Office of Enterprise Assessments
Lessons Learned From Reviews of Construction Quality at U.S. Department of Energy Nuclear Facilities

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Acronyms

ASME	American Society of Mechanical Engineers
CFR	Code of Federal Regulations
CRAD	Criteria and Review Approach Document
DNFSB	Defense Nuclear Facilities Safety Board
DOE	U.S. Department of Energy
EA	Office of Enterprise Assessments
HVAC	Heating, Ventilation, and Air Conditioning
M&TE	Measuring and Test Equipment
NEC	National Electrical Code
NQA	Nuclear Quality Assurance
NTS	Noncompliance Tracking System
ORPS	Occurrence Reporting and Processing System
OSHA	Occupational Safety and Health Administration
PICA	Post Installed Concrete Anchor
PNOV	Preliminary Notice of Violation
QA	Quality Assurance
QC	Quality Control
SRS	Savannah River Site
WIPP	Waste Isolation Pilot Plant
WTP	Waste Treatment and Immobilization Plant

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EXECUTIVE SUMMARY

Since 2011, the Office of Enterprise Assessments (EA) and predecessor organizations have performed reviews of construction quality by assessing ongoing and completed construction work to determine whether projects are constructed in accordance with design engineering drawing and specification requirements and industry standards. This report summarizes and analyzes the results of reviews at five U.S. Department of Energy (DOE) nuclear project sites conducted from February 2011 through December 2015. This report also addresses the results of EA's review of ventilation system procurement activities for the Waste Isolation Pilot Plant, as well as a review of the DOE Occurrence Reporting and Processing System (ORPS) and the Noncompliance Tracking System (NTS) for nuclear safety occurrences and violations associated with construction quality reported from around the DOE complex.

Overall, the quality of construction work reviewed is adequate. Most materials and equipment were installed in accordance with applicable drawings and specifications. Quality control inspections of construction work activities were performed by qualified personnel in accordance with inspection processes that met or exceeded industry standards. For example, concrete quality consistently exceeds specification requirements, piping systems were properly installed and tested, and onsite welding programs are well controlled. Measuring and test equipment were properly calibrated for use in performance testing. Contractor corrective action programs have been generally effective in correcting specific construction related non-conforming conditions. While construction quality processes were providing assurance that nuclear projects were being constructed in accordance with design requirements, some project specific deficiencies were identified that are presented in support of organizational learning.

Overall, the reviewed construction project procurement programs comply with 10 CFR 830, *Nuclear Safety Management*, and DOE and industry quality assurance requirements. However, defects in procured materials and equipment continue to challenge the quality, schedule, and cost of DOE construction projects. For example, some components and hardware that approved vendors supplied have not complied with the requirements in material requisitions and purchase orders and sometimes have resulted in mechanical failures during transport or after installation at the site. The number and nature of deficiencies in procured materials and equipment indicate the need for more effective quality assurance by vendor organizations and continued vigilance by DOE contractors performing receipt inspections. EA plans to increase focus on receipt inspection and validation of received items that have been manufactured in accordance with the standards of American Society of Mechanical Engineers NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications,* to determine whether process improvements are warranted.

Contractor corrective action programs have been generally effective in identifying and correcting specific non-conforming conditions. However, DOE field offices and contractors have not effectively used the processes required by DOE Order 232.2, *Occurrence Reporting and Processing System*, for reporting deficient items or materials. Although many of the procurement and defective item problems discussed in this report would meet the reporting criterion for deficient items or materials, a review of the last five years of OPRS data indicated that no DOE construction site has issued a report under this criterion. Use of the Occurrence Reporting and Processing System to share lessons learned as a result of non-conformances related to nuclear safety in procurement and other construction quality topics would benefit current and future major projects. As a result of this data analysis, EA plans to increase focus of ORPS reporting processes at construction sites.

Review of the NTS data from 1999 to 2016 disclosed that only a limited number of construction-related non-compliances were reported. There are no specific DOE requirements or regulations for reporting non-compliances in NTS.

EA identified some best practices during the construction quality reviews that are discussed in Section 3 of this report. Recommendations based on lessons learned during the construction quality reviews are listed in Appendix A.

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE) Office of Enterprise Assessments (EA) manages the Department's independent oversight program, which is designed to enhance DOE safety and security programs by providing DOE and contractor managers, Congress, and other stakeholders with an independent assessment of the adequacy of DOE policy and requirements, and the effectiveness of DOE and contractor line management performance in safety and security and other critical functions as directed by the Secretary of Energy. The program is described in and governed by DOE Order 227.1, *Independent Oversight Program*, as well as a comprehensive set of internal protocols and criteria and review approach documents (CRADs).

Since 2011, EA and its predecessor organization have performed reviews of construction quality across the complex. These reviews were performed within the broader context of an ongoing program of assessments of nuclear safety at DOE major nuclear construction projects. Because of the complexity and significant cost of the Hanford Waste Treatment and Immobilization Plant (WTP) project, EA has also been performing quarterly reviews since February 2011 to assess the quality of construction at the WTP construction site.

1.1 Report Scope

This report analyzes the overall observations and conclusions from independent reviews of construction quality from February 2011 to December 2015 at the Savannah River Site (SRS) Salt Waste Processing Facility, the SRS Waste Solidification Building, WTP, the Hanford K-West Annex Facility, and the Los Alamos National Laboratory Transuranic Waste Facility. The reviews were performed to determine whether the construction contractors met the requirements of 10 CFR 830, *Nuclear Safety Management*, Subpart A, *Quality Assurance Requirements* and American Society of Mechanical Engineers NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications.* This report also addresses the results of an independent review of ventilation system procurement activities for the Waste Isolation Pilot Plant (WIPP). The sites and facilities reviewed, along with associated contractors, local DOE offices, and DOE Headquarters program offices, are listed in Table 1 below.

The scope of the construction quality reviews included observations of ongoing work activities; review of the contractors' programs for identifying, documenting, and resolving non-conforming conditions; and examination of the implementation of selected requirements in contractor quality assurance (QA) programs. EA reviewed procedures, specifications, drawings, and records; interviewed key personnel responsible for work activities; and conducted site walkdowns to observe work activities and inspect installation of hardware and components. The effectiveness of DOE site office oversight of construction contractor performance was not evaluated.

EA also reviewed data from the DOE Occurrence Reporting and Processing System (ORPS), which contains reportable events, and the Noncompliance Tracking System (NTS), which reports violations of DOE nuclear safety rules, as part of developing this report to determine if themes identified in the construction quality reviews were consistent with nuclear safety occurrences and violations reported from around the DOE complex.

Table 1. Nuclear Facilities, DOE Program Offices, and Local DOE Offices in the Review

Review Site	Facility Reviewed	Construction Contractor	Headquarters Program Office	DOE Field Element
Hanford Site	WTP Project	Bechtel National, Inc. (Designer/Constructor)	Office of Environmental Management	Office of River Protection
Hanford Site	K-West Annex	Federal Engineers and Constructors	Office of Environmental Management	Richland
SRS	Salt Waste Processing Facility	Parsons (Designer/Constructor)	Office of Environmental Management	Savannah River Operations Office
SRS	Waste Solidification Building	Baker Concrete Construction, Inc.	Office of Environmental Management	Savannah River Operations Office
Los Alamos National Laboratory	Transuranic Waste Facility	Los Alamos National Security, LLC	National Nuclear Security Administration	Los Alamos Field Office
WIPP	WIPP	Nuclear Waste Partnership, LLC & URS Corporation	Office of Environmental Management	Carlsbad Field Office

1.2 Requirements and Guidance

The construction quality reviews considered the requirements of 10 CFR 830, Subpart A, and the appropriate DOE Order 414.1B, C, or D, *Quality Assurance*, specified in the construction contract. The DOE Order and 10 CFR 830, Subpart A, specify that contractors use national consensus standards to implement DOE QA requirements. The national consensus standard and basis for contractor QA programs is American Society of Mechanical Engineers (ASME) NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications*. Contractors are required to submit their QA program for review and approval by DOE before start of construction. The QA program establishes a management system of planned and systematic actions necessary to ensure that structures, systems, and components will perform satisfactorily in service.

The principal criteria used for the evaluations were based on a sample of data and focused on the implementation of construction quality processes using selected portions of the CRADs listed below:

- CRAD 45-12, *Nuclear Safety Component and Services Procurement*
- CRAD 45-34, *Rev. 1, Fire Protection Inspection Criteria, Approach, and Lines of Inquiry*
- CRAD 45-52, *Construction – Piping and Pipe Supports;*
- CRAD 45-53, *Construction – Mechanical Equipment Installation;*
- CRAD 64-15, *Construction – Structural Concrete;*
- CRAD 64-16, *Construction – Structural Steel, and*
- CRAD 64-20, *Feedback and Continuous Improvement Inspection Criteria and Approach – Contractor.*

These CRADs specify assessment criteria, activities, and lines of inquiry. In addition, EA examined installation of electrical equipment and cables at one site. EA used the electrical construction and quality requirements in the approved contractor specifications and national standards specified in the contract as the basis for reviews of installation of electrical equipment and cables.

The remainder of this report is organized into the following sections:

- Section 2 provides an overall assessment of the results of the construction quality reviews and recommendations.
- Section 3 describes the attributes and construction practices that were beneficial in promoting effective QA controls at one or more DOE construction projects.
- Appendix A provides recommendations for consideration as potential improvements at all sites.
- Appendix B provides supplemental information on the organization and team members contributing to the review.

2.0 OVERALL ASSESSMENT RESULTS

2.1 Construction Quality

Work activities that EA observed included concrete placements; structural steel erection; welding; installation of pipe supports and heating ventilation and air conditioning systems; installation of post installed concrete anchors; electrical cable installation; equipment installation; pressure testing, flushing, and cleaning of piping; preservation and maintenance of installed equipment; and the construction fire protection program. Overall, construction quality at all reviewed facilities is adequate with the exception of a few deficiencies discussed below. Quality control (QC) inspections are performed by qualified personnel in accordance with inspection processes that meet or exceed industry standards. Concrete quality routinely exceeds specification requirements. Pressure testing of piping is well controlled and demonstrates completed piping/systems are leak tight. Onsite welding programs are effective in assuring that welds meet or exceed quality requirements. Contractor programs for control and calibration of measuring and test equipment used in performance of inspection and testing activities comply with QA requirements, and calibration of the equipment is traceable to the National Bureau of Standards. For the most part, contractors are effective in identifying specific construction related non-conforming conditions and documenting the non-conformances in their corrective action programs. Corrective actions to disposition non-conformances have generally been effective in resolving the problem identified and preventing recurrence. Construction fire prevention programs are generally adequate. Fire protection systems have been installed in accordance with design requirements. Although overall construction quality processes were providing assurance that nuclear projects were constructed in accordance with design requirements, some specific deficiencies associated with a single project were identified and are discussed below in support of organizational learning.

Overall, contractor procurement programs across the complex comply with 10 CFR 830 and ASME NQA-1 requirements. However, deficiencies in procured materials and equipment have adversely impacted quality, schedule, and cost. Specifically, some components and hardware supplied by approved vendors have not complied with project technical and quality physical and/or documentation requirements specified in material requisitions and purchase orders, and in some cases, have resulted in mechanical failures during transport to the sites or after installation at the sites. Resolution of deficiencies in procured components and hardware identified during receipt inspections and review of technical and quality verification documentation required to be submitted by vendors continue to challenge engineering organizations. For example, at one project, approximately 70 percent of the 235 non-conformance reports initiated in 2015 were the result of deficiencies with procured items that were only recently identified, even though many of the affected components and hardware were delivered to the project between 5 and 10 years ago. At another project, approximately 40 percent of the 160 non-conformance reports initiated in the first 7 months of 2015 were the result of procurement and supplier deficiencies. A significant problem at that site was the necessity to cancel a contract with a major vendor because the work that the vendor performed did not meet specification and quality requirements. At a third site, the receipt inspection for a critical safety significant system component identified shipping damage, and the resulting extent of condition review identified additional weld deficiencies requiring repairs. The contractor's surveillances of the vendor shop welding activities were appropriate given the NQA-1 qualification of the vendor. However, as a lesson learned, the contractor's subsequent procurement specifications for large system components require the vendor to submit and receive approval for its shipping plans. Although identified deficiencies have been corrected, the number and nature of issues in this area indicate the need for more effective QA by vendor organizations and continued vigilance by DOE contractors performing receipt inspections and DOE organizations overseeing procurement programs. For future reviews, EA plans to increase focus on receipt inspection and validation of received NQA-1 items to determine if process improvements are warranted.

The paragraphs that follow below amplify the specific details for each activity reviewed by EA and provide a brief summary of the construction quality review results.

<u>Structural Steel Erection:</u> EA observed structural steel erection and installation and tensioning of high strength structural bolts. EA verified erected structural steel member sizes and configuration conformed to the installation details shown on the construction drawings and that structural bolts and structural steel welds were the size and type specified on the drawings. EA also reviewed quality records documenting: (1) quality control inspections performed for structural steel construction activities; (2) results of chemical and physical tests performed on bolts, weld filler materials, and structural steel members to demonstrate that the materials conformed to the purchase specification requirements; (3) results of welder qualification testing; and (4) fabrication of structural steel members.

Overall, structural steel construction work complied with project specification and drawing requirements and in accordance with the approved QA program. However several deficiencies were identified and resolved at one site. These included: (1) Bolts were identified that had not been tensioned in one or more connections. QC records indicated the bolts had been tensioned. All accessible connections had to be re-inspected to verify the bolts were tensioned; (2) The method used to install high strength structural steel tension control bolts did not conform to industry standards; (3) Although a construction procedure that defines the requirements for erection and inspection of structural steel was revised to clarify QC inspection processes and to provide an improved record keeping method to document QC inspection results, EA identified several errors in the procedure appendices that included the changes to the inspection records in two revisions of the procedure that had been approved and issued by the contractor's Design Engineering and Construction organizations.

<u>Concrete:</u> EA observed batching/mixing, QC testing, placement, and curing of concrete. Activities observed included inspection of the concrete batch plant; observation of in-process QC testing performed on the freshly mixed concrete to verify that concrete properties comply with specification requirements; acceptance of the concrete by QC for placement (correct mix delivered to job site); discharging of concrete into the forms and consolidation of the concrete; curing controls for maintaining concrete within a specified temperature range and for control of moisture within the time period specified for the concrete to obtain minimum strength; and performance of unconfined compression tests on concrete samples. EA also reviewed QA records that demonstrate ingredients used for manufacture of concrete meet specification requirements, concrete mix design data, certification records for the concrete batch plant, concrete pre-placement inspection records (for reinforcing steel placement, installation of embeds, cleanliness of forms, etc.) concrete batch records, results of tests performed on freshly mixed and hardened concrete, concrete curing records, and concrete post-placement inspection records.

Concrete quality exceeds specification requirements on all projects. However, at one site, the project engineer is permitted, at his discretion, to authorize concrete placement that has one property (percent entrained air) that exceeds the specification limits. The specification does not specify an upper limit on the percentage of entrained air that is too high for the project engineer to accept. Final acceptance of the concrete is based on testing to determine if the concrete meet design strength requirements. Since the percent of entrained air affects concrete strength (concrete strength decreases as percent entrained air increases), this is an at-risk approach that will have an adverse impact on the project if the tests show the concrete strength is low. The cost to perform a design review to determine if the low strength concrete could affect structural integrity or long term performance of the structure, determine the extent of condition, and possibly delay the project would greatly exceed the production cost of the concrete.

Post Installed Concrete Anchors: Post installed concrete anchors (PICAs) are installed in the concrete structure after the concrete has attained its design strength to provide anchorage for hardware and components such as pipe supports, electrical equipment and instrumentation. EA reviewed design drawings, specifications and procedures that specify technical details (size, installation depth, spacing, and capacity), installation methods, and inspection requirements. EA also reviewed procurement records for the PICAs, qualification test data, and installation and inspection records. EA examined completed PICAs and verified the PICAs conformed to the criteria specified in the design and installation specifications.

Installation of PICAs was well controlled and adequate at all projects except one. At that site, multiple PICA installation deficiencies were discovered after DOE site inspectors discovered discrepancies in records prepared by the contractor's field engineers documenting installation of PICAs. The deficiencies included: PICAs installed too close to other PICAs or to embed plates; PICAs with insufficient installation depth; loads tests to demonstrate PICA load carrying capacity were incorrectly performed; missing hardware; insufficient installation torque; and incomplete installation records. This site uses seven types of PICAs. The installation and inspection criteria differ for each type, requiring training for the craft and field engineers on the installation and inspection method for each type of PICA. The contractor attributed causes of the installation errors to confusing and overly complicated installation criteria and inadequate training of craftsman and field engineers regarding the unique installation criteria for each type of PICA. Corrective actions to resolve the deficiencies included retraining of craftsman and field engineers to clarify PICA installation requirements, re-inspection of all previously installed PICAs (approximately 10,000), and revising the Engineering Specification for PICAs. PICAs identified during the re-inspection program that did not conform to the specification requirements were documented on a deficiency report and transmitted to design engineering for evaluation. Design Engineering's failure to issue a revised Engineering Specification until 30 months after the PICA installation problems were initially identified contributed to a delay in resolution of the PICA installation deficiencies, and in some cases required additional rework. Although the Specification and procedure revisions clarified some installation and inspection requirements, the PICA installation process remains complicated due to the fact the site still uses seven types of PICAs. Typically, most projects select one or two types of PICA to simplify the PICA installation process.

Installation of Pipe Supports: EA examined installed pipe supports that had been inspected and accepted by the QC inspectors. EA compared the pipe supports to the construction details shown on the design drawings. Attributes examined included member types, lengths, and sizes, weld details (type, size, and length), method of support attachment to the building structure, and the method used to connect the piping to the pipe support. EA also reviewed quality records for (1) QC inspections of pipe supports, (2) results of chemical and physical tests performed on weld filler materials, structural steel, concrete anchors, and other pipe support hardware to demonstrate that the pipe supports were constructed using materials that conformed to purchase specification and quality requirements, (3) welder qualifications, (4) installation of PICAs, and (5) piping attachment details. EA determined that pipe support construction and installation complied with design requirements except for a few supports identified at one site that had been installed by craftsmen using design drawings that had been superseded by revised drawings that modified the pipe support construction details. QC inspectors had used the superseded drawings to inspect and accept the supports.

Structural Steel and Pipe Welding: Welding is considered a special process and is required to be controlled in accordance with QA Requirement 5 of DOE Order 414.1C and Criterion 9 of ASME NQA-1. The requirements for welding of structural steel, which includes building steel, pipe supports, cable tray supports, and other structural steel components are specified in the American Welding Society (AWS) specifications. The requirements for welding of piping and pressure vessels are specified in ASME specifications. EA reviewed contractor specifications and procedures for welding and verified the specifications and procedures complied with the requirements of the ASME and AWS specifications. EA reviewed site programs for qualification of welding processes, qualification of welders, procurement and control of weld filler materials, and inspection and acceptance of completed welds. EA examined completed welds, results of physical and chemical tests performed on weld filler materials, welder qualification records, and weld inspection records. The onsite welding programs at all sites evaluated met or exceeded specification and quality requirements.

Pressure Testing of Piping: EA observed hydrostatic and pneumatic pressure testing of piping systems that are performed to ascertain whether piping systems are leak tight. EA also observed some cleaning and flushing sequences performed to remove debris from completed piping systems. EA attended pre-job briefings, reviewed specifications, test procedures, and piping drawings, examined the testing apparatus, verified measuring and test equipment was calibrated, and examined the piping sections, valve lineups, and test tags designating valve position (open or closed) attached to valves that were within pressure test boundaries. EA observed the pressurization sequence, verified piping was pressurized to designated test pressure, verified the test pressure was maintained for minimum specified hold time before the system walk downs were initiated to examine the piping system for leakage, and witnessed the system walk downs performed by test engineers and/or QC inspectors.

Pressure testing of piping complied with Specification and ASME Code requirements. The results of most pressure tests demonstrated the constructed piping systems were leak tight at designated Code test pressures which are in excess of system operating pressures. When a leak was identified, an infrequent occurrence, a test deficiency report was documented and entered into the corrective action program. Cleaning and flushing operations were adequate. However, at one site EA identified discrepancies in the valve lineup prior to the start of a pneumatic test. Since some of the valves were not in the position specified in the test procedure, the test engineer delayed the start of pressurization until the valves in the piping section to be tested were re-examined. A few valves were identified that were in the incorrect position. After the valve positions were corrected, the test proceeded.

Heating, Ventilation, and Air Conditioning (HVAC) Ductwork Installation and Testing: HVAC systems are installed by subcontractors who are responsible for all aspects of the HVAC installation, including design, installation, inspection, testing, and quality assurance. A field engineer or subcontract technical specialist is assigned by the general contractors to monitor and review the work performed by the HVAC subcontractor. EA reviewed design drawings and installation procedures, examined completed sections of HVAC ductwork and supports, and observed pressure tests performed on sections of ductwork to demonstrate that the ductwork met project specification requirements regarding permissible leakage. EA also reviewed the following for the HVAC subcontractors: corrective action programs, QC inspector qualifications, welder qualifications, weld filler material controls, and the QA program.

EA concluded that the installation of HVAC systems was adequate and in accordance with the HVAC subcontractor's QA program. General contractors subcontract representatives adequately monitored and reviewed work performed by HVAC subcontractors.

Electrical Construction Work Activities: EA observed the following electrical construction work at one site: Electrical cable installation (cable pulling); routing of cables between cable trays and electrical cabinets; cable terminations; installation of electrical panels and cabinets; certification of electrical panels and cabinets; labeling of electrical equipment; and review of the Authority Having Jurisdiction (AHJ) to approve electrical equipment and determine if the installation of the equipment complies with the National Electrical Code (NEC).

Overall electrical construction work activities observed at this site were satisfactory, but EA identified several issues requiring corrective action. These issues included multiple examples of errors in design documents that resulted in installation of some incorrect size cables, cables incorrectly terminated in electrical panels, incorrect size breakers, and locating electrical panels where the assessable work space for workers to safely perform maintenance does not comply with NEC or OSHA requirements. Other deficiencies identified include inconsistencies in labeling of electrical components, questions regarding the use of national recognized testing laboratories to certify electrical components, an example that some electricians were not informed of changes to the cable installation specification, deficiencies in documenting nonconforming conditions, and electrical field engineers failing to identify some wiring installations that violated NEC requirements. The installation of some electrical cabinets at this site in locations with work spaces and clearances that do not comply with the NEC and/or OSHA regulations was initially identified in 2007. Corrective actions have not been effective to resolve this issue.

EA also identified a potential conflict of interest with the designer/constructor being assigned the AHJ and the ability to evaluate their design and electrical equipment installation for compliance with the NEC. The contractor's design engineering organization has sometimes failed to provide timely responses to questions from construction regarding electrical installation problems.

Mechanical Equipment Installation: EA reviewed a sample of procedures for installation of mechanical equipment such as pump, motors, cranes, and various types of transfer carts. The installation procedures were based on manufacturer's recommendation and included instructions for equipment pre-installation checks, locating, setting, leveling, and aligning the equipment. Installation tolerances and pre-operational checks were also specified in the procedures. The procedures were adequate for proper installation of the equipment. EA observed installation of tanks at one site and reviewed completed installations of mechanical equipment at all sites reviewed. The mechanical equipment examined by EA was installed in accordance with the installation procedures.

Preventative Maintenance, Preservation, and Protection of Installed Equipment: EA examined the preventative maintenance and preservation programs for protecting permanent plant equipment from damage and for preventing degradation of the equipment after installation and prior to plant startup. EA performed walk downs to examine preventative measures in place to protect installed equipment. These included covering equipment with tarps or plastic covers, covering motor and pump shafts with metal shields, covering open ends of pipes and instrument lines with caps or tape to maintain internal cleanliness, and protecting fragile equipment from damage by providing wooden or metal enclosures. EA reviewed manufacturer recommendations for preservation and preventative maintenance of equipment and performed walk downs to examine implementation of these recommendations. These included protective covers for equipment, periodic manual rotation of pump and motor shafts, replacement of lubrication when recommended by the manufacturer, providing energized heat lamps and desiccants installed under motor covers to prevent buildup of moisture, and using humidity-indicating devices to detect the presence of moisture. EA observed contractor personnel performing equipment checks which were documented on check lists that are maintained as permanent records.

The equipment preventative maintenance and protection programs were adequately implemented. However, at one site, EA found protective caps were missing from some open instrumentation channels, some through wall pipe sleeves were not covered to prevent entrapment of debris, and some motors were not covered.

QC Inspector Qualification Records: EA reviewed records documenting contractor qualification and certification programs for QC inspectors to verify that inspectors performing safety related inspection activities met DOE Quality Assurance and ASME NQA-1 requirements. The certification programs require documentation and verification by employers to certify QC inspectors are qualified by education, work experience, on the job training, and testing.

The contractor QC inspector certification programs complied with DOE and ASME NQA-1 requirements at all sites except one. The one exception concerned failure of the contractor to independently verify inspector experience and qualifications. The contractor's QC manager based inspector certification primarily on their resumes. The contractor subsequently reviewed their inspectors' qualifications and determined the inspectors were qualified to perform inspections. The contractor updated their records to document the results of their independent review to verify their QC inspectors' qualifications. EA also performed an independent review of records maintained by national professional organizations that document qualifications of selected inspection personnel to verify the qualifications of the contractor's QC inspectors.

Corrective Action Programs: EA reviewed contractor programs for identifying, documenting, and correcting nonconforming conditions. EA reviewed open and closed reports that document nonconforming conditions.

Overall, contractor corrective action programs are generally effective in correcting specific construction related non-conforming conditions. Contractors have developed appropriate corrective actions to disposition the specific problems identified in completed and closed nonconformance reports. However, at one site, field engineers have not been fully effective in identifying non-conforming conditions, and corrective actions have been significantly delayed by a lack of timely support from design engineering. Corrective actions at this site have also not been effective to resolve deficiencies regarding electrical cabinets that had been installed without providing the minimum working clearances specified in the NEC and OSHA regulations necessary to perform safe maintenance activities. This issue was initially identified in 2007.

Receipt Inspection and Storage of Equipment, Hardware and Materials: EA reviewed site programs for receiving, inspecting, and storage of items (components and hardware). EA reviewed procedures for performing receiving inspections, reviewed the receipt inspection process that is performed by warehouse receiving and inspection personnel when items are delivered to the site, examined the documentation review program used by contractors to verify items delivered to the site comply with purchase specifications, and performed walk downs in warehouses and outside storage areas. Standard practices at all sites is to check shipments to confirm the correct quantity received, check items for damage, and verify documentation required by the purchase specifications had been transmitted to the site. Generally items are placed in hold areas and are not released until offsite procurement engineers complete a detailed documentation review to verify the items comply with the purchase specifications. Oversized components such as large vessels and transformers are generally installed directly into their designated location in the facility, with the documentation review being completed afterwards.

In onsite warehouses and storage areas, EA observed that nonconforming or potentially nonconforming items were segregated from qualified items, items were stored in accordance with manufacturer recommendations, and the majority of items were protected from becoming contaminated while in storage. At one project, Defense Nuclear Facilities Safety Board (DNFSB) staff performed a QA review and examined storage of items at onsite and offsite warehouse and storage facilities. The DNFSB identified a few examples of deteriorated storage tents being used as Level C storage facilities for onsite storage of items at this site. (Level C storage requires protection from debris and inclement weather.) EA had also previously identified some minor storage deficiencies at this site. Numerous examples of deficient storage conditions were identified by the DNFSB at two large offsite storage facilities associated with this same project. With the exception of these deficiencies associated with one project, EA concluded the onsite receipt inspection process and onsite storage of items was adequate.

A significant issue that has impacted the schedules at many sites is the fact that some components and hardware supplied by approved vendors have not complied with project technical and quality physical and/or documentation requirements specified in material requisitions and purchase orders. These deficiencies were identified by procurement or design engineers by performing timely detailed vendor documentation reviews, or in some cases by QC inspectors performing physical inspections of components. In addition to documentation reviews, some sites also perform independent materials testing to verify the chemical, physical, and mechanical properties of hardware comply with the purchase specification requirements. A significant problem at one site was the necessity to cancel a contract with a vendor who was fabricating safety significant tanks because the work that the vendor performed did not meet specification and quality requirements. However, the contractor identified this problem early in the fabrication process, before the tanks were delivered to the site.

Deficiencies in procured materials and equipment have also adversely impacted quality, schedule, and cost at another site. At this project, approximately 70 percent of the 235 non-conformance reports initiated in 2015 were the result of deficiencies with procured items that were only recently identified, even though many of the affected components and hardware were delivered to the project between 5 and 10 years ago. The majority of these deficiencies were not identified earlier because the contractor failed to perform the necessary documentation reviews promptly. Some of the vendors who supplied the affected components are no longer in business. A number of the non-conformance reports were initiated to document defective vendor welds in large safety significant tanks. In some cases the contractor had assigned QC inspectors to the vendor shops to inspect the welds. The DOE Office of Inspector General issued a report in November 2015 that stated that some of these shop inspectors were not qualified to inspect welds. Resolution of these deficiencies presents a significant challenge to the contractor’s design engineering organization.

Control of Measuring and Test Equipment (M&TE): EA reviewed the programs for control of M&TE used for construction, inspection and testing activities and verified the program complied with DOE and NQA-1 QA requirements. EA verified that M&TE was calibrated at frequencies recommended by manufacturers by a qualified facility, the standards used for calibration were traceable to the National Bureau of Standards, and M&TE was properly stored when not in use. EA reviewed records for a sample of M&TE to verify the M&TE was calibrated at the specified frequency. Some sites have programs to demonstrate that M&TE is providing accurate measurements by performing a calibration verification check in the range the M&TE was used on a daily, weekly, or monthly basis. Records for M&TE include a list of the activity and the identification of the M&TE item used. EA reviewed the corrective action process used by contractors for M&TE that fails to meet the calibration standards. Contractor programs for control and calibration of measuring and test equipment used in performance of inspection and testing activities is adequately controlled in accordance with DOE and NQA-1 QA requirements.

QA Audits and Self-Assessments: EA reviewed QA audits and self-assessments that are required to be performed to comply with Criterion 9 and 10 of DOE Order 414.1C. Self-assessments (Criterion 9) are required to be performed by managers and assigned personnel in line organizations to evaluate the performance of the organizations and to identify and correct problems that may hinder the organization from achieving it assigned objectives. Samples of self-assessments reviewed by EA included evaluations of the performance of QC inspectors, field engineers, office personnel, and warehouse personnel. Examples of specific activities addressed in the self-assessments included welding, concrete placements, electrical work, and piping installation, control of measuring and test equipment, QC inspections, receipt inspections, storage, maintenance of quality records, and document control. QA audits (Criterion 10) are required to be performed by QA organizations that are independent from construction line management. In addition to QA audits, QA personnel may also perform surveillances to complement QA audits and evaluate onsite quality-related work activities and processes. For specialized QA audits and QA surveillances, contractors require subject matter experts to perform surveillance activities. Examples of QA audits reviewed by EA included those documenting observations by QA personnel to determine if welding work activities, concrete placement and inspection, electrical cable pulling and terminations, installation of cable and conduit supports, piping and piping support installation, control of measuring and test equipment, receipt inspection and storage, and subcontractor work were performed in accordance with procedure and QA program requirements.

EA concluded that the QA audit and surveillance programs were adequate, effective, and assessed the full range of ongoing work activities. EA identified deficiencies in the conduct of the self-assessment program at one site. Self-assessments performed to evaluate the performance of the field engineering organization at this site did not cover the full range of work activities, but instead were concentrated in the accuracy of records and implementation of corrective actions to resolve previously identified nonconforming conditions.

Fire Protection System Installation and Fire Protection During Construction: EA reviewed fire protection programs at three construction sites. The reviews included fire prevention and protection during construction and installation and testing of the permanent fire protection system. Fire protection construction activities reviewed included installation of fire alarm systems, sprinklers, fire dampers, application of fire proofing materials, and penetration seals. EA also reviewed construction and testing of the fire water supply systems, including underground distribution systems and fire hydrants.

Although a few deficiencies were identified at three sites in various aspects of new construction for fire protection systems installation, EA concluded that implementation of fire prevention and protection was adequate, and that construction of new fire protection systems was adequate. Identified deficiencies included isolated examples of inadequate application of fire proofing to structural supports, inadequate fire penetration seals, incorrectly installed fire sprinklers, and missing fire wrapping on HVAC ducts.

2.2 Occurrence Reporting and Processing System and DOE Office of Nuclear Safety Enforcement Data Analysis

EA reviewed DOE-wide ORPS data for 2015 to identify any trends relevant to the nuclear construction quality. Of the 1037 ORPS reports filed across the DOE complex in 2015, none of them were directly related to the nuclear construction quality. DOE Order 232.2, *Occurrence Reporting and Processing of Operations Information*, applies to construction of DOE facilities (reference the Order 232.2 definition of "operations"); however, construction sites rarely report items meeting applicable ORPs criteria addressing procurement or construction quality topics. For example, Order 232.2 reporting criterion 4C(3) states, "Discovery of any defective item or material, other than a suspect/counterfeit item or material, in any application whose failure could result in a loss of safety function, or present a hazard to public or worker health and safety." Although many of the procurement and defective item problems discussed in section 2.1 of this report would meet this criterion, a review of the last five years of OPRS data indicated that no DOE construction site has issued a report under this criterion. As a result of this data analysis, EA plans to increase focus of ORPS reporting processes at construction sites.

EA also reviewed the NTS database for 2015 to determine whether any data correlated with nuclear construction quality. None of the 89 nuclear safety NTS reports filed in 2015 directly related to the topics discussed in this report. EA enforcement investigation documentation from 2007–2015 was reviewed for violations or potential violations related to construction or procurement. Two Preliminary Notices of Violation (PNOVs) were issued to and two consent orders were entered into with one of the six contractors within the scope of this lessons learned report. The first PNOV noted one Severity Level I, six Severity Level II, and two Severity Level III violations, most of which occurred because of deficiencies in the fabrication and procurement of black cell piping and the flow down of design requirements into specifications. The second noted six Severity Level II violations concerning deficiencies associated with joggled wall penetrations, commercial grade dedication, software procurement, and review of supplier submittals. The primary weaknesses included fabrication quality, procurement, and adequacy of contractor reviews. The consent orders involved issues related to construction and procurement, including commercial grade dedication and welding deficiencies in black cell vessels, calling into question whether the vessels could perform their design and safety function.

As reported in Section 2.1 of this report, a significant number of the thousands of non-conformance reports generated at sites across the complex are related to procurement. EA reviewed all data in NTS from 1999 through 2015 (for 265 facilities). A limited number of construction-related non-compliances were reported in NTS across the complex. These reports usually related to welding, loss of material control, falsification of records, procurement, construction modifications, and construction contractor issues. Using NTS to report construction related non-compliances is voluntary. There are no specific DOE regulations or requirements for reporting construction non-compliances in NTS.

DOE construction projects are not effectively utilizing ORPS to report procurement and construction deficiencies. DOE construction projects do not have a common database or reporting system to enable sites to share lessons learned as a result of non-conformances related to nuclear safety in procurement and other construction quality topics.

3.0 BEST PRACTICES

3.1 Quality Control Inspections

Using qualified personnel, contractors performed effective QC inspections in accordance with industry standards. Construction contractors at all sites reviewed use subcontractor inspection organizations to supplement their QC inspection staffs when necessary to perform specialized QC inspection activities. Qualified and experienced QC inspectors monitor work in progress and are able to identify potential deficiencies that are easy to correct as an on-the-spot correction. The QC inspectors are not directly involved in performing the work activities they inspect. Whereas field and construction engineers are directly involved in assisting craft in performance of work activities, QC inspectors are more objective and provide an unbiased assessment of the quality and acceptance of the completed work activity.

3.2 Control and Calibration of Measuring and Test Equipment

Contractor programs for control and calibration of measuring and test equipment (M&TE) used in performance of inspection and testing activities is controlled in accordance with DOE QA requirements, and calibration of the equipment is traceable to the National Bureau of Standards. The contractors at WTP and SWPF check the accuracy of their M&TE at frequent intervals to ensure the M&TE is within calibration tolerances when the M&TE is used in the field. These accuracy checks are sometimes performed, daily, weekly, or monthly, depending on the type of M&TE and its usage, although the calibration standards may only require annual calibration of the M&TE. In cases where an M&TE is found to be out of calibration or damaged, it is necessary to identify and review all work performed using that M&TE since the last known date that the M&TE had been calibrated, or an accuracy check had been performed on that M&TE. This can result in additional field work to verify that equipment was installed correctly. For example, if a torque wrench is out of calibration, it is necessary to verify the fasteners that were installed using the suspect torque wrench were installed at the proper torque. Components or systems that had been tested using suspect M&TE also require retesting in some cases. The advantage of performing frequent accuracy checks at short intervals is that the quantity of work or tests that could be affected by inaccurate M&TE is minimized.

3.3 Concrete Testing

At WTP, the subcontractor that supplies the concrete for the project has a full-time onsite QC inspector who monitors concrete manufacture and performs QC tests of the freshly mixed concrete at the concrete batch plant. The QC inspector tests the first batch of concrete on each shift and as needed during concrete batching operations to verify that the concrete properties comply with specification requirements before release for placement in WTP facilities. Although the subcontractor tests are not official, the subcontractor's QC inspector can identify when a change to a concrete batch is necessary to compensate for changing environmental conditions. This method of operation ensures with a high degree of confidence that the concrete is within specification requirements when it is delivered to the jobsite and point of placement. The subcontractor's testing program improves the efficiency of concrete placement operations by reducing waste (concrete found to be not meeting specification requirements is wasted) and reduces delays during concrete placements because concrete placements are on hold until concrete meeting specification requirements is delivered to the jobsite from the batch plant. An independent testing organization under contract to Bechtel National, Inc., performs the official testing that forms the basis for accepting the concrete.

3.4 Receiving Inspection Program

At the Salt Waste Processing Facility, the receiving warehouse uses material testing equipment to perform limited mechanical and physical tests on hardware and components and to verify the chemical contents of the hardware and some components. The Salt Waste Processing Facility sends samples of hardware and materials to independent laboratories for testing to verify the hardware and materials comply with specification requirements. This independent inspection and testing program is effective in identifying hardware and components that do not comply with specification requirements. The implementation of this type of test and inspection program permits early identification of nonconforming components and hardware before the items are released from the warehouse and installed in the SWPF facility. Early identification of nonconforming items also permits purchase of replacement items so that the construction schedule is not impacted.

Appendix A
Recommendations

The recommendations discussed below are based on lessons learned during the EA construction quality reviews and the related analysis discussed in this report. While the underlying deficiencies and weaknesses did not necessarily apply to all the sites, the recommendations provide additional insights into potential improvements at all sites. Consequently, U.S. Department of Energy (DOE) organizations should evaluate the applicability of the following recommendations to their operations and consider their use as appropriate to improve contractor oversight and construction quality.

The DOE Office of Quality Assurance and DOE field and contractor line organizations should reevaluate the use of ORPS to promote sharing of lessons learned from non-conformances identified at individual projects with other projects within the DOE complex.

DOE project contractors should report design deficiencies, procurement deficiencies, construction errors, and violations of quality assurance programs in ORPS when they meet applicable ORPS reporting criteria.

DOE contractors and subcontractors should assess their oversight of vendors supplying materials and equipment to determine whether this oversight is sufficient to ensure that vendors have established and implemented effective quality assurance programs. Inspectors assigned to vendor manufacturer and fabrication facilities must be trained, qualified, and certified to perform their assigned inspections.

Appendix B
Supplemental Information

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