PG-90.1.4 Reviewing a selected number of the Manufacturer's design calculations to verify compliance with Section I (PG-90.3).

PG-90.1.5 Witnessing and approving proof tests to establish Maximum Allowable Working Pressure (MAWP) (A-22).

PG-90.1.6 Verifying that the Certificate Holder has sufficient material control to assure that material used for construction complies with the applicable requirements of this Section (PG-10, PG-11, PG-105.4, A-302.4).

PG-90.1.7 When cutting plate material into two or more pieces is necessary, verifying that the Certificate Holder's controls provide a positive means of identification to maintain traceability of materials (PG-77.2, A-302.4).

PG-90.1.8 Verifying that the Certificate Holder's personnel are examining cut edges before welding (PW-29.3).

PG-90.1.9 Verifying that all welding procedure specifications, procedure qualification records, welder and welding operator qualification records conform to the requirements of this Section (PW-1.2, PW-28, PW-40.2, PW-44.3, PW-47, PW-48, PW-53, PB-47, PB-48).

PG-90.1.10 If welded repairs are necessary, accepting the method and extent of repairs and verifying that only qualified welding procedures, welders, and welding operators are used (PG-78, PG-93.2, PW-40, PW-44.9, PW-54.2, PB-33).

PG-90.1.11 Verifying that all required heat treatments have been performed and are properly documented (PG-19, PG-20, PG-11.3.4, PW-39, PW-44.4, PW-44.6, PW-49 and Nonmandatory Appendix VIII).

PG-90.1.12 Verifying that required nondestructive examinations and tests have been performed by qualified personnel and that the results are properly documented (PG-20.1.2, PG-25.2, PG-93.1, PW-11, PW-44.7, PW-44.8, PW-51, PW-52).

PG-90.1.13 Performing the required inspections and witnessing hydrostatic tests (PG-99, PW-54, PB-49, PMB-21, PEB-17, PEB-18).

PG-90.1.14 Verifying that the responsible representative of the Certificate Holder has signed the Data Report and that it is correct before being signed (PG-104, PG-112, PG-113, PW-1.2.5, PB-1.4.5).

PG-90.1.15 Prior to stamping, verifying that the item is in compliance with the requirements of this Section. After stamping, verifying that the stamping is correct and that the nameplate, if used, has been properly attached (PG-106, PG-108, PG-109, PW-1.2.5, PB-1.4.5).

PG-90.3 The Manufacturer is responsible for the preparation of design calculations to show compliance with the rules of Section I and his signature on the Manufacturers' Data Report Form shall be considered to include certification that has been done. The Manufacturer shall make available such design calculations as the Authorized Inspector may request. The Authorized Inspector has the duty to review a selected number of the Manufacturer's design calculations to verify compliance with Section I.

PG-91 QUALIFICATION OF INSPECTORS

The inspection required by this Section shall be by an Inspector employed by an ASME accredited Authorized Inspection Agency. These Inspectors shall have been qualified in accordance with ASME QAI-1.

PG-93 EXAMINATION AND REPAIR OF FLAT PLATE IN CORNER JOINTS

PG-93.1 When flat plate greater than 1/2 in. (13 mm) thickness is welded to other pressure parts to form a corner joint, such as in flat heads [Figure PG-31, illustrations (g-1), (g-2), (i-1), and (i-2)], waterlegs of firebox boilers or combustion chambers of wetback boilers [Figure A-8, illustrations (I) through (n) and (p)], and the exposed edges of the plate are closer to the edge of the weld than a distance equal to the thickness of the plate, the peripheral plate edges and any remaining exposed surface of the weld joint preparation shall be examined after welding by either the magnetic particle or liquid penetrant method. When the plate is nonferromagnetic, only the liquid penetrant method shall be used. The requirements of this paragraph shall not apply to those joints when 80% or more of the pressure load is carried by tubes, stays, or braces, or when the exposed edges of the plate are farther from the edge of the weld than a distance equal to the thickness of the plate.

PG-93.2 Laminations, cracks, or other imperfections found during the examination required by PG-93.1 that would affect the safety of the vessel shall be repaired in accordance with PG-78. The imperfection(s) may be pursued by any suitable method (grinding, chipping, etc.). The repaired area shall be subjected to the same examination that first revealed the imperfection.

PG-93.3 Methods and acceptance criteria for magnetic particle and liquid penetrant examination shall be in accordance with A-260 or A-270, respectively.

PG-99 HYDROSTATIC TEST

Hydrostatic testing of the completed boiler unit shall be conducted in accordance with the following requirements:

After a boiler has been completed (see PG-104), it shall be subjected to pressure tests using water at not less than ambient temperature, but in no case less than 70°F (20°C). Where required test pressures are specified in this paragraph, whether minimum or maximum pressures, they apply to the highest point of the boiler system. When the boiler is completed in the Manufacturer's shop
proper interpretation of the nondestructive examinations. If there is a question regarding the surface condition of the weld when interpreting radiographic film, the film shall be compared to the actual weld surface for determination of acceptability.

**PW-35.2** The weld reinforcement need not be removed except to the extent necessary to meet the thickness requirements in PW-35.1.

**PW-35.3** Backing strips used at longitudinal welded joints shall be removed and the weld surface prepared for volumetric examination as required. Inside backing rings may remain at circumferential joints of cylinders, provided they meet the requirements of PW-41.

**PW-35.4** The welded joint between two members joined by the inertia and continuous drive friction welding processes shall be full penetration weld. Visual examination of the as-welded flash roll of each weld shall be made as an in-process check. The weld upset shall meet the specified amount with ±10%. The flash shall be removed to sound metal.

**PW-36 MISCELLANEOUS WELDING REQUIREMENTS**

**PW-36.1** Before applying weld metal on the second side to be welded, the root of double-welded butt joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, so as to secure sound metal at the base of weld metal deposited on the face side, except for those processes of welding by which proper fusion and penetration are otherwise obtained and by which the root of the weld remains free from impurities.

**PW-36.2** Fillet Welds. In making fillet welds, the weld metal shall be deposited in such a way as to secure adequate penetration into the base metal at the root of the weld. Undercuts on pressure-retaining boundaries shall not exceed the lesser of \(\frac{1}{32}\) in. (0.8 mm) or 10% of the nominal thickness of the adjoining surface and shall not encroach upon the required section thickness. The surface of the welds shall be free from coarse ripples or grooves, and shall merge smoothly with the surfaces being joined. Concavity of the face of the weld is permissible, provided it does not encroach on the required weld thickness.

**PW-36.3** When attachment welds are made to the clad portion of pressure parts constructed from P-No. 5B, P-No. 6, or P-No. 15E and other creep-strength-enhanced ferritic steels having weld metal buildup or corrosion-resistant weld metal overlay, the rules of PW-44.2(a) and PW-44.2(b) shall be followed.

**PW-38 PREHEATING AND INTERPASS TEMPERATURES**

**PW-38.1** The Welding Procedure Specification for the material being welded shall specify the minimum preheating and maximum interpass requirements in accordance with the rules of this Section and Section IX.

The temperatures in Table PW-38-1 are recommended unless otherwise mandated by this Part.

For P-No. 1 materials, the rules for preheating only apply when mandated by PW-39 for exemption of postweld heat treatment.

**PW-38.2** Preheat for welding or thermal cutting may be applied by any method that does not harm the base material or any weld metal already applied, or that does not introduce into the welding area foreign material that is harmful to the weld. If preheating is performed using electric resistance heating pads, it is recommended that it be performed in accordance with the requirements of Mandatory Appendix C-6 except that these requirements are mandatory for P-No. 15E materials.

**PW-38.3** No welding or thermal cutting operations shall be carried out on boiler components when the temperature of the base metal in the welding or cutting zone is below 50°F (10°C).

**PW-38.4** The base metal temperature for the parts to be welded or thermally cut shall be at or above the minimum required temperature as specified in the Welding Procedure Specification.

For tubes and pipes with an outside diameter and wall thickness not exceeding 10 in. (250 mm) and 1 in. (25 mm) respectively, minimum preheat is to be established for a distance not less than 3 times the thickness of the weld on either side of the weld. For all other welds, preheat temperature is to be established in all directions from the point of welding for a distance of 3 in. (75 mm) or 1.5 times the larger thickness of the pressure parts being joined, whichever is greater. Shorter distances than these are acceptable if preheat temperature is achieved for the full depth of the weld. Recommended minimum temperatures are given in Table PW-38-1. Higher preheat temperatures shall be applied as required by Tables PW-39-1 through PW-39-14 when rules for exemption from postweld heat treatment are applied.

It is cautioned that the preheating temperatures listed in Table PW-38-1 do not necessarily ensure satisfactory completion of the welded joint. In order to produce a successful welded joint in certain individual materials within a given P-Number listing, it may be necessary to preheat the materials to temperatures higher than indicated by these recommendations.

**PW-38.5** For tack welds the base metal temperature shall be at or above the minimum temperature specified in the Welding Procedure Specification for a distance not less than 1 in. (25 mm) in all directions from the point of welding.
Table PW-39-14
Mandatory Requirements for Postweld Heat Treatment of Pressure Parts and Attachments
— P-No. 51

<table>
<thead>
<tr>
<th>Material</th>
<th>Minimum Holding Temperature, °F (°C)</th>
<th>Over 2 in. (50 mm) to 5 in. (125 mm)</th>
<th>Over 5 in. (125 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-No. 51</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Postweld heat treatment is neither required nor prohibited for joints between materials of the P-No. 51 group.

PW-39.3 In the procedures that follow, the volume of metal required to be heated, to meet or exceed the minimum postweld heat treatment temperatures listed in Tables PW-39-1 through PW-39-14, is defined as the soak band. As a minimum, the soak band shall contain the weld and a portion of the base metal on each side of the weld being heat treated, including the weld heat-affected zones. The width of each portion of base metal to be included in the soak band shall be equal to the lesser of the vessel or shell thickness, or 2 in. (50 mm). A greater amount of base material, on either or both sides of the weld, may also be heated to permit temperature gradient control.

The weldment shall be heated slowly to the temperature specified in Tables PW-39-1 through PW-39-14 and held for the specified time, and shall be allowed to cool slowly in a still atmosphere to a temperature not exceeding 800°F (425°C). Suggested heating and cooling rates for postweld heat treatment are shown in A-101. The heating and cooling rates for postweld heat treatment described in A-101 are provided as a general guide; the requirements for individual materials within the P-Number listing may have rates more or less restrictive than this general guide. Several weldments of varied thickness may be postweld heat treated in the same furnace at the same time.

If heating of P-No. 15E materials is performed using electric resistance heating pads, it is recommended that the heating be performed in accordance with the requirements of Mandatory Appendix A. While not mandatory for other materials, the Appendix may be used as a guide for the heat treatment of those other materials.

The term “nominal thickness” as used in Tables PW-39-1 through PW-39-14 is defined as follows:

(a) For full penetration butt welds, the nominal thickness is the thinner of the parts being joined.
(b) For full penetration corner welds, the nominal thickness is the depth of the weld.
(c) For partial penetration groove and material repair welds, the nominal thickness is the depth of the weld.
(d) For fillet welds, the nominal thickness is the weld throat. When a fillet weld is used in conjunction with a groove weld, the nominal thickness is either the depth of the groove weld or the fillet throat dimension, whichever is greater.
(e) For Figure PW-16.1, except as stipulated in (f) below, the nominal thickness is the depth of the groove, if present; through the shell or nozzle or reinforcing pad, or the throat of any fillet weld, whichever is greater.
(f) When multiple openings depicted in Figure PW-16.1 form a ligament where the spacing between centers is less than twice the average diameter, the nominal thickness of a combination groove and fillet weld shall be the sum of the groove depth and fillet weld throat.

The holding time at temperature as specified in Tables PW-39-1 through PW-39-14 need not be continuous. It may be an accumulation of time of multiple postweld heat treat cycles.

Table PW-39.1
Alternate Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels

<table>
<thead>
<tr>
<th>Decrease in Temperature Below Minimum Specified Temperature, °F (°C)</th>
<th>Minimum Holding Time Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 (28)</td>
<td>2  (Note [1])</td>
</tr>
<tr>
<td>100 (56)</td>
<td>4  (Note [1])</td>
</tr>
<tr>
<td>150 (83)</td>
<td>10 (2)</td>
</tr>
<tr>
<td>200 (111)</td>
<td>20 (2)</td>
</tr>
</tbody>
</table>


NOTES:
(1) Minimum holding time per inch (25 mm) for thickness up to and including 2 in. (50 mm). Add 15 min per inch (25 mm) of thickness for thickness greater than 2 in. (50 mm).
(2) These lower postweld heat treatment temperatures permitted only for P-No. 1, Group 1 and 2 materials.
NONMANDATORY APPENDIX C
LOCAL HEATING OF WELDS IN CYLINDRICAL COMPONENTS OF P-NO. 15E MATERIALS WHEN USING ELECTRIC RESISTANCE HEATING

C1 SCOPE

The rules of this Appendix describe the minimum requirements that are to be followed during the setup and application of local controlled heat to weld joints, as opposed to heating the complete weldment in a furnace or oven. This Appendix applies specifically to the heating of P-No. 15E materials when using electric resistance heating pads.

C2 GENERAL

During the manufacture, fabrication, and repair of P-No. 15E cylindrical components, it may be necessary to heat components before welding (preheating), between passes, or after welding [postwelding or postweld heat treatment (PWHT)]. This Appendix provides instructions and minimum requirements for performing heating or heat treatment of welds when using electric resistance heating pads.

C3 TERMINOLOGY FOR LOCAL HEATING

This section defines the terms used in describing local circumferential band heating. See Figures C3-1 and C3-2. Minimum requirements for these regions are presented later in this Appendix.

axial temperature gradient: the change in temperature along the length of the component; usually stated as a maximum temperature difference between two points located a specified distance apart.

component orientation: for the purpose of this Appendix, orientation of cylindrical components or PWHT in the horizontal position shall mean that the longitudinal axis of the main component lies in the horizontal position, and in the vertical position shall mean that the longitudinal axis of the main component lies in the vertical position.

control thermocouple: a single temperature-measuring device that is located within the control zone to control the temperature of that control zone.

control zone: a grouping of one or more electrical heating pads that are controlled electrically based on input from a single temperature-measuring device (typically a thermocouple). One or more zones may be present in both the circumferential and/or axial directions.

gradient control band (GCB): the surface area over which insulation and/or supplementary heat source(s) may be placed. The gradient control band encompasses the soak band, the heated band, and sufficient adjacent base metal to ensure that harmful temperature gradients are not generated within the heated band.

gradient control heaters: extra heaters that, under certain circumstances, are installed adjacent to the heated band to add heat to control thermal temperature gradients, or to provide thermal biasing to counter increased thermal mass or to counter a vertical bias in the temperature distribution in the heated band during PWHT in the vertical position. Also called blocking heaters.

heated band (HB): the surface area over which the heat is applied to achieve the required temperature in the soak band. The heated band consists of the soak band width on the outside surface of the component plus any adjacent base metal necessary both to control the temperature and to achieve an acceptable temperature on the inside of the pipe or tube.

monitoring thermocouple: a temperature-measuring device used to measure the temperature at the position where it is located.

soak band (SB): the through-thickness volume of metal that is required to be heated to within the postweld heat treatment temperature range. At a minimum, it shall consist of the weld metal, the HAZ, and a portion of the base metal adjacent to and on each side of the weld being heated.

through-thickness temperature gradient: the difference between the temperature on the outside of the weld or component and the temperature on the inside of that same component, on the same radial line, and in the same axial plane.
**LOCAL CIRCUMFERENTIAL BAND HEATING**

Local heating of parts or components shall be accomplished by heating circumferential bands. Since local heating of cylindrical components is typically from the outside, when designing heat treatment procedures, radial (through-thickness) temperature gradients shall be considered.

### 4.1 SOAK BAND

The requirements for soak band width shall at a minimum be equal to the following (where referenced, \( t \) = wall thickness):

(a) **Soak Band Width for Preheat**. The minimum requirement for preheating shall be an area 3 in. (75 mm) or 1.5\( t \), whichever is greater, in all directions from the point of welding.

(b) **Soak Band Width for PWHT**. The minimum requirements for PWHT shall be as follows:

1. For components less than or equal to NPS 4 (DN 100), the soak band shall be 1.5\( t \) on each side of the weld at its greatest width.

2. For components greater than NPS 4 (DN 100) but less than or equal to NPS 8 (DN 200), the soak band shall be 6\( t \) on each side of the weld at its greatest width.

(c) **Soak Band Width for Postheating**. The minimum requirement for postheating shall be \( t \) or 2 in. (50 mm), whichever is less, on each side of the weld at its greatest width.

### 4.2 HEATED BAND

The requirements for heated band width for PWHT shall at a minimum be equal to the soak band width plus 4\( t \) on each side of the weld, where \( t \) = nominal wall thickness.

### 4.3 GRADIENT CONTROL BAND

The primary function of this band is to control the axial temperature gradient at the outer edges of the heated band. It also serves to minimize heat loss in the heated band. The width of the insulated area directly affects the axial temperature gradient.

The requirements for the gradient control band width shall at a minimum be equal to the following:

(a) **Gradient Control Band Width for Preheating and Postheating**. The insulation may be limited to covering the heaters to protect the welder.
Definitions of Terms for Local Circumferential Band With Branch Connection Attachment Weld to Cylindrical Component

Legend:

GCB, GCB = gradient control band (minimum width of insulation and/or gradient heat source)
HB, HB = heated band (width of heat source) shown as shaded area
R, R = inside radius of pipe or branch connection
SB = soak band width on the outside surface of the material over which the holding temperature equals or exceeds the minimum and equals or is below the maximum required. The minimum width is typically specified as W plus a multiple of t on each side of the weld attaching the branch connection.
SB = soak band width on the outside surface of the material on the branch connection. The minimum width is typically specified as W plus a multiple of t on each side of the weld attaching the branch connection.
t, t = nominal thickness of component or branch connection
W = widest width of weld attaching the branch connection to the component
(b) Gradient Control Band Width for PWHT. Requirements for the gradient control band width shall be the heated band width plus 4\( r \) on each side of the weld, where \( r = \) nominal wall thickness.

NOTE: If the component wall thickness changes, attachments are present within the gradient control band, or the pipe is being welded to flanges, valves, etc., the use of supplemental heat source(s) within the gradient control band may be required.

4.4 AXIAL TEMPERATURE GRADIENT

The axial temperature distribution plays an important role in limiting induced stresses during PWHT. The temperature gradient shall be controlled such as to be reasonably uniform around the component.

(a) Axial Temperature Gradient for Preheating and Post-heating. Control of the axial temperature gradient is not required.

(b) Axial Temperature Gradient for PWHT. The maximum axial temperature gradient for PWHT shall be limited such that the temperature at the outer edge of the heated band shall be no less than one-half the temperature at the edge of the soak band during heating, soak time, and cooling.

5 MEASUREMENT OF TEMPERATURE

Measurement of temperature is required during heating operations. During the heating cycle, whenever temperatures exceed 800°F (425°C), a continuous record of the temperature shall be made.

5.1 TEMPERATURE-INDICATING CRAYONS AND PAINTS

Temperature-indicating crayons and paint are permissible only up to 600°F (316°C). Above that temperature, thermocouples shall be used and shall be attached using the capacitor discharge method of welding.

5.2 SELECTION OF THERMOCOUPLES

(a) Thermocouples shall be selected based on their maximum recommended temperature rating.

(1) Type J, Iron-Constantan shall not be used above 1,400°F (760°C).

(2) Type K, Chromel-Alumel shall not be used above 2,300°F (1,260°C).

(b) The maximum size of thermocouple wire to be used in local heating (with attachment by capacitor discharge welding) shall be #20 American Wire Gage (AWG), which has a diameter of 0.032 in. (0.81 mm).

5.3 INSTALLATION OF THERMOCOUPLES

Thermocouples shall be attached using capacitor discharge welding. Each wire shall be attached separately to the surface of the workpiece. The maximum separation of the wires shall be held to 1/8 in. (6 mm).

5.4 CONTROL THERMOCOUPLES

Control thermocouple locations shall be based on the location of the heating pads and the component being heated. Each electrically separate circuit containing heating pads shall be known as a control zone and shall be controlled by one control thermocouple. This thermocouple shall be approximately centrally located such that it experiences the greatest expected temperature within the control area. When installing the control thermocouple, an electrically separate, spare control thermocouple shall be installed immediately adjacent to it.

5.5 MONITORING THERMOCOUPLES

Monitoring thermocouples shall be placed to ensure that all of the parameters specified to control the local heating operation are being achieved. They shall be placed to measure the maximum and minimum anticipated metal temperatures. To achieve this, thermocouples shall be placed at the centerline of the weld, the edge of the soak band, and the edge of the heated band. These shall be located as described in 6.3.4. There shall also be at least one thermocouple, either control or monitoring, located under each heating pad.

6 DESIGN OF THE HEATING PROCESS

Choice of the size, the number, and the electrical configuration of electric heating pads shall be based on the geometrical configuration of the parts, the soak band area, and the heated band areas.

All heating pads used in a single heat treatment shall be manufactured from the same materials and shall be of the same watt density.
Prior to installation, each heater shall be inspected for broken ceramic beads and frayed heater wires. If found and judged to be detrimental to the process, the heaters shall be replaced.

### 6.1 PREHEAT

(a) Heating pads shall be symmetrically located on either side of the weld preparation. The heating pads shall be installed such that the edges of the pads shall be approximately 1 in. (25 mm) away from the edge of the weld preparation.

(b) Each side of the weld shall be considered a separate and distinct heated area with its own temperature monitoring and control zones.

(c) Preheat temperature shall be monitored at a number of locations around the weld, with each location 0.5 in. (13 mm) away from the edge of the weld preparation. At a minimum, the six o'clock position shall be monitored to ensure that the minimum preheat has been achieved.

1. There shall be at least one control thermocouple installed per control zone, and in the case of horizontally oriented pipe and tube, at least one of these control thermocouples shall be installed at the twelve o'clock position.

2. One control or monitoring thermocouple shall be installed under each heater.

### 6.2 POSTHEATING

Heating pads shall be symmetrically located over the centerline of the weld. There shall be at least one control thermocouple installed per control zone, and in the case of horizontally oriented components, at least one of these control thermocouples shall be installed at the twelve o'clock position.

### 6.3 POSTWELD HEAT TREATMENT

#### 6.3.1 Heating Pads

The heating pads across the soak band shall be installed in such a way the gaps between the heaters are minimized. When the nominal wall thickness of the pipe is less than or equal to 1 in. (25 mm), the gaps between the heaters shall not be greater than \( \frac{3}{8} \) in. (10 mm). When the nominal wall thickness of the component exceeds 1 in. (25 mm), the gaps between the heaters shall not be greater than \( \frac{3}{16} \) in. (12.7 mm). Where this is not possible, a monitoring thermocouple shall be welded in the center of the gap.

1. There shall be no overlapping of heaters.
2. Heater tail shall not be allowed to cross any other pad or heater tail.
3. Heater tails shall be insulated from the pipe.
4. Heater tails shall be brought out through the insulation as close to the edge of the heater as possible.

#### 6.3.2 Control Zones

Control zones shall be as a minimum be laid out as per Table 6.3.2-1.

### 6.3.3 Locations of Thermocouples

At least one thermocouple shall be installed at both the twelve o'clock and six o'clock positions on the weld centerline. These thermocouples may be either a control thermocouple or a monitoring thermocouple. Additional thermocouples may be necessary depending on the part configuration and size. Monitoring thermocouples shall also be installed at the outer edges of the soak band and at the outer edges of the heated band.

### 6.3.4 Examples of Thermocouple Locations

Figures 6.3.4-1 through 6.3.4-4 show examples of the thermocouple locations for common local circumferential band PWHT applications. In some instances, both monitoring and control thermocouples have been shown. Figures 6.3.4-1 through 6.3.4-3 provide required monitoring and control thermocouple locations for PWHT of butt welds in horizontally oriented components with one, two, and four control zones. Figure 6.3.4-4 provides required monitoring thermocouple locations for PWHT of a weld attaching a branch connection. Control thermocouples shall be attached as required by the control zone layout.

### 6.4 SPECIAL CONSIDERATIONS

#### 6.4.1 Circumferential Welds Joining Components in the Horizontal Position

Due to natural internal convection heat flow, the twelve o'clock position on a circumferential weld in horizontally oriented piping cylindrical components will be considerably hotter than the six o'clock position. To avoid exceeding the maximum allowed temperature, one control thermocouple shall always be installed at the twelve o'clock position. In addition, control zones and control thermocouples shall be installed as specified in 6.4.2 through 6.4.7.
Figure 6.3.4-1
Location of Thermocouples (Monitoring and Control) for Pipe Sizes Up to 6 NPS (150 DN) and One Control Zone

Legend

Monitoring thermocouple location
on outer surface

Control thermocouple location
on outer surface

Plane A — Edge of Heated Band
Plane B — Edge of Soak Band
Plane C — Weld Centerline
Plane D — Edge of Soak Band
Plane E — Edge of Heated Band
Location of Thermocouples (Monitoring and Control) for Pipe Sizes 8 NPS Through 12 NPS (200 DN Through 300 DN) and Two Control Zones

Legend

- Monitoring thermocouple location on outer surface
- Control thermocouple location on outer surface
Figure C-6.3.4-3
Location of Thermocouples (Monitoring and Control) for Pipe Sizes 14 NPS Through 30 NPS (350 DN Through 750 DN) and Four Control Zones

Legend

- Monitoring thermocouple location on outer surface
- Control thermocouple location on outer surface
Figure 6.3.4-4
Location of Monitoring Thermocouples for Branch Nozzle or Attachment

Legend

_monitoring thermocouple location

on outer surface

Legend

_monitoring thermocouple location

on outer surface

Planes A and F — Edge of Heated Band
Plane B — Edge of Soak Band
Plane E — Edge of Soak Band

Section C-C

Section D-D

Located on weld (typ.)
6.4.2 Butt Welds Joining Components in the Vertical Position. Due to natural internal convection heat flow, the upper side of the heated band in vertical components will be hotter than the lower side. Several approaches may be used to address this issue.

(a) Air circulation dams may be placed inside the pipe, preferably above the weld, to block the "chimney effect" within the pipe.
(b) The heated band may be biased such that approximately 60% of the heated band area is below the weld.
(c) Separate control zones above and below the weld may be used. For electric resistance heating, gradient control or blocking heaters may also be installed below the weld to balance the heat flow and in effect form a biasing of the heated band.

6.4.3 Butt Welds Joining Components to Valves and Flanges. During PWHT of butt welds between cylindrical components and components such as valve bodies or heavy flanges, consideration shall be given to the uneven conductive heat loss (or so-called heat sink effect) on each side of the weld. To counter this, the heat input may be biased to the thicker side of the joint. This may be accomplished by the following:
(a) use of separate control zones on the thicker and thinner components.
(b) biasing the heating elements toward the heavier component.
(c) reducing the volume of insulation used on the thinner-section heated band to achieve the desired temperature profile across the soak band.

In such instances, additional monitoring thermocouples shall be used to ensure that the required temperatures are achieved on both the thinner and heavier wall thickness components.

6.4.4 Welds Joining Branch Connections or Attachments to Cylindrical Components.

(a) For welds joining branch connections or attachments to cylindrical components, circumferential band PWHT practices shall be used on both the piping cylindrical components and the connection. The entire nozzle or attachment shall be included in the soak band.
(b) For branch connections where the heating pads fitted to the weld will not contour to the shape without leaving larger than normal gaps between the heaters, additional monitoring thermocouples shall be placed in the expected cold spots to ensure that the cold spots achieve the desired temperature.
(c) Where small branch connections, 1/2 in. to 1 1/2 in. (13 mm to 38.1 mm) diameter, are welded to larger sections, circumferential bands around both the larger component and smaller branch connection shall be hested using heaters with control thermocouples on the larger component and with monitoring thermocouples on the smaller branch connection. If separate control zones are used for the larger component and smaller branch connection, they shall each have separate control thermocouples.

6.4.5 Intersection With Branch Connections and Attachments Not Requiring PWHT.

(a) The soak band, heated band, and/or gradient control band of welds that require PWHT may intersect branch connections or attachments that do not require PWHT. To avoid distortion and/or induced residual stresses during PWHT, the temperature gradient across the components that are intersected shall be minimized. This may require the application of a supplementary heat source(s) to the branch connection or attachment.

Alternatively, a reasonably uniform temperature shall be maintained across these components. The soak band, heated band, or gradient control band, whichever intersects, shall be extended in the axial direction such that it ends beyond the weld on the opposite side connecting the attachment or associated pad to the component for at least half of the soak band, heated band, or gradient control band, whichever is appropriate.

Figure 6.4.5-1 provides an example of such an approach when the heated band from a weld requiring PWHT intersects a nozzle that does not require PWHT.

(b) Although the nonspecific term "reasonably uniform" is used in (a) to describe the temperature drop across the intersected component, the aim is to maintain a reasonably constant temperature drop across the intersected component. However, to provide a measurable limit, a maximum temperature drop is recommended.

The maximum temperature drop across an intersected component shall be 100°F (56°C) or that resulting from application of the maximum permissible axial temperature gradient (i.e., 50% of the temperature at the edge of soak band divided by \(2\sqrt{R_e}\), whichever is less. Based on experience or analysis, larger temperature gradients across nozzles or attachments may exhibit permissible levels of distortion or residual stress.

6.4.6 Proximity of Pipe-to-Nozzle Welds to Shell or Head. Consideration shall be given to whether local circumferential band PWHT of pipe-to-nozzle welds may result in heating the nozzle and/or surrounding shell or head section to temperatures that may cause distortion and harmful induced stresses.

6.4.7 Lower Critical Temperature (LCT) of P-No. 15E Weld Metal. Variations in P-No. 15E weld metal chemistry are known to have a significant effect on its lower critical transformation temperature. Consideration shall therefore be given to ensuring that the upper limit of the heat treatment temperature does not exceed the LCT of the weld metal.
Example of One Approach When the Heated Band from Weld Requiring PWHT Intersects Weld Not Requiring PWHT

**Legend:**
- GCB = gradient control band (minimum width of insulation and/or gradient heat source)
- HB = heated band (width of heat source)
- \( L \) = minimum distance over which the temperature may drop to one half of that at the edge of the soak band
- \( R \) = inside radius of pipe
- \( A + B \approx L = 2\sqrt{\frac{Rt}{t}} \) = soak band (width of the volume of the material where the holding temperature equals or exceeds the minimum and equals or is below the maximum required. The minimum width is typically specified as a multiple of \( t \) on each side of the weld.)
- \( t \) = nominal thickness of pipe

**GENERAL NOTES:**
(a) The total distance over which the temperature drops from that at the edge of the soak band to 50\% (\( A + B \)) is greater than or equal to \( L = 2\sqrt{\frac{Rt}{t}} \).
(b) The intent is to maintain an "approximately constant" temperature across the intersected component. However, a maximum temperature drop of 100°F (55°C) or that resulting from application of the maximum recommended axial temperature gradient, whichever is less, is permitted.

**NOTE:**
(1) The nozzle attachment weld "not requiring PWHT" does not imply that such a weld would not require PWHT. It simply means that it does not require PWHT now. For example, it may have previously received PWHT.
C.7 THE THERMAL CYCLE, PWHT

It is important to control the following four aspects of the thermal cycle associated with heating operations: temperature uniformity, the heating rate above a specified temperature, the specified hold temperature and time, and the cooling rate down to a specified temperature.

(a) Maximum Temperature Differences for PWHT. During heating and cooling, the maximum temperature difference within the heated band shall be 250°F (139°C), or as limited by the maximum axial temperature gradient.

(b) The Maximum Heating Rate. Above 800°F (425°C), the rate of heating shall not be more than 400°F/hr (222°C/h) divided by the maximum material thickness in inches (millimeters), but in no case more than 400°F/hr (222°C/h).

(c) The Maximum Hold Temperature and Time. During hold, the requirements for the maximum hold temperature and time shall be as defined in PW-39.

(d) The Maximum Cooling Rate. Above 800°F (425°C), the rate of cooling shall be not more than 500°F/hr (278°C/h) divided by the maximum material thickness in inches (millimeters), but in no case more than 500°F/hr (278°C/h).

C.8 INSULATION

(a) Classification of Insulation. The requirements for the gradient control band width are based upon insulation R values of 2°F-ft²-hr/Btu to 4°F-ft²-hr/Btu (0.35°C-m²/W to 0.70°C-m²/W). Refractory ceramic fiber insulation with a density of 6 lb/ft³ to 8 lb/ft³ (96.1 kg/m³ to 128.1 kg/m³) meets this requirement. A layer at least 1 in. (25 mm) thick shall be used for temperatures up to 1,200°F (650°C); a layer at least 2 in. (50 mm) thick shall be used for temperatures above 1,200°F (650°C).

(b) Attachment of Insulation. The pieces of insulation shall be sized such that when the piece(s) are wrapped around the component, the component surfaces shall be fully covered, with the ends of the insulation either butted against each other or overlapped to preclude heat loss. No gaps shall be permitted in the insulation layer, and any inadvertent gaps shall be filled with insulation. The insulation may be held in place with banding or tie wire. The insulation shall not be compressed to less than three-quarters of its original thickness during banding or tying.

(c) During heating, the insulation has a tendency to shrink and thus create gaps. Inspection shall therefore be carried out at various times during the heating cycle to identify and rectify any gaps that may occur during the heating.

(d) When multiple layers of insulation are used, the seams shall be staggered to minimize the possibility of gaps.

(e) The insulation shall extend beyond the edge of the heated band out to the edge of the gradient control band to diminish heat loss and to ensure that the permissible maximum axial temperature gradient from heated to unheated sections is not exceeded.

C.9 QUALITY ASSURANCE SYSTEM

C.9.1 INTRODUCTION

To ensure that local heating operations are in compliance with various codes, standards, practices, or specifications, all heating shall be performed in accordance with an established quality assurance system.

All work shall be performed in accordance with a written quality assurance system. This system shall be described in a Quality Assurance Manual and shall define the organizational structure, responsibilities, procedures, processes, and resources for implementing quality management. The written description of the quality assurance system shall be available for review.

C.9.2 PROCESS CONTROL

Written procedures and associated drawings shall be used. The Standard Procedure for Local Heating shown in Form C.9.2-1, or an equivalent, shall be used in conjunction with a drawing/sketch that specifies placement of thermocouples, heat sources (including control zones), and insulation.

C.9.3 DOCUMENTATION

A record of the thermal cycle shall be produced. The temperature resolution of the record shall be within 5°F (3°C), and the time resolution shall be within 5 min.

(a) The record of the thermal cycle shall be submitted to the customer upon the completion of local heating. The record of the thermal cycle shall contain information such as the temperature and time scales and correspondence between thermocouple numbers on the record and those on the drawing/sketch. The records provided may be either electronic or printed copy.

(b) Copies of the procedures, drawings/sketches, Certificates of Conformance for thermocouples and extension wire, and calibration records for temperature-recording devices shall be submitted to the customer along with the record of the thermal cycle for each weld or group of welds.

(c) Form C.9.3-1, Standard Documentation Checklist for Local Heating, shall be used as a basis for provision of documentation. This checklist and supporting documentation shall be submitted to the customer at the completion of local heating.
9.4 CONTROL OF INSPECTION, MEASURING, AND TEST EQUIPMENT

All thermocouples and extension wire shall be traceable to Certificates of Conformance. Calibration of temperature-recording devices shall be traceable to national standards such as those maintained by the National Institute for Standards and Technology (NIST).

9.5 TRAINING

All personnel performing local heating shall be trained in the proper use and application of the associated processes and equipment, including safety, calibration, maintenance, and inspection considerations. Each organization shall be responsible for defining its own training program, and documentation of such training shall be maintained and made available on request.

9.6 SERVICING

All equipment shall be serviced at appropriate intervals as recommended by the manufacturer to ensure proper performance. Documentation of such servicing shall be maintained and made available on request.

10 OTHER CONSIDERATIONS

Additional issues, including the following, shall be considered when performing local heating of components:

(a) the structural integrity of the component.
(b) the strength of the component at temperature. The component should have sufficient strength at temperature to be self-supporting.
(c) the potential for the components to experience an unacceptable permanent distortion.
(d) natural convection within the component.
(e) natural convection within otherwise sealed-off sections of cylindrical components. Closing valves, blinding flanges, and other techniques to seal off a section of cylindrical components may not prevent this form of natural convection. The resulting circulating airflow may cause undesirable heat transfer on the inside surface of the component. For pipe in the horizontal position, this may result in significant temperature differences between the twelve o'clock and six o'clock positions.
(f) natural drafts. These can occur when a flow of air is possible through parts of a cylindrical component system that are not sealed off. This is often referred to as the "chimney effect." Such flow can result in considerable convection losses on the inside surface of the component.
(g) thermal expansion of the component. Large thermal stresses can develop during PWHT if adequate provisions to permit thermal growth are not made.
(h) the presence of internal fluids within or adjacent to the heated area.
FORM 9.2-1 STANDARD PROCEDURE FOR LOCAL HEATING

Procedure No. __________  Revision No. __________  Date __________

Governing Code __________

Workpiece Identification Number __________

Material Specification __________

Component Dimensions __________

Thermocouple, Heater, and Insulation Layout Drawing Number __________

Thermal Cycle

Heating Rate __________ °/hr (specify max. or min.) above __________ °

Hold Temperature Range __________ to __________ °.

Minimum Hold Time __________ hr  Maximum Hold Time __________ hr

Cooling Rate __________ °/hr (specify max. or min.) above __________ °

Procedure

Step 1. Match procedure/drawings to workpiece, including verification of workpiece identification number. Check the appropriateness of specified thermal cycle to the material and application.

Completed by: __________ Date __________

Step 2. Install and test power/control equipment, including power supplies, temperature controllers, and temperature recorders.

Completed by: __________ Date __________

Step 3. Check validity of calibration date on all temperature recorders. Enter serial number and date next calibration due for each recorder.

Serial number __________ Date next calibration due __________

Serial number __________ Date next calibration due __________

Serial number __________ Date next calibration due __________

Serial number __________ Date next calibration due __________

Completed by: __________ Date __________

Step 4. Install thermocouples (including spares) per drawing/sketch using approved methods. Direct attachment by capacitor discharge welding (§3.3.1) is recommended.

Completed by: __________ Date __________

Step 5. Verify specified (per drawing/sketch) placement of thermocouples.

Verified by: __________ (QC Inspector) Date __________

Step 6. Install heat sources and insulation per drawing/sketch using approved methods.

Completed by: __________ Date __________

Step 7. Verify specified (per drawing/sketch) placement of heat sources and insulation before the start of heating.

Verified by: __________ (QC Inspector) Date __________
Step 8. Install and connect thermocouple extension wire. Check operation of all thermocouples. Check for reversal of thermocouple polarity. Note that it may only be possible to detect a double polarity reversal visually. (When checking for polarity reversal, use the mnemonic device "BIG-RED-NEGATIVE" as a guide.)

Completed by Date

Step 9. Install and connect power cables. Check operation of all heat sources.

Completed by Date

Step 10. Obtain approval to begin the heating operation.

Approved by (QC Inspector) Date

Step 11. Perform and document periodic checks during heating, including equipment operation (recorder and power supplies) and adherence to specified heating rate. If a deviation occurs during heating, follow approved corrective action. If it appears that achieving the hold temperature will be difficult and requires excessive time, the QC Inspector should be notified and a decision made regarding whether to continue heating.

Completed by Date Time

Completed by Date Time

Completed by Date Time

Step 12. Verify the start of the hold period, i.e., all soak band thermocouples are within the required temperature range.

Verified by (QC Inspector) Date

Step 13. Perform and document periodic checks during the hold period, including equipment operation (recorder and power supplies) and adherence to required hold temperature range. If a deviation occurs during the hold period, follow approved corrective action. A maximum time in the hold temperature range may be specified for certain materials. If it appears that the maximum time limit will be exceeded, the QC Inspector should be notified and a decision made regarding whether to continue heating.

Completed by Date Time

Completed by Date Time

Completed by Date Time

Completed by Date Time

Completed by Date Time

Step 14. Verify completion of the hold period, i.e., all soak band thermocouples remained within the required temperature range for the minimum required time. Must be verified before the start of cooling.

Verified by (QC Inspector) Date

Step 15. Perform and document periodic checks during cooling period, including equipment operation (recorder and power supplies) and adherence to specified cooling rate. If a deviation occurs during cooling, follow approved corrective action.

Completed by Date Time

Completed by Date Time

Completed by Date Time

Step 16. Deactivate power/control equipment after the temperature is below that where cooling-rate control is required.

Completed by Date

Step 17. Remove all equipment after the temperature is safe for personnel. Cut thermocouple wires, and mark locations of attached thermocouples for light filing/grinding.

Completed by Date
Step 18. Note any deviations such as heating rate, hold time, temperature, or cooling rate that occurred during the thermal cycle. If no deviations occurred, enter “None.”

Completed by __________________ Date ____________

Step 19. Complete and submit to the Customer appropriate documentation in accordance with Standard Documentation Checklist for Local Heating (Form C-9.3-1).

Received by __________________ Date ____________

(Customer's Representative)

FORM C-9.3-1 STANDARD DOCUMENTATION CHECKLIST FOR LOCAL HEATING

The following documentation shall be provided by the supplier of local heating services at the completion of work:

☐ 1. Procedure (Form C-9.2-1) with all required information completed

☐ 2. Drawings/sketches for thermocouple, heater, and insulation layout

☐ 3. Certificates of Conformance for thermocouple and extension wire

☐ 4. Certified Material Test Reports for any filler metals being used that match the P-No. 15E materials (The customer shall provide a copy of the CMTRs for filler metals matching the P-No. 15E materials being heat treated, which shall include the Lower Critical Transformation Temperature.)

☐ 5. Calibration records for temperature-recording device

☐ 6. Hardness testing results (if applicable)

☐ 7. Strip chart record of the entire thermal cycle with the following information:
   - a. Date(s), time period, and location of work performed
   - b. Identification of contractor/personnel performing the work
   - c. Identification number of the workpiece
   - d. Temperature and time scales
   - e. Correspondence between thermocouple numbers on the chart(s) and on the drawing/sketch
   - f. Heating rate above specified temperature
   - g. Hold period temperature and time
   - h. Cooling rate above specified temperature