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| U.S. Department of Energy<br><br>Office of Safety and Emergency Management Evaluations<br><br>Criteria Review and Approach Document | Subject: Nuclear Facility Construction – Mechanical Equipment Installation<br><br>Acting Director, Office of Safety and Emergency Management Evaluations<br>Date: 06/26/12<br><br>Phillip D. Aiken, Criteria Lead, Nuclear Facility Construction – Mechanical Equipment Installation<br>Date: 06/26/12 | HS: HSS CRAD 45-53<br>Rev: 0<br>Eff. Date: June 26, 2012<br><br>Page 1 of 18 |

**Acronyms**

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| ASHRE | American Society of Heating, Refrigerating and Air Conditioning |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials (now ASTM International) |
| AWS | American Welding Society |
| CMTR | Certified Material Test Report |
| COC | Certificate of Conformance |
| DOE | U.S. Department of Energy |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IEB | NRC Office of Inspection and Enforcement Bulletin (now called NRC Bulletins) |
| IN | NRC Information Notice |
| NFPA | National Fire Protection Association |
| NRC | U. S. Nuclear Regulatory Commission (also USNRC) |
| NDE | Nondestructive Examination |
| NQA | Nuclear Quality Assurance |
| PQR | Procedure Qualification Record (for qualifying welding processes) |
| QA | Quality Assurance |
| QC | Quality Control |
| SNT | American Society for Nondestructive Examination |
| WPS | Welding Procedure Specification |

## 1.0 PURPOSE

The mission of the Office of Safety and Emergency Management Evaluations (HS-45) within the Office of Health, Safety and Security (HSS), is to assess the effectiveness of controls used by field organizations to protect our workers, the public, and the environment from the hazards associated with activities at Department of Energy (DOE) sites. This mission included independent assessment of the quality of work performed during construction of DOE nuclear facilities. The purpose of this Criteria Review and Approach Document (CRAD) is to define the inspection criteria for review of mechanical equipment installation at a nuclear facility/site. Our Inspection Criteria, Approach, and Lines of Inquiry are for use by HSS and are also available for use by DOE line and contractor assessment personnel in developing and implementing effective DOE oversight and contractor self-assessment and corrective action processes.

## 2.0 APPLICABILITY

The following Inspection Criteria document is approved for use by the Office of Health, Safety and Security.

## 3.0 FEEDBACK

Comments and suggestions for improvements on these Inspection Criteria, Approach, and Lines of Inquiry can be directed to the Office of Safety and Emergency Management Evaluations on (301) 903-5392.

## NUCLEAR FACILITY CONSTRUCTION - MECHANICAL EQUIPMENT INSTALLATION

**Sample Selection**

For the purpose of this criteria review and approach, this CRAD includes mechanical equipment installation, including connections of this equipment to installed piping systems, and attachments of the equipment to structures (concrete, structural steel, or embed plates). Mechanical equipment includes items such as pumps and motors, valves, tanks, glove boxes, heat exchangers, ion exchangers, service air systems, fire pumps and tanks, and heating, ventilation, and air conditioning (HVAC) equipment such as fans, scrubbers, and filters. Inspection of installation of emergency diesel generators and any supporting mechanical equipment, such as fuel tanks and pumps, starting air and exhaust systems are also included in this CRAD. Selection of nuclear facility mechanical equipment for inspection should be based on a review of current construction status and information in the facility preliminary documented safety analysis to identify systems that are identified as safety class, safety significant, or important to safety. Sample selection should be focused on systems or parts of systems that have more critical safety functions, unique characteristics, or equipment installed in areas that will have limited personnel access after operations. This CRAD does not address procurement, manufacture, offsite fabrication of mechanical equipment, or installation of piping or HVAC ductwork.

**Inspection Criteria**

The following DOE directives and industry standards are applicable to the extent that they are referenced in design basis documents and contract specifications and apply to the design, fabrication, installation, inspection, and testing of piping systems:

- Quality assurance programs established and implemented in accordance with 10CFR830, Subpart A, *Quality Assurance Requirements,* ASME NQA-1, *Quality Assurance Requirements for Nuclear Facilities Applications,* DOE Order 414.1C, *Quality Assurance,* and DOE Order 226.1A, *Implementation of DOE Oversight Policy.*
- Design and construction requirements for fire protection systems contained in applicable National Fire Protection Association (NFPA) codes and standards.
- Heating, Ventilating, and Air Conditioning (HVAC) ducting and components fabricated and installed in accordance with American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), standards and manuals.
- Individuals inspecting mechanical equipment installation, including supports, are qualified in accordance with the requirements of ASME, American Welding Society Standard (AWS), or the American Society for Nondestructive Testing Standards.

**Inspection Activity**

Depending on the status of work, observe the following construction activities and review records, design documentation, and manufacturer's instructions to assess the quality of mechanical equipment installation to determine if requirements specified by design basis documents, procurement specifications, and applicable codes and standards have been met:

- Review the mechanical equipment installation procedures and ascertain whether the specified technical requirements for installation conform to the requirements of the construction contract, design basis documents, manufacturer's recommendations, and referenced codes and standards.
- Review project procedures for mechanical equipment and verify that they are adequate for (1) receipt, handling, and storage of mechanical equipment; (2) specify maintenance requirements for the equipment while in storage; and (3) specify adequate quality control inspection practices.
- Review mechanical equipment installation procedures and verify that they are adequate for (1) installation of the mechanical equipment; (2) attachment of mechanical equipment to supporting foundations or structures; (3) maintenance of the equipment after installation prior to turnover to

operations; (4) specify adequate quality control inspection practices, including identification and control of inspection hold points and inspection criteria; and (5) provide adequate controls for design changes.

- Observe ongoing construction work to determine if mechanical equipment installation work activities and the quality of work meet the requirements of applicable specifications, procedures, drawings, and codes.
- Observe construction testing and pre-operational testing of systems and components.
- Observe quality control (QC) inspection activities and examine mechanical equipment which has been inspected and accepted by QC to assess the effectiveness of the QC program. Review the qualification of QC inspection personnel.
- Review records documenting the quality of completed mechanical equipment installation. These records should include documentation of design changes, drawings documenting the as completed equipment installation (as-built drawings), QC inspection records, and pre-operational test results.
- Review the QA surveillance and audit program for mechanical equipment installation work activities.

**Inspection Lines of Inquiry**

- Procurement of Materials Necessary for Mechanical Equipment Installation and Onsite Fabrication of Mechanical Equipment and Components:
  - Are procurement specifications for materials used for installation of mechanical equipment consistent with design basis documents, equipment manufacturer's recommendations, and contract requirements? Examples of materials required for equipment installation include weld filler materials and welding supplies, grout, shims, and fasteners.
  - Mechanical equipment frequently requires onsite assembly and/or onsite fabrication of various components. These activities are performed in a shop by the manufacturer, a subcontractor, or the general contractor. These fabricators may use third party inspection organizations to perform shop inspections. The third party inspection organization must have an approved NQA-1 Quality Assurance program and their inspection personnel must be qualified in accordance with the applicable requirements of ASME, AWS, and the American Society for Nondestructive Testing standards. Are the requirements for the onsite fabrication shop inspection and quality assurance programs, including NDE, clearly stated in the contract documents? Have the following controls been established to ensure the quality required by design documents:
    - An approved NQA-1 quality assurance program that has been audited by the general contractor or a designated third party;
    - Preparation of fabrication drawings approved by the manufacturer and/or design engineering organization;
    - A receipt inspection program to verify purchased materials meet purchase specification requirements;
    - A quality control inspection program for inspection of assembly and fabrication activities, including welding, configuration, and material traceability.
    - A welding program and a weld inspection program that meets applicable code requirements;
    - An adequate number of qualified QC inspectors?

  - Do materials purchased meet appropriately specified quality levels and are certified as such by suppliers? Were hardware/materials supplied by vendors on an approved suppliers list established by the projects procurement program?
  - Are weld filler materials (electrodes) and other welding supplies certified by the manufacturer?
  - Are manufacturers/suppliers of materials on the project's approved suppliers list and have audits been performed by either the general contractor, DOE, the manufacturer, subcontractor or by an approved third party to validate the certifications furnished by these vendors?

Note: Review of programs and processes used for procurement of mechanical equipment is beyond the scope of this CRAD. Use HSS CRAD 45-12, *Nuclear Safety Component and Services Procurement Inspection Criteria, Inspection Activities, and Lines of Inquiry,* to assess mechanical equipment procurement programs and processes.

- Receipt Inspection and Storage of Mechanical Equipment
  Note: Mechanical equipment and components may be delivered to an offsite material handling and storage yard for future transfer to the project site, or delivered directly to the project site. The lines of inquiry below apply to both locations:
  - Was mechanical equipment adequately inspected for compliance with applicable specifications before it was delivered for installation? Does the documentation furnished by the manufacturer demonstrate qualification of the equipment and include installation instructions and vendor manual? Has the documentation been reviewed by a qualified individual (subject matter expert) to verify equipment complies with purchase specifications?
  - Were materials and components required for installation of mechanical equipment inspected for compliance with applicable specifications before they were made available for use at the construction site? Does the documentation furnished by the suppliers demonstrate qualification of the materials and has the documentation been reviewed by a qualified individual (subject matter expert) to verify equipment complies with purchase specifications?
  - Are methods for onsite handling and transporting of the mechanical equipment adequate to prevent damage to equipment?
  - Does the receipt inspection program include inspection for damage and internal cleanliness of the mechanical equipment and other components?
  - Are receipt inspection records being generated to document condition and quality of the equipment and materials received?
  - Is the equipment and components identified through use of an adequate system for identification of components which will not deteriorate while the equipment is in storage?
  - Is the equipment stored under appropriately defined and designated conditions to protect items from damage or deterioration, including temperature and humidity?
  - Have in-storage maintenance recommendations from manufacturers been identified and applied to equipment and components to ensure internal cleanliness, and prevention of corrosion, use of desiccants, internal purge with an inert gas, and mechanical damage? Have other in-storage maintenance recommendations from manufacturers been identified and applied to mechanical equipment such as periodic rotation of pumps and motors and lubrication?
  - Are non-conforming materials clearly identified and stored in an area segregated from qualified materials?
  - Are any electrical components, e.g., valve operators, and other sensitive components, associated with the mechanical equipment stored in accordance with manufacturer recommendations?
  - Are weld filler materials (electrodes) stored in sealed containers, per manufacturer's requirements?
  - Are fasteners stored in closed containers and protected from dirt and moisture? Are containers stored in a protected shelter and are not in contact with ground?
  - Are filler materials stored in an oven or otherwise protected from moisture after removal from original packaging?
  - Is pre-packaged grout protected from moisture? Is the shelf life of the grout controlled?
  - If applicable, is shelf life of consumables used for construction and inspection processes controlled?

- Has a system been established to verify all required vendor manuals, including updates, are received and reviewed by design engineering or the project staff?

- Mechanical Equipment Installation
  - Are safety class boundaries described in design documents reflected accurately on construction drawings?
  - Are installation drawings adequately controlled to insure the latest approved drawings are being used for equipment installation, including timely posting of design changes?
  - Do design drawings, specifications, and manufacturer's instructions specify minimum inspection and acceptance requirements for installation of mechanical equipment?
  - Are sufficient cleanliness controls in place where necessary to prevent entry of foreign material into mechanical equipment internals during installation and construction activities?
  - Have pre-installation checks been performed prior to installing equipment to verify layout and size of anchor bolts, and to verify the equipment foundation is properly prepared (level, cleaned, and/or coated)? Have required slid plates/bed plates or sole plates specified by manufacturer or on design drawings been installed?
  - Are work activities for locating, setting, and leveling (plumbing) equipment properly controlled to ensure equipment is not damaged during handling and is properly located, leveled, shimmed to bring equipment to the proper elevation, and is in rough alignment with piping and other components such as gear boxes, motors, or couplings?
  - Are work activities for grouting of equipment adequate to ensure proper type of grout is specified, mixing of grout is performed in accordance with supplier's instructions, grout is placed before setting, adequate vent holes are provided in equipment bases to ensue all voids are filled with grout, grout is properly cured and tested, and the equipment base is checked to verify the absence of voids under the base? Have procedures for grouting of equipment bases been approved by design engineering, and has grouting been inspected and accepted by QC?
  - Are work activities for final alignment of equipment performed in accordance with manufacturer's instructions to ensure shafts are precisely aligned and positioned axially, equipment is level and plumb, and absence of soft foot or rocking? Has piping been connected to equipment prior to performance of final equipment alignment and coupling? Are precision measurements performed to establish parallel and angular alignment, coupling gap, face runout, rim runout, etc.?
  - Are valves (especially check valves) installed in the specified location and proper orientation (e.g., vertical or horizontal)?
  - Have all measuring and test equipment required to be used in the installation and acceptance of mechanical equipment been calibrated and controlled in accordance with approved procedures, and is calibration traceable to approved national standards?
  - Do installation procedures limit use of jacks or rigging for pulling piping into position for support installation or welding so that cold spring allowances are not exceeded for that particular material, pipe size, and length of pipe run?
  - For piping not in alignment with the connection point to the mechanical equipment, has a design modification been implemented to modify the piping to achieve proper alignment?
  - Are the correct number and type supports and restraints necessary to support the equipment and connected piping installed at the locations and spacing specified on design documents, and within tolerances and alignment specified on equipment installation drawings? Are supports and restraints fabricated and installed as shown on design drawings?
  - Are correct material and sizes of fasteners (bolts, nuts, washers) used for bolted connections and supports and are they installed properly (e.g., perpendicular to base plates, proper embedment, tight, and with full thread engagement)?
  - Is installed equipment and components free of damage, corrosion, and arc strikes?

- Are specified clearances for thermal growth of piping/tubing provided on supports/restraints and installed equipment?
- Is field welding of piping controlled and is it performed in accordance with requirements of applicable ASME or AWS Codes?
- Are modifications to equipment installation required by field conditions performed in accordance with applicable code requirements, and have field changes been evaluated and approved by the manufacturer or engineering?
- Have cleanliness inspections been performed prior to closure of mechanical systems?
- Are inspections of mechanical equipment installation performed by qualified personnel?
- Do procedures indicate that inspectors who inspect and accept welds are required to meet requirements of AWS D1.1 or SNT-TC-1A?
- Are inspections of mechanical equipment installation performed when required and by qualified personnel? Are inspectors who perform inspection of mechanical systems certified in the area of mechanical systems and are they required to pass annual eye exams and be physically able to perform their duties?

- Field Welding
  - Are field welding processes used for installation of mechanical equipment in accordance with manufacturer's instructions and are they qualified as required by AWS or ASME codes with a procedure qualification record (PQR) and are weld methods documented on a written welding procedure specification (WPS)? Is heat generated by welding controlled to prevent damage to internal components such as tank linings and pump seals?
  - Do welder qualification records, including results of test assemblies (coupons), indicate that welders are qualified per the applicable code?
  - Are weld filler materials (electrodes) used as specified in the applicable codes and site weld procedures?
  - Are storage and handling of welding materials in accordance with the manufacturer's instructions and AWS or ASME Codes?
  - Are weld joints prepared as specified in the welding procedures and specifications (i.e., are they free of paint, oil, dirt scale, rust, moisture and other foreign materials), and are gaps between faying surfaces within specification requirements?
  - Are pre-heat, interpass temperature, and post weld heat treatment controlled in accordance with specification requirements?
  - Are welding process and equipment used as specified in PQR and WPS?
  - Are welds the size and type as specified on the manufacturer's or design drawings?
  - Are weld surfaces free of grooves, abrupt ridges, valleys, undercuts, cracks, discontinuities or other detrimental indications that appear to exceed code limitations?
  - Are welds inspected and are NDE inspection personnel qualified in accordance with either AWS, ASME, or SNT-TC-1A as required?
  - Are weld records maintained to verify welds meet specification requirements? Do these records identify weld location, type and size, identify filler material used, welder identification, materials joined, joint preparation, WPS, thermal treatment, NDE performed and results, and NDE inspector?

- Concrete Expansion Anchors
  Grouted or cast in place anchor bolts are the preferred type bolts used to anchor mechanical equipment. Concrete expansion anchors should not be used to anchor rotating equipment, since equipment vibration may cause the anchors to loosen. They are sometimes used for anchoring

stationary equipment such as tanks. Refer to HSS CRAD 45-52 *Nuclear Facility Construction – Piping and Pipe Supports* for guidance on qualification and inspection of concrete expansion anchors.

- Equipment Maintenance After Installation and Prior to Turnover to Operations
  - Have the manufacturer's maintenance recommendations been identified and applied to equipment and components to ensure internal cleanliness and prevention of corrosion (use of desiccants or an internal purge with an inert gas), and mechanical damage?
  - Have the manufacturer's in-storage maintenance recommendations been identified and applied to mechanical equipment such as periodic rotation of pumps and motors and lubrication?
  - Have plugs, blank flanges, strainers, or internal dams been installed in attached piping to prevent debris from construction activities from entering tanks, pumps or other mechanical equipment? Are protective covers in place to prevent damage from construction activities?
  - Is a system in effect, such as a foreign material exclusion program, to control entry into equipment and tanks after installation is complete?
  - Are replacement parts installed during maintenance activities qualified to original specification requirements?
  - Are records maintained to document maintenance activities, including documenting parts which were replaced after installation was completed?

- System Testing
  - Have all temporary supports, including wooden blocks and internal packing materials, been removed prior to system testing?
  - Have systems and piping been properly cleaned and flushed to remove debris prior to testing?
  - Have required pre-operational testing, such as pressure testing, flow testing, thermal expansion, and vibration been completed, inspected, and documented?
  - Have results of pre-operational tests been reviewed by a qualified individual (subject matter expert)?
  - Have testing discrepancies been identified, documented in the corrective action program, and resolved?
  - Have records been maintained documenting results of testing and resolution of test deficiencies?

- Qualification of QC Inspection Personnel
  - Do training and qualification records confirm that NDE welding inspection personnel are qualified in accordance with AWS, ASME, or SNT-TC-1A as required?
  - Do QC inspection personnel demonstrate adequate knowledge of the requirements of their work activities?
  - Is the number of qualified QC personnel at the construction site commensurate with the work in progress?
  - Are QC inspectors who perform inspection of mechanical equipment installation certified in the area of mechanical/piping installation in accordance of NQA-1?
  - Do qualification records document results of annual eye and physical exams for QC and NDE inspectors?

- Quality Records
  - Do records of mechanical equipment installation, including field welding activities, provide adequate documentation of work and inspections?
  - Are as-built drawings being maintained and updated to reflect actual installation?
  - Do records include sufficient detail to document the results of inspections were completed in accordance with applicable Code requirements?

- Are records legible, complete, reviewed by QC and/or engineering personnel, and readily retrievable?
- Do receipt inspection records of fabricated items (base plates, shim supports/restraints), fasteners and weld materials confirm that required material characteristics (physical and chemical), performance tests, nondestructive test, and other specification requirements were met and traceability between hardware and records has been maintained?
- Were hardware/materials supplied by vendors on an approved suppliers list established by the project procurement program?
- Do records confirm that mechanical equipment has been installed in accordance with design requirements and that appropriate inspections have been completed?
- Do nonconformance/deviation records include current status of reported conditions and do they include the status of corrective action or resolution?
- Do training/qualification records establish that QA/QC personnel are adequately qualified to perform their assigned duties and responsibilities and that craft personnel have been trained in their assigned tasks? Are these records complete and current and show which activities inspectors are qualified to perform?

**Inspection Guidance**

Mechanical equipment installation covered by this CRAD is considered either stationary or rotating. Examples of rotating equipment are pumps and motors, compressors, fans, blowers, scrubbers, generators, and turbines. High efficiency particulate filter components are also considered rotating equipment since they are assembled in units with internal blowers and fans. Rotating equipment is subject to vibration and may have insulated pads or feet to dampen the effects of vibration. Locking devices are required on anchor bolts which attach rotating equipment to its foundation. Performance of alignment operations is critical for proper operation of rotating equipment. Examples of stationary equipment are tanks, vessels, glove boxes, heat exchangers, and filters. For stationary equipment, alignment operations are not performed, except to assure that piping is in alignment before final attachment, either by a welded joint or a bolted flange, of the piping to the equipment. Allowance for thermal expansion is a consideration for installation of equipment, by using sliding bases or base plates with slotted holes.

The project safety design analysis, nuclear facility safety basis documents, and approved project QA program specify design, construction, and QA/QC requirements. These requirements are implemented through the construction specifications, drawings, work procedures, and QC/QA implementing procedures. The design and operation requirements for mechanical equipment are based on the nuclear facility safety basis documents and design requirements.

The Code of Federal Regulations 10CFR 830.122 and DOE, ASME, and AWS codes and standards specify Quality Assurance requirements for installation, inspection, and testing of mechanical equipment for nuclear facilities as required by project/site contracts. The editions and applicable sections of these codes and standards applicable to the project will be referenced in the specifications and the nuclear facility design safety basis documents. However, the project specifications, drawings, and procedures specify and control the installation and inspection processes. The construction specifications must translate design requirements into details sufficient to define the technical requirements for mechanical equipment installation. The specifications should provide for control of design changes. QA/QC inspection and construction procedures should be reviewed and compared with the requirements of the applicable codes and specifications. QA/QC procedures must provide for effective inspections which will ensure that work is performed in accordance with specification requirements. The procedures and specifications must also incorporate the manufacturer's instructions for equipment installation. Pre-operational testing procedures must provide verification that equipment is operable. Qualified personnel

should review test results and determine if results are acceptable. Construction procedures must reference the required inspection hold points and must also address the QA/QC department stop-work authority. Procedures must also address activities required to maintain equipment.

Procurement of Mechanical Equipment and Components

Requirements for mechanical equipment will be specified in the nuclear facility safety basis documents and procurement specifications. Mechanical equipment is procured by the project from a variety of manufacturers. The design engineering organization or DOE project office prepares specifications detailing (1) the performance requirements for a particular piece of equipment; (2) design codes; (3) specific design requirements such as pressure, temperature, and seismic; (4) material specifications and traceability requirements; (5) operating environment such as exposure of the equipment to high radiation and hazardous chemicals; (6) quality control and quality assurance requirements; (7) specific controls required during equipment fabrication; (8) documentation requirements; and (9) any required equipment proof testing to be performed by the manufacturer. The manufacturer must have an approved NQA-1 Quality Assurance program, or use a third party inspection organization with an approved NQA-1 Quality Assurance program.

Equipment for a project will be furnished by a number of manufacturers. Each equipment item is uniquely identified using a technique which will permit identification and traceability to the fabrication drawings throughout the installation and final inspection process. This includes maintaining material traceability, welding details, and detailed fabrication data such as identification of shop welds, NDE, and other inspection requirements, including identification of welders and inspectors. Frequently, equipment will require modification to accommodate construction or design changes prior to installation. The modifications can be performed onsite by either the general contractor, the manufacturer, or by a subcontractor, or the equipment may be sent to an offsite shop for modification. Replacement parts for mechanical equipment must be equal to the parts furnished by the original manufacturer. For example, pump seals must be qualified using the same design basis accident testing for pressure, temperature, and radiation exposure the manufacturer used to qualify the pumps.

Various types of steels are required to fabricate base plates, sliding plates, sole plates, supports, and shims for installation of mechanical equipment. Other hardware items and materials required to install mechanical equipment include fasteners (bolts, nuts, and washers), welding electrodes and other welding supplies, grout, gaskets, and other special equipment. Chemical and mechanical (physical) tests for all hardware and materials used must indicate that purchase specification requirements have been met. Tests results may be provided by suppliers and fabricators on certified materials test reports (CMTR), on Certificates of Conformance (COC), or may be performed at an independent testing laboratory. Welding electrodes and other welding supplies are certified by the manufacturers. Fasteners are also certified by the manufacturer, and grade and type are clearly marked on the bolts, nuts, and washers. Suppliers of various components and materials required for installation of mechanical equipment must be on the Approved Suppliers List and should have an approved QA program. The general contractor is required to audit their suppliers through their vendor inspection program. The contractor's audit of suppliers should verify the fabricator has an adequate QA program and are implementing these programs.

Review the general contractor's vendor inspection program to verify that the suppliers of various materials have QA programs that have been audited by the general contractor or a designated third party. Key areas are verification that the hardware and materials were supplied by a qualified supplier; that physical and chemical tests were performed to show purchased materials meets appropriate ASME/ASTM requirements (either a CMTR, COC, or tests from an independent test laboratory); that receipt inspection of purchased materials included review of chemical and physical tests; and, where appropriate, that dimensions were checked to verify sizes of the purchased materials meet mill tolerances

specified in the procurement specifications. The audit should also include a review of the supplier's shop inspection program that provides verification that fabricated components meet drawing and specification requirements; a review of fabricator's welding program; a review of the shop weld inspection program; a review of the pipe support fabricator's audit of their steel suppliers; and verification that the fabricator's QC inspectors are qualified.

There have been significant problems in numerous industries with fasteners being supplied with fraudulent documentation indicating the fasteners met various industry standards. These fasteners are generally referred to as counterfeit fasteners. There have also been problems with various types of steel and piping system components for which fraudulent documentation was provided as the basis for certification of quality. Refer to DOE G 414-1-3, Suspect/Counterfeit Items Guide for Use with 10 CFR 830 Subpart A, Quality Assurance Requirements, for additional guidance on counterfeit items.

Receipt Inspection and Storage of Mechanical Equipment

When mechanical equipment is received onsite, a receipt inspection is performed to assure that documentation is supplied to demonstrate that the equipment complies with project specifications and that no shipping/handling damage has occurred. The documentation may include CMTRs, COCs, inspection releases from the manufacturer, and manuals which provide installation, operation, and maintenance instructions. The receipt inspector is required to verify the information on the equipment name plates and serial numbers on the equipment matches the documentation supplied. When inspecting for shipping damage, the receipt inspectors should verify protective covers are not damaged or missing. To the extent practical, components and equipment in storage areas should be segregated by types of materials and sizes. If equipment is damaged or documentation is missing or inadequate, the item is considered nonconforming and must be documented in accordance with the project's corrective action program so corrective actions can be initiated to correct any problems. Non-conforming or unqualified equipment is required to be segregated from qualified equipment and materials. The CMTRs, COCs, and inspection documentation which accompanied the shipment should be reviewed in detail by a subject matter expert to assure the equipment meets specification requirements. This review may be performed by the procurement engineering organization or by design engineering. The purpose of this review is to determine if the equipment conforms to the specifications and purchase order requirements. The manufacturer's recommendations specified in the manuals and documentation provided by the manufacturer need to be reviewed to determine the required level of storage and any preventative maintenance required prior to installation of the equipment.

When equipment is placed in storage, it is necessary that the equipment is oriented correctly. Equipment and associated components are required to be identified through use of an adequate marking system. Some equipment and components may require ongoing preventive maintenance during storage to protect equipment internals from corrosion or other damage by use of desiccants or maintenance of an internal purge using an inert gas. Some equipment may require application of a low heat or current to prevent accumulation of moisture during storage. Opening in equipment are required to be capped to maintain internal cleanliness. Mechanical equipment should be covered under canvas and plastic waterproof tarps or stored in a warehouse for protection from the elements. All equipment and associated components are required to be stored on an adequate system of dunnage or timber cribbing so they are not submerged or partially submerged in standing water, or become coated with mud or debris. Stainless steel equipment and materials should not be stored on timber dunnage treated with chemicals containing excessive levels of halogens and/or chlorides. Sensitive instruments which are to be installed in mechanical systems may be required to be stored in a temperature and humidity controlled environment. Some mechanical components such as rotating equipment may require periodic rotation of pumps and motors and periodic oil changes and lubrication of various parts during storage to protect bearings and critical surfaces from

corrosion or other damage. The grease and oil must be compatible with that provided by vendor. The minimum requirements for storage may be specified by the manufacturer as a pre-requisite for maintaining the manufacturer's warranty. Storage controls, materials identification, protection and preventive maintenance, and segregation are required to be maintained until installation in the facility and final inspection and acceptance. Appropriate quality records are required to demonstrate compliance with storage requirements.

When materials such as weld filler materials, fasteners, and grout required to complete installation of mechanical equipment are received onsite, a receipt inspection is also performed to assure that documentation is supplied to demonstrate that the materials comply with project specifications. This documentation includes CMTRs and COCs from the manufacturer or supplier. The containers in which the materials were shipped are inspected for shipping damage. If the shipping containers or packages are damaged or documentation is missing or inadequate, the item is considered nonconforming and must be documented in accordance with the project's corrective action program to initiate corrective action to disposition the problem. Non-conforming or unqualified materials are required to be segregated from qualified materials. The CMTRs and COCs should be reviewed in detail by a subject matter expert to assure the materials meet specification requirements.

Weld filler materials (electrodes) are stored in sealed containers, per manufacturer's requirements. If the containers are opened or damaged upon receipt or in storage, the electrodes in the damaged/open containers are considered non-conforming, After filler materials are removed from original packaging, they are required to be protected or stored in an oven so welding characteristics are not changed.

Fasteners are stored in closed containers and protected from dirt and moisture. Containers are required to be stored in a protected shelter, minimum Level C storage area (outside and covered), and not in contact with ground. Note: Manufacturers generally apply a protective coating to fasteners to prevent corrosion and facilitate installation. If fastener components become dirty or rusty, they are not considered acceptable for permanent installation. Some fastener components may be used after cleaning and re-lubrication depending on manufacturer's instructions.

Pre-packaged grout needs to be stored in a dry environment, usually in a warehouse, where it is protected from moisture. The manufacturer may have additional requirements for storage of epoxy grout mixes, such as temperature controls. Grout mixes have a limited shelf life. Pre-packaged grout which has exceeded the shelf life is nonconforming and needs to be removed from the warehouse so it is not inadvertently used on the project.

Mechanical Equipment Installation

Drawings showing mechanical equipment installation details require input from both the manufacturer and the design engineering organization. The manufacturer's drawings will show support requirements such as type, size, and spacing of the supports, tolerances for alignment, and allowances for thermal expansion. Details shown on the drawings developed by design engineering will show equipment location and elevation, minimum clearances from the building structure and other equipment, and requirements for seismic restraints. All changes to mechanical equipment installation details require approval of the design engineering organization and input from the manufacturer. Typical problems encountered during installation are the need to adjust equipment locations due to interferences, or missing or incorrectly installed anchor bolts or base plates. Field changes need to be documented and submitted to design engineering for approval. After completion of equipment installation, accurate as-built drawings showing all as constructed details of piping systems needs to be prepared by construction and

approved by design. The as-built drawings will be used to evaluate required design modifications during facility operation. The as-built drawings are very important to document equipment installation details in areas where access is limited due to high or extremely high radiation levels after facility start-up.

The most significant problems that occur during equipment installation involve failure to detect material, fabrication, or installation deficiencies early in the process. Improperly qualified material, lack of material traceability, welding process or production problems, incorrectly prepared equipment foundations, interferences with existing equipment, insufficient clearances to building structures (concrete wall, structural steel) are examples of significant errors during equipment installation. These errors can result in construction delays resulting from the need to re-inspect completed work, requirements for design evaluations of defects and extensive re-work and repairs. Inappropriate engineering involvement or actions in evaluating design changes and insufficient pre-operational testing are other areas of vulnerability. Other deficiencies which can occur in equipment installation are installing valves in incorrect locations and/or orientation, excessive arc strikes on piping, internal cleanliness problems, excessive cold springing of piping, and using outdated or uncontrolled drawings for installation.

The installation sequence for rotating mechanical equipment generally includes the following steps:

1. Performance of pre-installation checks should include verification that (a) anchor bolts are the proper size and correctly located; (b) steel surfaces are clean, free of burrs and mill scale, and coated as required by design specifications; (c) equipment is inspected and clean; (d) area where equipment is to be installed is free of obstructions; (e) necessary preparations have been made to maintain internal cleanliness of equipment; and (f) verification that required pre-installation QC inspections have been completed.
2. Locating, setting, and leveling equipment should include verification that (a) rigging and handling preparations are properly completed to prevent damage to equipment to be installed, to equipment and components in proximity to the installation location, and to anchor bolts and foundation; (b) position of equipment after installation is checked by surveyors to assure it is properly located (correct elevation and position) and level; and (c) proper type and size shims are placed to maintain correct elevation and leveling screws are backed off.
3. Rough alignment checks should include performance of an alignment check to assure equipment is located close enough to the required tolerances so that a precision alignment can be performed after grout placement. Precision instruments are required when performing the rough alignment check such as micrometers or dial calipers to assure drive shafts are parallel and closely aligned. The instruments are required to be calibrated and traceable to national standards. Alignment of piping to be connected to the equipment should also be checked.
4. Grouting of base plates under the equipment is performed to provide a uniform bearing surface for the equipment. The nuts on the anchor bolts are generally loosened prior to grout placement. The type of grout to be used is usually specified in the project specification or on the design drawing. Procedures for grouting of equipment bases must be approved by design engineering. There are several types of proprietary grout mixes which are pre-packaged, although on some projects grout mix may be obtained from a concrete batch plant. These include non-shrink grout, epoxy grout, and standard sand/cement grout mixes. The pre-packaged grouts have a shelf life which will be stamped on the bags or listed in the CMTRs or COCs for each lot. Proper mixing of the grout is important. Mixing of grout must be performed in accordance with supplier's instructions. Quantities of ingredients should be carefully measured and mixed in accordance with the instructions. The foundation where the grout is to be placed must be properly prepared and the grout must be placed before setting (critical for epoxy grout). Adequate vent holes must be provided in equipment bases to prevent entrapment of air under the base plate so all voids are filled with grout. After the grout is properly cured, the equipment base should be checked to verify the absence of voids under the base? The grout is sampled for testing to verify it meets the

required design strength. All grouting operations are witnessed by civil QC inspectors. Records are prepared to document that grouting has been inspected and accepted by QC.

5. Precision alignment of equipment is performed after the anchor bolts are tightened and locking devices installed. Precision alignment may be performed several times to verify shafts are precisely aligned and positioned axially, the equipment is level, and there are no soft feet or rocking (all feet support equal weight of the equipment). Alignment is performed in accordance with the manufacturer's instructions using precision calibrated instruments. Installation tolerances will be specified by the manufacturer. Alignment must be monitored when piping is attached to the equipment and when performing any welds on equipment base plates. A final alignment check is made after the piping is connected and the system is pressure tested.
6. The system is checked for cleanliness and final closure. Required coatings are applied and insulation, if required, is installed.

The installation and work steps for stationary equipment are the same as for rotating equipment except that the only alignment checks that are required are those for piping to be connected to the equipment. The installation steps for stationary equipment are performance of pre-installation checks, position and level equipment, fasten equipment to foundation, grout equipment, perform final assembly, connect piping, cleaning and closure. In the event the piping is not in alignment with connection point to the mechanical equipment, either rotating or stationary, a design modification must be implemented to modify the piping as required to achieve proper alignment. The use of jacks or rigging to pull piping into position for support installation or welding is known as cold springing. This may result in additional uncontrolled stresses in the piping which have not been evaluated in the pipe stress analysis, can cause increase loads on supports, increased stresses in tank nozzles or at the piping connection point to equipment, and can result in equipment alignment issues.

Bolting

Fasteners are certified by the fastener manufacturers. Grade and type are clearly marked on the bolts, nuts, and washers. Manufacturers furnish CMTRs to demonstrate compliance with project specifications and industry codes. Verify the manufacturers/suppliers of these materials are on the project's approved suppliers list and that audits have been performed to validate the CMTRs furnished by these vendors. Unless otherwise specified on the installation drawings, verify all bolts in a connection or flange are snug tight prior to final tightening of bolts. Verify correct fasteners (bolts, nuts, washers) are used and that washers are on correct side of fastener (under turning element). Bolts must have sufficient thread engagement.

Verify the following attributes: correct size and type fasteners, correct tensioning (tightening) method, tensioning sequence, and tightened (torqued) to proper tension. Verify bolts have sufficient thread engagement. Before final tightening of anchor bolts, adjustments for levelness and alignment of equipment must be completed. Locking devices such as double nuts or lock nuts are used on anchor bolts for rotating equipment to prevent nuts from becoming loose during operation of equipment. For stationary equipment subject to thermal expansion, sliding plates or base plates with slotted holes are used. Nuts are not tightened on the base plates with slotted holes, but a slight gap may be left under the nut to permit thermal movements, with a locking nut to prevent the bottom nut from moving and maintain the prescribed gap, which will be specified by the manufacturer.

Field Welding

Welding to connect piping to mechanical equipment is performed in accordance with the applicable ASME Boiler and Pressure Vessel Code. Welding of supports and structural steel which provide the foundations for pipe supports is generally performed in accordance with AWS Structural Welding Code, AWS D1.1. However, welding to install some components such as tanks may be governed by various sections of the ASME Code, or by special instructions furnished by the manufacturer. Refer to these codes for detailed requirements. When welding is performed in proximity to or on mechanical equipment, extreme caution must be taken to control the effect of heat on sensitive internal components such as lining in tanks, or gaskets in pumps or valves. When gaps between equipment and base plates exceed those indicated on the design or installation drawings, the weld size for attachment of the equipment will require adjustment. Changes in weld sizes must be approved by design engineering.

The following are minimum requirements to insure a good quality welding program. The welding process (type of joint) is qualified in a procedure qualification record (PQR). The weld method is documented on a written welding procedure specification (WPS). All welders are qualified per the applicable code, which requires preparation of test assemblies (coupons) which are inspected and tested. Weld filler materials (electrodes) used are as specified in the code and applicable WPS and PQR. Storage, handling, and issue of welding materials are controlled per code requirements. Weld joints are prepared as specified in the WPS, are free of paint, oil, dirt scale, rust, moisture and other foreign materials, and gaps between fraying surfaces do not exceed specification requirements. Thermal (reheat, interpass temperature control, and post weld heat) treatment of welding is performed in accordance with code requirements. The welding process and equipment used are as specified in the PQR and WPS. All welds are inspected by qualified NDE inspection personnel who are required to be qualified in accordance with either the ASME or AWS codes, or SNT-TC-1A. A document typically referred to as a weld traveler is issued to document each weld or group of welds. The locations of welds are shown on a weld map which is a permanent record. The weld traveler identifies the weld location, type and size, identifies the filler material used, the identification of the welder, materials joined, joint preparation, the PQR and WPS, thermal treatment, NDE performed and results, and identification of the NDE inspector. When welds require repair to meet quality requirements, the repair process is documented on a weld traveler.

Qualification of QC personnel

The qualifications (education and experience) of QC inspection personnel must be verified by the employing organization. Personnel qualifications must be supported by documentation, which include results of written and practical examinations. Inspection personnel are required to be periodically re-qualified. Individuals who inspect welds are required to be qualified in accordance with ASME or SNT-TC-1A for the type of welding specialty inspections they perform, e.g., visual, ultrasound, radiographic, etc. Welding inspectors may be qualified to perform visual inspections only, or may have multiple certifications. Acceptance of all welds must be performed by inspectors qualified in accordance with ASME or SNT-TC-1A. The requirements for equipment support welds, if classified as structural welds, are specified in AWS D1.1. Inspectors who perform inspection of mechanical equipment installation need to be certified as inspectors in the area of mechanical. All inspectors are required to pass an annual eye exam, and be physically able to perform their duties. The minimum education and experience requirements for inspection personnel are specified in ASME NQA-1, AWS D1.1, and SNT-TC-1A.

Quality Records

Sufficient records are required to document that mechanical equipment was installed in accordance with the design drawings and specifications. Records are required to document qualification of materials, setting and leveling of equipment, alignment of equipment with piping or other equipment, field welding activities, QC inspections, testing, and details of as-built conditions. The records should indicate the actual conditions encountered in the field and provide adequate documentation of work and inspections. Records should include sufficient detail to document the results of inspections; and repairs, if necessary were completed in accordance with design requirements. Records should be legible, complete, reviewed by QC and/or engineering personnel, and readily retrievable. Training and qualification records for craft and QC inspection personnel and nonconformance and deviation records which include corrective actions and resolution of identified deficiencies also required to be maintained. Additional records required to be maintained are those that establish that the required audits were performed and that deficiencies identified during audits were corrected.

**Prevalent Errors and Recent Concerns**

This section is included to provide background, for inspectors, on past equipment problems due to installation and construction deficiencies that have been identified and on certain areas that should be more closely scrutinized. Examples of equipment installation problems are summarized below (Note - these are not listed in order of their perceived importance to safety):

- Records did not include sufficient detail to document the results of inspections, or that inspections were completed in accordance with applicable code requirements.
- Records were not legible, complete, and readily retrievable.
- Design changes had not been reviewed and approved by engineering.
- Inadequate QA/QC records documenting equipment installation work activities.
- Failure to follow manufacturer instructions during equipment installation.
- Cold springing pipe to connect with equipment.
- Missing or defective welds. Defective welds included undersized welds, welds with excessive undercut, excessive porosity, slag or impurities, incorrect type of weld, and welds with deficient alignment or fit-up.
- Failure to control weld filler materials.
- Improper modifications to equipment supports. These included incorrect fabrication of supports such as changing members, missing members, altering members without design approval, and incorrect weld type, location, length or size.
- Improper storage and preventative maintenance during storage of mechanical equipment and components.
- Multiple problems with bolts/fasteners including use of incorrect bolt type, mismatched bolts and nuts, missing washers, or missing bolts, bolts not tightened to specification requirements, e.g., loose nuts and use of counterfeit fasteners. Counterfeit fasteners are those with fraudulent documentation of chemical and physical properties. In some cases, uncalibrated torque wrenches were used to tighten fasteners, or fasteners were not brought to snug tight condition prior to tightening.
- Failure to install locking devices on anchor bolts.
- Failure to remove internal packing materials, wooden blocks, temporary supports or leaving blank flanges or strainers in equipment.
- Internal contamination of systems with construction debris such as weld rod stubs, miscellaneous hardware, cigarette butts, tools, garbage, and grit.
- Inadequate design, or failure to control design changes

- QC inspections not done conscientiously, or inspections performed by unqualified personnel.
- Intentional violation of work procedures by craft personnel.
- Intimidation of QA/QC inspectors by construction personnel.

**INDUSTRY EXPERIENCE**

Counterfeit Items

DOE G 414-1-3, Suspect/Counterfeit Items Guide for Use with 10 CFR 830 Subpart A, Quality Assurance Requirements. Note: See DOE Website for a training guide on counterfeit items.

NRC IEB 82-01, 83-07, 83-06, 87-02, and 88-05; IN 89-56, 89-70, 91-09, 92-68, 95-12, and 2008-04.

Commercial Grade Dedication Issues

IN 89-14, 89-59, 90-17, 91-21, and 2011-01

Design and Construction Issues

IEB 79-02, 79-04, 79-07, 79-14, IN 90-17, 95-09, 2001-14, 2007-04

Welding and NDE Issues

IN 95-45 and 2010-08

**REFERENCES**

Code of Federal Regulations 10 CFR 830.122, Quality Assurance Criteria for DOE Facilities.

American Society of Mechanical Engineers (ASME)

ASME NQA-1, Quality Assurance Requirements for Nuclear Facility Applications.

American Welding Society (AWS)

AWS D1.1, Structural Welding Code - Steel.

AWS D1.6, Structural Welding Code – Stainless Steel

American Society for Non-Destructive Testing

SNT-TC-1A, Recommended Practice No. SNT-TC-1A Non-Destructive Testing

National Fire Protection Association

NFPA 20, Standards for the Installation of Stationary Pumps for Fire Protection

NFPA 22, Standards for Water Tanks for Private Fire Protection

American Society of Heating, Refrigerating and Air-Conditioning Engineers

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), standards and manuals.

American Society for Testing and Materials International Standards

Specific ASTM standards for chemical and physical requirements for structural steel, fasteners, and weld filler materials will be listed in the specifications. These standards specify the test methods and acceptance criteria for materials testing.