Replacement of Chromium Electroplating Using Advanced Material Technologies On Gas Turbine Engine Components

By Jerry D. Schell & Mark Rechtsteiner

Navy and Army Depots, and Air Force Air Logistics Centers (ALCs) generally use electrolytic hard chrome (EHC) plating in gas turbine engine maintenance operations to rebuild worn or corroded parts, restore dimensional tolerance, and replace worn or damaged chrome previously applied. This process involves the use of hexavalent chromium (hex-chrome), a known carcinogen. Hex-chrome is listed on the U.S. EPA's list of 17 "toxic enemies" and its 33/50 program targeted for hazardous material reduction. OSHA is considering decrease of the personal exposure limit for hex-chrome from the current 0.1 mg/m^3 to 0.005 mg/m^3. Complying with these new regulations will significantly increase the compliance burden and operational cost of EHC plating. This paper, from the 2000 AESF Aerospace/Airline Plating and Metal Finishing Forum, outlines a joint project by the ALCs and OEMs (including GE Aircraft Engines) to demonstrate and approve thermal spray and HVOF coatings of gas turbine engines. The project, budgeted for more than $3M over three years, is starting in fiscal year 2000. It is anticipated that this project will demonstrate not only reduced pollution but also reduced weapon system cradle-to-grave costs by lowering the cost of operation and maintenance. Expected benefits include: (1) Processing time will be significantly shorter for thermal spray and HVOF coatings than EHC; (2) reductions in hex-chrome emissions; and (3) thermal spray and HVOF coatings are expected to reduce the frequency of component repair and defer the need to fabricate replacement parts for older engines.

Electrolytic hard chrome plating (EHC) has been widely used by OEMs and the Department of Defense (DoD) weapon systems community in the sustainment of weapon systems' performance. The overhaul of gas turbine engines at military depots is no exception. The traditional uses of EHC on gas turbine components can include rebuilding of local areas that have experienced wear, corrosion, or material loss of previously existing surface treatments such as EHC, nitriding or carburizing. The primary use of EHC has been limited to applications where continuous use temperatures range up to about 427°C (800°F), which causes excessive oxidation of the EHC at higher temperatures. A few applications exist, however, where short exposures ranging up to about 538°C (1000°F) occur during the engine cycle.

EHC is applied by reduction of hexavalent chromium ions (hex-chrome) to form metallic chromium on the surface being plated while it is immersed in a solution of chromic acid. The EHC plating process is a low-efficiency process that results in vigorous gas evolution at the electrode. This can result in airborne mist that contains hex-chrome, a known human carcinogen. It is the airborne mist that has been widely recognized as an environmental, safety, and occupational health problem. OSHA air standards currently allow a permissible exposure limit (PEL) of 0.1 mg/m^3. A 1996 OSHA study, at a PEL of 0.051 mg/m^3, by Johns Hopkins estimated about 285-342 excess deaths per 1,000 workers among chrome plating workers. These numbers are somewhat higher than the comparable figures were for asbestos. New PELs of 0.005 mg/m^3 to as low as 0.0005 mg/m^3 have been discussed by OSHA, and were scheduled to be implemented as law in October, 1999. The new PEL, however, has been temporarily delayed while opposing advocacy groups contest over the final new PEL value.

Another EHC environmental issue that has perhaps received less recognition has been the permissible concentrations of hex-chrome in plant discharge water that goes into publicly owned treatment works (POTWs). The EPA has plans to release new lowered limits by a court ordered deadline of December 2002. The current EPA metal finishing category standards (CFR 40, Part 433) look at total chrome limits without distinguishing hex-chrome. The maximum daily limit for total chrome is 2.77 mg/L with a monthly average limit of 1.71 mg/L. The new limits being looked at for the Metal Products and Machinery (MP&M) category legislation were initially set at 0.3 mg/L maximum daily limit and 0.2 mg/L monthly average after Phase 1. These proposed limits are currently under further review in public hearings.

The lower air and water permissible limits and reporting requirements for hex-chrome will result in significant compliance costs. The DoD community is responding to these future compliance issues by closely examining the uses of alternative materials and processes with careful attention to technical requirements and life cycle costs. A major effort to address EHC use in the DoD was organized in 1996 in a DoD and industry collaboration known as the Hard Chrome Alternatives Team (HCAT). HCAT recently linked up with the DoD's Propulsion Environmental Working Group (PEWG), which brings together the DoD and GTE manufacturers, and their suppliers, to address environmentally driven technical issues for gas turbine engines.

In general, HCAT has been finding that not only do cost-effective alternatives for EHC exist, but they often result in improved performance that would warrant making the changes from EHC to the alternatives on technical merit alone. During the past 18 months, a DoD/OEM team was formed under HCAT and PEWG to reduce or eliminate EHC usage in GTEs at military depots.

Survey of EHC Usage for Gas Turbine Engine Components

A number of OEMs and depots that maintain GTEs have been formulating plans to address the reduction of EHC usage. Table 1 summarizes the OEMs, DoD depots, engine models, and number of components that have been identified that utilize EHC for sustainment of the GTEs used in weapon systems. The major OEMs participating include GE Aircraft Engines, Pratt & Whitney, Rolls Royce-Allison, and Pratt & Whitney-Canada. Efforts are also underway to secure participation by Rolls Royce-UK for the AV-8B Harrier engine. The DoD maintenance facilities involved at this time include USN Jacksonville and Cherry Point Naval Aviation Depots (NADeps), USAF Air Logistics Command (ALCs) at Oklahoma City and San Antonio, and the USN Naval Surface Warfare Center's North Island Depot (GTEs for ship propulsion). U.S. Army participation by Corpus Christi Army Depot for helicopter GTEs is uncertain at this time.

The GTEs involved include J52, T56, T58, T64, T400, T700, TF30, TF33, TF34, TF39, F100, F101, F110, F118, F404, F406, and LM2500. The initial emphasis has been to identify components for which the EHC can be replaced easily by high velocity oxygen fuel (HVOF) or air plasma spray (APS) thermal spray coatings. Current estimates are that about 70 percent of all EHC-plated GTE components can be thermal sprayed. A total of 282 EHC-plated GTE components have been identified, so far, that could be thermal sprayed instead of EHC-plated. The largest number of EHC-plated components on one engine is 42, and the lowest number is three. Components with EHC, considered previously to be non-repairable or throw away parts, remain unaffected by the program at this time.

Most of the components can be grouped by function into a few families. These include shafts, housings, gears, seals, and a miscellaneous category to catch the remaining assorted types of components. Table 2 gives a representative listing (for GE Aircraft Engines) by families of components from various GTE models that are viable candidates for

Table 1
Depots, Engine Models, OEMs, Weapon System, & Number of Components

Potentially Affected Defense System Programs

Depot	**Engine Models**	**OEM**	**End Use Weapon System**	**Number Components**
NADEP Cherry Point	T58	GEAE	CH-46 helicopter (Navy and Marines)	29
	T64	GEAE	CH-53 helicopter (Navy and USAF)	27
	T400	P&W Canada	UH-1N (Marines)	6
	F406/408	RR UK	AV-8B (Marines)	
NADEP North Island (TF39 Core)	LM2500	GEAE	Military Marine (U.S. Navy & 23 International Navies)	22
NADEP Jacksonville	TF34	GEAE	S-3 (Navy); A-10 (Air Force)	29
	F404	GEAE	F/A-18 (Navy); F-117 (Air Force)	5
	J52	*P & W*	A-4; A-6; EA-6B	6
Oklahoma City ALC	TF33- P3/P103	P & W	B-52H (Air Force)	12
	TF33-P7A	P & W	C-141 (Air Force)	
	TF33-P100	P & W	E-3 (Air Force)	
	TF33-P102A/B	P & W	KC-135; C-18; E-8 (AF)	
	F100	P & W	F-15, F-16 (Air Force)	41
	F118	GEAE	B-2 (Air Force)	3
	F110-100/129	GEAE	F-16 (Air Force)	
	F110-400	GEAE	F-14 (Navy)	
	TF30-P109	P & W	EF-111A (Air Force)	
	TF30-P414	P & W	F-14 (Navy)	
San Antonio ALC	TF39	GEAE		
	T56	RR Allison	C-130	42
	T56-A-501K	RR Allison	Military Marine -ships	
	F100			
Corpus Christi Army Depot	T700	GEAE	H-60, AH-64, SH-2 helicopters	10
TOTAL				**232**

EHC replacement by HVOF or APS thermal spray coatings. The parent material of each component has been included in Table 2.

Component Parent Materials & Replacement Coating Materials

The GTE chrome replacement project differs from the other existing HCAT projects in two main respects. First, a GTE is a complete mechanical system that results in a wide variety of components with differing design considerations, operating conditions, and parent materials. Other HCAT projects focus on a specific family of components, such as landing gears or actuators having similar design considerations, operating conditions, and only involving several different parent materials. For GTEs, the resulting wide variety of parent materials used to make the GTE components are shown in Table 3.

The top half of Table 3 is a listing of the 18 different parent materials identified to date for the 282 components with EHC. The bottom half of Table 3 lists the nominal compositions of the seven representative parent material alloys selected for extensive testing in a joint test protocol (JTP) developed for the GTE chrome replacement program. These seven alloys were selected on the basis of use volume, as generic alloy family representatives, and for special considerations such as low tempering temperatures (9310) or very complex multi-step heat-plus-cryogenic treatments (AM355). They include IN718, IN901, A286, AM355, 17-4PH, 4340, and 9310.

The second way in which the GTE chrome replacement project differs from other HCAT projects is in the wider variety of thermal spray coatings being considered for use. Multiple considerations have contributed to the larger number of coatings being considered for GTEs:

- It is a direct fallout of the greater variety of applications and a desire to find the "best practices" for them.
- The depots involved may not all have HVOF equipment, or HVOF equipment may not be available when urgent jobs are scheduled. Adding APS equipment as an option will add flexibility.
- APS coatings have been used successfully in some commercial applications for EHC replacement.
- It is quite likely there will be a trade-off between direct replacement costs for EHC and life cycle costs based on the type of applications and whether APS or HVOF are used; having both options will add flexibility.
- All the proposed coatings are currently in use in GTEs for wear applications not involving replacement of EHC.

The six alternative coatings under consideration for replacement of EHC are listed in Table 4. They include four HVOF coatings: (1) WC-17 Co, (2) Cr_3C_2-20 NiCr, (3) Co-28 Mo-17 Cr-3 Si, (4) Co-28 Mo-8 Cr-2 Si; and two APS coatings, WC-17 Co and Co-28 Mo-8 Cr-2 Si. All of the above coating chemistries are starting powder compositions and are given in weight percent. The coating processes will be developed using statistically designed experiments based on such coating properties and process monitoring response factors as microstructure, microhardness, adhesion, deposition rate, coupon temperature during spray, and Almen strip deflections as an indicator of coating residual stresses. Several of the coatings have undergone property development in earlier HCAT project efforts.

Technical Considerations For EHC Replacement Coatings

One must begin with consideration of the purposes and function of EHC on the GTE components in determining the technical considerations for its replacement. EHC-plated components

Table 2
Examples of Selected Components, Families, & Parent Metal Alloys

Depot	Engine	Part No.	Nomenclature	Family	Material
NADEP	T58	4005T29P01	GG turbine rear shaft	Shafts	Lapelloy C
Cherry Point	T58	5002T30P01	PT wheel & shaft	Shafts	A286
	T58	5011T04G02	#4 Brg housing	Housing	Inco W
	T58	5016T95P01	Compressor rear shaft	Shafts	AM355
	T58	6010T57G04	HPC spool fwd shaft	Shafts	AM355
	T64	3008T42P01	Actuator piston	Misc	Greek Asc
	T64	4002T29P01	#3 seal runner	Seals	8740
	T64	4005T80P01	PTO radial drive shaft	Gears	9310
	T64	5007T03P02	Compressor front shaft	Shafts	AM355
	T64	6005T26P01	Compressor rear shaft	Shafts	IN718
	T64	6005T69P29	#3 Brg support	Housing	410 SS
	T64	6026T50P01	Aft differential brg sleeve	Housing	A286
NADEP	TF34	5027T53P01	#7 seal runner	Seals	IN718
Jacksonville	TF34	6008T48	Axis B bevel gear	Gears	9310
	TF34	6016T81P04	LPT rear shaft (ID & OD)	Shafts	IN718
	TF34	6052T85G01	B sump housing	Housing	IN718
ALC	F110	9502M27	#4 brg seal housing	Housing	A286
Oklahoma City	F110	1441M96	HPT rear shaft	Shafts	IN718
NADEP	LM2500	L25712P01	HPT rear shaft	Shafts	IN718
North Island					

may have originated as a result of the original new component designs or by introduction at engine overhaul. The reasons for incorporation of EHC plated surfaces may include: to provide a load-bearing surface; for dimensional build-up to provide for favorable grinding of high-precision tolerances or correction of mismachined dimensions; or to give surfaces with favorable erosion, wear, friction, or corrosion properties.

Component Design & Risk Level Considerations

Next, one must identify the component design considerations for those components with EHC to be replaced. This begins with assessing the risk levels for changes to the components. In order of decreasing risk levels, what are the flight safety, performance, and customer satisfaction concerns? The first risk area—flight safety—may depend on component location in the engine, in addition to how highly stressed the component is. The component location affects the flight safety in determining the risk level for changes from EHC to an alternative coating because of the potential for internal damage, should an unexpected failure occur. Critical rotating components are almost always higher risk than static components. Similarly, components in the front or core of the engine have the potential to do more damage in the event of failure than those located on the outside or near the exit end of the engine.

The second risk level is that the performance of an alternative coating may affect engine performance. For example, a change in the coating's ability to maintain a tight fit in the presence of wear may affect engine thrust or specific fuel consumption rates. An alternative coating that does not wear or corrode as much as the EHC it replaces may result in less performance degradation and, therefore, lower life cycle costs and/or increased weapon system readiness.

Some evidence for this has been seen, already. A few isolated instances of component changes from EHC to HVOF coatings have already happened. The HVOF coatings have reportedly resulted in components being returned to service up to several times without the necessity of HVOF coating refurbishment. Experiences such as this compare very favorably to prior EHC history on the same component, in that the EHC needed refurbishment at every depot exposure of the component. Conversely, a coating change that had negative results on maintenance of tight assembly fits of components could decrease fleet readiness and/or life cycle costs. Care must be taken to assure this does not happen.

As part of the component design risk assessment, effects of the EHC replacement alternatives on the material properties of the component parent material will need to be considered. Is the ultimate tensile strength or the heat treat condition of the parent metal affected? Is the fatigue strength affected, can hydrogen embrittlement occur, will thermal expansion coefficient matches be changed, or can other properties be affected? All such considerations are relative to the effects of the EHC and must result in properties equal to or better than those obtained with EHC. The component's minimum, maximum, and typical operating conditions have to be considered, along with what portion of time is spent at those conditions. These can include stress, temperature, surface contact loads, and whether it is lubricated or dry. Finally, the component geometry and location of the EHC area for thermal sprayability of the alternatives must be considered.

The third risk level is one of customer satisfaction and perceptions. These may include how the weapon system owner, engine assembly personnel, overhaul depot process engineers, or quality technicians perceive changes from EHC to alternative coatings. They may be alarmed by a different appearance, need to use different inspection or engine monitoring methods or, conversely, have a previous comfort level with the planned change based on past experiences. Sometimes there may or may not be a rational basis for application of those past experiences

Table 3
Components' Parent Metal Alloys

All Parent Metal Alloys Identified for Various Components

IN718	4140	17-4PH
Incoloy 901	4340	410 SS
Inco W	8630	L605
AM355	8740	C355
A286	9310	
Greek Ascolloy	17-22H	
	Nitralloy 135	
	Lapelloy C	

Nominal Compositions in Wt % of Parent Metal Alloys Selected for Materials Joint Test Protocol

Alloy	**AMS Spec**	**Ni (+Co)**	**Cr**	**Fe**	**Mo**	**Nb+Ta**	**Ti**	**Al**	**C**	**Mn**	**Cu**	**Si**	**B, other**
IN718	5663	50-55	19.0	19.0	3.0	5.1	0.9	0.50	0.08	0.35 max	0.75 max	0.45 max	0.006 max
IN901	5660												
	5661	41-44	13.5	35.0	6.0	——	2.7	0.25	0.05	——	——	——	0.01
AM355	5743	4.5	15.5	75.5	2.9	——	——	——-	0.13	0.85	——	0.5	0.1 Nit
A286	5731	26.0	15.0	52.7	1.3	——	2.1	0.3	0.04	1.5	——	0.7	0.005, 0.3 V
17-4PH	5355	4.1	16.0	76.4	——	0.28	——	——	——	——-	3.2	——	——
4340	6415	1.75	0.8	95.8	0.25	——	——	——	0.40	0.70	——	0.3	——
9310	6260	3.25	1.2	94.1	0.12	——	——	——	0.10	0.55	0.35 max	0.3	——
	6265												

to the current EHC replacement changes under consideration.

Alternative Coating/Process Considerations

There are also a number of factors that need to be considered for the EHC replacements relative to EHC effects. The adherence and cohesive strength of the replacement has to be comparable or better than EHC. The microstructure, composition and porosity of thermal spray alternatives need to be understood and controlled to assure consistent performance. The hardness of the EHC replacement will affect its load-bearing and wear characteristics and the wear characteristics of the opposing contact surface. Coating residual stresses should be compressive and controlled to assure that consistent favorable results are seen in the fatigue effects of the component parent metal. Similarly, component part temperature must be controlled during the alternative coating application process, and the acceptable temperatures can vary by parent material.

For example, a gear part made of 9310 steel should be kept below about 275°F because it has a low final tempering temperature of about 325°F. A 4340 steel component may tolerate 350°F during the coating application process because it has a higher tempering temperature. One must remember, however, that just because a parent material such as IN718 for a shaft may be capable of tolerating a higher application process temperature, factors such as annealing of shot peened layer residual stresses or discoloration of the component may be unacceptable from a design or customer satisfaction viewpoint.

Table 4
EHC Alternative Coatings in Weight %

HVOF Process	*APS Process*
WC-17 Co	WC-17 Co
Cr3C2-20 (Ni,Cr)	Co-28 Mo-8 Cr-2 Si
Co-28 Mo-17 Cr-3 Si	
Co-28 Mo-8 Cr-2 Si	

Surface preparation, coating deposition rate, starting powder size, and powder manufacturing method can affect other considerations, such as adherence, fatigue debits, residual stresses in the coating, or component temperature during coating application, either directly or indirectly. Careful attention, therefore, must be paid to these coating material and process factors as well. All these things must be considered during the approval process for EHC replacements, limits defined, and once approval has been obtained for the alternative, care must be taken to keep out variations not explored during approvals. The foregoing considerations strongly recommend the use of processes developed by statistically designed experiments to properly understand process limitations.

Post-Coating & In-Use Considerations

Additional considerations can arise after the component has been coated. First, EHC requires a post-plating bakeout to remove hydrogen. Does the alternative coating require any type of post-application heat treatment to remove gases, improve coating properties, provide for stress relief, or apply an oxidation pretreatment to the surface? Second, EHC surfaces are ground. Will the same grinding methods work for the alternative coating, and does it require the same surface finish? Chances are good that a better surface finish may be required if the alternative is a carbide coating against soft opposing surfaces, such as elastomer or organic resin matrix composite seals or metals with a low hardness value. Third, EHC surfaces often have a sealer applied to them. Should sealers be applied to the alternatives? The answer in most cases is probably not for the HVOF-applied alternatives, but may differ for APS-applied coatings because they tend to have more porosity. Fourth, if there are post-plating inspections of the EHC, can the same inspection methods be used on the alternatives? An example might be the use of the Barkhausen method to determine if grind burn has occurred.

There can be further considerations as the component is placed in use. This may begin at assembly. Some EHC parts are assembled to interference fits and may experience chipping or spalling at either initial assembly or subsequent teardown and re-assembly operations. There are usually engine manual limits on the allowable amounts of such damage. Do the same limits apply for the alternatives? Particulate wear debris is generated when wear occurs. Is it the same in size and hardness for the alternative coatings, where does it go, and what are the possible consequences? If the particulate wear debris is in a lube system that has a monitoring method for the wear debris such as a magnetic chip detector or periodic oil analysis, does that method still work for the alternative or does it require a different sensitivity or even another method? Finally, how often is the component exposed at overhauls? Will there be interim opportunities to inspect the part visually or by borescope?

Materials Joint Test Protocol For EHC Replacement In Gas Turbine Engines

A Materials Joint Test Protocol (JTP) is under development for the GTE project. Its purpose is to address all the generic technical concerns that arise when one proposes to replace EHC on a wide variety of components with alternative coatings applied by the HVOF and APS thermal spray processes. It will compare EHC and the alternative coatings on a variety of parent metals for different types of components. The parent metals and the alternative coatings that have been selected for the JTP are those previously identified in the bottom half of Table 3 and Table 4, respectively. It should be noted that the definition of the Materials JTP is a work in progress and will be subject to change.

The Materials JTP will include six primary tasks. These include:

- Spray process optimizations
- Fatigue testing
- Wear and friction testing
- Corrosion tests
- Producibility evaluations
- Scrap component evaluations

The spray process optimizations will be conducted using statistically designed experiments. The coating microstructure, tensile bond strength, microhardness, residual stresses as indicated by type N Almen strips, deposition rates, coupon temperatures achieved during spray, and final thickness will all be given consideration. Some of the HVOF alternative coatings have already been characterized in prior HCAT efforts and will not be repeated in the current project.

The fatigue testing will be conducted using smooth round bar specimens with a 6.35mm (0.25 inch) diameter gage section. Two types of fatigue tests will be conducted, a strain-controlled LCF test at an A ratio of 0.95 and a load-controlled HCF test at an A ratio of 0.5. Testing will be conducted to generate S/N curves at 300 and 750°F for uncoated alloys, EHC plated alloys, and alloys with the alternative coatings. The EHC and alternative coatings will be applied as 12-13 mm (0.5 in.) long sections centered in the fatigue specimen gage and given a ground finish. Thicknesses of 76 mm (0.003 in.) and 381 mm (0.015 in.) will be tested. The plan as currently laid out calls for 914 individual fatigue tests due to the numerous combinations of parent metal alloys and coatings.

The wear testing will consist of fretting wear tests and carbon seal tests. The fretting wear tests will be nested, statistically designed experiments in an effort to cover the seven alloys and seven coatings (EHC plus six alternatives) and a couple of different opposing surface materials. Design factors for the test matrix will include component parent material, opposing surface material, coating, load, surface finish, test temperature, and coating thickness. The full set of test matrices will encompass 208 as currently planned. The carbon seal test method has not been finalized, but the parent metal will be 9310 steel and only one representative carbon grade will be selected for testing. About 24 tests at 300°F are envisioned with variations in coating, contact load, and surface finish included in the test matrix.

Corrosion testing has been carried out on the EHC and HVOF alternative coatings in prior HCAT efforts. The current view is that ASTM B117 salt spray tests would be added for the thin APS coatings. A few EHC baseline specimens and HVOF Co-28 Mo-17 Cr-3 Si (this coating was not included in prior work) specimens would be added to the test matrix. The test plan includes 45 specimens that will be evaluated with and without scratches that penetrate the coatings.

The producibility evaluations will address a number of issues necessary for successful use of the EHC replacements. Current views on these include such things as grinding practices, stripping methods and assembly/disassembly trials. The methods to be used for each of these areas are yet to be determined. As a minimum, the grinding practice area would include a survey of the depots where the alternative coatings would be applied. The purpose would be to determine what the depots' current EHC grinding practices are and what other capabilities they have or would need to deal with the alternative coatings. The stripping evaluations would determine if current stripping methods are suitable on all the parent metals in the Materials JTP. It will assess chemical and mechanical methods available at the depots and known methods from the thermal spray industry. The assembly/disassembly evaluations would focus on whether chipping and spalling damage occurs, to what extent it increases with multiple assembly/disassembly cycles, and which coatings are most resistant to it. It may be conducted with actual scrap parts or simulative specimens.

Scrap component evaluations will include setting up actual processes and coating representative scrap components at each of the participating depots. These components will be destructively evaluated in metallurgical cut-ups to demonstrate the required coating properties. Coupons for evaluations such as tensile bond strength and Almen values will be mounted on and processed with the scrap components and IR temperature measurements made on the parts as they are coated. Repair TOs and DMRs (engineering control documents) will be written, which reflect the process used in successful scrap component trials for implementation of the alternatives on actual engine hardware.

Summary

An extensive project for the replacement of EHC plating on GTE components being overhauled at DoD depots has been launched. It will be about a three-year effort starting in the first quarter of 2000. Considerable work has already been accomplished in identifying 232 EHC plated GTE components at six depots, what functions they serve, and what the parent metal alloys are for these components. A number of technical requirements have been considered that go into meeting the design intent of these components and candidate alternative coatings have been selected for evaluation. A Materials Joint Test Protocol that would allow for wide ranging acceptance of the alternatives based on demonstrated capabilities in back-to-back comparisons to EHC in a variety of critical technical evaluations is nearing completion. The GTE chrome replacement project will not only identify the alternatives meeting a wide range of technical requirements, but will demonstrate them on a variety of components at the six DoD depots involved in the project. Implementing the results of this project, along with other HCAT projects for other types of components, will greatly reduce hex-chrome exposures at the depots involved. P&SF

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