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TECHNICAL SUPPORT FOR IMPLEMENTATION OF ALUMINUM ION VAPOR DEPOSITION TECHNOLOGY

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ABSTRACT

Industrial production and maintenance activities conducted at Army depots typically include metal plating operations. For many years, cadmium has been commonly applied as a surface coating, using conventional electroplating processes, to provide a protective, corrosion-resistant finish. Cadmium is a toxic, carcinogenic metal and cadmium electroplating generates sludges, rinse waters, and spent plating solutions. Alternatives to cadmium electroplating exist. In many cases, aluminum coatings can be substituted for cadmium coating to provide corrosion protection and other functional requirements. Aluminum ion vapor deposition (AIVD) is a process that can be used to plate aluminum on metal parts. This technology, which was originally developed in the 1970's for use on aircraft parts, does not generate the rinse waters, sludges, or spent electrolyte solutions that are associated with conventional electroplating. With the exception of a small quantity of waste generated during periodic cleaning of internal components of the system, AIVD coating generates no wastes.

The U.S. Army Environmental Center (USAEC) provided technical assistance to Tobyhanna Army Depot (TOAD) in regard to acquisition of an AIVD system. Information acquisition efforts included completion of site visits to facilities using AIVD to discuss and observe the operation and use of this technology in depot operations. Site visits to TOAD were also conducted to discuss and review current cadmium plating operations. Outputs of this technical support effort included Trip Reports, a Bid Specification for an AIVD system, an Economic Analysis (EA) for an AIVD system, a Work Order for installation of an AIVD system, and the collection of information on AIVD technology and coatings. This paper reviews the technology and its applicability at Army depots including discussion of costs, waste reduction, and other benefits (such as reduction of employee exposures to toxic metals).

1.0 INTRODUCTION

The Environmental Technology Division (ETD) of the USAEC conducts research and development to support environmental compliance at Army depots, ammunition plants, arsenals, and other Army installations and activities where industrial manufacturing and maintenance is conducted. Since the outset of the U.S. Army's hazardous waste minimization (HAZMIN) program, the USAEC has been an active supporter of HAZMIN initiatives at all Army industrial operations. Previous initiatives relating to U.S. Army Industrial Operations Command (IOC) facilities have included the demonstration and implementation of AIVD at Anniston Army Depot (ANAD).¹ Subsequent to the successful application of AIVD at ANAD, Corpus Christi Army Depot (CCAD) also implemented the use of AIVD technology. Most recently, the USAEC provided support for technology transfer and implementation of AIVD at TOAD.

1.1 BACKGROUND

Industrial production and maintenance activities conducted at Army depots typically include metal plating operations. For many years, cadmium has been commonly applied as a surface coating, using conventional electroplating processes, to provide a protective, corrosion-resistant finish. Cadmium plating offers good corrosion resistance in salt-water environments, provides a good base for soldering, and has a low coefficient of friction that gives cadmium-plated fasteners good threaded connections with low applied torque.¹ However, cadmium is a toxic, carcinogenic metal and cadmium electroplating generates sludges, rinse waters, and spent plating solutions. These residuals contain cadmium and are listed hazardous wastes under the Resource Conservation and Recovery Act (RCRA). Treatment of the rinse water and spent solutions also generates RCRA hazardous waste and that require special handling and disposal.

Alternatives to cadmium electroplating exist. In many cases, aluminum coatings can be substituted for cadmium coating to provide corrosion protection and other functional requirements. Aluminum can be applied by metal spraying, cladding, electroplating, or ion plating.² AIVD is a process that can be used to plate aluminum on metal parts. This technology does not generate the rinse waters, sludges, or spent electrolyte solutions that are associated with conventional electroplating. With the exception of a small quantity of waste generated during periodic cleaning of internal components of the system, AIVD coating generates no wastes.

At ANAD and CCAD, AIVD coatings have been successfully substituted for cadmium electroplated coatings on a variety of metal parts. Substitution of AIVD coatings for cadmium electroplated coatings can significantly reduce the volume of RCRA hazardous wastes that are generated by depot operations. It also reduces employee exposures to cadmium and other toxic components (e.g. cyanide and corrosive solutions) that are used in the conventional electroplating process.

Multiple regulatory incentives for substitution of cadmium coatings exist and are summarized in the draft "Strategic Plan for Eliminating Cadmium from United States Army Tactical Weapon Systems" prepared by the Army Acquisition Pollution Prevention Support Office.³ Regulation of cadmium usage and contamination has become increasingly more restrictive. This trend is expected to continue in the future. Increasing costs and increasing impediments to plating operations are associated with more stringent regulation. Implementation of alternatives to cadmium electroplating is being actively pursued by the Army to minimize the generation of hazardous waste and to ensure protection of worker's health and the environment.

1.2 SCOPE AND OBJECTIVES

The scope of the work documented herein was focused on providing technical assistance to TOAD in regard to acquisition of an AIVD system. Outputs of this technical support effort included a Bid Specification, an Economic Analysis (EA), and a Work Order for acquisition of an AIVD system at TOAD, and the collection of information on AIVD technology and coatings.

2.0 CADMIUM AND ALUMINUM COATINGS

2.1 ELECTROPLATED CADMIUM COATINGS

Cadmium is a soft, ductile, silver-white metal.⁴ Electroplating of elemental cadmium onto the surface of metal (e.g., fabricated steel and cast iron) parts has been commonly practiced by the military for over 50 years. Cadmium coatings offer excellent corrosion resistance in salt water environments and extend the life of metal components, such as those constructed of high strength steels. In addition to corrosion resistance, cadmium's natural lubricity enhances its use on threaded fasteners. It is also readily solderable and serves as a good substrate for finish coatings (i.e., chromate conversion coatings and paint finishes). Ease of electroplating and high rates of deposition in addition to the desirable characteristics of the coating resulted in the widespread use of this surface plating technology.⁴ Electroplated cadmium coatings have been used on components of military equipment for many years and numerous military specifications for metal parts

require the use of cadmium coatings. Requirements for electrodeposited cadmium coatings are specified in MIL SPEC QQ-P-416E, February 1987.⁵

Cadmium electroplating is typically carried out in an aqueous bath of cadmium oxide and sodium cyanide and other electrolytes.⁶ The part being plated serves as the cathode in the electrolytic cell and the cadmium solution serves as the electrolyte. Plating operations at Army depots typically involve relatively large (e.g., 4 ft wide by 10 ft long by 4 ft deep) open top plating tanks. Push-pull ventilation systems are typically used to control fumes. At TOAD, the typical sequence of cadmium plating operations is: ultrasonic cleaning, caustic dip, hydrochloric acid dip (to strip old cadmium coatings), cadmium electroplating, chromate conversion coating, and finish painting.⁷ Water rinses are conducted between operations.

Cadmium is a toxic metal and proper handling of the metal and industrial residues is required. Acute industrial poisoning can occur through the respiration of cadmium dusts or fumes during common operations such as melting, welding, or heating of cadmium-plated steel.⁴ Regulation of cadmium in the workplace and in the environment has continued to become increasingly more stringent. The Occupational Health and Safety Administration (OSHA) regulations set the permissible exposure limit (PEL) for cadmium at 5 µg/m³ in workplace breathing air.³

Cadmium can contaminate the workplace at Army depots through a variety of sources related to cadmium electroplated surfaces. Cadmium solutions and fumes must be managed during the electroplating operation. Dragout of cadmium on plated parts contaminates rinse waters which require subsequent treatment prior to discharge. The sludges generated at the wastewater treatment plant also become contaminated with cadmium. Additionally, during repair and maintenance activities, cadmium plated parts are routinely handled. Stripping of surface coatings, including cadmium electroplates, is accomplished by both physical and chemical means. These operations generate cadmium contaminated residuals such as spent shot blast media and chemical stripping solutions and sludges. Management and disposal of cadmium containing wastes and residuals is regulated under the hazardous waste regulations of the RCRA and under the Clean Water Act (CWA) by the U. S. Environmental Protection Agency (USEPA).

Increasingly more stringent requirements stipulated by environmental and health protection regulations have resulted in increasing costs associated with cadmium electroplating. Both the current costs associated with meeting requirements, such as waste management, transport and disposal, medical monitoring, record keeping, preparation of manifests, and the potential future costs that may be associated with potential future liabilities resulting from disposal of hazardous wastes, have impacted the use of this process. It is anticipated that tighter regulatory restrictions and increasing costs associated with meeting these environmental and health related restrictions will continue for the foreseeable future.

Methods to minimize the wastes generated and engineering controls to enhance workplace safety must continue to be employed and expanded. Generation of wastes (sludges, liquids, and gaseous emissions) is inherent to cadmium electroplating operations. The most effective control of cadmium contamination is process substitution and elimination of most or all of the cadmium electroplating conducted at Army depots.

2.2 ALUMINUM COATINGS

Aluminum is a soft, light, odorless, tasteless, nontoxic, nonmagnetic, and highly conductive metal.⁴ The formation of a thin, tightly adherent, oxide film provides excellent corrosion resistance.⁴ Aluminum coatings can be applied by metal spraying, cladding, electroplating, and ion deposition.² The ion deposition process is advantageous because of the control of thickness that it affords. Additionally, ion plated coatings typically have good adhesion and are applied at low substrate temperatures (90-150° F).² "Throwing power," the ability of the process to coat complex shaped parts, is another strong point of ion vapor deposition.² The main benefits of aluminum coatings as a substitute for cadmium are that they can provide better corrosion protection while avoiding both worker exposure to toxic metals and the generation of hazardous wastes.⁸ Advances in vacuum coating technology has significantly increased its competitiveness with conventional electroplating.⁹

AIVD technology was developed by the McDonnell-Douglas Aircraft Company to apply a uniform, dense and highly adherent coating of aluminum to aircraft parts.² Since its development, AIVD systems have been installed and operated at over 70 facilities, including both government/military and commercial applications.¹

The Navy uses this technology at both Jacksonville and Pensacola Naval Air Stations. The Air Force confirmed that substitution of AIVD coatings met or surpassed all requirements during testing of parts from multiple Air Logistics Centers by the McDonnell Aircraft Company.⁹ Air Logistics Centers, including Warner Robins, Ogden, Oklahoma City, and Sacramento, operate AIVD systems for coating of aircraft parts and are converting their cadmium plating workload to AIVD coatings. It is anticipated that about 80 percent of the cadmium work load can be converted.⁸ Parts that are too large, or that have deep recesses, are not candidates for AIVD coating and remain part of the workload for cadmium plating lines at these ALC's.

AIVD coatings are also applied during production, as opposed to overhaul and maintenance operations. For example, AIVD is the prime coating used on components of the Patriot, Amraam, and Lantirn projects.¹⁰ Other specialized applications of AIVD coatings include coating of ferrite assemblies on the Patriots phased array radar system.¹⁰ The conductivity of aluminum allows it to be used for electrical bonding and for EMI and RFI shielding.¹⁰ Most recently, AIVD has been used to coat plastics and composites.⁶

Military Specification MIL-C-83488C establishes the requirements for coating low alloy steel, stainless steel, aluminum alloy and titanium alloy parts with high purity (99 percent plus) aluminum.¹¹ For coatings of the same thickness, aluminum provides significantly greater corrosion resistance than cadmium based on the specified salt spray test requirements. For example, a 0.5 mil coating of cadmium must provide 96 hours of resistance (determined by formation of white corrosion products or corrosion of base metal) without a chromate conversion coating and 168 hours with a conversion coating.⁵ The same thickness of aluminum must provide 336 hours of protection without conversion coating and 504 hours with the chromate coating (without evidence of base metal corrosion).¹¹

AIVD generally produces a consistent coating thickness.² Variations in the thickness of the coating associated with the relative position of the parts in the chamber can occur during a single plating run.¹² However, the consistency and thickness of the coating in deep recesses or the interior of holes is difficult to control.¹⁰ Aluminum coatings will be applied in recesses or bores to a depth approximately equal to the diameter. However, the coating typically loses uniformity and thickness at a depth exceeding 0.5 diameter.¹⁰ The AIVD coating, as deposited, has significant microporosity that is a result of the way in which aluminum accumulates on the surface during plating. The AIVD coatings must be densified by peening (burnishing) with glass beads to consolidate the coating.¹² Porous coatings breakdown more quickly, provide less protection from corrosion, and potentially can cause hydrogen embrittlement of high strength steel substrates.¹³

A higher torque is usually required to install an AIVD coated fastener than a cadmium coated fastener because of aluminum's higher coefficient of friction.² Torque-tension relationships have been a concern of the aerospace industry for flight-critical fasteners. As a result of this concern, AIVD coatings have been subjected to rigorous testing and evaluation. The use of a cetyl alcohol lubricant can reduce torque requirements by up to 70 percent.^{2,9} In addition, this concern led to the development of aluminum-teflon paints.² AIVD coated fasteners have been used in aerospace applications for nearly 15 years. Very few reports of problems related to the torque-tension issue have been reported.² In general, it has been found that the use of a lubricant has been adequate and that the differences have not been sufficient enough to warrant changes in installation procedures, tools, or hole sizes.²

While AIVD processing is a technologically advanced system, the degree of operator competence required is similar to that of conventional cadmium electroplating. It has been found by ANAD and CCAD, that the systems are well received by plating shop personnel and that existing personnel could be readily trained and become productive and efficient AIVD operators.

3.0 AIVD PROCESSING

3.1 EQUIPMENT AND OPERATION

Currently, two equipment vendors provide AIVD systems that are similar in function and appearance. Major components of the system include the vacuum chamber, vacuum pumps (a roughing pump, a mechanical pump, and a diffusion pump), parts handling equipment (e.g., dollies, racks, barrel coaters, etc.), and a computer controller. Although the system can be operated manually, computer controllers facilitate use and increase production efficiency. The production area should be clean and air conditioned as the presence of contamination and humidity greatly increase pump down times and can affect the quality of the coating. A separate, positive pressure room which the AIVD chamber opens into, is typically constructed to house the parts handling and operator control area. The size of the work area can be varied, however, sufficient room to allow the use of multiple parts racks and dollies increases productivity.

AIVD is conducted in a cylindrical shaped vacuum chamber constructed of mild steel. The internal size of a standard chamber is approximately 6 ft in diameter by 12 ft long. This yields a usable plating zone of approximately 5 by 10 feet.² System utilities include electricity (e.g., 480 V, 3 Phase, 60 Hz, 300 amp service), argon gas (compressed cylinder supply), non-contact cooling water (~25 gpm at 40 psig) and gaseous nitrogen for the cryogenic pump, and compressed air (60 - 80 psig) to operate vent valves and air ride dollies. Ancillary equipment, such as glass bead peening booths and grit blast booths require compressed air (e.g., 70 cfm at 80 psig) and electricity (460 V, 3 phase, 60 Hz, 3 amps and 110 V, 1 phase, 60 Hz, 6 amps).

Surface contamination, including rust, mill scale, and residues of cleaning, can affect the quality of the AIVD coating including reduced adhesion and less corrosion protection.¹² Subsequent to cleaning, the parts are dry blasted with aluminum oxide (150 - 220 mesh) to prepare the surface for plating.⁹ Cleaned parts to be plated are hung from a rack which is then slid into place in the chamber. Because the surface of the parts must be clean and free of surface contamination, operators typically wear cotton gloves to avoid transfer of skin oils to the parts. The number of parts plated during a cycle and their relative positions and orientation, can affect plating thickness and quality. To facilitate parts loading, specialized dollies that have air flotation pads on the legs allow the parts racks to be easily moved. In addition to standard parts racks and dollies, specialized racks (e.g., rotating racks) and barrel coaters are available. The use of air ride dollies necessitates that the shop area have a flat, smooth floor.

A mechanical pumping system is used to achieve the 9×10^{-6} torr operating vacuum.¹⁰ To decrease pump down times, a cryogenic cooler can be used to remove water vapor present in the chamber. Pump down time is adversely and significantly impacted by the presence of humidity in the chamber. Therefore, the front end of the chamber is located in an air conditioned room. This allows control of humidity and helps to minimize contamination of the parts prior to coating. The only discharge from the system is the exhaust from the vacuum pumps. A single 4 inch diameter PVC vent pipe is used for this purpose. This is the sole discharge from the system. Environmental permits are not required for installation and operation.

Once parts have been loaded into the chamber and the vacuum (10^{-6} torr) achieved, argon gas is introduced to raise the pressure to about 6×10^{-3} torr. A high-voltage negative potential is applied to the substrate which generates a plasma within the chamber. The bombardment of the surface by argon ions provides a final cleaning of the parts.¹⁰

Aluminum wire is fed to ceramic boats that are electrically heated to 2000° F. The aluminum vaporizes and is deposited on the surface of the parts hung in the chamber. The boats are mounted on a motorized, movable rack which traverses the length of the chamber and back. The number of passes made by the boat rack, the speed of the ceramic boats, and the feed rate of the aluminum wire are critical operating parameters that affect coating thickness, consistency, and quality. While AIVD plating is not a strict line-of-site process, the distance between parts and between the parts and the boats and their relative orientation can affect the thickness and consistency of the coating. Therefore placement of parts is also a critical parameter that must be controlled by the operator. Depending upon the complexity of its shape, the parts may have to be turned and the plating process repeated to ensure complete coverage. Alternately, rotating racks may be

used to move the parts during plating. Depending upon the operating parameters and the level of humidity in the chamber, pump down and plating can take 1 to 2 hours.

At the completion of the plating process, a cool down period of about ten minutes is allowed to elapse. The chamber is then vented to return to atmospheric pressure. The parts rack is then removed from the chamber. At this point, the AIVD coating is porous due to the columnar structure associated with the plated aluminum.⁹ This porosity is reduced and the coating densified by peening (burnishing) the surface with glass beads at 20 - 30 psi in a glove box or blast booth.¹⁰ The peening not only serves this function but also ensures that proper adhesion of the coating to the substrate was achieved.

3.2 WASTE GENERATION

Removable stainless steel liners (thin panels) are used to avoid coating of internal components of the chamber with aluminum. The liners must be periodically removed and cleaned, either by mechanical or chemical stripping, to remove accumulations of aluminum. The panels not only protect the chamber but they also serve to reduce the time required to pump down to vacuum. If the accumulations of aluminum are not removed periodically, their porous nature will trap gases and moisture which will then off gas during pump down. This can significantly increase the time required to achieve the working vacuum. The panels can be stripped chemically, for example by dipping in a sodium hydroxide solution, which generates a caustic residue. This residue is a RCRA characteristic hazardous waste (corrosive) and is the only waste stream directly associated with the AIVD process. Because the depots typically have a sodium hydroxide dip tank as part of their conventional plating operations, this residue is not a new or additional waste. Alternately, the aluminum removed from the shields potentially can be recovered and recycled, though not directly back to the AIVD process.¹⁴ The frequency of cleaning is dependent on production rates and is indicated by noticeable increases in pump down times. The volume of this waste stream is dependent upon the workload put through the AIVD system.

Other wastes are generated during pre- and post-treatment of parts plated by AIVD. However, these treatments are not unique to the AIVD process and are the same treatments commonly used in conventional cadmium electroplating (e.g., degreasing, stripping of existing paint and surface coatings, grit blasting, chromate conversion coating, and finish painting). While such waste streams are not avoided through the substitution of AIVD for cadmium electroplates, they would not become contaminated with cadmium in the case of complete substitution. However, even after implementation of AIVD coating, the pre-treatment of parts during overhaul and maintenance will continue to generate cadmium contaminated residues until all cadmium parts are returned from the field, cycled through the maintenance system, and plated with AIVD coatings.

3.3 COST

The cost of an AIVD system is dependent upon a number of variables including system options, delivery distance, and other factors. Site preparation costs typically will include construction of an air conditioned clean room with a smooth, flat floor that can accommodate the weight of the system and production parts. The estimated cost range for an AIVD system is presented in Table 1. The delivery time for an AIVD system can be anticipated to be in the range of 24 to 36 weeks.

Depending on the application, the capital and operating costs for an AIVD system can be higher than those for conventional cadmium plating.⁶ However, the benefits to the life-cycle costs achieved by the avoidance of hazardous waste generation, worker exposure to toxic metals and corrosive solutions, and the need for ventilation and fume control, can offset this differential. The cost differential is anticipated to continue to decrease in the future as cadmium plating becomes increasingly more expensive due to increasingly stringent environmental and health regulations. Advances in vacuum plating technology which increase productivity and reduce cost are also likely to continue as the use of this technology expands.

TABLE 1. ESTIMATED COST RANGE FOR AN AIVD SYSTEM.

Item	Estimated range, \$
AIVD System (6 by 12 ft chamber)	\$480,000 - \$510,000
Parts racks/dollies (2)	\$44,000 - \$46,000
Barrel coating rack	\$40,000 - \$42,000
Cryogenic pump	\$32,000 - \$40,000
Shipping, installation, training, and spare parts	\$20,000 - \$70,000
Pressure glove boxes	\$15,000 - \$25,000
Site preparation	\$50,000 - \$50,000
Total	\$681,000 - \$783,000

4.0 AIVD PLATING OPERATIONS AT ARMY DEPOTS

During the course of the technical assistance provided under this project, site visits and meetings were held at ANAD, CCAD, and TOAD. The purpose of this activity was to obtain information on the success of implementation of AIVD technology at ANAD and CCAD and to obtain information on lessons learned that could benefit implementation at TOAD.

4.1 ANAD

An AIVD plating system was first installed at ANAD in early 1991 under a previous USAEC demonstration project.¹ Subsequently, a second system has been installed to increase production capabilities. Both systems are co-located in a common shop area. Aluminum coatings are applied to various vehicle and engine parts.

Although the original unit did not include a cryogenic cooler, it has since been retrofitted with one. The bid specification used for the acquisition of the second AIVD unit required a cryogenic cooler. This system component reduces pump down time to approximately 30 minutes and is seen as a critical element for efficient operation. Standard air flotation dollies supplied by the manufacturer are used to hold and move the large parts racks. Multiple dollies and racks were purchased to enhance productivity. The use of multiple dollies and racks allows the operators to load and/or unload parts during AIVD plating cycles. The size of the shop must take into account the number of dollies and parts racks that will be used and must allow room to maneuver them to and from the chamber.

The plating process at ANAD includes pretreatment consisting of vapor degreasing, chemical stripping of existing cadmium or aluminum coatings and, abrasive blasting with aluminum oxide. The blast booths (glove boxes) used for the abrasive aluminum oxide blasting are dedicated for use on parts that will be plated by AIVD (i.e., pretreatment of parts is segregated to avoid contamination of parts with residuals that could affect the AIVD coatings). Subsequent to completion of the AIVD coating cycle, aluminum coated parts are peened (burnished at 20 - 30 psi) with glass beads in dedicated blast booths (glove boxes). The parts then receive a conventional chromate conversion coating.

Depot personnel have modified the parts racks, through the addition of fixed eye bolts and alligator clips, to facilitate the placement and removal of parts. Additionally, operators initiated treatment of the protective shields with boron nitride.¹ This treatment serves as a release agent making removal of aluminum accumulations much easier. Lessons learned at ANAD indicate that both a cryogenic cooler and a computer controller should be included in the equipment bid specifications for any new AIVD system. Additionally, operator training, multiple parts racks and dollies should also be incorporated to maximize the efficiency of startup and operation. Finally, dedication of pre- and post-treatment equipment (e.g., blast booths/glove boxes) was recommended to help minimize contamination of parts which can result in inadequate coatings.

4.2 CCAD

An AIVD system was installed at CCAD in early 1993 and has been successfully used in plating operations since that time. The CCAD is equipped with an automated computer controller (Intel 486 based). This controller is programmed to control all operational parameters including pump down, argon cleaning, the number of passes and the speed of the ceramic boats, and the aluminum wire feed rate. The controller has also been programmed to permit initiation of an automatic startup sequence which initiates warmup of the system prior to start of the production shift. This significantly reduces the initial startup time for the operators. Additionally, the operating parameters associated with specific parts, including the number of parts and their specific placement on the parts racks, can be entered into the system's data base. This historical information assists the operator in ensuring that consistent coatings are applied.

Standard air floatation dollies are used at CCAD. As at ANAD, CCAD operators have made modifications to the parts racks that facilitate parts handling. The addition of eye bolts, fixed in strategic locations on the rack, speed the loading and unloading operations for commonly plated parts. This modification also helps avoid electrical short circuiting that can occur if parts touch or are not properly attached to the rack. The parts racks have been modified by CCAD operators, with the addition of fixed eye bolts, to aid in the placement of parts.

Lessons learned at CCAD confirm that a cryogenic cooler and a computer controller (including a color monitor and 24-pin narrow carriage printer) should be included on any new system. Operator training by the equipment vendor should be included in the purchase package. CCAD operators recommend that a week of initial training be completed prior to actual use. After a month of operating experience is gained, a second week of training is recommended to enhance operator skills and to address problems encountered during initial operations.

A substantial volume of cooling water is currently used by CCAD to operate the system. CCAD operators recommend that the use of a water chiller be investigated as a potential means to reduce the quantity of water required. This would also permit the use of conditioned water that would prevent buildup of calcium scale in the cooling system. Other recommendations included construction of a clean-room large enough to allow use of multiple parts racks and dollies, and inclusion of a pre-award survey at the vendors facility to ensure that the specific equipment to be installed is fully operational prior to shipment. The latter recommendation should help minimize startup times.

4.3 TOAD

TOAD supplies and maintains Army communications and electronic equipment, approximately 40 percent of the current work load is overhaul and maintenance. New fabrication makes up the balance of the workload and is increasing. Application of cadmium surface coatings by electroplating is used during standard operations and wastes typical of cadmium plating are generated. Additionally, abrasive blasting and hand sanding generates residuals contaminated with cadmium. Because cadmium contamination is present in approximately 60 percent of the total hazardous waste generated by the depot, TOAD is seeking to replace at least part of its cadmium plating with aluminum AIVD. The AIVD system, when acquired, will be installed in a new Industrial Operations building which is currently being designed.

5.0 IMPLEMENTATION OF AIVD AT TOAD

In general, the AIVD coating process is impacted by few regulatory restrictions and generates essentially no wastes. Based on the HAZMIN benefits and on specific successes achieved by ANAD and CCAD and other military and commercial applications, TOAD Production Engineering staff determined that AIVD would benefit their operations. Review of the capital equipment acquisition process revealed the need for preparation of formal Bid Specifications, an Economic Analysis, and a Work Order.

5.1 BID SPECIFICATIONS

An equipment Bid Specification was prepared in the format specified by the TOAD Production Engineering staff. Because a significant time will lapse prior to procurement of an AIVD system, the Bid Specification

will have to be reviewed and updated/revised as necessary to reflect current conditions at the depot and any advances in AIVD technology. The Bid Specification identifies the minimum requirements for the design, manufacture, inspection, performance, and installation of an AIVD system. The specification sets minimum criteria so that technological advances are not limited. A full size chamber, 6 by 12 feet, is specified. Although smaller chambers are available and the possibility of specifying a smaller vacuum chamber was discussed with the Production Engineer, a full size system has greater flexibility in operation and throughput. Based on lessons learned at ANAD and CCAD, a cryogenic pump ("cryopump") and a computer controller are included in the Bid Specification as requirements. Standard features including air ride dollies, parts racks, and dual barrel coaters are also included. In addition to the equipment, the specifications also address provisions for technical manuals and training of operators.

5.2 ECONOMIC ANALYSIS

An Economic Analysis (EA) was prepared for implementation of AIVD at TOAD. However, all data and information required for completion of an actual economic analysis was not available. Critical information including current and projected work loads, number of parts that will be plated with the substitute coating, and waste generation rates for specific cadmium plating operations was either not available or is anticipated to change prior to implementation. Therefore, a draft EA was prepared to serve as a guide for subsequent revision when the anticipated procurement is immanent. Several significant assumptions were required for completion of the draft EA. Most significantly, the relative number of parts that would receive the AIVD coating was estimated as a percentage of the cadmium plated workload. This assumption controls the number of shifts that an AIVD system would operate, which in turn controls labor and utility costs. Similarly, the actual reduction in cadmium waste generation rates had to be estimated.

5.3 WORK ORDER

A Work Order was prepared for completion of site preparation work necessary for installation of an AIVD system at TOAD. This Work Order was prepared to facilitate reviews and planning that will be conducted by the facility engineers. The information included in the draft Work Order provides information on required space, utilities, floor loadings, etc., that will be used by the designers of the new building in planning for an AIVD system. The Work Order specifies the requirements for a "clean room", approximately 26 by 37 feet, to serve as the air conditioned AIVD plating shop. This room must have smooth (no cracks or grooves), level (to 1/4 inch in 5 feet or better) floors. Epoxy floor coating is recommended. The floor loading limit must be 1000 pounds per square foot, or greater. The air conditioning must be capable of maintaining $70^{\circ}\text{F} \pm 2^{\circ}$ at a relative humidity of 50 percent ± 5 percent. A single 4 inch diameter PVC exhaust duct will vent the vacuum pump through a roof ventilator. This is the only air discharge. Non-contact cooling water (40 psig, $<80^{\circ}\text{F}$, 24 gpm) will be required for the pumps. Other utilities include electrical (480 V, 3 Phase, 60 Hz, 300 amp for the AIVD system and 460 V, 3 Phase, 60 Hz, 3 amp and 110 V, 1 Phase, 60 Hz, 6 amp for the blast booths), air (60-80 psig, 70 cfm for the blast booths and parts rack dollies), welding quality compressed argon and nitrogen gas. An area of approximately 44 by 37 feet will be required for the AIVD system, including the clean room, all mechanicals, and pre- and post-treatment blast enclosures.

5.4 SUBSTITUTION OF COATINGS

The substitution of aluminum coatings for cadmium coatings is controlled by the weapons or systems program office responsible for the part. Each part must be evaluated by the program office to determine if the substitute coating is acceptable. Qualification testing and acceptance process can be a time consuming undertaking.⁸ "Blanket approvals" are not typical and the approval process is carried out separately for each specific part. A specific logic chart should be developed at each location (i.e., depot) and potentially for each weapon system or parts program office/manager during implementation of AIVD coatings. The chart should be developed with input from the production engineering group, the plating shop, and the program manager responsible for the part or system. Print and assembly drawings of the part and the weapon system must be reviewed during the assessment to acquire information on tolerances and critical coatings, etc.

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