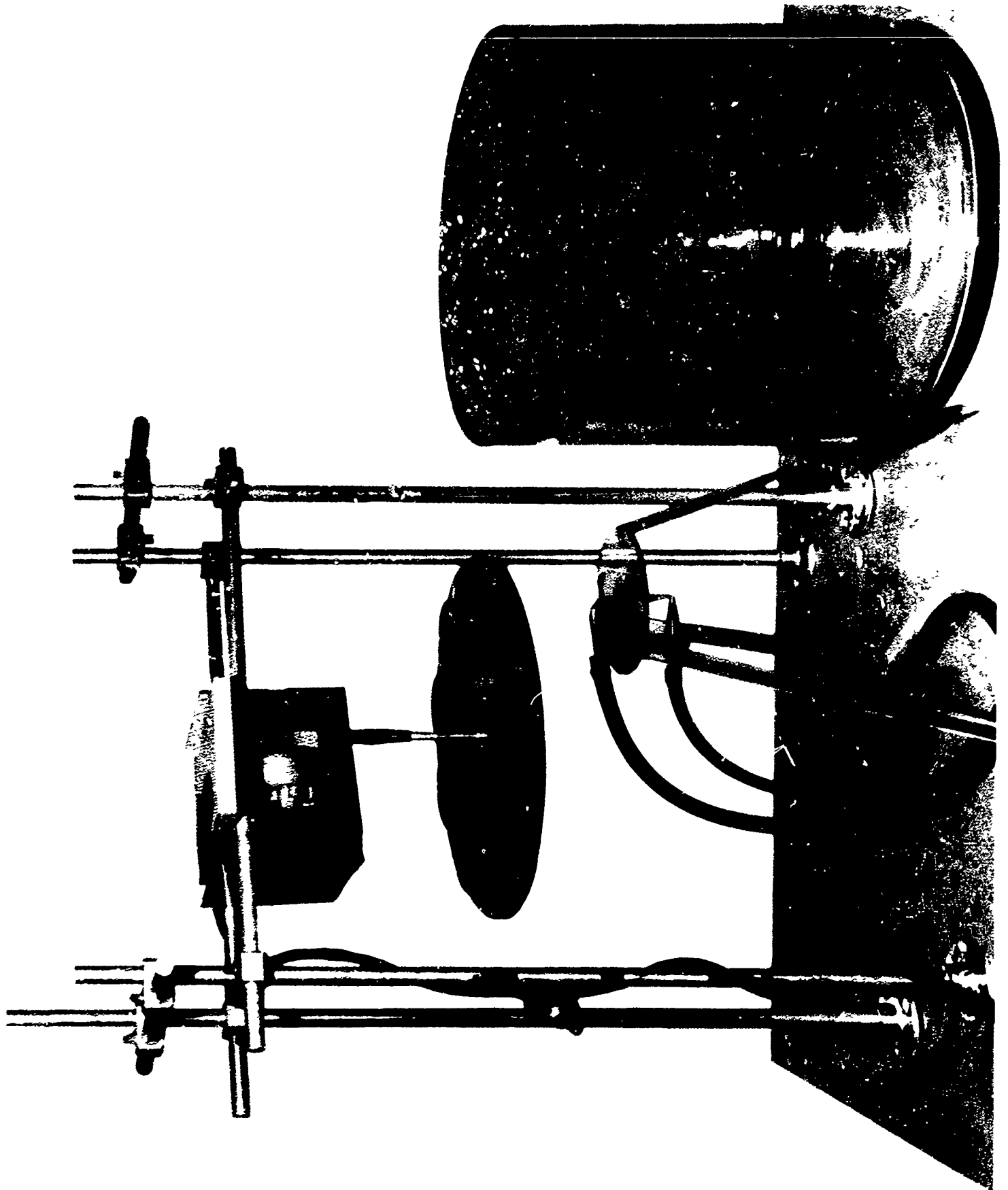
4. Environment Stability: Insertion or removal of specimens can be accomplished without disturbing the established environment.

5. Low Cost: The complete unit can be assembled at a material cost not exceeding \$100.00.

IV. RECOMMENDATIONS

It is recommended that the wet test chamber as a specification test be included in the evaluation of contact corrosion preventive compounds.

It is further recommended that its use be extended in testing other types of protective surface applications and finishes.



COMPONENTS OF ENVIRONMENTAL WET TEST CHAMBER

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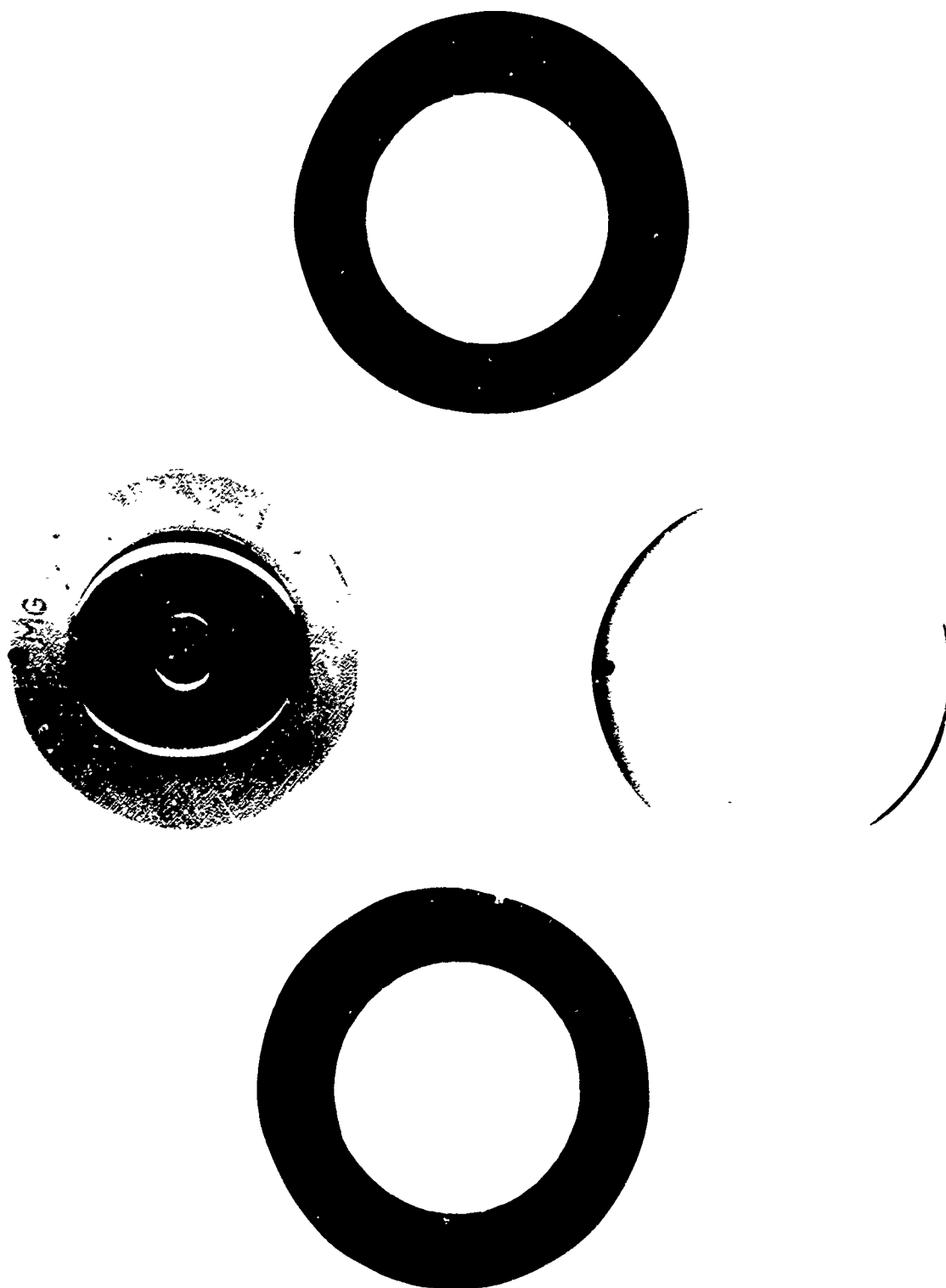
PLATE 1



WATER JACKET, TEST SPECIMEN AND SPECIMEN HOLDER

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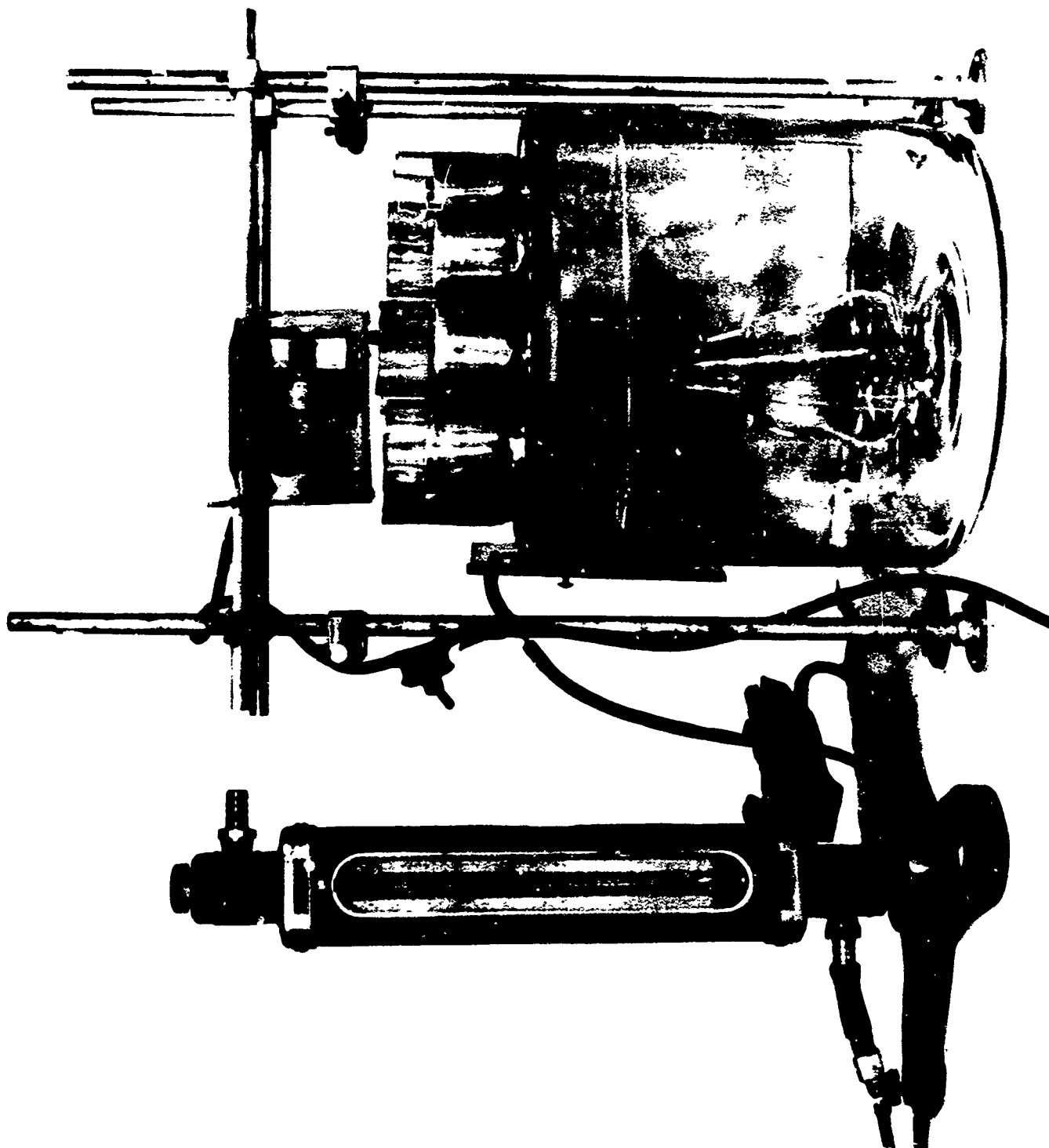
PLATE 2



DISSIMILAR METAL SPECIMEN, STEEL SPECIMEN, FRONT AND REVERSE VIEWS OF
SPECIMEN HOLDER

PHOTO NO: CAN-367430(L)-3-65

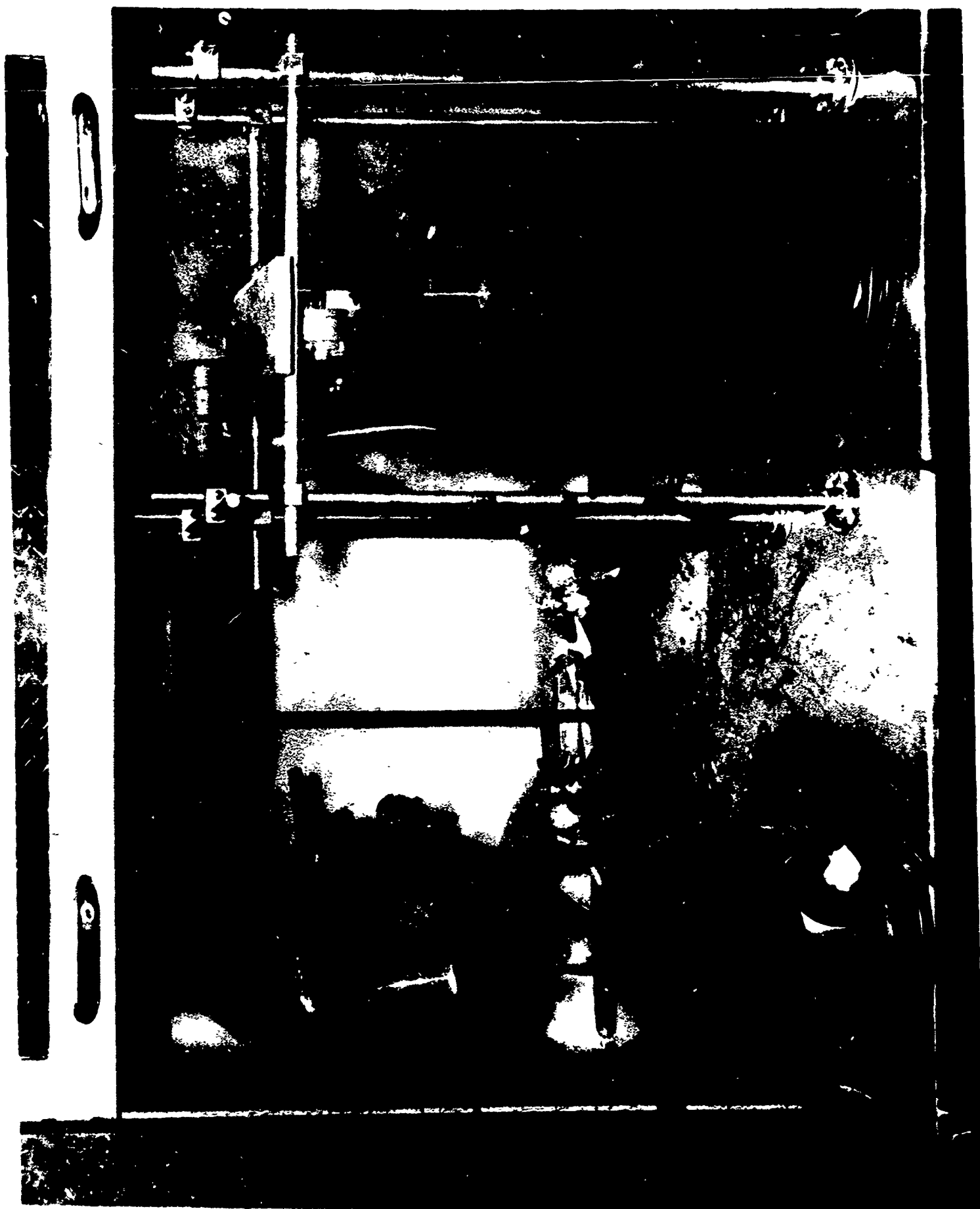
PLATE 3



OPERATIONAL ASSEMBLY VIEW OF WET TEST CHAMBER

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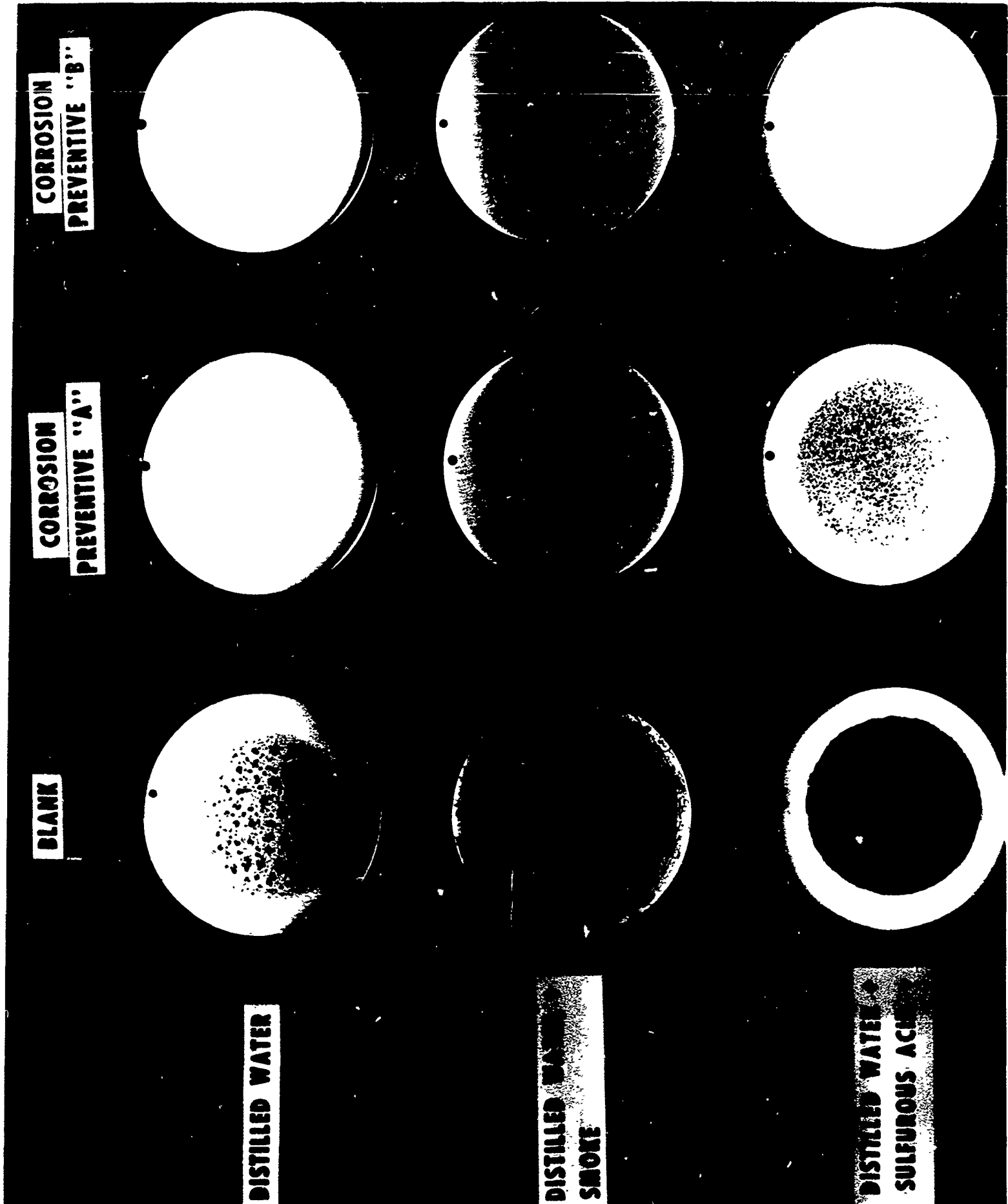
PLATE 4



METHOD OF DRAWING COMBUSTION PRODUCTS INTO CHAMBER

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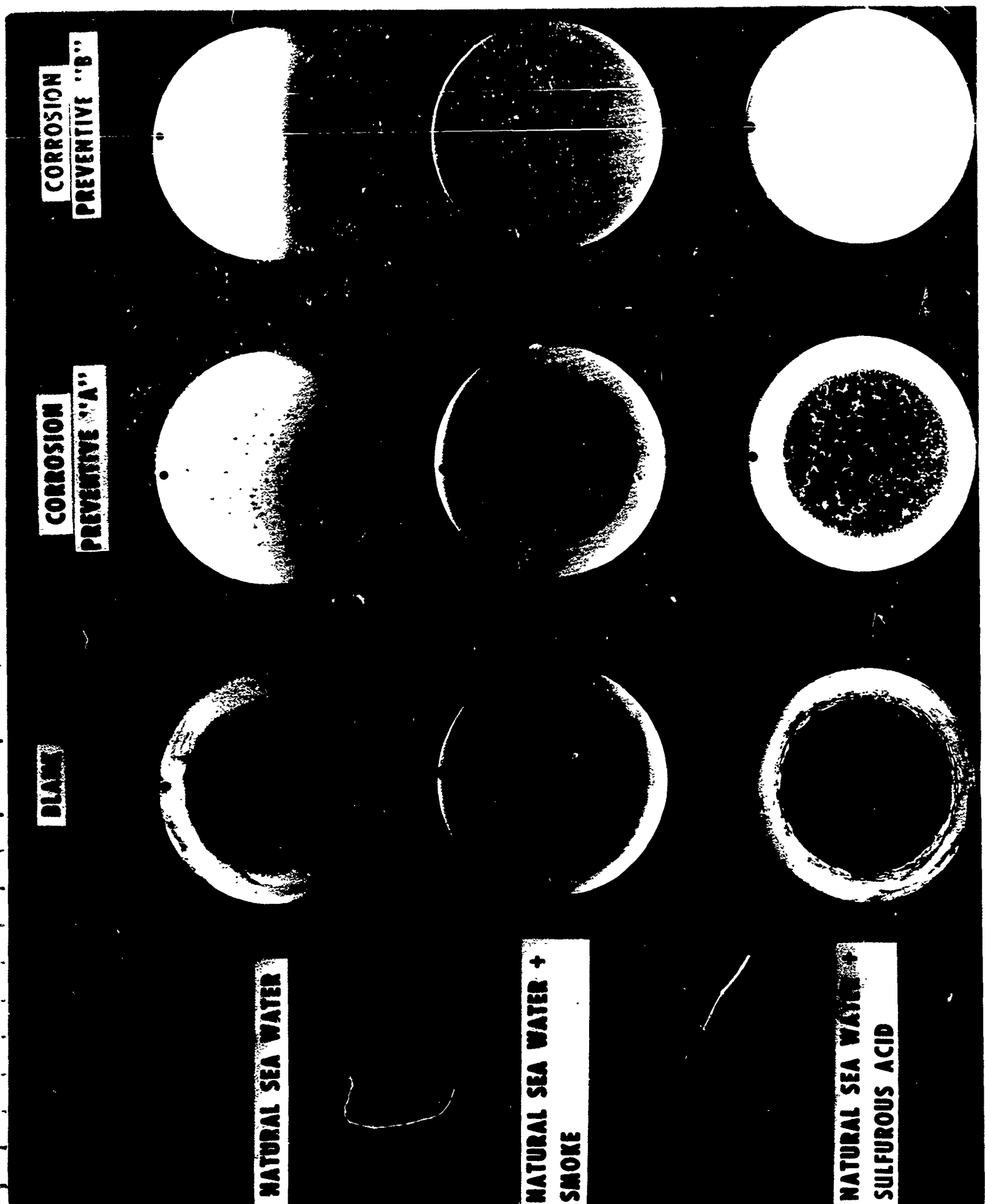
PLATE 5



RESULTS OF EXPOSURE OF STEEL SPECIMENS TO DISTILLED WATER, DISTILLED WATER/SMOKE, AND DISTILLED WATER/ACID ENVIRONMENTS

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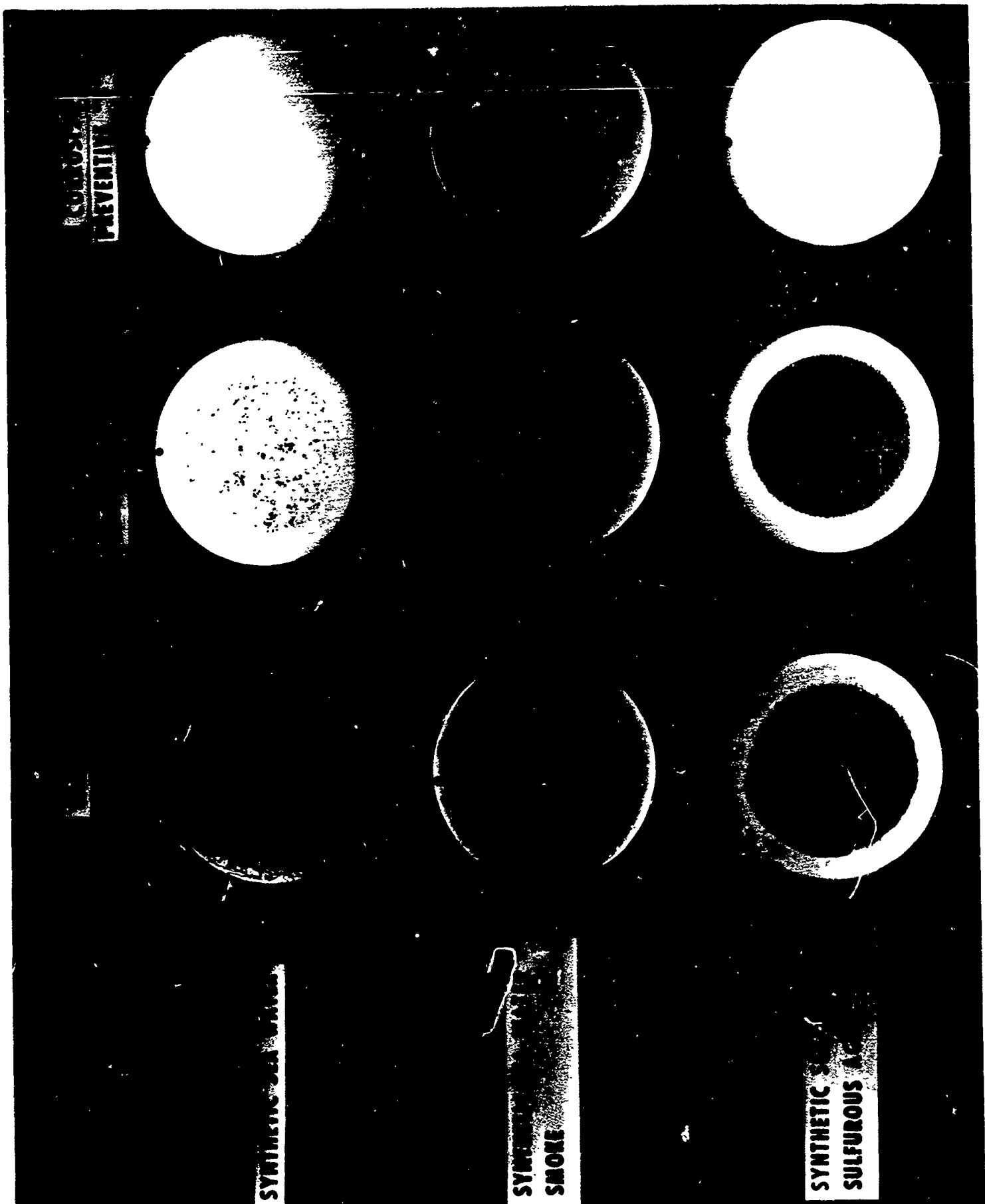
PLATE 6



RESULTS OF EXPOSURE OF STEEL SPECIMENS TO NATURAL SEA WATER, NATURAL SEA WATER/ SMOKE, AND NATURAL SEA WATER/ACID ENVIRONMENTS

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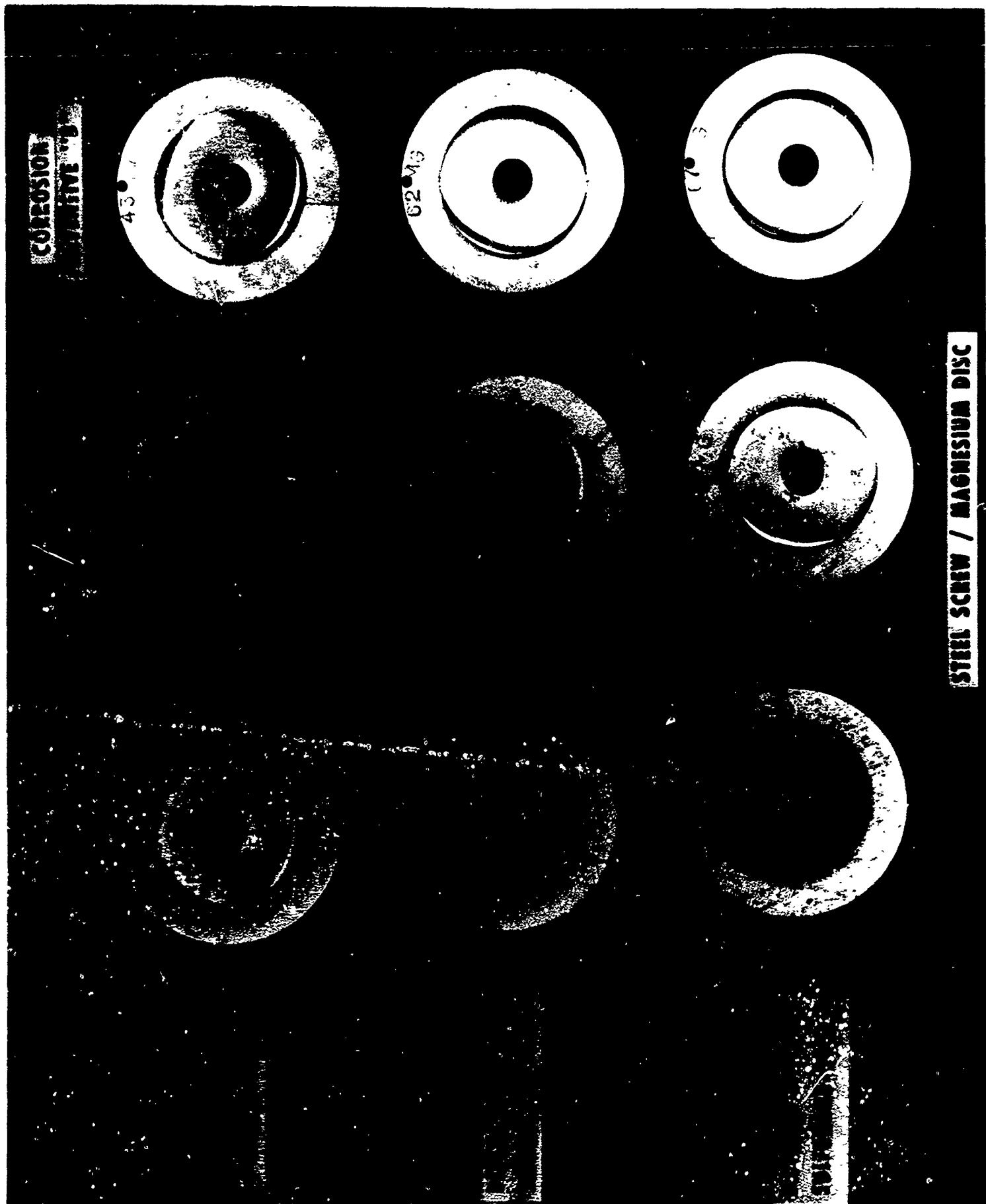
PLATE 7



RESULTS OF EXPOSURE OF STEEL SPECIMENS TO SYNTHETIC SEA WATER,
SYNTHETIC SEA WATER/SMOKE, AND SYNTHETIC SEA WATER/ACID ENVIRONMENTS

PHOTO NO: CAN-367436(L)-3-65

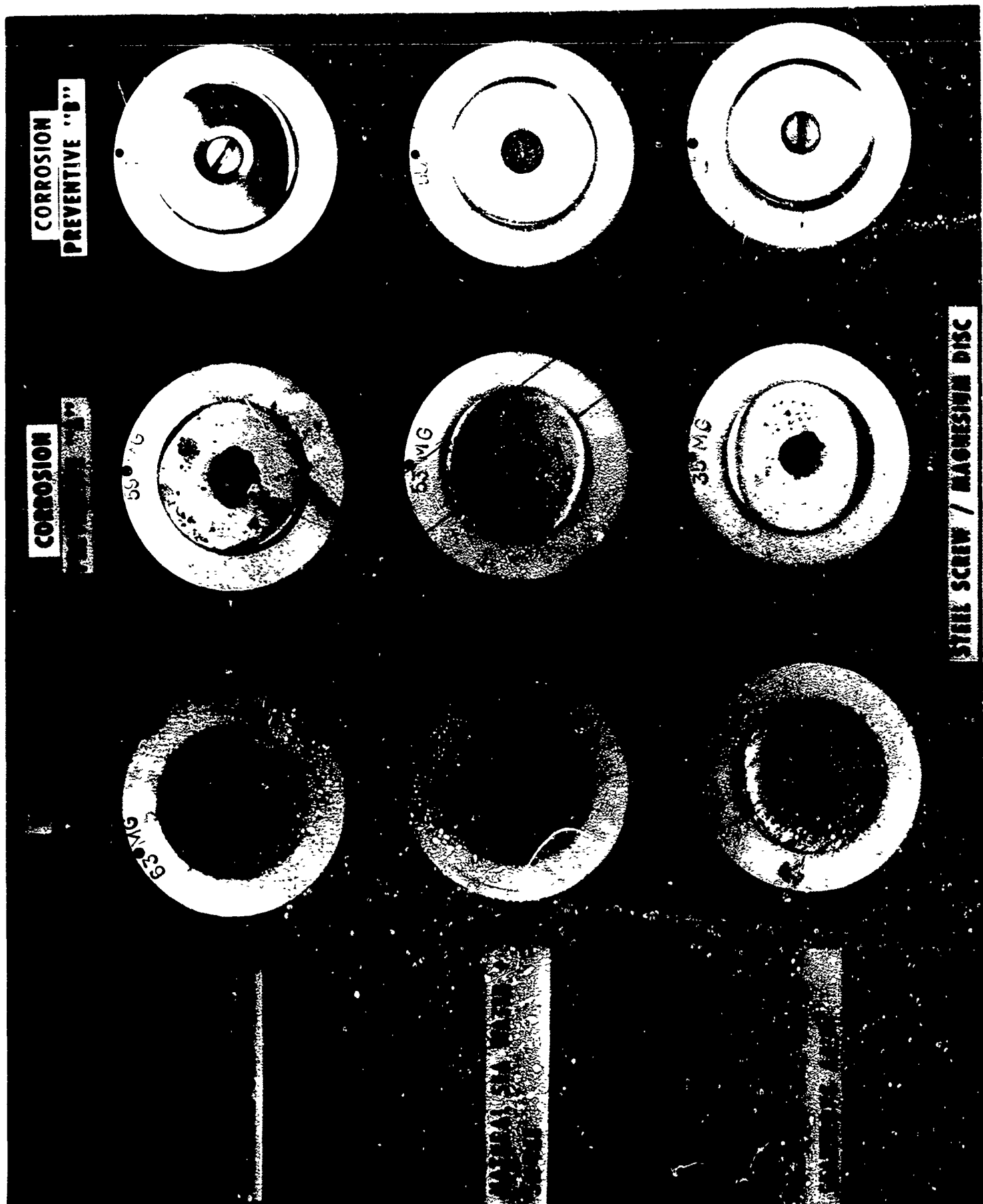
PLATE 8



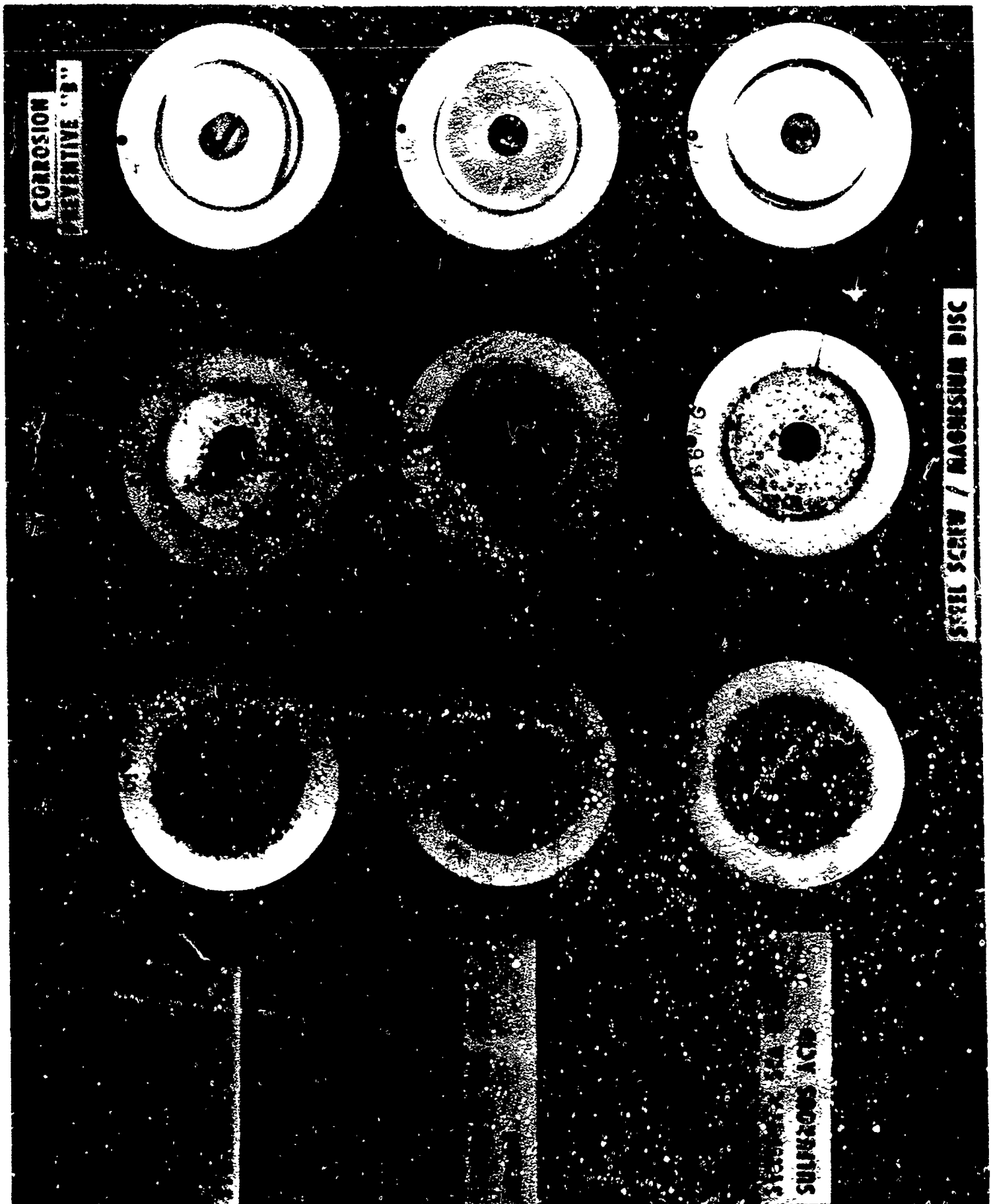
RESULTS OF EXPOSURE OF DISSIMILAR METAL SPECIMENS TO DISTILLED WATER,
DISTILLED WATER/SMOKE, AND DISTILLED WATER/ACID ENVIRONMENTS

PHOTO NO: CAN-367438(L)-3-65

PLATE 9



RESULTS OF EXPOSURE OF DISSIMILAR METAL SPECIMENS TO NATURAL SEA WATER, NATURAL SEA WATER/SMOKE, AND NATURAL SEA WATER/ACID ENVIRONMENTS



RESULTS OF EXPOSURE OF DISSIMILAR METAL SPECIMENS TO SYNTHETIC SEA WATER, SYNTHETIC SEA WATER/SMOKE, AND SYNTHETIC SEA WATER/ACID ENVIRONMENTS

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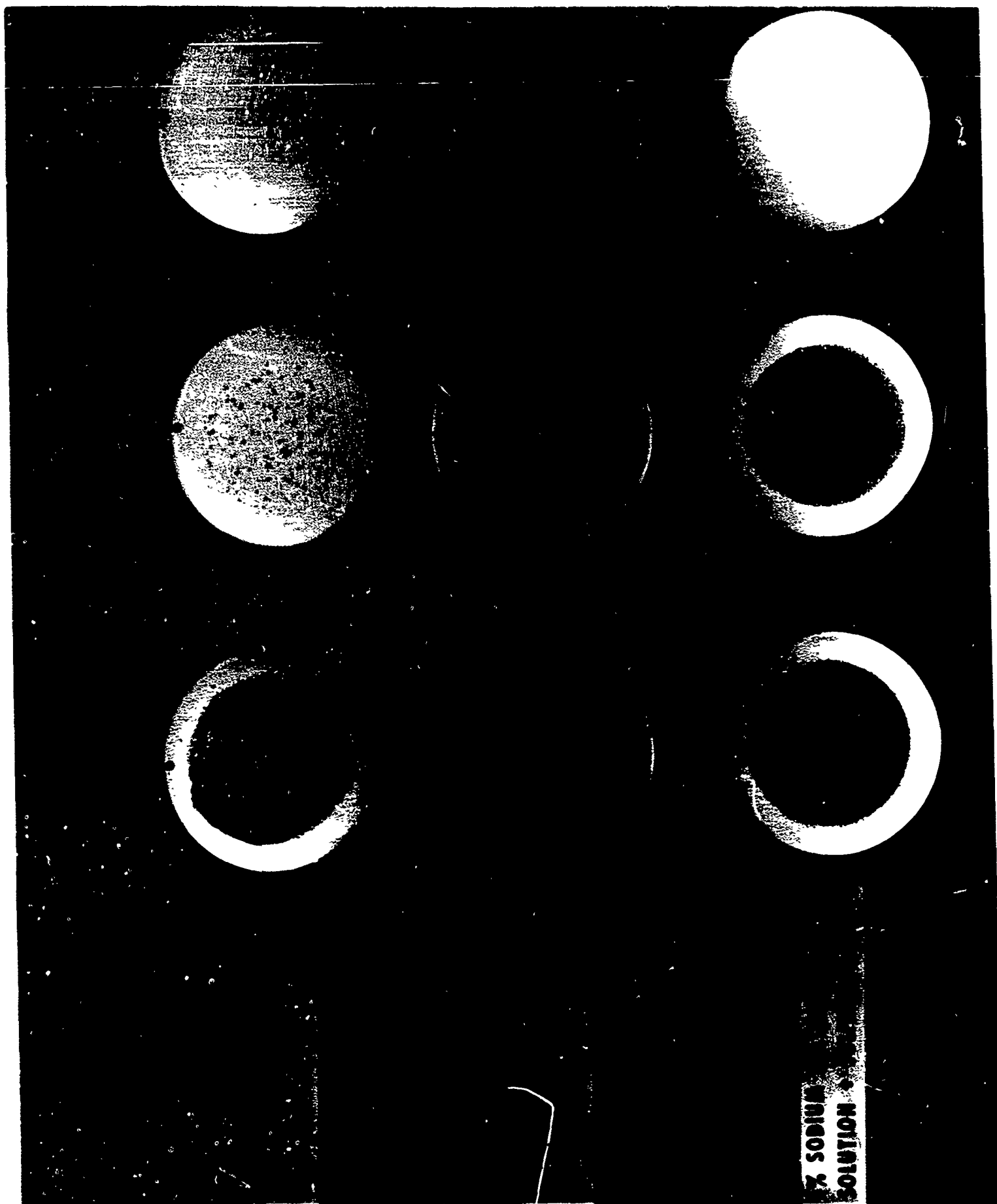
PLATE 11



CLOSE-UP OF DISSIMILAR METAL SPECIMENS AFTER EXPOSURE TO
SALT WATER ENVIRONMENT

PHOTO NO: CAN-567428(L)-3-65

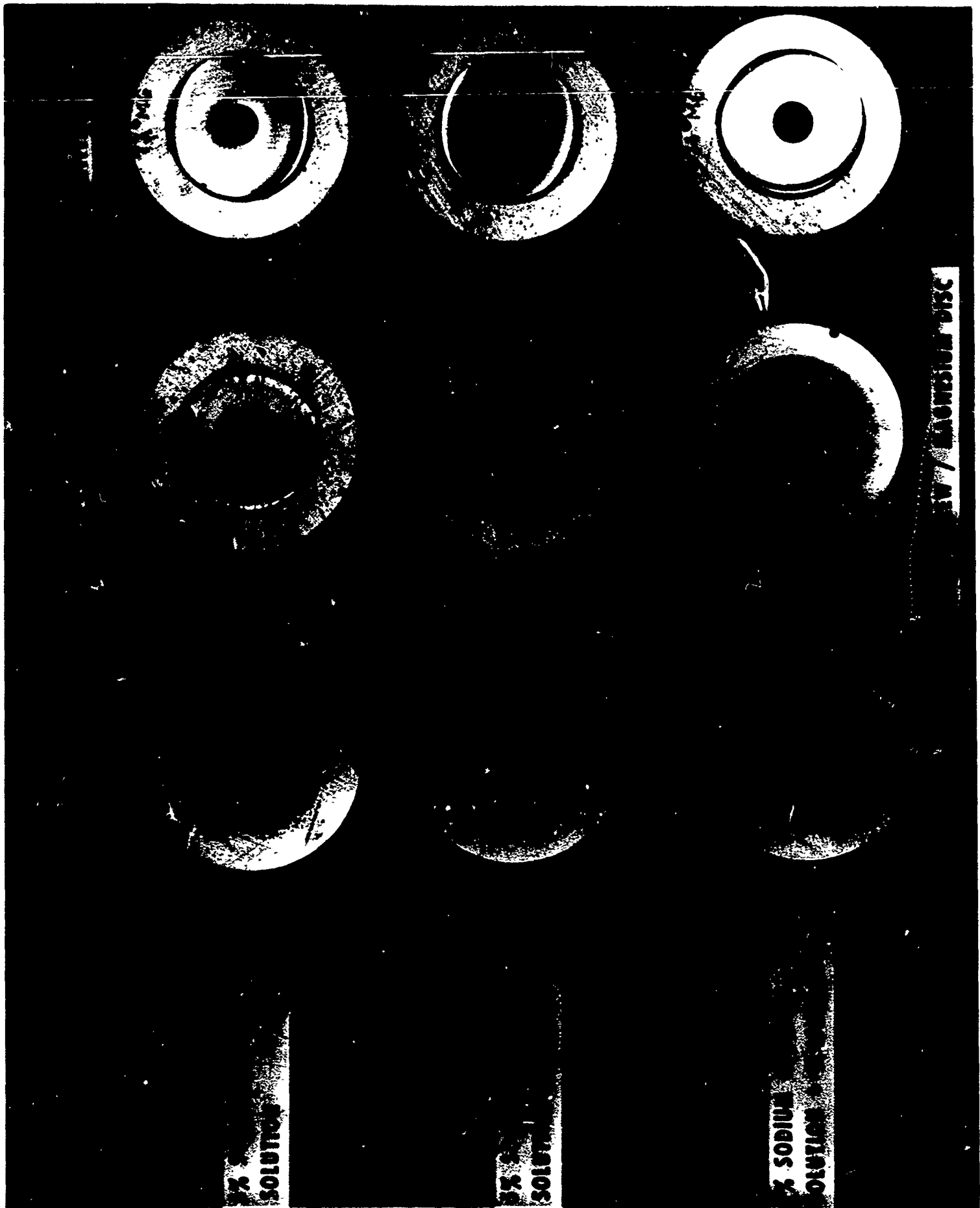
PLATE 12



RESULTS OF EXPOSURE OF STEEL SPECIMENS TO 5% NaCl SOLUTION, 5% NaCl SOLUTION/
SMOKE, AND 5% NaCl SOLUTION/ACID ENVIRONMENTS

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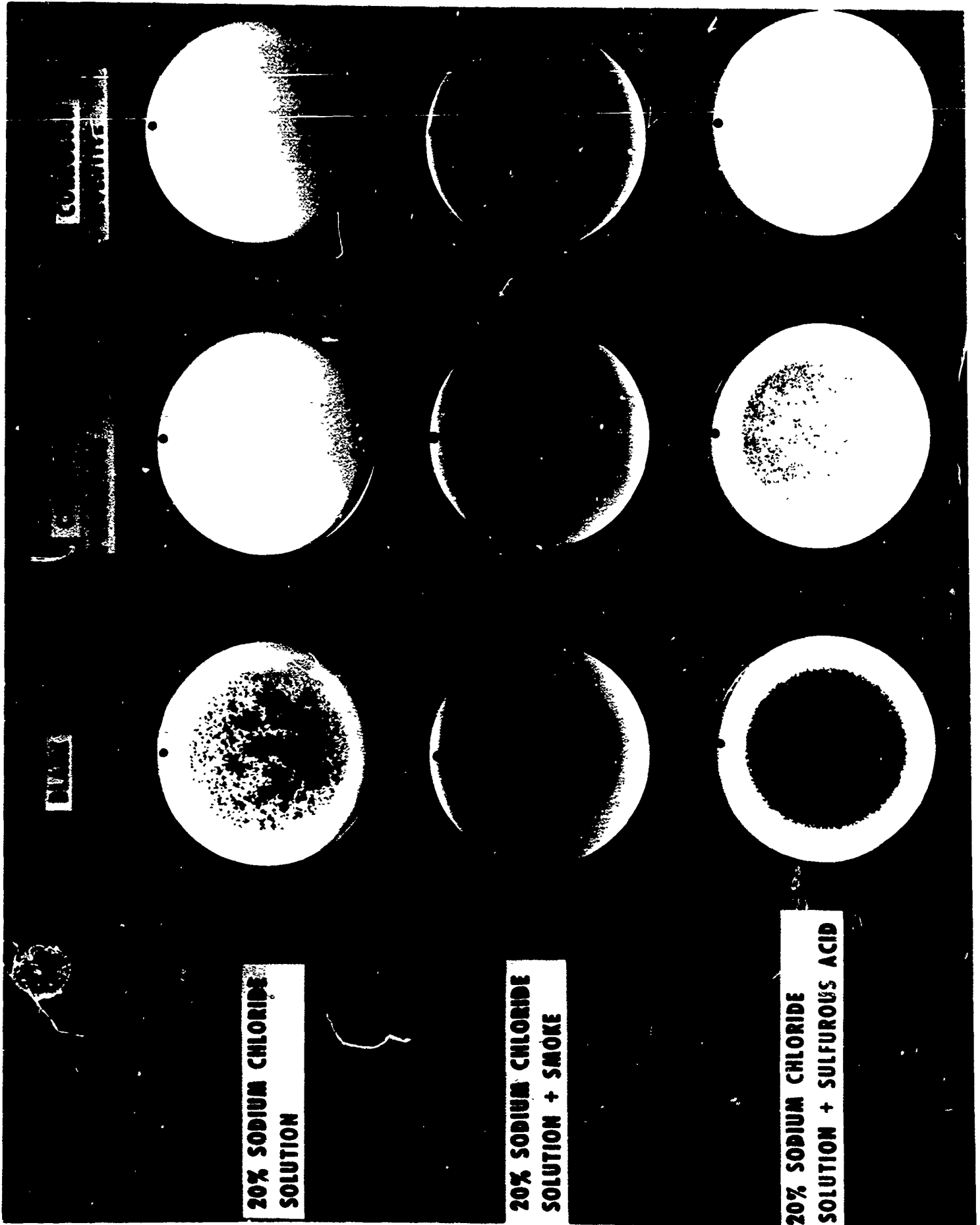
PLATE 13



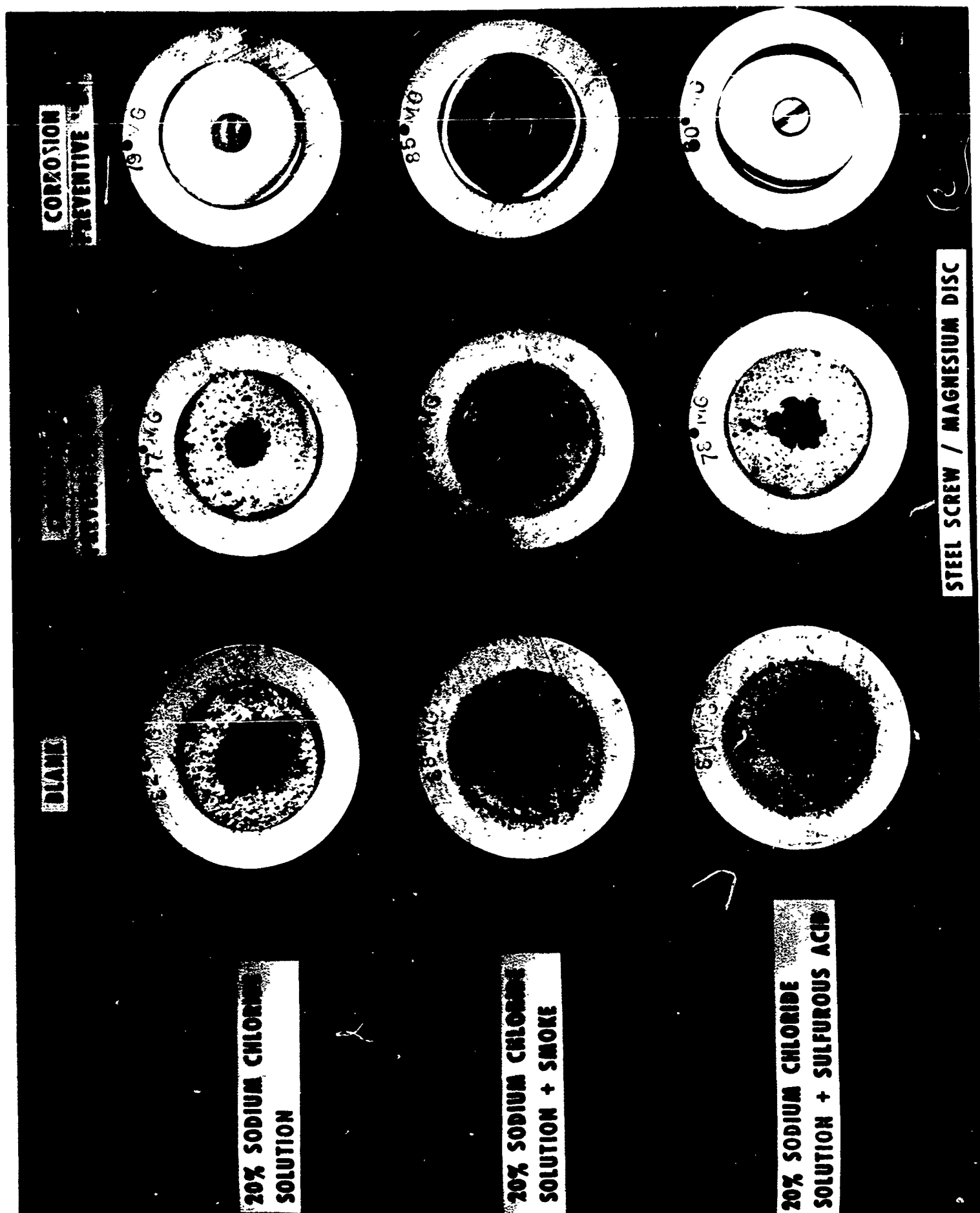
RESULTS OF EXPOSURE OF DISSIMILAR METAL SPECIMENS TO 5% NaCl SOLUTION, 5% NaCl SOLUTION/SMOKE, and 5% NaCl SOLUTION/ACID ENVIRONMENTS

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PLATE 14



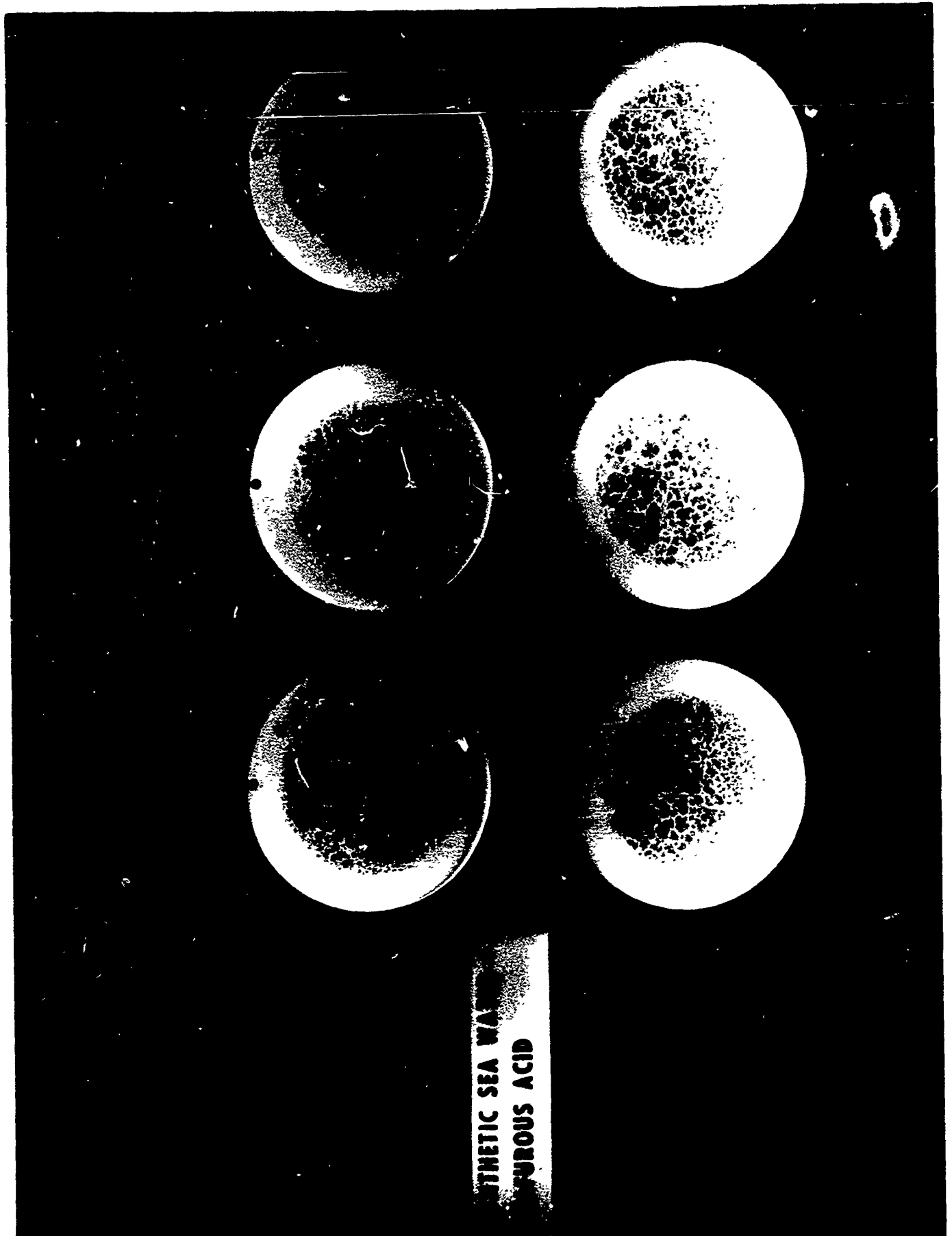
RESULTS OF EXPOSURE OF STEEL SPECIMENS TO 20% NaCl SOLUTION,
20% NaCl SOLUTION/SMOKE, AND 20% NaCl/ACID ENVIRONMENTS



RESULTS OF EXPOSURE OF DISSIMILAR METAL SPECIMENS TO 20% NaCl SOLUTION, 20% NaCl SOLUTION/SMOKE, AND 20% NaCl/ACID ENVIRONMENTS

PHOTO NO: CAN-367435(L)-3-65

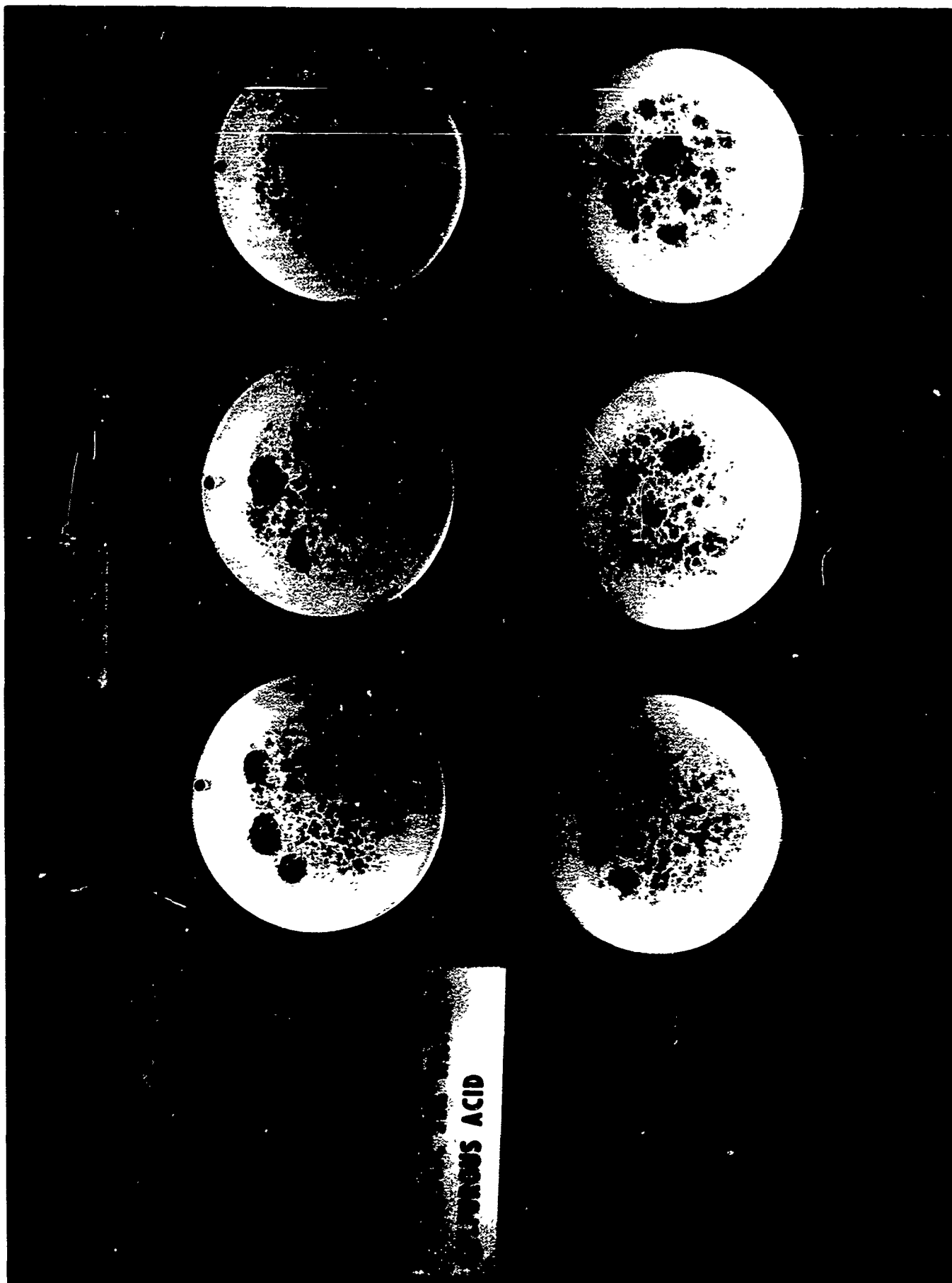
PLATE 16



RESULTS OF EXPOSURE OF STEEL SPECIMENS (COATED WITH A LIGHT OIL CONTAINING 35% INHIBITOR) TO A SYNTHETIC SEA WATER/ACID ENVIRONMENT

PHOTO NO: CAN-367596(L)-4-65

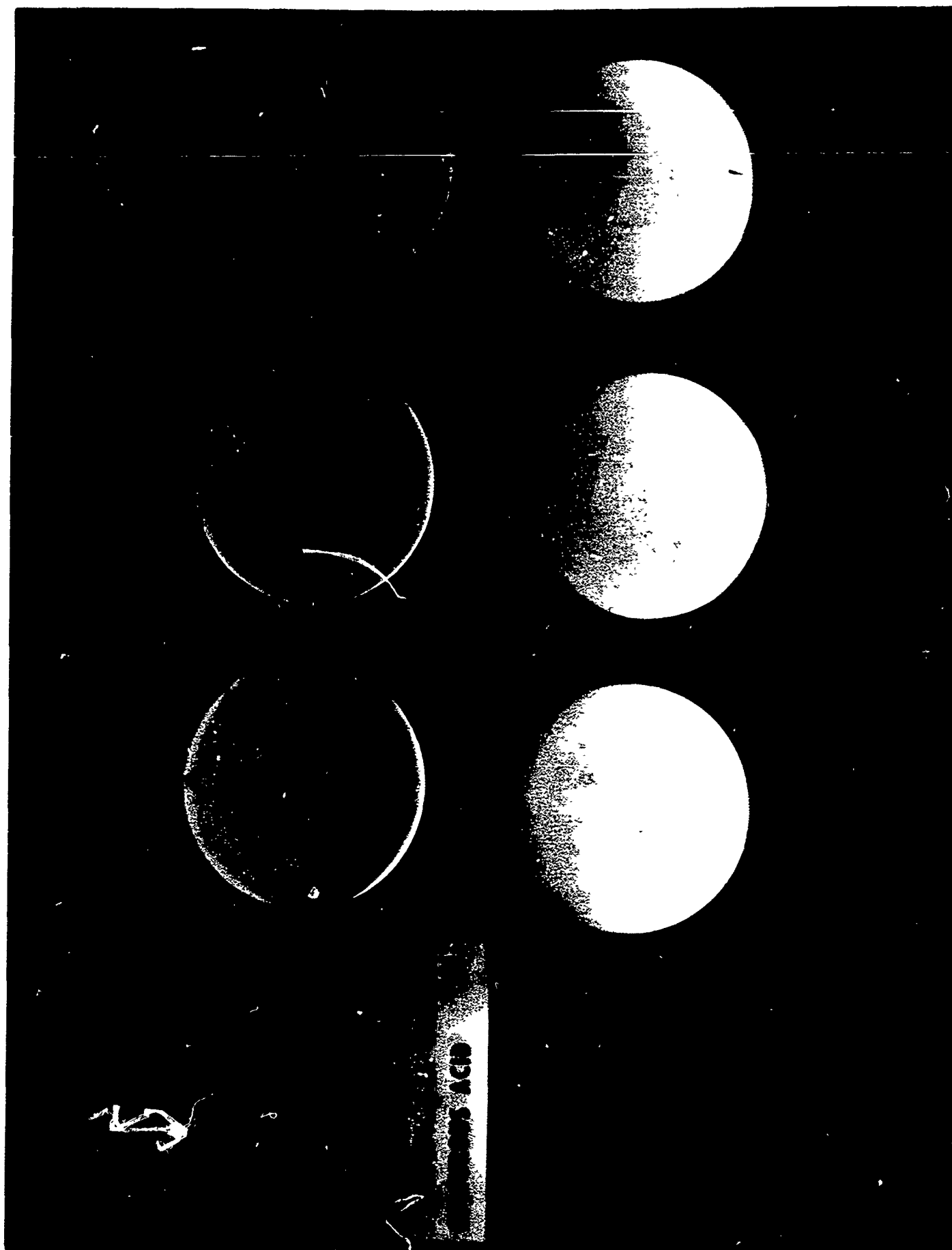
PLATE 17



RESULTS OF EXPOSURE OF STEEL SPECIMENS (COATED WITH A LIGHT OIL CONTAINING 50% INHIBITOR) TO A SYNTHETIC SEA WATER/ACID ENVIRONMENT

PHOTO NO: CAN-367594(L)-4-65

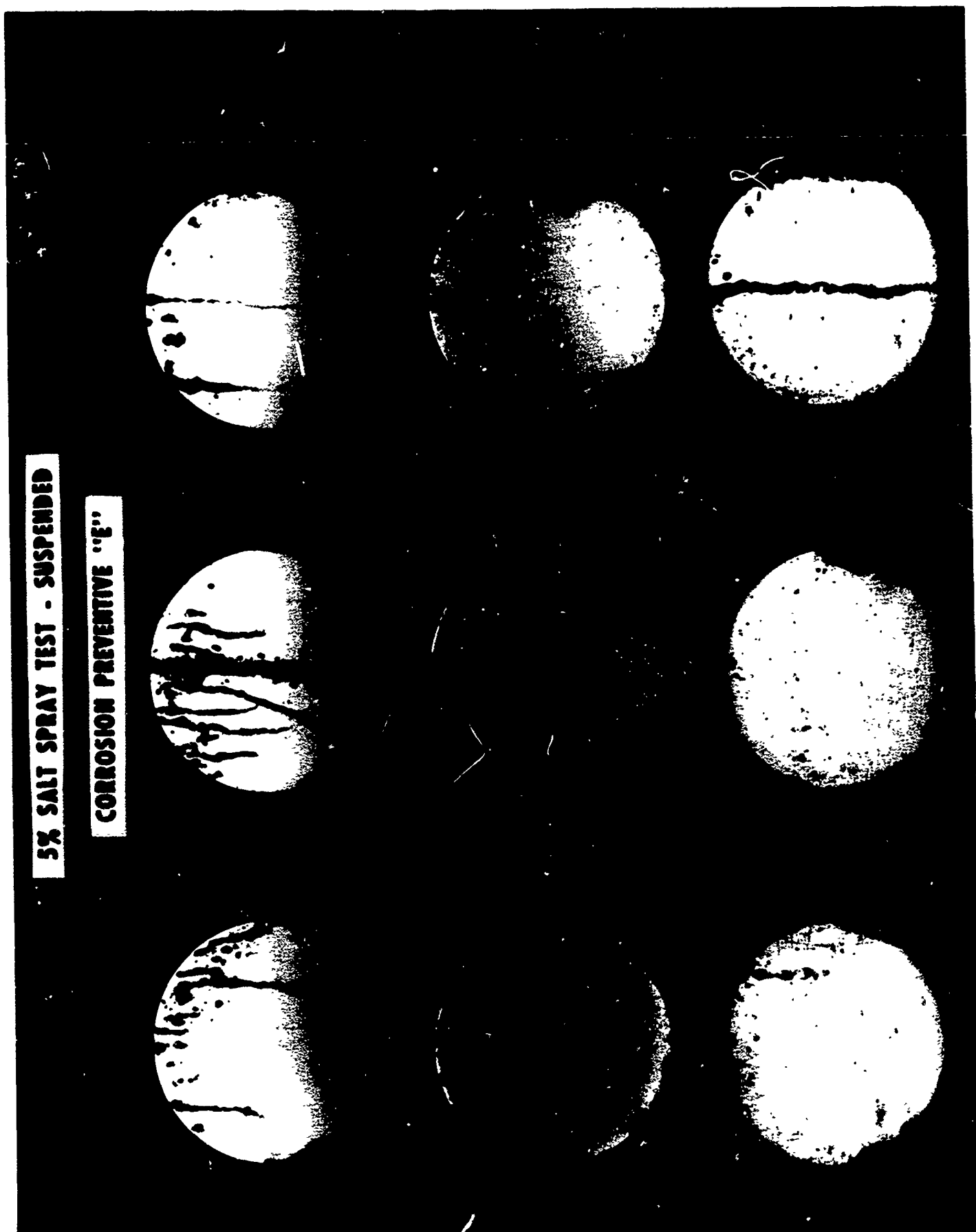
PLATE 18



RESULTS OF EXPOSURE OF STEEL SPECIMENS (COATED WITH A LIGHT OIL CONTAINING 60% INHIBITOR) TO A SYNTHETIC SEA WATER/ACID ENVIRONMENT

PHOTO NO: CAN-367595(L)-4-65

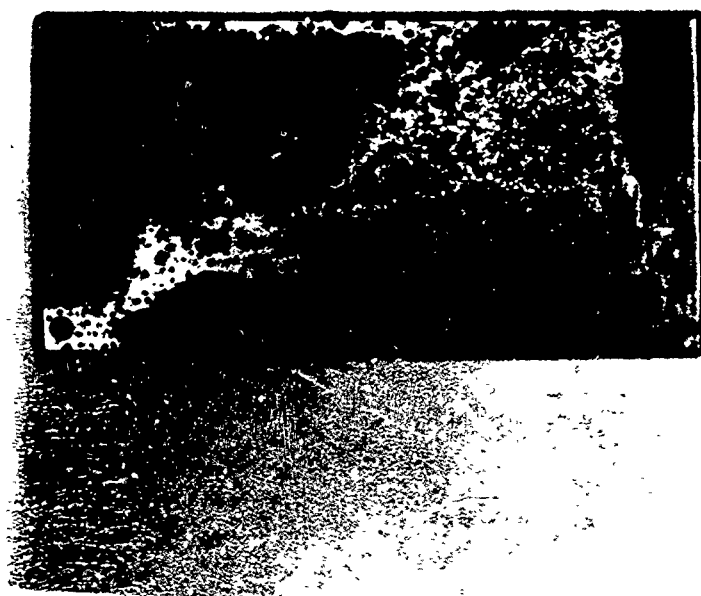
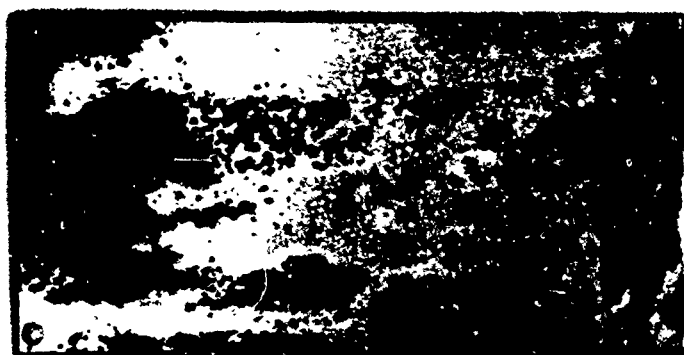
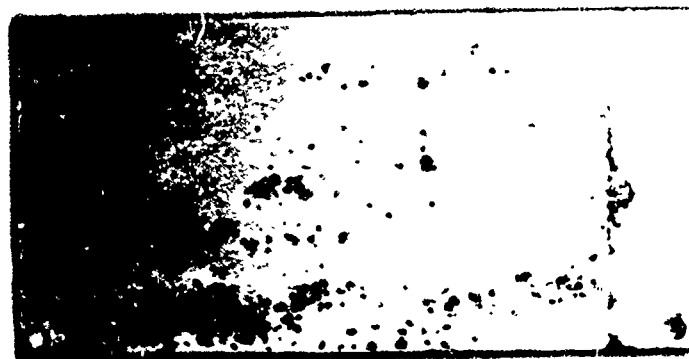
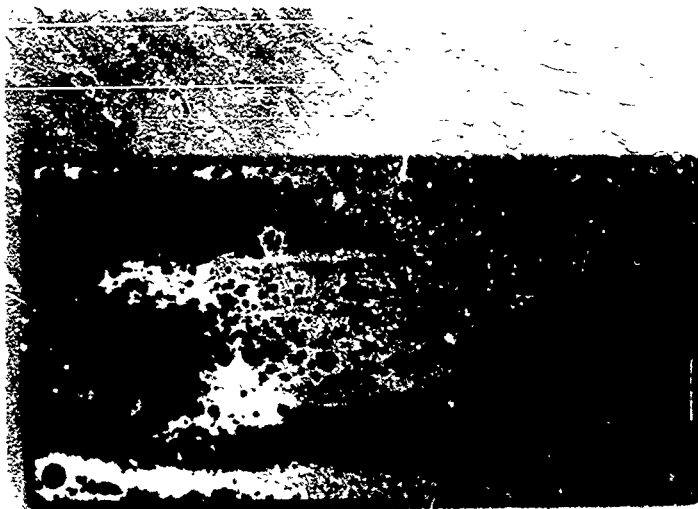
PLATE 19



RESULTS OF EXPOSURE OF STEEL SPECIMENS (COATED WITH A LIGHT OIL CONTAINING 60% INHIBITOR) IN THE 5% SALT SPRAY CABINET

PHOTO NO: CAN-367705(L)-4-65

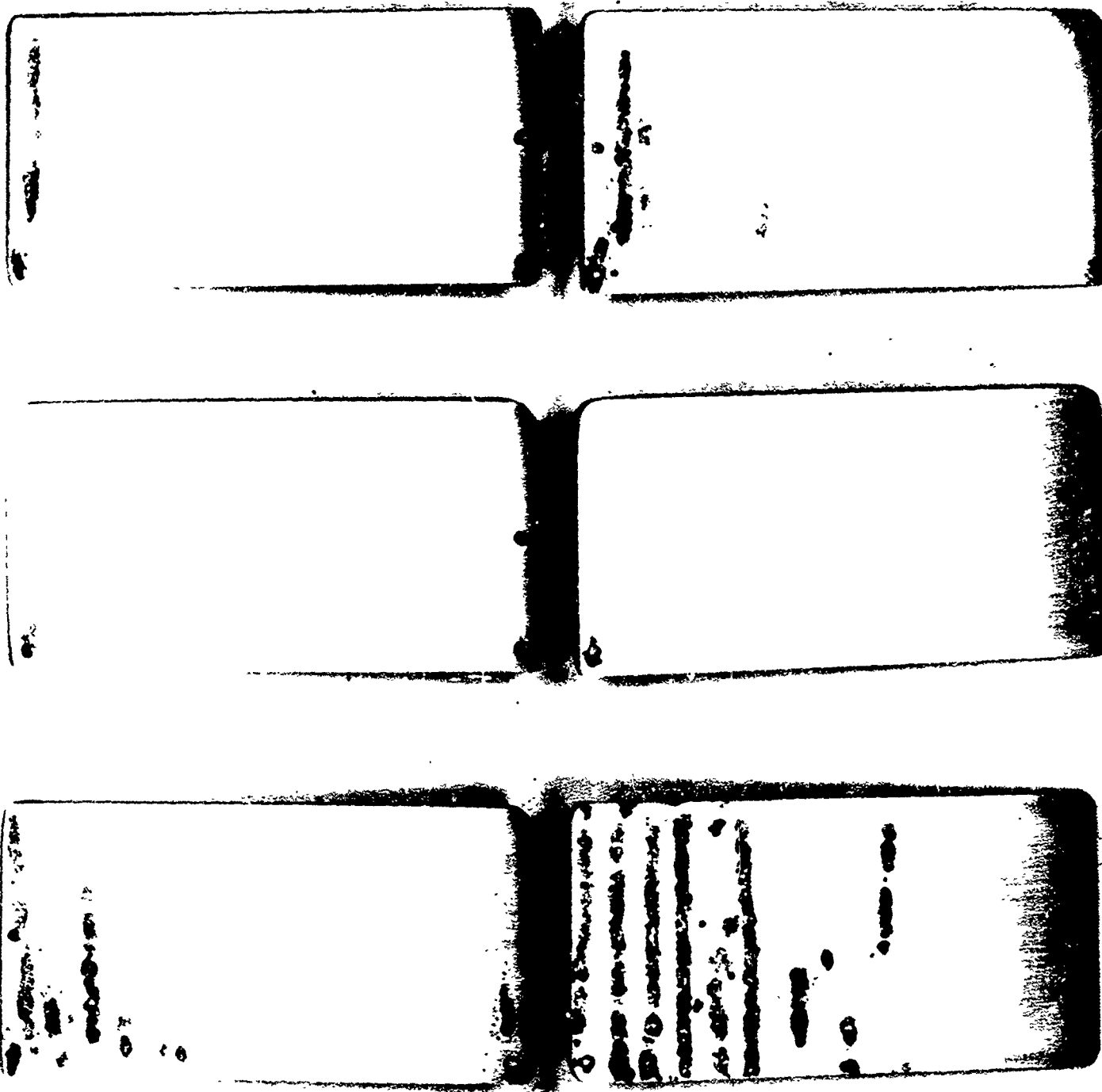
PLATE 20



RESULTS OF EXPOSURE OF STEEL SPECIMENS (COATED WITH A LIGHT OIL CONTAINING
10% INHIBITOR) IN THE 5% SALT SPRAY CABINET

PHOTO NO: CAN-370708(L)-4-65

PLATE 21

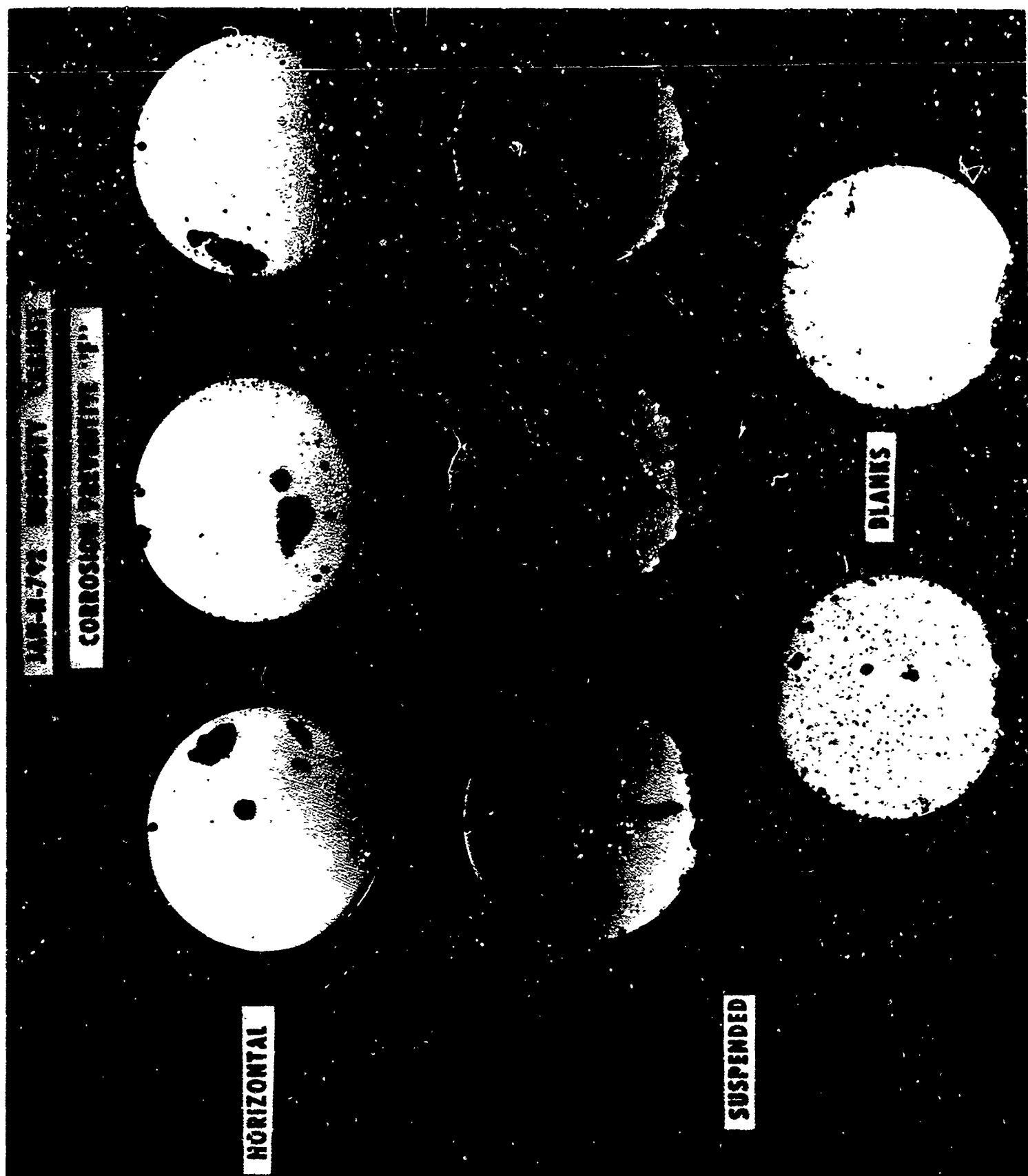


2

RESULTS OF EXPOSURE OF STEEL SPECIMENS (COATED WITH A LIGHT OIL CONTAINING
10% INHIBITOR) IN THE JAN-H-792 HUMIDITY CABINET

PHOTO NO: CAN-370707(L)-4-65

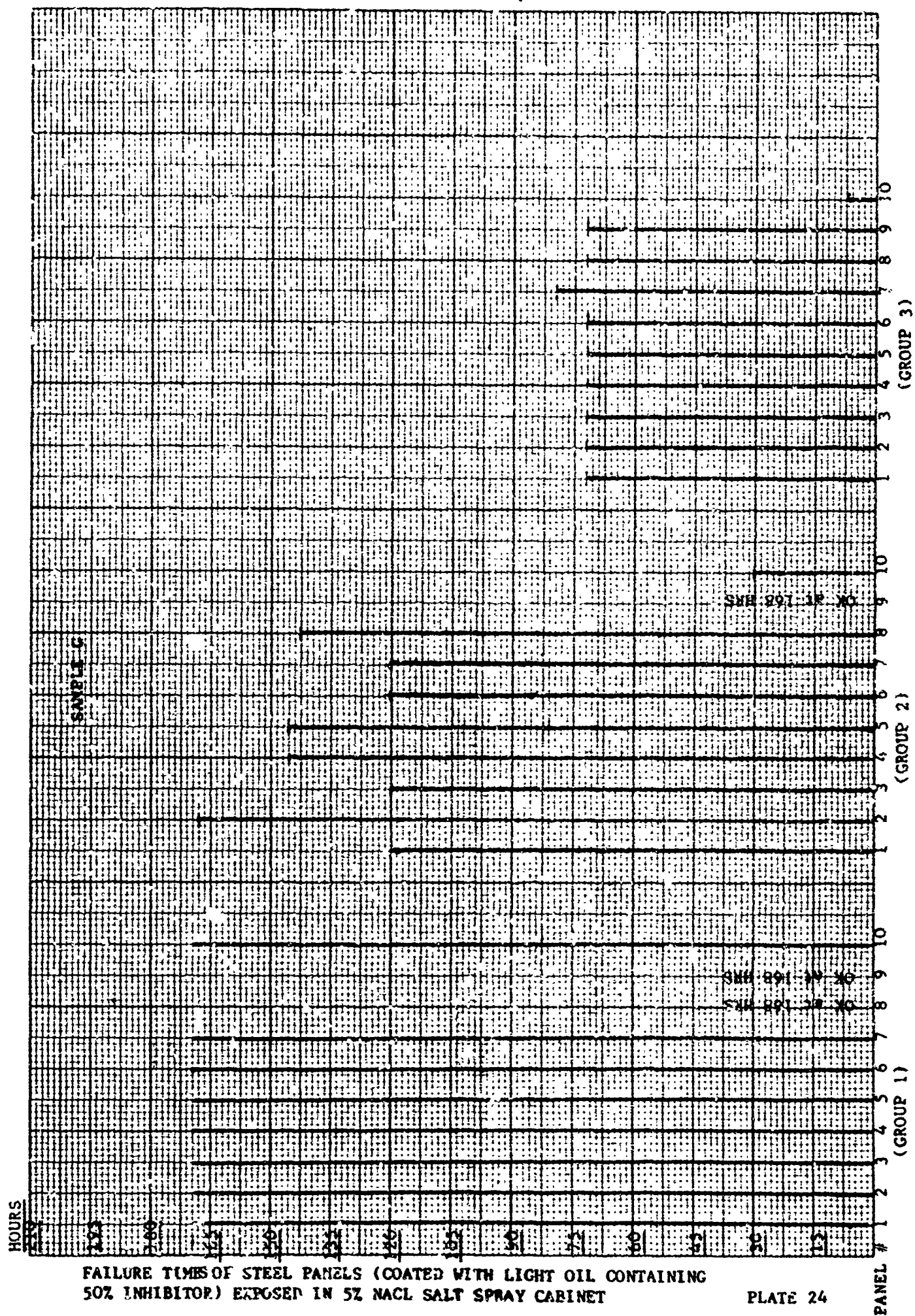
PLATE 22



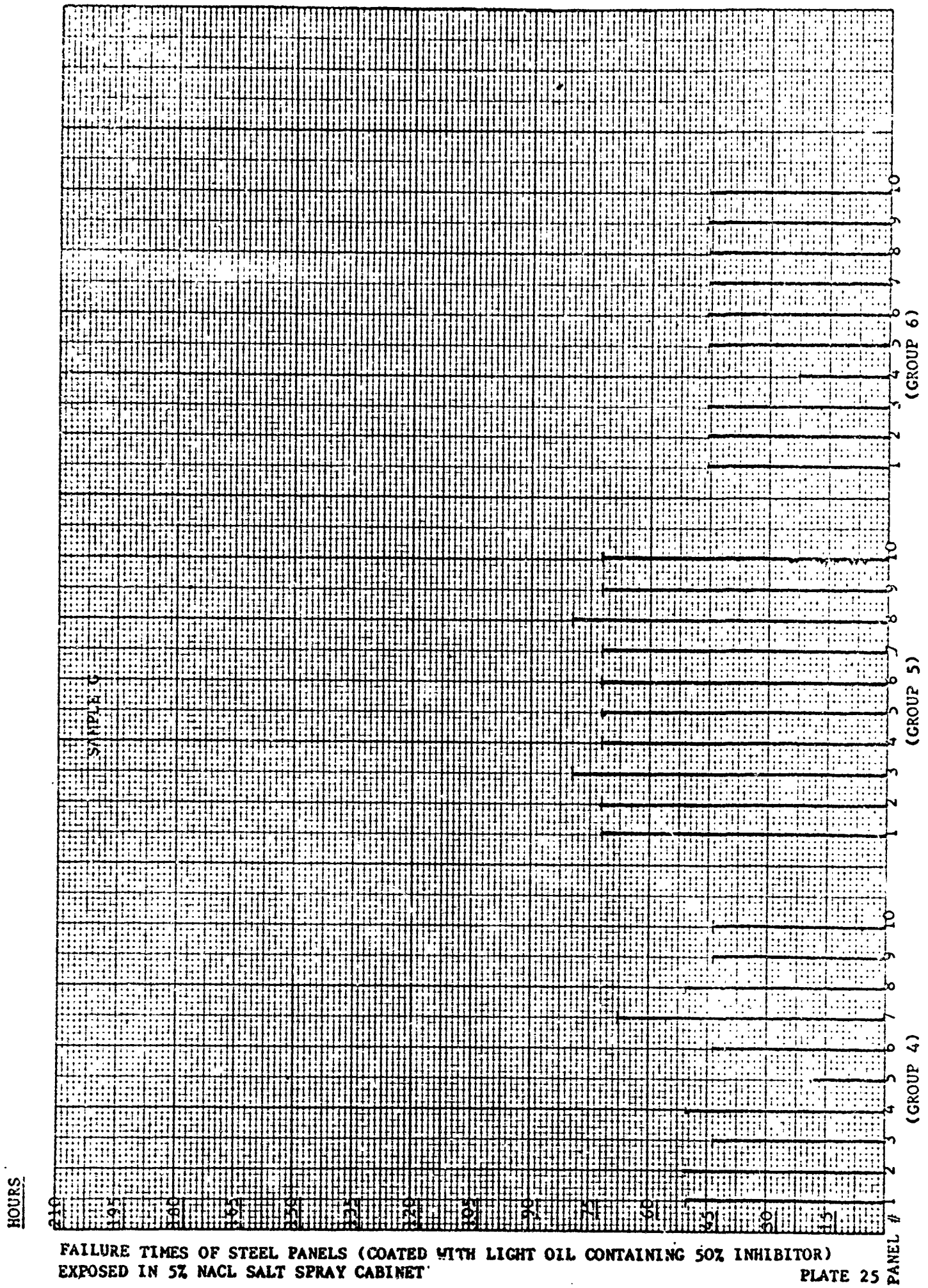
RESULTS OF EXPOSURE OF STEEL SPECIMENS (COATED WITH A LIGHT OIL CONTAINING 1% INHIBITOR) IN THE JAN-H-792 HUMIDITY CABINET

PHOTO NO: CAN-367703(L)-4-65

PLATE 23



FAILURE TIMES OF STEEL PANELS (COATED WITH LIGHT OIL CONTAINING 50% INHIBITOR) EXPOSED IN 5% NaCl SALT SPRAY CABINET

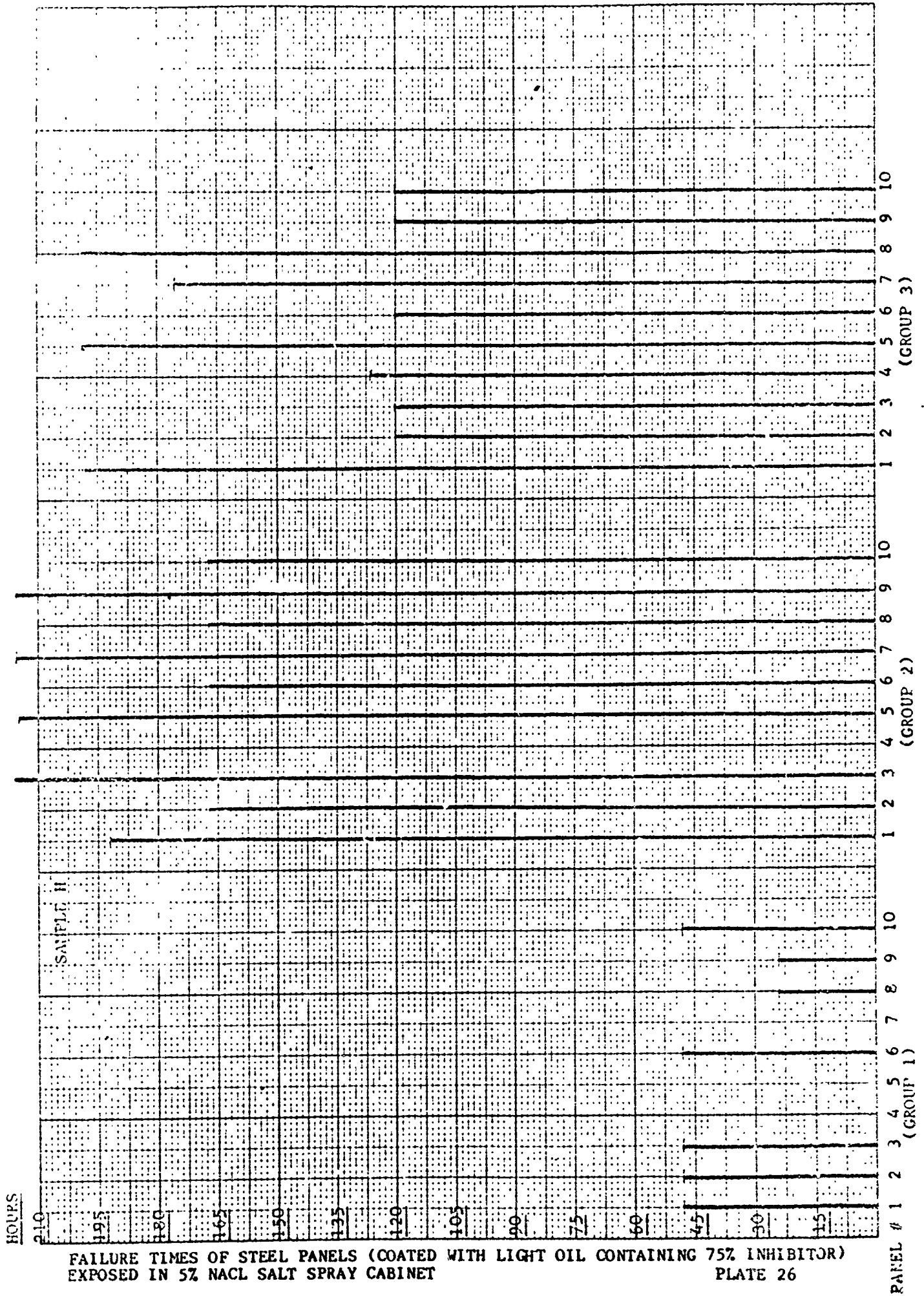


FAILURE TIMES OF STEEL PANELS (COATED WITH LIGHT OIL CONTAINING 50% INHIBITOR)
EXPOSED IN 5% NaCl SALT SPRAY CABINET

(GROUP 6)

(GROUP 5)

(GROUP 4)



FAILURE TIMES OF STEEL PANELS (COATED WITH LIGHT OIL CONTAINING 75% INHIBITOR)
EXPOSED IN 5% NAEL SALT SPRAY CABINET

PLATE 26

