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July 2003

DEFENSE MANAGEMENT

Opportunities to Reduce Corrosion Costs and Increase Readiness

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GAO-03-753

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Highlights

Highlights of GAO-03-753, a report to Congressional Committees

July 2003

DEFENSE MANAGEMENT

Opportunities to Reduce Corrosion Costs and Increase Readiness

Why GAO Did This Study

The Department of Defense (DOD) maintains equipment and infrastructure worth billions of dollars in many environments where corrosion is causing military assets to deteriorate, shortening their useful life. The resulting increase in required repairs and replacements drives up costs and takes critical systems out of action, reducing mission readiness.

GAO was asked to review military activities related to corrosion control. Specifically, this report examines the extent of the impact of corrosion on DOD and the military services and the extent of the effectiveness of DOD's and the services' approach to preventing and mitigating corrosion.

What GAO Recommends

The departmentwide strategic plan currently being developed should contain clearly defined goals; measurable, outcome-oriented objectives; and performance measures. The strategy should also identify standardized methods for evaluating project proposals, estimating resource needs, and coordinating projects in an interservice and servicewide context. The military services should develop overarching strategic plans consistent with the departmentwide plan. In written comments, DOD agreed with all of these recommendations.

www.gao.gov/cgi-bin/getrpt?GAO-03-753.

To view the full product, including the scope and methodology, click on the link above. For more information, contact William Solis at (202) 512-8365 or solisw@gao.gov.

What GAO Found

Although the full impact of corrosion cannot be quantified due to the limited amount of reliable data captured by DOD and the military services, current cost estimates, readiness, and safety data indicate that corrosion has a substantial impact on military equipment and infrastructure. In 2001, a government-sponsored study estimated the costs of corrosion for military systems and infrastructure at about $20 billion annually and found corrosion to be one of the largest components of life-cycle costs for weapon systems. Corrosion also reduces readiness because the need to repair or replace corrosion damage increases the downtime of critical military assets. For example, a recent study concluded that corrective maintenance of corrosion-related faults has degraded the readiness of all of the Army's approximately 2,450 force modernization helicopters. Finally, a number of serious safety concerns have also been associated with corrosion, including Navy F-14 and F-18 landing gear failures during carrier operations and crashes of several Air Force F-16 aircraft due to the corrosion of electrical contacts that control fuel valves.

DOD and the military services do not have an effective approach to prevent and mitigate corrosion. They have had some successes in addressing corrosion problems on individual programs, but several weaknesses are preventing DOD and the military services from achieving much greater benefits, including potentially billions of dollars in additional net savings annually. Each service has multiple corrosion offices, and their different policies, procedures, and funding channels limit coordination. Also, the goals and incentives that guide these offices sometimes conflict with those of the operational commands that they rely on to fund project implementation. As a result, proposed projects are often assigned a lower priority compared to efforts offering more immediate results. Together, these problems reduce the effectiveness of DOD corrosion prevention. While DOD is in the process of establishing a central corrosion control activity and strategy, it remains to be seen whether these efforts will effectively address these weaknesses.

Examples of Corrosion Damage in the South Pacific

Sources: U.S. Air Force and Navy.

Left: Corroded 500-pound bombs, Guam. Right: Corroding bridge column, Pearl Harbor.

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Abbreviations

ASPRCS	Aviation Systems Performance Readiness and Corrosion Study
DOD	Department of Defense
GPRA	Government Performance and Results Act of 1993
HMMWV	High Mobility Multipurpose Wheeled Vehicles

July 7, 2003

The Honorable John Ensign
Chairman
The Honorable Daniel Akaka
Ranking Minority Member
Subcommittee on Readiness and Management Support
Committee on Armed Services
United States Senate

The Honorable Joel Hefley
Chairman
The Honorable Solomon Ortiz
Ranking Minority Member
Subcommittee on Readiness
Committee on Armed Services
House of Representatives

The Department of Defense (DOD) maintains equipment and infrastructure worth billions of dollars in many environments where corrosion, in one form or another, is causing military assets to deteriorate, shortening their useful lives. The resulting increase in needed repairs and replacements drives up costs and takes critical systems out of action, reducing mission readiness.[1] Corrosion can also create severe safety hazards leading to loss of life when, for example, corroded electrical contacts in aircraft cause system failures during flight. Because numerous advances in products and technologies have been found to enhance efforts to prevent and mitigate corrosion, it is critical that DOD, as the steward of an enormous investment in military assets, ensure that all appropriate measures are implemented to reduce corrosion costs to the greatest extent possible.

[1] Readiness is generally defined as a measure of the Department of Defense's ability to provide the capabilities needed to execute the mission specified in the National Military Strategy. At the unit level, readiness refers to the ability of units, such as Army divisions, Navy ships, and Air Force wings, to provide capabilities required of the combatant commands.

The Congress, recognizing corrosion as a serious military concern, enacted legislation as part of the Bob Stump National Defense Authorization Act for Fiscal Year 2003 which requires DOD to designate a senior official or organization responsible for preventing and mitigating the corrosion of military equipment and infrastructure.[2] The act requires the designated official or organization to oversee and coordinate efforts throughout the department, recommend policy guidance, and review the funding levels proposed by each military service. The Secretary of Defense is required to develop and implement a long-term strategy to reduce the effects of corrosion.

You requested that we review military activities related to the prevention and mitigation of corrosion. In this report we address the following questions: (1) What is the extent of the impact of corrosion on the military services' equipment and facilities? (2) To what extent do DOD and the military services have an effective approach to prevent and mitigate corrosion?

To respond to these questions, we reviewed numerous studies and discussed military corrosion impact issues with experts in and outside DOD. To examine DOD and the military services' approach to corrosion prevention and mitigation, we visited field installations and developed several case studies on specific corrosion prevention and mitigation efforts that are summarized in appendix II and referred to throughout the report. More detailed information about our scope and methodology is contained in appendix I.

[2] P.L.107-314, section 1067.

Results in Brief

Although the full impact of corrosion cannot be quantified due to the limited amount of reliable data captured by DOD and the military services, data on current cost estimates,[3] readiness, and safety indicate that corrosion has a substantial impact on military equipment and infrastructure. For example, in 2001, a 2-year, government-sponsored study estimated the direct costs of corrosion for military systems and infrastructure at approximately $20 billion annually and found corrosion to be one of the largest components of life-cycle costs for military weapon systems.[4] Another study puts the cost at closer to $10 billion.[5] Corrosion has also been shown to substantially increase equipment downtime, thereby reducing readiness. For example, a 2001 study concluded that corrective maintenance of corrosion-related faults has degraded the readiness of all of the Army's approximately 2,450 force modernization helicopters; the Army estimated in 1998 that approximately $4 billion was spent on corrosion repair of helicopters alone. In 2001, DOD also reported that more than two thirds of its military facilities have serious deficiencies and are in such poor condition that they are unable to meet certain mission requirements; corrosion was identified as a major contributor to much of this deterioration. Finally, a number of safety concerns have also been associated with corrosion. During the 1980s, the crashes of several F-16 aircraft were traced to corroded electrical contacts that caused uncommanded fuel valve closures. More recently, Navy F-14 and F-18 aircraft have experienced landing gear failures (collapses) during carrier operations that were attributed to corrosion-related cracking.

DOD and the military services do not have an effective approach to prevent and mitigate corrosion. While the military services have achieved some successes on individual corrosion prevention projects, their overall approach to corrosion control has significant weaknesses that have decreased the effectiveness of their efforts. For example, DOD does not have a strategic plan for corrosion prevention and mitigation, and the services have either not developed such plans or have not implemented them. While DOD is in the process of establishing a central corrosion

[3] Cost estimates were not audited.

[4] Koch, Gerhardus H. et al., *Corrosion Cost and Prevention Strategies in the United States*, CC Technologies and NACE International in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Sept. 30, 2001.

[5] *Corrosion in DOD Systems: Data Collection and Analysis (Phase I)*, Harold Mindlin et al.; Metals Information Analysis Center, February 1996.

control office, no single office exists within each of the military services to manage corrosion control over equipment and infrastructure. Instead, each service has multiple corrosion offices within various operational units and weapon systems programs. These offices often have different policies, procedures, and funding channels that limit coordination and standardization. In many cases, corrosion control officials were not aware of the activities and achievements of their counterparts in other commands and across the services. Further, corrosion control offices act largely in an advisory role and are guided by goals and incentives that sometimes conflict with those of the operational commands that they rely on to fund project implementation. As a result, many proposed projects—even those with the potential for very large future-year cost savings—are often assigned a low funding priority compared to operations and repair projects offering more immediate results. These weaknesses combine to reduce the overall effectiveness of DOD's approach to corrosion control and result in the services missing important opportunities to achieve greater benefits, including potentially billions of dollars in additional net savings annually that would accrue from a long-term reduction in corrosion of military equipment and infrastructure.

To strengthen DOD's approach to corrosion control, we are recommending that it define and incorporate into its long-term corrosion mitigation strategy measurable, outcome-oriented objectives and performance measures that show progress toward achieving results. In addition, we are recommending that the strategy include a number of elements to address problems and limitations we identified in current corrosion prevention efforts. In comments on a draft of this report, DOD generally concurred with all our recommendations. The department also provided technical clarifications, which we incorporated as appropriate.

Background

Corrosion affects all military assets, including approximately 350,000 ground and tactical vehicles, 15,000 aircraft and helicopters, 1,000 strategic missiles, and 300 ships. Maintenance activities—including corrosion control—involve nearly 700,000 military (active and reserve) and DOD civilian personnel, as well as several thousand commercial firms worldwide. Hundreds of thousands of additional mission support assets and thousands of facilities are also affected.

Corrosion is defined as the unintended destruction or deterioration of a material due to interaction with the environment. It includes such varied forms as rusting; pitting; galvanic reaction; calcium or other mineral build up; degradation due to ultraviolet light exposure; and mold, mildew, or other organic decay. It can be either readily visible or microscopic. Factors influencing the development and rate of corrosion include the type and design of the material, the presence of electrolytes (water, minerals, and salts), the availability of oxygen, the ambient temperature, and the amount of exposure to the environment. The rate of corrosion increases exponentially when the ambient humidity is over 50 percent. Corrosion can also occur in the absence of water, but only at high temperatures, such as in gas turbine engines.

The effects of corrosion on DOD equipment and infrastructure have become more prominent as the acquisition of new equipment has slowed and more reliance is placed on the service of aging equipment and infrastructure. The aging of military systems poses a unique challenge for maintenance and corrosion control for all services.[6]

A number of DOD and commercial studies have identified and evaluated technologies and techniques for corrosion prevention and control. The studies indicate that although effective corrosion prevention and control methods and technologies are well known and have been recommended for years, they have not been implemented effectively. The studies also identify a number of relatively simple solutions—such as covered storage, controlled environment, washing and rinsing, spray-on rust inhibitors, and protective wrapping—to mitigate and control the effects of corrosion.

Congress has recognized the need to significantly reduce the economic burden on the military services of the damage caused by corrosion and of the efforts to mitigate its adverse affects. In November 2002, Congress passed the Bob Stump National Defense Authorization Act for Fiscal Year 2003, which required the Department of Defense to take the following steps:

- Designate a responsible official or organization within the department to (1) oversee and coordinate corrosion prevention and mitigation of military equipment and infrastructure; (2) develop and recommend policy guidance; (3) review programs and funding levels; and

[6] For example, the average age of the Air Force aircraft fleet is 22 years. By fiscal year 2020, the average age will increase to nearly 30 years, with current programmed investments. This would translate to 60-year-old tankers, 47-year-old reconnaissance/surveillance platforms, and 44-year-old bombers. (The B-52 would be nearly 60 years old.)

(4) provide oversight and coordination of the efforts to incorporate corrosion control during the design, acquisition, and maintenance of military equipment and infrastructure.

- 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 not later than 1 year after the date of the enactment of the act.
- Submit to Congress an Interim Report regarding the actions taken to date by the corrosion control office when the President submits the budget for fiscal year 2004. On May 22, 2003, DOD submitted the report.

Impacts on Military Costs, Readiness, and Safety Indicate That Corrosion Is an Extensive Problem

Numerous studies in recent years have documented the pervasive nature of corrosion and its various effects on military equipment and infrastructure. Although the full impact of corrosion cannot be quantified due to the limited amount of reliable data captured by DOD and the military services, current cost estimates, readiness, and safety data indicate that corrosion has a substantial effect on military equipment and infrastructure. Costs are significant because corroded military assets must often be repaired or replaced at great expense. Readiness is also severely impaired because corrosion increases the maintenance needed and, therefore, the downtime on a large quantities of military equipment. The effects extend to infrastructure, which, in turn, has an adverse impact on the military's ability to meet mission requirements. Further, corrosion has an equally profound effect on the safety of equipment and infrastructure.

Corrosion Costs Appear to Be Enormous

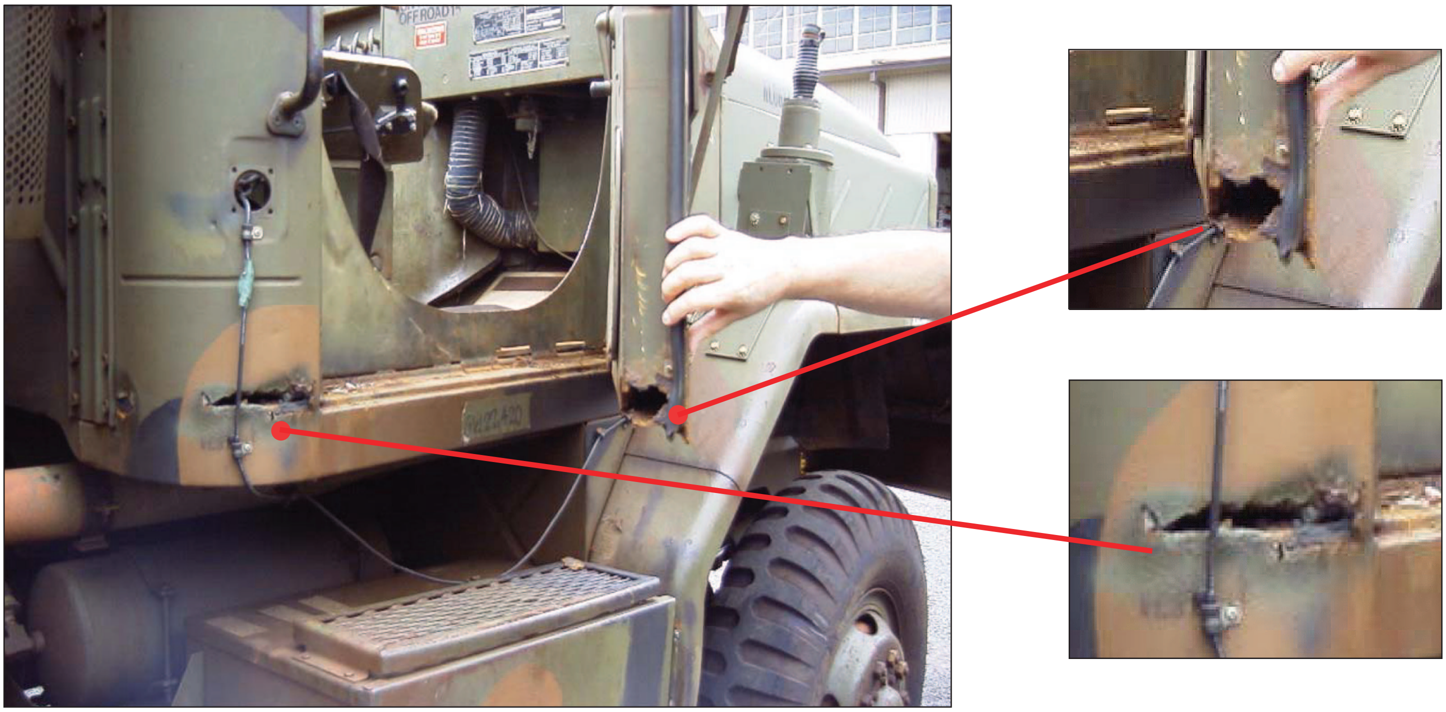
Corrosion's impact on military costs appears to be enormous, representing one of the largest life-cycle cost components of military weapon systems. In a 2001 government-sponsored study, corrosion is estimated to cost the Department of Defense at least $20 billion a year. Another study done in 1996 puts the cost at closer to $10 billion annually. The costs identified in these reports are direct costs such as the manpower and material that are used primarily to inspect and repair damage resulting from corrosion. However, there are also indirect costs that, were they to be quantified, would significantly increase the total reported costs. Indirect costs include the loss of the opportunity to use equipment that is not in operating condition. Although extensive equipment downtime results from corrosion, the attendant financial impacts have not been fully captured. Even more difficult to quantify is the cost of using equipment that, while not inoperable, has diminished utility due to corrosion. Considering the enormous total value of all of the equipment owned by the military services, these costs are considerable, to say the least. Corrosion also shortens the service life and accelerates the depreciation of DOD facilities, which in a recent GAO report are estimated to have a replacement value of over $435 billion.[7] This impact on facilities translates into costs that are not included in the government corrosion cost study.

There are numerous examples of how profoundly corrosion affects costs. For example, in 1993, the Army estimated spending about $2 billion to $2.5 billion a year to mitigate the corrosion of wheeled vehicles, including 5-ton trucks.[8] (See fig. 1.)

[7] U.S. General Accounting Office, *Defense Infrastructure: Changes in Funding Priorities and Strategic Planning Needed to Improve the Condition of Military Facilities*, GAO-03-274 (Washington, D.C.: February 2003).

[8] *Corrosion Prevention for Wheeled Vehicles*, DOD Inspector General Audit Report, Number 93-156, August 13, 1993.

Figure 1: Corrosion on Army 5-Ton Truck in Hawaii



Source: U.S. Army.

Corrosion was found to be so extensive on some of the trucks that the repair costs were greater than 65 percent of the average cost of a new vehicle. Cost impacts appear to be even greater on Army helicopters, as evidenced by a 1998 analysis estimating costs of about $4 billion to repair damage attributed to corrosion.[9] Corrosion is also a formidable cost driver to the Navy. As an illustration, the Navy's Pacific and Atlantic Fleets estimate that about 25 percent of their total combined annual maintenance budget is directed to the prevention and correction of corrosion. Navy officials told us that the prevention and removal of corrosion on shipboard tanks alone costs the Navy over $174 million a year. Navy facilities such as waterfront structures are also decaying because of corrosion, and

[9] U.S. Army TACOM-ARDEC communication referenced in *Corrosion Costs and Preventative Strategies in the United States*, Gerhardus H. Koch, Ph.D., et al.; CC Technologies Laboratories, Inc., September 30, 2001.

these facilities will need to be replaced at considerable cost. For example, naval military construction projects estimated to cost $727 million are required to restore 20 piers that have suffered extensive corrosion damage. (See fig. 2.)

Figure 2: Corroding Bridge Columns at Naval Station Pearl Harbor, Hawaii

Source: U.S. Navy.

In 1990, the Air Force estimated the cost of corrosion to be about $700 million. Interestingly, even though the number of operational Air Force aircraft decreased significantly, corrosion costs for the Air Force increased to over $1 billion by 2001,[10] or $300 million more than previously reported.

[10] Cost of Corrosion: Final Report, prepared for Air Force Research Laboratory, NCI Systems, Inc., Fairborn, Ohio, March 26, 2003.

Corrosion Substantially Degrades Equipment and Facilities Readiness

Corrosion has been shown to substantially increase equipment downtime, thereby reducing readiness. Whether it affects a truck, helicopter, ship, or pipeline, corrosion is a major contributor to the amount of maintenance required on military equipment and infrastructure. Depending on the kind and severity of corrosion, the maintenance may be performed as part of the scheduled maintenance cycle or as emergency repairs, especially when it involves safety concerns. Whether scheduled or not, maintenance translates into equipment downtime. As a result, readiness is diminished because the equipment cannot be used for training purposes or for other kinds of operations. In addition, corrosion contributes to or accelerates the deterioration of equipment and, therefore, reduces its service life. As a result, the condition of some equipment is assessed to have deteriorated beyond repair capability and the equipment is no longer usable.

The effects on readiness are extensive throughout the military services, and they are clearly evidenced in regard to military aircraft. For example, a 2001 study concluded that corrective maintenance of corrosion-related faults has degraded the readiness of all of the Army's approximately 2,450 force modernization helicopters. (See fig. 3.)

Figure 3: Corrosion on Army UH-60L Black Hawk Helicopter

Fuel cell compartment

Control rod linkage

Spindle bolts

Source: U.S. Army.

The effects on the Air Force's KC-135 are particularly pronounced, with corrosion identified as the reason for over 50 percent of the maintenance needed on the aircraft. While the Air Force has yet to quantify the total impact, one study identified corrosion of avionics equipment contacts to be a significant cause of failure rates on all Air Force aircraft. Because these failure rates affect equipment that is sophisticated and often occurs in hard-to-access areas, a significant amount of time is needed for testing, inspection, and repair. This extends aircraft downtime and reduces readiness levels. Corrosion has also reduced the readiness levels for the Navy's P-3C aircraft. According to Navy officials, corrosion has always been responsible for a large part of maintenance required for the aircraft, but the amount has doubled in recent years. While these officials do not have specific information regarding the effects of corrosion, they did note that in just the past year they had to ground two aircraft specifically because of severe corrosion.

The effects on readiness extend well beyond aviation and include virtually every type of equipment maintained and operated by the military. Corrosion also severely affects the readiness of other types of equipment, such as Army vehicles. In 1996, the Army identified corrosion as the reason why 17 percent of its trucks located in Hawaii were not mission capable. Earlier in 1993, the availability of the Army's High Mobility Multipurpose Wheeled Vehicles (HMMWV) had been particularly diminished because of corrosion. While some of the vehicles were out of service for as long as a year, others had such severe corrosion that they had to be scrapped after 5 years, many years short of their expected 15-year service life. The Air Force also identified severe corrosion on its ground vehicles, resulting in increased maintenance and downtime. Some of the vehicles showed significant deterioration just months after being delivered to field units.

Corrosion and its impact on readiness are especially a concern for the Navy, because its ships operate in highly corrosive salt water and in high-humidity locations. A notable example of these effects occurred in 2001 on the aircraft carrier *USS John F Kennedy.* Maintenance problems, including many that were corrosion-related, were so severe that the carrier could not complete its planned operations. Even more recently, the carrier *USS Kitty Hawk* returned from a series of deployments, including Operation Enduring Freedom, with significant maintenance problems that also included topside corrosion. As a result, the carrier is expected to undergo extensive maintenance.

Such effects are found Navy-wide, and the Navy estimates that about 25 percent of its fleet maintenance budget goes toward corrosion prevention and control. This and other kinds of maintenance are largely completed at a Navy depot and require an average of 6 months. During this extended period of time, the ship is not available for service. The amount of time the ship is in the depot is due in part to the repairs needed because of corrosion; Navy officials told us this amount of corrosion-related maintenance is understated because it does not include the vast amount of manpower and resources spent on corrosion removal and repainting while the ships are on operations. These repairs, too, have an impact on readiness, because crew members who would normally be undergoing training or other kinds of operations are, instead, required to perform maintenance.

Corrosion also impairs the readiness of military armament. For example, the Army reported a significant number of failures due to corrosion on the 155 mm medium-towed howitzer so severe that they resulted in aborted missions. The study estimates that between 30 to 40 percent of the aborts are direct results of corrosion. Corrosion is also identified as accounting for 39 percent of all unscheduled maintenance for the howitzer, further reducing the readiness levels of the equipment. In addition, corrosion has affected the readiness of the Air Force's general purpose iron bombs. (See fig. 4.)

Figure 4: Corroded 500-Pound Bombs at Andersen Air Force Base, Guam

Source: U.S. Air Force.

According to Air Force records, of the approximately 450,000 bombs of this type in the Air Force inventory, more than 107,000 (or over 24 percent) have varying levels of deterioration caused by corrosion and, as a result, are not mission capable. While many of these bombs are repairable, a certain level of maintenance is needed to restore most of them to acceptable operational condition. Some of the bombs, however, are too severely corroded to be salvageable.

Military facilities are also decaying due to corrosion and, as a result, readiness is affected adversely. In 2001, the Department of Defense reported that more than two-thirds of its military facilities have serious deficiencies and are in such poor condition that they are unable to meet certain mission requirements. The department identifies corrosion as a major contributor to much of this deterioration. According to military service officials, the most significant area of concern may be the condition of military airfields. Each of the military services has reported runway cracking so severe that the runways were judged unusable. Deterioration of this kind was even identified in airfields used for operations during Enduring Freedom. For example, runway cracks at Pope Air Force Base, North Carolina, were so extensive that several C-130 cargo planes and A-10 fighters heading for Afghanistan were diverted to other U.S. installations. Further, Navy facilities officials told us that infrastructure deterioration is so significant that it has adverse impacts on the service's ability to perform required maintenance on its equipment. For example, they said that parts of the ceiling of an aircraft hanger located at North Island Naval Air Station, California, had crumbled as a result of corrosion. Because of the safety hazard and potential damage to aircraft, the hanger had to be closed down for several months for repairs and the aircraft relocated to other storage facilities. Corrosion of facilities and the impacts on readiness go well beyond problems experienced at airfields and hangars. The Pacific Air Force Command cited corrosion as the cause of failures of numerous critical infrastructure, including aircraft refueling, fire protection, electrical, and command and control facilities. The Command noted that this kind of deterioration can significantly impact its ability to perform its mission.

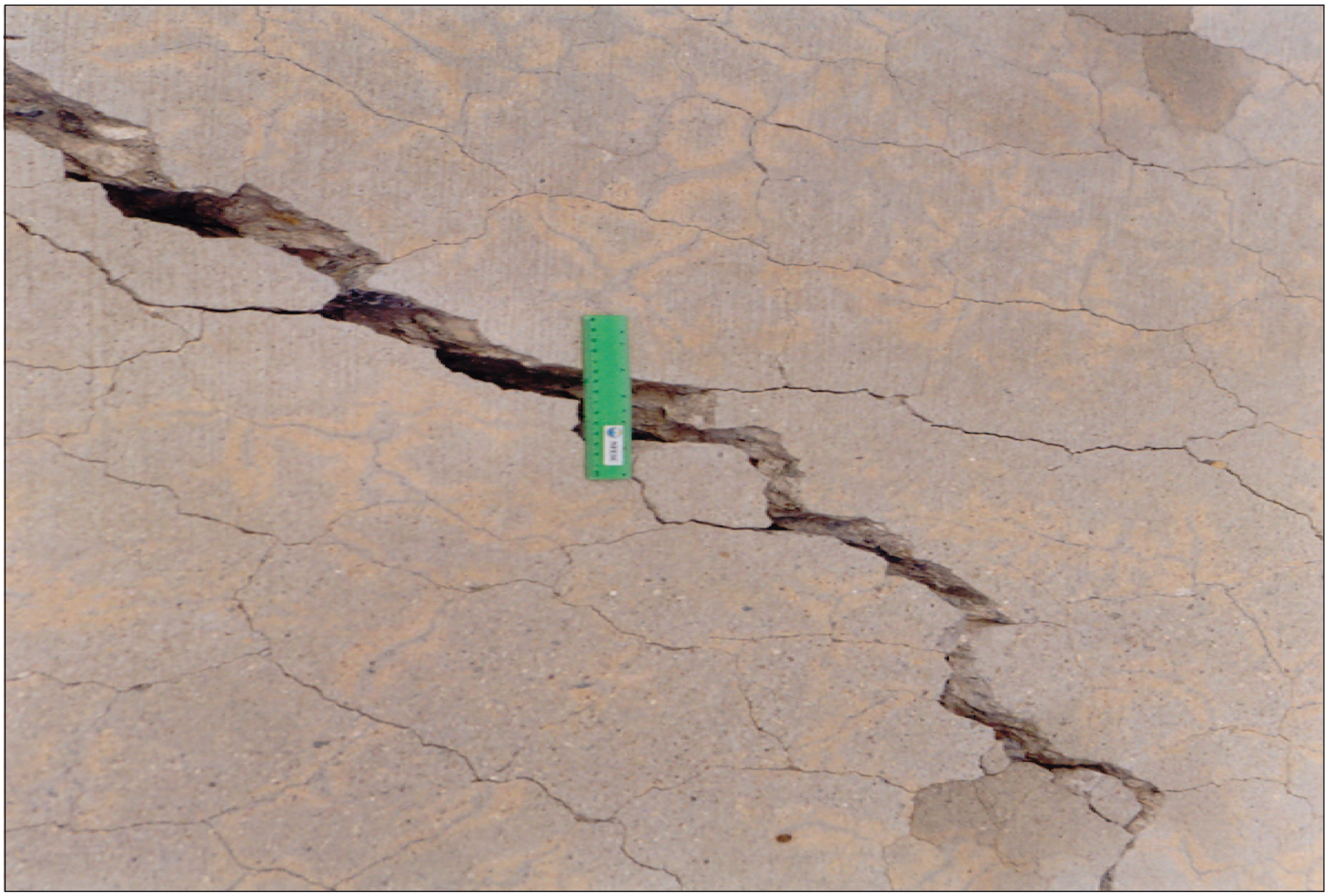
Corrosion Poses Numerous Safety Risks

Corrosion also poses numerous safety risks and is a source of major concern to all military services. This concern is particularly acute when associated with the safety of military aircraft. According to an Army study, from 1989 through 2000 the Army experienced 46 mishaps, 9 fatalities, and 13 injuries directly related to corrosion. During calendar year 2001, the Army issued four Safety of Flight messages for its rotary wing systems due to corrosion-related material deficiencies that adversely affected 2,100, or over 88 percent, of its force modernization helicopters. As recently as March 2002, the Navy suspended carrier operations for F-14 aircraft when one aircraft crashed because its landing gear collapsed due to corrosion.

Just 2 years earlier, the Navy had identified corrosion as the cause of a landing gear failure on a F-18 that occurred during carrier operations. Despite regular inspections, stress cracking in the landing gear evaded detection, and the problem was not revealed until after the accident when the equipment was examined under an electron microscope. Perhaps even more difficult to detect, but nevertheless just as significant, are the safety risks corrosion presents on F-16 avionics connectors. This aircraft has sophisticated electronics equipment that is housed in Line Replaceable Units. Although these containers provide considerable protection from the elements, they cannot entirely eliminate moisture from entering, and even microscopic amounts of moisture can cause catastrophic accidents. For example, during the 1980s, uncommanded fuel valve closures caused several F-16 aircraft crashes. The equipment failures were believed to be the result of corrosion on the avionics connectors.

Corrosion also poses major safety hazards at military facilities. Perhaps the greatest safety risk, according to facilities officials, is the cracking of concrete runways at airfields operated by all of the military services. (See fig. 5.)

Figure 5: Cracked Runway at Point Mugu Naval Air Station, California



Source: U.S. Navy.

One of the causes of this deterioration results from a corrosive chemical process called alkali-silica reaction, which occurs when alkalis react with water in ways that cause cracking, chipping, and expansion of concrete. As airfields continue to decay and crumble, more pieces of concrete are left on the runway, and these pieces have been absorbed by military aircraft and cited as the causes of innumerable aircraft safety incidents and accidents. Airfield cracking due to corrosion and the safety risk that it presents is so extensive that all the military services have experienced serious incidents resulting from this hazard. Examples of this kind of damage have been reported at Osan Air Base, Korea; Ft. Campbell Army Airfield, Kentucky;

Naval Air Station Point Mugu, California; and Marine Corps Air Station, Iwakuni, Japan. The foreign object debris hazard was so severe at the Little Rock Air Force Base that the Air Mobility Command assessed a taxiway as unsuitable for operations. At Naval Air Station Pensacola, several recent incidents were reported of Navy aircraft penetrating cracked airfield pavement and jeopardizing pilot safety.

Pipelines that contain natural gas and other kinds of fuel also pose a safety risk at military facilities. A majority of the pipelines are quite old and are constructed largely of metal that is susceptible to corrosion, which is the major cause of pipeline ruptures. Air Force facilities officials told us that some of the pipelines were installed as far back as the 1950s, and older pipelines pose an even greater hazard because they have a higher probability of rupturing from corrosion. The services are gradually replacing many of the metal pipelines with pipelines made of high-density polyethylene plastic and other materials that are more corrosion resistant. The use of cathodic protection devices also helps to prevent corrosion. Facilities officials told us that despite these measures and periodic inspections, they have experienced numerous pipeline ruptures they attribute to corrosion. They said that until all of the existing pipelines are replaced, such ruptures will continue to be a source of major concern. However, replacing pipelines is very expensive, and facilities officials said that it would take many years to obtain enough funds to replace all of them. Facilities officials at Marine Corps Base Camp Pendleton, California, said that they have experienced several fuel line ruptures, many of them caused by corroded pipe valves. They said fuel lines that run alongside base housing pose the greatest safety concern, and they have begun to replace these lines first. Eventually they hope to replace all of them throughout the base.

Full Impact of Corrosion Unknown Due to Incomplete Cost, Readiness, and Safety Data

For more than a decade, a number of DOD, military service, and private-sector studies have cited the lack of reliable data to adequately assess the overall impact of the corrosion problem. Studies done in 1996 and 2001 on DOD corrosion data collection and analysis found that, while individual services have attempted to quantify the cost of corrosion, neither the mechanisms nor the methodologies exist to accurately quantify the problem.[11] A 2001 Army study found that no single data system provides aggregate corrosion data related to cost, maintenance, and readiness, and that the existence of many separate databases restrict the ability to collect standardized data reflecting consistent characteristics.[12] The study, which focused on Army aviation, concluded that existing automated information systems do not provide decision makers with complete, accurate, or timely corrosion repair and replacement data. An Air Force study came to similar conclusions.[13] Navy officials told us that information regarding the cost of corrosion is incomplete because these costs are difficult to isolate from overall maintenance costs. They said these data limitations make it difficult to determine the severity of the problems and to justify the funding needed to prevent corrosion problems in the future. Facilities officials at Marine Corps Base Camp Pendleton said that their databases do not specifically identify data as corrosion related. They told us they would prefer to have better data for making investment decisions but instead must rely primarily on information obtained from periodic and annual corrosion inspections.

We identified many examples of how the lack of reliable and complete information impeded the funding and progress of corrosion prevention projects. In addition, military officials at the unit level told us that they had trouble obtaining sufficient data and analysis to justify the cost effectiveness of prevention projects. They cited the lack of information as one of the main reasons why corrosion mitigation projects were not being funded. For example, Air Force officials told us that an aircraft rinsing

[11] *Corrosion in DOD Systems: Data Collection and Analysis (Phase I)*, Harold Mindlin, et al.; Metals Information Analysis Center, February 1996; and Corrosion Costs and Preventative Strategies in the United States, Gerhardus H. Koch, Ph.D. et al.; CC Technologies Laboratories, Inc., September 30, 2001.

[12] Aviation Systems Performance Readiness and Corrosion Study (ASPRCS), Ken Mitchell, Study Director, Center for Army Analysis, 2001.

[13] A Study to Determine the Annual Direct Cost of Corrosion Maintenance for Weapon Systems and Equipment in the United States Air Force, prepared for the Air Force Corrosion Program Office, NCI Information Systems, Inc., Fairborn, Ohio, February 6, 1998.

facility at Hickam Air Force Base is no longer operable, and they need about $4 million for a new facility. They also said that although they do not have sufficient data to accurately estimate expected cost savings from reduced maintenance, they believe it would far exceed initial investment costs. They added that their inability to move forward stems largely from a lack of the data and analysis needed to justify the projects. The Marine Corps faced similar obstacles in justifying the installation of a helicopter rinsing facilities at Marine Corps Air Facility, Kaneohe Bay. (See fig. 6.)

Figure 6: Marine Corps Helicopter Rinsing Facility Kaneohe Bay, Hawaii

Source: U.S. Marine Corps.

Officials told us that the corrosion maintenance costs they would avoid in the first year alone would exceed the total amount of funding needed to build an additional facility, but they do not have the data or resources to support the necessary analysis, and without it they cannot justify the project or obtain approval for the funds.

DOD and Services' Approach to Corrosion Control Is Not Effective but Has Achieved Some Successes

While the military services have achieved some successes on individual corrosion prevention projects, significant weaknesses in their overall approach to corrosion control have decreased the effectiveness of their efforts. An important limitation is the lack of a strategic plan that includes long-term goals and outcome-based performance measures. In addition, coordination within and among the services is limited, and the priorities of organizations that plan corrosion prevention projects and those that implement and fund them are frequently in conflict. As a result, promising projects often fall far short of their potential, and many are never initiated at all.

Some Corrosion Prevention Improvements Are Being Introduced during and after Acquisition Production Process

Major commands, program offices, and research and development centers servicewide have made and continue to make improvements in the methods and techniques for preventing corrosion. Corrosion prevention improvements can either be introduced during the design and production phases or some time after equipment is fielded. For example, durable coatings, composite materials, and cathodic protection are being incorporated to an increasing extent in the design and construction of military facilities and equipment to reduce corrosion-related maintenance. Systems as diverse as the joint strike fighter, the DD-X destroyer, amphibious assault vehicles, and HMMWV trucks plan to use composite materials and advanced protective coatings to increase corrosion resistance. The military services estimate that as much as 25 to 35 percent of corrosion costs can be eliminated by using these and other corrosion prevention efforts, which would amount to billions of dollars in potential savings each year. Our recent report on total ownership costs of military equipment discusses some of the approaches DOD is using to incorporate maintenance reduction techniques, including corrosion mitigation, into the design and development of new systems.[14]

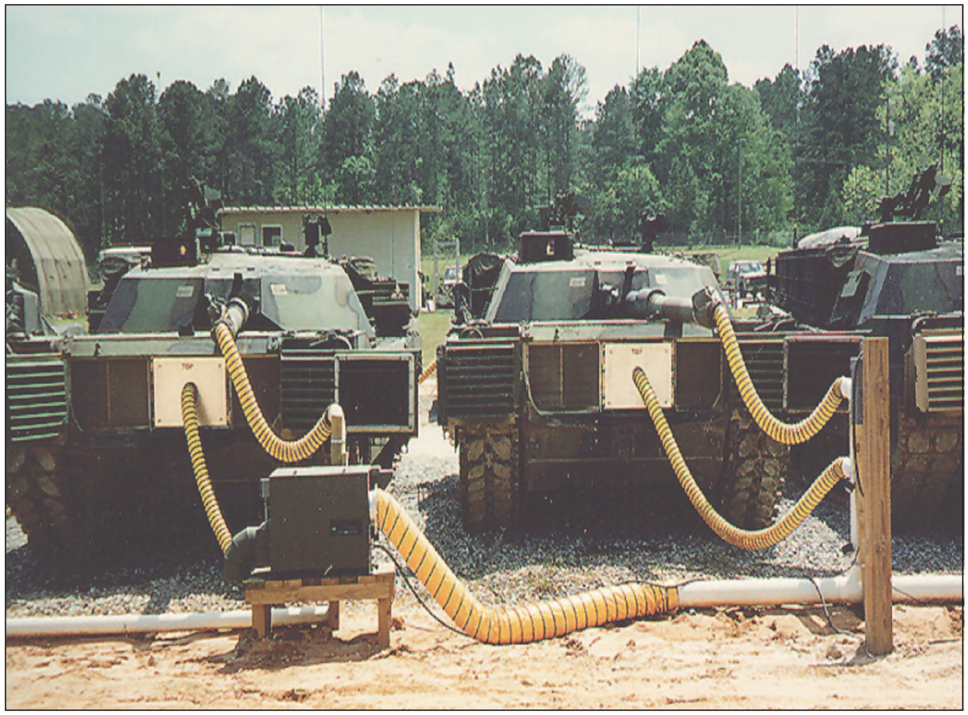
Regarding the maintenance of existing equipment and infrastructure, we have identified several examples of projects that show potential for a high return on investment and advances in the technologies of corrosion prevention but which have not, for various reasons, been fully implemented. For example, the Naval Sea Systems Command has

[14] U.S. General Accounting Office, *Best Practices: Setting Requirements Differently Could Reduce Weapon Systems' Total Ownership Costs*, GAO-03-57 (Washington, D.C.: February 2003).

developed durable coatings that increase the amount of corrosion protection for various kinds of tanks (such as fuel and ballast tanks) on Navy ships to 20 years instead of the 5 years formerly possible. The installation of the coatings started in fiscal year 1996. However, by the end of fiscal year 2002, the Navy had installed these coatings on less than 7 percent of the tanks, for an estimated net savings of about $10 million a year. The tank preservation effort has not been widely implemented because, Navy officials told us, the fleet has other needs that have a higher priority. Navy officials told us they frequently have to defer the installation of the new coatings because of the limited availability of ships due to the increased pace of Fleet operations and more pressing maintenance requirements. As a result, the Navy estimates that it is about $161 million short of achieving the total annual net cost savings projected for this corrosion prevention effort. The Command has numerous other projects that have fallen short of their potential because the fleet had higher priorities. While these projects have total projected annual net savings of another $919 million, they have achieved about $33 million in yearly savings to date. Once implemented, the benefits of these efforts extend well beyond cost savings because they have the potential to significantly reduce ship maintenance, thereby increasing the availability of ships for operations.

The Army National Guard's Controlled Humidity Preservation project represents another example of a high potential savings effort that has not been fully realized. Under this project, dehumidified air is pumped into buildings or equipment to reduce the rate of corrosion. (See fig. 7.)

Figure 7: Army National Guard Controlled Humidity Preservation



Source: Army National Guard Bureau.

Project officials claimed net savings of $225 million through the end of fiscal year 2002. While officials state the project has proven to be a success so far, they now estimate that it will take about 15 years to achieve the total projected savings, or 5 years longer than originally planned. Army National Guard officials told us they could achieve greater savings if they receive additional funding earlier than is currently planned.

The Air Force's bomb metalization project is also not achieving its full cost savings potential. According to an Air Force study, treating cast iron, general-purpose bombs with a special protective metallic spray coating would save the Air Force at least $30 million in maintenance costs over 30 years, although one study estimated the savings to be as much as $100 million. The Air Force stores about 450,000 of this type of bomb in locations throughout the world. Air Force officials told us that the total investment costs for the project are about $5 million, which, based on the higher cost savings estimate, translates into a return on investment ratio of 20 to 1. After several years of planning and implementation, about 15,000 bombs, or 3 percent, have received the treatment.

Appendix II provides more detailed information about these and other examples of projects that are not reaching their full potential.

Strategic Plan Lacking for DOD and Service Corrosion Efforts

DOD does not currently have a strategic plan for corrosion prevention and mitigation, and the services either have not developed such plans or have not implemented them.

However, DOD is required within 1 year of enactment of the Bob Stump National Defense Authorization Act for Fiscal Year 2003 (i.e., by December 2, 2003) to submit to Congress a report setting forth its long-term strategy to reduce corrosion and the effects of corrosion on military equipment and infrastructure.[15] The act requires DOD include in its long-term strategy performance measures and milestones for reducing corrosion that are compatible with the Government Performance and Results Act of 1993 (GPRA).[16] GPRA offers a model for developing an effective management framework to improve the likelihood of successfully implementing initiatives and assessing results. Under GPRA, agencies at all levels are required to set strategic goals, measure performance, identify levels of resources needed, and report on the degree to which goals have been met. Without implementing these critical performance-measuring elements, management is unable to identify and prioritize projects systematically, allocate resources effectively, and determine which projects have been successful. As a result, managers are not in a position to make sound investment decisions on proposed corrosion control projects.

[15] No later than 18 months after date of enactment of the act GAO is required to submit to Congress an assessment of the extent that DOD has implemented its long-term strategy to reduce corrosion.

[16] P.L. 103-62, Aug. 3, 1993.

The military services either have not established effective strategic plans that include goals, objectives, and performance measuring systems[17] or they have not implemented them. The limitations to the military services' efforts to establish strategic plans are as follows:

- The Army created a comprehensive corrosion control program plan—including goals, objectives, and performance measures—but the plan was never fully implemented.[18] As part of the plan, the Army defined specific performance measures to track the progress of corrosion mitigation efforts, but these were not put into effect. The strategy called for the creation of panels comprised of top government and industry corrosion experts who would use performance metrics to evaluate proposed and ongoing projects against approved goals and objectives. However, the panels were never established and the metrics were not implemented. Army corrosion control officials told us that they have very little performance data, such as return on investment or annual savings, for any of their corrosion control initiatives. Officials at the Army Center for Economic Analysis told us they have not measured performance for the purpose of determining the return on investment for any corrosion control project for many years; the last performance evaluation was carried out in 1997.

- In 1998, the Air Force published a business plan for equipment corrosion control, but the plan was implemented for a short time and did not contain all of the elements of a strategic plan. For example, it identified three management goals,[19] but did not include performance measures. Also, the Air Force Equipment Maintenance Instruction that identifies responsibilities for the Air Force Corrosion Prevention and Control Office does not identify goals or performance measures. Although an Air Force Instruction on Performance Management states that performance

[17] Performance measures can include such data as return on investment, frequency of required corrosion maintenance, equipment availability, readiness rates, and mean time between failures.

[18] The plan included three main objectives: decrease life-cycle costs by 40 percent, increase readiness by reducing downtime, and reduce the maintenance burden on diminishing active and reserve workforce resources.

[19] The goals are as follows: (1) identify, advance and apply emerging materials and processes to existing and future weapon systems; (2) identify current corrosion traits of weapon systems and logistics processes, and (3) maintain data and technical manuals related to corrosion control and provide expert consultation and technical support to field and depot activities.

management, including goals and performance measures, is the Air Force's framework for a continual improvement system, officials told us that the business plan was no longer being used. They said that, in the past, there has been more emphasis on creating goals and monitoring performance, but because of limited resources, reductions in personnel, and increased optempo these activities are no longer performed.

- The Navy commands (Naval Air Systems Command and Naval Sea Systems Command) have engaged in some strategic planning for corrosion control, but the Navy does not have a servicewide strategic plan in this area, and its corrosion control offices lack the information and metrics needed to track progress. The Naval Air Systems Command planned to establish a corrosion control and prevention office but the plan—which included goals and objectives and outlined how progress would be measured—was never approved. The corrosion control and prevention activity at Naval Sea Systems Command is also not a formal program, and it lacks clearly defined overall goals and objectives. This office has identified cost avoidance projects and tracks the amount of savings achieved to date. However, more could be done to monitor performance. For example, there was no analysis of the reasons why specific projects were proceeding at a slow pace. Without this information, the office is not in a position to know what actions can be taken to improve the effectiveness of these projects.

- The Marine Corps has a corrosion control plan that includes long-term, broadly stated goals but does not include measurable, outcome-oriented objectives or performance measures. Marine Corps officials told us that they are in the process of revising the plan to include measures that will track progress toward achieving servicewide goals.

Corrosion control officials said they measure progress through a combination of field surveys, special corrosion assessments, and Integrated Product Teams.[20] They also rely on the evaluations of operational and installation commands and program offices but readily acknowledge that this is not sufficient. They told us that they would prefer

[20] Integrated Product Teams are comprised of individuals representing a variety of competencies or disciplines such as material science, system engineering, logistics, and environmental management. These teams are assembled to take a multidisciplinary approach to finding solutions to routine and nonroutine maintenance and acquisition problems.

to have more systematic performance measures and that these tools would improve the success of individual projects and the corrosion effort as a whole.

Limited Coordination Within and Among the Services

DOD has multiple corrosion control efforts—with different policies, procedures, and funding channels—that are not well coordinated with each other; as a result, opportunities for cost savings have been lost. DOD is in the process of establishing a central corrosion control office in response to the authorization act, but no single office exists within each of the military services to provide leadership and oversight for corrosion control of equipment and infrastructure. Although the services have attempted to establish central corrosion control offices, the responsibility largely falls on numerous commands, installations, and program offices to fund and implement projects. Military officials told us the offices were not fully established, primarily because of limited funding. The Army, for example, has established a central office for corrosion control of all service equipment; the chain of command for the Army corrosion office for facilities is separate from this office. Although a central office for equipment exists, each Army command also has separate corrosion control offices that are responsible for certain types of equipment—for example, tanks/automotive, aviation/missiles, armaments, and electronics. Further, individual weapon system program offices within each command may have their own corrosion control functions. In addition, installations implement their own corrosion control projects with the assistance of the Army Department of Public Works and the Army Corps of Engineers. The recently established Army Installation Management Agency provides overall management and funding for upkeep on Army installations.

The Navy and Air Force also have multiple corrosion prevention and mitigation offices. The Navy manages them through the materials offices within the Naval Sea Systems Command and Naval Aviation Command. The Air Force Materiel Command manages the Air Force's efforts at an office located at Robins Air Force Base. Like the Army, these commands have multiple weapon systems program offices that also plan and implement corrosion projects. The Navy and Air Force also have separate organizations that are responsible for corrosion prevention and mitigation efforts related to infrastructure. The Naval Facilities Engineering Center at Port Hueneme, California, provides this service for both the Navy and Marine Corps and, in turn, relies on the individual installations to manage and implement their own efforts. The Air Force Civil Engineering Support Agency provides this service for the Air Force.

This fragmentation of corrosion prevention efforts minimizes coordination and limits standardization within and among the services, as evidenced by the following examples:

- A June 2000 corrosion assessment of the Army's Pacific area of operations concluded that no standard corrosion control program, policy, or training exists for any Army commodity, which reduces the effectiveness of the Army's efforts to control corrosion on vehicles, tanks, and other equipment.

- Even when the services are in a severely corrosive environment in which they operate relatively near to one another, few formal mechanisms exist to facilitate the exchange of corrosion information. For example, in Hawaii Army officials for the Reserve and National Guard and active units stated that they had limited knowledge of one another's corrosion control activities or the activities of other services. Army officials told us they cannot afford to miss an opportunity to use the latest corrosion control products and practices, and it would be unfortunate to be deprived of any advances, especially if they are available and being used elsewhere. In addition, Air Force facilities officials in Hawaii told us that they are not aware of any formal process for sharing corrosion prevention and control information with other services.

- Officials at Marine Corps Air Facility Kaneohe Bay, Hawaii, an area of high humidity and salt, told us that temporary shelters can be a very cost-effective way to reduce the corrosion of equipment such as vehicles, transformers, and aviation ground equipment that are currently stored outside because of limited space. (See fig. 8.)

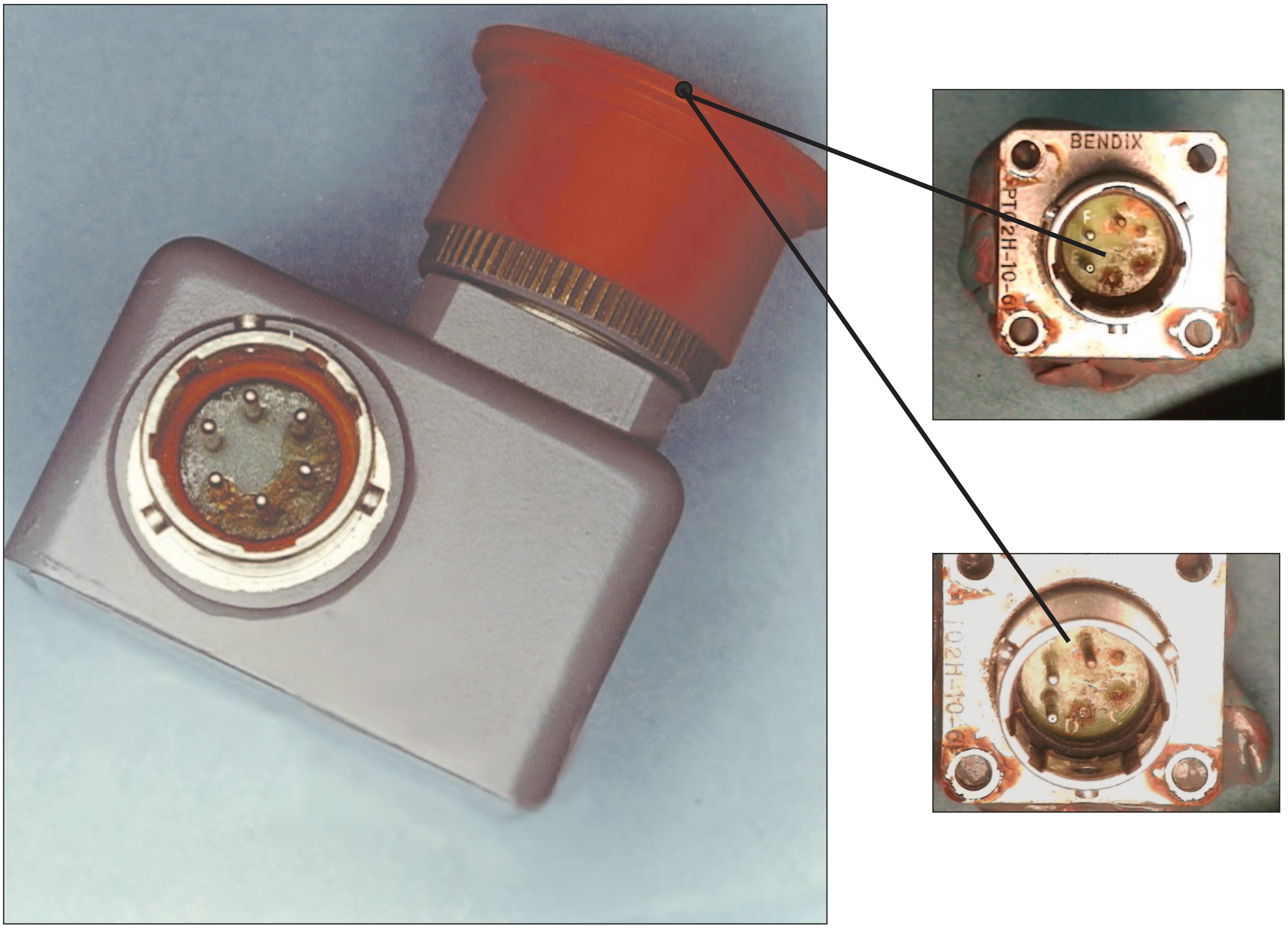
Figure 8: K-Span Shelter at Army Reserve Unit Fort Shafter, Hawaii

Source: GAO.

These officials were unable to acquire the shelters because they did not have the time or resources to undertake the analysis necessary to support the purchase. They were aware that temporary shelters are being used at other Marine Corps and Army installations, but they did not know how the installations acquired the shelters or justified their purchase. The officials suggested a standard mechanism for gathering and communicating the information necessary to justify purchase of the shelters.

- The Air Force conducted a series of multiyear studies that found that using inexpensive corrosion-inhibiting lubricants on aircraft electrical connectors has the potential to save hundreds of millions of dollars annually. (See fig. 9.)

Figure 9: Corroded Connectors on Air Force F-16 Main Fuel Shutoff Valve



Source: U.S. Air Force.

Air Force officials estimate that using corrosion-inhibiting lubricants could save more than $500 million annually on the F-16 fleet alone. Although the use of these lubricants is recommended in a joint technical manual on avionics corrosion control,[21] their use is not required. The Air Force and Navy have developed different product specifications for the lubricants. The Navy's specification covers the lubricants' use on both metal surfaces and electrical connectors, and more than a dozen products have qualified for use under the specification. However, Air Force studies determined that while some of the products work well on electrical connectors, others are detrimental. As a result, the Air Force created a new specification for lubricant use, limiting it to electrical connectors. Air Force officials want the Navy to modify its specification so that only the appropriate products can qualify; otherwise, Air Force officials believe, those who refer to the joint manual containing both specifications could order a product detrimental to electronic systems. An Air Force contractor has drafted specification revisions for the Navy, but due to differing requirements and changes of personnel, the Navy has apparently decided to conduct further studies before revising its specifications. According to Air Force officials, these and other difficulties in coordinating with the Navy have prompted the Air Force to consider withdrawing from participation with the Navy in joint service manuals on corrosion control of aircraft and avionics.

- Army National Guard officials in Hawaii told us that they were not aware of the status of the Army's nearby corrosion inhibitor application center. (See fig. 10.) The facility currently has the capacity to apply corrosion inhibitors to about 6,000 vehicles per year. National Guard officials told us that they often store vehicles for long periods of time, and corrosion is always a problem. They indicated interest in finding out more about the Army's facility and any opportunities for participating with the Army if the corrosion inhibitors can reduce corrosion cost effectively.

[21] Technical Manual Organizational/Unit and Intermediate Maintenance, Avionics Cleaning and Corrosion Control, NAVAIR 16-1-540, Air Force TO-1-1-689, Army TM-1-1500-343-23; September 1, 2000.

Figure 10: Corrosion Inhibitor Application Facility at Army's Schofield Barracks, Hawaii

Source: GAO.

The services have created some valuable mechanisms, including special working groups[22] and annual corrosion conferences, which make important contributions to corrosion prevention efforts and help facilitate intra- and inter-service coordination. However, these mechanisms do not represent a systematic approach to coordination. The effectiveness of these mechanisms is often dependent on the individual initiative of those who participate directly, as well as on the funds available to initiate corrosion-related activities. For example, each of the services hosts an annual corrosion conference, but individuals attend only to the extent that available time and travel funds allow. Furthermore, the dissemination of conference information relies to a large extent on attendees taking the initiative to use the information or communicate it to others. Limited follow-up is carried out to determine the extent to which this information

[22] Special working groups—within and across the services—have been established, such as the Joint Council for Aging Aircraft, Air Force Corrosion Prevention and Advisory Boards, and various Science and Technology Advisor programs. DOD has also established working groups such as the Maintenance Technology Senior Steering Group, Joint Technology Exchange Group, and the Joint Logistics Commanders to share information on acquisition and maintenance issues, including corrosion control.

is used in new applications. Several of the officers acting as corrosion coordinators in Hawaii indicated that their commands were often unable to allow them the time or travel funds to attend corrosion conferences. They added that some, but not all, of the conference papers and briefings were available to them.

Conflicting Incentives and Priorities Limit Corrosion Project Implementation

Because of the differing priorities between short-term operational needs and long-term preventative maintenance needs, corrosion projects are often given a low priority.

Corrosion control offices act largely in an advisory role, providing guidance, information, and expertise on initiatives and practices. They have limited funding and authority, and they promote initiatives with benefits that may not become apparent until a project is far along in its implementation, which may be years in the future. These priorities and incentives are very different from and sometimes conflict with those held by the operational or installation commands and their subordinate units. While these commands also strive for better corrosion prevention, they place a greater emphasis on more immediate, short-term needs that are directly tied to current operations.

Because the corrosion control offices generally receive only limited start-up funding for corrosion prevention projects, they must rely heavily on operational commands and other program offices to provide the necessary resources and implementation. However, these commands often have limited resources beyond those needed to carry out their immediate mission objectives, and the military services have not established sufficient incentives for the commands (which have the approval and funding authority) to invest in the long-term, cumulative benefits of corrosion prevention and control efforts. As a result, many proposed corrosion control projects—even those with large cost saving potential and other benefits, such as increased readiness and enhanced safety—often remain underfunded because they are a low priority to the commands compared to operational and repair projects that offer more immediate results.

These conflicting incentives and priorities are demonstrated by the fact that the services have sacrificed the condition of their facilities and infrastructure by using base maintenance accounts, including funds for corrosion prevention and control, to pay for training and combat operations. We were told at many of the bases we visited that the problem with maintaining the infrastructure was that base commanders siphon off infrastructure maintenance and repair funds for other operational priorities. For example, at Fort Irwin we were told that only 40 percent of infrastructure requirements were funded and that most preventative maintenance is deferred. Officials at Marine Corps Base Camp Pendleton said that they have an infrastructure maintenance backlog totaling over $193 million and many of the projects are to repair facilities that have deteriorated due to corrosion. The backlog is not limited to this location, as the Navy reports an infrastructure backlog of $2 billion Navy-wide. Navy officials said they do not have accurate data but estimate that a large percentage of the deferred maintenance is corrosion related. Hickam Air Force Base facilities officials also told us that they often have to defer or reduce corrosion prevention projects because the base continually needs funds for higher priorities, usually those associated with operations. At the same time, the Army, in its 2002 Annual Report to Congress, stated that it cannot continue to fully fund its Combat Arms Training Strategy without further degrading its infrastructure and related activities. The Army recently established a new agency that centralizes all installation management activities to ensure that maintenance dollars, including those for corrosion control, are disbursed equitably and efficiently across installations. Officials of the new Installation Management Agency said that the goal of centralization is to halt the trend of major commands transferring funding from infrastructure maintenance accounts to pay for other operations.

The Navy's corrosion projects are similarly affected by a tendency to postpone maintenance projects to address more immediate demands. For example, the Navy's efforts to reduce corrosion on more than 11,700 tanks on Navy ships are very time-consuming and expensive. (See app. II for more details of this case study.) To reduce costs, the Navy developed advanced coatings that are intended to last much longer, require less maintenance, and result in net savings of over $170 million annually. As of the end of fiscal year 2002, the Navy has only been able to install the new coatings on about 750 tanks, or less than 7 percent. Navy officials attribute the slow pace to the fact that shipyards place a higher priority on maintenance that requires immediate attention. These officials told us that the shipyards are hard-pressed to complete even necessary repairs and have little incentive to undertake prevention projects that will not show any benefits for many years.

Conflicting priorities are also evidenced by Navy and Marine Corps efforts to prevent the corrosion of underground pipelines. Navy officials informed us that pipeline corrosion is one of their major facilities maintenance concerns. According to these officials, many pipelines at multiple Navy installations are several decades old and made of metal that is highly susceptible to corrosion. (See fig. 11.)

Figure 11: Corrosion on High Temperature Pipelines at Air Force Tracking Facility Antigua, West Indies

Source: U.S. Air Force.

Naval Facilities Engineering Service Center officials told us that they do not have accurate data, but they estimate that several million dollars are being spent each year to fix leaks and ruptures that result from corrosion. They further stated that they could save significant maintenance costs if they were to aggressively start replacing existing pipelines with pipelines made of high-density polyethylene plastic and other nonmetallic material that is much more corrosion resistant. Naval facilities officials said that while this replacement project would be a big money-saver in the long run, the strategy would require a substantial investment, and they need to place a higher priority on fixing more immediate problems that disrupt or impair current operations. The Marine Corps is faced with similar conflicting pressures. At Marine Corps Base Camp Pendleton, officials told us that they have old and decaying pipelines and valves throughout the installation. To save significant repair costs, they would prefer to replace them with pipelines and valves made of high-density polyethylene plastic as quickly as possible. (See fig. 12.)

Figure 12: Corroded Air-Conditioning Valves at Quantico Marine Corps Base, Virginia

Source: GAO.

However, the process is labor-intensive and, therefore, very expensive. They said that as a rule they must attend to more immediate problems, and only when resources permit are they able to invest in projects that have more long-term benefits.

Conclusion

At present, DOD and the military services do not systematically assess proposals for corrosion control projects, related implementation issues, or the results of implemented projects, and they disseminate project results on a limited, ad hoc basis. Without a more systematic approach to corrosion problems, prevention efforts that have a high return on investment potential will likely continue to be underresourced and continue to proceed at a slow pace. As a result, DOD and the military services will continue to expend several billion dollars annually in avoidable costs and continue to incur a significant number of avoidable readiness and safety problems. Since corrosion that is left unmitigated only worsens with time, costs will likely increase as weapon systems and infrastructures age. Perhaps this is why the adage “pay now or pay more later” so appropriately describes the dilemma with which the military services are repeatedly confronted when making difficult investment decisions. The military services will continue to pay dearly for their limited corrosion prevention efforts and will be increasingly challenged to find the funds for ongoing operations, maintenance, and new systems acquisitions.

Recommendations for Executive Action

In an effort to improve current military approaches to corrosion control, the Bob Stump Defense Authorization Act of 2003 requires the department to develop and implement a long-term strategy to mitigate the effects of corrosion in military equipment and infrastructure. If properly crafted, this strategy can become an important means of managing corrosion control efforts and addressing the problems and limitations of these efforts as described in this report.

To craft an effective strategy, we recommend that the Secretary of Defense direct that the department’s strategic plan for corrosion prevention and mitigation include the following:

- develop standardized methodologies for collecting and analyzing corrosion cost, readiness, and safety data;
- develop clearly defined goals, outcome-oriented objectives, and performance measures that show progress toward achieving objectives (these measures should include such elements as the expected return on investment and realized net savings of prevention projects);
- identify the level of resources needed to accomplish goals and objectives;
- establish mechanisms to coordinate and oversee prevention and mitigation projects in an interservice and servicewide context.

To provide greater assurances that the department’s strategic plan will be successfully implemented, we recommend that the secretaries of each of the services

- develop servicewide strategic plans that are consistent with the goals, objectives, and measures in the departmentwide plan and
- establish procedures and milestones to hold major commands and program offices that manage specific weapon systems and facilities accountable for achieving the strategic goals.

Agency Comments

In commenting on a draft of this report, DOD concurred with our recommendations. The comments are included in this report in appendix III. DOD also provided technical clarifications, which we incorporated as appropriate. In its technical comments, DOD did not concur with our finding that the department does not have an effective approach to prevent and mitigate corrosion. DOD noted that the department develops and incorporates prevention and mitigation strategies appropriate to DOD’s national defense mission within various constraints associated with operational needs, affordable maintenance schedules, environmental regulations, and other statutory requirements. DOD noted that corrosion is one of many issues that must be managed and incorporated into an overall defense mission. DOD also noted that it continually endeavors to improve its ability to manage corrosion through advanced research, upgrading of systems and facilities, application of new materials, processes and products and continuous information sharing. Our report recognizes and mentions DOD's efforts and successes with corrosion mitigation. However, we believe that DOD lacks an effective approach to deal with corrosion since it lacks an overall strategy, has limited coordination within and among the services, and conflicting incentives and priorities. As we noted in our report, the current DOD approach has led to readiness and safety issues as well as billions of dollars of corrosion-related maintenance costs for DOD and the services annually.

We are sending copies of this report to the Secretary of Defense; the Director, Office of Management and Budget; and other interested congressional committees. We will also make copies available to others upon request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

Please contact me on (202) 512-8365 if you or your staff have any questions concerning this report. Key contributors to this report were Allan Roberts, Allen Westheimer, Dorian Dunbar, Sarah Prehoda, Sandra Sokol, and Susan Woodward.

William M. Solis, Director
Defense Capabilities and Management

Scope and Methodology

Our study focused on how the military services implement and manage corrosion prevention and control efforts for both equipment and infrastructure. To perform our review, we contacted corrosion control offices and officials in each of the four military services. We also reviewed studies and discussed military corrosion issues with experts within and outside the Department of Defense (DOD). To develop an in-depth understanding of how corrosion prevention projects are initiated and managed, we visited field installations and developed case studies on corrosion prevention and mitigation efforts. We also contacted and obtained information from DOD, services headquarters, materiel management, research and development, logistics, systems acquisitions, safety, and installation management and maintenance organizations.

To determine the extent of the military services' corrosion problems, we reviewed numerous studies and contacted experts in both government and private industry. We contacted and obtained information from DOD, military service headquarters, strategic planning, research and development, systems acquisitions, materiel management, logistics, safety, and installation management and maintenance organizations. We also attended the U.S. Navy and Industry Rust 2002 Corrosion Technology and Exchange Conference, and we reviewed papers and presentations of other service and private industry corrosion conferences and forums. In addition, we contacted private industry suppliers, consultants, and research organizations. We contacted the following research organizations to obtain information regarding the extent of military service corrosion problems:

- National Research Council
- National Materials Advisory Board
- NCI Information Systems, Inc.
- CC Technologies Laboratories, Inc.
- American Power Jet Company
- Science Applications International Corporation
- Battelle Laboratories
- Calibre Systems, Inc.

- Sandia National Laboratories
- Metals Information Analysis Center
- Center for Army Analysis
- Joint Council on Aging Aircraft
- Services Command Corrosion Assessments and Surveys
- Services Corrosion Prevention and Advisory Boards
- Services Science and Technology Advisor Programs
- Services Corrosion Conferences and Forums

To determine the extent to which DOD and the military services have an effective approach to corrosion control, we interviewed officials and obtained documentation from the four military services' corrosion control program offices for equipment and infrastructure. For equipment, these included the Army Corrosion Prevention and Control Program, the Air Force Corrosion Prevention and Control Office, the NAVAIR and NAVSEA Corrosion Prevention and Control Programs, and the Marine Corps Corrosion and Prevention Program. For infrastructure we contacted the Army Corps of Engineers and Department of Public Works, the Air Force Civil Engineer Support Agency, and the Naval Facilities Engineering Service Center Command. We also contacted and obtained information from DOD, service headquarters, strategic planning, materiel command, and field command officials. We reviewed corrosion prevention and control plans, policies, procedures, instructions, regulations, studies, trip reports, memos, and other forms of documentation. We also visited selected military bases, where we held discussions with unit commanders, facilities engineering and maintenance officials, and users of DOD equipment such as aircraft, ships, tanks, trucks, and support equipment, including discussions with operators, logistics, and maintenance personnel. We interviewed officials and gathered data at the following installations in California and Hawaii:

California

- Fort Irwin Army Base
- Los Angeles Air Force Base
- March Air Force Reserve Base
- North Island Naval Air Station
- Point Mugu Naval Air Station
- Port Hueneme Naval Base
- Marine Corps Base Camp Pendleton
- Marine Corps Air Station Miramar

Hawaii

- Fort Shafter Army Base
- Schofield Barracks Army Base
- Wheeler Army Air Field
- Diamond Head Complex, Hawaii Army National Guard
- Pearl City Unit Training and Equipment Site, Hawaii Army National Guard
- Hickam Air Force Base
- Pearl Harbor Naval Complex
- Lualualei Naval Magazine
- Marine Corps Air Facility Kaneohe Bay
- Marine Corps Camp H.M. Smith

We conducted our review from August 2002 through April 2003 in accordance with generally accepted government auditing standards.

Examples of Corrosion Prevention Efforts That Have Not Realized Their Full Potential

Durable Coatings for Tanks on Navy Ships

The Navy has over 11,700 tanks, such as ballast, fuel, and potable water tanks, on all of its surface vessels and submarines. Because of their constant exposure to salt and moisture, these tanks rapidly lose their exterior and interior protective coatings and begin to corrode. Although maintenance personnel spend considerable time and resources removing as much of the visible corrosion as possible and repainting while the ship is deployed, some of the work cannot be accomplished until the ship returns to its home port and undergoes scheduled and unscheduled maintenance. Maintaining the tanks is labor intensive, costly, and extends the amount of time ships must spend undergoing maintenance, thereby reducing their operational availability. Naval Sea Systems Command has developed coating systems that are expected to last 20 years instead of the 5 years that existing coatings last. According to the Navy, the effort could potentially save more than $170 million a year in maintenance costs. The initiative appears to be somewhat successful, because the Navy reports that it has achieved net savings of about $10 million a year. However, in the past several years, the Navy has installed the new coatings on only about 750 tanks, or less than 7 percent of the total. Navy officials attribute the slow pace to the fleet placing higher priorities on other needs, and explained that they often must defer the installation of the new coatings because of the limited availability of ships due to increased optempo and more pressing maintenance requirements. Navy officials added that because of higher operational and maintenance priorities, resources in the form of funding and manpower usually go to these needs instead of prevention efforts such as tank coatings. These officials told us that the shipyards that perform most of the maintenance for the fleet have difficulty trying to complete the work currently scheduled with available resources and would be further challenged by having to add the application of new coatings to their existing workload. In addition, the officials told us that there is limited incentive for shipyard maintenance workers to carry out preventive projects that show benefits only in later years instead of completing more immediate repairs that show more immediate benefits.

Army National Guard Controlled Humidity Preservation

The Army National Guard maintains a wide range of equipment that includes M1 tanks, howitzers, air defense artillery systems, and radars. This equipment is susceptible to corrosion, and one of the primary causes of corrosion is humidity. The Army National Guard estimates it could achieve cost savings totaling more than $1.6 billion over 10 years by storing its equipment in short- and long-term controlled-humidity preservation centers. Depending on the type of equipment, some will be stored in long-term facilities and some will be stored for the short-term. Equipment that is not required for regular training use will be preserved in metal shelters for an average of 3 years, while equipment for which there is a recurring need will be preserved by installing dehumidifying air ducts in crew compartments and other vehicle spaces. The project, which started in 1997, is expected to have a return on investment of over 9 to 1. According to Army National Guard officials, through the end of fiscal year 2002, the project has achieved a total of $225 million in cost savings. While Army officials state that the project has proven to be a success so far, they now estimate that it will take about 15 years to accomplish the total projected savings, or 5 years longer than originally planned. They attribute the delay to other needs being given a higher priority and, as a result, not receiving the necessary funds and having to defer the installation of some controlled-humidity centers. These officials still expect to acquire and install all of the facilities, but at a slower pace. They acknowledge that the delay will likely mean deferring a significant amount of cost savings—perhaps as much as $100 million—for several years.

Fly Ash in Concrete Airfields

Concrete airfield pavements for all of the military services have experienced cracking and expansion that pose significant safety hazards, impair readiness, and increase maintenance costs. One of the causes of this deterioration results from a corrosive chemical reaction called alkali-silica reaction, which occurs when alkalis react with water in ways that cause cracking, chipping, and expansion of concrete. Examples of this kind of damage have been reported at facilities for all military services, such as Osan Air Base, Korea; Ft. Campbell Army Airfield, Kentucky; Naval Air Station Point Mugu, California; and Marine Corps Air Station, Iwakuni, Japan. The foreign object debris hazard caused by cracking and crumbling concrete was so severe that the Air Mobility Command assessed a taxiway at Little Rock Air Force Base as unsuitable for use. While the military services do not have cost estimates, DOD facilities officials told us that significant resources are spent each year on mitigating the effects of alkali-silica reaction.

The Navy determined that one way to mitigate the effects of alkali-silica reaction in the future is to substitute fly ash for a certain amount of cement. According to a Navy study, the use of fly ash increases the strength and durability of cement structures such as airfields. Navy officials told us that this mitigation would increase the operational availability of airfields because the facilities would experience less cracking and chipping and, therefore, pose fewer foreign object debris hazards. While the Navy did not perform the analysis, these officials told us that perhaps the greatest benefit would be the savings that would result from a marked reduction in manpower needed for maintenance. The study did not include cost savings or a return on investment analysis because its focus was on the causes of and methods for mitigating the deterioration. The study did note that fly ash substitution could save the Navy about $4 million a year in construction costs because the material is less expensive than the kinds of cement currently being used. Navy officials told us that their understanding of the overall benefits is convincing enough that the use of fly ash is required for all Navy and Marine Corps construction projects that include pavements.

The Air Force recommends the use of fly ash, but only in certain circumstances. Air Force officials told us that requiring the use of fly ash for all construction projects is not feasible because fly ash is not available at all locations where the Air Force has facilities, and the additional cost and time involved in transporting the material to these places may be greater than the benefits from using it. However, Air Force officials acknowledge that they have not done a return-on-investment analysis that includes construction and maintenance costs, and additional information like this would be very useful in making decisions regarding the use of fly ash.

The services continue to study the effects of alkali-silica reaction and what to do about them. However, due to limited funding, efforts to identify feasible comprehensive solutions to the entire problem for all military services have been delayed. In the meantime, airfields continue to decay, resulting in high maintenance costs as well as restricted use.

Army Corrosion Inhibitors

Corrosion damage to tactical wheeled vehicles and ground equipment is costly and prolongs equipment downtime. According to officials of the Army Materiel Command, seawater that seeps into the inner cavities of equipment that is being transported overseas causes serious corrosion damage and represents the highest risk to the command. The equipment then decays rapidly in humid environments.

This kind of corrosion damage was so extensive that in 1998 the Commanding General U.S. Army Pacific requested that all ground vehicles shipped to his command be treated with rust inhibitors. Army data indicated that 17 percent of the Army trucks in Hawaii were so corroded that performance of their missions was impaired. In 1999, the

Commanding General of the 25th Infantry Division in Hawaii indicated that unit readiness was in serious jeopardy and requested funding for several corrosion control projects, including one to treat an estimated 3,000 remaining vehicles with corrosion inhibitors. Army testing had demonstrated that corrosion inhibitors, compared to other products, provided a high degree of corrosion protection and enough corrosion-reducing potential to warrant beginning their limited use. Initial estimates indicated a return on investment of 4 to 1 for every dollar spent.

In 2000, the Army awarded a contract for approximately $400,000 to treat 3,000 vehicles over a period of 12 months. The contract was later doubled, increasing costs to nearly $900,000 for 6,000 vehicles over a period of 24 months. Army officials plan to analyze the information obtained on the performance of the product before deciding whether to continue using it or expand the effort to other locations. The Army has over 341,000 tactical vehicles and pieces of ground support equipment worldwide, as well as 3,770 airframes, and a significant amount of this equipment is exposed to harsh, corrosion-inducing environments.

The Army originally planned to establish an all-purpose, full service corrosion control center to repair corrosion damage, as well as provide preventative corrosion-inhibitor treatments. The center, which would have had multiple service bays and wash racks would have processed more than 15,000 vehicles per year, was to have been used by all the military services in Hawaii. However, the center is currently only being used by the Army as a corrosion-inhibitor application facility.[1] In addition, a lack of coordination exists within the individual services. For example, at an Army National Guard facility in Hawaii officials told us that they were not aware of the status of the Army's corrosion-inhibitor application facility but that they would be interested in finding out more about it, the application of corrosion inhibitors, and participating in the project.

Air Force Bomb Metalization

The Air Force stores about 450,000 cast iron general-purpose bombs in locations throughout the world. The bombs are estimated to have a replacement cost exceeding $1 billion. Many of the locations are in high-humidity environments that contribute to corrosion. As of February 2003, more than 107,000 of these bombs, or 24 percent,

[1] The services could not reach agreement on location, funding, and standard application procedures.

have been assessed as being no longer mission capable because of excessive corrosion. The Air Force acquires new bombs and repairs existing ones so that it will have enough mission-capable bombs to meet its requirements. The Air Force spends about $7 million a year for corrosion protection of cast iron general-purpose bombs. Until 1996, all the bombs were renovated by maintenance personnel who removed any signs of corrosion and recoated them with liquid paint. The bombs would undergo this labor-intensive process every 3 to 8 years. In 1996, the Air Force converted a bomb renovation plant at Kadena Air Base, Japan, from a facility that used liquid paint to one that used a metal wire arc spray technique that is otherwise known as metalization. The plant conversion cost about $3 million. A metal wire arc spray coating is expected to preserve cast iron bombs for 30 years, or about 25 years longer than liquid paint. By using this preservation method, the Air Force estimates saving maintenance costs of $30 to $100 million over 30 years, resulting in a return on investment ratio of 20 to 1. The plant successfully renovated about 8,000 bombs. Based on previous successes, the Air Force decided to acquire and install mobile versions of the Kadena unit in other locations. In 2000, a prototype of the Mobile Bomb Renovation System was acquired and installed at Andersen Air Force Base, Guam, at a cost of about $2 million. About 500 bombs received the metal arc spray coating at Guam before the system experienced equipment failures. To date, the system remains inoperable. The Army has also refurbished and metalized about 6,500 bombs for the Air Force.

Air Force studies show that although the metal arch spray coating process is more expensive than the use of liquid paint, it greatly minimizes the risk that bombs will need costly maintenance or deteriorate so severely that they will need replacing. Despite these benefits, about 3 percent of Air Force bombs have been treated with this coating process. While Air Force officials recommended that a much higher percentage of bombs receive this treatment, they explained that their role is mostly advisory, and the Air Force Material Command and Pacific Air Force Command together must determine the relative importance of the project, given other competing priorities.

F-16 Aircraft Corrosion Inhibitors

Although not visible, the corrosion of connectors on aircraft electronics equipment is prevalent throughout DOD and a significant safety risk for aircraft in all military services. The resources spent on this kind of corrosion are so vast that it is estimated that the Air Force spends perhaps as much as $500 million a year on corrosion control on the F-16 fleet alone.

The costs are high because of the significant amount of labor that is involved in locating and eliminating the often microscopic sources of corrosion on very sophisticated avionics equipment. Avionics corrosion has been a topic of major interest to the Air Force for several decades. This concern was particularly heightened in 1989, when the Air Force reported several F-16 accidents caused by uncommanded fuel valve closures that were believed to have been caused by corrosion.

For several decades, the Air Force has conducted extensive studies on the corrosion of aircraft avionics connectors and what should be done about it. In the 1990s, several studies recommended the use of certain lubricants that have the potential of eliminating connector corrosion on F-16 aircraft, with estimated savings exceeding $500 million a year. Although the Air Force did not complete a return on investment analysis, the return would be very impressive, given the low cost of purchasing this off-the-shelf product. The Air Force has yet to take full advantage of these corrosion-inhibiting lubricants, even though they appear to be widely available. While the use of such lubricants is recommended in the joint service technical manual on avionics corrosion control, it is not required. We were told that the Air Force would need to amend in detail more than 200 specific technical orders and job guides to require the use of lubricant to protect F-16 aircraft electrical connectors, but progress in this area has been sluggish at best.[2] For every year that the Air Force does not require the use of the lubricants, the service loses the opportunity to avoid annual expenses that total hundreds of millions of dollars.

Army Helicopter Rinse Facilities

Conflicting incentives also impeded the Army's efforts to obtain modern helicopter rinse facilities called "birdbaths." According to the Army Aviation Corrosion Prevention and Control office, these facilities are expected to extend the life of costly aircraft components, reduce contractor man-hour expenditures, increase aircraft fleet readiness, and provide an added margin of crew safety. The project is estimated to cost $12 million for startup and $400 thousand per year in operating costs. Even more notable was the analysis showing a 31 to 1 return on investment, with the investment costs recouped within 2 years. Citing opportunities to implement and promote effective corrosion control, the

[2] The F-15 aircraft program has established a pilot program requiring use of corrosion inhibiting lubricants on electrical connectors during flightline depot maintenance by simply mandating the recommended use as stated in the joint service avionics technical manual.

Army recommended identification of locations and deployment areas for establishing birdbath rinse facilities. Despite the potential benefits, the project has not received funding to date. Army officials told us that the project cannot compete with efforts that have a higher priority, and they have deferred the request for funds until fiscal year 2005. The Army's attempt to obtain funding for a birdbath facility in Hawaii suffered the same fate. During our field visit to Hawaii, we were told that for a number of years a birdbath facility was included in a list of projects that required funding, but the facility never received the funds because other operational needs were considered to have a higher priority. Army officials said that funding more pressing operational needs almost always takes precedence over funding projects that have a strong potential to avoid future maintenance costs.

Comments from the Department of Defense

OFFICE OF THE UNDER SECRETARY OF DEFENSE

3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

June 11, 2003

Mr. William M. Solis
Director
US General Accounting Office
Washington DC 20548

Dear Mr. Solis:

This is the Department of Defense (DoD) response to the GAO draft report, GAO-03-753, "DEFENSE MANAGEMENT: Opportunities to reduce Corrosion Costs and Increase Readiness," dated May 9, 2003 (GAO Code 350219GAO-03-753). The Department appreciates the opportunity to comment on the draft report.

The Department considers corrosion to be an important issue associated with cost, readiness, and safety of its weapons systems and facilities. As a result, the DoD and the Military Departments have in the past and will continue in the future to combat corrosion in its many forms and to focus on means to prevent and mitigate corrosion within its overall mission and obligations. We hope that the inclusion of GAO in the recent strategic planning activities related to corrosion has been beneficial to both of us in helping to place corrosion within our national security context.

The GAO report makes two broad "Recommendations for Executive Action," each of which contain several more specific recommendations. The Department concurs with the Recommendations for Executive Action in the report and is committed to meeting the requirements of Congress and, to the extent compatible with its core mission, the positive recommendations of the GAO report.

The Department offers specific comments and recommendations (enclosed) directed towards improving the accuracy and balance of the report. We believe we are insitutionalizing a cross-cutting DoD-wide corrosion mitigation and prevention control program for both facilities and equipment. We are prepared to discuss these comments with you in more detail should you desire. The undersigned may be considered the Department's primary point of contact.

Sincerely,

Daniel J. Dunmire

Daniel J. Dunmire
Director, Corrosion Policy and Oversight

Enclosure

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