SECTION M3

WELDING REQUIREMENTS

1. GENERAL: This section addresses welding, post weld heat treating, and nondestructive examination requirements. Brazing and fusing may not be explicitly referenced, but the "welding" patterns and principals established herein shall apply to them. These activities shall comply with the applicable codes, regulations, standards, in effect as well as any manufacturer's recommendations.

1.1. The requirements for welding procedures, welding personnel qualifications, and welding materials are grouped by alloy system:

a. Carbon / Low Alloy Steels
b. Austenitic Stainless Steels
c. Creep Strength Enhanced Ferritic (CSEF) Steels
d. (Super) Duplex Stainless Steels (SDSS)

1.2. AWS A3.0, "Standard Welding Terms and Definitions," contains the standard welding terms referenced in this document.

2. WELDING PROCESSES: Unless otherwise specified, only the following welding processes shall be permitted within the restrictions specified herein.

a. Flux Cored Arc Welding (FCAW)
b. Gas Metal Arc Welding (GMAW)
c. Modified Short-Circuit Transfer GMAW (Mod. SC GMAW)
d. Gas Tungsten Arc Welding (GTAW)
e. Plasma Arc Welding (PAW)
f. Shielded Metal Arc Welding (SMAW)
g. Stud Welding (SW)
h. Submerged Arc Welding (SAW)

2.1. Other welding processes may be used, provided the governing code or standard permits it and written approval has been granted by the Buyer.

3. WELDING PROCEDURE QUALIFICATIONS: Procedures shall be developed and qualified in accordance with American Society of Mechanical Engineers (ASME) Section IX, and AWS Structural Welding Code D1.1 and D1.6 as applicable, except as modified by the Code of Construction and/or Code Case. Weld procedures and procedure qualifications shall meet all of the requirements of the latest issue of ASME Section IX in effect at the time of the contract award. This includes any toughness testing requirements (and supplementary essential variables) invoked via reference (e.g., B31.1 references B31T which specifies toughness requirements). The following tables modify the variables referenced in QW-250. These modified variables shall be treated as essential. Their intent is independent of the welding process. Seller shall conduct the tests required to qualify his welding procedures and shall conduct the performance qualifications

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of welders and welding operators who apply these procedures. Procedures or qualification of procedures or welders by organizations other than the Seller is not acceptable.

a. Table 3 – Modified Essential Variables for Procedure Qualification of Carbon and Low Alloy Steels
b. Table 5 – Modified Essential Variables for Procedure Qualification of Austenitic Stainless Steels
c. Table 8 – Modified Essential Variables for Procedure Qualification of CSEF alloys
d. Table 11 – Modified Essential Variables for Procedure Qualification of SDSS alloys

3.1. The Seller shall submit to the Buyer prior to use the Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR) for each welding procedure employed in the performance of the Work.

4. WELDING PERFORMANCE QUALIFICATIONS: Personnel shall be qualified in accordance with ASME Section IX, AWS Structural Welding Code D1.1, and AWS D1.6, as applicable for the performed welding, except as modified by the Code of Construction and/or Code Case. The following tables modify the variables referenced in QW-350. These modified variables shall be treated as essential. Their intent is independent of the welding process.

a. Table 2 – Modified Essential Variables for Performance Qualification

5. WELDING MATERIAL REQUIREMENTS: All welding materials shall meet the SFA-specifications of ASME II Part C. Additional requirements are described in the tables below.

a. Table 6 – Welding Material Requirements for Austenitic Stainless Steels
b. Table 9 – Welding Material Requirements for CSEF Steels
c. Table 12 – Welding Material Requirements for SDSS Alloys

6. GENERAL WELDING REQUIREMENTS:

6.1. JOINTS: The method used to prepare the base metal shall leave the weld joint with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil grease, and other deleterious material.

6.2. WELD END PREPARATION: Preparation of butt-welding ends of piping components shall be as follows; except when weld joint details are otherwise specified by design documents, they shall be prepared in accordance with the design documents.

6.2.1. Socket-weld connections shall be reamed to full inside diameter to remove all burrs and obstructions and to ensure proper assembly in accordance with ASME B31.1, Paragraph 127.3(e).

6.2.2. Shop butt welds shall be prepared in accordance with the fabricator's standard end preparation details and WPS.

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6.2.3. Field butt welds shall be prepared in accordance with ASME B16.25 and the following Table:

Table 1 - Butt Weld End Preparation

Wall Type	Wall Thickness	ASME B16.25 Detail
Nominal (Schedule)	Over 7/8" (22 mm)	Fig. 3.1-2(c)
	5/8" to 7/8" (16 mm to 22 mm)	Fig. 3.1-1(c)
	Under 5/8" (16 mm)	
	Valves	Fig. 3.1-1(b)
	Pipe and fittings	Fig. 3.1-1(a)
Special (Minimum Wall)	Minimum wall	Fig. 3.1-1(c) or 3.1-2(c)
Large diameter (26 inch [650 mm] and larger) carbon steel, low energy, with low internal cleanliness requirements		Fig. 3.1-1(a) or 3.1-2(a)
Wall thicknesses ≤ 0.12 inch (3 mm).		Ends square or slightly chamfered

6.2.4. To ensure satisfactory fit-up for circumferential butt welds in piping systems fabricated of rolled and welded plate, the following procedures shall be followed:

a. Concentricity: If weld metal is used to obtain concentricity, the weld deposit shall be free from porosity or other defects, and the inside surface shall be ground smooth and blended smoothly into the pipe wall.
b. Nondestructive Examination (NDE): Additional NDEs specified herein shall be evaluated in accordance with ASME B31.1, Power Piping Code, Paragraph 136.4, as applicable.
c. Radiographic or Ultrasonic Examination: Upon completion of the weld buildup and finishing procedures, the area shall be radiographed or ultrasonically examined (in accordance with ASME B31.1, Paragraph 136.4.5 or 136.4.6, as applicable) prior to shop welding to other sections or prior to shipment. The radiographs or ultrasonic records, as applicable, shall be submitted to Buyer to permit complete analysis of the joint after field radiography or ultrasonic examination.

6.2.5. Acceptable chemical cleaning methods include new or redistilled acetone (acetone reclaimed by other methods shall not be used), alcohol (ethyl, methanol, or isopropanol), methyl ethyl ketone, or toluene (toluol). Halogenated cleaning solvents shall not be used for cleaning or degreasing.

6.2.6. The work shall be protected from deleterious contamination (including arc strikes) and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

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6.2.7. Stress-free fit-ups shall be obtained without cold-springing or supplemental heating.

6.2.7.1. P91 pipe alignment shall be achieved through the use of mechanical devices. The use of temporary attachment welds for alignment is prohibited. If temporary lifting lugs were attached by the pipe fabricator to the P91 pipe, the lug materials shall be grade P91 and the weld material shall be "B9" grade material, and these lifting lugs shall be removed after assembly of the piping system, the weld area ground smooth and the area subjected to a PWHT the same as any other weld areas. The area shall also be MT examined after PWHT to verify that no cracking of the temporary weld has occurred.

6.3. PREHEAT: Preheat for welding or thermal cutting, when employed, shall be applied by a method that does not harm the base metal or any deposited weld metal, or which does not introduce deleterious material into the welding area which is harmful to the weld. It shall be applied uniformly over the complete weld or thermal removal process area.

6.3.1. Preheat and interpass temperatures shall be monitored and checked by temperature indicating crayons, thermocouples, surface contact pyrometers or thermometers, or other suitable methods at a frequency necessary to ensure compliance. Caution shall be exercised when using temperature-indicating crayons because some metals may be severely attacked by the chemicals in crayons at elevated temperatures. Furthermore, when temperature-indicating crayons are used, they shall be applied in a manner to avoid direct contact with the surface to be welded.

6.3.2. When preheat is applied mechanically, a preheat strip chart shall be included with the Quality records.

6.3.3. A preheating procedure shall be provided for review and approval.

6.3.4. Documentation of the pre-heat temperature achieved shall be provided.

6.3.5. For socket welds of P4, P5A, P5B, and P15E materials, the weld must be completed prior to any cooling below the required preheat temperature.

6.4. ADDITIONAL PREHEAT REQUIREMENT FOR P15E (CSEF) MATERIALS

6.4.1. CSEF or P15E material may only be flame preheated for the following joints:

- Tack welding during fit-up in the case of butt welded joints > 2 ½"(large bore).
- Complete welding of socket welds and butt welds of pipe less than or equal to 2 ½" diameter (small bore).
- Attachment welds of materials less than ½" thick.

6.4.2. If the above conditions cannot be satisfied, welding operations must utilize mechanical pre-heat.

6.4.3. Evidence of components being inter-critically heat treated (i.e., heated to a temperature at or above the material's lower critical temperature) during fabrication or stress

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relieving (e.g., from flame impingement) will require the weld and surrounding base metal to be removed.

6.5. STORAGE OF AS WELDED CSEF MATERIAL PRIOR TO PWHT:

6.5.1. The specific requirements for preheating in ASME B31.1, ASME B31P, and ASME Section 1 Mandatory Appendix VIII shall apply, as applicable. Between welding and PWHT, CSEF weldments shall be controlled by a maintenance procedure for avoiding contamination by hydrogen-producing sources. This procedure shall be submitted to the Buyer for review. Any weld exposed to hydrogen-producing sources shall be documented in the corrective action program and the nonconforming weld shall be controlled according to the supplier's Quality Assurance Program. The deviation shall be presented to the Buyer for resolution. The procedure shall specify the maximum delay between welding and PWHT (7 days or less), any interim environmental and storage controls, preheat maintenance or post weld hydrogen bakeout requirements, limitations on exposure to NDE chemicals, handling instructions, etc.

6.5.2. PWHT should be performed immediately after the phase transformation cycle of cooling below 200°F because CSEF alloys are susceptible to environmentally induced cracking mechanisms in the as-welded condition before PWHT. At a minimum, no water-based forms of NDE which contact the weld and heat-affected zone are to be performed prior to completion of PWHT.

6.5.3. A seven (7) day window is allotted between welding and PWHT which shall not be exceeded. During this time, the weldment shall be protected from moisture to the maximum extent practical (e.g., insulated, temporary enclosure, preheat etc.). Ultrasonic couplants which are tested in accordance with ASTM F519 and certified to be non-embrittling are allowed. Couplants shall not be reduced, diluted, extended, or utilized outside manufacturer's recommendations. All couplant shall be removed from the area of inspection using dry, clean cloths.

6.5.4. Before PWHT care shall be taken to ensure welds are not moved in such a way as to increase the stress applied to the joint. Prohibited actions include rigging and/or lifting of spool pieces, changing of elevation or shock loading in any way.

6.5.5. In the case that any of the protection provisions of this document or the applicable codes are not met, and an as-welded joint is impacted, that joint shall receive a visual inspection as well as an MT inspection post PWHT. If a defect is discovered, it shall be completely removed and repaired using an approved WPS.

6.6. Deviations from these instructions or approved procedures shall be documented and the nonconforming item shall be controlled according to the supplier's nonconformance or incident management procedure. Such deviations shall be sent to the Buyer for resolution.

6.7. For P91 materials, preheat and post weld heat treatment may be applied ONLY by use of electric heating sources for large bore piping. The use of "rose bud" torches or flame impingement of any sort on the P91 large bore pipe material is prohibited. Where "rose bud" torches are used on small bore piping, the piping must be insulated and wrapped after heating. Temperature monitoring of the preheat process shall be done to verify that uniform heating is

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achieved around the entire circumference of the pipe in the weld area. Induction heating shall not be used in the field.

6.8. POST WELD HEAT TREATMENT (PWHT): Detailed PWHT procedures shall be available for use and shall be made available to the Buyer for review when requested. The procedures shall provide details to accomplish the required PWHT, including personnel qualification, equipment calibration, weld joint preparation, weld joint documentation, heating and cooling rates, holding times, holding temperatures, minimum size of heated zones, precautions to preclude damage, attachment of thermocouples, welding specifications for attaching welding thermocouple wire using the capacitor discharge method (when used), weld joint insulation, and defined nominal thickness.

6.9. For all PWHTs, a sketch showing the thermocouple (TC) placement and for local PWHT, dimensions of various heated zones, shall be submitted with the time-temperature recordings. Heat treatment records shall be traceable to the item being heat treated, the equipment that performed the heat treatment, and the WPS that qualified the heat treatment.

6.10. Welding or heat treating valves, the valve manufacturer's recommendations (e.g., valve position, removal of internals, purge) shall be followed.

6.11. Direct flame heating for PWHT or flame impingement during PWHT is prohibited.

6.12. Enhanced temperature monitoring during PWHT of P91 materials shall be performed so as to provide better control of the PWHT temperature. To prevent overheating one control thermocouple must be placed under the center of each heat source (induction coil or resistance pad). The control thermocouple may also be used as a record thermocouple if appropriate. At least one record thermocouple must be placed at the center and at each extreme of the soak zone (circumferential band width required by the construction code to reach the PWHT temperature). All record thermocouples must be recorded on a time-temperature chart and be within the PWHT range during the entire required hold time. An additional record thermocouple must be placed under each junction between heat sources edges which are over the soak zone, both abutting and overlapping joints. Refer to AWS D10.10 Table 3 for the minimum number of circumferential zones to be controlled. If access to the ID surface of the pipe can be obtained, thermocouples shall be placed on the weld ID top and bottom as well. In all cases, the soak zone shall be sufficiently wide to assure that the required temperature is achieved on the ID surface of the pipe in the weld and HAZ area.

6.13. FURNACE PWHT: When PWHT is performed in a furnace, sufficient thermocouples shall be properly attached directly to the material or component in various representative locations, including the expected region(s) for the hottest temperature and the expected region(s) for the coolest temperature, to accurately indicate the metal temperature uniformity throughout the heat treatment cycle. Thermocouple placement shall account for any potential localized temperature gradients in the material or component caused by the furnace car or other material/components (i.e., a batch heat treatment).

6.14. LOCAL PWHT: When PWHT is performed locally, either electric resistance or induction heating methods shall be used. TC placement shall account for any potential localized

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temperature gradients (e.g., thickness transition or other configuration affecting heat transfer) and detrimental effects to equipment and valves.

6.15. ADDITIONAL CSEF OR P15E HEAT TREATMENT REQUIREMENTS:

6.15.1. The General requirements for PWHT in this document shall apply unless otherwise specified.

6.15.2. PWHT shall be required for all welds applicable including inadvertent arc strikes.

6.15.3. For CSEF or P15E materials, heat treatment heating rate may be unrestricted up to 600° F. Above 600° F heating shall be between 175° F and 250° F/hour. Cooling down to 600° F shall be between 225° F and 300° F/hr. Thicker sections over 1.5" shall be heated and cooled at a maximum rate of 250° F/hr. Below 600° F, the cooling rate is unspecified, however the pipe shall be cooled slowly by wrapping in insulation surrounded by still air.

6.15.4. Thermocouple placement shall comply with applicable codes and standards. Furnace heat treatment shall consider the general requirements herein for normalizing, solution annealing, and tempering. Heat treatment of all components shall include the use of contact thermocouples to accurately measure the surface temperature of the components.

6.15.5. Thermocouples installed under heating pads must be insulated so they measure the temperatures of each base material and not the pad temperature. One thermocouple shall be installed under each heating pad to verify that the material under the pad does not exceed the lower critical temperature.

6.15.6. PWHT holding temperature and holding time shall be as described in Table 10.

6.15.7. When welding Grade 91 to a lower alloy such as Grade 22 or Grade 11, the lower critical temperature of the lower alloy shall not be exceeded during PWHT. Reference ASME B31.1 Table 129.3.1 for Approximate Lower Critical Temperatures for various alloys.

6.15.8. If the holding temperature exceeds 1420°F or the lower critical temperature of the base material is exceeded, the Buyer/Engineer shall be notified for disposition, after which the material may require a re-normalizing and subsequent re-tempering heat treatment at the Buyer/Engineer's discretion. The Fabricator shall submit a normalizing and tempering procedure to the Buyer/Engineer for approval prior to this operation. In-situ re-normalizing & tempering is not acceptable.

6.15.9. The temperature range for normalizing is 1920°F to 1975°F and shall be held for a minimum of 10 minutes after full thickness has achieved target temperature. Cooling rate after normalizing, down to at least 900°F shall be no slower than 9°F per minute (for thin wall tube, still air cooling is typically adequate). After cooling to below 200°F, tempering shall be performed; tempering, stress relieving, and post weld heat treating shall be performed at 1350°F to 1420°F.

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6.15.10. To prevent the material from becoming too soft for the required mechanical properties, each completed weld shall not receive a PWHT cycle more than three times without review and approval of the Buyer/Engineer.

6.15.11. Temperature of all control thermocouples shall be maintained within ±5 °F of the target temperature.

6.15.12. A run of pipe utilizing local PWHT for welded branch connections shall be uniformly heated around its circumference.

6.15.13. For Local PWHT on CSEF material, Documentation shall be prepared showing thermocouple placement, the soak band, the heated band and the arrangement of the heating source and equipment channels, the gradient control band and the part geometry / wall thickness across it. The actual widths shall be recorded. All the required information shall be traceable to the weld joint. This sketch is considered a record and shall be submitted with the corresponding chart. For electronic charts, the time: temperature data file and power consumption curves shall be made available to Buyer when requested.

7. GAS: A backing gas shall be established prior to welding items having an ASME P-No. 5B or higher or similar compositions for any of the following conditions: single-sided complete joint penetration welds, repairs welded from one side, or weld repairs in which the base metal remaining after excavation is less than 3/16 inch (4.76 mm) from being through wall. The purge shall be maintained until either the root and hot pass have been deposited or welded thickness is greater than 3/16 inch (4.76 mm). For P91 welds, the weld joint area must be purged of oxygen using an Argon or Nitrogen shielding gas purge prior to the start of welding the root pass and hot pass.

7.1. A detailed procedure for root side purging shall be available at the shop facility or field site as applicable and shall be made available to the Buyer for review when requested. Purgeless applications shall be approved by the Buyer.

7.2. When backing gas is utilized, PFI Standard ES-50 shall be used to determine the acceptable level of discoloration as required by the applicable standard (direct requirement of B31.1 and B31.3).

8. TECHNIQUE: The root pass shall be deposited via a welding process in accordance with the requirements herein.

8.1. Welding slag and spatter shall be removed from all welds.

8.2. Arc strikes outside of the weld joint shall be ground to a smooth contour and included in any required heat treatment and final examinations for the weld in accordance with the applicable Code of Construction.

8.3. Where seal welding of threaded joints is performed, the exposed threads shall be either removed entirely or covered with weld metal.

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8.4. Block welding is not permitted. Welded joints shall be made by completing each weld layer before succeeding weld layers are deposited. Partial fill passes are permitted to correct localized underfill conditions and for the purpose of maintaining alignment.

8.5. For work on an installed system, welding machine ground leads and clamps shall be located to avoid passing welding current through equipment, snubbers, bearings, valves, or any other items where transfer of electrical current may cause damage these items.

8.6. Shop fabricators and material suppliers shall check for residual magnetism at each end of the machined field pipe weld bevels. Weld bevels containing residual magnetism greater than 5 gauss shall be demagnetized.

8.7. Field Welds: Where carbon/low alloy steel piping is to be welded to austenitic stainless steel components, and the carbon/low alloy steel piping is of such a thickness as to require PWHT, the end of the carbon/low alloy steel pipe shall be buttered accordingly; the buttered end shall be post weld heat treated. The weld joint shall then be made between the austenitic stainless steel and the buttering on the carbon/low alloy steel. This joining method is applicable only to groove welds unless written approval has been granted by Buyer.

8.8. Alloy-specific welding general requirements are found in the following tables.

a. Table 4 – Additional Welding General Requirements for Carbon and Low Alloy Steels
b. Table 7 – Additional Welding General Requirements for Austenitic Stainless Steels
c. Table 10 – PWHT Holding Temperature and Time (CSEF or P15E Material)
d. Table 13 – Additional Welding General Requirements for SDSS Alloys

9. Seller shall fill provide welding design information for terminal points and other field welds in an electronic format for weld tracking purposes. Design information includes:

a. Weld ID (primary key)
b. Drawing Number
c. Revision Number
d. Line Number
e. Code of Construction and Applicable Metadata (i.e. Design Pressure/ Temperature for B31.1, Fluid Service Category/Service Cyclic Conditions for B31.3, Radiant Heat / Water or Steam for ASME 1)
f. Material Information (i.e. specification/grade, size/thickness, material line class specification)
g. Joint Type (i.e. butt, branch, socket, attachment, seal)
h. Piping System

10. WELDING ROOT PASS METHOD SELECTION: Table 14 defines welding root pass method selection guidelines for Buyer and Seller designed piping systems, including vendor-skidded piping. Welding root pass method shall be chosen to ensure high-quality welds based on system parameters and cleanliness control requirements.

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11. POSITIVE MATERIAL IDENTIFICATION (PMI): PMI verification shall be performed in accordance with M4 - Quality and Examination Requirements.

12. HARDNESS TESTING: CSEF steels shall receive hardness testing in accordance with Section M4 - Quality and Examination Requirements.

Table 2 – Modified Essential Variables for Performance Qualification

Paragraph & Brief of Variable	Qualified Range
QW-404.3 QW-404.6 (Δ Size/Diameter)	For manual or semiautomatic processes, a change in the nominal size of the electrode(s) or filler metal(s), as applicable, beyond 1/2X to 2X the size used during the qualification test.
QW-404.23 (Δ Filler metal product form)	Any change from one of the following filler metal product forms to any other: • Bare / solid • Bare / metal cored • Flux cored • Flux coated • Powder
QW-404.24 (± or Δ Supplemental)	The addition, deletion, or change of more than 10% in the volume of supplemental filler metal

Legend:				
+ Addition	> Increase / greater than	↑ Uphill	← Forehand	Δ Change
- Deletion	< Decrease / less than	↓ Downhill	→ Backhand	

Table 3 – Modified Essential Variables for Procedure Qualification of Carbon and Low Alloy Steels

Paragraph & Brief of Variable	Qualified Range
QW-402.3 (Δ Backing)	Backing shall not be used.
QW-404.5 (Δ A-No.)	Filler metal shall be selected such that the final weld deposit has a chemical composition and mechanical properties as similar as possible to the base

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Paragraph & Brief of Variable	Qualified Range
	metals. For dissimilar metal ferritic welds, the filler metal shall be matched to either base metal or an intermediate alloy. For dissimilar metal austenitic welds, the filler metal shall be compatible with both base metals.
QW-404.12 (Δ Classification)	Filler metal shall be covered by an SFA specification. Additionally: "G" suffixes are prohibited. "L" grades are prohibited. Self-shielded FCAW electrodes are prohibited.
QW-404.14 (± Filler metal)	Autogenous GTAW or PAW is prohibited. The addition of filler metal is required.
QW-404.22 (± Consumable insert)	Consumable inserts are prohibited. Slugging is prohibited.
QW-404.33 (Δ Classification)	SMAW electrodes shall be low hydrogen, except for root passes on carbon steel. (6010) FCAW / SMAW electrodes having nominal compositions of -B3 and greater shall have an optional supplemental diffusible hydrogen designator of H4 maximum.
QW-404.34 (Δ Flux type)	For multi-pass welds, SAW fluxes shall be neutral. For single pass welds, SAW fluxes may be active be used when the weld pass thickness is ≤ ¼ inch (6.35 mm).
QW-404.36 (Recrushed slag)	Recrushed slag for SAW shall not be used.
QW-406.1 (< Preheat temperature)	The minimum preheat temperature shall be in accordance with the applicable Code of Construction, including any guidelines (e.g., no mandatory appendices).
QW-406.2 (Δ Preheat maintenance)	After welding commences, the minimum preheat temperature shall be maintained on P-Nos. 3, 4, 5A, 5B, and 6 weldments except when all of the following conditions are satisfied: A minimum of at least 3/8 inch (10 mm) thickness of weld is deposited or 25% of the welding groove is filled, whichever is less. For P-Nos. 3, 4, 5A materials, the weld is cooled slowly to room temperature. For P-Nos. 5B and 6 materials, EITHER the weld is subjected to an intermediate heat treatment between the minimum preheat and maximum interpass temperatures with a controlled rate of cooling, OR the welding materials shall be low-hydrogen electrodes / filler metals with an -H4

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Paragraph & Brief of Variable	Qualified Range
	designation or lower and the supplier's procedure for preventing hydrogen contamination has been approved by the Buyer. NOTE: prior to any required PWHT, P-No. 6 weldments shall be cooled below 200° F (93 °C).
QW-406.3 (> Interpass temperature)	The maximum interpass temperature shall be 600°F (315°C), or 500°F (260°C) if toughness testing is required by the Code of Construction.
QW-408.2 (Δ Single, mixture, or %)	Shielding gas shall comply with SFA-5.32
QW-408.5 (± or Δ in backing flow)	Solarflux (and similar) in lieu of backing gas is prohibited.
QW-410.9 (Δ Multiple to single pass / side)	Socket welds shall be multiple pass welds. Fillet welds greater than ¼ inch (6.35 mm) shall be multiple pass welds.
QW-410.26 (± Peening)	Peening is not permitted. The use of power tools for slag removal is not considered peening.

Legend:				
+ Addition	> Increase / greater than	↑ Uphill	← Forehand	Δ Change
- Deletion	< Decrease / less than	↓ Downhill	→ Backhand	

Table 4 – Additional Welding General Requirements for Carbon and Low Alloy Steels

Local PWHT For carbon and low alloy steels: TCs shall be placed uniformly around the weld, at the edges of the Code-required soak band, based on the number of equipment channels that will be used to heat the weld's circumference plus one (1) TC at the weld centerline.
Nondestructive Examination All welds shall receive 100 % final visual examination.

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Table 5 – Modified Essential Variables for Procedure Qualification of Austenitic Stainless Steels

Paragraph & Brief of Variable	Qualified Range
QW-402.3 (Δ Backing)	Backing shall not be used.
QW-404.5 (Δ A-No.)	Filler metal shall be selected such that the final weld deposit has a chemical composition and mechanical properties as similar as possible to the base metals. For dissimilar metal ferritic welds, the filler metal shall be compatible with both base metals.
QW-404.12 (Δ Classification)	Filler metal shall be covered by an SFA specification. Additionally: "G" suffixes are prohibited.
QW-404.14 (± Filler metal)	Autogenous GTAW or PAW is prohibited. The addition of filler metal is required.
QW-404.22 (± Consumable insert)	Consumable inserts are prohibited. Slugging is prohibited.
QW-404.36 (Recrushed slag)	Recrushed slag for SAW shall not be used.
QW-406.1 (< Preheat temperature)	The minimum preheat temperature shall be in accordance with the applicable Code of Construction, including any guidelines (e.g., nonmandatory appendices).
QW-406.3 (> Interpass temperature)	The maximum interpass temperature shall be 350° F (176°C).
QW-408.2 (Δ Single, mixture, or %)	Shielding gas shall comply with SFA-5.32
QW-409.1 (> Heat Input)	Welding heat input controls shall be specified in the applicable WPS and shall be such that the corrosion resistance of these materials is not compromised. Similarly, if these materials are subjected to PWHT, it shall not compromise the material's corrosion resistance.
QW-410.9 (Δ Multiple to single pass / side)	Socket welds shall be multiple pass welds. Fillet welds greater than ¼ inch (6.35 mm) shall be multiple pass welds.
QW-410.26 (± Peening)	Peening is not permitted. The use of power tools for slag removal is not considered peening.

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Paragraph & Brief of Variable	Qualified Range
QW-402.3 (Δ Backing)	Backing shall not be used.
QW-451 (+ Testing)	ASTM A262, "Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels"

Legend:				
+ Addition	> Increase / greater than	↑ Uphill	← Forehand	Δ Change
- Deletion	< Decrease / less than	↓ Downhill	→ Backhand	

Table 6 – Welding Material Requirements for Austenitic Stainless Steels

1. Unless otherwise specified, welding materials for austenitic stainless steels (ASME IX P-No. 8 base metals) that are in the post weld heat treated (PWHT) condition or are subjected to service temperatures greater than 700° F (371°C) shall be selected such that the deposited weld metal shall not exceed 12 FN (ferrite number) measured prior to PWHT. In lieu of measuring the deposited weld metal ferrite content, the 3xx series filler metal may be tested by completing a weld pad ferrite test in accordance with the applicable filler metal specification, or the filler metal may be purchased with a maximum 12 FN.
2. For service temperatures greater than 1,000° F (538°C), bismuth in the deposited weld metal shall not exceed 0.002% weight.

Table 7 – Additional Welding General Requirements for Austenitic Stainless Steels

Care shall be taken to minimize cross-contamination of austenitic stainless steels or nickel alloys with carbon or low alloy steels from wire brushes, grinders, files, flappers etc.
Grinding shall be by aluminum oxide, zirconium oxide, or silicon carbide grinding wheels that have not been used on carbon or low alloy steels. Hand or power wire brushing shall be by stainless steel brushes that have not been used on carbon or low alloy steels. All tools used in fabrication shall be protected to minimize contact with such steels or free iron. Grinding wheels and brushes shall be identified and controlled for their use on these materials only to ensure that contamination of these materials does not occur.
Anti-spatter compounds, marking fluids, marking pens, tape, temperature indicating crayons, and other tools shall have a total halogen content of less than 200 parts per million (mg/L).
Austenitic stainless steel instrument tubing shall be welded using only the GTAW process.
Socket welds or butt welds in all austenitic stainless steel instrument tubing lines shall require an inert gas backing (purge) using argon during welding to avoid oxidation.

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For materials that have been contaminated with steels or free iron, the Buyer may request a ferroxyl test or wet/dry test to identify iron contamination. Iron contamination identified by the ferroxyl or wet/dry test or by other identification means (e.g., visible rusting) shall be removed by mechanical or chemical cleaning. Mechanical cleaning methods, when used, shall be capable of removing the contamination without smearing or redepositing contaminants on the material surface. Chemical cleaning methods, when used, shall be performed in accordance with ASTM A380, Paragraph 6.4 and Annex A2. If requested, a ferroxyl or wet/dry test procedure and cleaning procedure shall be submitted to the Buyer for review.
All welds shall receive 100% final visual examination.

Table 8 – Modified Essential Variables for Procedure Qualification of CSEF Steels

Paragraph & Brief of Variable	Qualified Range
QW-251.2 (+ Supplementary essential variables)	For each welding process, the supplementary essential variables shall be treated as essential variables.
QW-402.3 (Δ Backing)	Backing shall not be used.
QW-403.11 (Δ P-No. qualified)	For PQRs qualified via a former P-No. system, a change in the nominal chemistry of the CSEF alloy. For example: a historical PQR qualified on Grade 9 base material does not qualify Grade 91 base materials.
QW-404.5 (Δ A-No.)	Table 9 – Welding Material Requirements for CSEF Steels For dissimilar metal ferritic welds, the filler metal shall be matched to the lesser base metal. For dissimilar metal austenitic welds, the filler metal shall be a Nickel base alloy of either NiCrFe-2 or NiCr-3.
QW-404.12 (Δ Classification)	For PQRs qualified via a former AWS Classification system, a change in the nominal chemistry of the CSEF welding material. Only current AWS Classifications within an SFA Specification are allowed.
QW-404.14 (± Filler metal)	Autogenous GTAW or PAW is prohibited. The addition of filler metal is required.
QW-404.22 (± Consumable insert)	Consumable inserts are prohibited. Slugging is prohibited.
QW-404.29 (Δ Flux designation)	A change in the manufacturer / trade name of SAW flux.

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Paragraph & Brief of Variable	Qualified Range
QW-404.33 (Δ Classification)	Optional supplemental designators, such as those used to indicate moisture resistance (i.e., XXXXR), diffusible hydrogen (i.e., XXXX H8, H4, etc.) shall be specified on the WPS.
QW-406.1 (< Preheat temperature)	The minimum preheat temperature shall be in accordance with the applicable Code of Construction, including any guidelines (e.g., nonmandatory appendices).
QW-406.2 (Δ Preheat maintenance)	After welding commences, the minimum preheat temperature shall be maintained except when all of the following conditions are satisfied: A minimum of at least 3/8 inch (10 mm) thickness of weld is deposited or 25% of the welding groove is filled, whichever is less. EITHER the weld is subjected to an intermediate heat treatment between the minimum preheat and maximum interpass temperatures with a controlled rate of cooling, OR the welding materials shall be low-hydrogen electrodes / filler metals with an -H4 designation or lower and the supplier's procedure for preventing hydrogen contamination has been approved by the Buyer. NOTE: prior to any required PWHT, CSEF weldments shall be cooled below 200°F (93°C).
QW-406.3 (> Interpass temperature)	The maximum interpass temperature shall be 600°F (315°C), or 500°F (260°C) if toughness testing is required by the Code of Construction.
QW-408.2 (Δ Single, mixture, or %)	Shielding gas shall comply with SFA-5.32
QW-408.5 (± Backing gas or Δ backing gas composition)	Backing gas, when used, shall be Argon (SG-A per SFA-5.32).
QW-409.2 (Δ Transfer mode)	Advanced waveform controlled technology shall be used for GMAW.
QW-410.9 (Δ Multiple to single pass / side)	Socket welds shall be multiple pass welds. Fillet welds greater than ¼ inch (6.35 mm) shall be multiple pass welds.
QW-410.26 (± Peening)	Peening is not permitted. The use of power tools for slag removal is not considered peening.
QW-451	Metallography

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Paragraph & Brief of Variable	Qualified Range
(+ Testing)	For new PQRs, a metallographic specimen consisting of the full thickness of the weld and include the weld metal, HAZ, and base metal. For Grade 91 and 92 alloys, a tempered martensitic microstructure shall be present; evidence of other microstructural phases (e.g., ferrite/pearlite) or untempered martensite is unacceptable. The evaluation, including photomicrographs of these regions, shall be reported on the PQR. Hardness Testing For new PQRs, hardness testing shall be performed according to ASME IX Paragraph QW-290.5(c) and Figure QW-462.12. Three (3) traverses shall be performed. Two (2) traverses located along lines just below the original base metal surfaces and one (1) traverse located at the approximate mid-plane thickness. The weld metal shall be measured for each traverse within 0.020 inch (0.5 mm) of the fusion line and at the weld centerline. The HAZ shall be measured at three (3) locations, one of which is within 0.020 inch (0.5 mm) of the fusion line. The hardness values shall be reported on the PQR. The hardness values shall be within the acceptable range specified herein.

Legend:				
+ Addition	> Increase / greater than	↑ Uphill	← Forehand	Δ Change
- Deletion	< Decrease / less than	↓ Downhill	→ Backhand	

Table 9 – Welding Material Requirements for CSEF Steels

1. CSEF welding materials shall meet the requirements provided in the latest edition of the EPRI Guidelines and Specifications for High-Reliability Fossil Power Plants.
2. Material test reports (MTRs), as defined in SFA-5.01, shall be provided for each material, and include any additional tests specified herein.
3. For dissimilar metal welds between Grade 91 and Grade 22 or 11, the filler metal shall be matched to the lower alloy.
4. Approved filler metal manufacturers:
   - ESAB
   - EuroWeld
   - Lincoln Electric
   - Select Arc
   - Voestalpine Bohler

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Table 10 – PWHT Holding Temperature and Time (CSEF or P15E Material)

Holding Temperature Range, °F	**Minimum Holding Time at Temperature for Control Thickness, t**		
	t ≤ 1 inch	**1 inch < t ≤ 2 inch**	**t > 2 inch**
1300 to 1425	1 hour	Per Table 132.1.1-1 ASME B31.1, or Table PW-39-5 ASME Sec. I as applicable	Per Table 132.1.1-1 ASME B31.1, or Table PW-39-5 ASME Sec. I as applicable
It is acceptable to reduce the holding temperature for thin welds per the Code of Construction.			

Table 11 – Modified Essential Variables for Procedure Qualification of SDSS alloys

Paragraph & Brief of Variable	**Qualified Range**
QW-251.2 (+ Supplementary essential variables)	For each welding process, the supplementary essential variables shall be treated as essential variables.
QW-402.1 (Δ Groove design)	A change from single-sided grooves to double-sided grooves or vice versa.
QW-402.3 (Δ Backing)	Backing shall not be used.
QW-402.4 and .5 (± Backing)	Permanent fusing backing is prohibited unless specifically shown on design drawings.
QW-402.10 (Δ Root spacing)	Single-welded CJP groove welds and welded branch connections, a change in the specified root spacing beyond the qualified root spacing ± 1/16 inch (1.59 mm).
QW-402.11 (± Retainers)	Nonmetallic retainers or non-fusing metal retainers may be used provided that: no fusion between metal retainer and the weld occurs; all foreign materials are removed from the weld.

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Paragraph & Brief of Variable	Qualified Range
QW-403.6 and .8 (Δ Base Metal Thickness)	The minimum base metal thickness qualified is the thickness of the test coupon T or 5/8 inch (16 mm), whichever is less. The maximum base metal thickness qualified is 2X the thickness of the test coupon 2T or 1-1/8 inch (29 mm), whichever is less. For test coupon thicknesses T greater than 1-1/8 inch (29 mm), the maximum base metal thickness qualified is T. This variable does not apply if the PQR is solution annealed after welding.
QW-403.11 (Δ P-No. Qualified)	A change in the UNS of the base metal.
QW-404.5 (Δ A-No.)	Applicable to both FERROUS and NONFERROUS weld metal. The chemical composition of the weld deposit shall be: For "process side" weld surfaces: overalloyed For "non-process side" weld surfaces: matching or overalloyed Table 12 – Welding Material Requirements for SDSS Alloys
QW-404.9 and .12 and .33 (Δ Classification)	A change in the manufacturer / trade name of FCAW and SMAW electrodes or SAW flux.
QW-404.22 (± Consumable insert)	Consumable inserts are prohibited. Slugging is prohibited.
QW-406.3 (> Interpass Temperature)	An increase in interpass temperature for the root, cold pass, and balance of welding (each). However, the interpass temperature shall not exceed that of API RP 582.
QW-407	PWHT is prohibited.
QW-408.2 (Δ Shielding gas)	Shielding gas shall comply with SFA-5.32. Mixtures containing hydrogen are prohibited
QW-408.5 (± Backing gas or Δ backing gas composition)	Any change in the backing gas composition. Backing gas shall be argon, nitrogen, or a mixture of argon and nitrogen in accordance with SFA-5.32. The O2 content shall be less than or equal to 0.5% (5000 parts per million or mg/L). Purgeless applications are prohibited in single-welded open root joints.
QW-409.1 (Δ Heat Input)	An increase in heat input for the root pass, cold pass, and balance each in single-sided CJP welds. Minimum heat input shall be 12.5 kJ/ in (492.1 kJ/m). The heat input of the cold pass (i.e., after the root) shall be approximately 75% of the root pass.

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Paragraph & Brief of Variable	Qualified Range
QW-410.1 (Δ String/Weave)	Stringer beads only for manual and semiautomatic welding processes.
QW-410.5 (Δ Method of Cleaning)	A deletion of chemical cleaning (e.g., acetone) methods for initial and interpass cleaning for both base metal and filler metal.
QW-410.9 (Δ Multiple to single pass / side)	Socket welds shall be multiple pass welds. Fillet welds greater than ¼ inch (6.35 mm) shall be multiple pass welds.
QW-410.26 (± Peening)	Peening is not permitted. The use of power tools for slag removal is not considered peening. The addition or deletion of surface stress improvement technologies or surface conditioning treatments.
QW-410.60 and .64 Use of thermal processes	The addition of thermal methods to prepare the surface to be welded. Weld grooves shall be prepared by thermal processes when such processes are to be employed during fabrication. This groove preparation shall also include back gouging, back grooving, or removal of unsound metal by thermal processes.
Other	The maximum deposited weld thickness for a single weld pass shall not exceed ¼ inch (6.35 mm).
QW-451 (+ Testing)	ASTM E562, "Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count" A cross-section of the weld metal, HAZ, and base metal shall be examined. The microstructure shall be suitably etched and examined at 400X magnification, or greater, and the ferrite content in the root pass and unreheated weld cap shall be in the range of 30 to 70%. The number of fields and points sampled shall comply with the 10% relative accuracy column in Table 3. Additionally, the ferrite content shall be measured at 3 locations (uniformly spaced) along the weld face and weld root of the PQR test coupon. The acceptance criteria shall be 30 to 70% as determined by an instrument calibrated to AWS A4.2.
	ASTM A923, "Standard Test Methods for Detecting Detrimental Intermetallic Phases in Duplex Austenitic/Ferritic Stainless Steel" A cross-section of the weld metal, HAZ, and base metal shall be examined. The microstructure shall be suitably etched and examined at 400X magnification and shall have grain boundaries with no continuous precipitates. Intermetallic phases, nitrides, and carbides shall not exceed 1.0% in total. The sigma phase shall not exceed 0.5%.

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Paragraph & Brief of Variable	Qualified Range
	ASTM G48, "Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution" Corrosion Testing The Ferric Chloride Pitting test specified via either Method A of ASTM G48 or Method C of ASTM A923 shall be performed. The acceptance criteria is no visible evidence of pitting (at 20X magnification) is allowed.
	Hardness Testing Hardness testing shall be performed in accordance with NACE MR0175. Hardness restrictions for 22% Cr welds shall not exceed the equivalent of 310 HV (average) and no single reading shall exceed 320 HV. Hardness restrictions for 25% Cr welds shall not exceed the equivalent of 330 HV (average) and no single reading shall exceed 350 HV.

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+ Addition	> Increase/greater than	↑ Uphill	← Forehand	Δ Change
- Deletion	< Decrease/less than	↓ Downhill	→ Backhand	

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Table 12 – Welding Material Requirements for SDSS Alloys

Base Material UNS No.	SFA-5.4 (SMAW)	SFA-5.9 (GMAW / GTAW)	SFA-5.22 (FCAW)
S31803	E2209	ER2209	E2209TX-X
S32205	E2209	ER2209	E2209TX-X
S32304	E2209	ER2209	E2209TX-X
S32550	E2594 or E2553	ER2594 or ER2553	"2594" equivalent chemistry
S32750	E2594 or E2553	ER2594 or ER2553	"2594" equivalent chemistry
For E2594 and ER2594, the pitting resistance equivalent number (PREN) shall be calculated for each heat/lot used in production welding using either of the following formulas. Values are expressed in weight percent. The minimum PREN shall be greater than or equal to 40.0. PREN = Cr + 3.3 Mo + 16 N PREN = Cr + 3.3 Mo + 1.65 W + 16 N			
NOTES: Material test reports (MTRs), as defined in SFA-5.01, shall be provided for each material, and include any additional tests specified herein.			

Table 13 – Additional Welding General Requirements for SDSS Alloys

Nondestructive Examination All welds shall receive a 100% final VT. All SDSS welds shall have a minimum of 10% of welds and 2 inches (50 mm) on either side of the joint shall be randomly selected for a wet/dry exposure by misting the area with clean, potable water and examining the area for evidence of rusting after 24 hours. The ferrite content shall be measured using a ferrite scope calibrated to AWS A4.2. Five (5) measurements at each test location shall be taken in the center of each weld cap and, if accessible, the root pass. Test locations shall be uniformly spaced around the circumference as follows: For NPS 24 (DN 600) and less, 2 tests For NPS (DN) from 26 (650) thru 36 (900), 3 tests For NPS (DN) 38 (950) and greater, 4 tests The measurements shall be averaged. The ferrite content shall be within 30-70%. If the test location average is unacceptable, one (1) additional set of measurements may be retaken and the new test average shall include both the original and additional measurements.

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Table 14 – Welding Root Pass Method Selection Guideline for Piping Systems

Welding Code	Definition	Examples (2)	Piping Material	Welding Root Pass (1)
WC-1	Cycle Systems	Steam or water systems that are part of the steam turbine cycle including Main Process Steam, Boiler Feedwater, Auxiliary Steam, and Condensate	CS	GTAW (4)
			Chrome	GTAW (4)
			SS	GTAW
WC-2	Utility Systems	Other steam or water systems that are not connected to a steam turbine including Circulating Water, Service Water, Fire protection, and Blowdown, CCW	CS	Std.
			Chrome	GTAW or Mod SC GMAW
			SS	GTAW or Mod SC GMAW
WC-3	Utility Systems	Potable Water and Demineralized Water	CS	GTAW or Mod SC GMAW
			SS	GTAW
WC-4	Oil Systems	Lubricating Oil Supply, Hydraulic Oil, Seal Oil, Lubricating Oil Return, Fuel Oil	SS	GTAW
			CS	GTAW
WC-5	Fuel Gas Systems	Fuel Gas (Natural Gas)	CS	GTAW or Mod SC GMAW
			SS	GTAW
WC-6	Compressed Gas Systems	Hydrogen, Carbon Dioxide, Instrument air, Nitrogen	CS	Std.
			SS	GTAW
WC-7	Chemical Systems	Ammonia, Acid, Caustic, etc.	-	GTAW
WC-8	High Cleanliness Systems (3)	Seal Steam, steam turbine piping (STP), steam piping to turbine downstream of steam blow flowpath,	CS	GTAW
			Chrome	GTAW
			SS	GTAW

Abbreviations: “CS” = Carbon Steel, "SS" = Stainless Steel, "Std." = Seller selected Welding Method per Section 2 of this Specification

Notes:

1. Root pass applies to open root joint configuration.
2. The systems listed are examples only and do not represent an exhaustive list. Seller shall confirm welding requirements with Buyer if system is not included in the system examples list.
3. Contractor shall consider service sensitivity to cleanliness and the ability to remove debris during post-weld cleaning when selecting root pass welding method. Where a higher level of cleanliness is required and/or weld debris cannot be adequately removed and verified as such, GTAW is the required root pass welding method. Examples listed in the High Cleanliness Systems row require GTAW root pass welding, even if listed as an example in another category allowing an alternative welding method.
4. Mod SC GMAW or similar method, producing a clean root pass similar to GTAW and listed as an approved welding method in the Sections herein, may be substituted for GTAW with Buyer/Engineer approval.

END OF SECTION

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WELD UPLOAD TEMPLATE

Project Name Smarr Combined Cycle Energy Facility
Project Number 20053149
Specification No.

Weld Design Information												Material #1										Material #2									
Weld ID	Unit	Location	Turnover Packag	Drawing #	Revision	Line # / Vendor Line #	Code of Constructior	Design Pressure (PSI)	Design Temp (°F)	Joint Type	PWHT Req'd	Item (Mark No.)	Line Class / Pipe Spec	P No.	G No.	Material Specificatior	Diameter (in.)	Schedule	Thickness (in.)	Product Form	Fitting Class	Item (Mark No.)	Line Class / Pipe Spec	P No.	G No.	Material Specificatior	Diameter (in.	Schedule	Thickness (in.)	Product Form	Fitting Class