ASME B31P-2023
(Revision of ASME B31P-2017)

Standard Heat Treatments for Piping

ASME Code for Pressure Piping, B31

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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The endnotes and preamble in this document (if any) are part of this American National Standard.

The American Society of Mechanical Engineers
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FOREWORD

In 2011, the B31 Standards Committee for Pressure Piping determined that more consistency was needed between the B31 Code Sections regarding preheat and postweld heat treatment (PWHT) rules. The B31 Fabrication & Examination Technical Committee decided that a B31 Standard covering these rules would be the best way to provide this consistency; a proposal was developed, which was accepted by the B31 Standards Committee and the BPTCS.

This Standard is intended to provide requirements for preheating and PWHT when mandated by the applicable Code Section or by the engineering design being used. While the Code Sections provide only preheat and PWHT rules for ferrous materials, this Standard may provide expanded rules and alternatives for a wider variety of materials, although all materials that may be possible to use may not be covered.

Under direction of ASME Standards and Certification, both U.S. Customary and SI units are provided.

Following approval by the B31 Committee and ASME, and after public review, ASME B31P-2017 was approved by the American National Standards Institute on November 15, 2017.

Following approval by the B31 Committee and ASME, and after public review, ASME B31P-2023 was approved by the American National Standards Institute on July 21, 2023.

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(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Standard

(4) to permit the use of a new material or process

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(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Standard and the paragraph, figure, or table number

(4) the editions of the Standard to which the proposed case applies

(d) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Approved cases are posted on the committee web page.

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ASME B31P-2023
SUMMARY OF CHANGES

Following approval by the ASME B31 Committee and ASME, and after public review, ASME B31P-2023 was approved by the American National Standards Institute on July 21, 2023.

The title of ASME B31P has been revised from "Standard Heat Treatments for Fabrication Processes" to "Standard Heat Treatments for Piping." In addition, ASME B31P-2023 includes the following changes identified by a margin note, **(23)**.

Page	*Location*	*Change*
1	1	Revised in its entirety
3	5.3	Subparagraph (d) revised
4	Table 5.1-1	Editorially revised
4	6.1.1	First and last sentences revised
5	Table 6.1.1-1	Revised
8	6.2	Subparagraph (b) revised
8	6.3.1	First paragraph revised
9	7.1.3	Added
9	8	First paragraph revised
10	A-2	Revised
21	B-5.6	In subparas. (a) and (b)(2), cross-references to Forms updated
22	Form B-5.6-1	(1) Former Form 1 redesignated (2) In Item 19, cross-reference updated
25	Form B-5.6-2	(1) Former Form 2 redesignated (2) In Item 1, cross-reference updated

STANDARD HEAT TREATMENTS FOR PIPING

(23) 1 INTRODUCTION

1.1 Scope

This Standard provides requirements for heat treatment of piping and pipelines that meet the requirements of the ASME B31 Code Sections. These requirements apply to

(a) preheating
(b) postweld heat treatment (PWHT)
(c) postforming heat treatment (PFHT) required by the ASME B31 Code Sections for other fabricated assemblies, including forming operations such as bending
(d) heat treatments required by contract documents

1.2 General

The heat treatments addressed in this Standard include weld preheating, PWHT, PFHT, and heat treatment to enhance material properties resulting from fabrication. Preheating is generally required on hardenable steels to reduce local hardness or to reduce the occurrence of hydrogen cracking. Preheat is typically required based on both hardenability (as indicated by the P-Number) and thickness at the weld. A minimum temperature for all materials prior to initiating a weld is expected to be needed to reduce the possibility of condensation. It should be noted that preheat is not considered a heat treatment, but it is a requirement of the ASME B31 Code Sections.

PWHT is generally required on hardenable steels to temper any hardened areas or to reduce residual stress in the weldment. PFHT may be used to address reduction of the properties within the bend after hot bending or to address the effects of strain after cold bending (the additional strain may cause a degradation of creep rupture properties when the operation is at high temperatures). In some cases of PWHT, PFHT, or material heat treatments, non-standard heat treatment may be required by the contract specification, e.g., an austenitizing heat treatment or a solution heat treatment.

This Standard is intended to provide consistent code heat treatment rules. It may be incorporated by reference in a code, or it can become a basis for code or contract requirements.

Appendices provide more-specific controls that may be needed or desired for specific applications. These specific controls are not mandatory unless specified.

Appendices are also included that outline alternative methods to exempt PWHT of welds when PWHT is difficult or impossible. The alternatives are required to be addressed within Welding Procedure Specifications (WPS) qualified in accordance with the industry standard specified by the referencing code, specification, or standard.

1.3 Exclusions

The requirements for the heat treatments done in accordance with material or product specifications are not addressed within this Standard. Such heat treatments are governed by those specifications.

1.4 Units of Measure

Either U.S. Customary or SI (metric) units may be used with this Standard. Local customary units may also be used to demonstrate compliance with this Standard. One system of units should be used consistently for requirements applying to a specific installation.

This Standard states values in both U.S. Customary and SI units. Within the text, the SI units are shown in parentheses; within tables, the SI units are shown in parentheses. The values stated in each system are not exact equivalents; therefore, each system of units should be used independently of the other.

When necessary to convert from one system of units to another, conversion should be made by rounding the values to the number of significant digits of implied precision in the starting value but to not less than four significant digits for use in calculations.

2 GLOSSARY

creep strength enhanced ferritic (CSEF) steel: steel in which the microstructure, consisting of lower transformation products, e.g., martensite or bainite, is stabilized by controlled precipitation of temper-resistant carbides, carbonitrides, and/or nitrides.

heat treatments:

annealing, full: heating a metal to a temperature above the transformation temperature range and holding it above that range for a proper period of time, followed by cooling to below that range.

austenitizing: heat treatment where a partial or complete phase transformation to austenite occurs.

normalizing: a process in which a ferrous metal is heated to a suitable temperature above the transformation range and is subsequently cooled in still air at room temperature.

quenching: a process in which a ferrous metal is heated to a suitable temperature above the transformation range and is subsequently rapidly cooled in a selected quenching medium.

tempering: reheating a hardened metal to a temperature range below the transformation range.

interpass temperature: the highest temperature in the weld joint immediately prior to welding, or in the case of multiple pass welds, the highest temperature in the area of the previously deposited weld metal, immediately before the next pass is started.

postforming heat treatment (PFHT): any heat treatment subsequent to a bending or forming operation.

postweld heat treatment (PWHT): any heat treatment subsequent to welding.

postweld hydrogen bakeout: raising the temperature of a completed or partially completed weld for the purpose of allowing hydrogen to diffuse out of the weld or heat-affected zone (HAZ).

preheat: the heat applied to base metal immediately prior to a welding or cutting operation.

residual stress: stress that occurs in a weldment after all external loads have been removed.

3 TEMPERATURE MEASUREMENT

3.1 Measurement Method

3.1.1 Preheat. The preheat temperature shall be measured by use of thermocouples, pyrometers, temperature indication crayons, or other suitable temperature-measurement devices, to ensure that the required preheat temperature is obtained prior to, and maintained during, the welding operation in the area to be welded immediately prior to welding.

3.1.2 Interpass Temperature. If required, the maximum interpass temperature shall be measured using devices allowed for preheat in para. 3.1.1.

3.1.3 PWHT or Other Heat Treatments. The temperature shall be measured using thermocouples attached directly to the surface to ensure the temperature is uniform and controlled within the required limits. Noncontact temperature-measuring devices shall not be used.

3.1.4 Protection. If thermocouples are attached using methods other than the capacitor discharge welding process, the thermocouple site shall be protected from the direct heat of the heat source.

3.2 Attachment of Thermocouples

3.2.1 Recommendations for thermocouples are given in Nonmandatory Appendix A.

3.2.2 Low-energy capacitor discharge welding may be used for the direct attachment of thermocouples without requiring preheat greater than 50°F (10°C) or subsequent PWHT (unless required for the weld joint), provided the following requirements are met:

(a) A Welding Procedure Specification (WPS) is prepared, describing the low-energy capacitor discharge welding equipment, the material to be welded on, and the technique of application. Qualification of this WPS is not required.

(b) The energy output of the low-energy capacitor discharge welding process is limited to 125 W-sec.

(c) Permanent thermocouple attachments on the surface from which temporary attachments are removed shall require visual examination but are exempt from further examination in accordance with code requirements.

4 TEMPERATURE CONTROL

4.1 Control of Heat Treatment Temperature

4.1.1 Minimum Requirements for Preheat. Minimum requirements are as follows:

(a) The base metal temperature for the parts to be welded shall be at or above the minimum temperature specified in all directions from the point of welding for a distance of the larger of 3 in. (75 mm) or 1.5 times the nominal material thickness (as defined in para. 6.4.3). For small-diameter piping less than 1½ in. (38 mm) outside diameter, the preheat distance from the weld may be reduced to the diameter of the piping in all directions or 1 in. (25 mm), whichever is greater. The base metal temperature for tack welds shall be at or above the specified minimum temperature for a distance not less than 1 in. (25 mm) in all directions from the point of welding.

(b) Preheat above ambient temperature may be applied using flame, electric resistance, induction, quartz lamp, or infrared heating. If flame heating is used, the application shall use a dispersive method and, if manually applied, the temperature shall be continuously monitored to prevent excessive temperatures being reached.

(c) If methods are employed that utilize heating adjacent to the preheat area, allowing the heat to conduct along the part to the preheat area, the temperature of the part in the approximate center of the heated area shall also be monitored.

4.1.2 Minimum Requirements for Furnace Heat Treatment. Minimum requirements are as follows:

(a) Furnace heat treatment should be used when practical.

(b) An assembly may be heat treated in more than one heat in a furnace, provided there is at least a 12 in. (300 mm) overlap of the heated sections and the portion of the assembly outside the furnace is shielded so that the temperature gradient is not harmful. This method may not be used for austenitizing heat treatments on ferritic steels except for P-No. 1 carbon steels.

(c) Direct impingement of flame on the assembly is prohibited.

(d) The furnace shall be surveyed and calibrated such that the PWHT can be controlled within the required temperature range.

(e) Thermocouples shall be placed directly on components to be heat treated and shall be located on the thinnest and the thickest components within the furnace. The placement of the thermocouples shall incorporate the high- and low-temperature locations within the furnace.

4.1.3 Minimum Requirements for Local Heat Treatment. Minimum requirements are as follows:

(a) PWHT may be performed locally by heating a circumferential band around the entire component, with the weld located in the approximate center of the band. The width of the band (soak band) heated to the specified temperature range shall be at least 3 times the nominal material thickness at the weld of the thickest part being joined. For nozzle and attachment welds, the width of the band heated to the specified temperature range shall extend beyond the nozzle weld, the reinforcement weld, or the attachment weld on each side at least 2 times the run-pipe nominal thickness and shall extend completely around the run pipe. Guidance for the placement of thermocouples on circumferential butt welds is provided in Nonmandatory Appendix B. Special consideration shall be given to the placement of thermocouples when heating welds adjacent to large heat sinks, e.g., flanges, valves, or heavy fittings, or when joining parts of different thicknesses.

(b) No part of the materials subjected to the heat source shall be heated to a temperature exceeding the lower transformation temperature of the material. Particular care must be exercised when the applicable PWHT temperature is close to the material's lower transformation temperature, such as for CSEF steel materials or when materials of different P-Numbers are being joined. The requirements of Appendix B are mandatory for P-No. 15E materials.

(c) Local heat treating shall not be used for austenitizing heat treatments on ferritic steels except for P-No. 1 carbon steels.

4.2 Heating and Cooling Rates

4.2.1 Heating. Above 800°F (425°C), the rate of heating shall be not more than 600°F/hr (335°C/h) divided by the maximum material thickness in inches, but in no case more than 600°F/hr (335°C/h).

4.2.2 Cooling. Above 800°F (425°C), the rate of cooling shall be not more than 600°F/hr (335°C/h) divided by the maximum material thickness in inches, but in no case more than 600°F/hr (335°C/h). (See Table 6.1.1-1 for special cooling rate requirements for certain materials.)

5 WELDING PREHEAT

5.1 Temperature

The minimum preheat temperature shall be as stated in Table 5.1-1 except as exempted in para. 3.2. Higher minimum preheat temperatures may be required by the WPS or as specified.

5.2 Different P-Number Materials

When welding two different P-Number materials, the minimum preheat temperature required shall be the temperature for the material with the higher required temperature, as shown in Table 5.1-1.

5.3 Interruption of Welding Preheat (23)

After welding commences, the minimum preheat temperature shall be maintained until any required PWHT is performed on P-Nos. 3, 4, 5A, 5B, 6, and 15E materials, except when all of the following conditions are satisfied:

(a) A minimum of at least $^{3}/_{8}$ in. (10 mm) thickness of weld is deposited or 25% of the welding groove is filled, whichever is less (the weld shall be sufficiently supported to prevent overstressing the weld if the weldment is to be moved or otherwise loaded). Caution is advised that the surface geometry prior to cooling should be smooth and free of sharp discontinuities.

(b) For P-Nos. 3, 4, and 5A materials, the weld is allowed to cool slowly to room temperature.

(c) For P-Nos. 5B, 6, and 15E materials, the weld is subjected to an adequate postweld hydrogen bakeout with a controlled rate of cooling. The preheat temperature may be reduced to 200°F (95°C) (minimum) for the purpose of root examination without performing postweld hydrogen bakeout. A postweld hydrogen bakeout for P-Nos. 5B, 6, or 15E materials may be omitted when using low-hydrogen electrodes and filler metals classified by the filler metal specification with an optional supplemental diffusible-hydrogen designator of H4 or lower and suitably controlled by maintenance procedures to avoid contamination by hydrogen-producing sources. The surface of the base metal prepared for welding shall be free of contaminants.

(23)

Table 5.1-1
Preheat Temperature

Base Metal P-Number [Note (1)]	Base Metal Group	Greater Nominal Material Thickness, in. (mm)	Additional Limits	Required Minimum Temperature, °F (°C)
1	Carbon steel	≤1 (≤25)	None	50 (10)
		>1 (>25)	%C ≤ 0.30 [Note (2)]	50 (10)
		>1 (>25)	%C > 0.30 [Note (2)]	200 (95)
3	Alloy steel Cr ≤ ½%	≤½ (≤13)	SMTS ≤ 65 ksi (450 MPa)	50 (10)
		>½ (>13)	SMTS ≤ 65 ksi (450 MPa)	200 (95)
		All	SMTS > 65 ksi (450 MPa)	200 (95)
4	Alloy steel ½% < Cr ≤ 2%	All	None	250 (120)
5A	Alloy steel	All	SMTS ≤ 60 ksi (414 MPa)	300 (150)
		All	SMTS > 60 ksi (414 MPa)	400 (200)
5B	Alloy steel	All	SMTS ≤ 60 ksi (414 MPa)	300 (150)
		All	SMTS > 60 ksi (414 MPa)	400 (200)
		>½ (>13)	%Cr > 6.0 [Note (2)]	400 (200)
6	Martensitic stainless steel	All	None	400 (200) [Note (3)]
9A	Nickel alloy steel	All	None	250 (120)
9B	Nickel alloy steel	All	None	300 (150)
10I	27Cr steel	All	None	300 (150) [Note (4)]
15E	9Cr–1Mo–V CSEF steel	All	None	400 (200)
All other materials			None	50 (10)

GENERAL NOTE: SMTS = specified minimum tensile strength.

NOTES:
(1) P-Numbers and Group Numbers are from ASME BPVC, Section IX, Table QW/QB-422.
(2) Composition may be based on ladle or product analysis, or meeting specification limits.
(3) Maximum interpass temperature is 600°F (315°C).
(4) Maintain interpass temperature between 300°F and 450°F (150°C and 230°C).

(d) After cooling and before welding is resumed, visual examination of the weld shall be performed to assure that no visible cracks are present.

(e) The joint shall be preheated before welding is resumed.

6 POSTWELD HEAT TREATMENT (PWHT)

6.1 Minimum PWHT Requirements

(23) **6.1.1 Temperature Range for PWHTs.** A qualified welding procedure specification (WPS) in accordance with the industry standard specified by the referencing code, specification, or standard, shall be available before applying the detailed requirements and exemptions in these paragraphs. All welds in materials included in the P-Numbers listed in Table 6.1.1-1 shall be given a PWHT within the temperature range specified, except as otherwise provided in paras. 6.2 and 6.3, and in Tables 6.1.1-2 and 6.1.1-3. (The range specified in Table 6.1.1-1 may be modified by Table 6.1.1-2 for the lower limit and para. 6.2 for the upper limit.) The materials in Table 6.1.1-1 are listed in accordance with the material P-Numbers and Group Numbers of ASME BPVC, Section IX, Table QW/QB-422. Welds on materials not included in Table 6.1.1-1 shall be heat treated in accordance with the WPS. Austenitizing PWHTs on ferritic materials may be performed in lieu of the heat treatments specified herein if required by the applicable WPS.

6.1.2 PWHT for High-Cr Filler Metal Welds. Pressure-part welds and attachment welds using ferritic filler metals that have a specified chromium content of more than 3% shall receive a postweld heat treatment. The postweld heat treatment time and temperature range used shall be that shown in Table 6.1.1-1 for any base metal of similar composition.

6.1.3 Hardness. Hardness tests are not required to verify proper heat treatment unless otherwise specified in the engineering design.

Table 6.1.1-1
Postweld Heat Treatment

(23)

P-Number, Group Number (ASME BPVC Section IX, Table QW/QB-422)	Holding Temperature Range, °F (°C) [Notes (1), (2)]	Minimum Holding Time at Temperature for Control Thickness [Note (3)]	
		Up to and Including 2 in. (50 mm)	Over 2 in. (50 mm)
P-No. 1, Group Nos. 1–3	1,100–1,200 (595–650)	1 hr/in. (1 h/25 mm), 15 min minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)
P-No. 3, Group Nos. 1 and 2	1,100–1,200 (595–650)		
P-No. 4, Group Nos. 1 and 2	1,200–1,300 (650–705)		
P-No. 5A, Group No. 1	1,250–1,400 (675–760)		
P-No. 5B, Group No. 1	1,250–1,400 (675–760)		
P-No. 6, Group Nos. 1 through 3	1,400–1,475 (760–800)		
P-No. 7, Group Nos. 1 and 2 [Note (4)]	1,350–1,425 (730–775)		
P-No. 8, Group Nos. 1–4	PWHT not required unless specified in the WPS		
P-No. 9A, Group No. 1	1,100–1,200 (595–650)		
P-No. 9B, Group No. 1	1,100–1,175 (595–630)		
P-No. 10H, Group No. 1	PWHT not required unless specified in the WPS. If performed, see [Note (5)].		
P-No. 10I, Group No. 1 [Note (4)]	1,350–1,500 (730–815)		
P-No. 15E, Group No. 1	1,300–1,425 (705–775) [Notes (6), (7)]	1 hr/in. (1 h/25 mm), 30 min minimum	1 hr/in. (1 h/25 mm) up to and including 5 in. (125 mm) plus 15 min for each additional inch (25 mm) over 5 in. (125 mm)
All other materials	PWHT as required by WPS	In accordance with WPS	In accordance with WPS

NOTES:
(1) The exemptions for mandatory PWHT are defined in Table 6.1.1-3.
(2) The holding temperature range is further defined in paras. 6.1.1 and 6.2.
(3) The control thickness is defined in para. 6.4.1.
(4) Cooling rate shall not be greater than 100°F (55°C) per hour in the range above 1,200°F (650°C), after which the cooling rate shall be sufficiently rapid to prevent embrittlement.
(5) If PWHT is required, it shall be performed in accordance with the heat treatment specified in the applicable material specification.
(6) The minimum PWHT holding temperature may be 1,250°F (675°C) for nominal material thicknesses (see para. 6.4.3) up to and including ½ in. (13 mm).
(7) The Ni + Mn content of the filler metal shall not exceed 1.2% unless specified, in which case the maximum temperature to be reached during PWHT shall be the A_1 (lower transformation or lower critical temperature) of the filler metal, as determined by analysis and calculation or by test, but not exceeding 1,470°F (800°C). If the 1,470°F (800°C) was not exceeded but the A_1 of the filler metal was exceeded, or if the composition of the filler metal is unknown, the weld must be removed and replaced. It shall then be rewelded with compliant filler metal and subjected to a compliant PWHT. If the 1,470°F (800°C) limit was exceeded, the weld and the entire area affected by the PWHT will be removed and, if reused, shall be renormalized and tempered prior to reinstallation.

Table 6.1.1-2
Alternate Postweld Heat Treatment Requirements for Carbon and Low-Alloy Steels, P-Nos. 1 and 3

Decrease in Specified Minimum Temperature, °F (°C)	Minimum Holding Time at Decreased Temperature, hr [Note (1)]
50 (30)	2
100 (55)	4
150 (85) [Note (2)]	10
200 (110) [Note (2)]	20

NOTES:
(1) Times shown apply to thicknesses up to and including 1 in. (25 mm). Add 15 min/in. (15 min/25 mm) of thickness for control thicknesses over 1 in. (25 mm). See para. 6.4.
(2) A decrease greater than 100°F (55°C) below the minimum specified temperature is allowable only for P-No. 1, Group Nos. 1 and 2 materials.

Table 6.1.1-3
Exemptions to Mandatory Postweld Heat Treatment

P-Number, Group Number (ASME BPVC, Section IX, Table QW/QB-422) [Note (1)]	Control Thickness, in. (mm) [Note (2)]	Type of Weld	Additional Limitations Required for Exemption From PWHT [Notes (3)–(5)]
P-No. 1, Group Nos. 1–3	All	All	1. Preheat of 200°F (95°C) is applied prior to welding on any nominal material thickness >1 in. (25 mm) 2. Multiple layer welds are used when nominal material thickness >$^{3}/_{16}$ in. (5 mm) [Note (6)]
P-No. 3, Group Nos. 1 and 2	≤$^{5}/_{8}$ in. (16 mm), except the thickness of a socket weld fitting or flange need not be considered	All	1. Preheat of 200°F (95°C) is applied prior to welding on any nominal material thickness >$^{1}/_{2}$ in. (13 mm) 2. Specified carbon content of the base materials ≤0.25% 3. Multiple layer welds are used when nominal material thickness >$^{3}/_{16}$ in. (5 mm) [Note (6)]
P-No. 4, Group No. 1	≤$^{5}/_{8}$ in. (16 mm)	Groove	1. Mandatory preheat has been applied 2. Specified carbon content of the base materials ≤0.15% 3. Multiple layer welds are used when nominal material thickness >$^{3}/_{16}$ in. (5 mm) [Note (6)]
	≤$^{5}/_{8}$ in. (16 mm), except the thickness of a socket weld fitting or flange need not be considered	Socket and fillet welds	1. Mandatory preheat has been applied 2. Throat thickness of the fillet weld or socket weld ≤$^{1}/_{2}$ in. (13 mm) 3. Specified carbon content of the pipe material ≤0.15% 4. Nominal material thickness of the pipe ≤$^{5}/_{8}$ in. (16 mm) 5. Multiple layer welds are used when nominal material thickness >$^{3}/_{16}$ in. (5 mm) [Note (6)]
	≤$^{5}/_{8}$ in. (16 mm)	Seal welds and non-load-carrying attachments [Note (7)]	1. Mandatory preheat has been applied 2. Multiple layer welds are used when nominal material thickness >$^{3}/_{16}$ in. (5 mm) [Note (6)]
P-No. 5A, Group No. 1	≤$^{5}/_{8}$ in. (16 mm)	Groove	1. Mandatory preheat has been applied 2. Specified carbon content of the base materials ≤0.15% 3. Multiple layer welds are used when nominal material thickness >$^{3}/_{16}$ in. (5 mm) [Note (6)]
	≤$^{5}/_{8}$ in. (16 mm), except the thickness of a socket weld fitting or flange need not be considered	Socket and fillet welds	1. Mandatory preheat has been applied 2. Throat thickness of the fillet weld or socket weld ≤$^{1}/_{2}$ in. (13 mm) 3. Specified carbon content of the pipe material ≤0.15% 4. Nominal material thickness of the pipe ≤$^{5}/_{8}$ in. (16 mm) 5. Multiple layer welds are used when nominal material thickness >$^{3}/_{16}$ in. (5 mm) [Note (6)]
	≤$^{5}/_{8}$ in. (16 mm)	Seal welds and non-load-carrying attachments [Note (7)]	1. Mandatory preheat has been applied 2. Multiple layer welds are used when nominal material thickness >$^{3}/_{16}$ in. (5 mm) [Note (6)]
P-No. 5B, Group No. 1	No exemptions from PWHT		
P-No. 6, Group Nos. 1–3	All	All	1. Specified carbon content of the base materials ≤0.08% 2. Nominal material thickness ≤$^{3}/_{8}$ in. (10 mm) 3. Weld filler metal is A-No. 8, A-No. 9, or F-No. 43 composition [Note (8)]
P-No. 7, Group No. 1	All	All	1. Specified carbon content of the base materials ≤0.08% 2. Nominal material thickness ≤$^{3}/_{8}$ in. (10 mm) 3. Weld filler metal is A-No. 8, A-No. 9, or F-No. 43 composition [Note (8)]

Table 6.1.1-3
Exemptions to Mandatory Postweld Heat Treatment (Cont'd)

P-Number, Group Number (ASME BPVC, Section IX, Table QW/QB-422) [Note (1)]	Control Thickness, in. (mm) [Note (2)]	Type of Weld	Additional Limitations Required for Exemption From PWHT [Notes (3)–(5)]
P-No. 7, Group No. 2	No exemptions from PWHT		
P-No. 8, Group Nos. 1–4	All	All	PWHT neither required nor prohibited
P-No. 9A, Group No. 1	All	All	1. Specified carbon content of the pipe material ≤0.15% 2. Nominal material thickness ≤½ in. (13 mm) 3. Mandatory preheat has been applied
P-No. 9B, Group No. 1	All	All	Nominal material thickness ≤⅝ in. (16 mm) and the WPS has been qualified using a material of equal or greater thickness than used in the production weld
P-No. 10H, Group No. 1	All	All	PWHT neither required nor prohibited
P-No. 10I, Group No. 1	All	All	PWHT neither required nor prohibited for nominal material thickness ≤½ in. (13 mm)
P-No. 15E	No exemptions from PWHT		

NOTES:
(1) If differences with the P-Number listed in Nonmandatory Appendix A are found, the P-Number listed in ASME BPVC, Section IX, Table QW/QB-422 applies.
(2) The control thickness is defined in para. 6.4.1.
(3) The nominal material thickness is defined in para. 6.4.3.
(4) No exemptions are permitted for PWHTs required by the WPS or as specified.
(5) Additional exemptions for welds made in accordance with para. 3.2.2 may be taken for the materials addressed.
(6) Single-layer or single-pass welds may be exempted from PWHT, provided the WPS has been qualified using single-pass welds with ±10% heat input and that all other conditions for exemption are met.
(7) Non-load-carrying attachments are defined as items where no pressure loads or significant mechanical loads are transmitted through the attachment to the pipe or pressure-containing material.
(8) A-Numbers and F-Numbers are found in ASME BPVC, Section IX, Tables QW-442 and QW-432, respectively.

Table 6.2-1
Approximate Lower Transformation Temperatures

Material	Approximate Lower Transformation Temperature, °F (°C)
Carbon steel (P-No. 1)	1,340 (725)
Carbon–molybdenum steel (P-No. 3)	1,350 (730)
1Cr–½Mo (P-No. 4)	1,375 (745)
1¼Cr–½Mo (P-No. 4)	1,430 (775)
2¼Cr–1Mo and 3Cr–1Mo (P-No. 5A)	1,480 (805)
5Cr–½Mo (P-No. 5B)	1,505 (820)
9Cr–1Mo (P-No. 5B)	1,475 (800)
9Cr–1Mo–V (P-No. 15E)	1,470 (800)

GENERAL NOTE: These values are intended for guidance only. The user may apply values obtained for the specific material in lieu of these values.

(23) ## 6.2 Mandatory PWHT Requirements

Heat treatment may be accomplished by a suitable heating method that will provide the desired heating and cooling rates, the required metal temperature, temperature uniformity, and temperature control.

(a) The upper limit of the PWHT temperature range in Table 6.1.1-1 is a recommended value that may be exceeded, provided the actual temperature does not exceed the lower transformation temperature of either material (see Table 6.2-1).

(b) When components of two different P-Numbers are joined by welding, the postweld heat treatment shall be that specified for the material requiring the higher PWHT temperature. When a nonpressure component is welded to a pressure component and PWHT is required for either component, the maximum PWHT temperature shall not exceed the maximum temperature acceptable for the pressure-retaining component.

(c) Caution is necessary to preclude metallurgical damage to some materials or welds not intended or qualified to withstand the PWHT temperatures required. The use of material transition joint designs may be required.

(d) The PWHT may be specified even if not mandatory in accordance with Table 6.1.1-1 or Table 6.1.1-3.

6.3 Exemptions to Mandatory PWHT Requirements

(23) **6.3.1 Exemptions.** For the following welds, postweld heat treatment is not required unless specified in the contract documents or the applicable WPS:

(a) welds in nonferrous materials except as required in Table 6.1.1-1

(b) welds exempted in Tables 6.1.1-1 and 6.1.1-3

(c) welds subject to temperatures during subsequent fabrication above the lower transformation temperature, provided the WPS has been qualified with PWHT at the temperature range to be reached

(d) thermocouple attachments made by low-energy capacitor discharge welding as exempted in para. 3.2

6.3.2 Chemical Composition. The postweld heat treatment exemptions of Tables 6.1.1-1 and 6.1.1-3 may be based on the actual chemical composition as determined by a ladle or product analysis in accordance with the material specification, in lieu of the specified or maximum specified chemical composition limits. Alternatively, the actual chemical composition may be determined by analysis of the material.

6.4 Definition of Thicknesses Governing PWHT

6.4.1 Control Thickness. Control thickness as used in Tables 6.1.1-1 and 6.1.1-3 is the lesser thickness of (a) or (b) as follows:

(a) the thickness of the weld (not including reinforcement)

(b) the thicker of the materials being joined at the weld or the thickness of the pressure-containing material if the weld is attaching a nonpressure-containing material to a pressure-containing material

6.4.2 Weld Thickness. Weld thickness, which is a factor in determining the control thickness, is defined as follows:

(a) groove welds (girth and longitudinal) — the thicker of the two abutting ends at the weld preparation, including machining of the inside or outside diameters

(b) fillet welds — the throat thickness of the weld

(c) partial-penetration welds — the depth of the weld groove preparation

(d) material-repair welds — the depth of the cavity to be repaired

(e) branch-connection welds — the weld thickness is the dimension that exists in a plane that intersects the longitudinal axes and is calculated as indicated for each detail using

$$t_c = \text{the smaller of } {}^{1}\!/\!_{4} \text{ in. (7 mm) or } 0.7t_{nb}$$

(1) for full-penetration branch-connection welds without a reinforcing pad or saddle

$$\text{weld thickness} = t_c + t_{nb} \text{ or } t_c + t_{nh}$$

where t_{nb} or t_{nh} is chosen based on the component that receives the full penetration weld

(2) for full-penetration branch-connection welds with a reinforcing pad or saddle

$$\text{weld thickness} = t_{nr} + \text{the weld thickness calculated in (e)(1)}$$

(3) for partial penetration branch connection welds

$$\text{weld thickness} = t_c + \text{the depth of the partial-penetration weld preparation}$$

where

t_c = nominal throat of cover fillet welds on branch connections
t_{nb} = nominal thickness of a branch pipe
t_{nh} = nominal thickness of a header or a run pipe
t_{nr} = nominal thickness of added reinforcement

NOTE: Typical branch connection details are shown in Nonmandatory Appendix C.

6.4.3 Nominal Material Thickness. Nominal material thickness as used in Table 6.1.1-3 is the thicker of the pressure-retaining materials being joined at the weld. If the material thicknesses are measured to determine the actual material thickness, the measured material thicknesses may be used to determine the PWHT hold-time requirements or exemptions for each joint on a case-by-case basis.

7 POSTFORMING AND MATERIAL HEAT TREATMENTS

This section covers postforming heat treatments (PFHT) and heat treatments intended to enhance the material microstructure.

7.1 PFHT

7.1.1 Hot Bending

7.1.1.1 Definition. Hot bending is a bending or forming process accomplished at a temperature above 1,300°F (705°C).

7.1.1.2 PFHT Requirements for Hot Bending and Forming. The applicable code or the design may require PFHT to recover material properties or to recover creep strength. Typically, the required heat treatment may involve normalizing and tempering or other heat treatment to recover the desired material condition.

7.1.2 Cold Bending

7.1.2.1 Definition. Cold bending is a bending or forming process accomplished at a temperature at or below 1,300°F (705°C).

7.1.2.2 PFHT Requirements for Cold Bending and Forming. The applicable code or the design may require PFHT to recover creep strength or to reduce residual stresses for components that have experienced cold strain. The required heat treatment may be a subcritical heat treatment in accordance with Table 6.1.1-1, a stress-relieving heat treatment for austenitic materials, or a normalizing and tempering heat treatment as specified by the applicable code or the design.

7.1.3 Heat Treatment After Forming of P-No. 10H Materials. For P-No. 10H materials, if heat treatment is required after forming, it shall be performed in accordance with the applicable material specification. (23)

7.2 Material Heat Treatment

A material heat treatment is not applicable when the heat treatment is accomplished as a requirement of a material specification. Heat treatment in accordance with this Standard may be specified when fabrication degrades the desired material properties.

8 ALTERNATIVES AND EXEMPTIONS TO PREHEAT AND PWHT REQUIREMENTS (23)

Exemptions to the rules for preheat and PWHT in sections 5 and 6 may be taken provided the specifying organization and the applicable regulatory authority agree. The WPS shall be qualified in accordance with the industry standard specified by the referencing code, specification, or standard, for the alternative preheat or PWHT to be used. The following are examples of exemptions:

(a) requiring an austenitizing PWHT on ferritic materials or a stress relief on austenitic materials

(b) requiring PWHT when necessary to enhance corrosion resistance even if the PWHT is not required by this Standard

(c) allowing low-temperature preheat [not below 50°F (10°C)] when other methods to specifically control high hardness or the susceptibility to hydrogen cracking are exercised

(d) accepting temper bead welding alternatives to PWHT if qualified in accordance with the rules of ASME BPVC, Section IX, QW-290 and the requirements of Nonmandatory Appendix D

(e) accepting fracture mechanics analysis as an alternative to otherwise required PWHT if qualified in accordance with the rules of ASME BPVC, Section IX and the requirements of Nonmandatory Appendix E

NONMANDATORY APPENDIX A
RECOMMENDATIONS FOR THE PROPER USE OF THERMOCOUPLES

A-1 THERMOCOUPLE TYPES AND USAGE

Thermocouples shall be selected based upon their maximum recommended temperature rating.

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

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

(23) A-2 PERMISSIBLE THERMOCOUPLE WIRE SIZE

The thermocouple wire size shall be a maximum of 20 gauge and a minimum of 24 gauge.

A-3 LOCATION

Each wire shall be attached separately to the surface of the workpiece, with the wires in close proximity [approximately $\frac{1}{4}$ in. (6 mm)] to each other. Maximum separation of the wires shall be held to $\frac{1}{4}$ in. (6 mm).

A-4 ATTACHMENT

The recommended attachment of thermocouples is in accordance with para. 3.2.

A-5 REMOVAL OF THERMOCOUPLES

During the removal stage, the location of each thermocouple should be adequately identified. Light filing or grinding followed by visual examination of the thermocouple attachment areas may be required. Care must always be exercised during filing or grinding to prevent removal of too much metal.

NONMANDATORY APPENDIX B
RECOMMENDATIONS FOR CONTROL OF NARROW TEMPERATURE RANGE HEAT TREATMENTS: LOCAL HEAT-TREATMENT METHODS

B-1 SCOPE

This Appendix describes the recommendations to be followed during the setup and application of local controlled PWHT when using electric resistance heating pads. The recommendations are required for P-No. 15E or other CSEF steel PWHTs [see para. 4.1.3(b)]. They are strongly recommended for dissimilar material welds where multiple temperature ranges overlap, requiring control of narrow ranges.

B-2 INTRODUCTION

During the manufacture, fabrication, or repair of P-No. 15E piping components, it may be necessary to heat components before welding (preheating), between passes (interpass heating), or after welding (hydrogen bakeout or PWHT). Typically, heat treatments are required by design or the applicable codes. Heat treatments can degrade materials or weldments if not properly accomplished by experienced personnel using controlled heat-treatment processes. If possible, local PWHT should be avoided in longitudinal welds due to higher pressure stresses, particularly for welds in CSEF steels. Furnace normalizing and tempering may be required by design.

B-3 GLOSSARY AND NOMENCLATURE FOR LOCAL HEATING

B-3.1 Glossary

This paragraph defines the terms used in describing local circumferential band heating. See Figures B-3.1-1 and B-3.1-2. Minimum requirements for these regions are presented in para. B-4.

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

component orientation: for the purposes of this Standard, 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: single temperature-measuring device that is located within the control zone to control the temperature of that control zone.

Figure B-3.1-1
Definition of Terms for Local Circumferential Band Heating of Pipe Weld

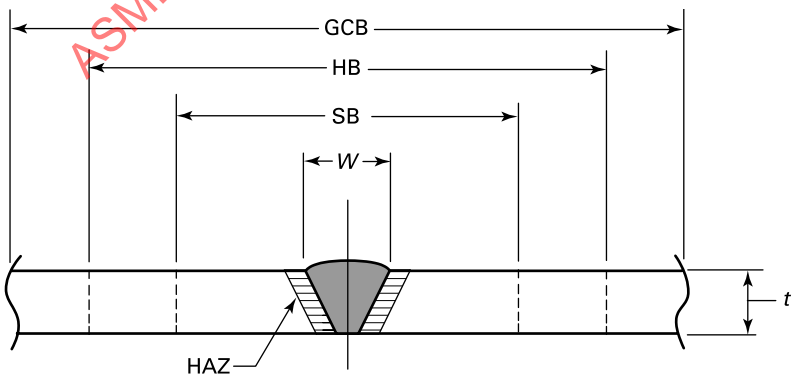
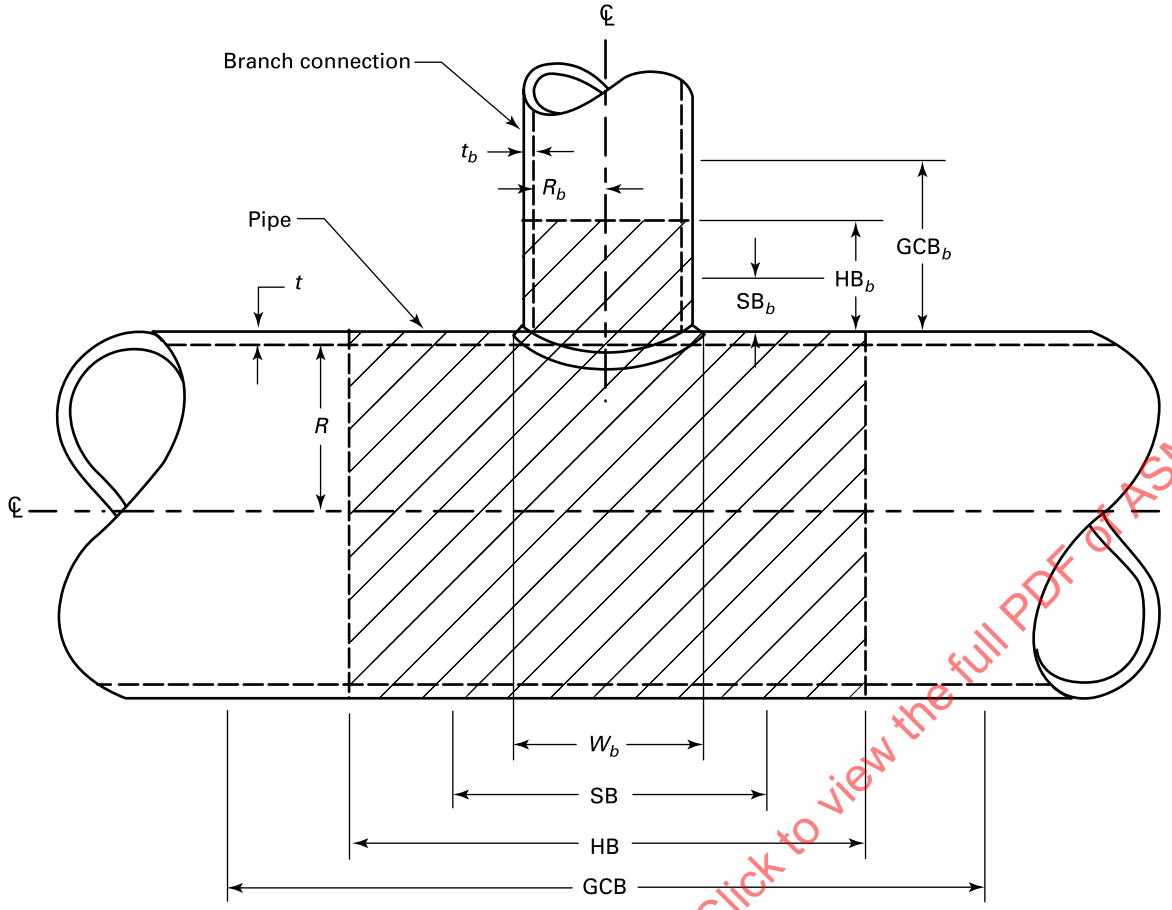


Figure B-3.1-2
Definition of Terms for Local Circumferential Band Heating of Branch Connection to Pipe Attachment Weld



Legend:

GCB, GCB_b = gradient control band (minimum width of insulation or gradient heat source, or both)
HB, HB_b = heated band (width of heat source), shown as shaded area
R, R_b = inside radius of pipe or branch connection
SB = soak band on pipe (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 W_b plus a multiple of t on each side of the weld attaching the branch connection.)
SB_b = soak band on branch connection. The minimum width is typically specified as a multiple of t_b beyond the widest width of the weld attaching the branch connection.
t, t_b = nominal thickness of pipe or branch connection
W_b = widest width of weld attaching the branch connection to the pipe

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

gradient control band (GCB): surface area over which insulation or supplementary heat source, or both, 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: under certain circumstances, extra heaters known as gradient control heaters or blocking heaters are installed adjacent to the heated band, to add additional 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.

heated band (HB): 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 to both control the temperature and achieve an acceptable temperature on the inside of the pipe or tube.

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

soak band (SB): through-thickness volume of metal that is required to be heated to within the postweld heat treatment temperature range. As 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.

B-3.2 Nomenclature

HAZ = heat-affected zone
t = nominal thickness of piping, branch connection, nozzle neck, or attachment
W = widest width of butt or attachment weld

B-4 LOCAL CIRCUMFERENTIAL BAND HEATING

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

B-4.1 Soak Band

The soak-band width for PWHT shall as a minimum be equal to the following. The thickness, t, is typically the nominal pipe wall thickness but measured thicknesses may be used.

(a) The minimum soak-band width requirement for PWHT shall be at least $3t$ with the weld at the centerline.

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

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

(d) For piping greater than NPS 8 (DN 200), the soak band shall be $10t$ on each side of the weld at its greatest width.

B-4.2 Heated Band

The minimum requirement for hydrogen bakeout heating shall be the lesser of t or 2 in. (50 mm) on each side of the weld at its greatest width.

The minimum requirement for the heated-band width shall be the soak-band width plus 2 in. (50 mm).

B-4.3 Gradient Control Band

The primary function of this band is to control the axial temperature gradient at the edges of the heated band. It also serves to minimize heat losses in the heated band. The width of the insulated area directly affects the axial temperature gradient. The insulated width may also need to be increased for personnel protection.

The gradient-control-band width shall as a minimum be equal to or greater than the heated-band width plus $4t$ on each side of the weld.

If the pipe-wall thickness changes, attachments are present within the gradient control band, or the pipe is being welded to flanges or valves, the use of one or more supplementary heat sources within the gradient control band may be required.

B-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.

During the heating, holding time, and cooling, the maximum axial temperature gradient for PWHT shall be limited such that the temperature at the edge of the heated band shall be no less than one-half the temperature at the edge of the soak band.

Table B-5.1-1
Requirements for Control Zones

Equivalent Pipe Size	Minimum Required Number of Circumferential Control Zones and Control Thermocouple Locations
Less than NPS 6 (DN 150)	One control zone, with the control thermocouple at 12 o'clock
NPS 6 (DN 150) up to and including NPS 12 (DN 300)	Two control zones, with control thermocouples at 12 o'clock and 6 o'clock
NPS 14 (DN 350) up to and including NPS 30 (DN 750)	Four control zones, with control thermocouples at 12 o'clock, 3 o'clock, 6 o'clock, and 9 o'clock
Over NPS 30 (DN 750)	Number of control zones and control thermocouples as required by actual heater configuration, circumferential spacing of heaters, and control bands, with at least one control thermocouple at 12 o'clock

B-5 DESIGN OF THE HEATING PROCESS

The design shall be as follows:

(a) Choice of the sizes, the number, and the electrical configuration of electric heating pads shall be based upon the geometrical configuration of the parts, the soak-band area, and the heated-band areas.

(b) All heating pads used in a single heat treatment shall be manufactured from the same materials and of the same watt density.

(c) 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.

(d) Heating pads shall be symmetrically located on either side of the weld preparation.

(e) Each control zone shall have at least one control thermocouple installed.

(f) In the case of horizontally oriented pipe and tube, a control thermocouple shall be installed at the 12 o'clock position.

(g) In the case of vertically oriented pipe and tube, at least one monitoring thermocouple shall be installed at the upper edge of the uppermost heating pad.

(h) One control or monitoring thermocouple shall be installed under each heater.

B-5.1 Postweld Heat Treatment

PWHT shall be as follows:

(a) The heating pads shall be installed to minimize gaps between the heaters. The gaps between the heaters shall not be greater than $^{3}/_{8}$ in. (10 mm) 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 one-third the wall thickness when the nominal wall thickness of the pipe exceeds 1 in. (25 mm). Where this is not possible, a monitoring thermocouple shall be placed in the center of all gaps that exceed this limit. The temperature shall not be less than the minimum soak band temperature within the gap.

(b) Overlapping of heaters is not allowed.

(c) Heater tails shall not be allowed to cross any other pad or heater tail.

(d) Heater tails shall be insulated from the pipe and shall be brought out through the insulation as close to the edge of the heater as possible.

(e) Control zones for horizontal piping shall as a minimum be in accordance with Table B-5.1-1.

(f) The number of control zones for vertical piping shall be in accordance with Table B-5.1-1. Separate control zones, above and below the weld, are required when more than one zone is required.

(g) Monitoring thermocouples shall also be installed at the outer edges of the soak band and at the outer edges of the heated band.

(h) The control zones for PWHT of welds joining piping to a thicker component or thicker pipe may require separate control zones for the thicker and thinner components. In such instances, additional monitoring thermocouples are recommended to ensure that the required temperatures are achieved on both the thinner and heavier wall thickness components.

B-5.2 Examples of Thermocouple Locations

Figures have been provided to show examples of the thermocouple locations for common local circumferential band PWHT applications. In some instances, both monitoring and control thermocouples are shown. Figures B-5.2-1 through B-5.2-3 provide required monitoring and control thermocouple locations for PWHT of butt welds in horizontally oriented piping with one, two, and four zones of control. Figure B-5.2-4 provides required monitoring thermocouple locations for PWHT of a weld attaching a branch connection to pipe. Control thermocouples shall be attached as required by the control-zone layout.

Figure B-5.2-1
Location of Thermocouples (Monitoring and Control) for Pipe Sizes Less Than NPS 6 (DN 150) and One Control Zone

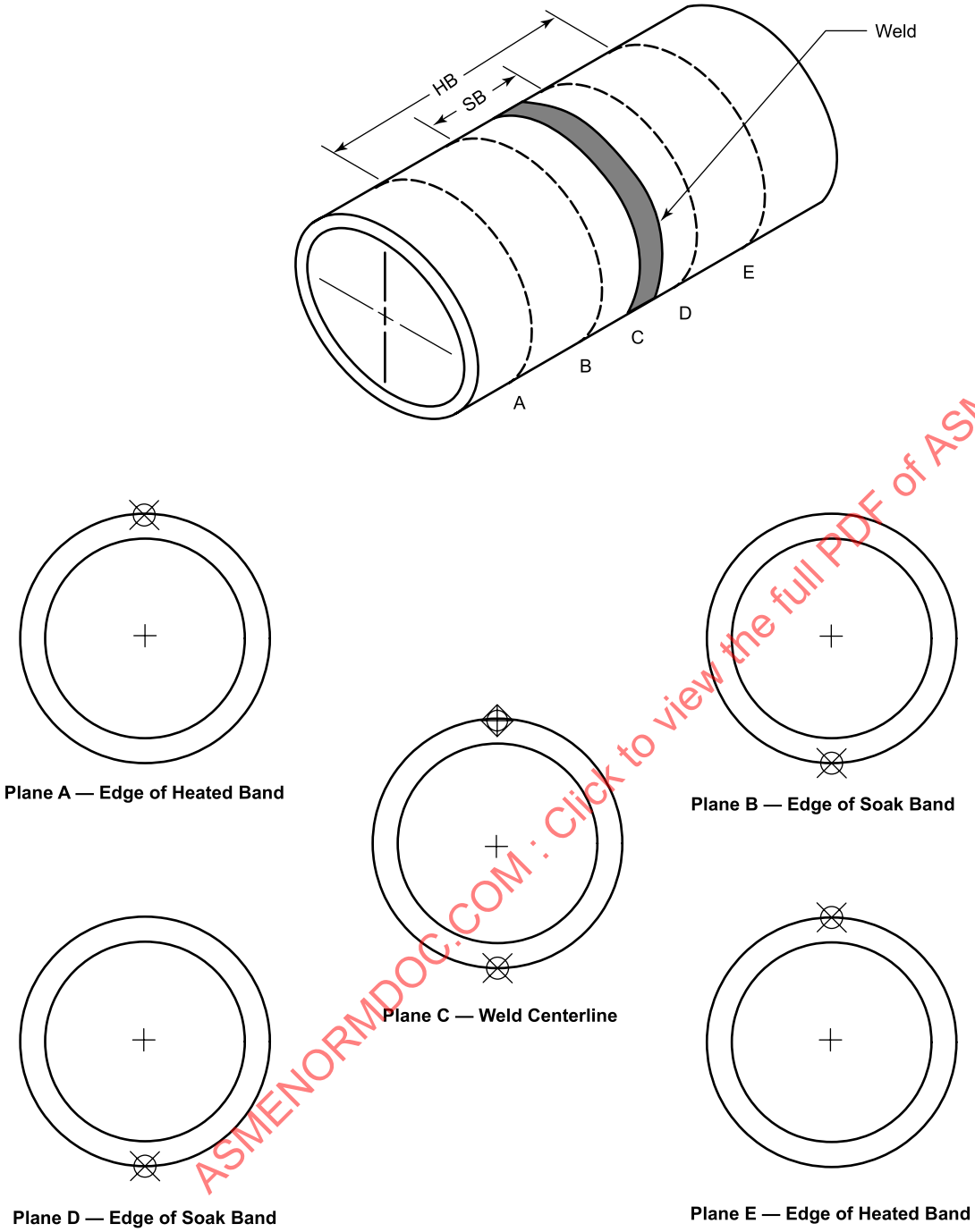


Figure B-5.2-2
Location of Thermocouples (Monitoring and Control) for Pipe Sizes NPS 6 (DN 150) Up to and Including NPS 12 (DN 300) and Two Control Zones

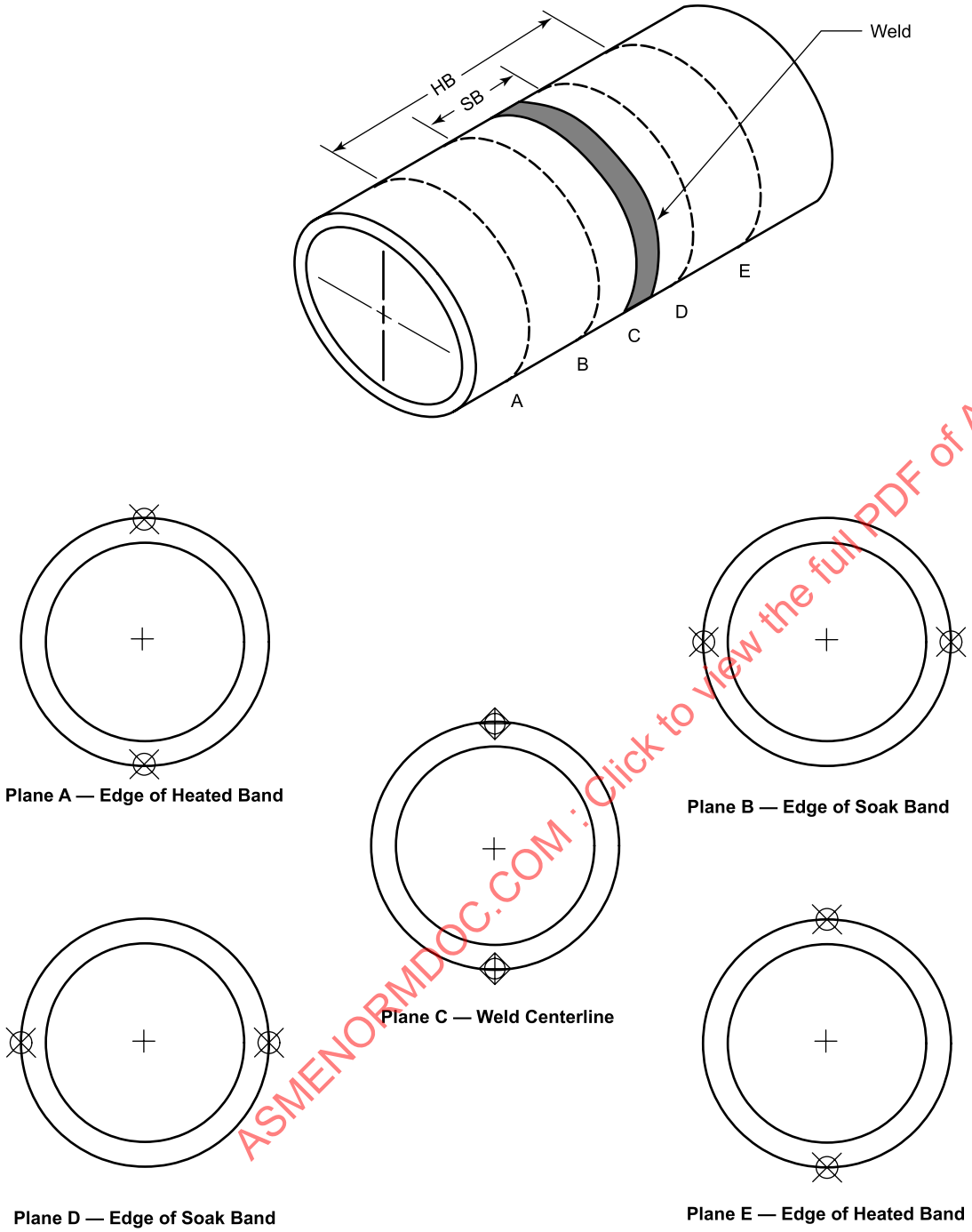
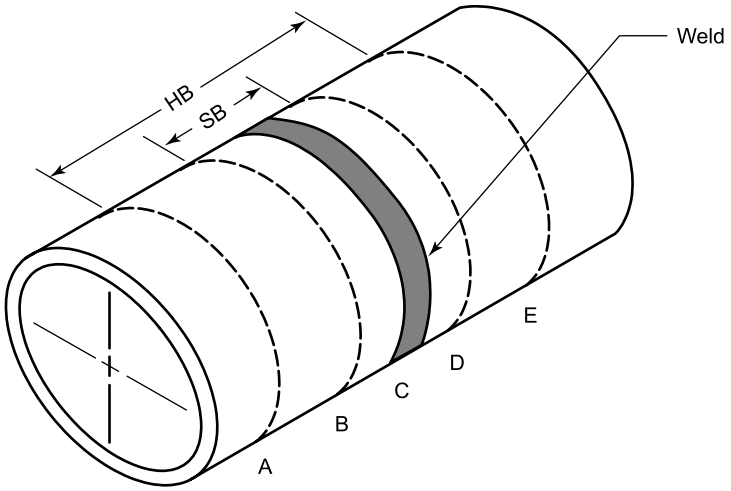
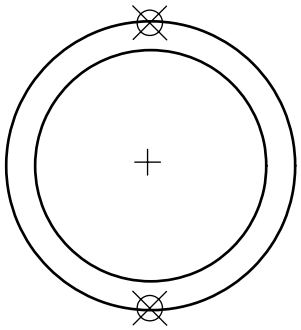
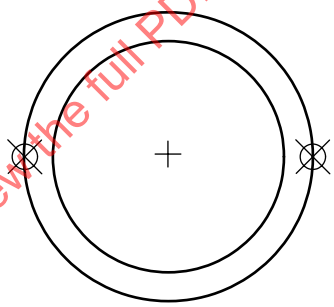


Figure B-5.2-3
Location of Thermocouples (Monitoring and Control) for Pipe Sizes NPS 14 (DN 350) Up to and Including NPS 30 (DN 750) and Four Control Zones

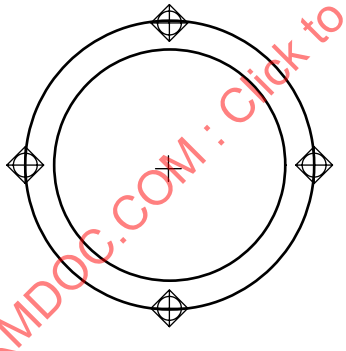




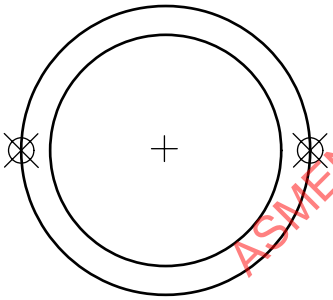
Plane A — Edge of Heated Band



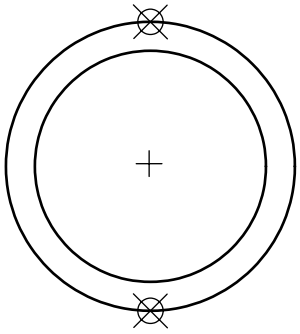
Plane B — Edge of Soak Band



Plane C — Weld Centerline



Plane D — Edge of Soak Band



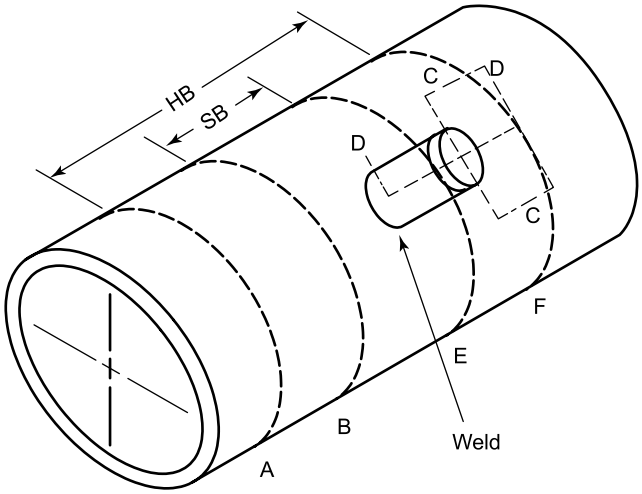
Plane E — Edge of Heated Band

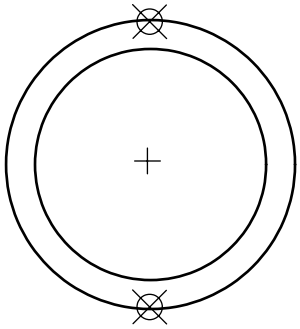
Legend:

Monitoring thermocouple location on outer surface

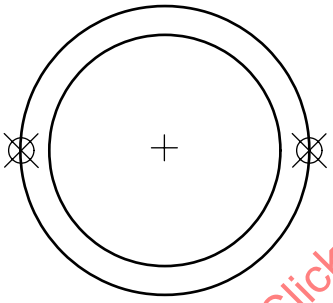
Control thermocouple location on outer surface

Figure B-5.2-4
Location of Monitoring Thermocouples for Branch Nozzle or Attachment Welds

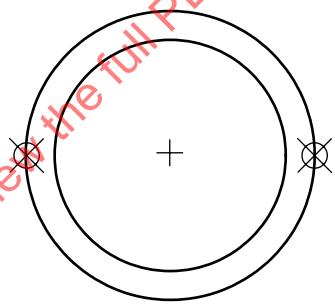




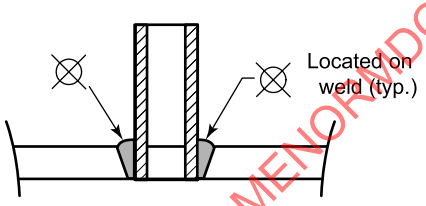
Planes A and F — Edge of Heated Band



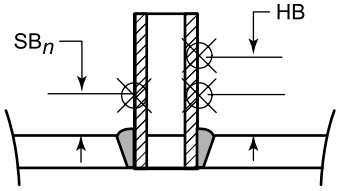
Plane B — Edge of Soak Band



Plane E — Edge of Soak Band



Section C-C



Section D-D

Legend:

⊗ Monitoring thermocouple location on outer surface

B-5.3 Special Considerations

Due to natural internal convection heat flow, the upper side of the soak or heated zones may be considerably hotter than the lower side. To help avoid exceeding the maximum allowed temperature, the following shall be considered in addition to the requirements in the Standard:

(a) Horizontal Piping. One control thermocouple shall always be installed at the 12 o'clock position for horizontal piping.

(b) Vertical Piping. For welds in vertical piping, the following shall be considered:

(1) Air circulation dams may be placed inside the pipe, preferably above the weld, to block the "chimney effect" within the pipe.

(2) The heated band may be biased such that approximately 60% of the heated band area is below the weld.

(3) Separate control zones, above and below the weld, may be used. Gradient control or blocking heaters may also be installed below the weld, to balance the heat flow and to form a biasing of the heated band.

(c) Butt Welds Joining Piping to Valves and Flanges. During PWHT of butt welds between piping and components such as valve bodies or heavy flanges, consideration shall be given to the uneven conductive heat loss on each side of the weld. 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. To counter the effect of different thicknesses, the heat input may be biased to the thicker side of the joint; this may be accomplished by

(1) use of separate control zones on the thicker and thinner components

(2) biasing the heating elements towards the heavier component

(3) reducing the volume of insulation used on the thinner section heated band to achieve the desired temperature profile across the soak band

(d) Butt Welds Joining Branch Connections or Attachments to Piping

(1) For welds joining branch connections or attachments to pipe, 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.

(2) 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.

(3) Where small branch connections, ½ in. to 1½ in. (13 mm to 38 mm) outside diameter, are welded to larger pipe sections, circumferential bands around both the larger pipe and smaller branch connection shall be heated using heaters with control thermocouples on the larger pipe and with monitoring thermocouples on the smaller branch connection. If separate control zones are used for the larger pipe and smaller branch connection, they shall each have separate control thermocouples.

(e) Intersection With Branch Connections and Attachments Not Requiring PWHT. 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 to the branch connection or attachment.

(1) 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.

(2) Figure B-5.3-1 provides an example of such an approach when the heated band from a weld requiring PWHT intersects a nozzle that does not require PWHT. Note that 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 $L = 2\sqrt{(Rt)}$.

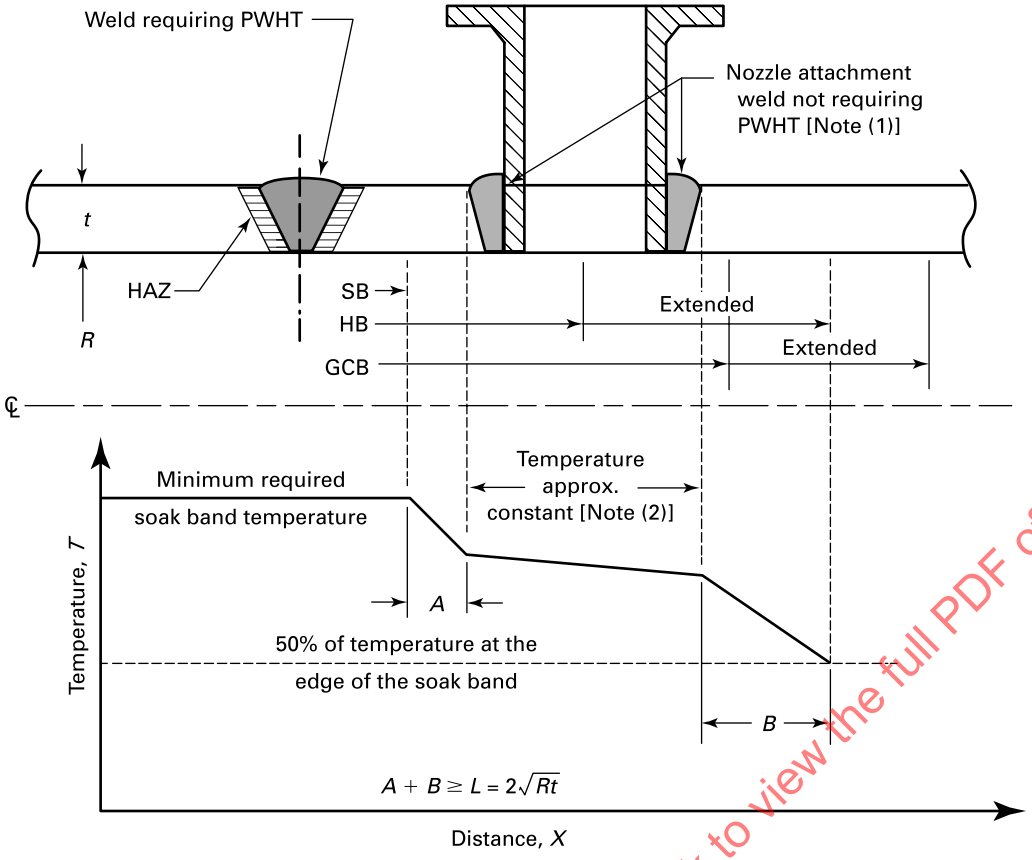
(3) It should be noted that although the nonspecific term "reasonably uniform" is used to describe the temperature drop across the intersected component, the aim is to maintain a "reasonably constant" temperature drop across the intersected component. However, to provide a measurable limit, a maximum temperature drop is recommended as stated below.

(4) The maximum temperature drop across an intersected component shall be 100°F (55°C) or that resulting from application of the maximum permissible axial temperature gradient.

(5) It is also recognized that based upon experience or analysis, larger temperature gradients across nozzles or attachments may exhibit permissible levels of distortion or residual stress.

(f) 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.

Figure B-5.3-1
Example of One Approach When the Heated Band From a Weld Requiring PWHT Intersects a 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
SB = 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

NOTES:
(1) The nozzle attachment weld shown as "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.
(2) 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.

(g) 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.

B-5.4 Control of the PWHT Thermal Cycle

Four aspects of the thermal cycle associated with heating operations shall be controlled. These are 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) Maximum Heating Rate. The maximum heating rate shall be as specified in para. 4.2.

(c) Maximum Hold Temperature and Time. During hold, the requirements for the maximum hold temperature shall be as defined in Table 6.1.1-1. The hold time shall be within the requirements of the WPS if limited.

(d) Maximum Cooling Rate. The maximum cooling rate shall be as specified in para. 4.2.

B-5.5 Insulation

(a) Classification of Insulation. The requirements for the gradient control band width are based upon insulation R-values of 2°F-ft^2-hr/Btu to 4°F-ft^2-hr/Btu (0.35°C-m^2/W to 0.70°C-m^2/W). Refractory ceramic fiber insulation with a density of 6 lb/ft^3 to 8 lb/ft^3 (96.1 kg/m^3 to 128.1 kg/m^3) meets this requirement. A minimum 1 in. (25 mm) layer of insulation thickness shall be used for temperatures up to and including 1,200°F (650°C); a minimum 2 in. (50 mm) of insulation thickness 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 pieces are wrapped around the pipe, the pipe surfaces shall be fully covered with the ends of the insulation either butted against or overlapped to preclude heat loss. No gaps shall be permitted in the insulation layer and any inadvertent gaps should 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-fourths of its original thickness during banding or tying.

(c) During heating, the insulation has a tendency to shrink and, in doing so, 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 losses and assure that the permissible maximum axial temperature gradient from heated to unheated sections is not exceeded.

(23) B-5.6 Quality Requirements

(a) Process Control. Written procedures and associated drawings shall be used. The standard procedure for local heating shown in Form B-5.6-1, or an equivalent, shall be used in conjunction with a drawing that specifies placement of thermocouples, heat sources (including control zones), and insulation.

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

(1) The record of the thermal cycle, including copies of the procedures and drawings, shall be available to the responsible organization upon the completion of local heating. The record of the thermal cycle should contain information such as the temperature and time scales and the correspondence between thermocouple numbers on the record and the drawing. The records provided may be electronic or printed copy.

(2) The standard documentation checklist for local heating shown in Form B-5.6-2, or an equivalent, shall be used as a basis for provision of documentation. While the format of the checklist need not be identical, the information it includes shall be the same. This checklist, plus supporting documentation, shall be submitted to the customer at the completion of local heating.

(c) 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, if requested, made available.

B-5.7 Other Design Considerations

Additional design issues shall be considered when performing local heating of pipe. Factors that may be important during the heat treatment cycle include the following:

(a) proper support of the pipe at the strength level that will exist at the maximum temperature to be reached

(b) convection air flow within the pipe

(c) due to thermal expansion, large thermal stresses can be developed during PWHT if adequate provisions to permit thermal growth are not made

(d) the presence of internal fluids within or adjacent to the heated area

(23)

Form B-5.6-1
Standard Procedure for Local Heating

Procedure no.: _____ Revision no.: _____ Date: _____

Governing code: _____

Workpiece identification no.: _____

Material specification: _____

Component dimensions: _____

Thermocouple, heater, and insulation layout drawing no.: _____

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 _____ ° _____

Steps

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: _____

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

   Completed by: _____ Date: _____

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

   Serial no.: _____ Date next calibration due: _____

   Serial no.: _____ Date next calibration due: _____

   Serial no.: _____ Date next calibration due: _____

   Serial no.: _____ Date next calibration due: _____

   Completed by: _____ Date: _____

4. Install thermocouples (including spares) in accordance with drawing/sketch using approved methods. See direct attachment by low-energy capacitor discharge welding, para. 3.2.

   Completed by: _____ Date: _____

Form B-5.6-1 (Cont'd)

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

   Verified by: _____ Date: _____

6. Install heat sources and insulation in accordance with drawing/sketch using approved methods.

   Completed by: _____ Date: _____

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

   Verified by: _____ Date: _____

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: _____

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

   Completed by: _____ Date: _____

10. Obtain approval to begin the heating operation.

    Approved by: _____ Date: _____

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 responsible organization should be notified and a decision made regarding whether to continue heating.

    Completed by: _____ Date: _____ Time: _____

    Completed by: _____ Date: _____ Time: _____

    Completed by: _____ Date: _____ Time: _____

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

    Verified by: _____ Date: _____

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 responsible organization 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: _____

Form B-5.6-1 (Cont'd)

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: _____ Date: _____

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: _____

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

    Completed by: _____ Date: _____

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: _____

18. Note any deviations such as in the heating rate, hold time and temperature, or cooling rate that occurred during the thermal cycle. If no deviations occurred, enter "None."

    _____

    _____

    _____

    _____

    _____

    Completed by: _____ Date: _____

19. Complete, and submit to the customer, appropriate documentation in accordance with the standard documentation checklist (Form B-5.6-2).

    Received by: _____ (customer's representative) Date: _____