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SURFACE PROTECTION STUDY FOR NAVY PROJECTILES

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13. ABSTRACT (Maximum 200 words)

This report documents the testing and evaluation of various organic and inorganic surface coatings exposed to marine environments.

Results from a comparative series of qualitative performance tests are presented with emphasis on paint primers, and primers plus topcoat. Both laboratory and field testing of an accelerated nature were done on steel substrates with the selected coatings.

Test specimens included both coupons and end items that consisted of Navy, gun-fired projectiles. The coatings examined included three types of powder coatings (epoxy, polyester, and nylon), an electrodeposited epoxy, a metallic-ceramic, an aluminized-phenolic, an inorganic zinc, a two-part epoxy, a silicon-oxide, and an alkyd paint system as control.

The main purpose was to identify surface coatings with improved corrosion resistance, abrasion resistance, and better compliance to environmental standards, than the present paint system used on Navy ammunition components.

The use of trade names and manufacturers' names in this report constitutes neither endorsement nor disapproval of any commercial entity.

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FOREWORD

Annual costs for maintaining the worldwide Navy ammunition inventories have always been measured in millions of dollars. With the present realignments of Navy infrastructure and smaller budgets, any cost saving effort has become more warranted than ever.

Corrosion control measures performed on the hundreds of thousands of projectiles and ammunition components in inventory account for a significant portion of ammunition maintenance cost. The life cycle for the present paint system on a projectile is roughly six to ten years. The surface protection system consists of a phosphate pretreatment, a primer, and a final topcoat. This method has been in use for over 50 years. Although the performance of the present coating can vary between adequate and marginal, many newer coatings offer superior durability as well as better compliance to clean air and environmental standards.

Additionally, Federal and state regulations on hazardous pollutants, have become more stringent as government acknowledges the correlation between poor health and the rise in industrial wastes. Since paint solvents and corrosion inhibitors are known pollutants, every ammunition procurement and maintenance activity is directly affected. Waivers for use of alternative coatings necessary for legal compliance at ammunition depots have become more frequent. In this study, it has been observed that new material technologies developed within the coating industry can meet environmental regulations and still offer good performance.

The purpose of this product improvement effort was to identify alternative, preferably "off-the-shelf", materials and processes that could be used for Navy ammunition. Compatibility with ordnance, associated production factors such as ease of application, and environmental issues were all of prime concern. Several candidate coatings were selected and evaluated in laboratory and in field tests. Relative comparisons and recommendations are presented herein.

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This report has been reviewed by John F. Perrine, Head, Munitions Branch, and Thomas N. Tschirn, Guns and Munitions Division.

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BACKGROUND AND INTRODUCTION

Corrosion of metal can be described as a destructive electrochemical action that usually begins at the surface. There are many texts available describing the oxidation/reduction mechanisms with corresponding transfer of electrons, chemical kinetics, etc. In the larger sense corrosion is a manifestation of the Second Law of Thermodynamics: the Law of Entropy.

The driving forces for metal interacting with the environment are related to the changes in free energy[1] between the chemical reactants and products. Since corrosion is an irreversible and dissipative process, the free energy of the products is always lower. From thermodynamics it can be proven that all metals, except gold and platinum, will corrode in an analogous manner that water will always run downhill to a lower energy level. From the science of kinetics and from everyday experience, these reaction rates can be vastly different (as in the water analogy of a glacier to a waterfall).

Most metals will form a surface oxide when exposed to the atmosphere. Some metals such as aluminum, will form a protective, non-porous, non-conductive oxide layer which stops further corrosive attack. In other metals such as iron or ferrous alloys this oxide layer is porous allowing moisture and oxygen to diffuse through; is conductive allowing electrochemical interaction; and is of greater specific volume and interfacial energy. The oxide spalls off thus allowing the corrosion process to continue unchecked at its own rate.

The rate of corrosion, like many chemical processes, is an exponential function involving temperature, concentrations, activation energies, compositions, etc. Because of the exponential nature, slight changes can have profound effects. The aim of any effort at corrosion control is to reduce the rate. This can be done in several ways such as by controlling the environment, alloying, cathodic protection, using chemical inhibitors, protective coatings, or combinations. For this study, physical separation between the steel substrate and the environment (plus cathodic protection in some cases), via coatings, was the primary method of control.

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[1] Free energy, or the Gibbs function, is a state variable as is temperature, pressure, entropy, etc. It is defined as the difference between internal energy and entropy ($\Delta G = U - T\Delta S$). It is a useful analysis tool along with activation energies and kinetics which determine reaction rates.

HISTORY

Mild to severe corrosive conditions have always been problems in the storage of conventional Navy gun ammunition, both ashore and afloat. Long term storage of ammunition frequently results in at least some light surface rust. Since shore magazines are neither temperature nor humidity controlled, temperature fluctuations permit condensation to readily form on metal parts. The conditions are exacerbated by the high chloride content of a marine environment. Corrosion inevitably occurs during a typical deployment especially wherever bare metal has been exposed by normal handling abrasions that occur during the on-loading and off-loading of ammunition.

Generally ammunition is maintained as long as there are ships afloat that can use it. This can be as long as 30 or 40 years. Appearance rather than functionality is usually the issue in judging the serviceability of the coating; however on rare occasions, projectile components become almost unserviceable when light surface rust is inadvertently allowed to progress into more serious pitting and exfoliation of the base metal. If severe rusting occurs on the bourrelets, the effective in-bore diameter of the projectile is reduced which in turn can lead to increased balloting, initial yaw, and loss of accuracy, thus jeopardizing the goals of the mission. Precise analysis of the effects of corrosion on accuracy could be very costly; the best approach is prevention. Archival documentation (See Appendix A, page A-3) arbitrarily specifying the extent of material loss from projectile bourrelets, illustrates that rusty ammunition has been a recurring problem.

CURRENT IMPETUS FOR PROGRAM

Waiver requests are often received from maintenance and production facilities for surface related problems such as the acceptance of rust pitted projectile bourrelets, the omission of the phosphate pretreatment, and lately for the use of alternative coatings that would meet local air quality standards. The last issue has become increasingly important as fewer projectile contractors can comply with state environmental restrictions using the present paint system. All jurisdictions have limits on the amounts of solvents which may be released into the atmosphere during coating operations. This Product Improvement Program addresses these issues for surface finish of Navy 2T cognizant ammunition.

PRESENT PAINT SYSTEM

Presently the metallic cleaning methods, the interior and exterior surface coatings, and the corrosion protection requirements for Navy projectiles are specified in MIL-P-18948 (Ref. 1). This process has remained almost unchanged for at least 50 years,[2] and starts with a metal degreasing phase. Either a hot

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[2] Original version is Ordnance Specification, O.S. 1427 dated 1944.

alkaline spray or vapor solvent is used for removal of adsorbed machine cutting lubricants and surface contaminants. A zinc phosphate coating (Ref. 2) is then applied to enhance paint adhesion. A corrosion inhibiting alkyd primer coating (Ref. 3) is then sprayed to a thickness of 0.4 to 0.6 mils. Finally an enamel top coat (TT-E-516 or equal) is applied. Color pigmentation for the top coat is determined by the functionality of the ammunition and is governed by NATO and US military standards. Table 1 summarizes the present Navy paint specifications for projectiles of all calibers.

TABLE 1. PAINT SPECIFICATIONS FOR NAVY PROJECTILES

PRETREATMENT **(All over)**	**Zinc Phosphate** **Fed. Spec. TT-C-490, Type I** **Thickness approx .0002 inch.**
INTERIOR	**Cavity Paint (asphalt), MIL-C-450, with Comp A-3 explosive filler.** **Alkyd Primer, TT-P-664, with PBXN-type explosive filler.**
THREADS	**Zn Phosphate only; MIL-G-81322 is used for interplant shipment.**
EXTERIOR PRIMER	**Alkyd Primer, TT-P-664.** **Dry film thickness .0005 to .0015 inch;** **except .0005 to .0010 on bourrelets.**
EXTERIOR TOPCOAT	**Enamel, TT-E-516; Color per MIL-STD-709.**
TOTAL SYSTEM	**Maximum dry film thickness .0015 on bourrelets.**

ENVIRONMENTAL REGULATIONS

Federal, state, and local antipollution regulations set limits on the amount of volatile organic compounds (VOC) released into the atmosphere. Civil penalties may be imposed for non-compliance, hence all attention has become focused on environmental issues throughout the coating industry. The U.S. Environmental Protection Agency (EPA) has defined a VOC as any compound which reacts with nitrogen oxide, in the presence of ultraviolet light, and produces ozone in the lower atmosphere.[3] The EPA has also restricted certain halogenated solvents that react with and deplete ozone in the upper atmosphere.[4]

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[3] Ozone, a triatomic allotrope of oxygen, is a major component of smog. At high ambient levels, it is harmful to the respiratory system and can also damage plant life. A maximum concentration consistent with good health is generally agreed to be approximately 0.12 ppm.

[4] The presence of ozone in the stratosphere, in contrast to lower elevations, is very beneficial since it absorbs short wave ultraviolet solar radiation. Skin cancer, eye disease, and damage to marine life, crops and forests increase as more of this radiation reaches the earth. International agreements were established at the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987.

Paints consist of a mixtures of pigments, chemical resins, and solvents. One function of a solvent is to reduce the viscosity of the mixture to a consistency which can be sprayed or brushed. Solvents eventually evaporate leaving behind the pigment and cured resin. Typically acetone, and aromatic (benzene ring) compounds such as toluene and xylene, are used for fluidity and evaporate quickly. These can be reduced at the expense of increased viscosity. Other solvents such as methyl ethyl ketone and esters evaporate more slowly and are necessary for proper curing and cross linking of the resin molecules. Paint manufacturers have been reformulating and introducing new products with lower solvent content but usually these high-solids paints are more viscous and difficult to apply. Alternatives are coatings in which volatiles have been eliminated completely. These include the water soluble, electrodeposited, and powder types. Several of these coating types have been tested in this program.

Lastly there are Occupational Health and Safety Agency (OSHA) regulations for the elimination of carcinogens, hexavalent chromate compounds and heavy metals. Certain prohibited materials such as zinc chromate ($ZnCrO_4$) and lead compounds had previously been used as pigments in anticorrosive coatings,[5] but now alternatives such as zinc-rich primers and zinc molybdate ($ZnMoO_4$) are more widely used. One type of zinc rich coating (inorganic zinc) has been included in this program.

OBJECTIVES

The purpose for this program was to demonstrate and make recommendation for a coating system(s) for use on projectiles and related ammunition that would attain as many of the following objectives as possible.

- Greater durability with resistance to corrosion and abrasion.
- Greater economy offering equal or better performance.
- Offer potential use in both new production (applied when projectiles are empty) or in maintenance (on loaded ammunition).
- Meet or exceed EPA and OSHA regulations with equal or better performance.
- Create the least impact to present production and maintenance facilities and equipment.

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[5] Metal based paints containing toxic white lead (lead carbonate) and red lead (lead tetroxide) had also been used to reduce marine growths on hulls of wooden ships. The Romans and ancient civilizations are reported to have used these materials for the same purpose.

APPROACH

ESTABLISHING PERFORMANCE REQUIREMENTS

The obvious starting premise is that a coating system should resist deterioration and protect the substrate metal in the environment of its intended use. Since the required degree of protection is a function of the environment, the first step was to characterize the latter so as to choose appropriate coatings. The environmental effects on Navy gun ammunition were roughly divided into three groups in the relative order of prevalence as follows.

Major Influence

Resistance to marine atmospheric environment - Although not in direct contact with seawater (until expended), Navy projectiles are exposed to salt laden air and humidity. The present primer coating specification calls for resistance to 336 hours of salt spray per ASTM B117. A literature search (Appendix A, pages A-4 and A-5) revealed that 336 hours is also about average for most coatings, but many coatings are specified for up to 500 or 1000 hours.

Surface Integrity - Hardness, good abrasion resistance, and adhesion were judged as very desirable mechanical characteristics for a good surface coating. Projectiles are stored in metal pallets and are subjected to abrasions and mild localized impacts during normal handling and transfer at loading plants, shore depots and aboard ship. This is especially true for the large caliber projectiles that are handled in bare configuration, i.e. not in an individual container (tank). A coating must also adhere well during cyclic thermal expansion and contractions.

Moderate Influence

Weather - Resistance to the effects of weather, including heat, rain, and ultraviolet radiation were judged as desirable but not absolutely necessary since gun ammunition is not normally stored outdoors for any significant length of time. A moderate degree of fading can be tolerated as long as colors remain easily distinguishable for proper identification of the type of ammunition.

Oil and hydraulic fluid resistant - Ammunition is exposed to machinery aboard ship. Some periodic and superficial contact with lubricants and hydraulic fluid spills is to be expected.

Corrosive atmosphere - Exposure to ambient sulfur gasses from the combustion of fossil fuels is probable at an urban manufacturer or seaport, otherwise highly corrosive industrial environments are unlikely. In rural locations (e.g. McAlester Army Ammunition Plant, Oklahoma, or Crane Army Ammunition Activity, Indiana) minute hygroscopic particles of airborne soil and fertilizer are known to contribute somewhat to atmospheric corrosion. Because of the low concentrations of these chemicals, their effects would only become significant in long term storage.

Minimal or No Concern

The service life of Navy gun ammunition is not normally subjected to the following environments therefore these were not factors in the selection of a coating:

a. Strongly acid or alkaline resistance.

b. Heat resistance. (Intumescent or ablative coatings had been considered in another program, but only for safety cookoff issues.)

c. Solvent or chemical resistant.[6]

d. Continuous seawater immersion.

e. Attack from anaerobic bacteria and other microorganisms.

Also the specific microstructural form of corrosion usually encountered on ammunition has been observed mostly as uniform attack, i.e. over the entire surface. Some crevice and galvanic corrosion occurs at the rotating band juncture; however, the exact mechanism of corrosion was not a factor in coating selection. The premise is that if a coating provides an effective barrier to the environment, corrosion of any form is prevented.

SPECIAL REQUIREMENTS FOR GUN AMMUNITION

Thickness Restrictions

A total coating film thickness not exceeding 1.5 mils is specified for projectile bourrelets (Ref. 4) because of dimensional interfaces within the gun barrel.[7] This imposes a severe

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[6] Chemical agent resistant coatings (CARC) are specified by the Army for use on all ammunition and ground equipment. CARC's also have limits on spectral as well as specular reflectance. These coatings must be resistant to chemical and biological decontamination solutions such as sodium carbonate, supertropical bleach (STB) and Decontamination Solution 2 (DS2; MIL-D-50030). Neutralization of toxic agents is either through oxidation or hydrolysis making the decon solutions very corrosive to metals. Although Navy ammunition is not directly exposed to the same battlefield threats, the Army paint system was included in this program for comparison.

[7] If a dimensionally oversize projectile becomes jammed in the forcing cone or origin of bore area of the gun, the breech cannot be closed, the gun cannot fire, nor can the projectile be immediately removed. If the gun is hot (e.g. ~500°F) from previous firings, and is thus fouled, a potentially dangerous cookoff may occur. In order to prevent this scenario, projectile inspection includes 100% ring-gauging before issue to the fleet.

limitation on most coatings since such thin layers usually do not form sufficient physical barriers to water and oxygen. Electrical resistance is also lower with a thin coating thus aiding electrochemical corrosion. (Many "barrier" type coatings offer excellent performance but at film thicknesses over 7 to 10 mils which is unacceptable for projectiles.)

Explosive Compatibility

Chemical compatibility between the coating system and the explosive filler is a major safety issue. Both the cured and uncured phases of the explosive must be considered. The final polymerization of a cast plastic bonded explosive (PBX) occurs within the projectile. Before a PBX has fully cured, potentially reactive materials such as the isocyanates and plasticizers should not enter into unwanted side reactions with an interior coating. After the explosive cures, it then remains in direct contact with the coating for a prolonged period.

Analysis and testing is required to ascertain that, of the many constituents present, none will interact exothermically or in the formation of more sensitive explosive products. If a pressed explosive, such as Composition A-3, is used as the main charge, curing inside the projectile is not an issue and only long term contact with the coating needs to be considered.

Color

Pigmentation of the final top coat, identification color bands, markings, etc. of all types ammunition are specified by NATO and Military standard (Ref. 5). For this investigation, olive drab, shade no. 34087 of FED-STD-595, was taken as the baseline since it is the most prevalent color of explosive ammunition items. Attempts were made to obtain all coating samples of this OD color but either pigmentation was inherently not possible to formulate for a particular coating, or else the cost for small quantities was excessive. Since the test coatings could not be pigmented, an OD finish coat was necessary.

Ammunition Maintenance

Scheduled maintenance typically involves refuzing and changing cargo expelling charges or other components of limited life. Repainting is done as required when the exterior coating condition is judged against visual standards (Ref. 6). Except for minor touch up, the present repainting process calls for abrasive blasting to bare metal, followed by the application of primer and top coat (Ref. 7).

The zinc phosphate pretreatment is not included in the maintenance documentation. The reason for this omission is simply the lack of facilities at most ammunition maintenance depots (and possibly the attractive short term cost savings). A recent demonstration test has shown that omitting the zinc phosphate pretreatment, as is the practice in maintenance, results in loss of primer adhesion and poor performance (Ref. 8).

Another consideration in the choice of a new coating for use on explosive ammunition during a maintenance cycle is the obvious upper limit on curing temperature.[8] Unfortunately it was found that many coatings with lower VOC's (such as powder coats), and with better performance (such as metallic-ceramics) cure by heating to upwards of 300°F.

SELECTION OF COATING CANDIDATES

The search for improved coatings was limited to existing materials which were already in widespread use. Developmental, unique or state-of-the-art coatings were avoided. Having multiple sources for a material was also desirable for competitive bids during production. Actual selection of candidates was done based on both experience at NSWC and through information conveyed by other knowledgeable sources in industry.

DESCRIPTION OF COATINGS EVALUATED

GENERAL DESCRIPTION

Polymers - Several types of organic polymer coatings were tested including an alkyd, an epoxy, a nylon, and a polyester. Generally polymers degrade by the rupturing of bonds within the polymer chains because of chemical attack (including ozone), heat (infrared) or ultraviolet (UV) radiation.

When polymer chains are broken the effective molecular weight and physical strength is reduced. Also increases in water absorption and residual stresses lead to cracking. Individual monomer units or chemical side-groups from the chains may either volatilize or produce undesirable byproducts. The macroscopic physical evidence of the degradation is visible as chalking in the early stages, followed by blistering and exfoliation.

Another failure phenomenon in polymers can occur from the ionizing effect of UV radiation. Rather than broken bonds, excessive cross-linking of the polymer chains, may lead to failure through brittleness. Whatever the failure mode, well designed coatings address degradation by the use of chemical stabilizers and radiation blocking pigments.

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[8] During development testing loaded projectiles are subjected to temperature and humidity fluctuations per MIL-STD-2105. A high temperature extreme of 165°F has been demonstrated to be safe on new ammunition, but it is felt that this extreme should be avoided with in-service ammunition.

Ceramics - Compared to metals or organic materials such as polymers, ceramics are very resistant toward atmospheric attack. (This is predictable since many ceramics such as rocks, clay, sand, even ice are found naturally in the earth's atmosphere.) The relative stability of ceramic coatings is attributable to the type of interatomic bonds which are generally covalent. High temperatures are usually necessary before chemical attack begins. Test samples included a metallic-ceramic and a polymer with inorganic, silicate monomer units (Siloxirane®).

SURFACE PREPARATION

A zinc phosphate pretreatment is specified as the optimum surface preparation by the manufacturers of most of the coatings tested. Phosphating involves a chemical reaction with a ferrous surface whereby non-metallic and non-conductive crystalline structures (hydrated $Zn_2Fe(PO_4)$ and $Zn_3(PO_4)_2$)are formed. The proportions of the two structures, the grain size, and the thickness deposited depends on process variables, which include temperature, pH and chemical formulation of the bath or spray.

Since phosphate coatings are on the order of 0.2 to 0.3 mils in thickness, they offer very limited corrosion protection alone. The main purpose is to provide a microscopically porous surface that mechanically retains the applied coating layer by capillary interlocking. This reduces the probability of breaking the paint film by thermal expansion, abrasion, or impact. Secondly the phosphating inhibits the spread of underfilm corrosion in a direction parallel to an exposed area of bare metal. (Phosphate coatings also have other uses such as to reduce friction and galling, to reduce reflectance of light, and to hold oils and lubricants.)

Properly preparing the surface by cleaning, degreasing and phosphating if required, is the most important and often the most complicated part of any coating operation. Many production problems are usually traced to faulty surface preparation. For this study all coating application and surface preparation was performed either under laboratory conditions or on a closely monitored production line by the respective coating contractors. Additional information regarding surface pretreatments is available in References 9 through 11.

ALKYD PRIMER (TEST CONTROL GROUP)

The current primer coating used for Navy gun ammunition is applied over a zinc phosphated surface. The primer consists of rust inhibiting pigments in an alkyd resin binder. The specified film thickness is less than 1.0 mil. Although this is insufficient as a physical barrier to corrosion, the chemical properties of the pigment act as an inhibitor. Instead of the traditional chromate or lead compounds, zinc phosphate is used as the rust inhibiting agent within the alkyd binder. The primer also contains a high percentage of iron oxide (Fe_2O_3). VOC content is listed as no more than 420 grams per liter. The drying mechanism is by solvent evaporation and curing is by oxidation of the resin at room temperature. Atmospheric oxygen is absorbed by the resin to create a polymeric chemical structure.

This primer is relatively quick drying, low cost, and easily applied with standard spray equipment. Alkyds are generally not intended for use in severe environments and are not as abrasion resistant as other coatings. A standard five percent salt spray exposure of 336 hours is specified.

All samples of this coating were obtained through Scranton Army Ammunition Plant operated by the Chamberlain Manufacturing Corporation. Preparation was done under identical conditions and specifications as Navy 5-Inch/54 ammunition being produced under a current contract. A block diagram of the application process is shown in Appendix B, page B-3.

POWDER COATINGS

Powder coatings are available with different resins and compositions depending on the usage and chemical resistance required. Three types were tested in this investigation: nylon, polyester and epoxy powders.

Powder coating technologies have been widely used in industry for over ten years. The fact that they are applied as powder means that there are no solvents and no VOC's. The powder contains all other elements of a paint system such as resin, pigments, additives, etc. Powder particles are sprayed and electrostatically attracted to the work surface. The equipment involved is relatively low cost. Oven curing at approximately 430°F is needed for paint particles to melt and fuse to the substrate.

To properly prepare the substrate for a powder application it must be adequately cleaned, degreased, and scoured or abraded such as by grit blasting. Phosphating is often not specified under powder coatings. The phosphate structure would decompose at the high curing temperatures as the water of crystallization is lost. (Uncoated zinc phosphate is temperature limited to about 225°F in open air for no more than 15 minutes.) An abrasive blasting operation is generally more economical than a chemical conversion coating, therefore powder coatings offer an advantage in that regard.

Test samples of these coatings were obtained at NSWC Dahlgren, and through the ISPA Company, Baltimore, Maryland. Powders were manufactured by Farboil Company of Beatrice Chemical Division.
A block diagram of the application process is shown in Appendix B, page B-4.

INORGANIC ZINC SILICATE

It is well documented that inorganic zinc (IOZ) is unaffected by most weather related environments including ultraviolet radiation and high humidity, is very abrasion resistant, and is anodic compared to steel. IOZ coatings are used in marine applications and in high sulfur dioxide, industrial environments. The particular type tested is covered by specification DOD-P-24648 (Ref. 12) and is intended as a primer applied over a clean abrasive-blasted surface.

"Inorganic" refers to the binder, which is a matrix of zinc silicate, into which zinc dust has been added. The zinc silicate bonds to the steel substrate by forming a chemical compound of iron and silica and does not undercut from localized corrosion. Except for very strong acids or bases inorganic zinc coatings are relatively inert. It was observed that the coating can sustain scratches down to the substrate since steel is relatively cathodic and remains electrochemically protected. Also the reactant products ($ZnCO_3$, $Zn(OH)_2$) often bridge over small scratches or pinholes.

Inorganic zinc had a flat grey appearance. Surface texture, similar to 200-grit abrasive paper, provides a good base for topcoat adhesion. An advantage of inorganic zinc is that there is no shrinkage during drying or curing which takes place at ambient temperatures. This eliminates residual stresses in the coating film and the potential for cracking. A water soluble type of inorganic zinc, containing no VOC's, was used for this evaluation.

In the initial test phase, the inorganic zinc coating samples were obtained directly from the chemical manufacturer: Inorganic Coatings, Inc., Malvern, PA. In later test phases, samples were obtained from Coating Technology, Inc., Malvern, PA using material procured from the former. A block diagram of the application process is shown in Appendix B, page B-5.

CATHODIC ELECTRODEPOSITED EPOXY PRIMER (E-COAT)

E-Coat was chosen because of its widespread use especially in the automotive industry. Military vehicles and most car companies have been using E-coat on wheels, fenders, radiator supports and other chassis items exposed to severe environments. Application is by immersion into an aqueous bath of electrically charged paint particles. Very uniform coverage results with film thickness determined by the applied voltage and paint conductivity. According to the literature (Ref. 13 and vendor), a thickness of 2.0 mils is adequate for long term environmental exposure.

Acrylics and epoxies are commonly used paint binder systems which can be made water soluble for E-Coat applications. An epoxy E-Coat covered by MIL-P-53084 (Ref. 13) was tested. A zinc phosphate pretreatment and a 350°F heat curing cycle are required. VOC content, lead, and prohibited chromate compounds were all within acceptable limits. A disadvantage in E-Coating is the high capital investment for special immersion tanks and equipment needed.

All test samples were procured through MetoKote Corporation, Lima, OH. Material used in Phase I was Pittsburgh Paint and Glass Co. PPG3002; material used in the later test phase was an improved version: PPG-CR640. The BASF Corporation is also a source of this material. A block diagram of the application process is shown in Appendix B, page B-6.

METALLIC-CERAMIC

These coatings are commonly used to protect against salt water corrosion and oxidation at high temperature which would destroy other types of organic polymers. Jet aircraft engine parts, landing gear axles, and aircraft stabilizers are examples of some uses. The coating consists of a water-base inorganic composition of powdered aluminum in a chromate/phosphate binder. The coating components provide anodic corrosion protection of the steel substrate.

Surface preparation consists of abrasive blasting and degreasing. After spraying and heat curing the coating forms a ceramic structure. Other intermediate steps make this somewhat labor intensive. The first coat must be burnishing, or lightly abraded, then a second coat applied. The coating tested was covered by MIL-C-81751, Type I, Class 3 (Ref. 14).

Initial test samples were obtained directly from the chemical manufacturer: Whitford Corporation, West Chester, PA. Samples for later tests used the same material as applied by Plas-Tech Co., West Chester, PA. (Sermatech Int'l Inc. also markets material meeting the same specifications.) The initial samples of this material had an optional ion vapor deposited (IVD) film of aluminum on the steel substrate prior to the main coating. The IVD was omitted from later tests as unnecessary. A block diagram of the application process is shown in Appendix B, page B-7.

SILOXIRANE® (SILICON-OXIDE/AROMATIC-OXIRANE)

This is a proprietary organic-inorganic coating originally developed by Advanced Polymer Sciences, Inc. for the aerospace industry. It is highly resistant to most acids, alkalis, solvents and other chemicals. Typical uses are for holding tanks, pumps, heat exchangers, fluid handling components, etc.

The cured chemical structure is a high-density, cross-linked polymer consisting of a silicon oxide group (inorganic) linked to an aromatic oxirane (organic). From the marketing literature, this coating has the flexibility and toughness of a polymer together with the corrosion and temperature resistance of silicon oxide. The coating specimens tested had the appearance of a glazed ceramic which was almost impossible to scrape off with hand tools.

VOC content is listed at 9 grams per liter which is very low. The coating is applied by spraying onto an abrasive blasted, clean surface. The curing stage requires four hours at 200° to 250°F.

A disadvantage is the relatively high film thickness recommended. Test samples had significantly less than the recommended film thickness of 16 to 20 mils because of the dimensional limitations for gun ammunition. A block diagram of the application process is shown in Appendix B, page B-8.

ALUMINIZED PHENOLIC

Aluminum paints have long been used to protect steel against corrosion at high temperatures. (The microscopically small aluminum flakes pack down to form an impervious layer which is also anodic to iron.) Various binder media are used in aluminum paints. The aluminized phenolic coatings were originally developed by the Boeing Company as dry-film lubricants for fasteners where high temperatures are encountered. Projectiles and threaded fasteners share a similar requirement in maximum coating film thickness, i.e. anything in excess of one or two mils is unsatisfactory. These coatings also show excellent resistance to the effects of humidity, salt spray, solvents, and other chemicals.

The coating is covered by MIL-C-85614 (Refs. 15 and 16). It is applied over a zinc phosphated surface and heat cured at 350°F for 1 hour. Test samples were obtained through Coating Technology Inc. using Everlube 6150 and 9301 made by Great Lakes Chemical E/M Corp., West Lafayette, IN. (The equivalent low VOC replacement for 6150 is 9301; both meet the same military specification.) A block diagram of the application process is shown in Appendix B, page B-9.

EPOXY PRIMER

This coating has a two-part epoxy resin binder. The various pigments include titanium oxide, zinc phosphate and an anti-corrosion additive. It is presently used by the Army with excellent results for 155 mm projectiles. Epoxies are generally more moisture and abrasion resistant than alkyds; therefore it was expected that this coating would be superior to the alkyd control.

The coating is applied over a zinc phosphated surface and quickly dries at ambient temperature. VOC is listed at 420 grams per liter; but this can be adjusted to meet the most stringent local requirements. This coating is covered by MIL-P-53022 (Ref. 17) and is manufactured by the Sherwin-Williams Company, Chemical Coatings Division.

All samples of this coating were obtained through Scranton Army Ammunition Plant operated by the Chamberlain Manufacturing Corporation. Preparation was done under identical conditions and specifications as Army 155mm ammunition being produced under a current contract. Application process is similar to that of the alkyd primer presently used.

FINISH COAT

None of the test coatings could be obtained in the required olive drab color. In some cases special formulations of pigments for an exact match were possible, but the added expense for the small quantity needed in this program was not justified. In many cases, such as the metallic-ceramic coating, E-coat, or IOZ, pigmentation was inherently not possible.

In the coupon tests pigmented finish coats were usually not applied so as not to introduce another variable and complicate the characteristics of the base coatings. For the end item projectile evaluations the physically larger size permitted simultaneous exposure to the environments with a symmetrical half of the item having a finish coat.

The same film thickness of the present Navy specified enamel top coat, TT-E-516, was applied to the test items. The Army 155mm components were top coated with enamel in accordance with MIL-E-52891, also manufactured by Sherwin-Williams. Specification requirements for the latter show greater resistance to accelerated weather and salt spray tests.

OTHER - For other coatings that were considered, see Appendix C.

TEST METHODS

Many types of destructive and non-destructive tests have been developed for quantitative and qualitative evaluation of surface coating degradation. Among these methods are infrared thermography, acoustic emissions, scanning electron microscopy and others. Often good results can be obtained after proper equipment setup, calibration, and experience. Some of these methods such as electrochemical impedance measurements are routinely used at NSWC but only for supplementary information in detecting incipient corrosion.

Ultimately the simplest, most cost effective, and probably the best method of evaluating the extent of corrosion is via the senses of an experienced observer. Accurate qualitative judgements were made by comparison to visual ASTM standards (Ref. 18), and by relative comparisons between the candidate and the control coatings, for surface chalking, blistering, undercutting at scribe marks, etc. Thickness, hardness, and adhesive measurements were also taken before and after test exposure.

MARINE ATMOSPHERIC EXPOSURE (NSWC FIELD TESTS, REF. 19)

Since corrosion evaluation under normal conditions can be a long and protracted process, accelerated testing is common practice. Two such tests were used in this evaluation and were devised at NSWC Carderock Division, to induce faster degradation in test coatings. One of these tests, termed Marine Atmospheric Exposure (MAE) contains all of the essential components of an exterior shipboard environment: exposure to salt-laden air on a continuous basis, diurnal ultraviolet radiation, ambient (unmonitored) sulphur dioxide from passing ships, and high meteorological temperature and humidity, all at semitropical latitude (Ft. Lauderdale, FL). This is considered a severity test for ammunition since storage conditions are neither outdoors nor always in proximity to salt air.

SEAWATER WETDOWN TEST

The Seawater Wetdown (SW) is the second of the NSWC devised accelerated tests and is the more aggressive. It contains the environments of the MAE and includes a cyclic 10-minute per hour per day seawater spray. The SW simulates intermittent seawater splashing and drying. For both SW and MAE, the test items are mounted on fiberglass racks at an angle of approximately 45°. Direction of exposure is primarily to the south. Photographs of the facilities are included in Appendix E.

SALT SPRAY, ASTM B117

Standard environmental salt spray (fog) testing was performed on coupons and actual parts in accordance to ASTM B117. This standard describes the apparatus, temperature, air supply and other test parameters. Both 3.5 percent and 5.0 percent sodium chloride solutions were used. The former is the concentration of seawater; the latter is specified by the ASTM. (In reality, the corrosive effects produced on test items are usually indistinguishable.)

It should be noted that salt spray testing is probably best used as a large scale screening or separating tool and should not be viewed as the ultimate corrosion test. There is on-going study in this area by the professional societies (SSPC of Ref. 11) and cyclic tests, similar to the MAE and SW described above, have shown greater realism.

TEMPERATURE AND HUMIDITY TEST, MIL-STD-2105

This test was also performed in an attempt to induce corrosion on coupons and on the end item which consisted of empty 5-Inch/54 projectiles. (The MAE and SW tests were done on sheet metal coupons and projectile sections.) Severity conditions were imposed by choosing temperature extremes of 160°F to -40°F on alternate days for a 28-day cycle. This temperature spread causes a total dimensional change of approximately .001 inches per inch length in a steel part.[9] The intent was to induce degradation in the coatings by differential thermal expansion and contraction with the substrate in the presence of moisture. Humidity was controlled at 95 percent in the hot phase and interim temperatures above freezing. Below freezing, humidity was not monitored.

HARDNESS, ASTM D3363

Film hardness readings were taken by scratching the coatings with calibrated drawing pencil lead of varying degrees of hardness in accordance with ASTM D3363. This is the typical hardness test method used for paints and coatings.

TAPE ADHESION

This is an extremely simple but useful test described in most military paint specifications. A line is scribed into the coating through to the base metal. Masking tape is firmly pressed onto the scribe area and peeled back upon itself at 180 degrees to check for coating removal.

THICKNESS

Non-destructive testing techniques for the measurement of paint film thickness are based on either eddy current or magnetic field principles. The amount of surface stand-off of a transducer through a non-magnetic and non-conductive coating produces a measurable output. (The KTA-Tator Inc. "Positector 6000 F2" and "Posipen" Model A, were used.)

EXPLOSIVE CHEMICAL COMPATIBILITY, MIL-STD-650

Vacuum Thermal Stability Test Method 503.1.1 was performed at NSWC, Indian Head Division, Yorktown, Detachment. As described in the standard, the test can be used for measuring the chemical stability of an explosive, or the stability of a material in the presence of a selected explosive. Specimens are immersed in a heat bath (100° or 120° C)for 40 hours. The amount of gas liberated is indicative of the reactivity. Coating samples were tested in the presence of PBXN-106 explosive.

ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY (EIS)

In this type of evaluation, the electrical impedance, consisting of inductive and capacitive reactance components, is

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[9] Approximate coefficient of linear expansion, 6.4 X 10^{-6} in/in/°F.

periodically measured on coated samples. A schematic of the laboratory setup is illustrated in Appendix A.

Coated samples are immersed in an electrolyte which eventually penetrates to the metal substrate by molecular diffusion. As the effective dielectric constant changes by nature of the coating degradation, the capacitance of the system changes.

Logarithmic plots of impedance and current phase angle vs applied frequency produce a family of slightly differing curves with time. At the time of incipient coating failure the curve generally assumes a characteristic shape.

The disadvantage on this technique is that there is often considerable skill required for data interpretation. EIS is still primarily a laboratory test and in this study the results were used as supplementary data. (There is still developmental work being done by various organizations toward standardizing the use of EIS as a non-destructive field test.)

SPECIMEN PREPARATION AND TEST SEQUENCE

The tests performed in this study were roughly divided into two phases starting with initial selection and attrition of coating candidates via severity testing of coupon samples. The second phase involved the coating application and testing of full scale parts using some of the more promising coatings from the first phase, and others such as the Army projectile coating system for which a good database existed.

COUPON EVALUATION

The substrate materials to be protected from the effects of corrosion consisted of both low-carbon steel plate coupons (See sketch in Appendix A, pages A-6 and A-7), and sectioned 76mm or 5-inch projectiles made from either medium-carbon or alloy steel. Table 2 shows the alloy compositions used in this study. In the latter part of the program, only the steel plate coupons were used for simplicity.

TABLE 2. ALLOY COMPOSITION OF TEST ARTICLES

ITEM	SUBSTRATE MATERIAL	TEST PHASE
Coupons, 3" X 3" X ⅛"	AISI 1008	Coupon
76mm	AISI 9260	Coupon
Pjctl Body, 5-Inch/54, Mk 41	AISI 1050; EXCEPT 0.80 - 1.35% Mn 0.15 - 0.30% Si	End item
5-Inch/54, Mk 48	AISI 1552	Coupon
5-Inch/54, Mk 55	AISI 0-6	End items (28-Day T&H only)
5-Inch/54, Mk 82	MIL-S-50783,HF-1	Coupon
155mm, Fwd Body, M864	AISI 4140	End item

According to sources such as Reference (20), the composition of ferrous alloys, type of environmental exposure, and corrosion rate of the exposed metal can be highly interdependent. Since test items were not bare metal, it was felt that coating degradation rates were only subtly effected by the metallurgy of the substrate as long as there was adequate adhesion. No deliberate effort was made to acquire data on the metal substrate after failure of the coating.[10]

Sample sections and coupons were sent to various contracted specialists mentioned previously for application of the candidate coatings. Surface substrates were also prepared as described previously, in the optimum manner for each coating type. Some coatings such as the Siloxirane® and the metallic-ceramic could be used without a topcoat, while others were intended to be used as primers. For equality of testing, coupon coatings were used as is, without topcoats. Supplementary data was also taken on some with topcoat as the tabulated data indicates.

Full depth scribe marks ("X" shape) were made on the coating specimens before exposure. This is a common practice for corrosion tests as it permits evaluating how well a coating would protect areas scratched in normal use.

END ITEM EVALUATION

Test samples in this phase were prepared from empty 5-Inch/54 Mk 41 and Mk 55 projectiles taken from station inventory at NSWC. A total of 36 samples were sent out to coating specialty contractors. Contractural configuration of the items are documented on NSWC SK 74674 (Appendix A). In order to remove the old paint and phosphate, the coating contractors were permitted to heat the projectiles up to 600° F. (The gilding metal rotating bands appear dark from heat discoloration in the photographs of Appendixes I and J).

With the exception of the E-Coat, none of the coatings could easily be applied to the projectile interiors; however in a production run special spray equipment could probably be used. E-Coat was the only type applied by immersion thus all surfaces were uniformly coated. (Contractor was permitted to coat the projectile fuze threads for the purposes of this study.)

None of the other coatings could meet the final OD color necessary for gun ammunition so a 180-degree sector of the test projectiles was given a 0.5 to 1.0 mil pigmented finish coat of OD

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[10] Certain generalizations can be made about the corrosion rates of different types of exposed steel: (a) For plain carbon and low alloy steels, corrosion rates are similar in water. Only when the alloy proportions approach those of stainless steel or high-silicon iron is corrosion rate reduced.(b) As carbon content increases, there is a slight increase in corrosion rate in seawater.(c) The presence of phosphorus and sulphur will increase corrosion rate, especially in an acidic environment. Sulfide inclusions will result in localized pitting. (d) As manganese content increases, corrosion rate will decrease since the formation of manganese sulfide reduces the amount of free sulfur. (e) The relative proportion of phases present from heat treatment also affects corrosion rate which decreases with higher levels of martensite. Galvanic corrosion will also occur between adjacent areas having different heat treatments as may be caused by welding or induction zone-hardening (e.g., rotating band seats of Mk 48 projectile body).

enamel as illustrated in the photographs. One 155mm, M864 forward body obtained from the Army was also included in this test group.

TEST RESULTS

COUPON TESTS

Eight types of coatings were evaluated in a preliminary investigation. Sectioned projectiles and steel plate coupons were examined in the salt fog, and the marine exposure tests described previously. After 500 hours of salt fog testing and one year of testing in the field, the following observations were made.

Salt Fog Test Results, Coupon Tests

Table 3 is a compilation of coatings tested, their thicknesses and performances after 500 hours of salt fog exposure. Numerical scores were assigned either in accordance with the respective ASTM, or subjectively if the characteristic was not covered by ASTM. After 500 hours of salt fog exposure to 3.5 percent sodium chloride, test specimens could be qualitatively sorted in one of three performance categories:

GROUP I (Good)
(1) IVD/Xylar coating
(2) E-Coat coating
(3) Nylon powder coating
(4) Siloxirane® coating

GROUP II (Moderate)
(5) Inorganic Zinc coating
(6) Powder coat - Epoxy
(7) Powder coat - Polyester

GROUP III (Poor)
(8) Alkyd primer
(9) Alkyd primer and topcoat (Control)

Appendix D, Figures D-1 and D-2 show the best coatings. The IVD/Xylar, Nylon powder coat, E-coat and Siloxirane® all performed well showing no signs of corrosion or protection breakdown.

Figure D-3 shows the inorganic zinc, epoxy powder, and polyester powder coatings of the second group. These performed moderately well but exhibited some protection breakdown particularly at the edges.

According to the vendor's data (Ref. 21), inorganic zinc coating protects the steel substrate by sacrificial action. In the salt fog test the coating itself showed signs of blistering and chalking. While it performed well in protecting the steel substrate from corroding, it was placed in the moderate group because of unacceptable surface appearance.

Both the epoxy and polyester powder coatings protected the flat surfaces of the samples to a moderate degree. The edges, however, showed signs of corrosion and bleeding. Both contractor and in-house samples were evaluated. The higher degree of rusting on the in-house coupons is thought to be attributable to the surface preparation as initial cleanliness cannot be verified.

The experimental control samples - zinc phosphate with alkyd primer, and zinc phosphate with primer and topcoat - performed poorly in the 500 hour salt fog (See Figure D-4).

TABLE 3. SALT SPRAY (FOG) RESULTS, 500 HRS, COUPONS

COATING	THICK (Mils)	BLEED (Subjective)	CHALK ASTM D659	BLISTER ASTM D714	RUST ASTM D610	FLAKE ASTM D772	TOTAL
IVD/Xylar	2.0	10	10	10	10	10	50
Siloxirane® 2033	14.9	9	10	10	8	10	47
Polyester Powder, NSWC	1.6	6	10	10	8	10	44
Epoxy Powder, ISPA	3.0	6	10	10	8	10	44
Nylon Powder	5.2	6	10	10	7	10	43
E-Coat	1.2	6	10	10	5	10	41
Polyester Powder, ISPA	3.0	6	10	7	8	10	41
Epoxy Powder, NSWC	2.3	6	10	7	8	10	41
Inorganic Zinc	3.0	10	3	5	10	5	33
CONTROLS							
Navy Primer & Topcoat	2.0	3	10	3	4	8	28
Navy Primer	0.6	3	10	3	3	8	27
Zn Phosphate, only	0.5	3	10	3	3	8	27

Marine Atmospheric Exposure Results, Coupon Test, First Round

The marine atmospheric exposure test lasted for approximately one year. The coatings were again subjectively put into one of the three performance groups as previously defined. The outcome was judged as:

GROUP I (Good)
(1) IVD/Xylar® coating
(2) E-Coat coating
(3) Nylon powder coating
(4) Siloxirane® coating
(5) Epoxy powder coating (retested)

None of these coatings showed signs of corrosion, blistering, undercutting, or chipping. Appendix E, Figures E-1 through E-3 show IVD/Xylar, Nylon powder coating and E-coat after 0, 4 and 9 months of exposure respectively on the atmospheric rack. In Figure E-4, Siloxirane® coating is shown after 0, 4 and 9 months exposure on the atmospheric rack.

GROUP II (Moderate)
(6) Polyester powder coating (retested)
(7) Inorganic Zinc coating

The inorganic zinc coating showed signs of chalking, loss of intensity of color and flaking after 6 months exposure on atmospheric racks. While no evidence of corrosion of the steel substrate was observed at this time, the sacrificial nature of zinc coatings was quite noticeable. Observations after 9 months exposure to the marine atmosphere revealed no evidence of corrosion of the steel substrate, supporting the corrosion protecting nature of zinc coatings. The external appearance of zinc coating was not acceptable due to chalking and loss of intensity of color (see Figure E-4).

GROUP III (Poor)
(8) Epoxy powder coating (initial)
(9) Polyester powder coating (initial)
(10) Alkyd Primer
(11) Alkyd Primer and Topcoat (Control)

The first test of the epoxy and polyester powder coatings showed signs of bleeding and edge corrosion after only 3 months. Figure E-5 shows them after 0, 4 and 9 months. These powder coatings showed signs of severe corrosion after one year. This observation was not consistent with previous experiences with powder coatings (Ref. 22). Poor surface preparation and/or poor application procedures may have led to early failure so a retest of these two systems was done for confirmation of the results.

In the case of the experimental controls (alkyd primer, and primer and topcoat) general corrosion was observed after 3 months of marine atmospheric exposure. The corrosion increased as a function of time in both the scribed and unscribed samples. Figure E-6 shows the condition of these coatings after 8 months of atmospheric exposure.

Retested Powder Coatings. New samples of the epoxy and polyester powder coats were obtained from ISPA and retested for a duration of two years on the MAE racks. Thickness averaged approximately 3.0 mils, vs 1.5 to 2.0 on the first test. Some samples were also top coated with MIL-P-24441. Random coupons were scribe marked to the steel substrate.

After one year of exposure, both scribed and unscribed samples were in good condition showing minor corrosion in the scribe line and at the edges. The results of the retest place all of the powder coatings in the "Good" category. (Photos are unavailable.)

After the comparative evaluation was terminated at the end of one year, the powder coated samples were left on the test racks. It was observed that after 18 months the severity of corrosion had become moderate; at two years complete failure was evident with general loss of adhesion, debonding and general rust throughout.

Marine Atmospheric Exposure Results, Coupon Test, Second Round

This phase was performed approximately a year after the first round of MAE coupon tests. In the interim it was decided to test the Army projectile coating system, and to begin evaluation of additional coatings that were highly recommended (by their vendors) and appeared promising.

The Army system consisted of the epoxy primer with a polyurethane topcoat both described in the last section. Samples were prepared on the production line of Scranton Army Ammunition Plant. The unscribed samples were found to be in good condition with no serious coating failure. The scribed samples showed signs of blistering, slight undercutting (underfilm corrosion) within and local to the scratch.

The Siloxirane® samples were freely provided by Advanced Polymer Sciences after being advised that the thickness of their previous samples of 2033 was excessive.

An E/M Corporation aluminized phenolic coating (Everlube 6150 per Mil. spec.) with lubricant qualities was also included and showed signs of generalized corrosion failure over the entire face of the sample.

The present Navy alkyd primer was included for control. The best candidate from the first round MAE test which was the Xylar or metallic-ceramic, was also included for comparison.

The rankings, judged independent of applied thickness, were seen as Xylar, Army system, Navy primer (alkyd primer over zinc phosphate), aluminized phenolic, E-coat and the Siloxiranes®. Results are photo-documented in Appendix E along with the first round tests. Table 4 summarizes all MAE evaluations discussed thus far.

MAE Coupon Test, Supplementary, 2½ Year Exposure

After the first round of MAE evaluations, some of the samples were left on the racks with no intent of further monitoring. The control samples had failed long before, but at 2½ years the Xylar and inorganic zinc coatings were found to be intact. The substrate metal was fully protected with no sign of rusting including inside of the scribe mark. Photos are included in Appendix E. Initial thickness of the coatings is shown in Table 4.

TABLE 4. MARINE ATMOSPHERIC EXPOSURE

COATING	THICK (Mils)	BLEED (Subjective)	CHALK ASTM D659	BLISTER ASTM D714	RUST ASTM D610	FLAKE ASTM D772	TOTAL
IVD/Xylar	2.0	10	10	10	10	10	50
Nylon Powder	5.2	10	10	10	9	10	49
Siloxirane® 2033	14.9	10	8	10	10	10	48
E-Coat	1.2	10	8	10	9	10	47
Inorganic Zinc	3.0	10	7	8	10	7	42
Epoxy Powder, ISPA	3.0	7	8	5	5	8	33
*Navy Primer	0.6	9	5	6	3	10	33
*Navy Primer & Topcoat	2.0	8	5	6	3	10	32
Epoxy Powder, NSWC	2.3	7	7	9	5	4	32
Polyester Powder, ISPA	3.0	7	5	3	3	8	26
Polyester Powder, NSWC	1.6	3	6	3	3	4	19
*Zn Phosphate, only	0.5	3	3	3	3	3	15
Xylar	0.9	10	10	10	10		40
with scribe mark		10		10	10	10	40
"Army" System	4.0	10	10	10	10		40
with scribe mark		8		3	1	3	15
"Navy" System	2.4	9	10	10	9		38
with scribe mark		9		8	5	3	25
Siloxirane® 2431	2.1	5	5	10	9		29
with scribe mark		5		10	2	5	22
Siloxirane® 2131	1.8	5	5	10	7		27
with scribe mark		5		10	1	5	21
Al Phenolic	0.7	5	5	10	1		21
with scribe mark		5		10	1	5	21
E-Coat	0.7	5	5	10	1		21
with scribe mark		2		10	1	5	18

Seawater Wetdown Exposure Results, Coupon Test

Based on physical appearance, dullness (due to U-V exposure) and overall corrosion of the coatings after one year, the seawater wetdown test samples can be put into two groups: good and poor.

GROUP I (Good)
(1) IVD/Xylar® coating
(2) Nylon powder coating
(3) E-Coat coating
(4) Siloxirane® coating

GROUP II (poor)
(5) Powder coatings (both Polyester and Epoxy)
(6) Inorganic Zinc coating
(7) Alkyd Primer
(8) Alkyd Primer and Topcoat (Control)

Since the SW is such an aggressive test, the fact that Group I coatings look good after one year attests to their excellent corrosion protection characteristics and durability. No signs of deterioration or breakdown were evident. Figures F-1 through F-4 show IVD/Xylar, Nylon powder coating, E-coat, and Siloxirane® after 0 and 9 months.

Although Siloxirane® 2033 coating performed well on the seawater wetdown rack there was one major drawback. The high thickness, 14.87 mils, exceeded the specified limits.

In the Group II samples, after about three months the edge effect and extension of undercutting (in scribed samples) were observed on both polyester and epoxy powder coatings. After one year, these powder coatings showed flaking and chipping along with signs of running rust. In a retest of these two powder coatings, epoxy and polyester, the samples were prepared with more attention to surface preparation. The results were generally better but failure was still evident after one year.

Figures F-5 and F-6 show the initial polyester and epoxy powder coat after 0 and 9 months. Photos of the re-tested samples are unavailable.

The inorganic zinc coating showed signs of blistering, chipping and flaking. No corrosion products of the steel substrate were observed (i.e., no signs of rust). After about 6 months, the appearance of the inorganic zinc coating was unacceptable. It appeared that the inorganic zinc coating on the seawater wetdown rack was wearing away. Figure E-7 shows the condition of inorganic zinc after 0 and 9 months.

As a crude rule of thumb based on *some* of the visual observations, corrosion observed after 500 hours of salt fog might be considered approximately equivalent to that observed after 3 months of seawater wetdown or six months of atmospheric exposure.

The two control samples were alkyd primer, and alkyd primer with OD finish coat. The former is shown in Figure E-8 at 0 and 3 months. After 3 months general corrosion was observed over the entire surfaces of both control samples. Observations for the seawater wetdown tests for all coatings are given in Table 5.

TABLE 5. SEAWATER WETDOWN RESULTS, ONE YEAR, COUPONS

COATING	THICK (Mils)	BLEED (Subjective)	CHALK ASTM D659	BLISTER ASTM D714	RUST ASTM D610	FLAKE ASTM D772	TOTAL
IVD/Xylar	2.0	10	10	10	10	10	50
Nylon Powder	5.2	10	9	10	9	10	48
Siloxirane® 2033	14.9	10	7	10	9	10	46
Inorganic Zinc	3.0	10	6	6	10	8	40
E-Coat	1.2	7	7	3	3	10	30
Polyester Powder, ISPA	3.0	6	7	3	3	8	27
Epoxy Powder, ISPA	3.0	6	7	3	3	8	27
Epoxy Powder, NSWC	2.3	7	7	3	3	4	24
Polyester Powder, NSWC	1.6	3	3	2	2	2	12
CONTROLS							
Navy Primer & Topcoat	2.0	5	6	3	3	5	22
Navy Primer	0.6	3	6	3	3	5	20
Zn Phosphate, only	0.5	1	1	1	1	1	5

SW Coupon Test, Supplementary, 2½ Year Exposure

Some of the samples were left on the racks with no plans toward further monitoring. Advanced corrosion and pitting is shown on the control samples (Appendix F). The Siloxirane® samples have also failed from cracking and undercutting. Only the IOZ and Xylar coatings are still protecting the substrate. Light surface rusting is evident on the IOZ samples where the original coating has been consumed. Only the Xylar coating appears to be in almost pristine condition. The initial thickness of the coatings are shown in Table 5.

SCRATCH HARDNESS

Coating samples were tested as previously described. For convenience, they can be ranked into three groups:

GROUP I (Hardest)
Xylar
Inorganic Zinc
Aluminized Coatings, 9031 and 6150
Siloxirane® 2131 and 2431

GROUP II (Moderate)
E-Coat
Epoxy Primer (Army)

GROUP III (Softest)
Alkyd Primer (Control)
Enamel Topcoat (Army)

As expected, the organic coatings of Groups II and III had the lower film hardness. On the assumption that the hardness is directly related to abrasion resistance, the hard coatings are more desirable. Table 6 summarizes the measured hardnesses. Test specimen photographs are shown in Appendix G.

TAPE ADHESION AND FILM THICKNESS

Adhesion problems, indicative of faulty surface preparation, were not encountered with any of the coatings. Film thicknesses for the coupons are shown in the respective tables, and in Appendix H for the end item projectiles.

ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY (EIS) RESULTS

Seven coatings were examined using EIS (Ref. 23) with the results summarized as follows.

GROUP I (Good) - EIS test ran for the full 60 days
Epoxy powder coat (NSWC applied)
Nylon powder coat
E-Coat
Metallic Ceramic (not tested but believed to be good)

GROUP II (Fair) - EIS test terminated at 30 days
Polyester powder coat (contractor, ISPA, applied)

GROUP III (Poor) - EIS test terminated at 16 days
Epoxy powder (ISPA applied)
Polyester powder coat (NSWC applied)

A sample of the metallic ceramic, Xylar, was left in the electrolyte for the full 60 days, but could not be evaluated by EIS because of the high conductivity of the coating. Macroscopic visual evaluation showed no sign of corrosion or blistering. Small pits were observed with an optical microscope but no corrosion products could be seen in the pits.

The samples in Group I showed high capacitance during the 60 days. Capacitance plots of Group II and III samples showed progressive increases due to water absorption and in Group III, delamination or blistering. All samples except the NSWC applied polyester powder coating passed the tape-pull adhesion tests.

TABLE 6. FILM HARDNESS BY PENCIL TEST (REF. ASTM D3363)

NSWC/D; 9 Nov 94; Bld 199

COATING TYPE	TRADE NAME	APPLIED BY CONTRACTOR	GOUGE HARDNESS	SCRATCH HARDNESS
Control (Navy production primer)	(Sherwin-Wms.)	Scranton Army Ammo Plant	H	F
Electrodeposited Primer	PPG-CR640	MetoKote Corp.	5H	3H - 4H
Metallic-Ceramic	Xylar	Plas-Tech	Off-Scale	9H (a)
Inorganic Zinc	IC-531	Coating Technology, Inc.	Off-Scale	9H (b)
Aluminized Phenolic	Everlube 6150	Coating Technology, Inc.	Off-Scale	9H (c)
	Everlube 9301	NSWC Dahlgren	Off-Scale	8H - 9H (a)
Silicon - Oxide	Siloxirane® 2131	Advanced Polymer Sciences	Off-Scale	Off-Scale (d)
	Siloxirane® 2431	Advanced Polymer Sciences	Unobtainable	2H - 9H (e)
Army system - epoxy primer	(Sherwin-Wms.)	Scranton Army Ammo Plant	3H	2H - 3H
Army system - enamel top coat	(Sherwin-Wms.)	Scranton Army Ammo Plant	H	H - F
Polyester Powder Coat		NSWC Dahlgren	5H	4H
Epoxy Powder Coat		NSWC Dahlgren	4H	3H
Nylon Powder Coat		ISPA, Baltimore		

Visual inspection at 7X with approx 10000 lux.
Instrumentation: KTA-Tator Inc., Pencil Hardness Gauge Model H-501

TEMPERATURE-HUMIDITY (T&H) TEST, END ITEMS

After the 28-day T&H test cycle described previously there was very slight macroscopic change in the coated projectiles. No coating failure, damage or disbond was introduced by the thermal shock. Only very minor rusting was evident in small localized areas where normal handling resulted in abrasions to bare metal. (See photos in Appendix I.)

Plastic spacers had been used to insulate all test specimens from the galvanized steel shipping pallet so as to eliminate the possibility of anodic protection. It may be concluded that all coatings performed successfully. The most apparent aftereffect of the test was the heavy residue of white powder (zinc carbonate) on the pallet frames. Close inspection of the IOZ coatings without topcoat showed a similar but less pronounced color change.

SALT SPRAY, END ITEMS

Following the T&H test, one projectile of each coating type was exposed to 5% salt spray per ASTM B117. Visual evaluations were performed at intervals of 168, 336 and 500 hours. Projectiles were suspended vertically in the test chamber.

Because of the dissimilar metals and the water retaining crevices, areas adjacent to the rotating band were severely corroded in all cases. Also the nose area immediately aft of the suspension lug was heavily rust-stained from runoff since the lifting lug, which was not a part of the test hardware, was unprotected. The effects from the rotating band and the lifting lug were disregarded in the evaluation and only the more distal areas were considered.

Salt spray results on the projectile bodies are summarized in Table 7. As in the coupon tests the coating performance may be divided in levels of relative success: in this case good and bad. Although there were some noticeable differences, all coatings looked satisfactory after 168 hours; more definitive results were evident at 336 hours. Photographs after 336 and 500 hours may be seen in Appendix J.

The "bad" category included the Siloxiranes® and the IOZ. After 336 hours, the former showed signs of cracking, some blistering; at 500 hours uniform corrosion had started in places. The "2131" performed better than the "2431." At 336 hours the appearance of the white zinc carbonate residue on the IOZ coating had an objectionable appearance. Removal of the residue with a 5 percent acetic acid solution showed that the substrate was still being protected, but at 500 hours uniform corrosion of the steel substrate was evident.

TABLE 7. SALT SPRAY RESULTS ON EMPTY 5-IN/54 MK 41 PROJECTILE BODIES
[RUST GRADES (ASTM D 610)]

COATING TYPE	168 HOURS	336 HOURS	500 HOURS	REMARKS
Control - Alkyd Primer & Enamel Topcoat	9	9	8-9	SN 4
Epoxy Primer & Enamel Topcoat (Army)	9	9	8-9	Army 155mm M864
E-coat Primer & Enamel Topcoat	9	8-9	8-9	SN 4
Aluminized Phenolic & Enamel Topcoat	9	8-9	8-9	SN 4
Xylar® & Enamel Topcoat	9	8-9	8	SN 4
Siloxirane® 2131 & Enamel Topcoat	9	8	8	SN 1
Siloxirane® 2431 & Enamel Topcoat	9	7	7	SN 2
Inorganic Zinc & Enamel Topcoat	9	6-7	6	SN 4

The "good" category included the E-Coat, Metallic-Ceramic (Xylar), Aluminized Phenolic, the Alkyd control and the Army epoxy primer/enamel topcoat system. At 336 hours the control, the Army system and the Xylar looked the best. All samples had no signs of deterioration beyond the surface abrasions that were present from the beginning of the test. After 500 hours the control and the Army system looked the best followed by the aluminized phenolic, xylar, and E-Coat in that order. Results are summarized in Table 6.

The performance of the alkyd control unit was surprising in view of the poor performance seen on the coupon samples from the MAE and SW tests. The explanation may lie either in the age of the coupon samples or the application process. The MAE and SW coupons were cut from empty projectiles made several years ago and already in inventory. The end item control samples were from recent production at Scranton Army Ammunition Plant (SAAP). Also SAAP routinely does salt-spray testing as part of their lot acceptance procedures. There was no quality assurance data directly available for the projectiles from which the coupons were cut other than the material condition was code "A."

EXPLOSIVE COMPATIBILITY

The following list summarizes the results of the vacuum stability tests performed with cured, plastic bonded explosive, PBXN-106. Reactive coatings will liberate more gas per weight of coating. In general, gas volumes less than two cubic centimeters per gram (cc/gm) indicate negligible reactivity, while two to four cc/gm indicates moderate reactivity. Over four cc/gm is generally unacceptable.

Metallic-Ceramic (Xylar)	1.04 gm/cc
Inorganic Zinc	1.24
Siloxirane® 2131	2.42
Alkyd Primer, TT-P-664	0.0

SUMMARY

Twelve candidate coatings had been selected, and samples of each obtained. Samples consisted of coated steel coupons and end items. Dozens of coupons were made from both sectioned end items and flat plate. End items consisted of a total of thirty-six 5-Inch/54 Navy projectiles and one 155mm Army projectile.

Coating samples were evaluated by standard quality assurance type testing, by laboratory testing, and through exposure to accelerated field conditions. Evaluations were mostly qualitative with visual one-to-one comparisons between samples. The present Navy projectile coating was chosen as the experimental control. At the risk of over simplification, Table 8 presents an abbreviated summary of the previously tabulated results. In order to make meaningful comparisons, the numerical scores have been normalized from 1 (worst) to 10 (best).

TABLE 8. CONSOLIDATED TEST SUMMARY

COATING TYPE	500 hr Salt Spray(a)	Marine Exposure	Seawater Wetdown	Film Hardness	Cost Index	Average
Xylar (metallic-cermaic)	9.5	10.0	10.0	9.5	4	9
Siloxirane	8.2	6.9	9.2	10.0	6	8 (b)
Polyester Powder	8.8	5.2	5.4	4.5	7	6 (b)
Epoxy Powder	8.8	6.5	5.4	3.5	7	6 (b)
Nylon Powder	8.6	9.8	9.6		7	9 (b)
E-Coat	8.6	7.0	6.0	4.0	2	6
Inorganic Zinc	6.3	8.4	8.0	9.5	9	8 (c)
Aluminized Phenolic	9.0	4.2		9.5	4	7
'Army' paint system	9.0	8.0		3.0	6	7
'Army' primer only				3.0		
CONTROLS						
'Navy' paint system	7.3 (d)	7.0	4.4	2.0	6	5
'Navy' primer only	5.4	6.6	4.0	2.0		5

Notes:
(a) Average of coupons and end-item projectiles.
(b) Eliminated for projectile use due to excessive required thickness.
(c) Eliminated for ammunition use due to objectionable appearance.
(d) Results between coupons and end items were variable.

One of the confounding factors in this effort was obtaining coating samples of the same specified thickness so as to be able to make valid comparisons of the performance. Often evaluations were necessary between coatings of different thicknesses. This was often simplified as the thicker coatings sometimes did not perform as well as some thinner types; for example, a thick coating of Siloxirane® was inferior to E-Coat. Also it should be noted that the single most restrictive requirement, at least for projectiles, is the maximum permissible film thickness (.0015 inches on the bourrelets).

SALT SPRAY TESTING

There were some variability observed in the performance of the control samples between the coupon and the end item testing. The latter fared much better, and as stated previously, it is believed that these results have greater credibility based on the quality assurance documentation of the end item samples. Based on the salt spray results the better performing coatings were observed to be, in no particular order, the Navy projectile system (Control), the Army projectile system, Xylar, Aluminized phenolic and E-Coat; the last three had the Navy OD finish coat. The nylon powder also appeared promising in the coupon tests but was disqualified because of excessive thickness. Powder coatings in general do not offer good performance at less than about 5 mils; some manufacturers recommend 10 mils. With the lesser amounts of applied powder, porosity and holidays in the coating increase since the microscopic gaps between particles do not fuse together.

MARINE ATMOSPHERIC EXPOSURE

The following coatings performed very well during 12 months of exposure: Xylar, nylon powder, E-Coat, and inorganic zinc. The Siloxirane® 2033 had to be rejected for excessive thickness. The IOZ was also rejected for grossly objectionable appearance, although performance was very good.

The epoxy powder, the Army system, and the present Control (Navy) primer did not protect the metal substrate as well, but appeared to be viable coatings. The Army system was fairly thick at 4 mils.

SEAWATER WETDOWN

After one year, the best coatings were Xylar, nylon powder and E-Coat and inorganic zinc. The Xylar and IOZ lasted over 2½ years. The control samples failed after 3 months. In the middle of these two extremes, were the polyester and epoxy powder paints.

HARDNESS

The hardest and most abrasion resistant coatings were the Xylar, inorganic zinc, aluminized-phenolic, and Siloxirane®. The present, organic Control coating was among the softest.

ENVIRONMENTAL COMPLIANCE

All coatings tested either met the current regulations on volatile organic solvent and heavy metal limitations, or were capable of being appropriately reformulated.

EXPLOSIVE COMPATIBILITY

Because of the logistic difficulty of obtaining samples, not all coatings could be tested for compatibility with PBXN-106 explosive. The Xylar and inorganic zinc were acceptable; the Siloxirane® was reactive; the remainder are unknown.

COST

A relative cost of application for each coating type has also been added in the summary table. Cost approximations are based on the pretreatment required for the substrate (e.g. abrasive blast or zinc phosphate), the curing conditions (e.g. hot or ambient temperatures), labor intensity, and necessary equipment. These factors have been previously discussed in the coating description section or have been illustrated in the flowcharts of Appendix B.

For this study the coating contractors charged a flat rate for the small quantities involved. A detailed economic analysis would have to be done to determine if the initial cost for some of the coatings would be offset by reduced maintenance over the life cycle of the item. For example, Xylar offered outstanding performance, however the application process is relatively labor intensive.

CONCLUSIONS AND RECOMMENDATIONS

1. Although the performance was not among the best, the current Navy projectile coating system performed well enough in the end item salt spray and marine atmospheric exposure tests so as not to warrant an immediate change. Performance of the Army projectile coating system was comparable. The Army's epoxy primer, MIL-P-53022, demonstrated slightly higher film hardness than the Navy alkyd primer, TT-P-664. It is therefore recommended that this epoxy primer be included as an alternative for use on Navy projectiles. (It is so specified for the 5-Inch cargo projectiles currently in development.)

2. It is recommended that MIL-C-81751, metallic-ceramic coating (Xylar) be considered for use on ammunition that is relatively expensive such as missiles or illuminating projectiles, or on items that cannot be easily returned for maintenance. This is because the performance advantage of this coating will probably be offset by its cost of application. The ingredients are mostly inorganic; VOC content is listed as 4.8 grams/liter, which is very low. Standard spray equipment may be used for the application, but the high-temperature cure schedule limits the coating application to empty ordnance items. The relative labor intensity may further limit the production volume. A top coat would not be necessary except for color identification purposes.

3. It is recommended that MIL-P-53084, electrodeposited primer (E-Coat) be considered for all ammunition items especially the more expensive types such as missiles, illuminating or ICM projectiles. E-Coat was the second best coating candidate. It was among the thinnest coatings, and extremely good performance per unit thickness was observed. VOC content is relatively low at 140 grams/liter. Disadvantages include a high-temperature cure schedule that limits the application to empty ordnance items. Also high capital investment is required for E-Coating. There are probably less than a hundred E-Coating facilities nation-wide, so subcontracting and transportation costs could make this more costly than the present coatings.

4. Powder coatings are recommended on weapons systems components where coatings can be both heat cured and applied relatively thick, for example, in excess of 5-6 mils. The powder coatings did not perform as well as the others at the minimal thicknesses required for projectiles. The biggest advantage would be not in performance, but in environmental compliance as the powder coatings release no VOC's. Facilities are relatively inexpensive and there is very widespread use of powder coatings throughout industry and at Naval shipyards.

5. The MIL-C-85614, aluminized coating is recommended as a viable coating for ammunition. It performed fairly well in the test schedule, especially when its low film thickness is considered. The high film hardness and dry film lubricant qualities may also be of advantage in other weapons systems or shipboard systems.

6. The DOD-P-24648, inorganic zinc coating was found to be effective in protecting the substrate metal from corrosion; however it cannot be recommended for ammunition on the basis of appearance. Corrosion products seemed to diffuse through the alkyd topcoat that was applied. Otherwise, it could have met the thickness criteria for projectiles, has no VOC's, and could be applied to loaded ammunition since it cures at room temperature. IOZ may be more suitable for other shipboard applications especially where high hardness and a high coefficient of friction are desirable without regard to appearance.

7. For gun ammunition that is being refinished during maintenance, no departure can be recommended for the present coatings, except some type of low temperature phosphate surface pretreatment should be included for better paint adhesion.

8. It is recommended that a follow-on effort to this study focus on the production economics of the better coatings such as Xylar, E-Coat, or aluminized phenolic. Powder coatings might also be reviewed to see if any recent developments by the industry have reduced the thickness required for good protection. An ammunition lot of several hundred units could be made for further field tests, fleet issue and long term surveillance.

9. Other opportunistic tests performed in this program are documented in Appendices K, L, and M. The value and feasibility of sleeve-web protectors and adhesive marking decals on 5-inch projectiles was demonstrated. Also salt-spray tests on the 76mm spiral-wrap cartridge case characterized its corrosion mode.

REFERENCES

(1) MIL-P-18948B, Projectiles, Painting, Marking, and Greasing of

(2) TT-C-490D, Cleaning Methods for Ferrous Surfaces and Pretreatments for Organic Coatings

(3) TT-P-664D, Primer Coating, Alkyd, Corrosion-Inhibiting, Lead and Chromate Free, VOC Compliant

(4) WS 18782, Weapons Specification for Painting, Marking and Lettering of Naval Gun Ammunition, Naval Sea Systems Command

(5) MIL-STD-709C, Ammunition Color Coding

(6) TW010-AC-ORD-010 and -020, Inspection Requirement Receipt, Segregation, and Issue of Navy and Marine Corp Ammunition, Sept 1981, Naval Sea Systems Command

(7) DMWR 9-1320-000-F78, Depot Maintenance Work Requirements, Naval Sea Systems Command

(8) NSWC Crane Memorandum dtd 23 Feb 94 from Code 4025 to file; Subj: Adhesion of Primer/Paint to Mk 48 Projectile Body

(9) MIL-HDBK-132, Protective Finishes for Metal and Wood Surfaces

(10) MIL-HDBK-205, Phosphate and Black Oxide Coatings of Ferrous Metals

(11) *Good Painting Practice*, Steel Structures Painting Manual, Volumes I and II, 3rd Ed., Steel Structures Painting Council, ISBN 0-938477-81-1, and 0-938477-60-9

(12) DOD-P-24687, Primer Coating, Zinc Dust Pigmented for Exterior Steel Surfaces

(13) MIL-P-53084, Primer, Cathodic Electrodeposited, Chemical Agent Resistant

(14) MIL-C-81751, Coating, Metallic-Ceramic

(15) MIL-C-85614, Coating, Fastener Aluminum Pigmented, Organically Bonded

(16) National Aerospace Standard NAS 4006, Aluminum Coating

(17) MIL-P-53022, Primer, Epoxy Coating, Corrosion Inhibiting, Lead and Chromate Free

(18) American Standards for Testing Material
    D610, Standard Method of Evaluating Degree of Rusting on Painted Steel Surfaces
    D659, Standard Test Method for Evaluating Degree of Chalking of Exterior Paint

REFERENCES (Continued)

D714, Standard Test Method for Evaluating Degree of Blistering of Paint.
D772, Standard Test Method for Evaluating Degree of Flaking (Scaling)of Exterior Paint.

(19) *1993 Year End Report for Surface Protection for Gun Ammunition*, Dr. Norris Lindsey, NSWC, White Oak Md; Memo NL-R33, 01 Dec 93

(20) H.H. Uhlig and R.W. Revie, *Corrosion and Corrosion Control*, 3rd Ed., John Wiley & Sons Inc

(21) *IC 531 Technical Manual*, Inorganic Coatings Inc., Malvern, Pa 19 55

(22) *Corrosion Studies of VLS Issues - Steel Uptake Hatches* (Unpublished), N. Lindsey and A. Costa, First Combined Combat Systems and Surface Ship Corrosion Control Conference, Louisville, Ky., Volume 3, 1993

(23) University of Southern California Letter Report to Code 683 NSWC CD: *Evaluation of Coating Performance with EIS and ENA*, F. Mansfield and L. Tien Han

*(24) John C. Russ, *Visualizations in Material Science*, Chapter 20, North Carolina State University, 1995; Internet address - http://vims.ncsu.edu/cgi/index/acgi

*(25) Hare, C. L. *Protective Coatings, Fundamentals of Chemistry and Composition*, Technology Publishing Co., 1994, ISBN 0-938477-90-0

* General references—not specifically mentioned in text.

APPENDIX A

SPREADSHEET DATABASE, DRAWINGS

DEPARTMENT OF THE NAVY
BUREAU OF ORDNANCE
Washington 25, D.C.

In Reply Refer To
Ma3b-1-AVM:eij
NT1/S78
9 March 1951

From: Chief, Bureau of Ordnance
To: Commanding Officer, Naval Ammunition Depot, Hingham, Mass.
Commanding Officer, Naval Ammunition Depot, Fort Mifflin, Pa.
Commanding Officer, Naval Ammunition Depot, Earle, N. J.
Commanding Officer, Naval Ammunition Depot, St. Juliens Creek, Va.
Commanding Officer, Naval Ammunition Depot, Mare Island, Calif.
Commanding Officer, Naval Ammunition Depot, Crane, Ind.
Commanding Officer, Naval Ammunition Depot, Hastings, Nebr.
Commanding Officer, Naval Ammunition Depot, McAlester, Okla.
Commanding Officer, Naval Ammunition Depot, Hawthorne, Nev.
Commanding Officer, Naval Ammunition Depot, Oahu, T. H.
Commanding Officer, Naval Ammunition & Net Depot, Seal Beach, Calif.
Commanding Officer, Naval Ordnance Depot, Puget Sound, Keyport, Wash.

Subj: Projectiles with rust pitted bourrelets; use of for service issue

Ref: (a) BUORD ltr S78-1 (5")(Pr6b) AVM:eij of 1 Oct 1947 (not to all)

1. Reference (a) specifies limits for the amount of pitted bourrelet surface which may be allowed for 5"/38 caliber projectiles to be used for non-fragmentation loading. It is now desired to extend these limits to apply to all calibers of projectiles for both service and target use. Accordingly, reference (a) is hereby canceled.

2. All Navy projectiles, calibers 20MM to 16 inch inclusive, which have become rusted and pitted shall be inspected visually with respect to condition of the bourrelet surfaces. If pitting of the bourrelet surfaces does not exceed the following limits, the projectiles are suitable for overhaul; or rework and service issue:

a. Maximum depth of pitting ---------------------------0".01
b. Maximum diameter of individual pit ---------------- 1/16"
c. Pitting along any fore and aft line of the bourrelet does not exceed 25% of the bourrelet width.

The above limits apply also to the rear of band surface of semi-fixed and bag gun projectiles where this diameter is the same as the bourrelet diameter. The pitted surfaces shall be thoroughly cleaned and repainted in accordance with NAVORD O.S. 3405 during overhaul or rework in order to prevent further corrosion.

3. Excessive quantities of badly rusted and pitted projectiles are continually being encountered and maximum effort should be made to adequately preserve all loaded and empty projectiles in storage in order to reduce the number of rejections currently being made due to corrosion.

M. F. SCHOEFFEL

A. H. TAYLOR

Copy to:
CO NM Port Chicago

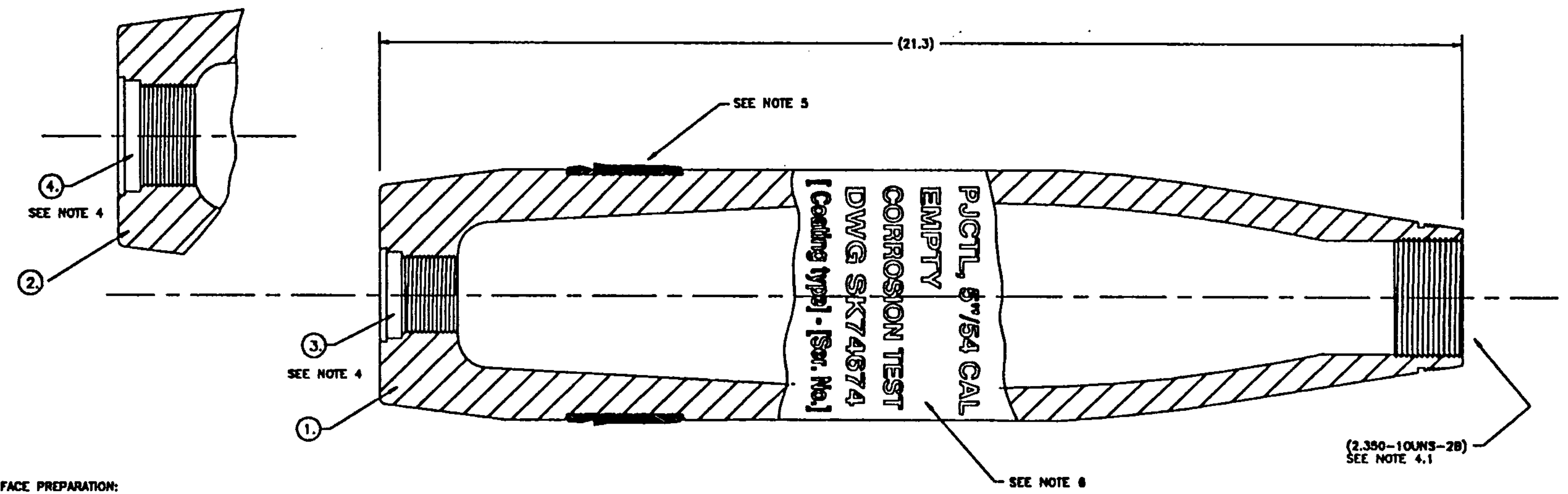
PRIMERS

TYPE COATING:	(Navy) Primer, Alkyd	Primer, Zn-Moly	Primer, Alkyd	Primer, Wash P	Primer, Alkyd	2-part Primer, Epoxy P	Primer,Zinc Dus	2-part Primer, Epoxy	2-part Primer, Epoxy	Primer, Electro	2-part Primer, Epoxy
SPEC NUMBER:	TT-P-664D	TT-P-645B	MIL-P-11414E	DOD-P-15328D/	MIL-P-22332B	MIL-P-23377	DOD-P-24648	MIL-P-53022B	MIL-P-53030	MIL-P-53084	MIL-P-85582A
Date of Spec:	1988	1990	1992	1992	1972	1989	1985	1988	1983	1988	1988
Intended Use:	Metals,rust inhib	Al & St, marine	Ammo, autom;	Increase adhesi Metals.	OK bare metal.	USAF	Severe marine/i	Metals. Replace MIL-23	Water reducing. Metals.	Metals.	NavAir
Pb and -CrO4 free:	yes	no CrO4;.06%p	yes				yes	yes	yes	yes	yes
C6H6 and Cl solvent free:		?					yes			yes	Sr, Ba chromates
VOC's:	420 gm/l, min	340 gm/l, max	420 gm/l, max	Low	Low	340 gm/l	none	420 gm/l, min	340 gm/l	144 gm/l	340 gm/l, min
Drying Time:	Quick.	slow	Quick.		Quick.		15 - 45 min.	Flash dry.		20' @ 350F	60'
SPEC REQUIREMENTS		Quantitative									
ADHESION TEST (Tape)		Requirements									
Surface Prep	Zn-Phos	Specified	Solv clean Sn-pl		Sanded & cleaned		Solv & SP10 bla	Zn Phos	Zn Phos	Zn Phos	Anodized Al
Thickness			2 mil		2 mil		3 - 5 mil	.9 - 1.1	.9 - 1.1	.9 - 1.1	.6 - .9
	1/16 inch, max.		1/8 inch, max.		1/16 inch, max.		No loss.	1/16 inch, max.	1/16 inch, max.	ASTM D3359, M-B	
BRITTLENESS (Knife Scrape											
Surface Prep	Zn-Phos		Solv clean Sn-pl	Solvent cleaned.	Sanded & cleaned			Zn Phos	Zn Phos	Zn Phos	
Thickness	.9 to 1.1	1 mil	2 mil	3 mil	2 mil			.9 - 1.1	.9 - 1.1	.9 - 1.1	
Result	No chips, etc.		No chips, etc.	No chips, etc.	No chips, etc.			No chips, etc.	No chips, etc.	No chips, etc.	
FLEXIBILITY (Bending)											
Surface Prep	Solvent clean.	Solv clean Sn-pl	Solv clean Sn-pl		Solvent clean.		Solv & SP10 bla	Solvent clean.	Solvent clean.	CrO4 film on Al	Anodized Al
Thickness	.9 to 1.1	1 mil	2 mil		.9 - 1		3 mil	.9 - 1	.9 - 1	.9 - 1	.6 - .9
Result	No cracks.	No loss on .12	No big chips, et		No cracks.		No loss on 1 Dia	No cracks.	No cracks.	No cracks.	Dent test, OK
WATER RESISTANCE											
Surface Prep	Zn-Phos	Sanded & clean	Solv clean Sn-pl		Sanded & clean	Al 2024-T3 chro	Solv & SP10 bla	Zn Phos	Zn Phos		Anodized Al
Thickness	.9 to 1.1	3 mil	2 mil		2 mil	.6 - .9 mils	3 - 5 mil	.9 - 1.1	.9 - 1.1		.6 - .9
Result	18 hrs	24 hrs & 4H pen	18 hrs		18 hrs		8 hrs, boiling wa	168 hrs	168 hrs		96 hr immerse
HYDROCARBON RESISTAN											
Surface Prep	Zn-Phos		Solv clean Sn-pl		Sanded & cleaned		Solv & SP10 bla	Zn Phos	Zn Phos		Anodized Al
Thickness	.9 to 1.1		2 mil		2 mil		3 - 5 mil	.9 - 1.1	.9 - 1.1		.6-.9 plus top coat
Result	4 hrs		4 hrs in toluene		4 hrs		30 day, toluene	168 hrs	168 hrs		24 hrs hot oil
SALT SPRAY (FOG)											
Surface Prep	Zn-Phos		Solv clean Sn-pl		Sanded & clean	Al 2024-T3 chro	Solv & SP10 bla	Zn Phos	Zn Phos	Zn Phos	Anodized Al
Thickness	.9 to 1.1		1.3 - 1.7		.9 - 1.1	.6 - .9 mils	3 - 5 mil	.9 - 1.1	.9 - 1.1	.9 - 1.1	.6 - .9
Top coat	-		-		-	MIL-C-83286 1.	-	-	-	-	-
Percent Salt	5% ASTM B117		5% 141 #6061		5% 141 #6061	5%	5% ASTM B117	5% ASTM B117	5% ASTM B117	5% ASTM B117	5% ASTM B117
Result	336 hrs		48 hrs		48 hrs	500 hrs	720 hrs	336 hrs	336 hrs	1000 hrs	1000 hrs
WEATHER											
Surface Prep	Zn-Phos		Solv clean Sn-pl		Sanded & cleaned			Zn Phos	Zn Phos	Zn Phos	
Thickness	.9 - 1.1		1.3 - 1.7		.9 - 1.1			.9 - 1.1	.9 - 1.1	.9 - 1.1	
Top coat: Thickness	1.4 - 1.6		-		.9 to 1.1			1.8 min.	1.8 - 2.2	1.8 - 2.2	
Spec	TT-E-489				TT-E-489			MIL-C-46168 or	MIL-C-46168	MIL-C-46168 or 53039	
Geographic location	Wash DC		Wash DC		Wash DC			Wash DC	Wash DC	Wash DC	
Result	24 mo		24 mo		18 mo			18 mo	18 mo	24 mo	
WEATHER, ACCEL ASTM G											
Surface Prep							Solv & SP10 blast				
Thickness							3 - 5 mil				
Result							1000 hrs, test D				
OTHER	Enamel and lacquer resist.		Lac'r resist	Toxicity, compat	Enamel & lacquer resist. Explosive comaptibility.		Hydra fluid resis 120F/100%RH/30day Cathodic Protection	DS2 Resisting	Oil Resisting water-reducible 2 part mix.	Epoxy, waterbor Chemical agent	Low IR reflectance Filiform ASTM2803
SEA WATER WETDOWN, NS											

TOP COATS

		(Navy)	(Army/Navy)	2-part		2-part plus pigm	SCAQMD		CARC; 1-part mix		(USAF)	(USAF)
TYPE COATING:	Paint, Oil (Alkyd	**Top Coat Enam**	Enamel	Epoxy-Polyamid	Epoxy, Powder	Epoxy, Coating	Polyureth Coat	Enamel, Alkyd	Polyureth Coat	Polyurethane, Aliphatic	Urethane	Zinc Flake
SPEC NUMBER:	TT-P-102	**TT-E-516A**	MIL-E-11195E	MIL-P-24441B	MIL-C-24712	MIL-C-22750E/A	MIL-C-46168D	MIL-E-52891B	MIL-C-53039A	MIL-C-81773	MIL-C-83286	MIL-C-87115
Date of Spec:	1992	1967	1993	1991	1989	1992	1987	1988	1988	CANCELLED	1980	1989
Intended Use:	General Exterior	Ammo finsh coat	Ammo finsh coat	Ship hull and	Steel & Alum, hi	Aircraft & AGE	Army equipment	Ammo.	Army equipment.		2 component	Zn Chromate ty
				sand blasted ext			CARC; finsih co	Finish coat.	CARC; finsih coat.		Aerosp equipmnt	
Pb and -CrO4 free:	yes		yes		yes			yes	Hexaval Cr6 free.			
C6H6 and Cl solvent free:	yes		.06% max		yes		Ethyl benzene, e	yes				Grey or black
VOC's:	low		420 gm/, min.	low	low		Low	OK	420 gm/l		low	
											Aliphatic isocyanate	
Drying Time:	8 hrs	Quick.	Fast.		60' gel; plus heat	4 - 6 hrs.		Quick.				
SPEC REQUIREMENTS												
ADHESION TEST (Tape)											Al 2024-T3 chromate MIL	Same
Surface Prep		Clean & acid etc	Solvent clean Sn	Sand blasted ste	Solv clean & abr	Al, chem conver,	.6-.9 primer	Clean & acid etch steel			Primer 22337 to .6-.9 mil	
Thickness		2 mil	2 mil	2 mil	8 to 12 mil	1.7 - 2.3 mil		.9 - 1.1			Top Coat 2.0 more	
		1/16 inch, max	1/8 inch, max	OK after water i	No loss.	OK after water i	-	1/16 inch, max				
BRITTLENESS (Knife Scrape)	Meth 6304, -141										Al 2024-T3 chromate MIL-C-81706	
Surface Prep	Soap & water cl	Solvent clean Sn	Solvent clean Sn	plated steel				Solvent Clean			Primer 22337 to .6-.9 mil	
Thickness .		.9 - 1	2 mil					.9 - 1.1			Top Coat 2.0 more	
Result	No chips, etc.	No chips, etc.	No chips, etc.				-	No chips, etc.				
FLEXIBILITY (Bending)												
Surface Prep	Soap & water cl	Solvent clean Sn	Solvent clean Sn	Solvent clean Sn	Solv clean & abr	Al panel, anodiz	Clean & acid etc	Solvent Clean				
Thickness	.9 - 1.1	.9 - 1	2 mil	1.5 mil	2.5 to 3.5 mil	1.7 to 2.3 mil	.9 - 1.1	.9 - 1.1				
Result	No cracks.	No cracks.	No cracks.	No cracks.	No loss.	No loss on 1/4 D	No cracks.	No cracks.				
WATER RESISTANCE												
Surface Prep		Clean & acid etc	Solvent clean Sn	Sand blasted ste	Solv clean & abr blast			Clean & acid etc	Zn Phos		Primer 22337 to .6-.9 mil	
Thickness		2 mil	2 mil	2 mil	8 to 12 mil		.9 - 1.1	.9 - 1.1	.9 - 1.1		Top Coat 2.0 more	
Result		18 hrs	18 hrs	10 weeks @ 200	24 hrs in boiling -OK		168 hrs	18 hrs	168 hrs		30 day @100RH, 120 F	
											4 day @ 110F (liquid)	
HYDROCARBON RESISTAN												
Surface Prep			Solvent clean Sn	Solvent clean Sn	Solv clean & abr	Al, chem conver,	.6-.9 primer		Zn Phos			
Thickness			2 mil	1.5 ml	8 to 12 mil	1.7 - 2.3 mil	.9 - 1.1		.9 - 1.1			
Result		Non-resistant	48 hrs	18 hrs in xylenes	30 day toluene-	OK on MEK rag	168 hrs		168 hrs			
SALT SPRAY (FOG)												
Surface Prep		Zn Phos	Zn Phos		Solv clean & abr blast			Zn Phos			Al 2024-T3 chromate MIL	4340 steel as is
Thickness		.9 - 1.1	1.3 - 1.7		8 to 12 mil			.9 - 1.1			Primer 22337 to .6-.9 mil	.2 - .4 mils
Top coat		-	-		-			-			Top Coat 2.0 more	
Percent Salt		5% 141 #6061	5% ASTM B117		5% ASTM B117		none specified	5% ASTM B117	none specified		5%	5%
Result		48 hrs	120 hrs		3000 hrs			150 hrs			500 hrs	400 hrs
WEATHER												
Surface Prep		Zn Phos	Zn Phos					Zn Phos	Zn Phos			
Thickness		.9 - 1.1	1.3 - 1.7					.9 - 1.1	.9-1.1 primer, epoxy: MIL- 23377, 52192,53022,53030,85582			
Top coat: Thickness		-	-					-	1.8 - 2.2			
Spec		-	-					-				
Geographic location		Wash DC	Wash DC				Wash DC	Wash DC	Wash DC			
Result		18 mo	18 mo				24 mo	18 mo	24 mo			
WEATHER, ACCEL ASTM G					Meth 1, BH	6Kwatt xenon arc lamp					Al 2024-T3 chromate MIL-C-81706	
Surface Prep	Solvent clean Al	Solvent clean Sn			Solv clean & abr blast			Solvent Clean	Clean & acid etch steel		Primer 22337 to .6-.9 mil	
Thickness	1.5 mil	.9 - 1			8 to 12 mil			.9 - 1.1	.9 - 1.1		Top Coat 2.0 more	
Result	200+ hrs, G53	168 hr			1000 hrs	500 hrs - OK	300 hrs	240 hrs	300 hrs		300 - 500 hrs	
OTHER					Thermal Shock	IR reflectance; D	DS2 resist;		DS2 resist		Oil resist	
					Abrasion; Hardn	Lub oil and hydr	Acid resist;		Acid resist		Hydro Fluid resist	
					Hydraul fluid resi	fluid resistance	Spectral req.		Spectral		Water	
					Chemical resist:	Heat resist 1 hr @250F					Pencil Hardness	
SEA WATER WETDOWN, NS												

LTR	DESCRIPTION	DATE	APPROVED
REVISIONS			



NOTES:

1. SURFACE PREPARATION:
   METAL SUBSTRATE SHALL BE PREPARED IN THE OPTIMUM MANNER PRESCRIBED FOR THE TYPE OF COATING BEING APPLIED. (SEE ASSEMBLY I.D. BLOCK.)

2. COLOR
   2.1 EXTERIOR – FOR THOSE COATINGS WHICH MAY BE PIGMENTED, COLOR SHALL BE OLIVE DRAB IN ACCORDANCE WITH FED-STD-595, COLOR CHIP NO. 34087.
   2.2 INTERIOR – COLOR OPTIONAL.

3. DRY FILM THICKNESS:
   3.1 EXTERIOR COATING THICKNESS SHALL BE COLOR DEPENDENT.
   OLIVE DRAB ________ .0015 INCH, MAXIMUM
   ANY OTHER COLOR _ .0012 INCH, MAXIMUM
   3.2 INTERIOR COATING THICKNESS OF .0025 INCH, MINIMUM IS PREFERRED.

4. SCREW THREADS:
   4.1 THREADS SHALL NOT BE COATED BUT MAY BE PHOSPHATED, OR SUBJECTED TO PRETREATMENT PER NOTE 1.
   4.2 BASE PLUG, ITEM 3 OR 4, REMOVAL DURING COATING PROCESS IS OPTIONAL.

5. PROJECTILE ROTATING BAND (COPPER ALLOY) SHALL NOT BE COATED.

6. MARKINGS SHALL BE IN APPROXIMATE POSITION SHOWN, 1/2-INCH HIGH, WHITE OR CONTRASTING LETTERING, WITH 1/4-INCH SPACING BETWEEN LINES. LAST LINE SHALL INCLUDE COATING TYPE AND A SERIAL NUMBER. (STENCILS CAN BE PROVIDED AS GFM ON REQUEST.)

7. EXPLOSIVE (PBXN-106) COMPATIBILITY TEST AT GOVERNMENT LABORATORY: A SAMPLE SCRAPING OF 5 TO 10 GRAMS OF CURED COATING MATERIAL SHALL BE SUBMITTED TO:
   NAVAL SURFACE WARFARE CENTER
   INDIAN HEAD DIVISION, YORKTOWN DETACHMENT
   CODE 9312A
   YORKTOWN, VIRGINIA 23691-0160

8. DESTINATION OF COATED PROJECTILES SHALL BE:
   NAVAL SURFACE WARFARE CENTER
   CODE G33
   DAHLGREN, VIRGINIA 22448-5100

DASH NO.	COATING TYPE	SPECIFICATION	CONTRACTOR
-7	"EVERLUBE" 6150	MIL-C-85614	EM CORP. /COATING TECH INC.
-6	INORGANIC ZINC	DOD-P-24648 TY I, CL 1, B	INORG. COATINGS, INC /COATING TECH INC.
-5	"SILOXIRANE"	#2431	ADVANC. POLYMER SC.
-4	"SILOXIRANE"	#2131	ADVANC. POLYMER SC.
-3	"XYLAR"	MIL-C-81751	PLAS-TECH COATINGS
-2	"E-COAT"	MIL-P-53084	METOKOTE CORP
-1	"CONTROL"	MIL-P-18948	CHAMBERLAIN MFG / SCRANTON ARMY AP

ASSEMBLY IDENTIFICATION

ITEM NO.	QTY REQD	CODE ID NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL OR NOTE
4	1	10001	2838417	PLUG, BASE	2.00-12UNS THREAD
3	5	10001	2838398	PLUG, BASE	1.50-12UNF THREAD
2	1	10001	2519588	PROJECTILE, 5"/54 CAL, MK 55 MOD 0 BODY ASSEMBLY	AISI 06 TOOL STEEL
1	5	10001	388749	PROJECTILE, 5"/54 CAL, MK 41 MOD 0 BODY ASSEMBLY	AISI 1050 STEEL

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
GENERAL TOLERANCES
± ± ±

✓

MATERIAL

INTERPRET DRAWING IAW MIL-STD-100
DO NOT SCALE THIS DRAWING

NAVAL SURFACE WARFARE CENTER

G33	R.G.	94-06-29
CHECKED	J.M.	94-06-28
DRAWN BY	J.M.	94-06-16

APPROVED Stan Grisca[illegible] DATE 94-06-30

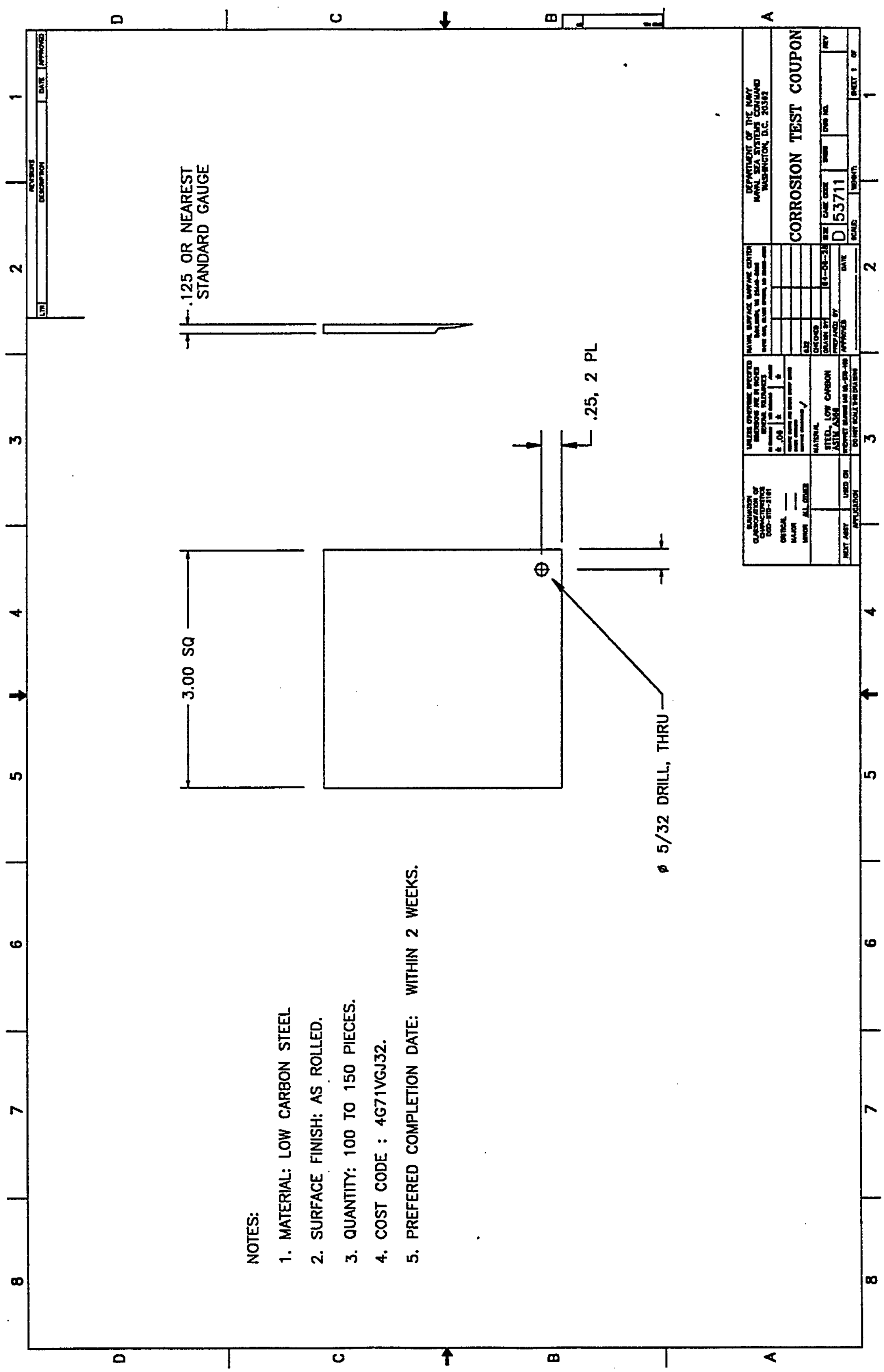
DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, D.C. 20362

PROJECTILE, 5 INCH 54 CALIBER
CORROSION TEST UNIT
PRODUCT IMPROVEMENT PROGRAM NO. 92AFAC01

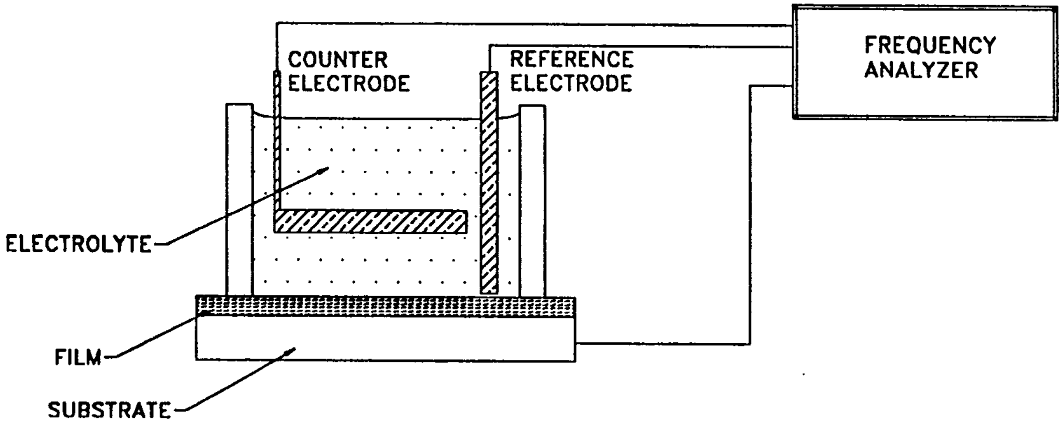
SIZE	CAGE CODE	SWBS	DWG NO.	REV
D	53711		SK 74674	

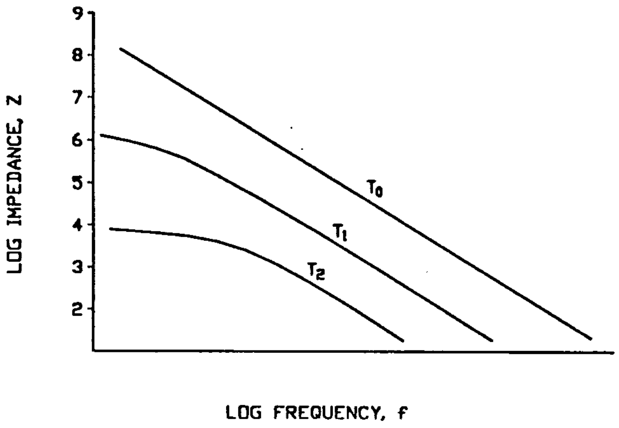
SCALE: 1/1 WEIGHT: (58 LBS) SHEET 1 OF 1

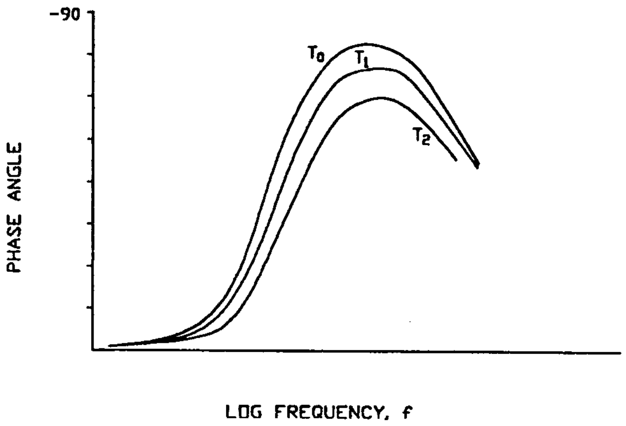
SK 74674


.125 OR NEAREST STANDARD GAUGE
.25, 2 PL
3.00 SQ
ø 5/32 DRILL, THRU
NOTES:
1. MATERIAL: LOW CARBON STEEL
2. SURFACE FINISH: AS ROLLED.
3. QUANTITY: 100 TO 150 PIECES.
4. COST CODE : 4G71VGJ32.
5. PREFERED COMPLETION DATE: WITHIN 2 WEEKS.
DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, D.C. 20362
NAVAL SURFACE WARFARE CENTER
CORROSION TEST COUPON
SIZE D
CAGE CODE 53711
DWG NO.
REV
SCALE
WEIGHT
SHEET 1 OF
MATERIAL
STEEL, LOW CARBON ASTM A366
± .06
DRAWN BY 94-08-25
CHECKED
PREPARED BY
APPROVED
DATE
CRITICAL
MAJOR
MINOR ALL OTHER
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE THIS DRAWING
REVISIONS
LTR
DESCRIPTION
DATE
APPROVED
A
B
C
D
1
2
3
4
5
6
7
8

TEST CELL SCHEMATIC
ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY (EIS)



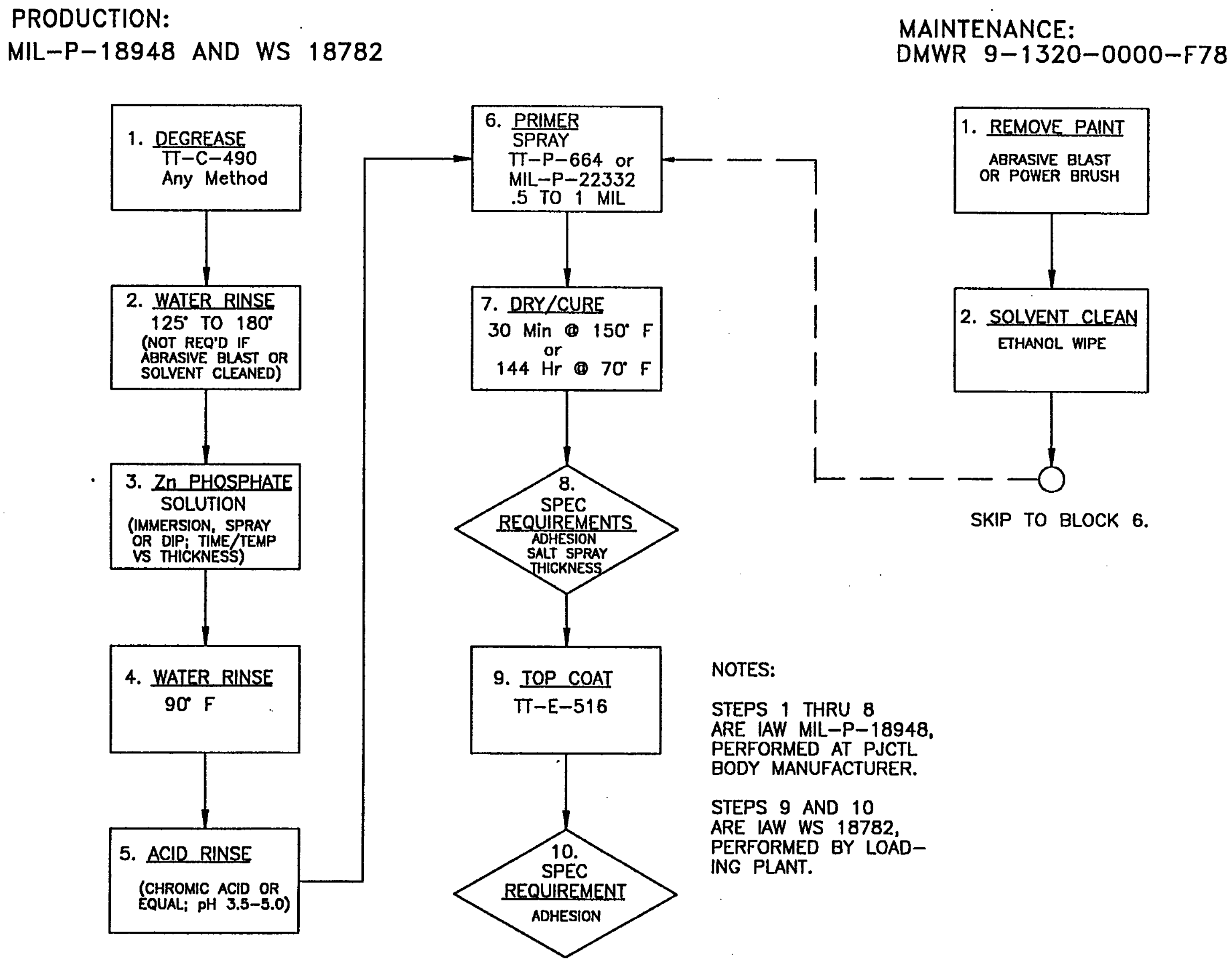




APPENDIX B

FLOWCHARTS - APPLICATION PROCESSES

NAVY PROJECTILE SURFACE PROTECTION APPLICATION PROCESS



NOTES:

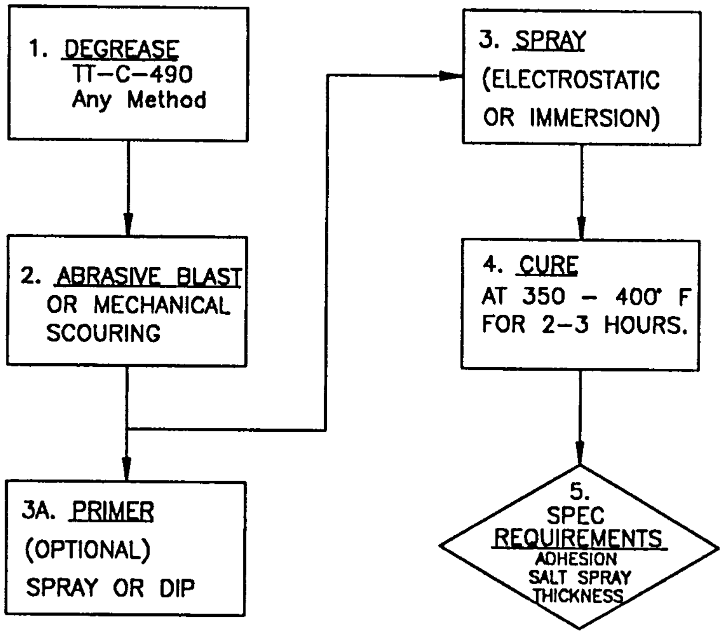
STEPS 1 THRU 8 ARE IAW MIL-P-18948, PERFORMED AT PJCTL BODY MANUFACTURER.

STEPS 9 AND 10 ARE IAW WS 18782, PERFORMED BY LOADING PLANT.

NAVY PROJECTILE SURFACE PROTECTION APPLICATION PROCESS

POWDER COAT (NYLON, POLYESTER, OR EPOXY)

PRODUCTION:



MAINTENANCE:

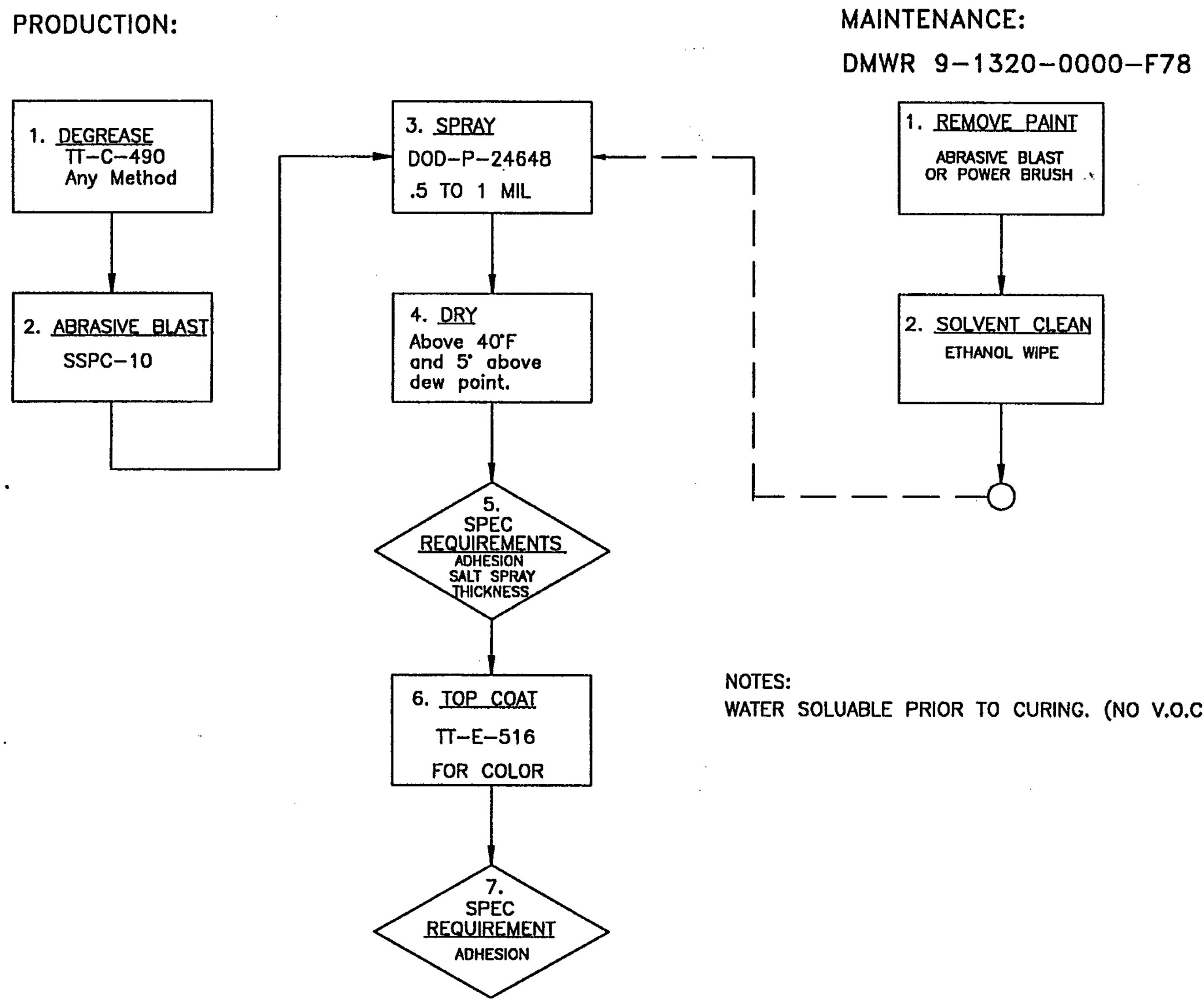
HIGH TEMPERATURES DURING CURING EXCEEDS SAFE LIMITS FOR EXPLOSIVE MATERIAL. DEPOT MAINTAINANCE USE IS NOT POSSIBLE.

NOTES:

4. WATER SOLUABLE PRIOR TO CURING. (NO V.O.C.)
3A. PRIMER RECOMMENDED FOR SEVERE SERVICE.
5. CAN BE PIGMENTED TO ANY DESIRE COLOR.

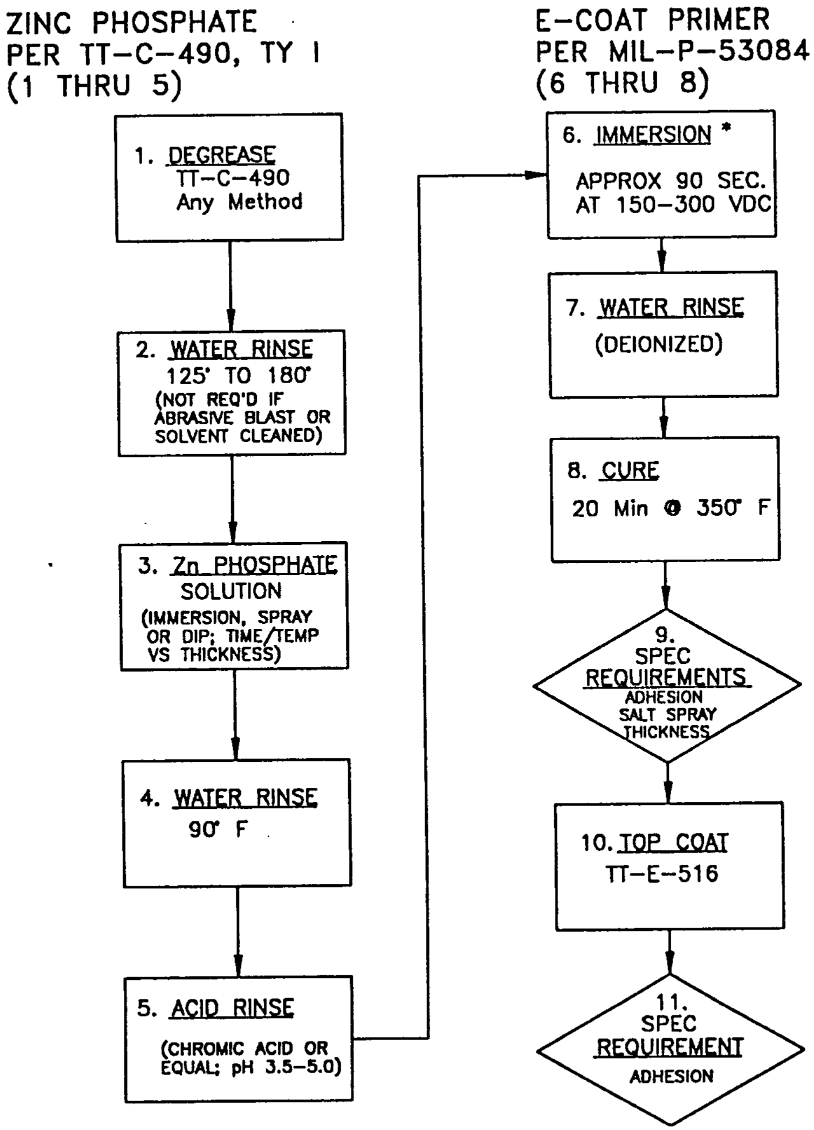
NAVY PROJECTILE SURFACE PROTECTION APPLICATION PROCESS

INORGANIC ZINC-DUST PRIMER, DOD-P-24648, TY I, CL I, COMP B



NOTES:
WATER SOLUABLE PRIOR TO CURING. (NO V.O.C.)

NAVY PROJECTILE SURFACE PROTECTION APPLICATION PROCESS WITH ELECTRO-COAT PRIMER



MAINTENANCE:

HIGH TEMPERATURES DURING IMMERSION AND CURING EXCEED SAFE LIMIT FOR MOST EXPLOSIVE MATERIAL. DEPOT MAINTENANCE USE NOT POSSIBLE.

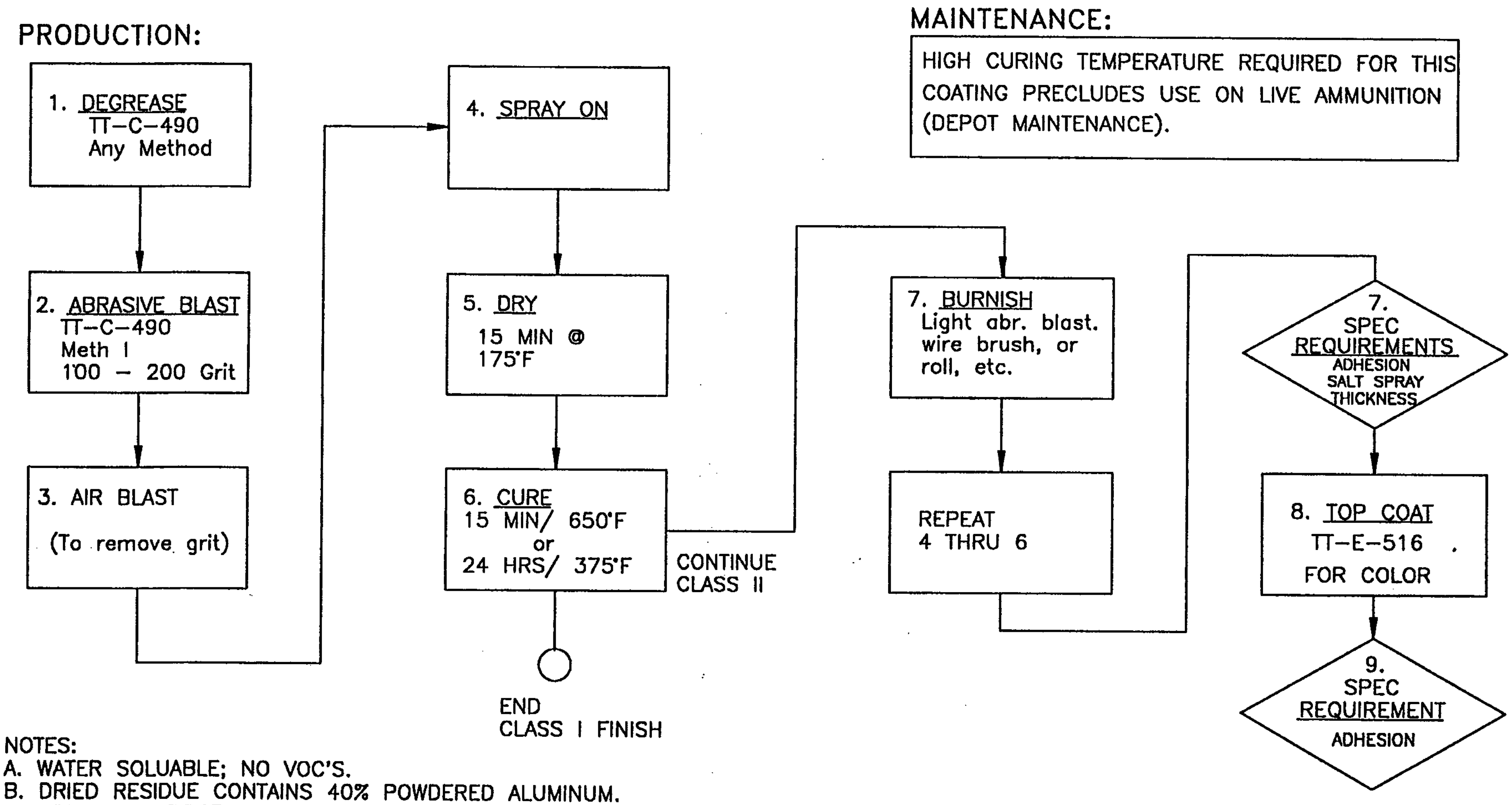
NOTES:

WATER SOLUABLE PRIOR TO CURING (NO V.O.C.).

* IMMERSION INTO MIXED RESIN, PIGMENT AND DE-IONIZED WATER.

NAVY PROJECTILE SURFACE PROTECTION APPLICATION PROCESS WITH METALLIC-CERAMIC

MIL-C-81751, TY I, CL 3

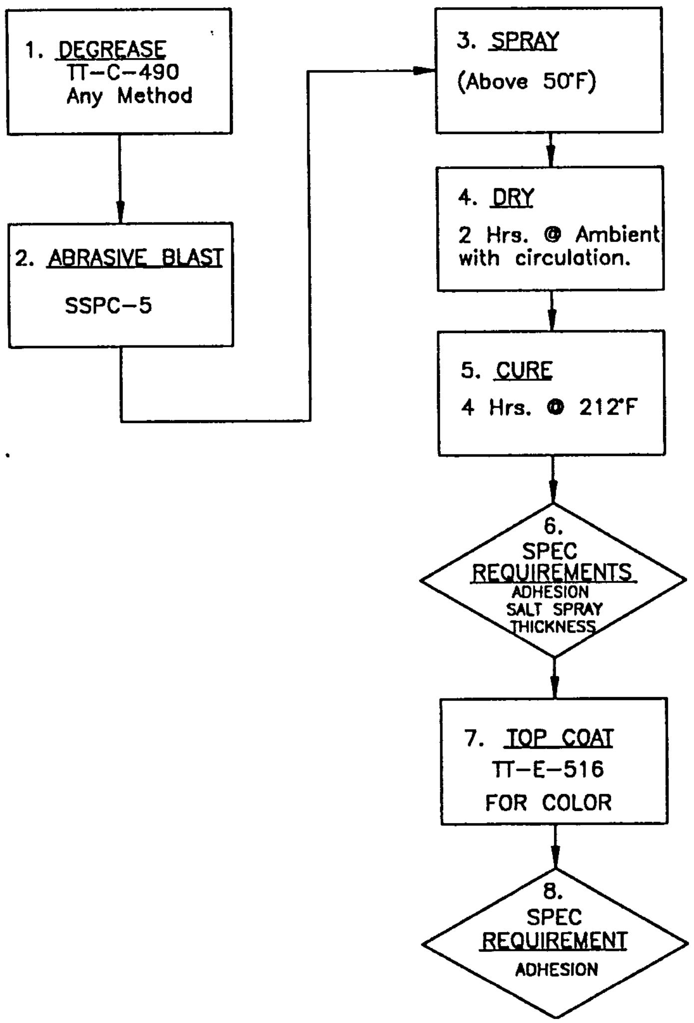


HIGH CURING TEMPERATURE REQUIRED FOR THIS COATING PRECLUDES USE ON LIVE AMMUNITION (DEPOT MAINTENANCE).

NOTES:
A. WATER SOLUABLE; NO VOC'S.
B. DRIED RESIDUE CONTAINS 40% POWDERED ALUMINUM.
DUST, HYDROGEN AND EXOTHERMIC REACTIONS POTENTIAL.
C. CLASS I SUFFICIENT FOR PROJECTILE INTERIOR CAVITY.

NAVY PROJECTILE SURFACE PROTECTION APPLICATION PROCESS WITH SILOXIRANE®

PRODUCTION:



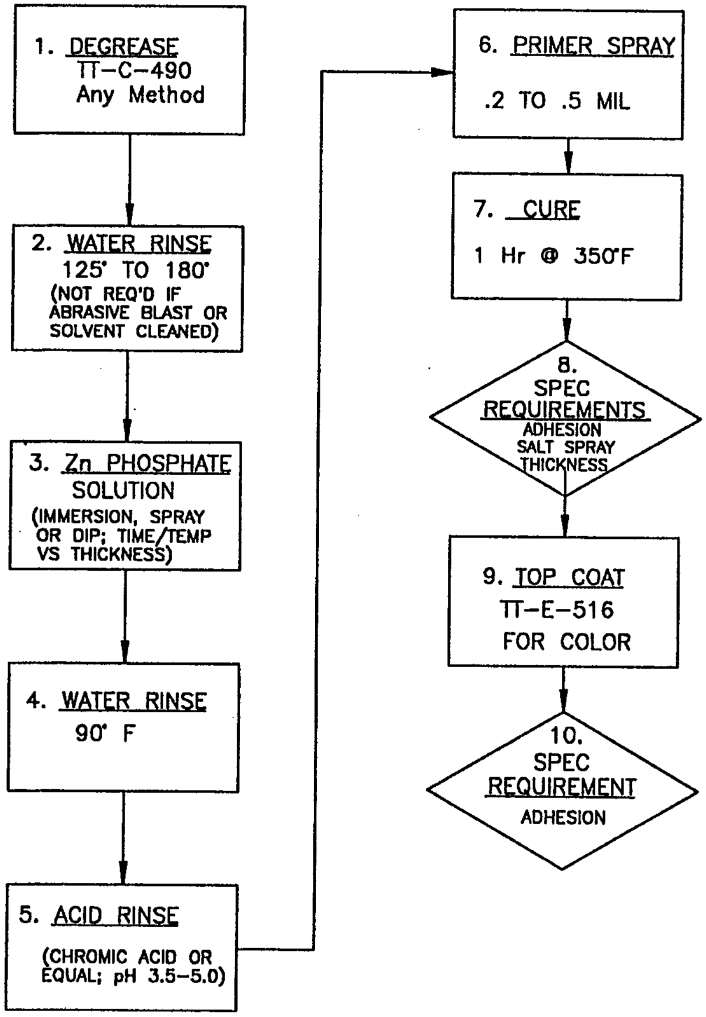
MAINTENANCE:

HIGH CURING TEMPERATURE REQUIRED FOR THIS COATING PRECLUDES USE ON LIVE AMMUNITION (DEPOT MAINTENANCE).

NOTES:
ACETONE OR MEK CLEAN UP.
LOW VOC.

NAVY PROJECTILE SURFACE PROTECTION APPLICATION PROCESS WITH ALUMINIZED PHENOLIC, MIL-C-85614

ZINC PHOSPHATE
PER TT-C-490, TY I
(1 THRU 5)



MAINTENANCE:

HIGH CURING TEMPERATURE REQUIRED FOR THIS COATING PRECLUDES USE ON LIVE AMMUNITION (DEPOT MAINTENANCE).

NOTES:

THINNED WITH ETHANOL, TOLUENE, AND N-BUTANOL.; EQUAL PARTS.

VOC 756 GM/L.

APPENDIX C

CONSIDERED BUT NOT TESTED

CONSIDERED BUT NOT TESTED

DIAMOND-LIKE NANOCOMPOSITE (DYLYN™)

This is a proprietary thin film coating material marketed by Advanced Refractory Technologies (ART), Inc, Buffalo, NY. It is described as two interpenetrating networks, one of an C-H hydrocarbon and the other of Si-O silicon dioxide structure.

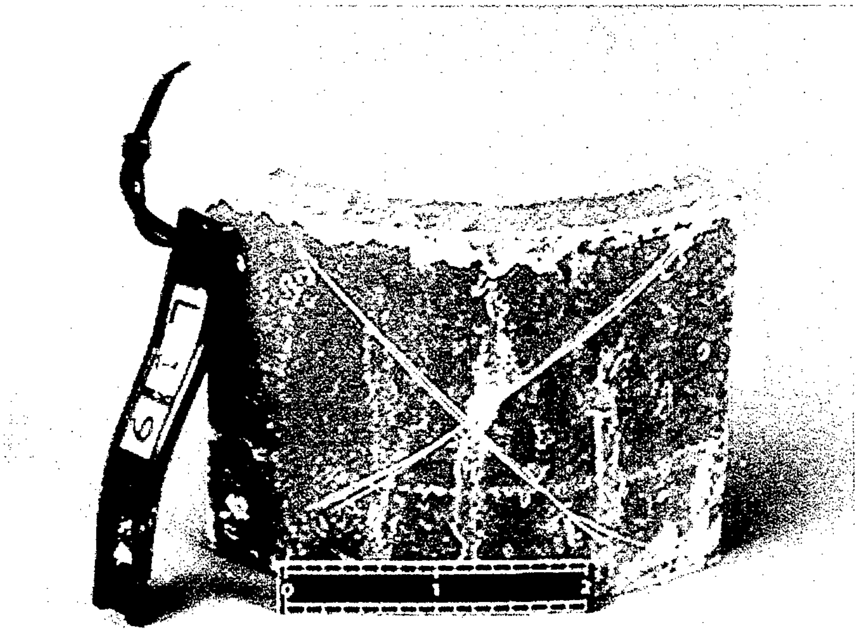
The term "diamond-like" refers to the type of atomic bonding. Both carbon and silicon are group IV elements with four valence electrons. Normally two are at the outermost s-level and two are at the outermost p-level. Hybrid bonding occurs in materials such as diamond where electron position, explained by quantum mechanics and wave functions, becomes one s and three p's. This permits each carbon or silicon atom to be bonded to four others. Crystal lattice structure is known as face centered cubic (FCC). In the case of diamond and others such as its prototype, zincblende (ZnS), atoms also occupy interior crystallographic positions of the unit cell with 109.5 degree separation angles between all atoms. Unlike diamond or crystalline silicon, the Dylyn structures are amorphous, i.e. there is no long range crystallographic order.

ART has done some work on Small Business Innovative Research contracts for the Air Force using Dylyn to protect plasma and microwave devices, and with the Marine Corp and Army in improving wear resistance and reducing friction. The positive aspects of Dylyn coated gun ammunition would be its high abrasion resistance combined with a very thin barrier coating.

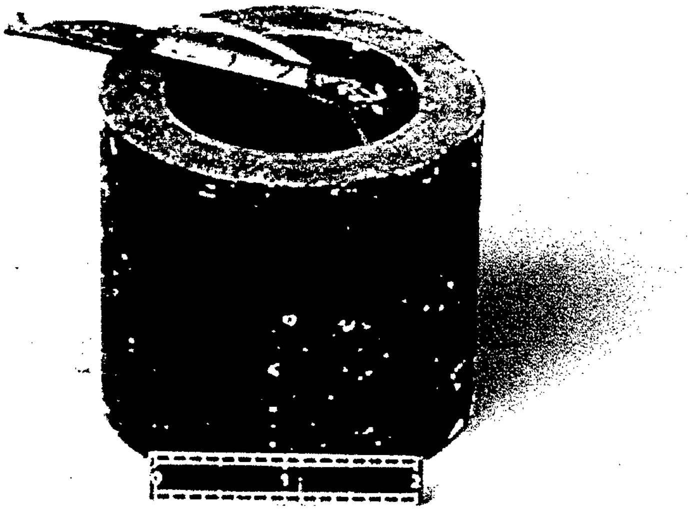
Overall it was felt that Dylyn was not a good candidate for Navy gun ammunition because large scale production use had not been proven. Extensive development would probably be necessary for the deposition process which involves plasma ion beam and vacuum chambers. Also its use would seem more apropos to physically small items of high value.

APPENDIX D

PHOTOGRAPHS, COUPONS AFTER SALT SPRAY TEST

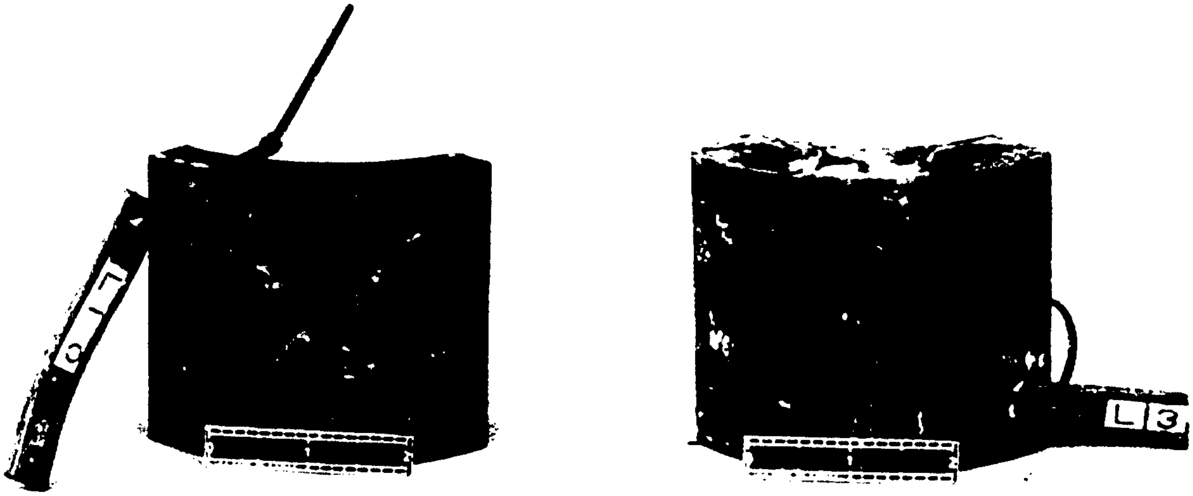


IVD/XYLAR

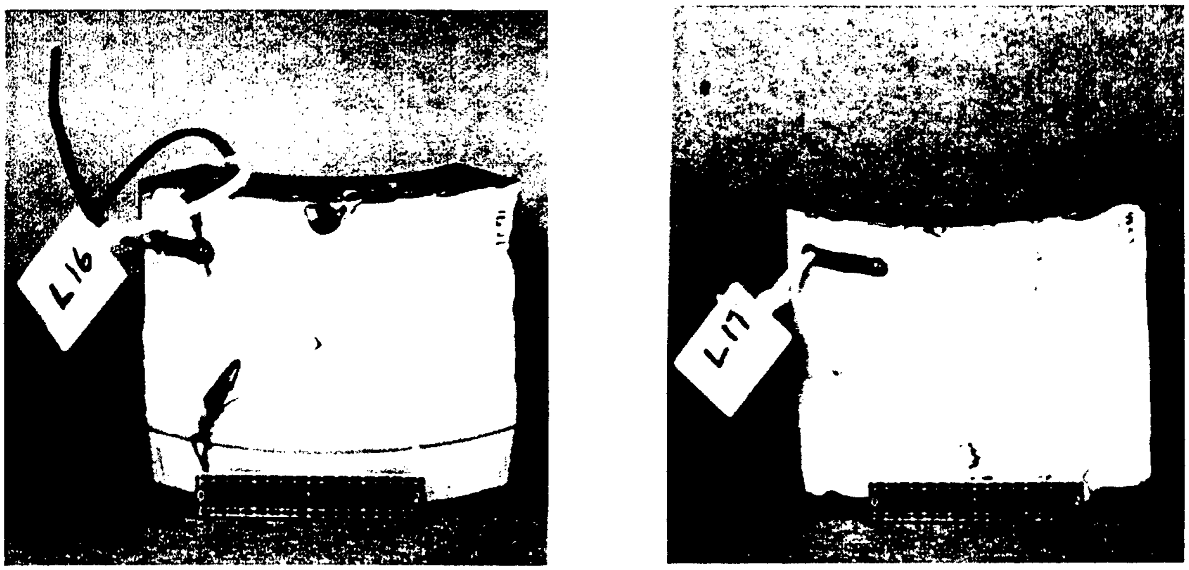


E-COAT

FIGURE D-1. IVD/XYLAR AND E-COAT AFTER 500 HOURS IN SALT FOG



NYLON POWDER



SILOXIRANE®

FIGURE D-2. SILOXIRANE® AND NYLON POWDER COATING AFTER 500 HOURS IN SALT FOG

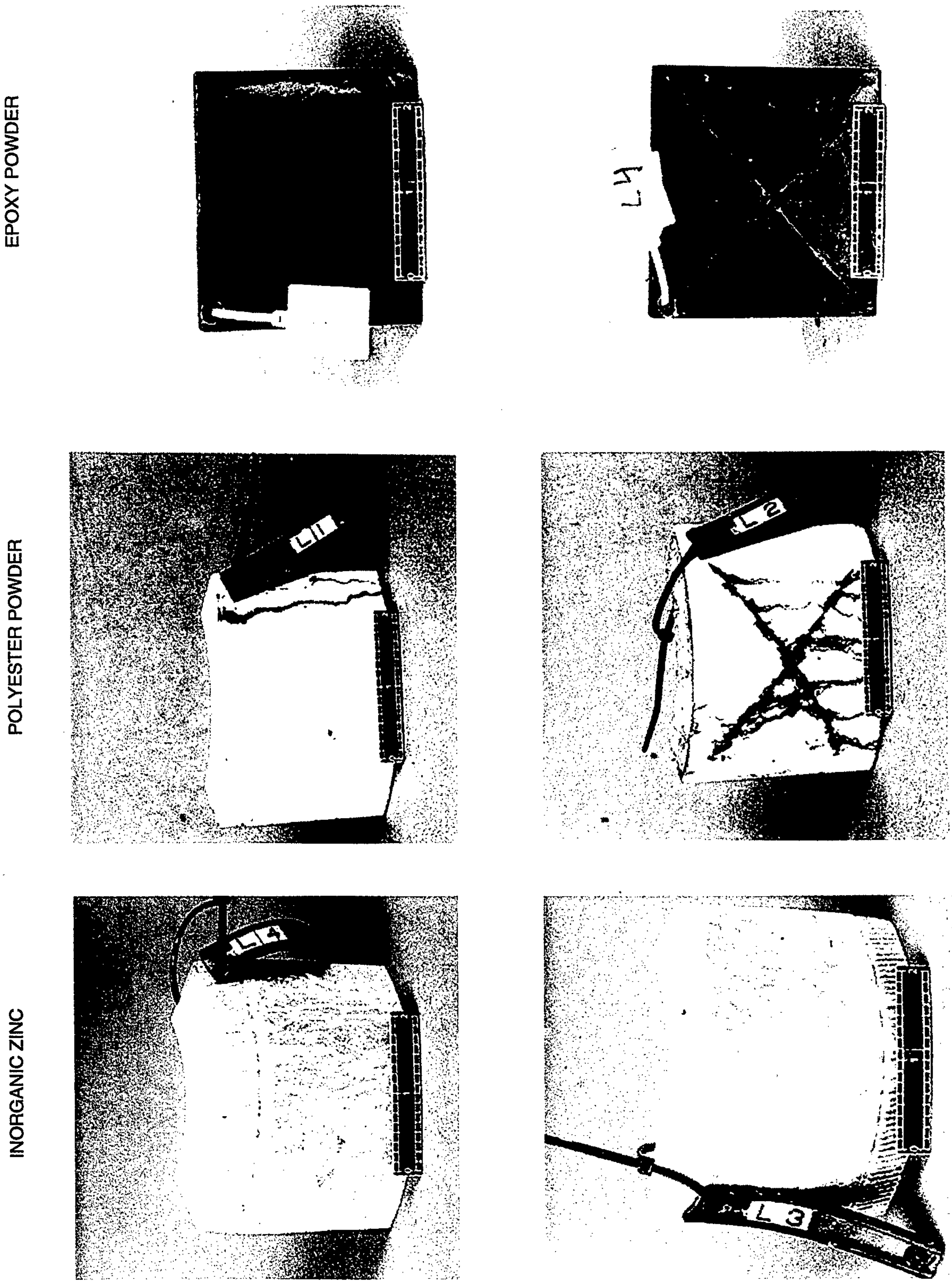
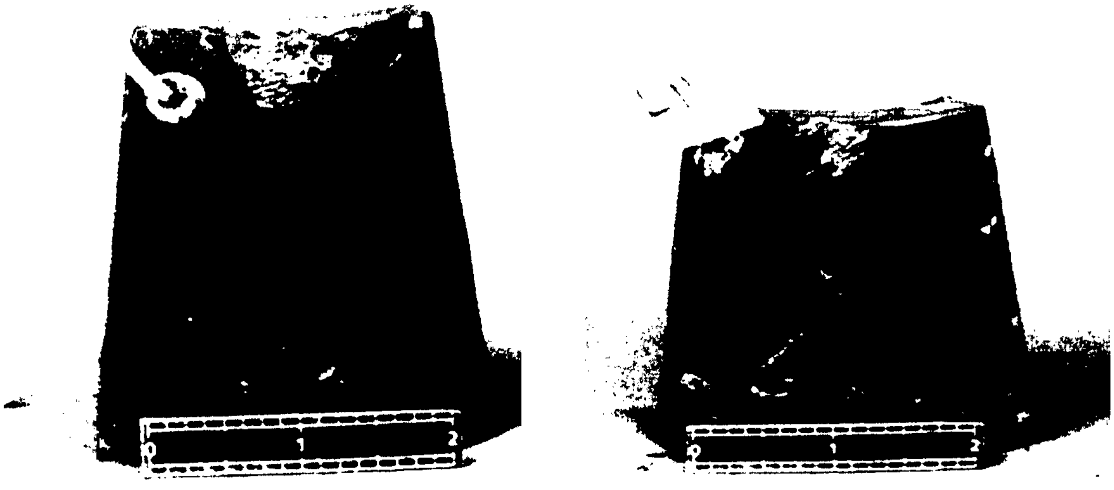
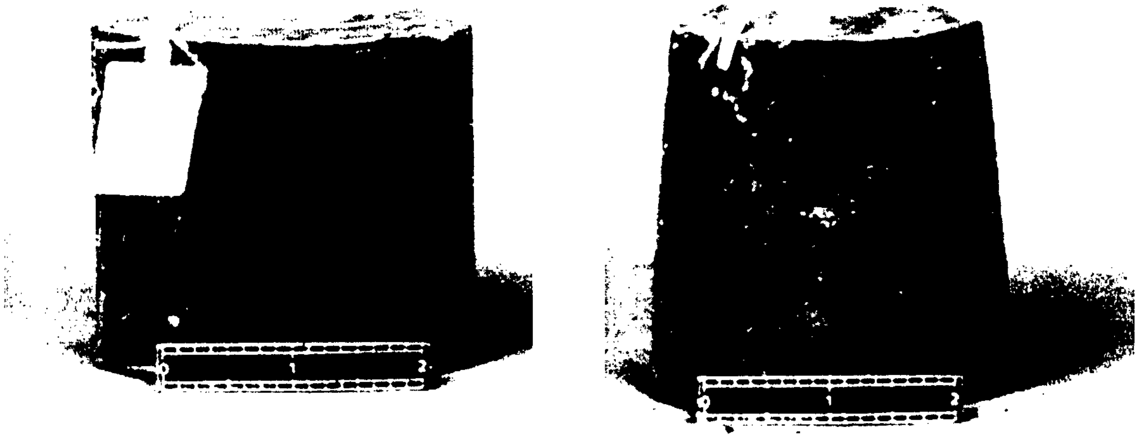


FIGURE D-3. INORGANIC ZINC AND POWDER COATINGS (EPOXY AND POLYESTER) AFTER 500 HOURS IN SALT FOG



ZINC PHOSPHATE WITH PRIMER

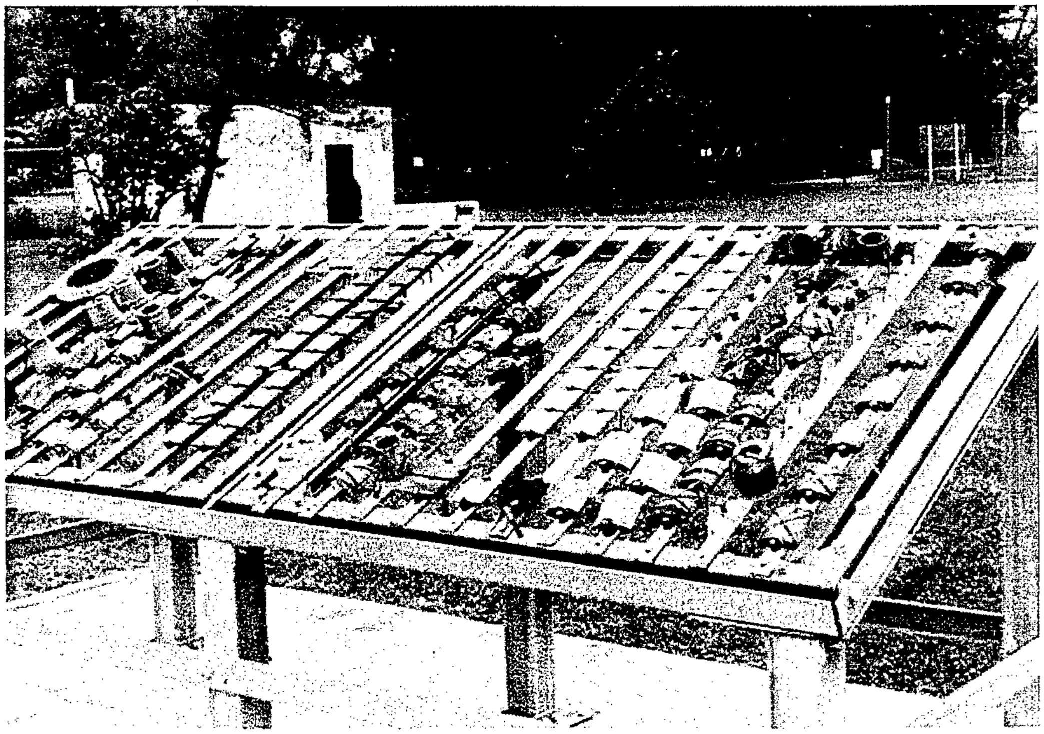


ZINC PHOSPHATE WITH PRIMER AND TOPCOAT

FIGURE D-4. ZINC PHOSPHATE WITH PRIMER AND ZINC PHOSPHATE WITH PRIMER AND TOPCOAT PAINT AFTER 500 HOURS IN SALT FOG

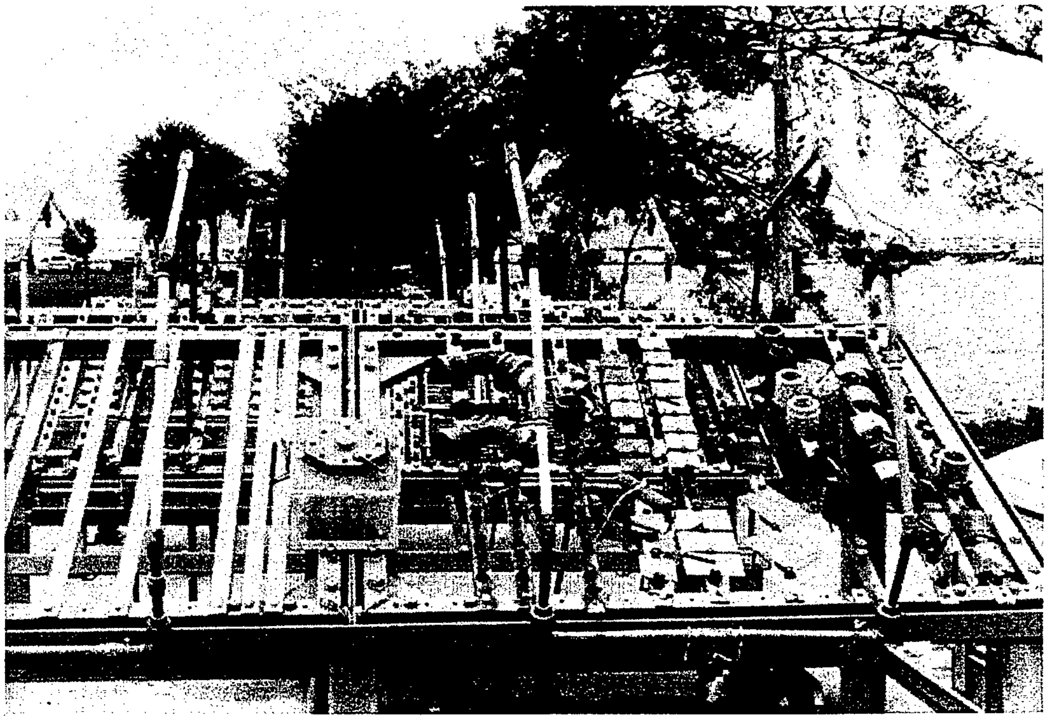
APPENDIX E

PHOTOGRAPHS, COUPONS AFTER MARINE EXPOSURE TEST



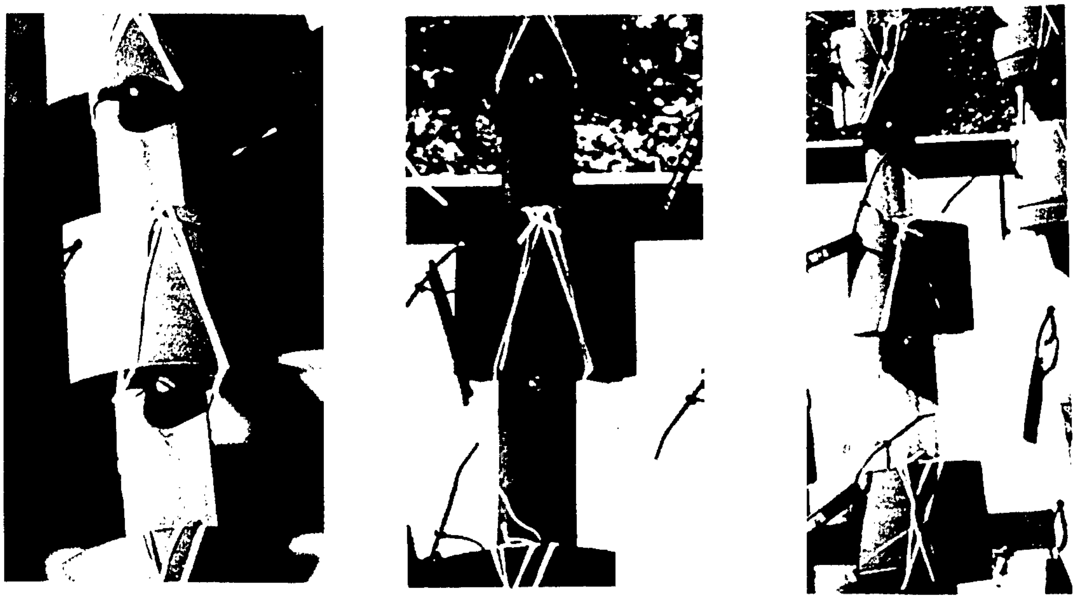
MARINE ATMOSPHERIC EXPOSURE RACK

NAVAL SURFACE WARFARE CENTER, FT. LAUDERDALE FL.



SEAWATER WETDOWN TEST RACK

NAVAL SURFACE WARFARE CENTER, FT. LAUDERDALE FL



0 MONTHS 4 MONTHS 9 MONTHS

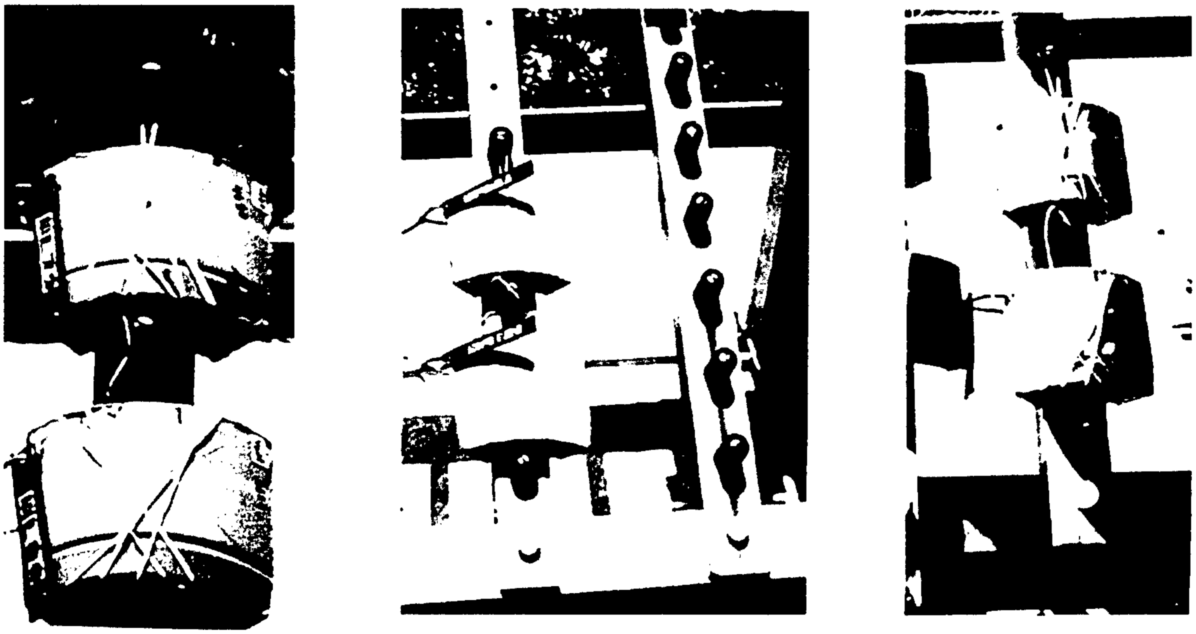
FIGURE E-1. IVD/XYLAR COATING AFTER 0, 4, AND 9 MONTHS ON MARINE ATMOSPHERIC RACK

0 MONTHS 4 MONTHS 9 MONTHS

FIGURE E-2. NYLON POWDER COATING AFTER 0, 4, AND 9 MONTHS ON MARINE ATMOSPHERIC RACK

0 MONTHS 4 MONTHS 9 MONTHS

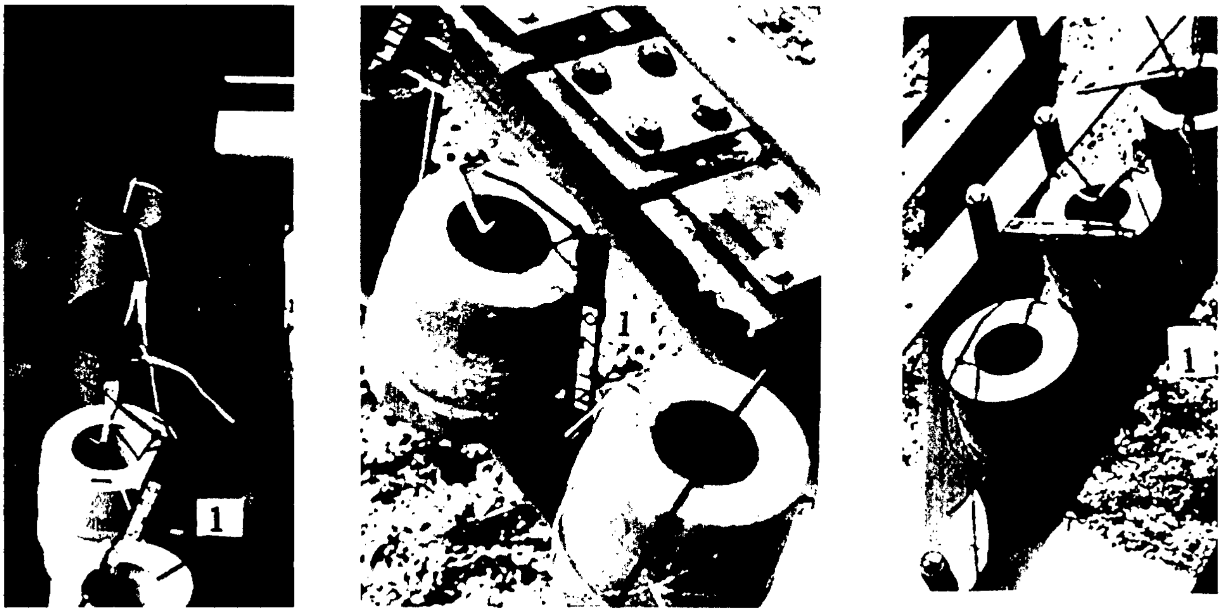
FIGURE E-3. E-COAT COATING AFTER 0, 4, AND 9 MONTHS ON ATMOSPHERIC RACK



0 MONTHS
SILOXIRANE®

4 MONTHS

9 MONTHS



0 MONTHS
INORGANIC ZINC IC-531

4 MONTHS

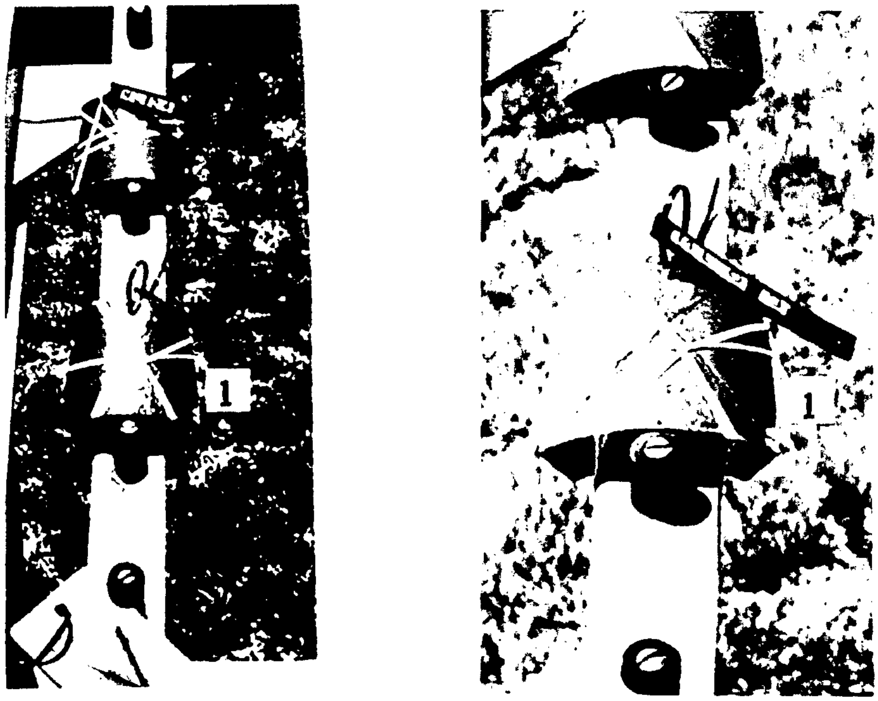
9 MONTHS

FIGURE E-4. SILOXIRANE® AND INORGANIC ZINC COATINGS AFTER 0, 4, AND 9 MONTHS ON ATMOSPHERIC RACK

0 MONTHS 4 MONTHS 9 MONTHS

0 MONTHS 4 MONTHS 9 MONTHS

FIGURE E-5. EXPOXY AND POLYESTER POWDER COATINGS AFTER 0, 4, AND 9 MONTHS ON ATMOSPHERIC RACK



0 MONTHS

3 MONTHS

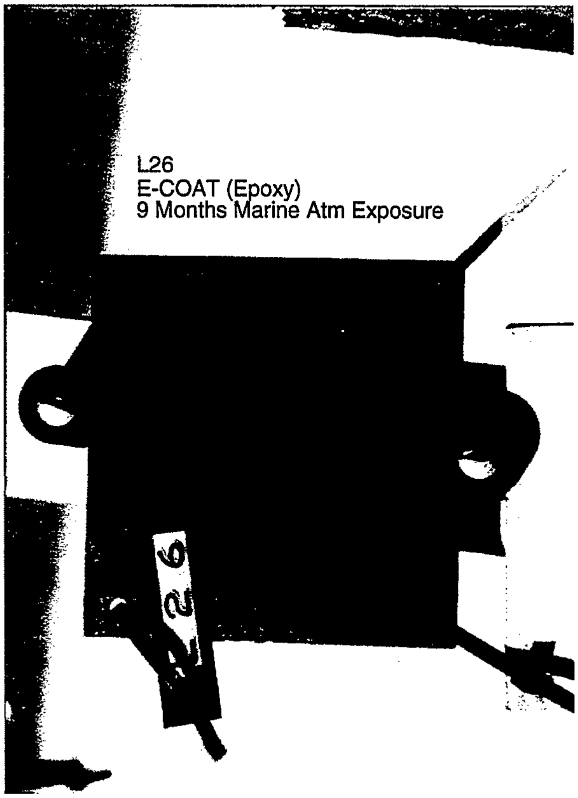
ZINC PHOSPHATE WITH PRIMER

0 MONTHS

3 MONTHS

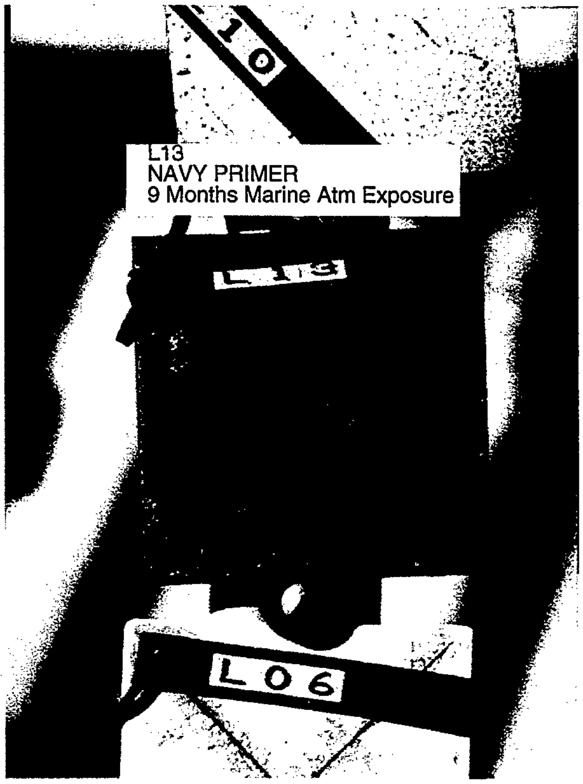
ZINC PHOSPHATE WITH PRIMER AND TOPCOAT

FIGURE E-6. ZINC PHOSPHATE WITH PRIMER AND ZINC PHOSPHATE WITH PRIMER AND TOPCOAT PAINT AFTER 0 AND 3 MONTHS ON ATMOSPHERIC RACK

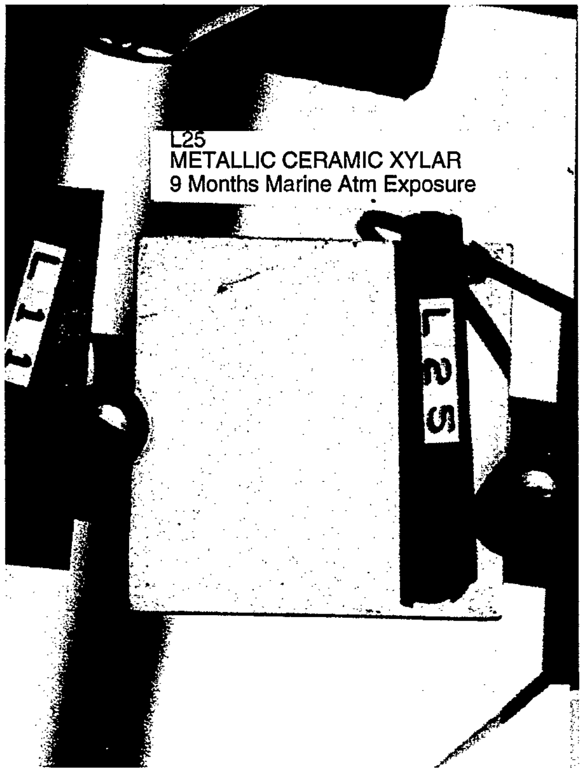


L26
E-COAT (Epoxy)
9 Months Marine Atm Exposure

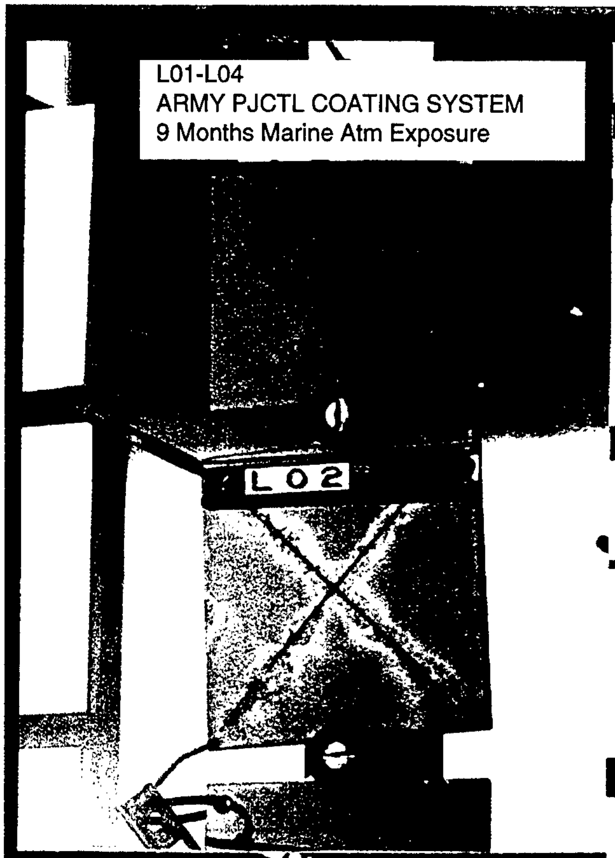
L10
ALUMINIZED PHENOLIC
9 Months Marine Atm Exposure



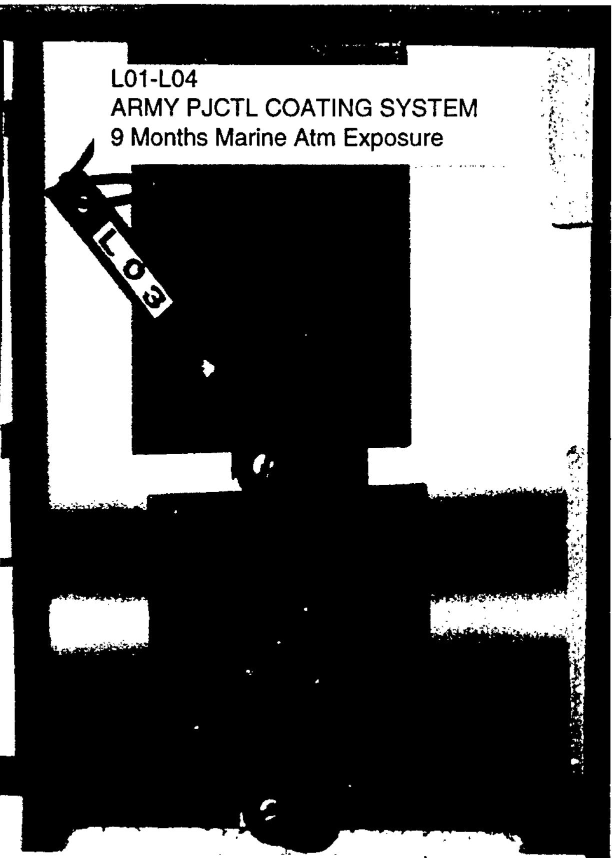
L13
NAVY PRIMER
9 Months Marine Atm Exposure



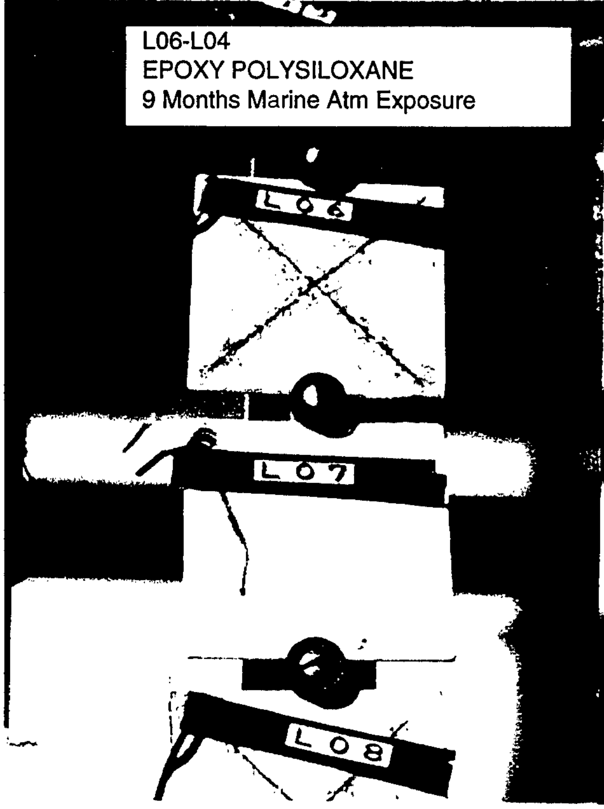
L25
METALLIC CERAMIC XYLAR
9 Months Marine Atm Exposure



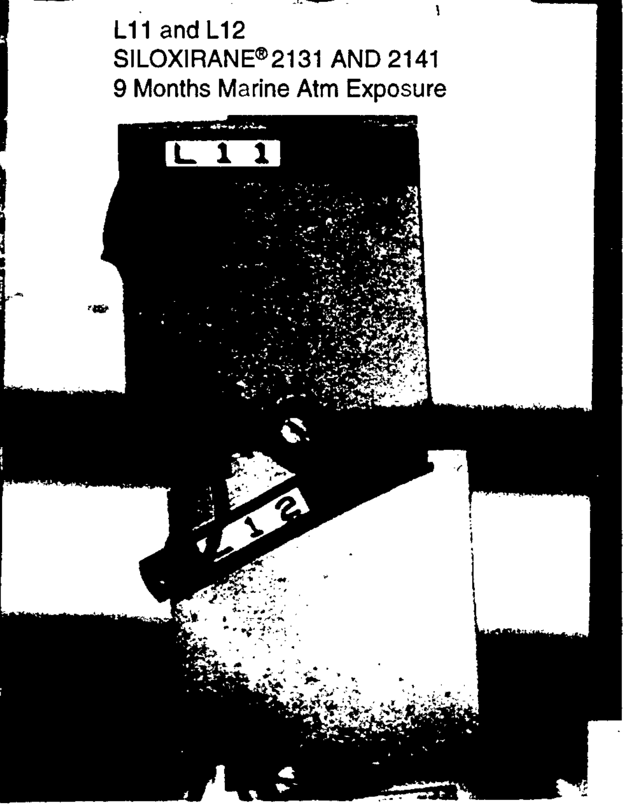
L01-L04
ARMY PJCTL COATING SYSTEM
9 Months Marine Atm Exposure



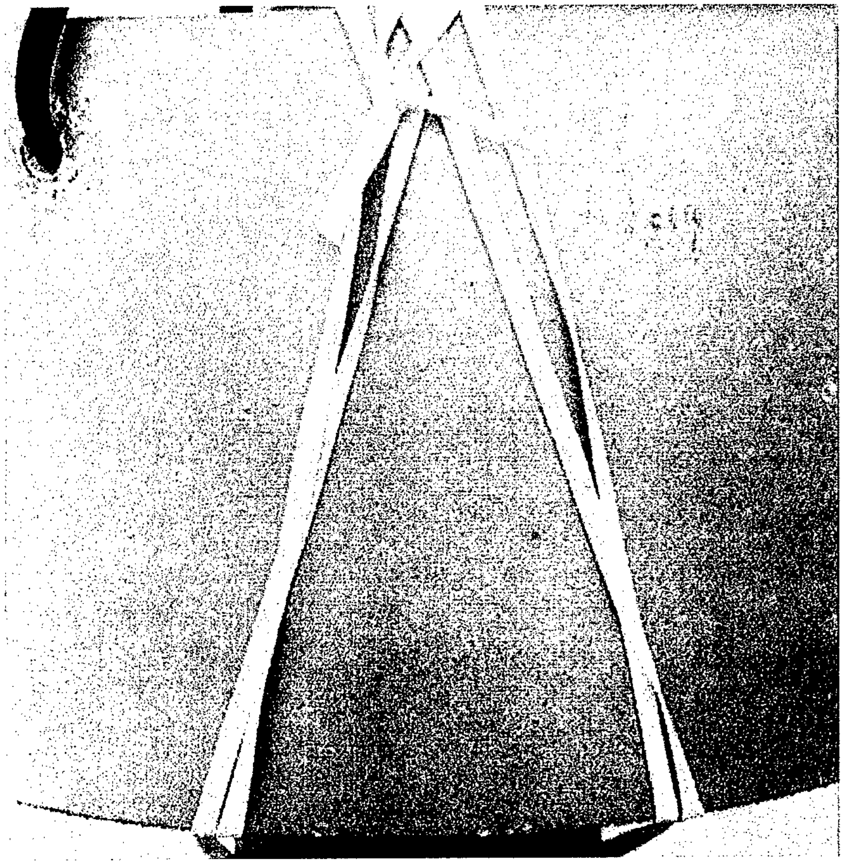
L01-L04
ARMY PJCTL COATING SYSTEM
9 Months Marine Atm Exposure



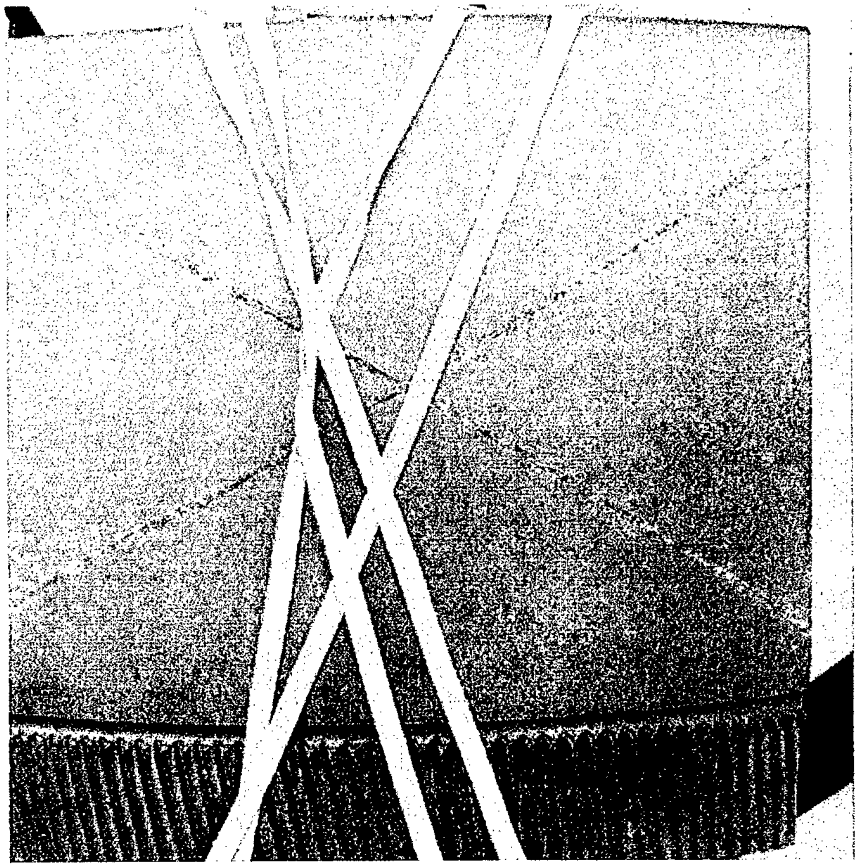
L06-L04
EPOXY POLYSILOXANE
9 Months Marine Atm Exposure



L11 and L12
SILOXIRANE® 2131 AND 2141
9 Months Marine Atm Exposure



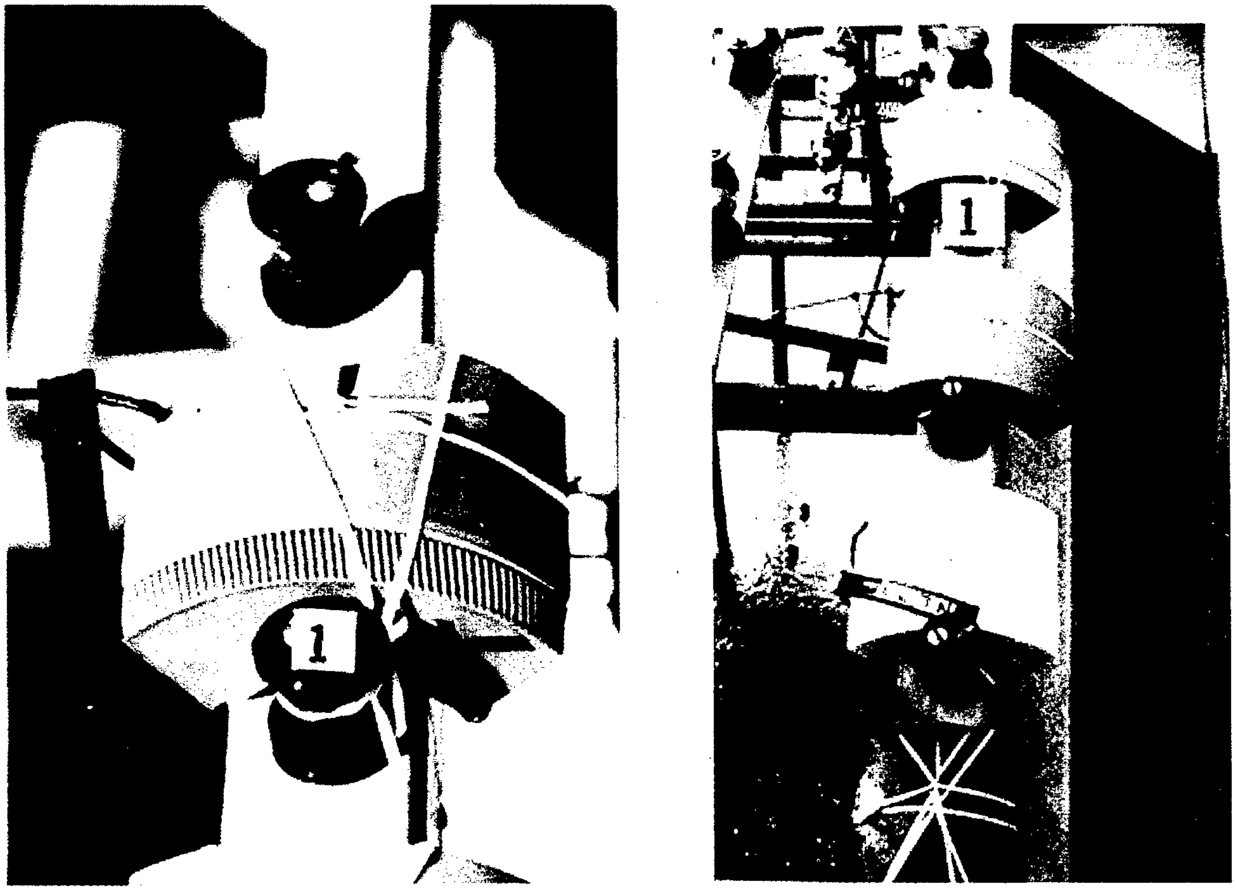
MARINE ATMOSPHERIC EXPOSURE
NSWC FT. LAUDERDALE, FLA
IVD XYLAR
START: 15 NOV 92
TODAY: 20 JUN 95



MARINE ATMOSPHERIC EXPOSURE
NSWC FT. LAUDERDALE, FLA
IVD XYLAR
START: 15 NOV 92
TODAY: 20 JUN 95

APPENDIX F

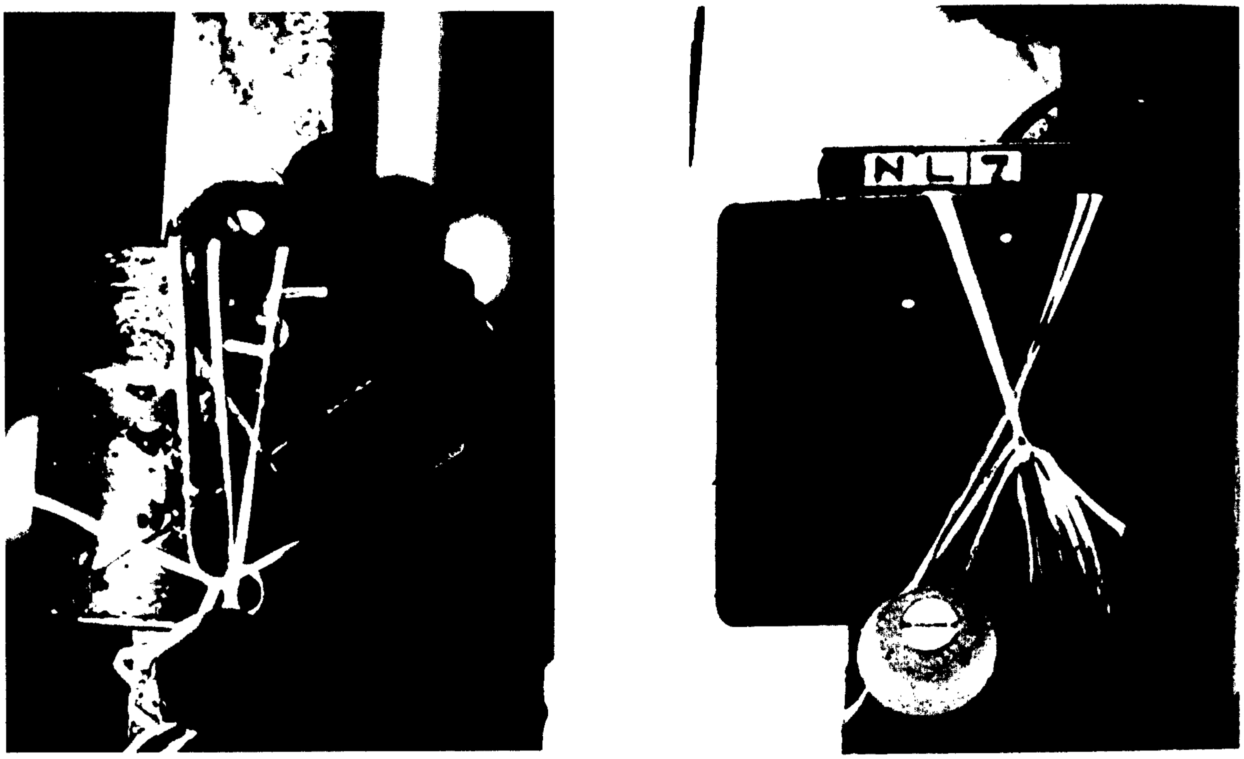
PHOTOGRAPHS, COUPONS AFTER SEAWATER WETDOWN TEST



0 MONTHS

9 MONTHS

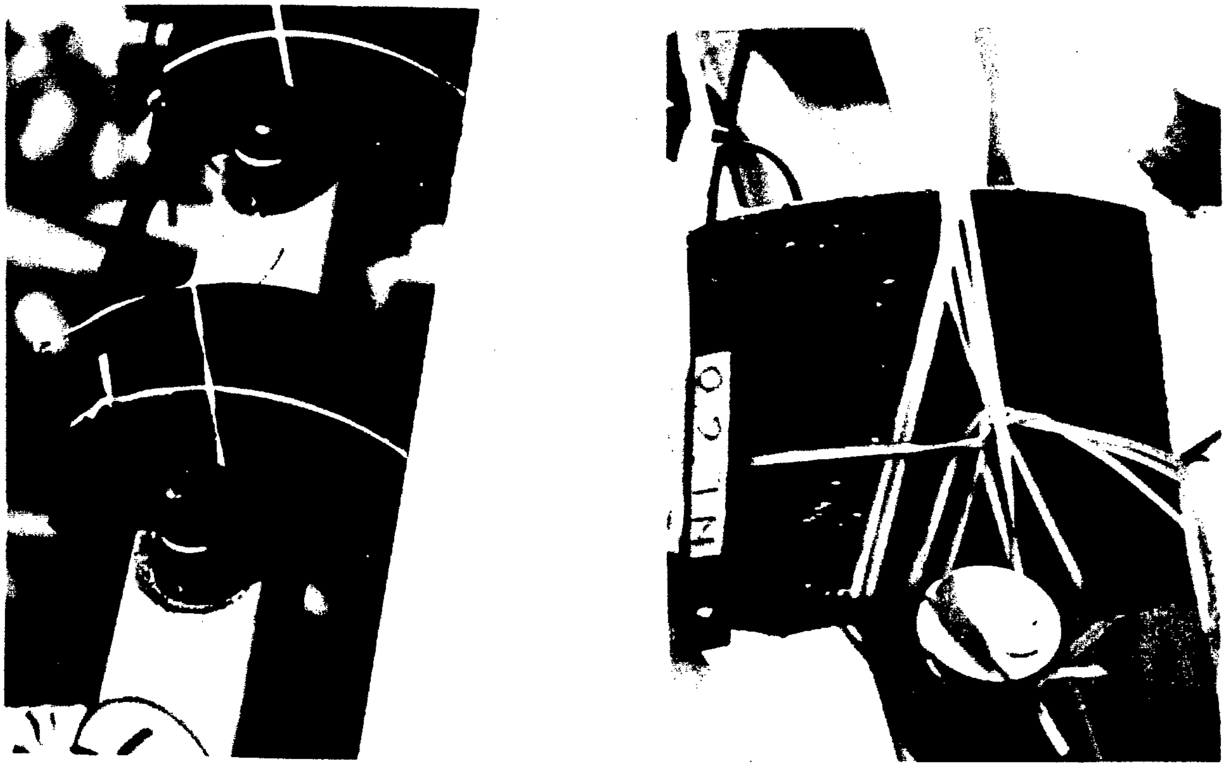
FIGURE F-1. IVD/XYLAR COATING AFTER 0 AND 9 MONTHS ON SEAWATER WETDOWN RACK



0 MONTHS

9 MONTHS

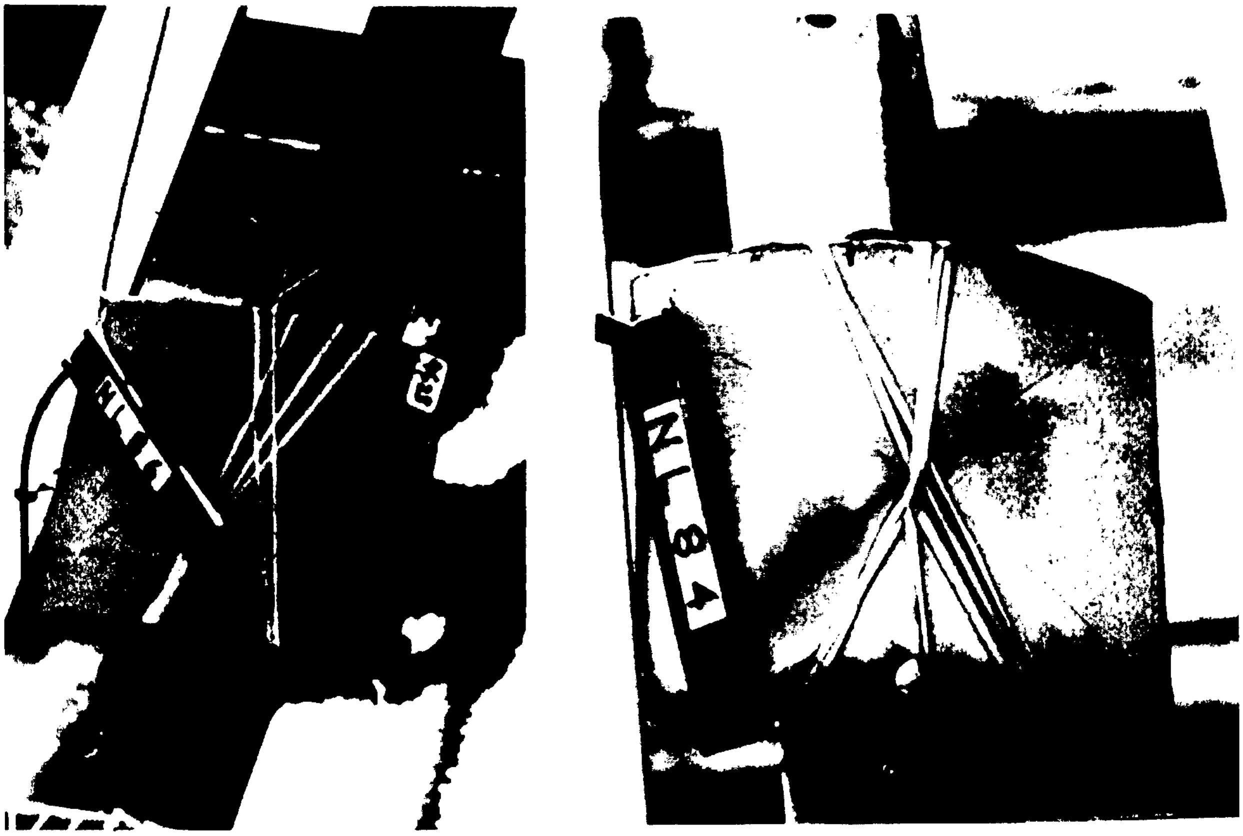
FIGURE F-2. NYLON POWDER COATING AFTER 0 AND 9 MONTHS ON SEAWATER WETDOWN RACK



0 MONTHS

9 MONTHS

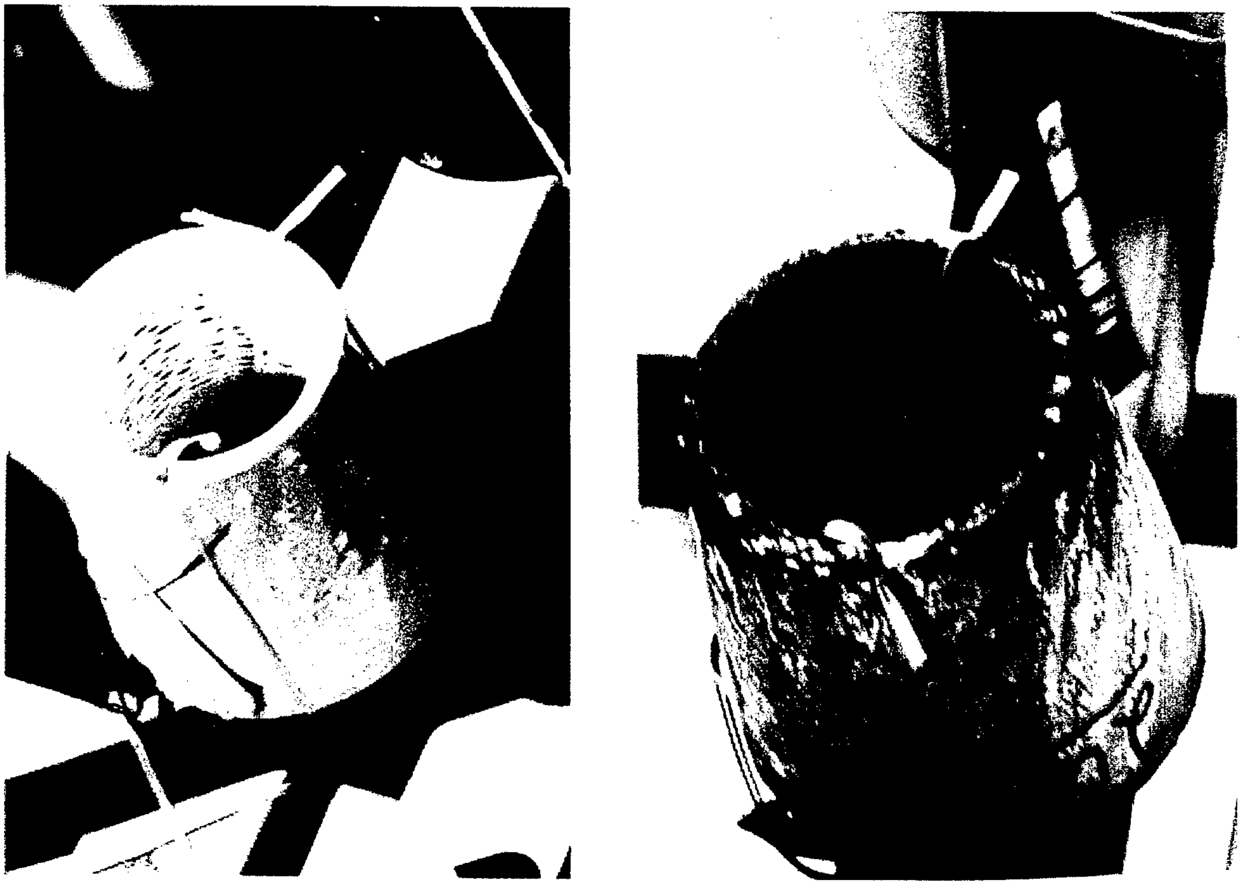
FIGURE F-3. E-COAT COATING AFTER 0 AND 9 MONTHS ON SEAWATER WETDOWN RACK



0 MONTHS

9 MONTHS

FIGURE F-4. SILOXIRANE® COATING AFTER 0 AND 9 MONTHS ON SEAWATER WETDOWN RACK



0 MONTHS

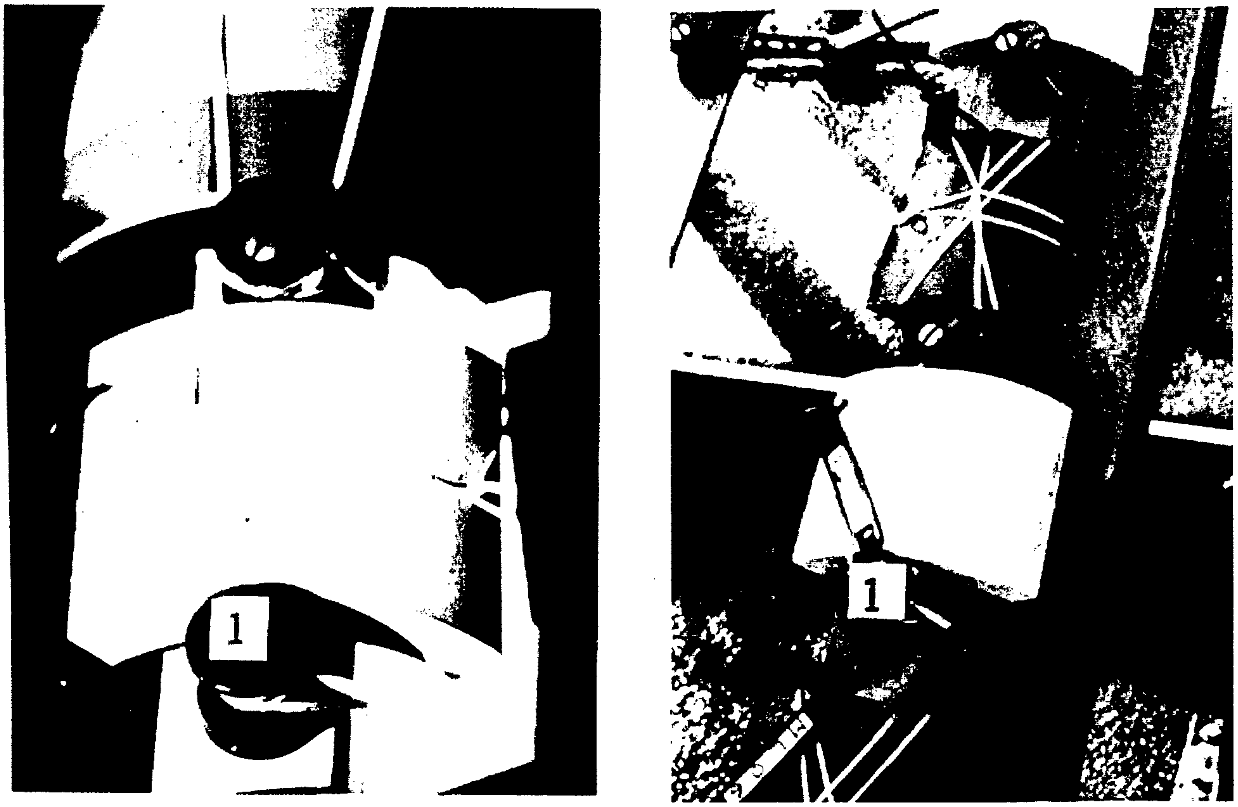
9 MONTHS

FIGURE F-5. POLYESTER POWDER COATING AFTER 0 AND 9 MONTHS ON SEAWATER WETDOWN RACK

0 MONTHS

9 MONTHS

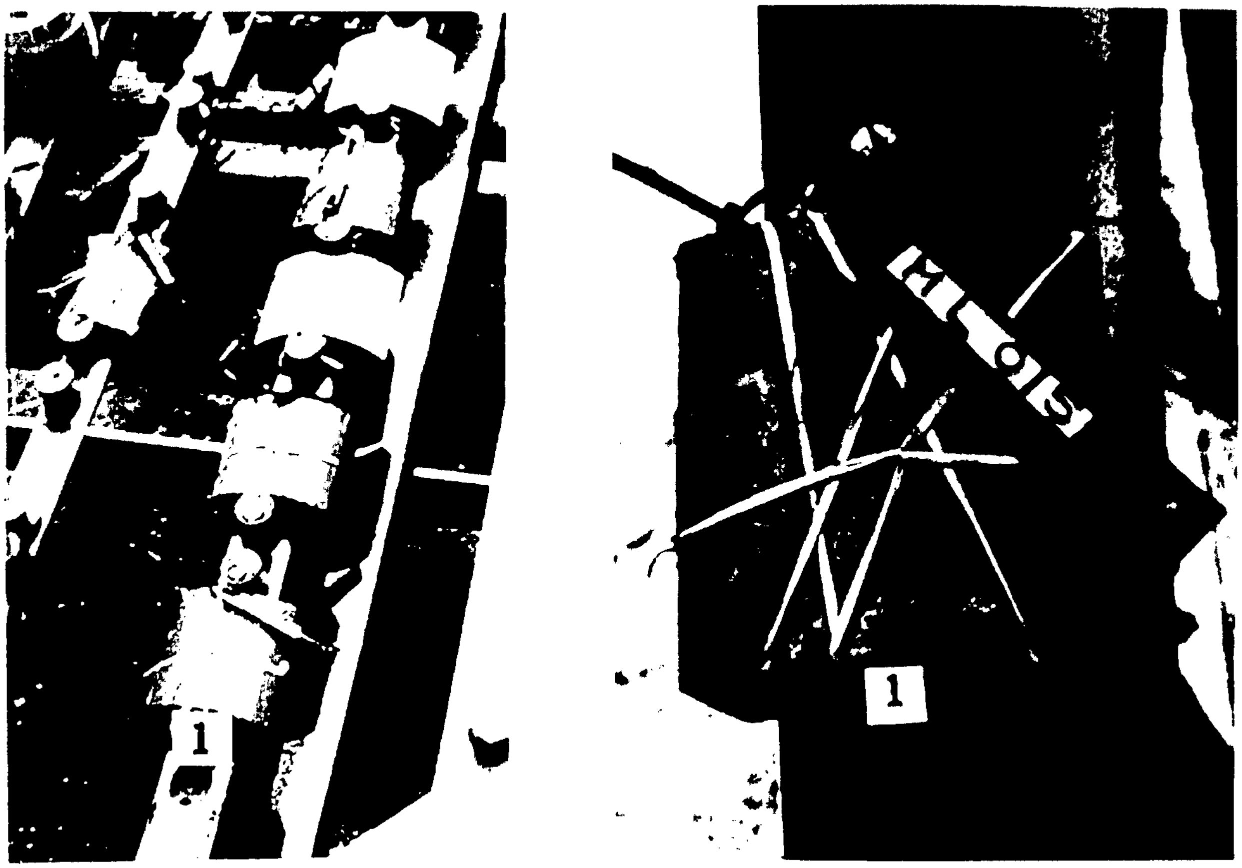
FIGURE F-6. EPOXY POWDER COATING AFTER 0 AND 9 MONTHS ON SEAWATER WETDOWN RACK



0 MONTHS

9 MONTHS

FIGURE F-7. INORGANIC ZINC COATING AFTER 0 AND 9 MONTHS ON SEAWATER WETDOWN RACK

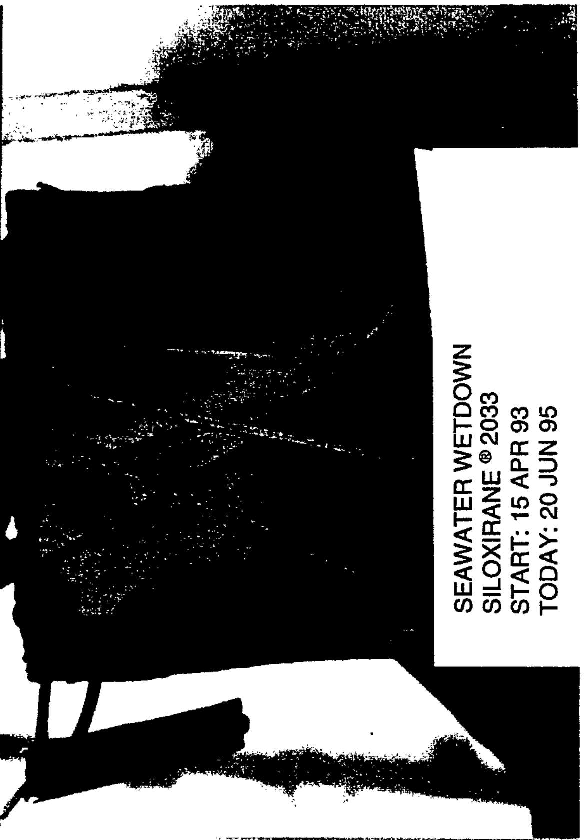


0 MONTHS

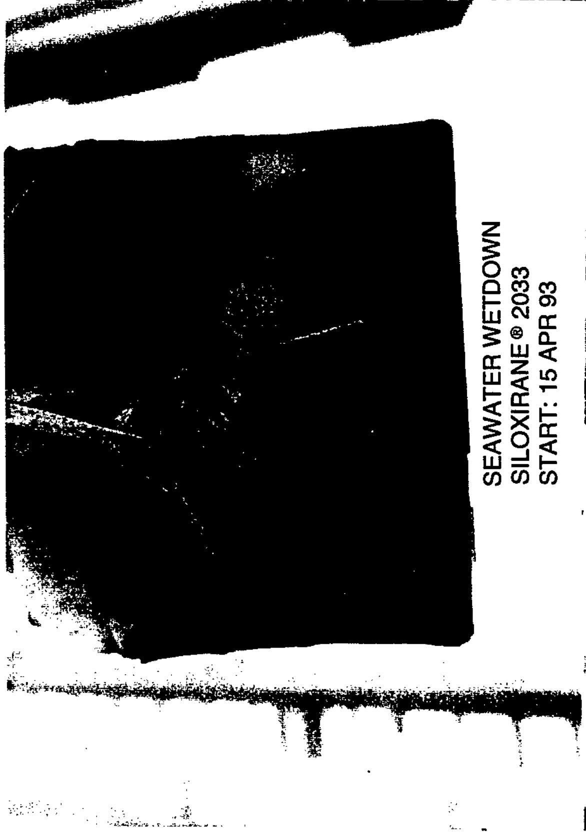
3 MONTHS

FIGURE F-8. ZINC PHOSPHATE WITH PRIMER COATING AFTER 0 AND 3 MONTHS ON SEAWATER WETDOWN RACK

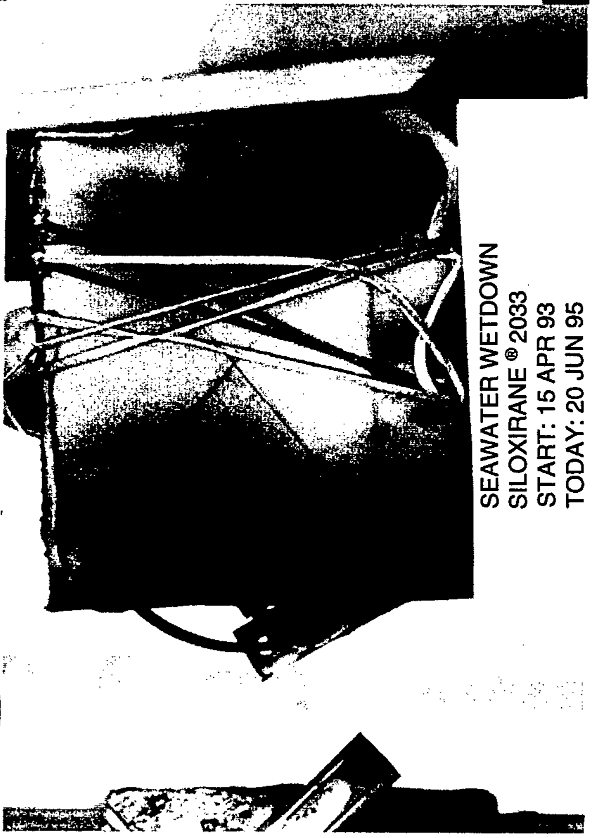
SEAWATER WETDOWN
SILOXIRANE® 2033
START: 15 APR 93
TODAY: 20 JUN 95



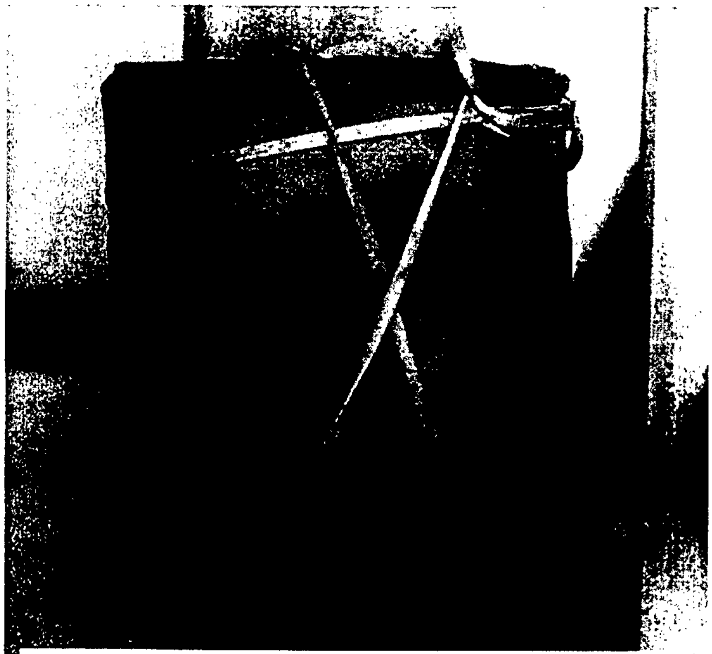
SEAWATER WETDOWN
SILOXIRANE® 2033
START: 15 APR 93
TODAY: 20 JUN 95



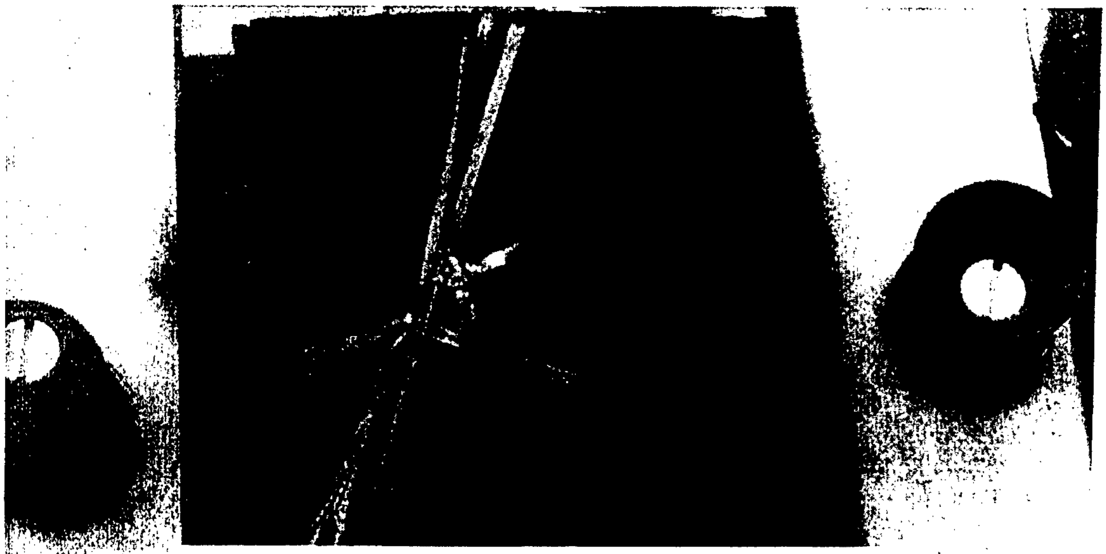
SEAWATER WETDOWN
SILOXIRANE® 2033
START: 15 APR 93



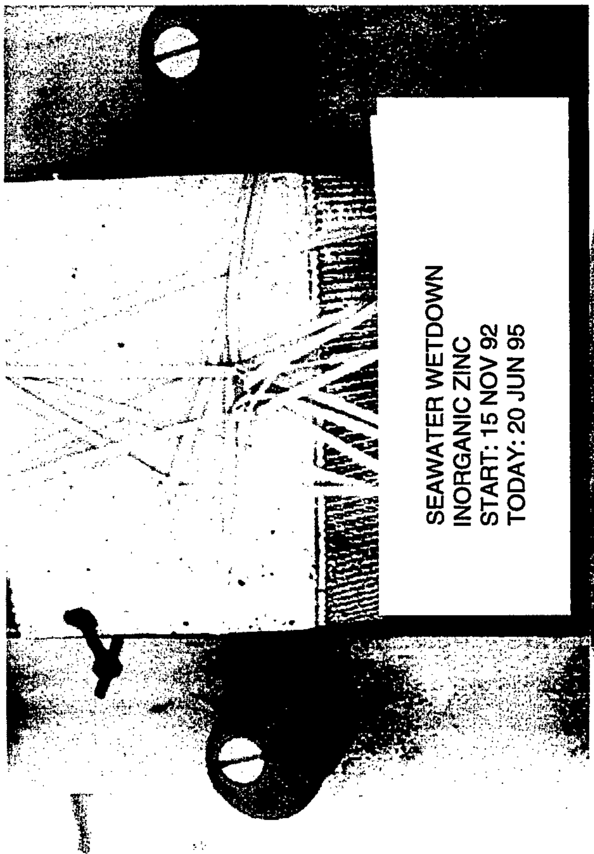
SEAWATER WETDOWN
SILOXIRANE® 2033
START: 15 APR 93
TODAY: 20 JUN 95



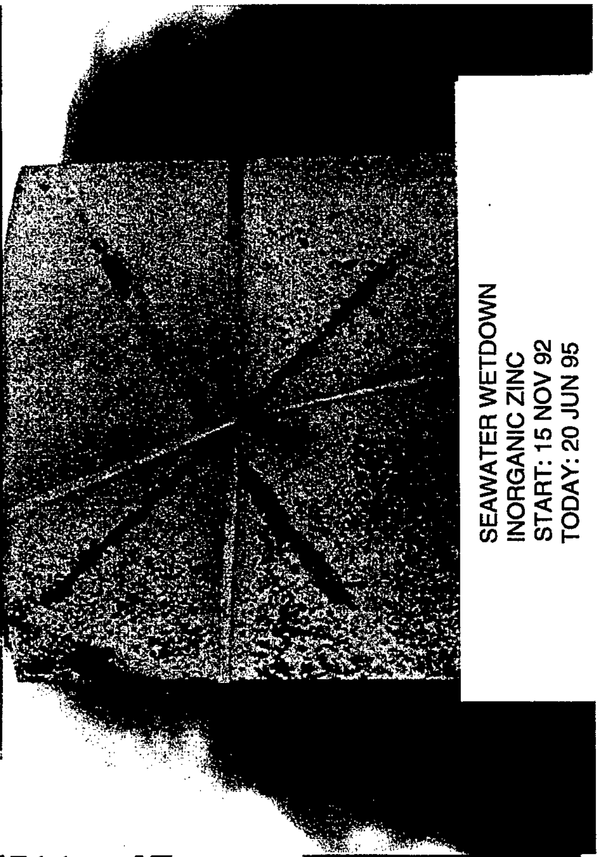
SEAWATER WETDOWN
"CONTROL" PRIMER & TOPCOAT
START: 9 SEP 93
TODAY: 20 JUN 95



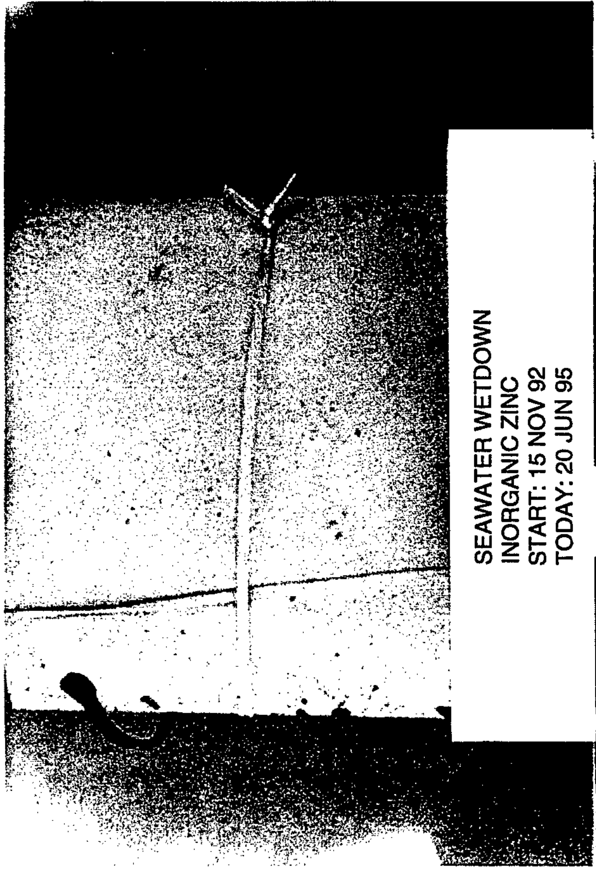
SEAWATER WETDOWN
"CONTROL" PRIMER & TOPCOAT
START: 9 SEP 93
TODAY: 20 JUN 95



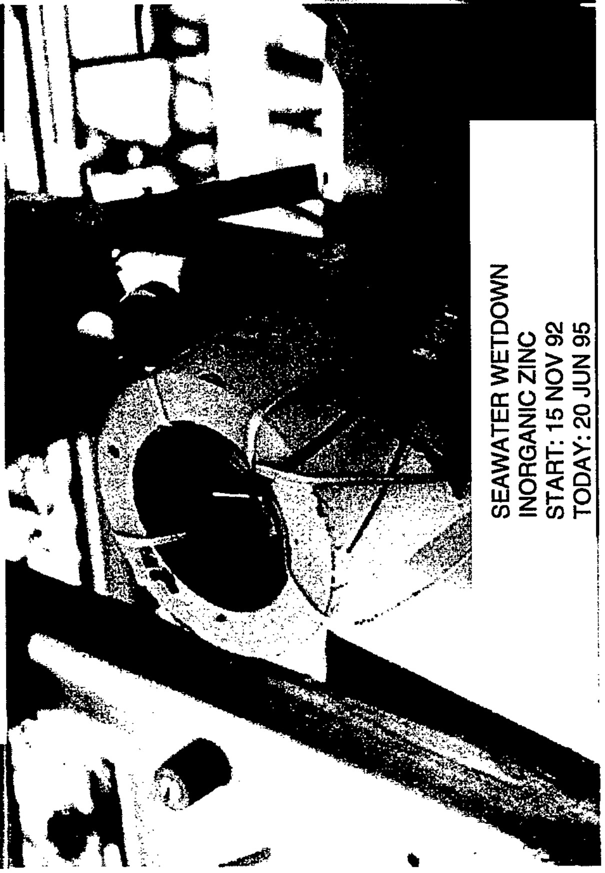
SEAWATER WETDOWN
INORGANIC ZINC
START: 15 NOV 92
TODAY: 20 JUN 95



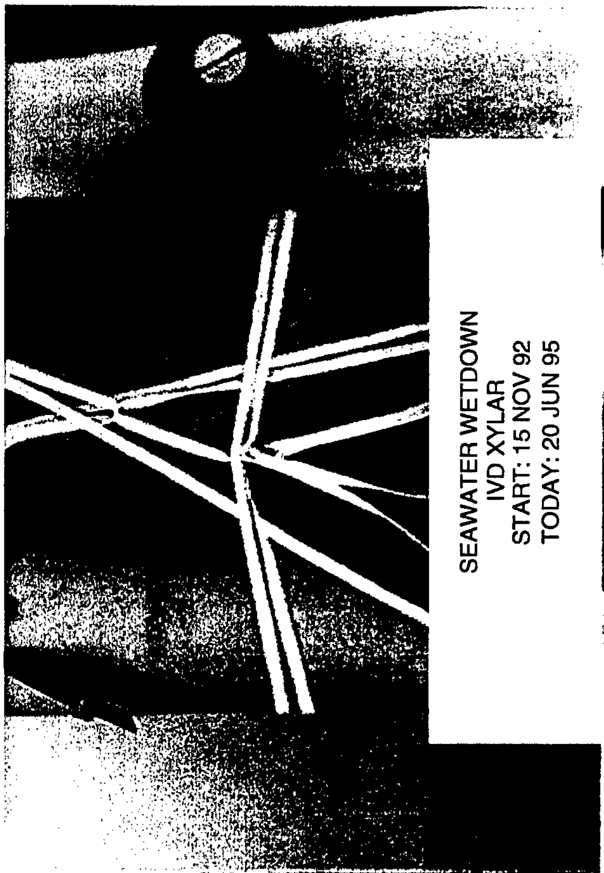
SEAWATER WETDOWN
INORGANIC ZINC
START: 15 NOV 92
TODAY: 20 JUN 95



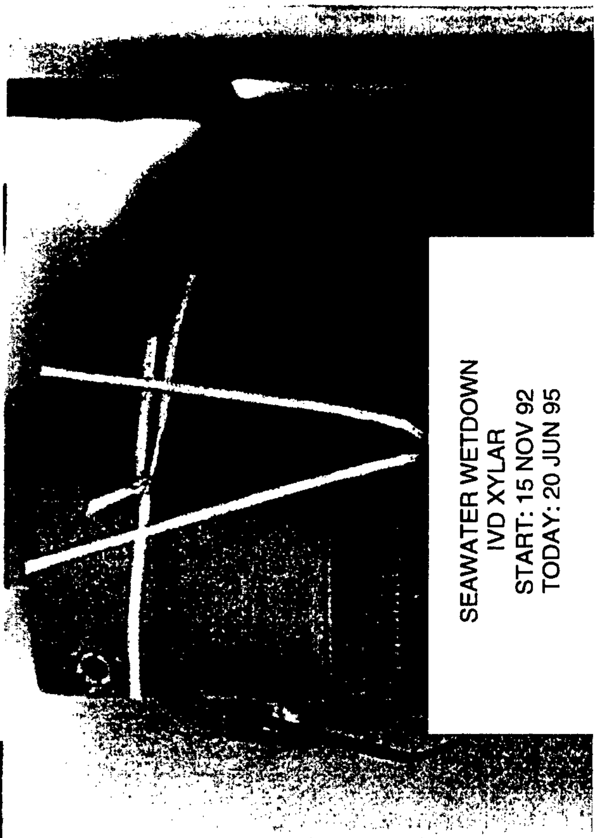
SEAWATER WETDOWN
INORGANIC ZINC
START: 15 NOV 92
TODAY: 20 JUN 95



SEAWATER WETDOWN
INORGANIC ZINC
START: 15 NOV 92
TODAY: 20 JUN 95



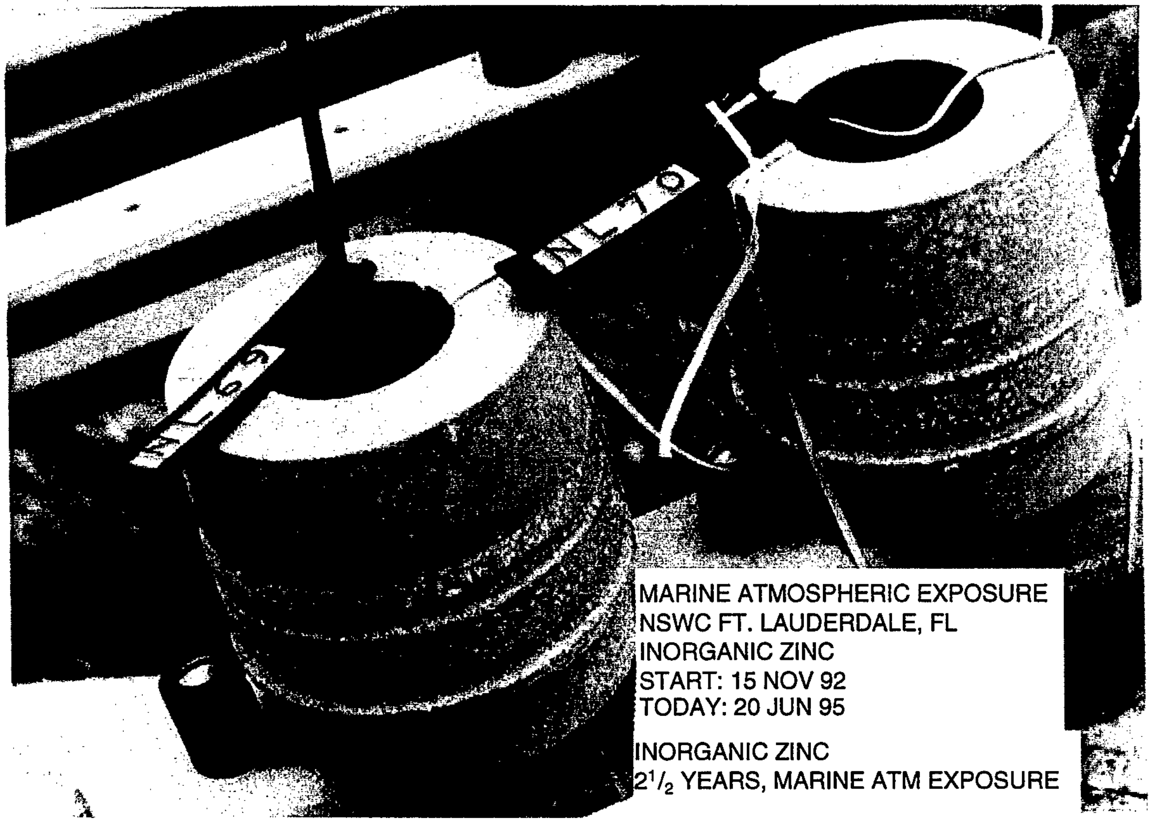
SEAWATER WETDOWN
IVD XYLAR
START: 15 NOV 92
TODAY: 20 JUN 95



SEAWATER WETDOWN
IVD XYLAR
START: 15 NOV 92
TODAY: 20 JUN 95

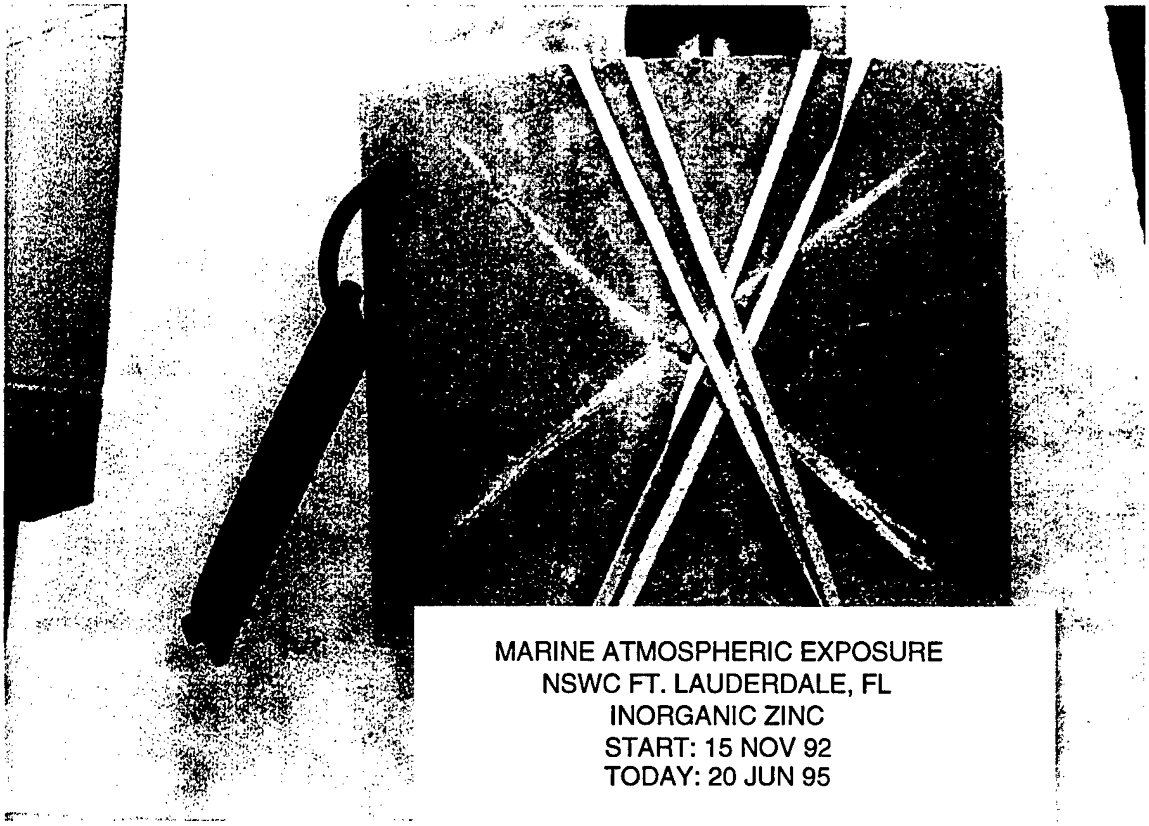
SEAWATER WETDOWN
IVD XYLAR
START: 15 NOV 92
TODAY: 20 JUN 95

SEAWATER WETDOWN
IVD XYLAR
START: 15 NOV 92
TODAY: 20 JUN 95

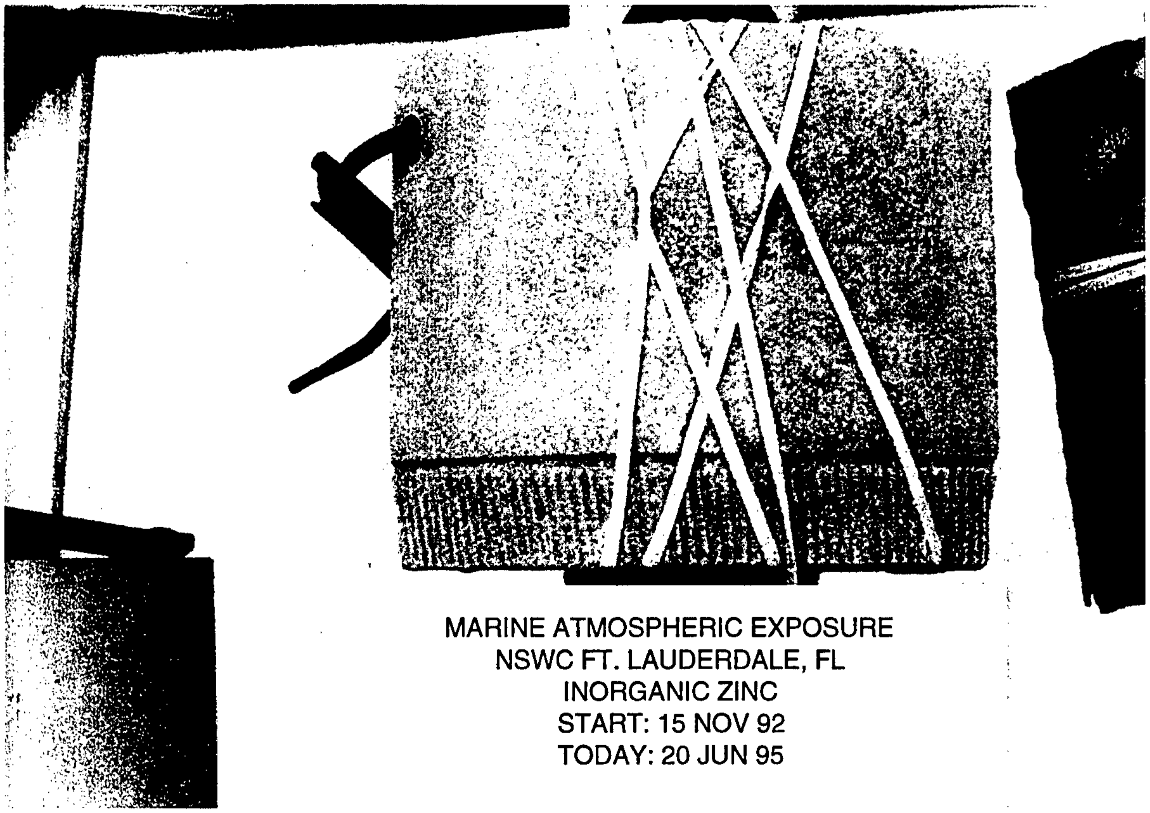


INORGANIC ZINC
$2^{1}/_{2}$ YEARS, MARINE ATM EXPOSURE

METALLIC CERAMIC, XYLAR®
$2^{1}/_{2}$ YEARS, MARINE ATM EXPOSURE



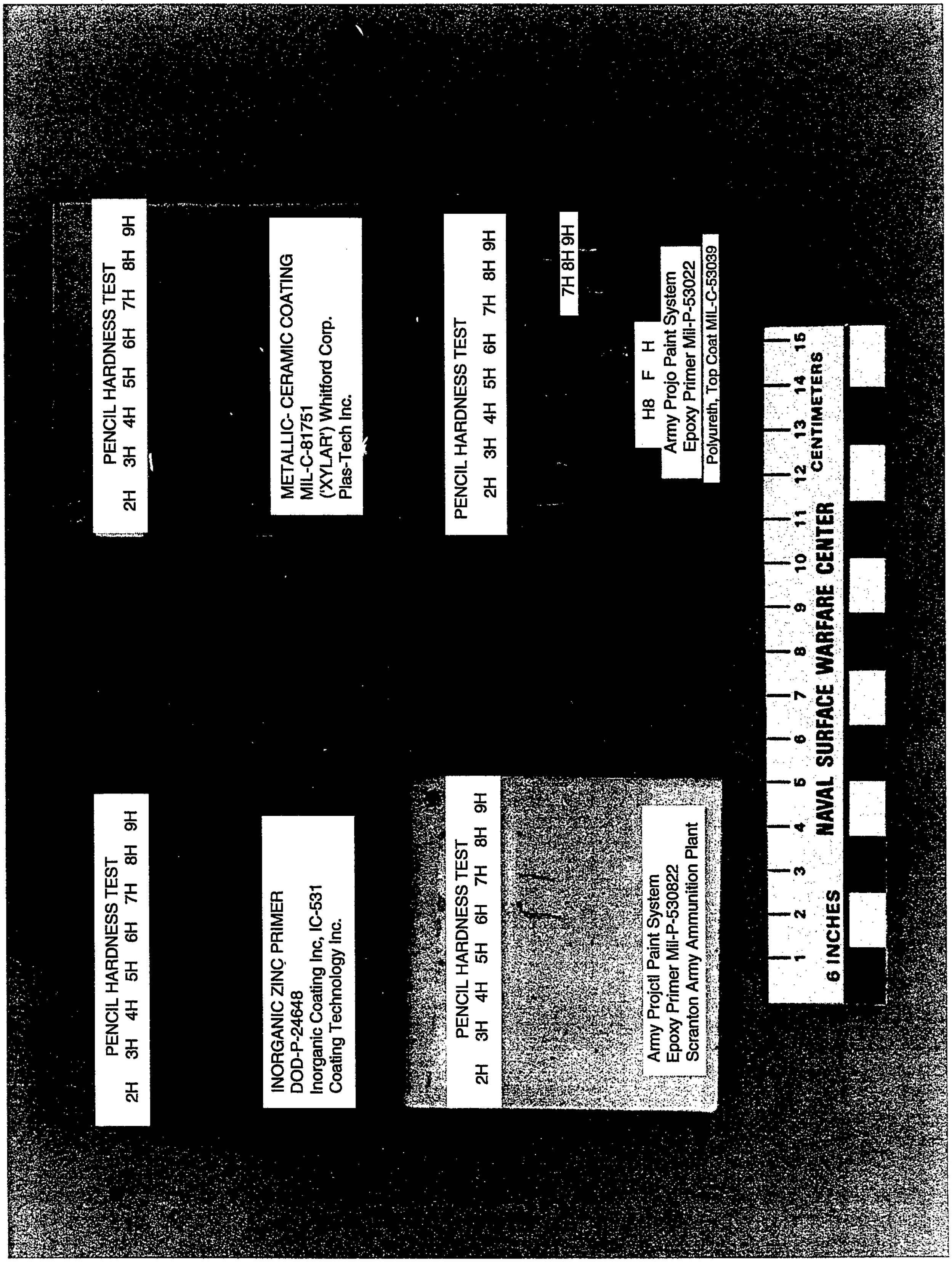
MARINE ATMOSPHERIC EXPOSURE
NSWC FT. LAUDERDALE, FL
INORGANIC ZINC
START: 15 NOV 92
TODAY: 20 JUN 95

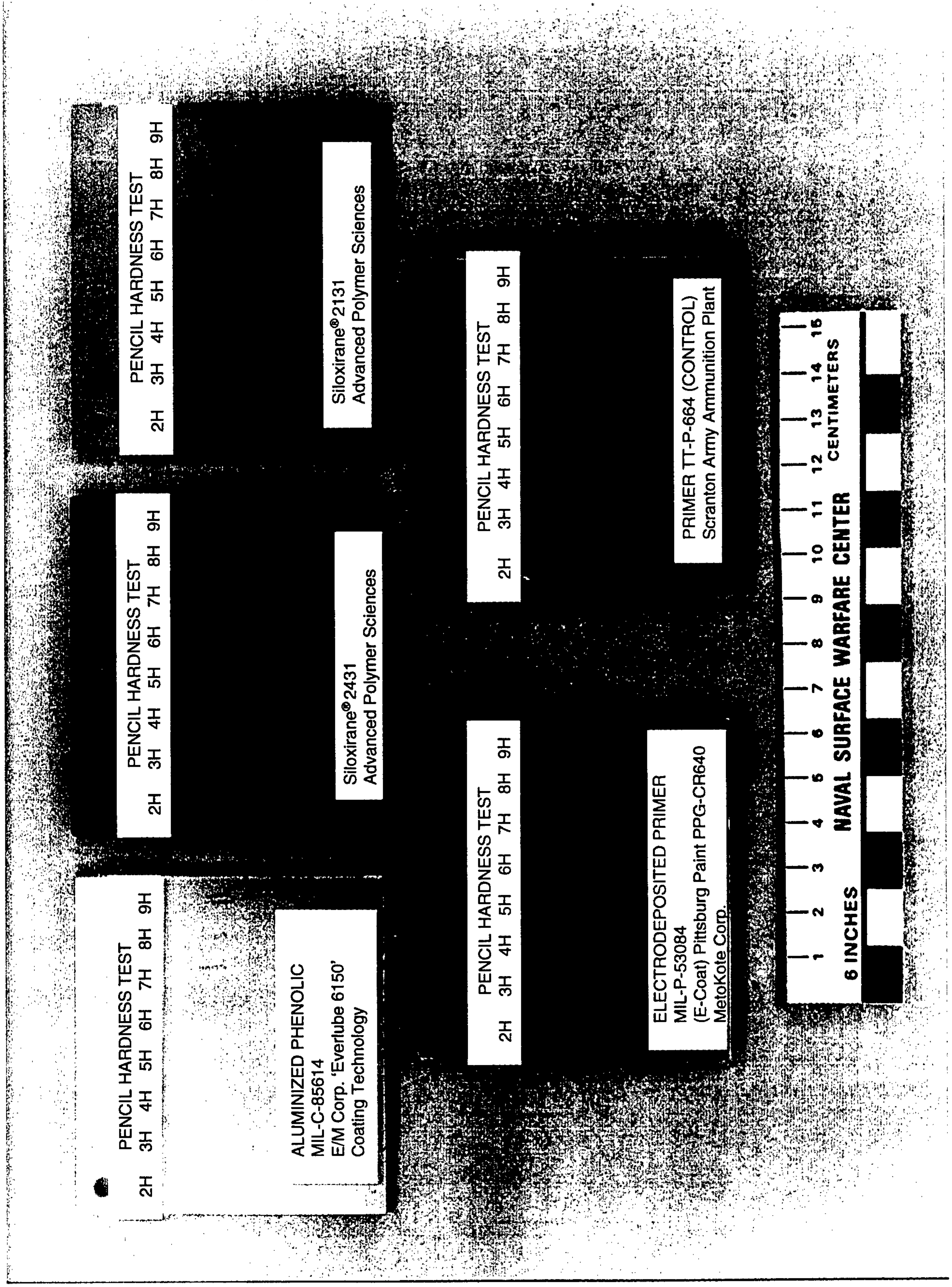


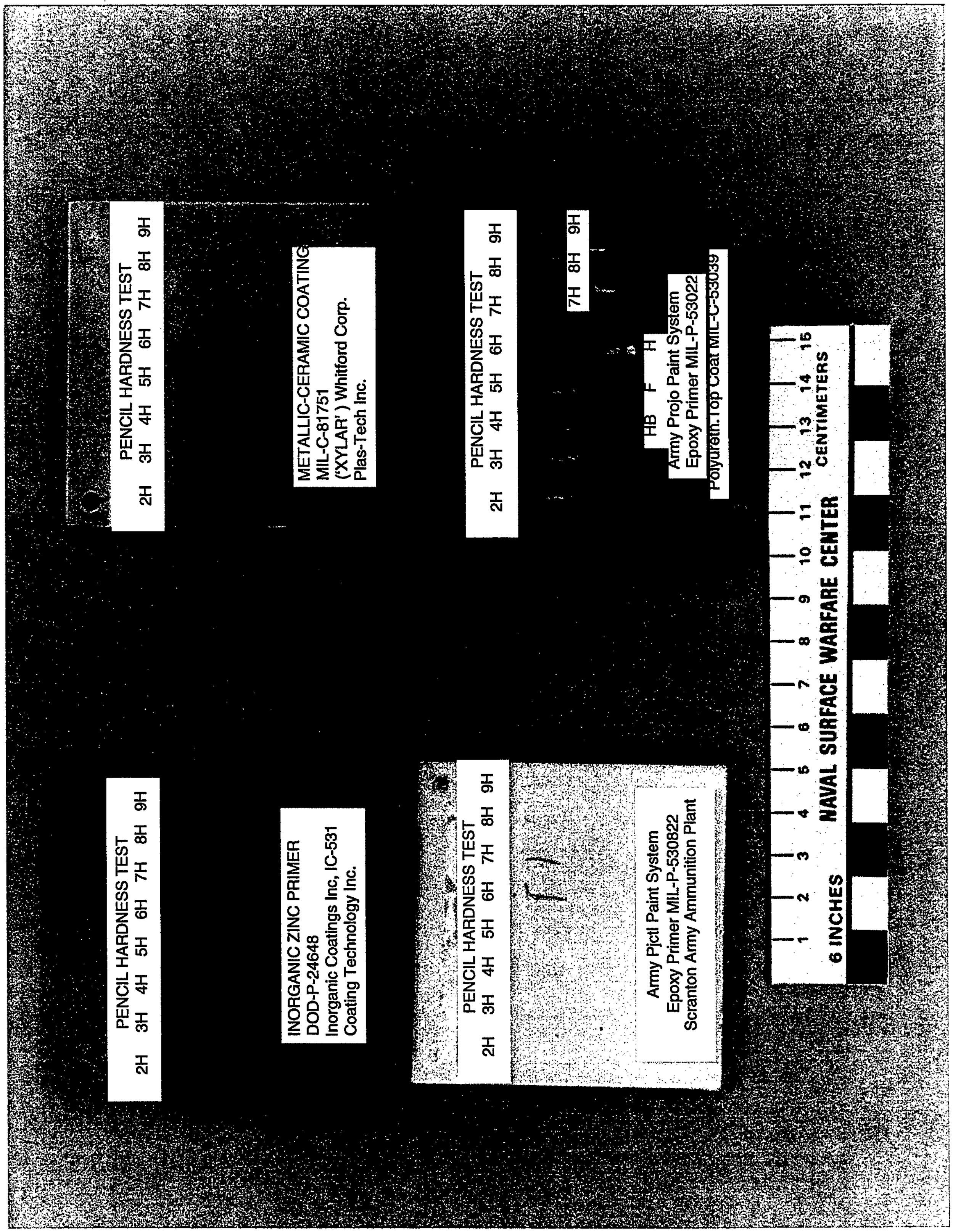
MARINE ATMOSPHERIC EXPOSURE
NSWC FT. LAUDERDALE, FL
INORGANIC ZINC
START: 15 NOV 92
TODAY: 20 JUN 95

APPENDIX G

PHOTOGRAPHS, SCRATCH HARDNESS RESULTS - NSWC/DL FILE PHOTOS P5914


PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
METALLIC- CERAMIC COATING
MIL-C-81751
('XYLAR') Whitford Corp.
Plas-Tech Inc.
PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
7H 8H 9H
HB F H
Army Projo Paint System
Epoxy Primer Mil-P-53022
Polyureth, Top Coat MIL-C-53039
PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
INORGANIC ZINC PRIMER
DOD-P-24648
Inorganic Coating Inc, IC-531
Coating Technology Inc.
PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
Army Projctl Paint System
Epoxy Primer Mil-P-530822
Scranton Army Ammunition Plant
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
CENTIMETERS
6 INCHES
NAVAL SURFACE WARFARE CENTER


PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
ALUMINIZED PHENOLIC
MIL-C-85614
E/M Corp. 'Everlube 6150'
Coating Technology
PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
Siloxirane®2431
Advanced Polymer Sciences
PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
Siloxirane®2131
Advanced Polymer Sciences
PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
ELECTRODEPOSITED PRIMER
MIL-P-53084
(E-Coat) Pittsburg Paint PPG-CR640
MetoKote Corp.
PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
PRIMER TT-P-664 (CONTROL)
Scranton Army Ammunition Plant
6 INCHES
NAVAL SURFACE WARFARE CENTER
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
CENTIMETERS


PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
METALLIC-CERAMIC COATING
MIL-C-81751
('XYLAR') Whitford Corp.
Plas-Tech Inc.
PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
7H 8H 9H
HB F H
Army Projo Paint System
Epoxy Primer MIL-P-53022
Polyuretn. Top Coat MIL-C-53039
PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
INORGANIC ZINC PRIMER
DOD-P-24648
Inorganic Coatings Inc, IC-531
Coating Technology Inc.
PENCIL HARDNESS TEST
2H 3H 4H 5H 6H 7H 8H 9H
Army Pjctl Paint System
Epoxy Primer MIL-P-530822
Scranton Army Ammunition Plant
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
CENTIMETERS
6 INCHES
NAVAL SURFACE WARFARE CENTER

APPENDIX H

COATING THICKNESSES, END ITEMS

PROJECTILE SURFACE PROTECTION
THICKNESS MEASUREMENTS* (Mils)

NSWC/D; 9 Nov 94; Bld 457
Coating Contractor: Scranton Army Ammunition Plant

A - Ogive, 4 inch aft of forward face
B - Fwd Bourrelet
C - Middle Bourrelet
D - Aft Bourrelet

PJCTL TYPE	PJCTL STATION	ROTATION			Primer Thickness	O.D. Topcoat (Spot checked)
		0	120	240		
Control 1	A	1.90	1.60	1.55	1.68	0.20
	B	1.80	1.80	1.60	1.73	0.35
	C	1.65	2.20	1.95	1.93	0.30
	D	0.95	1.30	1.35	1.20	0.55
					1.64	**0.35**
Control 2	A	1.85	1.70	2.30	1.95	0.50
	B	2.10	1.55	1.85	1.83	0.50
	C	2.40	1.65	1.95	2.00	0.30
	D	1.55	1.20	1.45	1.40	0.10
					1.80	**0.35**
Control 3	A	1.45	1.35	2.20	1.67	0.60
	B	1.50	1.85	1.75	1.70	0.40
	C	2.30	2.10	1.55	1.98	0.20
	D	1.75	1.70	1.40	1.62	0.90
					1.74	**0.53**
Control 4	A	2.10	1.20	1.35	1.55	1.00
	B	2.00	1.90	2.20	2.03	0.70
	C	1.65	2.10	2.10	1.95	0.20
	D	1.20	1.30	1.50	1.33	0.10
					1.72	**0.50**
Control 5	A	1.55	1.95	2.20	1.90	0.70
	B	2.40	2.10	2.20	2.23	0.40
	C	2.20	1.90	0.65	1.58	0.30
	D	1.60	0.95	1.30	1.28	0.10
					1.75	**0.38**
Control 6	A	1.60	1.85	2.20	1.88	0.70
	B	2.10	2.00	2.10	2.07	0.30
	C	2.60	1.90	2.20	2.23	0.50
	D	1.30	1.25	1.15	1.23	0.30
					1.85	0.45

* Instrumentation: KTA-Tator, Inc, 'Positector 6000-F2 gauge for dry film thickness.

PROJECTILE SURFACE PROTECTION

THICKNESS MEASUREMENTS* (Mils)

NSWC/D; 9 Nov 94; Bld 457
Coating contractor: MetoKote Corp.

A - Ogive, 4 inch aft of forward face
B - Fwd Bourrelet
C - Middle Bourrelet
D - Aft Bourrelet

PJCTL TYPE	PJCTL STATION	ROTATION			Primer Thickness	O.D. Topcoat (Spotchecked)
		0	120	240		
E-Coat 1	A	1.45	1.35	1.25	1.35	0.50
	B	1.45	1.40	1.25	1.37	0.45
	C	1.85	2.00	2.80	2.22	0.50
	D	1.65	1.50	1.30	1.48	0.60
					1.60	**0.51**
E-Coat 2	A	1.15	1.25	1.40	1.27	0.50
	B	1.20	1.45	1.30	1.32	0.55
	C	1.30	2.10	1.35	1.58	0.65
	D	1.55	1.90	1.85	1.77	0.30
					1.48	**0.50**
E-Coat 3	A	1.45	1.40	1.40	1.42	0.55
	B	1.35	1.35	1.70	1.47	0.30
	C	2.00	1.55	1.50	1.68	0.80
	D	1.95	2.20	2.10	2.08	0.55
					1.66	**0.55**
E-Coat 4	A	1.75	1.65	1.75	1.72	0.60
	B	1.60	1.85	1.75	1.73	0.45
	C	1.70	1.85	1.75	1.77	0.70
	D	2.10	2.20	2.40	2.23	1.20
					1.86	**0.74**
E-Coat 5	A	1.40	1.50	1.35	1.42	0.50
	B	1.60	1.55	1.60	1.58	0.45
	C	1.55	2.10	1.50	1.72	0.45
	D	2.20	2.20	1.95	2.12	0.50
					1.71	**0.48**
E-Coat 6	A	1.40	2.30	1.60	1.77	0.50
	B	1.35	1.40	1.60	1.45	0.50
	C	1.85	2.10	1.95	1.97	0.40
	D	1.90	1.40	2.10	1.80	0.55
					1.75	**0.49**

*** Instrumentation: KTA-Tator, Inc, 'Positector 6000-F2 gauge for dry film thickness.**

PROJECTILE SURFACE PROTECTION

THICKNESS MEASUREMENTS* (Mils)
NSWC/D; 9 Nov 94; Bld 457
Coating contractor: Plas-Tech

A - Ogive, 4 inch aft of forward face
B - Fwd Bourrelet
C - Middle Bourrelet
D - Aft Bourrelet

PJCTL TYPE	PJCTL STATION	ROTATION			Primer Thickness	O.D. Topcoat (Spotchecked)
		0	120	240		
Xylar 1	A	0.80	0.45	1.00	0.75	0.50
	B	0.60	0.70	0.45	0.58	0.80
	C	1.20	1.10	0.75	1.02	0.30
	D	1.30	1.15	0.95	1.13	0.60
					0.87	**0.55**
Xylar 2	A	1.10	0.85	0.85	0.93	0.55
	B	0.90	0.80	0.70	0.80	0.30
	C	1.45	0.70	0.70	0.95	0.25
	D	0.85	1.20	1.15	1.07	0.25
					0.94	**0.34**
Xylar 3	A	0.95	0.85	1.10	0.97	0.35
	B	0.70	0.80	0.85	0.78	0.35
	C	0.90	0.85	0.85	0.87	0.65
	D	1.25	1.30	1.15	1.23	0.75
					0.96	**0.53**
Xylar 4	A	1.10	0.85	0.80	0.92	0.25
	B	0.90	0.75	0.70	0.78	0.25
	C	0.70	0.75	1.15	0.87	1.00
	D	0.60	0.70	2.10	1.13	0.60
					0.93	**0.53**
Xylar 5	A	0.90	1.00	1.20	1.03	0.45
	B	0.90	1.15	1.15	1.07	0.75
	C	1.45	1.45	1.10	1.33	0.40
	D	1.55	2.30	1.00	1.62	0.75
					1.26	**0.59**
Xylar 6	A	0.95	1.00	1.00	0.98	0.40
	B	0.95	0.85	0.70	0.83	0.30
	C	0.90	1.65	0.75	1.10	0.25
	D	0.90	0.95	1.25	1.03	0.30
					0.99	**0.31**

* Instrumentation: KTA-Tator, Inc, 'Positector 6000-F2 gauge for dry film thickness.

PROJECTILE SURFACE PROTECTION

THICKNESS MEASUREMENTS* (Mils)
NSWC/D; 9 Nov 94; Bld 457
Coating contractor: Coating Technology, Inc.

A - Ogive, 4 inch aft of forward face
B - Fwd Bourrelet
C - Middle Bourrelet
D - Aft Bourrelet

PJCTL TYPE	PJCTL STATION	ROTATION			Primer Thickness	O.D. Topcoat (Spotchecked)
		0	120	240		
Inorg Zn 1	A	1.85	1.35	1.60	1.60	0.30
	B	0.85	1.05	1.05	0.98	0.20
	C	1.35	1.40	1.65	1.47	0.20
	D	1.05	1.10	1.40	1.18	0.40
					1.31	**0.28**
Inorg Zn 2	A	1.20	1.60	1.25	1.35	0.35
	B	0.80	1.00	0.90	0.90	0.35
	C	1.55	1.40	1.50	1.48	0.70
	D	1.15	1.05	1.45	1.22	0.30
					1.24	**0.43**
Inorg Zn 3	A	1.85	1.35	1.50	1.57	0.10
	B	1.50	1.00	0.90	1.13	0.30
	C	2.30	1.45	1.95	1.90	0.20
	D	2.00	1.30	1.20	1.50	0.10
					1.53	**0.18**
Inorg Zn 4	A	1.50	1.30	1.55	1.45	0.95
	B	0.85	0.95	1.60	1.13	0.20
	C	1.20	0.75	2.00	1.32	0.30
	D	1.35	1.05	1.70	1.37	0.60
					1.32	**0.51**
Inorg Zn 5	A	2.00	1.35	1.75	1.70	0.80
	B	1.80	1.55	1.20	1.52	0.50
	C	1.90	2.20	2.30	2.13	0.20
	D	1.60	1.90	2.10	1.87	0.10
					1.80	**0.40**
Inorg Zn 6	A	1.25	1.65	1.50	1.47	0.40
	B	1.30	1.45	1.10	1.28	0.10
	C	1.55	2.20	1.75	1.83	0.80
	D	0.75	1.75	1.55	1.35	0.55
					1.48	**0.46**

* Instrumentation: KTA-Tator, Inc, 'Positector 6000-F2 gauge for dry film thickness.

PROJECTILE SURFACE PROTECTION

THICKNESS MEASUREMENTS* (Mils)
NSWC/D; 9 Nov 94; Bld 457
Contractor: Coating Technology, Inc.

A - Ogive, 4 inch aft of forward face
B - Fwd Bourrelet
C - Middle Bourrelet
D - Aft Bourrelet

PJCTL TYPE	PJCTL STATION	ROTATION			Primer Thickness	O.D. Topcoat (Spotchecked)
		0	120	240		
Al-Phen 1	A	0.95	1.10	0.85	0.97	0.30
	B	0.65	0.50	0.60	0.58	0.30
	C	0.95	0.95	0.90	0.93	0.20
	D	0.65	0.60	0.45	0.57	0.40
					0.76	**0.30**
Al-Phen 2	A	1.05	0.90	0.90	0.95	0.20
	B	0.85	0.70	0.90	0.82	0.40
	C	1.30	1.20	1.20	1.23	0.25
	D	0.90	0.75	0.75	0.80	0.55
					0.95	**0.35**
Al-Phen 3	A	0.80	0.60	0.65	0.68	0.20
	B	0.70	0.50	0.50	0.57	0.10
	C	1.10	0.90	1.00	1.00	1.00
	D	0.60	0.45	0.55	0.53	0.35
					0.70	**0.41**
Al-Phen 4	A	0.90	0.55	0.70	0.72	0.40
	B	0.55	0.35	0.75	0.55	0.10
	C	0.90	1.05	0.70	0.88	0.10
	D	1.10	1.00	0.70	0.93	0.40
					0.77	**0.25**
Al-Phen 5	A	0.90	1.05	0.70	0.88	0.25
	B	0.25	0.45	0.45	0.38	0.30
	C	0.65	0.80	0.95	0.80	0.45
	D	0.85	0.45	0.35	0.55	0.35
					0.65	**0.34**
Al-Phen 6	A	1.15	1.15	0.90	1.07	0.10
	B	1.05	0.60	0.40	0.68	0.10
	C	1.05	0.90	0.90	0.95	0.20
	D	1.20	0.55	0.45	0.73	0.40
					0.86	**0.20**

* Instrumentation: KTA-Tator, Inc, 'Positector 6000-F2 gauge for dry film thickness.

PROJECTILE SURFACE PROTECTION

THICKNESS MEASUREMENTS* (Mils)
NSWC/D; 9 Nov 94; Bld 457
Coating contractor: Advanced Polymer Sciences

A - Ogive, 4 inch aft of forward face
B - Fwd Bourrelet
C - Middle Bourrelet
D - Aft Bourrelet

PJCTL TYPE	PJCTL STATION	ROTATION			Primer Thickness	O.D. Topcoat (Spotchecked)
		0	120	240		
Silox 2131-1 (Grey)	A	4.70	4.80	5.20	4.90	0.20
	B	5.00	4.80	3.80	4.53	0.20
	C	4.50	5.10	4.60	4.73	1.00
	D	4.20	5.90	4.40	4.83	0.10
					4.75	**0.38**
Silox 2131-2	A	2.30	3.70	4.40	3.47	0.10
	B	2.70	4.00	4.00	3.57	0.40
	C	3.10	3.60	3.40	3.37	0.10
	D	2.80	3.40	4.10	3.43	0.50
					3.46	**0.28**
Silox 2131-3	A	3.10	2.10	2.60	2.60	0.10
	B	3.00	2.50	2.70	2.73	0.10
	C	3.40	4.80	3.80	4.00	0.40
	D	3.30	3.20	4.30	3.60	0.50
					3.23	**0.28**

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* Instrumentation: KTA-Tator, Inc, 'Positector 6000-F2 gauge for dry film thickness.

PROJECTILE SURFACE PROTECTION

THICKNESS MEASUREMENTS* (Mils)
NSWC/D; 9 Nov 94; Bld 457
Coating contractor: Advanced Polymer Sciences

A - Ogive, 4 inch aft of forward face
B - Fwd Bourrelet
C - Middle Bourrelet
D - Aft Bourrelet

PJCTL TYPE	PJCTL STATION	ROTATION			Primer Thickness	O.D. Topcoat (Spotchecked)
		0	120	240		
Silox 2431-1 (Green)	A	2.60	2.50	2.10	2.40	1.00
	B	3.70	1.95	2.20	2.62	0.20
	C	3.20	2.40	2.70	2.77	0.40
	D	4.10	1.80	2.40	2.77	0.20
					2.64	**0.45**
Silox 2431-2	A	2.30	2.00	2.10	2.13	1.00
	B	1.50	1.60	2.20	1.77	0.30
	C	1.95	2.40	1.80	2.05	0.10
	D	1.85	2.70	2.30	2.28	0.40
					2.06	**0.45**
Silox 2431-3	A	2.90	2.60	2.40	2.63	0.50
	B	2.80	2.40	2.30	2.50	1.00
	C	2.40	2.60	3.10	2.70	0.50
	D	2.50	2.90	3.20	2.87	0.60
					2.68	**0.65**

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* Instrumentation: KTA-Tator, Inc, 'Positector 6000-F2 gauge for dry film thickness.

PROJECTILE SURFACE PROTECTION

THICKNESS MEASUREMENTS* (Mils)
NSWC/D; 10 Nov 94; Bld 457
Coating contractor: Scranton Army Ammunition Plant

W - Ogive, 4 inch aft of forward face
X - Ogive, 10 inch aft of forward face
Y - Fwd Bourrelet
Z - Middle Bourrelet

PJCTL TYPE	PJCTL STATION	ROTATION 0	ROTATION 120	ROTATION 240	**Aver Thickn
Army M864,	W	3.80	4.90	4.00	4.23
Empty	X	3.40	3.80	3.60	3.60
Primer &	Y	3.30	4.20	3.30	3.60
Top Coat	Z	3.50	4.10	3.20	3.60
					3.76

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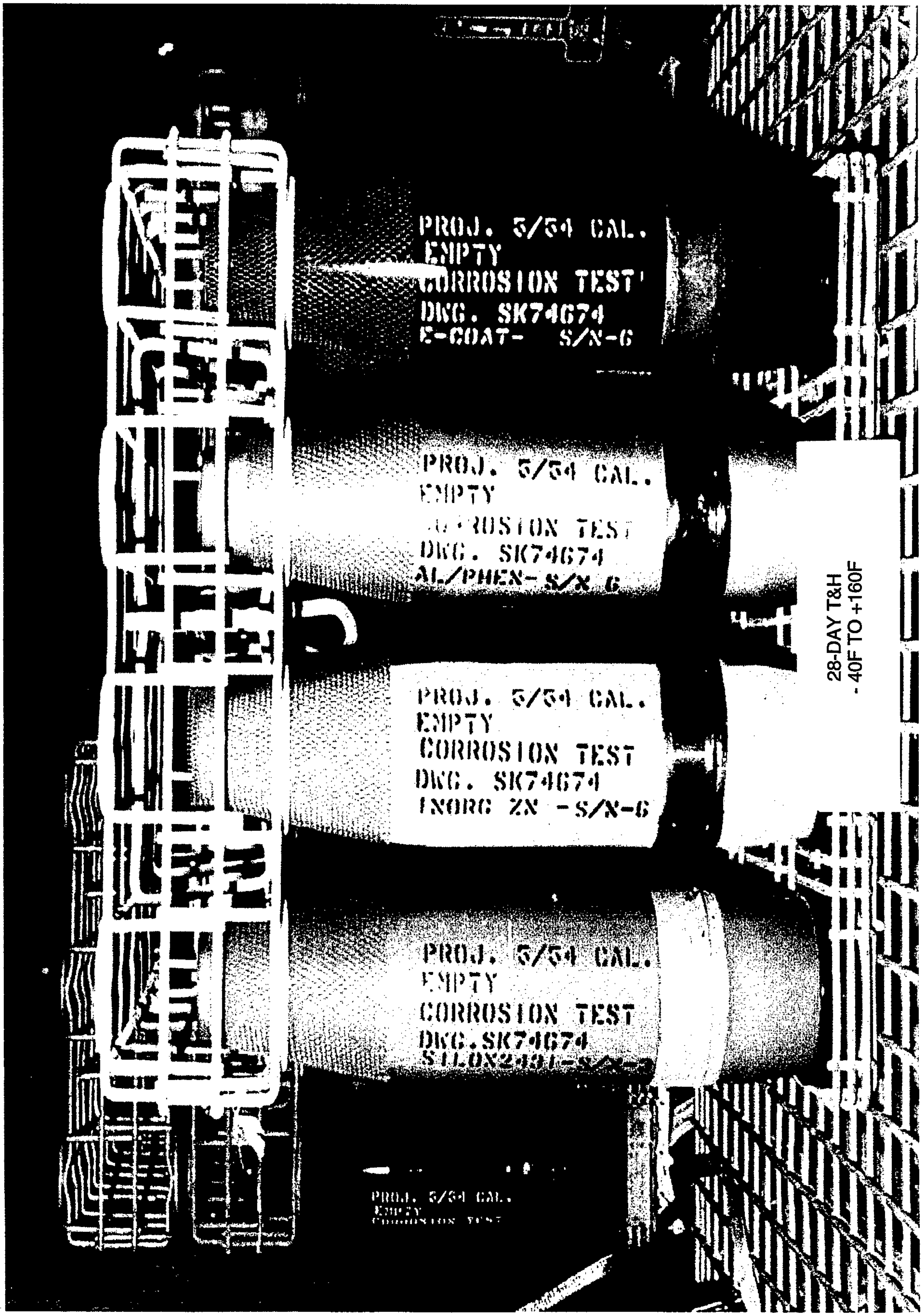
* Instrumentation: KTA-Tator, Inc, 'Positector 6000-F2 gauge for dry film thi

** Primer and Top Coat

APPENDIX I

PHOTOGRAPHS, END ITEMS AFTER 28-DAY T&H
(NSWC/DL FILE PHOTOS P5982)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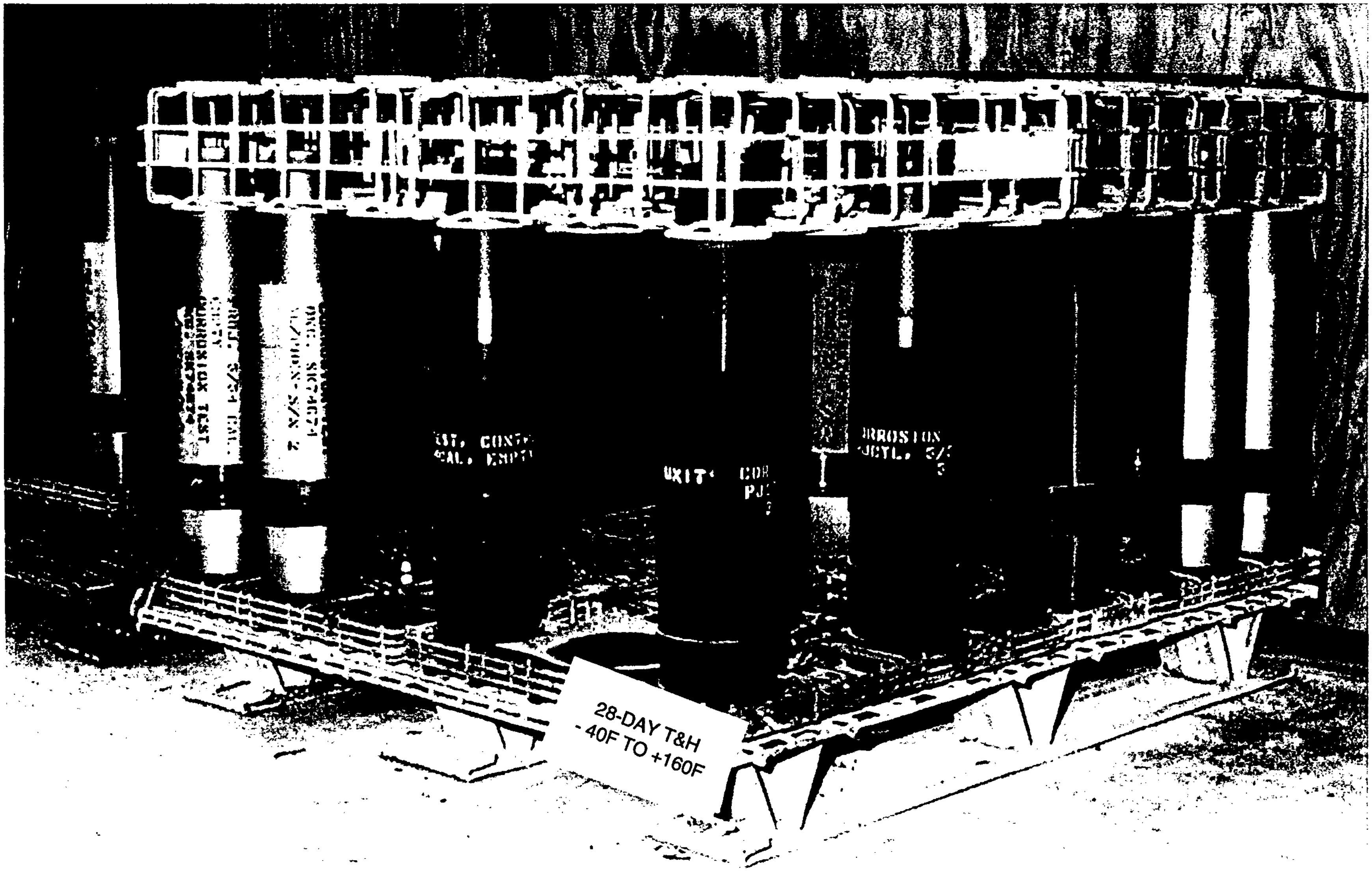
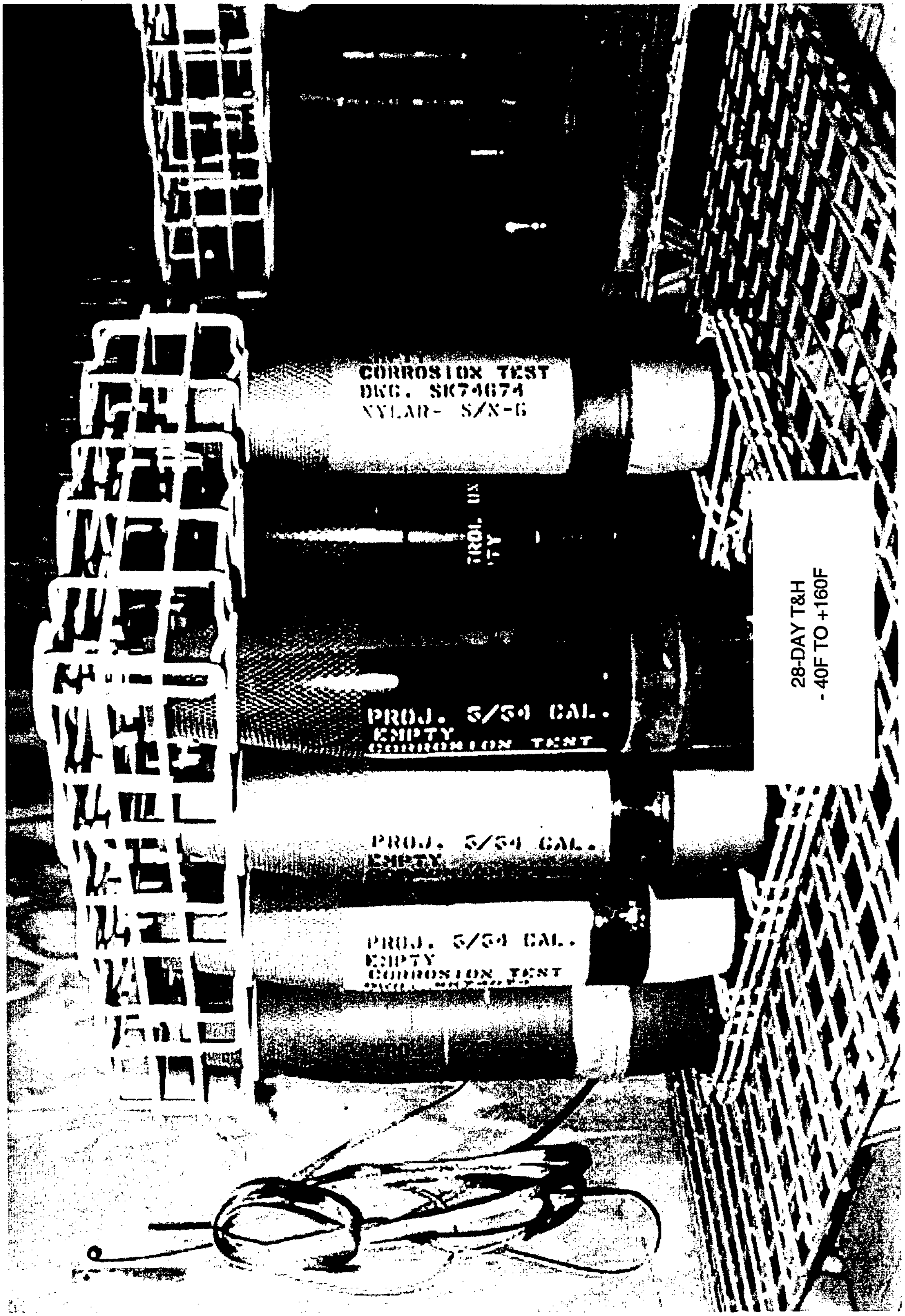
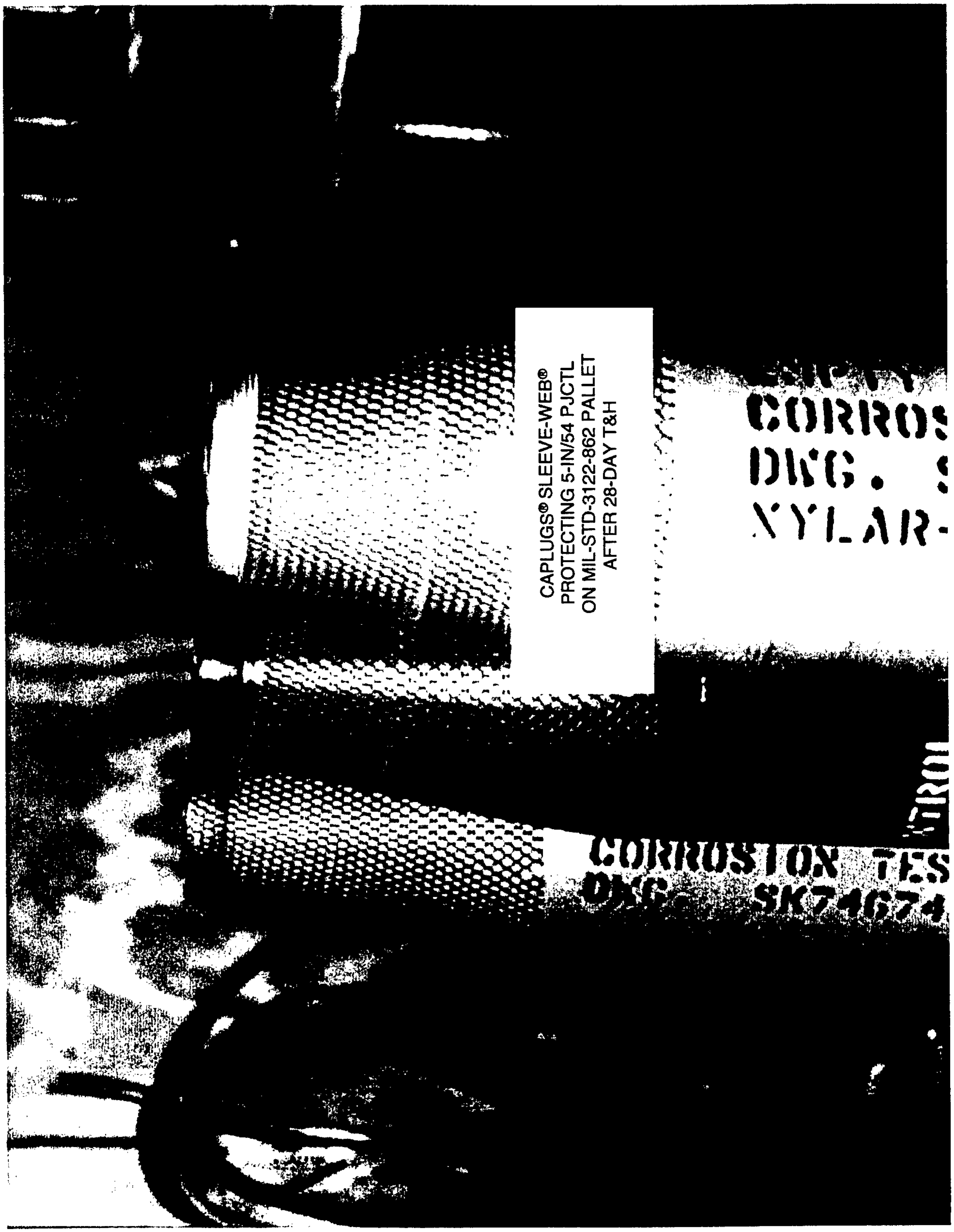
EMPTY
CORROSION TEST
DWG. SK74674
E-COAT- S/N-6
PROJ. 5/54 CAL.
EMPTY
CORROSION TEST
DWG. SK74674
AL/PHEN- S/N 6
PROJ. 5/54 CAL.
EMPTY
CORROSION TEST
DWG. SK74674
INORG ZN -S/N-6
PROJ. 5/54 CAL.
EMPTY
CORROSION TEST
DWG.SK74674
28-DAY T&H
- 40F TO +160F
PROJ. 5/54 CAL.
EMPTY
CORROSION TEST


28-DAY T&H
- 40F TO +160F
CORROSION TEST



28-DAY T&H
-40F TO +160F



CAPLUGS® SLEEVE-WEB®
PROTECTING 5-IN/54 PJCTL
ON MIL-STD-3122-862 PALLET
AFTER 28-DAY T&H

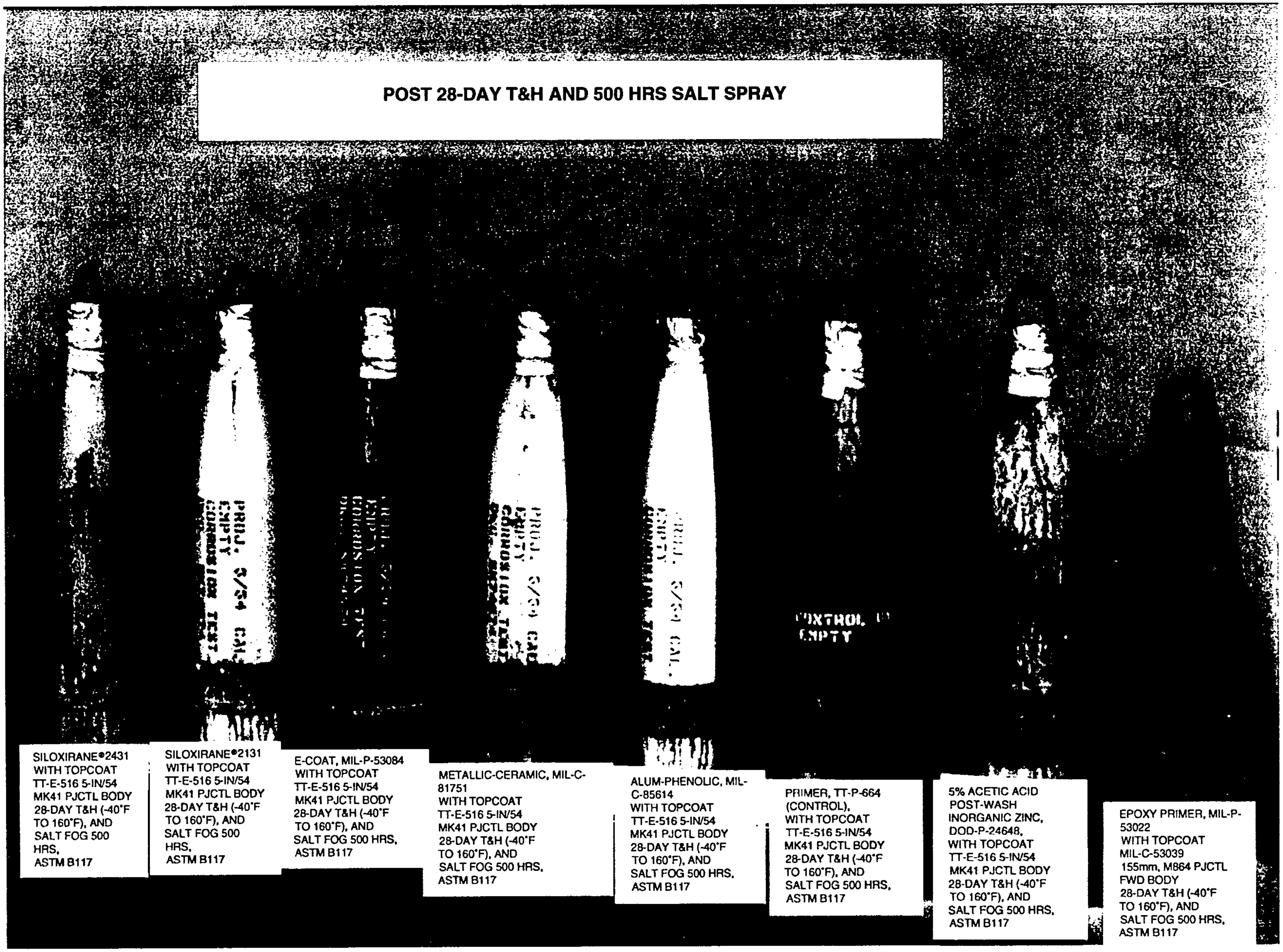
ADHESIVE MARKING DECAL,
MIL-M-43719,
ON 5-IN/54 PJCTL
AFTER 28-DAY T&H

APPENDIX J

PHOTOGRAPHS, END ITEMS AFTER SALT SPRAY (336 HR = NSWC/DL FILE PHOTOS P5982 AND 500 HR = NSWC/DL FILE PHOTOS P6195)

POST 28-DAY T&H AND 336 HR SALT SPRAY

LEFT TO RIGHT:
Army 155mm M864 Fwd
Aluminized Phenolic
Inorganic Zinc
Metallic Ceramic
E-Coat
'Control'
Siloxirane 2431
Siloxirane 2131
76mm Spirol Case (192 hrs, only)
76mm Spirol Case (14-Day T&H, only)



POST 28-DAY T&H AND 500 HRS SALT SPRAY

SILOXIRANE®2431
WITH TOPCOAT
TT-E-516 5-IN/54
MK41 PJCTL BODY
28-DAY T&H (-40°F
TO 160°F), AND
SALT FOG 500
HRS,
ASTM B117

SILOXIRANE®2131
WITH TOPCOAT
TT-E-516 5-IN/54
MK41 PJCTL BODY
28-DAY T&H (-40°F
TO 160°F), AND
SALT FOG 500
HRS,
ASTM B117

E-COAT, MIL-P-53084
WITH TOPCOAT
TT-E-516 5-IN/54
MK41 PJCTL BODY
28-DAY T&H (-40°F
TO 160°F), AND
SALT FOG 500 HRS,
ASTM B117

METALLIC-CERAMIC, MIL-C-81751
WITH TOPCOAT
TT-E-516 5-IN/54
MK41 PJCTL BODY
28-DAY T&H (-40°F
TO 160°F), AND
SALT FOG 500 HRS,
ASTM B117

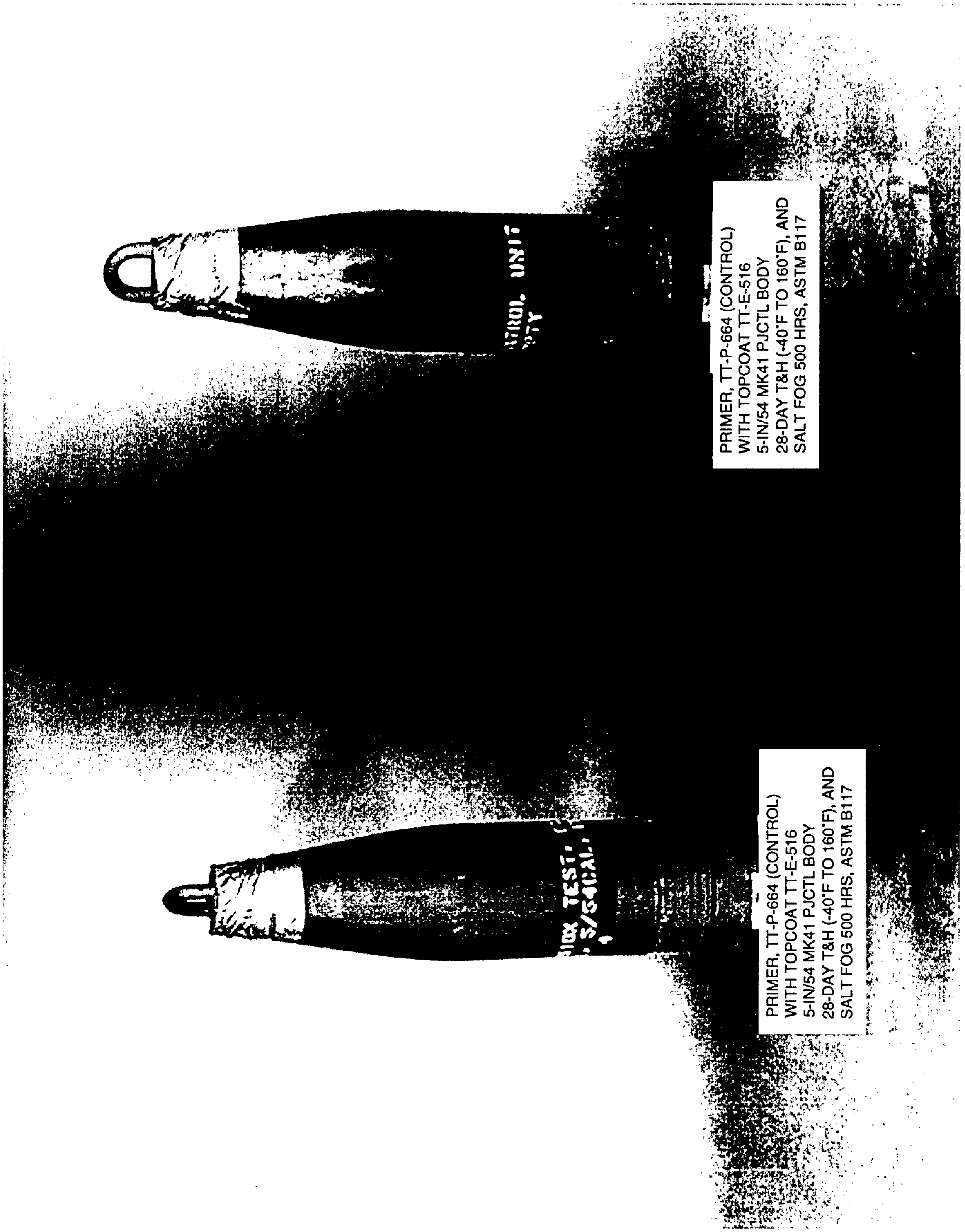
ALUM-PHENOLIC, MIL-C-85614
WITH TOPCOAT
TT-E-516 5-IN/54
MK41 PJCTL BODY
28-DAY T&H (-40°F
TO 160°F), AND
SALT FOG 500 HRS,
ASTM B117

PRIMER, TT-P-664
(CONTROL),
WITH TOPCOAT
TT-E-516 5-IN/54
MK41 PJCTL BODY
28-DAY T&H (-40°F
TO 160°F), AND
SALT FOG 500 HRS,
ASTM B117

5% ACETIC ACID
POST-WASH
INORGANIC ZINC,
DOD-P-24648,
WITH TOPCOAT
TT-E-516 5-IN/54
MK41 PJCTL BODY
28-DAY T&H (-40°F
TO 160°F), AND
SALT FOG 500 HRS,
ASTM B117

EPOXY PRIMER, MIL-P-53022
WITH TOPCOAT
MIL-C-53039
155mm, M864 PJCTL
FWD BODY
28-DAY T&H (-40°F
TO 160°F), AND
SALT FOG 500 HRS,
ASTM B117

PRIMER,TT-P-664 (CONTROL)
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO -160°F), AND SALT FOG
336 HRS, ASTM B117

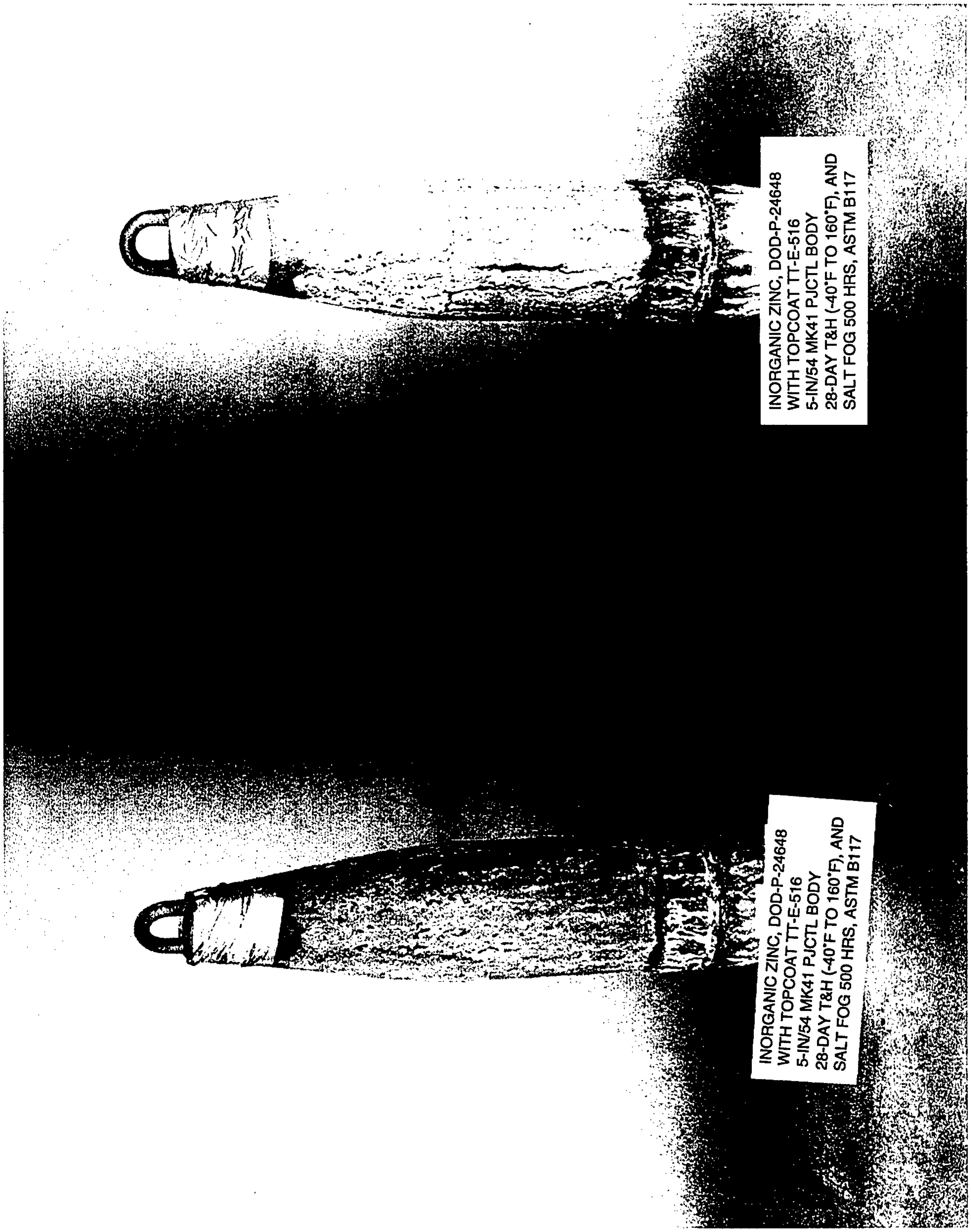


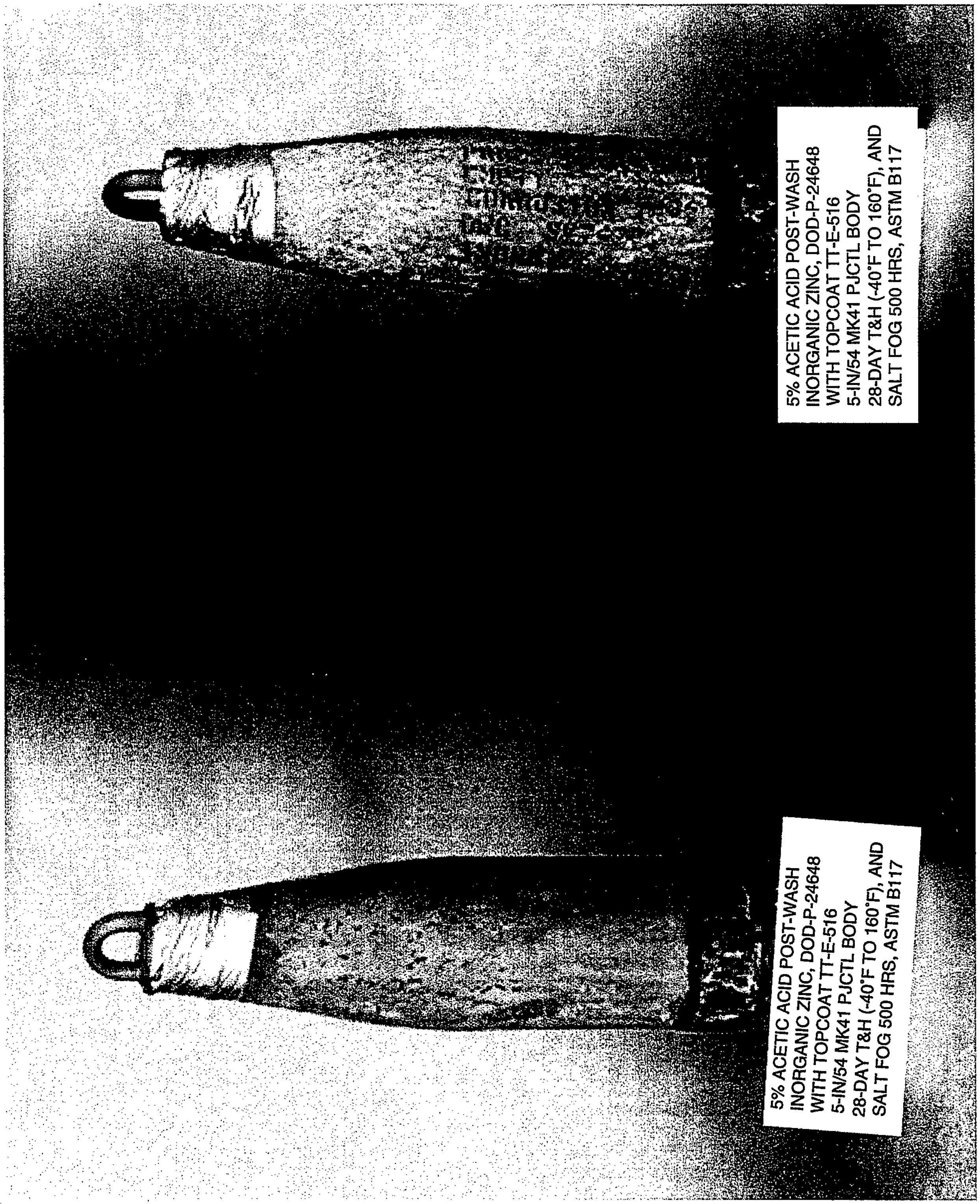
PRIMER, TT-P-664 (CONTROL)
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117

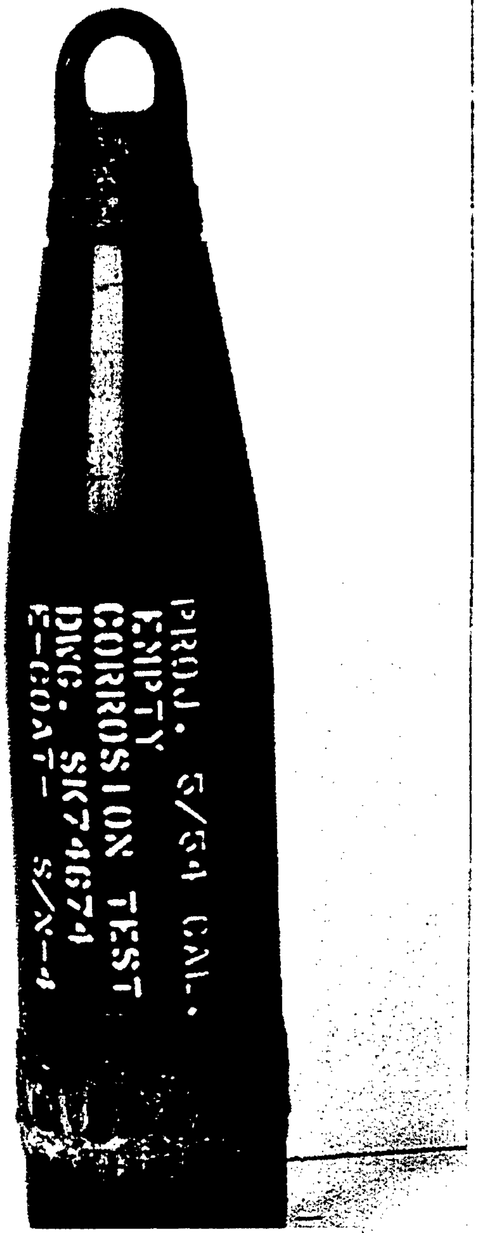
PRIMER, TT-P-664 (CONTROL)
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117

INORGANIC ZINC, DOD-P-24648
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117

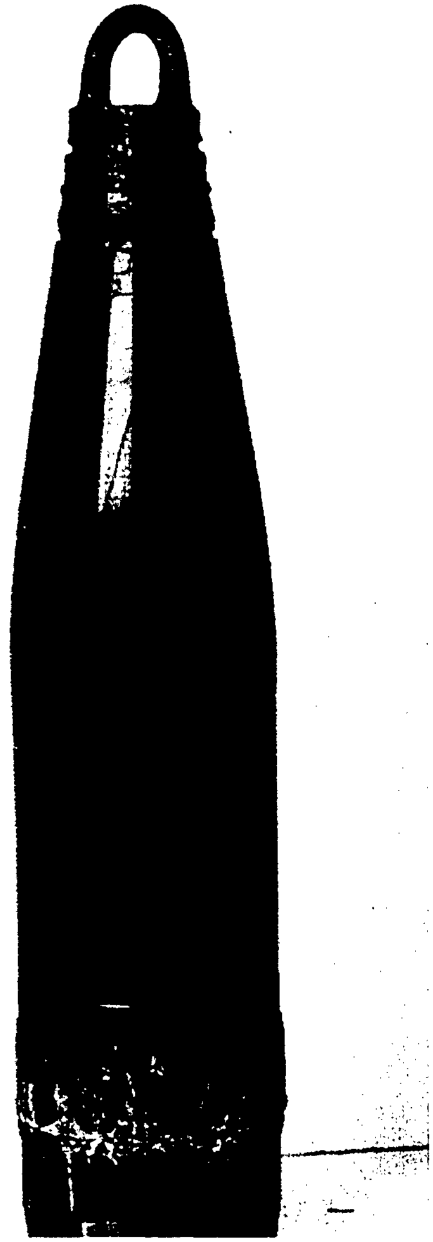
INORGANIC ZINC, DOD-P-24648
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117


INORGANIC ZINC, DOD-P-24648
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117
INORGANIC ZINC, DOD-P-24648
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117

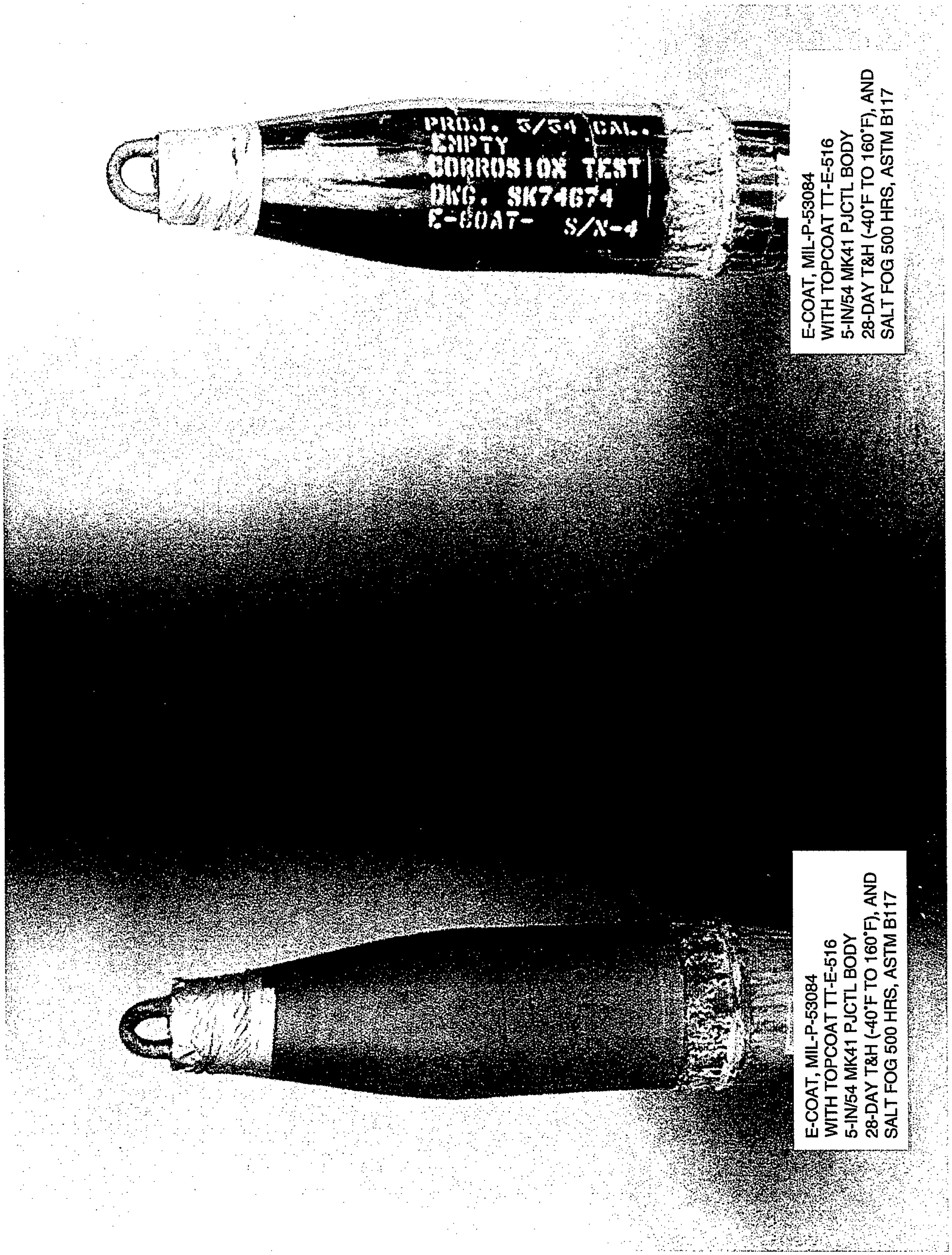

5% ACETIC ACID POST-WASH
INORGANIC ZINC, DOD-P-24648
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117
5% ACETIC ACID POST-WASH
INORGANIC ZINC, DOD-P-24648
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117



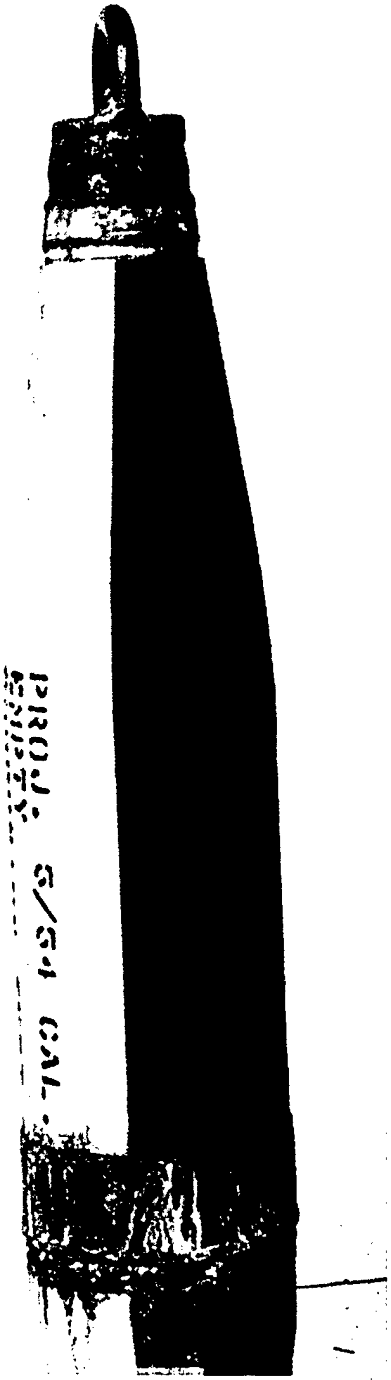
E-COAT, MIL-P-53084
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117



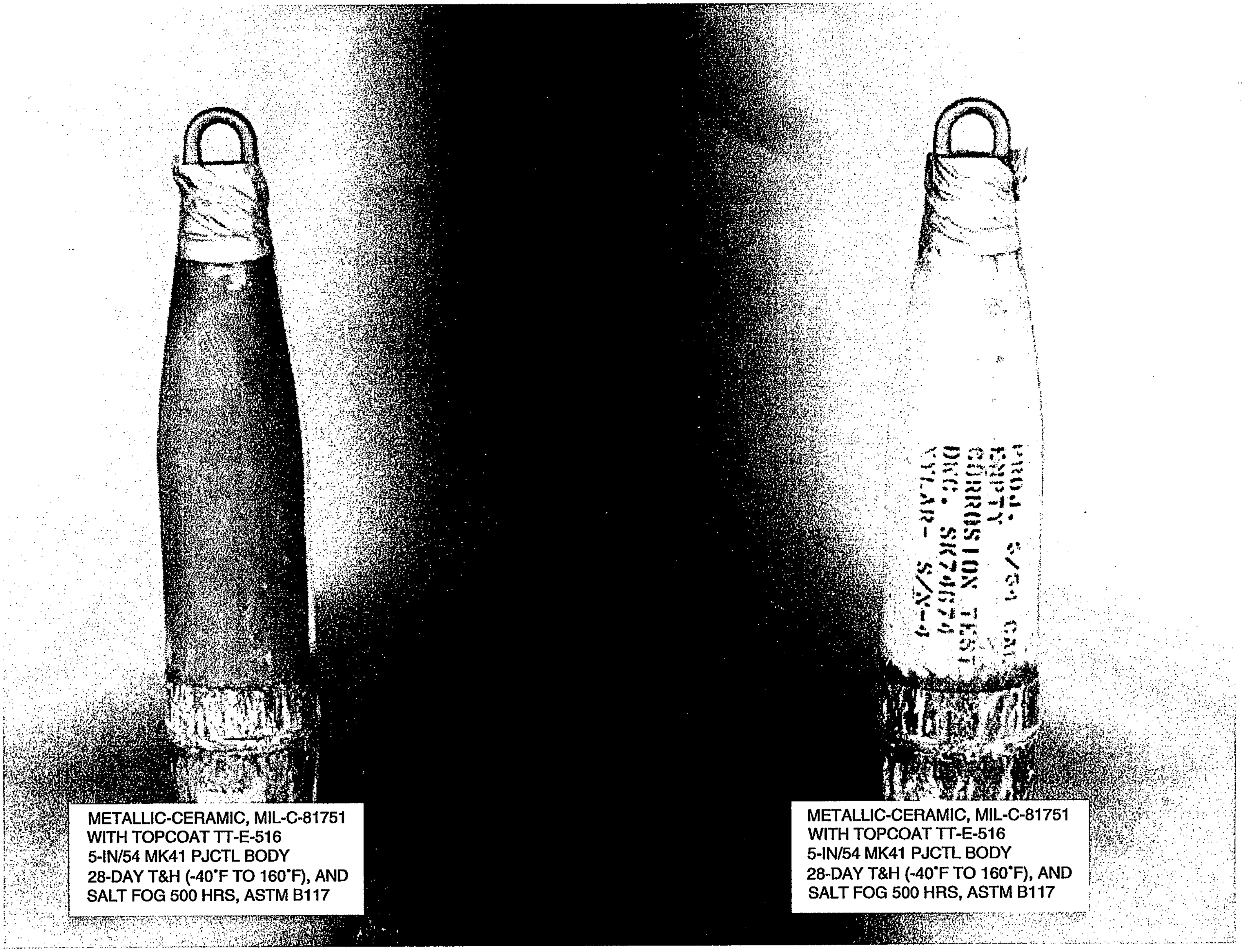
E-COAT, MIL-P-53084
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117


PROJ. 5/54 CAL.
EMPTY
CORROSION TEST
DWG. SK74674
E-COAT- S/N-4
E-COAT, MIL-P-53084
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117
E-COAT, MIL-P-53084
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117

METALLIC-CERAMIC, MIL-C-81751
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117

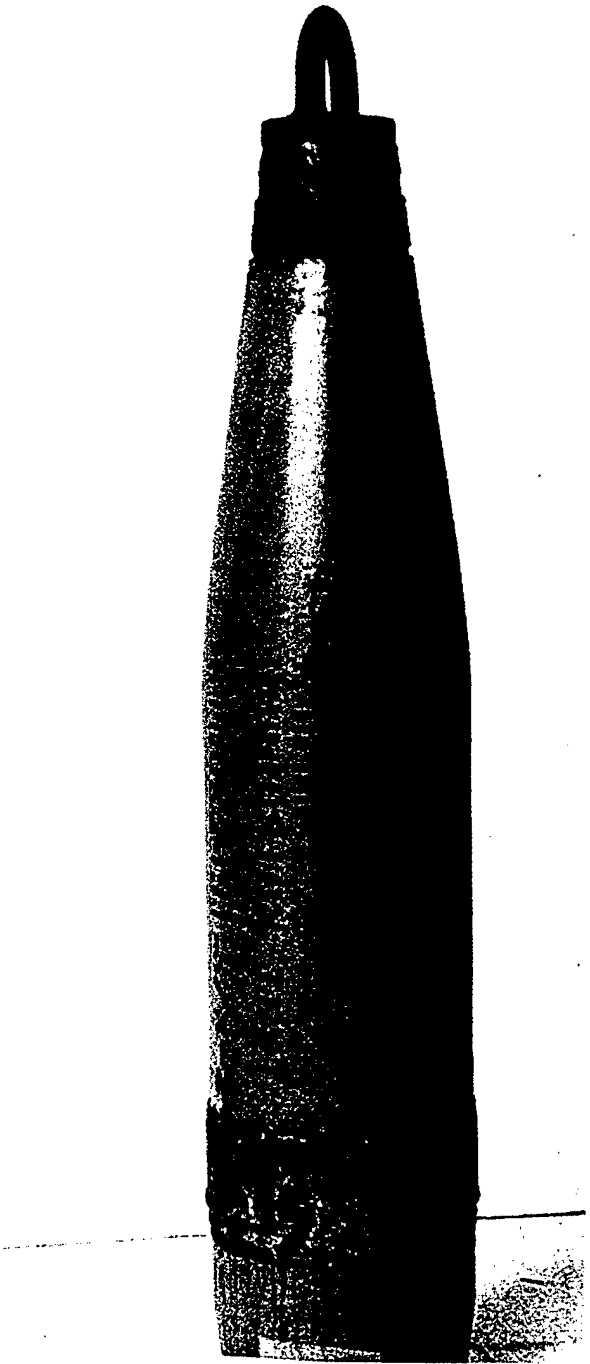


METALLIC-CERAMIC, MIL-C-81751
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117

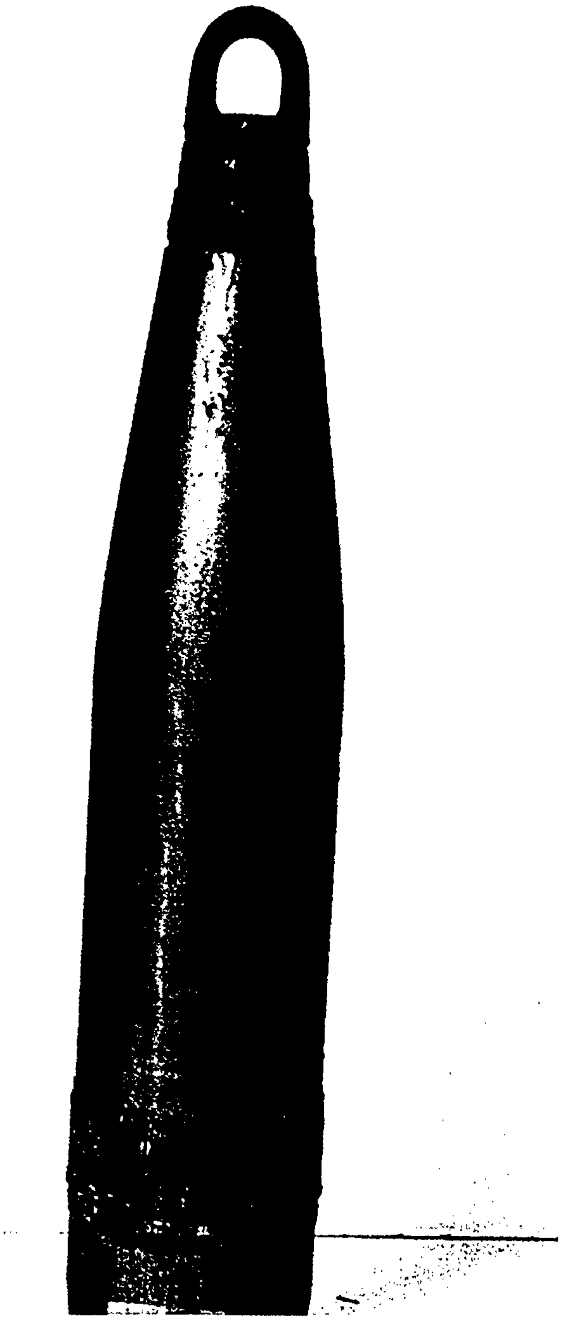


METALLIC-CERAMIC, MIL-C-81751
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117

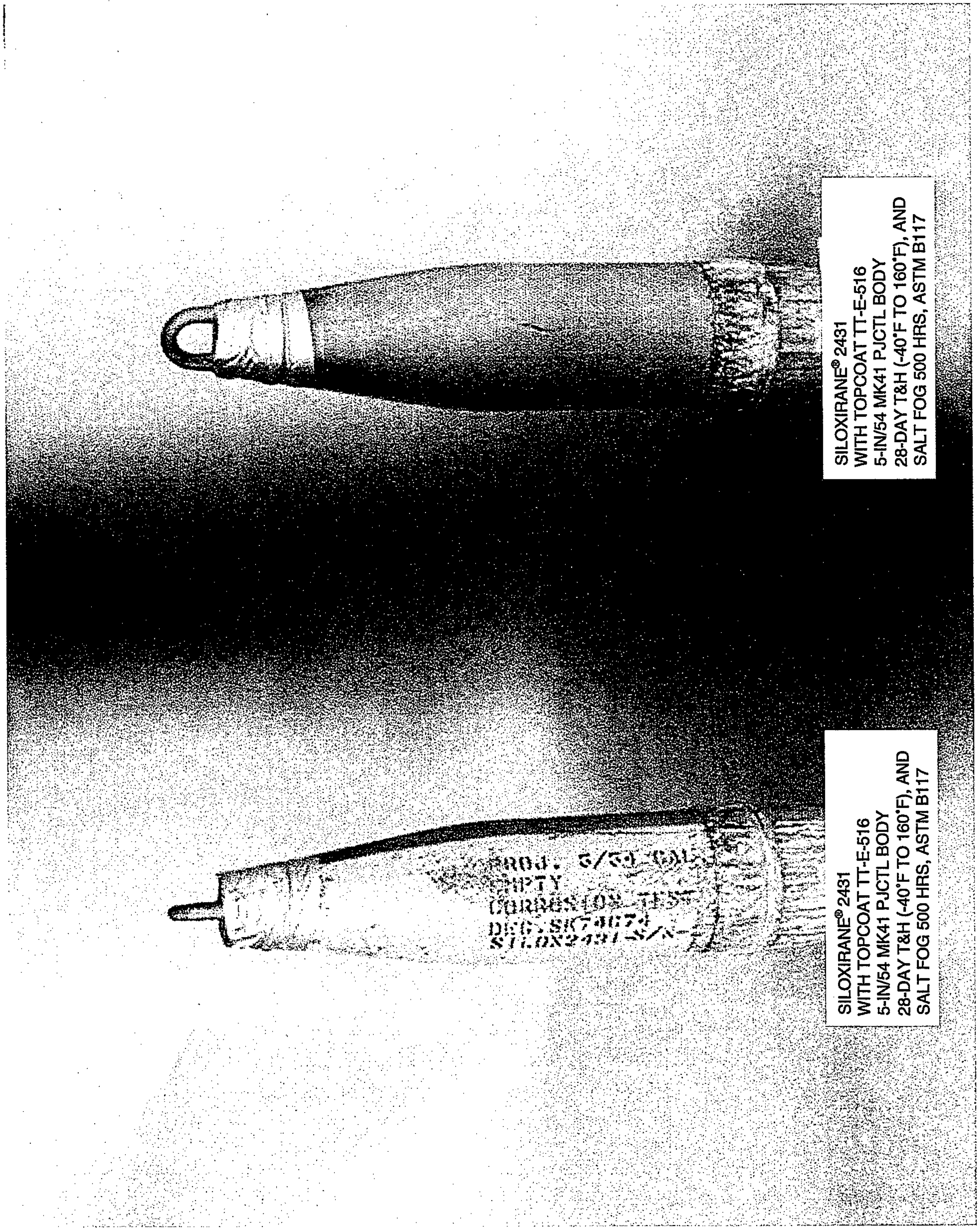
METALLIC-CERAMIC, MIL-C-81751
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117



SILOXIRANE® 2431
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117

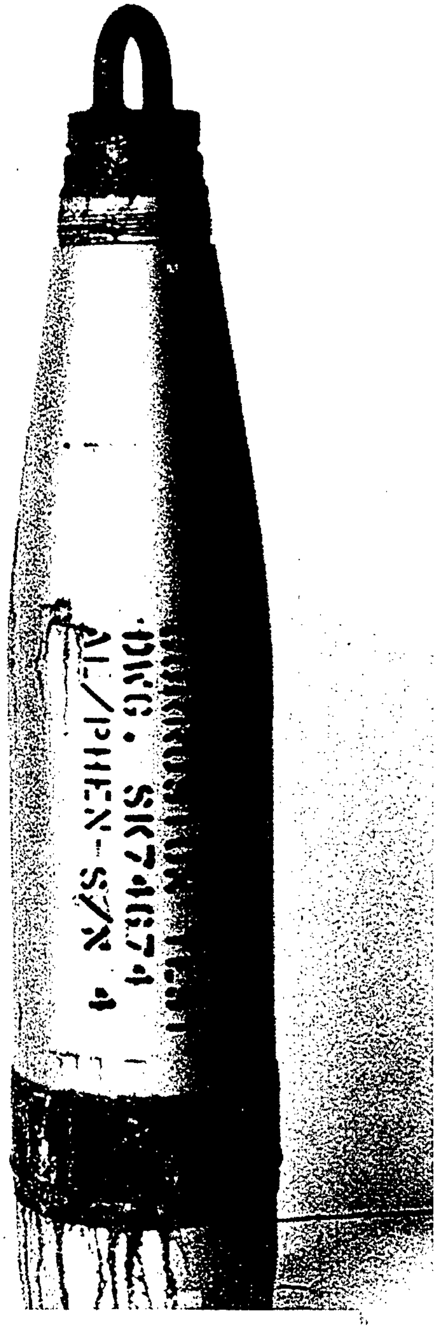


SILOXIRANE® 2431
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117

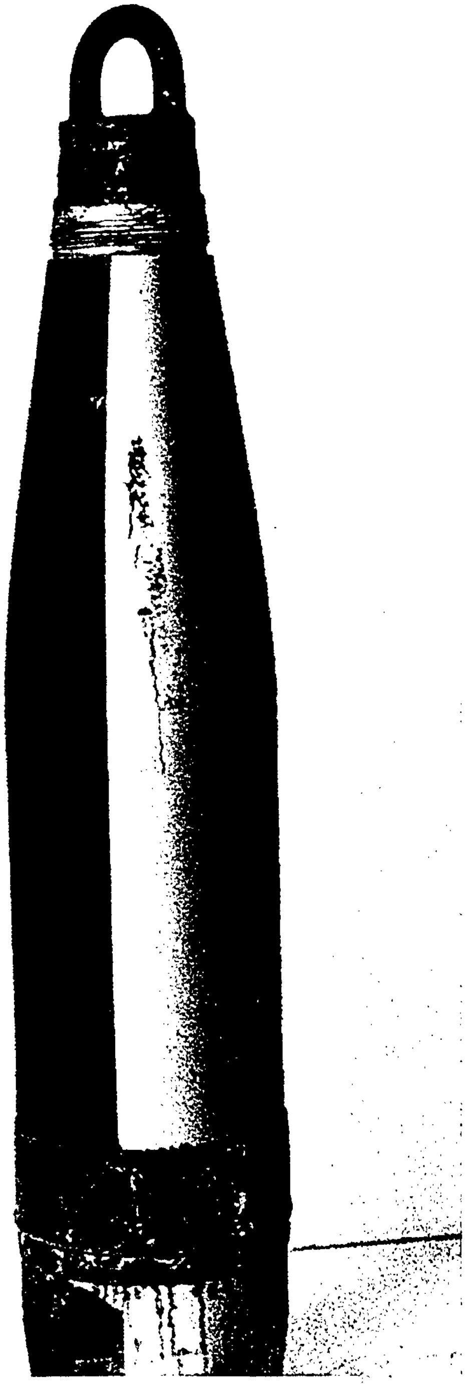


SILOXIRANE® 2431
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117

SILOXIRANE® 2431
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117



ALUM-PHENOLIC MIL-C-85614
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117



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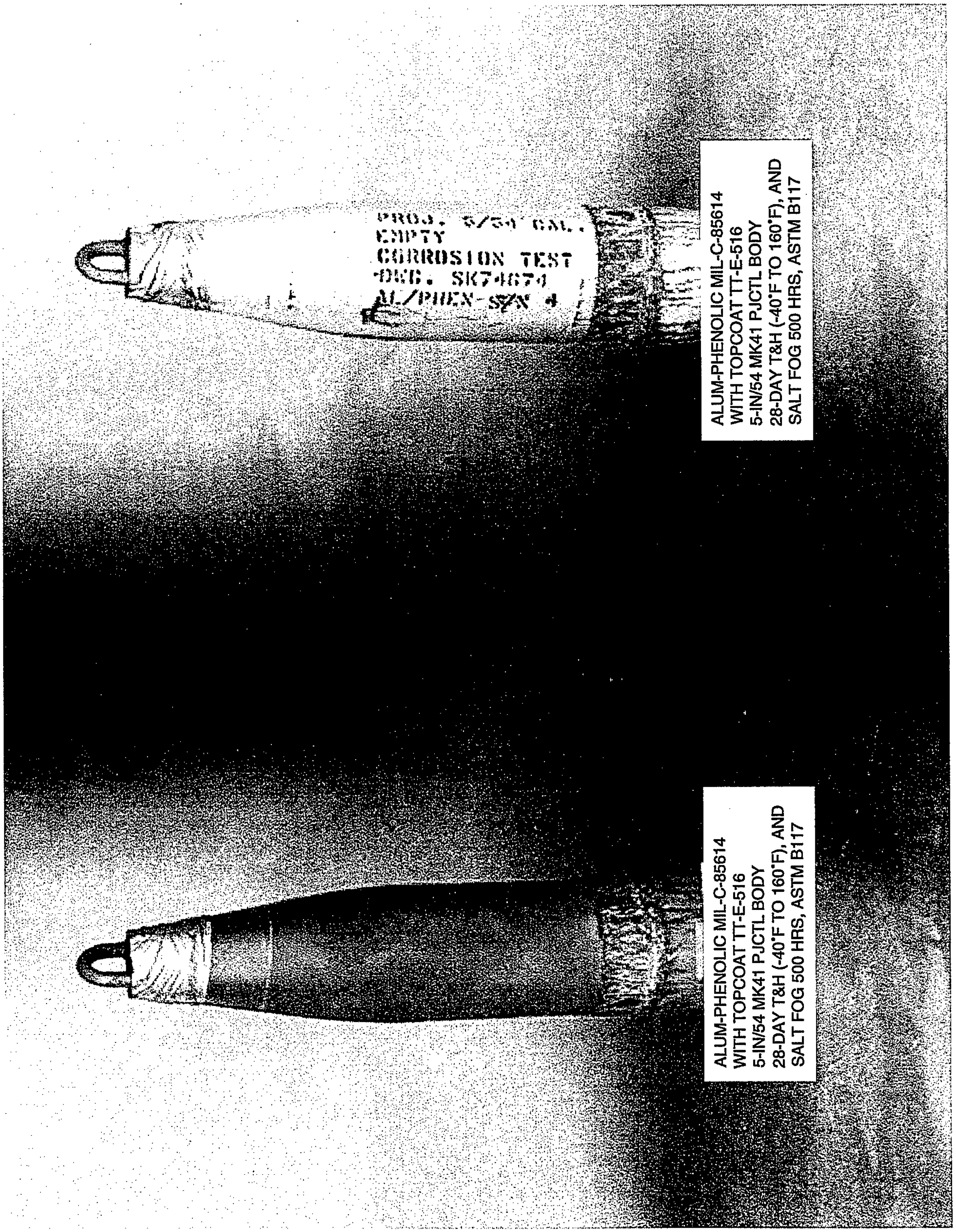
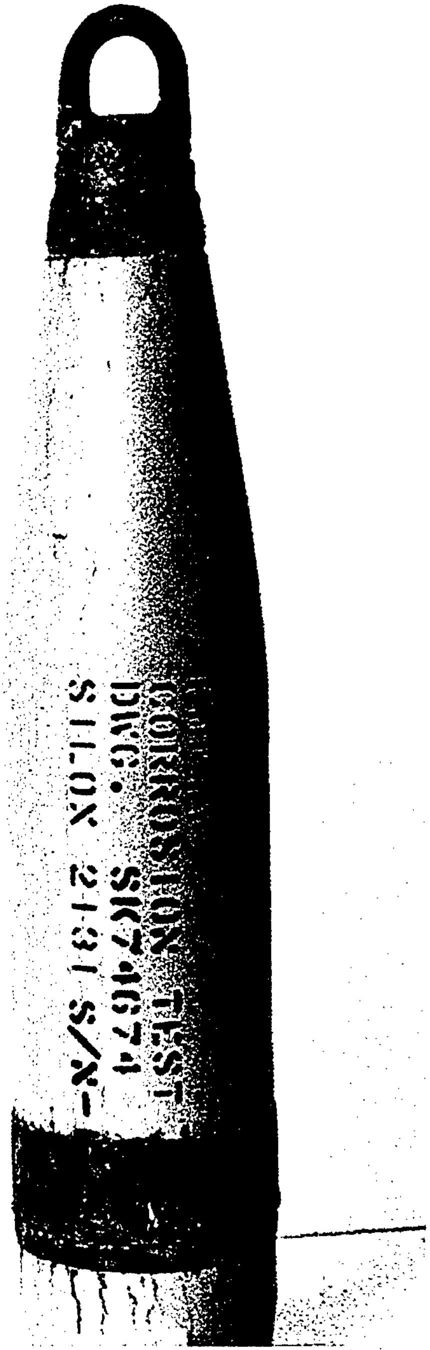
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117

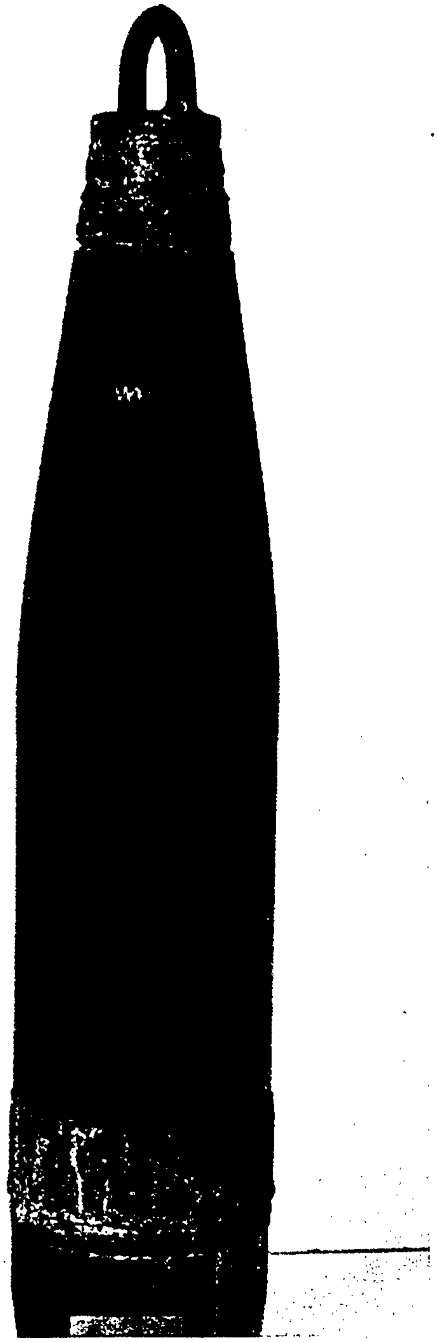


ALUM-PHENOLIC MIL-C-85614
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117

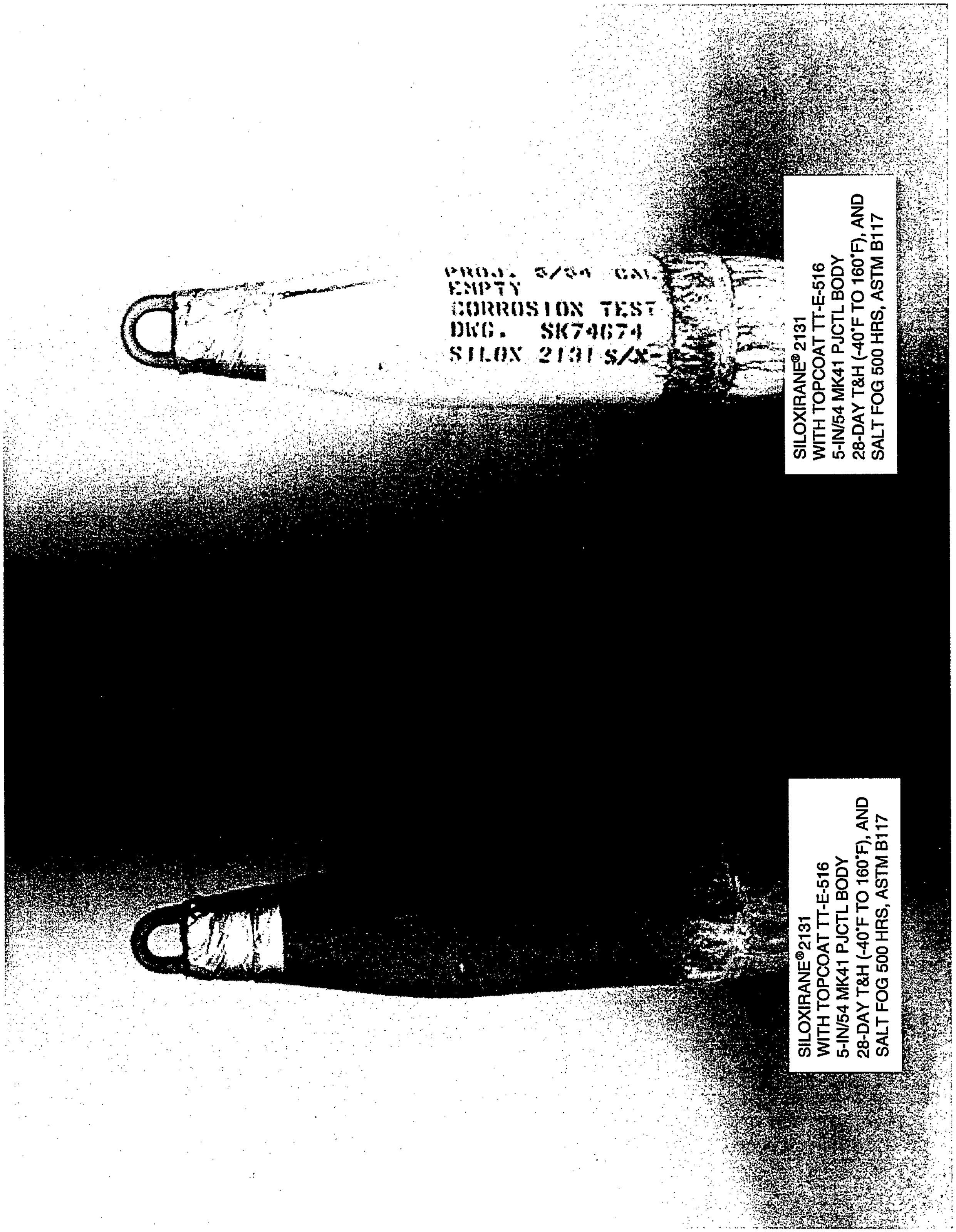
ALUM-PHENOLIC MIL-C-85614
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117

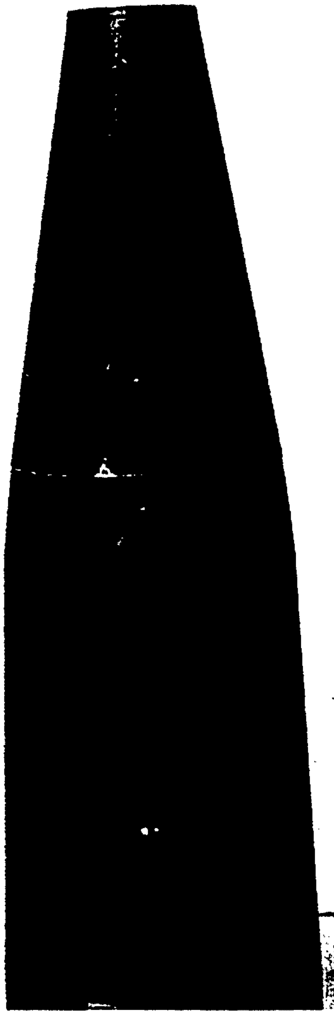


SILOXIRANE® 2131
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117

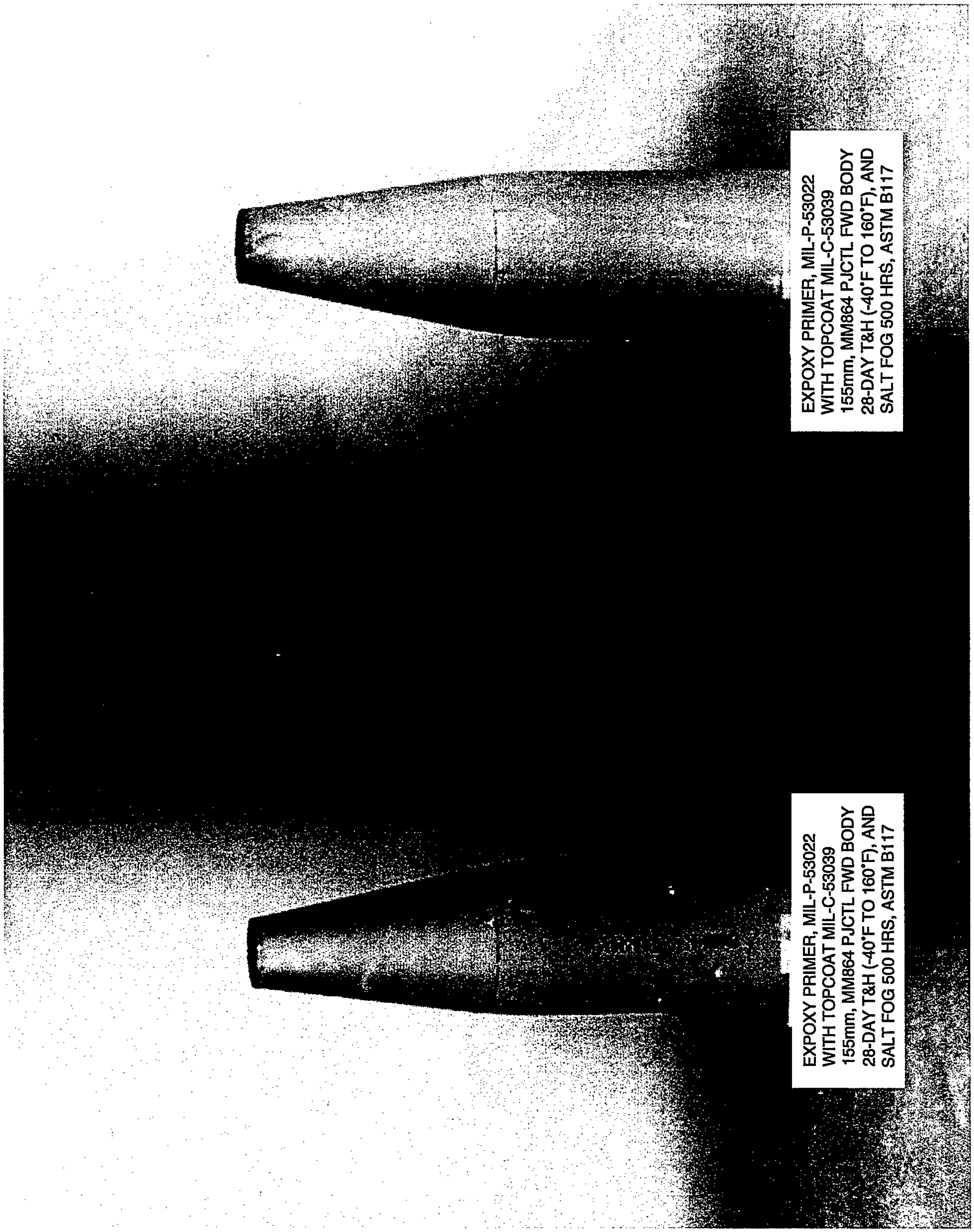


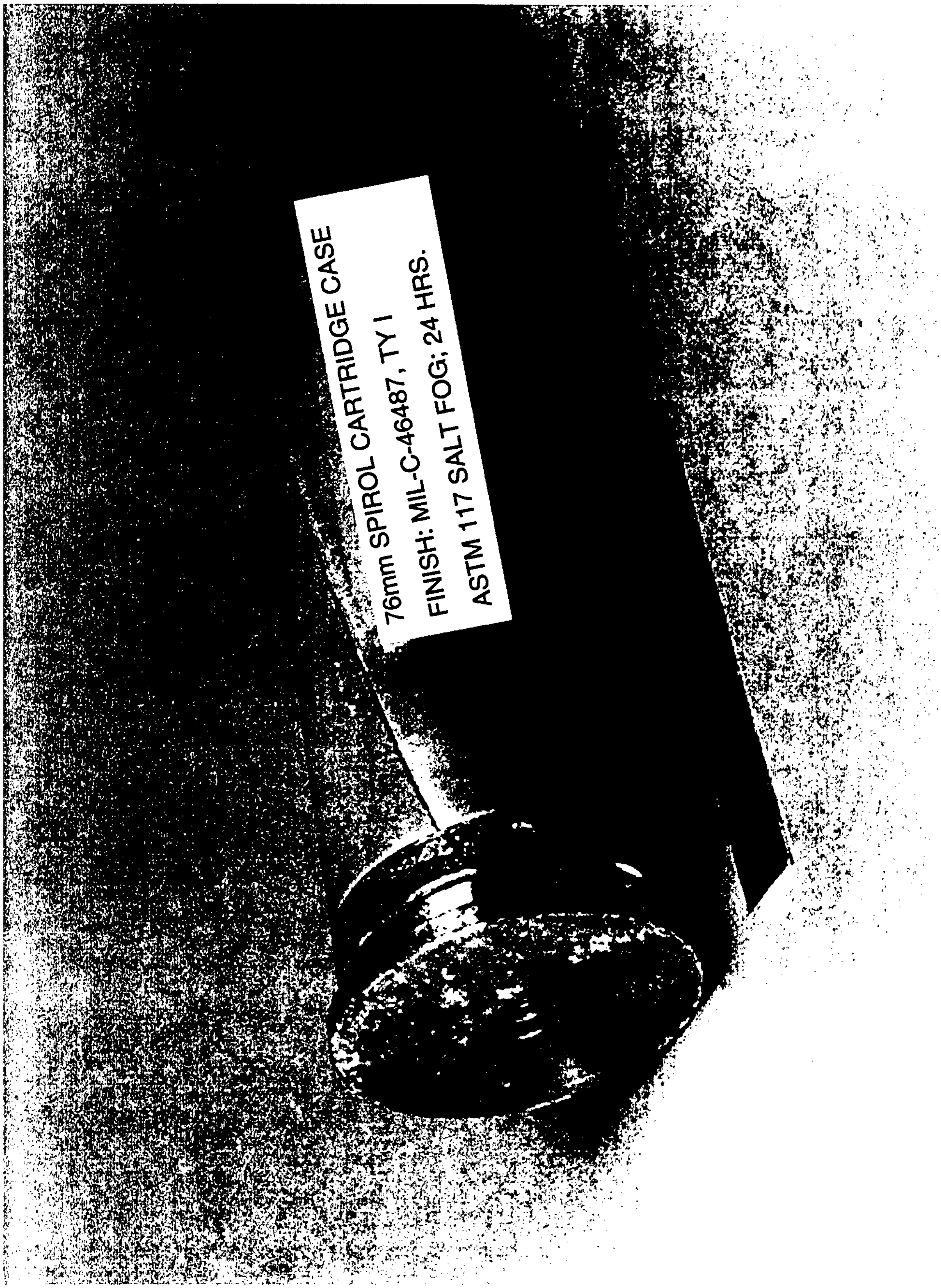
SILOXIRANE® 2131
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 336 HRS, ASTM B117

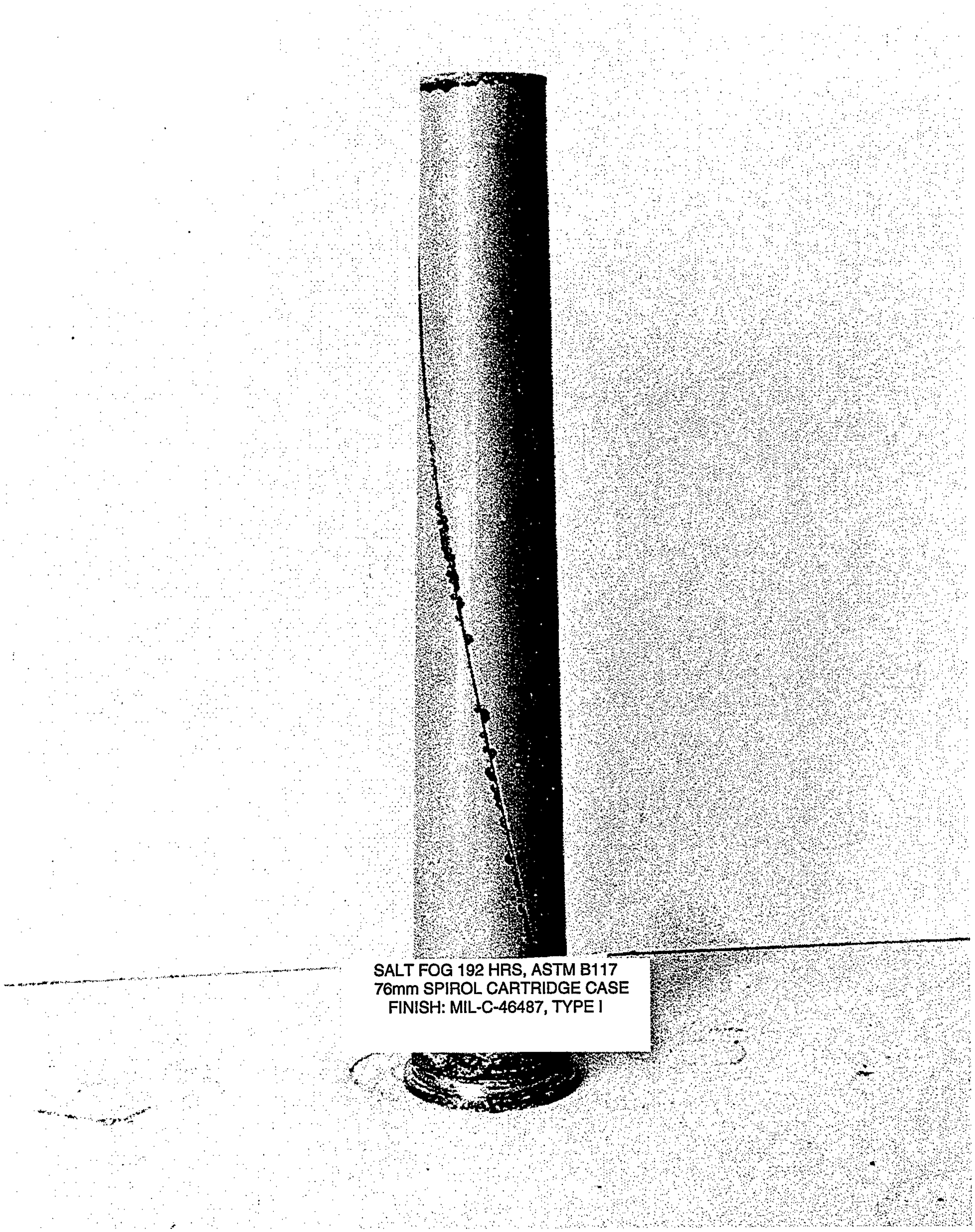

PROJ. 5/54 CAL
EMPTY
CORROSION TEST
DWG. SK74674
SILOX 2131 S/X-
SILOXIRANE® 2131
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117
SILOXIRANE® 2131
WITH TOPCOAT TT-E-516
5-IN/54 MK41 PJCTL BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117



EPOXY PRIMER, MIL-P-53022
WITH TOPCOAT
155mm, M864 PJCTL FWD BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 168 HRS, ASTM B117


EXPOXY PRIMER, MIL-P-53022
WITH TOPCOAT MIL-C-53039
155mm, MM864 PJCTL FWD BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117
EXPOXY PRIMER, MIL-P-53022
WITH TOPCOAT MIL-C-53039
155mm, MM864 PJCTL FWD BODY
28-DAY T&H (-40°F TO 160°F), AND
SALT FOG 500 HRS, ASTM B117


76mm SPIROL CARTRIDGE CASE
FINISH: MIL-C-46487, TY I
ASTM 117 SALT FOG; 24 HRS.


SALT FOG 192 HRS, ASTM B117
76mm SPIROL CARTRIDGE CASE
FINISH: MIL-C-46487, TYPE I

APPENDIX K

SLEEVE-WEB PROTECTORS ON PALLETIZED 5"/54 PROJECTILE LOAD

SLEEVE-WEB PROTECTORS ON PALLETIZED 5"/54 PROJECTILE LOAD

The Mk 11 pallet is used for both shipments of empty and loaded projectiles per MIL-STD-1322-862. With the loaded items, the steel pallet frame bears against the fuze protector cap and does not contact the projectile coating; however, for shipment of empty projectiles from manufacturer to loading plant, fuze protector caps are not used. The pallet frame is made to bear directly against the projectile body and thus damages the coating. The same procedure has been used for years with the loading plants applying touch up primer before spraying the topcoat.

Including some type of protector device between the projectile and the metal pallet frame would prevent this damge. Disposable plastic netting was used in this program to demonstrate feasibility. After the 28-day T&H test, there was no evidence of moisture entrapment or accelerated corrosion in the area of sleeve contact (see photographs in Appendix I). Also trial shipments by railcar from Scranton Army Ammunition Plant, PA to Crane Army Ammunition Activity, IN have been performed by NSWCC, Code 4025. A cost effectiveness analysis remains to be done, but from an engineering standpoint, the present cycle of deliberate damage and repair to the coating is objectionable.

Similar protectors are in use to protect in-process items at NSWC Indian Head, and have also been used by Lufkin Industries in the 5-inch ductile iron projectile program. Protector sleeves are available from the Caplugs Division, Protective Closures Co., Inc; part no. SW30.

APPENDIX L

SALT SPRAY RESULTS ON 76mm SPIRAL-WRAP CARTRIDGE CASE

SALT SPRAY RESULTS ON 76mm SPIRAL-WRAP CARTRIDGE CASE

This was an opportunistic test performed on a developmental cartridge case which is manufactured from wrapped sheet metal instead of a deep drawn forging.

The substrate material for the body sidewall is low carbon steel per ASTM A630, which is subsequently galvanized per ASTM A879 and varnished per MIL-C-46487, Type I. The base is galvanized A434 steel.

After 192,hours edge corrosion and localized blistering at the case mouth and the sidewall seams is evident. The galvanized surface of the base is being consumed. Elsewhere, the coating appears intact. Part is photo-documented in Appendix J.

APPENDIX M

DECALOMANIA FOR PROJECTILE MARKING

DECALOMANIA FOR PROJECTILE MARKING

Identification markings for Navy projectiles are presently paint stenciled onto the exterior as one of the final assembly operations. Markings are specified by WS 18782. The type of ammunition, lot numbers, part numbers, weight and other information is painted in 1/2-inch high letters. (Color coding, described previously in this report, is also used as a quick visual indication of ammunition type.)

Other ordnance such as torpedoes and missiles use adhesive backed, pressure sensitive decals, per MIL-M-43719, for the same identification purposes. (The specification includes tests for resistance to water, diesel fuel, weather, corrosion and fungus.)

Decals were applied to 5-Inch/54 projectiles before the 28-Day Temperature-Humidity test. After exposure there were no adverse effects, peeling, cracking or loss of adhesion. See photos in Appendix I.

Decals and paint are both inorganic materials. It seems very unlikely that decals would leave any residue in the gun barrel or cause accelerated wear. Test firings of a small number of projectiles with decals was performed at NSWC Dahlgren with no immediately apparent adverse effects.

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G33 MALAMAS	4