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REVIEW OF NASA'S PRESSURE VESSELS AND PRESSURIZED SYSTEMS PROGRAM

June 30, 2015

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Office of Inspector General

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Results in Brief

Review of NASA's Pressure Vessels and Pressurized Systems Program

June 30, 2015 IG-15-019 (A-14-020-00)

Why We Performed This Audit

To conduct its space and science operations, NASA uses a variety of pressure vessels and pressurized systems (PVS) such as storage tanks, cylinders, and piping that deliver compressed gas or liquid under significant pressure. Because of the nature of these gasses and liquids and how they are used, PVS may fail and cause harm to people, facilities, and the surrounding environment if not properly operated and maintained. NASA has experienced PVS failures in the past that resulted in loss of mission, injury, and property damage.

As of February 2015, NASA managed 10,109 active PVS and spent approximately $22 million annually to inspect and maintain these critical systems. Most PVS failures occur when a vessel or piping wall fails or ruptures because the internal pressure of the material inside exceeds the strength of the wall. Similar to the skin of a balloon that progressively grows thinner as inflated and weaker after multiple inflation-deflation cycles, over-pressurization or repeated pressurization and depressurization can gradually weaken the skin or walls of PVS, eventually leading to failure. Internal or external corrosion and physical damage (scratches, dings, and dents) can also increase the risk of PVS failure.

We initiated this audit to determine whether NASA had implemented appropriate policies and procedures to protect lives and facilities while ensuring reliable operation of its PVS. As part of the review, we visited Glenn Research Center (Glenn), Kennedy Space Center (Kennedy), and Langley Research Center (Langley) to inspect PVS and interview Center Pressure System Managers (PSM) and other responsible personnel. We also gathered information from PSMs at other NASA Centers and facilities via an electronic survey.

What We Found

NASA Centers could benefit from stronger oversight and clarification of policies and procedures to ensure reliable operation of their PVS, which in turn could reduce risk to personnel and facilities. Specifically, NASA policy and standards for the management, operation, inspection, and maintenance of PVS are intentionally written at a fairly high level and do not contain specific guidance regarding the application of national consensus codes and standards, and the level of experience, education, and training sufficient to qualify an individual to serve as a Center PSM. In addition, NASA's Office of Safety and Mission Assurance (OSMA) did not provide adequate oversight of Center PVS Programs.

We also found multiple issues of concern at each of the Centers we visited, including corrosion on a large number of PVS, inadequate inventory and property controls, and unclear assignment of PSM roles and responsibilities. For example, at Langley we identified significant corrosion on high pressure piping and components, ground water penetration, and obstructed piping and systems in an underground utility corridor that contains high pressure steam piping, electrical conduit, and fiber optic communication lines (as shown in the figure). If a rupture were to occur in this corridor, the resulting damage could cause power and communication outages that would impact Center operations.

High Pressure Lines in a Langley Utility Corridor

Source: NASA Office of Inspector General.

In our judgment, NASA's PVS Program could be improved by establishing clear lines of communication for resolving issues, implementing corrosion prevention and mitigation programs, and evaluating and providing the PVS Programs sufficient resources to meet Center mission goals and objectives.

What We Recommended

To improve NASA's PVS Program and reduce the likelihood of mishaps, we made five recommendations to the Chief of OSMA, including (1) reviewing PVS management at all NASA Centers, (2) revising applicable NASA guidance, (3) reassessing the effectiveness of OSMA oversight, (4) requiring Centers to perform an analysis to determine if having certain calibration and repair capabilities on site would be cost and mission effective, and (5) requiring each Center to implement a formal PVS corrosion prevention and mitigation program. We also made recommendations to the Glenn, Kennedy, and Langley Center Directors to improve the overall effectiveness of each Center's PVS Program.

In response to a draft of our report, management concurred or partially concurred with our recommendations and described corrective actions they plan to address them. We consider management's comments responsive; therefore, the recommendations are resolved and will be closed upon completion and verification of the proposed corrective actions.

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Acronyms

ASME	American Society of Mechanical Engineers
HQ	Headquarters
IFO	Institutional/Facility/Operational
NASA-STD	NASA Technical Standard
NCS	National Consensus Codes and Standards
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
OSHA	Occupational Safety and Health Administration
OSMA	Office of Safety and Mission Assurance
PSM	Pressure Systems Manager
PVS	Pressure Vessels and Pressurized Systems

INTRODUCTION

To conduct its space and science operations, NASA uses a variety of storage tanks, cylinders, and piping that deliver compressed gas or liquid under significant pressure. Due to the types and operating parameters of these gasses and liquids, pressure vessels and pressurized systems (PVS) can be extremely hazardous, and if not properly operated and maintained, PVS failure could cause harm to people, facilities, and the surrounding environment. In fact, NASA has experienced PVS failures in the past that resulted in loss of mission capability, injury, and property damage.

As of February 2015, NASA managed 10,109 active PVS that officials estimate would cost roughly $10 billion to replace. In addition, the Agency spends approximately $22 million per year to inspect and maintain these critical systems.[1] Many of the Agency's PVS were installed in the decades between 1950 and 1970, including approximately 1,800 active PVS installed before creation of the Occupational Safety and Health Administration (OSHA) in 1970 and the subsequent issuance of its governing standards.[2] Consequently, some of the PVS do not comply with these regulations, and due to their age and use, their structural integrity is suspect. In addition, the sheer number of systems makes it difficult to gain a thorough understanding of their physical condition. Accordingly, many of these systems require extensive maintenance, inspection, repair, or replacement.

We initiated this audit to assess NASA's management of its PVS Program. We sought to determine whether NASA had implemented appropriate policies and procedures to protect lives and facilities while assuring reliable operation of these systems. We personally visited three NASA Centers – Glenn Research Center (Glenn), Kennedy Space Center (Kennedy), and Langley Research Center (Langley) – to inspect PVS and interview the Center Pressure Systems Managers (PSM) and other responsible personnel. In addition, we gathered additional information from the PSMs at the other NASA Centers and facilities via an electronic survey. See Appendix A for details of the audit's scope and methodology.

Background

NASA's PVS vary from small, low-pressure laboratory setups to large, extremely high-pressure vessels weighing many tons. PVS include high pressure air and gas systems, propellant and oxidizer tanks, operational facilities, laboratory systems, facilities support, boilers, and vacuum systems, many of which are located adjacent to occupied buildings and well-traveled roadways (see Figure 1).

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1 Each Center captures overall PVS Program costs differently. This figure represents a rough estimate based on our analysis of responses by individual Centers and facilities.

2 OSHA is an organization within the Department of Labor that seeks to ensure safe and healthy working conditions for Americans by enforcing safety standards and providing workplace safety training.

Figure 1: Laboratory Setup and Hypersonic Facilities Complex at Langley

Source: NASA.

Most of the hazards associated with PVS occur when a vessel or piping wall fails or ruptures because the internal pressure of the material inside exceeds the strength of the wall. Similar to the skin of a balloon that progressively grows thinner as the balloon is inflated and weaker after multiple inflation-deflation cycles, over-pressurization or repeated pressurization and depressurization cycles can gradually weaken the skin or walls of PVS, eventually leading to failure. Internal or external corrosion and physical damage (scratches, dings, and dents) may also increase the risk of PVS failures. This rupture or bursting effect can be rapid and extremely violent, resulting in fragmentation of the PVS and the generation of a shock wave similar to detonation of an explosive device. In fact, the effects are so similar that the potential destructive force of a PVS rupture is measured by its TNT equivalency.[3]

Several mishaps at NASA have involved corrosion and erosion of the PVS vessels.[4] For example, in September 2003 a steam line on the Large Altitude Simulation System at the White Sands Test Facility (White Sands) suffered a catastrophic failure in an expansion loop located adjacent to a test stand steam ejector exhaust duct.[5] The resulting blast wave blew several large pieces of pipe into the surrounding desert, including a 19-foot section of pipe weighing 1,130 pounds propelled 400 feet from the test stand. (The area circled in red in Figure 2 identifies the location of the pipe prior to rupture.) Additionally, a 160-pound section of pipe impacted a hand-rail and fell into the flume area of the test stand, while a 1,205-pound, 20-foot section broke away from the facility main steam line and struck a test stand facility structure. A Mishap Investigation Board concluded that the primary cause of the steam line failure was pipe wall thinning from a combination of external corrosion and internal erosion and corrosion. Fortunately, no one was injured because pieces of the pipe blew in various directions away from occupied areas.

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[3] TNT equivalency is a comparative measure of the energy released in the detonation of Trinitrotoluene (TNT), a pale yellow solid organic compound commonly used as an explosive.

[4] Corrosion is the degradation of a component by its environment. The American Society for Testing and Materials defines corrosion as the chemical or electrochemical reaction between a material (usually metal) and its environment that produces a deterioration of the material and its properties. Erosion is the loss of material due to wear caused by moving fluid (liquid or gas) through a vessel, piping, or tubing.

[5] The Large Altitude Simulation System is a chemical steam generator used by several rocket engine test stands at White Sands to provide the atmospheric conditions representative of operating above 100,000 feet.

Figure 2: High Altitude Chamber Mishap at White Sands Test Facility

Source: NASA.

In addition to fragmentation and blast wave types of hazards, employees can also be exposed to hazards caused by improper design or modification of PVS. For example, in October 1998 at White Sands a 4-inch-diameter cast iron strainer used to trap particulate contamination in a steam line failed catastrophically releasing high pressure steam and hurling strainer pieces and other metallic parts into the equipment building. Fortunately, the scalding hot steam and projectiles caused no injuries and only minor damage to the steam piping and surrounding equipment. This failure was largely caused by inappropriate design and the use of substandard material for the strainer. According to the American Society of Mechanical Engineers (ASME) Code for Power Piping, the strainer should have been manufactured from steel rather than cast iron.[6] Although White Sands personnel performed a hazard analysis regarding the potential hazards to personnel, the analysis did not address the engineering system design and the effects of water hammer on the cast iron strainer.[7]

In another example, in July 2006 a worker at Kennedy was struck several times by a 2-inch steel vent pipe that began to spin when an air hose was disconnected from sandblasting equipment, releasing pressurized air through the unrestrained vent pipe. The employee sustained serious head trauma and had to be airlifted to a hospital. The investigation of the incident revealed that Kennedy had not conducted a hazard analysis for this operation and did not have a risk mitigation plan for the equipment

[6] ASME Code B31.1. ASME is a membership organization focused on knowledge sharing and skill development for engineering disciplines.

[7] Water hammer is recognized by a banging or thumping in water lines due to variability in pressures and often occurs due to improper design.

because the equipment was not part of the Center's PVS certification program. A hazard analysis would likely have identified that the vent pipe assembly had not been properly restrained, allowing the pipe to loosen and spin as it was venting.

Other PVS risks stem from potential release of the flammable, toxic, or poisonous gases and liquids they contain, including those generated from combustion by-products during a PVS fire, which could result in injury, death, and environmental damage. In addition, the inadvertent release of an inert gas such as nitrogen can result in the displacement of oxygen and pose an asphyxiation hazard.[8] Although due to operational issues rather than PVS integrity, such an event at Kennedy in 1981 caused three fatalities.[9]

PVS Program Oversight

The Chief of NASA's Headquarters (HQ)-based Office of Safety and Mission Assurance (OSMA) has overall responsibility for the Agency's PVS Program and has delegated day-to-day oversight of policy and procedures to the OSMA Technical Discipline Manager for Pressure Systems. In addition, each Center Director designates a civil servant PSM, who, along with other civil servant and contractor personnel, manages the day-to-day operations of the Center's PVS Program.

PVS Program guidance is provided by the NASA Policy Directive (NPD), the NASA Technical Standard (NASA-STD), NASA Procedural Requirements (NPR), and applicable Federal Regulations, as well as national consensus codes and standards (NCS), including the ASME Boiler and Pressure Vessel Code and the ASME B31 series Piping Codes.[10] These regulations and policies require NASA to certify and periodically inspect and recertify its PVS to ensure structural integrity and prevent mishaps. In addition, NASA must design, install, repair, operate, and maintain all ground-based PVS in accordance with applicable Agency and NCS standards.

The NASA Safety Center, which reports to OSMA, performs Institutional/Facility/Operational (IFO) Safety Audits and a variety of technical assessments to support the safety and mission assurance requirements of NASA's portfolio of programs and projects.[11] These audits and technical assessments evaluate the flow-down of pertinent Agency-wide directives, policies, and requirements from NASA HQ to NASA Center requirements and procedures. The audits are intended to provide Center management with an independent, objective, and constructive evaluation of the effectiveness and efficiency with which responsibilities and requirements are being implemented.

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8 Inert gasses such as nitrogen are odorless, colorless, and tasteless and upon release displace oxygen in a space. Whereas a "slow leak" can be insidious because there may be little sound associated with release of the gas, a "fast leak" will displace the oxygen faster giving a person less time to evacuate the space.

9 In 1981, three technicians were exposed to an oxygen deficient atmosphere and died while working in the aft section of the Space Shuttle. NASA determined that the deaths occurred because the oxygen within the closed space had been displaced during a gaseous nitrogen purge.

10 NPD 8710.5D, "Policy for Pressure Vessels and Pressurized Systems," March 12, 2008; NASA-STD 8719.17A, "NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)," November 6, 2009; and NPR 8715.3C, "NASA General Safety Program Requirements," March 12, 2008. NCS are nationally developed and agreed-upon standards and codes that NASA must follow in addition to the Agency's internal requirements.

11 NPR 8705.6B, "Safety and Mission Assurance (SMA) Audits, Reviews, and Assessments," May 24, 2011.

PVS Programs at Glenn, Kennedy, and Langley

As noted previously, we visited Glenn, Kennedy, and Langley to get a first-hand look at their PVS and interview staff responsible for PVS operation and maintenance. We picked these Centers based on the number and complexity of active PVS located there and the organizational structure and resources they have allocated to their PVS programs.

Glenn Research Center

At the time of our site visit in January 2015, Glenn had 1,584 active PVS on its two campuses – Lewis Field and Plum Brook Station, including the Spacecraft Propulsion Research Facility and Space Power Facility.[12] In 2011, the Center developed a 15-year risk-based plan for managing and certifying its PVS. Glenn's PSM reports to the Center's Facility, Test, and Maintenance Directorate and oversees the Pressure System Office, the operation of which is contracted to Mainthia Technologies, Inc. The $32.5 million, 5-year contract, signed in 2009, includes a 2-year base period and three 1-year options. Mainthia's work is split into two tasks: (1) Glenn Pressure Systems Certification, a $3.7 million per year task for the recertification of PVS, and (2) Cryogenics Operations and Maintenance, a $500,000 per year task for cryogenic PVS operations and maintenance. Funding for Glenn's PVS Program comes primarily from its Center Management and Operation budget, although some funds come from project sources.

Glenn has a Safety Permit Program managed by a safety committee composed of representatives from the Center Safety and Health Divisions, as well as individuals with engineering and/or operational expertise commensurate with the planned activity. When planned work involves the use of PVS, the PSM is automatically included in the permit review process. The Glenn PVS certification process is also tied directly to its Safety Permit Program and requires all PVS to be certified, excluded from NASA-STD 8719.17A requirements, or operated under an approved variance.[13] The status of PVS is verified during the system permit review or other reviews such as routine health and safety inspections.

Kennedy Space Center

At the time of our site visit in November 2014, Kennedy had 2,018 active PVS. The Center developed a 10-year risk-based plan in 2011 to ensure its PVS comply with NASA-STD 8719.17A, and the PSM reports to its Safety and Mission Assurance Directorate. Kennedy's PVS are controlled by three Directorates, each of which has contracted PVS work to a separate contractor.[14] Each contractor has a unique program for performing PVS maintenance, certification, recertification, and in-service inspections. All three contractors are responsible for managing their PVS certification programs, performing inspections and tests, and maintaining a database for their assigned PVS. In April 2014, NASA leased the Launch Pad 39A complex and its affiliated PVS under a Space Act Agreement to Space Exploration Technologies Corporation (SpaceX). The Agreement requires SpaceX to comply with NASA requirements and assess and confirm that the company's PVS requirements for the site provide an equivalent level of safety to

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[12] NASA's Spacecraft Propulsion Research Facility is the world's only facility capable of testing full-scale upper-stage launch vehicles and rocket engines under simulated high-altitude conditions. The Space Power Facility houses the world's largest and most powerful space environment simulation facilities, which includes the Space Simulation Vacuum Chamber, Reverberant Acoustic Test Facility, and Mechanical Vibration Facility.

[13] NASA-STD 8719.17A establishes the minimum requirements each Center must follow to ensure the structural integrity of their PVS.

[14] PVS is a relatively small part of each of the contractors' work and not easily separated; therefore, we were unable to reliably determine the funding provided or spent on Kennedy's PVS Program.

NASA personnel and property. In accordance with NASA STD 8719.17A, the PSM is responsible for reviewing the safety assessment and determining whether the SpaceX-operated PVS pose a risk to NASA personnel, facilities, or equipment.

Langley Research Center

At the time of our field work in October 2014, Langley had 209 active PVS. Langley developed a 15-year risk-based plan in 2011 to ensure the Center's PVS comply with NASA-STD 8719.17A. Langley's PSM, a Center Operations Directorate mechanical engineer, works in conjunction with a Facility Systems Safety Engineer from the Center's Safety and Mission Assurance Directorate to oversee Langley's PVS Program. In September 2013, Langley selected Jacobs Technology, Inc. (Jacobs) as the prime contractor tasked with maintaining, certifying, recertifying, and performing in-service inspections on Center PVS. Jacobs also provides Langley core support services in the areas of institutional and research operations, maintenance, and engineering. In fiscal year 2014, Langley spent approximately $1.2 million for PVS recertification services.

NASA's PVS Program Needs Improvement to Ensure Continued Protection of Life and Property

We found that NASA Centers could benefit from stronger oversight and clarification of policies and procedures to ensure reliable operation of their PVS, which in turn could reduce risk to personnel and facilities. Specifically, the decentralized nature of NASA's management and oversight of its PVS Program hinders its overall effectiveness. While we understand that a certain amount of Center-specific tailoring is prudent and warranted, the Program could benefit from stronger oversight and clarity from NASA HQ and increased sharing of best practices among Centers.

We also found multiple issues of concern at each of the Centers we visited, including unclear Center assignment of PSM roles and responsibilities, corrosion on a large number of PVS, and inadequate inventory and property controls. In our judgment, the Centers' PVS Programs could be improved by establishing clear lines of communication for resolving issues, implementing corrosion prevention and mitigation programs, and evaluating and providing the PVS Programs sufficient resources to meet Center mission goals and objectives.

Center PVS Programs Lack Specific HQ Guidance and Adequate Oversight

NASA policy and standards for the management, operation, inspection, and maintenance of PVS are intentionally written at a fairly high level and do not contain specific guidance regarding the application of NCS and the level of experience, education, and training sufficient to qualify an individual to serve as a Center PSM. In addition, OSMA did not provide adequate oversight of Center PVS Programs.

Unclear Guidance in PVS Program Standard

We found NASA-STD-8719.17A lacks sufficient detail regarding the use of NCS in the application of the design, selection, certification, and recertification of critical PVS components such as relief valves, burst discs, flex hoses, and hydraulic systems. For example, the Kennedy PSM requested clarification from OSMA regarding which NCS to use in retesting or replacing flexible hoses. The NASA-STD requires flexible hoses that could cause an unacceptable hazard to personnel or mission risk if ruptured be retested at least every 5 years, but does not address at what point such hoses should be replaced. In addition, the Glenn and Kennedy PSMs told us they are unclear regarding requirements for retesting flexible hoses in areas where there is no appreciable hazard to personnel and about how many strands of a hose's structural braid (external webbing) can be broken before it needs to be replaced.

The Glenn PSM also expressed concerns over the ambiguity of relief valve test requirements and stated that OSMA should provide specific guidance because "this is an area of much contention and expense" and "there could be benefit to the Agency in clarifying requirements." He added that he also believes that guidance regarding relief valve test requirements for air compressors, propane and fuel tanks, hot water heaters, and Department of Transportation cryogenic vessels and compressed gas cylinders, as well as guidance for shops certified by the National Board of Boiler and Pressure Vessel Inspectors to calibrate relief valves and verify set pressures, require greater specificity.[15] We agree with the Glenn PSM and found different interpretations regarding how to perform pressure relief valve testing with respect to opening set pressure, closing set pressure, leak rate, and flow rate. Finally, 9 of NASA's 12 PSMs indicated in their responses to our survey that OSMA should clarify the NASA-STD's requirements and provide specific guidance related to relief valves, flex hoses, and hydraulics.

Lack of Core Competency and Training Requirement for PVS Personnel

Although we found the PSMs at the Centers we visited adequately qualified, we noted that NASA policy and standards do not define minimum qualification criteria for the various personnel that administer and work within Center PVS Programs. NASA policy requires Center Directors "designate an individual qualified to perform the PSM duties" but does not define what makes an individual qualified for the position.[16] The policy also requires that management of the organization responsible for ground-based PVS "ensure that personnel are properly trained, qualified, and certified (when required) to operate a specific PVS," but does not define the specific training, qualification, or certification needed.[17] One of the PSMs we interviewed indicated that he and the contractor are doing the best they can to implement a training and qualifications program for their Center, but without basic criteria could not ensure the program's compliance with NASA's policy. Therefore, we believe that OSMA should clarify NASA's policy and provide recommended minimum qualification criteria for various personnel that administer and work within Center PVS Programs.

Most Centers Lack a "VR" Code Stamp Shop

A "VR" Code Stamp is a certification by the National Board of Boiler and Pressure Vessel Inspectors that a facility's repair and quality control system complies with National Board Inspection Code requirements. As part of the certification process, the Board must witness the repair of several sample pressure relief valves and verify the repaired valves meet applicable ASME Code requirements for performance and relieving capacity.

NASA-STD-8719.17A requires that ASME coded stamped items be repaired or altered only by National Board certified organizations in strict conformance with the approved quality manual. This certification process is performed to ensure that pressure relief devices and assemblers of pressure relief valves are designed, constructed, tested, and marked in accordance with specified codes.

At Kennedy, which has not carried a VR stamp since June 2014, repairs to coded relief valves were occurring without certification by the National Board.[18] When a coded relief valve is repaired or altered by a noncertified organization, it can no longer be used in a system that requires a coded relief valve.

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[15] A cryogenic vessel is a vacuum flask or insulated container used for the storage and dispensing of low-temperature fluids.

[16] NPD 8710.5D, paragraph 5.c.(1).

[17] NPD 8710.5D, paragraph 5.d.(2).

[18] The PSM told us that in August 2014 he sent an e-mail to all PVS-owning Directorates and their contractors making them aware that all repairs had to be performed at a VR certified shop.

According to the PSM, the certification of the VR shop had lapsed due to other funding priorities. All three Kennedy contractors had to send their relief valves offsite to be repaired by five different shops located across the country. This action added another layer of complexity to the calibration and repair process and resulted in increased turn-around time and cost.

Only Marshall Space Flight Center, Stennis Space Center, and White Sands have a VR shop on site. The White Sands PSM told us that management decided to repair certain relief valves onsite because it alleviates concerns about cleanliness and potential contamination during handling and transportation. He said White Sands spends approximately $5,000–$10,000 every 3 years for a VR certificate, and around $30,000–$50,000 to operate a National Board certified valve repair facility. Therefore, depending on the Center mission objectives, number of relief devices, level of effort, available equipment, and resident expertise, it may be cost effective for other Centers to develop a VR stamp capability.

Insufficient HQ OSMA's Oversight

In addition to the lack of clear guidance, OSMA oversight of Center PVS Programs is inadequate. The Chief of Safety and Mission Assurance assigns a single civil servant, the Technical Discipline Manager for Pressure Systems, to oversee the Agency PVS Program. One of his responsibilities is to interpret, update, and document NASA PVS policy and safety standards and attend ad hoc working group meetings such as the quarterly Pressure Vessels Committee meetings. However, he does not have authority to direct Center PVS Program personnel and has no oversight role or direct responsibility for Center PVS Programs.

OSMA uses the NASA Safety Center in Cleveland, Ohio, to assess Center PVS programs as part of its IFO audit program. The Safety Center's Audits and Assessments Office performs an IFO audit at each NASA Center and component facility at least once every 3 years. However, we found instances in which the PVS Program was not included in these triennial audits.[19] Specifically, IFO audit teams do not automatically include personnel with PVS expertise. Rather, when preparing for a particular audit, the Safety Center will submit a request for participation from Center PSMs that are not being audited. If no PVS expertise is available, the audit will not include an assessment of the Center's PVS Program. As a result, some Center's PVS have not been audited by the Safety Center for more than 7 years. We found this occurred at 5 of NASA's 12 Centers and component facilities. For example, the last IFO audit at Kennedy that included PVS took place in 2007, and PVS at Ames Research Center and Johnson Space Center have not been audited since 2008. Similarly, Goddard Space Flight Center and White Sands PVS have not been audited for at least 5 years. Further, although OSMA reviews Center PVS policies and procedures to ensure they do not contradict NASA policy and standards, it does not ensure the implementation of recommendations or corrective actions are taken as a result of IFO audits. Without a robust PVS audit process OSMA is not able to verify the effectiveness of requirements, activities, and processes, or assess the application and technical excellence of tools, knowledge, techniques, and practices (including risk management as applied to safety and mission success).

[19] The Safety Center is in the process of changing the frequency of the IFO audits to 4 years, a development we find troubling. In our prior reviews of the Jet Propulsion Laboratory's Occupational Safety Program (IG-11-004, December 13, 2010) and NASA's Explosives Safety Program (IG-13-013, March 27, 2013) we found similar issues with NASA's IFO audit process.

Unclear Roles and Responsibilities Inhibit PSM Effectiveness

Due to the complexity of organizational structures and unclear roles and responsibilities, some Center PSMs believe they are inhibited from fulfilling their responsibilities, exercising their authority, operating independently, and avoiding undue influence from those they oversee.

Complexity of Organizational Structure

The Kennedy PSM believes he lacks authority and is inhibited from performing his duties. Specifically, the Directorates and their PVS contractors have not consistently informed him of design changes to safety-critical PVS and he was not afforded the opportunity to review design and procurement specifications for new PVS as required by NPD 8710.5D and NASA-STD 8719.17A. We believe this occurred, in part, due to a complex "stovepipe" organizational structure at Kennedy that includes three Directorates with their own PVS contractor and unique PVS procedures and configuration management systems. According to the PSM, this organizational complexity makes it difficult for him to perform the appropriate level of review and oversight.

Although we acknowledge the Kennedy PSM is presented with a challenging scenario, we believe this condition is attributable to a lack of effective cross-functional communication and coordination between the contractors, Directorates, and PSM. Similar to Kennedy, the Marshall Space Flight Center's PVS Program consists of three contractors; however, the Center's Safety and Mission Assurance Directorate manages the contractors and coordinates all PVS activities to ensure that the PSM has sufficient authority to perform his duties and there is effective communication and coordination across the Program.

Unclear Roles and Responsibilities

The Kennedy and Langley PSMs do not have oversight of Department of Transportation-certified compressed gas cylinders and containers.[20] At Kennedy the Center Operations Directorate PVS Subject Matter Expert indicated that he has this responsibility because the Department of Transportation cylinders do not fall under the purview of the Kennedy PVS Program. At Langley the cylinders fall under the facilities engineering organization and are procured and used without the Langley PSM's knowledge. NASA-STD-8719.17A excludes these cylinders from the PVS certification program, provided OSHA inspection requirements are met; however, these cylinders contain potentially harmful materials and operate under high pressure and therefore, in our judgment, should fall under the Agency's PVS Program.[21]

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[20] Compressed gas cylinders are portable pressure vessels that may be bundled together, secured, and connected to one another via a system of tubing and valves called a manifold. Due to their portability and because they can be transported on public highways, the Department of Transportation is the governing regulatory agency responsible for establishing recertification requirements.

[21] Glenn uses a Safety Permit Program to ensure either a certification, an exclusion, or an approved variance be included in any permit application package containing a PVS.

Inadequate Oversight of Leased PVS Systems

In accordance with NASA-STD-8719.17A, PSMs are required to determine whether both NASA owned or operated and contractor or tenant ground-based PVS pose a risk to NASA personnel, facilities, or equipment.[22] However, the Kennedy PSM indicated that since SpaceX took over operation of Launch Pad 39A in April 2014, he has had no oversight of modifications, designs, or analysis of associated PVS. Further, he was unable to identify each PVS change that potentially affects the baseline risk assessment throughout the life of the PVS and take appropriate actions to analyze, plan, track, and control the risks associated with each change. This condition occurred because the PSM was not familiar with and did not invoke the provisions in NASA's Space Act Agreement that require SpaceX to provide NASA an assessment confirming that their PVS requirements and procedures provide a level of safety equivalent to NASA's.

We observed a clear line of demarcation, whereby the PSM or contractor (ISC – URS Federal Technical Services Corporation) was no longer responsible for PVS (see Figure 3). This is occurring in spite of the Space Act Agreement that requires SpaceX to assess and confirm that the company's PVS requirements provide an equivalent level of safety to NASA personnel and property. Nevertheless, at the time of our site inspection, the Center PSM stated that he had no knowledge of any such assessment by SpaceX. Subsequently, personnel in the Kennedy Safety and Mission Assurance Directorate confirmed they had not requested such an assessment from the company. They indicated, however, that SpaceX had met the intent of the Agreement by providing its safety plan for review. Furthermore, although the Directorate performed a safety surveillance inspection of Launch Pad 39A in October 2014, it did not include PVS in this review, and the inspectors questioned how Kennedy personnel are kept informed about hazards at the launch pad.

Figure 3: Sign at Launch Pad 39A

Source: NASA Office of Inspector General.

Potential Conflict of Interest

During Glenn's IFO audit in September 2005, the IFO audit team raised a possible conflict of interest issue regarding the PSM position within the Facilities and Test Directorate. Specifically, the PSM in 2005 told the IFO audit team that Facilities and Test Directorate managers provided him direction inconsistent with his safety responsibilities. Since that time, the PSM position has been moved to fall under the Planning and Integration Office within the Facilities, Test, and Manufacturing Directorate. Although the current PSM told us that the present organizational structure may still provide the appearance of a conflict of interest, he believes he is functionally independent and is not unduly influenced by his management organization. To comply with the NASA policy requirement that the PSM must be functionally independent, the Safety and Mission Assurance Director was in the process of

[22] Exclusions such as flight vessels and systems that are not addressed in the NASA-STD 8719.17A receive safety assessments by the Center's Systems Safety Engineering Office.

assessing the PSM organizational structure and contemplated several options.[23] One of the options was to place the PSM position under the Safety and Mission Assurance Directorate, and appoint an operational Pressure System Engineer in the Facilities and Test Directorate who could provide funding to perform PVS repairs as needed. As of May 2015, no decision had been made.

Lack of Plan to Identify, Monitor, and Assess Risk from Internal Corrosion

Although some Centers have Center-wide corrosion prevention programs, Glenn, Kennedy, and Langley had no formal plans to identify, monitor, and mitigate PVS corrosion and assess the risk of failure from internal corrosion or erosion. While the Goddard Space Flight Center was in the process of implementing such a plan, only the Stennis Space Center had a documented PVS corrosion prevention and mitigation plan in place. Without such a plan, PVS may be at risk of failure due to a weakening in the structural integrity of a vessel or piping wall. Throughout our field inspection, we identified numerous instances of corrosion that indicated a lack of due diligence, attention to detail, and oversight of PVS.

Corrosion at Langley

At Langley we identified significant visual corrosion on high pressure piping and components in an underground utility corridor that contains high pressure steam piping, electrical conduit, and fiber optic communication lines (see Figure 4). If a rupture were to occur in the underground tunnel, the resulting damage could cause power and communication outages that would impact Center operations and missions.

Figure 4: High Pressure Lines in a Langley Utility Corridor

Source: NASA Office of Inspector General.

[23] NPD 8710.5D, Paragraph 5.c.(7).

Throughout the corridor we observed openings in the tunnel wall through which ground water has penetrated. The water seeping into the tunnel, along with the accumulation of condensate from high temperature steam lines, may have caused or exacerbated existing corrosion on high pressure lines and components. Furthermore, we observed degradation of thermal insulating wraps and components that may pre-date OSHA and therefore, may contain asbestos. The high volume of air that circulates through the corridor could distribute loose asbestos material, presenting a potential respiratory hazard to personnel working in the tunnel.[24]

In the tunnel, we also observed new piping and valve systems that were installed on top of older, decaying systems and infrastructure. Access to survey and monitor the corrosion rate or repair or replace piping may be difficult due to obstruction from the new piping and systems. Because the risk of PVS failures tends to increase as a vessel or system ages, the older system piping could be at risk of failure. The unmitigated corrosion we observed could be attributed to a lack of preventive maintenance, ineffective prioritization, or the misinterpretation of risks by Center personnel.

We also identified extensive corrosion at the 8-Foot High Temperature Tunnel (see Figure 5).[25] The primary mission of this test facility is to simulate hypersonic flight conditions for testing advanced, large-scale, flight-weight structural and propulsion concepts. This facility includes storage and use of liquid oxygen and highly combustible fuels such as methane and pyrophoric materials. Although at one time the facility was isolated from occupied buildings, as the Center grew, structures and buildings began to encroach into the open spaces that used to adjoin this facility, making a PVS failure potentially devastating.

Figure 5: Top of Liquid Nitrogen Tank and View of 8-Foot High Temperature Tunnel

Source: NASA Office of Inspector General.

[24] Following our inspection in October 2014, Langley safety personnel walked all Center tunnels and identified materials that tested positive for asbestos. Due to the degraded condition of the thermal insulated wraps and the presence of materials containing asbestos, the Langley Industrial Hygienist was directed to take air samples to determine potential asbestos exposure to Center personnel. Although results showed asbestos below allowable exposure limits, work orders were placed and funded to repair the degraded insulation.

[25] The unplanned availability of a lifting device at the time of our site visit provided us an opportunity to observe the top of the external tank, which due to accessibility challenges and low risk, is not routinely inspected by Center personnel.

Corrosion at Kennedy

Although Kennedy has a Center-wide corrosion prevention program, the program does not address the unique hazards associated with corrosion of high pressure vessels and systems. Specifically, the current program does not include inspections to detect internal corrosion or erosion. Although visual corrosion can be a good indicator of more serious corrosion issues (see Figure 6), pressure-related mishaps have occurred in NASA systems where no visual corrosion was present or there was limited access for inspection (i.e., underground). For example, in May 1992 during preparation for a liquid hydrogen flow test at Kennedy's Launch Equipment Test Facility, a section of pipeline was inadvertently over-pressurized, resulting in a protective cap being blown approximately 350 feet away. Post-mishap troubleshooting disclosed that a valve was blocked by corrosion and foreign contamination. Consequently, systems need to be inspected for internal corrosion or erosion that is not readily identified to monitor and decrease the risk to facilities, personnel, and mission.

Figure 6: Corroded PVS Components at Kennedy

Source: NASA Office of Inspector General.

Corrosion at Glenn

Glenn does not have a documented formal PVS corrosion prevention program. However, a representative for the Glenn PVS contractor stated that if corrosion is detected during periodic visual inspections, the affected PVS is tested and repaired as necessary. As previously stated, a visual inspection is only an indicator of corrosion and cannot detect internal corrosion or erosion, nor is it a reliable method to ascertain the extent of or to predict future corrosion growth. Understanding what caused the corrosion and predicting the future corrosion rate is essential to fitness-for-service and run-or-repair decisions.

We observed significant corrosion throughout the Center, including components at and adjacent to the Glenn Steam Plant in Building 12 (see Figure 7). Over the years, Glenn has experienced several mishaps from corrosion issues. For example, in July 1993 a 125-pound-per-square-inch pressure air-line failed by splitting along a longitudinal weld causing the 10-inch diameter steel pipe to rupture for about 15 feet. As a result of this failure, four manhole covers were blown into the air. The section of piping that failed was in a covered ground trench undisturbed for approximately 15 years. During that time, moisture resulting from surface water leakage caused considerable corrosion to the pipe wall. A post-mishap analysis revealed that the original quarter-inch thickness of the pipe wall had been significantly reduced to almost zero in some places.

Figure 7: Corroded PVS Components at Glenn

Source: NASA Office of Inspector General.

Addressing Corrosion at NASA Centers

Environmentally induced corrosion is one of many different types of corrosion and is typically found wherever there is substantial moisture in the air, such as in coastal environments. Although many NASA Centers are located near the coast or adjacent to large bodies of water, NASA-STD 8719.17A does not require Centers to develop and implement requirements for a formal PVS corrosion prevention and mitigation program. As evidenced by the mishaps cited in this report, in our judgment and the opinion of ASME and the American Petroleum Institute, all PVS should be evaluated for fitness-of-service and wall-thinning, especially when they are subjected to harmful environments or conditions that could result in corrosion or erosion.[26]

[26] American Petroleum Institute, "American Petroleum Institute Recommended Practice 579, Fitness for Service." American Society of Mechanical Engineers, "Manual for Determining the Remaining Strength of Corroded Pipelines, Supplement to ASME B31, Code for Pressure Piping" (ASME B31G).

Inadequate Inventory and Property Controls to Account for Pressure Vessels and Pressurized Systems

When asked, Kennedy could not provide an accurate accounting of Center PVS. Specifically we could not reconcile the number of PVS at Kennedy because some had been excessed or transferred without the PSM's knowledge. This is at least partially attributable to Kennedy relying on three different contractors reporting to three different Directorates. Each contractor maintains its own risk-based plan and PVS configuration management database using different software (e.g., Excel spreadsheets, Microsoft Word, in-house files, etc.). Each database has different identifying fields and each contractor manages its respective PVS Program in accordance with its own policies and procedures. As a result, the databases could not be automatically merged into one single database for tracking and updating all Center PVS. Tracking PVS attributes – system status, analysis updates, recertification dates, types of pressure vessels, locations, compliance with NASA Standards, and waivers – could help Center management trace PVS to the component level, allowing multiple users to update the database and generate a standard metric and reporting capability, including alerts for upcoming certification and expiration.

For example, during our inspection of an area marked "inactive" a contractor employee identified an excessed property that could not be accounted for in the PVS database. We also found PVS that had been identified as "inactive" but the vessel and system had a gauge pressure of 1,200 pounds per square inch. The lack of a Center-wide PVS database issue was identified in an April 2012 assessment performed by the Kennedy Safety and Mission Assurance Integration Office that recommended the Kennedy PSM implement a Center-wide, web-based PVS database. However, the recommendation was not implemented.[27]

Based on our survey of PSMs, we found most NASA Centers and facilities have only one contractor responsible for PVS certification and consolidated inventory. Although the Marshall Space Flight Center has three contractors working in the PVS Program, the Center's PSM has one database to directly manage the overall PVS inventory while the pressure system-owning organizations manage individual databases containing PVS component level data. Glenn developed their own centralized PVS database that evolved over a 10-year period and has an estimated annual cost of $30,000 for updates and maintenance. This customized, Government-owned database system has several benefits, including data accessibility by PVS users, links to other databases, and automatic alerts and reminders for the recertification of critical PVS components. The Glenn PSM characterized the database as "user friendly" and providing quick and ready access to PVS. The Glenn PSM offered to share the database with other Centers to save initial software development costs. We believe that a Center-wide standardized PVS database is a best-practice and could provide ready access to reliable, accurate data, and help other Center PSMs effectively manage and oversee PVS at their Centers.

[27] Although Kennedy implemented a website whereby the Directorates and contractors submit certification reports and a listing of approved exclusions requests, this website is not inclusive of all PVS and does not have sufficient detail to be used for configuration management.

Lack of Resources and Communication between the PSM and Procurement Office

We determined that some Centers are applying an insufficient level of resources to ensure the safety of their PVS. For example, at Langley we found the Center's Safety Office was not adequately staffed and budgeted to assist the PSM in performing PVS safety analysis. In 2003, the Center employed three civil servant engineers and three contractor employees to assist the civil servant engineers with design reviews and safety risk assessments. Currently, the Safety Office is staffed with two civil servant engineers and two contractor engineers who are expected to perform the same level of work as their predecessors.[28] The two civil servant engineers are in charge of 18 high risk facilities and their schedules preclude them from working more closely with the PSM and the Recertification Group Manager to perform safety analysis of PVS systems. Furthermore, the other two contractor engineers have no knowledge of PVS.

The Langley PSM stated that while the contractor could meet the performance goals identified in the PVS risk-based plan, the final certification goals would be difficult to meet because the PVS budget did not include the cost of operating the Component Verification Facility when its management and operation was reassigned from the Center Maintenance Program to the Recertification Program. In response to this lack of funding, the Langley contractor indicated that it will have to downsize its workforce. In addition, the PSM does not have dedicated funding for PVS repairs identified during the recertification work. Although the current backlog for repairs is $294,000, the PSM is expecting more repairs and maintenance in the next 10 years due to aging PVS.

At Glenn, we found a lack of communication between the PSM and procurement office that resulted in undocumented PVS. The PSM had a backlog of 193 uncertified PVS that were never recorded, documented, and certified as required by NPD 8710.5D and NASA-STD 8719.17A. Without adequate certification, Glenn cannot ensure the structural integrity of the PVS or determine if the vessels and their contents pose a risk to NASA personnel, facilities, or equipment. The PSM said he identified these PVS through a random survey and classified them as backlogged, waiting to be certified. He did not perform this survey on a regular basis and said that if he did it is likely he would find more undocumented vessels and systems. The PSM stated that the use of undocumented and uncertified PVS was due to Glenn not having a process in place to require contracting officers and owners of the systems to notify him of new PVS purchases.[29] He also stated that reviewing uncertified PVS before operation would likely be a more efficient and potentially less costly approach to managing the PVS.

[28] As of April 2015, the number of Langley PVS increased by 45 due to their Revitalization Plan and other Agency initiatives.

[29] NPD 8710.5D, section 5.d.(3) requires "the management of the organization responsible for the ground-based PVS to submit designs or procurement specifications for new PVS or modifications to existing PVS for review and evaluation by the PSM or designee prior to initiating the procurement action or the modification." In addition, NPD 8710.5D, section 5.f.(1) requires the contracting officer to notify the PSM of a proposed procurement for PVS that has not been reviewed by the PSM.

CONCLUSION

Although NASA has not experienced a serious pressure-related incident since 2006, there exists opportunities for Program improvement that could further reduce the likelihood of a serious mishap. We found NASA has implemented a PVS Program that relies heavily on Centers' implementation of Agency policies and standards that should contain additional specific guidance to enable responsible personnel to perform their duties. This, combined with a relatively hands-off approach by OSMA, has resulted in an increased risk that issues of concern will not be recognized until it is too late. Increased communication and coordination among Center personnel responsible for various parts of NASA's PVS Program is critical to ensure all requirements are met. Finally, the amount of corrosion we observed on PVS across several Centers is testament to the lack of due diligence, resources, and the need for policy revisions to address and prevent PVS-related issues.

RECOMMENDATIONS, MANAGEMENT'S RESPONSE, AND OUR EVALUATION

To improve NASA's PVS Program and reduce the likelihood of mishap, we recommended the Chief of OSMA

1. initiate a review of PVS management at all NASA Centers to identify deficiencies, take corrective actions, and share best practices;
2. revise NASA-STD 8719.17A to provide more specific guidance related to relief valves, flex hoses, and hydraulics, and include recommended minimum core competencies that would qualify PVS Program personnel;
3. reassess the effectiveness of OSMA PVS oversight and explore alternative audit processes to ensure sufficient evaluation of Center PVS Programs to protect lives and property and comply with NASA requirements;
4. require Centers perform a cost-benefit analysis to determine if an onsite relief valve calibration and repair shop with a VR Code Stamp capability would be cost and mission effective; and
5. require each Center implement a formal PVS corrosion prevention and mitigation program and perform a baseline corrosion survey of all Center PVS; conduct a formal risk assessment to assist in prioritizing and determining impact to personnel, environment, and mission; and implement procedures to monitor, predict, and determine future corrosion rates as well as develop future prevention and mitigation strategies.

To improve the overall effectiveness of PVS Programs at the Centers we visited, we also recommended

6. the Glenn Center Director implement a process to require contracting officers and owners of PVS to notify the PSM of any new purchases so that the PVS can be properly identified, documented, and certified in accordance with NASA-STD 8719.17A;
7. the Kennedy Center Director (a) reevaluate the Center's organizational structure to ensure the PSM has the appropriate level of authority and independence to perform his responsibilities; (b) consolidate the three contractor operated and maintained PVS databases into a single Center-wide database, and require the PVS contractors revise and integrate their risk-based plans and notify the PSM of all PVS excessed and transferred; and (c) ensure appropriate lines of communication and integration between SpaceX, the Safety and Mission Assurance Directorate, and the Center PSM, and validate that SpaceX PVS policies and procedures meet NASA requirements; and
8. the Langley Center Director reexamine the resources and budget allocated to the Langley PVS Program and ensure the amount is sufficient to meet Program needs.

We provided a draft of this report to NASA management, who concurred or partially concurred with our recommendations and described planned corrective actions. Because we consider management's comments responsive to our recommendations, the recommendations are resolved. We will close the recommendations upon completion and verification of the proposed corrective actions. Management's full response to our report is reproduced in Appendix B. Technical comments provided by management have also been incorporated, as appropriate.

Major contributors to this report include, Raymond Tolomeo, Science and Aeronautics Research Director; Ronald Yarbrough, Project Manager; Anh Doan, Management Analyst; Jiang Yun Lu, Auditor; and Frank Martin, Aerospace Technologist.

If you have questions about this report or wish to comment on the quality or usefulness of this report, contact Laurence Hawkins, Audit Operations and Quality Assurance Director, at 202-358-1543 or laurence.b.hawkins@nasa.gov.

Paul K. Martin
Inspector General

APPENDIX A: SCOPE AND METHODOLOGY

We performed this audit from September 2014 through May 2015 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

We reviewed NASA policies and standards related to PVS as well as Center-specific policies and procedures that corresponded with NASA guidance, public laws, and NCS related to pressure vessels to determine whether NASA has adequate policies and procedures that will ensure the safe procurement and operation of PVS:

- NPD 1000.0B, “Governance and Strategic Management Handbook,” November 26, 2014
- NPD 1000.3D, “The NASA Organization w/Change 66,” December 3, 2008
- NPD 8700.1E, “NASA Policy for Safety and Mission Success,” October 28, 2008
- NPD 8710.5D, “Policy for Pressure Vessels and Pressurized Systems,” March 12, 2008
- NPR 8705.6B, “Safety and Mission Assurance (SMA) Audits, Reviews, and Assessments,” May 24, 2011
- NASA-STD-8719.17, Revision A, “NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS),” November 6, 2009
- GLM-QS-1700.1.5, "Glenn Safety Manual Oxygen w/Change 1 (4/11/2014),” December 19, 2012
- GLM-QS-1700.1.6, "Glenn Safety Manual Chapter 6 Hydrogen w/Change 1 (4/14/2014)," June 3, 2010
- GLM-QS-1700.1.7, “Pressure Systems Safety w/Change 1 (6/27/2014),” December 19, 2012
- GLM-QS-1800.1.9, "Glenn Safety Manual Chapter 9 Lockout/Tagout w/Change 1 (4/28/2014),” April 28, 2012
- KNPR 8715.3-1, “KSC Safety Procedural Requirements Volume 1, Safety Procedural Requirements for Civil Servants/NASA Contractors, Rev. Basic-2,” June 28, 2012
- KNPR 8715.3-3, “KSC Safety Procedural Requirements Volume 3, Safety Procedural Requirements for Partners Operating in Exclusive-Use Facilities,” May 19, 2014
- LPR 1710.40, “Langley Research Center Pressure Systems Handbook,” August 29, 2011
- LPR 1710.42, "Safety Program for the Recertification and Maintenance of Ground-based Pressure Vessels and Piping Systems," March 7, 2012
- OSHA Standards for General Industry (29 C.F.R. 1910), 1910 Subpart H, Subpart M, Subpart O, and Subpart R
- ASME B31G, Manual for Determining the Remaining Strength of Corroded Pipelines, Supplement to ASME B31, Code for Pressure Piping, American Society of Mechanical Engineers, Reaffirmed in 2004

- American Petroleum Institute:
  - API 510, “Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration, 9th edition,” June 2006
  - RP 572, “Inspection Practices for Pressure Vessels, 3rd edition,” November 2009
  - RP 579, “Fitness for Service, American Petroleum Institute,” July 2007

To determine whether NASA implemented a risk-based system to identify and prioritize PVS and adequate controls to account for all PVS, we interviewed NASA personnel and contractors at Glenn, Kennedy, and Langley about their roles and responsibilities, resources to staff their PVS Program, their staffs’ experience and training, and Program procedures and processes. We also inspected PVS at these Centers to determine whether NASA implemented a robust in-service inspection and recertification program. We interviewed the HQ OSMA Technical Discipline Manager for Pressure Systems to determine whether NASA provided adequate oversight to ensure that all Federal regulations and NASA unique requirements are followed to ensure the safety of personnel and assets.

In addition, we surveyed PSMs from the following NASA Centers and component facilities regarding their Pressure System program operation and practices:

- Ames Research Center
- Armstrong Flight Research Center
- Goddard Space Flight Center
- Jet Propulsion Laboratory
- Johnson Space Center
- Marshall Space Flight Center
- Stennis Space Center
- Wallops Flight Facility
- White Sands Test Facility

Use of Computer-Processed Data

To identify our audit universe, we used computer-processed data from the Centers’ Pressure System Database. We obtained and reviewed the current inventory list of PVS from Glenn, Kennedy, and Langley. We did not validate the accuracy of the data in the systems, and the data is only as accurate as that entered by the PVS Program personnel.

Review of Internal Controls

We performed an assessment of the internal controls associated with NASA’s PVS Programs. Throughout the audit we reviewed controls associated with the audit objectives and determined that NASA’s internal controls need improvement in some areas, including Program oversight, and inventory and property controls. The control weaknesses we identified are discussed in the report. Our recommendations, if implemented, will correct the identified control weaknesses.

Prior Coverage

During the past 5 years, the NASA Office of Inspector General and the Government Accountability Office have not issued any reports of particular relevance to the subject of this report.

APPENDIX B: MANAGEMENT'S RESPONSE

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

June 23, 2015

Reply to Attn of: Office of Safety and Mission Assurance

TO: Assistant Inspector General for Audits

FROM: Chief, Safety and Mission Assurance
Director, Glenn Research Center
Director, Kennedy Space Center
Director, Langley Research Center

SUBJECT: Response to OIG Draft Audit Report, "Audit of NASA's Pressure Vessels and Systems" (A-14-020-00)

NASA appreciates the opportunity to review the Office of Inspector General (OIG) draft report entitled, "Audit of NASA's Pressure Vessels and Systems" (A-14-020-00).

In the draft report, the OIG makes a total of eight recommendations intended to improve the overall Pressure Vessels System (PVS) program. The OIG makes five recommendations to the Chief, Safety and Mission Assurance (SMA), along with one recommendation each addressed to the Director, Glenn Research Center (GRC); the Director, Kennedy Space Center (KSC); and the Director, Langley Research Center (LaRC).

Before outlining our response to the OIG's recommendations, including planned corrective actions, we want to make you aware that there are statements and implications in the report that we believe require clarification or correction.

Specifically:

> The Office of Safety and Mission Assurance (OSMA) believes the emphasis that the report gives to corrosion issues is misplaced. While Centers do not have documented PVS corrosion programs separate from the ongoing fitness-for-service efforts involved in PVS certification, every NASA Center addresses corrosion during inspections and as a part of remaining life assessments in accordance with existing requirements in NASA-STD-8719.17A. While corrosion should be prevented and mitigated as much as reasonably possible, OSMA cautions that allocation of more than the necessary resources in this area would result in less resources for other issues of greater criticality.

In order to improve the overall PVS program, NASA will take actions based on all of the OIG's recommendations. NASA's actions are outlined in the management responses below:

Recommendation 1: Initiate a review of PVS management at all NASA Centers to identify deficiencies, take corrective actions, and share best practices.

Management's Response: Partially concur. The Chief, SMA will institute an assessment of PVS management through a survey of PVS management practices at the NASA Centers to identify deficiencies and corrective actions, with follow-up site visits if needed. While OSMA does not directly manage PVS programs at the Centers, OSMA will provide its findings to the Centers, so they may identify and implement appropriate corrective actions. OSMA will continue sharing of best practices via working group meetings.

Estimated Completion Date: August 31, 2016

Recommendation 2: Revise NASA-STD-8719.17A to provide more specific guidance related to relief valves, flex hoses, and hydraulics, and include recommended minimum core competencies that would qualify PVS Program personnel.

Management's Response: Concur. The Chief, SMA will assess the need for more specific standards and guidance and will make needed changes related to relief valves on recharger and hydraulic systems, and for flex hose rejection criteria, including responsibilities in cases where no national consensus standards or manufacturer recommendations exist. Changes will include qualification criteria for PVS program personnel.

Estimated Completion Date: December 30, 2016

Recommendation 3: Reassess the effectiveness of OSMA PVS oversight and explore alternative audit processes to ensure sufficient evaluation of Center PVS Programs to protect lives and property and comply with NASA requirements.

Management's Response: Concur. The Chief, SMA will direct the NASA Safety Center to assess the overall utility and effectiveness of the PVS audit process and implement any necessary revision.

Estimated Completion Date: October 31, 2016

Recommendation 4: Require Centers perform a cost-benefit analysis to determine if an onsite relief valve calibration and repair shop with a VR Code Stamp capability would be cost and mission effective.

Management's Response: Concur. The Chief, SMA will direct Centers to provide a cost-benefit analysis to determine if an onsite relief valve calibration and repair shop with a VR Code Stamp capability would be cost and mission effective.

Estimated Completion Date: April 29, 2016

Recommendation 5: Require each Center to implement a formal PVS corrosion prevention and mitigation program and perform a baseline corrosion survey of all Center PVS; conduct a formal risk assessment to assist in prioritizing and determining impact to personnel, environment, and mission; and implement procedures to monitor, predict, and determine future corrosion rates as well as develop future prevention and mitigation strategies.

Management's Response: Partially concur. OSMA believes that a corrosion prevention and mitigation program separate from existing remaining life and risk assessments would not be the most effective use of limited resources. OSMA will emphasize existing requirements for corrosion assessment, related risk assessment, and documentation in appropriate PVS and management forums. In particular, the Chief, SMA will advise Centers to perform a baseline corrosion survey of any PVS overdue for such an assessment within the existing integrity assessment, remaining life assessment, and inspection programs as required by NASA-STD-8719.17A.

Estimated Completion Date: October 30, 2015

The OIG also recommends:

Recommendation 6: The Glenn Center Director implement a process to require contracting officers and owners of PVS to notify the PSM of any new purchases so that the PVS can be properly identified, documented, and certified in accordance with NASA-STD 8719.17A.

Management's Response: NASA GRC's Director concurs with the OIG's recommendation and will establish procedures assuring the Pressure Systems Manager (PSM) is notified of any new PVS purchases as required by NPD 8710.5. Corrective action will include a systematic review of all types of new PVS purchases made at the Center and the identification/establishment of Center level procedures and documents assuring PVS purchases for both new work and modifications are forwarded to the PSM for review. New procedures and documents shall be modeled after GRC's existing successful controls that address safety and environment purchases and currently trigger a review by the NASA GRC Safety and Health Division.

Estimated Completion Date: It is anticipated that the plan should be implemented by February 29, 2016. This includes a complete review of all of NASA GRC's Center-level procedures and documents required to request PVS purchases and the implementation of the document modifications.

Recommendation 7: The Kennedy Center Director (a) reevaluate the Center's organizational structure to ensure the PSM has the appropriate level of authority and independence to perform his responsibilities; (b) consolidate the three contractor operated and maintained PVS databases into a single Center-wide database, and require the PVS contractors revise and integrate their risk-based plans and notify the PSM of all PVS excessed and transferred; and (c) ensure appropriate lines of communication and integration between SpaceX, the Safety and Mission Assurance Directorate, and the Center PSM, and validate that SpaceX PVS policies and procedures meet NASA requirements.

Management's Response: KSC management partially concurs with this recommendation. The recommendation has three segments. Each segment is addressed individually below:

a) Concur. The Center will take action to reevaluate the Center's organizational structure to ensure the Pressure System Manager (PSM) has the appropriate level of authority and independence to perform his responsibilities.
b) Partially concur. The Center will take action to reevaluate the three contractor operated and maintained Pressure Vessels System (PVS) databases and determine benefits versus cost of creating a single Center-wide database, as well as reevaluating the value of including all PVS that are excessed and/or out of service.
c) Concur. The Center will take action to ensure that appropriate lines of communication and integration occur between SpaceX and the Center, ensure appropriate communication occurs with Center PSM, and validate that SpaceX PVS policies and procedures meet NASA requirements.

Estimated Completion Date: April 30, 2016

Recommendation 8: The Langley Center Director reexamine the resources and budget allocated to the Langley PVS Program and ensure the amount is sufficient to meet Program needs.

Management's Response: The LaRC Center Director concurs with the OIG's recommendation. LaRC will conduct a review of the PVS program resources and budget. This review will include staffing of the Center Operations Director to execute the PVS Program and the Safety and Mission Assurance staffing to support this function. As a minimum, the following budget areas will be reviewed: engineering assessments of existing/new PVS, in-service inspections to ensure PVS integrity, repair of issues found during PVS assessments/inspections, and configuration management of PVS documentation. The findings will be presented to the Center's leadership by the end of the 2015 fiscal year.

Estimated Completion Date: October 1, 2015

We have reviewed the draft report for information that we believe should not be publicly released and have communicated our concerns regarding the public release of certain information contained in your report.

Thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Ms. Kelly Kabiri at (202) 358-0590 or by e-mail at kelly.kabiri@nasa.gov.

Terrence W. Wilcutt

APPENDIX C: REPORT DISTRIBUTION

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House Committee on Oversight and Government Reform
    Subcommittee on Government Operations

House Committee on Science, Space, and Technology
Subcommittee on Oversight
Subcommittee on Space

(Assignment No. A-14-020-00)