Corrosion Policy, Directives and Guidance –

Corrosion Planning Imperative; for Weapon, Facility & Infrastructure Procurements

1 May 2017

Table of Contents

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1. The Imperative

The American Society of Civil Engineers releases "*Report Card for America's Infrastructure*" every four years describing the condition and performance of all manner of American infrastructure from dams and bridges to roads, airports and schools. The report card is common fodder in the press when released and has not rated America's infrastructure terribly well in the past. The most recent 2013 report card grade is D+ requiring and suggested an estimated $3.6 trillion investment was required nationwide by 2020.[1] The reasons are myriad to be sure. Each of the 16 categories contained in the report are evaluated on "capacity, condition, funding, future need, operation and maintenance, public safety, resilience, and innovation."[2] Digging deeper into the reasons reveals those areas are heavily influenced by a number of factors such as age, material choices, and changing use demands. In many of the categories examined, corrosion is an underlying key factor contributing to the declining conditions.

In 2002, the *US Federal Highway Administration* released a study of direct metallic corrosion costs across a wide range of American industrial sectors. Required by Congress in the *1999 Transportation Equity Act for the 21st Century*, the study estimated the cost of corrosion in the United States at $276 billion dollars.[3] A 216-page *National Association of Corrosion Engineers International* study released earlier this year shows the cost in the US to now be estimated at $451.3 billion dollars or 2.7% of the US Gross Domestic Product (GDP).[4]

The Department of Defense (DoD) is equally familiar with the cost of fighting corrosion. The DoD manages more than 555,000 facilities (buildings, structures, and linear structures) located across more than 5,000 sites worldwide covering more than 28 million acres. The cost of corrosion specific to facilities at the time was estimated at $1.549 billion dollars.[5] The total annual cost of corrosion for DoD in 2014 was estimated at $24.7 billion dollars. That estimated cost is inclusive of weapon systems across the military services as well as facilities and infrastructure. Facilities and infrastructure costs accounted for $3 billion dollars of that total; 14.4% of the annual maintenance budget.[6]

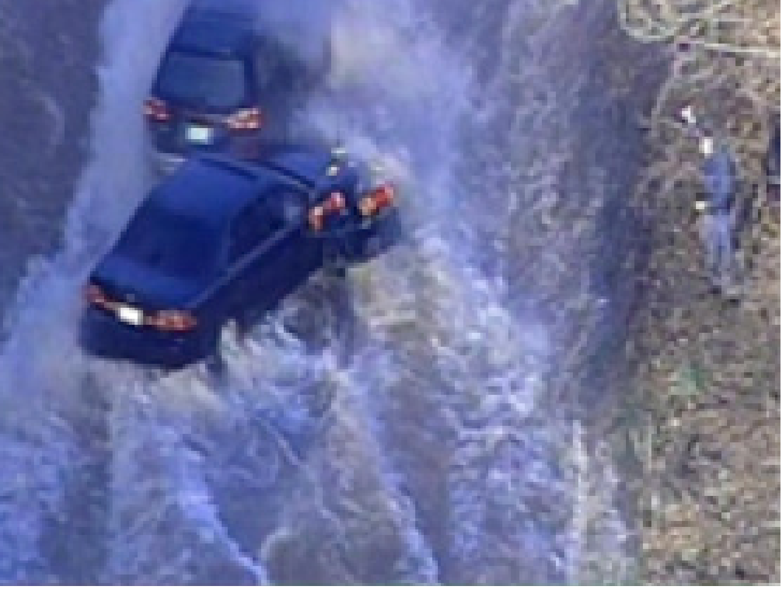
These numbers above are exceedingly large and paint equally daunting challenges. With challenges that large being wrestled by the United States Congress and agencies of the Federal Government, it's important to understand individual readers can indeed have an impact at affecting a reduction in those numbers and the impact of corrosion to weapon systems, facilities and infrastructure. The intent of this paper is to frame the issue with more than just numbers and percentages of budgets or GDP, illustrate where efforts at impact are being directed, and offer specific suggestions the reader can and should consider where possible to have an effect at the individual level.

1. http://www.infrastructurereportcard.org/
2. Ibid
3. Corrosion Costs and Preventive Strategies in the United States, Pub# FHWA-RD-01-156, Koch, Brongers, Thompson, Virmani & Payer, pg. 2.
4. International Measures of Prevention Application, & Economics of Corrosion Technologies Study, NACE International, 1 Mar 2016, pg. 4.
5. Facilities and Infrastructure Corrosion Evaluation Study, DoD Office of Corrosion Policy & Oversight, July 2013, pg. iii.
6. Metrics, Impact & Sustainment brief, DoD Corrosion WIPT, Corrosion Forum 36, 15-16 Jul 2014, pg. 5.

2. More Than Just Numbers

Consequences of Material Degradation

Corrosion is all around us. We see it in rust spots on our cars and in fence gates that don't swing as they once did when newly installed. Corrosion, or more broadly, material degradation, has at times revealed itself to be the fundamental cause in spectacular and sometimes truly tragic failures of systems, facilities and infrastructure. There are often numerous contributing factors to any calamity. Material degradation is often one of those factors and the following abstracted stories are provided to make the issue clearly relevant to all as well as underpin the importance of the issue in the framework of an acquisition and procurement process.



66-Inch Water Main Break

Christmas Eve 2008 was an otherwise normal day for commuters on River Road in Bethesda, MD until a four-foot high wall of water began raging down the two-lane road. Drivers became trapped in their cars and stranded in 20-degree weather. A 66-inch main owned by the *Washington Suburban Sanitary Commission* (WSSC), had burst, releasing 150,000 gallons of water per minute.[7]

Drivers called 911 reporting water was filling their cars and emergency rescuers arrived by helicopter and boat to pull victims to safety. Firefighters came to the aid of two women trapped inside a vehicle by gushing frigid water. The women were rescued by a firefighter who then had to be rescued in a basket lowered by a helicopter when the boat filled with water. A total of fourteen trapped motorists, including children, were rescued. Three victims were treated for hypothermia.

A forensic analysis found the 66-inch pipe, buried in 1964, was installed directly against a rock leading to the formation of cracks and then corrosion. The report states the contractor that installed the pipe had failed to properly cushion it in a bed of gravel. WSSC's chief engineer Gary J. Gumm said the problem could have been caught sooner if inspections had been up to date. According to the WSSC, inspections are $225,000 per mile of pipe. Due to budget cuts inspections had been reduced.

Some 35 million gallons of water was released as a result of the break. The financial cost of the repairs came to $1.67 million, including roadwork, dredging silt from the creek at the bottom of the hill and compensating motorists for lost property. WSSC crews replaced 80 feet of pipe after the incident. Trees that fell onto a power line knocked down a utility pole, complicating repair work and the road suffered two sinkholes and erosion.

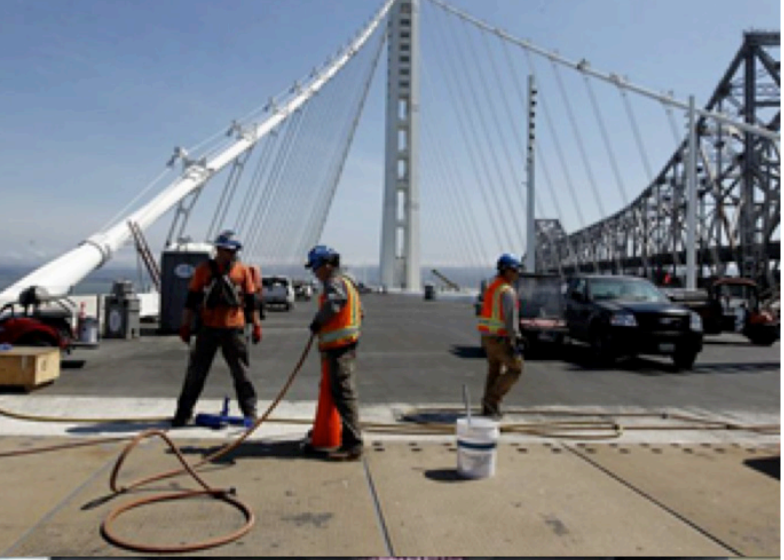
WSSC said water quality was not impacted, although users reported discolored water in Bethesda and elsewhere. A hospital, where three people rescued were treated, diverted ambulances, canceled elective surgeries and closed its trauma division because the main break left it with no water pressure. Over 12 schools across the county and a YMCA closed; all food services at a nearby mall were shut down as mandated by Health and Human Services. The *National Institutes of Health* campus and *National Naval Medical Center* were also affected by water outages.

> **"Much of the world's drinking water infrastructure, with millions of miles of pipe, is nearing the end of its useful life. For example, nearly 170,000 public drinking water systems are located across the United States, and there are an estimated 240,000 water main breaks per year, most of which are caused by corrosion."**
>
> **-NACE International Impact Study**
> **Mar 2016, pg 52**

The contractor did not install the pipe to meet proper standards. Had an inspector been required at the time the pipeline was installed or had there been a lifecycle plan for the pipeline, the issues that led to corrosion and ultimately the pipeline failure could have been averted.

San Francisco-Oakland Bay Bridge

As the second busiest bridge in the nation, the San Francisco-Oakland Bay Bridge carries 270,000 cars each



day between Oakland and San Francisco. The bridge was first built in 1936. In 1989, a 6.9-magnitude earthquake struck the Bay area causing part of the deck to buckle and killed a motorist. A design was proposed for a new span and after years of political and engineering debates, it was finally built alongside the old one to replace the damaged 2.2 miles of bridge stretching east toward Oakland.

One of the largest public works projects in the United States, the construction of the eastern span of the Bay Bridge was 10 years late and $5.2 billion over budget. In March 2013, it seemed that the new span was well on its way to completion, until workers tightened 32 steel bolts intended to stabilize the bridge during an earthquake and discovered the bolts were brittle and cracked.

For a bridge built between two major earthquake faults, the failure of the bolts placed the entire seismic safety system of the new span into question. The 32 bolts that failed were among 96 bolts delivered in 2008. After the bolts were installed, they were covered by the bridge roadways and are no longer accessible to remove or replace. The *California Department of Transportation* (Caltrans) devised a plan to add a metal saddle or collar around the seismic-stability structures to do the bolts' job.

The bolts hardened, galvanized steel had been contaminated by hydrogen, which caused them to become brittle and crack. The bolts were contaminated either during manufacturing or from being left in holes that filled up with rainwater. Hundreds of documents released by Caltrans show its inspectors found structural

"There are approximately 583,000 bridges in the U.S. Of this total, 200,000 are constructed of steel, 235,000 are conventional reinforced concrete, 108,000 are constructed using prestressed concrete, and the balance is made with other construction materials. Approximately 15% of these bridges are structurally deficient because of corroded steel and steel reinforcement. Annual direct cost estimates total $8.3B, including $3.8B to replace deficient bridges over the next 10 years, $2B for maintenance and capital costs for concrete bridge decks and $2B for their concrete substructures, and $0.5B for maintenance painting of steel bridges. Indirect costs to the user, such as traffic delays and lost productivity, were estimated to be as high as 10 times that of direct corrosion costs."

-NACE International Study
Corrosion Costs & Preventative Strategies in the US
2002, pg 3

integrity issues with some of the bolts years before they were installed and had failed to meet certain standards during testing on three occasions. In addition, to protect the bolts from corrosion the contract statement of work called for bundles of high-strength wire under tension to be grouted within 30-days of installation. These bundles were severely corroded after having been left exposed for 15 months.

The projected cost overrun due to corrosion issues that occurred before the bridge was even finished was $23 million. Caltrans may try to replace 736 of the 2,200 rods, the ones at greatest risk of cracking, depending on the outcome of tests. To pay for the bridge's construction, a higher toll of $6.00 per car was adopted.

These corrosion related failures made headlines in the press. In a nationally televised interview, a UC Berkley materials science and engineering professor bluntly criticized Caltrans for generalizing engineering knowledge required for the bridge work, and not employing metallurgical and corrosion expertise. Many others agreed, noting the corrosion occurred quickly making the problem and public safety risk evident before the bridge was completed which gave Caltrans time to make sufficient repairs. In this case, Caltrans did have a written corrosion plan but executed it without qualified personnel.

El Paso Natural Gas Pipeline Explosion

A 30-inch natural gas pipeline owned by *El Paso Natural Gas* (EPNG) exploded on August 2000, leaving a crater about 86 feet long, 46 feet wide and 20 feet deep. The released gas ignited and burned for 55 minutes and was reported visible 20 miles to the north in Carlsbad, NM. Twelve people, including children, camping under a concrete-decked steel bridge supporting the pipeline across the river were engulfed in a 1,200-degree fireball and helpless to escape the inferno when the gas ignited. Their three vehicles were destroyed.

In a report by the *National Transportation Safety Board*, the cause of the explosion was determined to be a significant reduction in the pipe wall thickness due to severe internal corrosion on a 50-year-old pipeline. The severe corrosion occurred because EPNG's corrosion control program failed to prevent, detect, or control internal corrosion within the pipeline. Contributing to the accident were ineffective Federal pre-accident inspections of EPNG that did not identify deficiencies in the company's internal corrosion control program. The safety issues identified in this corrosion failure stemmed from poor design and construction of the pipeline, inadequacy of EPNG's internal corrosion control program, inadequacy of Federal safety regulation implementation for natural gas pipelines, and inadequacy Federal oversight of the pipeline operator.

The greatest cost of the pipeline explosion was clearly the human loss — 12 fatalities, including children and infants. The explosion destroyed two other pipeline bridges nearby, and the total property damage was estimated at nearly $1 million. EPNG was required to pay a $15.5 million civil penalty and committed to spend $86 million to modify the 10,000-mile pipeline system.

After the accident, EPNG developed a program to train company personnel in internal corrosion control and mitigation procedures and implemented an integrity management program to better care for the company's 46,000 miles of gas pipelines. EPNG identified 60 segments of pipeline where the risk of internal corrosion was judged to be the greatest. These segments were then inspected using in-line inspection or other non-destructive means. Internal corrosion was discovered in eight pipelines. In six

"Corrosion is the primary factor affecting the longevity and reliability of pipelines that transport crucial energy sources throughout the nation. There are more than 528,000 km (328,000 miles) of natural gas transmission and gathering pipelines, 119,000 km (74,000 miles) of crude transmission and gathering pipelines, and 132,000 km (82,000 miles) of hazardous liquid transmission pipelines. The average annual corrosion-related cost is estimated at $7B to monitor, replace, and maintain these assets. The corrosion-related cost of operation and maintenance makes up 80% of this cost."

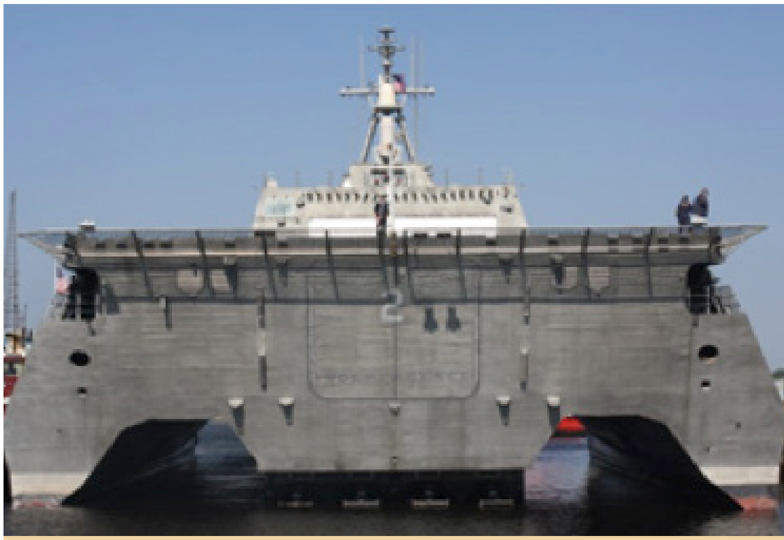
-NACE International Study
Corrosion Costs & Preventative Strategies in the US
2002, pg 3

of these lines, the company judged the corrosion to be isolated instances. EPNG sent sections of the remaining two pipelines to the company's metallurgical laboratory for analysis and chemical testing. The tests found a portion of one of these lines had general internal corrosion and localized pitting had reduced the pipe wall thickness by approximately 42 percent.

Leading up to this tragedy, EPNG failed to employ suitably qualified personnel in corrosion control; failed to investigate and mitigate internal corrosion in two of its pipelines transporting corrosive gas; and failed to suitably monitor those two pipelines to determine the effectiveness of steps taken to minimize internal corrosion. Proper lifecycle planning implemented from the construction of this pipeline and continued as required throughout the life of the pipeline could have prevented this incident.

Littoral Combat Ship 2; USS Independence

In 2002, the U.S. Navy initiated its Littoral Combat Ship (LCS) program to develop 55 fast, agile, focused-mission ships designed for operation in near-shore environments for missions such as clearing mines, tracking submarines, and humanitarian relief. The ships were intended to be affordable and easy to maintain over their lifespans. The budget for the future fleet of ships was $37.4 billion, and the Navy awarded its first contracts for as many as 10 LCSs each to two contractors; Austal and Lockheed Martin. Austal won a $465 million contract for the first ship with potential for contracts up to $3.78 billion.



"The number of ships in the U.S. includes 737 vessels on the Great Lakes, 33,668 inland and 7,014 ocean vessels, 12.3 million recreational boats, and 122 cruise ships serving North American ports. The shipping industry cost of corrosion is $2.7B, broken down into new ship construction ($1.1B), maintenance and repairs ($0.8B), and corrosion-related downtime ($0.8B)."

-NACE International Study
Corrosion Costs & Preventative Strategies in the US
2002, pg 3

The USS Independence (LCS 2), the first ship delivered by Austal, suffered galvanic corrosion within one year of being built. The Navy later found another ship, the USS Freedom, had a crack through its hull and in November 2013, it was discovered the same ship has experienced issues with its ship service diesel engines, a corroded cable and faulty air compressor. Due to these design issues, the LCS program has changed its acquisition plan multiple times and canceled contracts with both competing teams.

Commissioned in January 2010 and made mostly of aluminum, the LCS 2's early deterioration was due to a design flaw. Corrosion was concentrated in the ship's propulsion system where steel impeller housings came in contact with the surrounding aluminum structure. When two dissimilar metals come into electrical contact, as they did in this case, those metals corrode at different rates. A cathodic protection system, which would have prevented this was never specified for the ship and therefore never installed.

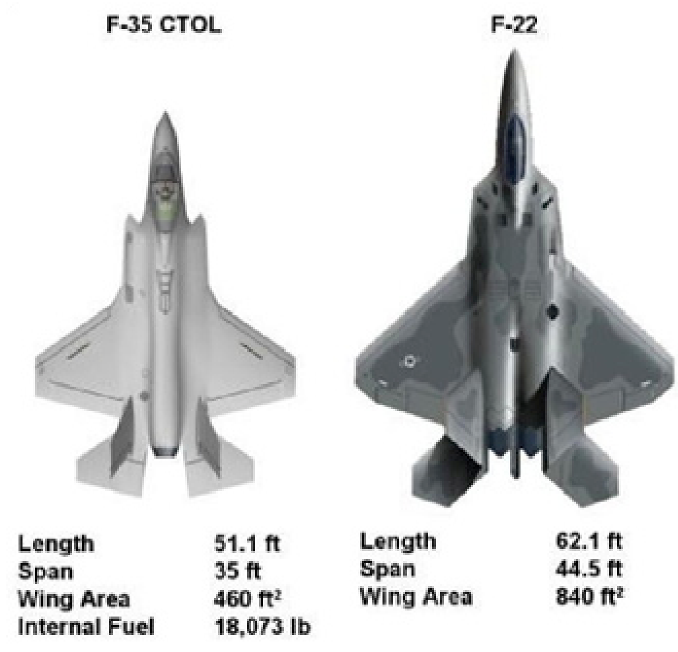
Using coatings, cathodic protection systems and other measures, the Navy has had to create a "*comprehensive corrosion management solution*" for the additional ships in the LCS class. The effort includes remediating the corrosion in the $432 million aluminum LCS 2, now in service, installing doubler plates around parts of the propulsion system as a short-term fix. Long-term repairs require installation of a cathodic protection system which will be included in the design of future LCS ships.

F-22 Raptor & F-35 Lightning II Joint Strike Fighter

The previous four vignettes presented were very synopsized examples of corrosion related failures. These vignettes presume the reader understands many circumstances, factors and myriad other issues contributed to the final failure. The following case study is treated in considerable more detail to help illustrate where better planning for corrosion and/or material degradation might have brought about very different outcomes.

Background

The F-22 and F-35 represent two of the largest, most complex and expensive acquisition programs in DoD's



history. Both have been plagued by design and corrosion problems leading to some of the largest cost overruns in DoD history. A 1980's design, the F-22 intended to avoid detection by Soviet radars, and many of its fifth-generation capabilities can be found in the F-35. These similarities also mean the F-35 faced many of the same design and cost overrun issues.[8]

A decade after its initial design, it was estimated it would take nine years and $12.6 billion to develop the F-22. Instead it took 19 years and a cost of $26.3 billion, not including the production of any aircraft. By the time production was completed, the F-22 cost an average of $412 million each; up from the original estimate of $149 million.[9] However, a GAO report found that, "*despite a 70 percent reduction in quantities for the (F-22) program, total acquisition costs only decreased by 14 percent*."[10] Similarly, estimates for the F-35 total cost of acquisition was nearly $400 billion, up 42 percent from the estimate in 2007; the price per plane has doubled since project development began in 2001. Cost overruns now total $1 billion.[11]

By October of 2007, a total of 534 corrosion findings were documented on the F-22, and substructure corrosion occurrences were becoming prevalent. Realizing this rate of corrosion damage was not sustainable, the F-22 program office began developing, testing, and installing new materials and fixes on both fielded and production aircraft. As time passed however, corrosion issues have continued to plague both programs in ways that would be largely preventable had there been adequate planning, preparation and testing.

Acquisition Issues

Cost overruns have been heavily driven by corrosion issues in both programs. There were several acquisition issues that also influenced the delays and cost overruns. Performance Based Acquisition (PBA) contracting was used in both the F-22 and F-35 systems. PBA contracting resulted in a forced government dependence on the contractor, which reduced organic expertise and limited government oversight and influence beyond the Performance Baseline.[12] For example, with the F-22, the Air Force did not include a corrosion prevention user requirement, resulting in the contractors performing exactly as prescribed and not including corrosion prevention efforts in their designs.[13] There was also no F-22 operational-level test for corrosion conducted on the prior to initial operating capability (IOC) and the length of F-22 full-scale climatic testing was cut in half.[14]

Over the four-year period, the F-22's average maintenance time per hour of flight grew from 20 hours to 34, with skin repairs accounting for more than half of that time—and more than half the hourly flying costs—last year, according to the test and evaluation office.

The Air Force says the F-22 cost $44,259 per flying hour in 2008; the Office of the Secretary of Defense said the figure was $49,808. The F-15, the F-22's predecessor, has a fleet average cost of $30,818.

-Congressional Research Service
Air Force F-22 Fighter Program: Background & Issues for Congress
2009, pg 35

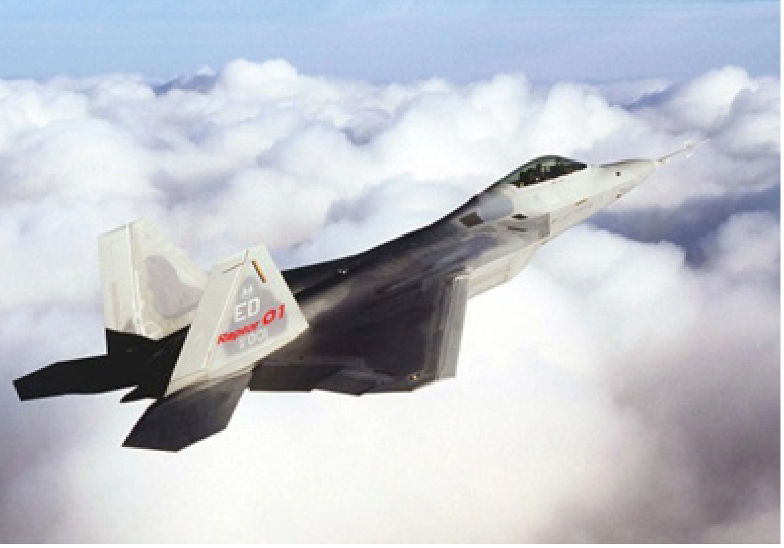
In the case of the F-22, programmatic pressure drove the government to accept these premature designs and a lack of focus on life cycle cost.[15] In the case of the F-35, there was unprecedented technical design complexity, fueled by a joint international program with three different aircraft variants.[16] A Congressionally mandated DoD corrosion evaluation of the F-35 also found that the systems engineering processes and engineering council and risk management were relatively immature.

Expertise and Organizational Issues

The corrosion evaluation team conducting the Congressional review found a common lack of corrosion focused knowledge as well as insufficient expertise in addressing low observable (LO) material and non-developmental item corrosion capability among both program offices. With the F-22, this resulted in stove piped disciplines of unequal authority, impacting corrosion performance. Both program offices were also found to be missing a considerable amount of documentation, which resulted in further organizational challenges. As a result, the contractor was unmotivated to trust or accept the organic and Corrosion Prevention Advisory Board (CPAB) expertise on LO materials and corrosion mitigation efforts. These problems have been slightly mitigated in the F-35 program office. The contractors now operate across program offices to minimize the stove piping effect, but their input is kept at a lower more appropriate level. Organizational changes integrating personnel working with corrosion materials and processes with stealth or low-observable technology are also resulting in more integration of signature corrosion materials and processes to functional areas. For example, the F-35 drainage design is significantly improved to combat corrosion compared to that of the F-22.[18]

Requirements Flow Down and Qualification Issues

As it relates to corrosion matters, the largest issue in both the F-22 and F-35 programs was the lack of requirements flow down and qualification. Neither program had a direct corrosion requirement in the acquisition strategy or contracts, resulting in a lack of corrosion focus as mentioned above. The F-22's largest problem was unrealistic contractor testing, resulting from a lack of corrosion focus during the design. In addition to the lack of operational-level corrosion testing prior to IOC, climatic



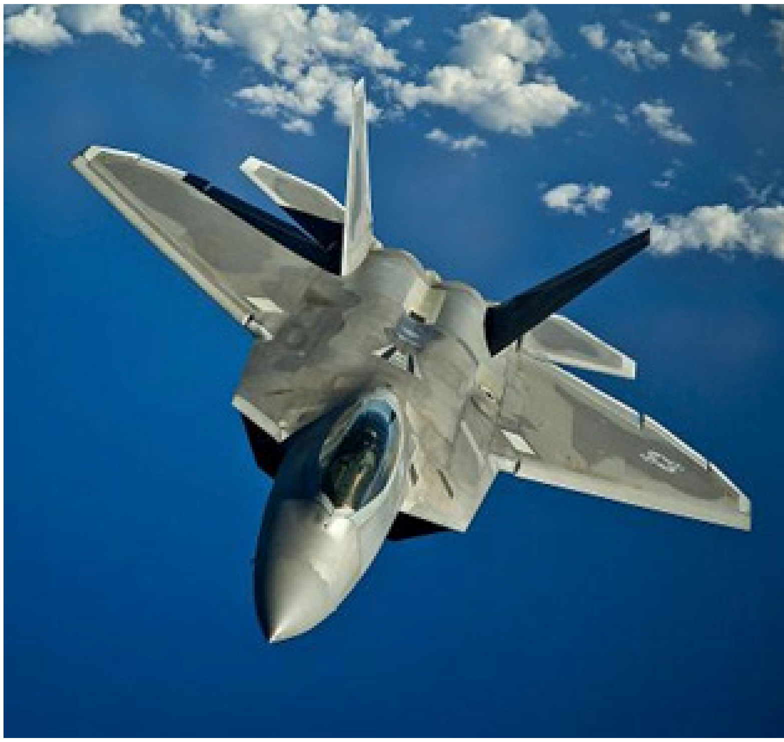
testing was severely reduced for the F-22, limiting the ability to identify corrosion issues early in the program for the aircraft user. Climactic tests can be critical to finding areas on the aircraft susceptible to corrosion. If full-scale tests had been completed, it is possible many of the corrosion issues that dogged the F-22 would not have been a problem.[19] The F-35 has experienced similar challenges. Even though system specifications call for a design service life of 20 years for the F-22 and 30 years for the F-35, there is no method for verifying tests on aircraft components will translate into these respective service lives.[20]

Both program offices frequently delegated design authority down multiple levels to subcontractors, which masked real additional risk and resulted in inconsistent Prime contractor requirements flow down.[21] For example, a F-22 sub-tier supplier changed the configuration of a flight-critical avionics system mistakenly believed to be below the purview of government review. The F-22 program office was unaware the supplier had made the change, resulting in increased aircraft field maintenance, putting it out of service, driving up costs and reducing availability.[22]

Scenarios like these illustrate the lack of qualification in both the F-22 and F-35 programs. The corrosion evaluation team executing the Congressional review found the F-22 program office frequently assumed best case scenarios and qualified designs because of similarity, rather than having an adequate system level verification of the functional baseline for corrosion in place or allowing for independent testing of contractor designs and redesigns.[23]

Design Trade Off Issues

Both the F-22 and F-35 are incredibly complex and technically advanced systems. With this level of complexity comes a set of difficult design tradeoffs and decisions. For example, corrosion performance is often lost to stealth, weight and environmental concerns. Without proper analysis and contract incentives, these tradeoffs can result in unknown lifecycle costs. The F-22 program office knew early on there were corrosion issues, but decided to prioritize other design elements ahead of corrosion risk.



For example, Col Kenneth Merchant implemented a design change that would switch out the metal used in certain panels from aluminum to titanium. This change made the system only slightly heavier but more vulnerable to radar. Overseeing the F-22 production and sustainment efforts at the time, Brig Gen C.D. Moore overruled the change due to higher radar vulnerability in order to find "the right balance" between durability, performance and low radar observability, even though the engineers "understood there was a corrosion risk."[24] In other cases, the F-22 used a non-chromated primer for environmental reasons on the outer mold of the aircraft. This primer did not provide adequate corrosion protection and resulted in increased costs to use a more corrosion-resistant hexavalent chromium coating.[25]

The F-35 faced similar issues. The choice of primer coating on the F-35 airframe represented a significant corrosion risk. In the judgment of the corrosion evaluation team, non-chromated primers may pose a larger corrosion risk than primers that contain chromates. In its section on "potential future corrosion issues for the F-35," the GAO report stated: "*The F-35 has also chosen to use a non-chromated primer that has never been tested on an aircraft in a corrosive operating environment*."[26] Fixes to issues like these were often implemented without adequate planning and testing, creating a circular loop of problems.

Leadership, Politics and Budget

In some acquisition and development programs, leadership or inexperience may be to blame for missteps such as these. The blame in the case of the F-22 and F-35 seems to lie less with individual leaders and more with politics, budget restrictions and technical complexity that developed over long life of both programs. The F-22 program has spanned more than 30 years, during which there were many changes of command in the Program Executive Office and leadership positions. All those changes make it difficult to pinpoint any one personal failure of leadership.

The early years of the F-22 development effort came right during the middle of the post-Cold War draw-down. Being the Air Force's highest priority program, the Raptor survived, but just barely.[27] As budgets fell, the Air Force was compelled to reduce overall procurement numbers from 750 to 648. The *1997 Quadrennial Defense Review* further reduced the Raptor program to 339 aircraft.[28] The largest blow to the F-22 was *Program Budget Decision 753*, issued by Secretary of Defense Rumsfeld on 23 Dec 2004. The memorandum axed over $10 billion from the program and reduced the total buy to 179 aircraft.[29]

In 2002, a $690 million cost overrun was reported, resulting in the firing of Brig Gen William Jabour as F/A-22 program executive officer and Brig Gen Mark Shackleford as F/A-22 system program director.[30] A leadership change happened again in 2008 when the Air Force openly clashed with then Secretary of Defense Robert Gates; the Air Force supported a much larger fleet of F-22s than Secretary Gates thought was necessary resulting in the forced resignation of Air Force Chief of Staff Gen T. Michael Moseley and Secretary of the Air Force Michael W. Wynne.[31]

The F-35 program also had a similar removal of leadership due to costs overruns and delays. In Feb 2010, Secretary Gates removed the F-35 Program Manager, Marine Corps Maj Gen David Heinz, and withheld $614 million in payments to Lockheed Martin because of program costs and delays.[32] Because cost overruns were cited as cause for all of these incidents, it follows that better planning and proper corrosion precautions might have reduced some overruns and there might have been less disagreement and leadership discontinuity.

Conclusion

Clearly there were several common and recurring problems with the F-22 and F-35 corrosion prevention issues, such as prioritization of other design elements, inadequate testing, lack of qualification and verification, lack of a corrosion design requirement consideration, lack of program documentation, frequent and open disagreement of leadership, and confusing contracting and management processes. While problems weren't limited to any one area, many tied to material selection and corrosion or material degradation could have been better addressed or prevented with a vetted and approved corrosion prevention and control plan. One conclusion to draw from the beleaguered F-22 and F-35 programs is that better planning and focus on corrosion prevention could literally have saved billions of dollars and maybe a few jobs.

7. http://www.washingtonpost.com/wp-dyn/content/article/2008/12/23/AR2008122302853.html
8. http://www.f-16.net/f-22-news-article2579.html
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17. Ibid.

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27. http://www.flightglobal.com/features/Lockheed-Martin-F-22-Raptor-Special/F22-History/

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3. Corrosion Related Policy & Guidance

The synopsized corrosion, or material degradation, vignettes in the preceding pages are but a few of countless others underscoring the cost and consequence of a dire issue plaguing society. With the cost and consequence understood, it's entirely reasonable for the reader to ask.....what's being done to address the issue? In short; quite a lot. The following focuses on efforts within the Department of Defense (DoD) to prevent and mitigate the effects of material degradation on weapon systems, facilities and infrastructure.

Title 10 U.S.C. 2228

As was mentioned earlier, corrosion in all its forms costs the department some $25 billion dollars annually. DoD leadership and Congressional appropriators took notice some years ago and with the intent of bringing these costs down, created the *Office of Corrosion Policy & Oversight (CPO)* within the *Office of the Secretary of Defense*. Section 1067 of the *Bob Stump National Defense Authorization Act for Fiscal Year 2003, Public Law Number 107-314*, enacted in *Title 10 U.S.C. 2228*, created the DoD CPO and charged it with the responsibility for establishing a long-term strategy to reduce corrosion and its effects.

The law requires a strategy be developed emphasizing corrosion prevention and mitigation across DoD; application of uniform requirements and criteria for testing and certification of new corrosion-prevention technologies; implementation of programs to collect, review, validate, and distribute information on proven methods and products; and establishment of a coordinated research and development program including transition of new corrosion prevention technologies into operational systems. Equally important, the law requires establishment of policy guidance, performance measures and milestones, and an assessment of the personnel and funding necessary to accomplish the long-term strategy. The law also requires regular reporting to Congress regarding progress in achieving program requirements

(d) Long-Term Strategy. —

(1) The Secretary of Defense shall develop and implement a long-term strategy to reduce corrosion and the effects of corrosion on the military equipment and infrastructure of the Department of Defense.

(2) The strategy under paragraph (1) shall include the following:

(A) Expansion of the emphasis on corrosion prevention and mitigation within the Department of Defense to include coverage of infrastructure.

-Title 10 U.S.C. 2228, Office of Corrosion Policy and Oversight Established

and objectives. Original requirements have been amended periodically and planning has been updated as needed to respond to the latest provisions of the law.

Ultimately the DoD CPO is attempting to change a bureaucratic culture's thinking about corrosion and material degradation. Purposefully changing any culture is daunting; changing an entrenched bureaucratic one like that of the DoD is then monumentally daunting. Toward that end CPO efforts include training development, outreach & communication, funding research & development efforts, and maybe most significantly, addressing the need for changes in policy, regulations and guidance. Cultural change efforts are by their nature measured, incremental and unfortunately sometimes slow to reach the organizational working level where individual DoD employees responsible for weapon systems, facilities and infrastructure can exercise difference making decisions. Just the same, an abundance of policy, regulations and guidance exists for those decision makers. Being aware of that guidance can only help change the culture and reduce the cost of corrosion to the taxpayer.

Defense Federal Acquisition Regulation Supplement (DFARS)

Within the federal government any acquisition of supplies or services is governed by the *Federal Acquisition Regulation* (FAR) as the principal set of rules guiding the acquisition or procurement process. The FAR system consists of sets of regulations issued by agencies of the federal government to govern the three phases of the "acquisition process;"

(1) need recognition and acquisition planning,
(2) contract formation, and
(3) contract administration

Nowhere in the FAR is corrosion or material degradation addressed at the moment. To be clear, the FAR is designed largely to prescribe **how** to conduct an acquisition and **not what** to acquire.

It's important to note the FAR and its agency supplements are said by the federal courts to have "*the force and effect of law*," see Davies Precision Machining, Inc. v. U.S., 35 Fed. Cl. 651 (1995). This is done pursuant to a legal doctrine known as the *Christian Doctrine*, and is based on the underlying principle that government regulations have the force and effect of law, and government personnel may not deviate from the law without proper authorization.

While often thought of as a contracting regulation, the FAR also addresses topics that apply throughout an item's life cycle, including such critical aspects as acquisition planning (Part 7), market research (Part 10), description of needs (Part 11), and contract administration (Part 42). Those involved in acquisition, whether programmatic, technical, financial, or contracting, will be familiar with many requirements as a result of their daily activities.

Each federal agency in turn publishes its own supplement to the FAR. In the case of DoD, it's the *Defense Federal Acquisition Regulation Supplement* or DFARS. While the FAR doesn't address corrosion, the DFARS does. In the section *Procedures, Guidance and Information* (PGI) section describing the content of acquisition plans under logistics considerations, program managers are

PGI 207.105 Contents of written acquisition plans; (13) Logistics considerations.

(ii) Discuss the mission profile, reliability, and maintainability (R&M) program plan, R&M predictions, redundancy, qualified parts lists, parts and material qualification, R&M requirements imposed on vendors, failure analysis, corrective action and feedback, and R&M design reviews and trade-off studies. Also discuss corrosion prevention and mitigation plans

-PGI 207.1 - Acquisition Plans

instructed to make corrosion prevention and mitigation plans a factor in their acquisition planning.

Assuming program managers adhere to these and other requirements in creating acquisition plans, thought should be reasonably given to corrosion and material degradation concerns as they apply to desired operational performance, reliability and maintenance among other factors in trade-off studies. Choosing the perfect material might provide operational performance and optimum corrosion protection at an untenable price. The trade-off in choosing a lesser material then requires consideration on how performance might be affected and corrosion protection measures to ensure appropriate reliability and maintainability. As a result, corrosion and material degradation should always be factored into decision making.

The Defense Acquisition System - Reference by Inference

The management process used to provide effective, affordable and timely systems to users is specified by DoD Directive (DoDD) 5000.01; *The Defense Acquisition System and DoD Instruction* (DoDI) 5000.02; *Operation of the Defense Acquisition System*. Much like the FAR and DFARS, these documents provide program managers and acquisition staffs across the department guidance on **how** to acquire systems in support various assigned military missions. A principle tenet of the military acquisition process is to ensure fair and reasonable prices are paid for goods and services acquired. Acquisition staffs are always challenged in weighing cost, schedule and performance against available budgets. Various terms of art such as "*total life-cycle costs*", "*sustainment costs*", "*cradle-to-grave*", and "*total ownership costs*" among others all refer to policy on the **how** guidance program managers and those responsible for establishing acquisition requirements are expected to be mindful of. The paragraph below highlights the importance specifically.

> **DoDD 5000.01; Encl 1 – Additional Policy, E1.1.18. Products, Services, & Technologies.** The DoD Component(s) shall consider multiple concepts and analyze possible alternative ways to satisfy the user need. System concepts shall be founded in an operational context, consistent with the National Military Security Strategy, Defense Strategic Planning Guidance, Joint Programming Guidance, Joint Concepts, and joint integrated architectures. The DoD Components shall seek the most cost effective solution over the system's life cycle. They shall conduct market research and analysis to determine the availability, suitability, operational supportability, interoperability, safety, and ease of integration of the considered and selected procurement solutions.

Much the same as with DFARS guidance, the guidance here holds similar weight when making trade-off decisions. If a system's expected life cycle is only months, perhaps a cheaper less corrosion resistant material is an appropriate choice. If, however, that system, facility or infrastructure is expected to last decades, then it probably makes sense to select a more corrosion resistant material that stands a lesser chance of having to be replaced over those decades and in turn keeps total life cycle costs down.

Clearly the case for corrosion as a consideration factor is being made by inference as a potential factor that could affect the acquisition, operational use and maintenance of a system, infrastructure or facility. A similar inference is made in the paragraph below also excerpted from DoDD 5000.01.

> **E1.1.29. Total Systems Approach.** The PM shall be the single point of accountability for accomplishing program objectives for total life-cycle systems management, including sustainment. The PM shall apply human systems integration to optimize total system performance (hardware, software, and human), operational effectiveness, and suitability, survivability, safety, and affordability. PMs shall consider supportability, life cycle costs, performance, and schedule comparable in making program decisions. Planning for Operation and Support and the estimation of total ownership costs shall begin as early as possible. Supportability, a key component of performance, shall be considered throughout the system life cycle.

In order to realize the goals of the total systems approach described, the PM should logically factor corrosion and material degradation concerns into programmatic decision making. Ultimately PMs, and anyone with acquisition responsibilities, are in a position of weighing factors of cost, schedule and performance against each other and available budget. Since there never seems to be enough available budget, making well considered and prudent decisions between the three is then the bigger challenge. Being mindful of how corrosion considerations can influence those factors in light of the totality of an acquisition is potentially helpful in addressing the decision making.

Corrosion Specific Policy & Guidance

Guidance and policy at the highest levels of an organization often tends to be more general than specific in nature. As various levels of an organization seek to implement higher level policy, that lower level guidance or instruction becomes more and more specific. The DoD is no different. What follows is a synopsis of various levels of DoD and Military Services level policy and guidance where corrosion is specifically called out. The intent here is not to present an exhaustive description and explanation of all corrosion related policy and guidance, but rather to illustrate for the reader that at all levels within the Department of Defense, corrosion is in fact a very real concern.

Department of Defense Instruction (DoDI) 5000.02; *Operation of the Defense Acquisition System*

Enclosure 3 – Systems Engineering

15. CORROSION PREVENTION AND CONTROL. The Program Manager will identify and evaluate corrosion considerations throughout the acquisition and sustainment phases that reduce, control, or mitigate corrosion in sustainment. The Program Manager will perform corrosion prevention and control planning and include corrosion control management and design considerations for corrosion prevention and control in the SEP and Life-Cycle Sustainment Plan. The Program Manager will ensure that corrosion control requirements are included in the design and verified as part of test and acceptance programs.

DoDD 4151.18; *Maintenance of Military Materiel*

3. POLICY. It is Policy that

3.3.7. Corrosion prevention and control programs and preservation techniques shall be established throughout the system life cycle. Examples of preventative and control methods may include using effective design practices, material selection, protective finishes, production processes, packaging, storage environments, protection during shipment, and maintenance procedures……

DoDI 5000.67; *Prevention and Mitigation of Corrosion on DoD Military Equipment and Infrastructure*

4. POLICY. It is DoD policy that

a. Trade-off decisions involving cost, useful service life, and effectiveness shall address corrosion prevention and mitigation in accordance with paragraph E1.1.17. of DoD Directive 5000.01 (Reference (e)).

Deputy Under Secretary of Defense (DUSD) Installations & Environment Policy; *Facility Corrosion Prevention and Control*

"Planning, design, and construction provide the best opportunities to incorporate the necessary corrosion prevention technology into our facilities………Military Departments are directed to review their facility design, construction and maintenance procedures to ensure current corrosion prevention measures and technologies are being incorporated into facilities acquisition and maintenance….."

Defense Acquisition Guidebook; chapter 4 – *Systems Engineering*

4.3.18.5. Corrosion Prevention and Control

Elements of good CPC engineering include, but are not limited to, the following:

- Examination of legacy systems for possible corrosion design improvements
- Open and transparent assessment of alternative materials and processes that offer increased protection against corrosion
- Inclusion of CPC as a consideration in trade studies involving cost, useful service life, and effectiveness
- Incorporation of CPC criteria into relevant contractual documentation
- Identification, planning, resourcing, and acquisition of corrosion-related features for longevity, lowest total ownership cost (TOC), and maximum of effectiveness in support of the program

DoD Corrosion, Policy & Oversight Office Guidebook; *Corrosion Prevention and Control Planning Guidebook for Military Systems and Equipment*

4.0 Overview of Corrosion Prevention and Control Planning

PMs and supporting activities should consider CPC as a key issue in design, procurement, and maintaining DoD systems, equipment and their associated facilities. As shown in Figure 2, there are two primary aspects of CPC planning and implementation: Management of the planning and implementation; and Technical and design considerations (e.g., requirements and tradeoffs) that lead to viable CPC planning and implementation.

Naval Facilities Engineering Command (NAVFAC) MO-307; *Corrosion Control*

2.1 POLICY.

Corrosion control is an integral part of the design, construction, operation, and maintenance of all facilities. Petroleum, oil, and lubricant (POL) systems; buildings; utility systems; and antenna systems have the most critical facilities in terms of a combination of risk from corrosion, the need to provide a continuity of direct Fleet support, and the cost effectiveness of using appropriate corrosion control systems......

Air Force Enterprise Corrosion Prevention and Control Strategic Plan

Scope

This strategic plan applies to all elements of the Air Force including weapons systems, munitions, missiles, vehicles, equipment, facilities, and other infrastructure. The focus of this strategic plan is the incorporation of corrosion prevention, control and mitigation in the weapon system and infrastructure life cycle........

Air Force Corrosion Control Facility Reference Guide

I. Introduction

This document should be used in conjunction with UFC 4-211-02, which was updated to make recommendations from the AF CCFRG mandatory.

Army Regulation 750–1; *Army Materiel Maintenance Policy*

8–20. Army Corrosion Prevention and Control Program

c. CPC will be achieved by incorporation of the latest state-of-the-art corrosion control technology in the original equipment design, in the manufacturing, in all levels of maintenance, in supply, and in the storage processes. The objective is to minimize corrosion by using design and manufacturing practices that address selection of materials; coatings and surface treatments; production processes; process specifications; system geometry; material limitations; environmental extremes; storage and ready conditions; preservation and packaging requirements; and repairs, overhaul, and spare parts requirements.

Army Regulation 420-1; *Army Facilities Management*

Section VI, *Army Corrosion Prevention and Control Policy for Facilities*

2–32. General

a. This section addresses policy concerning DA long-term strategy to minimize the effects of corrosion on Army facilities and equipment.

b. The principal objectives of corrosion prevention and control (CPC) policy are to:

1. Design, construct, and maintain dependable and long-lived structures, equipment, plants, and systems.
2. Conserve energy and water resources.
3. Reduce costs due to corrosion, scale, and microbiological fouling.
4. Ensure compliance with Environmental Protection Agency (EPA), Department of Transportation, Occupational Safety and Health Administration (OSHA), and other applicable regulations and guidance.

The synopsized excerpts presented above only touch on the broad spectrum of policy, directives and guidance issued by the Office of the Secretary of Defense and all the Military Services. It applies to weapon systems, facilities and infrastructure and makes clear corrosion should be a consideration factor when planning and expending taxpayer dollars.

4. Conclusions - Thinking About & Planning for Corrosion

With a total estimated cost of $24.7 billion dollars or almost a quarter of the DoD maintenance budget, it becomes clear quickly addressing corrosion or material degradation issues in systems, facilities and infrastructure is logical and an area where improvement is needed. The intent of this writing was not to describe particular corrosion control measures, but rather to illustrate the imperative for **thinking** about and planning for corrosion and material degradation as it might apply to a planned acquisition. Being aware of current policy, directives and guidance can help ensure planning and careful consideration is made where needed and where appropriate.

Across the Department of Defense there's a desire; a mandate, to maximize the spending of every dollar appropriated by Congress. That thinking is reflected repeatedly and broadly in DoD's highest level acquisition guidance where "*DoD Components shall seek the most cost effective solution over the system's life cycle*." Policy and guidance at lower levels becomes more and more specific, calling out corrosion planning as an explicit requirement. Congress clearly demonstrated it is no less concerned about corrosion issues and directed the establishment of a specific office to address corrosion and material degradation related issues under Title 10 U.S.C. 2228.

The examples of corrosion induced failure described are obviously dramatic and were selected exactly for that purpose. No project manager wants to see multi-million-dollar cost overruns or the loss of life because something failed. Yet in each case, a review points to a lack of planning or thinking about corrosion as it might affect the project in the future. Thinking about corrosion in a project's planning stages might have resulted in a different material selection or in ensuring certain procedures were adhere to. Thinking about corrosion during a new acquisition when weighed against cost, schedule and performance demands might or might not result in a different material choice. Thinking about corrosion might instead result in some other mitigation plan to preclude failure. In the end, it is the awareness, consideration and thinking about corrosion that then is the real imperative.

5. Post Script - Corrosion Planning Standard

The Society for Protective Coatings (SSPC) and National Association of Corrosion Engineers (NACE) International recently published the *Joint Standard Practice for Corrosion Prevention and Control Planning*. This standard defines the key elements of corrosion prevention and control (CPC) planning for all public and private sector users as well as the suppliers of products. This includes equipment, systems, platforms, vehicles, support equipment and items. It can also be used to address corrosion planning for facilities and infrastructure such as buildings, airfields, port facilities, surface and subterranean utility systems, heating and cooling systems, fuel tanks, pavements and bridges.

The standard is intended for use by public and private owners and purchasing agencies that require their suppliers or facility owners to address corrosion prevention and control as an aspect of their purchased product or facility deliverable. The standard includes such items as:

- Attributes that impact planning for CPC
- Considerations for material selection and design to minimize corrosion
- Items or topics that should be addressed in corrosion prevention and control planning which affect CPC in design, fabrication and construction, operation and use, and maintenance and sustainability.

The new standard also includes checklists that can be used to identify which requirements are applicable to the specific program or project of the user. The electronic version of the document is made easily navigable with hyper-linked checklists to requirements. In turn, the requirements are linked to the detailed guidance in the appendix.

When the joint task group first convened to begin developing the standard, myriad ad hoc sources reflecting the individual elements of CPC planning existed to assist DoD program managers, notes Stephen J. Spadafora, a task group leader and senior technical advisor for the DoD Corrosion Office. "But no single published standard existed that defined the key elements and composition of CPC planning for all public and private sector users, including suppliers of all equipment, systems, platforms, vehicles, support equipment, and specialized components," he says. "Nor did these standards address CPC planning for the country's vast array of facilities—including all buildings, structures, airfields, port facilities, surface and subterranean utility systems, heating and cooling systems, fuel tanks, pavements, and bridges."

According to a 2016 study published by NACE, corrosion costs the United States an estimated $451 billion each year. "Government and industry need this new standard to support future CPC improvements to the procurement, contracting, and sustainment of weapons systems and facilities at an acceptable cost," Spadafora says. "The fact that program and project managers can now reference this new standard, which defines the deterioration of materials, CPC planning characteristics, and the appropriate application of CPC technologies and practices, provides much-needed uniformity for government and industry."[33]

33. http://www.materialsperformance.com/news/2017/03/nace-international-sspc-publish-standard-on-corrosion-control-planning

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