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SERDP- Mike Hathaway

# ALTERNATIVE SURFACE COATINGS AND SURFACE TREATMENTS FOR HAZARDOUS CADMIUM PLATING OF SMALL PARTS

**FINAL REPORT**
**30 SEPTEMBER 1995**

**NAVAL SEA SYSTEMS COMMAND**
**CORROSION CONTROL DIVISION, SEA 03M1**

Prepared by:
NAVSEA 03M1
M. Rosenblatt & Son, Inc.
Ocean City Research Corporation



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SERDP , NAVY 077-94
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13. ABSTRACT (Maximum 200 words)

This report provides the results of a program to evaluate environmentally acceptable alternatives to cadmium plating in U.S. Navy applications. Conclusions resulting from mechanical testing and two-month exposure tests are provided. Several alternative coatings appear to provide corrosion resistance comparable to cadmium on non-complex shapes. In areas with a complex shape, none of the alternatives assessed performed as well as cadmium. No single alternative investigated performed as a universal substitute for cadmium plating.

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## RESEARCH TEAM

The research team for this program included:

**Naval Sea Systems Command**
Mr. A. R. Parks - Program direction.
Mr. B. Brinckerhoff - Engineering direction and program oversight; co-author.

**M. Rosenblatt and Son, Inc.**
Ms. K. R. Thomas - Program management support; co-author.

**Ocean City Research Corporation**
Staff Engineers - Test and evaluation, and data analysis; co-authors.

**Naval Surface Warfare Center, Crane Division**
Mr. Don Hileman - Weapon systems problem identification.

**Naval Research Laboratory**
Mr. E. D. Thomas - Engineering support.

The authors would like to express their appreciation to all those who contributed to this program, including NAVSEA life cycle managers and Navy logistics personnel who helped identify where cadmium plating is currently used.

# ALTERNATIVE SURFACE COATINGS/SURFACE TREATMENTS FOR HAZARDOUS CADMIUM PLATING OF SMALL PARTS (SERDP 077-94)

## REPORT CONTENTS

# REPORT INTRODUCTION

The goal of this program was to develop and evaluate environmentally acceptable alternatives to cadmium plating for implementation within U. S. Navy maintenance and original procurement operations. In addition to being safe for handling, the coating selections would have to withstand harsh weathering conditions and uphold the strict in-service performance standards required to support the Fleet's operational tempo. The seizing of topside fasteners due to corrosion product buildup or a non-lubricious surface is to be avoided. Likewise, the failure of hardware due to environmentally assisted cracking could also pose dangers to ship's force and impede mission readiness. Any successful coating process developments would benefit a broad range of industries including defense, automotive, and even appliance manufacturers. The criticality of this hazardous material issue is evident as replacement of cadmium plated parts has expanded into a worldwide concern affecting all levels of daily operation from individual factory workers to international commerce.

Our research program was originally designed to extend over a two year period, allowing for a two-phase test regime. Shortly after the receipt of project funds, we were advised to modify (compress) our test program so that it be completed by September 1995, a one year time frame. The two year design would have allowed for an initial optimization of the process parameters (Phase I) for relatively "novel" coating techniques (e.g. plasma source ion implantation) not fully ready for marine environment service. This would be achieved by screening basic, yet critical, coating characteristics (e.g. adhesion and lubricity) on test samples. A more in-depth mechanical and corrosion testing of only the best performing technologies (Phase II) was to follow. Although we still refer to Phase I and Phase II testing, the breadth of the original intent (to have a primary test screening of materials) has been lost, as an overlap of phases and redundancy of test specimens was required in order to complete the program in the given duration. Other challenges were overcome by the decision to continue certain aspects of the program, including shipboard and atmospheric exposures, with non-SERDP funds during the upcoming year. Results from follow through testing obviously can not be reported at this time.

The following sections have been compiled from individual reports submitted by key program personnel. The report format resembles the methodology established for the program. As the first step, database searches were performed to identify as much of the Navy equipment containing cadmium plating as was practical. Specific plated parts, parent equipment, and their location aboard ship were determined whenever possible. Concurrent to all stages was the coordination of our efforts (step two) with those of other services and civilian operations who are investigating similar issues including cadmium replacement and surface modification technologies. Step three was to screen potential replacement coatings based upon existing information on environmental hazards or performance limitations. This information was used to devise laboratory and shipboard test plans incorporating any early findings into the design of metal sample configurations and the testing of specific engineering properties desired. Incorporating the results of each of these efforts, a guidance plan was generated to assist Navy managers in efficiently and effectively phasing out the use of cadmium plated parts and to ensure that the program information obtained would not go unutilized.

## SECTION 1: CADMIUM PLATED COMPONENTS USED WITHIN THE U.S. NAVY

### CONTENTS

## SECTION 1: CADMIUM PLATED COMPONENTS USED WITHIN THE U.S. NAVY

## DATABASE FINDINGS

### BACKGROUND

Cadmium use has been regulated by the Occupational Safety and Health Administration (OSHA) since 14 December 1992 (Federal Register, Title 29 CFR, Part 1910.1027). As a result of this regulation, permissible exposure limits (PELs) were reduced twenty-fold in arriving at the current PEL of 5 micrograms of cadmium per cubic meter of air ($5 \mu g/m^3$) for all cadmium compounds, dust, and fumes. According to this standard, it is the employers responsibility to ensure that "no employee is exposed to excessive airborne concentrations of cadmium".

Cadmium is also recognized within the Department of Defense (DoD) 'Listings of Toxic Chemicals, Hazardous Substances, and Ozone-Depleting Chemicals' (Defense Standardization Program, SD-14). Exposure to this chemical poses a threat to military personnel, especially in confined shipboard spaces or while performing localized surface touch-ups in the vicinity of plated hardware. For these reasons, the Naval Sea Systems Command is investigating potential alternatives to cadmium for implementation within the U.S. Navy. The database search comprises one of several means by which the Navy is addressing this adversary to the health of both military personnel and equipment suppliers.

### OBJECTIVES

1) Determine how widespread the use of cadmium plating is on equipment within the Fleet.

2) Identify the specific shipboard equipment *components* containing cadmium plating, and use this information to determine the material and/or coating properties required for substitute parts.

3) Use the gathered information to notify the appropriate organizations of potentially hazardous equipment within their cognizance and assist them in taking the necessary precautions; facilitate changeover to alternate materials; and supply Life Cycle Managers with the necessary information to modify appropriate documentation, especially that which is currently under revision for other reasons.

### APPROACH

A crucial prerequisite to the elimination of any hazardous material from use is the identification of alternate materials to be used in its place. Cadmium plating usage is extremely widespread within the U.S. Navy. Therefore, acquiring insight into the coating's most critical engineering functions would ease the task of identifying alternate materials (both plating and substrate) able to withstand the inclement environmental conditions experienced aboard ship. Database searches were performed to identify as much of the Navy equipment containing cadmium plating as was practical. Specific plated parts, parent equipment, and their shipboard location were determined whenever possible. Laboratory and shipboard test plans incorporated any early findings into the design of metal sample configurations and the testing methodology for specific engineering properties desired.

The general approach to identifying the scope of the cadmium usage problem included placing a series of inquiries with numerous Department of Defense organizations. The first of these was made within the Naval Sea Systems Command. On 30 September 1994, a NAVSEA memo (Ser 03M/063) was distributed to fourteen Code SEA 03 Life Cycle Managers (LCMs) requesting that all equipment within their cognizance be reviewed for items potentially utilizing cadmium plating. A summary of additional organizations contacted is provided below. (See Appendix A for further details.)

- NAVSEA 03 LCMs
- NAVSEA 03R42 - Military Specs Group
- NAVSEA 03K Reservist
- NAVSUP - Hazardous Materials Operations Branch
- NSWC Crane Division, Louisville, KY - Corrosion Control Group
- NSWCCD Annapolis, MD - Environmental Quality Department
- NSWCCD (SSES) Philadelphia - Habitability
- DCSC - Logistics Management Group
- DGSC - Hazardous Materials Group
- DLSC Battle Creek, MI - Tailored Data Product Services
- SPCC Mechanicsburg, PA - Provisioning & Data Maintenance

Some of the difficulties encountered during our efforts to obtain a comprehensive listing of hardware protected from corrosion by cadmium plating included:

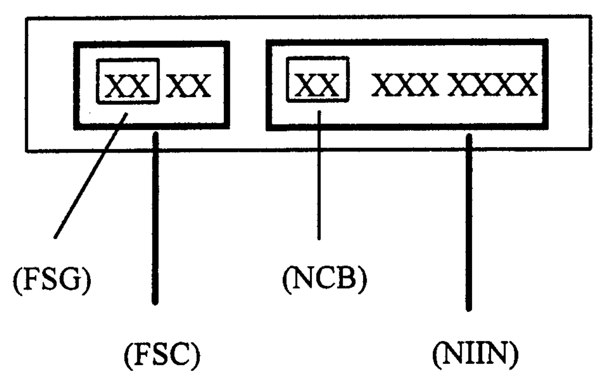
- The vast amount of data to sort requires a powerful computer with large memory (data storage capacity).
- Information is spread out among many databases which are not compatible. Therefore, one database can not give us every existing NSN for cadmium plated parts.
- A minimum of two databases (with multiple caretakers) must be linked. This necessitates an interactive search.
- Logistics and data maintenance personnel tend to have niched expertise, with minimal programming knowledge and computer fluency. There is a lack of familiarity with the methods by which one would access the part information requested. The optimum search would be performed by a computer programmer with both logistics training and adequate resources.
- Milspecs may not directly require or prohibit the use of cadmium plating as a critical component necessary to meet performance. There may be several plating options for a given material. Unless one were to contact each manufacturer directly to inquire about a specific piece of equipment, it may not be readily apparent that cadmium is contained therein.
- Cadmium *plating* is not encoded as a hazardous material within the Hazardous Materials Information System (HMIS) which is linked with Material Safety Data Sheets (MSDSs).

• Many of the databases available can not be queried via a simple key word search (e.g. 'cadmium' or 'plating').
• Because of the widespread use of cadmium on a variety of components, and the crucial nature of hardware to most systems, cadmium could not be singled out by investigating only one Federal Supply Grouping (e.g. bearings, valves, or piping).
• Databases which track defense supply systems typically include items for all services within the Department of Defense, rather than being Navy-specific. Likewise, non-Navy inventory managers monitor most items used by the Navy.

## OVERVIEW OF U. S. NAVY MATERIAL IDENTIFICATION

An overview of material identification is provided[1] since a basic understanding of part descriptors is essential to interpreting our findings and identifying additional methods by which the data may be utilized and the proper personnel notified. Each manufacturer assigns an alphanumeric *part number* designation, not to exceed 26 characters, to each product. As several manufacturers may use similar nomenclature, the part number alone does not uniquely identify a part. To remedy this, a five digit number called the Federal Supply Code for Manufacturers (FSCM) is assigned to individual suppliers, manufacturers, and corporations and is published on microfiche by Defense Logistics Services Center (DLSC). This five digit prefix differentiates between part numbers which may be identical. The Ships Parts Control Center (SPCC) maintains the ability to cross reference part numbers to the most recent National Stock Numbers (NSNs) via the Master Cross Reference List (MRCL) computer file. The National Stock Number (NSN) is a 13 digit number used to uniquely identify supply system items. DLSC is responsible for assigning NSNs. The breakdown of the stock number and significance of its components are as follows:

**13-DIGIT NATIONAL STOCK NUMBER**




The two-digit Federal Supply Group (FSG) number designates a major class of "commodities". The last two digits of the Federal Supply Classification (FSC) refer to a subgroup of the FSG commodity classification. The two-digit National Codification Bureau Code (NCB) refers to the country within the North Atlantic Treaty Organization (NATO) which established the item cataloging, and serves as the preface to the nine digit National Item Identification Number (NIIN). NCB codes of 00 and 01 are assigned to the United States.

---

[1] Information on material identification logistics and the FSG category nomenclature of Table 1 was obtained from the NAVSEA Supply Support Handbook for Acquisition Managers. Supply System Overview Section .

## RESULTS

### NAVSEA Life Cycle Manager Inquiry

Approximately 43 military specification numbers, 7 part names (or manufacturers), and 27 drawings which potentially still contain reference to the use of cadmium plating were identified via the inquiry placed with NAVSEA LCMs. Several groups maintained that elimination of cadmium had already taken place within their codes in response to earlier directives received. This factor in combination with some of the difficulties outlined above help to account for the relatively low number of positive responses received. See Appendix B for a listing of items identified by the LCMs as using cadmium plating. The results of this survey were insufficient in scope to definitively identify the major categories of cadmium components used within the U.S. Navy.

#### *Galley & Other Habitability Items*

Ingestion and inhalation are the primary means by which cadmium compounds may threaten human health. Therefore, elimination of cadmium plating within the galley of a ship should target one of the largest sources for potential food contamination. As Life Cycle Managers for NAVSEA 03H, the Naval Surface Warfare Center in Philadelphia, PA (NSWC-SSES Code 9724) completed a review of roughly 500 pieces of food service equipment and more than 175 drawings of office and berthing/stateroom furnishings. This included investigations into military specifications (Milspecs) and equipment manufacturers. Not included in this review by NSWC-SSES were the following: joiner bulkheads, medical/dental equipment, messing furniture, sanitary spaces and fixtures, service spaces (barber shop and ships store), sheathing systems, storerooms, and stowages. A nearly negligible number of food service equipments were identified as still utilizing cadmium plated parts. The parts identified were primarily hardware items including screws, bolts, latches, and brackets. The military/federal specifications used for the procurement of laundry and dry cleaning equipments were previously updated to prohibit the use of cadmium plated parts. Office and berthing furnishings are addressed in MIL-F-243E and MIL-F-902J in the paragraphs noted in Section 2 of Appendix C. Appendix C - Section 3 lists sixty-one drawing numbers which contain references to cadmium plated hardware in office furnishings. Thirty-one drawings for berthing and stateroom furnishings were identified as containing references to cadmium components. Note that all of these drawings were issued between 1942 and 1984. The drawing revision process is both time consuming and costly. Drawings are typically modified only when major changes have been necessitated. A move is currently underway to consolidate Navy drawings by making them multifunctional. One drawing would serve as the guideline for designing similar furnishings, perhaps of slightly different dimensions (e.g., a flip top writing desk and a drawing table). Through our contacts we learned that some drafting groups are aware that cadmium hardware can no longer be incorporated into Navy drawings.

### National Stock Numbers Via Federal Logistics Information System

Defense Logistics Services Center (DLSC) houses the main database for all the stock numbers in the system. The Federal Logistics Information System (FLIS) database allows key word searches for item names, but not for descriptive characteristics (extraneous text). Resident within FLIS are several smaller databases including FEDLOG, Master Cross Reference Lists (MRCLs), and cage information. DLSC's Tailored Data Products group provided us with a computer disk containing a file of 3,105 National Stock Number (NSNs) and respective names which identify cadmium plated Navy items. Since the stock numbers and item names alone would prove difficult to use in addressing engineering considerations aboard ship, further data manipulation was required.

**Ship Equipment Identification Via Weapon Systems File**

Ships Parts Control Center (SPCC) Code 0424 took DLSC's search several steps further by utilizing the Weapon Systems File (WSF), based in Mechanicsburg, PA. The advantage of the WSF database is that its contents are Navy specific. The file provides a breakdown of every ship in the Navy's inventory and is continuously updated as new information is received from both ashore and afloat activities. WSF has the capability of identifying "each part, component, equipment, system or sub-system to its next higher or lower application". SPCC identified the specific equipment to which the cadmium plated parts belong, and then sorted the data by its parent equipment. Additionally, SPCC provided us with a listing of all ships on which each cadmium part is known to be located. Due to the extreme size of the file in its entirety (~3500 pages in length, requiring 45 minutes to load), the data has not been included in this report. An abbreviated version of the end-product resulting from the combined efforts of DLSC and SPCC can be found in Appendix D. Table 1 enumerates the Federal Supply Groups (FSGs) to which each cadmium plated part identified belongs. As shown, one third of the stock numbers fall into the category of hardware and abrasives. Roughly one fifth of the numbers referred to electrical and electronic components. (Although, our laboratory tests do not address aluminum substrates, such as those used for electrical connectors.) A lesser amount of cadmium plated parts could be categorized as part of mechanical power transmission equipment, lighting fixtures and lamps, and engine accessories.

**Combat Systems Components**

The Naval Surface Warfare Center Louisville provided a detailed list of several thousand cadmium plated weapon system components overhauled at the Naval Ordnance Station. Sample pages from this listing may be found in Appendix E. A large portion of this work entailed the use of manual data retrieval. Resources used include bills of material, production process reports, technical manuals, ordnance drawings, military specifications, military standards, industrial specifications, aperture cards, and communications with the in-service engineering agencies. We were provided with listings of base materials, substitute coatings already listed within specifications (for the Mk75 gun mount), next higher assemblies, and the exposure regime on the ship (topside, engineering space, protected, and unprotected). Both carbon steel and aluminum substrate materials were identified as possessing cadmium plating. Results of this effort comply well with those from other database searches. The two largest groups of items identified as containing cadmium plating were general hardware and electrical connectors. Within four of the major active systems, over one thousand different connectors were identified to be cadmium plated. Although extremely tedious to perform, this search will prove highly beneficial to the Naval Ordnance Station as soon as alternate coatings and base materials have been identified through the laboratory and shipboard testing. In-service engineering agents can be notified readily of the specific parts that they are responsible for eliminating during weapon system overhauls.

**Department Of Defense Information Standardization Service**

Results of a search of the Department of Defense Information Standardization Service (DODISS) database (Appendix F) were provided to us by the NAVSEA 03K reservist. The DODISS system contains the text for military specifications and standards, as well as status information for these documents. One should note that these results include listings of items containing cadmium compounds (e.g. batteries), in addition to plated parts. Yet, a separate search of DODISS using two delimiters, cadmium and plating, yielded a list of roughly only one or two dozen documents. Specificity of nomenclature may yield too few matches. Therefore, it can be seen that a search for cadmium plated items can prove to be misleading since other modifiers may be used in place of the word 'plating'. The positive revelation of this search was that the specifications for many cadmium plated hardware items (e.g. specific bolts) have already been cancelled or revised.

## CONCLUSIONS/RECOMMENDATIONS

Two of the major objectives established for the database investigations have been accomplished. These studies have revealed that cadmium plating is still widely used within the U.S. Navy (meeting objective #1). Hardware, electrical equipment, and electronics components account for over 50% of these cadmium plated parts (meeting objective #2). Although, it should be noted that this study is not all-inclusive. The difficulties encountered in searching for cadmium use illustrate the limitations of this report.

The third objective pertains to the distribution and use of the information gathered. This will be accomplished in the upcoming months. Research performed in support of this program has shown that there is neither a concerted nor coordinated effort to eliminate the use of cadmium plated parts in the USN. Through the distribution of a guidance document to all critical USN support personnel, we plan to assist the Fleet in eliminating specific parts usage and substituting non-hazardous materials which meet or exceed the engineering requirements into these applications. This guidance will restate the requirements of Title 29 CFR and DoD SD-14 concerning reduction and/or elimination of cadmium. An effort will also be directed to identifying the existing document, used by drafters, which prohibits the design or manufacture of cadmium plated components.

**TABLE 1**: Select FSG numeric designators (ranked in order of the frequency of matches to a cadmium plating query) are listed below with their titles:

| FSG# - (Matches) | | % of Total | FSG Title |
|---|---|---|---|
| 53 - | (301) | 33.0% | Hardware and abrasives |
| 59 - | (161) | 17.7% | Electrical and electronic equipment and components |
| 30 - | (105) | 11.5% | Mechanical power transmission equipment |
| 62 - | (50) | 5.5% | Lighting fixtures and lamps |
| 29 - | (43) | 4.7% | Engine accessories |
| 25 - | (34) | 3.7% | Vehicular equipment components |
| 28 - | (25) | 2.7% | Engines, turbines, and components |
| 48 - | (24) | 2.6% | Valves |
| 43 - | (16) | 1.8% | Pumps and compressors |
| 47 - | (16) | 1.8% | Pipe, tubing, hose, and fittings |
| 66 - | (15) | 1.6% | Instruments and laboratory equipment |
| 61 - | (13) | 1.4% | Electric wire, and power distribution equipment |
| 58 - | (12) | 1.3% | Communication equipment |
| 31 - | (11) | 1.2% | Bearings |
| 20 - | (10) | 1.1% | Ship and marine equipment |
| 13 - | (9) | 1.0% | Ammunition and explosives |
| 49 - | (9) | 1.0% | Maintenance and repair shop equipment |
| 41 - | (7) | 0.8% | Refrigeration and air conditioning equipment |
| 44 - | (7) | 0.8% | Furnace, steam plant, and drying equipment; and nuclear reactors |
| 14 - | (5) | 0.5% | Guided missiles |
| 45 - | (5) | 0.5% | Plumbing, heating, and sanitation equipment |
| 63 - | (5) | 0.5% | Alarm and signal systems |
| 35 - | (3) | 0.3% | Service and trade equipment |
| 39 - | (3) | 0.3% | Materials handling equipment |
| 42 - | (3) | 0.3% | Fire fighting, rescue, and safety equipment |
| 10 - | (2) | 0.2% | Weapons |
| 16 - | (2) | 0.2% | Aircraft components and accessories |
| 36 - | (2) | 0.2% | Special industry machinery |
| 38 - | (2) | 0.2% | Construction, mining, excavating, and highway maintenance equipment |
| 40 - | (2) | 0.2% | Rope, cable, chain, and fittings |
| 51 - | (2) | 0.2% | Hand tools |
| 54 - | (1) | 0.1% | Prefabricated structures and scaffolding |
| 12 - | (1) | 0.1% | Fire control equipment |
| 34 - | (1) | 0.1% | Metalworking machinery |
| 70 - | (1) | 0.1% | (Unassigned at time of reference publication) |
| 71 - | (1) | 0.1% | Furniture |
| 79 - | (1) | 0.1% | Cleaning equipment and supplies |
| 80 - | (1) | 0.1% | Brushes, paints, sealers, and adhesives |

# APPENDIX A

# POINTS OF CONTACT

## PRIMARY POINTS OF CONTACT FOR THE DATABASE SEARCHES

| ORGANIZATION | LOCATION | NAME | PHONE |
|---|---|---|---|
| NAVSEA: | Arlington, VA | | 703-602- |
| PMS 400 | | CDR Wm. Landay | -7090 x246 |
| 03E22 | | Bruce Jackson | -7440 x390 |
| 03H | | Edward Meere | -1400 x103 |
| | | Stephen K. Chun | -9297 |
| 03K | | Larry McMurray | -9121 x203 |
| | | CDR Rick Rogers (Reservist) | (N/A) |
| | | Rick Kahn | -7191 x338 |
| | | S. Kuniyoshi | -7191 x313 |
| 03M1 | | Beau Brinckerhoff | -0214 x113 |
| 03R | | Joe Stegall | -9343 x402 |
| 03V | | Tien M. Ngo | -8144 x313 |
| 03W | | Paul Crabb | -1895 x110 |
| | | W. C. Strohmann | -1895 x113 |
| | | Kenneth Brayton | -5272 x400 |
| 03X44 | | Robert Coblenz | -6757 x176 |
| 07E | | Thomas Grossman | -4266 |
| NAVSUP | Arlington, VA | CDR Steve Olson | 703-607-0902 |
| NSWC Crane Division | Louisville, KY | Don Hileman | 502-364-5231 |
| NSWCCD | Annapolis | Linda Aberts | 410-293-2652 |
| | | Donna Smith | " |
| NSWCCD (SSES) | Philadelphia, PA | Cy Beeman | 215-897-7309 |
| DCSC | | Mike Robeano | 614-692-4839 |
| | | Mark Deem | 614-692-4689 |
| DLSC | Battle Creek, MI | Lyle Stokes | 616-961-4415 |
| | | Debbie Hock | 616-961-7424 |
| SPCC | Mechanicsburg, PA | Don Schumann (Rtd.) | 717-790-3912 |
| | | George Essip | 717-790-7808 |

# APPENDIX B

# NAVSEA LIFE CYCLE MANAGER SURVEY RESULTS

**CADMIUM PLATED PARTS**
Identified throught the LCM survey
Oct/Nov 1994

PMS 4005F: CDR W. Landay

Ingalls uses Thomas & Betts DURAPLATE (Cd-coated steel) *conduit fittings* with ANAMET Shieldtite flexible conduit.

03E (& 03J): Bruce Jackson (1990) from 1596 specs addressing cadmium use, which were identified by 03R4.

1) MIL-E-917 was to be modified to prohibit cadmium, as the following mil-specs contained a reference to that document.

| | |
|---|---|
| MIL-C-2212 | CONTACTORS & CONTROLLERS, ELE |
| MIL-D-24304 | DIFFTIAL PRESS. TRANSDUCER EQUIPT. |
| MIL-P-24212 | PRESSURE TRANSDUCER EQUIP ELECT |
| MIL-P-15736 | POWER SUPPLY, CATHODIC PROTECTION |
| MIL-P-15736/1 | " , METALLIC RECTIFIER |
| MIL-P-15736/5 | " , METALLIC RECTIFIER |
| MIL-P-15736/6 | " , GUIDED MISSILE & |
| MIL-P-15737/7 | POWER SUPPLY, METALLIC RECTIFIER |
| MIL-P-15L76/8 | " , CATHODIC PROTECTION |
| MIL-P-15736/9 | " , " |
| MIL-M-23167 | METERS |
| MIL-C-17361 | CIRCUIT BREAKERS, AIR ELECTRIC, INSULATED |
| MIL-C-17587 | CIRCUIT BREAKERS, ELECTRIC, AIR |
| MIL-C-17588 | CIRCUIT BREAKER AUTOMATIC |
| MIL-T-17221 | TRANSFORMERS, POSER, DIST. SINGLE PHASE |
| MIL-W-19088 | WATTMETER, SWITCHBOARD |
| MIL-S-16104 | SYNCHROSCOPE |
| MIL-B-16392 | BRAKES, MAGNET |

03E22: Bruce Jackson (1991-1992) 56 SEA 03 specs identified by SEA 08 as *primary concerns*.

A. "Until the revision of MIL-E-917 goes into effect, cadmium will not be prohibited in 32 of the specifications *on the NAVSEA 08 list*."
(N.B. We have this 1991 list. Proposed revision was 22 Nov 91.)

B. In the same 1991-92 survey, the following parts required cadmium or did not prohibit Cd & were identified as needing revision (yet no plan to do so was mentioned):

MS 17831 Bus Disconnect (says spec is not used; Mare Island DWG used since mid 70's)

MIL-M-16125 Meters

03H32: Stephen K. Chun

"They do not specify the use of any Cd in their hardware. Although they have not precluded the use of Cd in the Shipbuilding Specifications, they are not aware of any use of Cd in the items that they are responsible for."

03K21: Larry McMurry

Negative response.

03M1:

Negative response. No cadmium specified.

03V13: Tien M. Ngo

Plug-In Relay Socket uses gold diffused silver cadmium oxide as a *contact material*.

Mfr.= MSD, Inc., Darlington, S.C. Part = #219ABAP

03W13: WC Strohmann

Cd plate is used extensively on the weapons handling dolly and, on certain classes of submarines, on the dolly lashing strap.

*Weapons Handling Dollies*: SSN 637 Class, SSN 688 Class, and SSBN 726 Class

*Dolly lashing strap, saddle, link, and adapter*: SSN 637 Class

03W4: Kenneth Brayton

All of their specs prohibit cadmium plating, but they did find cadmium plated parts on 3 equipments:

STD DWG 2255405 Accom Ladder, Boat Fender PC 121 - Cd plated *fasteners*. Drawing is being changed.

DWG 805-4629248 Door Metal Joiner, Honeycomb Core - *Hinge Screws*. NSWC (SSES) has been tasked to redesign hinge.

STD DWG 803-2700.151 Elevator Undercar Linkage - *Cd clevis*. Change to CRES would be cost prohibitive ($600 for CRES versus $34 for Cd).

03X44: Robert Coblenz

MIL-G-17859 Propulsion Gears - Prohibits Cd on parts exposed to oil.

MIL-C-23233 Couplings - Blanket prohibition on Cd
MIL-C-18087 Clutches - Blanket prohibition

SSBN726 CLASS WT HATCH AND DOOR COATINGS 1/13/94

LET UPPER HATCH

| ITEM | MATERIAL | PRESENT COATING | NEW COATING |
|---|---|---|---|
| Handwheel | STL (MIL-T-20157) | Zinc | EPC |
| Operating Shaft | NICU (QQ-N-281) | Teflon | none |
| Shackle | STL | Plastisol | EPC |

BRIDGE UPPER HATCH

| ITEM | MATERIAL | PRESENT COATING | NEW COATING |
|---|---|---|---|
| Upper handwheel | STL (MIL-S-22689) | Galv./paint | EPC |
| Lower handwheel | STL (MIL-T-20157) | Chrome | EPC |
| Latch handle | STL (MIL-S-15083) | Chrome | EPC |
| Latch | STL (MIL-S-15083) | Chrome | EPC |
| Latch Shaft | NICUAL (QQ-N-286) | Teflon | none |

LET LOWER HATCH

| ITEM | MATERIAL | PRESENT COATING | NEW COATING |
|---|---|---|---|
| Upper handwheel | BRZ (QQ-C-390) | Chrome | none |
| Lower handwheel | BRZ (QQ-C-390) | Chrome | none |
| Speed handle | BRS (QQ-B-637) | Chrome | none |
| Speed spindle | BRS (QQ-B-637) | Chrome | none |
| Speed nut | BRS (QQ-B-637) | Chrome | none |
| Dog clevis | STL (MIL-S-15083) | Chrome | EPC |
| Dog fork | STL (MIL-S-15083) | Chrome | EPC |
| Latch spring | STL (QQ-W-470) | Cadmium | Cadmium |
| Interlock spring | STL (QQ-W-470) | Cadmium | Cadmium |

BRIDGE LOWER HATCH

| ITEM | MATERIAL | PRESENT COATING | NEW COATING |
|---|---|---|---|
| Upper handwheel | BRZ (QQ-C-390) | Chrome | none |
| Lower handwheel | BRZ (QQ-C-390) | Chrome | none |
| Speed handle | BRS (QQ-B-637) | Chrome | none |
| Speed spindle | BRS (QQ-B-637) | Chrome | none |
| Dog clevis | STL (MIL-S-15083) | Chrome | EPC |
| Dog fork | STL (MIL-S-15083) | Chrome | EPC |
| Latch spring | STL (QQ-W-470) | Cadmium | Cadmium |
| Interlock spring | STL (QQ-W-470) | Cadmium | Cadmium |

EPC - epoxy powder coating
none - no coating required

## SSN688 CLASS WT HATCH AND DOOR COATINGS

### BRIDGE UPPER HATCH

| ITEM | MATERIAL | PRESENT COATING | NEW COATING |
|---|---|---|---|
| Latch | STL GR B (MIL-S-15083) | Chrome | EPC |
| Lower Handle | STL GR B (MIL-S-15083) | Chrome | EPC |
| Upper Handwl | STL (MIL-S-20166 or 22698) | Galvanized | EPC |
| Lower Handwl | MN BRZ TYI (QQ-C-390 ALY C3) | Chrome | none |
| Speed Handle | Brass (QQ-B-637 half hard) | Chrome | none |
| Speed Spindle | Brass (QQ-B-637 half hard) | Chrome | none |
| Speed Nut | Brass (QQ-B-637 half hard) | Chrome | none |

### BRIDGE LOWER HATCH

| ITEM | MATERIAL | PRESENT COATING | NEW COATING |
|---|---|---|---|
| Upper Handwl | MN BRZ TYI (QQ-C-390 ALY C3) | Chrome | none |
| Lower Handwl | MN BRZ TYI (QQ-C-390 ALY C3) | Chrome | none |
| Speed Handle | Brass (QQ-B-637 half hard) | Chrome | none |
| Speed Spindle | Brass (QQ-B-637 half hard) | Chrome | none |
| Speed Nut | Brass (QQ-B-637 half hard) | Chrome | none |
| Forks | STL GR B (MIL-S-15083) | Chrome | EPC |
| Clevises | STL GD C (MIL-S-22698) | Chrome | EPC |
| Latch spring | STL (QQ-W-470) | Cadmium | Cadmium |
| Interlk spring | STL (QQ-W-470) | Cadmium | Cadmium |

### ESCAPE TRUNK UPPER HATCH

| ITEM | MATERIAL | PRESENT COATING | NEW COATING |
|---|---|---|---|
| Handwheel | STL TYP E (MIL-T-20157 CD) | Zinc | EPC |
| Shackle | STL | Plastisol | EPC |

### ESCAPE TRUNK LOWER HATCH

| ITEM | MATERIAL | PRESENT COATING | NEW COATING |
|---|---|---|---|
| Upper Handwl | MN BRZ TYI (QQ-C-390 ALY C3) | Chrome | none |
| Lower Handwl | MN BRZ TYI (QQ-C-390 ALY C3) | Chrome | none |
| Speed Handle | Brass (QQ-B-637 half hard) | Chrome | none |
| Speed Spindle | Brass (QQ-B-637 half hard) | Chrome | none |
| Speed Nut | Brass (QQ-B-637 half hard) | Chrome | none |
| Forks | STL GR B (MIL-S-15083) | Chrome | EPC |
| Clevises | STL GD C (MIL-S-22698) | Chrome | EPC |
| Latch spring | STL (QQ-W-470) | Cadmium | Cadmium |
| Interlk spring | STL (QQ-W-470) | Cadmium | Cadmium |

### WT DOOR

| ITEM | MATERIAL | PRESENT COATING | NEW COATING |
|---|---|---|---|
| Handles | STL GD B (MIL-S-15083) | Chrome | EPC |

EPC - epoxy powder coating
none - no coating required

UNREP (SEA [illegible]W24) EQUIPMENT WHERE CADMIUM COATED PARTS ARE SPECIFIED - 10/12/94

| DRAWING | TITLE |
|---|---|
| 2555038 | LITTER, PROTECTIVE FRAME & FLOATATION GEAR FOR TRANSFER AT SEA |
| 2580100 | MK II CARGO DROP REEL 5700 LB CAPACITY, TOP DRAWING |
| 2580249 | STAR (SURF TRAVELING - ACTUATED REMOTELY) TOP DRAWING |
| 2580257 | TRAVELING SURF, STREAM (TYPE II) |
| 4472625 | STATION MARKERS, DAY |
| 4629270 | STAR LATCH ASSEMBLY |
| 4648129 | OUTHAUL AIR CLUTCH ASD |
| 4667020 | AIR-CLUTCH ANTI-SLACK DEVICE AIR MODULE ASSEMBLY |
| 4684657 | HIGHLINE/SPANWIRE AIR-CLUTCH ANTI-SLACK DEVICE TOP DRAWING |
| 4760101 | HYDRAULIC HIGHLINE/SPANWIRE 1" ANTI-SLACK DEVICE TOP DRAWING |
| 4847450 | THREE-SPEED/TWO-SPEED SADDLE WINCH TOP DRAWING |
| 5020317 | TRANSMISSION, NAVY STANDARD |
| 5177023 | STRONGBACK, CARGO STREAM HEAVY LIFT MK 5 MOD 1 |
| 5184095 | STREAM UNREP TROLLEY |
| 5210069 | HYDRAULIC BRAKE ASSEMBLY |
| 5210113 | WINCH ASSEMBLY, SINGLE DRUM |
| 5210114 | WINCH ASSEMBLY, DOUBLE DRUM |
| 5210115 | WINCH ASSEMBLY, HAULING |
| 5363358 | SLIDING BLOCK ASSEMBLY |
| 6352180 | NAVY STANDARD GYPSY WINCH |
| 6574401 | NAVY STANDARD SLIDING BLOCK DRIVE W/SLIP CLUTCH |
| 6574461 | RAM ASSY - NS RAM TENSIONER |
| 6695866 | UNREP CARGO KINGPOST ASSY - NS KINGPOST |
| 6695867 | UNREP FUEL KINGPOST ASSY - NS KINGPOST |

# APPENDIX C

## GALLEY & HABITABILITY ITEMS IDENTIFIED BY NSWCCD (SSES)

FOOD SERVICE EQUIPMENT UTILIZING CADMIUM PLATING

| MANUFACTURER[1] | EQUIPMENT | CADMIUM PARTS |
|---|---|---|
| Alloy Metal Products | reefers/freezers/thaw boxes | 5% of screws/bolts[2] |
| Cecilware Corp. | coffee/hot chocolate ice tea machines | external screws[3] |
| Frymaster Corp. | deep fat fryers | external screws/bolts[4] |
| Hollymatic Corp. | meat/fish molding machine | bolts/motor frame/ sub-base |
| Precision Metal Products | cold food counters | latches/shelf supports |

[1]All cadmium parts listed are not in the food zone or heat zone as required by National Sanitation Standards (NSF).

[2]Very willing to change to Stainless steel screws and bolts.

[3]Will be changing over to either zinc or stainless steel screws.

[4]Can provide all screws/bolts in stainless steel but cost of unit will be affected.

FURNITURE LIST OF SPECIFICATIONS LISTING CADMIUM

| SPEC NUMBER | TITLE | PARAGRAPH |
|---|---|---|
| MIL-F-243E (SHIPS) A2<br>15 JAN 1974 | FURNITURE, SHIPBOARD, STEEL | 2.1, 3.2.3.3,<br>3.2.3.3.1,<br>3.2.5.1, 3.2.7,<br>4.2.4 |
| MIL-F-902J SHIPS) A1<br>15 JAN 1974 | FURNITURE, SHIPBOARD, ALUM | 2.1, 3.2.3.3,<br>3.2.2.2.1,<br>3.2.5.1, 3.2.7,<br>4.2.4 |

OFFICE FURNISHINGS

LIST OF DOCUMENTS WHICH LIST CADMIUM PLATING 19 JAN 1995

OFFICE DRAWINGS

| DWG NUMBER | YEAR | DRAWING TITLE | CADMIUM | NSN | PART NAME | PC NUMBER |
|---|---|---|---|---|---|---|
| 0631136 | | DESK, FLAT TOP | YES | | BINDER | 2 |
| 0632481 | 1964 | CABINET, PLAN, TYPE A-E | YES | | NUT | 12 |
| | | | | | MACHINE SCREW | 11 |
| | | | | | MACHINE SCREW | 8 |
| | | | | | NUT | 9 |
| 0633490 | 1945 | BOOKCASE, 48-IN | YES | 2590-00-269-1239 | MACHINE SCREW | 5 |
| 0638434 | 1946 | TABLE, WRITING 21X32 | YES | 2090-00-369-4572 | MACHINE SCREW | 18 |
| | | | | | NUT | 19 |
| | | | | | LOCKWASHER | 20 |
| | | | | | RIVET | 22,23 |
| 0860055 | 1964 | HARDWARE FOR METAL FURN | YES | | VARIOUS | NOTE 4 (ALL STEEL) |
| 0860056 | 1960 | LATCH, DRAWER FOR METAL FURN | YES | | STEEL | 3,4,10,12,13,14,15,21 |
| 0860177 | 1942 | CABINET & LOCKER TYPES A & B | YES | | SLIDING LATCH | 23 |
| | | | | | FIXED LATCH | 24 |
| 0860188 | 1937 | DESK, TYPEWRITER,S-PED | YES | | STOP | 9 |
| 0921770 | 1963 | CLIPS & SUB-BASES, METAL | YES | | HARDWARE | 2,3,6,8,13 |
| 0921997 | 1958 | DESK, FLAT TOP | YES | | BOLT | 8 |
| 0964111 | 1950 | BOARD, ABSENTEE, OFCRS | YES | 2090-00-269-1098 | SPRING | 4 |
| | | | | 2090-00-269-1099 | MACHINE SCREW | 5 |
| | | | | 2090-00-269-1100 | NUT | 6 |
| 1627072 | 1957 | CHAIR, FOLDING, TYPE VII | YES | | BRACKET | 12 |
| | | | | | CLIP | 13 |
| | | | | | LINK | 14 |
| 1629902 | 1966 | SAFES, BURGLAR, TYPE 1,2 | YES | 7110-178-1591 | VARIOUS HDWR | 33,34,35,37,40,41,42 |
| | | | | 7110-178-1592 | | |
| 1641663 | 1971 | DESK, TYPEWRITER, SGL PED | YES | | LATCH ARM | 15 |
| | | | | | LATCH PULL | 16 |
| | | | | | RIVET | 30 |
| | | | | | MACHINE SCREW | 31 |
| | | | | | NUT | 32 |
| | | | | | LOCK WASHER | 33 |
| 1642368 | 1962 | FURN, METAL, CONST | YES | | VERMIN PLUG | 13 |
| 1648651 | 1966 | DESK, EXECUTIVE FOR VIP SPACES | YES | | VARIOUS HDWR | 12-17, 19 & 20 |
| 1648654 | 1968 | CREDENZA FOR VIP SPACES | YES | | VARIOUS HDWR | 6-11, 14-16, 19 |
| 1749061 | 1960 | RACK, BOOK, TYPES A,B,C | YES | | MACHINE SCREW | 13 |
| 1749064 | 1960 | SHELVING, LIBRARY | YES | | COMPRESSOR ROD | 11 |
| | | | | | COTTER PIN | 14 & 15 |
| | | | | | BOLT & LOCK NUT | 29 |
| 2224391 | 1969 | DESK, FLAT-TOP, SGL PEDESTAL | YES | | VARIOUS | 24,25,2627,29,30,33 |
| 2254970 | 1972 | CASE, BOOK & LEDGER | YES | | LATCH SPRING | 15 |
| | | | | | TRACK SPRING | 17 |
| 4597951 | 1973 | FURN, SHIPBOARD, COMM | YES | | PARA F/COATINGS | |
| 4597954 | 1973 | SUBBASE ETS, METAL FURN, STEEL | YES | | TOP HASP | 8 |
| | | | | | PAD | 9 |
| | | | | | STUD | 10 |
| | | | | | WING NUT | 11 |

# BERTHING/STATEROOM FURNISHINGS

BERTHING DRAWINGS 30 MAR 1995

| DWG NUMBER | YEAR | DRAWING TITLE | CADMIUM | NSN | PART NAME | PC NUMBER |
|---|---|---|---|---|---|---|
| 0550320 | | COT, FURNITURE, ALUMINUM | YES | | STL PLATE & FASTENER | 11,12,13,18,23,24,25 |
| 0630718 | | LOCKER, CLEANING GEAR, ALUM | YES | | FASTENERS | 18, 19 |
| 0630948 | | TABLE, EXTENSION, ALUMINUM | YES | | PIN & FASTENERS | 7,10,11,12,14 |
| 0631211 | | TABLE, EXTENSION, ALUMINUM | YES | | FASTENERS | 17-20,22,23 |
| 0631889 | | TABLE, EXT, FOR WARDROOM, ALUM | YES | | FASTENERS | 15, 18-22 |
| 0632293 | | TABLE, EXT, FOR WARDROOM, ALUM | YES | | PIN, BRACKET & FASTENRS | 6,15,17,18,23,24,26,2[illegible] |
| 0638173 | | TABLE, COFFEE, ALUMINUM | YES | | PLATE & FASTENERS | 7-10 |
| 0638243 | | TABLE, END, ALUMINUM | YES | | PLATE & FASTENERS | 9, 10, 12 |
| 0866327 | | TABLE, EXTENSION, ALUMINUM | YES | | FASTENERS | 17, 20 |
| 0918374 | | LKR, SEA RACK, ALUMINUM | YES | | FASTENERS, HINGE LINER | 5, 6 |
| 0921757 | 1949 | LKR, TYPE E, F, G, H TYP COMPT | YES | | HEX HD NUT & BOLT | 32, 30 |
| 0921837 | 1952 | TABLE, FOLDING, ALUMINUM | YES | | 1/8 COTTER PIN | 25, 26, 11 |
| | | | | | 90% OF ALL STEEL | |
| 0921921 | | LOCKER, FLIGHT CLOTHES, TYPE H | YES | | FASTENERS & BRACKET | 15, 18, 23 |
| 0962455 | | TABLE, BERTHING AND READING | YES | | FASTENERS | 11,15,16,30,42,43 |
| 1409485 | | BERTH, CREWS W/WO LKR UNDER | YES | | VARIOUS (HARDWARE) | 19, 20, 22-24, 38, 39 |
| 1622993 | | FURN, MOD, UNIT NO 5, LONG WRDRB | YES | | FASTENERS | 25, 26 |
| 1622995 | 1964 | FURN, MOD, UNIT NO 8, SEC BUREAU | YES | | STACKING CLIP | 20 |
| 1623973 | | UNIT, LAVATORY F/CRCKS STRM | YES | | FASTENERS | 14, 23, 25-29 |
| 1625829 | 1966 | FURN, MODULAR, SIDEBOARD & SRV | YES | | STOP,PHMS,WSHLK,NUT | 16-18,30-31 |
| 1626265 | 1958 | LKR, CLOTHS, TYPE A & D, ALUM | YES | | PHMS, WSH LOCK | 18, 19 |
| 1626472 | | LKR, CLOTHES, TYPE B-1, B-2 | YES | | FASTENERS | 18 & 19 |
| 1629985 | | TABLE, CARD | YES | | VARIOUS (HRDWRF,FASTNRS) | 3-8, 14, 15, 17 |
| 1629986 | | MIRRORS, MOUNTED | YES | | FASTENERS | 5, 6, 7 |
| 1629990 | | LKR, CLOTHES, MARINE | YES | | LOCK BAR, RIVET & HANGER | 16, 17, 19 |
| 1630197 | | BERTH, SUBMARINE | YES | | ALL STEEL FASTENERS | (DWG NOTE 11) |
| 1630198 | | BERTH, SUBMARINE | YES | | FASTNRS & MISC HARDWARE | 13, 17, 38 |
| 1630723 | | LKR, CLOTHES, TROOP | YES | | LOCK BAR & FASTENERS | 18, 19 |
| 1631103 | | BERTHS, OFCR, SGL, DBL, SIZE 1 | YES | | FASTENERS | 17, 18 |
| 1634193 | | BERTHS OFCR, SGL, DBL, SIZE 2 | YES | | FASTENERS | 15, 16 |
| 1634397 | | BERTHING, UNIT, CREWS, SGL, DBL | YES | | VARIOUS | 16-20,22-28,30,31,3[illegible] |
| 1634565 | | BENCHES, PADDED WITH STOW | YES | | FASTENER | 13 |

| | | | | | |
|---|---|---|---|---|---|
| 1635533 | | BERTHING UNIT, CPO | YES | VARIOUS | 3,4,12-19,22,23,25,30,33, |
| 1636410 | | FURN, MODULAR 14 | YES | HARDWARE & FASTENERS | 19, 20, 21, 30, 36 |
| 1637199 | | BERTH-TRANSOM, OFCR, WALL BERTH | YES | FASTENERS & PLATE | 12, 20, 21, 22, 42, 50 |
| 1637202 | | BERTH-TRANSOM, OFFICER, DETAILS | YES | FASTENERS | PC NO'S NOT SHOWN |
| 1637203 | | BERTH-TRANSOM, OFCR, WALL, PAN | YES | VARIOUS | PC NO'S NOT SHOWN |
| 1637639 | | FURN, MODULAR, UNIT 15, SEC/DWR | YES | HARDWARE & FASTENERS | 19,20,21,30,36 |
| 1637670 | 1965 | FURN, MODULAR, UNIT 16, LKR | YES | SUB-BASE,NUT | 20, 21 |
| 1640910 | 1964 | DOORS, LKR, & FR, SUBMARINE | YES | MISC LOCKING | 15-23 |
| 1640931 | 1964 | BUREAU, SECRETARY, UNIT 55 | YES | SPRG PIN,SPRG,SCREW | 12, 13, 26 |
| 1641660 | 1964 | LKR, WRB, BUILT-IN DETAILS | YES | NUT (SL-LCKG), MS | 20, 21, 22 |
| 1641662 | 1964 | DRAWER UNITS 56, 7, 8, 9, SUBM | YES | STACKING CLIP | 7 |
| 1645143 | 1964 | BERTH, TRANSOM, CC SUBMARINE | YES | FASTS,HEX NUT,END PAD | 17, 41, 58 |
| 1645299 | | TABLE, WRITING, BHD MNT, SUBM | YES | SCREW | 9 |
| 1646700 | 1964 | WARDROBE, SHORT, HANGING, S1, S2 | YES | LCKG BAR, NUT | 13, 17 |
| 1646701 | 1964 | WARDROBE, LONG, HANGING, S3, S4 | YES | LCKG BAR, NUT | 13, 18 |
| 1648289 | 1964 | LKR, UTILITY, UNITS S10, 11, 12 | YES | LCKG BAR, CTR PIN | 6, 20, 21 |
| 1648661 | 1969 | TABLE, COFFEE, FOR VIP SPACES | YES | SOCKET,NUT,STUD,MS | 5,8,9,10 |
| 1648663 | 1968 | LKR, STOW, CLNG GEAR & BD STATION | YES | PHMS,LWSHR,NUT,RIVET | 14-16 & 20 |
| 1648667 | 1962 | LKR, SOILED CLOTHES (CPO,CRW,MAR) | YES | MS,NUT,PHMS,NUT | 11-14 |
| 1749012 | 1952 | TRANSOM, 72 IN ALUM, DETAILS | YES | MACH BOLT, NUT, MS | 7-9 |
| 1749020 | 1958 | BED, FOR CABIN STATEROOM | YES | MS, BINDER, CRS, HINGE | 8-10,26 |
| 2214455 | 1971 | TABLE, SERVING FOR VIP SPACES | YES | STUD,HEX NUT,BOLT,RHMS | 9-11, 17, 18 |
| 2214460 | 1966 | TABLE, COFFEE, CURVED, 60IN, VIP | YES | SOCKET,HN,STUD,MS | 5,8,9,10 |
| 2214469 | 1966 | PARTITION, BERTH, END, CREW,CPO | YES | PNHM, SELF-LOCK NUT | 8, 9 |
| 2214471 | 1970 | TABLE PORTABLE VIP SPACES | YES | WASHER | 10 |
| 2217400 | 1966 | BENCH W/STOW UNDER FLT DK SHELF | YES | MACHINE SCREW, LOCK WSHR | 10-14 |
| 2217401 | 1969 | TABLE, DINING, RND TOP, VIP | YES | MACHINE BOLT, STUD,NUT | 5, 10, 11 |
| 2217419 | 1969 | TABLE, COFFEE, RND, VIP | YES | MACHINE BOLT, STUD,NUT | 5, 10, 11 |
| 2217422 | 1967 | CHAIR, LOUNGE, VIP SPACES | YES | MACHINE BOLT, NUT | 8-9 |
| 2224385 | 1969 | TRANSOM, VIP SPACES | YES | | |
| 2224397 | 1969 | TABLE, END, CURVED TOP VIP | YES | MSHH,WASHER,MS,WASHER | 8, 9, 10, 11 |
| 2224396 | 1969 | TABLE, END, RECTANGULAR TOP VIP | YES | MSHH,WASHER,MS,WASHER | 8, 9, 10, 11 |
| 2253852 | 1971 | MIRROR, MNT. SHOCK HARDENED | YES | MOUNTING BRACKET | 2 |
| 4597973 | 1974 | TABLE, 2 & 4 MAN, SGL PEDESTAL | YES | MACHINE SCREW | 8 |
| 4623537 | 1984 | MIRROR, FULL LENGTH, BHD MNT | YES | STUD, HNUT, FLAT WSHR | 10-12 |
| 4623539 | 1973 | LKR, CREWS, WARDROBE | YES | SUB BASE | 3 |
| 4629249 | 1994 | TABLE, MESS WARDROOM | YES | HEX NUT, FLAT WASHER | 11-12 |
| 4629250 | 1974 | TABLE, RECREATION, CREW | YES | PLATE, RIVET CSK | 6, 19, 20 |

# APPENDIX D

# DLSC & SPCC COMBINED SEARCH RESULTS

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9G5975001521074 LOCKNUT,ELECTRICAL | AZ4230743 RO-530/UYK,LINE PRINTER,DATA,FFH01 CLASS |
| 9N5950012591614 COVER,COIL | AZ4230752 IP-1449/USQ-69(V),DISPLAY UNIT,DATA TERM,FFH01CL |
| 9Z5365001698018 RING,RETAINING | AZ6040092 MK38MOD0,CARRIAGE,5 INCH FMS ANZAC UNIQUE |
| 9C1005009286534 YOKE LATCH | A002005120 GUN POD MK4 MOD 0 20MM FIRING 12K RDS PER QTR |
| 9Z5360009228038 SPRING,FLAT | A002500400 FEEDER DELINKING FIRING 15K PER QTR |
| 9C4930002001841 COUPLING,GREASE GUN | A005020002 MK16MOD1T8,LAUNCHING SYSTEM SSE |
| 9Z5340010249030 INSERT,SCREW THREAD | A006090003 MK15,PHALANX CIWS I-LEVEL REPAIR |
| 1H1350001071676 LIFTING PLATE | A006100101 MINE HANDLING EQUIPMENT FOR MOMAG DET, AND UNIT, |
| 1H1350008907917 LIFTING PLATE | A006100101 MINE HANDLING EQUIPMENT FOR MOMAG DET, AND UNIT, |
| 9Z5365006631245 RING,RETAINING | A006300300 MK46MOD0,TORPEDO,ACCESSORIES |
| 9G4925008320521 PLUNGER | A006340001 SUBROC WORKSHOP EQUIPMENT |
| 9G4921013829166 TOOL,INSTALLATION A | A006380004 TORPEDO EQUIP. N TOOLS, OFF LINE |
| 9Q7920000187052 BRUSH,BRISTLE | A006380005 CONSUMABLES |
| 9N5935004334439 COVER,ELECTRICAL CO | A006390019 SUPPORT AND TEST EQUIPEMENT, MK50 TORPEDO |
| 9Z5365002819885 RING,RETAINING | A006390023 MK50 TORPEDO, SERVICE SCHOOL COMMAND |
| 9Z5365002526853 RING,RETAINING | A006400225 M16A1,RIFLE,5.56MM NMCB ONLY |
| 9Z5365005140362 RING,RETAINING | B200003006 AFTER CAPSTAN DR CHAIN X SPROCKETS |
| 9Z5365005981474 RING,RETAINING | B380013005 FILTER CASING X DAMPERS |
| 9C4820004734870 PARTS KIT,FLUID VAL | B590033002 PIPE FITTINGS ACNG SYS |
| 9G6350005570290 BUZZER | B650040021 SIGNALING DEVICES-AUDIBLE |
| 9G6350004913591 BELL,ELECTRICAL | B650040029 SIGNALING DEVICES AUDIBLE |
| 1H8140010216421 COVER,BOMB DISPENSE | B780004004 COVERS-BOMB DISPENSER |
| 9G6685003318141 GAGE,PRESSURE,DIAL | B870001507 GAGES PRESS VAC X CMPD |
| 9G5120000910756 WRENCH SPECIL | B910134001 ALRE CENTRAL TOOL CONTROL ROOM, HAND TOOLS |
| 9Q5120005111432 WRENCH,SPUD CLOSET, | B911274002 TOOLS HAND PIPE |
| 9Z5365008142511 RING,RETAINING | C000929040 COMPRESSOR GAS TURBINE REPAIR PARTS |
| 9Z5340012124901 LATCH ASSEMBLY | C200034125 STAR-SURF TRAVELING REMOTELY ACTUATED-DELIVERY |
| 9G5975001881164 PLATE,WALL,ELECTRIC | C620014075 CABLE ASSY DUPLEX OUTLET 25FT |
| 9G6230009687831 BRACKET ASSEMBLY, L | C820004001 BOAT X CRAFT STD EQUIPAGE X SPCL NOTES |
| 9G5120010639385 WRENCH,SPECIAL | C830024044 SPECIAL TOOLS-ARGR/BARRICADE SPARE MK7 MOD2 MOD3 |
| 9C4930007590639 SWIVEL,LUBRICATION | C920013215 LUBRICATION EQUIPAGE-SUBMARINES |
| 9C4710004250460 TUBE ASSEMBLY,METAL | C990000402 DEPLOYED PACK-UP FOR 65FT PATROL BOAT,MK3 |
| 9C2540001237226 ARM,DRIVE | C990000405 UNIT SUPPORT MATERIAL |
| 9C2815002157985 RING,VIBRATION DAMP | C990000405 UNIT SUPPORT MATERIAL |
| 9C2805003531661 CUP,ENGINE | C990000405 UNIT SUPPORT MATERIAL |
| 9C2920008438440 PLATE,TERMINAL,STAR | C990000405 UNIT SUPPORT MATERIAL |
| 9Z5340008721513 BRACKET,MAGNETO | C990000405 UNIT SUPPORT MATERIAL |
| 9N5985002880178 ATTENUATOR,FIXED | H670051773 4689 AEL 90513-20(78591) |
| 9Z5310011543381 NUT | L016140081 PUMP CTFGL 35GPM 8.66PSI 1750RPM MCC VLT |
| 9N5930007852143 BRACKET,ELECTRICAL | L152250024 CONTROLLER AC STATIC 440V 13501205-1 |
| 9Z5365004203856 RING,RETAINING | L572240009 CRANE BR X TRVLG CAP 30000 LBS |
| 9Z3110008698857 BEARING,BALL,ANNULA | L572240010 CRA 60TN MN HST 0-30FPM AUX HST 5TN 0-200FPM |
| 9Z5365004203857 RING,RETAINING | L620420302 WINCH ELECT 1DM GYP MAX CAP 18200LBS FPM LH |
| 9Z5306000975847 BOLT,CONNECT ROD | L665360269 DIESEL ENG. MDL 38ND8 1-8 12 CYL |
| 9Z5365002813634 RING,RETAINING | L694920024 GEAR ASSY SPD DECR AUX 4.10 TO 1 RATIO |
| 9C4820010735941 DOG BUSHING,VALVE | L883117395 VALVE RELF 2.00IPS 76T 90PSI FLGE STL |
| 9Z5365008802666 RING,RETAINING | MA063260 AM-6518/UR LHA, AMPLIFIER,RADIO FREQUENCY |
| 9N5985010108773 LINE,RADIO FREQUENC | MB003698 CY-8277/SRC DDG-993, CABINET |
| 9N5985010108774 LINE,RADIO FREQUENC | MB003698 CY-8277/SRC DDG-993, CABINET |
| 9Z5365006827492 RING,RETAINING | MB046490 T-1045A/SQS-26CX DD963/DDG993, TRANSMITTER,SONAR |
| 9N5930002296616 ADAPTER,SWITCH ACTU | MB072508 RT-246A/VRC DD963, RECEIVER-TRANSMITTER,RADIO |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9N5895011477048 COVER,ELECTRONIC CO | MB072508 RT-246A/VRC DD963, RECEIVER-TRANSMITTER,RADIO |
| 9N5935006700271 STRAP NUT,PLUG-IN E | MB490120 ME-502/U DD993, VOLTMETER |
| 9N5935010561552 CONNECTOR,RECEPTACL | MB568110 PP-7100/SQS-53 DD963/DDG993, POWER SUPPLY |
| 9Z5365002005234 RING,RETAINING | MB766739 CV-3033/SQS-53A DD963/DDG993, CONVERTER,A-SCAN |
| 9Z5365001748695 RING,RETAINING | MB974513 TS-3304/SQS-53 DD963/DDG993, TEST SET,TRMT MOD |
| 9Z5365009982926 RING,RETAINING | MB974513 TS-3304/SQS-53 DD963/DDG993, TEST SET,TRMT MOD |
| 9Z5365001156848 RING,RETAINING | MC798361 QM-2 CG47(92755), CONTROL MONITOR GROUP |
| 9N5930012738025 ARM,SWITCH ACTUATOR | MEJ00068 AM-7159/SPY-1B DDG2313CL, AMPLIFIER,RADIO FREQ |
| 9Z5340006164545 STUD,FRICTION CATCH | ME009055 AN/BSY-1(V) UNIT 1120, CONTROL-INDICATOR |
| 9G6680000735489 COUNTER,ROTATING KN | ME296910 AN/SPG-55B,RADAR SET,GMFCS MK76MOD8 2 RADARS |
| 9N5985010090645 COUPLER,DIRECTIONAL | ME296910 AN/SPG-55B,RADAR SET,GMFCS MK76MOD8 2 RADARS |
| 9N5999010531181 MAGNET | ME296910 AN/SPG-55B,RADAR SET,GMFCS MK76MOD8 2 RADARS |
| 9Z5365002821633 RING,RETAINING | MF039017 R-390A/URR FFG-7 CL, RECEIVER,RADIO |
| 9Z5365002054731 RING,RETAINING | MF137107 AN/UGR-9 FFG-7 CL, TELEPRINTER SET |
| 9Z5360005452785 SPRING,COMPRESSION | MF137107 AN/UGR-9 FFG-7 CL, TELEPRINTER SET |
| 9Z5365005846620 RING,RETAINING | MF138244 AN/UGC-6K FFG-7 CL, PRINTER,TTY PAGE |
| 9Z5305006774895 SCREW,ADJUSTING | MF138244 AN/UGC-6K FFG-7 CL, PRINTER,TTY PAGE |
| 9Z5365009000982 RING,RETAINING | MF138244 AN/UGC-6K FFG-7 CL, PRINTER,TTY PAGE |
| 9Z5365008235088 RING,RETAINING | MF138302 AN/UGC-77 FFG-7 CL, TELETYPEWRITER |
| 9N5895008842465 COVER,ELECTRONIC CO | MF841214 AN/VRC-46 FFG-7 CL, RADIO SET |
| 9N5960008923197 INSERT,ELECTRON TUB | MF841214 AN/VRC-46 FFG-7 CL, RADIO SET |
| 9N5920013811306 FUSEHOLDER,EXTRACTO | MG017791 AS-3606/URC-109(V), ANTENNA |
| 9G5975009824465 HANGER,CABLE | MK200022 AN/BQR-22A RECEIVING SET SONAR, POSEIDON |
| 9C3010001135939 CLUTCH ASSEMBLY,FRI | MK266704 AN/BQR-7E W/EC-1 |
| 9G6250001591379 LAMPHOLDER | MK266704 AN/BQR-7E W/EC-1 |
| 9G6250001091041 LAMPHOLDER | M0016481 AN/SQN-15(V)3 |
| 9Z5365005796297 RING,RETAINING | M016151057 PUMP CTFGL 20GPM 26PSI 1800RPM MD VLT |
| 9Z5365006347045 RING,RETAINING | M060950241 COMPRESSOR RFG VERT OPN |
| 9Z5365008083957 RING,RETAINING | M061190013 COMPRESSOR UNIT,AIR PORTABLE 1.6CFM 115VAC 60HZ |
| 9C4820013018042 SUCTION VALVE | M069990041 COMPRESSOR AIR LP 125CFM 125PSI |
| 9N5945000678582 RELAY,ELECTROMAGNET | M110140001 INVERTER 120VDC IN/120VAC OUT IV120-20000-120-3 |
| 9N5920011443108 FUSEHOLDER,BLOCK | M151011380 STARTER MTR MAG SIZE 1 440V 1SPD |
| 9N5945011488456 RELAY,ARMATURE | M15590A001 APPR'D MOD DWG 89096 M1397 |
| 9G5975005014924 PLATE,WALL,ELECTRIC | M219990749 SWITCH TGL SYM 780.5 |
| 9N5920012271875 FUSEHOLDER,BLOCK | M220160101 SWITCHBOARD PWR ELECTR/DISTRN 60HZ |
| 9G6350013580137 BELL,ELECTRICAL | M232490038 ALARM BELL 24VDC WATERTIGHT UDTV-10-24VDC |
| 9G6230011905393 RACK,BRACKET SEARCH | M241130067 SEARCHLIGHT 17IN SNLG XE9666-RF-H-B |
| 9G6250004844025 LAMPHOLDER | M241130068 SEARCHLIGHT 19 IN RIOT-D |
| 9N5945000526807 RELAY,ELECTROMAGNET | M251960031 ALARM GCMPS FLR 1878399 |
| 9G6250002270329 LAMPHOLDER | M259270011 ASSY,OPEN SCALE REPEATER 1976159-3 |
| 9Z5365002056716 RING,RETAINING | M345020050 MOTOR GROUP SS800R/5N8773 |
| 9Z5365002562852 RING,RETAINING | M432180001 MIXING MACH FOOD ELEC QT GALLEY 115V |
| 9G4130011707379 FILTER-DRIER,REFRIG | M482170001 FILTER SUCTION RSF-9625T |
| 9N5945012036042 RELAY,ELECTROMAGNET | M500540003 PANEL,ALM SPBD IAP-01HG8637 |
| 9N5945001236170 RELAY,ELECTROMAGNET | M503640004 PANEL IND DOOR POSITION 13605-WT-DPNL-66 |
| 9C2590006237721 FILLER NECK | M529990037 HYD PWR UNIT |
| 9C3040012698064 BALL JOINT | M529990075 POWER UNIT ASSY,HYD OIL/CAP 70GAL |
| 9Z5365005308144 RING,RETAINING | M612020029 CONTROL POSITIONER 5311450C2 |
| 9Z5365012722793 RING,RETAINING | M619610103 ACTUATOR-ELECTRO-MECHANICAL ROTARY |
| 9Z5365012722795 RING,RETAINING | M619610103 ACTUATOR-ELECTRO-MECHANICAL ROTARY |
| 9C2520004467518 BREATHER | M621120014 WINCH ELE 2DM MAX CAP 12600LBS |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9C2930003528085 FERRULE,WATER DIREC | M664810094 ENGINE DSL D398TA |
| 9C3040001190612 BALL JOINT | M664810120 ENGINE, DSL MDL D349 1070HP 1800RPM CCW |
| 9C3820006730335 PANEL,INSTRUMENT,EN | M666010452 ENGINE,DIESEL 8CYL 469HP 1800RPM |
| 9C2805000850844 PISTON,INTERNAL COM | M668250056 MOTOR, OUTBOARD GAS 25HP MDL E25RLCIM |
| 9C2805000771737 RING,FRICTION | M668250109 OUTBOARD MOTOR GAS 25HP MODEL E25RLCCA |
| 9Z5365008422613 RING,RETAINING | M698880332 TRACTION MACHINE CAP 10000LBS |
| 9C4820012228323 VALVE,PILOT | M882220294 VALVE PLT .50 IPS 2T20PSI FLGE ALUM |
| 9C4820011978997 VALVE,CONT.PLT AIR | M882242362 VALVE,LINEAR DIRECT .50IPS 250PSI FPT ALU |
| 9C3040011894266 LEVER,MANUAL CONTRO | M882291555 VALVE BTFL 2.50IPS 200PSI BLT BRZ |
| 9C4730011027450 ELBOW,TUBE TO BOSS | M950`35906 STEERING SYSTEM |
| 9G4130006471723 VALVE,COMPRESSOR | N060150197 COMPRESSOR RFG SEMI-HERMETIC |
| 9G4130004570133 FILTER-DRIER,REFRIG | N328880402 CHILLER RFG |
| 9Z5365008013007 RING,RETAINING | N419990104 LATHE ENGINE BCH 16.0 X 40.0IN MDL 1640 |
| 9Z5365004203859 RING,RETAINING | N571140001 CRANE BR X TRVLG 9000LBS/ON SHIP 12000LBS ON SH |
| 9C3040011354368 LEVER,REMOTE CONTRO | N694040026 TRANSMISSION MECH P220L 2.160 TO 1 RTO |
| 9Z5365002604883 RING,RETAINING | N854060056 LEVEL WIND ASSY |
| 9Z5340001110799 DOOR RETAINING SPR | RCR054BHJ SHOP STORE NON STANDARD |
| 9Z5307000047362 STUD,LOCKED IN KEYE | RCR054ICR ICR PROGRAM |
| 9Q8040000656578 PRIMER,ADHESIVE | RCR054ICR ICR PROGRAM |
| 9G5975001521071 LOCKNUT,ELECTRICAL | RCR054ICR ICR PROGRAM |
| 9G3439012156406 TIP,ELECTRIC SOLDER | RCR054ICR ICR PROGRAM |
| 9C4520012319776 FRAME ASSEMBLY,DUCT | RCR054ICR ICR PROGRAM |
| 9N5905010999312 HOLDER,RESISTOR | RCSHIPALT NON-STANDARD SHIPALT MATL NON EQUIPMENT RELATED |
| 9Z5310003671456 NUT,CONNECTOR | RCSHPSTR1 LBNSY NON-STANDARD SHOP STORE ITEMS |
| 9G5975010262405 LOCKNUT,ELECTRICAL | RCSHPSTR7 PHILA NSY,NON-STANDARD SHOP STORE ITEMS |
| 9C3040001665361 CONNECTING LINK,RIG | T016400030 PUMP RCIPG HND |
| 9C3020011984371 GUARD,MECHANICAL DR | T174754984 MOTOR AC 230/460V .25HP 1725RPM TRAINING DEVICE |
| 9Z5325010631884 FASTENER,PANEL | T229990190 SWITCHBOARD HULL OP/CMN ALARM PNL 401-5216330-31 |
| 9G6250008810558 LAMPHOLDER ASSEMBLY | T271010536 INDICATOR TRIM ANGLE 401-4695009-1 |
| 9Z5360008807161 SPRING,FLAT | T4120500 OJ-172(V)/UYK TRIDENT, I/O CONSOLE |
| 9N5999008384466 CAP,ELECTRICAL | T4146101 C-11217/B, CONTROL-AMPLIFIER,UNIT 1,TRIDENT |
| 9Z5365005682596 RING,RETAINING | T4250500 PERISCOPE TYPE 8L MOD(T) TRIDENT |
| 9G2040008969472 CONNECTOR,RECEPTACL | T4250500 PERISCOPE TYPE 8L MOD(T) TRIDENT |
| 9C4440012172683 PLUG ASSEMBLY,UPPER | T440210042 DEHYDRATOR FLTR DSCC 165SCFM 5100PSIG |
| 9Z5365008821435 RING,RETAINING | T4410555 R-2320/URR TRIDENT, PROGRAMMABLE SCANR COMM RECR |
| 9Z5315010448855 GUIDE PIN,ELECTRICA | T4412735 MU-1038/BSC-1 TRIDENT, RAM DISK |
| 9N5895002699257 DISK,KEYER | T4414205 TT-624B(V)1/UG TRIDENT, TELEPRINTER |
| 9G4140013138291 GUARD,FAN IMPELLER | T4414270 CV-4056(V)1/USC-38(V) TRID, APCU/MWPSUB |
| 9G6250004447684 LAMPHOLDER | T4416014 C-10256/BRR-6 TRIDENT, CONTROL INDICATOR |
| 9Z5365004425845 RING,RETAINING | T4416032 RL-275/BRR-6 TRIDENT PORT REELING MACHINE |
| 9C3040011852427 SHAFT HANDLE | T4416034 AN/BRR-6 TRIDENT HYDRAULIC CONTROL VALVE GROUP |
| 9Z5340010626333 RETAINER ASSEMBLY | T460200009 DETECTOR SHIPS DPH 1804724 |
| 9C3020011529272 GEAR,DRIVE MOTION | T611890005 ACTUATOR,ASSY EMERG REMOTE |
| 9Z5360008724663 SPRING,IDLER | T760010103 CENTRIFUGAL LUBE OIL PURIFIER 225 GPH |
| 9N5945011220914 RELAY,ARMATURE | T820240013 WELDING MACH ARC TRNFRCTF AC 230/460V INP 300A |
| 9N5945012258796 RELAY,ELECTROMAGNET | T820240100 ELECTROSLOPE 30V 040 258 |
| 9Z5360010905880 SPRING,FLAT | T882081371 VALVE PG 1.25IPS PSI FLGE SSTL |
| 9C4820011903603 DIAPHRAGM,VALVE | T882191822 VALVE DPHRM CONT PLT OPER .37IN FTHRD STL |
| 9Z5305011509674 SCREW,MULL ADJUST | T882235319 VALVE LIN DRTNL CONT 4WAY HYD 3000PSI ALUM |
| 9Z5305011551729 LOCKING,SCREW | T882235319 VALVE LIN DRTNL CONT 4WAY HYD 3000PSI ALUM |
| 9Z5305011757752 SCREW,NOZZLE,ADJUST | T882235449 VALVE LIN DRTNL CONT 4WAY HYD 3000PSI ALUM |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9Z5305011757753 RETAINER,SCREW | T882235449 VALVE LIN DRTNL CONT 4WAY HYD 3000PSI ALUM |
| 9C4820012025699 DOG,VALVE,RELIEF | T883115624 VALVE RELF 1.50IPS 401T 500PSI SBU BRZ |
| 9C4820011150920 SPRING SEAT,VALVE | T884095009 VALVE RED 1.50IPS 700PSI 5T 20PSI FLGE BRZ |
| 9C4820010631885 SUBPLATE ASSEMBLY,V | T889901192 SUBPLATE ASSY 1 VL |
| 9G6670011388749 WEIGHT,BALANCE | WEP000004 ITEM PENDING LOAD TO ESO FILES |
| 9G6670011388750 WEIGHT,BALANCE | WEP000004 ITEM PENDING LOAD TO ESO FILES |
| 9Z5365007214594 RING,LOCK,KEYED | Z00D20001 SPECIAL PROGRAM INTEREST ITEMS |
| 9C2920004721642 CONTROL BOX,PROTECT | Z00D20004 SPECIAL PROGRAM INTEREST ITEMS |
| 9G4240010490804 COVER,PROTECTIVE,TU | Z00D20004 SPECIAL PROGRAM INTEREST ITEMS |
| 9G5975006304520 HOLDER ASSEMBLY | Z87000020 ITEMS WITH NUCLEAR APPLICATIONS |
| 9Z5365004196465 RING,RETAINING | Z87000065 ITEMS WITH NUCLEAR APPLICATIONS |
| 9C3040011196673 LEVER | Z87000073 ITEMS WITH NUCLEAR APPLICATIONS |
| 9Z5340002819892 BUTTON,PLUG | Z87000092 ITEMS WITH NUCLEAR APPLICATIONS |
| 9Z5340011689003 CLAMP,CONNECTOR | Z89100003 PSI ITEMS WITH SSPO APPLICATIONS |
| 9Z5340001506710 CLEVIS,TESTER | Z89100010 PSI ITEMS WITH SSPO APPLICATIONS |
| 9Z5365009648410 RING,RETAINING | Z89100010 PSI ITEMS WITH SSPO APPLICATIONS |
| 9Z5365000525413 RING,RETAINING | Z89100013 PSI ITEMS WITH SSPO APPLICATIONS |
| 9C4730002221819 BUSHING,PIPE | Z89100019 PSI ITEMS WITH SSPO APPLICATIONS |
| 1H5340007314321 MOUNT,RESILIENT | Z89100021 PSI ITEMS WITH SSPO APPLICATIONS |
| 1H5935005239423 SHELL,ELECTRICAL CO | Z89100023 PSI ITEMS WITH SSPO APPLICATIONS |
| 9C2815000741929 CLAMP AND SCREW,ROC | Z89100029 PSI ITEMS WITH SSPO APPLICATIONS |
| 9C2815002792438 ADAPTER,SPEEDOMETER | Z89100038 PSI ITEMS WITH SSPO APPLICATIONS |
| 9G5975007935550 LOCKNUT,ELECTRICAL | Z89100050 PSI ITEMS WITH SSPO APPLICATIONS |
| 9N5930010505060 SWITCH,PUSH | Z89100060 PSI ITEMS WITH SSPO APPLICATIONS |
| 9Z5365002857965 RING,RETAINING | Z89100065 PSI ITEMS WITH SSPO APPLICATIONS |
| 9G5975006427265 LOCKNUT,ELECTRICAL | Z89100065 PSI ITEMS WITH SSPO APPLICATIONS |
| 9N5945010251066 RELAY,ELECTROMAGNET | Z89100066 PSI ITEMS WITH SSPO APPLICATIONS |
| 9Z5365006850092 RING, EXT THREAD | Z89100092 PSI ITEMS WITH SSPO APPLICATIONS |
| 9Z5365005272094 RING,RETAINING | Z89100094 PSI ITEMS WITH SSPO APPLICATIONS |
| 9Z5365002856695 RING,RETAINING | Z89100095 PSI ITEMS WITH SSPO APPLICATIONS |
| 1H5340007826095 BUTTON,PLUG | Z89100095 PSI ITEMS WITH SSPO APPLICATIONS |
| 9G4921000033384 STANDOFF, HEXAGON, | 0R10318005 ORDALT 10318,MK443MOD1,TEST SET |
| 9Z5340010333269 LOCKING DEVICE ASSE | 0R16196005 ORDALT 16196,MK15MOD1,WEAPON SYSTEM,CLOSE-IN |
| 9G6250002841307 LAMPHOLDER | 0R32990001 ORDALT 3299,MK56MODS,DIRECTOR,GUN |
| 9G6250003201190 LAMPHOLDER | 0R57480001 ORDALT 5748,MK4MODALL,WEAPONS DIRECTION EQUIPMEN |
| 9N5999008249657 HEAT SINK,ELECTRICA | 0R67160001 ORDALT 6716,MK25MOD3,RADAR EQUIPMENT |
| 9C3020002312901 GEAR,PICK OFF,INNER | 0R69200001 ORDALT 6920,MK68MOD3X4X6X8T11X13X16X19,FCS,GUN |
| 9C3020002312905 GEAR, PICK OFF, OUT | 0R69200001 ORDALT 6920,MK68MOD3X4X6X8T11X13X16X19,FCS,GUN |
| 9N5945008866261 RELAY,ELECTROMAGNET | 0R81530001 ORDALT 8153,MK33MOD9,SWITCHBOARD,FIRE CONTROL |
| 9Z5365005306777 RING,RETAINING | 0R85540001 ORDALT 8554,MK31MOD2X3,SLIDE |
| 9Z5365005140379 RING,RETAINING | 0R85870001 ORDALT 8587,MK25MOD1X2,LAUNCHING SYSTEM,GM |
| 1H5945008139714 RELAY,ELECTROMAGNET | 0R88570001 ORDALT 8857,MK286MOD0T2,PANEL,CONTROL |
| 9G5975002085413 LOCKNUT,ELECTRICAL | 00000828 TD19E22, TRNG DEVICE |
| 9G5975002806079 LOCKNUT,ELECTRICAL | 00000828 TD19E22, TRNG DEVICE |
| 9Z5365006600982 RING,RETAINING | 00001472 14A11, MULTI-ENVIRONMENT TRNR,(MET) SAUDI NAVY |
| 9N5905003337202 HOLDER,RESISTOR | 00003728 AS-3640/GRC, ANTENNA |
| 9G5975006427261 LOCKNUT,ELECTRICAL | 00003728 AS-3640/GRC, ANTENNA |
| 9C4730010375536 NIPPLE,BOSS | 00003824 OK-410(V)2/SQR UNIT 4, ESS,CONTROL STATION ASSY |
| 9G5975000978099 LOCKNUT,ELECTRICAL | 00005740 TD19F1A, ADVANCED FIREFIGHTER TRNR |
| 9C3020012213758 WHEEL,SPROCKET | 00006528 RO-566/FQA-5(V), SONAR DATA RECORDER UNIT 1360 |
| 9Z5365002814422 RING,RETAINING | 00007053 LS-518(77327), SIGNAL GENERATOR |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9G5975007015265 CLAMP,CABLE | 00007364 AN/SQS-26CX WITH FC1 THRU EC-18 |
| 9Z5340002904545 BUTTON,PLUG | 00008695 83592B-002(28480), GENERATOR,SWEEP |
| 9C3010001113420 CLUTCH ASSEMBLY,FRI | 00010670 AN/BQS-14A EC-13 |
| 9C3010001113421 CLUTCH ASSEMBLY,FRI | 00010670 AN/BQS-14A EC-13 |
| 9Z5340002708553 BUTTON,PLUG | 00010776 TA-829/FT, GENERATOR,RINGING,STATIC |
| 9C3020007588129 GUARD,MECHANICAL DR | 00011497 OA-9141/TSM-170, REPAIR GROUP,AUXILIARY EQUIP |
| 9G5975008914762 CLAMP,ELECTRICAL CO | 00012505 AN/SPS-48E MISCELLANEOUS EQUIPMENT |
| 9N5985013248489 ATTENUATOR,FIXED | 00012508 R-2299/SPS-48E, RECEIVER |
| 9N5945007812558 RELAY,ELECTROMAGNET | 00012580 02-788205-11(52414), POWER SUPPLY |
| 9Z5340010481269 RETRACTOR,CABLE | 00013246 OL-357/FSC-97, SIGNAL PROCESSOR GROUP |
| 9G5975007015262 CLAMP,CABLE | 00013623 OT-47D/SPS-48A(V), TRANSMITTER GROUP |
| 9G6150002630655 LINK,TERMINAL CONNE | 00014092 OA-9234/G, ELECTRONIC EQUIPMENT ROOM |
| 9C3040010607161 BALL JOINT | 00016662 83403361-1(12339), MASTER CONTROL UNIT |
| 9N5905003558575 HOLDER,RESISTOR | 00016664 874200-02(51290), REMOTE EMITTER UNIT J-BAND |
| 9G5975010818095 PLATE,WALL,ELECTRIC | 00017262 AN/GSC-39A(V)1 MISC, FIXED SITE SATCOM |
| 9N5840011552160 STOP,SPRING | 00017327 AB-994B/SPN-42, ANTENNA PEDESTAL |
| 9N5840011552162 GUIDE,SPRING | 00017327 AB-994B/SPN-42, ANTENNA PEDESTAL |
| 9N5895011667298 RETAINER,KEYPAD | 00017732 AN/ULQ-16(V)1, PULSE ANALYZER SET |
| 9Z5365005307957 RING,RETAINING | 00020469 AN/SQR-19(V) UNIT 29, TOWED BODY |
| 9G5975001008776 LOCKNUT,ELECTRICAL | 00021585 1339AS900-2(30003), MOBILE FAC INTEGRATION UNIT |
| 9G5975007755267 LOCKNUT,ELECTRICAL | 00021585 1339AS900-2(30003), MOBILE FAC INTEGRATION UNIT |
| 9Z5340013661441 HOLDER,DOOR | 00022272 CW-1186B/SLQ-32(V), ENCLOSURE COUNTERMEASURE EQP |
| 9G6250006170462 LAMPHOLDER | 00022607 161901005(31795), APCS DIESEL GEN SET |
| 9Z5340000519769 BUTTON,PLUG | 00022971 8519906-1(98750), ANT TEST SYS VCATS |
| 9C3010005407646 COUPLING,SHAFT,RIGI | 00025094 FT-203-88(14632), IF TAPE CONVERTER |
| 9Z5365009935303 RING,RETAINING | 00026069 AM-7450/SPN-43C, AMPLIFIER,VIDEO |
| 9Z5340011254689 INSERT | 00026198 AN/SPS-40E, RADAR SET |
| 9N5985011999093 PLATE,SUPPORT | 00026198 AN/SPS-40E, RADAR SET |
| 9C4730012683558 BOLT,FLUID PASSAGE | 00026866 M1022(16128), MOBILIZER |
| 9G6150012541664 BUS,CONDUCTOR | 00029617 AN/TMQ-35, MK IV WEATHER VAN |
| 9Z5340000044046 BUTTON,PLUG | 00032495 0N475898-2(98230), SASS CONTROL UNIT OP |
| 9N5945000387776 RELAY,ELECTROMAGNET | 00033415 AN/URC-131A LSD PAL, HF RADIO GROUP |
| 9N5895011419305 COVER,ELECTRONIC CO | 00033955 PP-3916D/UR N/A FOR COSAL USE |
| 9Z5340009721467 GRILLE,METAL | 00062635 TD14E28, TRNG DEVICE,FFG SQS-56 SONAR OPERATOR T |
| 9G6150010778195 BUS,CONDUCTOR | 00062638 TD14E31A/B, AN/BQQ-5 BASIC SONAR OPERATOR TRNR |
| 9C3020012248404 SPROCKET AND SHAFT | 002430007 AMCM WINCH DRUM LOADING MECHANISM |
| 9Z5340013740393 CLIP,SPRING TENSION | 002440066 AMCM MK 105 PLATFORM TEST SET AN/ALM-159 |
| 9Z5340013742302 CLIP,SPRING TENSION | 002440066 AMCM MK 105 PLATFORM TEST SET AN/ALM-159 |
| 9Z5340010367309 HANDLE,HAND PUMP | 002441001 MAGNETIC MINESWEEPING GEAR MK105 MOD 2 SLED |
| 9Z5340002683513 PLUG,EXPANSION | 002450002 AN/ALQ-141 AND AN/AQS-14 INTERFACE REMOVABLES |
| 9Z5365007350196 RING,LOCK,SERRATED | 002450002 AN/ALQ-141 AND AN/AQS-14 INTERFACE REMOVABLES |
| 9Z5365010065633 RING,RETAINING | 002500020 ADAPTER ASSEMBLY,GAU&2B/A |
| 9Z5340010291949 CLIP,SCREW ASSY | 002700025 TEST SET A/E24T&123 FOR 20MM GUN POD GPU&2/A |
| 9Z5365006875803 RING,RETAINING | 004020006 MK13MOD0,LAUNCHING SYSTEM,GUIDED MISSILE |
| 9C3010008439476 COUPLING,SHAFT,RIGI | 004020059 MK372MOD0,CONTAINER,SHIPPING AND STORAGE |
| 9Z5365008345579 RING,RETAINING | 004120001 MK10MOD0,LAUNCHING SYSTEM,GUIDED MISSILE |
| 9Z5365008013006 RING,RETAINING | 004120005 MK10MOD7,LAUNCHING SYSTEM,GUIDED MISSILE |
| 9Z5365005141459 RING,RETAINING | 004120104 MK10MOD7,LAUNCHING SYSTEM,GUIDED MISSILE GLAKES |
| 9Z5365006808735 RING,RETAINING | 004120106 MK81MOD0,BOOSTER,HANDLING ATTACHMENT |
| 9Z5365007866665 RING,EXTERNALLY THR | 004130157 BOOSTERS X SUSTAINERS TERRIER BWO BW1 |
| 9C1450010253560 BOX,BOOSTER,TEST ST | 004130251 MK12MOD0,STAND,TEST,BOOSTER |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9N5935005043337 STRAP NUT,PLUG-IN E | 004230015 AN/DSM-60,TEST SET,GUIDED MISSILE |
| 9G8140010227213 LUG,STACKING ASSEMB | 004920136 MK200MOD0,CONTAINER,SHIPPING AND STORAGE |
| 9C3020004506666 SPROCKET WHEEL | 004920172 DOLLYS MSL X BSTR TFR MK 7X8 MOD 0 |
| 9Z5340007115483 POST,ELECTRICAL-MEC | 004920172 DOLLYS MSL X BSTR TFR MK 7X8 MOD 0 |
| 9Z5365005980953 RING,RETAINING | 004920197 MK6MOD0,CONTAINER,TORPEDO MK34MOD1 |
| 9C1450010226700 RING,LIFTING | 004920256 MK6MOD1,DOLLY,MISSILE TRANSFER,TERRIER |
| 9Z5365003826607 RING,LOCK,SERRATED | 005020001 MK7MOD1,CARRIAGE,ASROC LAUNCHER |
| 9Z4010006737812 WIRE ROPE ASSEMBLY, | 005020001 MK7MOD1,CARRIAGE,ASROC LAUNCHER |
| 9C2520010352645 BREATHER | 005020001 MK7MOD1,CARRIAGE,ASROC LAUNCHER |
| 9G6250005426534 LAMPHOLDER | 005110001 MK17MOD8,TRANSMITTER,BEARING |
| 9N5945001259251 RELAY,ELECTROMAGNET | 005110111 MK11MOD0,BOX,SWITCH |
| 9G6250007299382 LAMPHOLDER | 005210001 MK39MOD1,CONSOLE,ATTACK CONTROL |
| 9Z5365009577776 RING,RETAINING | 005750049 AN/SKQ-3A,RECEIVING-RECORDING-SCORING SET TELEM |
| 9G5975002960534 LOCKNUT,ELECTRICAL | 005750081 MK143MOD1,LAUNCHER,ARMORED BOX |
| 9C4320012496625 MOTOR,HYDRAULIC | 005750081 MK143MOD1,LAUNCHER,ARMORED BOX |
| 9Z5365002269980 RING,RETAINING | 006020129 MK2MOD2,HOIST,5 INCH AMMUNITION |
| 9Z5365008837404 RING,RETAINING | 006020129 MK2MOD2,HOIST,5 INCH AMMUNITION |
| 9Z5365002822389 RING,RETAINING | 006020141 MK2MOD1,RAMMER,5 INCH |
| 9Z5365002527750 RING,RETAINING | 006020148 MK35MOD2,CARRIAGE,5 INCH |
| 9C1020003341123 DOG AND SHAFT | 006020204 MK33MOD1,SHIELD,5 INCH |
| 9Z5365008172417 RING,RETAINING | 006050005 MK19MOD3,DRIVE,POWER TRAIN |
| 9G6250000197259 LAMPHOLDER | 006060202 AN/SPG-53C,RADAR SET |
| 9Z5365012219714 SPACER SET,PLATE | 006070024 MK35MOD0,SLIDE 76MM/62 CAL |
| 9C1015012893662 ROD,EXTENSION | 006070027 MK42MOD1,BORESIGHT |
| 9Z5310010887556 NUT,RETAINER | 006080016 MK160MOD0,CONTROL,SERVO |
| 9Z5310010887557 NUT,RETAINER | 006080016 MK160MOD0,CONTROL,SERVO |
| 9N5985012494833 WAVEGUID | 006080059 MK92MOD2,FIRE CONTROL SYSTEM (BASELINE) |
| 9Z5365011491993 GUARD,FLEX TUBE,SPR | 006090032 MK15MOD5,WEAPON SYSTEM,CLOSE-IN,SAUDI |
| 9N1285011623207 CLAMP,BASE PLATE | 006090051 MK15MOD1,WEAPON SYSTEM,CLOSE-IN (A SUB O) |
| 9Z5325012026350 RECEPTACLE,QUARTER- | 006090051 MK15MOD1,WEAPON SYSTEM,CLOSE-IN (A SUB O) |
| 9Z5330011673913 GUIDE,CARD | 006090125 MK15MOD3,WEAPON SYSTEM,CLOSE-IN(FMS) |
| 9Z5365004219083 RING,LOCK,SERRATED | 006090150 MK15MOD1T4X6 CIWS DEPOT O/H NA FOR COSAL USE |
| 9Z5340012968830 HOLDER,DOOR | 006090238 MK20MOD0,ELECTRONIC ASSEMBLY,ENCLOSURE |
| 9Z5340012972875 HOLDER,DOOR | 006090238 MK20MOD0,ELECTRONIC ASSEMBLY,ENCLOSURE |
| 9C30400017[illegible]0561 CONNECTING LINK,RIG | 006110332 MK1AMOD13,COMPUTER |
| 9N5935002013099 STRAP NUT,PLUG-IN E | 006110346 MK25MOD3,RADAR |
| 9Z5365008285005 RING,RETAINING | 006130116 MK42MOD6,COMPUTER |
| 9G6250000606442 LAMPHOLDER | 006210057 MK5MOD2,DIRECTOR,ATTACK |
| 9Z5365000624256 RING,RETAINING | 006210106 MK7MOD0,ANALYZER |
| 9C2530008398738 CAP,GREASE | 006300404 WEAPON SKID,AERO 21A-C |
| 9Z3120008496353 ROLLER,LINEAR-ROTAR | 006300404 WEAPON SKID,AERO 21A-C |
| 9G5975002806083 LOCKNUT,ELECTRICAL | 006300434 MK24MOD1,DOLLY,HANDLING |
| 9N5945005393624 RELAY,ELECTROMAGNET | 006320058 MK25MOD0,TUBE,TORPEDO,SURFACE VESSEL |
| 9Z5340005454716 LOCK, TRUCK | 006340006 MK434MOD0,TEST SET,HYDRAULIC |
| 9C3040012813627 LEVER,REMOTE CONTRO | 006350078 MUNITIONS TRANSPORTER, MHU-191 |
| 9C3040012813628 LEVER,REMOTE CONTRO | 006350078 MUNITIONS TRANSPORTER, MHU-191 |
| 9C3040013091455 LEVER,REMOTE CONTRO | 006350078 MUNITIONS TRANSPORTER, MHU-191 |
| 9Z5325002765660 STUD,SNAP FASTENER | 006400199 HOWITZER 105MM |
| 9N5945006177420 RELAY ASSEMBLY | 006400199 HOWITZER 105MM |
| 1H3010004036108 COUPLING,SHAFT,RIGI | 006400200 MK4MOD0,MORTAR,60 MM |
| 9N5945009874662 RELAY,ELECTROMAGNET | 006600052 MK33MOD4,SWITCHBOARD,FIRE CONTROL |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9N5945008866262 RELAY,ARMATURE | 006600184 MK41MOD3,SWITCHBOARD,ATTACK CENTER |
| 9Z5365001930688 RING,RETAINING | 006900024 D-2145-0001, (0AJL2),MK2MODO (RCT) |
| 9Z5365005589412 RING,RETAINING | 006900033 LIMPET MK 4 SERVICE 10001/2499908 |
| 9Z5365006646723 RING,RETAINING | 007100006 HELLFIRE TS-100 ASSY |
| 2E1325012727659 RING, CLAMPING | 007100020 GATOR-WINGS/FINS |
| 2E5306012741537 BOLT, SOCKET, HEAD | 007100020 GATOR-WINGS/FINS |
| 9Z5360009284033 SPRING,FLAT | 007160001 SIDEWINDER 9G G&C MK18 MOD2 |
| 9Z5365009870258 RING,EXTERNALLY THR | 007160001 SIDEWINDER 9G G&C MK18 MOD2 |
| 9C1450011421706 ADAPTER,FUZE CABLE | 007170007 SIDEWINDER 9-H G&C MK18 MOD3&4 |
| 9N1420011093904 DOME,HOUSING | 007189011 SIDEWINDER 9-L TRAINING MSL GDU-5C |
| 9G5975010205091 CLAMP,ELECTRICAL CO | 007230032 AN/DPM-21G,SPARROW TEST SET |
| 9C4730012303757 RING,INTERNALLY THR | 007230032 AN/DPM-21G,SPARROW TEST SET |
| 9G6110002415499 DISTRIBUTION BOX | 007230042 SPARROW III MISSILE A1M-7E2 |
| 9Z5340003038124 LOCK RING,CONNECTOR | 007230042 SPARROW III MISSILE A1M-7E2 |
| 9Z5360010309851 SPRING,FLAT | 007230052 ROCKET MOTOR MK 58 MOD 2 SPARROW |
| 9G5975013033271 COVER,SWITCH TERMIN | 007230200 SPARROW AIRBORNE INERT MISSILE SIMULATOR |
| 9N5905003959997 HOLDER,RESISTOR | 007240200 SPARROW GUIDANCE UNIT SYSTEM TEST STATION |
| 9N5935004522213 EXTENSION,ELECTRICA | 007400018 TEST SET GD WPN ANDSM 96 |
| 9N5935004522214 EXTENSION,ELECTRICA | 007400018 TEST SET GD WPN ANDSM 96 |
| 9N1420004071391 COUPLING,MISSILE SE | 007500002 STANDARD ANTI-RADIATION MISSILE |
| 9C1450010761221 SUPPORT,PALLET,GUID | 007600053 PHOENIX AIM-54A GUIDANCE SEC CONT CNU-234/E |
| 9Z5340010760663 CAP,PROTECTIVE,DUST | 007700003 HARPOON MISSILE-SUSTAINER SECTION |
| 9Z5306010840233 BOLT ASSEMBLY | 007700015 HARPOON&MISSILE SUBSYSTEM TEST SET AN/DSM&127 |
| 9Z5325002532789 TENSION LATCH ASSEM | 007700039 ADAPTER CLAMPING HARNESS ADU-417/E |
| 9Z5340011830464 CAP,PROTECTIVE,DUST | 007715040 USN HARPOON AN/DSM-127-4 TEST STAND UNIT 4 |
| 9Z5365004116515 RING,RETAINING | 007722022 HARPOON FMS DVR DEPOT TEST SET (UK) |
| 9Z5365000807329 RING,RETAINING | 008100001 MK57MOD0,MINE,SERVICE |
| 6T1350010420312 GUIDE,CABLE | 008100055 MK60MOD0,MINE,UNDERWATER,(CAPTOR) |
| 9Z5365005987548 RING,RETAINING | 008100092 MK67MOD2, MISC. PARTS, SLMM |
| 9Z5325002401854 FASTENER,PANEL | 008110018 AN/SLQ-37,AUTOMATIC CONTROL UNIT |
| 9Z5365007214825 RING,RETAINING | 008990122 MK5MOD0,BOOM,FORKLIFT TRUCK |
| 9C1450011954427 FITTING ASSEMBLY | 008990230 BEAM,HOISTING,CANISTER |
| 9Z5365003758944 RING,RETAINING | 016400003 PUMP RCIPG HND GPM SPM PSI |
| 9Z5365009549666 RING,RETAINING | 016460018 PUMP RCPG PWR VSSA |
| 9C4320011435441 LINK,PUMP | 016620004 PUMP RC1PG HND 2.20CU IN 500PSI |
| 9G3655004382434 LOAD RING,PACKING | 016670006 PUMP RCIPG PWR HSDA 4LBPM 1800PSI |
| 9Z5365006116732 RING,LOCK,KEYED | 017180012 PUMP RTY PWR |
| 9Z5365002527769 RING,RETAINING | 017210101 PUMP RTY PWR 22.00GPM 90PSI 1165RPM ATT |
| 9Z5307006162902 STUD,PLAIN | 017440021 PUMP RTY PWR 11.60GPM 654PSI 3250RPM CW GED |
| 9C3020002882405 PULLEY,GROOVE | 017610007 PUMP CTFGL 280GPM 40PSI 2700RPM EVB VLT |
| 9C3040005809548 PLATE,RETAINING,SHA | 017610011 PUMP CTFGL 55GPM 23PSI 4000RPM MVB VLT |
| 9C3020012257054 PULLEY | 017610086 PUMP CTFGL 246GPM 33PSI 3200RPM MVB VLT |
| 9C3020005912674 PULLEY,GROOVE | 017610109 PUMP CTFGL 150GPM 15PSI 3600RPM EBD VLT |
| 9C3040002186768 GEARSHAFT,HELICAL | 017620039 PUMP RTY PWR 64.00GPM 60PSI 1531RPM ATT |
| 9Z5365001806034 RING,RETAINING | 017760004 PUMP RTY PWR 5.42GPM 20PSI 2000RPM ATT |
| 9Z5365011958048 RING,RETAINING | 017780024L PUMP RTY PWR GPM PSI RPM ATT |
| 9C4930006309823 TOGGLE,SHUTTLE | 018490009E PUMP,LUBRICATOR,PNEU MDL 222-069 |
| 9C4820005863190 SEATING TOOL,VALVE | 018560002 PUMP RC1PG FT DR 1.18CU IN12500PSI |
| 9C4320012604455 PISTON,PUMP | 018630028 PUMP RCIPG AIR HP 9800PSIG MAXOUT 150MAX PSI |
| 9C3040012213478 CAM,CONTROL | 018880266 PUMP RCIPG PWR HSSA 6.2GPH PSI |
| 9C2910003359333 LEVER,REMOTE CONTRO | 018950008 PUMP FUEL INJ DENG TY DBG-F-C-229-4R |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9C2805002001980 BREATHER | 018960034 PUMP FUEL INJ DENG TY APE6B-90QK300-S577 |
| 9Z5365009422540 RING,RETAINING | 018960245 PUMP FUEL INJ DENG APFICQ170T6491A 4320022 |
| 9Z5365004152483 RING,RETAINING | 018990003 PUMP FUEL INJ DENG TY 10-19120-4 |
| 9Z5365007218963 RING,RETAINING | 019160695 PUMP AXIAL PSTN 208.0GPM 1200RPM 3350PSI VDEL |
| 9N5920001569229 FUSEHOLDER,EXTRACTO | 02013050 20130, RECTIFIER POWER SUPPLY |
| 9Z5365002813114 RING,LOCK,SERRATED | 052010001 TURBINE GAS GEN MDL 502-6 |
| 9N5935008940743 STRAP NUT,PLUG-IN E | 052020003 TURBINE GAS GEN 300KW MDL T520J-5 |
| 9Z5365005597590 RING,LOCK,SERRATED | 052020029 ENGINE GAS TURB |
| 9Z5365007215502 RING,LOCK,SERRATED | 052020029 ENGINE GAS TURB |
| 9Z5365000150300 RING,LOCK,SERRATED | 052020041 ENGINE GAS TURB 300KW MDL114205-0 |
| 9Z5365008121767 RING,RETAINING | 052020041 ENGINE GAS TURB 300KW MDL114205-0 |
| 9Z5365000524264 RING,RETAINING | 052040002 ENGINE GAS TURB START SYS |
| 9Z5365008151100 RING,LOCK,SERRATED | 052040002 ENGINE GAS TURB START SYS |
| 9Z2835003407682 RETAINER,FAN BEARIN | 052040008 ENGINE GAS TURB START SYS |
| 9Z5365007217485 RING,RETAINING | 052050005 ENGINE GAS TURB MN PROSN 7LM1500PE103 |
| 9Z5365004392504 RING,RETAINING | 052050018 GAS GENRATOR ASSEMBLY MDL L25250G12 |
| 9Z5365008507044 RING,RETAINING | 052090005 ENG.ASSY.GAS TURB MDL 501K34 |
| 9Z2840002278887 RING,COMPRESSOR ROT | 052100003F ENGINE GAS TURBINE MN PROSN FT4A&12CW |
| 9Z2840005603003 SPACER,COMPRESSOR B | 052100003F ENGINE GAS TURBINE MN PROSN FT4A&12CW |
| 9Z2840005603004 SPACER,COMPRESSOR B | 052100003F ENGINE GAS TURBINE MN PROSN FT4A&12CW |
| 9Z2840005669094 PLUG,COMPRESSOR ROT | 052100003F ENGINE GAS TURBINE MN PROSN FT4A&12CW |
| 9Z2840005669150 SHIELD,HEAT,AIRCRAF | 052100003F ENGINE GAS TURBINE MN PROSN FT4A&12CW |
| 9Z5365005821954 RING,RETAINING | 052100003F ENGINE GAS TURBINE MN PROSN FT4A&12CW |
| 9Z5365005982092 RING,RETAINING | 052100003F ENGINE GAS TURBINE MN PROSN FT4A&12CW |
| 9J2840006297549 SHIELD,HEAT,AIRCRAF | 052100003F ENGINE GAS TURBINE MN PROSN FT4A&12CW |
| 9Z5365006648464 RING,RETAINING | 052100003F ENGINE GAS TURBINE MN PROSN FT4A&12CW |
| 9Z5306008324572 BOLT,MACHINE | 052110001 ENGINE GAS TURB MN PROSN |
| 9N5935008763902 NUT,BUSHING RETAINE | 052110001 ENGINE GAS TURB MN PROSN |
| 9N5935008763903 NUT,BUSHING RETAINE | 052110001 ENGINE GAS TURB MN PROSN |
| 9N5935008766539 NUT,BUSHING RETAINE | 052110001 ENGINE GAS TURB MN PROSN |
| 9Z2840008766682 DOWEL,HOLLOW | 052110001 ENGINE GAS TURB MN PROSN |
| 9Z5365005141290 RING,RETAINING | 053010008 TURBOCHARGER DIESEL C-ND 2116 A3 MDL H564PT |
| 9N5935002593054 STRAP NUT,PLUG-IN E | 05515795 NIKE HERCULES RADAR, AFWR |
| 9G6250002995748 LAMPHOLDER | 05515795 NIKE HERCULES RADAR, AFWR |
| 9N5935008187958 STRAP NUT,PLUG-IN E | 05515795 NIKE HERCULES RADAR, AFWR |
| 9Z5365008093938 RING,RETAINING | 057260191 TURBINE STM GEN 500KW |
| 9Z5365005986250 RING,RETAINING | 057800113 TURBINE STM GEN 300KW |
| 9C2910011942034 ADAPTER,FUEL PUMP | 059950006 POWER PLANT ASSY MDL 115354-201 T-1000S-28AA |
| 9C4710012598000 ADAPTER,LINKAGE | 059950006 POWER PLANT ASSY MDL 115354-201 T-1000S-28AA |
| 9N6625003560191 LEAD SET,TEST | 06008600 60086, MULTIMETER |
| 9Z5340002765853 PLUG,EXPANSION | 061390025 COMPRESSOR AIR LP 300.0CFM 125PSI CL R |
| 9C4310004203507 GUIDE,VALVE SPRING | 061430053 COMPRESSOR AIR LP 10.0CFM 600PSI CL T |
| 9C4310001193220 YOKE GUARD,COMPRESS | 061900005 COMPRESSOR AIR HP 20.0CFH 3000PSI CL A |
| 9Z5340003989137 CAP,PROTECTIVE,DUST | 061900005 COMPRESSOR AIR HP 20.0CFH 3000PSI CL A |
| 9C4310003319817 GUARD,DISCHARGE VAL | 061900150 COMPRESSOR AIR LP 100.0CFM 100PSI CL R |
| 9C4310006238748 CYLINDER SLEEVE | 061900180 COMPRESSOR AIR HP 30.0CFH 3000PSI CL SPL |
| 9C3040006596619 WEIGHT,COUNTERBALAN | 061900180 COMPRESSOR AIR HP 30.0CFH 3000PSI CL SPL |
| 9C4310006780957 PISTON,COMPRESSOR | 061900180 COMPRESSOR AIR HP 30.0CFH 3000PSI CL SPL |
| 9Z5310009368761 NUT,CROSSHEAD,SPECI | 061900180 COMPRESSOR AIR HP 30.0CFH 3000PSI CL SPL |
| 9C4730010387977 NIPPLE,TUBE | 061900181 COMPRESSOR AIR HP 20.0CFH 3000PSI CL A |
| 9C4310006564388 PLATE,REED VALVE | 061900190 COMPRESSOR AIR LP 200.0CFM 100PSI CL S |

| NSN. PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9C4820010745067 COVER,VALVE | 061900211 COMPRESSOR AIR HIP 13.0CFH 4500PSI CL AA |
| 9C4310010742357 MANIFOLD,COMPRESSOR | 061900222 COMPRESSOR AIR HIP 13.0CFH 4500PSI CL AA |
| 9C4310013052368 FILTER,ELEMENT,FLUI | 061900367 COMPRESSOR AIR LP 200.0CFM 125PSI CL S |
| 9C4820010452277 CARTRIDGE,REGULATIN | 061900378 COMPRESSOR CTFGL 1400CFM PSI 2STG MD |
| 9C4710002337947 TUBE ASSEMBLY,METAL | 061910003F COMPRESSOR AIR LP |
| 9G5977002170942 ELECTRODE | 070170007 HEATER COLNT ENG 24V DC MDL B75-17 |
| 9C2530005898537 CAP,GREASE | 070340001 HEATER VENT DCTP MDL BT400-40 |
| 9C4730002889513 COUPLING,CLAMP,PIPE | 074690008 HEATER STM HTG |
| 9Z5306011914525 TIE DOWN BOLT | 112700006 POWER SUPPLY 440V AC INP 450V 400HZ 150 KWOPT |
| 9C3040011461040 CONNECTING LINK,RIG | 140301483 CIRCUIT BREAKER ACB 3200FR 3200TRP ACB-3200HR |
| 9N5920011323321 FUSEHOLDER,BLOCK | 151910001 STARTER MTR MAG LVP SZ 1 460V 1SPD 1WDG DRPR |
| 9G5940010836619 CHANNEL,MOUNTING | 159990132F CONTROLLER AC SZ 7 460V |
| 9G6670010217181 WEIGHT,BALANCE | 162900200D GENERATOR AC 400HZ 977JO31&2 |
| 9C3040009365204 SHAFT ASSEMBLY,FLEX | 165300031 DRIVE ASSEMBLY, TACHOMETER |
| 9C2910006764957 PUMP,FUEL,ELECTRICA | 166120001 GENERATOR SET DENG 700KW |
| 9C2990009741165 CONTROL,OVERSPEED S | 168000020 GENERATOR AC 120V 30 KW 1800RPM |
| 9G5975006427266 LOCKNUT,ELECTRICAL | 169090001 GENERATING PLANT ACET 500CFH MDL M500P |
| 9G3655009860498 HOLDING TOOL,PISTON | 169120001 RECONDENSER O MODEL A DUTCH |
| 9Q5120006120215 REMOVAL TOOL,BONNET | 169160010S GENERATOR O X N MDL-GB2 |
| 9G5977000383586 HOLDER,ELECTRICAL C | 171180098 MOTOR DC 2SPD 230V 7.5 / 2.5 HP |
| 9Z5365004686130 RING RETAINING | 173870111 MOTOR AC 440V 3HP 3540RPM |
| 9G5977007565157 HOLDER,ELECTRICAL C | 18107A001 APPROVED MACHALT ECP NO 283 B/L0098 |
| 9Z5360010366885 SPRING,FLAT | 181280100 MOTOR GENERATOR 90/120V .75HP 129/134V .144KW |
| 9N5930002966327 SWITCH,TOGGLE | 211010284 SWITCH TGL 8684-PS |
| 9N5950005380028 CORE,ELECTROMAGNET | 211040001 RELAY STRTR ENG ELECL 24V MDL 18-MS-24 |
| 9G6250001588924 LAMPHOLDER | 220010058 SWITCHBOARD IC ENG RM FWD |
| 9G1680008793081 CONTROL ASSEMBLY,PU | 221510001 SWITCHBOARD DEGUSG PC109D0100-1 |
| 9G6250003104804 LAMPHOLDER ASSEMBLY | 232060034 SEARCHLIGHT 18 IN DCY-18-44043A |
| 9G6220006889825 CAP AND SPRING ASSY | 232470001 LIGHT IND GU63041 |
| 9G6150012138771 HOUSING,ELECTRICAL | 241130077 SEARCHLIGHT 10 IN SNLG 10SL8168E-2 |
| 9K5930010351785 SWITCH,ROTARY | 249990670 LIGHT SNL TY A PRTL |
| 9G6250003346672 LAMPHOLDER | 259200008 PLOTTING BOARD SHSTS |
| 9C3040012402623 CONNECTING LINK,RIG | 260150001 PROJECTOR SMP 90-25EMI |
| 9G6250008460945 LAMPHOLDER | 282130001 PLOTTING TABLE MK NC2 MOD2 |
| 9G6670008984499 WEIGHT,COUNTERBALAN | 2878[illegible]002 STABLE PLATFORM DWG 1511709 |
| 9C4530003837889 COUPLING,ATOMIZER | 300020001 BURNER OIL PRESS ATMG 2200.00LBS 19.562IN BBL |
| 9C4530009314583 PLATE,SPRAYER,ADAPT | 300080072 BURNER OIL PRESS ATMG 1000.00LBS 32.375IN BBL |
| 9C4460008762460 PULLER,WHEEL | 303000002 BURNER CATALYTIC |
| 9C4530000303112 EXTENSION,ELECTRODE | 309990010F BURNER,OIL PRESSURE |
| 9G2040010337305 ACTUATOR BODY,INTER | 312310001C DOOR MTL SLDG VERT TORP PORT |
| 9G2040010337306 CATCH,INTERLOCK,MAR | 312310001C DOOR MTL SLDG VERT TORP PORT |
| 9Z5340010337447 PLUNGER,DETENT | 312310001C DOOR MTL SLDG VERT TORP PORT |
| 9G2040010337307 ACTUATOR BODY,INTER | 312310002C DOOR MTL SLDG VERT TORP STBD |
| 9Z5340004723997 BRACKET,FIXED CONTA | 31233904 601680-1(12344), PAPER TAPE PUNCH |
| 9Z5340010490257 ARM,TRANSMISSION CH | 31269207 1824(12705), PRINTER |
| 9G6250009279576 LAMPHOLDER | 31349917 208U-3-522-3264-001(13499), AMPLIFIER PWR LINE 3 |
| 9Z5310000035466 NUT,RETAINER PLATE | 31397306 105692-100(13973), AUDIO CONTROL,CCTV |
| 9Z5340006849492 BUTTON,PLUG | 31404101 5-124A(14028) |
| 9G6250006357334 LAMPHOLDER | 31463200 960 VHF(14632) |
| 9Z5360003478583 SPRING,FLAT | 31463311 R-2126/G, RECEIVER |
| 9Z5340001402141 CATCH,MAGNETIC | 31677773 16777301-002, HONEYWELL 96 VP1-12 14 |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9C3020010400944 PULLEY,GROOVE | 31765703 TMS70-MOD1(17691), MAGNETIC TAPE CERTIFIER |
| 9Z3130002710096 BEARING UNIT,ROLLER | 318040005 CHOCK RLR STE 9RLR 4VERT 5HORZ RETR MECHM |
| 9Z5365005768452 RING,RETAINING | 318080005 BOW THRUSTER ASSY-HULLBORNE STEERING |
| 9N5945011725754 RELAY | 320230061 ICE CREAM FREEZER |
| 9N5985000567470 SUPPORT,ANTENNA REF | 32493020 AN/TPN-22 MISCELLANEOUS EQUIPMENT |
| 9G4130002343865 DEHYDRATOR,DESICCAN | 325000167 REFRIGERATION SYSTEM FOOD STO CAP .50TON |
| 9N5945011463614 RELAY,ELECTROMAGNET | 325000443 CONDENSING UNIT |
| 9G4130011112217 FILTER-DRIER,REFRIG | 325000479F REFRIGERATION PLANT MDL 076-59523-001 |
| 9C4820000363760 POWER ASSEMBLY,THER | 325050001 MANIFOLD RFGT LIQ CONT |
| 9C4820007080879 POWER ASSEMBLY,THER | 325050018 MANIFOLD RFGT LIQ CONT |
| 9G4130007782054 FILTER-DRIER,REFRIG | 325130013G REFRIGERATION PLANT AIR CNDN |
| 9G6250007335883 LAMPHOLDER | 32848004 608E PRE 833(28480) |
| 9Z3130008961414 BEARING UNIT,PLAIN | 330080003 AIR CONDITIONER SZ-5 |
| 9N5945010994512 RELAY | 33033150 6/16(30331), PROCESSOR |
| 9Z5340002765849 PLUG,EXPANSION | 340020217 STARTER ENG ELECL MDL 1113162 |
| 9C2920005931558 COLLAR,PINION STOP | 340020249 STARTER ENG ELECL 12V CCW MDL 1109489 |
| 9Z5365002869391 RING,RETAINING | 345000003C STARTER GTRB MDL 36E129-2B |
| 9Z5365005261481 RING,RETAINING | 345000003C STARTER GTRB MDL 36E129-2B |
| 9Z5365005980768 RING,RETAINING | 345000003C STARTER GTRB MDL 36E129-2B |
| 9G6250004786196 LAMPHOLDER | 34829450 RD-445/FYQ-71(V), MAGTAPE TRANSPORT |
| 9C2540010230172 SHAFT AND PIVOT ASS | 350050035B WIPER WND ELEC |
| 9Z5365010399967 BUSHING,WIPER ARM | 350050040 WIPER WND ELEC |
| 9G6350001606741 BUZZER | 36495720 T106-4537(64959), POWER COORDINATOR UNIT 367 |
| 9Z5360002363727 SPRING,FLAT | 38000969 475(80009), OSCILLOSCOPE |
| 9G6250000651744 LAMPHOLDER | 38001009 491 DD963(80009), SPEC ANALYZER |
| 9Z5310009101030 NUT,SELF-LOCKING,CL | 38006412 SM-F-795900(80063), INTERCONNTING GR AN/FSC-78A |
| 9C5410009194958 STEP | 38190245 S-598/SSQ-74(V), SHELTER,ELECTRICAL EQUIPMENT |
| 9Z5365005978475 RING,RETAINING | 382030001 INDICATOR 3UNIT LPHLDR RFLTR OBSN |
| 9N5945008664121 RELAY,ELECTROMAGNET | 38560400 KS36-30M(85604), POWER SUPPLY |
| 9G6250002994727 LAMPHOLDER | 38827250 883 PM MODEM W/SHELF GA-465 |
| 9N5999009383531 DELAY LINE | 38939901 CV-2511/USQ-34(V), DISPLAY ADAPTER |
| 9C4720009045063 HOSE ASSEMBLY,NONME | 390010086 TRANSMISSION HYD X207266D |
| 9Z5365005141303 RING,RETAINING | 390040002 CLUTCH MAG PARTICLE 99X73 |
| 9C3040013320121 BUTTRESS PLATE,MAGN | 390730001 CLUTCH,ELECTRIC FEA047599135100-100VDC |
| 9N5935002599850 STRAP NUT,PLUG-IN E | 39141700 TDMS(91417) |
| 9N5935002599853 STRAP NUT,PLUG-IN E | 39141700 TDMS(91417) |
| 9N5935006860220 STRAP NUT,PLUG-IN E | 39141700 TDMS(91417) |
| 9G6250001866390 LAMPHOLDER | 39484603 01100-512-1(94756), FTAS SYS VP CONFIGERATION |
| 9N5945011205551 RELAY,ELECTROMAGNET | 39484634 01100-512-21(94756), VP FTAS 15 |
| 9C3010010263999 COUPLING HALF,SHAFT | 400270049 DAMPER-VENT |
| 9S1430009809232 ARM,DAMPER | 400350016 DAMPER COMB CONT |
| 9Z3130011881973 CAP,PILLOW BLOCK | 400560182 FAN VNXL |
| 9C3040000038615 LEVER,MANUAL CONTRO | 418110149 SAW RDL OVRM WWKG 16IN 230/460V AC MDL3571 |
| 9C4310010034191 PNEUMATIC MUFFLER,E | 418540015 MOTOR PNEUM 4AM-NRV-70C |
| 9C4540009478196 HEATING ELEMENT,ELE | 430000423 FRYER D FAT ELEC 60LBS FAT 18.0KW AC 440V |
| 9N5945013937267 RELAY,ELECTROMAGNET | 430150032 MEAT SLICING MACHINE ELEC MDL 775LR 115VAC |
| 9C4540001144361 HEATING ELEMENT,ELE | 431530046 FRYER D FAT ELEC AC 480V 40LB |
| 9C3040001418909 BALL JOINT | 440020001 DEHUMIDIFIER DSCC ELEC SZ 36-255 |
| 9C4810011305529 VALVE ASSEMBLY,DRAI | 440300029 DEHYDRATOR FLTR RFGT 30SCFM |
| 9C4910011745943 ADAPTER,DIESEL TEST | 460920005 TESTER DIESEL FUEL INJECTOR NOZZLE |
| 9Z5365000579848 RING,EXTERNALLY THR | 464780001 TEST STAND HYD VL |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9Z5365002056711 RING,RETAINING | 467340006 DYNAMOMETER RUN IN CLOSED SYS |
| 9Z5365005762561 RING,LOCK,SERRATED | 480020214 FILTER FDPRESS MDL R9W1531 |
| 9Z5365006190824 RING,RETAINING | 480020219 FILTER FDPRESS MDL R9W1549/OIL |
| 9C4460011223428 FILTER,AIR,ELECTROS | 480790022 PRECIPITATOR ELCTSTC |
| 9C4460011977754 SCREEN | 480790049 FILTER AIR ELCTSTC 44-9581 |
| 9C2910001767147 VALVE,IDLE ADJUSTIN | 490040009 CARBURETOR TY UPDFT MDL 62AJ10 |
| 9Z5365003602562 RING,RETAINING | 49402533 AN/SPG-51C,RADAR SET PHASE 2B XMTR BASELINE MODS |
| 9N5960006174721 INSERT,ELECTRON TUB | 49402533 AN/SPG-51C,RADAR SET PHASE 2B XMTR BASELINE MODS |
| 9N5960006174722 INSERT,ELECTRON TUB | 49402533 AN/SPG-51C,RADAR SET PHASE 2B XMTR BASELINE MODS |
| 9N5960006174723 INSERT,ELECTRON TUB | 49402533 AN/SPG-51C,RADAR SET PHASE 2B XMTR BASELINE MODS |
| 9N5945007360179 RELAY,ELECTROMAGNET | 49402708 MK9MOD0,MOTOR,GENERATOR |
| 9Z5340002286379 POST,ELECTRICAL-MEC | 49402967 MK5MOD0,TELEVISION,LOW LIGHT LEVEL |
| 9N5920010862213 FUSEHOLDER,BLOCK | 502110009 PANEL PWR DISTRN SK28373-3 |
| 9N5945011792448 RELAY,ELECTROMAGNET | 509990821F PANEL FIRE SAFTEY WMEC555-008 |
| 9G6250009247876 LAMPHOLDER | 51547719 AN/GSH-19 |
| 9Z5305002254897 JACKSCREW,SHORT FEM | 51547729 AN/GSH-33(V) |
| 9Z5340006795152 POST,MDA COMPONENT | 51547916 AN/GSH-25A |
| 9Z5340012634381 ASSY,LIFTING PLATE | 520760003 E-54/SQA-13(V), HOIST MECHANISM,SONAR |
| 9C3010011367717 COUPLING,SHAFT,RIGI | 520760033 POWER SUPPLY HYD |
| 9C2590011247647 FILLER NECK | 520770003 POWER UNIT HYDRAULIC |
| 9G6250004982563 LAMPHOLDER | 52502683 AM-4783/GRC-159(V), AMPLIFIER,RADIO FREQUENCY |
| 9C3020006062898 SPROCKET WHEEL | 52504907 AM-2155/SPS-37, AMPLIFIER ASSEMBLY |
| 9C3040011429785 END FITTING,FLEXIBL | 29907010 POWER SUPPLY ASSY. |
| 9N5935005491239 STRAP NUT,PLUG-IN E | 53478100 AN/APX-1, RADAR EQUIPMENT |
| 9Z5365003514715 RING,RETAINING | 54057600 AN/BPS-4, RADAR SET |
| 9Z5365007765938 RING,RETAINING | 54059400 AN/BQA-3, COMPUTER-INDICATOR GROUP |
| 9C3020005417418 SPROCKET WHEEL | 54066105 AN/BQR-2B, LISTEN SET, SONAR |
| 9C3020005417419 SPROCKET WHEEL | 54066105 AN/BQR-2B, LISTEN SET, SONAR |
| 9C3020009218263 SPROCKET WHEEL | 54068215 AN/BQS-4C, DETECTING-RANGING SET,SONAR |
| 9G6250006830124 LAMPHOLDER | 54068697 AN/BQS-8(XN-2), DETECTING SET,INTEGRATED ICE |
| 9N5950001479942 CORE,ELECTROMAGNET | 54070005 AN/BRN-6, NAVIGATION SET,RADIO |
| 9N6060010448603 CONNECTOR,PLUG,FIBE | 54634410 AN/FAC-2A(V) MISC |
| 9G6250000011528 LAMPHOLDER | 54649610 AN/FGC-158X, TELETYPEWRITER SET |
| 9G6250005778347 LAMPHOLDER | 54672196 AN/FLR-7(XN-1), RECEIVING SET,COUNTERMEASURES |
| 9Z5365005434203 RING,RETAINING | 54745200 AN/FPN-36, RADAR SET |
| 9Z5340002910502 PLUG,PROTECTIVE,DUS | 54745752 AN/FPN-52, RADAR SET |
| 9N5950006173184 COVER,ELECTRICAL TR | 54745752 AN/FPN-52, RADAR SET |
| 9N5950006173186 COVER,ELECTRICAL TR | 54745752 AN/FPN-52, RADAR SET |
| 9G6350002699820 BUZZER | 54767405 AN/FPS-6A, RADAR SET |
| 9N5999005017201 CAP,ELECTRICAL | 54767410 AN/FPS-6B, RADAR SET |
| 9G5975002960539 LOCKNUT,ELECTRICAL | 54767411 AN/FPS-20U, LONG RANGE SEARCH RADAR |
| 9Z5365002633841 RING,RETAINING | 54883000 AN/FRR-10, RECEIVING SET,RADIO |
| 9G7105002051578 MIRROR,GLASS | 54884100 AN/FRR-21, RECEIVING SET, RADIO |
| 9G6150004718925 BUS,CONDUCTOR | 54905700 AN/FRT-3, TRANSMITTING SET,RADIO |
| 9C3040002946813 COUPLING HALF,SHAFT | 54905901 AN/FRT-5A, TRANSMITTING SET,RADIO |
| 9N5935001749101 STRAP NUT,PLUG-IN E | 54907100 AN/FRT-17, TRANSMITTING SET, RADIO |
| 9N5920007991348 FUSING ASSEMBLY | 54908500 AN/FRT-31, TRANSMITTING SET, RADIO |
| 9C3010000609417 COUPLING,SHAFT,RIGI | 54909320 AN/FRT-39D, TRANSMITTING SET, RADIO |
| 9G5975009042527 CLAMP,ELECTRICAL CO | 54912000 AN/FRT-67, TRANSMITTING SET,RADIO |
| 9G6150009168593 BUS,CONDUCTOR | 54912000 AN/FRT-67, TRANSMITTING SET,RADIO |
| 9G6150009168595 BUS,CONDUCTOR | 54912000 AN/FRT-67, TRANSMITTING SET,RADIO |

| NSN. PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9C3010001483672 COUPLING,SHAFT,RIGI | 54914205 AM-6048/FRT-85(V), AMPLIFIER |
| 9C4310006403774 BREATHER | 54925673 AN/FSC-78(V) MISC PARTS, SATCOM TERMINAL |
| 9Z3130012549269 CAP,PILLOW BLOCK | 550140002 REELING MACHINE CBL NMAG |
| 9Z3110002770153 BEARING,ROLLER,SELF | 550140003 REELING MACHINE CBL NMAG |
| 9Z3110002710015 BEARING,ROLLER,SELF | 550140005 REELING MACHINE CBL NMAG |
| 9Z5360009674181 SPRING,FLAT | 550200045 REELING MACHINE CBL SPR DR |
| 9G5977001457335 SUPPORT, ELECTRICAL | 550200099 REELING MACHINE CBL SPR DR |
| 9Z5365002054722 RING,RETAINING | 55376100 AN/GRC-27, RADIO SET |
| 9Z5365002007282 RING,RETAINING | 55376101 AN/GRC-27A, RADIO SET |
| 9G6250009595446 LAMPHOLDER | 55430915 AN/GRN-9C, RADIO SET |
| 9Z5365012079684 SPACER,SLEEVE | 560270011 DAVITS BOAT BOOM LH |
| 9G5975002960541 LOCKNUT,ELECTRICAL | 56031296 AN/MPS-26 MOD, RADAR SET |
| 9N5945006447117 RELAY ASSEMBLY | 56169900 AN/MRN-9, TRANSMITTING SET,RADIO |
| 9Z5340005655647 CLIP,WIRE | 56242063 AN/MSC-66 OPERATION VAN |
| 9G6250009959074 LAMPHOLDER | 56242063 AN/MSC-66 OPERATION VAN |
| 9N5935009519881 STRAP NUT,PLUG-IN E | 56616100 AN/PRC-25, RADIO SET |
| 9Z5365002007293 RING,RETAINING | 56617797 AN/PRC-41(XN-2), RADIO SET |
| 9C3010002571710 COUPLING,SHAFT,RIGI | 56919800 AN/SPN-20, BEACON,RADIO |
| 9C3010009832723 COUPLING HALF,SHAFT | 56945200 AN/SLR-10 |
| 9G6250002205345 LAMPHOLDER | 56982410 AN/SPA-25, INDICATOR GROUP |
| 9Z5310009221667 WASHER,SPHERICAL,AS | 56986401 AN/SPA-72, ANTENNA,ROTATING S-BAND |
| 9N5935002592577 STRAP NUT,PLUG-IN E | 56986673 AN/SPA-73, INDICATOR GROUP |
| 9N5840000049401 SLEEVE L S GEAR | 56986693 AN/SPA-72B, ANTENNA GROUP |
| 9G6250002839679 LAMPHOLDER | 57036600 AN/SPS-10, RADAR SET |
| 9C2805006181085 BREATHER | 57036649 AN/SPS-10 FC5 |
| 9N5999010650167 PLATE,ELECTRICAL SH | 57040405 AN/SPS-48A(V), RADAR SET |
| 9N5999010162750 CAP | 57041000 AN/SPS-55, RADAR SET |
| 9Z5365000107658 RING,RETAINING | 57091608 AN/SQS-26AXR, DETECTING-RANGING SET,SONAR |
| 9Z5310007946035 WASHER,SPECIAL | 57091608 AN/SQS-26AXR, DETECTING-RANGING SET,SONAR |
| 9N5895000894231 COVER,ELECTRONIC CO | 57112000 AN/SRC-20, RADIO SET |
| 9N5895000894229 COVER,ELECTRONIC CO | 57112100 AN/SRC-21, RADIO SET |
| 9Z5365005590637 RING,RETAINING | 57129740 AN/SRN-6, RADIO SET |
| 9C3010000498782 COUPLING HALF,SHAFT | 57153400 AN/SRT-16, TRANSMITTING SET, RADIO |
| 9C3010000498783 COUPLING HALF,SHAFT | 57153400 AN/SRT-16, TRANSMITTING SET, RADIO |
| 9C3040002884409 COUPLING HALF,SHAFT | 7153400 AN/SRT-16, TRANSMITTING SET, RADIO |
| 9C3010002945546 COUPLING HALF,SHAFT | 57153400 AN/SRT-16, TRANSMITTING SET, RADIO |
| 9C3040003120780 COUPLING HALF,SHAFT | 57153400 AN/SRT-16, TRANSMITTING SET, RADIO |
| 9Z5365001366130 RING,RETAINING | 572570006 CRANE PDSTL |
| 9C3040004471931 LEVER,MANUAL CONTRO | 57441102 AN/TNH-11(V) |
| 9G6250010191321 LAMPHOLDER | 57599665 AN/TPS-65, RADAR SET |
| 9C3810013951192 PAD,SLIDE,CRANE | 578880096L CRANE ASSY MODEL AMD-949 |
| 9C3950000048342 PLATE,FRICTION | 580230041 HOIST ELEC WIRP PWRDN TRLY CAP 2000LBS |
| 9Z5340010455473 PLUG,VENT | 581060026 TORPEDO HNDL EQPT |
| 9G6250000161715 LAMPHOLDER | 58118001 AN/UAT-2A, TRANSMITTING SET,INFRARED |
| 9G6250000011527 LAMPHOLDER | 58138788 AN/UGC-109, TELETYPEWRITER SET |
| 9N5815008596551 BAR,SELECTOR,TELETY | 58139088 AN/UGC-41, TELETYPEWRITER SET |
| 9N5985003784733 PROBE,WAVEGUIDE | 58253800 AN/UPA-22, ANTENNA GROUP |
| 9N5935006551423 STRAP NUT,PLUG-IN E | 58284900 AN/UPM-99, TEST SET,RADAR |
| 9N5935003571592 CONNECTOR,ELECTRON | 58286300 AN/UPM-115,CALIBRATOR,RANGE |
| 9G5940010438558 TERMINAL STRIP,GROU | 58289804 AN/UPM-98D, RADAR TEST SET |
| 9F3040009854145 BALL JOINT | 58502705 AN/URN-20B(V)2, RADIO SET |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9C3040004828279 BALL JOINT | 58502706 AN/URN-20B(V)1, RADIO SET |
| 9Z5340007863758 POST,ELECTRICAL-MEC | 58537055 AN/URR-52B, RECEIVING SET |
| 9C3010002541145 COUPLING,SHAFT,RIGI | 58556509 AN/URT-7C, TRANSMITTING SET, RADIO |
| 9G5970005183356 INSULATOR,STANDOFF | 59010100 AN/WRT-1 SER 1-141, TRANSMITTING SET, RADIO |
| 9C3020007620080 SPROCKET WHEEL | 59010104 AN/WRT-1A 93346, TRANSMITTING SET,RADIO |
| 9C3910009598891 CARRIER LINK | 590390008 CONVEYOR VERT TRAY TY CAP 175LBS @ 72FPM |
| 9Z5315009694289 PIN,CHAIN | 590390023 CONVEYOR VERT TRAY TY CAP 175LBS @ 72FPM |
| 9C3910009155285 LINK,INNER CARRIER | 590390055 CONVEYOR VERT TRAY TY CAP 175LBS @ 72FPM |
| 9C3910004976779 CARRIER LINK,OUTER | 590390058 CONVEYOR VERT TRAY TY CAP 3000LBS @ 30FPM |
| 9C3910004757791 LINK,CARRIER | 590390110B CONVEYOR VERT TRAY TY CAP 85LBS @ 56FPM |
| 9C3010002946798 COUPLING HALF,SHAFT | 59148401 AS-484A/SPS-8, ANTENNA |
| 9N5985011415470 BOTTOM COVER ASSY | 59201800 AS-1018/URC, DIPOLE,OMNIDIRECTIONAL |
| 9N5840010362238 RETAINER,ELAPSED TI | 59226806 AS-3263/SPS-49(V), ANTENNA |
| 9N5985011575190 LINE,RADIO FREQUENC | 59226806 AS-3263/SPS-49(V), ANTENNA |
| 9Z5340012083381 BREATHER | 59226806 AS-3263/SPS-49(V), ANTENNA |
| 9N5985001392348 ADAPTER,WAVEGUIDE | 59309930 AS-2591/BLA-4(V), ANTENNA ASSEMBLY |
| 9Z5365000915266 RING,RETAINING | 59368600 AT-186/UQC-1, TRANSDUCER,SONAR |
| 9C3020001320550 PULLEY,GROOVE | 598880067 ELEVATOR WEAPON HANDLING L.S. 6 |
| 9Z5365005796114 RING,RETAINING | 600280002 STEERING GEAR ELEC HYD RAM TYPE PF-42156 |
| 9C3040008012699 BALL JOINT | 611040030 CONTROL MECH MDL MT-HD 1LEV |
| 9C3040011612772 BALL JOINT | 611040052 CONTROL ASSY ENG 1HNDL |
| 9G6680010532477 SENSOR,ULTRASONIC,L | 611390004B CONTROL UNIT D10025 |
| 9Z5365004173557 RING,RETAINING | 612010171Z CONTROL MDL 58N FLOW TRMT W/VARI ELEMENT |
| 9G6685001874309 PLATE AND STUD ASSE | 612010194 CONTROL VL FO 21N 300PSI |
| 9N5905012103753 BRACKET ASSEMBLY,RE | 612190045 CONTROL BOX,MOTOR GENERATOR |
| 9G6250004470282 LAMPHOLDER | 61311300 C-3113/WIH, CONTROL,REMOTE SWITCH |
| 9G6250008861712 LAMPHOLDER ASSEMBLY | 61367495 C-3674A/USQ-20(V)-SYLVANIA, CONT,INTRODUCER |
| 9G5975011877340 HANGER,CABLE | 616050481 CONSOLE DAMAGE CONTROL 63E901682G4 |
| 9G5975011877341 HANGER,CABLE | 616050481 CONSOLE DAMAGE CONTROL 63E901682G4 |
| 9N5999011914476 COVER,PROTECTIVE | 616050481 CONSOLE DAMAGE CONTROL 63E901682G4 |
| 9Z5365006498045 RING,RETAINING | 616350044 ACTUATOR ASSY HYD DVG |
| 9C3040011982940 CAP,LINEAR ACTUATIN | 616700001 SERVO GEAR TRAIN |
| 9N5999008502022 CAP,ELECTRICAL | 61883384 236(93346) |
| 9N5935009865805 CONNECTOR,ELECTRON | 61897221 DAS-10A(91417) |
| 9N5945009058135 LINK | 61901815 AG-440B(92739) |
| 9C4410012328964 CLAMP ASSEMBLY | 619040086 CONTROL ACTUATOR DOUBLE ACTING MDL 10035 |
| 9C4410012328183 POINTER,ACTUATOR | 619040121 CONTROL PNEUM ACT |
| 9C4410012328963 ARM ASSEMBLY,LOCKIN | 619040121 CONTROL PNEUM ACT |
| 9Z5365000786268 RING,RETAINING | 61905205 SP-300(92739), RECORDER,TAPE |
| 9N5945011429580 RELAY,ELECTROMAGNET | 619990136 CONTROLLER THREE WINCH FLSD4010 |
| 9C3040011948084 LEVER,MANUAL CONTRO | 620420055 WINCH ELEC 2DM GYP MAX CAP 1200LBS105FPM LH |
| 9Z5325010124095 FASTENER,PANEL | 62263920 0N221777(98230), MULTIPLEXAR |
| 9N5935012074834 CONNECTOR,ELECTRICA | 62264121 TD-1271B/U, UHF DAMA MUX-DEMUX |
| 9Z5340002708532 BUTTON,PLUG | 62365000 CN-186/U, REGULATOR, LINE VOLTAGE |
| 9N5999000547008 RELAY-SWITCH | 62392200 MICROWAVE-SET(13499) |
| 9Z5360009581143 SPRING,DOOR,ADJUSTA | 62758086 CV-1686/BQS-6B, SWITCH ASSY,PHASE SHIFTING |
| 9G6150008506471 BUS,CONDUCTOR | 62762690 CV-1123/USQ-20(V), CONVERTER,DIGITAL DATA |
| 9G6150008515136 BUS,CONDUCTOR | 62762690 CV-1123/USQ-20(V), CONVERTER,DIGITAL DATA |
| 9Z3120005112336 WASHER HALF,THRUST | 62773406 KS-5574-01L230A(64959) |
| 9G6250004352654 LAMPHOLDER | 62775001 ID-1344/FQA-7(V), ANNUNCIATOR UNIT 475 |
| 9G6250002300920 LAMPHOLDER | 62775236 G612782(64959) |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9C3020013149388 SPROCKET WHEEL | 629990109 WINCH ELECTRIC |
| 9C4210010735568 ADAPTER,RECHARGING | 640060032 FIRE EXTINGUISHING SYSTEMS FIXED CO2 |
| 9C4210010747967 LINK ASSEMBLY,FUSIB | 640060033B FIRE EXTINGUISHING SYSTEM FIXED |
| 9Z5365004680331 RING,RETAINING | 650030002 LUBRICATOR MDL SF 4 FD RCHT DR RH |
| 9G6680005706299 GAGE ROD-CAP,LIQUID | 664030003 ENGINE DSL 2 6MDJB3R 6 KW 1800RPM |
| 9C3040009302869 BALL JOINT | 664030017 ENGINE DSL 4 15RDJ3R149C 1800RPM CW |
| 9Z5365010510976 RING,RETAINING | 664030046 ENGINE DSL 3.0DJA-1E/2236U |
| 9Z5340000541415 PLUG,EXPANSION | 664040004 ENGINE DSL 4 GD193 52.5HP 2000RPM |
| 9C2805005663386 SCREW,ADJUSTING,VAL | 664100009 ENG DSL MDL DSD-662/2714E 380 CID 6CYL 75HP |
| 9G6150006357760 BUS,CONDUCTOR | 664470005 ENGINE DSL 6 DD ORIG TY HD 105HP 1885RPM CW |
| 9Z5340002683508 PLUG,EXPANSION | 664810019 ENGINE DSL 4 D8800 77HP 900RPM CCW |
| 9C2520003627883 HANDLE,CLUTCH LEVER | 664810041 ENGINE DSL 12 D397 452HP 1200RPM CCW |
| 9Z5365002825583 RING,RETAINING | 664810079 ENGINE DSL 6 D353TA 400HP 900RPM CW |
| 9Z5365002570203 RING,RETAINING | 665060001 ENGINE DSL 6 HSGA-601 120HP 1200RPM CCW |
| 9C2815003902451 LOCK,VALVE SPRING R | 665360001 ENGINE DSL 10 38D8 1-8 1800HP 800RPM CW |
| 9C2815009690219 PULLER ASSEMBLY | 665360164 ENGINE DSL 10 38ND8 1-8 1440HP 720RPM CCW |
| 9C2990012022014 CABLE,CONTROL ENGIN | 665360202 ENGINE DSL 8 38D8 1-8 1070HP 720RPM |
| 9Z5340004154596 HANDWHEEL,COVER | 665710001 ENGINE DSL 6 6-278 650HP 800RPM CCW |
| 9Z5365006017546 RING,RETAINING | 665710001 ENGINE DSL 6 6-278 650HP 800RPM CCW |
| 9Z5365006197309 RING,RETAINING | 665710003 ENGINE DSL 3 3-268A 145HP 1200RPM CCW |
| 9C2815003663555 PLATE,BLOWER | 665710290 ENGINE DSL 12 12-567C 1080HP 720RPM CCW |
| 9C3040008208104 BALL JOINT | 666010048 ENGINE DSL 6 6-71RC28H6051 225HP 2100RPM CCW |
| 9C2990004580200 ARRESTOR,SPARK,EXHA | 666010055 ENGINE DSL 6 6-71RC56 6083 143HP 1200RPM CCW |
| 9Z5365005503732 RING,LOCK,SERRATED | 666010106 ENGINE DSL 4 4901ANM 127HP 1800RPM CCW |
| 9C2590005742467 CONTROL ASSEMBLY,PU | 666010189 ENGINE DSL 4 5043-72014-53RC 87HP 2200RPM CCW |
| 9Z5340007865663 PLUG,EXPANSION | 666010248 ENGINE DSL 12 7122-300012V71L 400HP 2100RPM CW |
| 9C2990004906204 BOLT LATCH,AIR INTA | 666010301 ENGINE DSL 4 5044-8000 4-53NRO 93HP 1890RPM |
| 9G6150009129093 BUS,CONDUCTOR | 666010359 ENGINE DSL 4 1043-7005-4-71RC |
| 9C2990008138207 LEVER,REMOTE CONTRO | 666010451F ENGINE DSL 1063-7305SHIPALT180C-B-400 |
| 9C3040007353477 CONNECTING LINK,RIG | 666018000 ENGINE DSL 4 4150E4-71RC 75KW 1800RPM CCW |
| 9Z5365003646662 RING,ADJUSING,FUEL | 666510006 ENGINE DSL 6 DWXDS 98HP 1800RPM CCW |
| 9C4710005920349 TUBE ASSEMBLY,METAL | 666510022 ENGINE DSL 6 DFXE 76HP 1200RPM CCW |
| 9C2815007184764 SCREW,ADJUSTING,VAL | 666510034 ENGINE DSL 4 DD198PU 41.0HP 1500RPM CCW |
| 9Z5340002765835 PLUG,EXPANSION | 666510035 ENGINE DSL 4 D2300X45 HP RPM |
| 9C2910003560837 BAIL,SEDIMENT BOWL | 668020001 ENGINE GAS 1 B 2.75HP 3200RPM CCW |
| 9C2910003537614 LINK,CARBURETOR | 668020014 ENGINE GAS 1 233434-0023A 7.21HP 2400RPM |
| 9Z5310006240421 NUT,CONTROL ROD | 668020017 ENGINE GAS 1 142302TY0016-01 6HP 3600RPM |
| 9C3040001065618 BALL JOINT | 668200030 ENGINE GAS MDL F227 4254 6CYL 2400RPM |
| 9Z5365009115307 RETAINING,RING | 668250018 OUTBOARD MOTOR GAS 18 HP MDL 1960 15032 |
| 9C2910000771712 LEVER,REMOTE CONTRO | 668250026 OUTBOARD MOTOR GAS 18 HP MDL 18903DE02632 |
| 9C2805001247091 DRIVER CUP | 668560007 ENGINE GAS 8 MERCRUISER250 250HP 4200RPM |
| 9C3040004597062 CONNECTING LINK,RIG | 668560009 ENGINE GAS 8 MERCRUISER325 325 HP 4200RPM |
| 9C3040002882655 BALL JOINT | 668570011 ENGINE GAS 4 L600 2KW 1800RPM |
| 9C3010004158441 COUPLING HALF,SHAFT | 668650001 ENGINE GAS 12 4M2500 W14 1350HP 2400RPM CW |
| 9Z5365008363589 RING,RETAINING | 668900033 ENGINE GAS 4 VE4DSPEC187762 HP RPM CW |
| 9C2805008678819 BREATHER | 668900035 ENGINE GAS 4 4AC84&3 20HP |
| 9C2805009273910 ENGINE MOUNT,FRONT | 668900035 ENGINE GAS 4 4AC84&3 20HP |
| 9Z5365006850772 RING,RETAINING | 690070011 GEAR OPERATING . IN SHAFT |
| 9C3020011768540 ADAPTER | 691020008E GEAR ASSY SPD DECR MN 46296R1 |
| 9C2010011780702 RING,PROTECTION | 691020008E GEAR ASSY SPD DECR MN 46296R1 |
| 9C2010011786513 SUPPORT,COLLAR | 691020008E GEAR ASSY SPD DECR MN 46296R1 |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9Z5360002130480 SPRING,BRAKE RELEAS | 691200003 GEAR ASSY SPD DECR STBD 2.29 TO 1 RTO |
| 9Z5365002007203 RING,RETAINING | 691200093 GEAR ASSY SPD DECR MN PORT 3.794 TO 1 RTO |
| 9Z5365000673732 RING,RETAINING | 691300114 GEAR ASSY SPD DECR MN . TO RTO |
| 9Z5365009145837 RING,RETAINING | 692510055 GEAR ASSY SPEED REDUCER |
| 9G5975001410554 EXTENSION,CABLE RAC | 69275129 IP-929/BLR-10A, INDICATOR, AZIMUTH |
| 9G5975004893162 EXTENSION,CABLE RAC | 69275129 IP-929/BLR-10A, INDICATOR, AZIMUTH |
| 9C2910003750138 CONNECTOR | 701070098 GOVERNOR MECH DENG OVSP GC-3015-D |
| 9C2990003917600 BALLHEAD | 701110016 GOVERNOR HYD DENG REGG 011292 |
| 9Z5340003541147 PLUG,EXPANSION | 701110063 GOVERNOR HYD DENG REGG 040430 |
| 9Z5340005934301 BUTTON,PLUG | 701110271 GOVERNOR ELEC TURB 8250003 |
| 9Z5365001015903 RING,RETAINING | 701110292 GOVERNOR HYD DENG REGG 8240-002 |
| 9Z5307002361861 STUD LOCKED IN,KEYE | 701110353 GOVERNOR HYD GTRB OVSP 407570 |
| 9Z5365010132182 RING,RETAINING | 701110374B GOVERNOR HYD DENG REGG 9900-112 |
| 9C2990001262487 SPRING,RETAINER | 702060001 GOVERNOR HYD DENG REGG B101B |
| 9C2990001261892 RETAINER,ADJUSTING, | 702060003 GOVERNOR HYD DENG REGG B110E |
| 9C2990003644434 NEEDLE,GOVERNOR | 702060003 GOVERNOR HYD DENG REGG B110E |
| 9Z5340008041208 CAP,PROTECTIVE,DUST | 702080005 GOVERNOR MECH GENG REGG T-84-H |
| 9G5975009551714 SLEEVE,GROUNDING,RA | 71192100 KWF-1/TSEC SER 1-4292, MOUNT,SLIDE |
| 9G5975009551715 SLEEVE,GROUNDING,RF | 71192100 KWF-1/TSEC SER 1-4292, MOUNT,SLIDE |
| 9G6250009952923 LAMPHOLDER | 720020129 LANDING CRAFT MECHZ MK6 MOD2 |
| 9C2990003081930 CONTROL ASSEMBLY,PU | 720380009 SWIMMER DELIVERY VEHICLE MK IX |
| 9Z5310005720218 NUT,CAP | 720390044 TRANSPORTER, DRY DECK SHELTER |
| 9N5945011864167 RELAY,ELECTROMAGNET | 72734492 2032(29736), MAGNETIC DRUM,DATA STORE UNIT 1014 |
| 9Z5365006600977 RING,RETAINING | 73003350 M-33/MSQ-44 |
| 9C2910004460013 NOZZLE,AIR EJECTOR | 730060014 EJECTOR ASSEMBLY 135PSI 2NZL 2STG DSTL |
| 9Z5365005984304 RING,RETAINING | 74673503SB MK25MOD8,RADAR EQUIPMENT |
| 9C3040001522431 SPINDLE,MECHANICALL | 760010001 PURIFIER CTFGL LO 125GPH |
| 9C4330001522451 BEARING PLACER,OIL | 760010001 PURIFIER CTFGL LO 125GPH |
| 9C3040001522430 SPINDLE,MECHANICALL | 760010005 PURIFIER CTFGL LO 250GPH |
| 9C4330012117100 RETAINER | 760010109C PURIFIER CTFGL FO 135GPM |
| 9G6250001589025 LAMPHOLDER | 77261005 NGA-1, SOUND EQUIPMENT,ECHO |
| 9Z5340010590053 KEY,SOCKET | 77899888 O-1107/SRC-16, FREQUENCY STANDARD |
| 9N5999006438169 CAP,ELECTRICAL | 77946100SA OA-460/SPS-8A, RCVR-TRANSMITTER GRP,RADAR |
| 9C4730002033615 COUPLING,CLAMP,PIPE | 780060004 COUPLING CLP PP2.5IN STYLE 77 GRADE T |
| 9C3010003034180 COUPLING,SHAFT,RIGI | 78036600 OA-496/SSA, SWITCHING GROUP,DATA |
| 9C3040003439712 DISC,BRAKE | 782650014 COUPLING SHFT FLEX MAX BORE 1.500 INTNL GR TY |
| 9G6150006660860 BUS,CONDUCTOR | 78730700 OS-8/U, OSCILLOSCOPE |
| 9Z5365003146642 RING,RETAINING | 800020044 BRAKE ELEC TORQ MTR 10.0IN 125FTLB 440VAC DRPR |
| 9Z5340003559533 RETAINER,SPRING | 81151100 R-1511/GR, RECEIVER,RADIO |
| 9Z5340006641824 BUTTON,PLUG | 81151313 R-1696/GGR |
| 9C3020010263215 CHAIN ASSEMBLY,ROTA | 813030060 HEAD SOOT BLR ROT ROTN CCW 360DEG CHN DR |
| 9N5905002579197 HOLDER,RESISTOR | 81449800 RBS, RECEIVING SET, RADIO |
| 9N5999001704460 CAP,ELECTRICAL | 81470205 RBY-1, RECEIVING SET,RADIO-PANORAMIC |
| 9Z5365005140386 RING,RETAINING | 81696100 RD-261/USQ-34(V), RECORDER-REPRODUCER, MTP |
| 9N7025000196957 DRAG PAD ASSY | 81696600 RD-270(V)/UYK, RECORDER REPRODUCER,DIGIT DATA |
| 9N5945011772030 RELAY,ELECTROMAGNET | 820240107 WELDING MACH ARC 208/230VAC INP 24AMP |
| 9Z5365005974636 RING,RETAINING | 831000285 HUB ASSY LEFT HAND |
| 9C2010012049644 DRIVE,DIAPHRAGM | 831000316L ADAPTER DRIVE ASSY |
| 9C2010012059399 ADAPTER,DRIVE SHAFT | 831000316L ADAPTER DRIVE ASSY |
| 9C2805012179296 DEFLECTOR,DIRT AND | 831000316L ADAPTER DRIVE ASSY |
| 9C3020011350007 PULLEY,GROOVE | 832900010 BOW THRUSTER |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9C3020000454485 PULLEY,FLAT | 83317803 RO-312/G, CARD PUNCH,HIGH SPEED |
| 9L6685012687057 GAGE,ABSOLUTE PRESS | 842000163 ANESTHESIA UNIT MODEL:885 |
| 9C3020004588544 SPROCKET WHEEL | 842000210 PROCESSOR,X-RAY FILM MODEL: M6B |
| 9L5945012220675 RELAY,ELECTROMAGNET | 845000156 X-RAY APP R/F |
| 9C2530004006439 NUT,CAP,DUAL WHEEL | 845000290 CLEANER, SEPTIC TANK |
| 9Z5365004484660 RING,RETAINING | 854730001 RECEIVING UNIT MSL TFR FAST |
| 9C3020004956196 PULLEY,GROOVE | 854730001 RECEIVING UNIT MSL TFR FAST |
| 9C3020005715873 PULLEY,GROOVE | 859990735 SLIDING PADEYE SYSTEM RETR |
| 9C3020005746497 PULLEY,GROOVE | 859990735 SLIDING PADEYE SYSTEM RETR |
| 1H1398010108506 CHAIN ADAPTER,KINGP | 859990735 SLIDING PADEYE SYSTEM RETR |
| 1H1398010108507 CHAIN ADAPTER,KINGP | 859990735 SLIDING PADEYE SYSTEM RETR |
| 1H1398010108508 CHAIN ADAPTER,KINGP | 859990735 SLIDING PADEYE SYSTEM RETR |
| 1H1398010108509 CHAIN ADAPTER,KINGP | 859990735 SLIDING PADEYE SYSTEM RETR |
| 1H1398010108510 CHAIN ADAPTER,KINGP | 859990735 SLIDING PADEYE SYSTEM RETR |
| 9G5975006143555 LOCKNUT,ELECT | 86523500 SM-225/GP, SIMULATOR,RADAR TARGET |
| 9N5999007929624 CAP,ELECTRICAL | 86523500 SM-225/GP, SIMULATOR,RADAR TARGET |
| 9N5999007969380 CAP,ELECTRICAL | 86523500 SM-225/GP, SIMULATOR,RADAR TARGET |
| 9N5915005013471 CAPACITOR-RESISTOR | 870070004 AMPLIFIER OSCILLATOR UWTR LOG DWG 24600 |
| 9C4820009599869 COMPRESSION TOOL,AS | 882051938 VALVE GLB W TSTG CSTG 8.00IPS 250PSI FLGE BRZ |
| 9C4820012361264 SEAT ASSEMBLY | 882117599 VALVE RELF PRESS TT 1.00IPS 993T1300PSI FLGE |
| 9C3040011961509 CONNECTING LINK,RIG | 882180307 VALVE SOL 3WAY 1.00IPS 100PSI 115V AC FLGE |
| 9C3040012102823 CONNECTING LINK,RIG | 882181991 VALVE SOL 1.00IPS 150PSI 110V AC FLGE BRZ |
| 9C3040012175773 CONNECTING LINK,RIG | 882181991 VALVE SOL 1.00IPS 150PSI 110V AC FLGE BRZ |
| 9C4810010610420 PLATE,VALVE | 882182576 VALVE SOL .75IPS 1350PSI 32V DC |
| 9Z5340011853616 LEVER,MANUAL CONTRO | 882183298 VALVE SOL 2.00IPS 65PSI 115V AC FLGE BRZ |
| 9C4820012165364 CLAMP,STEM ASSEMBLY | 882220045 VALVE PLT .25IPS 2T 20PSI FLGE BRZ |
| 9Z5365002056729 RING,RETAINING | 882236594 VALVE DRTNL CONT 3WAY HYD 3000PSI GSKT MNT ALUM |
| 9C3040011277221 SHAFT,VALVE | 882241747 VALVE SPCL 1.312-12UN-3B X 1.062-12UN-3A |
| 9Z5365013868158 RING,RETAINING | 882242573 VALVE CONT ENG 10.00IPS 3000PSI FLGE STL |
| 9C4820008543766 DISK,POSITIONING | 882280093 VALVE OPER 4 WAY .50IPS 3000PSI FPT |
| 9Z5365002054236 RING,RETAINING | 882291792 VALVE&BTFL SHUTOFF |
| 9Z5365010987450 RING,RETAINING | 882302065 VALVE B 3WAY 1.00IPS 100PSI SB X FLGE BRZ |
| 9C4820012130075 STEM,FLUID VALVE | 882304242 VALVE B GLB 1.00IPS 720PSI FPT CRBNSTL |
| 9C4820012016721 VALVE,SHUTTLE | 882353006 MANIFOLD 12VL 3000PSI FLGE |
| 9Z5306011856120 BOLT,VALVE | 883117503 VALVE RELF .50IPS 40T 49PSI SBU BRZ |
| 9C3040011865972 LEVER,MANUAL CONTRO | 883117555 VALVE RELF .50IPS 140 T169 PSI MPT X FPT BRS |
| 9C4710012012800 TUBE ASSEMBLY,METAL | 88486220 T-1430/SPS-52C(V), TRANSMITTER RADAR |
| 9N5945012334251 RELAY,ELECTROMAGNET | 890000406 MISCELLANEOUS PARTS LIST FOR CV 0041 |
| 9Z5365004510185 RING,DEE | 890001759 MISCELLANEOUS PARTS LIST FOR SSN 0680 |
| 9N5945012281762 RELAY,ELECTROMAGNET | 890003052 MISCELLANEOUS PARTS LIST FOR IX 0509 |
| 9G3510003897694 LIFTER,BALL | 910000014 EXTRACTOR LDRY 30IN CTFGL TY MDL 7031 |
| 9C4820011820647 VALVE,PILOT | 910190037 PRESS,DRY CLEANING 100PSI TYI CLASS B |
| 9G3510011937085 CLAMP,MOUNTING BRAC | 910250073 LAUNDRY PRESS CMRL PNEUM OPER MDL DFB |
| 9Z5330009691446 SEAL,SHAFT | 910340002 DRY CLN UNIT ASSY MDL 22CO |
| 9G3510009732868 DISK,VALVE,DUMP | 910570009 WASHER-EXTRACTOR LDRY CMRL 100LB CAP MDL 6WE100N |
| 9N5905002522031 HOLDER,RESISTOR | 92010100 TS-403/U, GENERATOR, SIGNAL |
| 9N5905002522035 HOLDER,RESISTOR | 92010100 TS-403/U, GENERATOR, SIGNAL |
| 9N5905002562970 HOLDER,RESISTOR | 92010100 TS-403/U, GENERATOR, SIGNAL |
| 9N5930009954686 SWITCH,ROTARY | 92078901 TS-1379A/U, ANALYZER,SPECTRUM |
| 9Z5340001071673 RETRACTOR,CABLE | 92233576 TS-2476/SRC-23(V), TEST SET-MONITOR RADIO |
| 9Z5340006908890 BUTTON,PLUG | 92600830 KOI-3/TSEC |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9Z5340006908891 BUTTON,PLUG | 92600830 KOI-3/TSEC |
| 9N5935005020006 STRAP NUT,PLUG-IN E | 92601030 TSEC/KO-6A |
| 9G6250006359903 LAMPHOLDER | 92820235 TT-47G/UG, TELETYPEWRITER |
| 9Z5340010208919 LATCH | 950004273 ENG X RETRV SYS ARGR MDL M21 |
| 9Z5340010208923 LATCH | 950004273 ENG X RETRV SYS ARGR MDL M21 |
| 9G1670002942954 RING ASSY,CARGO TIE | 950004567 POWER DISTRIBUTION SYSTEM 604AS244&1 |
| 9C2805008609857 LOCK,VALVE SPRING R | 950012039 ENGINE GAS 8 MDL-V-478 234HP 3600RPM |
| 9C2815000717958 LOCK,VALVE SPRING R | 950012205 ENGINE DSL MDL CH43 |
| 9C2805009628689 SCREW,ADJUSTING,VAL | 950012460 ENGINE GAS 351C |
| 9C2805004354529 LOCK,VALVE SPRING R | 950013067 ENGINE GAS 2 NIC120 |
| 9Z5340001181738 PLUG,EXPANSION | 950013245 ENGINE GAS 6 V6-305C 157 HP 4000RPM |
| 9Z5340000587959 PLUG,EXPANSION | 950013251 ENGINE GAS 4 G193-2228 72 HP 2800RPM |
| 9Z3120004419991 BEARING BRACKET | 950013320 ENGINE DSL 4 G188D 57HP 2000RPM |
| 9C4720003584009 HOSE ASSEMBLY,NONME | 950013519 ENGINE GAS 6 F245 69HP 2250RPM |
| 9G6250001589029 LAMPHOLDER | 950014273 ENGINE GROUP |
| 9Z5365008301626 RING,RETAINING | 950053142 CLUTCH GROUP |
| 9C2920005474335 DRIVE,ENGINE,ELECTR | 950060337 FUEL SYSTEM GROUP |
| 9C2910002463318 PUMP,FUEL,ELECTRIC | 950062516 FUEL SYSTEM GROUP |
| 9C2910006916170 RETAINER,BOWL | 950062524 FUEL SYSTEM GROUP |
| 9C2910009336104 PUMP,FUEL,ELECTRICA | 950063356 FUEL SYSTEM GROUP |
| 9C3040004109698 BALL JOINT | 950063691 FUEL SYSTEM GROUP |
| 9C2920003942701 RELAY-SOLENOID,ENGI | 950064213 FUEL SYSTEM GROUP |
| 9C2540004364579 VALVE,FUEL CONTROL | 950064764 FUEL SYSTEM GROUP |
| 9C4710011269108 TUBE ASSEMBLY,METAL | 950065180 FUEL GROUP |
| 9C2990007166661 CAP,EXHAUST DEFLECT | 950071198 EXHAUST SYSTEM GROUP |
| 9C2990009864126 MUFFLER,EXHAUST | 950072014 EXHAUST SYSTEM GROUP |
| 9C2990004596732 MUFFLER,EXHAUST | 950073154 EXHAUST SYSTEM GROUP |
| 9C2990006893308 MUFFLER,EXHAUST | 950073289 EXHAUST SYSTEM GROUP |
| 9C2990007573675 CAP ASSEMBLY,PROTEC | 950073777 EXHAUST SYSTEM GROUP |
| 9Z5340002470485 BRACKET,MUFFLER | 950074005 EXHAUST SYSTEM GROUP |
| 9C2990004106812 MUFFLER,EXHAUST | 950075491 EXHAUST GROUP |
| 9Z5330010198808 SEAL,ROTARY | 950082706 COOLING SYSTEM GROUP |
| 9G3655005299858 CAP,HYDROGEN GENERA | 950083233 COOLING SYSTEM GROUP |
| 9G6685005153478 GAGE,PRESSURE,DIAL | 950091714 ELECTRICAL SYSTEM GROUP |
| 9C2920009365461 DRIVE,ENGINE,ELECTR | 950092648 ELECTRICAL SYSTEM GROUP |
| 9C2920001170981 DRIVE,STARTER | 950092831 ELECTRICAL SYSTEM GROUP |
| 9G6350004801410 BUZZER | 950093053 ELECTRICAL SYSTEM GROUP |
| 9C2920000743616 RELAY-SOLENOID,ENGI | 950093350 ELECTRICAL SYSTEM GROUP |
| 9C2920012192150 SWITCH,SAFETY,NEUTR | 950095577 ELECTRICAL GROUP |
| 9C2920012167729 SWITCH,SAFETY,NEUTR | 950095880 ELECTRICAL GROUP |
| 9E5930011416333 SWITCH,OVERSPEED | 950096062 ELECTRICAL |
| 9C2920012411659 SWITCH,SAFETY,NEUTR | 950096309 ELECTRICAL GROUP |
| 9C2920013915890 RELAY-SOLENOID,ENGI | 950096396 ELECTRICAL GROUP. |
| 9C2520009144680 BREATHER | 950101884 TRANSMISSION GRP |
| 9C3040008485690 BALL JOINT | 950102080 TRANSMISSION GROUP |
| 9C3040012217822 BALL JOINT | 950105961 TRANSMISSION GROUP |
| 9Z5365006336585 RING,RETAINING | 950142842 FRONT AXLE GROUP |
| 9C3040000378071 CONTROL ASSEMBLY,PU | 950162281 BRAKE GROUP |
| 9Z5305008345549 SCREW,BRAKE ADJUSTI | 950163237 BRAKE GROUP |
| 9C2530009872568 LINK AND PIN ASSEMB | 950163250 BRAKE GROUP |
| 9Z5305004827035 SCREW,BRAKE ADJUSTI | 950163280 BRAKE GROUP |

| NSN, PART DESCRIPTION | PARENT EQUIPMENT |
|---|---|
| 9C2530008939837 SLEEVE,SHOE ADJUSTI | 950164005 BRAKE GROUP |
| 9C2530003262523 ACTUATOR,SIDE AND S | 950164074 BRAKE GROUP |
| 9Z5305008586013 SCREW,ADJUSTING,BRA | 950164248 BRAKE GROUP |
| 9Z5340008480760 DISK,SOLID,PLAIN | 950164752 BRAKE GROUP |
| 9Z5310009315367 NUT,SPECIAL | 950171982 WHEEL GROUP |
| 9Z5307008526542 STUD,WHEEL | 950172225 WHEEL GROUP |
| 9C2530001044367 RING SEGMENT,WHEEL | 950172558 WHEEL GROUP |
| 9Z5365004232586 RING,RETAINING | 950172663 WHEEL GROUP |
| 9Z5306009364715 BOLT,WHEEL | 950172819 WHEEL GROUP |
| 9C2590007739602 PLATE,WORM | 950233921 WINCH GROUP |
| 9G6645007915284 TIMER,INTERVAL | 950302478 ELECTRICAL EQUIPMENT GROUP |
| 9C2940011173679 FILLER CAP ASSEMBLY | 950315636 HYDRAULIC SYSTEM GROUP |
| 9G6680007374077 SHAFT ASSEMBLY,FLEX | 950331897 GAGE X MEASURING DVC GP |
| 9C3040004970395 SHAFT ASSEMBLY,FLEX | 950333631 GAGE X MEASURING DVC GP |
| 9G6685000083349 GAGE,PRESSURE,DIAL | 950333785 GAGE X MEASURING DVC GP |
| 9C3040007591797 SHAFT ASSEMBLY,FLEX | 950335482 GAGES X MEASURING DEVICES GROUP |
| 9C4310008915733 VALVE,BLOW DOWN | 950342212 PNEUMATIC EQUIPMENT GP |
| 9C2530011243416 PIVOT,FRONT AXLE | 950395074 SWEEPING EQUIPMENT GROUP |
| 9Z3130011385142 BEARING UNIT,BALL | 950395074 SWEEPING EQUIPMENT GROUP |
| 9C4930001955738 COUPLING,GREASE GUN | 950403208 SERVICING EQUIPMENT GP |
| 9C4930001955740 ADAPTER,GREASE GUN | 950403208 SERVICING EQUIPMENT GP |
| 9C4210010407812 HANDLE,ROOF TURRET | 950514620 FIRE FIGHTING GROUP |
| 9G5975005714143 HANGER,WIRE STRAND | 950522779 AIR CONDITIONING GROUP |
| 9Z5330005995036 SEAL,PLAIN ENCASED | 950823209 OUTBOARD DRIVE GROUP |
| 9N5945010372153 RELAY,ELECTROMAGNET | 952000846 FRYER DEEP FAT ELEC MDL 22EFSD |
| 9C4820011439052 VALVE,MANIFOLD | 952001393 DRYER AIR FD1500X2 |
| 9G6250001091068 LAMPHOLDER | 95408100 VK, RADAR REPEATER |
| 9C2990008361780 PULLEY,ENGINE START | 954340038 PNEUMATIC EQUIPMENT GP |
| 9Z5340002683515 PLUG,EXPANSION | 955050001 EXPANSION PLUG KIT |
| 9Z5340002683517 PLUG,EXPANSION | 955050001 EXPANSION PLUG KIT |
| 9Z5365006645389 RING,RETAINING | 955220001 KIT SNAP RING 2067 |
| 9Z5365009053633 RING,RETAINING | 955220001 KIT SNAP RING 2067 |
| 9Z5340002765851 PLUG,EXPANSION | 956000016 EONS 02/N2 |
| 9Z5340012997775 BRACKET,ANGLE,SLIDE | 956000016 EONS 02/N2 |
| 9C3020012998530 PULLEY,GROOVE | 956000016 EONS 02/N2 |
| 9C3020012998531 PULLEY,GROOVE | 956000016 EONS 02/N2 |
| 9C3040003768475 PAWL | 956100001 LEA-20 LIGHTWEIGHT EARTH ANCHOR TOOL KIT |
| 9C2805010615268 GUIDE,TIMING | 956100001 LEA-20 LIGHTWEIGHT EARTH ANCHOR TOOL KIT |
| 9Z5310000869910 NUT,SPECIAL | 970010024 RECEIVER MICROW |
| 9C3040000975381 CONNECTING LINK,RIG | 990200001 NOZZLE PRESS FUEL SER |
| 9G2040002465171 NOSE,PROBE ASSY | 990200006 PROBE X CARRIER ASSY 150 PSI |
| 9G2040004426380 HANDLE,SPECIAL | 990200007 RECEIVER ASSY 150 PSI |
| 9Z5365009431044 RING,RETAINING | 990990503S 7L16B AUX AREAS 29-00321 |
| 9Z5365009435321 RING,RETAINING | 992000195 RECOVERY ASSIST, SECURING AND TRAVERSING SYSTEM |

□

# APPENDIX E

## COMBAT SYSTEMS RESULTS
## (SAMPLE OF NSWC LOUISVILLE'S REPORT)

# Table of Contents

## ACTIVE SYSTEMS



## FOREIGN MILITARY SYSTEMS



## INACTIVE SYSTEMS

## Alternative Plating Key

1. Zinc Flake / Chromate IAW MIL-C-87115, Class 3
2. Aluminum Ion Vapor Deposition IAW MIL-C-83488, Class 2, Type II
3. Galvanize (Mechanically) per ASTM B695-85, Class 12, Type II
4. Zinc Electro-deposit per ASTM B633-85, Type II Fe / Zn 12
5. Zinc Plate IAW ASTM B633-78, Type III, Class 2

## Environment Key

A = Above Deck Protected
B = Above Deck Unprotected
C = Below Deck Protected
D = Below Deck Unprotected
E = Various

MK19 MACHINE GUN-1

| PART NUMBER | NOMENCLATURE | MATERIAL | NEXT HIGHER | ENVIR |
|---|---|---|---|---|
| 2814024CAD+GF | CADMIUM GANG | INCLUDED | DL2580275 | |
| 2814024CAD+OW | CADMIUM GANG | INCLUDED | DL2580275 | |
| 2580275CAD+GF | CADMIUM GANG | INCLUDED | LD 624290 | |
| 2580275CAD+OW | CADMIUM GANG | INCLUDED | LD 624290 | |
| 323997CAD+OW+GF | TRAY SUBASSY | INCLUDED | 324003;324129 | |
| 510751-1+GF | SPRING | MIL-S-16846 ASTM A231 OR A232,OIL TEMPERED COND | LD168646 | |
| 510751-1+OW | SPRING | MIL-S-16846 ASTM A231 OR A232,OIL TEMPERED COND | LD168646 | |
| 5209751CAD+OW | PLATE PART | INCLUDED | 5209703 | |
| 2580178 | RETAINER, SPRING | STEEL AISI C1010-C1020 | 2580275 | |
| 2658419 | SIGHT ASSY | STEEL AISI 1010-1020 | 2658436 | |
| 2856795 | PLATE SELECTOR | AISI 1010-1020/AISI 4140-4340 | 2843470 | |
| 2580233 | COUPLING PISTON | STEEL AISI 1010-1020 ALT:TUBE,STEEL QQ-T-830 MT 1010-1020 SEAMLESS | 2843456 | |
| 2655767 | HOUSING FIRING PI | ALLOY STEEL QQ-S-624, MIL-S-13048 OR MIL-S-5626 | 2843456 | |
| 2856792 | STOP, DEPRESSION | AISI 4140-4340 | 2843459 | |
| 2856774 | SHAFT TORQUE | AISI 4130-4340 HEAT TREAT PER MIL-H-6875 | 2843459 | |
| 2856772 | BUSHING, ADJ | AISI 4130-4340 HEAT TREAT PER MIL-H-6875 | 2843459 | |
| 2856773 | NUT JAM TRAIN BR | AISI 4130-4340 HEAT TREAT PER MIL-H-6875 TO TENSILE STRENGTH 125,000-150,000 | 2843459 | |
| 2856769 | ARM, TRAIN BRAKE | AISI 4130-4340 HEAT TREAT PER MIL-H-6875 | 2843459 | |
| 2856786 | COLLAR, ELEV BRAI | AISI 4130-4340 HEAT TREAT PER MIL-H-6875 | 2843459 | |
| 2856782 | BEARING ASSY | AISI 4140-4340 HEAT TREAT PER MIL-H-6875 | 2843459 | |
| 2856789 | SLEEVE | AISI 4130-4340 HEAT TREAT PER MIL-H-6875 | 2843459 | |
| 2580229 | TRUNNION, LEFT | STEEL AISI 4130-4140 | 2580275 | |
| 2856785 | TRUNNION, RIGHT | AISI 4130-4340 HEAT TREAT PER MIL-H-6875 | 2843459 | |
| 2580231 | SLIDE | STEEL C1010-C1020 | 2843459 | |
| 2580224 | CARRIAGE | STEEL AISI 1010-1020 HR | 2843459 | |
| 281746-1 | SPRING | STEEL QQ-S-698CRCQ/QQ-W-428 TYPE II | 2555313 | |
| 323967-2 | SPRING | ASTM A230-41 | 323967 | |
| 323967-1 | SPRING | ASTM A230-41 | 323967 | |
| 323947-4 | SPRING | MUSIC WIRE 22-W-11 ALT:ASTM A228-39T | 323997 | |
| 323947-2 | SPRING | MUSIC WIRE 22-W-11 ALT:ASTM A228-39T | 323997 | |
| 510751-1 | SPRING | STEEL ASTM A231/A232 | 510751 | |
| 323927-1 | SPRING | MUSIC WIRE 22-W-II ALT:ASTM A228-39T | 323927 | |
| 323927-2 | SPRING | MUSIC WIRE 22-W-II ALT:ASTM A228-39T | 323927 | |
| 323928-1 | SPRING | MUSIC WIRE 22-W-II ALT:ASTM A228-39T | 323928 | |
| 323933-2 | SPRING | SPRING STEEL WIRE SAE 1085 ALT: SAE 1045 | 323933 | |
| 323970-4 | PLUNGER SPRING | MUSIC WIRE 22-W-11 ALT: ASTM A228-39T | 323970 | |
| 323971-4 | PLUNGER SPRING | MUSIC WIRE 22-W-11 ALT: ASTM A228-39T | 324003 | |
| 323900-5 | CATCH BRACKET | CAST BRONZE 49-B-3 ALT: CL A QQ-B-726 | 324003 | |
| 342649 | SPRING | MUSIC WIRE, QQ-W-470 | 5338628 | |
| 323986-2 | PLUNGER SPRING | ALLOY STEEL NO 2 (49-S-2) | 323982 | |

## MK15 PHALANX CIWS CADIUM CONNECTOR REPORT

| | PART NUMBER | DESCRIPTION | MATERIAL | NEXT ASSEMBLY | ENVIRONMENT |
|---|---|---|---|---|---|
| 1 | 1819365-001 | CONNECTOR | MELAMINE / BRASS WITH CADMIUM PLATING | | A |
| 2 | 1819367-001 | CONNECTOR | MELAMINE / BRASS WITH CADMIUM PLATING | | A |
| 3 | 1819369-001 | SHELL, CONNECTOR | MELAMINE / BRASS WITH CADMIUM PLATING | | A |
| 4 | 2840409-1 | CONNECTOR | 302 STEEL/ALUMINUM ALLOY/CADMIUM PLATED | 1498787 | A |
| 5 | 2840409-17 | CONNECTOR | 302 STEEL/ALUMINUM ALLOY/CADMIUM PLATED | 5942954 | A |
| 6 | 2840675-1 | CONNECTOR | 302 STEEL/ALUMINUM ALLOY/CADMIUM PLATED | 5543293 | A |
| 7 | 5187244 | ADAPTER, COAX CABLE | BRASS ALLOY 360 IAW QQ-B-626 / TIN PLATE | 5187997 | A |
| 8 | 5187387-4 | CONNECTOR, SMA | ALUMINUM ALLOY WITH CADMIUM PLATING | 5188363/5543148 | A |
| 9 | 5187412 | ADAPTER, COAX CABLE | BRASS COMP 22 IAW QQ-B-626 | 5187171 | A |
| 10 | 5188037-1 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | 5188116 | A |
| 11 | 5188783 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | | A |
| 12 | 5188783 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | 5188979 | A |
| 13 | 5189010-001 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 14 | 5189010-002 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 15 | 5189010-003 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 16 | 5189010-004 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 17 | 5189010-005 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 18 | 5189010-006 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 19 | 5189010-007 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 20 | 5189010-008 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 21 | 5189010-009 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 22 | 5189010-010 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 23 | 5189010-011 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 24 | 5189010-012 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 25 | 5189010-013 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 26 | 5189010-014 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 27 | 5189010-015 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 28 | 5189011-002 | CONNECTOR, TACHOMETER | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 29 | 5189011-004 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 30 | 5189012-019 | CONNECTOR | ALUMINUM ALLCY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 31 | 5189013-037 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 32 | 5189013-075 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 33 | 5189014-012 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 34 | 5189014-013 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 35 | 5189014-025 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 36 | 5189014-026 | CONNECTOR | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |
| 37 | 5189017-001 | CONNECTOR, PLUG | ALUMINUM ALLOY WITH CADMIUM PLATING | MULTI-USAGE | A |

MK34 GUN WEAPON CADMIUM COMPONENTS

| | PART NUMBER | DESCRIPTION | MATERIAL | NEXT ASSEMBLY | ENVIRONMENT |
|---|---|---|---|---|---|
| 1 | 6325547 | SCREW, MODIFIED | STEEL IAW MS16997-35 | 6325550 | C |
| 2 | 6325604 | SHIM, LAMINATED | ALUMINUM ALLOY IAW MIL-S-22499 | 6325454 | C |
| 3 | 6325605 | HANDLE | ALUMINUM ALLOYIAW 2321877-7 | 6325454 | C |
| 4 | 6325610 | SCREW, CAPTURE | STEEL, CADMIUM PLATED IAW QQ-P-416, CLASS3, TY II | 6325462 | C |
| 5 | 6325613 | SHIM | ALUMINUM ALLOY IAW MIL-S-22499 | 6325455 | C |
| 6 | 6325661 | HANDLE, BOW, LATCHING | STEEL ALLOY 4130 PER ASTM A505 | 6325477 | C |
| 7 | 6325699 | CROSSPIN | STEEL 300 SERIES PER QQ-S-763 OR ASTM A582 | 6325454 | C |
| 8 | 6325705 | SHIM | ALUMINUM ALLOY IAW MIL-S-22499, COMP 1 TY 1 CL 2 | 6325454 | C |
| 9 | 6325744 | CARRIER STRAPS | STEEL AISI 1010 COLD ROLLED PER ASTM A109 | 6325735 | C |
| 10 | 6325744 | RACKS | STEEL AISI 1018 COLD ROLLED, CASE HARDENED | 6325735 | C |
| 11 | 6325744 | BRACKETS | STEEL AISI 4130 PER MIL-S-18729, CONDITION N | 6325735 | C |
| 12 | 6325744 | PIN BOLTS | STEEL AISI 4340 PER MIL-S-5000 | 6325735 | C |
| 13 | 6325744 | SHUTTER PIVOT PINS | STEEL AISI 1018 PER QQ-S-634 | 6325735 | C |
| 14 | 6325744 | TRIGGER PIVOT PINS | STEEL AISI 4340 PER MIL-S-6758 | 6325735 | C |
| 15 | 6325744 | SHAFT PINS | STEEL AISI 4340 PER MIL-S-6758 | 6325735 | C |
| 16 | 6325744 | PINIONS | STEEL AISI 1018 COLD ROLLED | 6325735 | C |
| 17 | 6325744 | SHAFT | STEEL AISI 4340 PER MIL-S-6758 | 6325735 | C |
| 18 | 6325744 | BOLT ROLLERS | STEEL AISI 1215 PER ASTM A108 | 6325735 | C |
| 19 | 6325744 | ROLLER BUSHINGS | STEEL AISI 4130 PER MIL-S-6758 | 6325735 | C |
| 20 | 6325744 | TRIGGER SPRING | STEEL MUSIC WIRE PER ASTM A228 | 6325735 | C |
| 21 | 6325744 | SHUTTER SPRINGS | STEEL MUSIC WIRE PER ASTM A228 | 6325735 | C |
| 22 | 6568213 | ADAPTER | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325454 | C |
| 23 | 6568214 | ADAPTER AY, BULKHEAD | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325454 | C |
| 24 | 6568218-1 | FITTING, END, FLEX TUBING | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325450 | C |
| 25 | 6568218-2 | FITTING, END, FLEX TUBING | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325451 | C |
| 26 | 6568218-3 | FITTING, END, FLEX TUBING | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325452 | C |
| 27 | 6568218-4 | FITTING, END, FLEX TUBING | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325453 | C |
| 28 | 6568302 | COVER, CONNECTOR | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325454 | C |
| 29 | D38999/46FD18PN | CONNECTOR, PLUG | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325454 | C |
| 30 | D38999/46FD18SN | CONNECTOR, RECEPTICLE | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325454 | C |
| 31 | D38999/46WD18PN | CONNECTOR, PLUG | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325454 | C |
| 32 | D38999/46WD18SN | CONNECTOR, RECEPTICLE | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325454 | C |
| 33 | D38999/24WE26PN | CONNECTOR, PLUG | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 6325454 | C |
| 34 | MS16998 | SCREW, CAP, SOCKET HEAD | STEEL ALLOY IAW ASTM A574 | 6325454 | C |
| 35 | D38999/44FD18AN | CONNECTOR | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 20012180 | C |
| 36 | D38999/44FD35AA | CONNECTOR | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 20012180 | C |
| 37 | D38999/44FD35AC | CONNECTOR | ALUMINUM ALLOY 6061-T6 IAW QQ-A-225/8 | 20012180 | C |
| 38 | FC-37 ST | CONNECTOR, D-SUB 37 PIN | STEEL ALLOY IAW ASTM A506 | 20012180 | C |
| 39 | DC SF-37S-A197 | CONNECTOR, D-SUB 37 PIN | STEEL ALLOY IAW ASTM A506 | 20012180 | C |
| 40 | 747052-1 | CONNECTOR, D-SUB RECP | STEEL ALLOY IAW ASTM A506 | 20012274 | C |
| 41 | DCMAMR37P | CONNECTOR, D-SUB PLUG | STEEL ALLOY IAW ASTM A506 | 20012280 | C |

MK45 CADMIUM COMPONENT REPORT

| | PART NUMBER | DESCRIPTION | MATERIAL | NEXT ASSY | ENVIRONMENT |
|---|---|---|---|---|---|
| 1 | 1611492-0002 | BRACKET, STRAP | CRES IAW AISI 304; UNS S30400 | 5586222 | C |
| 2 | 1611492-0003 | BRACKET, STRAP | CRES IAW AISI 304; UNS S30400 | 5586222 | C |
| 3 | 1611493-0001 | BRACKET, STRAP | CRES IAW AISI 304; ALT: QQ-S-766 CL 304, FIN 2D | 2862443 | A |
| 4 | 1611493-0002 | BRACKET, STRAP | CRES IAW AISI 304; ALT: QQ-S-766 CL 304, FIN 2D | 2862443 | A |
| 5 | 1611494-0001 | BRACKET, STRAP | CRES IAW AISI 304; UNS S30400 | 2862443 | A |
| 6 | 1611494-0002 | BRACKET, STRAP | CRES IAW AISI 304; UNS S30400 | 2852443 | A |
| 7 | 2814468+GF | CLAMP | STEEL 1010 TY A GR II; ALT: QQ-S-633 C1010 | 2852443 | A |
| 8 | 2814528+GF | CLAMP | STEEL 1010 TY A GR II; ALT: QQ-S-633 C1010 | 6143452 | A |
| 9 | MS16625-1075 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 10 | MS16625-1087 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 11 | MS16625-1100 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 12 | MS16625-1106 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 13 | MS16625-1112 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 14 | MS16625-1118 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 15 | MS16625-1131 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 16 | MS16625-1137 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 17 | MS16625-1150 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 18 | MS16625-1162 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 19 | MS16625-1187 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 20 | MS16625-1193 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 21 | MS16625-1231 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 22 | MS16625-1350 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 23 | MS16625-1412 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 24 | MS16625-1600 | RETAINING RING | CARBON STEEL 1055 THRU 1090 IAW FED-STD-66 | MULTI-USAGE | E |
| 25 | MS16997-105 | SKT HD CAPSCREW | ALLOY STEEL IAW FF-S-86 | MULTI-USAGE | E |
| 26 | MS16997-107 | SKT HD CAPSCREW | ALLOY STEEL IAW FF-S-86 | MULTI-USAGE | E |
| 27 | MS16997-110 | SKT HD CAPSCREW | ALLOY STEEL IAW FF-S-86 | MULTI-USAGE | E |
| 28 | MS16997-20 | SKT HD CAPSCREW | ALLOY STEEL IAW FF-S-86 | MULTI-USAGE | E |
| 29 | MS16997-33 | SKT HD CAPSCREW | ALLOY STEEL IAW FF-S-86 | MULTI-USAGE | E |
| 30 | MS16997-38 | SKT HD CAPSCREW | ALLOY STEEL IAW FF-S-86 | MULTI-USAGE | E |
| 31 | MS16997-44 | SKT HD CAPSCREW | ALLOY STEEL IAW FF-S-86 | MULTI-USAGE | E |
| 32 | MS16997-61 | SKT HD CAPSCREW | ALLOY STEEL IAW FF-S-86 | MULTI-USAGE | E |
| 33 | MS16997-63 | SKT HD CAPSCREW | ALLOY STEEL IAW FF-S-86 | MULTI-USAGE | E |
| 34 | MS16997-79 | SKT HD CAPSCREW | ALLOY STEEL IAW FF-S-86 | MULTI-USAGE | E |
| 35 | MS17829-12C | SLF LKG HEX NUT | STEEL C1137 IAW FED-STD-66 | MULTI-USAGE | E |
| 36 | MS17829-24C | SLF LKG HEX NUT | STEEL C1137 IAW FED-STD-66 | MULTI-USAGE | E |
| 37 | MS17829-4C | SLF LKG HEX NUT | STEEL C1137 IAW FED-STD-66 | MULTI-USAGE | E |
| 38 | MS17829-6C | SLF LKG HEX NUT | STEEL C1137 IAW FED-STD-66 | MULTI-USAGE | E |
| 39 | MS17829-8C | SLF LKG HEX NUT | STEEL C1137 IAW FED-STD-66 | MULTI-USAGE | E |
| 40 | MS17984-309 | QUICK RELEASE PIN | CRES OR ALUM ALLOY (SEE MS 17984 ATTACHED) | MULTI-USAGE | E |
| 41 | MS20427-4C7 | RIVET | CARBON STEEL 1010-1015 IAW FED-STD-66 | MULTI-USAGE | E |
| 42 | MS21044-N10 | SLF LKG HEX NUT | STEEL 1008-1010,1015,1018,1035,1137.11L37,1213,12L14 | MULTI-USAGE | E |
| 43 | MS21044-N10 | SLF LKG HEX NUT | DUPLICATE OF ITEM 1332 | MULTI-USAGE | E |
| 44 | MS21078-6 | SLF LKG PLATE NUT | CARBON STEEL 1018,1040,1110,1137,11L37,4130,4340,8740 | MULTI-USAGE | E |

# APPENDIX F

# DODISS SEARCH RESULTS

| New/ Rev | Document Number | St | Title |
|---|---|---|---|
| | MIL-Z-291G | A | ZINC OXIDE, TECHNICAL |
| | MIL-P-3420F | A | PACKAGING MATERIALS, VOLATILE CORROSION INHIBITOR TREATED, OPAQUE |
| | MIL-B-3990D (3) | A | BEARINGS, ROLLER, NEEDLE, AIRFRAME, ANTIFRICTION, INCH |
| | MIL-T-5544C | A | THREAD COMPOUND, ANTISEIZE, GRAPHITE-PETROLATUM |
| | MIL-C-6151A CANC NOTICE 1 | H | CADMIUM OXIDE |
| | MIL-H-7195G | A | HARDWARE, PARACHUTE, GENERAL SPECIFICATION FOR |
| | DOD-B-8565/2A CANC NOTICE | H | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM, FORCED-AIR COOLED, 24 VOLT, 30 AMPERE HOUR (USE MIL-B-81757/12) |
| | MIL-B-8565/10 | A | BATTERY, STORAGE, AIRCRAFT, HIGH-RATE, TYPE 2, NICKEL-CADMIUM, 35 AMPERE-HOUR, CHARGE CONTROLLED |
| | MIL-C-8837B (1) | A | COATING, CADMIUM (VACUUM DEPOSITED) |
| | MIL-B-8914B (3) | A | BEARING, ROLLER, SELF-ALIGNING, AIRFRAME, ANTIFRICTION |
| | MIL-B-8952A (1) | A | BEARING, ROLLER, ROD END, ANTIFRICTION, SELF-ALIGNING |
| | MIL-B-11453A (4) | A | BATTERY, STORAGE BB-401( )/U |
| | MIL-T-12400A VALID NOTICE | A | TEST SET, BATTERY TS-776( )/U |
| | MIL-C-18668 CANC NOTICE 1 | H | CADMIUM RED (PAINT PIGMENT) |
| | MIL-S-19234 CANC NOTICE 1 | H | SOLDER, CADMIUM-SILVER |
| | MIL-T-21014D (1) | A | TUNGSTEN BASE METAL, HIGH DENSITY |
| | MIL-T-21014/1 CANC NOTICE | H | TUNGSTEN BASE PARTS, HIGH DENSITY METAL (SINTERED OR HOT PRESSED), COATED, ELECTRODEPOSITED CADMIUM |
| | MIL-T-21014/2 CANC NOTICE | H | TUNGSTEN BASE PARTS, HIGH DENSITY METAL (SINTERED OR HOT PRESSED), COATED, VACUUM DEPOSITED CADMIUM |
| | MIL-B-21442B CANC NOTICE 1 | H | BATTERY, STORAGE, NICKEL-CADMIUM |
| | MIL-I-22110C | A | INHIBITORS, CORROSION, VOLATILE, CRYSTALLINE POWDER |
| | MIL-S-22215A CANC NOTICE 1 | H | SILVER-COPPER-CADMIUM-NICKEL-ALLOY |
| | MIL-P-23242B | A | PLASTIC COATING COMPOUND, STRIPPABLE, FOR ELECTROPLATING |
| | MIL-B-23272B CANC NOTICE 1 | H | BATTERY, STORAGE: ALKALINE, NICKEL-CADMIUM (USE A-A-52417) |
| | MIL-B-0023272A | H | BATTERY, STORAGE: ALKALINE, NICKEL-CADMIUM (USE A-A-52417) |

| New/ Rev | Document Number | St | Title |
|---|---|---|---|
| | MIL-B-23272/1B CANC NOTICE | H | BATTERY, STORAGE: BB-634/U, 12 VOLT, 70 AMP HOUR CAPACITY ALKALINE, NICKEL-CADMIUM (USE A-A-52417) |
| | MIL-B-0023272/1 | H | BATTERY, STORAGE: BB-634/U, 12 VOLT, 70 AMP HOUR CAPACITY ALKALINE, NICKEL-CADMIUM (USE A-A-52417) |
| | MIL-I-23310B | A | INHIBITORS, CORROSION, VOLATILE, OIL TYPE |
| | MIL-P-23408B VALID NOTICE | A | PLATING: TIN-CADMIUM (ELECTRODEPOSITED) |
| | MIL-P-23469/8 CANC NOTICE | H | PIN, SWAGE-LOCKING, BRAZIER HEAD, FOUR LOCKING GROOVE, ALUMINUM ALLOY, CORROSION RESISTANT STEEL AND CARBON STEEL, CADMIUM COATED (USE MIL-P-23469/2) |
| | MIL-P-23469/9 CANC NOTICE | H | PIN, SWAGE LOCKING, BUTTON HEAD, FOUR LOCKING GROOVE, ALUMINUM ALLOY, CORROSION RESISTANT STEEL AND CARBON STEEL, CADMIUM COATED (USE MIL-P-23469/4) |
| | MIL-P-23469/10 CANC NOTICE | H | PIN, SWAGE-LOCKING, FLAT HEAD, 90 DEG. COUNTERSUNK, FOUR LOCKING GROOVE, ALUMINUM ALLOY, CORROSION RESISTANT STEEL AND CARBON STEEL, CADMIUM COATED (USE MIL-P-23469/6) |
| | MIL-B-26026B (1) | A | BATTERY, STORAGE, AIRCRAFT, TYPE MA-2-1 |
| | MIL-B-26220D (4) | A | BATTERIES, STORAGE, AIRCRAFT, NICKEL-CADMIUM GENERAL SPECIFICATION FOR |
| | MIL-B-26509A CANC NOTICE 1 | H | BATTERIES, STORAGE, NICKEL-CADMIUM, STARTING, LIGHTING, AND IGNITION AUTOMOTIVE TYPE, GENERAL SPECIFICATION FOR |
| | MIL-B-44374 | A | BINDING ASSEMBLY, SNOWSHOE, SNOW AND ICE TRAVERSING EQUIPMENT (SITE) |
| | MIL-P-48188A | A | PROJECTILES, 155MM, HE, M692 AND M731 METALLIC HARDWARE FOR |
| | MIL-P-49139 (2) | A | POWER SUPPLY PP-6148( )/U |
| | MIL-G-49140 | A | GENERATOR, DIRECT CURRENT G-67( )/G |
| | MIL-C-49144 (3) | A | CHARGER, BATTERY, PP-7286/U |
| | MIL-T-49388A | A | TRAY ASSEMBLY, BATTERY CHARGING MX-10154( )/U |
| + | MIL-B-49436B SUPP 1 | A | BATTERIES, RECHARGEABLE, NICKEL CADMIUM SEALED |
| | MIL-B-49436/1B | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM, BB-590/U |
| | MIL-B-49436/2B | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM, BB-588/U |
| | MIL-B-49436/3B | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM, BB-586/U |

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| | MIL-B-49436/4A | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM BB-557/U |
| | MIL-B-49436/5 VALID NOTICE | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM, BB-541/U |
| | MIL-B-49436/6C | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM, BB-516/U |
| | MIL-B-49436/7A | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM BB-507/U |
| | MIL-B-49436/8A | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM BB-506/U |
| | MIL-B-49436/9A | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM BB-505/U |
| | MIL-B-49436/10A | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM BB-503/TAS |
| | MIL-B-49436/11A | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM, BB-593/U |
| | MIL-S-49442 | A | SHOP EQUIPMENT, BATTERY SERVICING, SHELTER MOUNTED AN/TSM-133 |
| | MIL-B-49450 SUPP 1 | A | BATTERY, RECHARGEABLE, NICKEL-CADMIUM, VENTED, AIRCRAFT, BB-716/A |
| | MIL-B-49450/1 | A | BATTERY, RECHARGEABLE, NICKEL-CADMIUM, VENTED, AIRCRAFT, BB-716/A, INTERCELL CONNECTORS |
| | MIL-B-49450/2 | A | BATTERY, RECHARGEABLE, NICKEL-CADMIUM, VENTED, AIRCRAFT, BB-716/A, DIODE ASSEMBLY |
| | MIL-B-49450/3 | A | BATTERY, RECHARGEABLE, NICKEL-CADMIUM, VENTED, AIRCRAFT, BB-716/A, BELLEVILLE SPRING |
| | MIL-B-49450/4 (1) | A | BATTERY, RECHARGEABLE, NICKEL-CADMIUM, VENTED, AIRCRAFT, BB-716/A, CELL VENT ASSEMBLY |
| | MIL-B-49450/5 (2) | A | BATTERY, RECHARGEABLE, NICKEL-CADMIUM, VENTED, AIRCRAFT BB-716/A, HARNESS ASSEMBLY |
| | MIL-B-49450/6A | A | BATTERY, RECHARGEABLE, NICKEL-CADMIUM, VENTED, AIRCRAFT, BB-716/A, LOW CAPACITY CELL |
| | MIL-B-49450/7A (1) | A | BATTERY, RECHARGEABLE, NICKEL-CADMIUM, VENTED, AIRCRAFT, BB-716/A, CELL |
| | MIL-B-49450/8 (3) | A | BATTERY, RECHARGEABLE, NICKEL-CADMIUM, VENTED, AIRCRAFT BB-716/A |
| | MIL-P-50002B VALID NOTICE | A | PHOSPHATE COATING COMPOUNDS, FOR PHOSPHATING FERROUS METALS |
| | MIL-E-50739 | A | ELECTRONIC COMPONENT ASSEMBLY: 11738818 (CHARGE CONTROL) |
| | MIL-L-52292B | A | LIGHT ASSEMBLY, MARKER |
| | MIL-N-53094 | A | NOZZLE ASSEMBLY, CLOSED-CIRCUIT REFUELING, ARCTIC SERVICE |

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| | MIL-B-55118A SUPP 1D | A | BATTERIES, STORAGE, (CELLS), VENTED, NICKEL- CADMIUM |
| | MIL-B-55130A SUPP 1 | A | BATTERIES, RECHARGEABLE, SEALED NICKEL CADMIUM |
| | MIL-B-55130/1 | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM BB-411/U |
| | MIL-B-55130/2 | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM BB-412/U |
| | MIL-B-55130A/3 | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM BB-416/U |
| | MIL-B-55130A/4 | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM BB-417/U |
| | MIL-B-55130A/5 | A | BATTERY, RECHARGEABLE, SEALED NICKEL CADMIUM BB-625/U |
| | MIL-B-55363 (1) | A | BATTERIES, STORAGE, VENTED, NICKEL-CADMIUM |
| | MIL-T-55691 VALID NOTICE 1 | A | TEST SET, BATTERY AN/USM-63( )/U |
| | MIL-B-60298A CANC NOTICE 1 | H | BATTERY, NICKEL-CADMIUM, VENTED: 10541198 |
| | MIL-S-81269 | A | STABILIZER, BARIUM-CADMIUM |
| | MIL-C-81562B VALID NOTICE | A | COATINGS, CADMIUM, TIN-CADMIUM AND ZINC (MECHANICALLY DEPOSITED) |
| | MIL-B-81757C SUPP 1 | A | BATTERIES AND CELLS, STORAGE, NICKEL-CADMIUM, AIRCRAFT, GENERAL SPECIFICATION FOR |
| | MIL-B-81757/1C | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM, CELL |
| | MIL-B-81757/2B | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM, VENTED FILLER CAP |
| | MIL-B-81757/3B | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM CONNECTOR, STRAP |
| | MIL-B-81757/4C | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM, CONNECTOR, TAB |
| | MIL-B-81757/5B | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM, CONNECTOR, CURVED |
| | MIL-B-81757/6A CANC NOTICE | H | BATTERY, STORAGE, AIRCRAFT, NICKEL CADMIUM, COVER (USE MIL-B-81757/7, MIL-B-81757/8, MIL-B-81757/9) |
| | MIL-B-81757/7C | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM, 24 VOLTS, 10 AMPERE-HOUR (BB-432A/A) |
| | MIL-B-81757/8D | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM, 24 VOLTS, 20 AMPERE-HOUR (BB-434/A) |
| | MIL-B-81757/9C | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM, 24 VOLTS, 30 AMPERE-HOUR (BB-433A/A) |
| | MIL-B-81757/10B | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM 23 VOLTS, 6 AMPERE-HOUR |

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| | MIL-B-81757/11D | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM 24 VOLTS, 20 AMPERE-HOUR (LOW FREQUENCY VIBRATION) |
| | MIL-B-81757/12A | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM FORCED-AIR COOLED, CHARGE CONTROLLED, 24-VOLT, 30 AMPERE-HOUR |
| | MIL-B-81757/13A | A | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM 24-VOLT, 30 AMPERE-HOUR |
| | MIL-C-82596 CANC NOTICE 1 | H | CELL, MERCURY CADMIUM, BATTERY, UNDERWATER MINE |
| | MIL-W-82598 VALID NOTICE 1 | A | WIRE, COPPER-CADMIUM ALLOY |
| | MIL-W-82599 VALID NOTICE 1 | A | WIRE, INSULATED, HARD DRAWN ALLOY OF COPPER-CADMIUM, NO. 23 AWG |
| | MIL-B-82623 VALID NOTICE 1 | A | BATTERY, STORAGE, NICKEL-CADMIUM (FOR TALOS MISSILE) |
| | MIL-C-82624 VALID NOTICE 1 | A | CELLS, STORAGE, NICKEL-CADMIUM (FOR TALOS MISSILE) |
| | MIL-B-83424 CANC NOTICE 1 | H | BATTERY SYSTEMS, SEALED-CELL, NICKEL-CADMIUM, INTEGRAL CHARGE CONTROL, AIRCRAFT, GENERAL SPECIFICATION FOR |
| | MIL-B-83424/1 CANC NOTICE | H | BATTERY SYSTEM, SEALED CELL, NICKEL CADMIUM, INTEGRAL CHARGE CONTROL, AIRCRAFT, 20 AMPERE HOUR, DC INPUT, COMMON INPUT/OUTPUT |
| | MIL-V-83976 CANC NOTICE 1 | H | VACUUM CADMIUM METALIZING SYSTEM |
| | DOD-C-85050 (2) | A | CHARGERS, BATTERY, NICKEL-CADMIUM, AIRCRAFT, GENERAL SPECIFICATION FOR |
| | DOD-C-85050/1A | A | CHARGER, BATTERY, NICKEL-CADMIUM, AIRCRAFT 30-AMPERE CHARGER, DC INPUT |
| | MIL-C-87115A | A | COATING, IMMERSION ZINC FLAKE/CHROMATE DISPERSION |
| | NAVY 46-C-7A | H | CADMIUM: INGOTS (SUPERSEDED BY QQ-C-61) |
| | NAVY 46-P-1 | H | PLATING, CADMIUM (SUPERSEDED BY QQ-P-416) |
| | MIL-STD-870B | A | CADMIUM PLATING, LOW EMBRITTLEMENT, ELECTRODEPOSITION |
| | MIL-STD-1204C | A | INORGANIC SALTS AND COMPOUNDS, TECHNICAL GRADE (CADMIUM CARBONATE THROUGH CUPRIC SULFATE) |
| | DOD-STD-1446 | A | METAL ORGANIC COMPOUNDS, REAGENT GRADE (METRIC) (INCLUDING ACS AND USP-NF COMPOUNDS) |
| | MIL-STD-1500B | A | CADMIUM-TITANIUM PLATING, LOW EMBRITTLEMENT, ELECTRODEPOSITION |
| | MIL-STD-1568B | A | MATERIALS AND PROCESSES FOR CORROSION PREVENTION AND CONTROL IN AEROSPACE WEAPONS SYSTEMS |

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| | DOD-STD-1578B VALID NOTICE | A | NICKEL-CADMIUM BATTERY USAGE PRACTICES FOR SPACE VEHICLES |
| | DOD-STD-1866 NOTICE 1 | A | SOLDERING PROCESS GENERAL (NON-ELECTRICAL) |
| | MIL-STD-2193A | A | HYDRAULIC SYSTEM COMPONENTS, SHIP |
| | MS9048 REV A | H | PIN - SPRING, STEEL, CADMIUM PLATED (USE MS171401 THRU MS1719000002) |
| | MS9088 REV A VALID NOTICE | A | BOLT, MACHINE, STEEL, DRILLED 12 POINT HEAD, .190 (NO. 10)-32 (CADMIUM PLATE) |
| | MS9152 REV B | A | BOLT-MACHINE, STEEL, 12 POINT HEAD, .5625-18, CADMIUM PLATE |
| | MS9183 REV B CANC NOTICE 1 | H | SCREW, MACHINE, STEEL, DRILLED 12 POINT HEAD, .138 (NO.6)-40, CADMIUM PLATE (ASG) |
| | MS9184 REV A CANC NOTICE 1 | H | BOLT-MACHINE, STEEL, DRILLED, 12 POINT HEAD, .164 (NO.8)-36, CADMIUM PLATE |
| | MS9185 REV C CANC NOTICE 1 | H | SCREW, MACHINE, STEEL, 12 POINT HEAD, .138 (NO. 6)-40, CADMIUM PLATE |
| | MS9186 REV B CANC NOTICE 1 | H | BOLT-MACHINE, STEEL, 12 POINT HEAD, .164 (NO. 8)-36, CADMIUM PLATE |
| | MS9192 REV B | A | BOLT-MACHINE, STEEL, DRILLED 12 POINT HEAD, .164 (NO. 8)-36 CADMIUM PLATE |
| | MS9206 CANC NOTICE 1 | H | SCREW, MACHINE, STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, DOUBLE HEXAGON EXTENDED WASHER HEAD, .138-40 UNJF-3A |
| | MS9207 CANC NOTICE 1 | H | SCREW, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, DOUBLE HEXAGON EXTENDED WASHER HEAD, .164-36 UNJF-3A |
| | MS9208 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, DOUBLE HEXAGON EXTENDED WASHER HEAD, .190-32 UNJF-3A |
| | MS9209 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, DOUBLE HEXAGON EXTENDED WASHER HEAD, .250-28 UNJF-3A |
| | MS9210 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, DOUBLE HEXAGON EXTENDED WASHER HEAD, .3125-24 UNJF-3A |
| | MS9211 CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, DOUBLE HEXAGON EXTENDED WASHER HEAD, .375-24 UNJF-3A |
| | MS9212 | A | BOLT, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, DOUBLE HEXAGON EXTENDED WASHER HEAD, .4375-20 UNJF-3A |
| | MS9213 CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, DOUBLE HEXAGON EXTENDED WASHER HEAD, .500-20 UNJF-3A |
| | MS9215 CANC NOTICE 1 | H | SCREW, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATE, DOUBLE HEXAGON, EXTENDED WASHER HEAD, DRILLED, .138-40 UNJF-3A |

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| | MS9216 | A | SCREW, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATE, DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, .164-36 UNJF-3A |
| | MS9217 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATE, DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, .190-32 UNJF-3A |
| | MS9218 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL, AMS 6304, DIFFUSED NICKEL-CADMIUM PLATE, DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, .250-28 UNJF-3A |
| | MS9219 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL, AMS 6304, DIFFUSED NICKEL-CADMIUM PLATE, DOUBLE HEXAGON EXTENDED WASHER HEAD, .3125-24 UNJF-3A |
| | MS9220 CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATE, DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, .375-24 UNJF-3A |
| | MS9221 CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATE, DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, .4375-20 UNJF-3A |
| | MS9222 CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATE, DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, .500-20 UNJF-3A |
| | MS9223 CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATE, DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, .5625-18 UNJF-3A |
| | MS9397 | A | BOLT, TEE HEAD - AMS 6322, CHAMFERED, .190-32 UNJF-3A, CADMIUM PLATE |
| | MS9398 | A | BOLT, TEE HEAD - AMS 6322, CHAMFERED, .250-28 UNJF-3A, CADMIUM PLATE |
| | MS9399 | A | BOLT, TEE HEAD - AMS 6322, CHAMFERED,.3125-24 UNJF-3A, CADMIUM PLATE |
| | MS9400 | A | BOLT, TEE HEAD - AMS 6322, CHAMFERED, .375-24 UNJF-3A, CADMIUM PLATE |
| | MS9401 | A | BOLT, TEE HEAD - AMS 6322, CHAMFERED, .4375-20 UNJF-3A, CADMIUM PLATE |
| | MS9402 | A | BOLT, TEE HEAD - AMS 6322, CHAMFERED, .500-20 UNJF-3A, CADMIUM PLATE |
| | MS9438 REV A | A | SCREW, MACHINE - STEEL, AMS 6304, DIFFUSED NICKEL- CADMIUM PLATED, HEXAGON HEAD, DRILLED, .138-40 UNJF-3A |
| | MS9439 REV A | A | SCREW, MACHINE - STEEL, AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, HEXAGON HEAD, DRILLED, .164-36 UNJF-3A |

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| | MS9440 VALID NOTICE 1 | A | BOLT, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, HEXAGON HEAD, DRILLED, .190-32 UNJF-3A |
| | MS9441 VALID NOTICE 1 | A | BOLT, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, HEXAGON HEAD, DRILLED, .250-28 UNJF-3A |
| | MS9442 | A | BOLT, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, HEXAGON HEAD, DRILLED, .3125-24 UNJF-3A |
| | MS9443 | A | BOLT, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, HEXAGON HEAD, DRILLED .375-24 UNJF-3A |
| | MS9444 VALID NOTICE 1 | A | BOLT, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, HEXAGON HEAD, DRILLED, .4375-20 UNJF-3A |
| | MS9445 | A | BOLT, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, HEXAGON HEAD, DRILLED, .500-20 UNJF-3A |
| | MS9446 | A | BOLT, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, HEXAGON HEAD, DRILLED, .5625-18 UNJF-3A |
| | MS9447 | A | BOLT, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, HEXAGON HEAD, DRILLED, .625-18 UNJF-3A |
| | MS9448 | A | BOLT, MACHINE - STEEL AMS 6304, DIFFUSED NICKEL-CADMIUM PLATED, HEXAGON HEAD, DRILLED, .750-16 UNJF-3A |
| | MS9482 | A | WASHER, FLAT - STEEL AMS 6437 OR AMS 6485, DIFFUSED NICKEL-CADMIUM PLATED, COUNTERSUNK |
| | MS9516 REV C | A | SCREW, MACHINE, HEXAGON HEAD, STEEL, CADMIUM PLATED, .138-40 UNJF-3A |
| | MS9517 REV C | A | SCREW, MACHINE, HEXAGON HEAD, STEEL, CADMIUM PLATED, .164-36 UNJF-3A |
| | MS9518 REV A VALID NOTICE | A | BOLT, MACHINE, HEXAGON HEAD STEEL, CADMIUM PLATED, .190-32 UNJF-3A |
| | MS9519 REV A | A | BOLT, MACHINE, HEXAGON HEAD, STEEL, CADMIUM PLATED, .250-28 UNJF-3A |
| | MS9520 REV A | A | BOLT, MACHINE, HEXAGON HEAD, STEEL, CADMIUM PLATED, .3125-24 UNJF-3A |
| | MS9521 REV A | A | BOLT, MACHINE, HEXAGON HEAD, STEEL, CADMIUM PLATED, .375-24 UNJF-3A |
| | MS9522 REV C | A | BOLT, MACHINE, HEXAGON HEAD, STEEL, CADMIUM PLATED, .4375-20 UNJF-3A |
| | MS9523 REV A | A | BOLT, MACHINE, HEXAGON HEAD, STEEL, CADMIUM PLATED, .500-20 UNJF-3A |
| | MS9524 REV C | A | BOLT, MACHINE, HEXAGON HEAD, STEEL, CADMIUM PLATED, .5625-18 UNJF-3A |
| | MS9525 REV A | A | BOLT, MACHINE, HEXAGON HEAD, STEEL, CADMIUM PLATED, .625-18 UNJF-3A |

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| | MS9526 REV A | A | BOLT, MACHINE, HEXAGON HEAD, STEEL, CADMIUM PLATED, .750-16 UNJF-3A |
| | MS9527 REV B REINST | A | SCREW, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .138-40 UNJF-3A |
| | MS9528 | A | SCREW, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .164-36 UNJF-3A |
| | MS9529 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .190-32 UNJF-3A |
| | MS9530 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .250-28 UNJF-3A |
| | MS9531 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .3125-24 UNJF-3A |
| | MS9532 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .375-24 UNJF-3A |
| | MS9533 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .4375-20 UNJF-3A |
| | MS9534 VALID NOTICE 1 | A | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .500-20 UNJF-3A |
| | MS9535 CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .5625-18 UNJF-3A |
| | MS9536 CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .625-18 UNJF-3A |
| | MS9537 CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATE, DRILLED, 1 HOLE, HEXAGON HEAD, .750-16 UNJF-3A |
| | MS9597 REV B | A | BRACKET, ANGLE, 90 DEG., CADMIUM PLATED, .190 X .250 BOLT |
| | MS9598 REV B | A | BRACKET, ANGLE, 90 DEG., CADMIUM PLATED, .190 X .312 BOLT |
| | MS9599 REV B | A | BRACKET, ANGLE, 90 DEG., CADMIUM PLATED, .190 X .375 BOLT |
| | MS9680 REV B REINST | A | BOLT, MACHINE - STEEL AMS 6322, CADMIUM PLATED, DOUBLE HEXAGON EXTENDED WASHER HEAD, CUPWASHER LOCKED, .190-32 UNJF-3A |
| | MS9681 REV B VALID NOTICE | A | BOLT, MACHINE - STEEL AMS 6322, CADMIUM PLATED, DOUBLE HEXAGON EXTENDED WASHER HEAD, CUPWASHER LOCKED, .250-28 UNJF-3A |
| | MS9682 REV B CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATED, DOUBLE HEXAGON, EXTENDED WASHER HEAD, CUPWASHER LOCKED, .3125-24 UNJF-3A |

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| | MS9683 REV B CANC NOTICE 1 | H | BOLT, MACHINE-STEEL AMS 6322, CADMIUM PLATED, DOUBLE HEXAGON, EXTENDED WASHER HEAD, CUPWASHER LOCKED, .375-24 UNJF-3A |
| | MS9685 VALID NOTICE 1 | A | BOLT, MACHINE - HEXAGON HEAD, DRILLED, 1 HOLE, PD SHANK, STEEL AMS 6304, DIFFUSED NICKEL CADMIUM PLATE, .190-32 UNJF-3A |
| | MS9686 VALID NOTICE 1 | A | BOLT, MACHINE - HEXAGON HEAD, DRILLED, 1 HOLE, PD SHANK, STEEL AMS 6304, DIFFUSED NICKEL CADMIUM PLATE, .250-28 UNJF-3A |
| | MS9687 VALID NOTICE 1 | A | BOLT, MACHINE - HEXAGON HEAD, DRILLED, 1 HOLE, PD SHANK, STEEL AMS 6304, DIFFUSED NICKEL CADMIUM PLATE, .3125-24 UNJF-3A |
| | MS9689 CANC NOTICE 1 | H | BOLT, MACHINED-HEXAGON HEAD, DRILLED 1 HOLE, PD SHANK, STEEL AMS 6304, DIFFUSED NICKEL CADMIUM PLATE .4375-20 UNJF-3A |
| | MS9690 CANC NOTICE 1 | H | BOLT, MACHINED-HEXAGON HEAD, DRILLED 1 HOLE, PD SHANK, STEEL AMS 6304, DIFFUSED NICKEL CADMIUM PLATE .500-20 UNJF-3A |
| | MS9692 CANC NOTICE 1 | H | BOLT, MACHINED-HEXAGON HEAD, DRILLED 1 HOLE, PD SHANK, STEEL AMS 6304, DIFFUSED NICKEL CADMIUM PLATE .625-18 UNJF-3A |
| | MS9693 CANC NOTICE 1 | H | BOLT, MACHINED-HEXAGON HEAD, DRILLED 1 HOLE, PD SHANK, STEEL AMS 6304, DIFFUSED NICKEL CADMIUM PLATE .750-16 UNJF-3A |
| | MS9767 REV B REINST | A | NUT, DOUBLE HEXAGON - CUPWASHER LOCKED, AMS 6322, CADMIUM PLATED MIL-S-8879 |
| | MS9881 REV B REINST | A | NUT, PLAIN HEXAGON - AMS 6322, CADMIUM PLATE MIL-S-8879 |
| | MS9882 | A | NUT, PLAIN, HEX - DRILLED, AMS 6322, CADMIUM PLATE MIL-S-8879 |
| | MS9912 CANC NOTICE 1 | H | SCREW, MACHINE-DOUBLE HEXAGON EXTENDED WASHER HEAD, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, 0.138-40 UNJF-3A |
| | MS9913 CANC NOTICE 1 | H | SCREW, MACHINE-DOUBLE HEXAGON EXTENDED WASHER HEAD, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, 0.164-36 UNJF-3A |
| | MS9914 | A | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .190-32 UNJF-3A |
| | MS9915 CANC NOTICE 1 | H | BOLT, MACHINE-DOUBLE HEXAGON EXTENDED WASHER HEAD SHANK, STEEL AMS 6322, CADMIUM PLATED, .250-28 UNJF-3A |
| | MS9916 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .3125-24 UNJF-3A |
| | MS9917 | A | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .375-24 UNJF-3A |

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| | MS9918 | A | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .4375-20 UNJF-3A |
| | MS9919 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .500-20 UNJF-3A |
| | MS9920 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .5625-18 UNJF-3A |
| | MS9921 CANC NOTICE 1 | H | SCREW, MACHINE-DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, 0.138-40 UNJF-3A |
| | MS9922 CANC NOTICE 1 | H | SCREW, MACHINE-DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, 0.164-36 UNJF-3A |
| | MS9923 | A | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .190-32 UNJF-3A |
| | MS9924 | A | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .250-28 UNJF-3A |
| | MS9925 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .3125-24 UNJF-3A |
| | MS9926 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .375-24 UNJF-3A |
| | MS9927 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .4375-20 UNJF-3A |
| | MS9928 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .500-20 UNJF-3A |
| | MS9929 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .5625-18 UNJF-3A |
| | MS9930 CANC NOTICE 1 | H | SCREW, MACHINE-DOUBLE HEXAGON EXTENDED WASHER HEAD, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, 0.138-40 UNJF-3A |

| New/ Rev | Document Number | St | Title |
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| | MS9931 CANC NOTICE 1 | H | SCREW, MACHINE-DOUBLE HEXAGON EXTENDED WASHER HEAD, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, 0.164-36 UNJF-3A |
| | MS9932 CANC NOTICE 1 | H | BOLT, MACHINE-DOUBLE HEXAGON EXTENDED WASHER HEAD FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .190-32 UNJF-3A |
| | MS9933 VALID NOTICE 1 | A | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .250-28 UNJF-3A |
| | MS9934 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .3125-24 UNJF-3A |
| | MS9935 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .375-24 UNJF-3A |
| | MS9936 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .4375-20 UNJF-3A |
| | MS9937 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .500-20 UNJF-3A |
| | MS9938 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .5625-18 UNJF-3A |
| | MS9939 CANC NOTICE 1 | H | SCREW, MACHINE-DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, 0.138-40 UNJF-3A |
| | MS9940 CANC NOTICE 1 | H | SCREW, MACHINE-DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, 0.164-36 UNJF-3A |
| | MS9941 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .190-32 UNJF-3A |
| | MS9942 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .250-28 UNJF-3A |
| | MS9943 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .3125-24 UNJF-3A |
| | MS9944 VALID NOTICE 1 | A | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .375-24 UNJF-3A |

| New/ Rev | Document Number | St | Title |
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| | MS9945 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .4375-20 UNJF-3A |
| | MS9946 CANC NOTICE 1 | H | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .500-20 UNJF-3A |
| | MS9947 VALID NOTICE 1 | A | BOLT, MACHINE - DOUBLE HEXAGON EXTENDED WASHER HEAD, DRILLED, FULL SHANK, STEEL AMS 6322, CADMIUM PLATED, .5625-18 UNJF-3A |
| | MS9957 CANC NOTICE 1 | H | BOLT, MACHINE, HEXAGON HEAD, DRILLED, 6 HOLE, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .190-32 UNJF-3A |
| | MS9958 VALID NOTICE 1 | A | BOLT, MACHINE, HEXAGON HEAD, DRILLED, 6 HOLE, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .250-28 UNJF-3A |
| | MS9959 CANC NOTICE 1 | H | BOLT, MACHINE, HEXAGON HEAD, DRILLED, 6 HOLE, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .3125-24 UNJF-3A |
| | MS9960 CANC NOTICE 1 | H | BOLT, MACHINE, HEXAGON HEAD, DRILLED, 6 HOLE, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .375-24 UNJF-3A |
| | MS9961 CANC NOTICE 1 | H | BOLT, MACHINE, HEXAGON HEAD, DRILLED, 6 HOLE, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .4375-20 UNJF-3A |
| | MS9962 CANC NOTICE 1 | H | BOLT, MACHINE, HEXAGON HEAD, DRILLED, 6 HOLE, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .500-20 UNJF-3A |
| | MS9963 CANC NOTICE 1 | H | BOLT, MACHINE, HEXAGON HEAD, DRILLED, 6 HOLE, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .5625-18 UNJF-3A |
| | MS9964 VALID NOTICE 1 | A | BOLT, MACHINE, HEXAGON HEAD, DRILLED, 6 HOLE, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .625-18 UNJF-3A |
| | MS9965 CANC NOTICE 1 | H | BOLT, MACHINE, HEXAGON HEAD, DRILLED, 6 HOLE, PD SHANK, STEEL AMS 6322, CADMIUM PLATED, .750-16 UNJF-3A |
| | MS16232 | H | BOLT, LAG: SQUARE HEAD, CARBON STEEL ZINC OR CADMIUM COATED, GIMLET POINT (USE MS16992) |
| | MS16638 REV A | H | SCREW, SHOULDER, SOCKET HEAD, HEXAGON ALLOY STEEL, CADMIUM OR ZINC PLATED, UNC-3A (USE MS51975) |
| | MS16997 REV D | A | SCREW, CAP, SOCKET HEAD AND SCREW, CAP,SOCKET HEAD, SELF-LOCKING: ALLOY STEEL, CADMIUM PLATED, UNC-3A |

| New/ Rev | Document Number | St | Title |
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| | MS16998 REV E | A | SCREW, CAP, SOCKET HEAD AND SCREW, CAP, SOCKET HEAD, SELF-LOCKING: ALLOY STEEL, CADMIUM PLATED, UNF-3A |
| | MS18063 REV A VALID NOTICE | A | SETSCREW, HEXAGON SOCKET, CUP POINT, 250 DEG. F SELF LOCKING ELEMENT, ALLOY STEEL, CADMIUM PLATED |
| | MS18065 REV A CANC NOTICE | H | SET SCREW, HEXAGON SOCKET, FLAT POINT, 250 DEGREE F SELF LOCKING ELEMENT, ALLOY STEEL, CADMIUM PLATED |
| | MS18067 REV A VALID NOTICE | A | SETSCREW, HEXAGON SOCKET, CONE POINT, 250 DEG. F, SELF-LOCKING ELEMENT, ALLOY STEEL, CADMIUM PLATED |
| | MS21316 REV C | A | THUMBSCREW (SHOULDERED), FLAT POINT, CARBON STEEL, CADMIUM PLATED, UNC-2A |
| | MS21317 REV B | H | THUMBSCREW (WITHOUT SHOULDER), CARBON STEEL, CADMIUM PLATED, UNC-2A (USE MS21316) |
| | MS21318 REV A | A | SCREW, DRIVE, ROUND HEAD, TYPE U, STEEL, CARBON, CADMIUM PLATED |
| | MS21342 REV A CANC | H | SETSCREW, FLUTED SOCKET, ALLOY STEEL, CADMIUM PLATED UNC-3A |
| | MS24496 REV G | A | BATTERY, AIRCRAFT STORAGE, NICKEL-CADMIUM 24 VOLTS, 11 AMPERE HOUR, 27 DEG. C (80 DEG. F) |
| | MS24497 REV F | A | BATTERY, AIRCRAFT STORAGE, NICKEL-CADMIUM 24 VOLTS, 22 AMPERE HOUR, 27 DEG. C (80 DEG. F) |
| | MS24498 REV F | A | BATTERY, AIRCRAFT STORAGE, NICKEL-CADMIUM 24 VOLTS, 34 AMPERE HOUR, 27 DEG. C (80 DEG. F) |
| | MS24511 | H | BATTERY, STORAGE, AIRCRAFT, NICKEL-CADMIUM TYPE 24 VOLT, 60 AMPERE HOUR, 27 DEG. C (80 DEG. F) (USE MIL-B-26026) |
| | MS24530 | H | BATTERY-STORAGE, NICKEL-CADMIUM, 35-AMP HR (SUPERSEDED BY MS53073) |
| | MS24531 | H | BATTERY-STORAGE, NICKEL-CADMIUM,70-AMP HR (SUPERSEDED BY MS53074) |
| | MS24545 REV B CANC | H | BATTERY, STORAGE, NICKEL-CADMIUM, 100-AMP HR, 6 VOLT |
| | MS24546 REV B | H | BATTERY, STORAGE, NICKEL-CADMIUM, 125-AMP HR, 6 VOLT |
| | MS24583 REV A | H | SCREW, MACHINE-FLAT COUNTERSUNK HEAD, CROSS-RECESSED, CARBON STEEL, CADMIUM PLATED (USE MS35190, MS35191) |
| | MS24584 REV A | H | SCREW, MACHINE-PAN HEAD, CROSS-RECESSED, CARBON STEEL, CADMIUM PLATED (USE MS35206, MS35207) |

| New/ Rev | Document Number | St | Title |
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| | MS24615 REV B CANC | H | SCREW, TAPPING-THREAD FORMING, TYPE A, FLAT 82 DEG. COUNTERSUNK HEAD, CROSS RECESSED, STEEL, CARBON, CADMIUM PLATED (USE MS51862) |
| | MS24617 REV B CANC | H | SCREW, TAPPING-THREAD FORMING, TYPE A, PAN HEAD, CROSS RECESSED, STEEL, CARBON, CADMIUM PLATED (USE MS51861) |
| | MS24629 REV C VALID NOTICE | A | SCREW, TAPPING-THREAD CUTTING, TYPES D, F, G, OR T PAN HEAD, CROSS-RECESSED, STEEL, CARBON CADMIUM PLATED |
| | MS24635 REV A CANC | H | SCREW, TAPPING, THREAD FORMING, TYPE A, FLAT COUNTERSUNK HEAD, SLOTTED, STEEL, CARBON, CADMIUM PLATED (USE MS24615) |
| | MS24637 REV A CANC | H | SCREW, TAPPING, THREAD FORMING, TYPE A, PAN HEAD, SLOTTED, STEEL, CARBON, CADMIUM PLATED (USE MS24617) |
| | MS24639 REV A CANC | H | SCREW, TAPPING, THREAD FORMING, TYPE B, FLAT COUNTERSUNK HEAD, SLOTTED, STEEL, CARBON, CADMIUM PLATED (USE MS24619) |
| | MS24641 REV A CANC | H | SCREW, TAPPING, THREAD FORMING, TYPE B, PAN HEAD, SLOTTED, STEEL, CARBON, CADMIUM PLATED (USE MS24621) |
| | MS24643 REV A | H | SCREW, TAPPING, THREAD CUTTING, SPACED THREADS, FLAT HEAD, SLOTTED, TYPES BF, BG OR BT, STEEL, CARBON, CADMIUM PLATED (USE MS24623) |
| | MS24645 REV A CANC | H | SCREW, TAPPING, THREAD CUTTING, SPACED THREADS, TYPES BF, BG, OR BT, PAN HEAD, SLOTTED, STEEL, CARBON, CADMIUM PLATED (USE MS24625) |
| | MS24647 REV A CANC | H | SCREW, TAPPING, THREAD CUTTING, TYPES D, F, G OR T, FLAT COUNTERSUNK HEAD, SLOTTED, STEEL, CARBON, CADMIUM PLATED (USE MS24627) |
| | MS24649 REV A CANC | H | SCREW, TAPPING, THREAD CUTTING, TYPES F, D, G, OR T, PAN HEAD, SLOTTED, STEEL, CARBON, CADMIUM PLATED (USE MS24629) |
| | MS24668 REV A CANC | H | SCREW, CAP, SOCKET HEAD, FLAT COUNTERSUNK, ALLOY STEEL, CADMIUM PLATED, UNF-3A |
| | MS27040 REV B | A | NUT, PLAIN, SQUARE - STEEL, CADMIUM PLATED |
| | MS27183 REV F | A | WASHER, FLAT (ROUND, STEEL, CADMIUM PLATED) GENERAL PURPOSE |
| | MS27307 REV E | A | CELL, BATTERY, AIRCRAFT STORAGE, NICKEL-CADMIUM |
| | MS27546 | A | BATTERY, AIRCRAFT, STORAGE, NICKEL-CADMIUM, 24V, 5 AMP HOUR (1 HR RATE) 25 DEG. C |

| New/ Rev | Document Number | St | Title |
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| | MS35190 REV F | A | SCREW, MACHINE-82 DEG. FLAT COUNTERSUNK HEAD, CROSS-RECESSED, CARBON STEEL, CADMIUM PLATED, UNC-2A |
| | MS35191 REV G | A | SCREW, MACHINE-82 DEG. FLAT COUNTERSUNK HEAD, CROSS-RECESSED, CARBON STEEL, CADMIUM PLATED, UNF-2A |
| | MS35192 REV A | H | SCREW, MACHINE-FLAT COUNTERSUNK HEAD, CROSS-RECESSED, CARBON STEEL, CADMIUM OR ZINC PLATED, NC-2A & UNC-2A (USE MS35190) |
| | MS35193 REV A | H | SCREW, MACHINE-FLAT COUNTERSUNK HEAD, CROSS-RECESSED, CARBON STEEL, CADMIUM OR ZINC PLATED, NF-2A & UNF-2A (USE MS35191) |
| | MS35206 REV H | A | SCREW, MACHINE-PAN HEAD, CROSS-RECESSED CARBON STEEL, CADMIUM PLATED, UNC-2A |
| | MS35207 REV F (1) | A | SCREW, MACHINE-PAN HEAD, CROSS-RECESSED, CARBON STEEL, CADMIUM PLATED, UNF-2A (IN./MM) |
| | MS35208 REV A CANC | H | SCREW, MACHINE, PAN HEAD, CROSS-RECESSED, CARBON STEEL, CADMIUM OR ZINC PLATED, NC-2A & UNC-2A (USE MS35206) |
| | MS35209 REV A CANC | H | SCREW, MACHINE, PAN HEAD, CROSS-RECESSED, CARBON STEEL, CADMIUM OR ZINC PLATED, NF-2A & UNF-2A (USE MS35207) |
| | MS35223 REV B | H | SCREW, MACHINE, PAN HEAD, SLOTTED, CARBON STEEL, CADMIUM PLATED, NC-2A AND UNC-2A (USE MS35206) |
| | MS35224 REV A CANC | H | SCREW, MACHINE, PAN HEAD, SLOTTED, CARBON STEEL, CADMIUM PLATED, NF-2A AND UNF-2A (USE MS35207) |
| | MS35225 REV A CANC | H | SCREW, MACHINE, PAN HEAD, SLOTTED, CARBON STEEL, CADMIUM OR ZINC PLATED, NC-2A AND UNC-2A (USE MS35206) |
| | MS35226 REV A CANC | H | SCREW, MACHINE, PAN HEAD, SLOTTED, CARBON STEEL, CADMIUM OR ZINC PLATED, NF-2A AND UNF-2A (USE MS35207) |
| | MS35239 REV A CANC | H | SCREW, MACHINE, FLAT COUNTERSUNK HEAD, CARBON STEEL, CADMIUM PLATED, NC-2A AND UNC-2A (USE MS35190) |
| | MS35240 REV A CANC | H | SCREW, MACHINE, FLAT COUNTERSUNK HEAD, SLOTTED, CARBON STEEL, CADMIUM PLATED, NF-2A AND UNF-2A (USE MS35191) |
| | MS35241 REV A CANC | H | SCREW, MACHINE, FLAT COUNTERSUNK HEAD, SLOTTED, CARBON STEEL, CADMIUM OR ZINC PLATED, NC-2A AND UNC-2A (USE MS35190) |

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| | MS35242 REV A CANC | H | SCREW, MACHINE, FLAT COUNTERSUNK HEAD, SLOTTED, CARBON STEEL, CADMIUM OR ZINC PLATED, NF-2A & UNF-2A (USE MS35191) |
| | MS35267 REV B | H | SCREW, MACHINE, DRILLED FILLISTER HEAD, SLOTTED, CARBON STEEL, CADMIUM OR ZINC PLATED, NC-2A AND UNC-2A (USE MS35265) |
| | MS35268 REV B CANC | H | SCREW, MACHINE, DRILLED FILLISTER HEAD, SLOTTED, CARBON STEEL, CADMIUM OR ZINC PLATED, NF-2A AND UNF-2A (USE MS35266) |
| | MS35291 REV A CANC | H | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), LOW CARBON STEEL, CADMIUM OR ZINC FINISH, UNC-2A (USE MS90725) |
| | MS35292 REV A CANC | H | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), LOW CARBON STEEL, CADMIUM OR ZINC FINISH, UNF-2A (USE MS90726) |
| | MS35297 REV A CANC | H | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), MEDIUM CARBON STEEL, CADMIUM OR ZINC FINISH, UNC-2A (USE MS90725) |
| | MS35298 REV A | H | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), MEDIUM CARBON STEEL, CADMIUM OR ZINC FINISH, UNF-2A (USE MS90726) |
| | MS35303 REV A CANC | H | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), ALLOY STEEL, CADMIUM OR ZINC FINISH, UNC-2A (USE MS90728) |
| | MS35304 REV B CANC | H | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), ALLOY STEEL, CADMIUM OR ZINC FINISH, UNF-2A (USE MS90727) |
| | MS35355 REV B | A | BOLT, MACHINE, SQUARE HEAD, STEEL, CADMIUM OR ZINC PLATED, UNC-2A |
| | MS35457 REV B | A | SCREW, CAP, SOCKET HEAD-HEXAGON, ALLOY STEEL, CADMIUM OR ZINC, UNC-3A (USE MS16997) |
| | MS35458 REV B | A | SCREW, CAP, SOCKET HEAD-HEXAGON, ALLOY STEEL, CADMIUM OR ZINC, UNF-3A (USE MS16998) |
| | MS35751 REV D | A | BOLT, SQUARE NECK, ROUND HEAD (CARRIAGE), STEEL, CADMIUM OR ZINC PLATED, UNC-2A |
| | MS35752 REV B | H | BOLT, SQUARE NECK, TRUSS HEAD, (STEP) STEEL, CADMIUM OR ZINC PLATED, UNC-2A (USE MS35751) |
| | MS35753 REV B | H | BOLT, SQUARE NECK, FLAT HEAD, (ELEVATOR) STEEL, CADMIUM OR ZINC PLATED, UNC-2A (USE MS35754) |
| | MS35754 REV B | A | BOLT, SQUARE NECK, COUNTERSUNK (PLOW), STEEL, CADMIUM OR ZINC PLATED, UNC-2A |
| | MS35810 REV B | A | PIN, STRAIGHT, HEADED (CLEVIS PIN) - STEEL, CADMIUM OR ZINC PLATED |

| New/ Rev | Document Number | St | Title |
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| | MS36116 REV A | H | CADMIUM COMPOUNDS, ACS & ANALYZED REAGENT, INORGANIC (USE MIL-STD-1218, MIL-STD-1222) |
| | MS51017 REV A | H | SETSCREW, HEXAGON SOCKET, CUP POINT, ALLOY STEEL, CADMIUM OR ZINC, NC-3A AND UNC-3A (USE MS51963) |
| | MS51018 REV A | H | SETSCREW, HEXAGON SOCKET, CUP POINT, ALLOY STEEL, CADMIUM OR ZINC, NF-3A AND UNF-3A (USE MS51964) |
| | MS51025 REV A | H | SETSCREW, HEXAGON SOCKET, FLAT POINT, ALLOY STEEL, CADMIUM OR ZINC, NC-3A AND UNF-3A (USE MS51965) |
| | MS51026 REV A | H | SETSCREW, HEXAGON SOCKET, FLAT POINT, ALLOY STEEL, CADMIUM OR ZINC, NF-3A AND UNF-3A (USE MS51966) |
| | MS51034 REV A | H | SETSCREW, HEXAGON SOCKET, CONE POINT, ALLOY STEEL, CADMIUM OR ZINC, NC-3A AND UNC-3A (USE MS51973) |
| | MS51035 REV A | H | SETSCREW, HEXAGON SOCKET, CONE POINT, ALLOY STEEL, CADMIUM OR ZINC, NF-3A AND UNF-3A (USE MS51974) |
| | MS51041 REV A | H | SETSCREW, HEXAGON SOCKET, HALF-DOG POINT, ALLOY STEEL, CADMIUM OR ZINC, NC-3A AND UNC-3A (USE MS51977) |
| | MS51042 REV A | H | SETSCREW, HEXAGON SOCKET, HALF-DOG POINT, ALLOY STEEL, CADMIUM OR ZINC, NF-3A AND UNF-3A (USE MS51976) |
| | MS51049 REV A | H | SETSCREW, HEXAGON SOCKET, OVAL POINT, ALLOY STEEL, CADMIUM OR ZINC, NC-3A AND UNC-3A (USE MS51981) |
| | MS51050 REV A | H | SETSCREW, HEXAGON SOCKET, OVAL POINT, ALLOY STEEL, CADMIUM OR ZINC, NF-3A AND UNF-3A (USE MS51982) |
| | MS51053 REV A | H | SETSCREW, FLUTED SOCKET, ALLOY STEEL, CADMIUM PLATED, NC-3A (SUPERSEDED BY MS51963, MS51965, MS51973, MS51977, MS51981) |
| | MS51054 | A | SETSCREW, SQUARE HEAD, CUP POINT, CARBON STEEL, CADMIUM OR ZINC, UNC-2A |
| | MS51055 REV A | H | SETSCREW, SLOTTED, CUP POINT, CARBON STEEL, CADMIUM OR ZINC, NC-2A (USE MS51017) |
| | MS51095 REV F | A | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), HEAD DRILLED FOR LOCKING WIRE, STEEL, GRADE 5, CADMIUM PLATED, UNC-2A, PLAIN AND SELF-LOCKING |
| | MS51096 REV E | A | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), HEAD DRILLED FOR LOCKING WIRE, STEEL, GRADE 5, CADMIUM PLATED, UNF-2A, PLAIN AND SELF-LOCKING |

| New/ Rev | Document Number | St | Title |
|---|---|---|---|
| | MS51104 REV A | H | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), SHANK DRILLED FOR COTTER PIN, STEEL, GRADE 5, CADMIUM PLATED, UNF-2A (USE MS51106) |
| | MS51105 REV D VALID NOTICE | A | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), SHANK DRILLED FOR COTTER PIN STEEL, GRADE 5, CADMIUM PLATED, UNC-2A |
| | MS51106 REV C | A | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), SHANK DRILLED FOR COTTER PIN, STEEL, GRADE 5, CADMIUM PLATED, UNF-2A |
| | DS51409 VALID NOTICE 1 | A | SETSCREW, SLOTTED HEADLESS, CONE POINT CARBON STEEL, CADMIUM PLATED, METRIC |
| | DS51410 VALID NOTICE 1 | A | SETSCREW, SLOTTED HEADLESS, CUP POINT CARBON STEEL, CADMIUM PLATED, METRIC |
| | DS51411 VALID NOTICE 1 | A | SETSCREW, SLOTTED HEADLESS, FLAT POINT, CARBON STEEL, CADMIUM PLATED, METRIC |
| | MS51963 REV C | A | SETSCREW-HEXAGON SOCKET, CUP POINT, ALLOY STEEL, CADMIUM PLATED, UNC-3A, PLAIN AND SELF-LOCKING |
| | MS51964 REV E | A | SETSCREW, HEXAGON SOCKET, CUP POINT, ALLOY STEEL, CADMIUM PLATED, UNF-3A, PLAIN AND SELF-LOCKING |
| | MS51965 REV B | A | SETSCREW-HEXAGON SOCKET, FLAT POINT, ALLOY STEEL, CADMIUM PLATED, UNC-3A, PLAIN AND SELF-LOCKING |
| | MS51966 REV A | A | SETSCREW-HEXAGON SOCKET, FLAT POINT, ALLOY STEEL, CADMIUM PLATED, UNF-3A, PLAIN AND SELF-LOCKING |
| | MS51967 REV D VALID NOTICE | A | NUT, PLAIN, HEXAGON-CARBON STEEL, CADMIUM PLATED, UNC-2B(IN./MM) |
| | MS51968 REV C VALID NOTICE | A | NUT, PLAIN, HEXAGON-CARBON STEEL, CADMIUM PLATED, UNF-2B(IN./MM) |
| | MS51973 REV B | A | SETSCREW-HEXAGON SOCKET, CONE POINT, ALLOY STEEL, CADMIUM PLATED, UNC-3A, PLAIN AND SELF-LOCKING |
| | MS51974 REV B VALID NOTICE | A | SETSCREW-HEXAGON SOCKET, CONE POINT, ALLOY STEEL, CADMIUM PLATED, UNF-3A PLAIN AND SELF-LOCKING |
| + | MS51975 REV D | A | SCREW, SHOULDER - SOCKET HEAD, HEXAGON, ALLOY STEEL, CADMIUM PLATED, UNC-3A |
| | MS51976 REV A VALID NOTICE | A | SETSCREW-HEXAGON SOCKET, HALF-DOG POINT, ALLOY STEEL, CADMIUM PLATED, UNF-3A |
| | MS51977 REV C | A | SETSCREW-HEXAGON SOCKET, HALF-DOG POINT, ALLOY STEEL, CADMIUM PLATED, UNC-3A |
| | MS51981 REV C | A | SETSCREW-HEXAGON SOCKET, OVAL POINT, ALLOY STEEL, CADMIUM PLATED, UNC-3A |
| | MS51982 REV A | A | SETSCREW-HEXAGON SOCKET, OVAL POINT, ALLOY STEEL, CADMIUM PLATED, UNF-3A |

| New/ Rev | Document Number | St | Title |
|---|---|---|---|
| | MS51988 REV B | A | NUT, SELF-LOCKING, FLANGED - PREVAILING-TORQUE, STEEL, CADMIUM, UNC AND UNF, (IN./MM) |
| | MS53073 REV A CANC NOTICE | H | BATTERY, STORAGE - ALKALINE, NICKEL-CADMIUM 12 VOLT, 35 AMPERE-HOUR CAPACITY |
| | MS53074 REV A CANC NOTICE | H | BATTERY, STORAGE-ALKALINE, NICKEL-CADMIUM 12 VOLT, 70 AMPERE-HOUR STORAGE |
| | MS90725 REV D VALID NOTICE | A | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), STEEL, GRADE 5, CADMIUM PLATED, UNC-2A |
| | MS90726 REV B VALID NOTICE | A | SCREW, CAP, HEXAGON HEAD (FINISHED HEXAGON BOLT), STEEL, GRADE 5, CADMIUM PLATED, UNF-2A |
| | AN-TT-L-421 CANC NOTICE 1 | H | LITHOPONE; CADMIUM, DRY |
| | MSFC-PROC-1768 | A | THE DESTRUCTIVE PHYSICAL ANALYSIS OF AEROSPACE NICKLE CADMIUM CELLS, PROCEDURES FOR |
| | NHB 8073.1 | A | MANUFACTURING AND PERFORMANCE REQUIREMENTS OF NASA STANDARD AEROSPACE NICKEL-CADMUN CELLS, NASA SPECIFICATION FOR |
| | QPL-23272 CANC NOTICE 3 | H | BATTERY, STORAGE, ALKALINE, NICKEL-CADMIUM |
| | QPL-26220-20 (1) | A | BATTERIES, STORAGE, AIRCRAFT, NICKEL-CADMIUM GENERAL SPECIFICATION FOR |
| | QPL-81757-15 | A | BATTERIES AND CELLS, STORAGE NICKEL-CADMIUM, AIRCRAFT GENERAL SPECIFICATION FOR |
| | QPL-85050-1 | A | CHARGERS, BATTERY NICKEL-CADMIUM, AIRCRAFT, GENERAL SPECIFICATION FOR |
| | A-A-449 CANC | H | DRILL, ELECTRIC, PORTABLE, NICKEL CADMIUM BATTERY POWERED |
| | A-A-1275 CANC | H | BATTERY, NICKEL-CADMIUM, SECONDARY, ANSI KR142/XXX (SUPERSEDED BY ANSI C18.20002) |
| | A-A-1276 CANC | H | BATTERY, NICKEL-CADMIUM, SECONDARY, ANSI KR257/XXX (SUPERSEDED BY ANSI C18.20002) |
| | A-A-1277 CANC | H | BATTERY, NICKEL-CADMIUM, SECONDARY, ANSI KR334/XXX (SUPERSEDED ANSI C18.2) |
| | A-A-1278A CANC | H | BATTERY, STORAGE (NICKEL-CADMIUM, SECONDARY, NEDA 1604NC) (ANSI C18.2) |
| | A-A-50799 | A | CHARGER/ANALYZER FOR VENTED CELL NICKEL-CADMIUM BATTERIES |
| | A-A-50800 VALID NOTICE 1 | A | CADMIUM OXIDE |
| | A-A-51126A | A | ANODES, CADMIUM |
| | A-A-52417 | A | BATTERY, STORAGE: ALKALINE, NICKEL-CADMIUM |

| New/ Rev | Document Number | St | Title |
|---|---|---|---|
| | W-C-265A CANC | H | CHARGER, BATTERY, METALLIC RECTIFIER TYPE (FOR CHARGING NICKEL/SILVER-CADMIUM POWER PACKS) |
| | W-J-800F | A | JUNCTION BOX: EXTENSION, JUNCTION BOX; COVER, JUNCTION BOX (STEEL, CADMIUM, OR ZINC COATED) |
| | W-O-806 (1) | H | OUTLET-BODIES; IRON (CAST OR MALLEABLE), CADMIUM- OR ZINC-COATED, WITH COVERS AND ACCESSORIES, (FOR SHORE USE) |
| | W-O-821A (2) | H | OUTLET-BOXES, STEEL, CADMIUM OR ZINC-COATED, WITH COVERS AND ACCESSORIES |
| | QQ-A-671A CANC | H | ANODE, CADMIUM (SUPERSEDED BY A-A-51126) |
| | QQ-C-61 CANC | H | CADMIUM; ANODES |
| | QQ-P-416F (1) | A | PLATING, CADMIUM (ELECTRODEPOSITED) |
| | QQ-S-571E INT AMD 6 | A | SOLDER, ELECTRONIC (96 TO 485 DEG. C) |
| | TT-C-80 CANC | H | CADMIUM RED (CADMIUM LITHOPONE) DRY PAINT PIGMENT (SUPERSEDED BY TT-P-341) |
| | TT-C-83 | H | CADMIUM-YELLOW (CADMIUM LITHOPONE), DRY (PAINT-PIGMENT) (SUPERSEDED BY TT-P-342) |
| | TT-P-341A CANC | H | PIGMENT, CADMIUM RED (CADMIUM LITHOPONE); DRY |
| | TT-P-342 CANC | H | PIGMENT, CADMIUM-YELLOW (CADMIUM LITHOPONE), DRY |
| | PPP-B-140C | A | BATTERIES, STORAGE, INDUSTRIAL, AUTOMOTIVE, AIRCRAFT AND NAVY PORTABLE: PACKAGING OF |
| | FED-STD-128B CANC | H | JUNCTION BOX, EXTENSION, JUNCTION BOX; COVER, JUNCTION BOX, (STEEL, CADMIUM OR ZINC COATED) |
| | DESC-DWG-89090 | A | CONNECTOR, ELECTRICAL, CIRCULAR, PLUG, STRAIGHT, REMOVABLE CRIMP CONTACTS, SERIES III, HYBRID CONSTRUCTION |
| | DESC-DWG-89093 | A | CONNECTOR, ELECTRICAL, CIRCULAR, RECEPTACLE, WALL MOUNTING FLANGE, REMOVABLE CRIMP CONTACTS, SERIES III, HYBRID CONSTRUCTION |
| | DESC-DWG-89094 | A | CONNECTOR, ELECTRICAL, CIRCULAR, RECEPTACLE, JAM NUT MOUNTING, REMOVABLE CRIMP CONTACTS, SERIES III, HYBRID CONSTRUCTION |
| | AIA/NAS NAS 73 | A | BUSHING-CLAMP-UP, STEEL, CADMIUM PLATED (REV. 6) *NOT CURRENT DOCUMENT |
| | ASTM A165 | A | STANDARD SPECIFICATION FOR ELECTRODEPOSITED COATINGS OF CADMIUM ON STEEL *NOT CURRENT DOCUMENT |
| | ASTM B32 | A | STANDARD SPECIFICATION FOR SOLDER METAL *NOT CURRENT DOCUMENT |
| | ASTM B224 | A | STANDARD CLASSIFICATION OF COPPERS E1 *NOT CURRENT DOCUMENT |

| New/ Rev | Document Number | St | Title |
|---|---|---|---|
| | ASTM B545 | A | STANDARD SPECIFICATION FOR ELECTRODEPOSITED COATINGS OF TIN *NOT CURRENT DOCUMENT |
| | ASTM B766 | A | STANDARD SPECIFICATION FOR ELECTRODEPOSITED COATINGS OF CADMIUM E1 |
| | ASTM D2492 | A | STANDARD TEST METHOD FOR FORMS OF SULFUR IN COAL |
| | ASTM D3335 REV A | A | STANDARD TEST METHOD FOR LOW CONCENTRATIONS OF LEAD, CADMIUM, AND COBALT IN PAINT BY ATOMIC ABSORPTION SPECTROSCOPY (R 1991) E1 |
| | ASTM E34 | A | STANDARD TEST METHODS FOR CHEMICAL ANALYSIS OF ALUMINUM AND ALUMINUM BASE ALLOYS |
| | ASTM E40 | A | STANDARD TEST METHODS FOR CHEMICAL ANALYSIS OF SLAB ZINC (SPELTER) *NOT CURRENT DOCUMENT |
| | ASTM E146 | A | STANDARD METHODS FOR CHEMICAL ANALYSIS OF ZIRCONIUM AND ZIRCONIUM ALLOYS *NOT CURRENT DOCUMENT |
| | ASTM E351 | A | STANDARD TEST METHODS FOR CHEMICAL ANALYSIS OF CAST IRON - ALL TYPES E1 |
| | ASTM E1019 | A | STANDARD TEST METHODS FOR DETERMINATION OF CARBON, SULFUR, NITROGEN, OXYGEN, AND HYDROGEN IN STEEL AND IN IRON, NICKEL, AND COBALT ALLOYS |
| | SAE AMS 2416G | A | NICKEL-CADMIUM PLATING DIFFUSED |
| | SAE AMS 2419A | A | CADMIUM-TITANIUM PLATING |
| | SAE AMS 2515E | A | POLYTETRAFLUOROETHYLENE (PTFE) RESIN COATING LOW BUILD, 370 - 400 DEGREES C (698 - 752 DEGREES F) FUSION |
| | SAE MA 3289 | A | BOLT, MACHINE-HEX HEAD- PD SHANK MJ THREAD, AMS 6322, CADMIUM PLATE, METRIC (R 1991) |
| | SAE MA 3302 | A | NUT, PLAIN HEX - UNS G87400, CADMIUM PLATE, MJ THREAD, METRIC (R 1991) |
| | SAE MA 3304 | A | BOLT-MACHINE, HEX HEAD, DRILLED, PD SHANK, MJ THREAD, AMS 6322, CADMIUM PLATE, METRIC (R 1991) |
| | SAE MA 3339 | A | BOLT, MACHINE-SPLINE EXTENDED WASHER, PD SHANK, LONG THREAD, AMS6322, CADMIUM PLATED, METRIC (R 1991) |
| | SAE MA 3353 | A | NUT, SELF LOCKING - SPLINE DRIVE, EXTENDED WASHER, UNS G87400, CADMIUM PLATE, MJ THREAD, METRIC (R 1991) |
| | SAE MA 3354 | A | NUT, PLAIN HEX - THIN, UNS G87400, CADMIUM PLATE, MJ THREAD, METRIC (R 1991) |

| New/ Rev | Document Number | St | Title |
|---|---|---|---|
| | SAE MA 3421 | A | NUT, PLAIN HEX - DRLD, UNS G87400, CADMIUM PLATE, MJ THREAD, METRIC (R 1991) |
| | SAE MA 3425 | A | NUT, CASTELLATED, HEX - UNS G87400, CADMIUM PLATE, MJ THREAD, METRIC (R 1991) |
| | SAE MA 3427 | A | NUT, CASTELLATED, HEX - THIN, UNS G87400, CADMIUM PLATE, MJ THREAD, METRIC (R 1991) |
| | SAE AIR 4275 | A | JET REFERENCE FLUID STUDY FOR FUEL TANK SEALANTS |
| | NATO STANAG 4247 ED 1 AMD | A | (DRAFT) BATTERY CHARGERS, NON- ROTATING, FOR LEAD/ ACID AND NICKEL/ CADMIUM BATTERIES |

## SECTION 2: COORDINATION OF EFFORTS

## CONTENTS

## SECTION 2: COORDINATION OF EFFORTS BY THE U. S. NAVY

## IDENTIFYING POTENTIAL ALTERNATIVES TO CADMIUM PLATING

### BACKGROUND

Since the issuance of the latest and most stringent regulation on cadmium in 1992, by the Occupational Safety and Health Administration (OSHA), many independent groups have invested research dollars in processes and materials which may serve as replacements for the multitude of uses for cadmium. Although, it has been evident from our communications that a significant amount of the elimination efforts have been directed towards forms of cadmium other than plating, such as cadmium use in fertilizers, as pigments, or in batteries. Despite their abundance, these programs which focus on cadmium *compounds* were able to contribute little to our cadmium *plating* elimination process. There are also indications that perhaps as early as ten or more years ago, an effort to take heed to the use of cadmium was initiated within the U. S. Navy, yet not fully executed. Findings and final guidance apparently never made it to distribution.

Given the short duration of this SERDP funding (roughly one year), it was imperative that some of the background information that would be used to establish a Navy guidance plan be derived from outside sources. Through a coordinated effort, the reduction of cadmium plated items used within the U. S. Navy can proceed much more expediently. This requires communication amongst groups involved with the cadmium issue and publication of results so that a large audience may benefit. This leverage stage serves as one of the means by which we are facilitating the phasing out of cadmium plated items in the Navy stock system, in Navy facilities, and aboard ships.

### OBJECTIVES

1) Leverage off of existing cadmium replacement programs to maximize results obtainable from a set budget and prevent duplication of efforts.

2) Compile engineering data that would be relevant to the needs of the U. S. Navy, especially results gained from exposure of replacement coatings and substrate materials to seawater or salt spray. Build upon any promising data obtained by others.

3) Establish how the position of the United States compares to that of European countries with regards to environmental regulations and limits on cadmium, success at reduction in its production and use, and (ultimately) alternative materials implemented in place of cadmium.

4) Assist not only the Fleet, but also other individuals and organizations, with environmental compliance by providing them with results from this work.

## APPROACH

The investigation was initiated with the compilation of a list of those organizations thought to be most likely to have addressed the issue of cadmium replacement, and to possess information that would be beneficial to the Navy's needs. This included Department of Defense (DoD) agencies, research laboratories, manufacturers, material suppliers, the automobile industry, and the Swedish Embassy. Through phone calls, meetings, conferences, and published reports, contacts were established and developed. Some attempts to contact groups rumored to have performed relevant investigations over the last decade or so, were stifled due to personnel turnovers and other discontinuities.

Once it was determined what specific R&D was being performed in the material coatings area, several questions had to be addressed to determine the applicability of them for substitution within shipboard equipment. Environmental considerations, performance criteria, and the availability and scale of coating application operations would all help to establish the feasibility of implementing new or existing processes.

## RESULTS

Findings obtained from some of the more profitable communications (and valuable resource materials) are detailed below. Organizations from which pertinent information was obtained include several branches of the U.S. military, the U. K. Navy, private industry, and others. This report is intended to highlight cooperative efforts and the information obtained from such contacts, rather than providing results of a complete literature survey. The latter would be too extensive to detail in full.

### U. S. Military

*Navy*

In June of 1989, an Engineering Change Proposal (ECP NO. N-266) for a cadmium-free LM2500 Gas Turbine Engine was submitted by General Electric (GE). This was provided in response to the Navy direction within military standard MIL-E-17341D for "Engines, Gas Turbine, Propulsion and Auxiliary Naval Shipboard", Paragraph 3.3.1.1.1, "Prohibited Materials". The provisions of the applicable specifications stated that the replacement material must perform "equal to, or better than" the existing cadmium plated parts. In the majority of cases, stainless steel was proposed as the substitute material. (Although, 300 series stainless steel did not meet shock requirements for certain applications.) The only problem of interchangeability foreseen was that of the existing *course-threaded* cadmium plated MS51849 series bolts (and respective nuts) being altered to *National Fine thread* MS9489 series bolts. The use of nickel plating as a potential substitute was rejected by the U. S. Navy on the grounds that it might cause hydrogen embrittlement; but GE maintained that under a well controlled plating process, this would be avoided. Some specific examples of material changes drawn from the ECP follow:

- Cd plated steel EMI bonding posts → stainless steel
- Cd plated copper bonding straps → nickel plated
- Cd plated AISI 1010 or 1020 recessed washers → AISI 304 or 321 stainless steel
- Cd plated steel alloy band clamps for shock mount assembly → A286 alloy steel
- Cd plated steel fasteners in the Flame Detector → passivated stainless steel
- Cd plated aluminum electrical connector shells in leads & harnesses → 321 stainless steel
- Cd plated steel solenoid housing → electroless nickel finish
- Cd plated steel gearbox key-lock insert & studs → A286 & Inconel alloy, respectively
- Cd plated self-tapping gearbox inserts → zinc plated
- Ni-Cd coated alloy steel bolts of compressor frame → Alloy 718

Although this was an admirable attempt to efficiently rid the gas turbine engines of cadmium plated parts, much of this effort was unfortunately defeated during maintenance operations. During repair, cadmium plated hardware was placed back on many of these systems. Proper coordination with the supply system and repair depots, in addition to changing the necessary documentation, is crucial to the successful changeover to cadmium-free systems. This should be acknowledged as an important lesson learned.

*Army Research Laboratory*

The thrust of the Army Research Laboratory's (ARL) SERDP funded research is the delineation of applications for which ion vapor deposited aluminum (IVD Al) can and can not perform adequately, as there have been mixed reports as to the adequacy of IVD Al coatings in service. The ARL Materials Directorate is especially concerned with replacement coating options for high strength materials, since environmentally assisted cracking prevents these metals from being operationally compatible with many sacrificial coatings. They are working on applications geared specifically towards the needs of Corpus Christi Army Depot (CCAD). Main landing gear drag beams are one application for which IVD Al coatings are intended because the current use of cadmium plating provides unsatisfactory performance.

Another of the ARL's interests is the potential for use of IVD Al coatings of 0.5 mil or less. They believe that the standard thickness of IVD coatings, which is often too thick to be used on fastener threads, is perhaps greater than what is necessary to provide ample sacrificial protection to the underlying metal. A flow chart is being developed by them to help users evaluate which military parts can be replaced with IVD Al coatings. Laboratory work in support of their entries includes testing of coated materials at various potentials and stress intensities, and monitoring of crack growth rates. The program includes specimen immersion in 3.5% NaCl, as well as cyclic salt spray tests interrupted by periodic torque-tension measurements.

*Army Materials Technology Laboratory*

The U. S. Army Materials Technology Laboratory performed some research in support of the M1A1 tank and Bradley fighting vehicle which employed cadmium coated grade 8 steel bolts in conjunction with armor steel and Al 5083. The primary goal of this work is evident from the resultant report entitled "The Effects of Co-Mingling Dissimilar Fastener Coatings on the Corrosion Behavior of Steel Bolt Assemblies". Yet, cadmium replacement issues were addressed in tandem. Tests performed included ASTM B117 salt spray, salt water immersion with continuous electrochemical measurements, and breakaway torque (correlated to coefficient of friction) after bolt exposure. The findings most relevant to the U.S. Navy study were that a modified zinc phosphate conversion coating was completely inadequate, while the zinc-nickel coating yielded the best overall performance.

*Army Materiel Command*

Ocean City Research Corporation performed laboratory work for the Army Material Command's Acquisition Pollution Prevention Support Office in the early 1990's. This research was initiated for the purpose of reducing the production of hazardous wastes, specifically those related to the cadmium plating process, at Army maintenance facilities. A combination of exposure tests and mechanical tests were used to evaluate a total of fifteen different coatings which included organic, metallic, and ceramic types. The best abrasion resistance was obtained from titanium nitride coatings and nickel coatings. IVD Al, tin-zinc, and electrodeposited epoxy were some of the coatings exhibiting the highest substrate adhesion. Zinc-containing coatings were found to be the least porous. IVD Al and IVD Al with a metallic ceramic topcoat performed well in exposure tests and also possessed higher breaking torques than cadmium plated control specimens. The cadmium control faired best in the slow strain rate tests used as an indicator of environmentally assisted cracking, but IVD Al and tin-zinc were next in the running. Due to the extent of the information obtained under this program, the original report (OCRC, 1991) should be consulted for specific details. A follow-on report (OCRC, 1993) tested multi-layer coating systems of sacrificial layers with lubricious topcoats for their applicability to threaded fasteners. ASTM B 633 zinc coatings, lacking a Type II or III chromate passivation treatment, matched cadmium controls in torque tension properties.

*Air Force*

McDonnell Douglas Corporation prepared reports documenting a three phase study for Wright Patterson Air Force Base on the merits and feasibility of making an across-the-board substitution of IVD Al in place of cadmium electroplate. The study was initiated in response to concerns of hazardous waste generation and disposal at Air Logistics Centers (ALCs). During Phase I, reviews of technical aspects, environmental concerns, and economic impacts were made. The IVD Al process was found to be non-polluting and generally less expensive than cadmium when taking environmental impact into account. It was determined that approximately 80% of the Cd plated ALC parts could be replaced with IVD Al without technical concern. Phase II carried out the research recommended within the Phase I report. Based on the major applications which raised concern, studies were performed to analyze coverage of internal surfaces, lubricity, and corrosion resistance. These tests showed that the IVD Al process had limited ability to coat deep recesses without the assistance of additional protective systems. With a lubricating layer, enough promising IVD Al data was generated to allow them to proceed confidently with the process demonstration of Phase III. Warner Robins ALC was chosen as the demonstration site where the coating equipment procured during Phase II would be used. As a finale to this effort, the cadmium plating line at Warner Robins ALC was closed, and visits to other facilities sparked the implementation of IVD Al coating processes at four additional ALCs.

**U. K. Navy**

*Ministry of Defence*

Guidance for the United Kingdom Navy is contained within the Ministry of Defence (MoD) Sea Systems Controllerate Instruction (SSCI) No. 5/93 entitled 'Restriction in the use of Cadmium'. Versions of this policy has been in effect since 1984. According to this document, cadmium should only be specified where there is no acceptable alternative, as when it is essential for safety reasons. Additionally, cadmium plated components for which there are suitable alternatives are to be eliminated from both new and existing equipment" by attrition. Naval aircraft and armament stock are exempted. One major source of cadmium still in use is that within the Trident missile system supplied by the United States.

NAVSEA visited MoD in July of 1995, and learned some of the following details which supplement earlier phone conversations and written correspondence. Approximately ten years ago, the UK Navy began to replace cadmium plated parts with zinc plated parts. Numerous failures have since been observed, especially with exposed fasteners on the weather deck. SermeTel 725 coated steel has been considered to be one of their most promising substitutes based on results obtained from carefully handled test specimens. From these test cases, the UK Navy expects that the SermeTel coated fasteners will endure for 5-7 years. Although, there are several precautions which must be taken. These drawbacks include: threads on the substrate steel must be modified during manufacture to allow for the 50-100 μm standard thickness of the coating, the coating is brittle, and frequent disassemblage of equipment might preclude the use of such a 'fragile' coating due to the necessity of hardware replacement whenever the surface became damaged. Other formulations of SermeTel are now on the market and may resolve some of these issues.

A 300 series CRES base material (BS6105 grade A4-80) has been substituted for some applications with good success. Cost and potential for the material to crevice corrode are the two difficulties which may be encountered with its use. ROCOL dry lubricant film is another product which has caught their interest, but it does not satisfy the primary concerns of the U.S. Navy. In addition to the aforementioned information on replacement materials, the U.K. MoD also provided us with a report entitled "Alternatives to Cadmium Coatings", written by J. Edwards.

**Industry**

*Automotive Industry*

The automotive industry has relied heavily upon the use of zinc-nickel (Zn-Ni) for its corrosion resistance and paintability (Smith, 1993). A dual material coating of electroless nickel with diffused polytetra fluoroethylene (PTFE) over Zn-Ni was shown to increase the wear resistance of the surface nearly 5½ times, from a wear life of 42,600 feet for Zn-Ni alone to 231,800 feet for the combined treatment, while reducing the coefficient of friction by one half. Although, cost factors were not addressed within this paper. Corrosion testing consisted of only 100 hours within a salt spray cabinet, and red rust coverage after this exposure was approximately 2%. A second reference confirmed the prevalence of Zn-Ni as a cadmium replacement within the auto industry. By the early 1990's, Honda, Toyota, Mazda, Chrysler Corporation, and Ford Motor Company had already instituted specification requirements or Engineering Change Codes for Zn-Ni to replace cadmium plating (Zaki & Budman, 1991).

*Concurrent Technologies Corporation*

Concurrent Technologies Corporation (CTC) in Johnstown, PA operates a National Defense Center for Environmental Excellence (NDCEE). The purpose of this organization is to facilitate technology transfer by bringing environmentally friendly commercially available processes up to full scale production. The Center's cadmium replacement program was conceptualized in 1994, with a planned completion after 3.2 years. Specifically, the first stage of the program involves a literature search to be completed by January of 1996. This time schedule falls well behind the Navy's goals, since NAVSEA's SERDP funding will have already expired by this time. Although, a preliminary report containing abstracts from the initial background literature search and considerations for process substitution was released in September of 1994. In May of 1995, the NDCEE hosted a two day conference entitled "Cadmium Alternatives: An Information Exchange". The conference proceedings contain presentations on ion implantation, IVD Al, alkaline Zn-Ni, Tin-Zinc, Aluminum-ceramic, and other coating processes. Many contacts were gained during our attendance at these meetings. CTC's decision to repeat this conference next year will promote the coordination and distribution of results obtained from the broad range of organizations represented at this conference.

## European Countries

*Germany*

Within a German reference paper published in the United Kingdom (Tötsch, 1990), the use of zinc plating was only recommended if used in conjunction with a chromate conversion coating to enhance the corrosion protection, since zinc alone is readily attacked in chloride-containing media and its corrosion products are very bulky. They too are in accord that zinc-nickel alloys (with about 12% nickel) are the preferred selection. All of these materials require a lubricant in order to provide adequate performance for applications in which a low coefficient of friction is desired. A system containing an organic binder with zinc powder and a lubricant such as PTFE or $MoS_2$ will suffice, if evenness of the final coating layer is not a requirement. In terms of attaining the combined qualities of reliable corrosion protection, lubricity, and minimal coating thickness, cadmium significantly outperforms these other systems.

*France*

The French Navy performed a study of potential alternatives to cadmium on fasteners. Results obtained indicated that Zn-Ni and a Zn-Al based inorganic coating called DACROMET

500 showed the most promise of the coatings tested. Both processes invoke the use of chromates, which we would prefer to keep at a minimum. Control of deposit thickness, cost, coefficients of friction, and resistance to red rust were all beneficial properties (or factors) exhibited by these two coatings.

*Sweden*

Sweden was a forerunner in addressing and responding to the wave of anxiety generated by the heightened awareness to the general health hazards of cadmium. In 1985, they published the 'Ordinance on Cadmium' under the Swedish Code of Statutes (SFS 1985:839). Because of this, it appeared that the Swedes would be a valuable starting point for learning of well-developed alternatives to be used in place of cadmium plating. Although very active on these topics, as exhibited by their leadership within the European Economic Community (EEC), they are most concerned with the elimination of cadmium within paints, fertilizers, and the like. They have concentrated their efforts on reducing the amount of cadmium in soils and thereby preventing the public's intake through food. In terms of cadmium plating, the Swedish standard has an important clause which exempts the need for material substitution on marine vessels, warships, arms, and ammunition. Therefore, although much acknowledged for their pioneering, Sweden apparently has little to offer at this time in the area of coatings for hardware, especially those in the marine environment.

## DISCUSSION

The coordination efforts served their greatest utility as an initial screening device for replacement coatings being considered. During the upcoming year, benefits will also be derived from maintaining contact with the organizations who are actively testing replacement materials and incorporating their data into future engineering decisions. As stated earlier, the U. S. Navy has special needs due to the severe conditions experienced aboard ship with the constant presence of humidity and sea spray. It appears that this Navy program includes one of the most comprehensive material selection and mechanical test matrices underway. The coatings chosen for the NAVSEA program were screened based upon environmental hazard information obtained from suppliers, manufacturers, and regulatory agencies. Therefore, coatings such as electroless nickel were not considered to be suitable alternatives due to pending environmental regulations affecting material usage.

## CONCLUSIONS/RECOMMENDATIONS

Based upon our coordination efforts, two coatings appear to show the most promise for immediate substitution into the USN operations and other applications. Both of these coatings, Zn-Ni and IVD Al, are included in the Navy test program currently underway since data obtained in chloride containing environments is most limited. The Zn-Ni specimens currently being studied have been further enhanced with a lubricious topcoat, as is sometimes recommended.

Very few organizations seem to be deeply involved in readying 'innovative' environmentally friendly processes like ion implantation or plasma source ion implantation for broad scale use. Although the Army Research Laboratory was considering pursuing more basic

(6.1) research on the process of Magnetron Sputtering as a coating option. Laboratory test results under this Navy program have shown that the ion implantation system evaluated is inadequate as a protective coating in the marine environment, as it readily yields to corrosion. Future data obtained on the use of developmental processes applied to alloys employed in seawater environments may prove invaluable in helping to resolve hazardous material elimination issues. Likewise, efforts to scale-up these developmental processes could reap profound benefits across multiple industries.

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## SECTION 3: MATERIAL SELECTION

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## SECTION 3: MATERIAL SELECTION

## EXECUTIVE SUMMARY

Increasing restrictions on the use of and worker exposure to cadmium has caused the U.S. Navy to investigate alternatives to cadmium plating. OSHA and EPA regulations are causing rapid increases in the costs associated with cadmium plating; purchasing, handling, and disposal. The wide use of cadmium within the Navy has forced the Navy to find an effective, environmentally acceptable replacement for cadmium plating.

A comprehensive literature/background search was performed to determine possible alternatives to cadmium plating. Through data base searches, vendor surveys, review of previous testing and reports, and review of information collected at relevant national conferences, a list of potential alternatives was formed. Various types of replacements were on this list including electroplating processes, vacuum deposited coatings, ion implantation, coatings, and alternative base metals. Information on cost, corrosion resistance, environmental impact, susceptibility to hydrogen embrittlement, adhesion, lubricity, and wear resistance was gathered, as relevant, for each candidate. The potential alternatives were then reviewed for possible inclusion in physical testing. Selection for inclusion in future testing was based on the merits of the alternative and its potential to equal cadmium's performance in the above mentioned characteristics.

Zinc/nickel plating with an organic based topcoat and ion implantation were selected for a process characterization study. The process characterization study was used to determine which variables of the application process influence the performance of the final product. These variables could then be adjusted to produce the most effective plating or implantation. Zinc/nickel has performed well in previous corrosion and mechanical testing. With the addition of a topcoat, zinc/nickel plating has the potential to equal the performance of cadmium plating. Ion implantation is a newer technology but has performed well in the automotive and tooling industries.

In addition to the process characterization study, exposure testing, wear resistance, fatigue crack growth, and torque-tension (lubricity) testing were conducted. Several other potential replacements for cadmium plating were selected for this testing, in addition to the zinc/nickel plating and the ion implantation. These are: Ion Vapor Deposited Aluminum (IVD Al), zinc phosphate and epoxy paint topcoat, epoxy powder coat, inorganic zinc paint, tin/zinc plating, black oxide and epoxy paint topcoat, polysulfide and epoxy paint topcoat, silicone and epoxy paint topcoat, zinc plating (both alkaline and chloride baths), and SermeTel CR984. MIL-P-24441 and cadmium were selected as controls for comparison studies. Also selected for this testing were alternative base metals which could eliminate the need for any protective coating or plating. 316 and 304 stainless steel, Ti-6Al-4V ELI, and Zeron 100 were all selected for the testing. The details of the testing procedures and the results will be discussed in later sections.

## SECTION 3: MATERIAL SELECTION

### BACKGROUND

In response to numerous Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA) regulations and directives, the U.S. Navy is currently investigating environmentally acceptable alternatives to cadmium plating. Cadmium is considered a significant problem because the material can adversely impact the environment and worker health. OSHA regulations (20 CFR, Part 1910.1027) limit the exposure of personnel to airborne contaminants and EPA regulations (40 CFR 268.42) require stringent control of the handling and disposal of hazardous material. A listing of other laws, regulations, and policies relating to cadmium are listed in Appendix A. The use of cadmium creates both economic and administrative problems for facilities during every life cycle phase. Costs to purchase, handle, and dispose of cadmium are increasing and OSHA estimates that the United States will spend $159 million annually just to comply with the cadmium worker health regulations.[1] Problems include ensuring proper hazardous waste disposal and establishing acceptable work environments. The OSHA requirements could force Navy facilities to monitor worker exposure to cadmium and implement engineering controls such as filters and ventilation systems. Not only will Navy production shops be affected but any Navy facility (field activities, dry docks, ships) producing cadmium dust might be regulated. This dust could be generated by abrasive blasting or power tool cleaning that may be performed on a surface containing cadmium plated fasteners. The costs and risks associated with the use of cadmium force the Navy to find a replacement for the cadmium plating that is currently used.

Internationally, cadmium has been recognized as a potential environmental and worker hazard. Germany, Finland, Japan, Australia, Austria, and Sweden have all established restrictions on the use of and worker exposure to cadmium. Although Sweden's policy on cadmium is the strictest, there are many exclusions. These include certain safety applications, Nicad batteries, several "grandfathered" products, and marine vessels.[1] These international policies might affect Navy operations worldwide, specifically any repair or maintenance work performed overseas.

Alternatives to cadmium plating have been sought for several years. The lowering of the OSHA PEL to 5 $\mu g/m^3$ in 1992, created an increased urgency for cadmium's replacement. Thus far, no one-for-one replacement for cadmium plating has been discovered. It is more likely that replacements will be selected based on the requirements of the individual parts. Therefore, there will be more than one alternative for the cadmium plating now in the fleet. Possible alternatives could be other platings, vacuum processes, or alternate base materials. This report discusses the literature search and careful material selection process for cadmium replacements.

## OBJECTIVE

- Identify and select candidate coating systems for evaluation as potential replacements of cadmium plating currently utilized in Navy systems.

## TECHNICAL APPROACH

The overall program consists of two phases. Phase I is the initial literature review, vendor contact, and Navy cadmium-application analysis. It includes the selection of materials to be tested in both phases of the program, and a process variable study of two platings/coatings that need further definition. Phase II is the mechanical and exposure testing of all materials chosen in Phase I as possible alternatives for the Navy's cadmium plating. This section will only detail the first part of Phase I, through the selection of materials to be tested.

The first step in the literature/background search was to determine where cadmium plating is used in the U.S. Navy. Data from the search were used to identify the principal conditions cadmium plating is exposed to in Navy applications. This information was to be used to research and locate potential cadmium replacements. The conditions were going to dictate what type of tests to perform on the chosen cadmium replacement candidates. However, due to a compressed program schedule this initial search had to be performed in parallel with the data search and vendor survey. Therefore assumptions were made on the environments cadmium plating was exposed to and on what items/parts cadmium plating was being utilized. A highly corrosive salt water/air environment was assumed to present a worst-case scenario. Cadmium plating was assumed to be primarily used for plating on fasteners and associated parts.

Data bases (e.g. DIALOG) were searched to find information on any possible cadmium replacements. Testing conducted and reports written by the Department of Defense and private companies were researched to identify previously tested alternatives as well as possible new ones. Vendor literature was reviewed to determine who had or was working on a replacement for cadmium. Information from relevant national conferences was gathered and reviewed as well. Once an initial list of possible alternatives was compiled, it was necessary to seek out as much information on each alternative as possible. Vendors were sent a list of questions to be answered as best they could about the basics of their process/product. Some of the questions and responses were vague, therefore the vendors were telephoned and asked to expand on some of their answers. In addition to asking the vendors about their products, periodicals and previous reports were reviewed to find information on any of the processes on the list. The information was then reviewed and alternative surface treatments were evaluated based on data obtained. Vendor survey information is included in Appendix B.

The information gathered on potential alternatives was evaluated based on a comparison to the characteristics of cadmium. Criteria used to compare the alternatives were corrosion resistance, cost, environmental impact, susceptibility to hydrogen embrittlement, adhesion, lubricity, and wear resistance. For each candidate replacement, cost data was requested for the treatment of 1/2"x4" bolts. The cost per bolt was estimated based on information provided by the vendor for treating 1000 bolts. Since some of the data was not available for certain alternatives, as much information as possible was gathered for each alternative. However, due to the inherent properties of some of the potential alternatives, not all of these criteria are applicable. There may be more than one candidate selected as a replacement for cadmium.

Based on the service conditions, different candidates may be able to successfully replace cadmium for certain applications.

Corrosion resistance was evaluated based on any previous testing as well as available vendor information on how the alternative might perform in a corrosive environment. This was subjective data and might not be a true representation of how the material will perform. Not all information provided by the vendors was supported with test data. Therefore caution was taken in assessing the corrosion resistance potential of new alternatives. The other criteria were also evaluated if any test data was provided on the process.

## RESULTS

Several potential alternatives to cadmium were identified during the literature/background search. Past testing, periodical articles, and vendor suggestions led to numerous possible replacements for cadmium. Table 1 contains the list of alternatives for cadmium that was developed during the background review. From the information obtained during the search, two novel surface treatments were chosen for inclusion in the process characterization study as possible replacements for cadmium plating. They were ion implantation and zinc/nickel plating with an anodic topcoat. Based on literature searches and data reviews for the criteria previously mentioned, these two processes were selected as promising candidates for the replacement of cadmium plating. Other studies performed in the program revealed that the U.S. Navy primarily uses cadmium plating on fasteners and small hardware.

In addition to these two processes, several other alternatives to cadmium were chosen for phase II testing. The application processes for these alternatives are well established and, therefore, will only be included in phase II testing. Phase II testing includes mechanical and exposure testing.

### Phase I Coatings

#### *Ion Implantation*

The ion implantation process is performed within a vacuum chamber. A beam of highly accelerated ions is directed towards a target where the ions become embedded (implanted) in the surface. The process does not alter the dimensions of the object but does modify the near surface area of the material. The process provides barrier type protection to the substrate metal.[2] The cost of ion implantation ( to treat a 1/2"x4" bolt ) in production is less than $1.00 per bolt. Two separate vendors, ISM Technologies and Implant Sciences Corporation, have claimed improved corrosion resistance of the substrate metal from ion implantation, although no formal test results were provided. The ion implantation process leaves no waste products, hazardous or otherwise. Therefore, there are no costs associated with environmental cleanup practices, potentially making the process cost competitive with total plating costs of cadmium. Although a relatively new technique, ion implantation has progressed far enough that it is a practical suggestion for the replacement of cadmium plating. Most of the applications of ion implantation have been in the tool making industry, focusing on cutting tool heads and bits where it has proved beneficial. Ion implantation improves a material's wear resistance[3] and reduces the materials coefficient of friction, yielding better surface lubricity.[4,5] Adhesion is not a problem with ion implantation since there is no coating being deposited onto the surface. Ion implantation was selected to be tested because of its potential to replace cadmium plating. It improves the wear resistance and

**Table 1**
**Cadmium Replacement Survey Results**

| CADMIUM REPLACEMENT | VENDOR | COST PER BOLT(1/2") | COST PER BOLT(1") | STATUS | OTHER TESTING | COMMENTS |
|---|---|---|---|---|---|---|
| ION IMPLANTATION | ISM TECHNOLOGY | LESS THAN $1 PER BOLT | LESS THAN $1 PER BOLT | BEING APPLIED TO PANELS FOR PHASE I | | |
| ZINC/NICKEL ANODIC TOP | HOWARD PLATING | $0.105 $.17/LB TC | $0.105 $.17/LB | BEING APPLIED TO PANELS FOR PHASE I | | ALLEGEDLY DID WELL IN SALT SPRAY TEST, VENDOR INFORMATION |
| IVD ALUMINUM | TITANIUM FINISHING CORP. | $1.55 | $2.90 | WELL DEFINED, TO BE INCLUDED IN PHASE II TESTING | OCRC AMC-5 ,AIR FORCE IS ALSO TESTING | PERFORMED WELL IN PREVIOUS TESTING |
| ZINC PHOSPHATE AND EPOXY | HOWARD PLATING | $0.10 | $0.10 | TO BE INCLUDED AS APPROPRIATE IN PHASE II TESTING | OCRC LAB IS TESTING AS AN UNDERCOAT WITH ZINC PLATING | MAIN PURPOSE IS TO SERVE AS AN ADHERER FOR AN EPOXY TOPCOAT OVER A ZINC PLATING |
| ELECTROSTATIC POWDER COAT | PCM | $0.50 - $0.70 | $0.70 - $0.80 | TO BE INCLUDED AS APPROPRIATE IN PHASE II TESTING | OCRC AMC - 45 FHWA - 4 | NOT FOR USE ON SIZE CRITICAL PARTS (i.e. FASTENERS) |
| INORGANIC ZINC | INORGANIC COATINGS, INC | $0.01 | $40-$50/GAL | TO BE INCLUDED AS APPROPRIATE IN PHASE II TESTING | OCRC AMC-5 | PERFORMED WELL IN PREVIOUS TESTS, BUT CAN'T BE USED TO COAT PARTS SMALLER THAN 1/2" |
| TIN/ZINC PLATING | RELIABLE PLATING | $0.10 - $0.15 | $0.15 - $0.20 | TO BE INCLUDED AS APPROPRIATE IN PHASE II TESTING | OCRC AMC-5 | TESTING BEING DONE ON FASTENERS |
| BLACK OXIDE WITH MIL-P-24441 TOPCOAT | KENNEY STEEL TREATING CORP. | $0.10 | $0.10 | TO BE INCLUDED IN PHASE II TESTING | | STANDARD FINISH ON COMMON SCREWS, PROVIDES VIRTUALLY NO SALT SPRAY RESISTANCE WITH OUT TOPCOAT |
| POLYSULFIDE & EPOXY | NAVY STANDARD | $0.06 | | TO BE INCLUDED IN PHASE II TESTING AS A CONTROL | | NOT FOR USE WHERE LUBRICITY IS A CONCERN |
| SILICONE & EPOXY | MIL-A-46146B | $0.52 | | TO BE INCLUDED AS APPROPRIATE IN PHASE II TESTING | | NOT FOR USE WHERE LUBRICITY IS A CONCERN |
| ZINC ALKALINE BATH | FREDERICK GUMM CHEMICAL | $0.10 - $0.15 | $0.15 - $0.20 | TO BE INCLUDED AS APPROPRIATE IN PHASE II TESTING | OCRC AMC-5 | |
| ZINC PLATING CHLORIDE BATH | PHILADELPHIA RUSTPROOFING | $0.10 | $0.15 | TO BE INCLUDED AS APPROPRIATE IN PHASE II TESTING | OCRC AMC-5 | ACTUAL COST IS $0.50 PER LB. OF BOLTS. 1000 BOLTS (1/2") IS ABOUT 200 LBS. |

**Table 1**
**Cadmium Replacement Survey Results (cont'd)**

| CADMIUM REPLACEMENT | VENDOR | COST PER BOLT(1/2") | COST PER BOLT(1") | STATUS | OTHER TESTING | COMMENTS |
|---|---|---|---|---|---|---|
| SERME TEL CR984LT | SERMATECH INTERNATIONAL | $1.00 | $1.00 | TO BE INCLUDED IN PHASE II TESTING | | |
| EPOXY | NAVY STANDARD | $0.02 | | TO BE INCLUDED IN PHASE II TESTING AS A CONTROL | | |
| **THE PROCESSES AND COATINGS BELOW HAVE BEEN EXCLUDED FROM TESTING FOR THE GIVEN REASONS** | | | | | | |
| ION BEAM ASSISTED DEPOSITION | SPIRE CORP. | CENTS PER BOLT IN PRODUCTION | | DROPPED BECAUSE SIMILAR TO ION IMPLANTATION | | DEPOSITION IS ZINC ALLOYED WITH EITHER NICKEL, ALUMINUM, CHROMIUM, TIN, AND/OR IRON |
| ION IMPLANTATION | IMPLANT SCIENCES | | | SCREENED OUT DUE TO LACK OF INTEREST | | NO RESPONSE |
| PLASMA SOURCE ION IMPLANTATION (PSII) | LOS ALAMOS NATIONAL LAB | $111.00 | $111.00 | SCREENED OUT DUE TO HIGH COSTS | | COST PER DAY IS $5000 AND ONLY 2.5 FT2 OF SURFACE AREA CAN BE DONE |
| ZINC/COBALT PLATING | SAPORITTO | $0.10 - $0.15 | $0.15 - $0.20 | SCREENED OUT DUE TO LOWER CORROSION RESISTANCE THAN ZINC/NICKEL | OCRC LAB IS TESTING ON FASTENERS FOR VIBRATION RESISTANCE | |
| ELECTRODEPOSITED EPOXY | HOWARD PLATING | $0.085 | $0.085 | SCREEN OUT DUE TO POOR PERFORMANCE | OCRC AMC-5 | POOR PERFORMANCE IN PREVIOUS EXPOSURE TESTING |
| ELECTROLESS NICKEL | STAPLETON CO | $0.10 - $0.15 | $0.20 | SCREENED OUT | OCRC AMC-5 | POOR PERFORMANCE IN PREVIOUS EXPOSURE TESTING |
| ELECTROLYTIC NICKEL | ANOPLATE CORP. | $0.10 - $0.15 | $0.15 - $0.20 | SCREENED OUT | OCRC AMC-5 | POOR PERFORMANCE IN PREVIOUS EXPOSURE TESTING |
| EMULSION WATER BASED SULFONATE/ CARBONATE | WITCO | $0.345 PER LB OF LIQUID | SAME | SCREENED OUT DUE TO HIGH CAPITAL COSTS | OCRC AMC-5 | COATING MUST BE DONE BY PURCHASER. NEED TO PURCHASE DIP TANK OR PRODUCTION LINE. |
| METALLIC CERAMIC COATINGS, INC | METALLIC CERAMIC INC | $1.00 - $8.00 | $1.00 - $8.00 | SCREENED OUT DUE TO POOR PERFORMANCE | OCRC AMC-5 | WAS ALSO TESTED AS A TOPCOAT OVER IVD AL |
| IVD TITANIUM NITRIDE | RICHTER PRECISION | $5.73 (4")<br>$6.88 (5") | $11.07<br>$13.27 | SCREENED OUT DUE TO INITIAL COST | OCRC AMC-5, TESTED AS AN INDIVIDUAL COATING NOT AS A TOPCOAT | IVD TiN COATING IS DONE ON TOP OF IVD Al |
| BOEING PROCESS (ZINC/NICKEL) | CTC | | | SCREENED OUT DUE TO CHROMATE TREATMENT | | IT IS A PROPRIETARY PROCESS WHICH LIMITS AVAILABILITY TO INFORMATION ON PROCESS |
| ZINC CYANIDE BATH | CAMBRIDGE PLATING CO. | $0.85 | $1.15 | SCREENED OUT | | CYANIDE BATH IS USED IN CADMIUM PLATING, CAUSES DISPOSAL COSTS |

lubricity, and should improve the corrosion resistance of the substrate metal, all at a competitive price. For these reasons, ion implantation is included in the process characterization study.

*Zinc/Nickel*

Zinc/nickel plating with an anodic top coat was also selected for inclusion in the process characterization study. It performed well in previous testing and showed almost equal resistance to corrosion as cadmium plating.[6] The topcoat is an organic coating applied by electro-coating (E-coat). A chemical conversion coating is used to increase the adhesion of the E-coat to the plating layer. With the addition of an anodic top coat, the lubricity and corrosion resistance should improve. The top coat is the standard recommended by the platers (Howard Plating); others may be tested in comparison. Zinc/nickel is inexpensive. Plating a 1/2"x4" bolt only cost $0.15. The plating layer is composed of 5-7% nickel with the remainder zinc, and applied from an alkaline zinc/nickel plating bath. This plating process is to be tested without the chromate conversion coating which is typically applied over the zinc/nickel plating. Eventually, chromium will probably be subjected to the same type of regulations as cadmium. Therefore, it is important not to replace cadmium with a material that is likely to be highly regulated. A zinc phosphate conversion coating will be used instead of the chromium conversion coating. Since plating processes follow well established procedures that are relatively easy to carry out, the zinc/nickel option is a strong candidate to replace cadmium plating.[7]

**Phase II Coatings**

The processes/coatings selected for the second stage of testing include a diverse group of materials. Each choice of alternatives attempt to remove the need for cadmium plating by addressing different material properties and can not be characterized in the same way (e.g., adhesion tests would not be relevant to a change of the base material to stainless steel). Therefore, it would be inaccurate to try to justify each material in the same way. The selected materials were chosen because of their individual merits and potential for replacing specific needs satisfied by cadmium plating within the Navy.

*Ion Vapor Deposited (IVD) Aluminum*

Ion Vapor Deposited (IVD) Aluminum is a thin layer of pure aluminum applied through a modified physical vapor deposition technique. Aluminum wire is melted and the ions are then transported to the substrate surface through a plasma field. It provides protection to the substrate metal from corrosion by the sacrificial properties of aluminum.[8] The IVD aluminum was applied in accordance with military specification MIL-C-83488 (Class 2, Type I).

The cost to treat 1/2"x4" bolt with IVD Aluminum would be $1.55. It has proved to have good corrosion resistance in previous testing.[5] IVD has less lubricity than cadmium but exhibits good wear resistance. There are no hazardous gases or fumes released by the process; the only waste generated is the aluminum contained in the vacuum chamber, and this can be recycled. IVD aluminum is currently being used on aircraft components and fasteners for corrosion protection.

*Epoxy Powder Coat*

Epoxy powder coat is a fusion bonded coating. During processing the part is grounded, and the nozzle of the gun is held at 100 KeV. As the powder is discharged through the nozzle it becomes charged. The charged particles are then attracted to the grounded part. Powder particles coalesce and form an epoxy film during a heated cure cycle. Minimum thicknesses of .5 to 1 mil make this type of coating prohibitive for use over tight tolerance areas such as threads of fasteners.

*Tin/Zinc*

Tin/zinc is a plating applied via an electroplating process. Tin/zinc provides corrosion protection through sacrificial anodic corrosion of the plating layer. The plating of a bolt would only cost $0.10-$0.15 which is consistent with other plating processes. In previous exposure tests tin/zinc showed average corrosion resistance.[5] It did prove not likely to influence environmental assisted cracking of the substrate. Hazards associated with tin/zinc plating are typical of those encountered with most chemical plating processes. Care must be taken when handling the concentrated acids, and bases used in the cleaning and plating baths.

*Inorganic Zinc*

Inorganic zinc coatings are spray applied coatings that provide the steel substrate with sacrificial and barrier type corrosion prevention.[7] The cost per bolt can be derived from the cost per gallon for inorganic zinc. A gallon of inorganic zinc costs approximately $60; therefore the bolt would cost $0.01 for the coating. Inorganic zinc is not lubricious and should not be employed where lubricity is a concern. It is also applied in a thick layer (3-4 mils recommended), and therefore should not be used for close tolerance parts. The coatings are not considered to be an environmental problem, however, prolonged skin contact or breathing of metal dust or zinc oxide can cause physiological damage to workers. Precautions should be taken when mixing and spray applying the paint.

*Zinc-Alkaline Bath*

In this process, zinc is applied via an electroplating process that uses an alkaline bath. It provides substrate protection by sacrificially corroding to protect the steel base metal.[7] To treat a ½"x4" bolt in the alkaline zinc plating, costs range from $0.10-$0.15 per bolt. Alkaline zinc plating performed well in previous corrosion exposure tests.[9] The use of the alkaline bath increases the possibility of the zinc plating causing environmentally assisted cracking. Alkaline baths are generally less efficient and therefore, more hydrogen is generated on the surface of the part during plating. The wear resistance of the alkaline zinc plating is better than that of cadmium plating. The process does not present any immediate dangers to the environment, however when workers are handling zinc powders and bath chemicals, skin and respiratory protection should be worn.

*Zinc-Chloride Bath*

Zinc plating is also applied using a chloride bath method. The cost to plate a bolt with the zinc chloride bath is $0.10. In previous exposure tests the corrosion resistance of the chloride zinc was less than the alkaline zinc, but it still performed well.[5] It has many of the same characteristics of alkaline zinc plating, but is used in applications where the high pH alkaline zinc plating bath is incompatible with a substrate such as cast iron. The wear resistance is better than cadmium's and environmental hazards are the same as the alkaline bath with the concern focused on worker safety.

*SermeTel CR984LT*

SermeTel CR984LT is a proprietary coating manufactured and distributed by Sermatech International. It is comprised of aluminum particles in a glassy, ceramic chromate/phosphate binder, which is grit blasted with aluminum oxide to develop into a conductive sacrificial coating. It is spray applied in a process that can precisely control the thickness down to 0.4 mils. The coating provides sacrificial corrosion protection and is claimed to perform equally to cadmium plating. It costs approximately $1.00 per bolt to apply this protection. The coating does not cause hydrogen embrittlement, either during application process or in-service.[10] The application process must be assessed to determine the impact of the chromate binder on the environment and worker safety. Cured SermeTel CR984LT contains $CR^{+3}$ and $CR^{+5}$. Coating thickness may make it prohibitive for fastener use, but useful for other small hardware.

*MIL-P-24441 Epoxy*

Navy standard MIL-P-24441 epoxy is used throughout the U.S. Navy. It is spray applied using conventional air spray equipment. Silicone alkyd is a standard topcoat used over the epoxy. Two coats of the epoxy (F150, F152) will be applied to 3.0 mils dry film thickness (DFT), top coated with one 3.0 mil DFT coat of MIL-P-24635 silicone alkyd. This coating will provide barrier protection to the substrate metal. The cost to coat a bolt with this system is minimal, approximately $0.02. The painting procedure is well established and there are no unusual dangers to the environment or workers. Proper safety equipment should be worn and work should be conducted in properly ventilated areas. Coating thickness may make this coating prohibitive for fastener use as well.

*Zinc Phosphate with Epoxy*

Zinc phosphate is used as an under coating in many cases, prior to painting. The surface of the metal reacts with a dilute solution containing phosphoric acid, and forms a protective layer of insoluble crystalline phosphate. The zinc phosphate is applied to increase corrosion protection.[11] The cost of this system is less than $0.06 per bolt.

*Black Oxide and Epoxy*

Black oxide is the typical coating applied to fasteners after machining. The black oxide is produced through immersion in an alkaline solution of caustic soda and potassium or sodium nitrate.[12] It provides short term corrosion protection until fasteners are ready for use (plating or installation). This system with the epoxy/alkyd paints has been included in the test program at the Navy's request. The cost to apply this black oxide and epoxy is $0.13 per bolt.

*Silicone Sealant and Epoxy*

Silicone sealant MIL-A-46146B Type II Group 1 was chosen for inclusion in the program because of its use for other applications within the Navy. Silicone sealant is applied to the nut and bolt of a system prior to attachment. The nut and bolt will then be fastened. The silicone with the epoxy paint system described above will be studied. Both the silicone sealant and the epoxy should provide barrier protection to the substrate. The cost to apply this system to a 1/2"x4" bolt is $0.52.

*Polysulfide Sealant and Epoxy*

Polysulfide sealant will be tested in the same way as the silicone sealant. It has also been added to the matrix because of its use for select Navy applications. This system is currently in use in the Navy for installing bolts in areas where there are no plans for removal. One issue that would need to be addressed is whether or not the sulfur in this sealant acts as a cathodic poison and increases the hydrogen uptake, thereby causing hydrogen embrittlement in high strength steels. The cost to apply this system is $40.13 per 1 pint kit. The cost of this system is $0.06 per bolt.

**Alternate Base Materials**

In addition to alternate coatings and surface treatments as replacements for cadmium plating, several changes in base metal were investigated. Low alloy carbon steels are frequently used as the substrate metal for cadmium applications. If a higher grade steel or alternate metal were used, the need for any protective coating might be eliminated. 316 and 304 stainless steel, Ti-6Al-4V ELI (titanium alloy), and Zeron 100 were all selected to be included in the testing. These all offer improved corrosion resistance over the low alloy carbon steel and present no environmental hazards.

**Eliminated Coatings**

The following coatings were reviewed and not selected for inclusion in testing because of their performance in previous corrosion tests (Table 1): electrodeposited epoxy, electroless nickel, electrolytic nickel, emulsion water-based sulfonate/carbonate, and metallic ceramic. They all performed poorly and showed far worse corrosion resistance then cadmium

Plasma source ion implantation and IVD titanium nitride were screened out prior to testing due to their high costs. In this case, the benefits do not outweigh the costs associated with the processes. To treat one bolt with the plasma source ion implantation technique would cost $111.00. This cost is based on the fixed rate of $5000.00 per day to use the chamber. The IVD titanium nitride process would be applied over the IVD aluminum and would cost over $7.00 per bolt, in addition to the cost of the IVD aluminum.

Zinc/cobalt was screened out because it has lower corrosion resistance than zinc/nickel plating. Since the majority of their other properties are similar, it was not necessary to test the zinc/cobalt plating.

The zinc plating using the cyanide bath was not selected for testing because its corrosion resistance is not any better than the alkaline or chloride zinc plating. Also, the cyanide bath presents disposal problems which will drive up the costs as well as lead to environmental compliance difficulties.

The Boeing Process (zinc/nickel plating) was not selected because it is a proprietary process and it includes a chromate treatment step in the procedure. $Cr^{+6}$ is a known carcinogen. The EPA has recently proposed new Air Emission Standards for $Cr^{+6}$ and Cr. OSHA will release a proposed rule this fall. Therefore, it would not be prudent to replace cadmium with an alternative that may not be compliant in the near future.

Ion Beam Assisted Deposition (IBAD) was screened out due to initial lack of response from the vendor. Also, IBAD is a similar process to the IVD process and therefore, testing this procedure would, in some respects, be in duplication of testing the IVD process.

## CONCLUSIONS

Based on the results of the literature review and vendor survey:

1. Ion Implantation and Zinc/Nickel with an anodic top coat were the most favorable choices to be included in the first phase testing (Process Variable Study) for the Environmentally Acceptable Alternatives to Cadmium Plating Program.

2. The following coatings/platings are possible replacements for cadmium plating. While there is data available for some properties, inclusion of these treatments in the mechanical and exposure testing for Environmentally Acceptable Alternatives to Cadmium Plating would be necessary to fill in missing data.

   Ion Implantation
   Zinc/Nickel with Anodic Topcoat
   IVD Al
   Zinc Phosphate & Epoxy
   Epoxy Powder Coat
   Inorganic Zinc
   Tin/Zinc
   Black Oxide & Epoxy
   Polysulfide & Epoxy
   Silicone & Epoxy
   Zinc- alkaline bath
   Zinc- chloride bath
   SermeTel CR984
   MIL-P-24441(control)
   Cadmium (control)

3. In addition to the coatings/platings, the following base metal alternatives are the logical possibilities to replace cadmium plated steel:

   316 Stainless Steel
   304 Stainless Steel
   Ti-6Al-4V ELI
   Zeron 100

4. Information on where in the Fleet cadmium is used is necessary in order to select the appropriate alternative(s).

## RECOMMENDATIONS

1. The following coatings were recommended for inclusion in the process characterization study for environmentally acceptable alternatives for cadmium:

Ion Implantation
Zinc Nickel with an Anodic topcoat

2. The following coatings were recommended for inclusion in the mechanical and exposure testing for environmentally acceptable alternatives for cadmium, where data is not currently available:

Ion Implantation
Zinc/Nickel with Anodic Topcoat
IVD Al
Zinc Phosphate & Epoxy
Epoxy Powder Coat
Inorganic Zinc
Tin/Zinc
Black Oxide & Epoxy
Polysulfide & Epoxy
Silicone & Epoxy
Zinc- alkaline bath
Zinc- chloride bath
SermeTel CR984
MIL-P-24441(control)
Cadmium (control)

3. In addition to the coatings/platings, the following base metal alternatives should be included in the testing:

316 Stainless Steel
304 Stainless Steel
Ti-6Al-4V ELI
Zeron 100

## REFERENCES

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# APPENDIX A

# LAWS, POLICIES, DIRECTIVES, AND REGULATIONS

# APPENDIX A - LAWS, POLICIES, DIRECTIVES AND REGULATIONS

The following is a list of laws, regulations, and policies that may impact cadmium (and other hazardous material) applications in weapon systems.

## LAWS, POLICIES, DIRECTIVES, AND REGULATIONS THAT IMPACT CADMIUM USE

- DoD Directives and Instructions:
    - DoD Directive 4210.15, "Hazardous Material Pollution Prevention."
    - DoD Directive 5000. 1, "Defense Acquisition Program Policy, Guidelines, and Management Responsibilities."
    - DoD Instruction 5000.2, "Defense Acquisition Management Policies and Procedures."
    - DoD Instruction 5000.2-M, "Defense Acquisition Management Documentation and Reports."
    - DoD Directive 4210.15, "Hazardous Material Pollution Prevention";
    - DoD Directive 5000. 1, "Defense Acquisition Program Policy, Guidelines, and Management Responsibilities";
    - DoD Instruction 5000.2, "Defense Acquisition Management Policies and Procedures";
    - DoD Instruction 5000.2-M, "Defense Acquisition Management Documentation and Reports"
- Executive Order 12856, "Federal Compliance With Right-to-Know Laws and Pollution Prevention Requirements."
- Executive Order 12873, "Federal Acquisition, Recycling, and Waste Prevention."
- OSHA Cadmium Standard (Title 29 CFR, Part 1910.1027).
- Federal and State laws such as the:
    - Resource Conservation and Recovery Act;
    - Federal Clean Water Act and Amendments;
    - Clean Air Act and Amendments; and

**Executive Order 12856, "Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements."** Executive Order 12856 requires the Military to conduct acquisition activities in a manner that minimizes hazardous waste generation through source reduction. One method of reducing the amount of hazardous material used is to substitute more environmentally-acceptable materials.. Executive Order 12856 establishes a goal of a 50% reduction in total toxic materials releases from each Federal agency by 31 December 1999. Reduction in the use of cadmium furthers the military's efforts under Executive Order 12856.

**Executive Order 12873, "Federal Acquisition, Recycling, and Waste Prevention."** Executive Order 12873 requires the Military to evaluate the use of environmentally preferable products as part of the acquisition planning process. In addition, requirements to conduct life cycle cost analyses are repeatedly discussed in Executive Order 12873. This plan is a tool to assist acquisition personnel in identifying environmentally preferable cadmium alternatives.

**OSHA Cadmium Standard (Title 29 CFR, Part 1910.1027).** The Department of Labor, through OSHA is charged with maintaining safe conditions in the workplace. OSHA revised the cadmium standard in the September 14, 1992, Federal Register, Part 11, Department of Labor, Occupational Safety and Health Administration, Title 29 CFR, Part 1910.1027, et al, "Occupational Exposure to Cadmium; Final Rules" (additional revisions were released in the Apn'l 23, 1993, Title 29 CFR, Vol. 58, No. 77). The revised cadmium standard reduces the allowable concentrations of airborne cadmium in the workplace by 95% and includes extensive provisions for medical monitoring and engineering controls. The new cadmium PEL of 5 ug/m3 is one of the lowest exposure limits for any compound (for example, the lead (Pb) PEL is 50 ug/m3) and is only one facet of the extremely complex overall standard.

There are two primary dangers associated with cadmium exposure: lung cancer and kidney dysfunction. Cadmium is primarily absorbed into the body from respirable particles. Secondary absorption routes include ingestion and as a by-product of tobacco smoking. Once inside the lungs, cadmium acts as a direct carcinogen. Cadmium entering the bloodstream also adversely affects the kidneys. The OSHA standard summarizes the danger of lung cancer in terms of deaths within statistical populations. OSHA estimates that for 45 years of occupational exposure to cadmium at the previously acceptable PEL level (i.e. 100, ug/m3), 59 to 157 lung cancer deaths are anticipated among 1000 workers. Using the same calculation procedure, the lower cadmium exposure levels in the 1992 cadmium standard (i.e. 5 ug/m3) will lead to between only 3 and 9 lung cancer deaths. OSHA used a similar statistical procedure to estimate cases of kidney dysfunction (e.g. an inability to retain high molecular weight proteins in the blood, and the bone disease osteomalacia) in exposed workers. OSHA estimates that for 45 years of occupational exposure to cadmium at the previously acceptable level (i.e. 100 ug/m3), 900 out of 1000 workers will experience some degree of kidney dysfunction. Using the same calculation procedure, the lower cadmium exposure levels in the 1992 cadmium standard (i.e. 5 ug/m3) will lead to only between 14 and 23 cases of kidney dysfunction.

Given the potential hazards posed by workplace cadmium exposure, applications for this metal must be reevaluated. Cadmium concentrations in a military workplace cannot exceed the limits described in the 1992 Cadmium Standard.

**State Permits.** Many Federal environmental laws set overall goals and provide the states with the authority to implement them. The permits are used to help achieve the environmental goals. These permits reflect not only the Federal objectives, but may also reflect local environmental concerns.

Table A-1 lists the primary Federal laws administered through state permits that may impact cadmium use at military or contractor facilities. It is important to note that the local rules associated with each permit vary from state to state and as such may be difficult to address as part of an overall acquisition program.

Table A-1. Federal and State Laws Requiring Permits.

| Federal Law | Acronym | Permit and Potential Impact |
|---|---|---|
| Resource Conservation & Recovery Act | RCRA | Hazardous waste disposal regulations create overhead costs and compliance risks. |
| Clean Water Act | CWA | Wastewater cadmium discharge levels are decreasing. More treatment systems may be required. |
| Clean Air Act and 1990 Amendments | CAA | CAA defines cadmium as a hazardous air Pollutant. |
| Pollution Prevention Act | PPA | Does not authorize permits, but does emphasize eliminating uses for hazardous materials. |

The following discussion sections briefly highlight the impact of these various regulations on cadmium use and disposal. The discussion sections highlight the Federal requirements, but individual facilities must ensure compliance with local regulations.

**Resource Conservation and Recovery Act.** RCRA is the primary law defining the handling and disposal of hazardous wastes in the United States. Military facilities that generate hazardous cadmium-bearing wastes may require some form of RCRA storage/treatment permit depending on facility operations. The most significant aspects of RCRA to the Military are:

1. The definition and classification of hazardous wastes,

2. The regulations concerning the handling and storage of hazardous wastes, and

3. The RCRA enforcement provisions.

As described in RCRA defining a hazardous waste is a complex task. Issues such as the waste type, its cadmium content, and hazardous component leachability all impact the process of hazardous waste definition. RCRA sets different cadmium content limits for different waste types.

For electroplating sludges and other listed waste streams (F-codes), RCRA provides heavy metal threshold concentration values. If an electroplating sludge has heavy metal ion concentrations that exceed these thresholds, it is classified as a hazardous waste. According to RCRA Code F006, (Title 40 CFR, Part 268.41 - "Cyanide bath electroplating aqueous wastes"), wastewater treatment sludges from electroplating containing more than 0.066 mg/l of cadmium are considered hazardous. This low threshold value for cadmium means any sludges generated from cadmium plating operations will cost more money to dispose (due to increased hazardous waste disposal costs) than wastes that are considered nonhazardous.

Another set of RCRA provisions apply to characteristic waste streams that contain cadmium. These provisions classify wastes as hazardous if they exhibit characteristics of toxicity per 40 CFR 26 1. These characteristics of toxicity are defined by a leaching test. If the leaching test shows the wastes contain soluble cadmium above the regulatory limit, the waste is considered hazardous. As was the case with plating sludges, the amount of soluble cadmium required to classify a general waste as hazardous is quite low. If the leachate from the test contains more than 1 mg/l cadmium, the waste is considered hazardous. Thus, wastes not directly associated with cadmium, such as those from an abrasive blasting paint removal process, may be defined as hazardous if they become contaminated with small amounts of cadmium from a plated fastener or hardware item. This low threshold value for cadmium means cadmium-bearing wastes will cost programs more money to dispose of (due to increased hazardous waste disposal costs) than wastes that are considered nonhazardous.

In addition to these potential direct costs, the Military must also be concerned about the RCRA administrative overhead costs. Cadmium-bearing, and all other, hazardous wastes generate paperwork (i.e. laboratory analysis, inspections, shipping manifests, etc.). This paperwork must be accurately completed by trained personnel. In addition, the wastes have to be stored in accordance with RCRA provisions leading to increased facility administrative costs. These costs are not investments that improve the quality of a product.

**Clean Water Act (CWA) and Amendments**. The CWA and its amendments grant states the authority, through the National Pollution Discharge Elimination System (NPDES), to issue water pollution discharge permits. These permits typically regulate the concentrations of hazardous materials that may be present in the water discharged by a facility treatment plant. Because these permits are issued to satisfy local pollutant management needs, every facility discharging cadmium-bearing water will have to comply with different requirements. Thus, facilities in California and Alabama may have completely different cadmium limits on treatment plant discharge water. Because some discharge permits require extremely low cadmium levels, facility wastewater treatment costs can be significant.

**Clean Air Act (CAA) and Amendments**. As was discussed above regarding CWA, the CAA grants state and local authorities the right to issue air pollution permits. To date, these permits have had a major impact on emissions of air pollutants such as volatile organic compounds (VOCS) and facility boiler exhausts. However, the

1990 Amendments to the Clean Air Act include a new category of Hazardous Air Pollutants (HAPs). Cadmium-bearing compounds are included in the HAPs list. Naval facilities emitting HAPs may have to install expensive pollution control equipment (i.e. scrubbers) to comply with these laws. Again, the costs associated with air pollution treatment systems to reduce HAPs emissions do not improve the quality of the final product.

**Pollution Prevention Act (PPA).** Finally, the PPA of 1990 encourages the private and public sectors to reduce pollution through source reduction. Table A-2 lists the states that have passed pollution prevention laws. New Jersey's 1991 pollution prevention law requires larger industrial plants in the state to reduce the amounts of hazardous waste generated by as much as 50%.

Table A-2. States with Pollution Prevention Acts

| Pollution Prevention Acts |
| --- |
| Alabama |
| Alaska |
| Arkansas |
| California |
| Connecticut |
| Georgia |
| Illinois |
| Indiana |
| Iowa |
| Kansas |
| Kentucky |
| Maryland |
| Massachusetts |
| Michigan |
| Minnesota |
| Missouri |
| New Jersey |
| New York |
| North Carolina |
| Ohio |
| Oklahoma |
| Oregon |
| Rhode Island |
| Tennessee |
| Virginia |
| Washington |
| Wisconsin |
| Wyoming |

# APPENDIX B

# VENDOR SURVEYS

# VENDOR QUESTIONNAIRE

VENDOR NAME:

PROCESS:

Please answer the following questions on the requested process with the most current information you have available. If cost questions can not be answered specifically, please try to answer as best you can comparing the cost to a cadmium coating. Thank You.

1. Is the process currently being used? If so, what has it been used for?

2. What substrate materials has the process been used on?

3. Is the process still being researched and developed?

4. What sort of atmospheric pollution results from the process?

5. Is any solid waste generated as a result of the process?

6. How does the process compare (or is expected to compare) in corrosion performance with cadmium plating?

7. Can the equipment for the process be purchased?

   If yes,

   7a. What would the capital costs for the equipment be?

   7b. What type of skilled personnel is needed to run the process?

   7c. What would on-going costs be to run the process? (i.e monthly, quarterly, yearly)

8. If the vendor does the process, how long would it take to complete a lot of 1000 bolts?

9. If the vendor does the process, what would be the cost to the customer for a lot of 1000 bolts?

½" x 4" bolts

1" x 4" bolts

ISM Technologies, Inc.
9965 Carroll Canyon Road
San Diego, CA 92131

# Fax Cover Sheet

| | | | |
|---|---|---|---|
| **DATE:** | December 6, 1994 | | |
| **TO:** | John Hebert<br>Ocean City Research | **PHONE:**<br>**FAX:** | 703 413-8266<br>703 413-8270 |
| **FROM:** | James R. Treglio | **PHONE:**<br>**FAX:** | 619 530-2332<br>619 530-2048 |

**RE:** Cadmium replacement with ion implantation.

**Number of pages including cover sheet: 3**

**Message**

Dear John:

I have tried to answer the questions on your questionairre. As you will see in the attached. I need more information to complete it.

I am sending you information on our equipment for your review. Our MEVVA systems were developed by ISM under license from Lawrence Berkeley Laboratory. This may be important to your project, since some of the Berkeley work was financed by the Office of Naval Research. In addition, much of the definitive work on corrosion resistance was conducted at the Naval Research Laboratory.

As I mentioned on the phone, the latest hardware, our MIP implanter, is not included in our normal sales material. It is the largest in the world, with a beam current of 300 ma. It is not yet being offered for sale, but if you wish more details, I can provide you with the system specifications.

I hope that this information helps. Looking forward to working with you.

Sincerely,

James R. Treglio

James R. Treglio

VENDOR NAME: ISM Technologies, Inc.

PROCESS: Metal ion implantation.

1. Is the process currently beign used? If so, what has it been used for? The metal ion implantation process is currently being used to extend the wear life of cutting tools and a wide variety of other components subject to wear and/or corrosion.

2. What substrate materials has the process been used on? Just about everyone. We have used metal ion implantation on tool, bearing, low carbon, low alloy, and stainless steels, cobalt-cemented tunsten carbide, hard-coated (TiN, TiC, etc.) materials, aluminum alloys, copper alloys, titanium alloys, and a wide variety of other metals; ceramics, including alumina, silicon carbide, and silicon nitride; plastics, including PEEK, PET, and polyethylene; and glass.

3. Is the process still being researched and developed? The process is still being researched and developed, as might be expected with such a wide variety of applications.

4. What sort of atomospheric pollution results from the process? If metal ion implantation is carried out with ISM's equipment, none, as the metal ions are produced via the cathodic arc process. It is possible that some might occur with standard Freeman type systems, which involve chlorine gas.

5. Is any solid waste generated as a result of the process. Very little, if any, and none of it hazardous.

6. How does the process compare (or is expected to compare) in corrosion performance with cadmium plating? Chromium ion implantation has proven to be very good at resisting chlorine attack, and outperforms almost everything else in salt spray tests. Tantalum implantation is superior for most acids, although we have seen molybedenum implantation increase resistance to sulfuric acid attack by a factor of 1500. Implantation of tantalum with an oxygen background has been shown by NRL researchers to also offer great promise.

7. Can the equipment for the process be purchased? The equipment can be purchased.

If yes,

7a. What would the capital costs for the equipment be? ISM manufactures a wide variety of metal ion implantation systems, ranging in beam current from 2 ma to 300 ma and in price from $150,000 to $2,000,000.

7b. What type of skilled personnel is needed to run the process? The largest systems are designed for production and therefore do not required skilled operators.

7c. What would on-going costs be to run the process? (i.e., monthly, quarterly, yearly) Material and energy usage are very minimal so most of the on-going cost is in the labor and overhead. If we assume that the base salary of the operators is $10/hr., then a good estimate of the hourly costs is $25. Assuming two shift operation we have monthly costs of $40,000, quarterly $120,000, and annual of $480,000.

8. If the vendor does the process, how long would it take to complete a lot of 100 bolts? If the bolts are made of low alloy steel, then the process temperature must be kept low, so it would take at least an hour to complete. It may take longer, depending on the size of the bolts and the size of the system.

9. If the vendor does the process, what would be the cost to the customer for a lot of 1000 bolts? **This question cannot be answered without knowing the size of the bolts and the expected annual production.**

MCCI

METALLIC CERAMIC COATINGS INC.

DIVISION OF JET-HOT

55 EAST FRONT STREET - BRIDGEPORT PA, 19045
(215) 277-2444
FAX: (215) 277-0135
TELEX: 277622

# MCCI FAX

TO: John Hebert

FROM: Sherm Mills

DATE: Dec 13, 94

NUMBER OF PAGES 3

-----MESSAGE-----

Here is your questionnaire you faxed to Kirk on the 7th. I'll be in the office tomorrow if you have any questions or you can call me this afternoon here in Northern Virginia. at 451-7525

Dec 12, 94

VENDOR QUESTIONNAIRE

VENDOR NAME: METALLIC CERAMIC COATINGS, INC (MCCI)

PROCESS: METALLIC CERAMIC COATING

Please answer the following questions on the requested process with the most current information you have available. If cost questions can not be answered specifically, please try to answer as best you can comparing the cost to a cadmium coating. Thank You.

1. Is the process currently being used? YES If so, what has it been used for? COATING FASTENERS, PIPE HANGERS & CLAMPS, TURBINE ENGINES. SEE MIL-C-81571

2. What substrate materials has the process been used on? STEEL, STAINLESS STEEL, CAST IRON, ALUMINUM.

3. Is the process still being researched and developed? NOT REALLY. WE MAKE IMPROVEMENTS FOR THE AUTOMOTIVE AFTERMARKET. THE COATING WAS DEVELOPED IN 1960'S AND HAS BEEN IN USE FOR PAST 24 YEARS

4. What sort of atmospheric pollution results from the process? NONE. THIS IS WATER BASED COATING. SPRAY BOOTH FILTERS PROTECT FROM AIR EMISSIONS.

5. Is any solid waste generated as a result of the process? YES. SPRAY BOOTH FILTERS, LIQUID SLUDGE, AND CLEANING RAGS. CONSIDERED HAZARDOUS AS THERE IS SMALL AMOUNTS OF CHROMATES

6. How does the process compare (or is expected to compare) in corrosion performance with cadmium plating? WITHSTANDS WELL OVER 1000 HOURS IN 5% SALT-SPRAY SOLUTION.

7. Can the equipment for the process be purchased? YES.

If yes,

7a. What would the capital costs for the equipment be? DEPENDS ON WHAT YOU WANT TO DO. $100,000 - $500,000

7b. What type of skilled personnel is needed to run the process? SEMI-SKILLED. MOST IMPORTANT PEOPLE ARE SPRAYERS AND QUALITY CONTROL.

7c. What would on-going costs be to run the process? (i.e monthly, quarterly, yearly) AGAIN, DEPENDS ON WHAT YOU WANT TO COAT. COULD BE $100,000 TO $1,000,000 PER YEAR.

8. If the vendor does the process, how long would it take to complete a lot of 1000 bolts? 2 DAYS WITH RIGHT EQUIPMENT

9. If the vendor does the process, what would be the cost to the customer for a lot of 1000 bolts? DEPENDS ON SIZE. AVERAGE RANGE IS $1.00 TO $8.00 EACH. IT IS MORE EXPENSIVE THAN CADMIUM. USUALLY IS COMPARED WITH STAINLESS STEEL

NOTE! METALLIC CERAMIC COATINGS HAVE BEEN USED BY THE NAVY SINCE 1980 FOR COATING FASTENERS. HUNDRED'S OF THOUSANDS OF FASTENERS HAVE BEEN COATED AND ARE STILL BEING COATED.

OVER THE PAST YEARS WE HAVE PROVIDED OCEAN CITY RESEARCH WITH INFO AND SAMPLES WITHOUT FEED BACK.

FOR FURTHER INFO CALL SHERM MILLS, VP. EXT 103 610-277-2444.

[signature]

12.12.94

55A56
Correspondence

# VENDOR QUESTIONNAIRE

VENDOR NAME: Howard Plating POC: Dave Ludeke

PROCESS: Zinc/Nickel plating w/ anodic Topcoat

Please answer the following questions on the requested process with the most current information you have available. If cost questions can not be answered specifically, please try to answer as best you can comparing the cost to a cadmium coating.
Thank You.

1. Is the process currently being used? If so, what has it been used for? Yes, all kinds of applications.

2. What substrate materials has the process been used on?
Stainless steel

3. Is the process still being researched and developed?
pretty well established, always looking for improvements

4. What sort of atmospheric pollution results from the process?
?

5. Is any solid waste generated as a result of the process?

6. How does the process compare (or is expected to compare) in corrosion performance with cadmium plating?
Should perform as well as cadmium

7. Can the equipment for the process be purchased?

If yes,
   7a. What would the capital costs for the equipment be?
   Yes, he does not know.

   7b. What type of skilled personnel is needed to run the process? Same as Cadmium
   Trained operator, does not need degree

   7c. What would on-going costs be to run the process? (i.e monthly, quarterly, yearly)
   Similar to Cadmium, utility costs, repair costs?

8. If the vendor does the process, how long would it take to complete a lot of 1000 bolts? ≈ 2 weeks

9. If the vendor does the process, what would be the cost to the customer for a lot of 1000 bolts?

≈ \$0.10/bolt + \$.17/lb of Top Coat used

* Mr. Ludeke claims good performance in salt spray tests. Claims anodic top coat is key to corrosion protection

SEA 56
Correspnc

# VENDOR QUESTIONNAIRE

**VENDOR NAME:** Anoplate Corp. – Syracuse NY

Milt STEVENSON, JR.

**PROCESS:** Electrolytic Nickel

Please answer the following questions on the requested process with the most current information you have available. If cost questions can not be answered specifically, please try to answer as best you can comparing the cost to a cadmium coating. Thank You.

1. Is the process currently being used? If so, what has it been used for? Yes

   Mainly for underplate beneath chrome, tin, or gold
   Sometimes used for brazing applications

2. What substrate materials has the process been used on?

   Fe, CRES, Mo, Ti, Al, Mag, Copper, etc. (almost any!)

3. Is the process still being researched and developed?

   I don't believe so — rather mature technology

4. What sort of atmospheric pollution results from the process?

   Is elevated temp, but far less than chrome but
   at same time more than cadmium

5. Is any solid waste generated as a result of the process?

   Could be drag-out but can be recoverd — same as Cd
   BUT → nickel sol'n more sensitive to contaminants than Cd

6. How does the process compare (or is expected to compare) in corrosion performance with cadmium plating?

   No comparison to cad — cad is electronegative to steel so get galvanic protection → nickel only provide barrier protection

7. Can the equipment for the process be purchased?

   Yes

   If yes,

   7a. What would the capital costs for the equipment be?

   Already have in-house

   7b. What type of skilled personnel is needed to run the process?

   Same as necessary for cad

   7c. What would on-going costs be to run the process? (i.e monthly, quarterly, yearly)

   Similar to cadmium —
   replace anodes, some chemistry to replace that dragged out; filtration of organic breakdown

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8. If the vendor does the process, how long would it take to complete a lot of 1000 bolts?

9. If the vendor does the process, what would be the cost to the customer for a lot of 1000 bolts?

need mat'l and size to do this —

nickel costs no more in time or dollars to do than cad —

nickel has some inherent drawbacks in that it must be routinely filtered and periodically carbon filtered; nickels tend to run @ elevated temperature and nickel doesn't off galvanic protection of cad (nor lubricity, nor galvanically similar to alum, etc. etc.)

P.2 • 02
TCA 56
Correspon

# VENDOR QUESTIONNAIRE

VENDOR NAME: PPG INDUSTRIES 151 Colfax Street
P.O. Box 127
Springdale, PA 15144

PROCESS: ELECTRODEPOSITION

Please answer the following questions on the requested process with the most current information you have available. If cost questions can not be answered specifically, please try to answer as best you can comparing the cost to a cadmium coating. Thank You.

1. Is the process currently being used? If so, what has it been used for?
   YES. PRIMER AND ONE COAT FINISH FOR VARIOUS INDUSTRIES INCLUDING AUTOMOTIVE (BODIES AND PARTS), APPLIANCES, AND INDUSTRIAL APPLICATIONS.

2. What substrate materials has the process been used on?
   HOT AND COLD ROLLED STEEL, GALVANIZED METAL, STAINLESS STEEL, ALUMINUM, COPPER, BRASS

3. Is the process still being researched and developed?
   Pretty much stabilized

4. What sort of atmospheric pollution results from the process?
   VOC of 0.4 - 1.0 #/GAL (-WATER)

5. Is any solid waste generated as a result of the process?
   NO

6. How does the process compare (or is expected to compare) in corrosion performance with cadmium plating?
   SHOULD DRAMATICALLY OUTPERFORM CADMIUM PLATING

7. Can the equipment for the process be purchased?

   If yes,
   7a. What would the capital costs for the equipment be?
       STARTING AT $/100 USD
   7b. What type of skilled personnel is needed to run the process?
       TRAINED (NOT DEGREED) OPERATOR
   7c. What would on-going costs be to run the process? (i.e monthly, quarterly, yearly)

8. If the vendor does the process, how long would it take to complete a lot of 1000 bolts?

NA, they sell process to job shops!

9. If the vendor does the process, what would be the cost to the customer for a lot of 1000 bolts?

NA

SEA 56
Correspondence

spire

4 January 1995

Mr. Hebert
Ocean City Research Corporation
1735 Jefferson Davis Highway, Suite 702
Arlington, VA 22202

Dear Mr. Hebert:

We would like to thank you for your interest in Spire and our cadmium replacement technologies and to apologize for the delay in responding to your December fax. I would like to summarize some of the more salient points that answers some of the questions on your vendor survey. Although some of the information you request is deemed sensitive at this time, I am prepared to provide you some background on the present status of our work.

Regarding the overall performance and types of films that we are presently investigating, we have had very good success. The primary film systems that we are evaluating are zinc alloys which essentially include zinc alloyed with either nickel, aluminum, chromium, tin, and/or iron. The functional use of cadmium has typically been to provide galvanic corrosion protection while at the same time offering a lower coefficient of friction than standard zinc coatings. Through the alloying of zinc with other agents, we are able to vary the relative galvanic potential and the associated tribological properties. Among the more notable performance conditions that we have attained are samples which withstand 500 to 1000 hours (and in some cases more) of straight B-117 salt spray testing. Tests have been conducted to verify material pliability, adhesion characteristics, microstructure, etc. All tests to date have been positive, but due to the nature of these systems the ultimate combined performance (tribological vs. corrosion) of any given film system can vary. Because of this, we would normally enter into a development program with interested companies to obtain the combination of tribological and corrosion pertinent performance characteristics on a case by case basis.

As you are well aware the process which we use of ion beam assisted deposition (IBAD) results in virtually zero discharge. The small amounts of solid wastes that are generated can generally be refined and reused, depending upon the facility in which the materials would be processed. In any case the waste materials appear to be minimal. The equipment used for this work can in fact be used for any of the alloy systems listed above and can switch from one alloy to another with minimal effort. The cost and capacity of these systems are based on specific customer requirements. As far as the ultimate costing of the process it should, in production, not be substantially different from present plating processes. As we discussed before, initial costing evaluations show a projected cost of less than one cent per square centimeter of surface area.

I hope this information provides some of the details that you are looking for. We have very high confidence and are extremely excited about the potential widespread use of this technology. It is interesting to note that a single system can provide any and all of the associated zinc alloys, pure zinc, ceramics and a wide host of other films. Accordingly, if one wishes to investigate alternate methods of protection for a given system of components, one coating system can do this. I look forward to speaking with you soon and toward the possibility of working together in 1995.

Yours truly,

Spire Corporation

Raymond J. Bricault

Raymond J. Bricault
Director of Biomaterial Operations

RJB:mlt

cc: Eric Tobin

DIPSOL GUMM VENTURES

FREDERICK Chemical

December 30, 1994

Ocean City Research
Tennessee Avenue and Beach Thorofare
Ocean City, NJ 08226

Attention: Mr. John Hebert

Dear Sir:

In response to the questionnaire that you forwarded, we are pleased to submit the following response. Please note that plating cost is generated by the plater (our customer), and not us (process manufacturer).

1. This process is currently being used both by captive and job plating shops in the United States, Mexico, Canada, Europe and Pacific Rim countries. It has been used for components for automotive, electrical, defense, bearing, and other industries.

2. The process was marketed as an alternative to cadmium electroplate or zinc electroplate on steel. Our customers also have plated on stainless steel, aluminum, cast steel, copper, and brass.

3. This and all of our processes are always under continual development.

4. We know of no atmospheric pollution resulting from this process.

5. When this process is waste treated, solid wastes that include sodium sulfate, calcium sulfate, zinc, and nickel precipitates will be generated.

6. Corrosion protection from our processes can be expected to out-perform cadmium in 5% neutral salt spray tests (ASTM B-117).

7. Equipment for these systems is nearly identical with equipment used for cadmium and zinc plating.

   7A. Capital costs are quoted as needed. Different size installations will have different capital expenditures.

   7B. Qualified electroplaters and technicians are needed to run the process. They should be properly trained in all safety and chemical handling procedures.

DIPSOL GUMM VENTURES
538 Forest Street, Kearny, New Jersey 07032 • 1-201-991-4171
Fax: 201-991-5855

7C. Ongoing costs would be expected to be under that of running a cadmium operation with the benefit that our processes do not contain cyanide.

8. We estimate that it would take less than 2 weeks to complete a test batch of 1,000 bolts.

9. The cost to Ocean City Research to plate 1,000 bolts would be the same as the last time we plated parts: GRATIS. We only ask that you share a copy of your printed report with us, as in the past.

Should additional questions arise, please do not hesitate to contact either myself or Mr. Edward Budman.

Sincerely,

Michael McCoy

Michael McCoy/EB

MM:df

VENDOR QUESTIONNAIRE

VENDOR NAME:

PROCESS:

Please answer the following questions on the requested process with the most current information you have available. If cost questions can not be answered specifically, please try to answer as best you can comparing the cost to a cadmium coating. Thank You.

1. Is the process currently being used? If so, what has it been used for?

2. What substrate materials has the process been used on?

3. Is the process still being researched and developed?

4. What sort of atmospheric pollution results from the process?

5. Is any solid waste generated as a result of the process?

6. How does the process compare (or is expected to compare) in corrosion performance with cadmium plating?

7. Can the equipment for the process be purchased?

   If yes,

   7a. What would the capital costs for the equipment be?

   7b. What type of skilled personnel is needed to run the process?

   7c. What would on-going costs be to run the process? (i.e monthly, quarterly, yearly)

8. If the vendor does the process, how long would it take to complete a lot of 1000 bolts?

9. If the vendor does the process, what would be the cost to the customer for a lot of 1000 bolts?

TABLE II

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Cadmium Plating (QQ-P-416) Philadelphia Rustproofing | Electrodeposited Epoxy PPG E-Coat | Electroless Nickel Stapleton Company |
|---|---|---|---|
| 1. Is the surface treatment considered an environmentally acceptable alternative to cadmium? | Not applicable | Yes | Yes |
| 2. How would the surface treatment protect a mild steel substrate from corrosion in a marine atmosphere? | Barrier/sacrificial | Barrier | Barrier |
| 3. What types of components have been treated using the process? | Fasteners, aircaft parts, electronic components | Automobiles, appliances, tractor hardware | Valves, pistons, metal parts |
| 4. Would you not recomend the surface treatment for any components? | Food containers, parts immersed in seawater | Yes, parts with narrow crevices and polymeric fittings | No, most parts can be plated |
| 5. What are the acceptable substrate materials for the production process? | Steel, copper acceptable Cast iron is difficult | Steel, zinc, cast iron, copper | Steel, aluminum, titanium cast iron, polymers |
| 6. Is the production process amenable to all component configurations, or is the process line of site limited? | Yes, immersion process coats most shapes. Current flow limits coating in crevices | Yes, immersion process coats most shapes. Current flow limits coating in crevices | Yes, autocatalytic process coats all surfaces |
| 7. What raw materials are utilized during the production process? | Cadmium, Cadmium Oxide, Sodium Cyanide, Brighteners, deionized water | Epoxy resin, epoxy color, deionized water | Deionized water, nickel hydrate, nickel carboxcylic acid, reducing agent |
| 8. Are any of the production process raw materials proprietary? | No | Yes, two vendors produce most electrodeposited epoxy materials | No |
| 9. Does operator skill have a strong influence on product quality? For example, the skill of a spray painter has a strong influence on the quality of a paint job. | No, provided the operator follows procedures, the bath chemistry controls coating quality | No, once parameters are set the process requires no operator input | No, automated process reduces operator influence |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| -Question Submitted to the Vendors | Cadmium Plating (QQ-P-416) Philadelphia Rustproofing | Electrodeposited Epoxy PPG E-Coat | Electroless Nickel Stapleton Company |
|---|---|---|---|
| 10. What are the skill levels of the process operators? | Low skill level worker (High school degree) | Low skill level worker (High school degree) | Low skill level worker |
| 11. What are the skill levels of the process supervisors? | B.S. Engineer or Chemist | B.S.- M.S. Engineer or Chemist | B.S. Engineer or Chemist |
| 12. What are the skill levels of the process maintenance staff? | Skilled tradesman, plumbers, and electricians | Skilled tradesman, plumbers, and mechanics | Skilled tradesman, plumber, or mechanic |
| 13. Do production workers require any special protective or safety equipment? | Yes, gloves, aprons, and face shields | Safety glasses, ear plugs | Yes, face shield, gloves, apron, steel toe shoes |
| 14. What is the approximate capitial cost of the production equipment? | Approximately $1,000,000 including pollution controls | $100,000 to $1,500,000 | $55,000 |
| 15. Is the production process equipment lisensed or patented? | No | Yes, some equipment is lisensed | Yes, process equipment is being patented |
| 16. Does the production process require a controlled environment? For example, a PVD process requires a vacuum. | No, just protection from rain and cold | No, just protection from rain and cold | No, equipment must be protected from rain and cold |
| 17. What is the production rate limiting step? | Time in the plating bath | Time in bath and or time in the curing oven | Time in the bath or time spent blast cleaning |
| 18. What are your typical quality control tests? | Visual, micrometer thickness | Bath QC insures parts are coated properly, periodic DFT measurments confirm bath performance | Statistical process control on bath, thickness and hardness on parts |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Cadmium Plating (QQ-P-416) Philadelphia Rustproofing | Electrodeposited Epoxy PPG E-Coat | Electroless Nickel Stapleton Company |
|---|---|---|---|
| 19. How does production equipment maintenance influence surface treatment? | Impurities in the bath (oil, metals) cause poor coating appearance | Contaminated baths lead to irregular thicknesses and coating pores | Oil or tramp elements in bath produce poor coatings |
| 20. Is atmospheric pollution generated during the production process? | No, room temperature bath produces little fume | No, little fume or mist is generated | Yes, 190 F bath produces fumes |
| 21. How is the atmospheric pollution controlled? | Industrial waste water treatment plant | Not required | Scubber on exhaust gases |
| 22. Are any forms of solid waste generated during the production process? | Yes, sludges and bath residue containing cadmium and other heavy metals | None, unless there is a process upset (power failure) | Yes, filter sytem modules are recycled to recover metals |
| 23. Are there any published technical reports describing the corrosion control performance of the surface treatment? | Yes, numerous technical reports are available | Yes, available from the vendor | Not yet |
| 24. Is a flow chart describing the production process available? | Yes, widely available | Yes, available from the vendor | Not yet |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Electrolytic Nickel<br>Anoplate Corporation | Emulsion/Inhibitor<br>Witco, Sonneborn Div. | Inorganic Zinc<br>Inorganic Coatings Inc. |
|---|---|---|---|
| 1. Is the surface treatment considered an environmentally acceptable alternative to cadmium? | Yes | Yes | Yes |
| 2. How would the surface treatment protect a mild steel substrate from corrosion in a marine atmosphere? | Barrier | Inhibitor/water displacement | Barrier/sacrificial |
| 3. What types of components have been treated using the process? | Nuts, caps, brackets | Fasteners, automobile parts | Bridges, bouys, large steel fasteners |
| 4. Would you not recomend the surface treatment for any components? | Yes, complex shapes with holes | Yes, parts to be painted parts subject to immersion service | Yes, parts subject to pH above 11 or below 4 |
| 5. What are the acceptable substrate materials for the production process? | Steel, both cast iron and aluminum can be plated with some difficulty | Steel, aluminum, cast iron | Steel, aluminum, copper |
| 6. Is the production process amenable to all component configurations, or is the process line of site limited? | No, complex parts with recesses do not coat evenly | Dip application is ammenable to most geometries | No, component must allow line of site coating with a spray gun and must have some blast profile |
| 7. What raw materials are utilized during the production process? | Deionized water, Ni anodes | Deionized water, emulsion concentrate | Water based inorganic binder, zinc powder |
| 8. Are any of the production process raw materials proprietary? | No | Yes, emulsion concentrate | No |
| 9. Does operator skill have a strong influence on product quality? For example, the skill of a spray painter has a strong influence on the quality of a paint job. | Yes, cleaning, rinsing, and part handling influence coating quality | Yes, operator controls coating thickness and uniformity of coverage | Yes, spray gun operator strongly influences coating quality |
| 10. What are the skill levels of the process operators? | low skill level worker | Low skill workers | Low skill level tradesman |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Electrolytic Nickel Anoplate Corporation | Emulsion/Inhibitor Witco, Sonneborn Div. | Inorganic Zinc Inorganic Coatings Inc. |
|---|---|---|---|
| 11. What are the skill levels of the process supervisors? | B.S. Engineers | Low skill workers with process experience | Moderate skill tradesman |
| 12. What are the skill levels of the process maintenance staff? | Skilled tradesman, plumber or mechanic | Skilled tradesman, mechanics or plumbers | Low skill tradesman |
| 13. Do production workers require any special protective or safety equipment? | Yes, face shield, gloves, steel toe shoes | Yes, gloves, face shields, aprons, well ventilated work place | Yes, eye protection, particulate respirator |
| 14. What is the approximate capitial cost of the production equipment? | Prohibitively high due to new facility pollution control requirements | Variable, small dip tank is inexpensive, large production line is very costly | $500 - $50,000 |
| 15. Is the production process equipment lisensed or patented? | No | No | No |
| 16. Does the production process require a controlled environment? For example, a PVD process requires a vacuum. | No, baths must be protected from rain and cold | No, the dip tanks must be protected from rain and cold | No, any dry space is acceptable |
| 17. What is the production rate limiting step? | Bath time for part | Cure time in an oven or coating drying time | Surface preparation (blasting) |
| 18. What are your typical quality control tests? | Visual, micrometer thickness | Visual, coupon salt spray | Visual blast inspection prior to coating, knife peal test after coating |
| 19. How does production equipment maintenance influence surface treatment | Oil or tramp metals in bath cause poor coatings | Some influence, oily tanks produce poor parts | Dirt in filter system causes poor coating adhesion |
| 20. Is atmospheric pollution generated during the production process? | No, room temperature bath produces no fumes | No | No, coating is water/alcohol based |
| 21. How is the atmospheric pollution controlled? | Not applicable | Not applicable | Not applicable |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Electrolytic Nickel<br>Anoplate Corporation | Emulsion/Inhibitor<br>Witco, Sonneborn Div. | Inorganic Zinc<br>Inorganic Coatings Inc. |
|---|---|---|---|
| 22. Are any forms of solid waste generated during the production process? | No solid wastes, counter current rinse recycles nickel some sludges during cleaning | Sludge and excess dried product are non-toxic wastes | No, solid waste is recycled to zinc manufacturers |
| 23. Are there any published technical reports describing the corrosion control performance of the surface treatment? | Yes, numerous | Yes, from the vendor | Yes, numerous |
| 24. Is a flow chart describing the production process available? | Yes, from vendor | Yes, from the vendor | Yes, supplied by the vendor |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Ion Vapor Deposited (IVD) Al Ti Finishing Corp. | IVD Al Alloy McDonnell Douglas | IVD Al/Metallic Ceramic Ti Finishing Corp. |
|---|---|---|---|
| 1. Is the surface treatment considered an environmentally acceptable alternative to cadmium? | Yes | Yes | Note: This process combines the techniques described in in the IVD Aluminum and Metallic Ceramic sections of survey. These sections should be referenced for further data. |
| 2. How would the surface treatment protect a mild steel substrate from corrosion in a marine atmosphere? | Barrier/sacrificial | Barrier/sacrificial | |
| 3. What types of components have been treated using the process? | Aircraft parts, fasteners, electronic components | Aircraft parts, fasteners, missile parts | |
| 4. Would you not recomend the surface treatment for any components? | Components containing materials that have a lower melting point than Al | Thin substrates, low melting point metals | |
| 5. What are the acceptable substrate materials for the production process? | Steel, aluminum, titanium; brass is difficult to coat | Steel, aluminum, titanium; brass is difficult to coat | |
| 6. Is the production process amenable to all component configurations, or is the process line of site limited? | Limited penetration in holes or recesses | Limited to shallow recesses, can throw two holes | |
| 7. What raw materials are utilized during the production process? | Pure Al, Argon gas | Aluminum/zinc wire, argon gas | |
| 8. Are any of the production process raw materials proprietary? | No | Yes, the wire is being patented | |
| 9. Does operator skill have a strong influence on product quality? For example, the skill of a spray painter has a strong influence on the quality of a paint job. | No, instrument controls coating quality, poor operator cleanliness can degrade coating quality | No, instrument controls coating quality, poor operator cleanliness can degrade coating quality | |
| 10. What are the skill levels of the process operators? | Skilled tradesman | Skilled technician with Associate degree | |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Ion Vapor Deposited (IVD) Al Ti Finishing Corp. | IVD Al Alloy McDonnell Douglas | IVD Al/Metallic Ceramic Ti Finishing Corp. |
|---|---|---|---|
| 11. What are the skill levels of the process supervisors? | B.S. Engineers | B.S. Engineers | |
| 12. What are the skill levels of the process maintenance staff? | Skilled tradesman | Skilled tradesman, electricians | |
| 13. Do production workers require any special protective or safety equipment? | Yes, gloves for hot parts | Gloves, steel toe shoes | |
| 14. What is the approximate capitial cost of the production equipment? | $650,000 | $500,000 - $1,000,000 | |
| 15. Is the production process equipment lisensed or patented? | Yes | Yes | |
| 16. Does the production process require a controlled environment? For example, a PVD process requires a vacuum. | Yes, vacuum chamber 10-20 millitorr | Yes, vacuum of 10-14 millitorr | |
| 17. What is the production rate limiting step? | Vacuum chamber loading, system evacuation | Time to load parts and pump down to vacuum | |
| 18. What are your typical quality control tests? | Salt spray on coupons, bend test on coupons, thickness measurements. | Micrometer thickness on test coupons, visual examination | |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Ion Vapor Deposited (IVD) Al Ti Finishing Corp. | IVD Al Alloy McDonnell Douglas | IVD Al/Metallic Ceramic Ti Finishing Corp. |
|---|---|---|---|
| 19. How does production equipment maintenance influence surface treatment? | A dirty pump or chamber can increase glow discharge | Poor vacuum leads to coating defects | |
| 20. Is atmospheric pollution generated during the production process? | No, all byproducts are recycled or inert | No, all gasses used are inert | |
| 21. How is the atmospheric pollution controlled? | Not applicable | Not applicable | |
| 22. Are any forms of solid waste generated during the production process? | Aluminum dust | Yes, powder of mixed Al/Zn is sold to a recycler | |
| 23. Are there any published technical reports describing the corrosion control performance of the surface treatment? | Yes, numerous | Yes, numerous reports are available from the vendor | |
| 24. Is a flow chart describing the production process available? | Yes, from vendor | Yes, from equipment vendor | |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Metallic Ceramic<br>Metallic Ceramic Coatings Inc. | Tin-Zinc Plating<br>Frederick Gumm Chemical | Titanium Nitride (Ion Plating)<br>ARMY CERL Laboratory |
|---|---|---|---|
| 1. Is the surface treatment considered an environmentally acceptable alternative to cadmium? | Yes | Yes | Yes, for certain applications |
| 2. How would the surface treatment protect a mild steel substrate from corrosion in a marine atmosphere? | Barrier/sacrificial | Barrier/sacrificial | Barrier |
| 3. What types of components have been treated using the process? | Fasteners, pipe hangers, ship hardware | Automotive components, electronics components | Machine tools, jewelry, gears |
| 4. Would you not recomend the surface treatment for any components? | Aluminum parts that can't take a 650°F bake. High Cr alloys are difficult to coat | None mentioned | Yes, flexible parts and parts subject to surface impact |
| 5. What are the acceptable substrate materials for the production process? | Carbon steel, cast iron | Steel | Metals, ceramics and for some processes, polymers |
| 6. Is the production process amenable to all component configurations, or is the process line of site limited? | Spray process is line of site, dip application coats complex congigurations | Immersion process coats all surfaces, holes and crevices are tough to coat | No, process cannot coat long tubes or holes |
| 7. What raw materials are utilized during the production process? | Metallic ceramic coating (see attached Mil-Spec) | Not specified, proprietary | Solid metals and gases |
| 8. Are any of the production process raw materials proprietary? | No | Yes, all are proprietary | No |
| 9. Does operator skill have a strong influence on product quality? For example, the skill of a spray painter has a strong influence on the quality of a paint job. | Yes, blast profile, spray and dip application control coating quality | Yes, operators must properly clean parts and follow standard procedures | Yes, operator controls part set-up and cleanliness which control coating quality |
| 10. What are the skill levels of the process operators? | Low skill tradesman | Experienced low skill level workers | Skilled machinist or tradesman |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Metallic Ceramic<br>Metallic Ceramic Coatings Inc. | Tin-Zinc Plating<br>Frederick Gumm Chemical | Titanium Nitride (Ion Plating)<br>ARMY CERL Laboratory |
|---|---|---|---|
| 11. What are the skill levels of the process supervisors? | Experienced operators, no education beyond high school required | B.S. Engineer or Chemist | B.S. Engineer |
| 12. What are the skill levels of the process maintenance staff? | Skilled tradesman, plumbers and mechanics | Skilled tradesman, plumbers electricians | Skilled machinist or tradesman |
| 13. Do production workers require any special protective or safety equipment? | Yes, cartridge respirators eye shields, gloves, steel toe shoes | Yes, eye shields, aprons, gloves, boots | Yes, welding type eye protection and gloves |
| 14. What is the approximate capitial cost of the production equipment? | Unknown, based on size of installation | Varies with size of installation | Unknown, depends on size and capabilities of the instrument |
| 15. Is the production process equipment lisensed or patented? | No, numerous vendors supply blasting/spray coating equipment | No | Some handling and set-up equipment is patented, technology is not |
| 16. Does the production process require a controlled environment? For example, a PVD process requires a vacuum. | No, a dry area protected from rain and cold is required | No, only protection from rain and cold | Yes, vacuum, controlled gas atmosphere |
| 17. What is the production rate limiting step? | Blasting complex parts, hand spraying complex parts | Rate limiting step has not been identified | Chamber cleaning, and pump down to vacuum |
| 18. What are your typical quality control tests? | Visual, blasting profile check, dry film thickness | Salt spray test on coupons solderability, tin wisker test for electronic parts | Visual, chemical etchant, tensile pull test |
| 19. How does production equipment maintenance influence surface treatment | Dirty oil and water traps can lead to poor coating | Strong influence, poorly maintained equipment produces | Instument maintenance does not effect parts, system operation |
| 20. Is atmospheric pollution generated during the production process? | No, only water vapor leaves oven, spray booth filters trap overspray | No | No, all byproducts are recycled or inert (Ar gas) |
| 21. How is the atmospheric pollution controlled? | Dry filters in spray booths | Not applicable | Simple dust filters |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Metallic Ceramic<br>Metallic Ceramic Coatings Inc. | Tin-Zinc Plating<br>Frederick Gumm Chemical | Titanium Nitride (Ion Plating)<br>ARMY CERL Laboratory |
|---|---|---|---|
| 22. Are any forms of solid waste generated during the production process? | Yes, overspray and booth filters must be disposed of as non-toxic wastes | No, the baths do not have to to be dumped | Metal dust |
| 23. Are there any published technical reports describing the corrosion control performance of the surface treatment? | Yes, numerous military reports | Yes, in Japanese, none are available in english | Yes, easily available |
| 24. Is a flow chart describing the production process available? | Yes, from the vendor | Yes, from the vendor | Unknown, possibly from vendor |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Zinc Plating (Chloride) Philadelphia Rustrproofing Inc. | Zinc Plating (Alkaline) Gumm Chemical Corp. | Zinc-Nickel Plating Gumm Chemical Corp. |
|---|---|---|---|
| 1. Is the surface treatment considered an environmentally acceptable alternative to cadmium? | Yes, widely used substitute | Yes, the process is used in Japan as cadmium substitute | Yes, used as a cadmium substitute in Japan |
| 2. How would the surface treatment protect a mild steel substrate from corrosion in a marine atmosphere? | Barrier/sacrificial | Barrier/sacrificial | Barrier/sacrificial |
| 3. What types of components have been treated using the process? | Appliance parts, automotive parts | Fasteners, automotive parts | Fasterners, automotive components, tube products |
| 4. Would you not recomend the surface treatment for any components? | Assemblies containing spot welds are difficult | Yes, cast iron parts | Yes, cast iron parts |
| 5. What are the acceptable substrate materials for the production process? | Steel and cast iron | Steel, high strength steel, aluminum, copper | Steel |
| 6. Is the production process amenable to all component configurations, or is the process line of site limited? | Immersion process coats most surfaces, holes and crevices are difficult to coat | Immersion process coats complex parts, anode location controls throw into crevices | Immersion process can coat complex shapes. Blind holes require internal anodes |
| 7. What raw materials are utilized during the production process? | Deionized water, potassium chloride, sodium chloride zinc anodes | Deionized water, zinc anodes NaOH, activators | Water, NaOH, Zn, Ni anodes |
| 8. Are any of the production process raw materials proprietary? | No | Yes, the activators | No |
| 9. Does operator skill have a strong influence on product quality? For example, the skill of a spray painter has a strong influence on the quality of a paint job. | No, bath chemistry controls the coating quality | Moderate, operator must follow established procedure | Yes, operators must properly clean and load parts |
| 10. What are the skill levels of the process operators? | Low skill level workers | Low skill level workers | Low skill tradesman |

VENDOR SURVEY QUESTIONNAIRE RESPONSES

| Question Submitted to the Vendors | Zinc Plating (Chloride) Philadelphia Rustrproofing Inc. | Zinc Plating (Alkaline) Gumm Chemical Corp. | Zinc-Nickel Plating Gumm Chemical Corp. |
|---|---|---|---|
| 11. What are the skill levels of the process supervisors? | B.S. Engineers | B.S. Engineer or Chemist | Experienced low skill level tradesman, B.S. chemists monitor bath chemistry |
| 12. What are the skill levels of the process maintenance staff? | Skilled tradesman, plumbers electricians | Skilled tradesman, plumber, electrician | Skilled tradesman, plumbers electricians |
| 13. Do production workers require any special protective or safety equipment? | Yes, goggles, aprons, steel toe shoes | Yes, face shield, gloves, apron, boots | Yes, eye shields, gloves, apron and boots |
| 14. What is the approximate capitial cost of the production equipment? | Estimated as $1,000,000+ including environmental controls | Unknown, based on the size of the installation | Unknown, varies with installation size |
| 15. Is the production process equipment lisensed or patented? | No | No | No |
| 16. Does the production process require a controlled environment? For example, a PVD process requires a vacuum. | No, only protection from rain and cold | No, only protection from rain and cold | No, only protection from rain and cold |
| 17. What is the production rate limiting step? | Time in the bath, as controlled by current density | Time in the plating bath as controlled by current density | Plating time in the tank |
| 18. What are your typical quality control tests? | Visual test, micrometer thickness on a coupon | Bake coating to see if it blisters, micrometer thickness, cut test | Bake a test coupon to see if the coating blisters, thickness by X-ray/magnetic |
| 19. How does production equipment maintenance influence surface treatment? | Strong influence, tramp elements contaminate coatings | Strong influence, small amounts of tramp elements contaminate coating | Strong influence, poorly maitained equipment produces |
| 20. Is atmospheric pollution generated during the production process? | No, low temperature bath produces no fume or mist | Yes, mists | Yes, mists rise off the plating tanks |
| 21. How is the atmospheric pollution controlled? | Not applicable | Foam traps mist, scrubbers remove residual mist | Mists may be scrubbed |

**VENDOR SURVEY QUESTIONNAIRE RESPONSES**

| Question Submitted to the Vendors | Zinc Plating (Chloride) Philadelphia Rustrproofing Inc. | Zinc Plating (Alkaline) Gumm Chemical Corp. | Zinc-Nickel Plating Gumm Chemical Corp. |
|---|---|---|---|
| 22. Are any forms of solid waste generated during the production process? | No, the tanks do not have to be dumped | No, tanks do not have to be dumped | No, zinc sludge is recycled |
| 23. Are there any published technical reports describing the corrosion control performance of the surface treatment? | Yes, numerous | Yes, numerous in Japanese, none in English | Yes, from the vendor |
| 24. Is a flow chart describing the production process available? | Yes | Yes, from the vendor | Yes, from the vendor |

## SECTION 4: PROCESS CHARACTERIZATION

## CONTENTS

## SECTION 4: PROCESS CHARACTERIZATION

## CONTENTS (cont'd)

## SECTION 4: PROCESS CHARACTERIZATION

## TABLES AND FIGURES

## SECTION 4: PROCESS CHARACTERIZATION

## EXECUTIVE SUMMARY

Potential replacements for cadmium electroplating include many traditional coating technologies and new, emerging technologies. This portion of the study was conducted to identify optimum process settings to produce the best-suited replacement technique for cadmium plating for two new technologies. The study involved the evaluation of test pieces plated by ion implantation and zinc-nickel plating with a topcoat. The voltage, dose, and implant species were altered for the ion implantation surface modification process. The thickness of the plating, type of chemical conversion coating, and type of topcoat were altered for the zinc-nickel/topcoat surface coating process.

In an ion implantation system, the voltage at which the system runs creates the driving force to implant the ions of the implant species into the surface of the substrate. Tests were conducted at voltages of 70, 50, and 40 keV. Chrome and molybdenum ions were implanted into the steel. The dose of implant species refers to the concentration of implant ions in the surface of the substrate. Dosage levels of $1\text{-}2\times10^{17}$ and $3\times10^{17}$ ions per square centimeter were tested.

Zinc-nickel electroplating was evaluated as an alternative system with the use of an electrodeposited polymer coating topcoat (E-coat). Zinc-nickel plating was provided from an alkaline bath at 0.2 and 0.5 mils plating thicknesses. A chemical conversion coating was used to treat the plating surface prior to application of the topcoat. Chromate and phosphate conversion coatings were examined. An epoxy based (dry coating applied by cathodic charging of the part), and phosphate based E-coat (applied by anodic charging of the part) were tested as potential topcoat materials.

Various tests were conducted to evaluate the quality of the surfaces produced from the various system settings. Ion implanted samples underwent short-term marine atmosphere exposure testing. Marine atmosphere exposure of ion implanted samples showed that none of the tested surfaces produced by this process provided any significant amount of corrosion resistance for the steel surface. Zinc-nickel/topcoat samples underwent thickness, porosity, adhesion, and throw power analysis testing. For the zinc-nickel/topcoat coatings, most variables did not strongly effect the throw power test results. The adhesion of the Anodic E-coat coatings was much better than the dry E-coat coatings. One dry E-coat system also had a much higher total system thickness than all other systems tested. The porosity of the coatings were slightly reduced by increasing the plating thickness.

None of the ion implantation variations were found to have acceptable corrosion resistance to replace cadmium. For zinc-nickel, changing parameters did affect the thickness, porosity and adhesion of the coatings. The throw power was not affected by changes of process or topcoat. The corrosion resistance of these variables will be determined in the next phase of this program.

## ENVIRONMENTALLY ACCEPTABLE ALTERNATIVES TO CADMIUM PLATING:

## SECTION 4: PROCESS CHARACTERIZATION

### BACKGROUND

In response to numerous regulations and directives the U.S. Navy is currently investigating environmentally acceptable alternatives to cadmium plating. Among the regulations which impact the use of cadmium plating for shipboard applications are OSHA cadmium standard 29 CFR, Part 1910.1027 for exposure of personnel to airborne contaminants and EPA regulation 40 CFR 268.42 regarding hazardous material handling and disposal. Due to the relative toxicity of cadmium (the OSHA Personal Exposure Limit is an order of magnitude lower than lead), the elimination of this material presents a significant personal exposure and pollution prevention benefit.

### OBJECTIVE

- For two cadmium alternative systems, identify the effect of variable application specification processes on system performance.

### TECHNICAL APPROACH

The overall cadmium alternatives program consists of two phases. Phase I consists of background research and a process characterization study. The background research and identification of possible candidates is detailed in Report 1 of this program[1].

Limited testing is included. The testing determined the effects of process parameters on the quality of a zinc-nickel plating/organic topcoat and ion implantation cadmium alternative systems. For these systems vendors supplied information on their processes and performed variable-parameter test runs. The zinc-nickel and ion implantation samples from this study were subject to testing for adhesion, porosity, throw power, and coating thickness. The results of these tests form a basis for process

[1]The subject report (report 2) will detail the effects of the parameters of two new technology candidates.

optimization[2]. The corrosion resistance and other performance attributes of the systems are fully covered in report Section 5.

**Test Specimens**

Two types of test specimens were used in the process variable study. The first was a complex panel designed to include the types of features that can cause coating defects, and the second was a flat plate specimen. Both test specimen types were fabricated from AISI 1010 steel and had a smooth (less than 1 mil profile), cold-rolled finish.

Figure 1 shows a schematic diagram of a complex test specimen. The panels were approximately 4 inches by 6 inches by 1/4 inch. As shown the complex specimen includes the types of details usually associated with coating failures, such as sharp corners, threaded fasteners, holes (various diameters/depths), shielded areas, crevices, and welds.

Flat 4-inch by 6-inch by 1/32-inch specimens were used for coating adhesion and porosity evaluations. Flat and complex specimens were coated during the same "batch" mode processing groups for zinc-nickel systems.

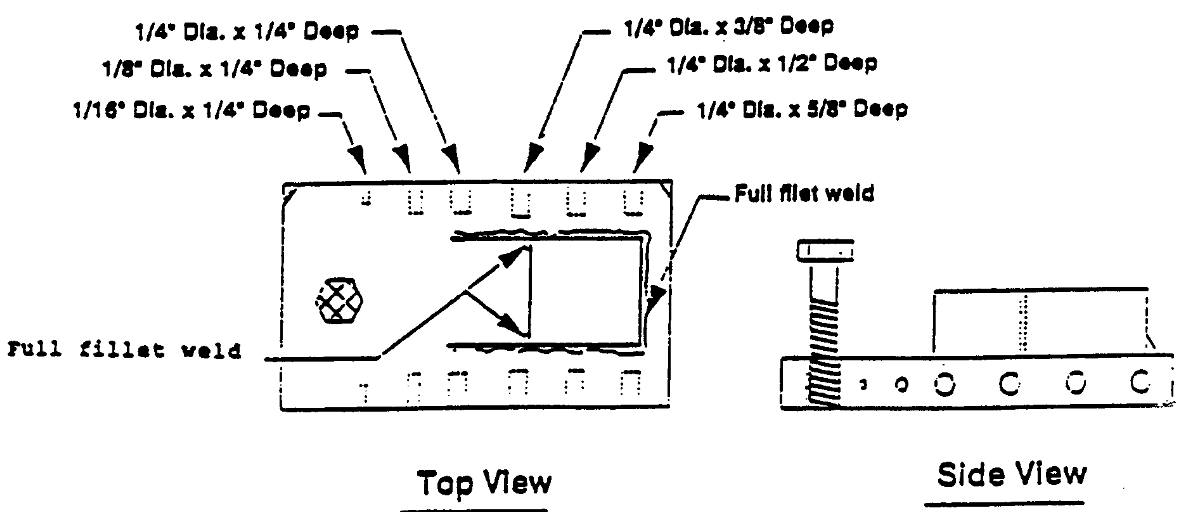



**Figure 1: Complex Test Specimen**

[2] Note that the zinc-nickel and ion implantation samples used for field testing were prepared by best current practices. This was one condition used for process characterization.

## Coating Systems

Ion implantation and the zinc-nickel/organic coating were introduced in Report 1. The surface layers produced by these processes are created from a combination of many different system settings and raw materials. The objective of the Phase 1 testing was to evaluate the performance of surfaces produced as the system settings and raw materials were altered. The following discusses the variation in the systems evaluated.

### *Ion Implantation*

Ion implantation is a process in which a beam of highly accelerated ions is directed toward a substrate. It does not coat the substrate, but rather it is a novel surface modification technique in which these ions become embedded within the surface of the substrate. Commercial applications are beginning to develop in several areas for this process. There are several potential variables which can be changed to alter the coating produced by the process. The implantation process is performed within a controlled environment. The type of ions implanted and the voltage used to accelerate the ions to the substrate are variable. Another variable is the length of time of implantation. This effects the total number of ions implanted into the substrate surface, which is also known as the ion dose.

#### Voltage

There is a voltage drop which is used to accelerate the ions of the implant species into the surface of the substrate. The higher the voltage is, the more kinetic energy each ion obtains. This aids in implanting these ions into the surface of the substrate to be coated. The recommended voltage was 70 keV. In order to examine the effects of reducing this voltage slightly (to reduce process power requirements) a voltage of 50 keV was also tested. Both of these voltage values create a high enough energy state to cause X-ray energy waves to also be produced during the creating and acceleration of ions. A voltage of 40 keV was also tested to determine the properties of a coating which was produced at a voltage level which did not generate these unwanted X-rays. The generation of X-rays creates the need for lead containment of the ion source chamber to protect workers.

#### Dose

The dose of the implant species indicates the number of atoms which have been implanted into a given surface area of the substrate. The concentration of implant ions in the surface layer will vary directly with the dose. A typical dose level is $1\text{-}2 \times 10^{17}$ ions/cm$^2$. This will provide a layer of approximately 5-10 atomic % of the implant species on the substrate.

A dose level of $3\times10^{17}$ atoms/cm$^2$ was also tested during this process evaluation program. To achieve a higher dose level, the implantation process is conducted for a longer period of time. As the implant ions bombard the surface, and embed themselves into the substrate, they also sputter away some atoms on the substrate surface. Initially the sputtered atoms are just substrate atoms (i.e., iron). Eventually an equilibrium is reached in which the number of implant species ions being embedded into the substrate equal the number of implant species atoms being sputtered off of the surface of the substrate.

**Species**

The species is the type of ions used to implant the surface of the substrate. Almost any type of material can be used to implant a substrate. Chromium and molybdenum are two elements which were recommended as potential implantation candidates to improve the corrosion resistance of a steel substrate. Chromium ions were the primary species of interest, and molybdenum ions were examined as a separate process variable.

**Atmosphere**

Ion implantation is conducted in a controlled atmosphere. A vacuum is typically used during the implantation process. Less air is in the way of the ions as they travel from the source to the substrate surface. This increases the efficiency of the process by increasing the percentage of ions which become implanted into the substrate as compared to the number of ions drawn from the ion source.

A vacuum is also used to control the type of modification which occurs on the substrate surface during implantation. When foreign atoms are in the chamber, they may be accelerated into a higher energy state by the implant ions. The ions may collide with these atoms as they travel toward the substrate. These excited foreign atoms may themselves become implanted into the surface or they may react with the surface to form different chemical reaction layers. The introduction of oxygen into the chamber can alter the typical implantation process and create a novel type of surface modification. The equilibrium concentration of implant ions can be altered by the changing of the surface layer chemistry. This is accomplished because the change in surface chemistry changes the binding energy of the substrate for the implant species.

*Zinc-Nickel with Topcoat*

Electroplating is a common procedure used to apply a metallic coating to the surface of a part. Zinc-nickel alloy platings are being considered potential replacements for cadmium electroplated coatings in some applications. More recent developments with zinc-nickel plating include the use of topcoats over the plating layer to enhance the properties of the coating. The coatings examined in this study were organic coatings applied by electro-coating (E-coat). Chemical conversion coatings were used to increase the adhesion of the E-coat to the plating layer.

**Zinc-Nickel**

The plating layer composition and deposition procedure were not altered during this process evaluation. Industry has used this process for many years and has had time to optimize these parameters. The composition of the plating layer was 5-7 percent nickel and the remainder zinc. It was provided from an alkaline zinc-nickel plating bath. The property of the zinc-nickel plating which was altered during the process evaluation was the thickness of the plating layer. A minimum thickness of 0.2 mil was tested along with a coating of 0.5 mil thickness. This latter thickness was obtained by increasing the coating time.

**Chemical Conversion Coating**

A chemical conversion coating was used to convert the surface of the plating from a zinc-nickel to a complex chemical combination of different elements. The purpose of this layer was to create a surface to which the supplemental E-coat could more readily adhere. It also may inhibit corrosion. Two different chemical conversion coatings were tested. A chromate conversion coating is most currently used over zinc-nickel. In addition to the increased adhesion of topcoats, the chromate inhibits corrosion through the leaching of hexavalent chromium ions from the film in contact with moisture. Unfortunately, hexavalent chromium is also a known carcinogen. The EPA and OSHA have begun to examine new regulations to restrict the use of this material. As an alternative to a chromate conversion coating, a zinc phosphate conversion coating was also examined over the zinc-nickel plating to increase the adhesion of the topcoat and retard corrosion. This coating also provides a chemical conversion coating layer on the surface of the zinc-nickel plating which provides a barrier to corrosive environments and an anchor layer to which topcoatings may adhere.

**E-coat**

An organic coating was applied as a topcoat to the plating/chemical conversion coating system. It is a process similar to electroplating in which a part is charged and submerged in a chemical bath where the coating is applied through electrostatic attraction of the charged coating particles to the artificially charged substrate surface. Two different coatings were examined in this process study. One system was a conventional epoxy E-coat barrier coating (a.k.a. Dry E-Coat). The other primary coating of interest was a phosphate E-coat which was applied by anodic charging of the part (a.k.a. E-coat).

*Coating System Process Variable Matrices*

The applicable production process parameters for each process were developed into a matrix for each system. Tables 1 and 2 present these matrices for ion implantation and zinc-nickel, respectively. Each line in the matrix represents three replicate test specimens of each type (complex and flat plate). Each of the significant production process variables is addressed in the matrix.

**Table 1**

**ION IMPLANTATION
PROCESS VARIABLE MATRIX**

| Sample Identification | Voltage 70kv | 50kv | 40kv | Dose $1\text{-}2\times10^{17}$ | $3\times10^{17}$ | Species Cr | Mo | Atmosphere Vacuum | $O_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 1A | X | | | | X | X | | X | |
| 1B | | X | | X | | X | | X | |
| 1C* | X | | | X | | X | | X | |
| 1D | | | X | X | | X | | X | |
| 1E | X | | | X | | | X | X | |
| 1F | X | | | X | | X | | | X |

* Industry recommended process.

**Table 2**

**ZINC-NICKEL PLATING WITH ANODIC TOPCOAT
PROCESS VARIABLE MATRIX**

| Sample Identification | Thickness of Plating 0.2 mils | 0.5 mils | Chemical Conversion Coating CCC | Zn Phos. | Type of Topcoat Anodic E-Coat | Dry E-Coat |
|---|---|---|---|---|---|---|
| 3A* | X | | X | | X | |
| 3B** | | X | | X | X | |
| 3C | | X | | X | | X |
| 3D | | X | X | | X | |
| 3E | X | | | X | | X |
| 3F | X | | | X | X | |

* Industry recommended process.

** Standard process used for Phase II testing except for marine exposure where each sample type was exposed.

The zinc-nickel system test matrix was made up of two different two-factor, two-level factorial design experiments. The factorial designs are used to measure the effects of different variables and potential interactions they may have. Tables 3 and 4 list the factorial design for the test runs which were combined to create the test matrix given in Table 2.

**Table 3**

**PLATING THICKNESS, CHEMICAL CONVERSION COATING INTERACTION MATRIX**

| ID | Plating Thickness | Chemical Conversion Coating |
|---|---|---|
| 3F | 0.2 mils | Zinc Phosphate |
| 3A | 0.2 mils | Chromate Conversion Coating |
| 3B | 0.5 mils | Zinc Phosphate |
| 3D | 0.5 mils | Chromate Conversion Coating |

**Table 4**

**PLATING THICKNESS, E-COAT TOPCOAT INTERACTION MATRIX**

| ID | Plating Thickness | E-coat Topcoat |
|---|---|---|
| 3F | 0.2 mils | Anodic E-coat |
| 3E | 0.2 mils | Dry E-coat |
| 3B | 0.5 mils | Anodic E-coat |
| 3C | 0.5 mils | Dry E-coat |

Each coating system listed in Table 3 had an Anodic E-coat topcoat. The Dry E-coat was only applied to the zinc-nickel plated substrates with zinc-phosphate conversion coating. This reduced the total number of test panels prepared and avoid excessive testing of systems containing hexavalent chromium.

## Testing

*Thickness*

An Elcometer 300 thickness gauge was used to make the thickness measurements on the zinc-nickel test panels. The thickness gauge was calibrated on an AISI 1010 steel surface using a 1.5-mil Mylar shim. The thickness data averages and standard deviations were calculated.

*Porosity*

Coating porosity of the zinc-nickel coating was measured utilizing a modified ASTM procedure for metallic platings over steel. The procedure, suggested in ASTM B733 paragraph 9.6.1, uses a ferricyanide solution to evaluate the porosity of nickel coatings over steel. The ASTM standard solution was prepared by dissolving 1295 g of potassium ferricyanide and 15 g of sodium chloride in 1 liter of distilled water.

Conceptually, the process worked by identifying pores in the steel's topcoat. When this solution contacts iron ions, a blue precipitate is formed. This precipitate marks defects or holes in the coating. Because zinc is electrochemically active to the steel substrate in most natural atmospheres, the material sacrifices to protect the steel from corroding at pores. To overcome this sacrificial corrosion of zinc and force iron ions into solution at the coating defects, the ASTM procedure was modified by the use of an impressed current between the steel substrate and a counter electrode. A filter paper was soaked in the ASTM standard ferricyanide solution and placed on the coated test specimen. A flat counter electrode was then placed on the top of the solution soaked filter paper. Electrical connections were made to the counter electrode and the test specimen. The positive terminal of a direct current source was connected to the test specimen, and the negative terminal was connected to the counter electrode panel. The current source caused the coated specimen to become anodic, while the counter electrode became cathodic. The voltage source was adjusted to produce approximately 18 to 20 milliamperes in the circuit. The current flow was maintained for 15 minutes.

Following this procedure, the filter paper was removed and inspected. Iron ions caused by the impressed electrical current reacted with the ferricyanide solution to form blue precipitates which stained the filter paper. The quantity of blue precipitates were counted. This number was then normalized by dividing by the surface area tested for each panel.

*Ion Concentration*

For the ion implantation process evaluation panels, the concentration of the ions implanted rather than porosity or thickness was determined. This was performed using X-ray florescence. A detection system was set up to count the number of X rays in an energy region characteristic of X rays from the implantation element. The count-rate intensity at this energy is at a minimum for a sample of the bare substrate therefore, concentration in the implanted element can be detected.

*Adhesion*

The adhesion tests on zinc-nickel were conducted using two ASTM standards: ASTM D522, "Standard Test Method for Elongation of Attached Organic Coatings with Conical Mandrel Apparatus," and

ASTM D4145, "Standard Test Method for Coating Flexibility of Prepainted Sheet." As described in ASTM D522, a 1/32-inch thick bend test specimen is deformed around a conical mandrel. The diameter of the 8 inch long mandrel varies linearly from 0.25 to 1.5 inches. The measured distance from the panel edge to the point at which no coating failures are apparent is converted to a failure diameter using trigonometry. Thus, test coating adhesion in terms of failure-diameter was calculated.

The minimum bend diameter that may be created using the ASTM 522 test was the minimum mandrel diameter (0.25 inch). To study adhesion failures caused by even smaller bend diameters, the ASTM D4145 technique was used. Triangular test sections satisfying the ASTM D4145 specified design criteria were formed by diagonally sectioning the flat specimens. The triangular specimens were repeatedly folded over, or bent through 180-degrees. Using each bend as the fulcrum for subsequent bends caused an increasing series of bend diameters. Test specimens were bent ten times creating discreet bend diameters ranging from approximately 0.062 inch to approximately 0.32 inch. Visual inspection at 10x magnification determined coating failure after each bend interval. Measuring the diameter of the first bend not to exhibit coating adhesion failure defined the failure-diameter. A coating failure has been determined to be a crack through the organic topcoat which is visible under 10x magnification.

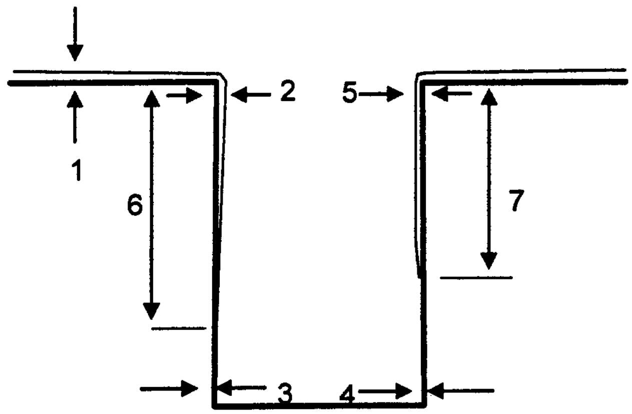
Conversion of the ASTM D522 results and the ASTM D4145 results into identical failure-diameter units allowed the results generated from the two techniques to be combined. The combined results form a range of bend diameters form 0.062-inch through 1.5-inches. Thus, adhesion failures were studied over a greater range than possible by either individual, standard technique. Because substrate plastic deformation is inversely related to bend diameter, coating systems with large failure diameters are considered less adherent than coating with smaller failure diameters.

*Throw Power*

The throw power of the zinc-nickel was the determination of the plating thickness inside the blind holes (see Figure 1). This analysis was conducted on complex panels coated using each of the production process parameter variations shown in Table 2. One test specimen for each process variation in the Table 2 matrix was used for the destructive coating thickness evaluation. The holes along the side (1/8 inch and 1/16 inch diameter) were cross-sectioned and examined metallographically.

Seven measurements were made on each metallographic cross-section of a blind hole. Figure 2 cross-section schematic uses the numbers 1 through 7 to designate individual measurements of the plating in each hole. The thickness of the coating immediately outside the hole was measured (location 1). The thickness of the coating was measured on each interior wall at two places - immediately inside the hole (locations 2 and 5) and immediately before the hole ended (locations 3 and 4). The furthest distance from the panels edge where coating appeared to have adhered was also determined (distances 6 and 7).

**Figure 2: Throw Power Analysis Measurement Locations**




In order to reduce the effects of local variation in coating process on the results of this program, the data were normalized. The normalizing approach was based on the premise that a thicker coating on the exterior surface of the panels would produce a greater thickness in the hole as well. Each thickness measurement inside the hole (locations 2 and 5) was expressed as a percentage of the thickness at the outside edge of the hole (location 1).

A normalization technique was applied of the throw power data. To allow comparison of the throw power in different sized holes, each measurement of "throw" into holes (distances 6 and 7) was expressed as a ratio to the hole diameter.

## RESULTS AND DISCUSSION

The samples discussed here were also planned to be subject to a range of critical corrosion and performance tests in Phase II of the program. For the zinc-nickel/topcoat systems, these results are in Report 3. The corrosion results of the ion implantation systems are described here to illustrate why the complex analysis of process parameters if ion implantation was not completed.

### Ion Implantation

Ion implantation was performed by ISM Technologies. Upon receipt of all the flat panels from ISM, three samples of each variable combination (listed in Table 1) were placed at Sea Isle to begin marine exposure (Phase II). These panels included all systems listed in Table 1 except for the panels implanted in an $O_2$ rich atmosphere (coating was not yet complete). A set of uncoated, cold rolled steel panels were also placed with them as a control. Figures 3 and 4 show the test panels after 3 and 7 days of exposure to a marine atmosphere. Rust is evident across the surfaces of all of the panels after 3 days of exposure. A slight difference can be seen in the panels implanted with the vendor's recommended practice and with a higher dose of Cr (slightly less rust for systems C and A). The remaining panels showed rust patterns similar to the steel control panels which were not subjected to ion implantation. After 7 days (total test was to be 365 days) under marine atmospheric exposure both the implanted and untreated panels were completely covered with rust. No difference was detected between any of the panels. This observation led to the determination that ion implantation would not be an acceptable cadmium replacement candidate due to the lack of corrosion resistance of the mild steel panels implanted with both the Cr or Mo ions. All further testing was focused on the zinc-nickel system.

**Zinc-Nickel with Topcoat**

*Thickness*

An Elcometer 300 electronic thickness gage was used to measure the coating thickness of the zinc-nickel system panels. It uses an electromagnetic induction technique to measure coating thicknesses over ferrous substrates. Previous OCRC work had verified that zinc-nickel plating thickness measurements obtained with the Elcometer 300 gauge matched those observed under metallographic analysis. Ten flat panel surfaces of each test variation listed in Table 2 had five thickness measurements taken across their surfaces. For each surface the high and low measurements were recorded along with the average and standard deviation for all five measurements. The individual thickness readings were combined for each coating system to determine the average thickness for each system.

Figure 5 shows the range of average system thicknesses for each coating variation listed in Table 2. 3E samples had the highest total system thickness at approximately 1.9 mils. The 3B, 3C, and 3D panels each had an average thickness between 0.5 and 0.9 mils. Each of these systems had a target base plating thickness of 0.5 mils. The 3A and 3F systems had average thicknesses between 0.6 and 0.7 mils. They both had a target base plating thickness of 0.2 mils and had an Anodic E-coat topcoat.

From analysis of the factorial experiment listed in Table 3 (thickness and chemical conversion coating) it is seen that increasing the specified plating thickness has a slight effect of the total system

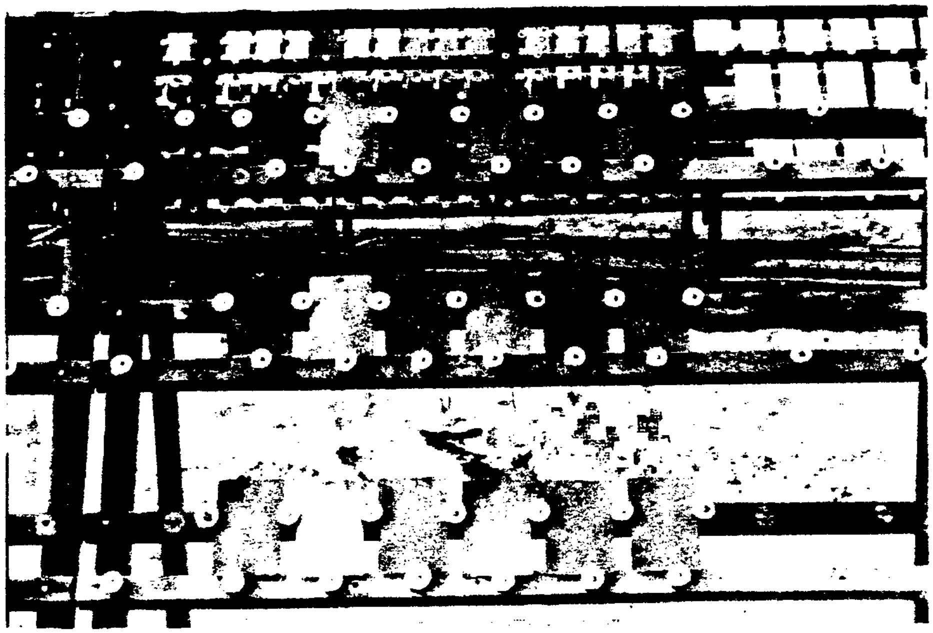


Figure 3. Ion Implanted Panels after 3 days Exposure at Sea Isle, NJ

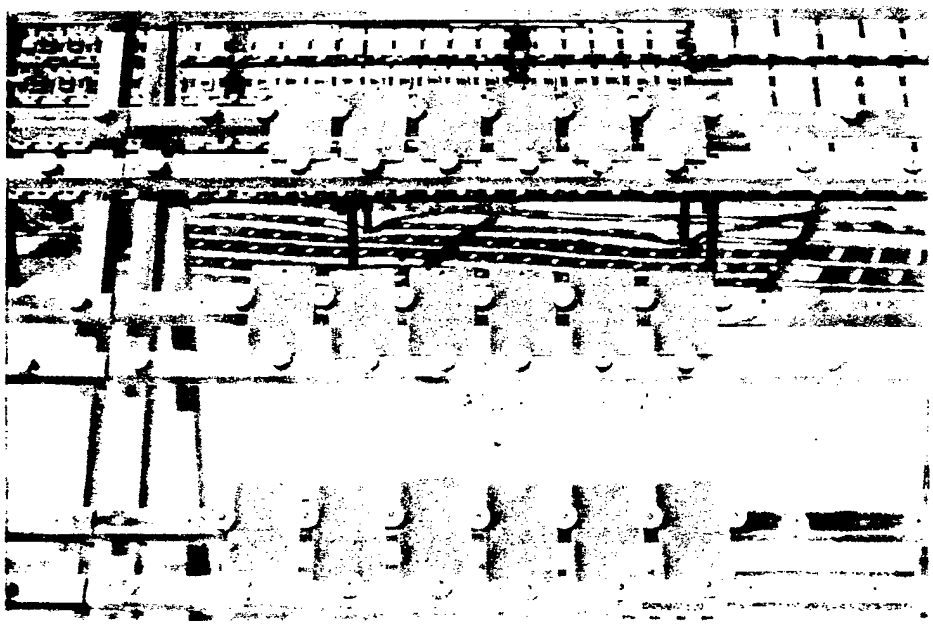


Figure 4. Ion Implanted Panels after 7 days exposure at Sea Isle, NJ

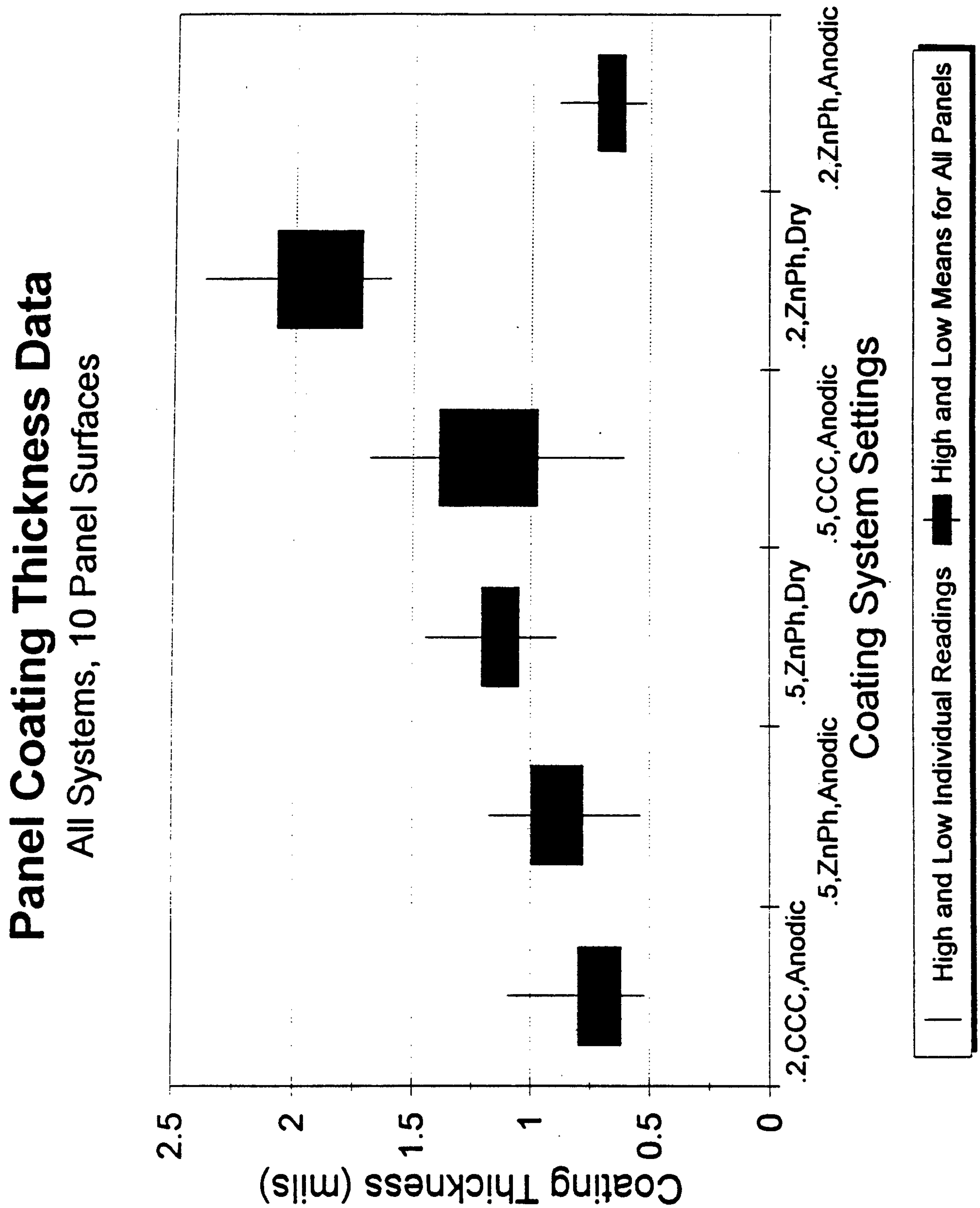

Panel Coating Thickness Data
All Systems, 10 Panel Surfaces
Coating Thickness (mils)
0
0.5
1
1.5
2
2.5
.2,CCC,Anodic
.5,ZnPh,Anodic
.5,ZnPh,Dry
.5,CCC,Anodic
.2,ZnPh,Dry
.2,ZnPh,Anodic
Coating System Settings
High and Low Individual Readings
High and Low Means for All Panels

Figure 5

thickness. From the experimental design listed in Table 4, no definite conclusions can be drawn from the measurements taken. The Dry E-coat topcoat appears to increase the thickness of the system, but because of the variability of its effect between the different variable combinations, this can not be said with statistical confidence.

The statistical analysis is based on analyzing data produced from two-level factorial design experiments of various numbers of variables. The assumption is made that changing each variable has no effect on the properties being measured. Calculations are then conducted to determine if this hypothesis is true. The variables themselves are analyzed as well as any possible interactions between the variables in the factorial design. The two levels chosen for each variable are assigned as positive or negative. Differences are calculated in the total values measured for the positives and negatives (i.e., 0.2 and 0.5 mil plating total system thickness measurements). If the variable has no effect on the property being measured, then the values for the positively assigned factor levels should be near those of the negatively assigned factor levels, and therefore their difference should be zero. Because of noise in measurements, confidence intervals are used to determine the potential range of the difference between the positive and negative factor levels. If this range of values overlaps zero, the variable is said to not affect the property measured. If the range does not include zero, the sign of the difference indicates which factor has an increasing effect on the measured property. Appendix A gives the effect ranges for each property measured for each variable altered, as listed in Tables 3 and 4.

*Porosity*

The number of pores across the surface of the panels varied between each panel in each coating system listed in Table 2. Figure 6 shows the pores-per-square inch rating given to each coating. Sample 3F was the only coating system which exhibited a significantly larger number of pores than the other coating systems. These panels had many small pores across their entire surface. Statistical analysis of the two factorial designed matrices indicates that increasing the specified plating thickness had a slight effect on lowering the pore density.

*Adhesion*

Bend adhesion was conducted on each type of coating listed in Table 2. After bending each system, the bend surface was examined for cracking. If any cracks were seen which revealed metal below the surface of the topcoat, the coating system was considered to have failed. The smallest diameter at which no cracking was detected was recorded as the critical adhesive bend diameter for the plating topcoat system. Figure 7 shows the average critical bend adhesion diameter for each coating system. Coating systems 3C and 3E both show high critical bend diameters (greater than 1.5"), indicating poor adhesion. These were the only two systems tested with the Dry E-coat topcoat. Systems 3A, 3B, 3D, and 3E all showed much lower critical adhesion diameters, near 0.25". All of these systems had an Anodic E-coat over various thickness zinc-nickel platings with different chemical pretreatments.

A limited metallographic analysis was conducted on panels subjected to bend diameters from 0.06 through 0.3 inches. Micrographs revealed that cracks which were visible through the E-coat topcoating also extended through the plating to the steel substrate. This indicates that, for these small diameters, all components of the coating system were failing during the adhesion test. This analysis was not conducted on

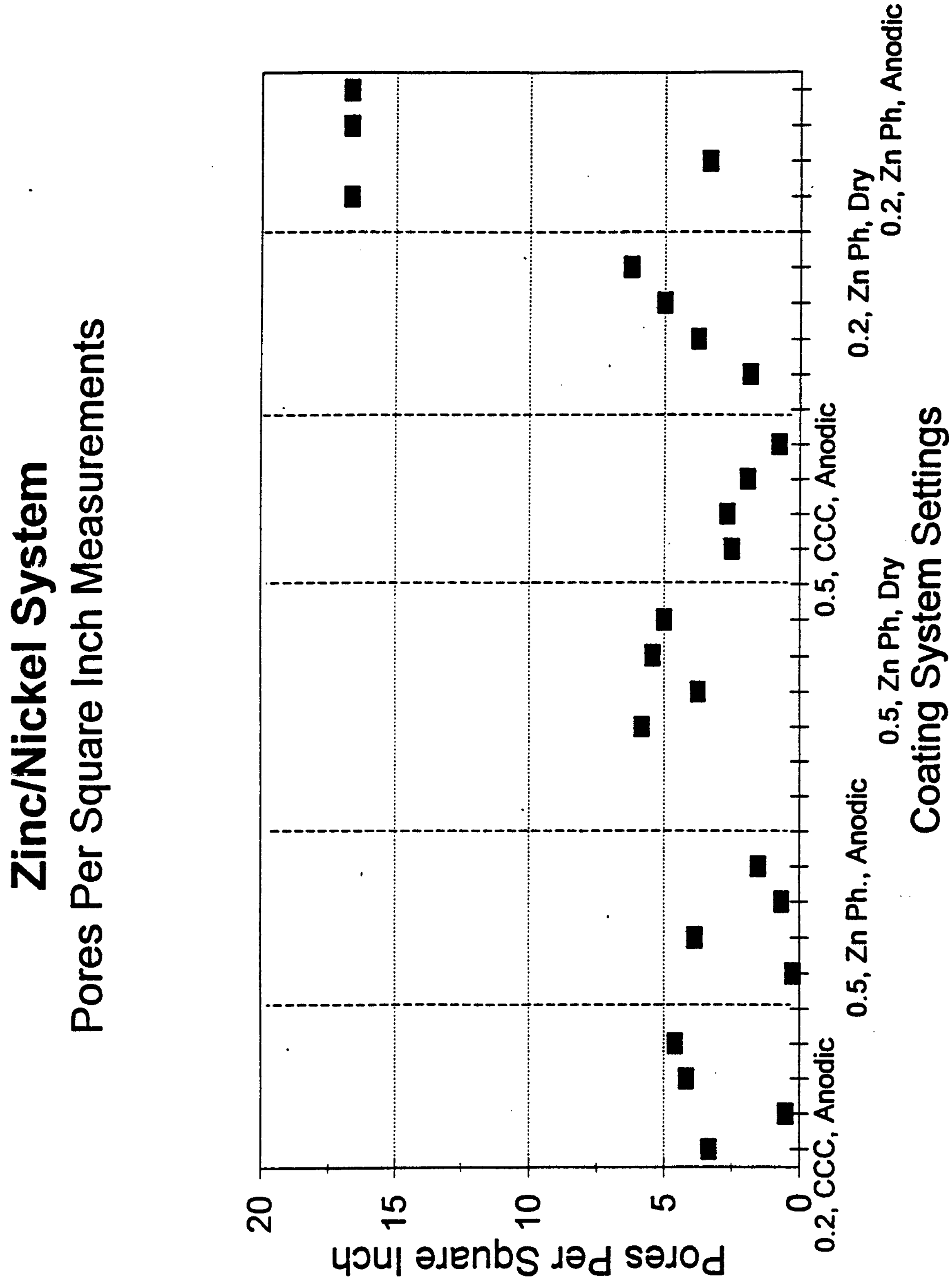

Zinc/Nickel System
Pores Per Square Inch Measurements
Pores Per Square Inch
0
5
10
15
20
0.2, CCC, Anodic
0.5, Zn Ph., Anodic
0.5, Zn Ph, Dry
0.5, CCC, Anodic
0.2, Zn Ph, Dry
0.2, Zn Ph, Anodic
Coating System Settings

Figure 6

larger bend diameter specimens. Previous OCRC testing has shown that a zinc-nickel alloy plating had a similar failure diameter to that measured for the test systems with the Anodic E-coat. Because the larger diameter bend specimens were not metallographically analyzed, it was not determined whether or not the plating had also failed at these cracks. Although, these *systems* can be said to have failed because their organic topcoat components were visibly cracked during testing.

From the statistical analysis of the thickness/chemical design (Table 3), very small decreases in adhesion were noted by the use of a 0.5 mil plating or a zinc phosphate conversion coating. From the thickness/E-coat design (Table 4), it can be seen that a large decrease in coating adhesion was created by the use of the Dry E-coat topcoat system.

*Throw Power*

The throw power of each system listed in Table 2 was measured by determining the depth of plating into a blind hole. The plating depth is expressed as a percentage of the hole diameter in Figure 8. Most systems showed a depth-to-diameter percentage between 8-24% for all holes examined. System 3A, 3E, and 3F samples each had one hole which had higher depth-to-diameter percentages of 40%, 100%, and 100%, respectively. Systems 3D and 3F were the only ones to have one hole with a lower plating depth percentage than most other holes (at 5% and 0%, respectively).

The statistical analysis of the factorial designed thickness and chemical conversion coating matrix shows potential increases in throw depth as a percentage of hole diameter for 0.2 mil platings and zinc phosphate conversion coatings, but these effects can not be stated with a high degree of confidence. The individual readings from these test systems are too variable. The interaction between plating thickness and E-coat type (thickness/E-coat designed analysis of Table 4) does show an increase in percent throw depth for 0.2 mil plating thicknesses. This may have been affected by the fact that the 0.2 and 0.5 mil plating thickness panels were processed in two different coating runs. The cleanliness of the plating bath or the spacing of the parts during the electroplating process may have changed.

Increasing the plating thickness is accomplished by increasing the plating time. This should not have an effect on the penetration of plating into the blind holes, but may have an effect on the total build-up of the plating thickness. The only possible detrimental effect of increased time on throw depth would be if the plating were to begin to dissolve with increased time. This is assumed not to have occurred because the processes occurring within the bath are causing the zinc-nickel materials to be deposited onto the substrate surface.

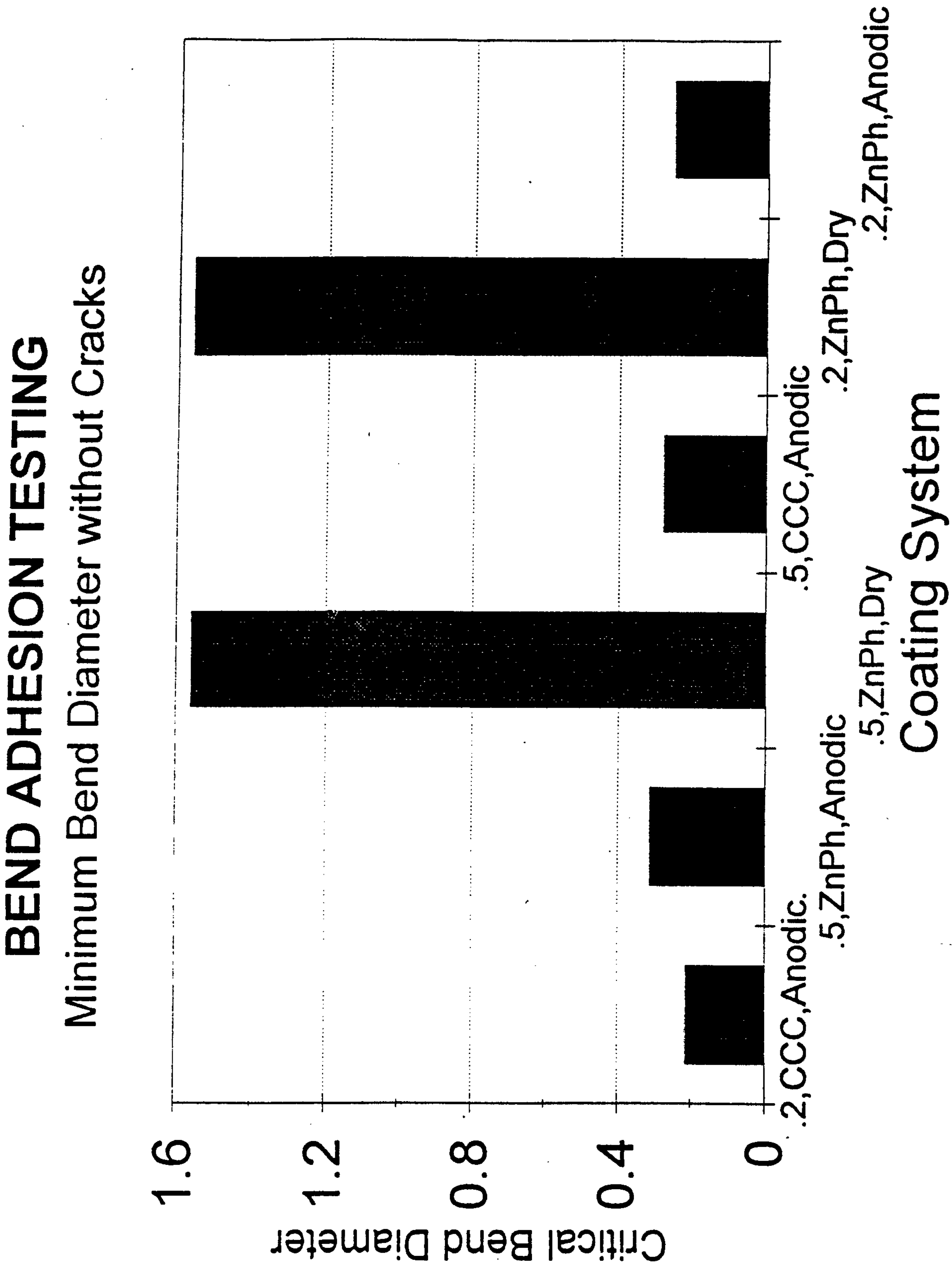
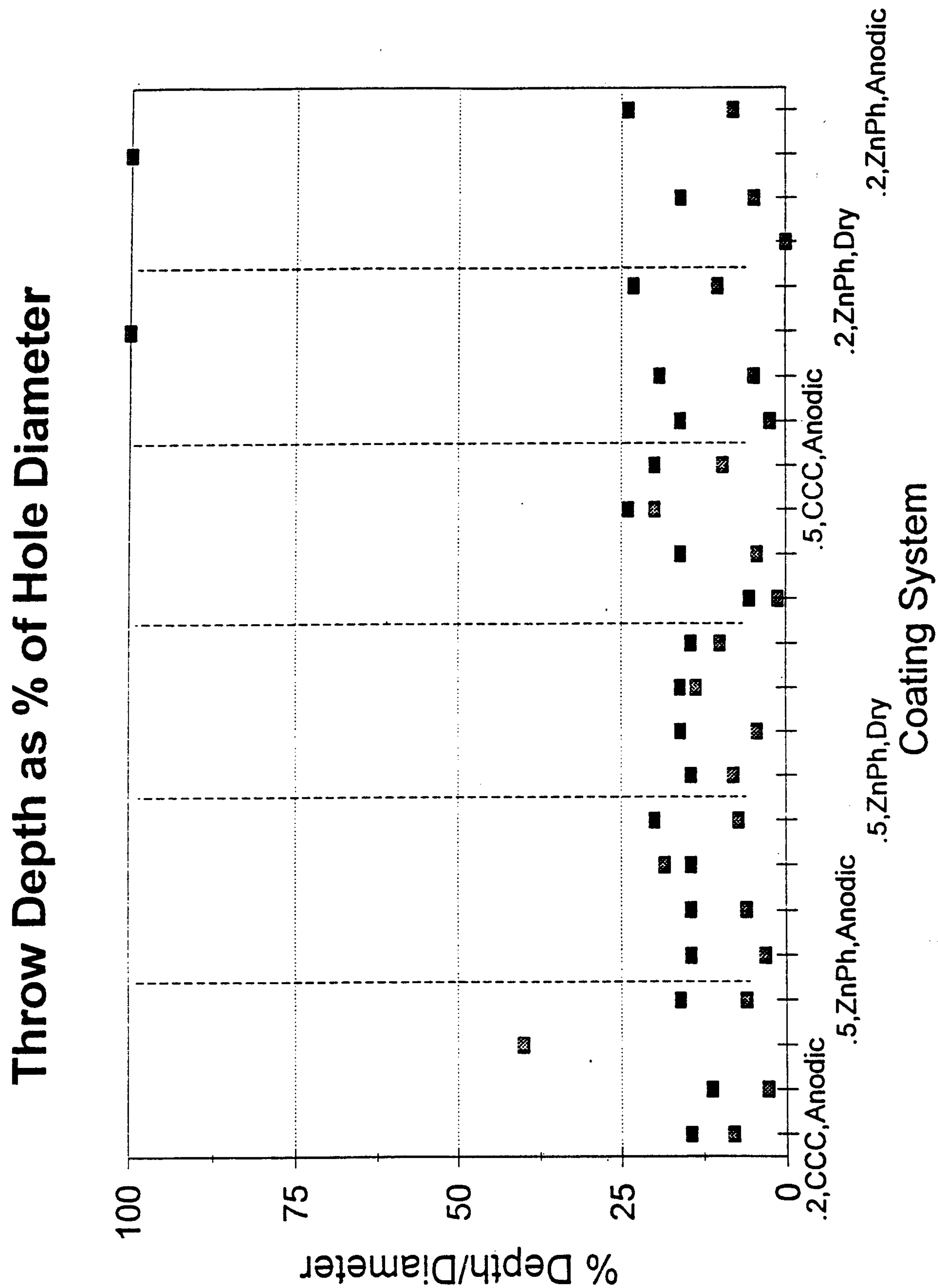

BEND ADHESION TESTING
Minimum Bend Diameter without Cracks
Critical Bend Diameter
1.6
1.2
0.8
0.4
0
.2,CCC,Anodic.
.5,ZnPh,Anodic
.5,ZnPh,Dry
.5,CCC,Anodic
.2,ZnPh,Dry
.2,ZnPh,Anodic
Coating System

Figure 7



Throw Depth as % of Hole Diameter
% Depth/Diameter
100
75
50
25
0
.2,CCC,Anodic
.5,ZnPh,Anodic
.5,ZnPh,Dry
.5,CCC,Anodic
.2,ZnPh,Dry
.2,ZnPh,Anodic
Coating System


Figure 8

## CONCLUSIONS

1. System settings were adjusted for ion implantation and zinc-nickel plating processes. Some coating system characteristics were affected (to various degrees) by these system setting changes.

2. Ion implanted samples exhibited poor corrosion resistance, regardless of the system settings tested.

3. Varying the zinc-nickel topcoat system parameters did indeed affect other coating properties of interest. The following lists the general effects observed:

   Thickness. Thickness varied for each coating tested. There was not a lot of variation between individual system panels. The 0.2 mil Zn/Ni, Zn Phosphate, Dry E-coat system had a much higher total thickness that the other systems tested. No variables in either of the factorial designs appeared to affect the total system thickness.

   Porosity. The number of pores varied for the test samples. The pores were generally small in size. The 0.2 mil Zn/Ni, Zn Phosphate, Anodic E-coat system had the greatest amount of pores for any of the coatings examined. Statistically, increasing the plating thickness decreased the number of pores, although only slightly.

   Adhesion. The Anodic E-coat systems exhibited good adhesion. Coating cracks formed in the Dry E-coat systems even at very high bend diameters, indicating poor coating adhesion. Statistically, the Dry E-coat was the only factor to significantly reduce the adhesion of the coating system.

   Throw Power. The throw power of all of the test systems was consistent. Each plating coated at a distance of approximately 8-24% of the hole diameter.

## RECOMMENDATIONS

1. Ion implantation of the type tested for mild steel should not be used as a corrosion control coating in any atmospheric environments.

2. In order to more effectively control the total system thickness, the Anodic E-coat should be used rather than the Dry E-coat.

3. To increase system adhesion, the Anodic E-coat should be used rather than the Dry E-coat.

4. The type of chemical conversion coating used did not have a large effect on the adhesion, therefore the zinc phosphate conversion coating should be used to eliminate the use of hexavalent chromium, a known carcinogen.

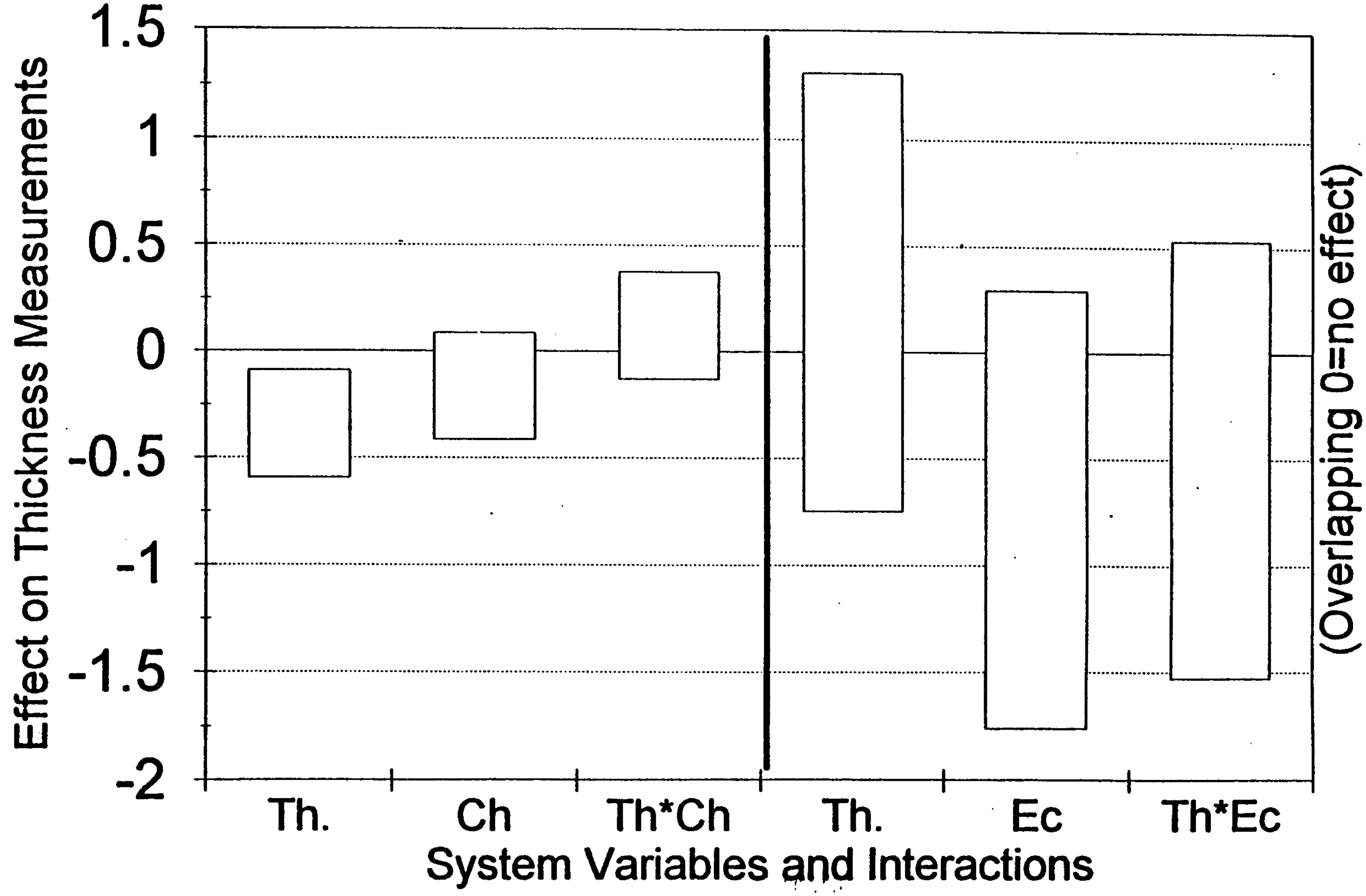
# APPENDIX A

## Statistical Analysis Result Graphs

## Two-Factor, Two-Level Factorial Design Experiments

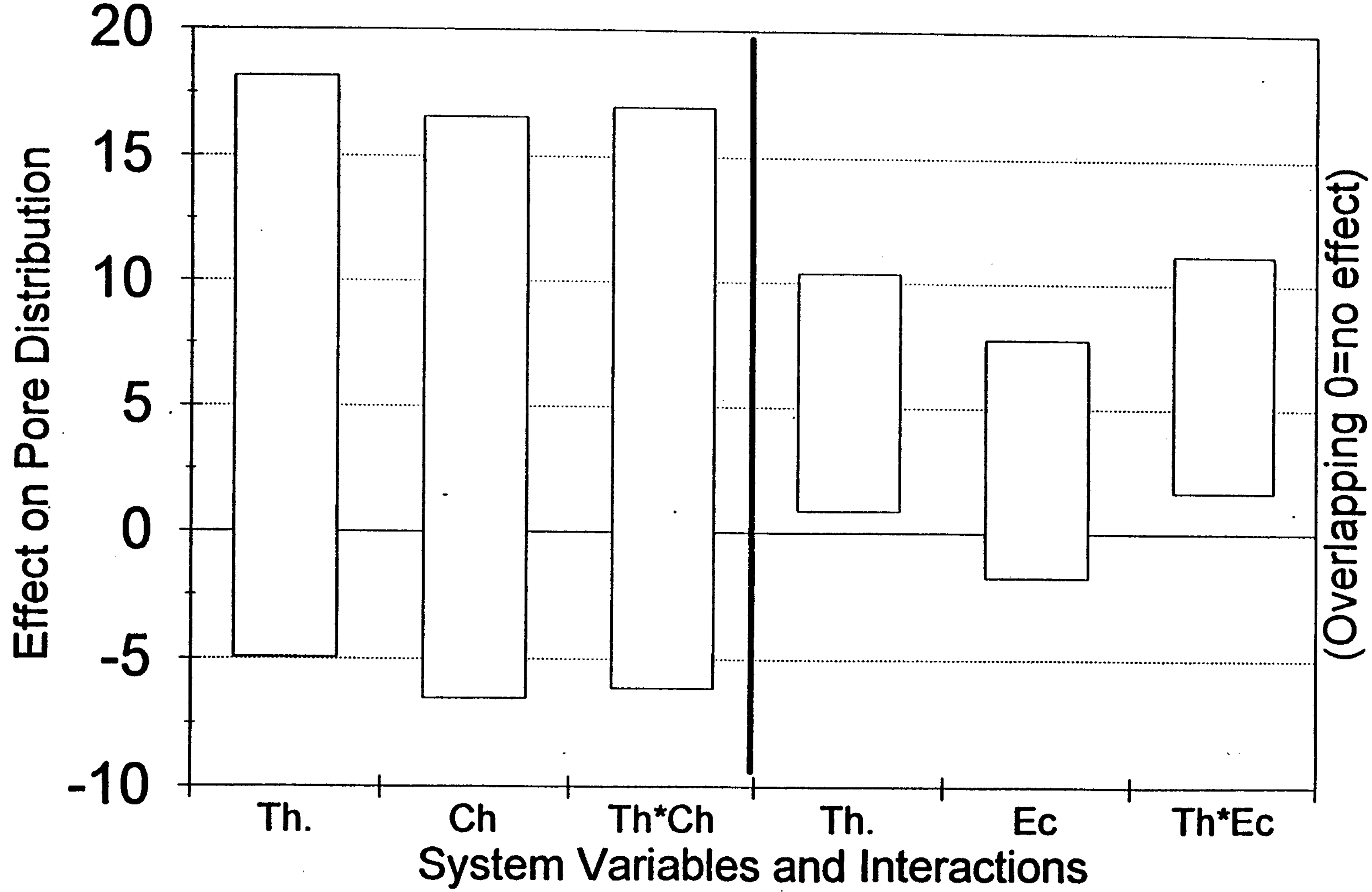
## Zn-Ni Coating System

Effects of System Variables



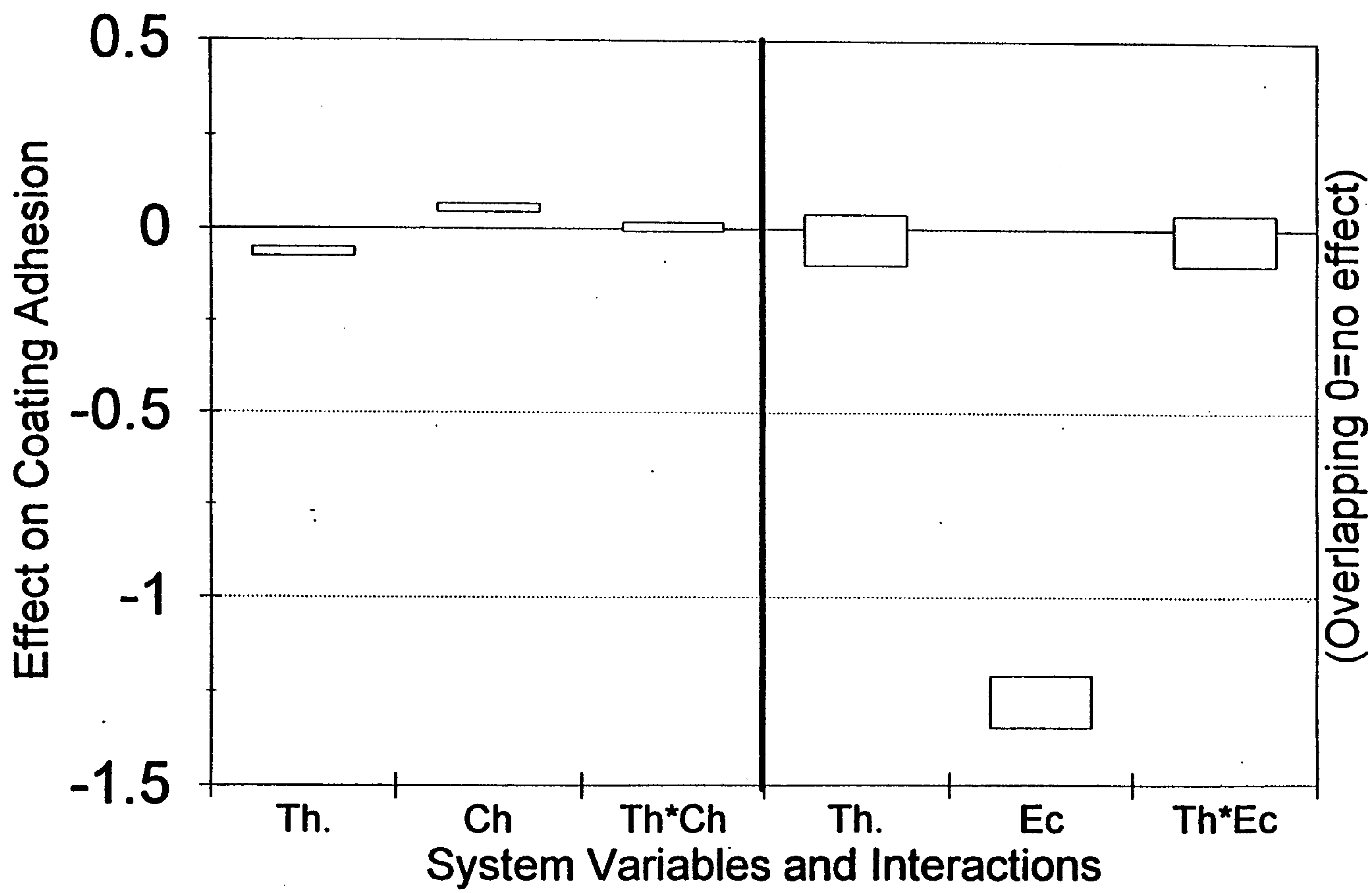
## Zn-Ni Coating System

Effects of System Variables



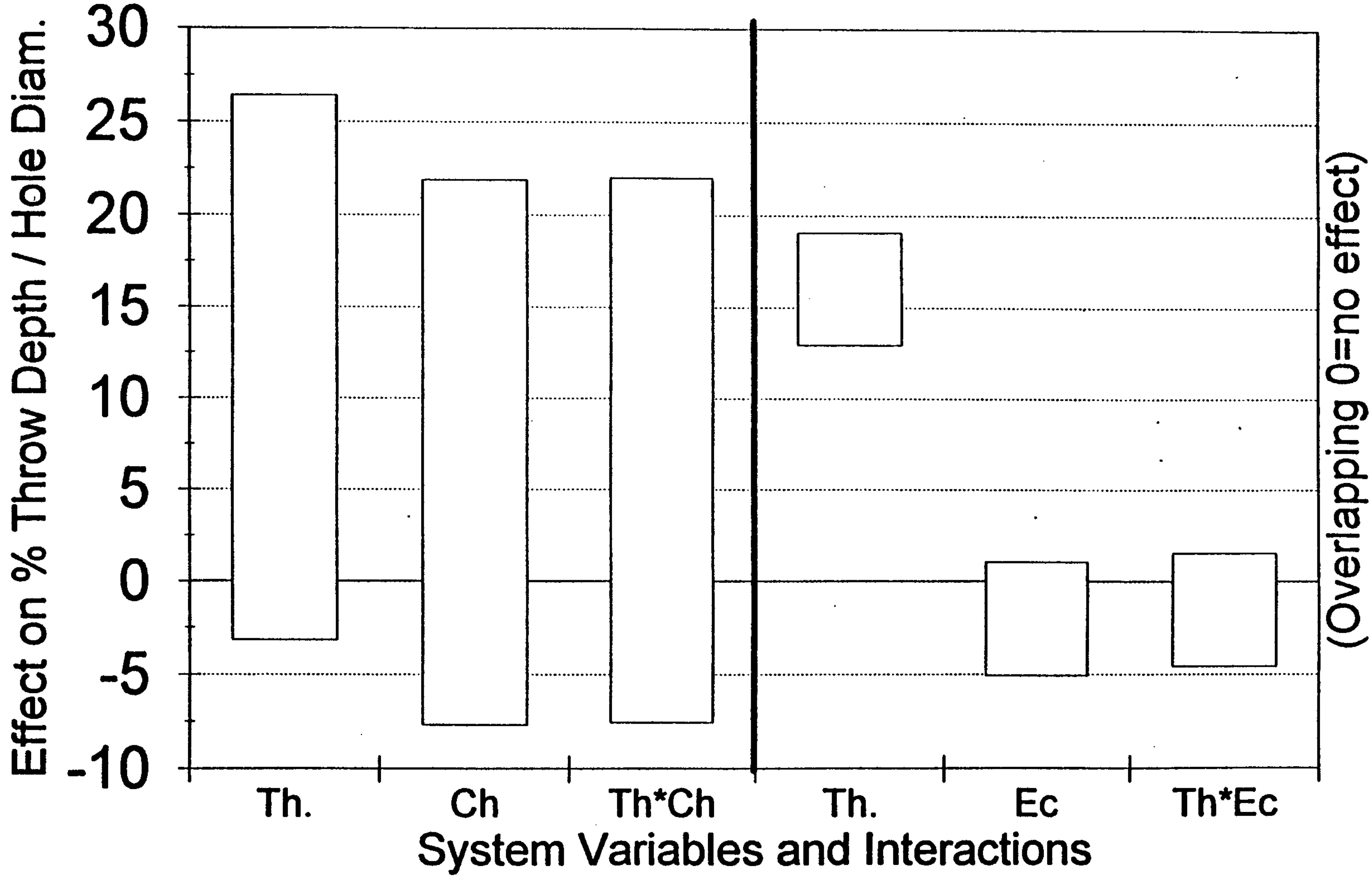
# Zn-Ni Coating System

## Effects of System Variables



## Zn-Ni Coating System

Effects of System Variables



# SECTION 5: PERFORMANCE TESTING OF CADMIUM REPLACEMENT MATERIALS

## BACKGROUND

In response to numerous regulations and directives, the U.S. Navy is currently investigating environmentally acceptable alternatives to cadmium plating. Among the regulations which impact the use of cadmium plating for shipboard applications are OSHA cadmium standard 29 CFR, Part 1910.1027 for exposure of personnel to airborne contaminants and EPA regulations 40 CFR 268.42 regarding hazardous material handling and disposal. Due to the relative toxicity of cadmium (the OSHA Personal Exposure Limit is an order of magnitude lower than lead), the elimination of this material presents a significant personal exposure and pollution prevention benefit.

## OBJECTIVES

1) Develop a broadly applicable body of data illustrating the performance of the alternative systems.

2) Based on laboratory and exposure testing, select coatings and/or base materials that may be suitable replacements for current cadmium applications.

## APPROACH

The program consisted of two phases. Phase I consisted of background research and a process characterization study. These were detailed in report Sections 3 and 4 for this program.

Phase II of the program included testing of environmentally acceptable candidates selected from the literature review and vendor survey of Phase I. Testing was done where prior data was not available. The matrix is included in Table 1. Testing consisted of long term natural marine atmospheric exposure and long term shipboard exposure (yet to be completed), as well as physical and mechanical tests which will be described in further detail.

**Table 1 - Cadmium Replacement Test Matrix**

| Cadmium Replacement System | Torque-Tension | FCG | Wear | Accel. Exp. | Ship Exp | Sea Isle | Step-Loading (NRL) |
|---|---|---|---|---|---|---|---|
| 4340 Steel (Control) | X | ❍ | X | X | X | X | ❍ |
| Ion Implantation | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ |
| Zinc/Nickel w/ topcoat | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ |
| IVD Al | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ |
| Cadmium | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ |
| Zinc Phosphate & Epoxy | X | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ |
| Epoxy Powder Coat | X | X | ❍ | ❍ | ❍ | ❍ | ❍ |
| Inorganic Zinc | X | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ |
| Tin/ Zinc | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ |
| Black Oxide & Epoxy | X | X | ❍ | ❍ | ❍ | ❍ | ❍ |
| Polysulfide & Epoxy | X | ❍ | X | ❍ | ❍ | ❍ | X |
| Silicone & Epoxy | X | X | X | ❍ | ❍ | ❍ | X |
| Zinc - alkaline bath | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ |
| Zinc - chloride bath | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ |
| SermeTel CR984 | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ | ❍ |
| MIL-P-24441 | X | X | ❍ | ❍ | ❍ | ❍ | X |
| 316 | ❍ | ❍ | X | ❍ | ❍ | ❍ | ❍ |
| 304 | ❍ | ❍ | X | ❍ | ❍ | ❍ | ❍ |
| Ti-6Al-4V ELI | ❍ | ❍ | X | X | ❍ | X | ❍ |

X - not tested
❍ - tested

**Test Specimens**

*Marine & Shipboard Exposure*

This exposure testing utilized the complex steel panels described in Section 4, Environmentally Acceptable Alternatives to Cadmium Plating: Process Characterization, but due to space limitations onboard the ship, only one panel of each coating/material was included on each rack. Two flat (Q) 4"x 6" panels were also included in this exposure.

*Accelerated Exposure*

The samples for this test were standard 4"x 6" flat steel (Q) panels, tested in triplicate. Each panel contained a 1" scribe placed at a 45° angle in the lower right corner of the panel.

*Torque–Tension*

This test employed ½"–20 UNC fine, 2½" long Grade 8 steel bolts and nuts that had been plated, coated, or implanted with the appropriate material. Bolts and nuts of stainless steel (316 and 304) and titanium were also tested.

*Fatigue Crack Growth*

The 4340 steel samples were compact tension specimens as per ASTM E 647. Samples were heat treated as follows:

Austenitized: 1550°F, ½ hour, par quench
Temper: 810°F, 2 hours, air cool

This heat treatment produced a hardness of between 42 and 45 Rockwell "C". These samples contained a pre-crack made after the samples had been plated.

*Abrasion*

Samples for the Taber Abrasion Wear test were 4" x 4" x 0.125" flat, 1010 cold rolled, steel panels.

**Coating System Application**

The Environmentally Acceptable Replacements for Cadmium: Material Selection Report (Section 3) gives a detailed description of the various test systems and a general description of their application process (i.e. plating, spray, immersion, etc.). The SermeTel, zinc-nickel/topcoat, IVD aluminum, tin/zinc, zinc (alkaline and acid), cadmium, black oxide, and epoxy powder coatings were all applied by outside vendors. Each was applied using best practices, to a target thickness of 0.5 mils (for platings and IVD aluminum). Inorganic zinc, zinc phosphate, polysulfide, silicone, and epoxy paint systems were applied by OCRC personnel according to manufacturers' recommended practices. Thickness measurements were taken for all coatings. Porosity was checked when there was concern about adequate plating coverage.

All of the above coating systems were applied to all surfaces of each test panel except for two items. The polysulfide and silicone coatings were not applied to all areas of the complex panels. Their potential use is as a sealant on bolt threads. On complex panels, each coating was applied to the threaded portion of the bolt. The bolt was then installed while the system was still wet. The polysulfide and silicone were applied over the entire area of the flat panels and allowed to dry prior to application of the epoxy paint system.

There were two systems that presented application problems. The silicone caused adhesion problems for the topcoat, epoxy system. Silicone sealant is not formulated to allow for topcoating. The only other system in which there were application problems was the inorganic zinc system. This coating did not adhere well to smooth steel surfaces. The manufacturer recommended that the coating be applied to a blast profile. This was not possible for high tolerance, machined test pieces or thin flat panels (residual stresses caused warping). The coating flaked off of some edges of flat panels and at the heads of bolts. Application of the coating system to compact tension and single notch bend specimens (for fatigue crack growth rate testing and rising step load testing respectively) was also difficult because of adhesion problems.

## Exposure Testing

### *Marine Exposure*

Outdoor exposure was performed on complex and flat panels in triplicate. Panels were placed on an exposure rack at Sea Isle, NJ in mid-July, 1995. This site provides a natural northern sea coast climate, characterized by high humidity, high time-of-wetness, high winds, salt laden air, and a broad annual temperature range ($\Delta t \approx 100^{O}F$). All panels involved in this test are sprayed twice each weekday with seawater and will be exposed for a minimum of one year. Periodic visual inspections were made on all panels. Different methods were used to evaluate the coating performance on these different panels. The ASTM D 610 method for evaluation of the degree of surface rusting was used on the bold surfaces of exposed flat panels (away from scribes). The numerical ASTM D 610 rating system related to a percent surface area on which rust was visible. This is not a linear relationship. The numbers correspond to the following percentages of surface area covered with rust:

| | | | |
|---|---|---|---|
| 0 - 100% | 3 - 16% | 6 - 1% | 9 - 0. 3% |
| 1 - 50% | 4 - 10% | 7 - 0.3% | 10 - 0% |
| 2 - 33% | 5 - 3% | 8 - 0.1% | |

The performance at the scribe was evaluated separately. The complex panels were evaluated in terms of which areas contained rust for the various test systems. The panels were broken down into nine different areas as shown in Figure 1.

#1) Front bold surface.
#2) Back bold surface.
#3) Inside weld channel including inner walls and face.
#4) Exterior walls of weld channel.
#5) Weld area.
#6) Edges.
#7) Holes drilled into the plate edges.
#8) Bolt head and shaft area.
#9) Bolt threads and nut.

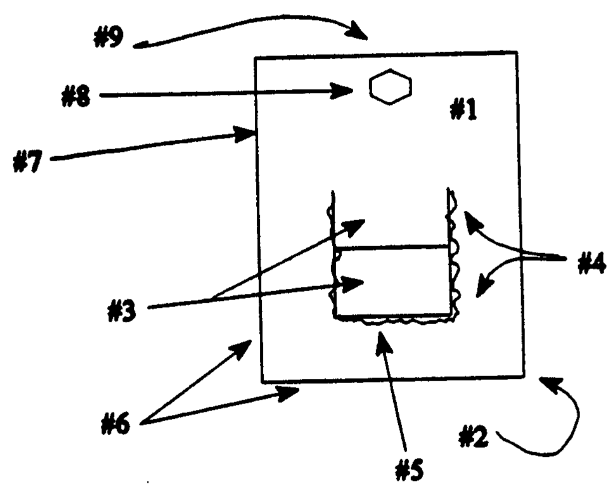



**Figure 1: Marine Atmosphere Complex Panel Inspection Sites**

*Shipboard Exposure*

Test panels were also exposed shipboard. This exposure test gave us the most realistic field data available. SURFLANT was contacted to nominate an appropriate platform on which two exposure racks were set up. One rack was located topside and the other in an engineering space. The exact length of time for this exposure as well as the inspection intervals was dependent upon the nominated ship's schedule. The estimated time of this exposure is 12 months. Flat panels were rated according to ASTM D 610. Complex panels were given a visual description.

*Accelerated Exposure*

In order to acquire supplemental data before the Strategic Environmental Research and Development Program (SERDP) deadline, it was decided to include accelerated weathering exposure in this test matrix. This was achieved via a cyclic salt spray test. The coated panels were suspended in a chamber similar to that described in ASTM B117. The ASTM B117 salt solution consisting of 5% NaCl was added to the cabinet, and the panels were cycled between this salt fog, and heated air. Each phase of the cycle was one (1) hour. The test continued for a total of 1000 hours. Triplicate test panels of each alternate system were tested. Intentional defects (scribes) were placed in the lower corner of each panel to determine the effectiveness of the coating in protecting the steel substrate at breaks in the coating. After exposure each test panel was air dried and examined for rusting. Panels were rated according to ASTM D 610.

**Mechanical Testing**

Mechanical testing was performed on all coating/material systems and alternate materials to determine any influence on mechanical properties and coating lubricity. Testing included torque-tension testing (lubricity), fatigue crack growth, abrasion, and step–loading. These tests were compared to the results of cadmium–plated (chromate treated) samples.

*Torque-Tension*

To illustrate the lubricity of the coatings and alternative base metals, a torque-tension test was performed in accordance with MIL-STD-1312. The specimens were held in a fixture containing a load cell, and tightened with a calibrated torque wrench to the appropriate torque. The induced load was then measured on the load cell and recorded. Torque versus tension curves were generated. Figure 2 is a photograph of the test apparatus. Five specimens per coating system were tested, except for stainless steel grades 304, 316 and epoxy powder coated grade 8 fasteners. Only two epoxy powder coated samples were completed due to potential damage to test apparatus. Three samples of each stainless steel grade were tested.

## SECTION 5: PERFORMANCE TESTING OF CADMIUM REPLACEMENT MATERIALS

## CONTENTS

## SECTION 5: PERFORMANCE TESTING OF CADMIUM REPLACEMENT MATERIALS

## CONTENTS (cont'd)

## SECTION 5: PERFORMANCE TESTING OF CADMIUM REPLACEMENT MATERIALS

## TABLES

## SECTION 5: PERFORMANCE TESTING OF CADMIUM REPLACEMENT MATERIALS

## FIGURES

## SECTION 5: PERFORMANCE TESTING OF CADMIUM REPLACEMENT MATERIALS

## EXECUTIVE SUMMARY

The U.S. Navy has recently completed the initial phases of a comprehensive study under SERDP sponsorship. (Final phases will be continued under separate funding.) The primary objectives of this study were to:

1) Determine the principal uses of cadmium as a protective plating of Navy steel components.

2) Illustrate the effects of various manufacturing variables on the performance of selected cadmium-alternative systems.

3) Develop a wide range of performance data on alternative preservation treatments/materials that may alleviate the need to use cadmium plating.

The following section provides the preliminary results of performance testing phases of this work, including very short term (i.e. two month) exposure data. Previous report sections addressed the issues surrounding materials selection and the influence of elected process variables on the physical characteristics of selected cadmium alternatives.

The range of preservation treatments/materials investigated covered a wide possibility of cadmium substitutes; specifically, alternatives included thin-film plating (target thickness of < 1 mil), high-build (> 1 mil) surface treatments combined with organic coatings/sealants, and alternative materials. These alternatives are weighed against the use of Type II Cadmium Plating (Federal Specification QQ-P-416F) which includes a chromate post treatment applied for purposes of retarding or preventing the formation of white corrosion products. This treatment is intended for parts not to be subsequently coated, whereas a phosphate treatment (Type III) would likely be chosen for parts to be coated. A significant range of preservation treatments/materials was studied because it was considered unlikely that a single alternative would suffice as a universal cadmium plating substitute. Providing information to the design engineer on a broad range of alternative preservation treatments/materials enables him/her to select a cadmium plating alternative for most current applications on steel substrates.

As some aspects of testing are still ongoing, definitive statements covering all performance areas can not yet be drawn. Therefore, completed areas of mechanical or exposure testing are addressed on an individual basis, and prove to be quite lengthy. Consult the Section 5 Conclusions and Recommendations for detailed information on the respective topics.

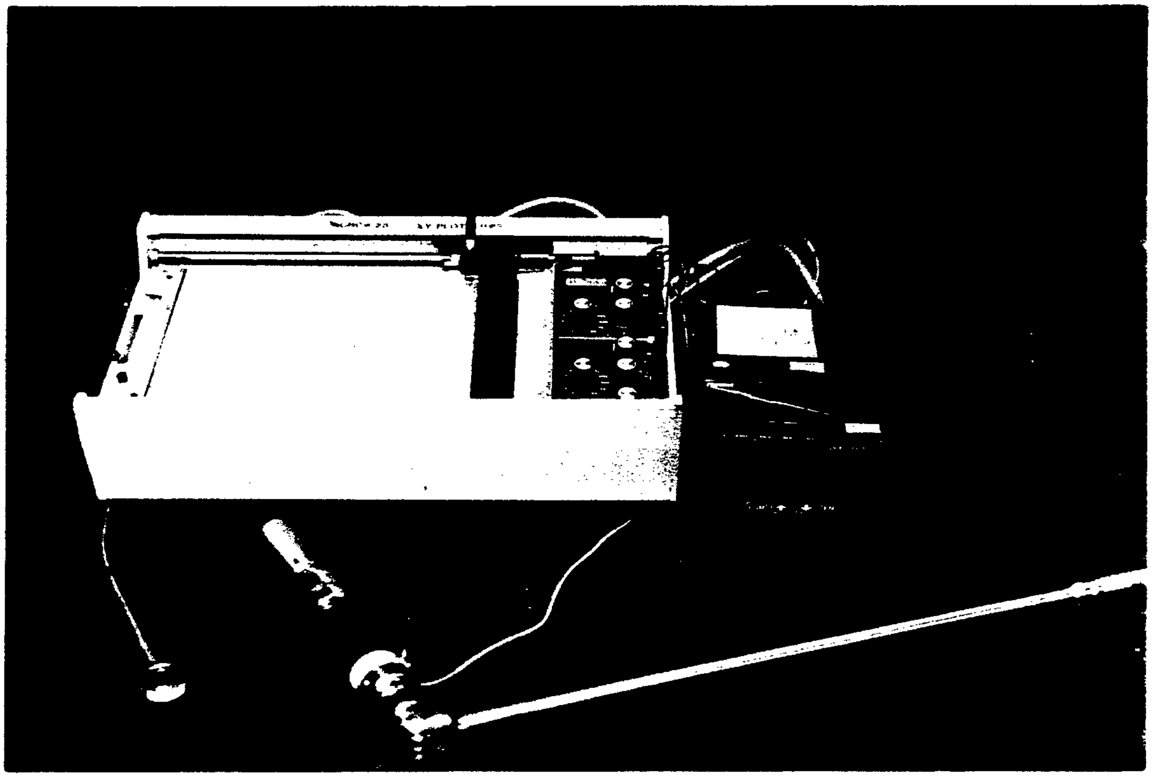


**Figure 2 - Torque-Tension Test Apparatus**

*Fatigue Crack Growth*

Fatigue crack growth was performed in accordance with ASTM E 647. The specimens were pre-cracked at room temperature with an R-ratio of 0.1. The specimens were then tested at room temperature in a 3.5% NaCl solution. Control samples were fatigued both in air and a 3.5% NaCl environment. All the tests were conducted under constant load, increasing K conditions with an R-ratio of 0.1. The crack length was determined by using a clip gage to monitor the crack-mouth opening of the specimen. At specific cyclic intervals, dynamic load and crack opening displacement (COD) measurements were made to determine the compliance of the specimen. The compliance measurements were then converted to physical crack extension using the Hudak and Saxena equation:

$$a/W = 1.0010 - 4.6695\, U_x + 18.46\, U_x 2 - 236.82\, U_x 3 + 1214.9\, U_x 4 - 2143.6\, U_x 5$$

Where $U_x = ([EVB/P]^{1/2} + 1)^{-1}$
a = crack length
W = width of the sample

Da/Dn vs. Delta K plots were constructed using the seven point polynomial technique per ASTM 647-93 for each specimen. Triplicates were tested for each system.

*Abrasion Testing*

Abrasion testing was performed in accordance with ASTM D 4060 "Standard Method for Abrasion Resistance of Organic Coatings by the Taber Abraser." The Taber Abraser apparatus applied a 1000 gram load normal to the rotation axis of two ceramic/rubber composite abrasive wheels (type CS–17). The wheels rested on the test specimen, which was mounted on a platen, and rotated around a horizontal axis that did not intersect the platen's central axis. As the platen rotated, the abrasive wheels rotated and translated over the test specimen surface. This rotation/ translation created a circular wear path on the test specimen. Coating wear resistance was quantified by counting the number of cycles required to expose an area of the substrate steel.

The number of cycles required to expose the steel substrate under a non-metallic coating was determined using iterative, visual techniques. Periodically during testing, the Taber Abraser was interrupted and the wear path examined. For systems with an organic topcoat, the appearance of a shiny metallic wear path defined the test end point. By consistently reducing the number of cycles between observations, the possibility of overshooting the actual number of cycles required to expose the substrate was reduced.

This iterative, visual technique was ineffective on metallic coatings. Visually, an abraded nickel, cadmium, aluminum, or zinc coating was difficult to distinguish from abraded steel. The Elcometer 300 DFT gauge and a seawater exposure test were used to determine the number of cycles required to expose the substrate. Periodic interruption of the abraser allowed the coating thickness inside and outside the wear path to be monitored using the Elcometer gauge. When less than 0.1 mil of coating remained, a controlled seawater exposure test determined the actual test endpoint.

The abrasion test specimen was exposed to seawater for approximately twelve hours. Two filter paper rings held the seawater in contact with the abrasion specimen. One filter paper ring was sized to cover only the abrasion wear path. A second smaller ring was sized to fit well inside the wear path. The two rings were soaked in seawater and placed on the specimen, one ring on the wear path, the other near the center of the specimen. The area between the rings was carefully dried to insure that sacrificial metallic coatings would not cathodically protect exposed steel in the wear path.

The brief exposure to the seawater soaked rings caused corrosion staining. However, it was short enough to prevent significant coating/substrate corrosion. Comparison of the corrosion staining from each of the seawater rings determined if the test endpoint was attained. Iron corrosion products appeared dark red brown. The corrosion products from the cadmium alternative test coatings were light gray or white. When the wear path appeared stained with dark red/brown iron oxide corrosion products, the abrasion test was complete. Using an iterative process, the number of cycles required to cause corrosion in the wear path of a metallic coating was determined.

*Step–Loading*

Step-loading tests are being performed by the Naval Research Laboratory (NRL) on samples provided by Ocean City Research Corporation (OCRC). These test procedures were developed by Lou Raymond and Associates (LRA) laboratory, under contract with the Navy. The test is being used to determine possible negative effects of a salt water environment on the plated material. This includes the plating's tendency towards enhancing either stress corrosion cracking or hydrogen embrittlement.

## RESULTS

Prior to any testing of the plated samples, thickness measurements were taken to confirm that the panels achieved the targeted plating/coating thickness (0.5 mils for platings, manufacturers recommendations for other coatings). The porosity was also checked. The following table lists the results of thickness and porosity testing.

**Table 2**
**Thickness and Porosity Measurements**

| Coating System | Thickness (DFT Gage), mils | Porosity (Pores/sq. in.) |
|---|---|---|
| Cadmium | 0.09 | 10 |
| SermeTel | 0.67 | 3 |
| Zn-Ni w/ topcoat | 0.43 | 30 |
| IVD Aluminum | 0.41 | 5 |
| Sn-Zn | 0.33 | 9 |
| Zn-alkaline | 0.60 | 1 |
| Zn-acid | 0.25 | 8 |
| Inorganic Zinc | 2.39 | Not Tested |
| Epoxy Powder Coat | 5.90 | Not Tested |
| Zinc Phosphate w/epoxy topcoat | 4.35 | Not Tested |

### Exposure Testing

*Marine Exposure*

An inspection after two months was performed on the panels exposed at OCRC's natural marine atmosphere exposure site. This inspection included the panels from the process characterization study of the zinc-nickel plating and the coating/material systems from this portion of the testing. Table 3 summarizes the results of the zinc-nickel/topcoat process characterization inspection.

All of the flat panels in the process characterization study are doing well. There is white corrosion product on the panels with the anodic E-coat and chalking of the epoxy E-coat on the rest. None are showing any corrosion of the bold surface. All are displaying small amounts of rust at the scribe. Differences on the coatings can be seen on the complex surfaces. All of the variations have trouble protecting the U-channel area of the complex panel, except 3E (0.2 mil Zn-Ni with chromate conversion coating and epoxy E-coat). This panel does exhibit rust beginning at the edges of the panel. After two months exposure, this appears to be the most promising of the variations.

**Table 3**
**Process Characterization: 2 Month Exposure Test Results**
**Natural Marine Atmosphere Exposure With**
**Daily Seawater Spray**
**Zinc-Nickel with Different Topcoats**

| COATING SYSTEM | FLAT PANELS D 610 RATING | COMPLEX | | |
|---|---|---|---|---|
| | | D 610 RATING FOR U-CHANNEL | AREAS WITH RUST | COMMENTS |
| **3A** 0.2 mil Zn/Ni Chromate Anodic E-Coat | 10 (Rust at scribe) | 8 | 3, 4, 5, 6 | White corrosion products seen on all surfaces |
| **3B** 0.5 mil Zn/Ni Zn Phosphate Anodic E-Coat | 10 (Rust at scribe) | 7 | 3, 4, 5 | White corrosion products seen on all surfaces |
| **3C** 0.2 mil Zn/Ni Zn Phosphate Epoxy E-Coat | 10 (Rust at scribe) | 9 | 3, 5 | Chalking of Epoxy |
| **3D** 0.5 mil Zn/Ni Chromate Anodic E-Coat | 10 (Rust at scribe) | 8 | 3 | White corrosion products seen on all surfaces |
| **3E** 0.2 mil Zn/Ni Chromate Epoxy E-Coat | 10 (Rust at scribe) | 10 | 4 | Chalking of Epoxy |
| **3F** 0.2 mil Zn/Ni Zn Phosphate Anodic E-Coat | 10 (Rust at scribe) | 5 | 3, 4, 5, 6, 7, 9 | White corrosion produces seen on all surfaces |

Marine exposure of the various coatings and materials also included flat and complex panels. Figures 3 and 4 show the panels from the current testing after 2 months of marine exposure. Appendix A contains detailed photos of these panels. The following are the results from this inspection.

**SermeTel 984**

The SermeTel coating displayed little sign of degradation during natural marine atmospheric exposure with sea water spray. Bold areas of exposed flat panels did not show rusting. Minor rusting was visible at scribes and on panel edges. The complex panels also showed little rusting during examination. A small amount of rusting was visible at the holes in the sides of the panel, and on the bolt head and threads. Less than 1% of the U-weld channel area contained rust. This area is highly sensitive to corrosion because its geometry makes it difficult to coat, there were several crevices and weld areas, and it retains moisture longer by trapping it in the channel area.

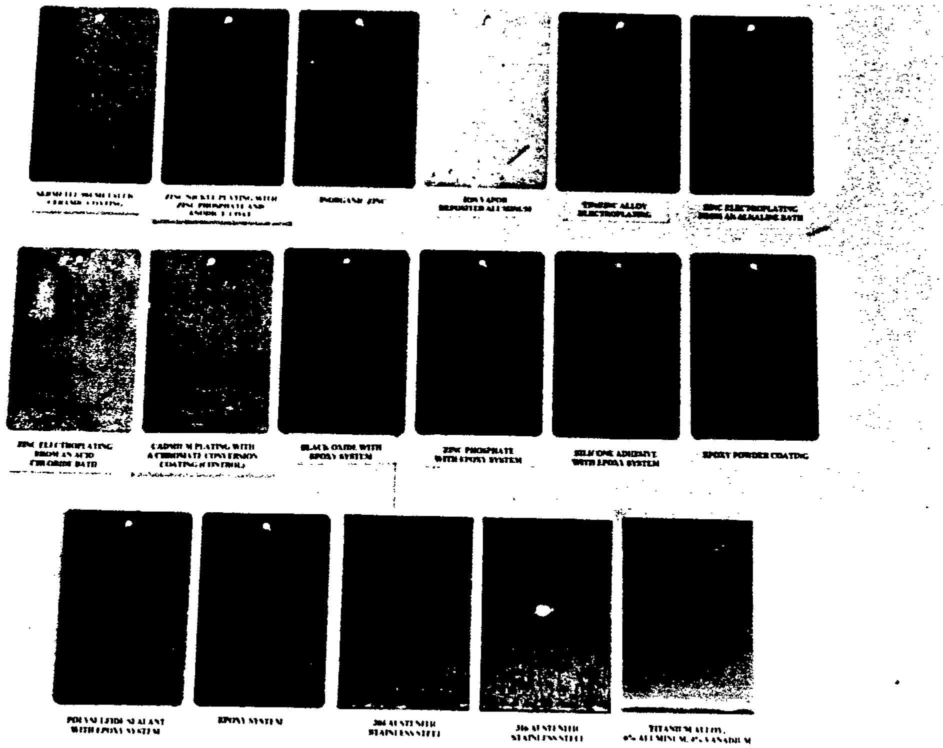


Figure 3 - Natural Marine Exposure - 2 Month Results. Flat Panels

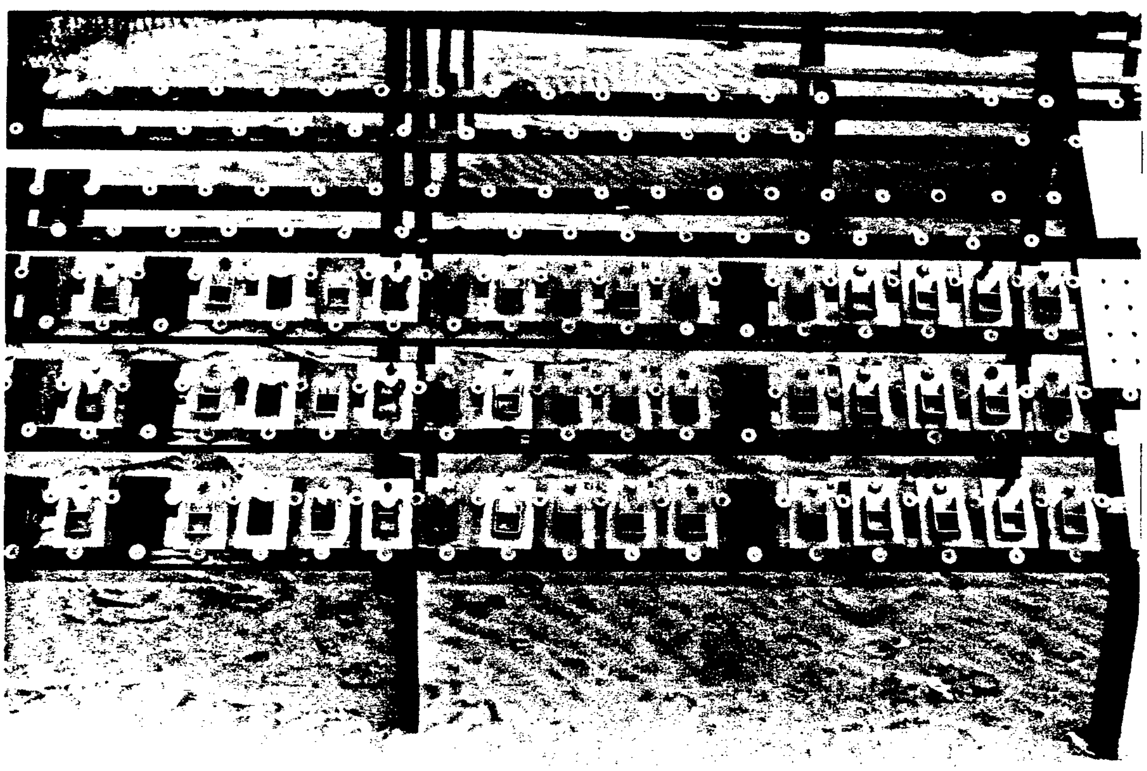


Figure 4 - Natural Marine Exposure - 2 Month Results. Complex Panels

**Zinc-Nickel with Anodic E-Coat Topcoat**

The zinc-nickel flat panels exhibited some rusting on their bold surfaces after two months of marine atmosphere exposure. The average area was approximately 1% of the surface area of the panels. This appeared to be primarily rusting through small pores in the coating system. The complex panels exhibited some rust at the panel edges and at the holes in the sides of the panels. The weld channel area contained approximately 2-3% surface area rust. The zinc-nickel panels for this testing contained more porosity and had a thinner layer of plating and topcoat than the equivalent coating from the process characterization study.

**Inorganic Zinc**

The inorganic zinc panels performed well during two months of marine atmospheric exposure. A small amount of rusting was evident on areas of the flat panels where some of the coating had flaked off (near edges). The complex panels exhibited some rust spots at the holes in the sides, on the bolt head, and on the bolt threads. There was no visible rusting inside of the weld channel area.

**IVD Aluminum**

The performance of the IVD aluminum varied greatly for different areas of the exposure samples. The flat panels did not exhibit visible rusting across their surface. The complex panels showed small amounts of rusting on the outer channel walls, on the weld, at the side holes, and on the bolt threads. The weld channel area was completely rusted, and exhibited dark red rust over the entire surface. Increasing the time of wetness appears to destroy any protective properties of the IVD aluminum coating.

**Tin/Zinc**

The tin/zinc plated flat panels exhibited rust spots in the center of the front surface of the exposure panels after two months of exposure. The complex panels exhibited some rusting, to various degrees, on all areas of the complex panels except for the edges. The U-channel area of these samples were severely rusted, showing almost 30% surface area rusting.

Tin/zinc plated panels exhibited rust beginning from the center of their surface. Limited testing was conducted to determine if there was a difference in the thickness of this plating in the center of the panel. It was found that this center region had a plating thickness which was as much as 50% lower than that of the plating thickness found on the outer edge portion of the panel. Limited testing was also conducted to evaluate the porosity of this plating as compared to the other metallic coatings tested. There were a few small pores scattered across the surface of the panel, with slightly more pores in the area toward the center of the panel. The porosity of the tin/zinc was not any greater than that of the other platings examined The difference on the corrosion performance suggests that the tin/zinc alloy did not galvanically protect the exposed steel as well as other platings.

**Zinc - Alkaline Bath**

These zinc plated flat panels did not exhibit rusting over their surfaces during the first two months of marine atmospheric exposure. They did however, exhibit a great deal of black discoloration associated with the corrosion of the zinc plating system. The complex panels showed some minor rust areas at the side holes and bolt threads. Approximately 15% of the surface area of the U-channel showed rusting.

**Zinc - Acid Bath**

The flat panels with zinc plating from an acid bath exhibited some rust spots near the edges of the sample, covering less than 1% of the total surface area of the sample. The complex panels showed rusting at the side holes and over approximately 20% of the surface area of the U-channel area.

**Cadmium**

The cadmium plated samples performed very well. There was no visible rust on the flat panels or on the complex panels.

**Black Oxide with Epoxy Paint System**

The bold areas of the flat panels did not show any rust. The scribe area was severely rusted and blistering of the paint system was seen extending from the scribe. The complex panels showed some rusting at the edges, side holes, bolt head, and bolt threads. The U-channel area showed a small amount of rusting and rust staining in its crevices.

**Zinc Phosphate with Epoxy Paint System**

The bold areas of the flat panels did not show any rust. The scribe area was severely rusted and blistering of the paint system was seen extending from the scribe. The complex panels showed some rusting at the edges, side holes, bolt head, and bolt threads. The U- channel area showed a small amount of rusting and rust staining in its crevices.

**Silicone with Epoxy Paint System**

The bold areas of the flat panels did not show any rust. The scribe area was severely rusted. There was no blistering of the paint system. Areas of the paint system were seen to have chipped off of the edges of the sample. The paint system could be peeled off by hand. It had little adhesion to the silicone. There was no rust on the areas of the flat panels which just had the silicone coating. The complex panels showed some rusting at the edges, side holes, bolt head, and bolt threads. There was not any rust visible at the crevice where the shaft of the bolt contacted the complex panel. This area was adequately protected by the excess silicone sealant which had been applied to the bolt prior to instillation. The U-channel area showed a small amount of rusting and rust staining in its crevices.

**Epoxy Powder Coat**

The bold areas of the flat panels did not show any rust. The scribe area was severely rusted, with no blistering. The complex panels showed some rusting at the weld, edges, side holes, bolt head, and bolt threads. The U-channel area showed a small amount of rusting and rust staining in its crevices.

**Polysulfide Sealant with Epoxy Paint System**

The bold areas of the flat panels did not show any rust. The scribe area was severely rusted. There was no blistering of the paint system. The complex panels showed some rusting at the edges, side holes, bolt head, and bolt threads. There was not any rust visible at the crevice where the shaft of the bolt contacted the complex panel. This area was adequately protected by the excess polysulfide sealant which had been applied to the bolt prior to instillation. The U-channel area showed a small amount of rusting and rust staining in its crevices.

**Epoxy Paint System**

The bold areas of the flat panels did not show any rust. The scribe area was severely rusted and blistering of the paint system was seen extending in from the scribe. The complex panels showed some rusting at the edges, side holes, bolt head, and bolt threads. The U-channel area showed a small amount of rusting and rust staining in its crevices.

**304 Stainless Steel**

The flat panels showed some superficial rusting and rust staining across their surfaces. The complex panels also showed some small amounts of superficial rusting across all areas of the panels. No severe pitting or dark corrosion was evident on any of the panels, indicating there was not any corrosion which would effect the bulk mechanical properties of the material after two months of marine atmosphere exposure. All of the corrosion appeared to only create cosmetic damage.

**316 Stainless Steel**

The flat panels showed some superficial rusting and rust staining across their surfaces. The complex panels also showed some small amounts of superficial rusting across all areas of the panels. The amount of superficial rusting was slightly less than on the 304 stainless steel samples.

**Titanium Alloy (6Al-4V ELI)**

There was no significant corrosion on any area of the flat or complex titanium panels.

Table 4 below summarizes the ASTM D 610 surface area of rust ratings for each of the flat panels and U-weld channel areas for the systems listed above. It also lists the areas on the complex panels where there were visible rust spots as determined by visual examination.

**Table 4**
**Sea Isle Exposure Corrosion Resistance Evaluation Results**

| Test System | ASTM D610 Rating | | Areas of Complex Panel Exhibiting Rust |
|---|---|---|---|
| | Flat Panels | Complex Panel Rating (Area 3) U Channel | |
| Cadmium | 10 | 10 | None |
| SermeTel | 10 | 7 | 3, 4, 6, 7, 8, 9 |
| Zinc-Nickel / Topcoat | 6 | 6 | 1, 3, 6, 7 |
| Inorganic Zn | 10 | 10 | 7, 8, 9 |
| IVD Al | 10 | 0 | 3, 4, 5, 7, 9 |
| Sn/Zn | 6 | 2 | 1, 2, 3, 4, 5, 7, 9 |
| Zn-Alkaline | 10 | 4 | 3, 7, 9 |
| Zn-Acid | 8 | 3 | 3, 7 |
| Black Oxide / Epoxy Paint | 10 | 7 | 3, 6, 7, 8, 9 |
| Zinc Phosphate / Epoxy Paint | 10 | 7 | 3, 6, 7, 8, 9 |
| Silicone / Epoxy Paint | 10 | 8 | 3, 6, 7, 8, 9 |
| Epoxy Powder Coat | 10 | 8 | 3, 5, 6, 7, 8, 9 |
| Polysulfide / Epoxy Paint | 10 | 8 | 3, 6, 7, 8, 9 |
| Epoxy Paint | 10 | 8 | 3, 6, 7, 8, 9 |
| 304 CRES | 9 | 8 | 1, 3, 5, 6, 8 |
| 316 CRES | 8 | 9 | 1, 3, 5, 6, 8 |
| Ti-6Al-4V ELI | 10 | 10 | None |

*Shipboard Exposure*

The USS CONOLLY (DD 979) was nominated for the shipboard exposure. This ship is based in Norfolk, VA. A ship check was performed in early May, and two spaces were selected. The first was in an auxiliary machine space. The racks were installed on beams of an empty bulkhead. The space was subject to high humidity, which was a requirement for selection of this space. The second space was located topside, near gas turbine exhausts and away from primary passageways. Therefore, a rack installated in this area would not interfere with crew operations, but would be exposed to sea spray and exhaust from the stacks. Both of these installations had the concurrence of ship's force. The racks were installed on 19 July 1995. The ship remained local throughout July, August, and September, but deploys to Puerto Rico and other parts of the Caribbean in the fall.

A two month inspection was performed September 20, 1995, so that interim results could be included in this final report. At that time, the auxiliary equipment space was at 84°F, with a relative humidity of 55%. The topside exposure area was at 87°F, with a relative humidity of 50%. Appendix B contains photographs of the complex panels from this inspection. Results of that inspection are as follows:

**SermeTel 984**

The SermeTel coating did not display any signs of degradation in the equipment space. The coating appeared as it did when installed. The SermeTel panels that were exposed topside showed more corrosion than those in the equipment space. The scribes on the flat panels contained corrosion, but did not have any cut-back from the scribe. On the complex panels there was corrosion of the U–channel, as well as corrosion beginning on the edges of the panel.

**Zinc–Nickel with Anodic Coating**

The zinc–nickel did not have any corrosion on the panels exposed in the equipment space. Both the flat–panels and the complex panel appeared in excellent condition. The topside panels also appeared in good condition. There was corrosion of the scribe, but no cut-back beyond the scribe on the flat panels. There was no corrosion of the substrate appearing on the complex panel. Small amounts of white corrosion products appeared on the surface.

**Inorganic Zinc**

Inorganic zinc did not show any signs of corrosion when exposed in the equipment space. Topside, adhesion to the bolt head appeared to be a problem. The bolt of the complex panel was corroded over three quarters of the bolt head surface. The coating had chipped off, and the remaining coating was easily lifted. The complex panel also showed corrosion on the underside of the panel. The flat panels showed corrosion of the scribe, but no further corrosion was present. Bold surfaces of both the complex and flat panels appeared corrosion free.

**IVD Aluminum**

The IVD aluminum panels did not have any corrosion present when exposed in the equipment space. The complex panel exposed topside contained large amounts of corrosion in the U–channel. The U–channel configuration causes chlorides to build up in this area. There is also a higher time of wetness for the U–channel. The flat panel contained corrosion in the scribe, but no cut-back from the scribe occurred. Bold surfaces of both the complex and flat panels appeared in good condition.

**Cadmium**

Cadmium plated panels did not show any signs of substrate corrosion in the equipment space. Topside, the flat panels exhibited corrosion of the scribed area. The complex panels did not show any substrate corrosion, but there was a white corrosion product on the surface.

**Zinc – Alkaline Bath**

Zinc did not show any signs of corrosion when exposed in the equipment space. The panels exposed topside did not show any substrate corrosion. There was a white corrosion product visible on the surface of the panels. There was no corrosion of the scribed area on the zinc plated panels. The zinc platings were the only coatings that sacrificially protected the substrate at the scribe at the 2 month mark. All other coatings, whether sacrificial or barrier show substrate corrosion at this point. Overall the panels were in good condition.

**Zinc – Chloride Bath**

Zinc did not show any signs of corrosion when exposed in the equipment space. Topside the flat panels exhibited corrosion in the scribe area and white corrosion product on the bold surface. As with the zinc–alkaline bath plating, this plating was sacrificially protecting the scribed region. White corrosion product was also visible on the surface of the complex panel. There was corrosion beginning at the crevices created by the U–channel. The zinc plating done in the chloride bath was not protecting the substrate as well as the zinc plated in the alkaline bath.

**Tin Zinc**

Tin-zinc was the only plating to show signs of substrate corrosion in the equipment space. Both the flat panels and the complex panel were degrading. As has been reported in previous OCRC reports.[1] The corrosion morphology was such that the coating begins to fail in the center of the panel without any failure at the edges. This was contrary to what occurs with most other platings. These usually fail at the edges first. The complex panels in the equipment space showed discoloration and white corrosion product. The flat panels had rust staining in the center of the panels. Topside, the condition of the panels was more deteriorated. The flat panels contained rust in the scribe area, and one had general corrosion covering three–fourths of the surface starting from the center. The complex panels had corrosion covering most of the U–channel.

**Black Oxide with Epoxy Paint System**

The black oxide with epoxy paint appeared to be in excellent condition in the equipment space. There were no signs of corrosion on the panels. Topside, the flat panels contained rust in the scribe, but there was no cut-back from the scribe. The rest of the surface was corrosion free. The complex panels were beginning to corrode in the crevices created by the U–channel.

**Zinc Phosphate with Epoxy Paint System**

The zinc phosphate with epoxy paint appeared to be in excellent condition in the equipment space. Results of this coating were typical of most of the panels that were epoxy coated. There were no signs of corrosion on the panels. Topside, the flat panels contained corrosion in the scribe, but there was no cut-back from the scribe. The rest of the surface was corrosion free. The complex panels were beginning to corrode in the crevices created by the U–channel.

**Silicone with Epoxy Paint System**

The silicone sealant used in this coating made adhesion of the paint system very difficult. This has not affected the corrosion resistance of the system thus far. The panels in the equipment space were in excellent condition. There were no signs of corrosion at this point. Topside the panels were also in good condition. As with all the other barrier coatings, there was some rust in the scribe of the flat panel, but that did not affect the rest of the panel. The complex panel was also in excellent condition, with no signs of corrosion at this time. Adhesion of the paint to the silicone does not appear to be a problem now.

**Epoxy Powder Coat**

The panels that were epoxy powder coated did not contain any corrosion in the equipment space. The flat panels that were topside contained rust in the scribe area, but the general surface was corrosion free. The complex panel that was exposed topside had corrosion on the edges of the bolt head. The powder coating appeared cracked, and the coating was flaking off. The general surface of the coating was in good condition. There was corrosion beginning at the crevices of the U–channel.

**Polysulfide Sealant with Epoxy Paint System**

No degradation of the system was observed on the polysulfide and epoxy panels exposed in the equipment space. The flat panels that were exposed topside showed rust in the scribe area. The general surface of the panel was in good condition. The complex panel exposed topside was beginning to form rust in the crevices formed by the U- channel. The rest of the surface was free from rust.

**304 Stainless Steel**

The 304 stainless steel was free from any degradation of its surfaces when exposed in the equipment space. This was not true of the samples exposed topside. The samples, because they were not coated, did not have scribes. The general surface of the 304 was stained with rust. The rust was more pronounced in the crevices of the U-channel.

**316 Stainless Steel**

The 316 stainless steel was free from any degradation of its surfaces when exposed in the equipment space. The samples exposed topside were covered with general rust staining of the surface. The flat panels and the complex panels were similar to the 304 stainless, but had a lesser degree of staining. The rust was more pronounced in the crevices of the U–channel, than on the bold surfaces.

**Titanium Alloy (6Al-4V ELI)**

The titanium samples did well in both spaces. As in previous studies, there was no degradation of the titanium. The surfaces were corrosion free.

Table 5 lists the ASTM D 610 ratings for flat panels of each material.

**Table 5**
**Shipboard Exposure Flat Panel ASTM D 610 Evaluation**

| Material | Topside | Equipment space |
|---|---|---|
| Cadmium | 10 | 10 |
| SermeTel | 10 | 10 |
| Zinc-Nickel w/topcoat | 10 | 10 |
| Inorganic Zinc | 10 | 10 |
| IVD Aluminum | 10 | 10 |
| Tin-Zinc | 3.5 | 7.5 |
| Zinc-alkaline bath | 10 | 10 |
| Zinc-chloride bath | 10 | 10 |
| Black Oxide w/epoxy paint | 10 | 10 |
| Zinc Phosphate w/epoxy paint | 10 | 10 |
| Silicone w/epoxy paint | 10 | 10 |
| Epoxy Powder Coat | 10 | 10 |
| Polysulfide w/epoxy paint | 10 | 10 |
| Epoxy paint | 10 | 10 |
| 304 CRES | 8.5 | 10 |
| 316 CRES | 9 | 10 |
| Ti-6Al-4V ELI | 10 | 10 |

The following list summarizes the ranking of these platings/materials after 2 months of shipboard exposure. This ranking takes into account the flat panel ratings, and the visual inspection on the complex panels.

| BEST | AVERAGE | WORST |
|---|---|---|
| Titanium | Inorganic Zinc | IVD Aluminum |
| Zn–Ni with anodic topcoat | Epoxy Powder Coat | Sn–Zn |
| Black Oxide w/ Epoxy | Zinc– chloride bath | SermeTel 984 |
| Zn Phosphate w/ Epoxy | Zinc– alkaline bath | |
| Silicone Sealant w/ Epoxy | 316 Stainless | |
| Polysulfide w/ Epoxy | 304 Stainless | |
| Epoxy (control) | | |
| Cadmium (control) | | |

*Accelerated Exposure (Prohesion)*

In order to develop a quick understanding of the corrosion resistance of the potential cadmium alternative systems, an accelerated exposure was conducted. Table 6 gives the average percent area rusted along with comments on corrosion at the scribes. Figure 5 shows one sample of each system after testing.

**Table 6**
**Accelerated Exposure Corrosion Resistance Evaluation Results**

| Test System | Bold Surface ASTM D610 Rating | Scribe Areas |
|---|---|---|
| Cadmium | 10 | None[2] |
| SermeTel | 10 | None[1] |
| Zinc-Nickel w/topcoat | 3 | Rust at Scribe |
| Inorganic Zinc | 10 | None |
| IVD Aluminum | 5 | Rust at Scribe |
| Tin-Zinc | 8.5 | Rust at Scribe |
| Zinc-alkaline bath | 2 | Rust at Scribe |
| Zinc-chloride bath | 1 | Rust at Scribe |
| Black Oxide w/ epoxy paint | 8.5 | Rust at Scribe |
| Zinc Phosphate w/ epoxy paint | 8.5 | Rust at Scribe |
| Silicone w/ epoxy paint | 8.5 | Rust at Scribe |
| Epoxy Powder Coat | 10 | Rust at Scribe |
| Polysulfide w/ epoxy paint | 9.5 | Rust at Scribe |

**Table 6**
**Accelerated Exposure Corrosion Resistance Evaluation Results, (cont'd)**

| Test System | Bold Surface ASTM D610 Rating | Scribe Areas |
|---|---|---|
| Epoxy paint | 8.5 | Rust at Scribe |
| 304 CRES | 9 | (No scribe) |
| 316 CRES | 9 | (No scribe) |
| Ti-6Al-4V ELI | 10 | (No scribe) |

[1] Some green corrosion product on the back surface (no rust).
[2] Yellow chromate conversion coating layer still visible on back surface.

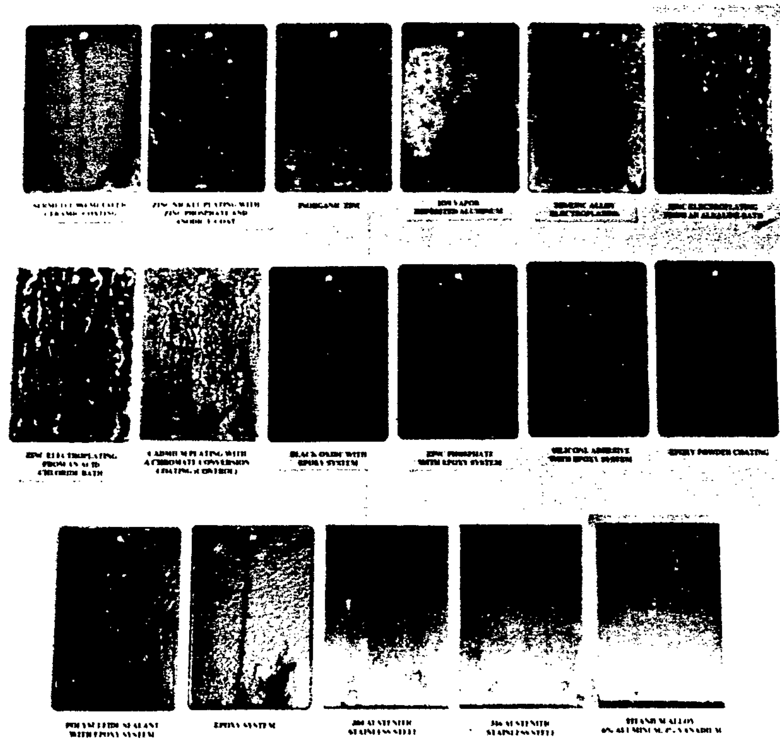


**Figure 5: Prohesion Test Panels after 1000 Hours**

From the test results it can be seen that only SermeTel, inorganic zinc, and titanium provided the same amount of corrosion resistance on bold surfaces and at areas of exposed base material as cadmium during this accelerated exposure. The SermeTel coating developed a green corrosion product on the back side of the panels. Other reports on this coating have noted similar occurrences.[2] This was most likely due to the chromate leaching out of the binder. Conversations with engineers at SermaTech indicate that this was a possibility. They had only seen this occurrence when testing undercured coatings.

indicate that this was a possibility. They had only seen this occurrence when testing undercured coatings.

The epoxy systems (powder coat or paint) provided good protection to the bold areas of the flat panels, but exhibited rusting at their scribes. These were sufficient barrier coatings but did not galvanically protect the substrate. The tin-zinc exhibited similar corrosion to the natural marine and shipboard exposures, rusting from the center. The 304 and 316 stainless steel panels exhibited a very small amount of rusting and rust staining during testing. The zinc-nickel with topcoat, IVD Al, and zinc plating systems did not effectively protect the substrate as either barriers or as sacrificial layers for the entire 1000 hour duration. The inorganic portions of these coatings corroded preferentially to the steel substrate during exposure, but they corroded at such a rate that their protective properties were exhausted before testing was completed.

The following data summary of Table 7 illustrates the recommendations of the program concerning thin-film plating alternatives to cadmium. The data were derived primarily through the D 610 rating data. This data is based on a logarithmic raking of the degree of corrosion observed on the steel panels. The scale was broken into three orders of magnitude: 10 (best), 7 to 9 (average), and 0-6 (worst). The results of the analysis are presented separately for flat surface and complex surfaces. This is necessary due to the significant benefits of cadmium apparent over complex surfaces. Assigning the test results a numerical score of three (3) for a "best" ranking, a two (2) for an "average" ranking, and a one (1) for a "worst" ranking allows a cumulative ranking of the test results. These are presented in Table 8.

**Table 7**
**Data Summary For Alternative Thin-Film Platings**

| | Best | Average | Worst | Comments |
|---|---|---|---|---|
| **Marine Exposure** | | | | |
| *Flat Surfaces* | Cadmium<br>Zn/Ni Anodic E-coat [1]<br>SermeTel<br>IVD Aluminum<br>Zinc-Alkaline Bath | Zinc-Acid Bath | Tin/Zinc | 1. Zn/Ni Anodic E-Coat ranking considers the results of the process characterization studies where these platings performed well. The reduced performance of this system in the Phase II studies was considered indicative of performance variability as opposed to its best properties. |
| *Complex Surfaces* | Cadmium | Zn/Ni Anodic E-coat [2]<br>SermeTel | IVD Aluminum<br>Tin/Zinc<br>Zinc-Alkaline Bath<br>Zinc-Acid Bath | 2. 0.5 mil Zn/Ni, Zn-Phosphate, Anodic E-coat |
| **Shipboard Exposures: Topside** | | | | |
| *Flat Surfaces* | Cadmium<br>SermeTel<br>Zn/Ni Anodic E-Coat<br>IVD Aluminum<br>Zinc-Alkaline Bath<br>Zinc-Acid Bath | (none) | Tin/Zinc | |
| *Complex Surfaces* | Cadmium<br>Zn/Ni Anodic E-coat | Zinc-Alkaline Bath | SermeTel<br>IVD Aluminum<br>Tin/Zinc<br>Zinc-Acid Bath | |

**Table 7**
**Data Summary For Alternative Thin-Film Platings (cont'd)**

| | Best | Average | Worst | Comments |
|---|---|---|---|---|
| **Shipboard Exposures: Interior** | | | | |
| *Flat Surfaces* | Cadmium<br>SermeTel<br>Zn/Ni Anodic E-Coat<br>IVD Aluminum<br>Zinc-Alkaline Bath<br>Zinc-Acid Bath | Tin/Zinc | (none) | |
| *Complex Surfaces* | Cadmium<br>SermeTel<br>Zn/Ni Anodic E-Coat<br>IVD Aluminum<br>Zinc-Alkaline Bath | Zinc-Acid Bath | Tin/Zinc | |
| **Accelerated Testing**[3] | | | | 3. The accelerated test data should be considered primarily indicative of potential failure modes, i.e., depletion of a sacrificial coating. The data should not be used alone to predict long-term corrosion performance. This is best illustrated by the performance of the tin/zinc system which does not perform as well as any of the other systems in any exposure, yet performs well in this environment. |
| *Flat Surfaces* | Cadmium<br>SermeTel | Tin/Zinc | Zn/Ni Anodic E-Coat<br>IVD Aluminum<br>Zinc-Alkaline Bath<br>Zinc-Acid Bath | |

**Table 8**
**Cumulative Ranking of Test Results**

| Material | Marine Exp. Flat | Marine Exp. Complex | Ship. Exterior Flat | Ship. Exterior Complex | Ship. Interior Flat | Ship. Interior Complex | Accel. Testing | Total | Comments |
|---|---|---|---|---|---|---|---|---|---|
| Cadmium | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 21 | Overall the best performing materials, esp. due to its performance on complex surfaces. |
| SermeTel | 3 | 2 | 3 | 1 | 3 | 3 | 3 | 18 | Good performance except on complex surfaces. |
| Zn/Ni Anodic E-Coat | 3 | 2 | 3 | 3 | 3 | 3 | 1 | 18 | Good performance except on complex surfaces. |
| Tin/Zinc | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 9 | A poor candidate. |
| IVD Aluminum | 3 | 1 | 3 | 1 | 3 | 3 | 1 | 15 | The IVD aluminum (as tested) did not perform well on complex surfaces thus lowering its rating. An adequate materials for flat surfaces. |
| Zinc - Alkaline Bath | 3 | 1 | 3 | 2 | 3 | 3 | 1 | 16 | The better of the two zinc plating materials. |
| Zinc - Acid Bath | 2 | 1 | 3 | 1 | 3 | 3 | 1 | 14 | Does not perform as well as the zinc-alkaline bath material. |

## Mechanical Testing

### *Fatigue Crack Growth*

Fatigue crack growth was performed by a sub-contractor, Westmoreland Mechanical Testing and Research Inc. Only the metallic platings, zinc phosphate with epoxy, and polysulfide with epoxy coatings were tested. These were the most likely to contain elements that would influence the fatigue crack growth of the base 4340 steel. 4340 was used because its high strength makes it susceptible to hydrogen embrittlement. Appendix C shows the Da/Dn versus Delta K plots for each of the materials tested. Figure 6 is a summary of the fatigue crack growth for Delta K=10 ksi $\sqrt{\text{in}}$. It was noted that there was no plating that showed any influence on the base metal at the levels tested. Inorganic zinc exhibited the highest deviation in crack growth rate of the materials tested.

### *Torque-Tension*

The torque-tension curve was a convenient format for presenting a considerable amount of data. It shows how much tensile force has been developed within a fastener when a torque is applied to the fastener system. The pounds of tensile force (clamping load) per foot-pound of tightening torque ratio (slope of the torque-tension curve) is dependent on many factors. Some of these include the size and thread dimensions of the fastener, friction forces between the bolt and nut with the washers, friction between the washers and joint material, and friction between the threaded surfaces. With all other factors being equal, a greater slope correlates with increased lubricity of the system and greater transfer efficiency (transfer of torque into tension). It is important to note that the torque-tension relationship was highly variable and can be affected by a number of variables.[3,4,5] Even with strict control, other variables beyond our control, such as thread condition make it difficult to reproduce exact results. Previous OCRC testing showed that a sample size of 5 was adequate for accurate data analysis.[6] Table 9 lists the pound to foot pound ratio for each coating.

Figure 7 shows a bar graph of the average slopes of the torque-tension curves for the different platings or coatings applied to grade 8 steel bolts. Figure 8 shows the torque-tension curves for the grade 8 bolts. The curves were generated by averaging tensile load readings taken at 0, 45, 75, 90, and 105 ft-lbs of torque for each tested fastener and plotting these measurements.

It can be seen from the data that the SermeTel coated fasteners provide the highest clamping load for each unit of torque applied. This indicates that the various friction forces present when assembling a fastener system are lower for a fastener coated with the SermeTel coating system and more of the energy applied to the fastener as torque is transferred into tensile load on the fastener (i.e., it has the highest lubricity). It needs to be noted that the SermeTel fasteners were not only coated with the SermeTel 984, but were also coated with a layer of SermeTel 751. This is a solvent based lubricating coating which is used to reduce binding and wear to the SermeTel base coating during assembly. It is recommended that this coating be used on the fastener threads. The SermeTel bolts were the only test pieces to be coated with this supplemental coating.

All other coated fasteners have a smaller tensile clamping load generated by each unit of applied torque than cadmium plated fasteners. The tin-zinc plated fasteners showed the closest relationship (141 lbs./ft-lb. vs cadmium at 164 lbs/ft-lb.), followed by zinc plated fasteners (acid chloride bath, 128 lbs/ft-

**Figure 6**
**Fatigue Crack Growth**

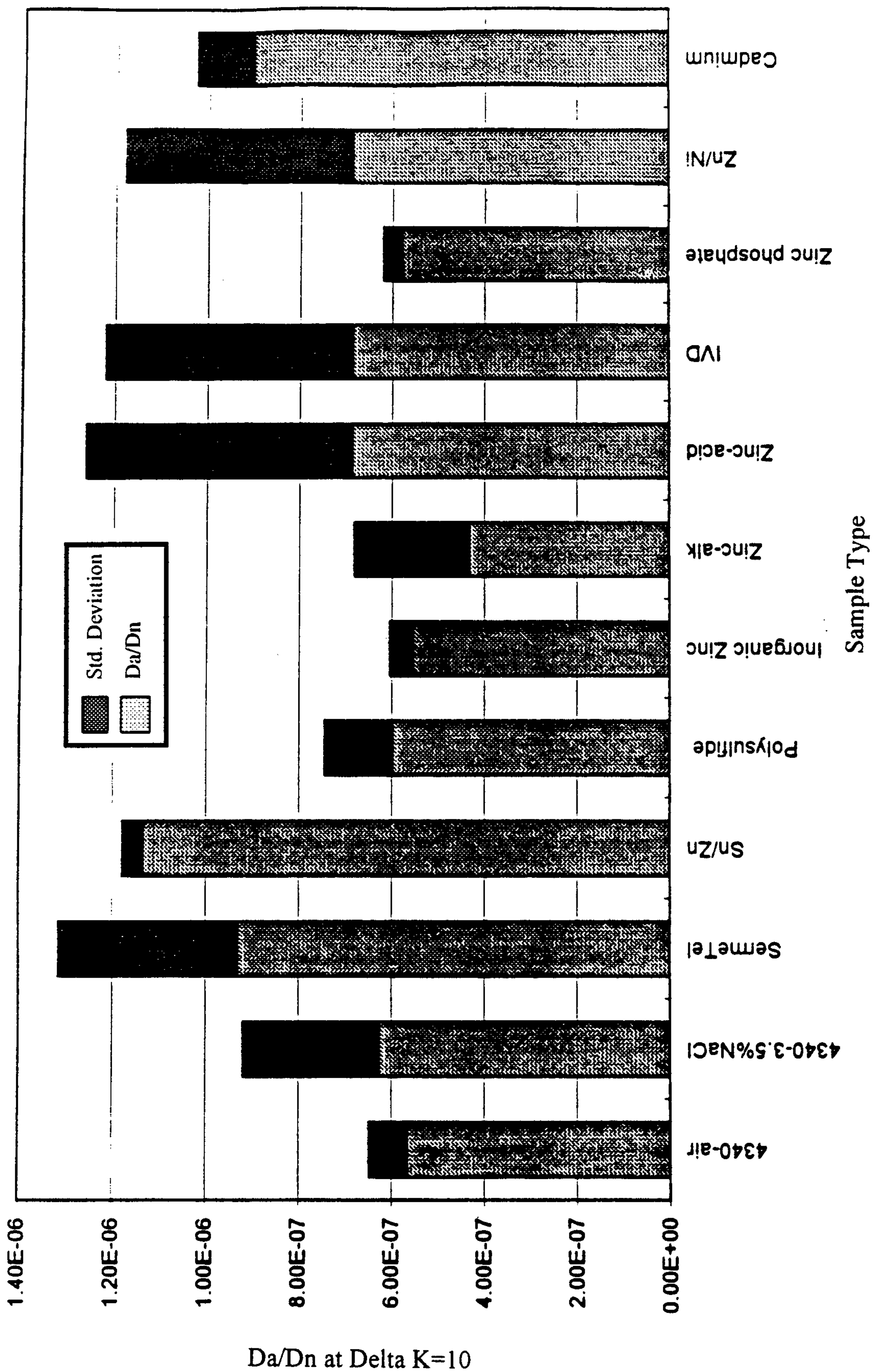


**Table 9**
**Tensile Load to Applied Torque Ratios**

| Test Coating System | Pound to Foot-Pound Ratio |
|---|---|
| Cadmium | 165 |
| SermeTel 984 with SermeTel 751 | 334 |
| Zinc-Nickel with Topcoat | 129 |
| IVD Aluminum | 110 |
| Tin-Zinc | 141 |
| Zinc-Alkaline | 80 |
| Zinc-Acid | 128 |
| Epoxy Powder Coating | 109 |
| 304 Stainless Steel | 178 |
| 316 Stainless Steel | 180 |
| Titanium 6A1-4V ELI (with Dry Film lubricant) | 365 |

lb.) and zinc-nickel topcoated fasteners (129 lbs/ft-lb). The zinc (alkaline bath) plated fasteners had the lowest tensile load to tightening torque ratio of all tested systems (80lbs/ft-lb.).

Previous OCRC testing of coatings over Grade 8 reference fasteners has indicated that the zinc and zinc alloy platings are slightly less lubricious than cadmium.[7] Zinc (acid chloride) bath and tin-zinc alloy platings have shown slightly less lubricity over Grade 8 fasteners. Zinc plating from an alkaline bath has shown the least lubricity, providing a significantly lower clamping load than cadmium plated fasteners. These previous test results were again affirmed by the fasteners tested in this program, although there were differences observed. They included differences in the magnitudes of the torque-tension readings and a switch in lubricity ranking for the zinc (acid chloride bath) and tin-zinc alloy platings. Torque-tension measurements are normally highly variable due to the large number of factors which combine to affect this measurement (e.g., many friction surfaces, bolt strength, bolt size, thread type and condition, coating, etc.). A student-t statistical analysis (Figure 9) of the data from this program and the data from previous testing indicate that the switch in the order of the lubricity ranking of these two coatings may be due to measurement variability. Statistically, it cannot be said that the pound to foot-pound ratio given for each coating system is not approximately equal when the measurement variability and sample size are considered. The differences in the magnitudes of the torque-tension relationship may be due to minor alterations in the test set-up which included the use of longer test bolts in the current program and a second set of washers for load distribution onto the load cell. Other testing over Grade 5 fasteners indicated zinc plating from an alkaline bath had similar lubricity to cadmium plating.

**Figure 7**
**Slope of Torque-Tension Curves**

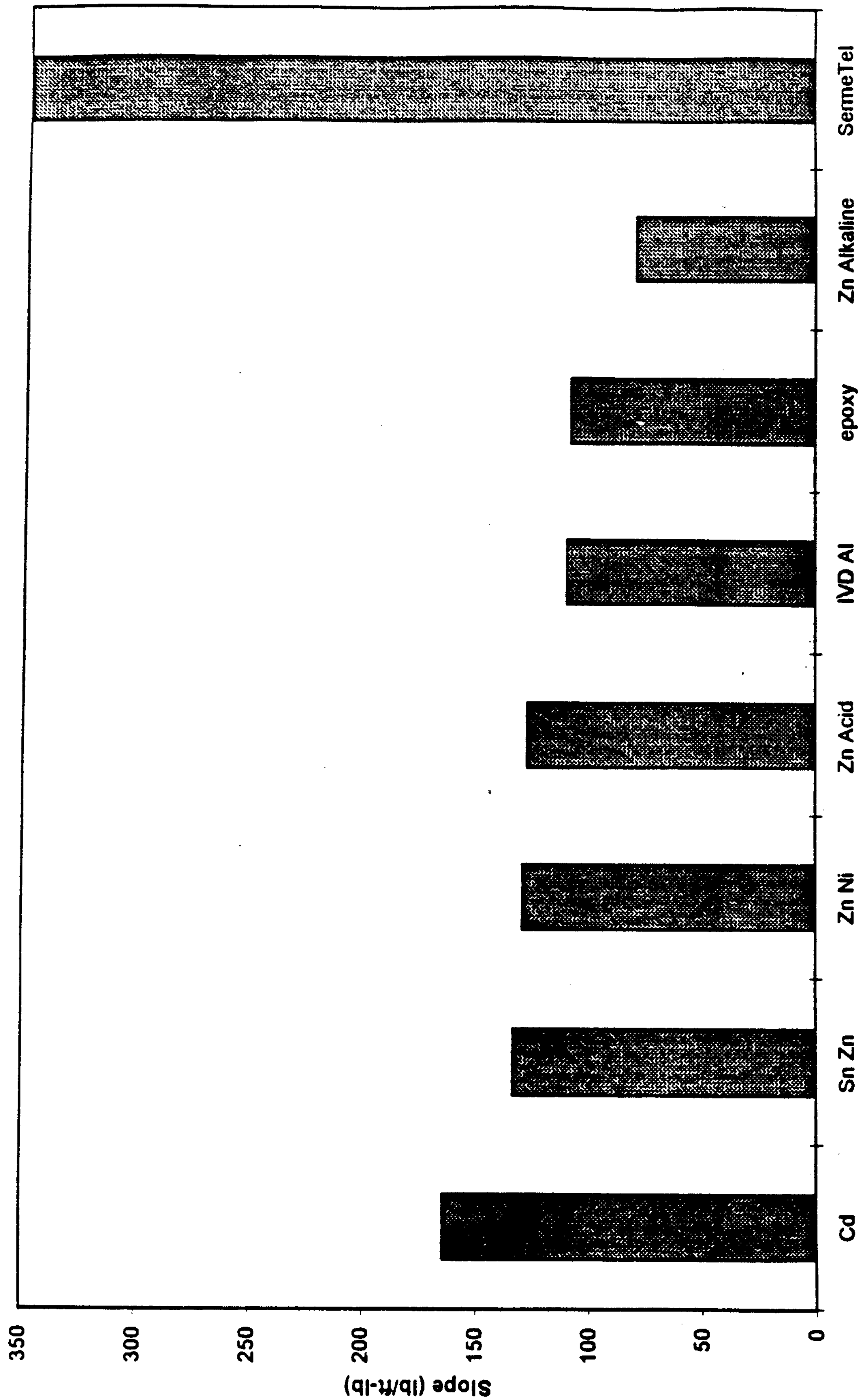


**Figure 8**
**Torque-Tension Curves**

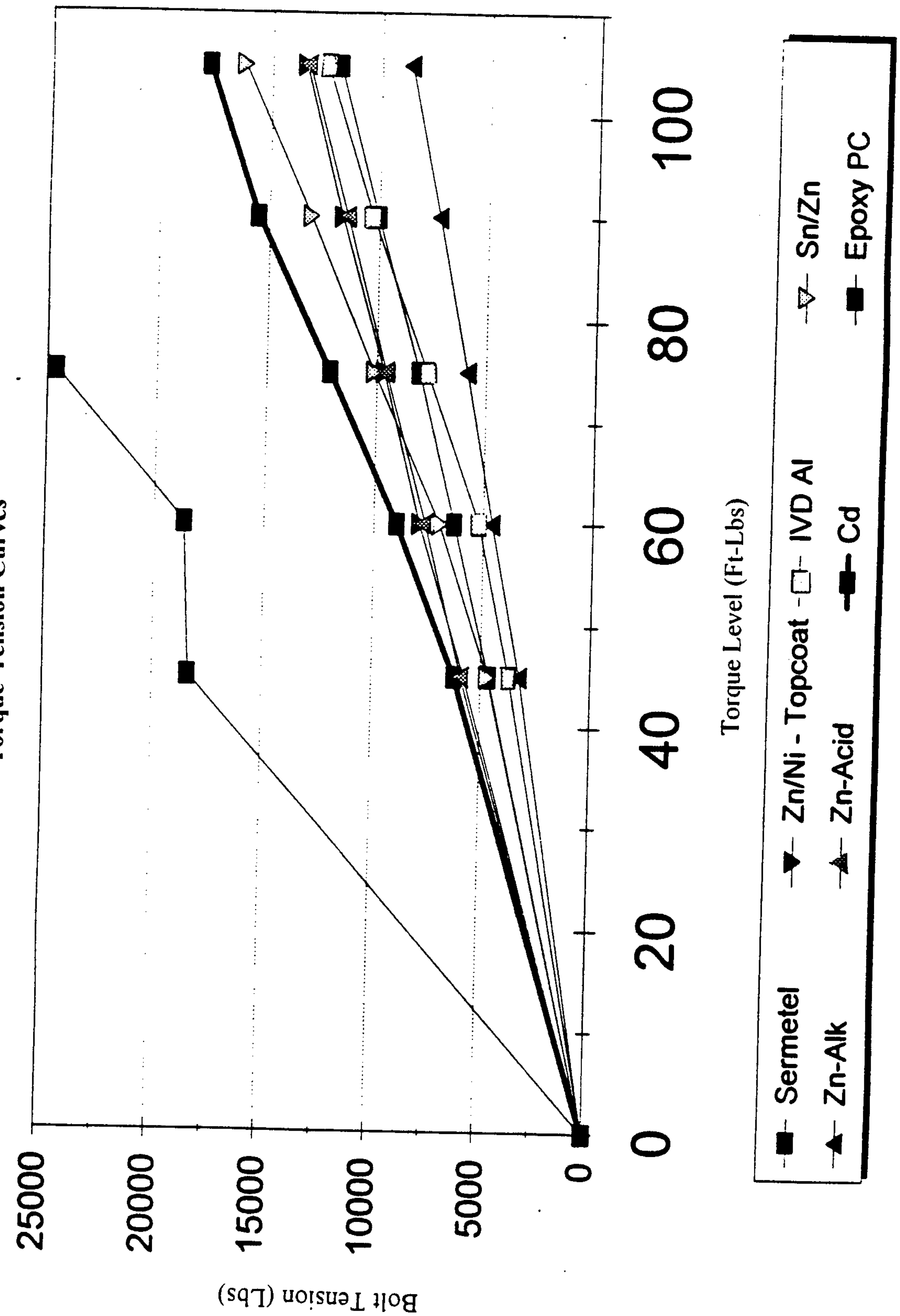
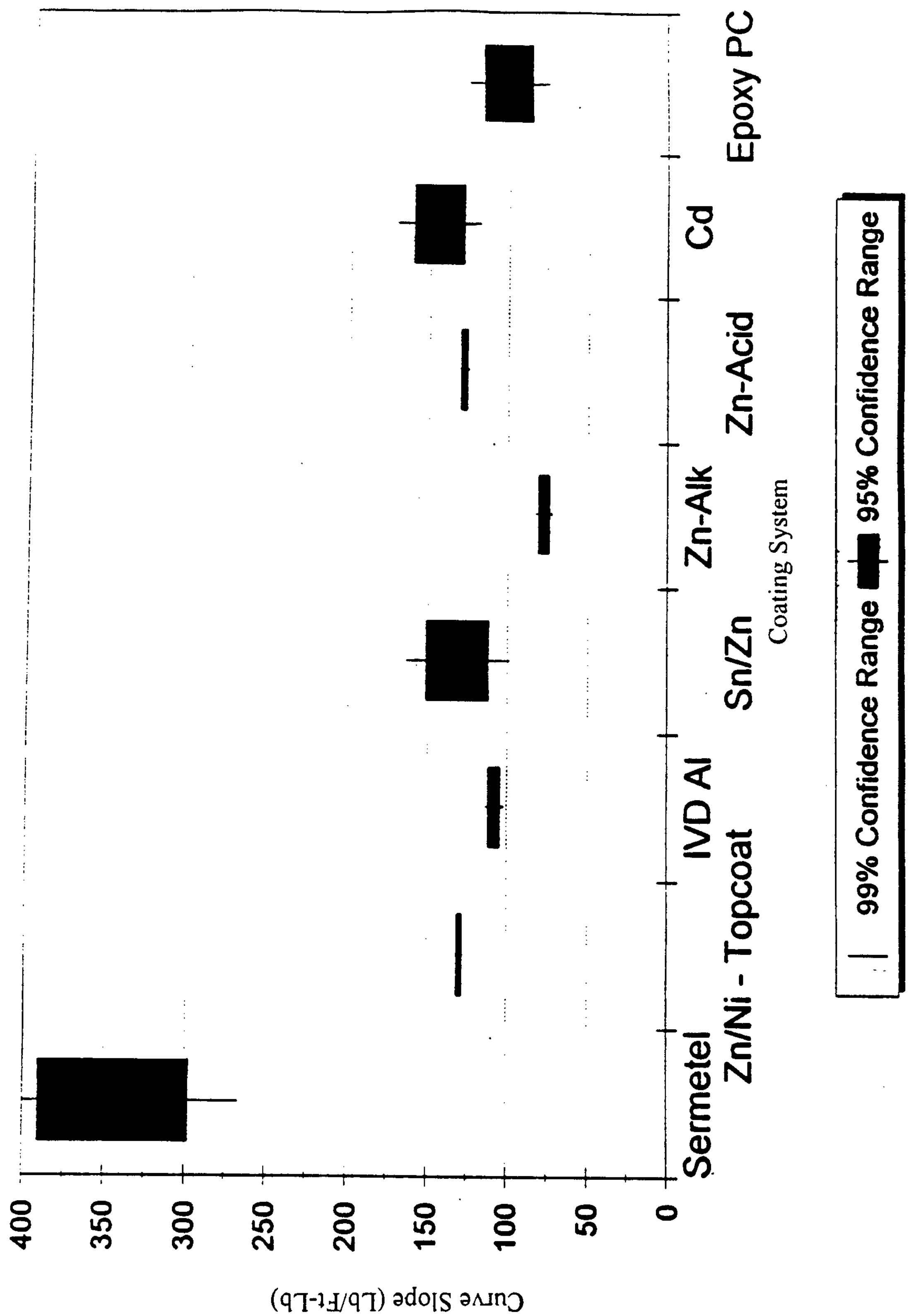


**Figure 9**
**Statistical Analysis**
**Torque-Tension Curve Slopes**



The IVD aluminum coated fasteners provided 110 lbs/ft-lb of clamping load per unit of torque. IVD aluminum and epoxy powder coating are not recommended for use on threaded fasteners. Previous OCRC work has shown that IVD aluminum will gall (cold weld) with itself on the mating surfaces of a coated nut and bolt.[1] This behavior is unacceptable for a fastener coating. Pieces were coated and tested in order to determine some base line data on the lubricious behavior of the aluminum coating. A potential solution to the galling problem is to add a supplemental coating to the threaded region of the bolts which will increase the lubricity of the system and may eliminate galling.

The epoxy systems included in the test program would not be used as a system over the threaded regions of a fastener because of the high total system thicknesses achieved by these coatings. Epoxy powder coating was tested to measure the torque-tension relationship of a fastener which was not coated on the threaded region of the fastener, but had an epoxy coating on all other areas of the fastener. The fasteners tested had the threaded regions of their nuts and bolts masked during coating so that the epoxy powder coating would not cover these areas. The coating covered all other surfaces of the nuts and bolts, including the bottom surface at the foot of the bolt.

Figures 7 and 8 include the pound to foot-pound ratio and torque-tension curves for the epoxy powder coated fasteners, respectively. These fasteners provided 109 lbs/ft-lb of clamping load per unit of tightening torque. During testing, even though the threaded areas were not coated, pieces of the epoxy powder coating from adjacent areas wore off and became entrapped between the mating threaded surfaces. This entrapped epoxy made disassembly of the test apparatus very difficult. Only two replicates were tested to avoid damaging the test equipment. Even though the threaded regions of a fastener system are not coated, epoxy powder coating should not be used on any area of the fastener system where it may wear off during assembly and interfere with the tightening and loosening of a bolt.

Figure 10 shows the torque-tension curves for the material substitutions. As noted above, there are many factors which affect the torque-tension relationships. The different clamping loads at various tightening torques are affected by the different friction factors between the mating surfaces of the materials, and differences in the strengths of the materials. The curves can be used to estimate required torque to achieve a desired pre-load.

The 304 and 316 stainless steel fasteners provided 178 and 180 pounds per foot-pound of clamping load per unit of tightening torque. The titanium 6Al-4V ELI fasteners provided 365 pounds per foot-pound of clamping load per unit of tightening torque. It is necessary to note that the titanium bolt threads were coated with a PTFE based dry film lubricant. It was reported that titanium also galls during assembly if mated to itself, and that commercial industries use a dry film lubricant over the bolt threads to prevent this. The lower yield and tensile strengths of the alternate base materials make them improper selections for applications requiring a high strength fastener. For lower strength applications where the clamping load of a fastener will be below the yield strengths of the stainless steels and titanium 6-4 ELI, these fasteners can be used. Table 10 gives the yield and tensile strengths for each of the materials tested.

Figure 10

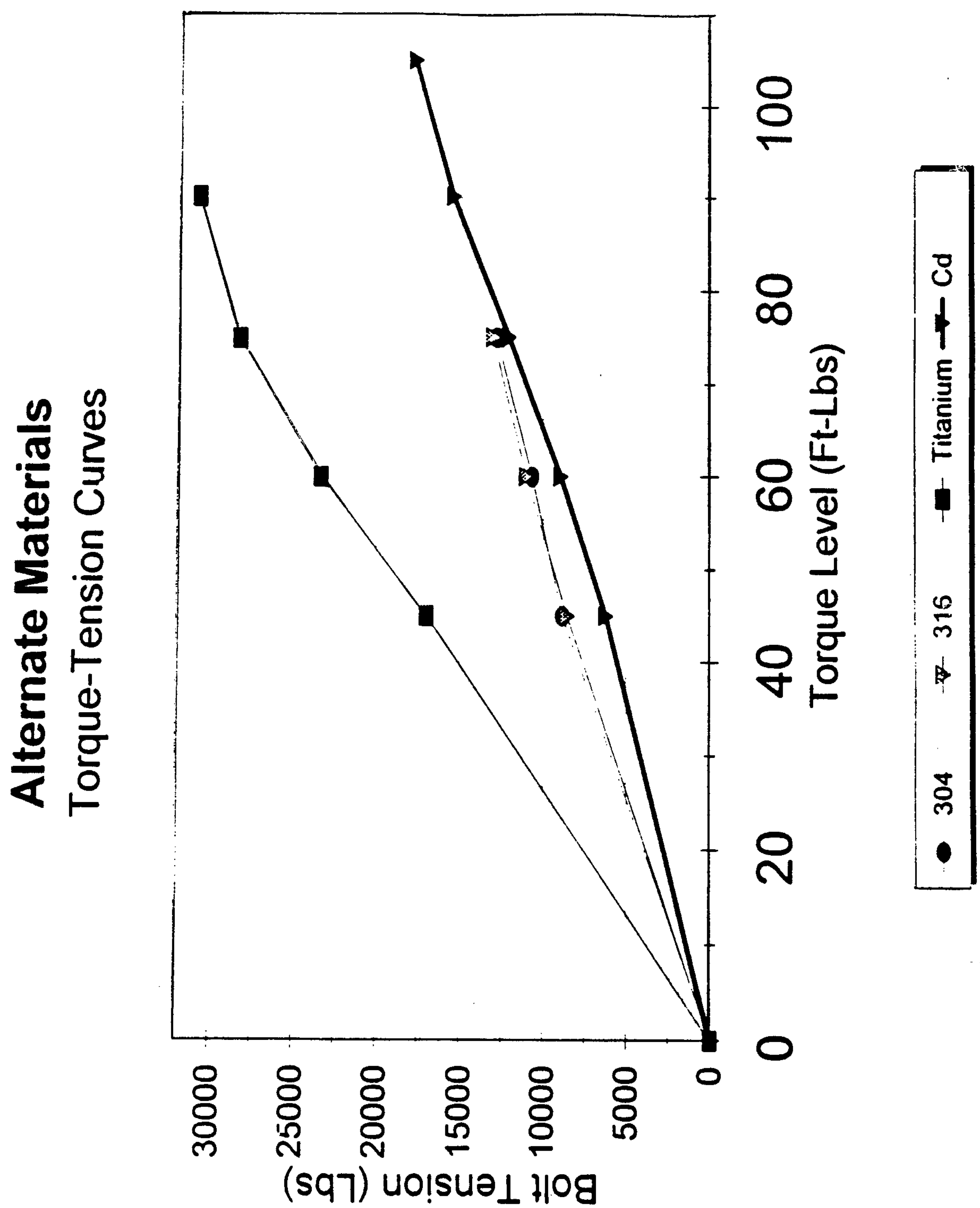

Alternate Materials
Torque-Tension Curves
Bolt Tension (Lbs)
30000
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
Torque Level (Ft-Lbs)
304
316
Titanium
Cd

**Table 10**
**Mechanical Properties of Alternative Fasteners Materials**

| Base Material | Yield Strength (ksi) | Ultimate Tensile Strength |
|---|---|---|
| 304 Stainless Steel[1] | 50 | 90 |
| 316 Stainless Steel[1] | 50 | 90 |
| Titanium 6 A1-4V ELI[2] | 130 | 137 |
| Grade 8, medium alloy steel[3] | ----- | 150-170 |

[1] Standard Handbook of Fastening and Joining, 2nd Edition, Ed. by Robert Poarmley, 1989, p. 1.28.
[2] Product Certificate of Test, B&G Manufacturing Co, Hartfield, PA.
[3] MIL-S-1222H.

*Abrasion Testing*

The abrasion testing was performed on the metallic coatings. The test was also run on the epoxy powder coat and the zinc-phosphate with epoxy coating. The zinc phosphate with epoxy was expected to be representative of all the epoxy coated systems, therefore repetition on all these coating was not necessary. The wear rates of those systems were driven by the epoxy coating, not the chemical conversion coating. The results of this testing are included in Figure 11. In general, the metallic platings wear at a similar rate to cadmium.

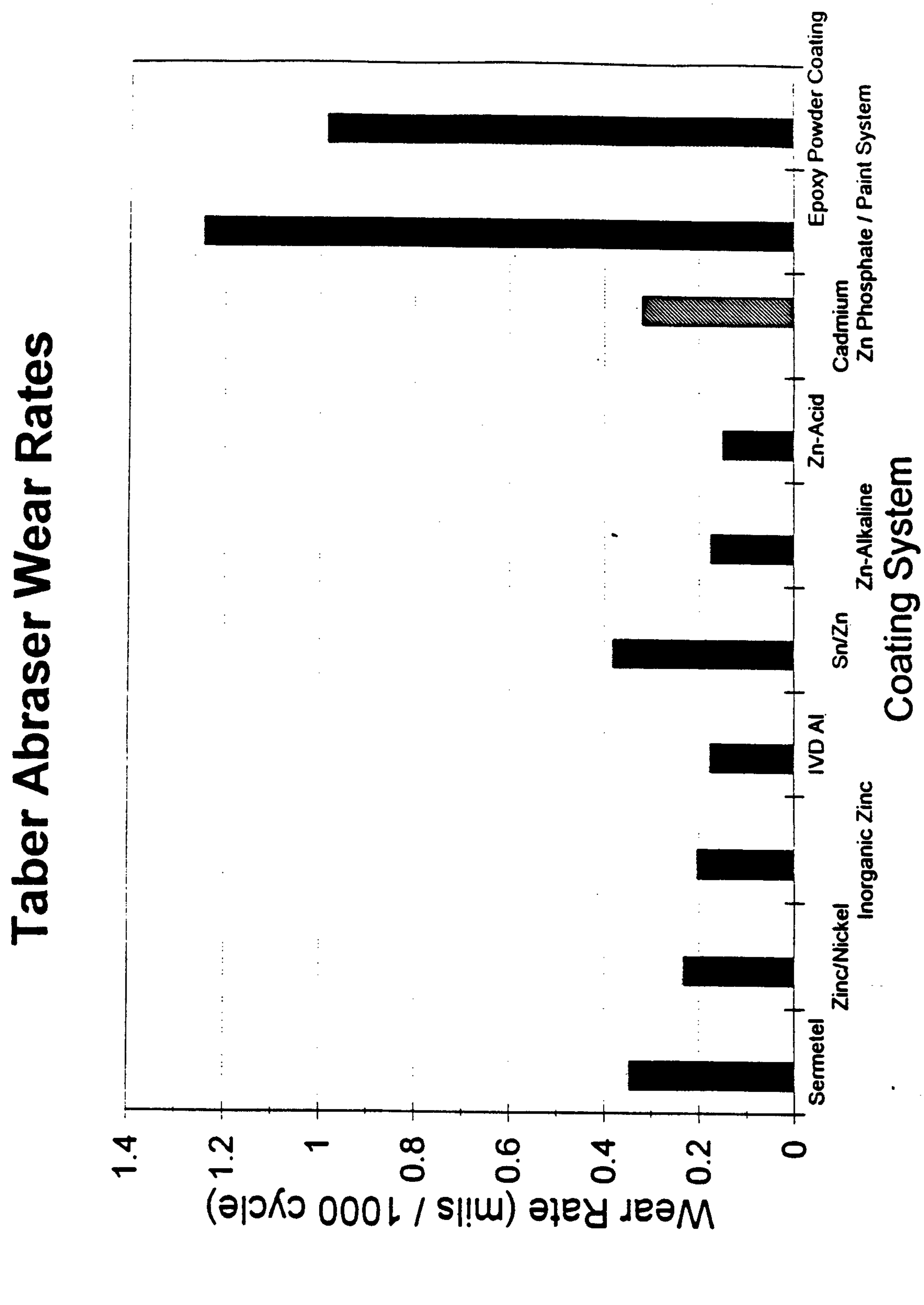
The following is a ranking of all the coatings tested for wear resistance:

| BEST | AVERAGE | WORST |
|---|---|---|
| Zinc-chloride bath | Inorganic zinc | Epoxy Powder Coat |
| Zinc- alkaline bath | SermeTel 984 | Zinc-phosphate with Epoxy system |
| IVD aluminum | Tin-Zinc | |
| | Cadmium | |

The platings with the best wear resistance were those with less than 0.2 mils per 1000 cycles of testing. Those in the average category maintained between 0.2 and 0.4 mils per 1000 cycles. These coatings most closely compared to the wear rate of cadmium. Cadmium had a wear rate of 0.32 mils per 1000 cycles. The coatings that had the worst wear resistance were those containing an epoxy system. These had wear rates close to or above 1 mil per 1000 cycles.

Note that in past reports, inorganic zinc had received poor wear resistance ratings.[4] In this program, the wear rate of inorganic zinc was better than that of cadmium (0.320 mils per 1000 cycles for cadmium versus 0.205 mils per 1000 cycles for inorganic zinc). The difference is due to the method of evaluation. The past report used visual inspection only to determine cycles to failure. The inorganic zinc coating polishes to a shiny metallic finish after just a few cycles. This finish is difficult to differentiate from the base steel. Therefore failure was cited prematurely. The technique being used in this program does not rely solely on visual examination. The thickness measurements combined with the exposure to seawater allows for an accurate determination of failure.

**Figure 11**


Taber Abraser Wear Rates
Wear Rate (mils / 1000 cycle)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Sermetel
Zinc/Nickel
Inorganic Zinc
IVD Al
Sn/Zn
Zn-Alkaline
Zn-Acid
Cadmium
Zn Phosphate / Paint System
Epoxy Powder Coating
Coating System

## CONCLUSIONS

The following are the primary conclusions resulting from mechanical testing and two month exposure tests. They are supported by the data within the report and supplemented as necessary by references to previous testing.

1. No single alternative preservation treatment/material investigated performed as a universal substitute for Type II cadmium plating with a chromate treatment. The broad range of engineering properties afforded by cadmium can not be matched simply by an across-the-board plating substitute.

2. With respect to thin-film plating alternatives for use in the marine environment, the data suggest that several alternatives offer corrosion resistance comparable to cadmium on non-complex (i.e., flat) surfaces. The most promising materials are SermeTel, zinc-nickel plating with an anodic E-coat topcoat, IVD aluminum, and zinc-plating from an alkaline bath.

In areas with a complex shape (e.g., fasteners, holes, weld beads, sharp edges) or areas that retain moisture (e.g. channels and crevices), none of these plating alternatives performed as well as cadmium.

These findings are consistent with previous work by OCRC which suggested that the best cadmium alternatives were IVD aluminum with a metallic ceramic topcoat (not tested in the current work), an IVD aluminum alloy, and zinc plating from an alkaline bath. Each of these alternative materials of the previous study was also found to be somewhat poorer than cadmium in protecting complex surfaces. These findings were attributed to inherent properties of the alternative materials, not to production problems.

3. Inorganic zinc coatings provide good corrosion protection to the substrate and all complex surfaces; yet the coating does not appear readily applicable at thin films and as such is not a direct substitute for many cadmium plating applications. The short term data indicates that at a thickness of 2-3 mils, it will perform as well as the cadmium (of less than 0.2 mil). The performance of the inorganic zinc will decrease if the substrate can not be abrasively blasted.

4. Tin/zinc plating and zinc plating from an acid-chloride bath do not perform as well as the other thin film platings with respect to corrosion resistance. This agrees with earlier testing.

5. All of the systems with an epoxy (MIL-P-24441) primer performed well throughout the test duration on preventing corrosion resistance on the boldly exposed surfaces. Corrosion was prevalent on each system at sharp edges and complex surfaces. The epoxy powder coat performed similarly to the solvent-based epoxy system.

6. The systems applied for purposes of investigating the efficiency of the alternative sealants did not show any performance differences between the silicone RTV versus the polysulfide sealant over the short test duration. The standard Navy topside epoxy primer does not adhere well to the silicone RTV, but does adhere to the polysulfide sealant. Both of the sealants appear effective in mitigating corrosion of a fastener installed in a boldly-exposed plate.

7. Moderate cosmetic corrosion was observed on the 304 and 316 stainless steel alloys, with the 316 stainless exhibiting slightly more cosmetic corrosion resistance. No corrosion was observed on the titanium materials. The data are in agreement with the long-standing knowledge of the industry.

In most applications (excepting high strength fastener requirements) these materials would be effective substitutes to eliminate concerns of substrate corrosion in the marine environment.

While not a specific objective of the current program, there is an additional concern with these materials relating to pretreatment prior to cosmetic painting. In general, without some type of surface pretreatment, paint adhesion can be poor. This issue has been addressed by others.

8. With respect to wear (e.g., abrasion) of the leading thin film platings, the zinc-nickel with an anodic E-coat topcoat, the IVD aluminum, and the zinc-plating from an alkaline bath all had a wear resistance exceeding cadmium. The SermeTel had a lower wear resistance to cadmium.

9. None of the materials applied over the high-strength 4340 steel substrates appeared to affect the gross fatigue crack growth rate of the base material in a 3.5% salt solution. Inorganic zinc exhibited the highest deviation in crack growth rate of the materials tested.

In previous constant extension rate tests (CERT), promising coatings such as the zinc plating from an alkaline bath appeared to be more likely to promote environmentally assisted cracking (EAC) than cadmium. CERT's can be very severe tests. Potential concerns regarding EAC or FCGR may be addressed by results of ongoing rising step load tests.

10. The data from the subject testing concerning the lubricious properties of the metallic plating suggests that cadmium is typically more lubricious than other plating materials. This is consistent with other reported research.

OCRC research also suggests that the torque-tension relationship exhibited by cadmium plated fasteners is variable over a significant range and is a function of material strength and fastener dimensions. In some applications, the lubricious properties afforded by other platings such as zinc from an alkaline bath can approach those of cadmium.

11. Many of the coatings considered in this program contain constituents that are controlled (to a lesser degree than cadmium) by federal regulations. While they do not pose the same hazards that cadmium does, the environmental impact of these materials must be more thoroughly assessed.

12. These conclusions apply to ambient temperature conditions only. No testing was performed at elevated or sub-ambient temperatures. (Additionally, replacement options for cadmium plated aluminum substrates were not addressed.)

## RECOMMENDATIONS

Based on the testing done in the Environmentally Acceptable Alternatives to Cadmium Plating Program, the following recommendations can be made:

1. Continue the shipboard exposure for the remainder of one year.

2. Continue the marine exposure at Sea Isle for at least the remainder of one year. One year or longer term exposure data is necessary to make definitive recommendations on the best replacements for cadmium.

3. For miscellaneous steel parts (at ambient temperature) for which EAC is not a concern and the part function calls for a thin film, select from zinc plating from an alkaline bath, IVD aluminum, SermeTel, or zinc-nickel plating with an anodic E-coat topcoat for corrosion protection. Select the plating based on the cost for the items to be plated.

   For steel parts without a thin film requirement, consider the use of the standard Navy organic solvent-based coating systems, powder coatings, or inorganic zinc (this latter coating should only be applied to abrasive blasted surfaces) for corrosion control. Select between the thin film plating or the organic coating systems based on the cost of material application.

   In this cost analysis, consider when the part will be coated. A significant use of cadmium plating is for simple cosmetic corrosion control prior to installation of the part and painting with the standard Navy coating system aboard ship. A steel part left without any treatment before shipboard painting may have significant corrosion before installation.

4. Defer selection of a cadmium alternative for high strength materials pending the results of the rising step-load tests. Based on previously available data, do not utilize a zinc plating from an alkaline bath for corrosion control on Grade 8 fastener materials in a marine environment. Where Grade 8 steel fasteners must be used without protective plating, utilize fasteners with an appropriate sealant and topcoat for protection. In applications where periodic seawater spray exposure (<u>not</u> immersion) is expected and routine maintenance is not likely, utilize an alternative material fastener with the requisite strength requirements (e.g., nickel-based or titanium based alloys).

5. Coatings/platings selected to replace cadmium for specific uses, must be approved by the Navy Environmental Health Center (NEHC).

## REFERENCES

1. Ocean City Research Corporation, "Evaluation of Acceptable Alternatives for Cadmium Plating," Report prepared for Army Materiel Command Acquisition Pollution Prevention Support Offices, December 1991.

2. Minor Trial MS 4/91, "SermeTel 725 and MRL Zn-Ni Plated Fasteners Aboard HMS Unicorn," 21 March 1995.

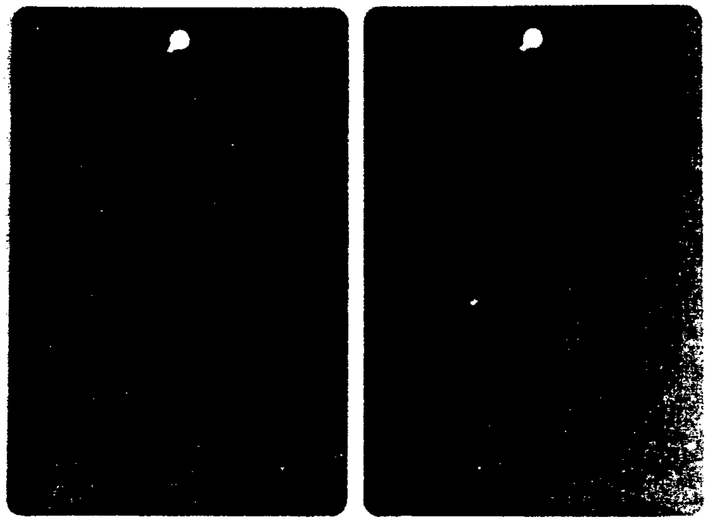
3. Wilhelm, Jack, "Torque-Tension Testing... A Practical Approach to Joint Design and Assembly," in *Advanced Fastener Application Engineering*.

4. Gardiner, William A., "Torque-Tension Relationships-What They Are, Why They Are Important," SME Technical Paper: AD75-771.

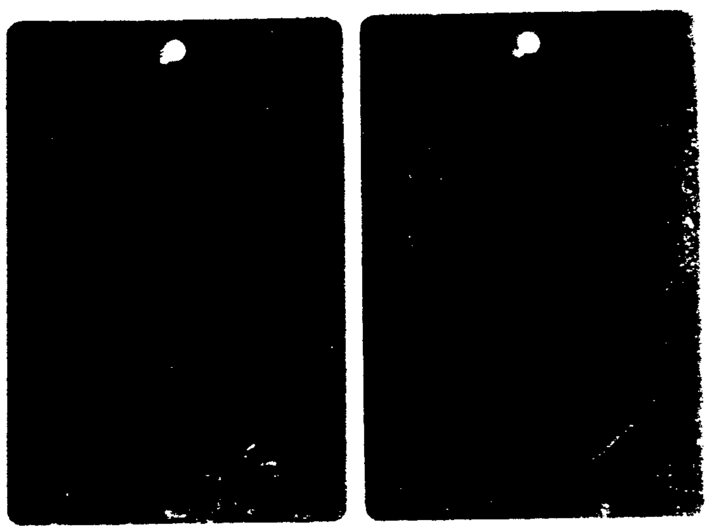
5. McKewan, John, "The Effects of Plating on Torque-Tension Relationships and Vibrational Resistance," SAE Technical Paper: 8004521980.

6. Ocean City Research Corporation, "Hybrid Fasteners as Potential Substitutes for Cadmium Plating," Final Report prepared for Army Materiel Command Acquisition Pollution Prevention Support Offices, December 1993.

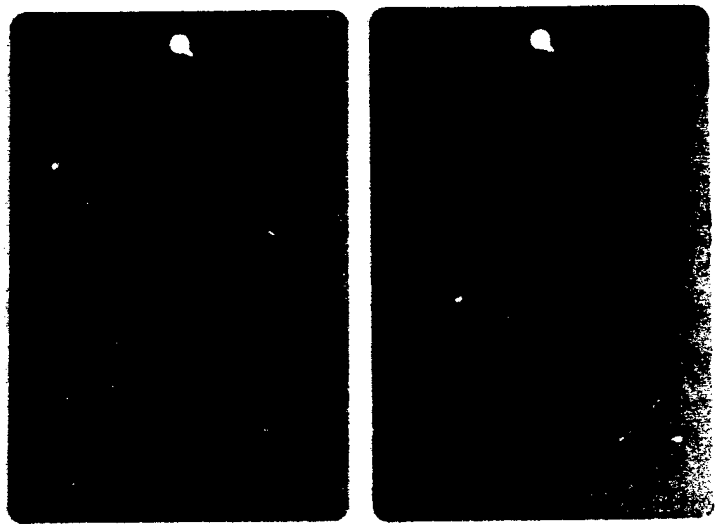
7. Ocean City Research Corporation, "Mechanical Performance Testing and Implementation Evaluations for Multi-Layer Cadmium Substitute Coating Systems," Final Report prepared for Army Materiel Command Acquisition Pollution Prevention Support Offices, August 1995.



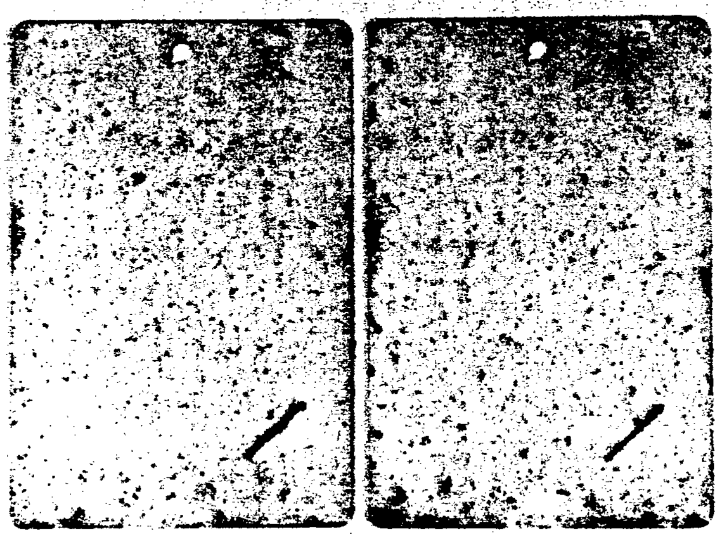
**SERMETEL 984 METALLIC CERAMIC COATING**
*2 Month Marine Atmosphere Exposure*



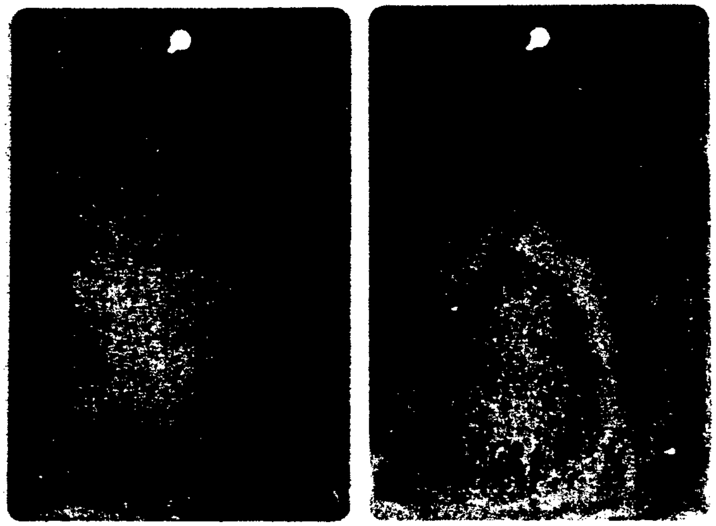
**ZINC/NICKEL PLATING WITH ZINC PHOSPHATE AND ANODIC E-COAT**
*2 Month Marine Atmosphere Exposure*



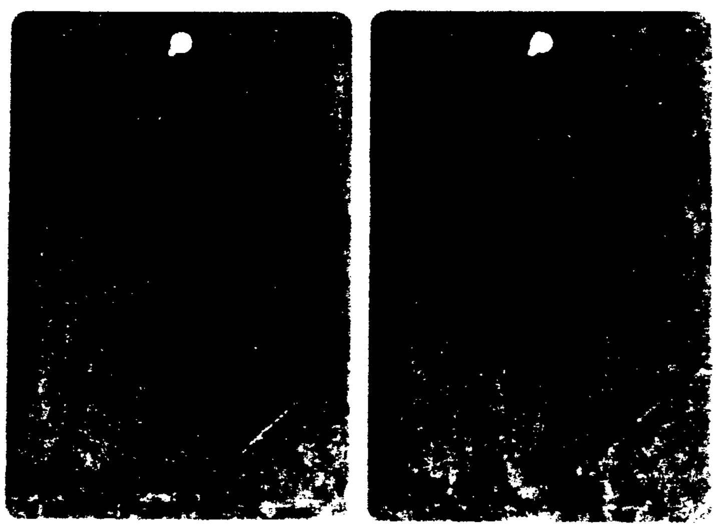
**INORGANIC ZINC**
*2 Month Marine Atmosphere Exposure*



**ION VAPOR**
**DEPOSITED ALUMINUM**
*2 Month Marine Atmosphere Exposure*

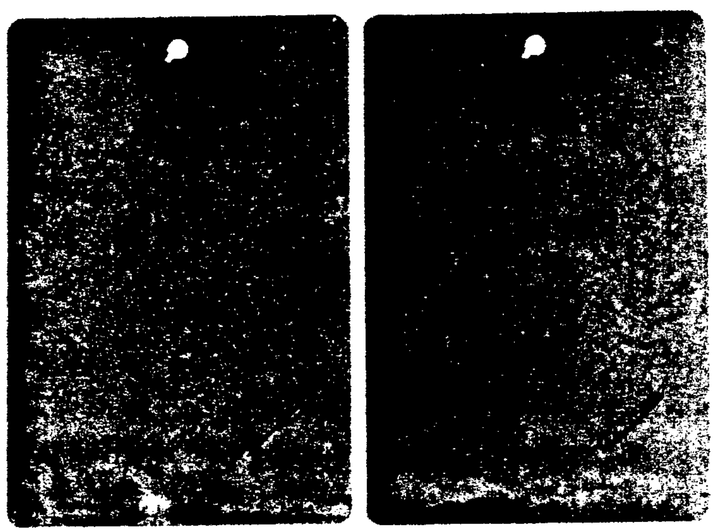


**TIN/ZINC ALLOY
ELECTROPLATING**
*2 Month Marine Atmosphere Exposure*

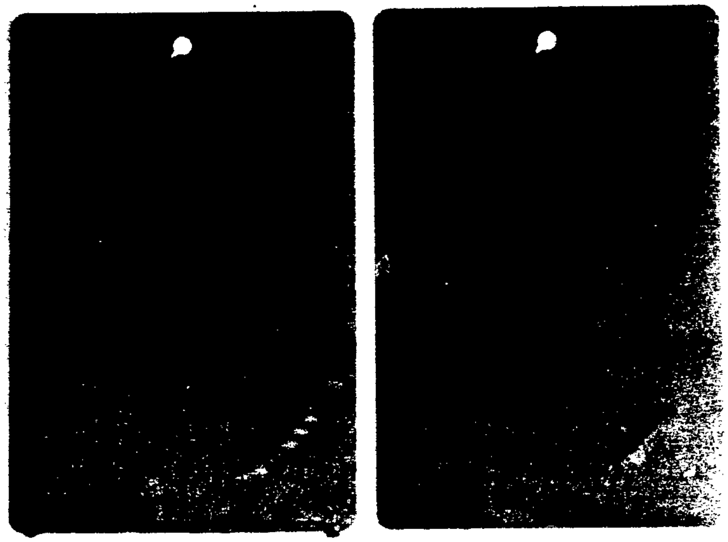


**ZINC ELECTROPLATING
FROM AN ALKALINE BATH**
*2 Month Marine Atmosphere Exposure*

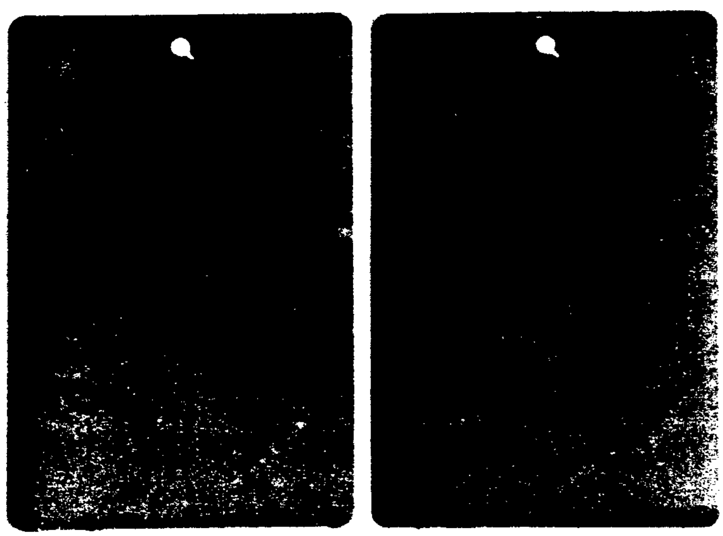
**ZINC ELECTROPLATING**
**FROM AN ACID**
**CHLORIDE BATH**
***2 Month Marine Atmosphere Exposure***



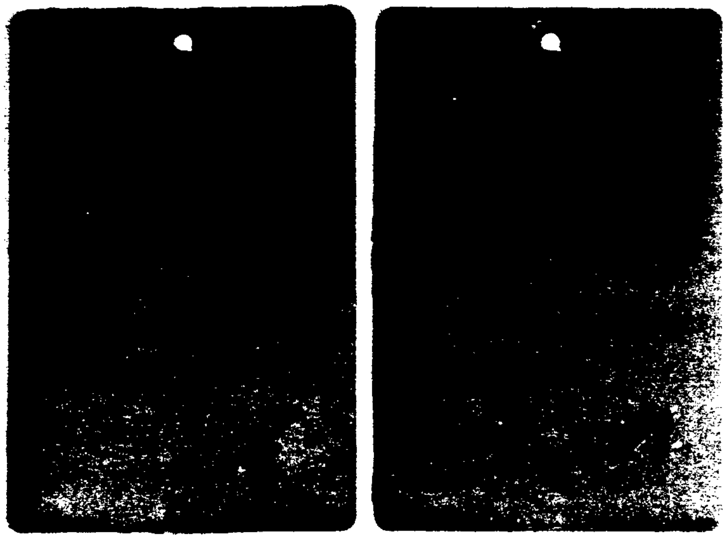
**CADMIUM PLATING WITH**
**A CHROMATE CONVERSION**
**COATING (CONTROL)**
***2 Month Marine Atmosphere Exposure***



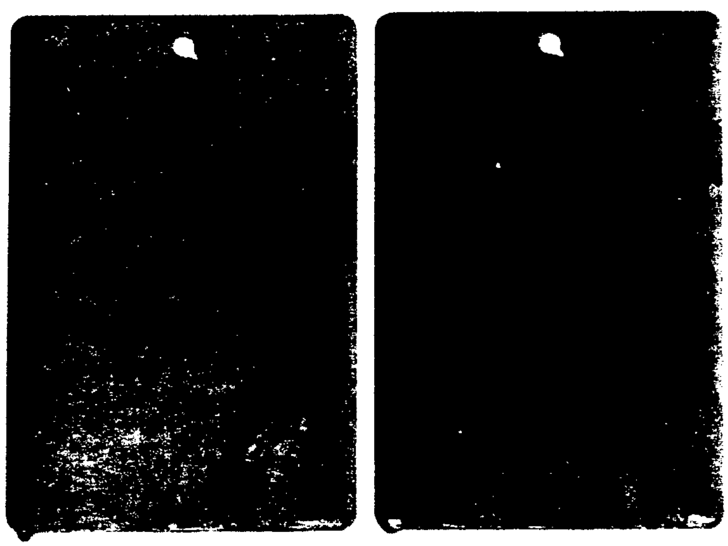
**BLACK OXIDE WITH**
**EPOXY SYSTEM**
***2 Month Marine Atmosphere Exposure***



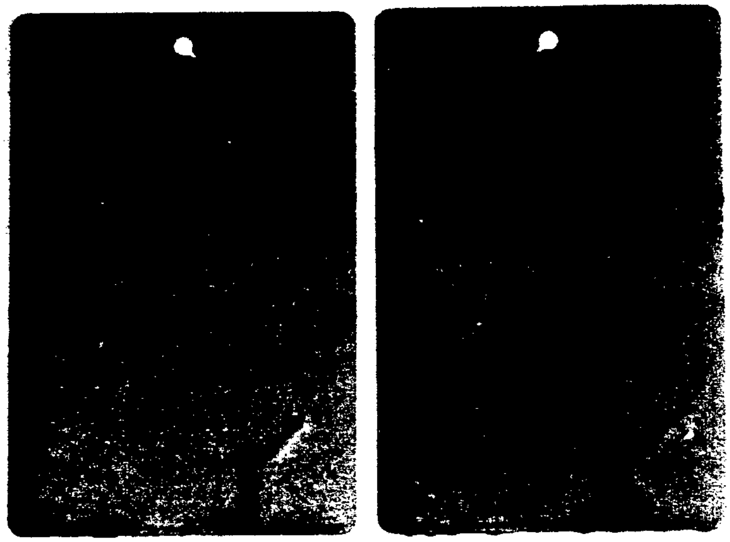
**ZINC PHOSPHATE**
**WITH EPOXY SYSTEM**
***2 Month Marine Atmosphere Exposure***



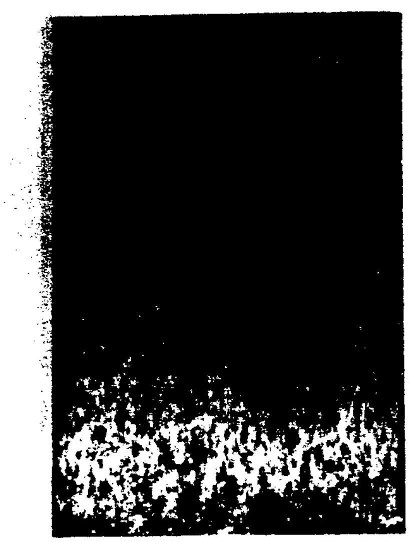
**SILICONE ADHESIVE**
**WITH EPOXY SYSTEM**
***2 Month Marine Atmosphere Exposure***



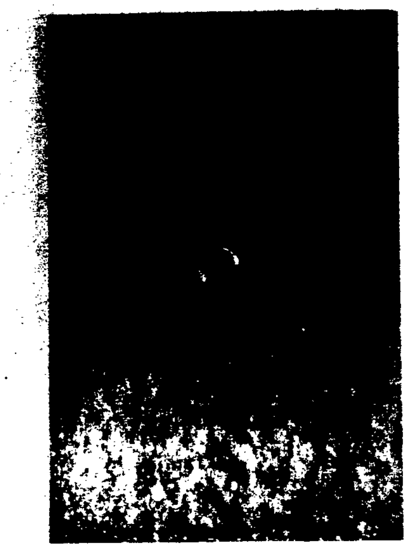
**EPOXY POWDER COATING**
***2 Month Marine Atmosphere Exposure***



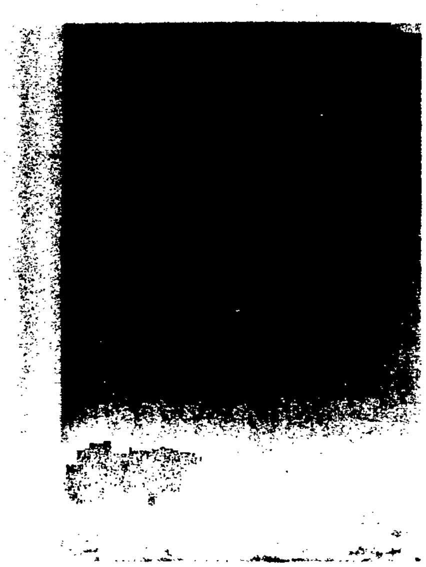
**POLYSULFIDE SEALANT**
**WITH EPOXY SYSTEM**
***2 Month Marine Atmosphere Exposure***



**304 AUSTENITIC**
**STAINLESS STEEL**
***2 Month Marine Atmosphere Exposure***

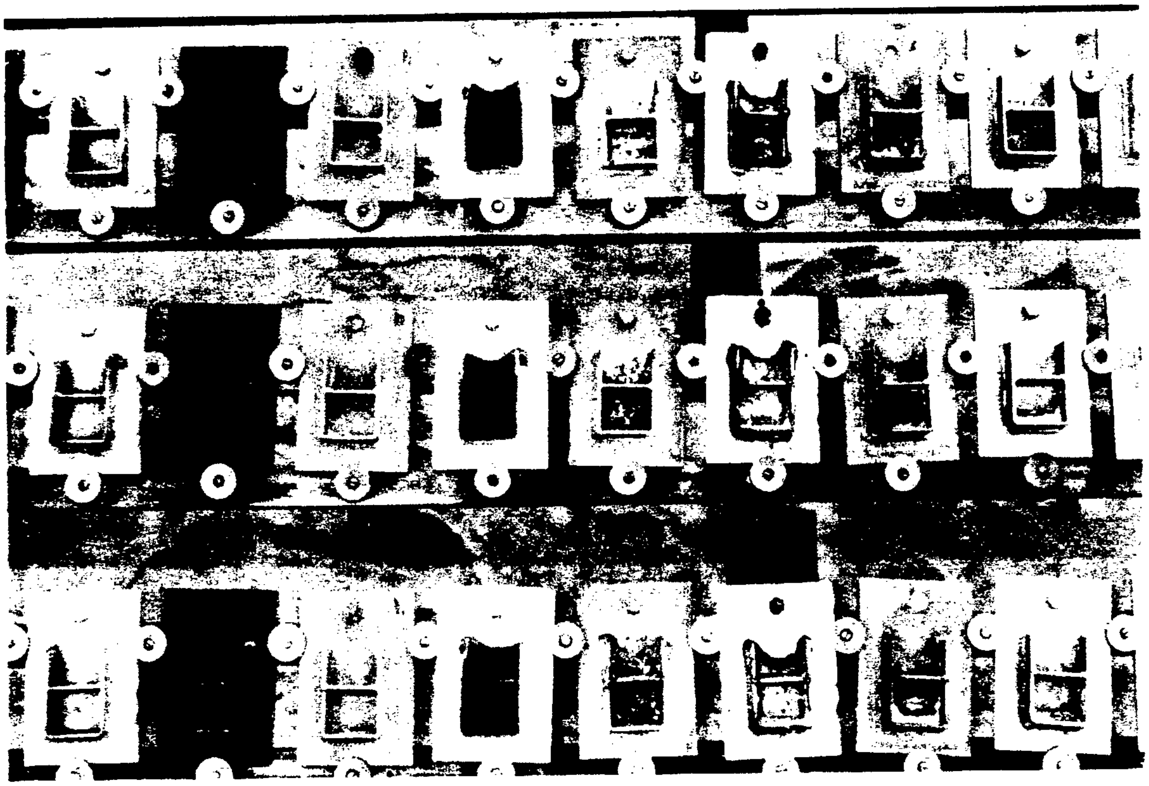


**316 AUSTENITIC**
**STAINLESS STEEL**
*2 Month Marine Atmosphere Exposure*

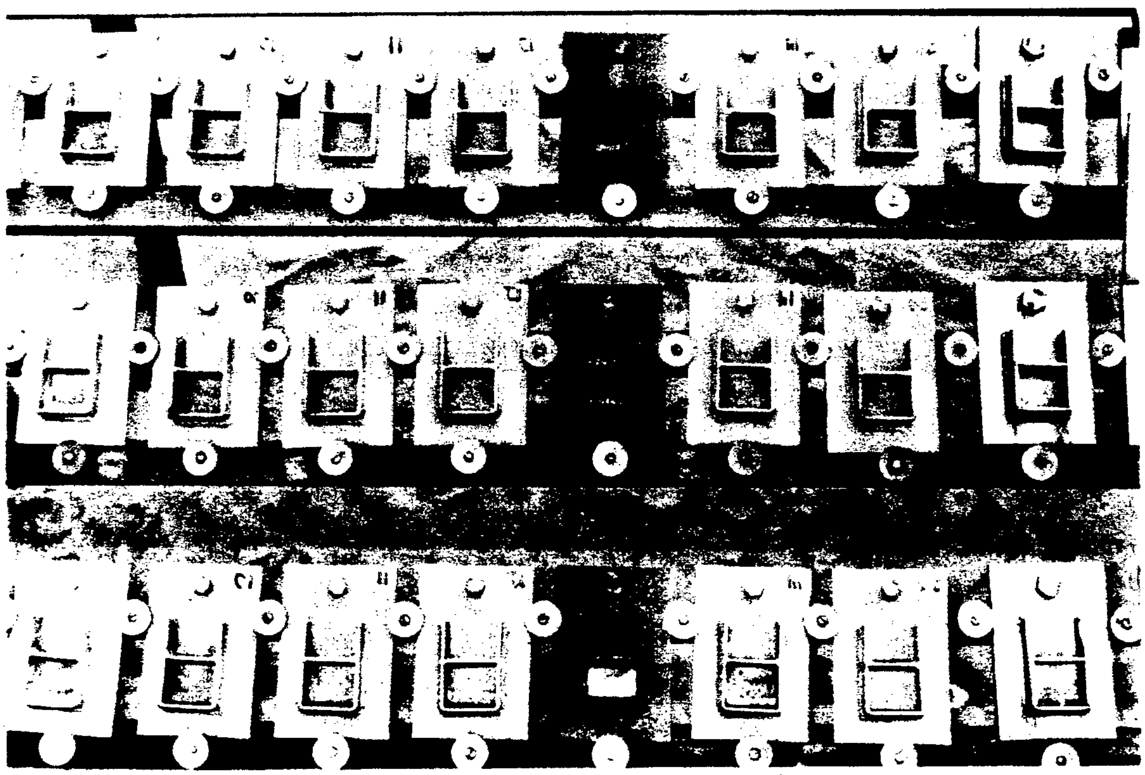


**TITANIUM ALLOY:**
**6% ALUMINUM, 4% VANADIUM**
*2 Month Marine Atmosphere Exposure*

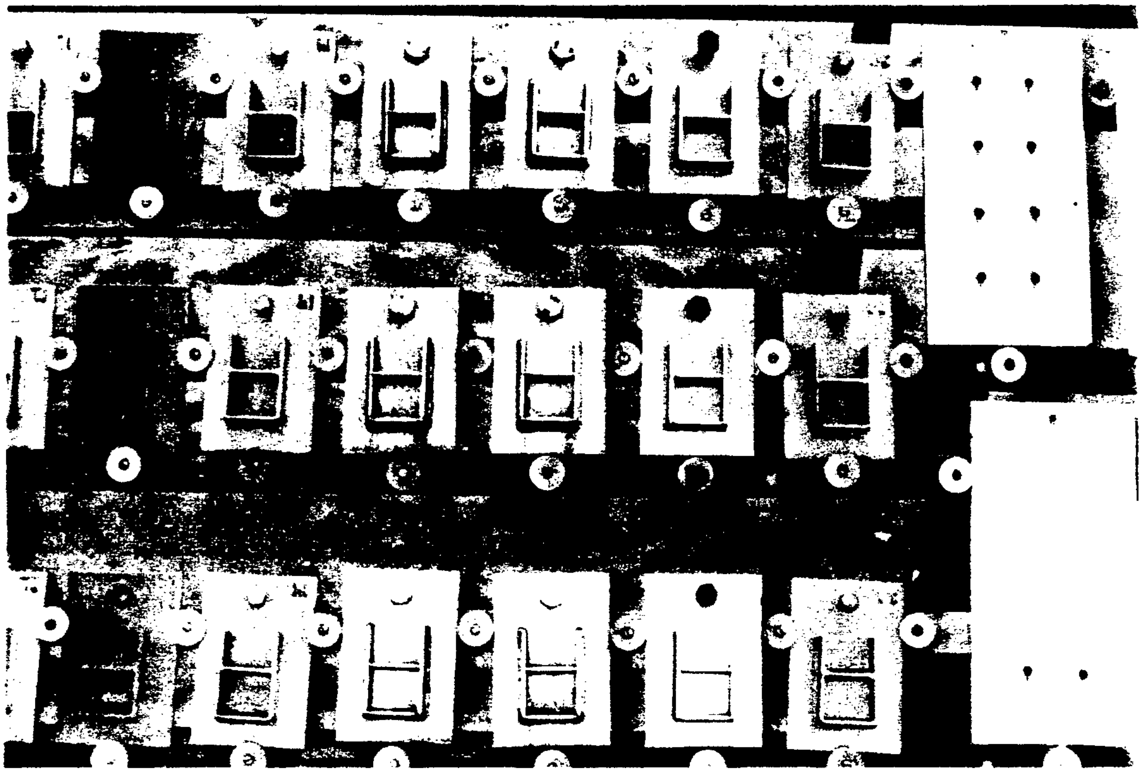
**EPOXY SYSTEM**
*2 Month Marine Atmosphere Exposure*



PLATING SYSTEMS (COMPLEX)



EPOXY SYSTEMS (COMPLEX)


ALTERNATE BASE MATERIALS SAMPLES

## KEY to Photos at Sea Isle, NJ

### Page A-10

Plating Systems - Complex Panels

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

Epoxy Systems - Complex Panels

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (9) | 10 | 11 | 12 | 13 | 14 | 20 | (16) |
| (9) | 10 | 11 | 12 | 13 | 14 | 20 | (16) |
| (9) | 10 | 11 | 12 | 13 | 14 | 20 | (16) |

### Page A-11

Alternate Base Materials - Complex Panels

| | | | | | |
|---|---|---|---|---|---|
| (13) | (14) | 15 | 16 | 17 | (20) |
| (13) | (14) | 15 | 16 | 17 | (20) |
| (13) | (14) | 15 | 16 | 17 | (20) |

* Numbers in the parenthesis () are not part of the set being photographed.

Coatings

2 - SermeTel 984

3 - Zn-Ni w/ anodic topcoat

4 - Inorganic Zinc

5 - IVD Aluminum

6 - Sn-Zn

7 - Zinc - alkaline bath

8 - Zinc - chloride bath

9 - Cadmium

10- Black oxide w/ paint system

11- Zn phosphate w/ paint system

12- Silicone w/ paint system

13- Epoxy powder coat

14- Polysulfide w/ paint system

15- 304 stainless steel

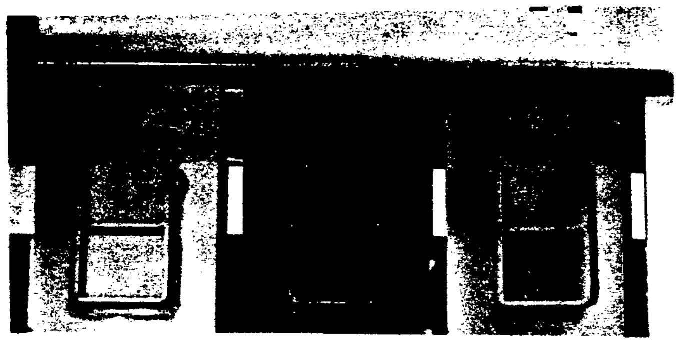
16- 316 stainless steel

17- Titanium (6Al-4V ELI)

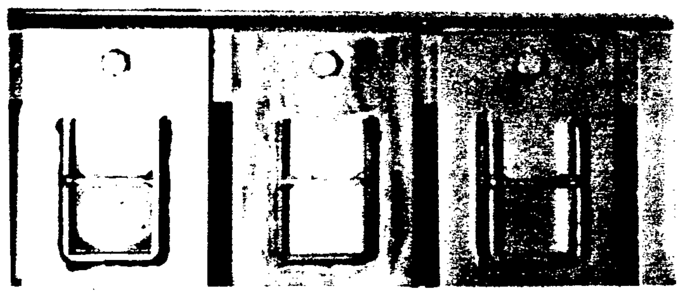
20- Paint system (control)

# Appendix B
## Results of 2-Month Shipboard Inspection

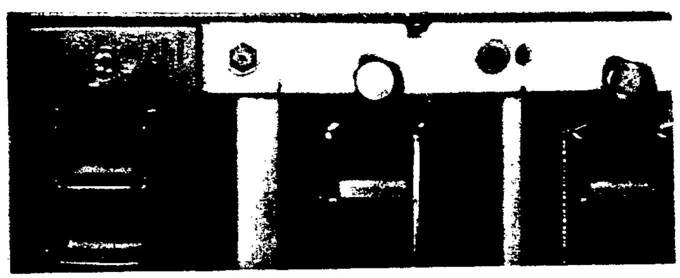
Sermetel 984
Zn-Ni w/anodic topcoat
Inorganic Zinc



Zinc-chloride bath
Sn-Zn
Black oxide w/paint system

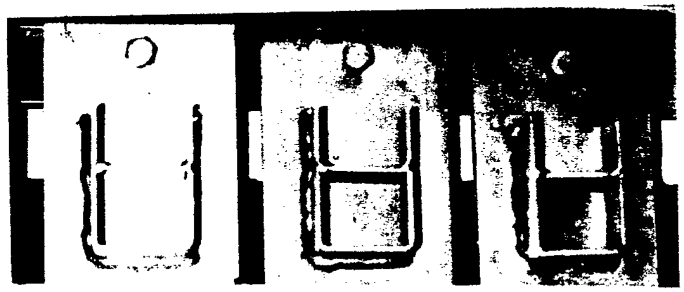


Polysulfide w/paint system
304 stainless steel
316 stainless steel

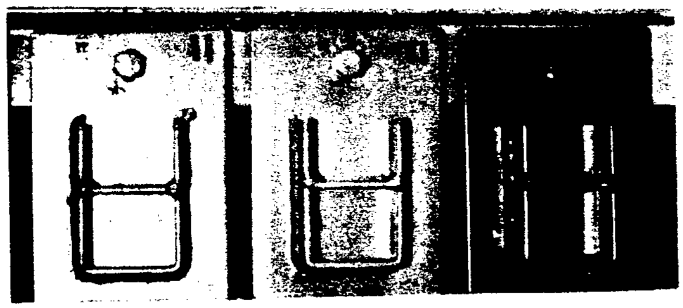


Equipment Space - Complex Panels

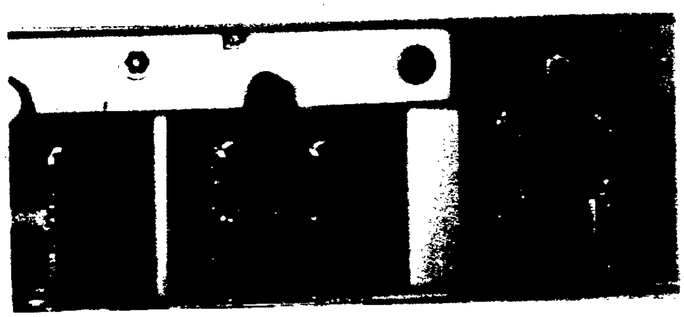
IVD Aluminum
Cadmium
Zinc-Alkaline bath



Zn phosphate w/paint system
Silicone w/paint system
Epoxy powder coat

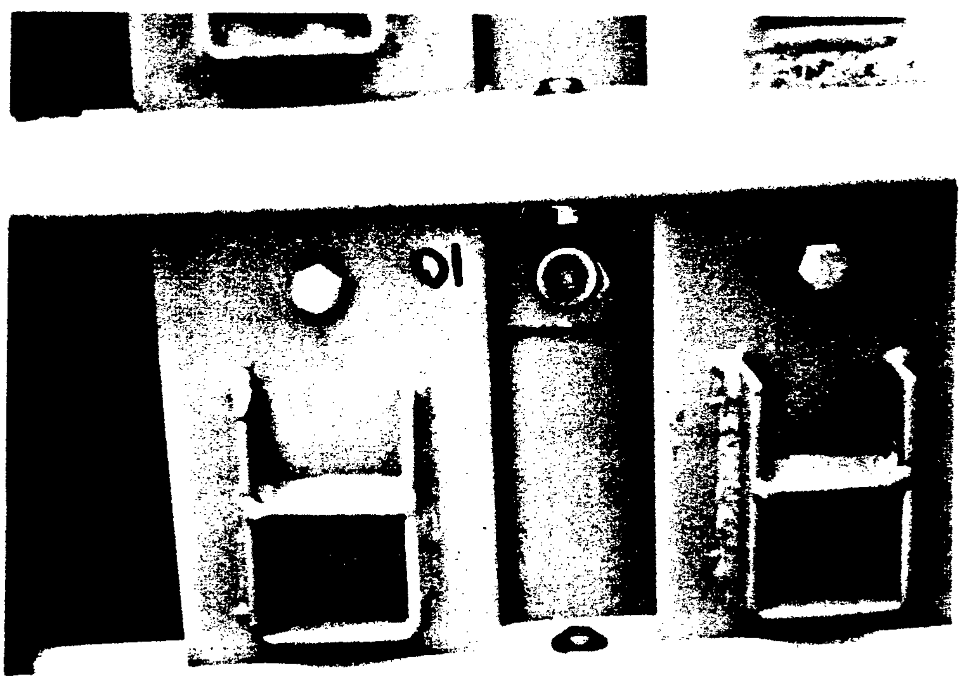


Titanium (6 A1-4V ELI)
Paint system (control)



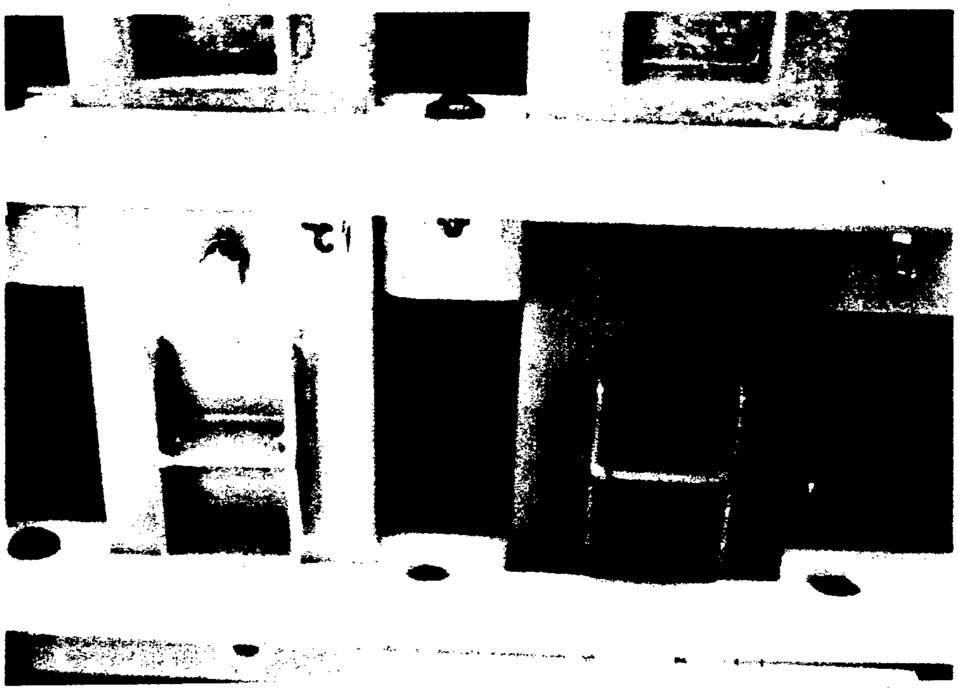
Equipment Space - Complex Panels

Zinc-chloride bath, Sn-Zn

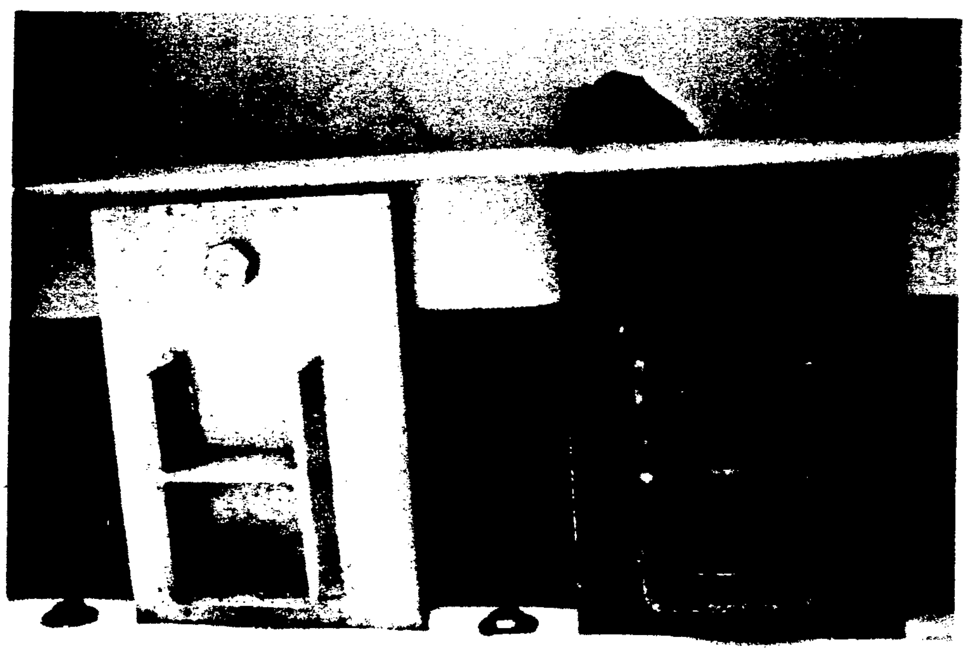



Black oxide w/paint system, Zn phosphate w/paint system

Topside - Complex Panels

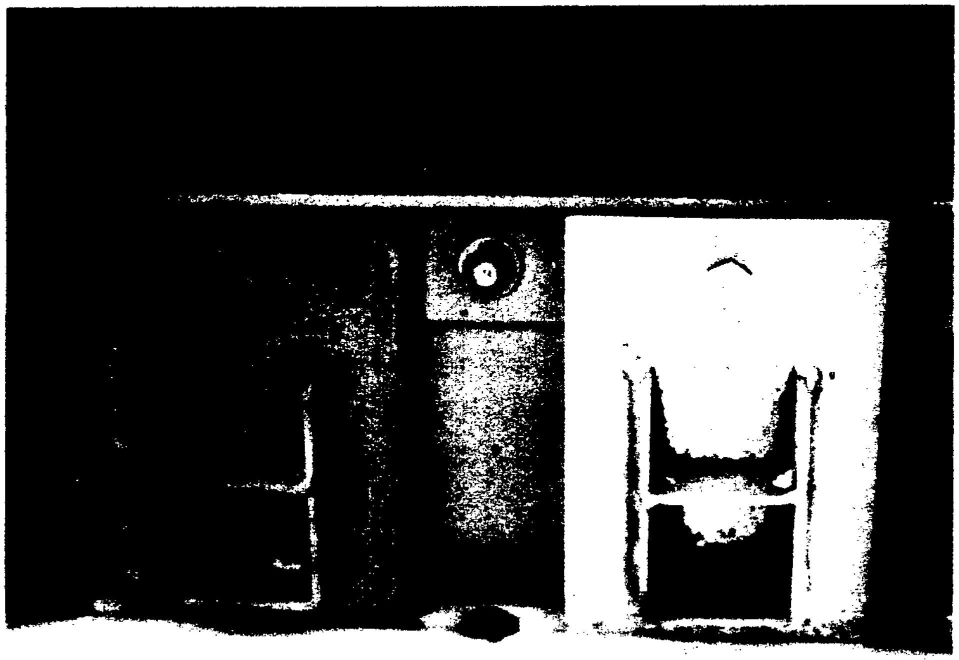


Silicone w/paint system, Epoxy powder coat



SermeTel 984, Zn-Ni w/anodic topcoat

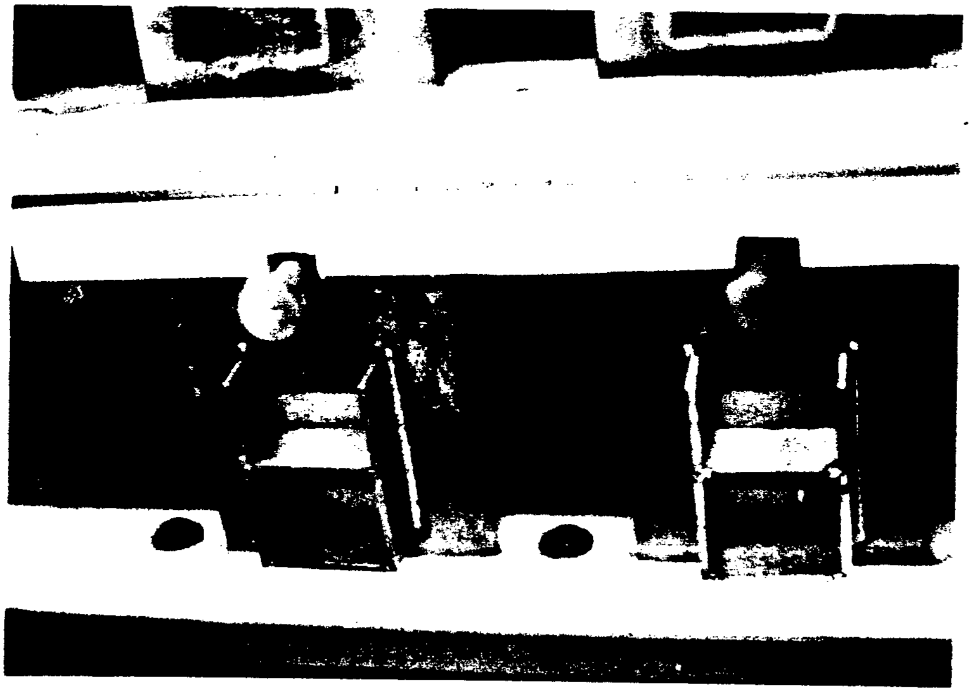
Topside - Complex Panels



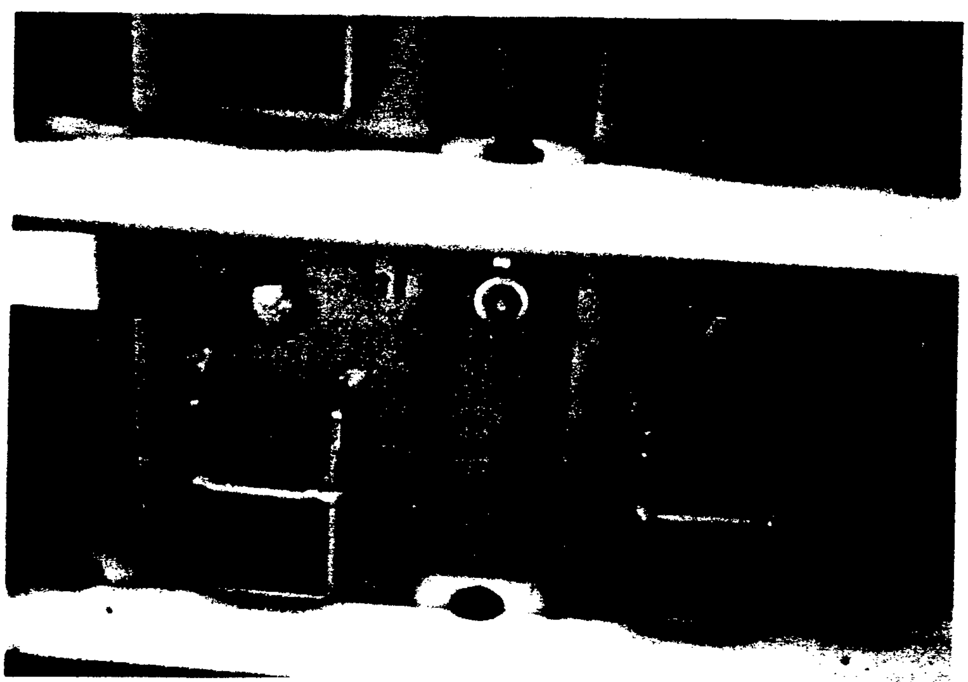
Inorganic Zinc, IVD Aluminum

Cadmium, Zinc-alkaline bath

Topside - Complex Panels

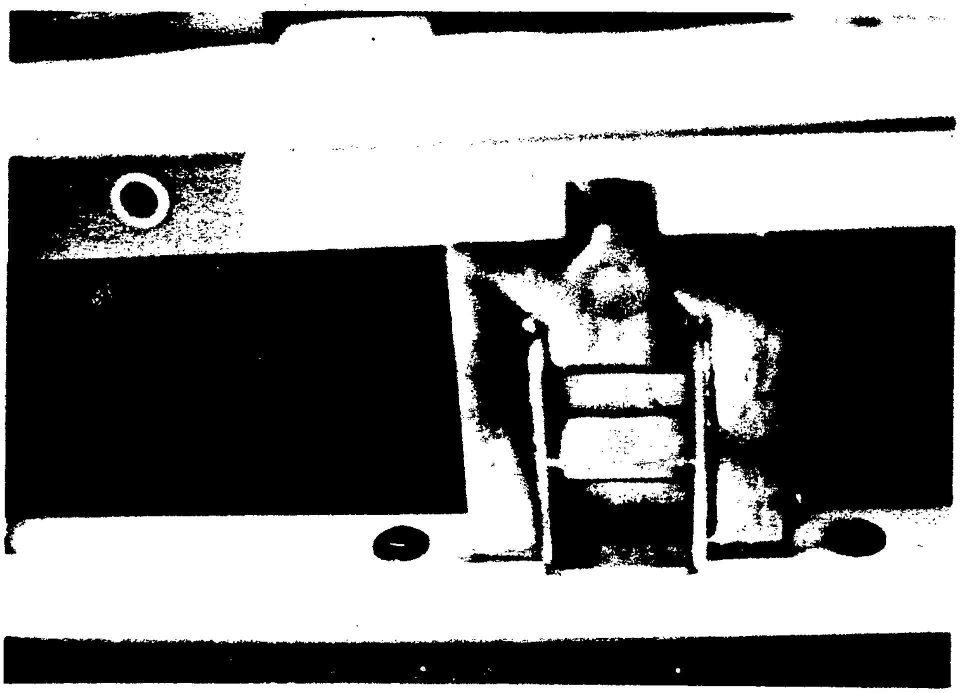


304 stainless steel, Titanium (6 A1-4V ELI)



Polysulfide w/paint system, Paint system (control)

Topside - Complex Panels



316 stainless steel

Topside - Complex Panels

# Appendix C
# Fatigue Crack Growth Graphs

## KEY

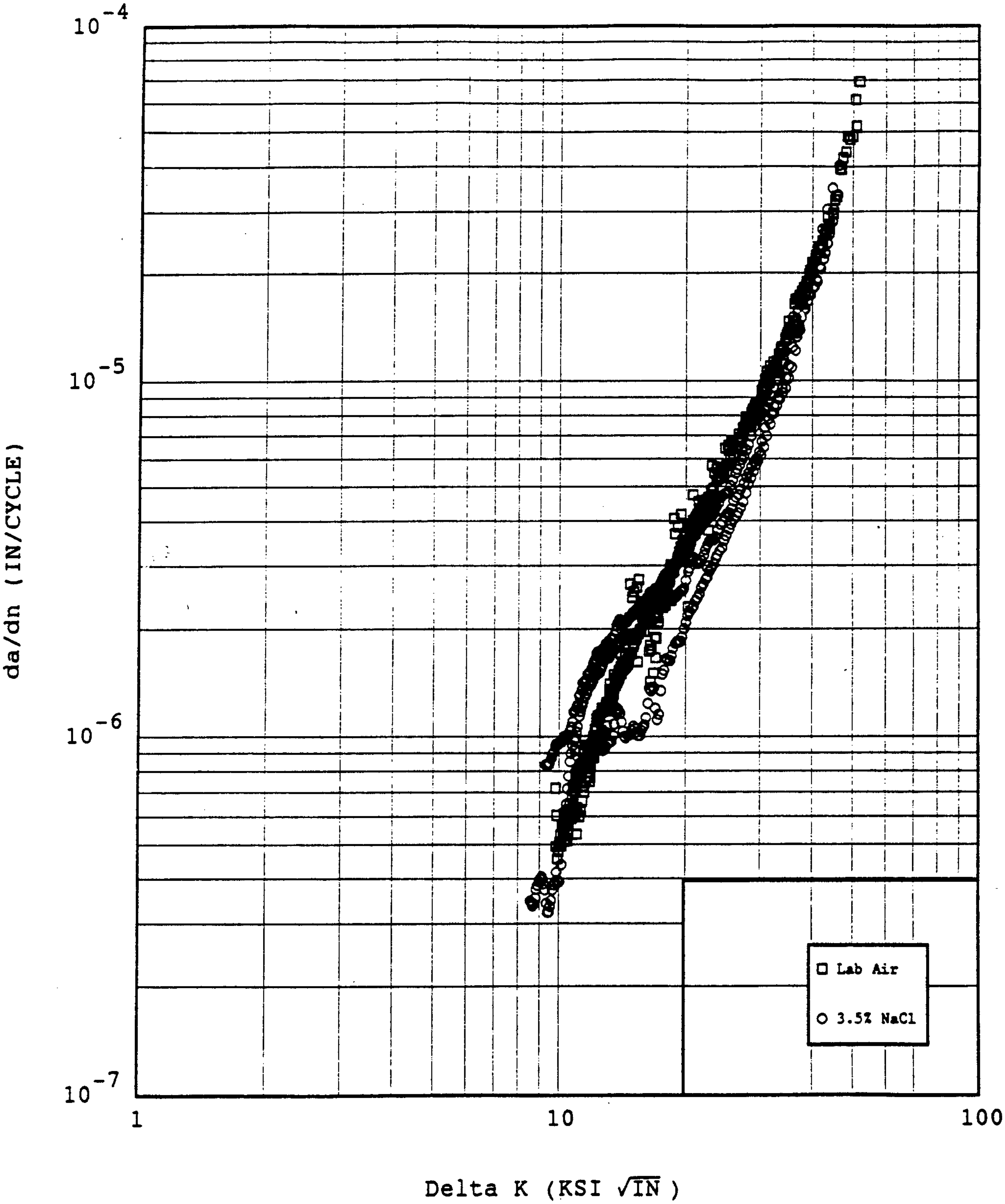
Cd = Cadmium
Zn/Ni = Zinc-Nickel
IVD = IVD Aluminum
Zn/Ph = Zinc Phosphate w/Epoxy
In = Inorganic Zinc
Sn/Zn = Tin Zinc
POLY = Polysulfide w/Epoxy
PQY = Polysulfide w/Epoxy
ALK = Zinc-alkaline bath
ZA = Zinc-acid (chloride) bath
SER = SermeTel

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

DaDn vs Delta K Graph Phone: (412)-537-3131

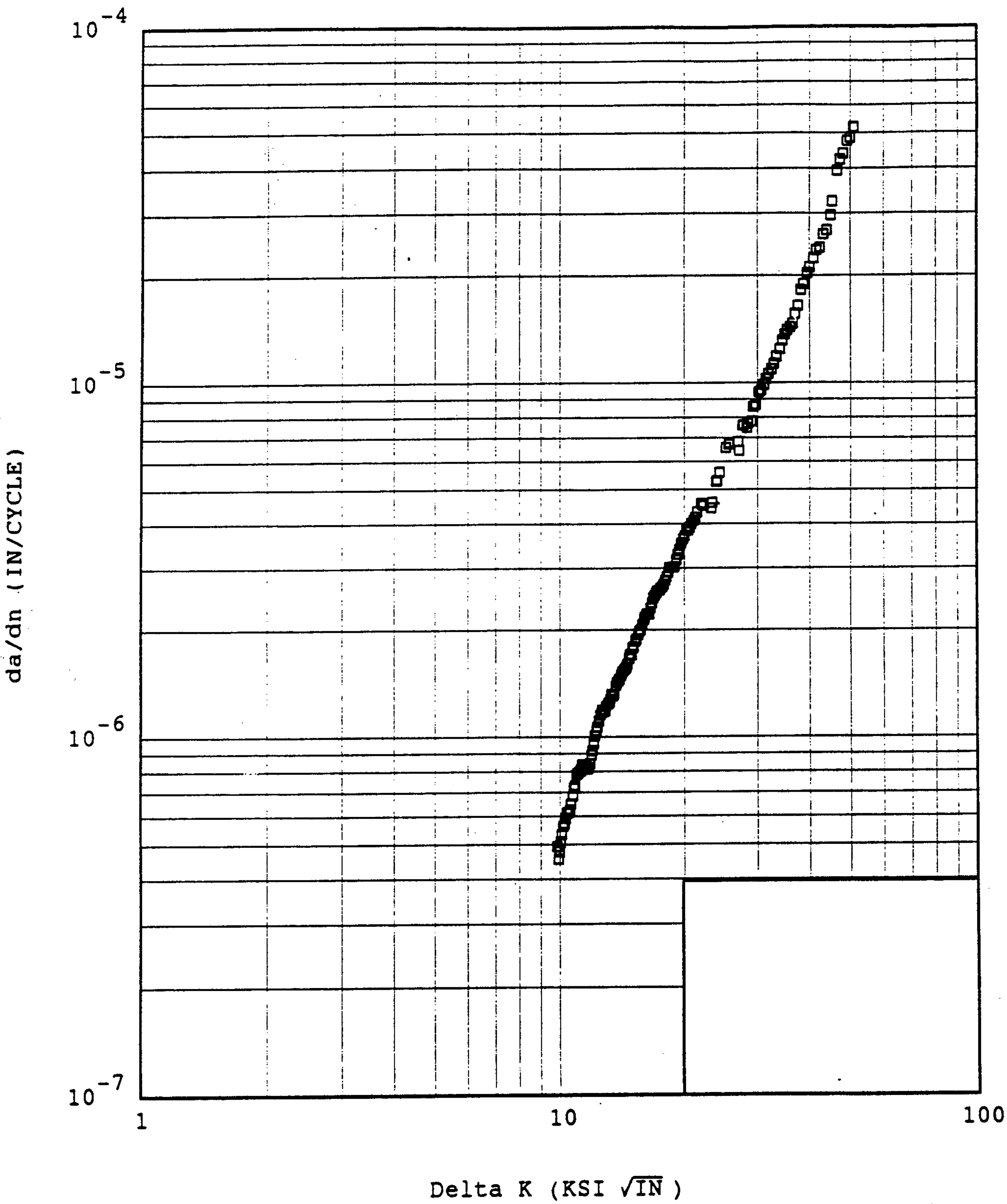
Customer: OCEAN CITY RESEARCH R-ratio: .1
WMTR Report No.: 5-07801
Test Date: 08-24-95

Test Temperature(F): Room




KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

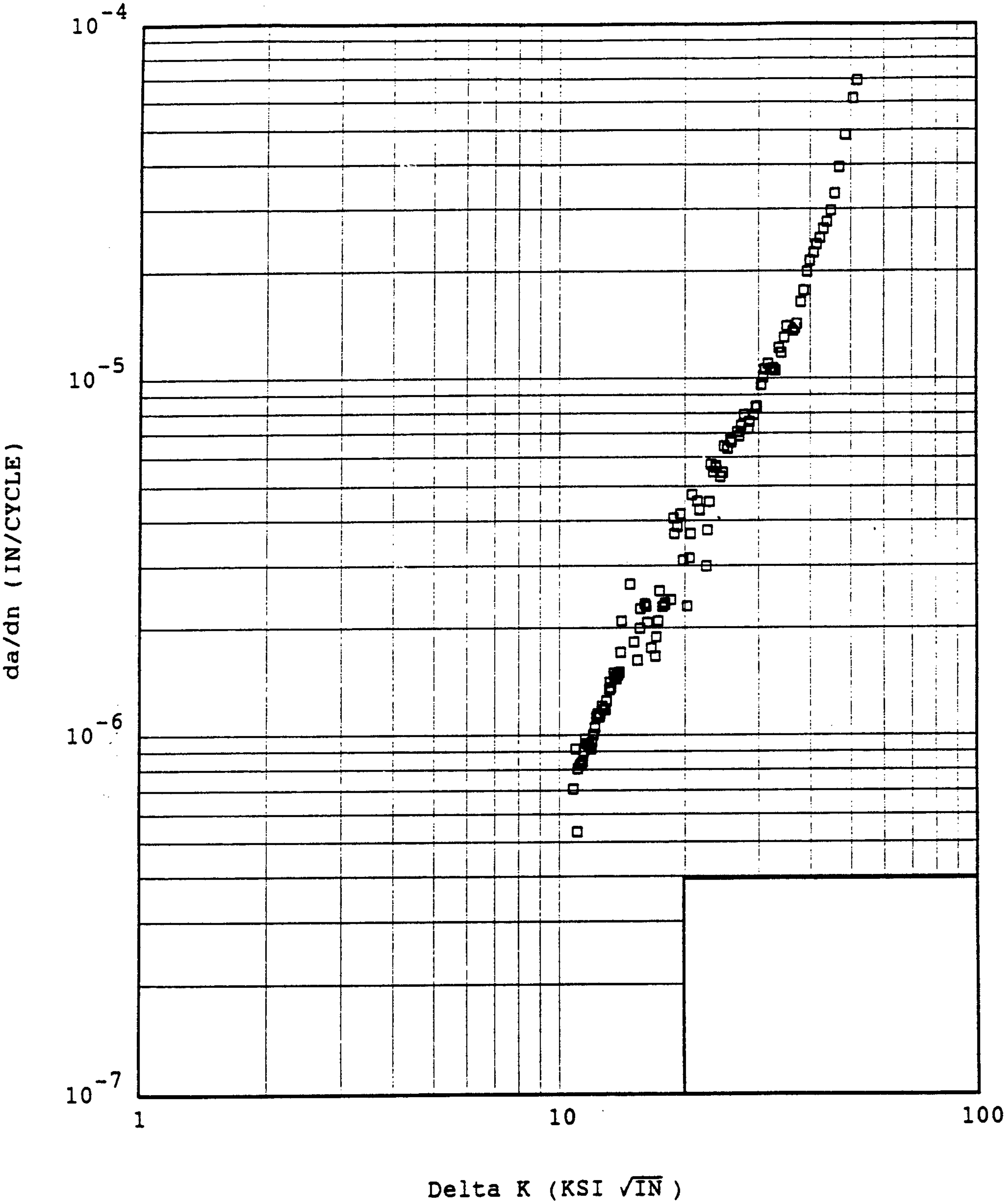
Customer: OCEAN CITY RESEARCH R-ratio: .1
WMTR Report No.: 5-07801
Test Date: 08-23-95
Specimen ID: 2
Test Temperature(F): ROOM




Testlog: 062786

Customer: OCEAN CITY
WMTR Report No.: 5-07801
Test Date: 08-23-95
Specimen ID: 9
Test Temperature(F): ROOM

R-ratio: .1




Testlog: 062785

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

DaDn vs Delta K Graph Phone: (412)-537-3131

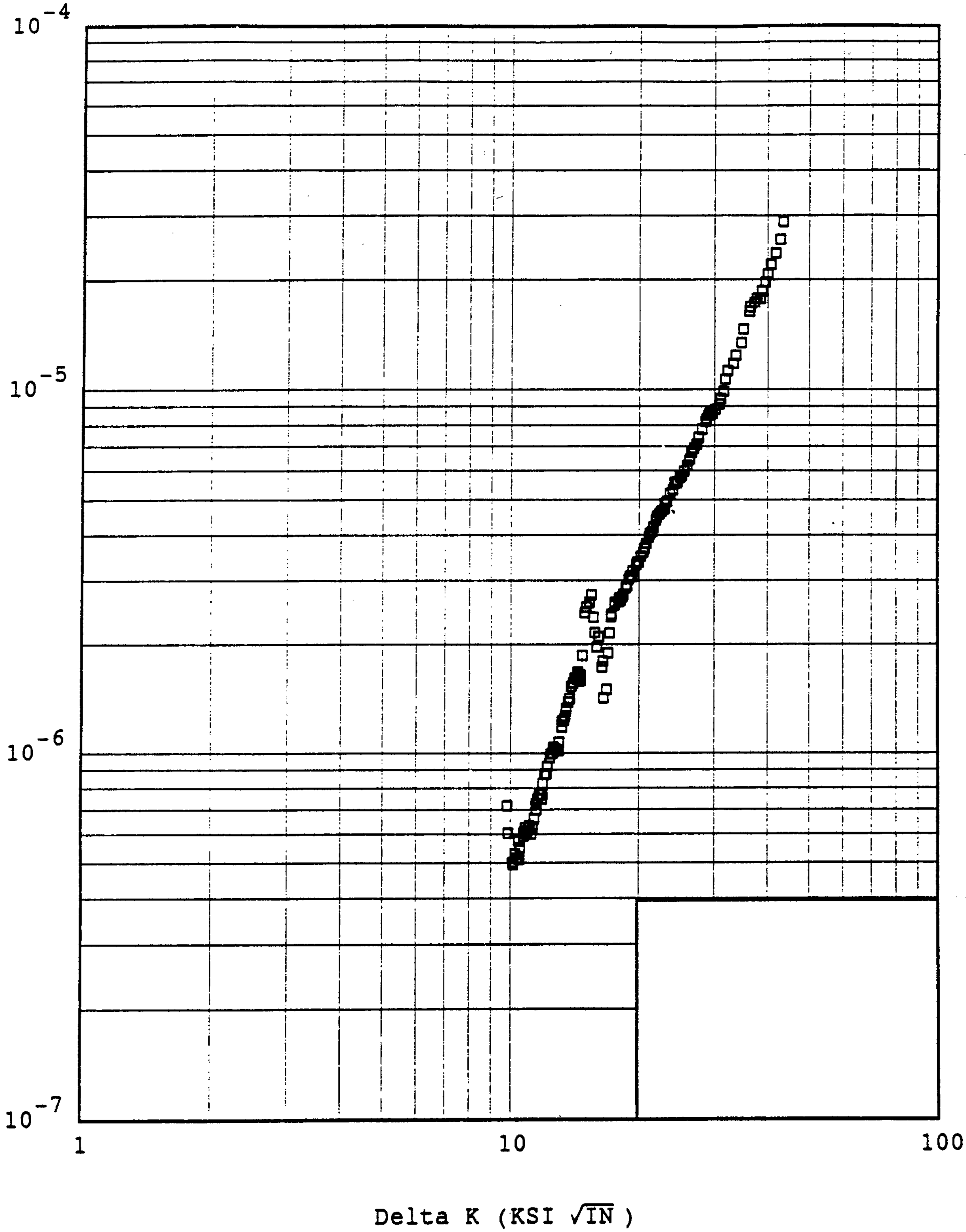
Customer: OCEAN CITY RESEARCH R-ratio: .1

WMTR Report No.: 5-07801

Test Date: 08-24-95

Specimen ID: 17

Test Temperature(F): Room




Testlog: 062784

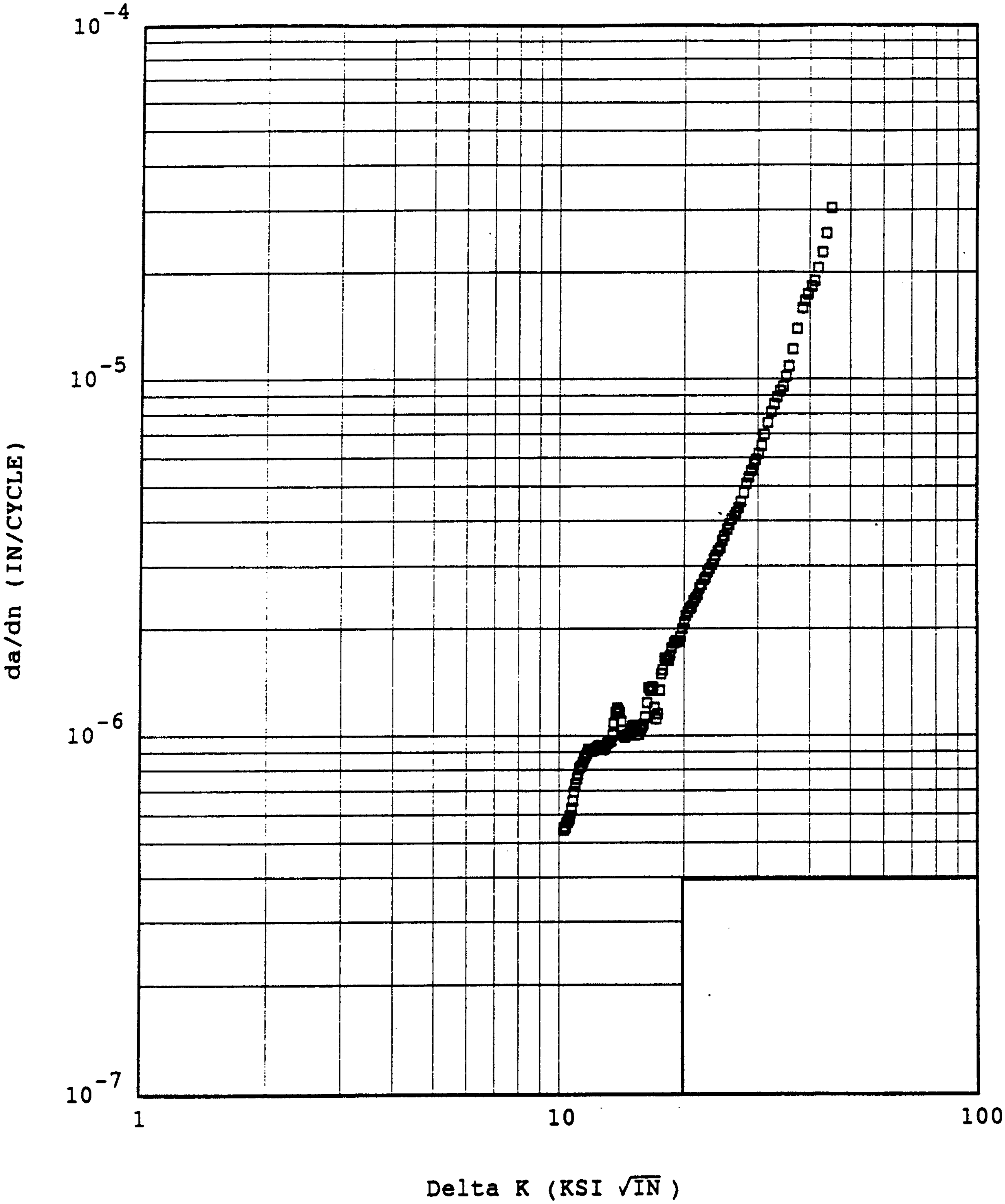
KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

DaDn vs Delta K Graph Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-07801
Test Date: 08-26-95
Specimen ID: 7
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl




Testlog: 062787

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

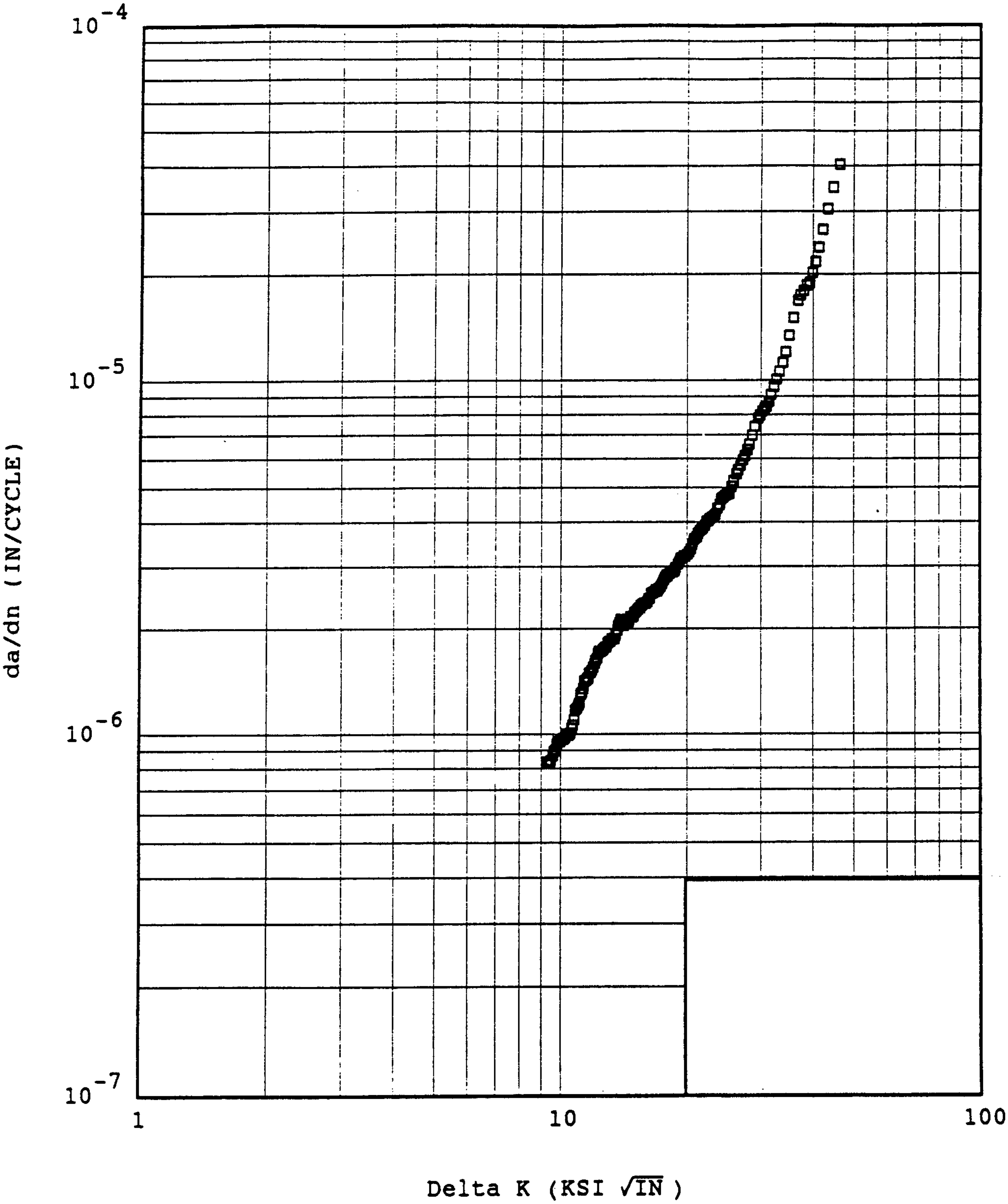
WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

DaDn vs Delta K Graph

Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-07801
Test Date: 08-25-95
Specimen ID: 13
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl

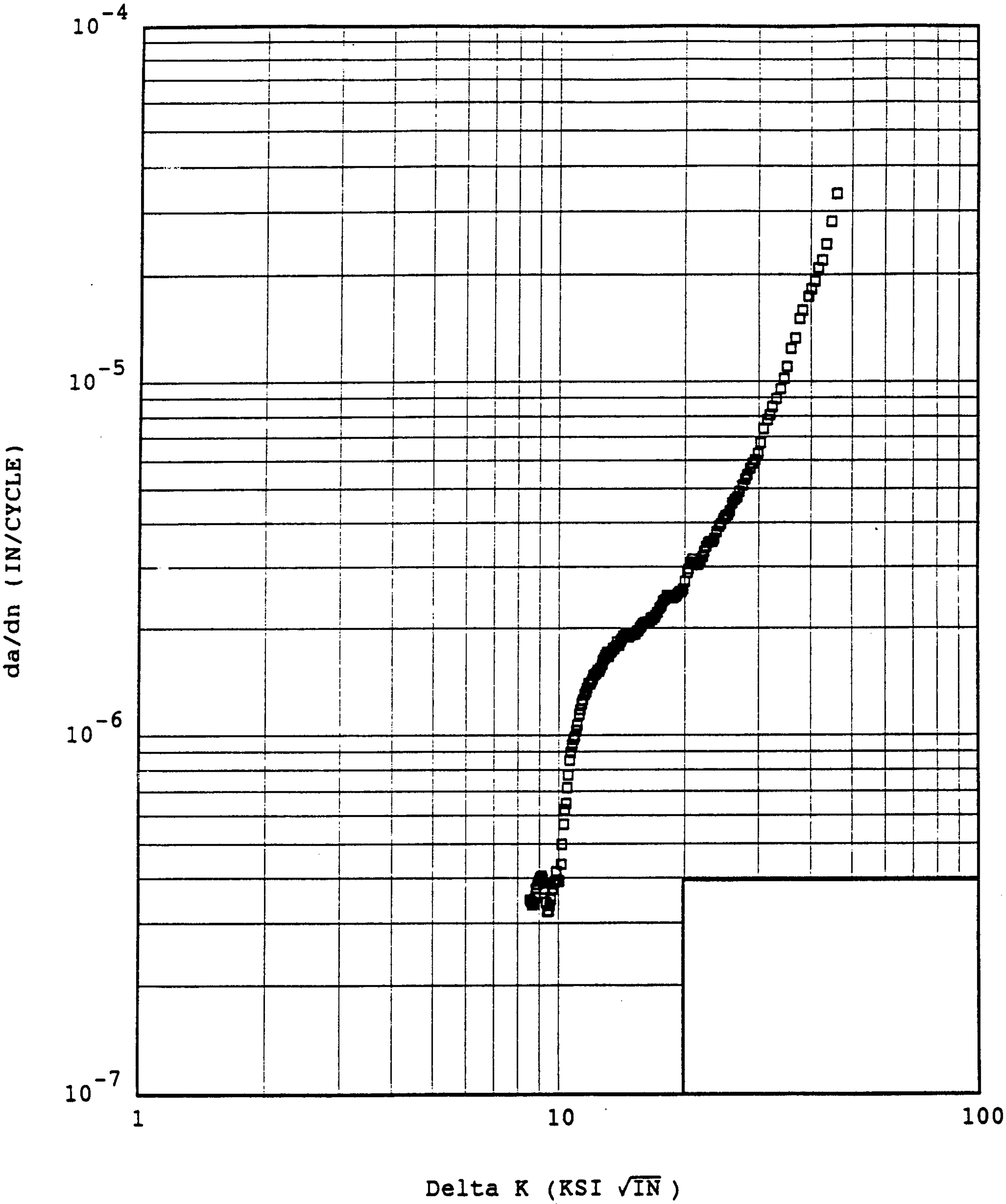



Testlog: 062788

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-07801
Test Date: 08-23-95
Specimen ID: 19
Test Temperature(F): Room

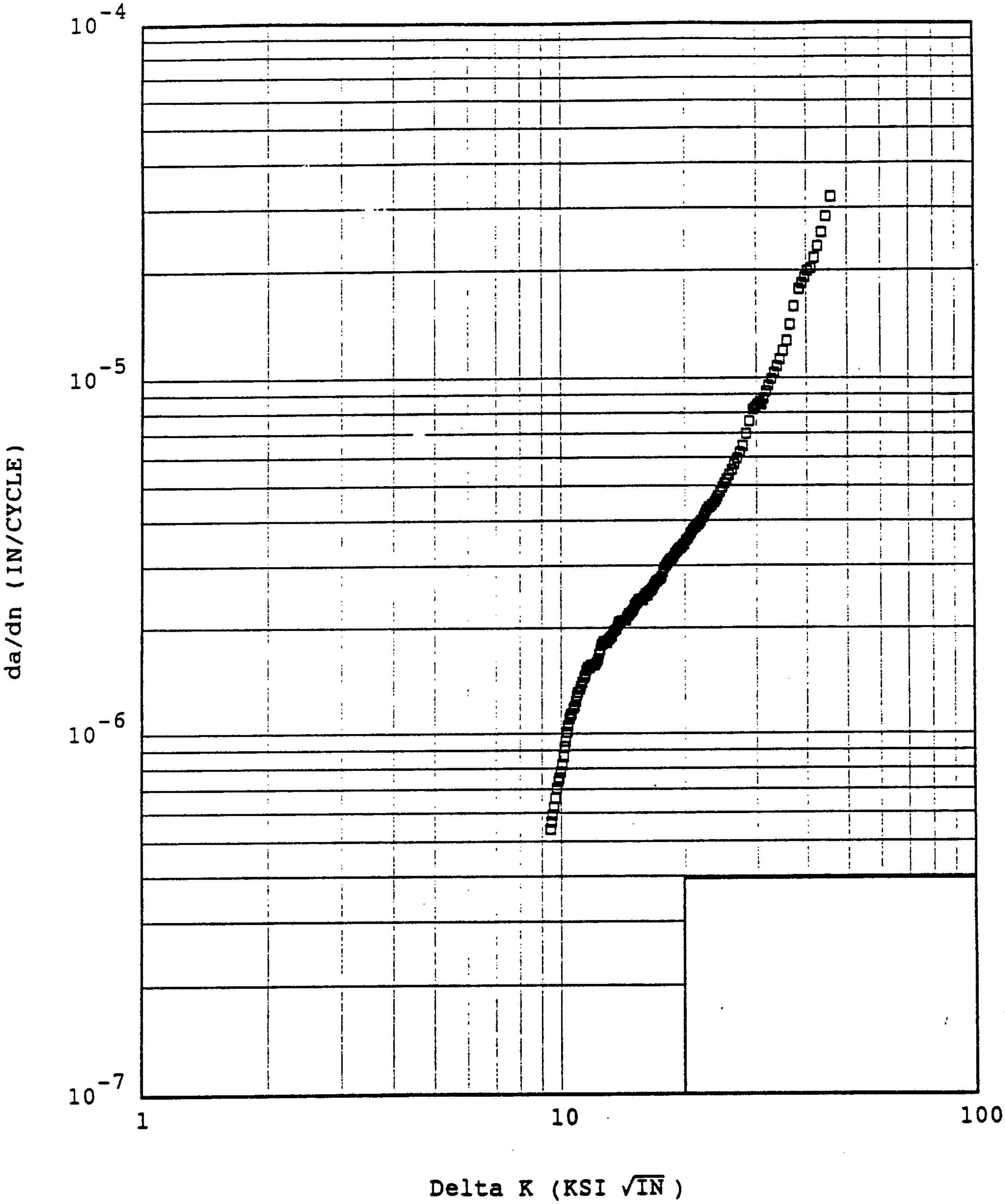
R-ratio: .1
ENVIRONMENT : 3.5% NaCl




Testlog: 062789

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-14-95
Specimen ID: 29
Test Temperature(F): Room

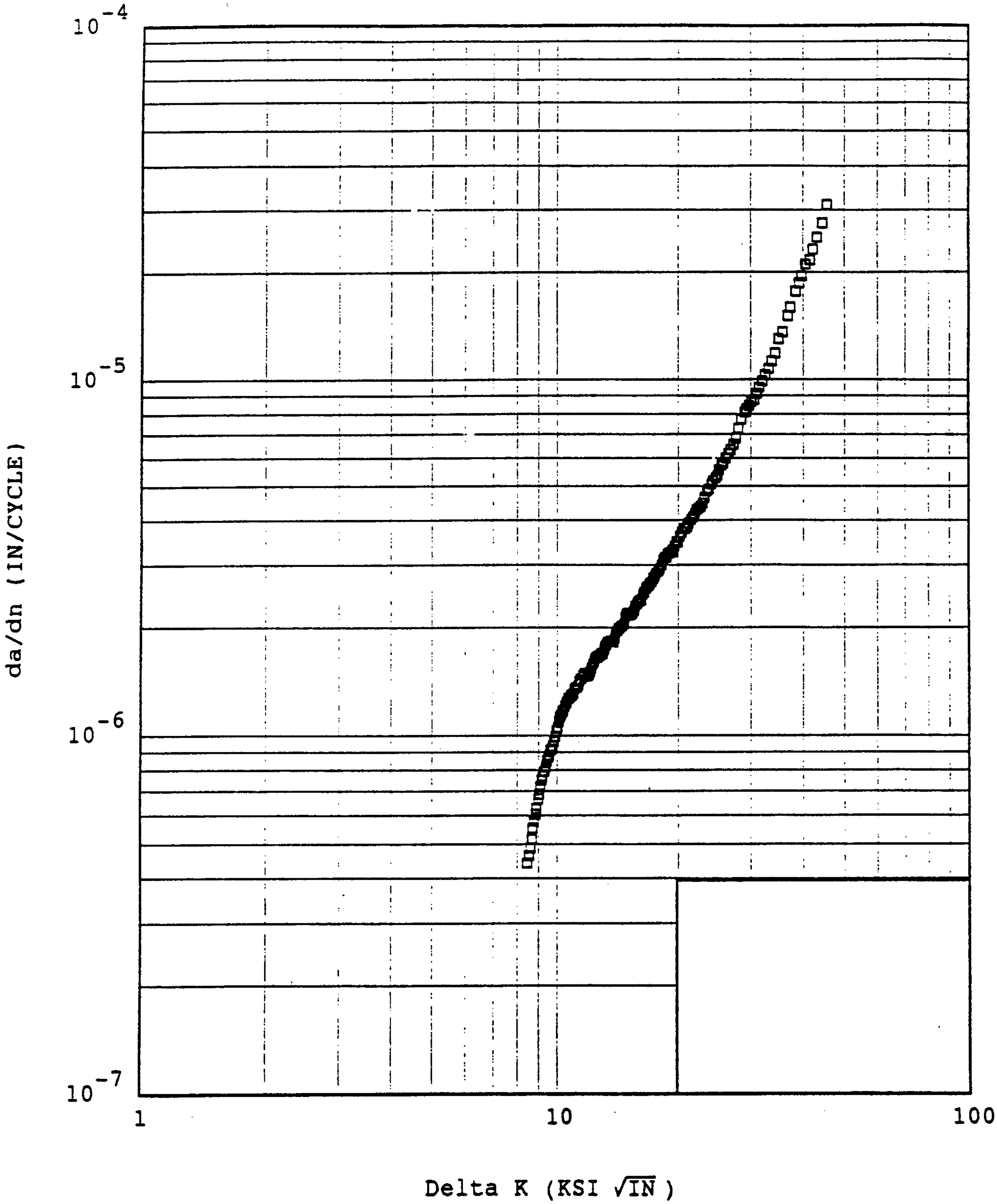
R-ratio: .1
ENVIRONMENT: 3.5% NaCl
COATING : Cd #1




Testlog: 069172

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-13-95
Specimen ID: 31
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING :Cd #2




Testlog: 069173

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

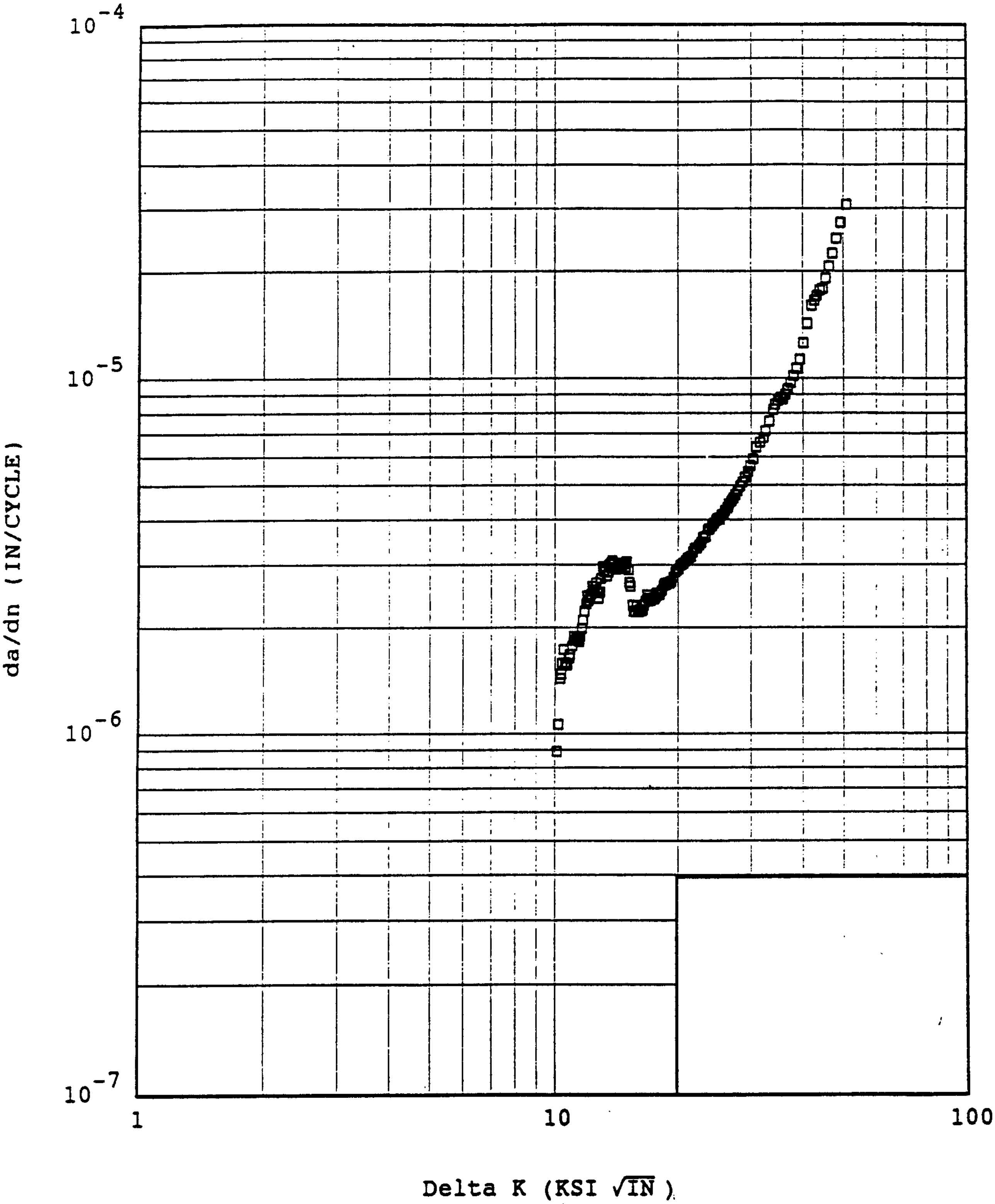
WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

DaDn vs Delta K Graph

Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-15-95
Specimen ID: 42
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT: 3.5% NaCl
PLATIONG : Cd #3

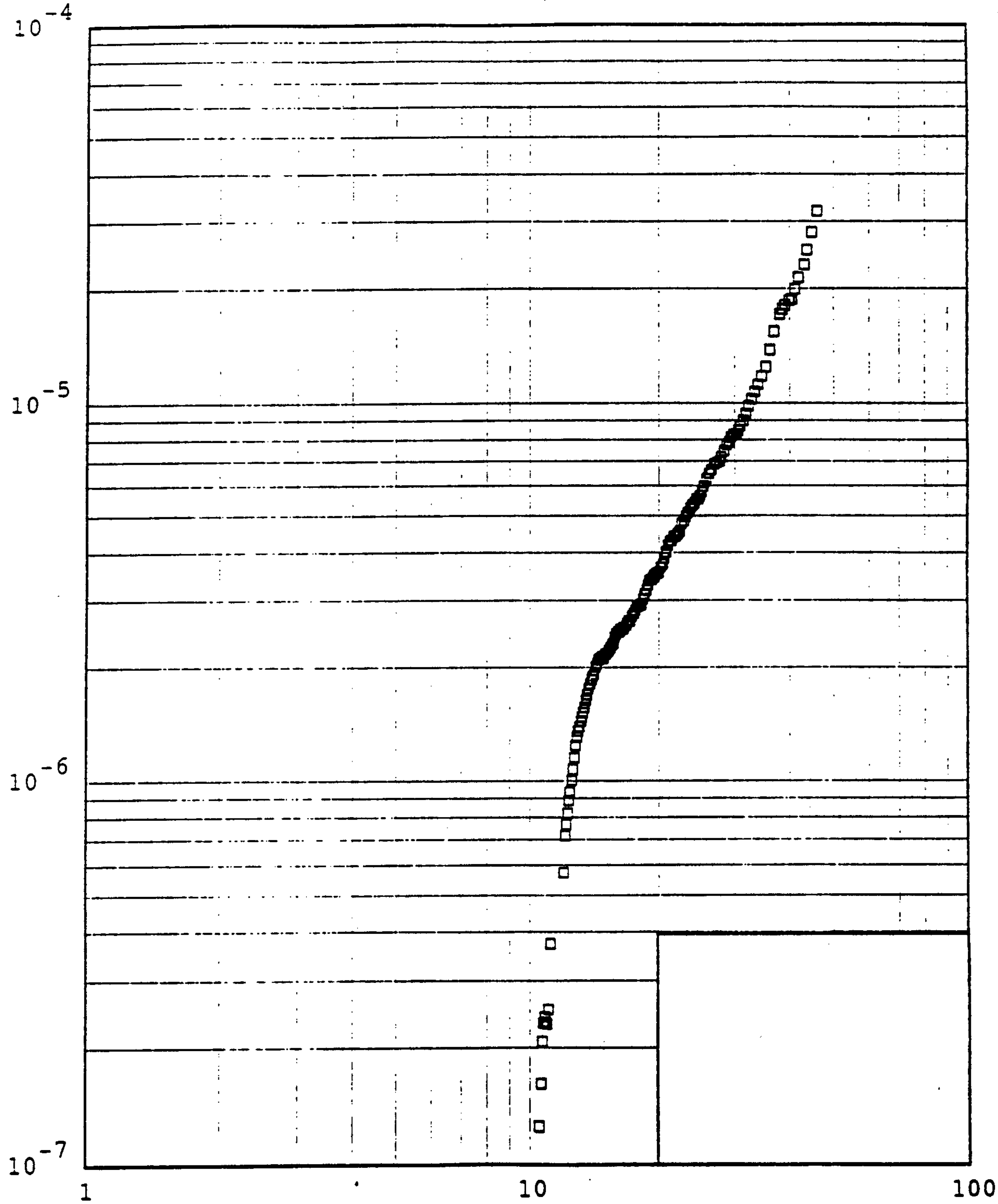



Testlog: 069174

**KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.**

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-10-95
Specimen ID: 14
Test Temperature(F): Room

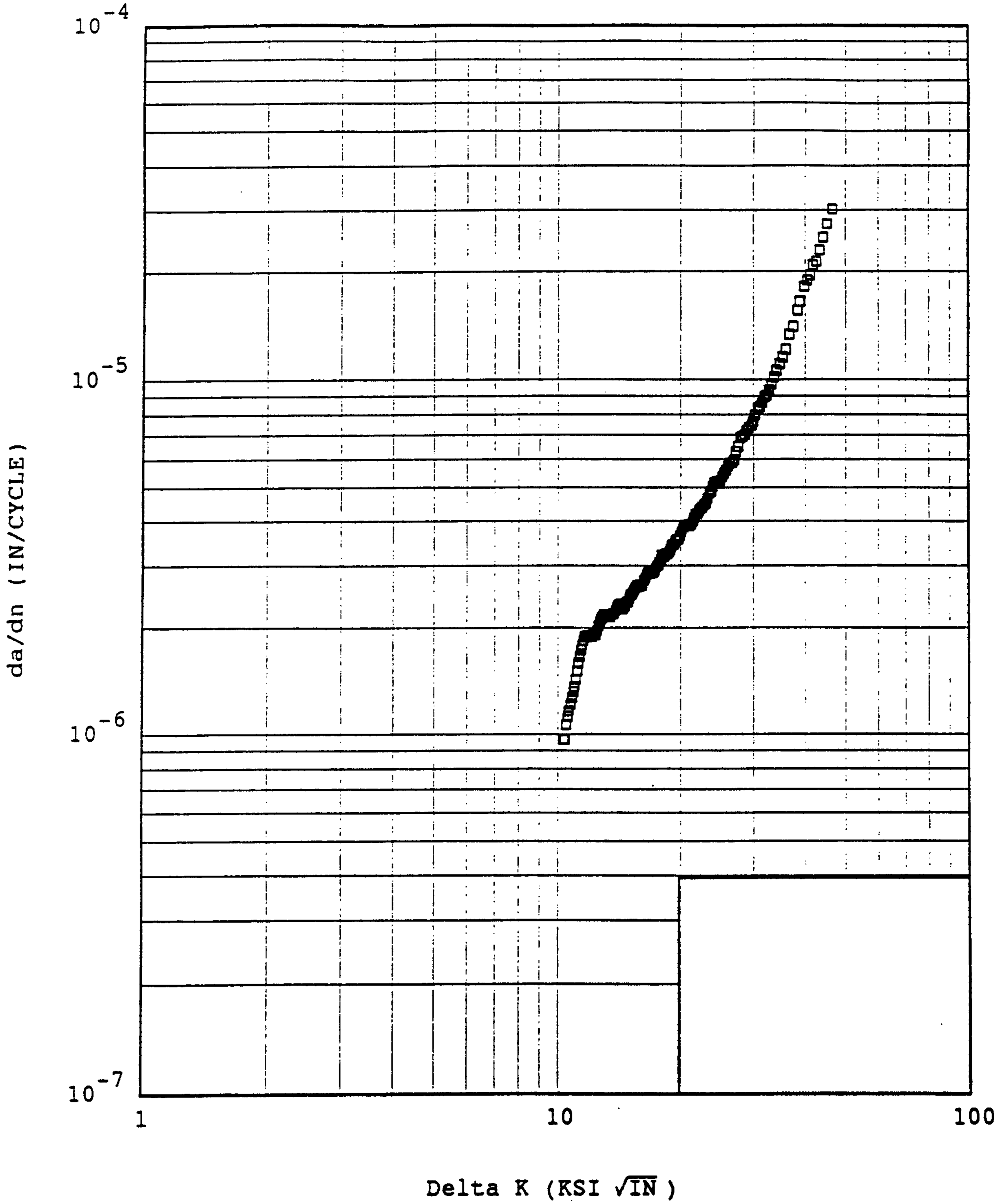
R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : Zn/Ni #1




Testlog: 067413A

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-05-95
Specimen ID: 15
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : Zn/Ni #2




Testlog: 067411

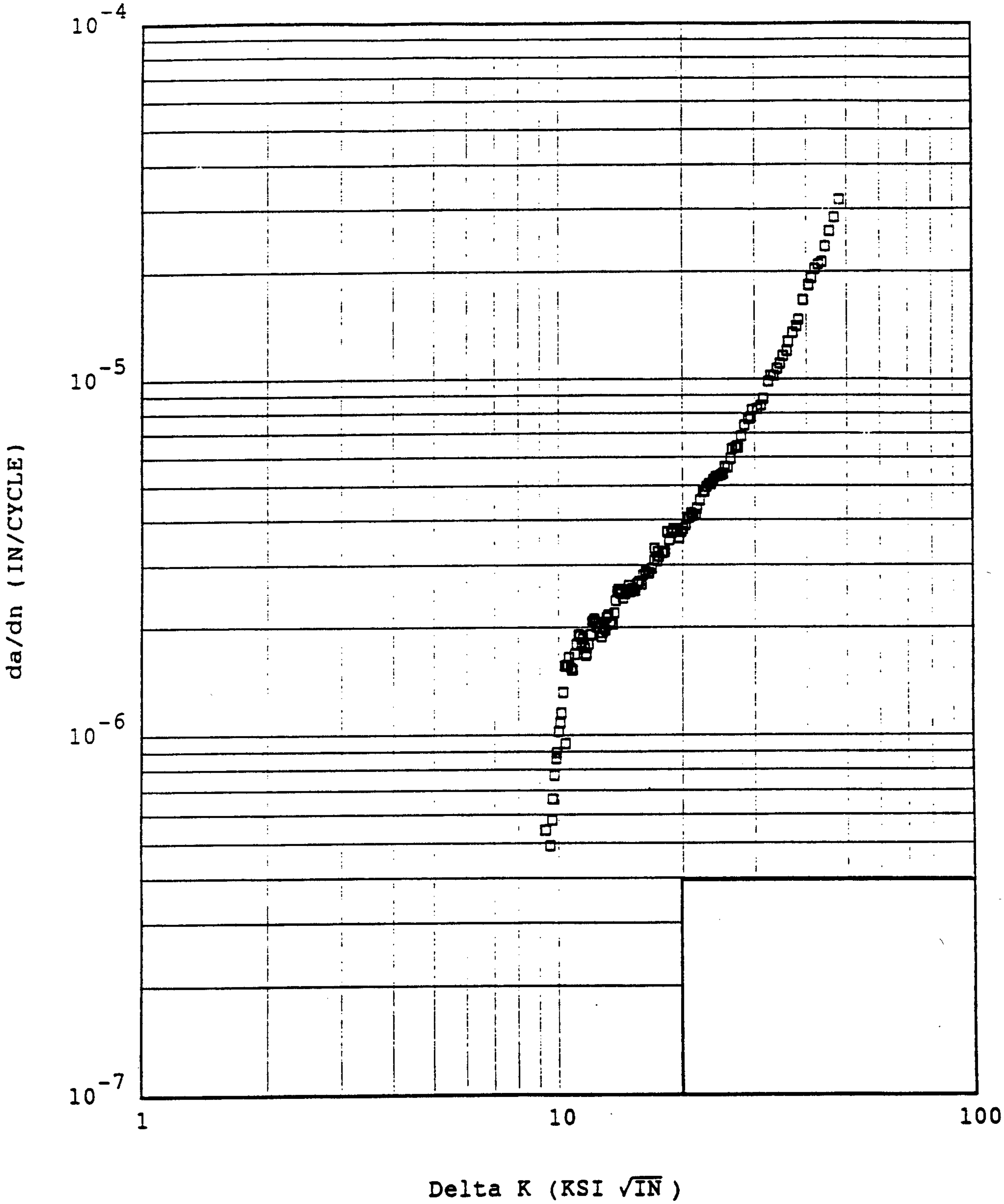
KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

DaDn vs Delta K Graph — Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-05-95
Specimen ID: 20
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : Zn/Ni #3

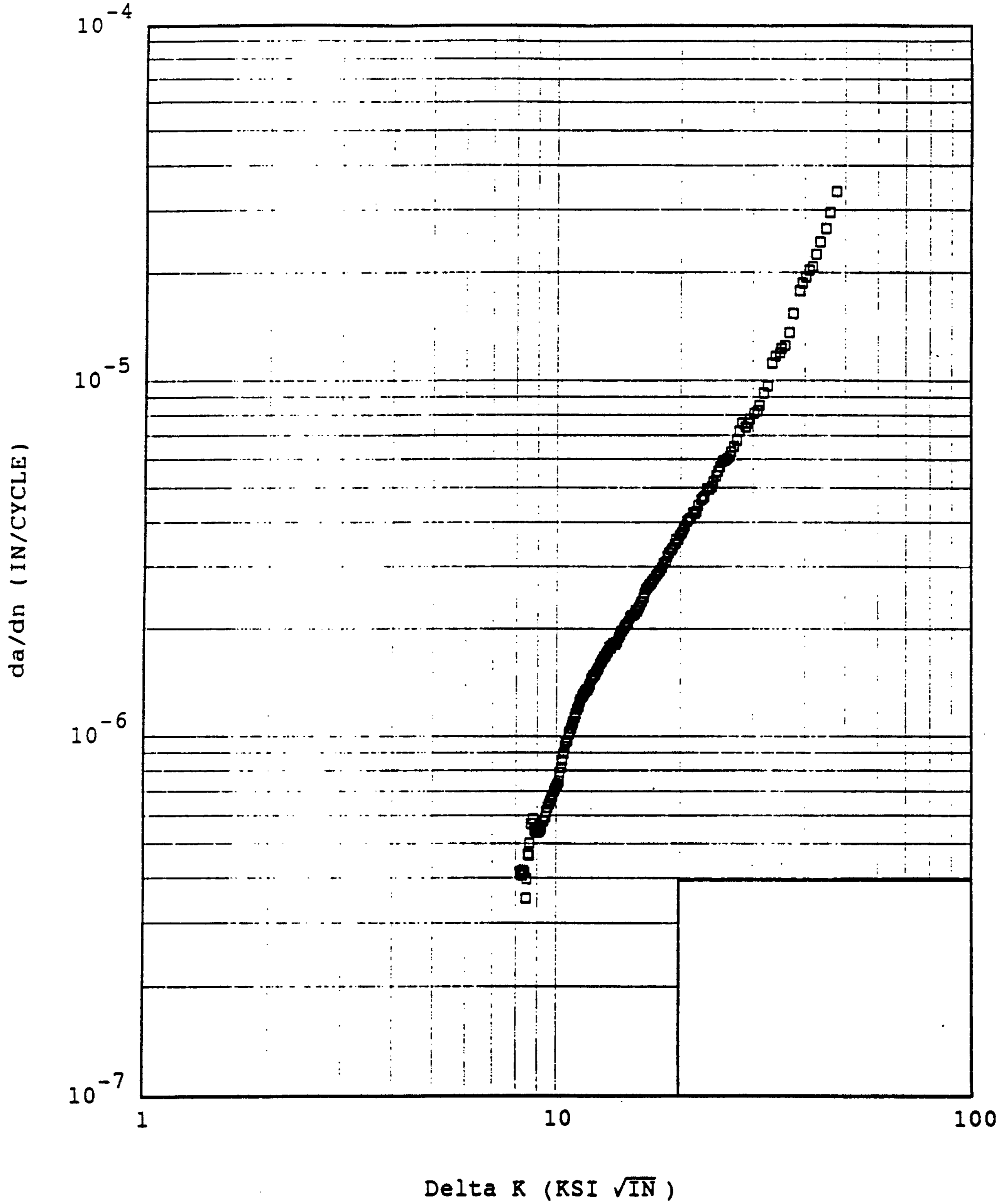



Testlog: 067412

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-08-95
Specimen ID: 7
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : IVD #1



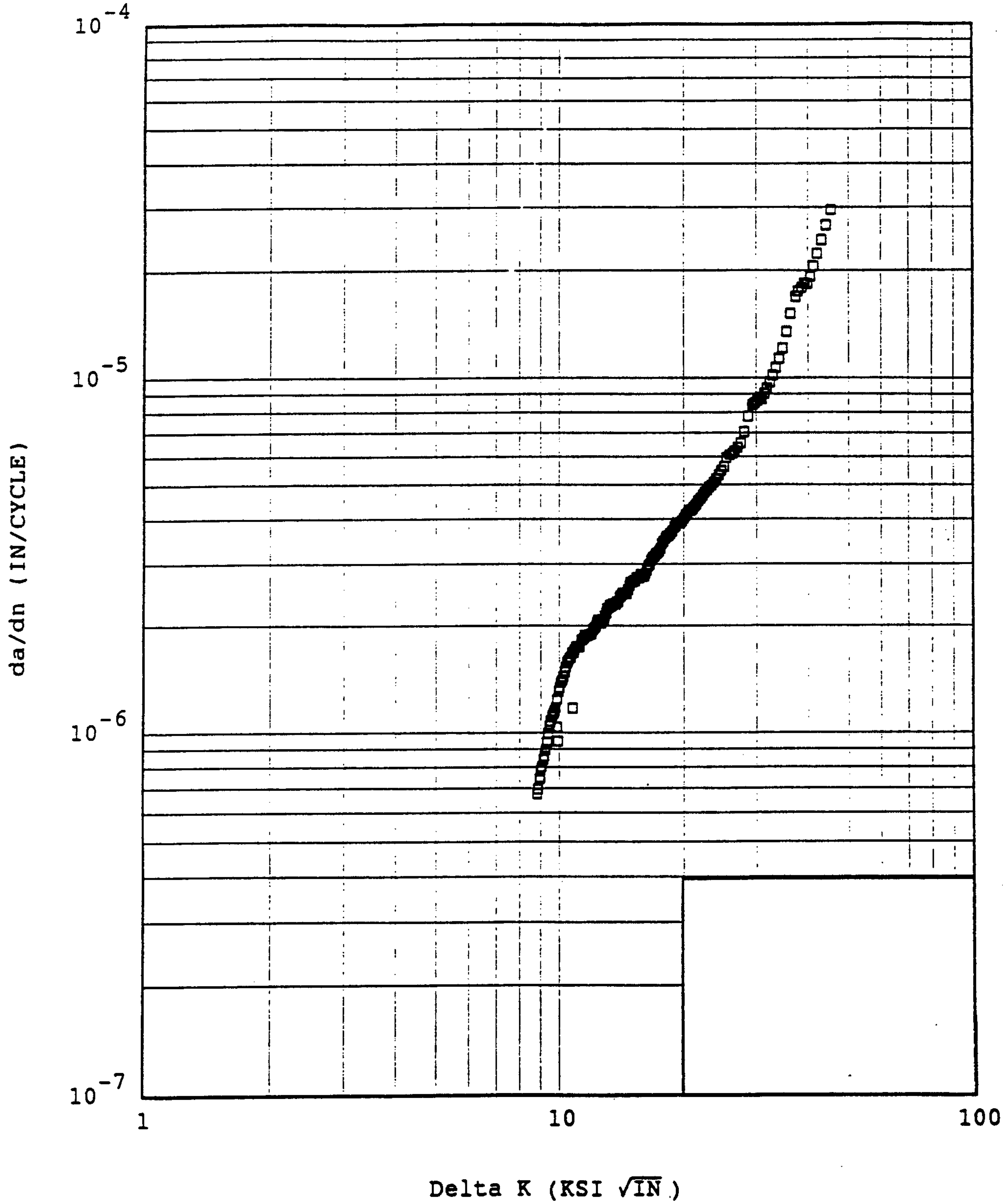

Testlog: 065360

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.
DaDn vs Delta K Graph Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-12-95
Specimen ID: 8
Test Temperature(F): Room

R-ratio: .1
CONDITION: 3.5% NaCl
PLATING : IVD#2




Testlog: 065361

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

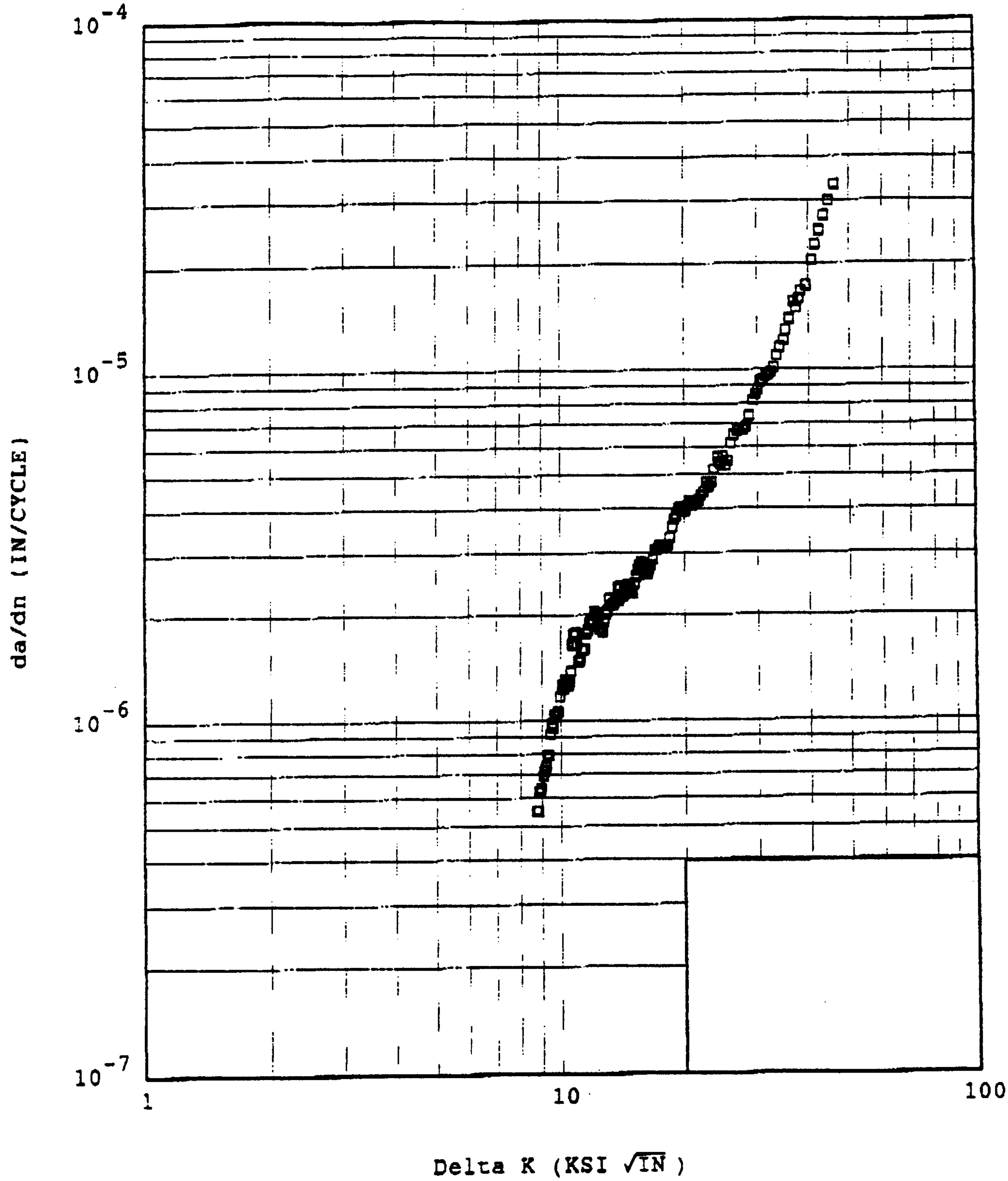
WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

DaDn vs Delta K Graph

Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-06-95
Specimen ID: 22
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : IVD #3

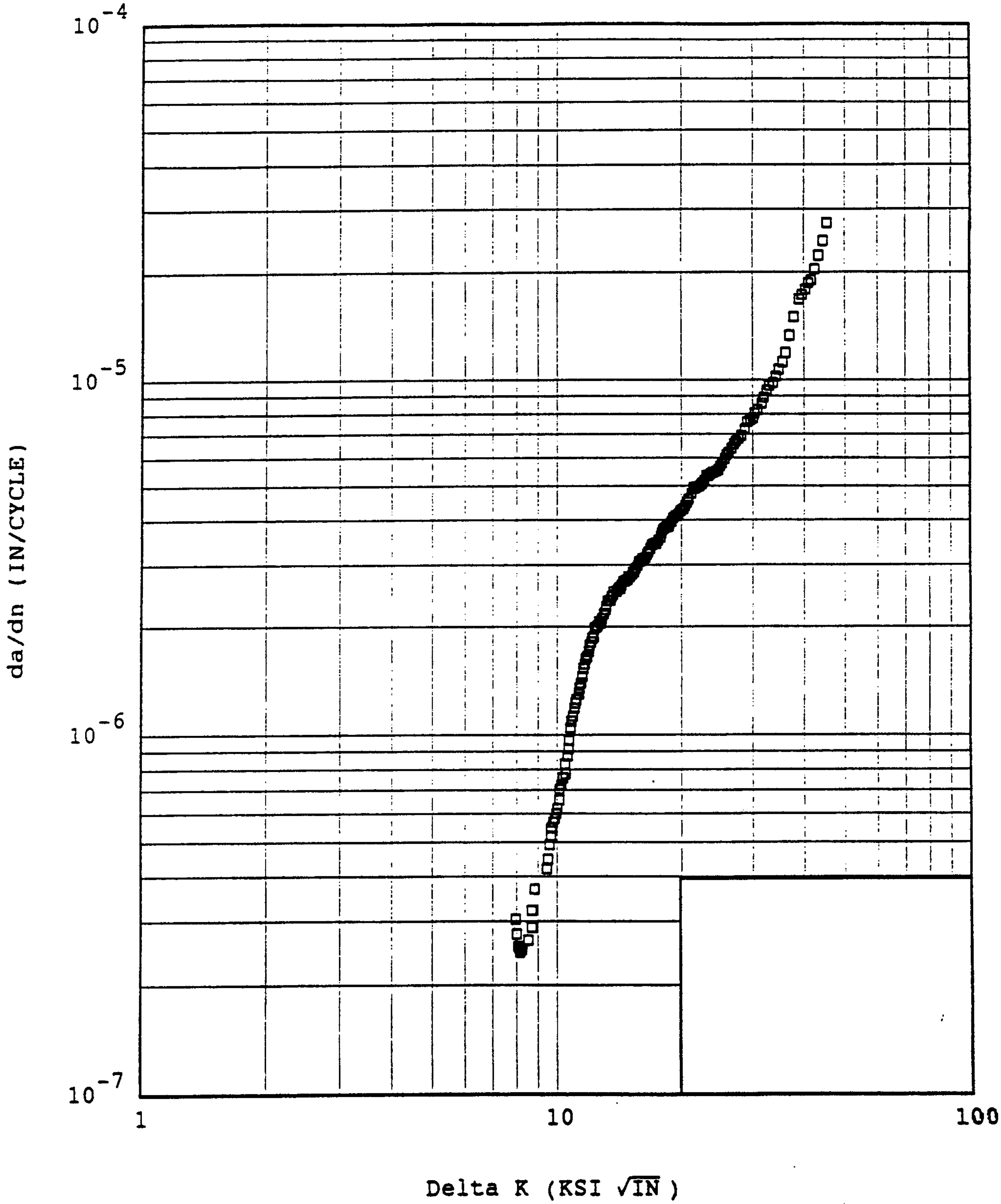



Testlog: 065359

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-20-95
Specimen ID: 11
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT: 3.5% NaCl
PLATING : Zn/PH #1




Testlog: 067691

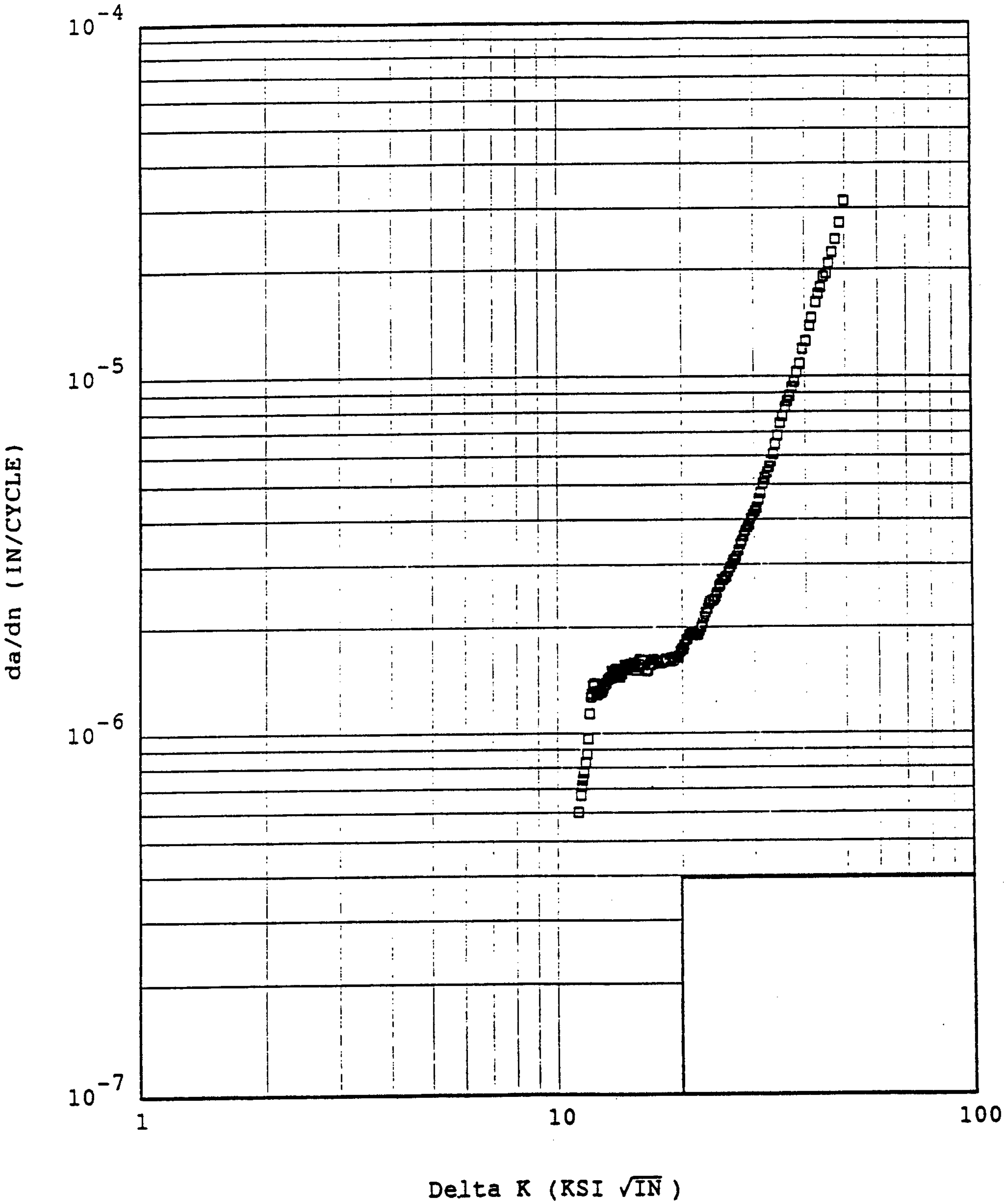
KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-15-95
Specimen ID: 21
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT 3.5% NaCl
COATING: Zn/PH #2




Testlog: 067688

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

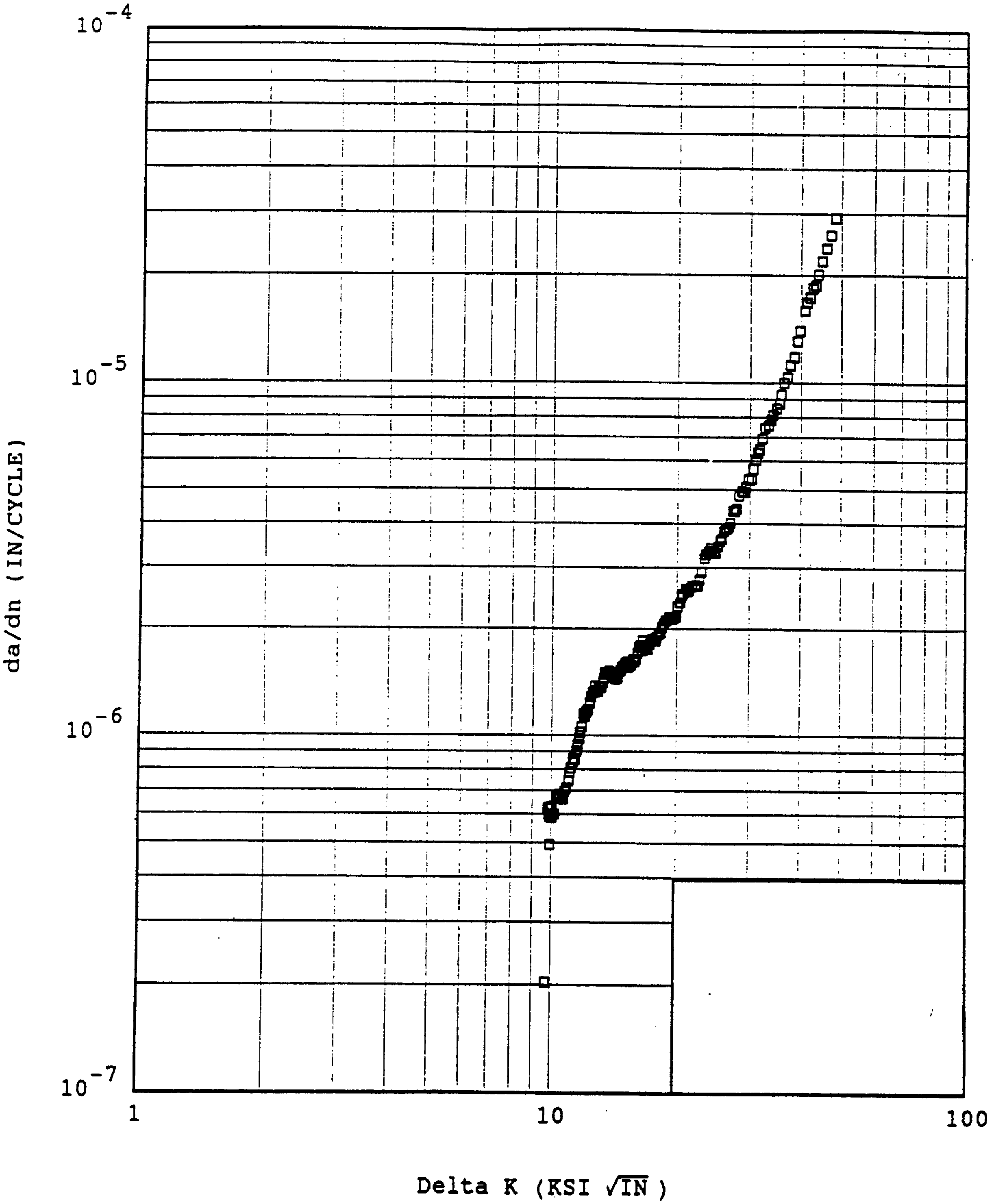
WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

DaDn vs Delta K Graph

Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-19-95
Specimen ID: 25
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT 3.5% NaCl
PLATING : Zn/PH #3




Testlog: 067690

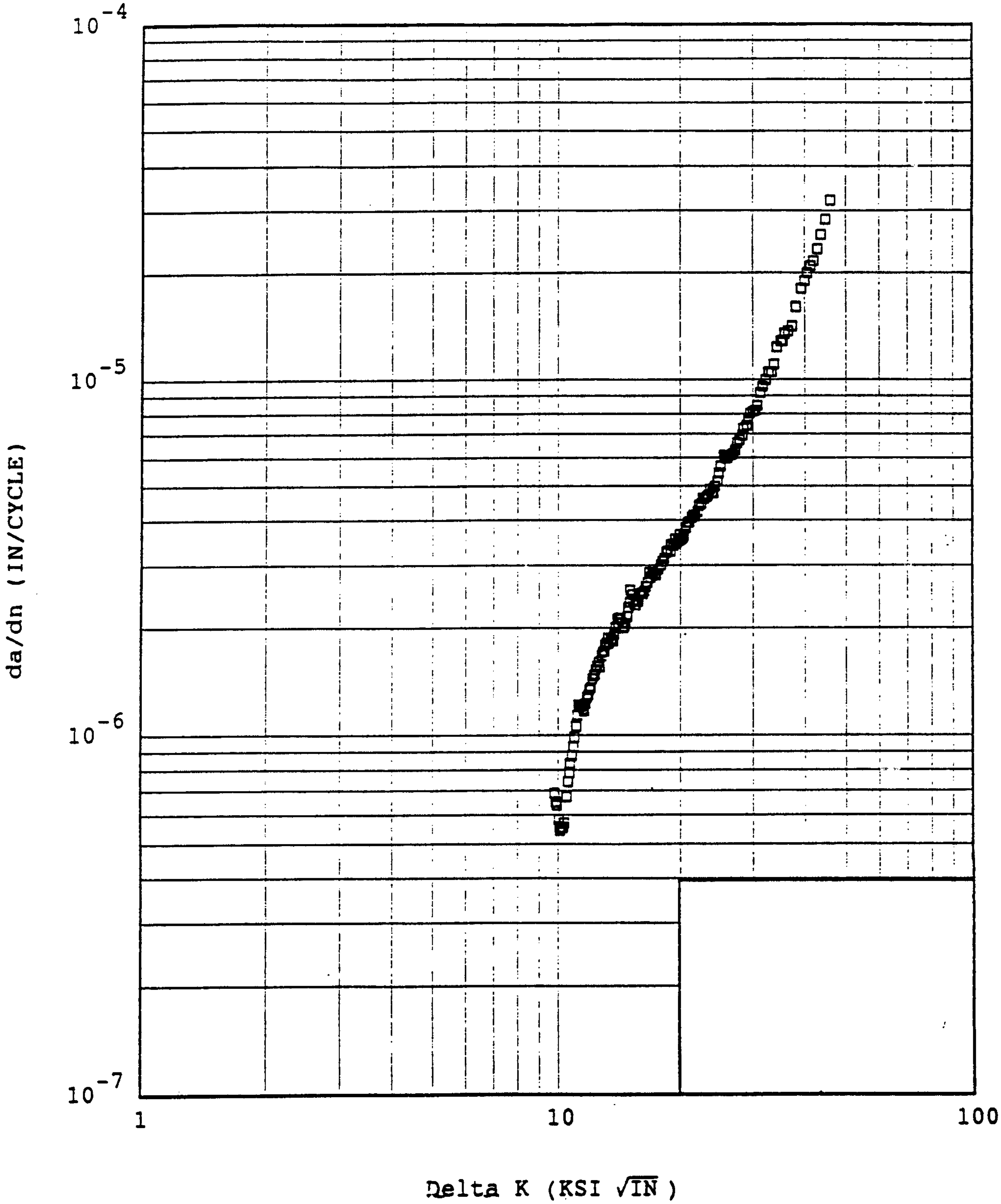
KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-06-95
Specimen ID: 24
Test Temperature(F): Room

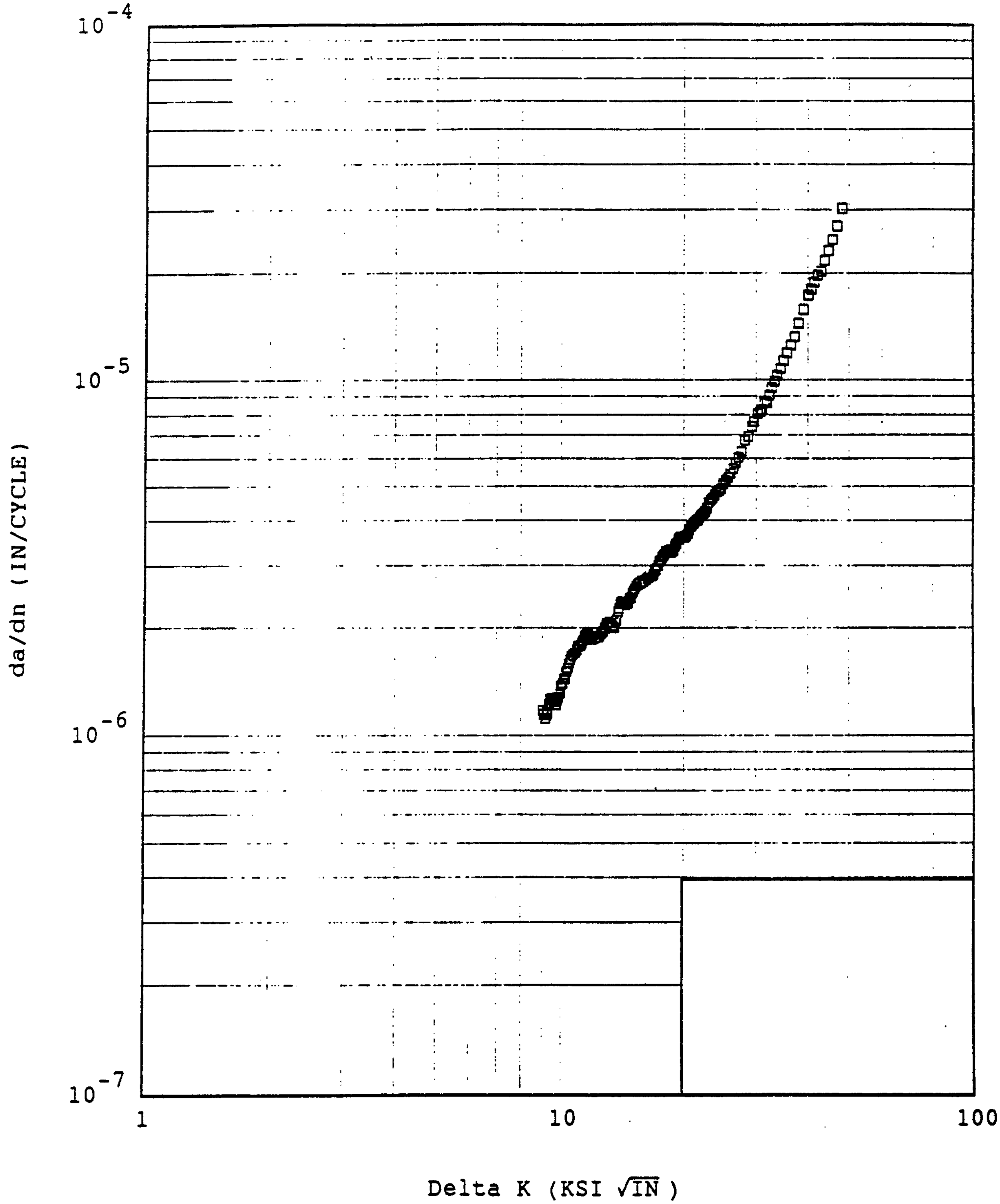
R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : IN #1




Testlog: 064853

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-07-95
Specimen ID: 34
Test Temperature(F): Room

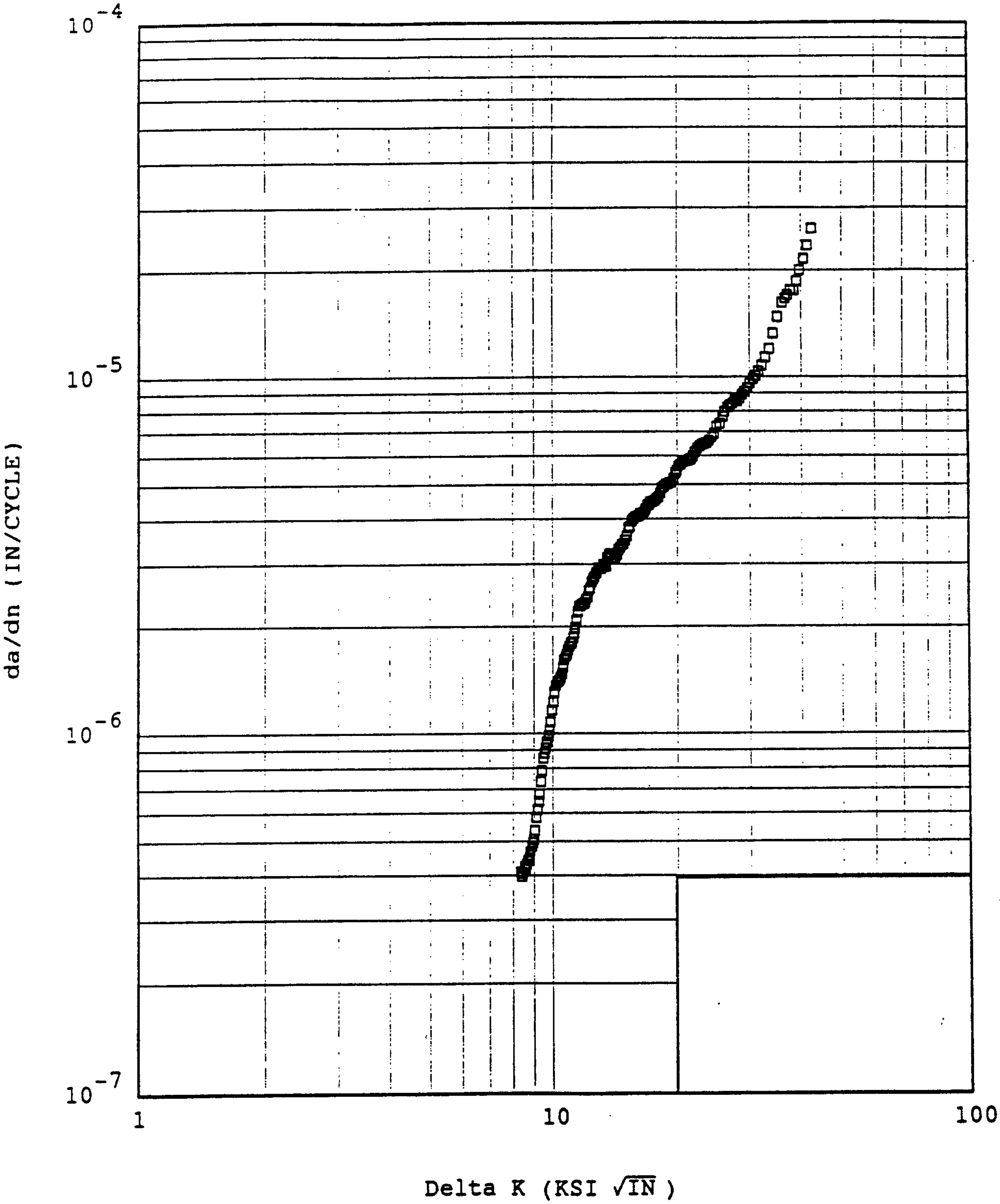
R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : IN #2




Testlog: 064855

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-03-95
Specimen ID: 35
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : IN #3



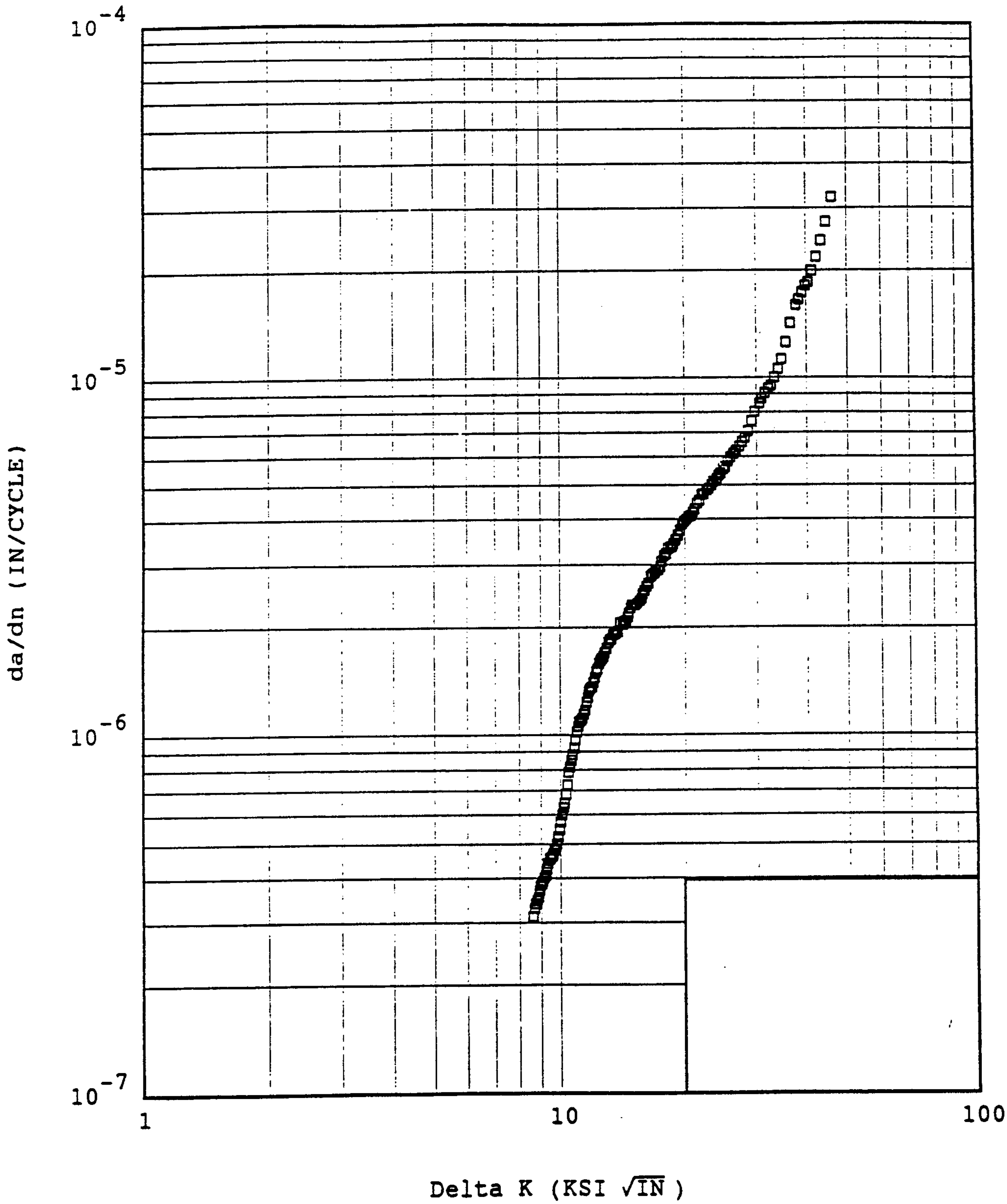

Testlog: 064850

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.
DaDn vs Delta K Graph
Phone: (412)-537-313.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 08-28-95
Specimen ID: 18
Test Temperature(F): Room

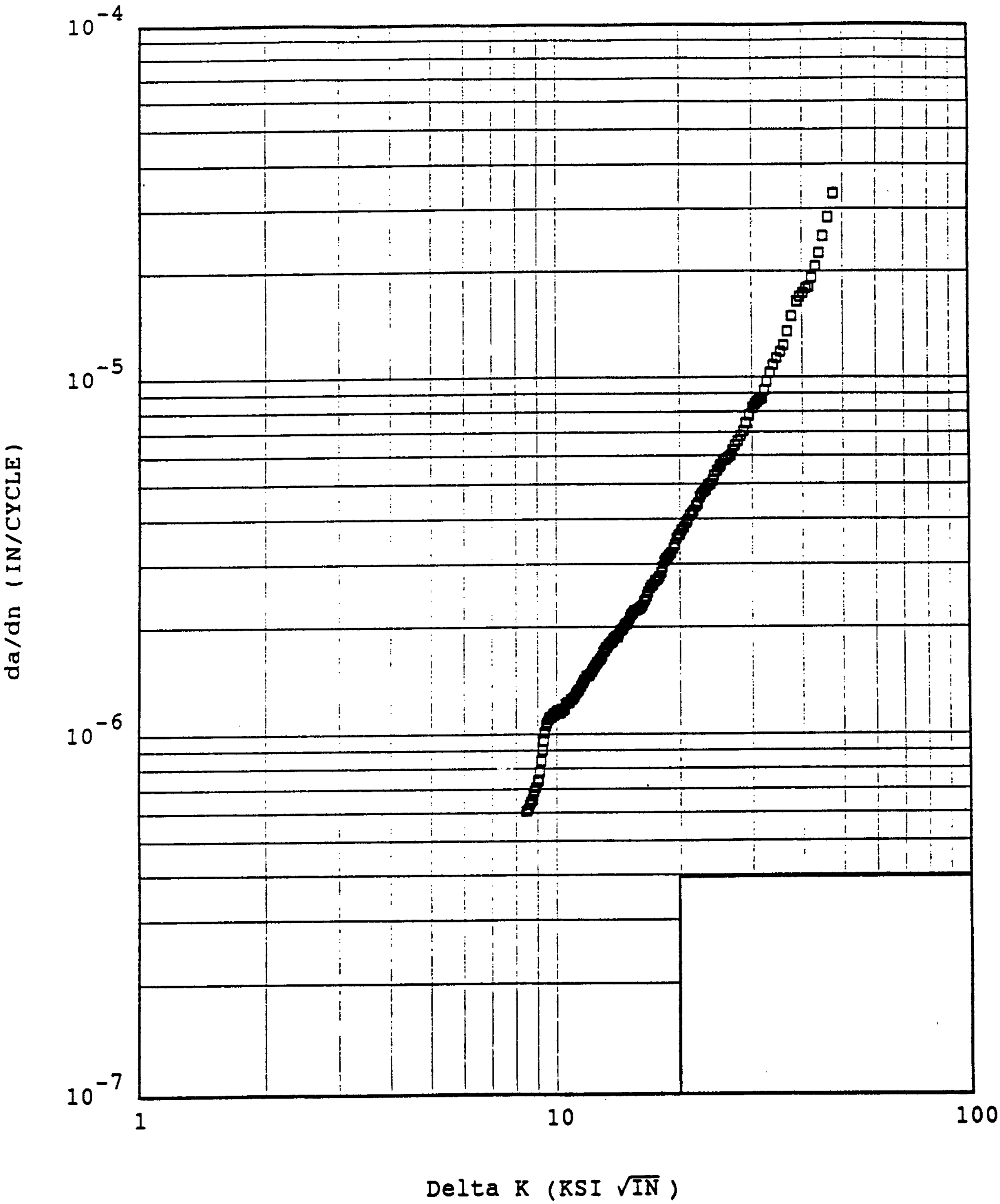
R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : Sn/Zn #1




Testlog: 064851

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-07-95
Specimen ID: 10
Test Temperature(F): Room

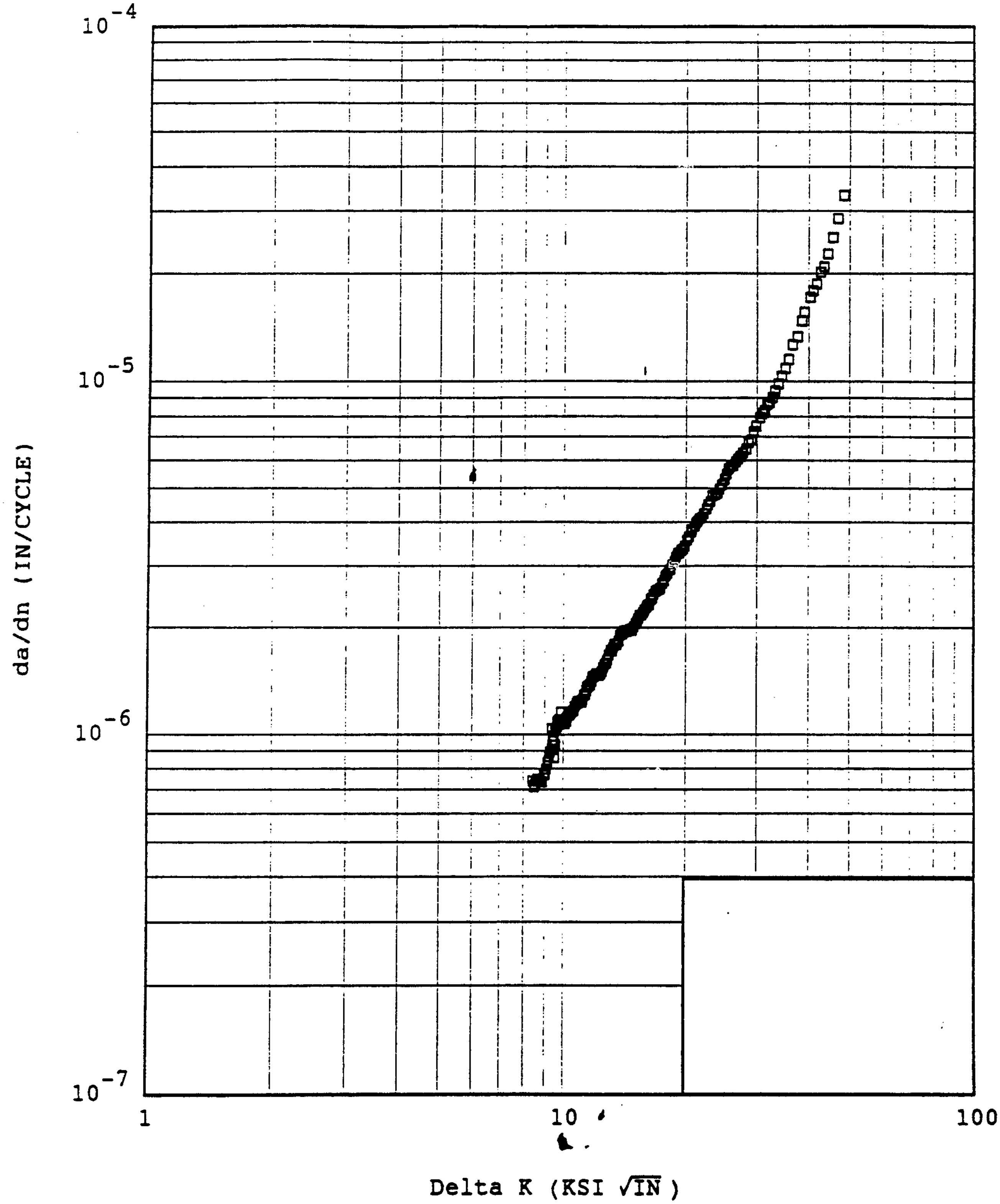
R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : Sn/Zn #2




Testlog: 064852

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 08-29-95
Specimen ID: 4
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : Sn/Zn #3



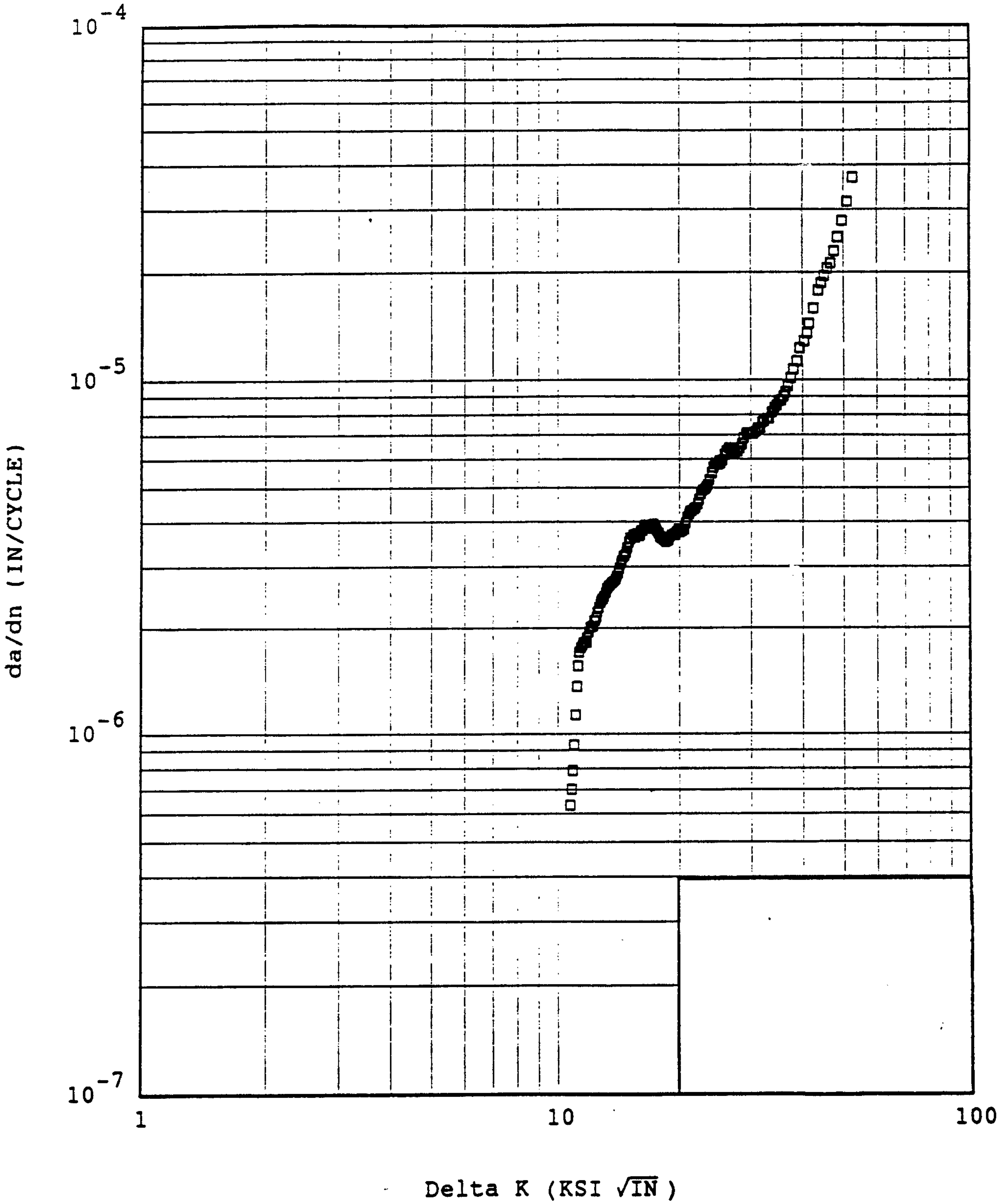

Testlog: 064854

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.
DaDn vs Delta K Graph
Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-15-95
Specimen ID: 6
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT: 3.5% NaCl
COATING: POLY #1

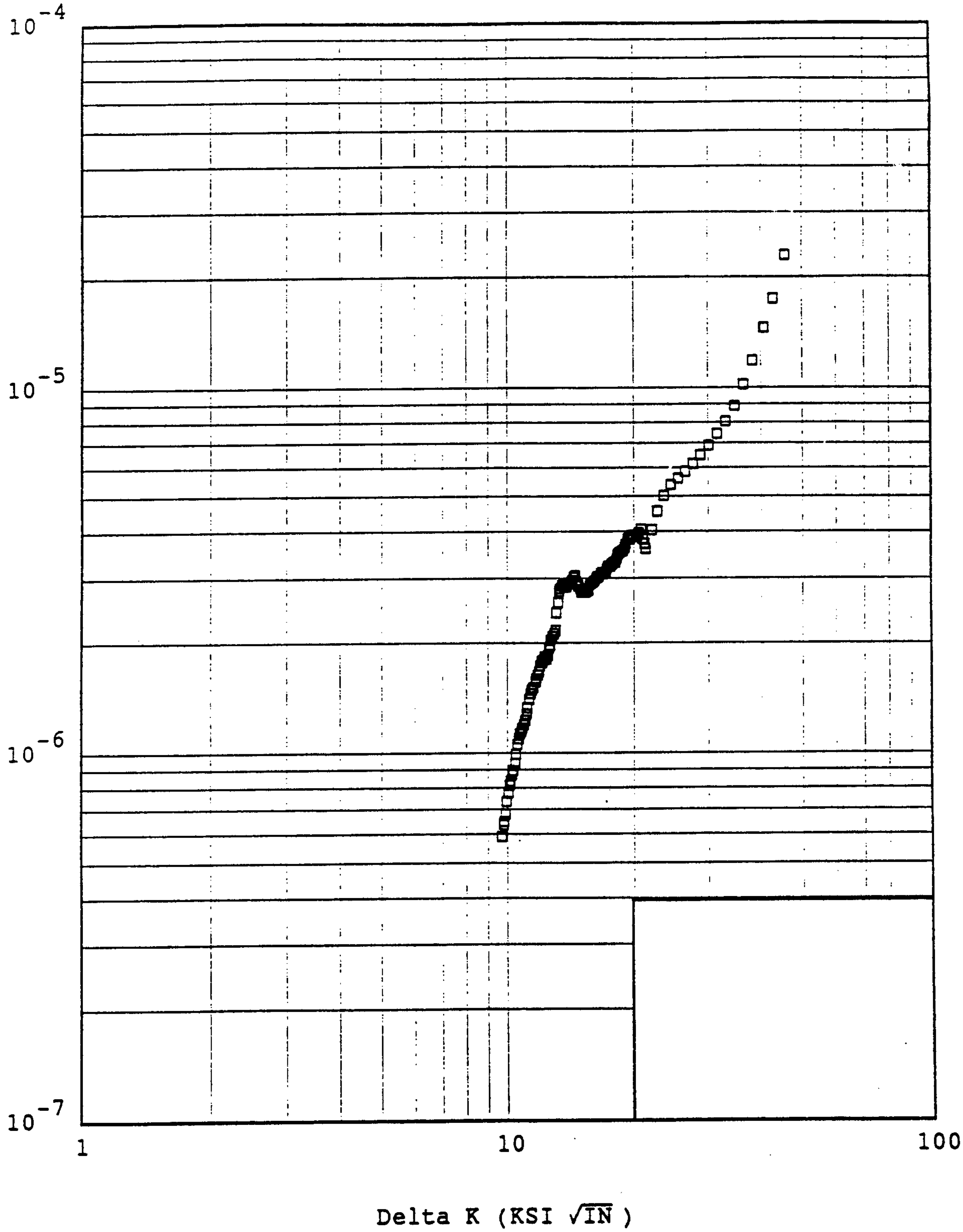



Testlog: 067687

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-17-95
Specimen ID: 32
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT: 3.5% NaCl
PLATING : PQY #2

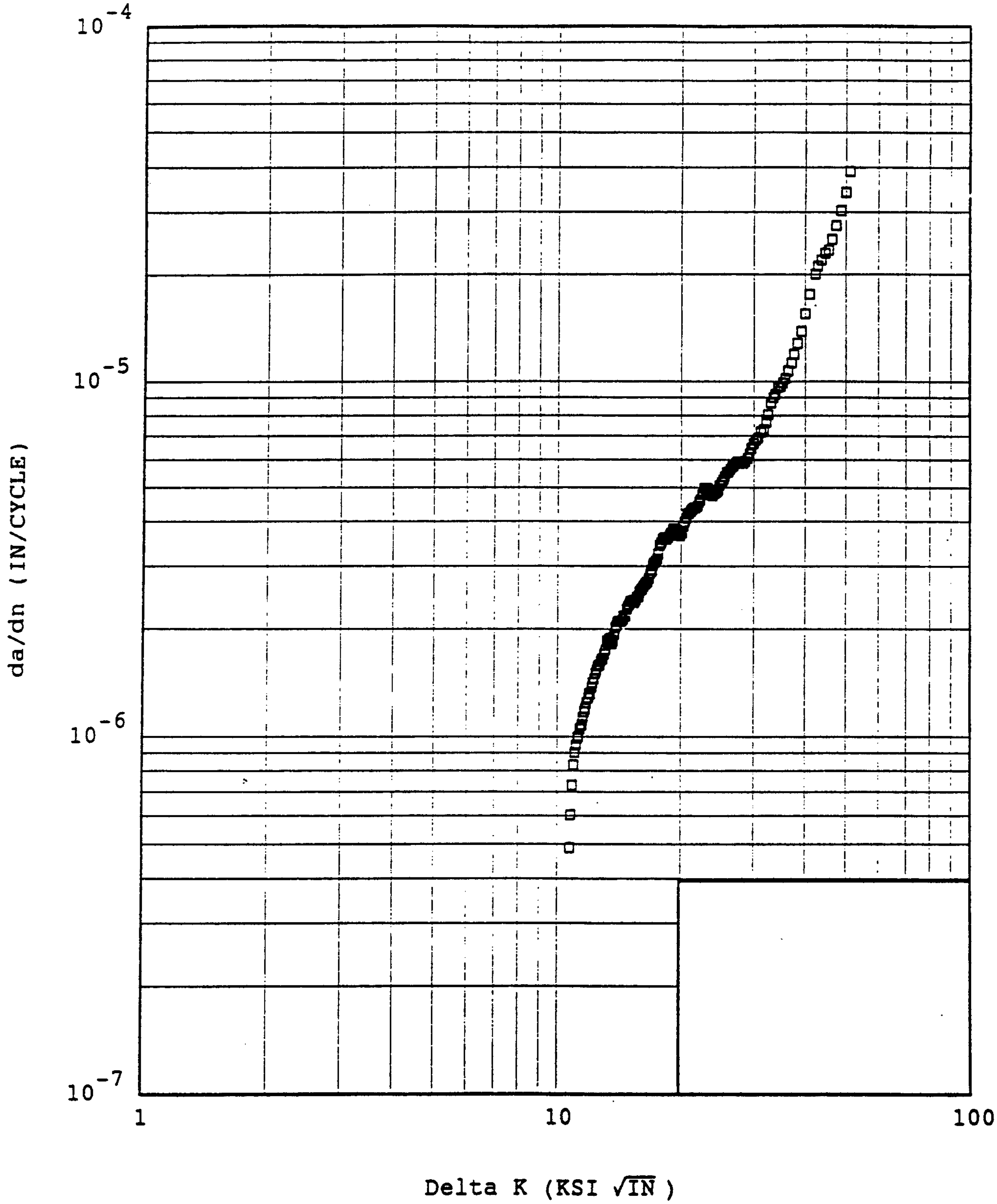



Testlog: 067689

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-14-95
Specimen ID: 39
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : POLY #3

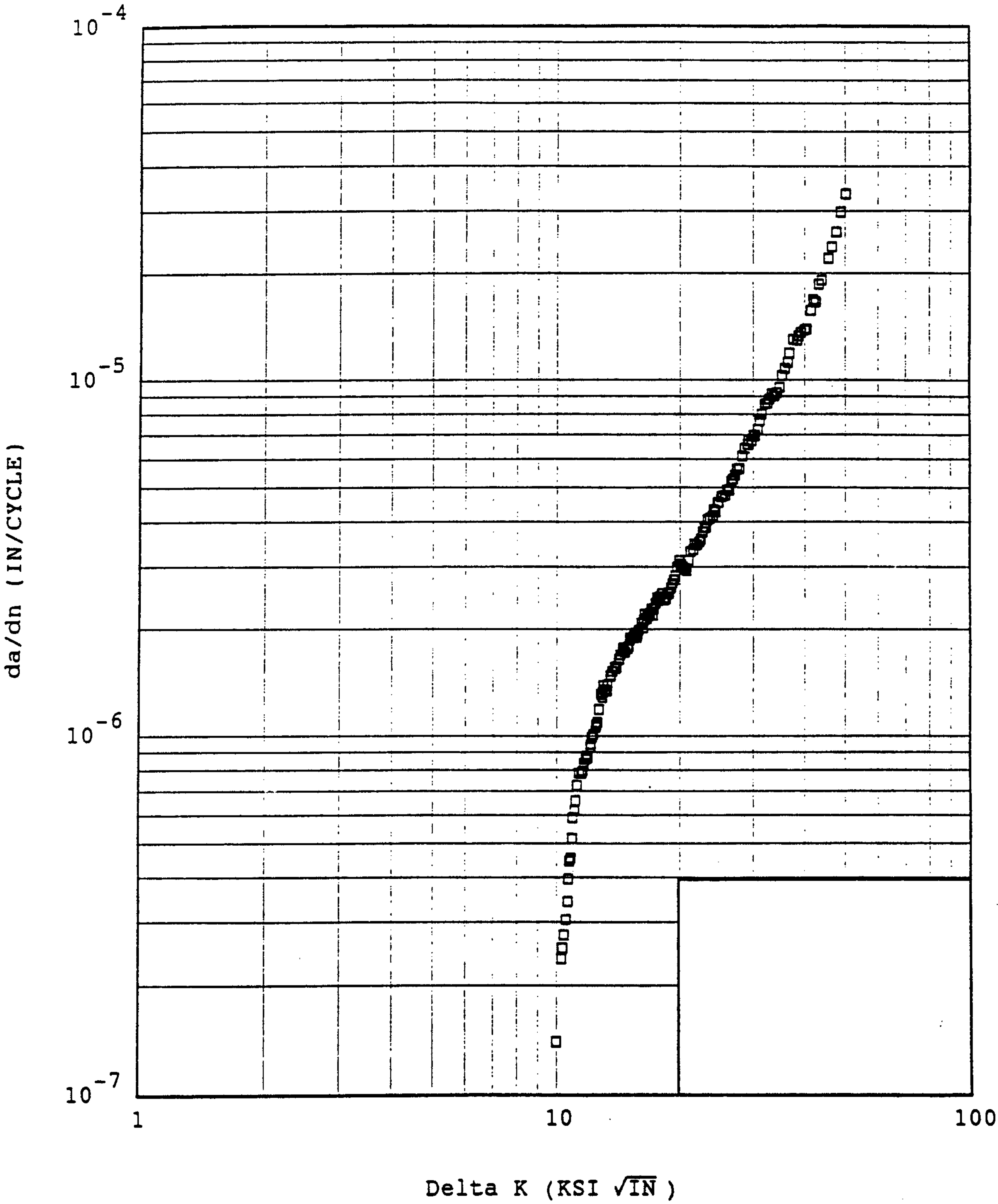



Testlog: 067686

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-19-95
Specimen ID: 26
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT 3.5% NaCl
PLATING : ALK #1

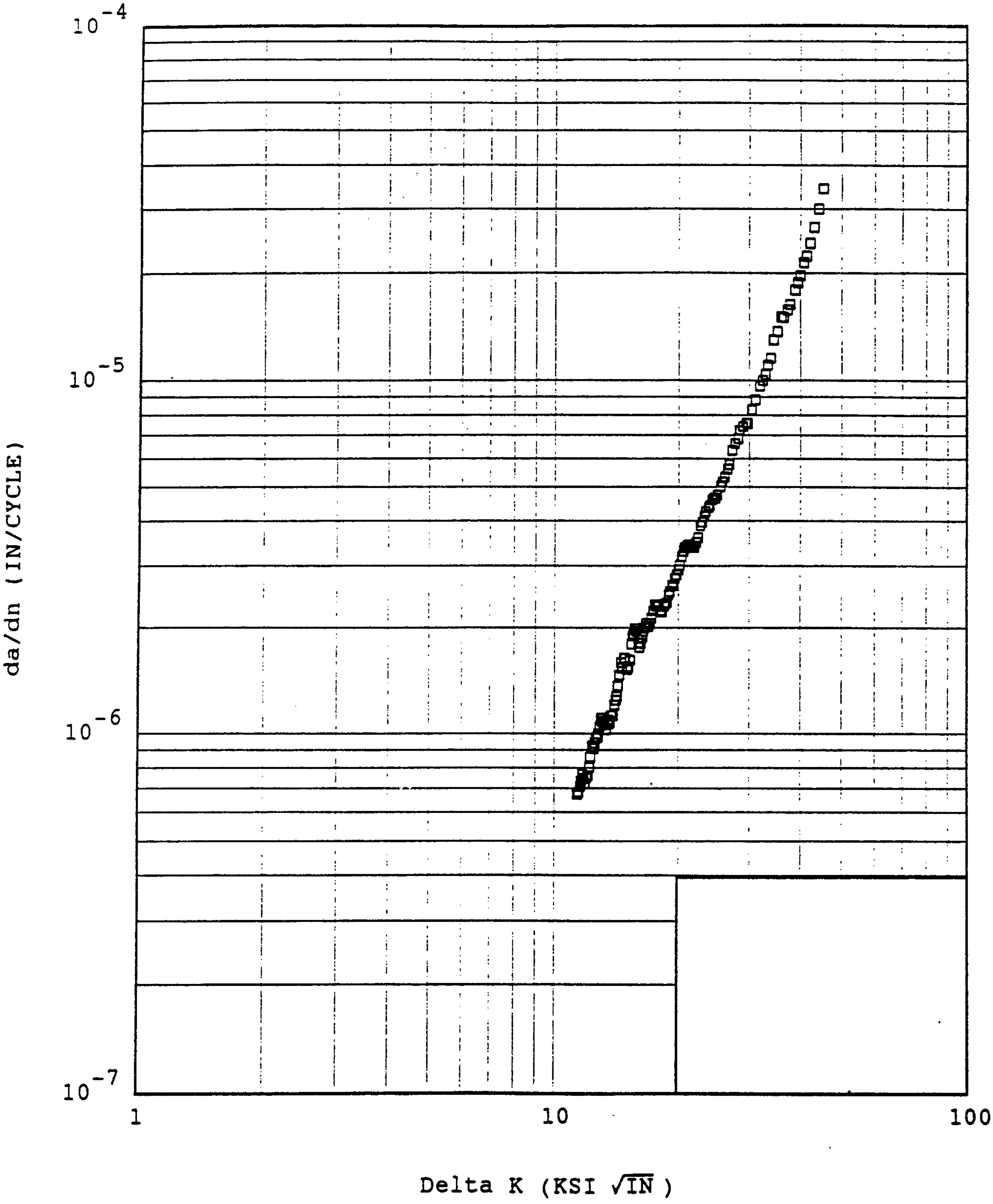



Testlog: 069170

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-18-95
Specimen ID: 27
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT: 3.5% NaCl
PLATING : ALK #2




Testlog: 069169

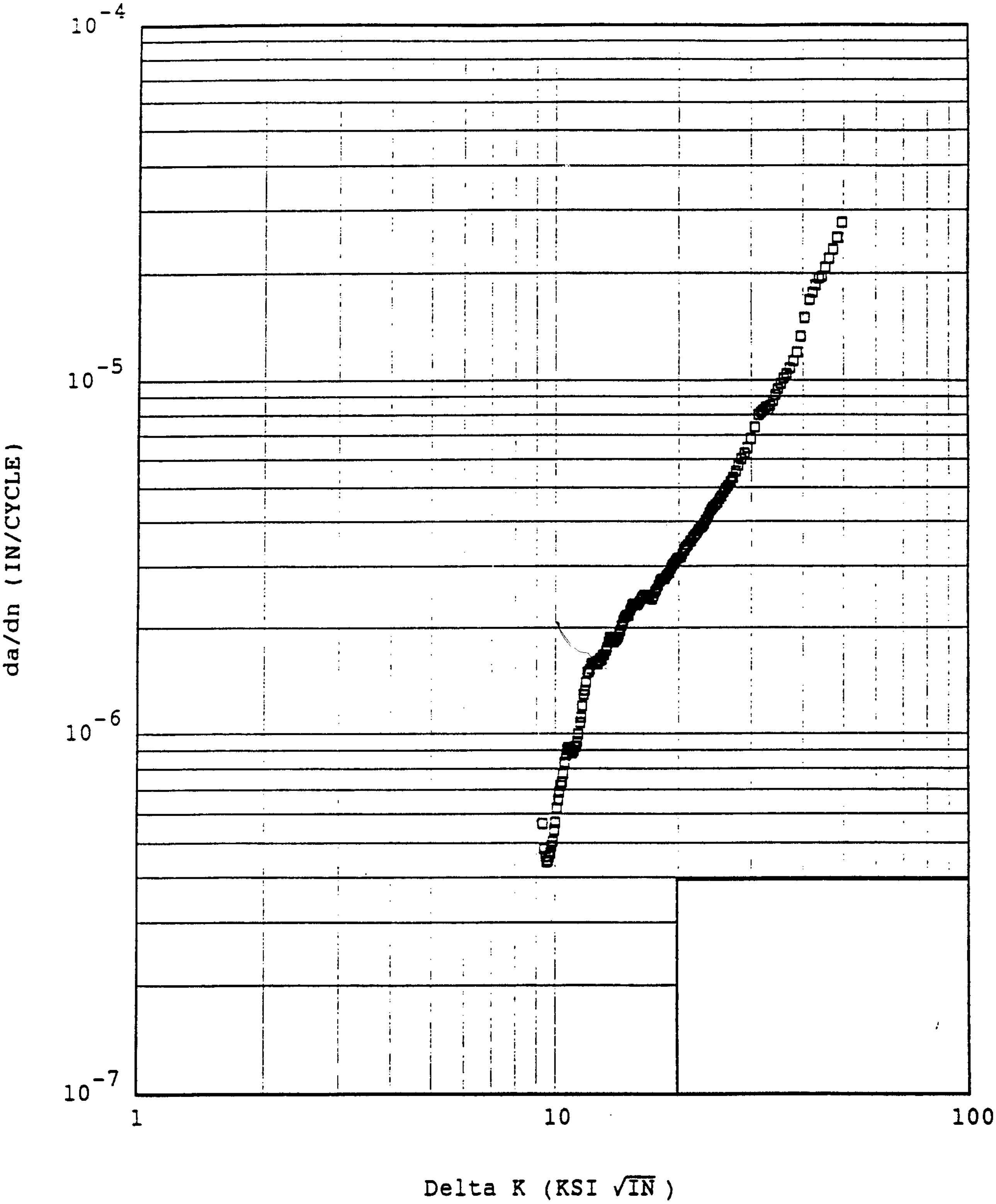
KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

DaDn vs Delta K Graph — Phone: [illegible]

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-13-95
Specimen ID: 37
Test Temperature(F): Room

R-ratio: .1
CONDITION: 3.5% NaCl
COATING : ALK #3

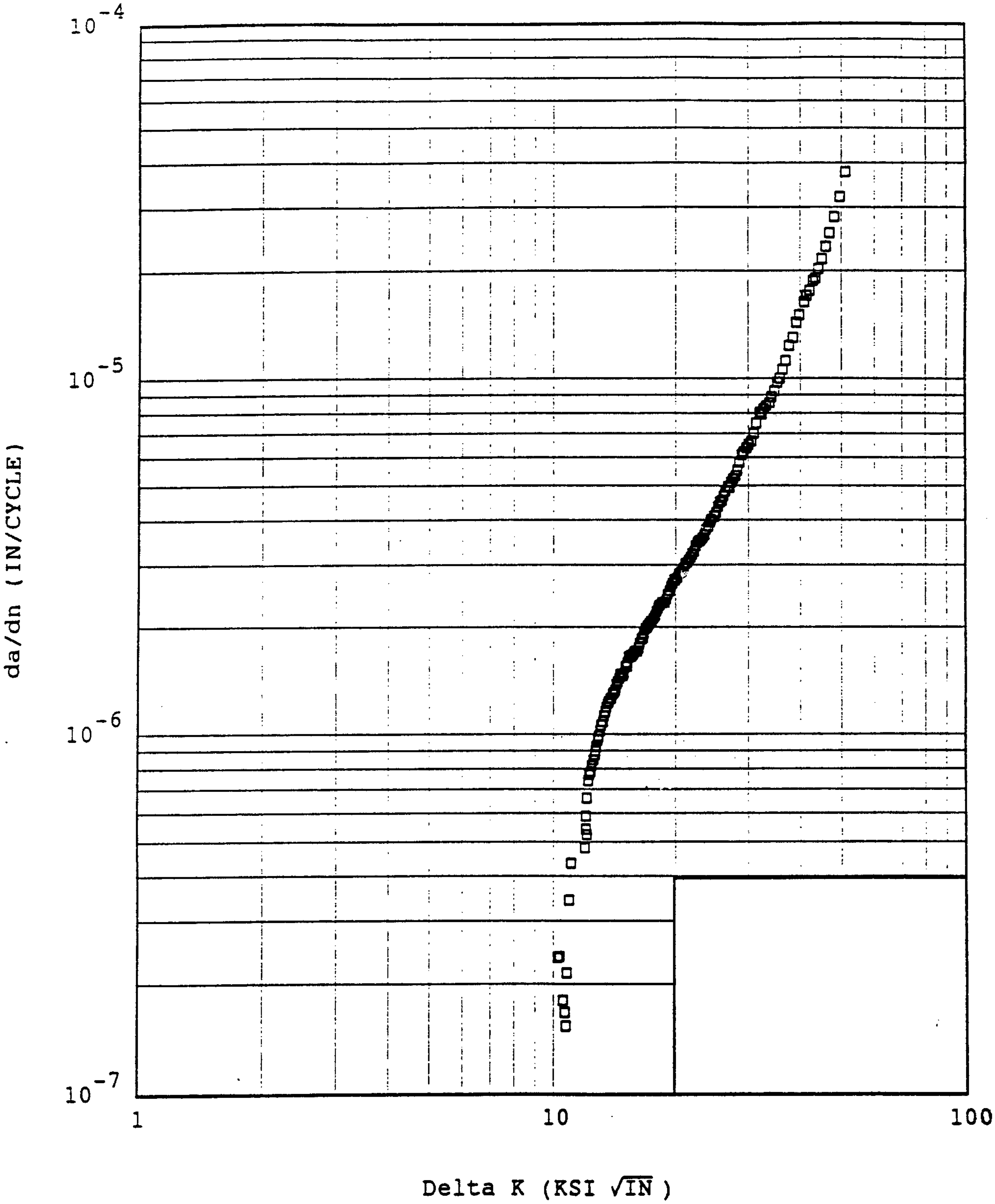



Testlog: 069171

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-14-95
Specimen ID: 28
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING : ZA #1

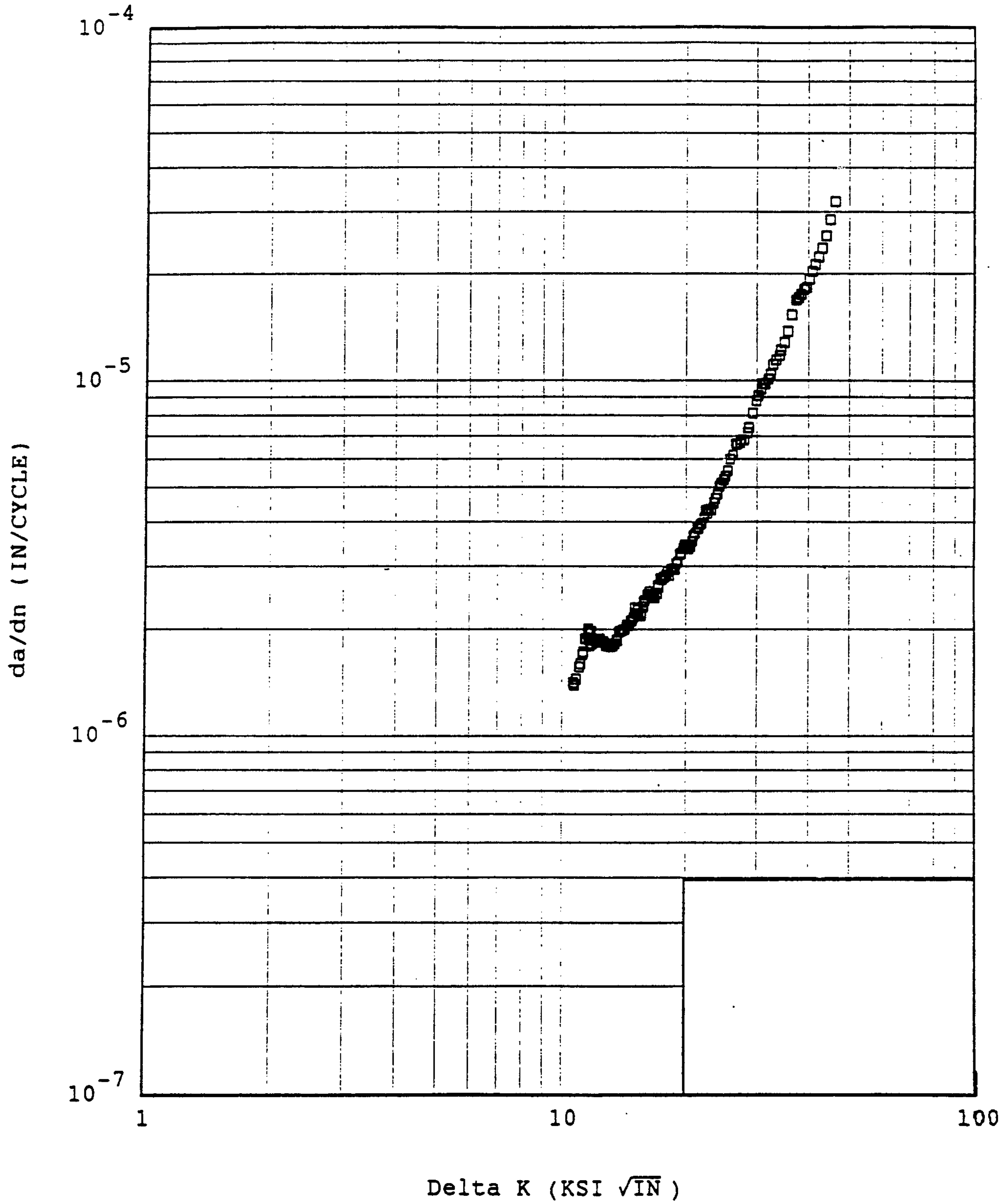



Testlog: 069168

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-19-95
Specimen ID: 30
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT: 3.5% NaCl
PLATING : ZA #2



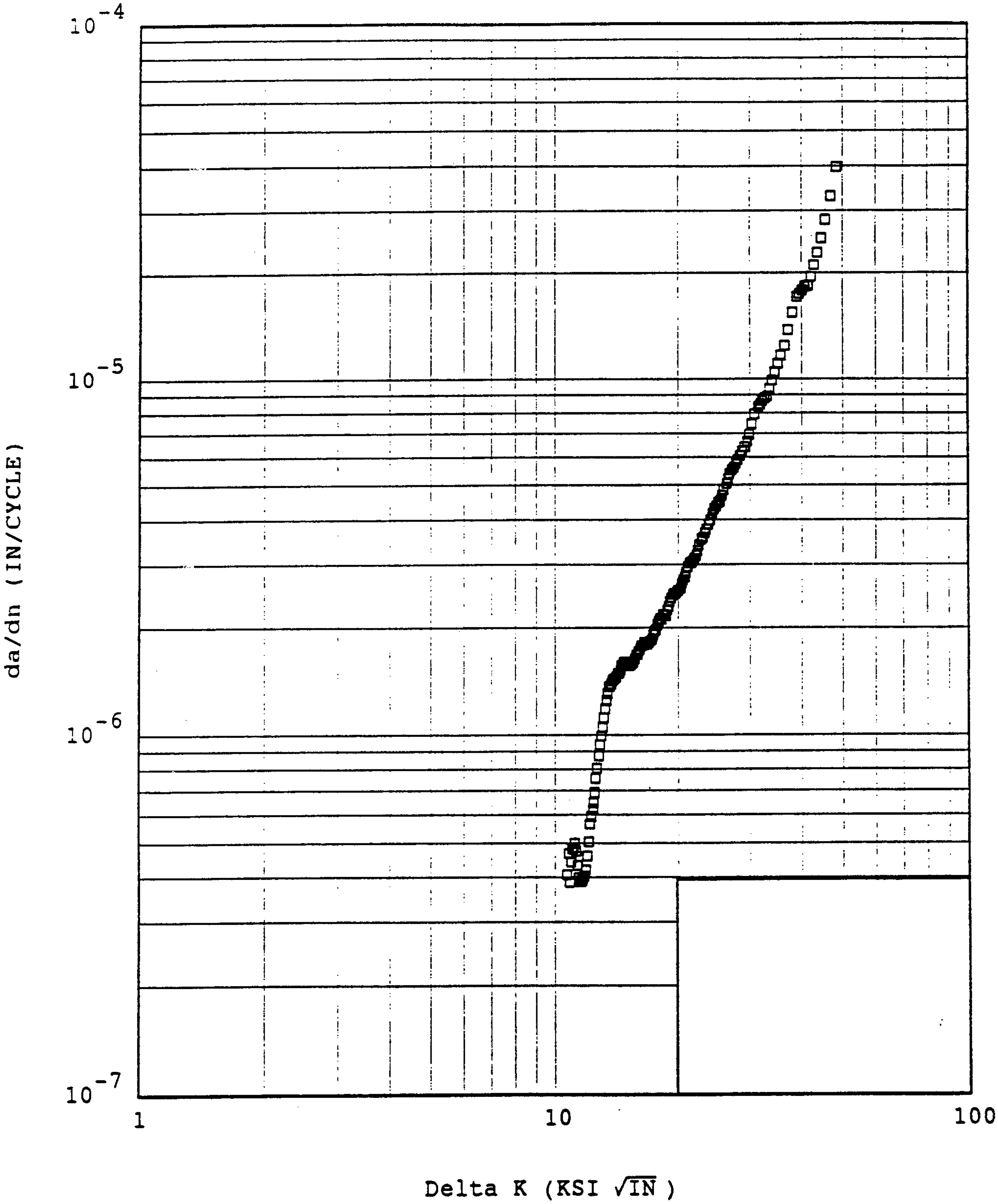

Testlog: 069167

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-17-95
Specimen ID: 38
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING :ZA #3

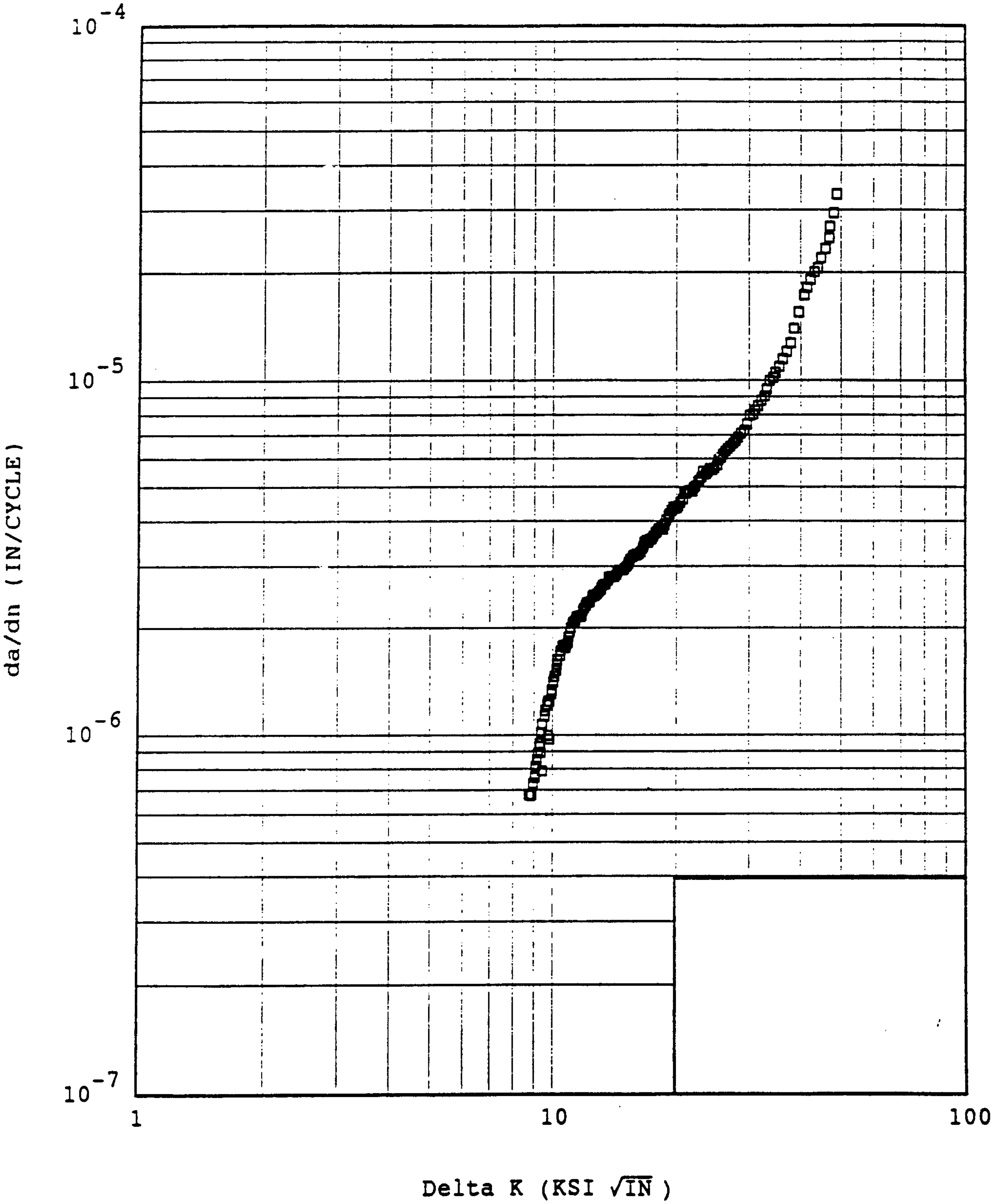



Testlog: 069166A

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-18-95
Specimen ID: 1
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT: 3.5% NaCl
PLATING : SER




Testlog: 067683

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

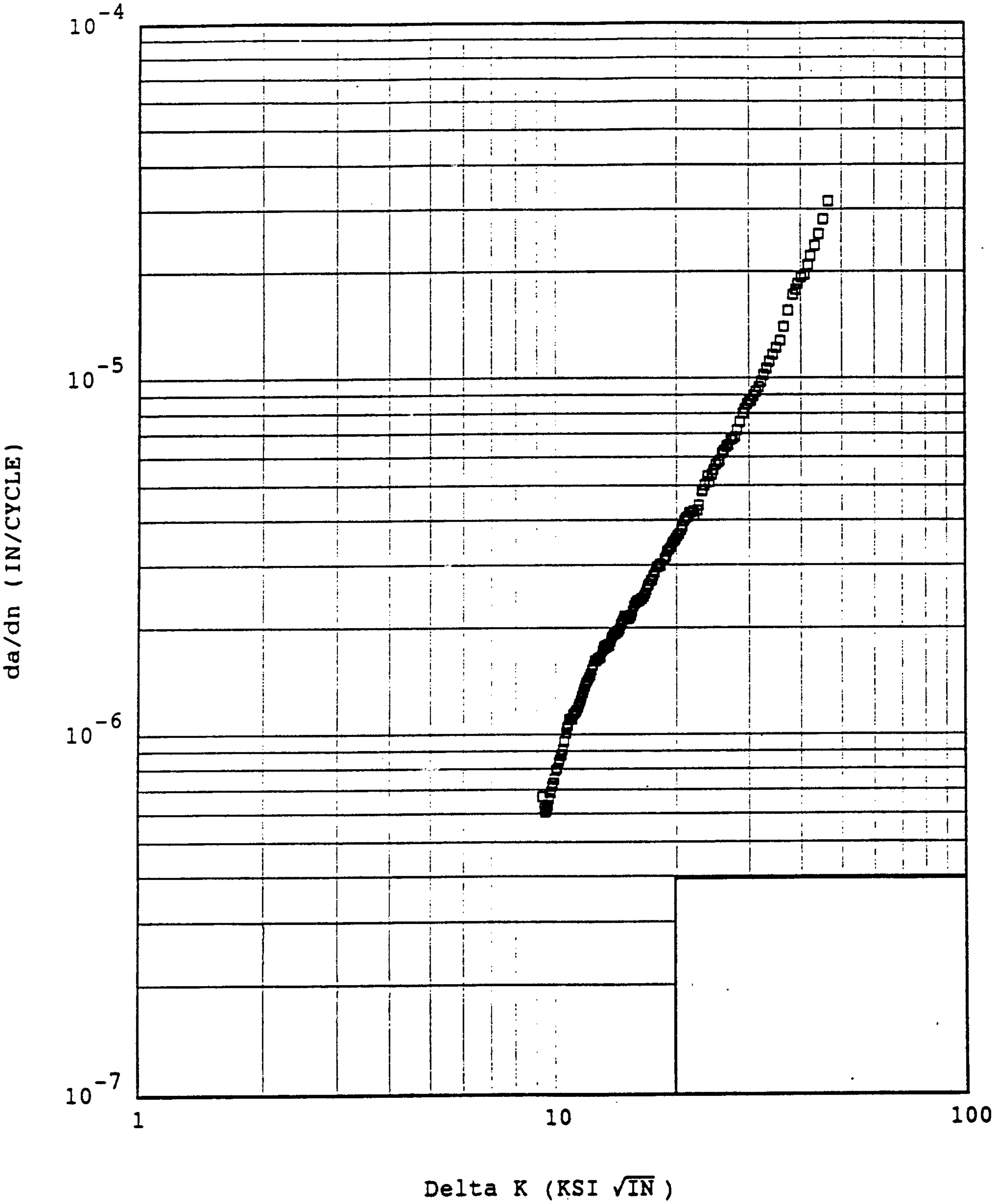
WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

DaDn vs Delta K Graph

Phone: (412)-537-3131

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-19-95
Specimen ID: 2
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT : 3.5% NaCl
PLATING :SER

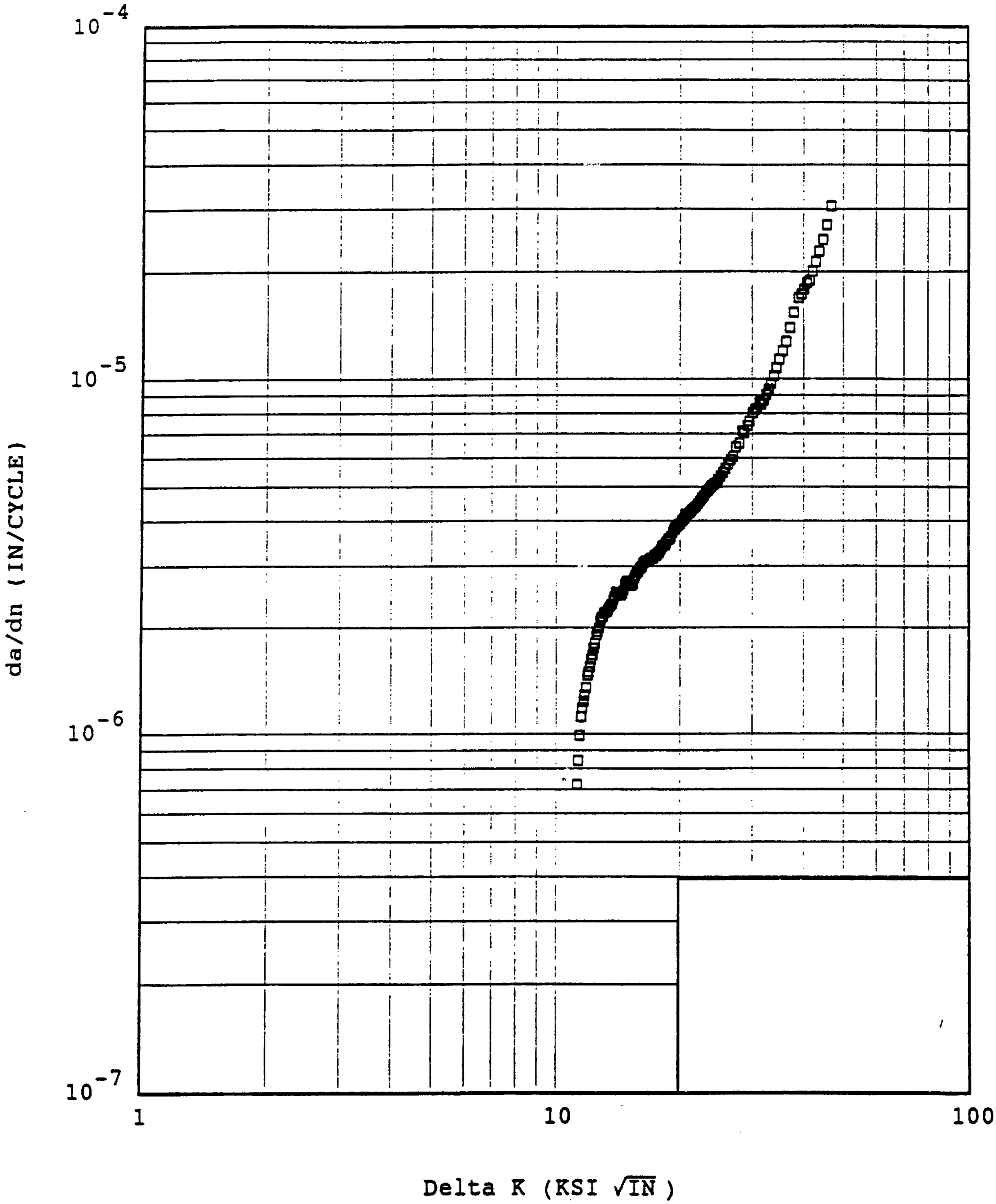



Testlog: 067684

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

Customer: OCEAN CITY RESEARCH
WMTR Report No.: 5-08076
Test Date: 09-08-95
Specimen ID: 3
Test Temperature(F): Room

R-ratio: .1
ENVIRONMENT: 3.5% NaCl
PLATING : SER




Testlog: 067685

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

The above listed solutions should be considered for replacement of cadmium plating on the following stock/part numbers:

**Table 1.**
**MK 75 Gun Mount Part Numbers and Names**

| | | | |
|---|---|---|---|
| 5518352+GF | BRACKET | 5518352+OW1 | BRACKET |
| 5518353+GF | FRAME | 5518353+OW | FRAME |
| 5518353+OW1 | FRAME | 5518500+GS | PIN |
| 5518505+GF | COVER | 5518505+GS | HOOK |
| 5518506+GS | PIN | 5518508+GF | HOOK |
| 5518508+GS | HOOK | 5518531+GS | ROD |
| 5518544+GS | HOUSING, SPRING | 5518551+GS | ROD |
| 5518554+GS | TIE ROD | 5518555+GS | SPACER |
| 5518558+GS | LINK, CLEVIS | 5518571+GS | ROD, SPRING |
| 5518572+GS | HOUSING, SPRING | 5518576+GS | SHAFT |
| 5518578 | NUT | 5518585+GS | WASHER |
| 5518586+GS | PIN | 5518587+GS | SPACER, RING |
| 5518591+GS | PIN | 5518592+GS | ROD |
| 5518593+GS | SPACER | 551848+GS | SPACER |
| 5518664-1+GS | SHIM | 5518664-2+GS | SHIM |
| 5518674+GS | RING | 5518683+GS | RING, FLAT |
| 5518731+GS | SHIM | 5518732-1+GS | SHIM |
| 5518732-2+GS | SHIM | 5518496+GS | HINGE |
| 5518497+GS | PIN | 5518498+GS | HINGE |
| 5518733+GS | SLEEVE | 5518754+GS | PLATE |
| 5518755+GS | WASHER | 5518757+GS | SPACER |
| 5518759-1+GS | SHIM | 5518759-2+GS | SHIM |
| 5518761-1+GS | SHIM | 5518761-2+GS | SHIM |
| 5518761-3+GS | SHIM | 5518762+GS | SPACER |
| 5519135+GF | FLANGE | 5519135+GS | FLANGE |
| 5519147+GF | HOUSING | 5519147+GS | HOUSING |
| 5519557+GS | STUD | 5519657+GS | HOUSING |
| 5519672+GS | PIN | 5519176+GS | SPACER |
| 5519686 | BOLT | 5519717+GS | T LOCK |
| 5519738+GS | HOUSING | 5519739+GS | ROD |
| 5519754+GS | STOP | 5519766+GS | AXLE |
| 5519767+GS | PULLEY | 5519768+GS | SPACER |
| 5519772+GS | SLEEVE | 5519773+GS | ROD |
| 5519774+GS | RING | 5519777+GS | SLEEVE |
| 5519892+GS | HOUSING | 5519897+GS | HOUSING |
| 5519924+GF | BRACKET | 5519924+OW1 | BRACKET |
| 5521066+GF | LEVER | 5521066+GS | LEVER |
| 5521067+GF | STUD | 5521068+GF | STUD |
| 5521068+GS | STUD | | |

## PRECAUTIONS BEFORE REPLACING CADMIUM PLATING

It is necessary to stress that even though exposure to cadmium can be dangerous to one's health, hasty substitution of cadmium plated parts with untested options could potentially threaten the safety of ship's force. It is imperative that while reviewing information on alternatives, unique engineering needs be taken into consideration. Consultations with other engineers are highly recommended and proposed modifications should be passed through all of the appropriate chains of command/approval.

We highlight that some of the information within the guidance document could be superseded once more laboratory or in-service data is obtained. (This data will be released once it is available.) Laboratory data is predictive, but not always reflective of long-term data. The mechanical test data is not exhaustive and must be supplemented by other sources. For example, data from shock testing or the high temperature operation of substitute materials would have to be obtained from outside sources or require separate review.

## SECTION 6: PLAN FOR IMPLEMENTATION OF CADMIUM REPLACEMENT MATERIALS WITHIN THE U.S. NAVY

### CONTENTS

## SECTION 6: PLAN FOR IMPLEMENTATION OF CADMIUM REPLACEMENT MATERIALS WITHIN THE U.S. NAVY

### BACKGROUND

As the final stages of the SERDP funded portion of the Cadmium Replacement Program have drawn to a close, it is imperative that the results of this effort be made available to those who can impart and impact the necessary changes within the U. S. Navy. This guidance provides important information to assist in the decision making process for cadmium replacement. The topics included are:

- Where cadmium plating is found
- Why cadmium plated parts are being eliminated
- What safety precautions to take in the interim
- How to go about effecting change
- Alternate surface coatings and base materials
- Factors to consider prior to making replacements

### OBJECTIVES

1) Inform Navy personnel of the importance of cadmium elimination.
2) Facilitate the transition to alternate materials by providing item managers with a primary source of guidance.
3) Encourage participation, since the task of product elimination is too large for just one group.
4) Ultimately eliminate cadmium plating by attrition of parts.

### DISTRIBUTION

The proposed distribution of the cadmium replacement guidance document includes NAVSEA's designated program management offices (SEA 91-surface ships and SEA 92-submarines), life cycle managers (LCMs) within the SEA 03 engineering directorate, and Naval Shipyard and SUPSHIP management and field activity support within SEA 07. Managing offices are expected to further the distribution to all appropriate activities within their command. Maintenance activities, in-service engineering agents (ISEAs), and NAVSEA's primary support laboratories should also be fully aware of the guidance. This listing may not be all inclusive. The desired effect is that all operational levels work towards the common goals of preventing cadmium plated components from entering into new construction and eliminating the existing plated parts during routine maintenance operations.

## APPLICATIONS FOR CADMIUM PLATING - Where to Look?

Through efforts funded by the Strategic Environmental Research and Development Program, we have identified a large portion of the shipboard applications which use cadmium. Cadmium plated hardware is used extensively aboard U. S. Navy ships. It is prized for its combined qualities of corrosion resistance, lubricity, thinness of surface film, and lustrous appearance, so far unmatched by any single replacement material. There are literally thousands of stock numbers for which cadmium is specified. Hardware, electrical equipment, and electronics components account for over 50% of cadmium plated parts. Mechanical power transmission equipment, lighting fixtures, engine accessories, vehicular equipment components, engine and turbine components, valves, pumps, compressors, pipe fittings, instrumentation, electrical power distribution equipment, communication equipment, and bearings may also use some degree of cadmium plating. The most prevalent metal substrates for the plating are steel for hardware, and aluminum alloys for electrical applications.

Specifically, cadmium plated parts include both high and low strength fasteners (e.g. bolts, nuts, screws, washers, etc.), electrical connectors, hinges, springs, pins, and rings. Somewhat larger items may also be plated including housings, flanges, levers, shafts, star wheels, caps, plates, and rods. Many of these items are found within combat systems like the Mk 75 gun mount, the Mk 45 gun mount, and the Mk 15 Phalanx. Nearly all cadmium has been eliminated from the galley, the area of greatest risk for food contamination. Although the use of cadmium in the manufacturing of food service equipment (e.g. cookware) is prohibited, plated hardware items like shelf brackets or latches may still be found in small numbers. Living quarters and office spaces may contain furnishings assembled with cadmium plated hardware.

## REASONS FOR CADMIUM ELIMINATION

By phasing out the use of cadmium plated parts aboard ships, the Navy will be providing a healthier working environment for the Fleet. Environmental regulations are affecting procurement and disposal costs. International regulations are starting to affect foreign military sales, leaving us with used equipment supplies that must be disposed of properly.

NAVSEA Notice 9074 (Appendix A) dated 16 May 1977, provides a thorough description of the issues most relevant to shipboard engineers and item managers. Among other things, the document advised that cadmium use be cancelled for applications operated above 205°C and that procurement orders should specify alternate materials (e.g. zinc plating) whenever an option was given within a specification. Most of the guidance within this document from nearly twenty years ago still pertains, yet progress has been slow in eliminating cadmium from Navy systems. While revising documentation, any options previously listed for alternate materials should be compared to new data available, including that provided within this report and any other applicable sources.

## SAFETY PRECAUTIONS

Some recommended (but not necessarily authoritative) safety measures to be taken while aboard ship have been identified during our program and are summarized below. Consult with the command or yard industrial hygienist or safety officer for comprehensive/authoritative guidance.

It is advised that ship's force use caution when working in the vicinity of equipment known to contain large quantities of cadmium plated hardware. Research indicates that prolonged exposures to cadmium can lead to lung cancer and kidney dysfunction. The plating material can often be recognized by its greenish-gold appearance, yet it appears in a broad range of colors including silver. Cadmium compounds are most detrimental to one's health once dust particles become airborne or ingested. These particles can not be smelled or tasted. Cadmium can be expected to be in particulate form once a plated surface has started to corrode (evident by a whitish surface film) or when material is removed from plated components (as during wire brushing or blasting). It is not known to be readily absorbed through the skin.* Shipboard exposure can be minimized by following some simple guidelines:

- Wear protective breathing gear while working in the vicinity of any surface preparation activity involving material removal (e.g. scraping, grinding, or blasting).
- Avoid heating cadmium plated surfaces, as the fumes can be toxic.
- Be sure to wash hands thoroughly prior to handling or consuming food.
- Cadmium is a hazardous waste. Disposal of plated hardware accordingly, and recycle when possible.
- Realize work hazards. Limit your exposure. Notify others.
- Consult with the your industrial hygienist or safety officer for comprehensive guidance.

## REPLACEMENT PROCESS OVERVIEW

An overview of the recommended replacement process follows:

1) Review all equipment documents which could feasibly specify cadmium plated parts.
2) Look for provisions for alternate materials.
   Some documents already have several coating options available. In cases like this, modification of documents by the simple deletion of cadmium plating may be an acceptable near-term solution, but not the best long-term solution. (Evaluate all options.).
3) Determine the conditions under which the component will operate (high temperatures, shock, etc.).
4) Review information on alternatives while taking unique engineering requirements of the application into consideration, including the service environment.
5) Ensure that the Navy Environmental Health Center (NEHC) has approved the process or material that you intend to use. (NEHC approval <u>must be</u> obtained.)
6) Modify documents and drawings as appropriate.
   Realize that some documents are already undergo revisions or reverting to commercial specifications.
7) Coordinate with the supply system as necessary.
8) Consult with NAVSEA 03M3 to resolve any packaging issues that may arise.
9) Monitor the performance of the newly installed parts. Keep a record of performance (both adequate and inadequate).
10) Report failures. (Weapon Systems File contains a data field for rates of failure.) This will prevent others from repeating same mistakes.

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* For detailed information on health effects of cadmium, refer to <u>Toxicological Profile for Cadmium</u> prepared by Life Systems, Inc., April 1993, for distribution by the U. S. Department of Health & Human Services, Agency for Toxic Substances and Disease Registry.

If you have already selected replacement materials, the following action is recommended:

Review this report. Determine if the replacement material or process is acknowledged. See if there are any material properties which appear as less than adequate for your application. If so, reconsider options. If not, proceed through the normal chain of approval (including NEHC) and be sure to monitor the system on a regular basis, especially if the substitute material is an untried process for the specific application.

## ALTERNATIVES FOR THE NAVY ENVIRONMENT

Despite the many alternatives being considered by other organizations for replacement of cadmium plated parts, very few coatings can match the corrosion resistance alone that cadmium plating provides within a marine environment. Therefore, it is emphasized that even though a coating may have performed well for someone else (e.g. the Air Force), it can not be expected to provide the same level of in-service performance for the Navy. A careful examination of available options must be made and compared to the specific application and service environment.

Based upon the remaining data to be obtained from Ocean City Research Corporation's follow-on testing, along with the stress corrosion cracking data from the Naval Research Laboratory, specific materials guidance will be given. Testing of aluminum substrates, as for electrical connectors, was not addressed and, at present, is not planned. One of the well utilized replacement options for moderate strength level fasteners would be the specification of stainless steels. Readers should refer to Section 5 for recommended alternatives.

### Specific Recommendations/Examples

Based on the preliminary results described in Sections 4 and 5, replacement options for selected cadmium plated parts of Table 1 are listed below. These solutions are provided for consideration by the appropriate Navy life cycle managers. The replacement recommendations are subject to change based on continued shipboard and marine atmospheric exposure, as discussed previously. In view of this, our intention was to select examples of components located in mild exposure areas (the ship's interior) on low strength materials. We recognize that the life cycle manager must carefully review the results presented in this report as they apply to their specific application. In many cases, this will require that drawings and specifications be pulled. When doing so, full regard must be given to the material's tendency for environmentally assisted cracking, strength requirements, galvanic compatibility, lubricity, temperature limitations, shock tolerance, cost, and any other attribute necessary for the particular application. And remember, all coatings, platings, and substrate materials selected to replace cadmium must be approved by the Navy Environmental Health Center (NEHC).

Feasible solutions are grouped below in accordance with their primary classification. Some options to avoid are also discussed.

<u>THIN FILM</u>. For miscellaneous steel parts (at ambient temperature) for which EAC is not a concern and the part function calls for a thin film, select from the following coatings based on the cost for the items to be plated.

- Zinc plating from an alkaline bath,
- IVD aluminum,
- SermeTel, or
- Zinc-nickel plating with an anodic E-coat topcoat for corrosion protection

<u>THICK FILM</u>. For corrosion control of steel parts *without* a thin film requirement, consider the use of:

- Standard Navy organic solvent-based coating systems,
- Powder coatings, or
- Inorganic zinc (only if applied to abrasive blasted surfaces)

Select between the thin film platings or the organic coating systems based on the cost of material application.

<u>MATERIAL CHANGES</u>: In most applications (excepting high strength fastener requirements), these materials would be effective substitutes to eliminate concerns of substrate corrosion in the marine environment. They should perform even better if parts are stored and installed in a protected space away from sea spray. (If parts are to be subsequently painted for cosmetic reasons, pretreatments may be necessary to promote coating adhesion.)

- Stainless steel 304
- Stainless steel 316
- Titanium alloy Ti-6Al-4V

<u>HIGH STRENGTH OPTIONS</u>. Defer selection of a cadmium alternative for high strength materials pending the results of the rising step-load tests. Based on previously available data, do not utilize a zinc plating from an alkaline bath for corrosion control on Grade 8 fastener materials in a marine environment. Where Grade 8 steel fasteners must be used without protective plating, utilize fasteners with an appropriate sealant and topcoat for protection. In applications where periodic seawater spray exposure (<u>not</u> immersion) is expected and routine maintenance is not likely, utilize an alternative material fastener with the requisite strength requirements (e.g., nickel-based or titanium based alloys).

<u>COST</u>. During the cost analysis, consider when (if at all) the part will be coated. A significant use of cadmium plating is for simple cosmetic corrosion control prior to installation of the part and painting with the standard Navy coating system aboard ship. A steel part left without any treatment before shipboard painting may corrode significantly by the time of installation. It is recommended that costs be verified/updated at the time of replacement, as costs will vary between vendors, with lot size, and according to the part configuration.

The above listed solutions should be considered for replacement of cadmium plating on the following stock/part numbers:

**Table 1.**
**MK 75 Gun Mount Part Numbers and Names**

| | | | |
|---|---|---|---|
| 5518352+GF | BRACKET | 5518352+OW1 | BRACKET |
| 5518353+GF | FRAME | 5518353+OW | FRAME |
| 5518353+OW1 | FRAME | 5518500+GS | PIN |
| 5518505+GF | COVER | 5518505+GS | HOOK |
| 5518506+GS | PIN | 5518508+GF | HOOK |
| 5518508+GS | HOOK | 5518531+GS | ROD |
| 5518544+GS | HOUSING, SPRING | 5518551+GS | ROD |
| 5518554+GS | TIE ROD | 5518555+GS | SPACER |
| 5518558+GS | LINK, CLEVIS | 5518571+GS | ROD, SPRING |
| 5518572+GS | HOUSING, SPRING | 5518576+GS | SHAFT |
| 5518578 | NUT | 5518585+GS | WASHER |
| 5518586+GS | PIN | 5518587+GS | SPACER, RING |
| 5518591+GS | PIN | 5518592+GS | ROD |
| 5518593+GS | SPACER | 551848+GS | SPACER |
| 5518664-1+GS | SHIM | 5518664-2+GS | SHIM |
| 5518674+GS | RING | 5518683+GS | RING, FLAT |
| 5518731+GS | SHIM | 5518732-1+GS | SHIM |
| 5518732-2+GS | SHIM | 5518496+GS | HINGE |
| 5518497+GS | PIN | 5518498+GS | HINGE |
| 5518733+GS | SLEEVE | 5518754+GS | PLATE |
| 5518755+GS | WASHER | 5518757+GS | SPACER |
| 5518759-1+GS | SHIM | 5518759-2+GS | SHIM |
| 5518761-1+GS | SHIM | 5518761-2+GS | SHIM |
| 5518761-3+GS | SHIM | 5518762+GS | SPACER |
| 5519135+GF | FLANGE | 5519135+GS | FLANGE |
| 5519147+GF | HOUSING | 5519147+GS | HOUSING |
| 5519557+GS | STUD | 5519657+GS | HOUSING |
| 5519672+GS | PIN | 5519176+GS | SPACER |
| 5519686 | BOLT | 5519717+GS | T LOCK |
| 5519738+GS | HOUSING | 5519739+GS | ROD |
| 5519754+GS | STOP | 5519766+GS | AXLE |
| 5519767+GS | PULLEY | 5519768+GS | SPACER |
| 5519772+GS | SLEEVE | 5519773+GS | ROD |
| 5519774+GS | RING | 5519777+GS | SLEEVE |
| 5519892+GS | HOUSING | 5519897+GS | HOUSING |
| 5519924+GF | BRACKET | 5519924+OW1 | BRACKET |
| 5521066+GF | LEVER | 5521066+GS | LEVER |
| 5521067+GF | STUD | 5521068+GF | STUD |
| 5521068+GS | STUD | | |

## PRECAUTIONS BEFORE REPLACING CADMIUM PLATING

It is necessary to stress that even though exposure to cadmium can be dangerous to one's health, hasty substitution of cadmium plated parts with untested options could potentially threaten the safety of ship's force. It is imperative that while reviewing information on alternatives, unique engineering needs be taken into consideration. Consultations with other engineers are highly recommended and proposed modifications should be passed through all of the appropriate chains of command/approval.

We highlight that some of the information within the guidance document could be superseded once more laboratory or in-service data is obtained. (This data will be released once it is available.) Laboratory data is predictive, but not always reflective of long-term data. The mechanical test data is not exhaustive and must be supplemented by other sources. For example, data from shock testing or the high temperature operation of substitute materials would have to be obtained from outside sources or require separate review.

## REPORT CONCLUSIONS

Through the combined efforts of the Defense Logistics Services Center (DLSC) in Battle Creek and Ships Parts Control Center (SPCC) in Mechanicsburg, 3,105 national stock numbers (NSNs) were identified which refer to cadmium plated parts in use throughout the U.S. Navy. These are present in systems such as radar, pumps, engines, and many other applications. Additionally, over 2,800 part numbers for cadmium plated components of shipboard weapon systems overhauled at the Naval Ordinance Station (NSWC) in Louisville were identified. The predominant usage classifications are steel based fasteners and small hardware, and aluminum based electrical connectors. The gathering of this data was necessary in order to target the required properties for replacement coatings and the greatest needs or voids associated with currently available technologies.

Three major concerns were priorities while identifying potential alternatives to cadmium plating which were to be incorporated into one or both of the test phases. These included: avoiding duplication of efforts with other organizations (both military and civilian) addressing this issue, maintaining compliance with present and impending environmental regulations, and insuring that use of the replacement processes would not be cost prohibitive. Coordination with NAVSEA life cycle managers (LCMs), other services, industry, and international contacts helped to ensure that these intentions were carried out. Section 3 (Material Selection) addressed environmental compliance issues and included a preliminary cost analysis for coatings using fasteners as an example.

Both the initial leveraging and screening efforts revealed that ion deposition and implantation processes, and zinc/nickel plating appeared to have the most promise for development and ultimate use within the unique Navy environment. Two coatings (zinc nickel and ion implantation) were selected to undergo additional development to optimize processing parameters (Phase I testing). Within the Phase II testing, a much more comprehensive list of plating and coating system alternatives was evaluated.

The following are the primary conclusions resulting from mechanical testing and two month exposure tests:

1. No single alternative preservation treatment/material investigated performed as a universal substitute for Type II cadmium plating with a chromate treatment (QQ-P-416E). The broad range of engineering properties afforded by cadmium can not be matched simply by an across-the-board plating substitute.

2. The type of chemical conversion coating used did not have a large effect on the adhesion of the zinc-nickel plating. Therefore, the zinc phosphate conversion coating should be used (as opposed to the chromate conversion coating) to eliminate the use of hexavalent chromium, a known carcinogen.

3. With respect to thin-film plating alternatives for use in the marine environment, the data suggest that several alternatives offer corrosion resistance comparable to cadmium on non-complex (i.e., flat) surfaces. The most promising materials are SermeTel, zinc-nickel plating with an anodic E-coat topcoat, IVD aluminum, and zinc-plating from an alkaline bath.

In areas with a complex shape (e.g., fasteners, holes, weld beads, sharp edges) or areas that retain moisture (e.g. channels and crevices), none of these plating alternatives performed as well as cadmium.

4. Inorganic zinc coatings provide good corrosion protection to the substrate and all complex surfaces, yet the coating does not appear readily applicable at thin films and as such is not a direct substitute for many cadmium plating applications. The short term data indicates that at a thickness of 2-3 mils, it will perform as well as the cadmium (of less than 0.2 mil). The performance of the inorganic zinc will decrease if the substrate can not be abrasively blasted.

5. Tin/zinc plating and zinc plating from an acid-chloride bath do not perform as well as the other thin film platings with respect to corrosion resistance.

6. All of the systems with an epoxy (MIL-P-24441) primer performed well throughout the test duration on preventing corrosion resistance on the boldly exposed surfaces. Corrosion was prevalent on each system at sharp edges and complex surfaces. The epoxy powder coat performed similarly to the solvent-based epoxy system.

7. Of the alternative sealants investigated, no performance differences were seen between the silicone RTV and the polysulfide over the short test duration. The standard Navy topside epoxy primer did not adhere well to the silicone RTV, but did adhere to the polysulfide sealant. Both of the sealants appear effective in mitigating corrosion of a fastener installed in a boldly-exposed plate.

8. Moderate cosmetic corrosion was observed on the 304 and 316 stainless steel alloys, with the 316 stainless exhibiting slightly more cosmetic corrosion resistance. No corrosion was observed on the titanium materials. The data are in agreement with the long-standing knowledge of the industry. In most applications, (excepting high strength fastener requirements) these materials would be effective substitutes to eliminate concerns of substrate corrosion in the marine environment.

While not a specific objective of the current program, there is an additional concern with these materials relating to pretreatment prior to cosmetic painting. In general, without some type of surface pretreatment, paint adhesion can be poor. This issue has been addressed by others.

9. With respect to wear (e.g., abrasion) of the leading thin film platings, the zinc-nickel with an anodic E-coat topcoat, the IVD aluminum, and the zinc-plating from an alkaline bath all had a wear resistance exceeding cadmium. The SermeTel had a lower wear resistance to cadmium.

10. None of the materials applied over the high-strength 4340 steel substrates appeared to affect the gross fatigue crack growth rate of the base material in a 3.5% salt solution. Inorganic zinc exhibited the highest deviation in crack growth rate of the materials tested.

In previous rigorous constant extension rate tests (CERT), promising coatings such as the zinc plating from an alkaline bath appeared to be more likely to promote environmentally assisted cracking (EAC) than cadmium. Potential concerns regarding EAC or FCGR may be addressed by results of ongoing rising step load tests.

11. The data from the subject testing concerning the lubricious properties of the metallic plating suggests that cadmium is typically more lubricious than other plating materials. This is consistent with other reported research.

OCRC research also suggests that the torque-tension relationship exhibited by cadmium plated fasteners is variable over a significant range and is a function of material strength and fastener dimensions. In some applications, the lubricious properties afforded by other platings such as zinc from an alkaline bath can approach those of cadmium.

12. Many of the coatings considered in this program contain constituents that are controlled (to a lesser degree than cadmium) by federal regulations. While they do not pose the same hazards that cadmium does, the environmental impact of these materials must be more thoroughly assessed.

13. These conclusions apply to ambient temperature conditions only. No testing was performed at elevated or sub-ambient temperatures. (Additionally, replacement options for cadmium plated aluminum substrates were not addressed.)

14. Detailed recommendations regarding use of the test alternatives for high strength applications are not addressed pending the completion of laboratory evaluations.

An implementation plan has been provided herein to assist equipment life cycle managers in assessing alternatives for their specific applications. Recall that the test data given applies to steel substrates rather than aluminum ones. Changes to the Naval Ships' Technical Manual (NSTM), Chapter 631 regarding surface preparation and coating of cadmium plated hardware aboard Navy ships were initiated early in the program. Those changes have received tentative approval by the cognizant Navy managers and are expected to be included in the next change notice to NSTM Chapter 631. Due to the awareness raised by this SERDP program, all references to cadmium within the military specification for heaters, ventilation, and ducting (MIL-H-16235) have recently been deleted during the revision process.

Most importantly, it should be noted that these conclusions may change based on continued exposure testing of the alternative coatings and materials. The continued efforts (including shipboard test monitoring, atmospheric exposure, and distribution of any new guidance to design engineers) will be pursued within the next year under non-SERDP funding. Furthermore, components for each system must be evaluated by the LCM on an individual basis with full regard for environmentally assisted cracking, strength requirements, galvanic compatibility, lubricity, temperature limitations, shock tolerance, cost, and any other attribute necessary for the specific application. All coatings, platings, and substrate materials selected to replace cadmium for specific uses, must be approved by the Navy Environmental Health Center (NEHC).