ArevaEPRDCPEm Resource

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Sent: Wednesday, June 23, 2010 6:28 PM
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Subject: DRAFT Response to U.S. EPR Design Certification Application RAI No. 278, FSAR Ch. 5, Supplement 5
Attachments: RAI 278 Supplement 5 Response - DRAFT.pdf

Getachew,

Attached is a draft response for RAI 278 Supplement 5. Earlier today, AREVA submitted Supplement 4 that provided a date for the final response as July 27, 2010. Let us know if you have any further questions or if we can submit as final

Sincerely,

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Response to

Request for Additional Information No. 278, Supplement 5
9/14/2009

U.S. EPR Standard Design Certification
AREVA NP Inc.
Docket No. 52-020
SRP Section: 05.02.03 - Reactor Coolant Pressure Boundary Materials
SRP Section: 05.03.02 - Pressure-Temperature Limits, Upper-Shelf Energy, and Pressurized Thermal Shock

Application Section: FSAR Ch. 5

QUESTIONS for Component Integrity, Performance, and Testing Branch 1 (AP1000/EPR Projects) (CIB1)

Question 05.02.03-20:

POTENTIAL OPEN ITEM

In RAI 05.02.03-18, the staff requested, in part, that the applicant modify Table 5.2-2 to list weld filler metal specifications and classifications used to weld various material types and combinations in the RCPB. The applicant responded, by letter dated April 23, 2009, and stated that weld filler material specifications are listed in U.S. FSAR Section 5.2.3.1 and that no revision to Table 5.2-2 is required. The staff notes that Table 5.2-2 lists weld filler material specifications and classifications for fabrication of the reactor coolant pump, and CRDM but does not provide weld filler material specifications and classifications for fabrication of the RCPB piping, steam generators or pressurizer. The staff requests that the applicant modify Table 5.2-2 to lists the weld filler material specifications and classifications for components listed in Table 5.2-2.

Response to Question 05.02.03-20:

U.S. EPR FSAR Tier 2, Table 5.2-2—Material Specifications for RCPB Components will be updated to include weld filler metal specifications. These include material specifications for ferritic steel, austenitic stainless steel, and nonferrous weld materials.

Weld filler metal classifications are provided for some of the specifications in U.S. EPR FSAR Tier 2, Table 5.2-2. Detailed weld classifications for the remaining weld specifications will be identified later in the design process, at which time these weld classifications will be made available for NRC inspection.

FSAR Impact:

U.S. EPR FSAR Tier 2, Table 5.2-2 will be revised as described in the response and indicated on the enclosed markup.

Question 05.02.03-21:

POTENTIAL OPEN ITEM

FSAR Section 5.2.3.4.6 states:

The RCP casing is made from ASME SA-351 Grade CF3 material with additional restrictions on silicon (1.5% maximum) and niobium (restricted to trace elements). In addition, the ferrite content of cast austenitic stainless components in the RCPB will be limited to a ferrite content of less than 20 percent. These restrictions reduce susceptibility to thermal aging (Section 3.6.3.3.6). For cast austenitic stainless steel material used in the RCPB, the percent ferrite is calculated using Hull's equivalent factors as indicated in NUREG/CR-4513 Rev. 1 (May 1994).

The FSAR statement above is acceptable for CASS materials currently listed in Table 5.2-2 which contain a maximum of 0.5 % molybdenum. However, in response to RAI 05.02.03-18, the applicant provided a proposed modification to Table 5.2-2. The applicant's proposed modified Table 5.2-2 includes RCPB valve specifications and grades as requested by the staff in RAI 05.02.03-18. The staff notes that the applicant's proposed revised Table now includes CASS grades CF3M and CF8M for the fabrication of RCPB valves. These two materials contain molybdenum ranging between 2.0-3.0% which increases their susceptibility to thermal aging embrittlement. To be consistent with staff guidance, these materials should have a ferrite content of ≤14% to be considered not susceptible to thermal aging embrittlement. The staff requests that the applicant modify the FSAR to limit the ferrite content of high Molybdenum RCPB CASS components, such as CF3M and CF8M, to ≤14%.

Response to Question 05.02.03-21:

For cast austenitic stainless steel components that will experience service temperatures greater than 482°F, the delta ferrite content is limited as described in the following changes to the U.S. EPR FSAR.

U.S. EPR FSAR Tier 2, Section 5.2.3.4.6 will be revised to include the following:

> "For cast austenitic stainless steel components that experience service temperatures greater than 482°F, the delta ferrite content is limited to less than or equal to 20 percent for low molybdenum content statically cast materials, less than or equal to 14 percent for high molybdenum content statically cast materials, and less than or equal to 20 percent for high molybdenum content centrifugally cast materials. Low molybdenum content is defined as 0.5 wt% maximum and high molybdenum content is defined as 2.0-3.0 wt%."

U.S. EPR FSAR Tier 2, Table 5.2-2—Material Specifications for RCPB Components will be revised to include a new Note 10 that explains the classification of cast austenitic stainless steel materials.

U.S. EPR FSAR Tier 2, Section 3.6.3.3.6 will be revised to include the following:

> "Ferrite limitations for CASS RCPB materials are described in Section 5.2.3.4.6."

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 3.6.3.3.6, Section 5.2.3.4.6, and Table 5.2-2 will be revised as described in the response and indicated on the enclosed markup.

Question 05.02.03-22:

POTENTIAL OPEN ITEM

In FSAR Section 5.2.3.4.1, the applicant states that stabilized grades of austenitic stainless steels have a stabilizing heat treatment above 800°F. The only stabilized stainless steel material (Grade 347), identified by the staff, used to fabricate components in the RCS pressure boundary, is used to fabricate the CRDM pressure housing. In response to RAI 05.02.03-17, dated June 5, 2009, the applicant stated that no stabilizing heat treatment will be performed for Grade 347 used for the CRDM pressure housing. There appears to be an inconsistency between the FSAR, which references stabilizing heat treatments and the applicant's response to RAI 05.02.03-17 which indicates that Grade 347 used to fabricate the CRDM will not receive a stabilizing heat treatment. The staff requests that the applicant address this inconsistency and modify the FSAR accordingly.

Response to Question 05.02.03-22:

The control rod drive mechanism (CRDM) pressure housings are the only reactor coolant system pressure boundary components that will be fabricated of stabilized austenitic stainless steel. Stabilizing heat treatment will not be performed on the stabilized austenitic stainless steel used for the CRDM pressure housing.

U.S. EPR FSAR Tier 2, Section 5.2.3.2.2 and Section 5.2.3.4.1 will be revised to be consistent with the Response to RAI 199, Supplement 1, Question 05.02.03-17.

U.S. EPR FSAR Tier 2, Section 5.2.3.4.1 will be modified to include the following:

> "Stabilizing heat treatment is not performed for the stabilized austenitic stainless steels. The only heat treatment performed in the course of steel manufacturing is solution annealing with a maximum temperature not to exceed 2012°F, followed by quenching in water or equivalent rapid cooling in air to prevent grain boundary carbide precipitation.
>
> Postweld heat treatment (PWHT) is performed on CRDM pressure housing components joined by welding. The sensitization concern in the stabilized austenitic stainless steel is eliminated by the compositional requirement and additional testing during welding procedure qualification. Welding procedure qualification is based on ASME Section III and Section IX with additional test requirements. During procedure qualification, tests and examinations are performed in the as-welded and PWHT condition. Corrosion testing per ASTM A 262 Practice E is performed to the qualification weld, which is identical to the actual welded joint including the stabilized austenitic stainless steel base metal.
>
> The carbon content of the sensitized material is limited to a maximum of 0.04 percent. The minimum stabilization ratio of niobium to carbon (Nb/C) is specified as 13 for the stabilized austenitic stainless steel component that receives PWHT. Additionally, the minimum allowable chromium content is increased to 18 percent. As required by the material specification, stabilized austenitic stainless steel is corrosion tested according to ASTM A 262 Practice E after being subjected to sensitizing heat treatment. In any ASTM A 262 test, intergranular attack is not permitted regardless of depth."

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 5.2.3.2.2 and Section 5.2.3.4.1 will be revised as described in the response and indicated on the enclosed markup.

Question 05.02.03-23:

POTENTIAL OPEN ITEM

FSAR Section 5.2.3.2.2 states that unstabilized austenitic stainless steels are not heated above 800°F, other than locally by welding operations, after the final heat treatment. FSAR Section 5.2.3.4.1 states that utilization of materials in the solution annealed plus rapidly cooled condition and the prohibition of subsequent heat treatments in the 800°F to 1500°F temperature range is one of five methods used to avoid intergranular attack in austenitic stainless steel. These statements appear to be inconsistent with the applicant's process for joining low alloy steel nozzles to austenitic stainless steel safe-ends which requires that safe-ends be subject to post weld heat treatment.

The staff requests that the applicant modify the FSAR to address these inconsistencies by discussing those components used in the solution annealed and rapidly cooled condition and those that will be used in the solution annealed and rapidly cooled condition followed by post weld heat treatment after welding.

In addition, in order to make the FSAR clear as to the requirements for testing of post weld heat treated stainless steel safe-ends, the staff requests that the applicant modify FSAR Section 5.2.3 to state that for post weld heat treated austenitic stainless steel safe-ends, non-sensitization of the safe-ends will be verified in accordance with RG 1.44.

Response to Question 05.02.03-23:

To the extent possible, fabrication sequences are selected to avoid subjecting austenitic stainless steel materials to post weld heat treatments. However, where this is not possible, as is the case of welding the austenitic stainless steel safe ends directly to the component low alloy steel nozzles, the materials are subjected to additional requirements to verify that they will not be sensitized during the heat treatments in accordance with RG 1.44. Specifically, the unstabilized austenitic stainless steels heated in the sensitization range of 800˚F - 1500˚F for ≥ 60 minutes will be tested in accordance with ASTM A-262 as required by RG 1.44. Additionally, low carbon (not exceeding 0.03wt% carbon) unstabilized austenitic stainless steel materials are used, as required by RG 1.44.

The welds between the low alloy steel nozzles and stainless steel safe ends of the reactor pressure vessel, steam generator and pressurizer nozzles are performed with NiCrFe alloy weld filler material and subjected to a post weld heat treatment. However, these may not be the only stainless steel materials in the reactor coolant system pressure boundary equipment (for which procurement has not been performed) that may be subjected to postweld heat treatment. The austenitic stainless steel safe ends are an example of when additional testing is required, but may not be the only components subjected to further testing.

U.S. EPR FSAR Tier 2, Section 5.2.3.4.1 will be revised to reflect this information.

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 5.2.3.4.1 will be revised as described in the response and indicated on the enclosed markup.

Question 05.03.02-7:

POTENTIAL OPEN ITEM

Provide a table of the data points (reactor coolant temperature vs. pressure) for each P-T curve displayed in Technical Report ANP-10283, Revision 1.

Response to Question 05.03.02-7:

Table 05.03.02-7-1—RCS Heatup Limits at 60 EFPY and Table 05.03.02-7-2—RCS Cooldown Limits at 60 EFPY contain the data points for Figure 6-1—U.S. EPR RCS P-T Limits – Normal Heatup with ISLH and Criticality Limit Curves Applicable to 60 EFPY and Figure 6-2—U.S. EPR RCS P-T Limits – Normal Cooldown Applicable to 60 EFPY in Technical Report ANP-10283P, "U.S. EPR Pressure-Temperature Limits Methodology for RCS Heatup and Cooldown," respectively.

Technical Report ANP-10283P has been revised to include Table 05.03.02-7-1 and Table 05.03.02-7-2.

While preparing the response to this question, an error was identified in the criticality limit on Figure 6-1 in Technical Report ANP-10283P. This figure has been revised to eliminate the error. Table 05.03.02-7-1 contains the correct data points for the criticality limit.

U.S. EPR FSAR Tier 2, Figure 5.3-1—Reactor Coolant System Heatup Pressure-Temperature Curve is also affected by the error identified in Figure 6-1. U.S. EPR FSAR Tier 2, Figure 5.3-1 will be revised to eliminate the error.

FSAR Impact:

U.S. EPR FSAR Tier 2, Figure 5.3-1 will be revised as described in the response and indicated on the enclosed markup.

Technical Report Impact:

ANP-10283P, "U.S. EPR Pressure-Temperature Limits Methodology for RCS Heatup and Cooldown," Revision 2 incorporates the changes as described in the response.

Table 05.03.02-7-1—RCS Heatup Limits at 60 EFPY

(Does not include margin for instrument uncertainty)

Normal Heatup		Criticality Limit		Inservice Leak and Hydrostatic Test Limit	
Fluid Temp. (°F)	Hot Leg Press. (psig)	Fluid Temp. (°F)	Hot Leg Press. (psig)	Fluid Temp. (°F)	Hot Leg Press. (psig)
50	0	221	0	200	1457
50	611	221	807	205	1705
55	611	225	868	210	1953
60	611	230	943	215	2202
65	611	235	1019	217	2301
70	611	240	1095	220	2400
75	611	245	1170	220.53	2476
80	611	250	1246		
85	611	251	1261		
90	611	255	1459		
95	611	260	1707		
100	611	265	1954		
105	611	270	2202		
110	611	272	2301		
115	611	275	2457		
120	611	275.37	2476		
125	611				
130	611				
135	611				
140	611				
145	611				
150	611				
155	611				
160	611				
165	611				
168	611				
170	641				
175	717				
180	792				
185	868				
190	943				
195	1019				
200	1095				
205	1170				
210	1246				
211	1261				
215	1459				
220	1707				
225	1954				
230	2202				
232	2301				
235	2457				
235.37	2476				

Table 05.03.02-7-2—RCS Cooldown Limits at 60 EFPY

(Does not include margin for instrument uncertainty)

Fluid Temp. (°F)	Hot Leg Press. (psig)
50	0
50	611
52	611
57	611
62	611
67	611
72	611
77	611
82	611
87	611
91	611
96	611
101	611
106	611
111	611
116	611
116	1468
121	1527
122	1680
123	1704
128	1830
133	1970
138	2099
143	2200
148	2312
153	2435
158	2572

Question 05.03.02-8:

POTENTIAL OPEN ITEM

Clarify the thickness value (including vessel thickness and cladding thickness) used to calculate the fluence at the 1/4t and 3/4t locations for all materials provided in Technical Report ANP-10283, Rev.1.

Response to Question 05.03.02-8:

Note 3 of Table 6-1—Chemical Composition and Projected Fluence for the U.S. EPR Reactor Vessel Materials through 60 EFPY in Technical Report ANP-10283P, "U.S. EPR Pressure-Temperature Limits Methodology for RCS Heatup and Cooldown," states that the neutron fluence at the 1/4T and 3/4T locations are calculated using Equation 3 of RG 1.99, Revision 2 using a vessel thickness of 9.84 inches with a cladding thickness of 0.20 inches (the cladding thickness value used in the calculation is a minimum value). The vessel and cladding thickness values were used to calculate the neutron fluence.

In RG 1.99, Revision 2, Equation 3, variable x is the depth into the vessel wall measured from the vessel inner (wetted) surface. The 1/4t and 3/4t locations are 1/4 and 3/4 through the vessel thickness (9.84 inches). Therefore, variable x is calculated as follows:

1/4t location: $x = [9.84 \times 0.25] + 0.20 = 2.66\ inches$

3/4t location: $x = [9.84 \times 0.75] + 0.20 = 7.58\ inches$

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 05.03.02-9:

POTENTIAL OPEN ITEM

Provide all values (i.e., chemistry factors, fluence factors, margins, ΔRT_{NDT}, etc.) used to calculate the ART at the 1/4t and 3/4t locations for all applicable materials provided in Technical Report ANP-10283, Rev. 1.

Response to Question 05.03.02-9:

The values used to calculate the 1/4T and 3/4T adjusted reference temperature (ART) values are provided in Table 05.03.02-9-1—Factors Used to Calculate the US EPR ART Values.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Table 05.03.02-9-1—Factors Used to Calculate the US EPR ART Values

Reactor Vessel Location	Initial RT_{NDT}, °F	60 EFPY Fluence, n/cm^2			Fluence Factor		Chemistry Factor, °F	ΔRT_{NDT}, °F at 60 EFPY		Margin, °F	
		Inner wetted surface (f_{surf})	1/4T Location	3/4T Location	¼T Location	¾T Location		¼T Location	¾T Location	¼T Location	3/4T Location
ANP-10283P Reference	Table 6-2	Table 6-1	Table 6-1 (1)	Table 6-1 (1)	Equation 3-3	Equation 3-3	Table 6-1	Equation 3-2	Equation 3-2	Table 6-2 Note 1	Table 6-2 Note 1
Nozzle Shell	-4	2.103E+17	1.111E+17	3.410E+16	0.118	0.050	51.0	6.0	2.6	6.0	2.6
Upper Core Shell	-4	1.375E+19	7.262E+18	2.230E+18	0.910	0.596	37.0	33.7	22.1	33.7	22.1
Lower Core Shell	-4	1.375E+19	7.262E+18	2.230E+18	0.910	0.596	37.0	33.7	22.1	33.7	22.1
Transition Ring	-4	4.406E+18	2.327E+18	7.145E+17	0.606	0.353	51.0	30.9	18.0	30.9	18.0
Weld #1	-4	2.103E+17	1.111E+17	3.410E+16	0.118	0.050	82.0	9.7	4.1	9.7	4.1
Weld #2	-4	1.368E+19	7.225E+18	2.218E+18	0.909	0.594	82.0	74.5	48.7	56.0	48.7
Weld #3	-4	4.406E+18	2.327E+18	7.145E+17	0.606	0.353	82.0	49.7	28.9	49.7	28.9

Note 1: See the response to Question 05.03.02-8 for the calculation of neutron fluence at depths of 1/4T and 3/4T.

Question 05.03.02-10:

POTENTIAL OPEN ITEM

To address PTLR Criterion 4(GL 96-03), clearly identify both the limiting adjusted reference temperature (ART) values and limiting materials at the 1/4t and 3/4 t locations (t= vessel thickness) used in the development of the P-T limits.

Response to Question 05.03.02-10:

The limiting adjusted reference temperature (ART) values were 126.5ºF at ¼ t and 93.4ºF at ¾ t for the circumferential seam weld and 63.4ºF at ¼ t and 40.2ºF at ¾ t for the base metal forging (generic bounding value considered for both upper and lower shell forging). The limiting circumferential seam weld is the upper shell to lower shell weld in the reactor pressure vessel beltline region. The limiting forging material is the reactor pressure vessel beltline upper and lower shell forging. The pressure-temperature limits were developed based on the above limiting circumferential seam weld and forging materials.

Technical Report ANP-10283P has been revised to reflect the limiting ART values and limiting materials.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Technical Report Impact:

ANP-10283P, “U.S. EPR Pressure-Temperature Limits Methodology for RCS Heatup and Cooldown,” Revision 2 incorporates the changes as described in the response.

U.S. EPR Final Safety Analysis Report Markups

3.6.3.3.6 Thermal Aging

Forged austenitic stainless steel is used for the MCL and SL piping. Austenitic stainless steel forgings have a low susceptibility to thermal aging. The welds in the MCL stainless steel piping are fabricated using the gas tungsten arc welding (GTAW) process and meet the requirements of the ASME Code, Section III and the guidance of RG 1.31, which minimizes the effects of thermal aging. Lower bound toughness properties used in flaw stability analysis conservatively considers reduction because of thermal aging in the stainless steel weld metal and the component nozzles.

The component in the RCS loop that is predicted to experience the greatest reduction in toughness due to thermal aging is the RCP casing, which is made of cast austenitic stainless steel, type CF-3. The accepted screening limit for aging considerations states that static cast low-molybdenum steels with <20 percent ferrite are not susceptible to thermal aging embrittlement at the RCP operating temperature to an extent that would be of concern. Delta ferrite (δ_c) is limited to <20 percent and silicon to <1.5 percent. Lower bound curves were developed using a predictive model. The material properties used in the LBB analysis are based on the results predicted for the saturated condition. Therefore, thermal aging is not a concern for the RCP case.

05.02.03-21

Ferrite limitations for CASS RCPB materials are described in Section 5.2.3.4.6.

The MSL piping is carbon steel and contains no cast materials. Therefore, thermal aging of the MSL piping is not a concern.

3.6.3.3.7 Thermal Stratification

Thermal stratification is a potential issue in horizontal pipe segments when fluid at a significantly different temperature than the fluid in the piping is introduced at low flow velocities. The U.S. EPR is designed to preclude those conditions (refer to Section 3.7 of Reference 10 and FSAR Section 3.12). Each of the piping systems is addressed below.

3.6.3.3.7.1 Main Coolant Loop Piping

The MCL piping is not susceptible to thermal stratification since it does not experience stagnant flow conditions.

3.6.3.3.7.2 Surge Line Piping

Section 3.7.2 of Reference 10 and FSAR Section 3.12 describe the design features that minimize the potential for thermal stratification in the SL. The SL geometry is also described in Section 5.4.10.

Enriched boric acid (EBA) is added to the RCS as a soluble neutron poison for core reactivity control. Lithium hydroxide enriched in lithium 7 is used as a pH control agent to maintain a slightly basic pH at operating conditions. This chemical is chosen for its compatibility with the materials and water chemistry of borated water/stainless steel/zirconium/nickel-base alloy systems. Lithium-7 is also produced in solution from the neutron irradiation of the dissolved boron in the coolant.

In addition to degasification during startup, two chemicals are added to the reactor coolant to control oxygen: (1) hydrazine during startup operations below 250°F; and (2) hydrogen immediately prior to and following criticality. Dissolved hydrogen is added to maintain a reducing environment by scavenging oxidizing molecular products formed by the radiolysis of water and with any oxygen introduced into the RCS with makeup water.

Suspended solids (corrosion product particulates) in the reactor coolant are minimized by the coordinated boron-lithium chemistry program and by filtration during shutdown operations. Other impurity concentrations are maintained below specified limits through the control of the chemical quality of makeup water and chemical additives and by purification of the reactor coolant through the mixed bed ion exchangers. Section 9.3.4 addresses RCS water chemistry control.

5.2.3.2.2 Compatibility of Construction Materials with Reactor Coolant

Ferritic low alloy and carbon steels used in principal pressure retaining applications have either austenitic stainless steel or nickel-base alloy corrosion resistant cladding on all surfaces that are exposed to the reactor coolant. The cladding of ferritic type base material receives a post-weld heat treatment, as required by ASME Section III.

Unstabilized austenitic stainless steel base materials with primary pressure retaining applications are used in the solution annealed and water quenched (or rapidly cooled) condition in accordance with RG 1.44. Unstabilized austenitic stainless steels are not heated above 800°F, other than locally by welding operations, after the final heat treatment.

05.02.03-22

~~Stabilized austenitic stainless steels have a stabilizing heat treatment above 800°F; the stabilizing element combines with the carbon to form carbide. Chromium carbides are prevented from precipitating if a subsequent heat treatment in the 800°F to 1500°F temperature range occurs.~~

Due to the control of oxygen, chlorides, and fluorides in the reactor coolant, any unstabilized stainless steel locally sensitized at the high temperatures used during fabrication are not expected to experience stress corrosion cracking during normal plant operation. Precipitation hardenable stainless steel (SA-453 Grade 660) is used as a necked-down bolt for the control rod drive mechanism; because of its location it will not have contact with reactor coolant. The RCP bolting is external to the wetted

paragraph NB-3211(d) of Section III are made to determine the mechanical properties of the quenched and tempered weld metal. To verify that the specified weld solidification pattern has been obtained and that the weld center is sound, either a macro-etch test or an impact test with the specimen notch located at the weld center is used. The tests specified are applied to each of the welds. In the event that properties obtained from tests identified are not acceptable, additional procedures qualification is performed.

Stainless steel corrosion resistant weld overlay cladding of low alloy steel components conforms to the requirements of RG 1.43, "Control of Stainless Steel Weld Cladding of Low-Alloy Steel Components." Controls to limit underclad cracking of susceptible materials conform to the requirements of RG 1.43.

Procedure Qualification Records and Welding Procedure Specifications performed to support welding of carbon and low alloy steel welds in the RCPB conform to the requirements of RG 1.50, "Control of Preheat Temperature for Welding of Low-Alloy Steel" and the guidelines of ASME Section III, Division 1, Nonmandatory Appendix D.

Interpass temperatures to support welding of low alloy steel welds in the RCPB are qualified per ASME Sections III and IX. The ~~typical minimum preheat temperature is 200°F and the~~ typical maximum interpass temperature is 600°F.

Welders and welding operators are qualified in accordance with ASME Section IX and RG 1.71, "Welder Qualification for Areas of Limited Accessibility."

The practices for storing and handing welding electrodes and fluxes comply with ASME Code, Section III, Paragraphs NB-2400 and NB-4400.

5.2.3.3.3 Nondestructive Examination for Ferritic Steel Tubular Products

Nondestructive examinations performed on ferritic steel tubular products to detect unacceptable defects will comply with ASME Section III, NB-2550 through NB-2570, and ASME Section XI examination requirements.

5.2.3.4 Fabrication and Processing of Austenitic Stainless Steels

5.2.3.4.1 Prevention of Sensitization and Intergranular Corrosion of Austenitic Stainless Steels

Austenitic stainless steels are susceptible to different forms of intergranular corrosion in aggressive environments when sensitized. Grain boundary carbide sensitization occurs when metal carbides precipitate on the grain boundaries when the material is heated in the temperature range of 800°F to 1,500°F.

Avoidance of intergranular attack in austenitic stainless steels is accomplished by five main methods:

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- Use of low carbon (~~less than~~not exceeding 0.03 wt% carbon) unstabilized austenitic stainless steels.
- Monitoring of the ferrite number of weld filler metals to ensure correct ferrite content.
- Utilization of materials in the solution annealed plus rapid cooled condition and, where possible, avoiding ~~the prohibition of~~ subsequent heat treatments in the 800°F and 1,500°F temperature range.
- Control of primary water chemistry to maintain an environment which does not promote intergranular attack.
- Control of welding processes and procedures to avoid heat affected zone sensitization as given in RG 1.44.

The water chemistry in the RCS is controlled to the ranges specified in Table 5.2-3 and by plant procedures to prevent the intrusion of aggressive species. Section 9.3.4 addresses RCS water chemistry control. Precautions are taken to prevent the intrusion of chlorides and other contaminants into the system during fabrication, shipping, and storage. The use of hydrogen in the reactor coolant inhibits the presence of oxygen during operation. The effectiveness of these controls has been demonstrated by tests and operating experience.

Measures are taken to prevent sensitization of unstabilized austenitic stainless steel materials during component fabrication; the wrought products listed in Table 5.2-2 are used in the solution annealed condition and rapidly cooled. Heat treatment parameters comply with ASME Section II. The material is either cooled by water quenching or cooled quickly enough through the sensitization temperature range to avoid carbide formation at the grain boundaries and sensitization. Non-sensitization of the base materials can be verified by a corrosion test – in accordance with ASTM A-262 (Reference 4), Practice A or E – as required by RG 1.44. When testing of the weld heat affected zone (HAZ) of materials is required, the tests are performed in accordance with ASTM A-262, Practice E. Low carbon austenitic stainless steel materials and their welds in product forms which do not have inaccessible cavities or chambers that would preclude rapid cooling when water quenching need not be corrosion tested, provided that the solution heat treatment is followed by water quenching or rapid cooling so as to avoid chromium carbide precipitation.

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All unstabilized austenitic stainless steel material, including weld material, has a maximum carbon content of ~~less than~~ 0.03 wt%. RG 1.44 requires that any material subjected to sensitizing temperatures subsequent to solution heat treatment should be material with a carbon content ~~of less than~~not exceeding 0.03 wt%.

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~~Stabilized austenitic stainless steels have a stabilizing heat treatment above 800°F where chromium carbides are prevented from precipitating after the stabilizing~~

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~~element combines with the carbon. Due to the stabilizing heat treatment, stabilized austenitic stainless steels are not expected to experience sensitization. The lack of sensitization in these alloys, in addition to the five points listed above, negates the concern of intergranular corrosion in stabilized austenitic stainless steels. Stabilized austenitic stainless steel is solution annealed and rapidly cooled so that the material is cooled through the sensitization temperature range rapidly to prevent sensitization. If means other than rapid cooling are used, the material is tested in accordance with Practice E of ASTM A262 to demonstrate the material is in the unsensitized condition~~Stabilizing heat treatment is not performed for the stabilized austenitic stainless steels. The only heat treatment performed in the course of steel manufacturing is solution annealing with a maximum temperature not to exceed 2012°F, followed by quenching in water or equivalent rapid cooling in air to prevent grain boundary carbide precipitation.

Postweld heat treatment (PWHT) is performed on CRDM pressure housing components joined by welding. The sensitization concern in the stabilized austenitic stainless steel is eliminated by the compositional requirement and additional testing during welding procedure qualification. Welding procedure qualification is based on ASME Section III and Section IX with additional test requirements. During procedure qualification, tests and examinations are performed in the as-welded and PWHT condition. Corrosion testing per ASTM A 262 Practice E is performed to the qualification weld, which is identical to the actual welded joint including the stabilized austenitic stainless steel base metal.

The carbon content of the sensitized material is limited to a maximum of 0.04 percent. The minimum stabilization ratio of niobium to carbon (Nb/C) is specified as 13 for the stabilized austenitic stainless steel component that receives PWHT. Additionally, the minimum allowable chromium content is increased to 18 percent. As required by the material specification, stabilized austenitic stainless steel is corrosion tested according to ASTM A 262 Practice E after being subjected to sensitizing heat treatment. In any ASTM A 262 test, intergranular attack is not permitted regardless of depth.

Due to necessary welding, the unstabilized austenitic stainless steel in the HAZ is heated in the sensitized temperatures range (800°F to 1500°F) during fabrication. Welding practices and material composition are controlled to manage the sensitization while the material is in this temperature range and all weld metals have a carbon content ~~of less than~~not exceeding 0.03 wt% to prevent undue sensitization. In addition, where unstabilized austenitic stainless steel materials are subjected to sensitizing temperatures for greater than 60 minutes during a post weld heat treatment, as is the case for welding the austenitic stainless steel safe ends directly to the low alloy steel nozzles of the reactor pressure vessel, steam generator and pressurizer, non-sensitization of the materials is verified by testing in accordance with Practice A or E of ASTM A-262, as required by RG 1.44.

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specimen notch located at the weld center is used. The tests specified are applied to each of the welds. The austenitic stainless steel production welding is monitored to verify compliance with limits for the process variables specified in the procedure qualification. In the event that properties obtained from tests identified are not acceptable, additional procedures qualification is performed.

5.2.3.4.5 Nondestructive Examination for Wrought Austenitic Stainless Steel Tubular Products

Nondestructive examinations performed on austenitic stainless steel tubular products to detect unacceptable defects will comply with ASME Section III, NB-2550 through NB-2570, and Section XI examination requirements.

5.2.3.4.6 Cast Austenitic Stainless Steel Materials used in the RCPB

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The RCP casing is made from ASME SA-351 Grade CF3 material with additional restrictions on silicon (1.5% maximum) and niobium (restricted to trace elements). ~~In addition, the ferrite content of cast austenitic stainless components in the RCPB will be limited to a ferrite content of less than 20 percent.~~ For cast austenitic stainless steel components that experience service temperatures greater than 482°F, the delta ferrite content is limited to less than or equal to 20 percent for low molybdenum content statically cast materials, less than or equal to 14 percent for high molybdenum content statically cast materials, and less than or equal to 20 percent for high molybdenum content centrifugally cast materials. Low molybdenum content is defined as 0.5 wt% maximum and high molybdenum content is defined as 2.0-3.0 wt%. These restrictions reduce susceptibility to thermal aging (Section 3.6.3.3.6). For cast austenitic stainless steel material used in the RCPB, the percent ferrite is calculated using Hull's equivalent factors as indicated in NUREG/CR-4513 Rev. 1 (May 1994).

5.2.3.5 Prevention of Primary Water Stress-Corrosion Cracking for Nickel-Base Alloys

Nickel-base alloy components in the RCS are protected from primary water stress-corrosion cracking (PWSCC) by:

- Using only Alloy 690 and Alloys 52/52M/152 weld metals in NiCrFe applications (Alloy 600 base metal and Alloys 82/182 weld metal is not used).
- Controlled chemistry, mechanical properties, and thermo-mechanical processing requirements that produce an optimum microstructure for resistance to intergranular corrosion for NiCrFe Alloy 690 base metal.
- Limiting the sulfur content of NiCrFe base metal in contact with RCS primary fluid to maximum 0.02 wt%.

Table 5.2-2—Material Specifications for RCPB Components
Sheet 1 of 6

Component	Material
RCPB Piping	
Reactor coolant piping & surge line	ASME SA-182 Grade F304 (see Notes 3 & 4) ASME SA-336 Grade F304 (see Notes 3 & 4)
Reactor coolant piping & surge line fittings & nozzles	ASME SA-182 Grade F304 (see Notes 3 & 4) ASME SA-336 Grade F304 (see Notes 3 & 4)
Reactor coolant piping other than loop & surge line	ASME SA-213 Grade TP304L (Seamless) (see Note 3 & 4) ASME SA-312 Grade TP304L (Seamless) (see Note 3 & 4) ASME SA-312 Grade TP316LN (Seamless) (see Note 3 & 4)
Reactor coolant piping fittings & nozzles other than loop & surge line fittings & nozzles	ASME SA-182 Grade F304L (see Note 3) ASME SA-182 Grade F316LN (see Notes 3 & 4) ASME SA-403 Grade WP304L Class S (see Notes 3 & 4) ASME SA-403 Grade WP316LN Class S (see Notes 3 & 4)
Pressure boundary welds	SFA 5.4 SFA 5.9 SFA 5.11 SFA 5.14 SFA 5.22
Steam Generators	
Pressure boundary forgings (including shells, heads, tubesheet, nozzles, & openings)	ASME SA-508 Grade 3 Class 2 (see Note 1)
Small nozzles	ASME SA-105 (see Note 6)
Secondary nozzle safe ends (except emergency feedwater nozzle safe end)	ASME SA-508 Grade 3 Class 1 (see Note 1)
Emergency feedwater nozzle safe end	ASME SA-403 Grade WP316L (Seamless) (see Notes 3 & 4) ASME SA-182 Grade F316L (see Note 3)
Inlet & outlet nozzle safe ends	ASME SA-182 Grade F316 (see Notes 3 & 4) ASME SA-336 Grade F316 (see Notes 3 & 4)
Tubes	ASME SB-163 Alloy 690 (see Note 2)
Openings covers (for manways, inspection holes, & handholes)	ASME SA-533 Type B Class 2 (see Note 1)
Openings studs (for manways, inspection holes, & handholes)	ASME SA-193 Grade B16 (see Note 1) ASME SA-193 Grade B7 (see Note 1)
Primary manway studs	ASME SA-193 Grade B16 (see Note 1)
Openings nuts (for manways, inspection holes, & handholes)	ASME SA-193 Grade B16 (see Note 1) ASME SA-193 Grade B7 (see Note 1)

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Table 5.2-2—Material Specifications for RCPB Components
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Component	Material
Pressure boundary welds	SFA 5.4 SFA 5.5 ← 05.02.03-20 SFA 5.9 SFA 5.11 SFA 5.14 SFA 5.17 SFA 5.18 SFA 5.20 SFA 5.22 SFA 5.23 SFA 5.28 SFA 5.29
Pressurizer	
Upper head	ASME SA-508 Grade 3 Class 2 (see Note 1)
Bottom head	ASME SA-508 Grade 3 Class 2 (see Note 1)
Cylindrical shells	ASME SA-508 Grade 3 Class 2 (see Note 1)
Manway	ASME SA-508 Grade 3 Class 2 (see Note 1)
Manway cover	ASME SA-533 Type B Class 2 (see Note 1)
Surge nozzle	ASME SA-508 Grade 3 Class 2 (see Note 1)
Safety valve nozzles	ASME SA-508 Grade 3 Class 2 (see Note 1)
Spray nozzles	ASME SA-508 Grade 3 Class 2 (see Note 1)
Venting nozzle	ASME SA-508 Grade 3 Class 2 (see Note 1)
Primary depressurization system valve nozzle	ASME SA-508 Grade 3 Class 2 (see Note 1)
Safe ends: • Spray nozzle • Surge nozzle • Safety valve nozzle • Primary depressurization system valve nozzle Nozzles: • Temperature measurement • Level measurement • Sample	ASME SA-182 Grade F316 (see Notes 3 & 4) ASME SA-336 Grade F316 (see Notes 3 & 4)
Heater sleeves	ASME SA-182 Grade F316 (see Notes 3 & 4) ASME SA-336 Grade F316 (see Notes 3 & 4)
Vent nozzle safe ends	ASME SA-182 Grade F316 (see Notes 3 & 4)
Vent manway nozzle	ASME SA-182 Grade F316 (see Notes 3 & 4)

Table 5.2-2—Material Specifications for RCPB Components
Sheet 3 of 6

Component	Material
Valve pilot nozzle	ASME SA-182 Grade F316 (see Notes 3 & 4)
Manway studs	ASME SA-193 Grade B16 (see Note 1)
Manway nuts	ASME SA-194 Grade 16 (see Note 1)
Pressure boundary welds	SFA 5.4 SFA 5.5 SFA 5.9 SFA 5.11 SFA 5.14 SFA 5.17 SFA 5.18 SFA 5.20 SFA 5.22 SFA 5.23 SFA 5.28 SFA 5.29
Reactor Coolant Pump	
Pressure forgings	ASME SA-182M Grade F304 (see Notes 3 & 4)
Cooler tubes	ASME SA-213M Grade TP316 (see Notes 3 & 4)
Support stand flange – integral part of casing closure bolted assembly	ASME SA-216M Grade WCC
Pressure casting	ASME SA-351M Grade CF3 (see Notes 3, ~~&~~ 5 & 10)
Bolting	ASME SA-453M Grade 660 Class B (see Note 7)
Thermowell	ASME SA-479M Type 304 (see Notes 3 & 4)
Flange – integral part of pressure boundary casing closure bolted assembly	ASME SA-508M Grade 3 Class 2 (see Note 1)
Pressure boundary stud bolts & nuts	ASME SA-540M Grade B24 Class 1 (see Note 1)
Pressure boundary casing closure stud & nuts	ASME SA-540M Grade B24 Class 3 (see Note 1)
Shaft seal pressure boundary parts	ASME SA-705M Type 630 H1150 (see Note 7)
Pressure boundary welds	SFA 5.4 E308L SFA 5.4 E316L SFA 5.9 ER316L
Control Rod Drive Mechanism	
Flange, connection piece, head, loose flange	ASME SA-479 Grade 347 (see Note 3)

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Table 5.2-2—Material Specifications for RCPB Components
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Component	Material
Latch housing	ASME SA-479 UNS S41500 (Code Case N-785)/SA-182 Grade F6NM (see Note 1) ~~(UNS S41500)~~
Seamless tube	ASME SA-312 Grade TP347 (Seamless) (see Note 3)
Bolt	ASME SA-453 Grade 660 (see Note 7)
Nut	ASME SA-437 Grade B4C (see Note 1)
Welding filler material	SFA 5.4 E347 SFA 5.9 ER347 SFA 5.14 ERNiCrFe-7 SFA 5.14 ERNiCrFe-7A
RCPB Valves~~Pressurizer Safety Relief Valves~~	
Bodies~~A vendor for the PSRV has not been chosen for the U.S. EPR~~	SA-182 Grade F304 (see Notes 3 & 4), Grade F304L (see Note 3), Grade F304LN (see Note 3), Grade F316 (see Notes 3 & 4), Grade F316L (see Note 3), Grade F316LN (see Note 3)
	SA-351 Grade CF3, Grade CF3A, Grade CF3M, Grade CF8 (see Note 4), Grade CF8A (see Note 4), Grade CF8M (see Note 4) (see Note 10 for all materials)
Bonnets	SA-182 Grade F304 (see Notes 3 & 4), Grade F304L (see Note 3), Grade F304LN (see Note 3), Grade F316 (see Notes 3 & 4), Grade F316L (see Note 3), Grade F316LN (see Note 3)
	SA-351 Grade CF3, Grade CF3A, Grade CF3M, Grade CF8 (see Note 4), Grade CF8A (see Note 4), Grade CF8M (see Note 4) (see Note 10 for all materials)
	SA-240 Type 304 (see Notes 3 & 4), Type 304L (see Note 3), Type 304LN (see Note 3), Type 316 (see Notes 3 & 4), Type 316L (see Note 3), 316LN (see Note 3)
Discs	SA-182 Grade F304 (see Notes 3 & 4), Grade F304L (see Note 3), Grade F304LN (see Note 3), Grade F316 (see Notes 3 & 4), Grade F316L (see Note 3), Grade F316LN (see Note 3)
	SA-351 Grade CF3, Grade CF3A, Grade CF3M, Grade CF8 (see Note 4), Grade CF8A (see Note 4), Grade CF8M (see Note 4) (see Note 10 for all materials)
	SA-479 Type 304 (see Notes 3 & 4), Type 304L (see Note 3), Type 304LN (see Note 3), Type 316 (see Notes 3 & 4), Type 316L (see Note 3), 316LN (see Note 3), XM-19 (see Note 3)
	SA-564 Type 630 (Conditions H1075, H1100, H1150)
	SB-637 UNS N07718 (see Note 8)

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Table 5.2-2—Material Specifications for RCPB Components
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Component	Material
Pressure Retaining Bolts	SA-193 Grade B7 (see Note 1), Grade B8 (see Note 3), Grade B16 (see Note 1)
	SA-453 Grade 660, Class A and Class B (see Note 7)
	SA-564 Type 630 (Condition H1100)
Pressure Retaining Nuts	SA-453 Grade 660, Class A and Class B (see Note 7)
	SA-194 Grade 2, Grade 2H (see Note 1), Grade 6 (see Note 1), Grade 8 (see Note 3)

Notes on Table 5.2-2

1. Quenched and tempered
2. Solution annealed and thermally treated
3. Solution annealed and rapidly cooled
4. Carbon content not exceeding 0.03 wt%
5. Silicon not greater than 1.5% and niobium restricted to trace elements
6. Annealed, normalized, normalized and tempered, or quenched and tempered.
7. Solution t~~T~~reatment and h~~H~~ardening.
8. Solution treatment and precipitation hardening.
9. Hot rolled or strain hardened.
10. For cast austenitic stainless steel components that experience service temperatures greater than 482°F, the delta ferrite content is limited to less than or equal to 20 percent for low molybdenum content statically cast materials, less than or equal to 14 percent for high molybdenum content statically cast materials, and less than or equal to 20 percent for high molybdenum content centrifugally cast materials. Low molybdenum content is defined as 0.5 wt% maximum and high molybdenum content is defined as 2.0-3.0 wt%.

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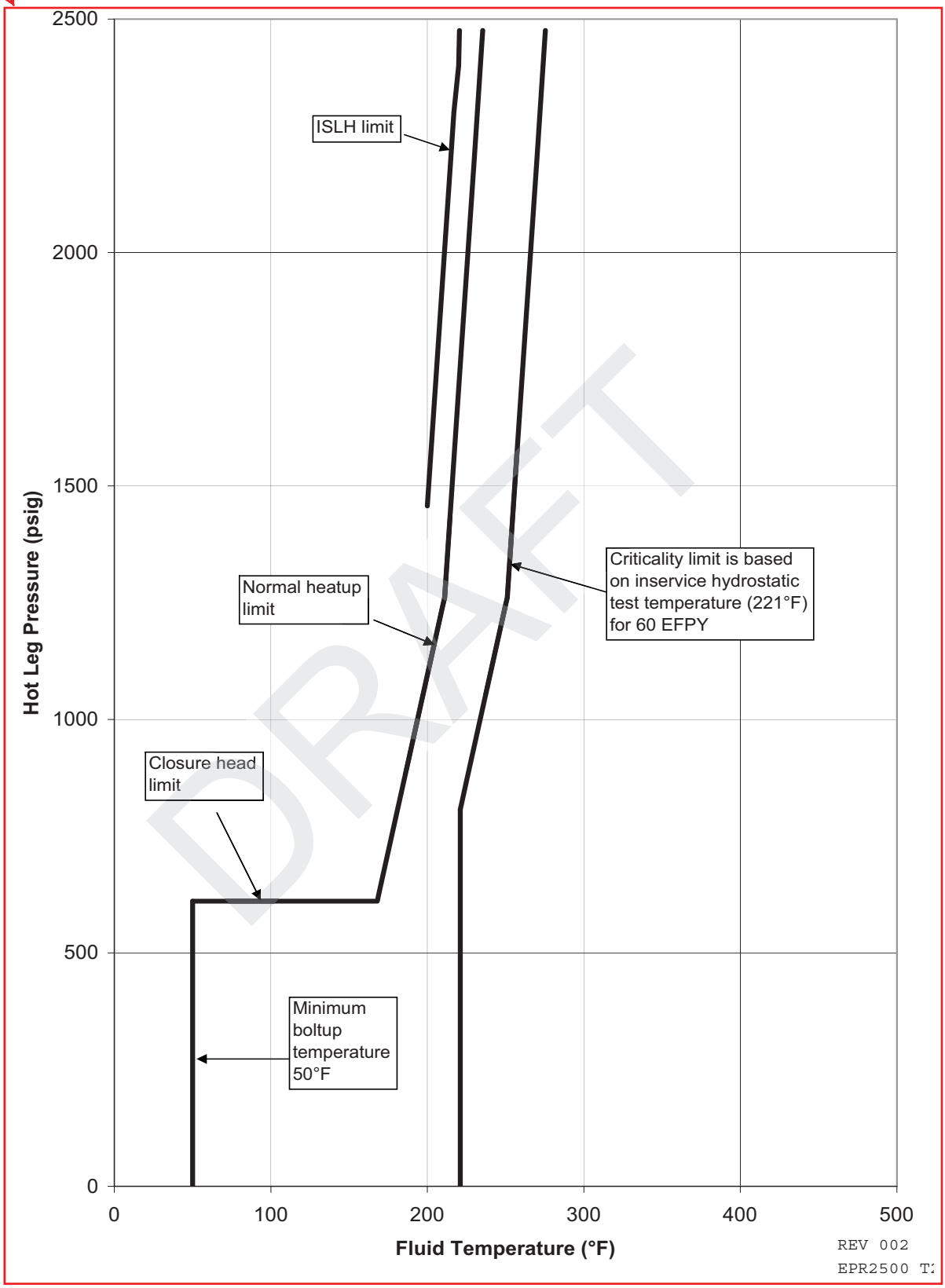
Figure 5.3-1—Reactor Coolant System Heatup Pressure-Temperature Curve



U.S. EPR Pressure–Temperature Limits Methodology for RCS Heatup and Cooldown Report Markups

The lowest allowable pressure at each time point yields a single lower bound P-T limit curve for normal heatup or normal cooldown. The P-T curves for normal plant heatup and cooldown are presented in Figure 6-1 and Figure 6-2, respectively, and are tabulated in Table 6-6 and Table 6-7, respectively. 05.03.02-7

The P-T limit curve for the closure head region is calculated separately. The allowable pressure from plant startup is maintained as a constant value of 635 psig (20 percent of preservice hydrostatic test pressure) from the bolt preload temperature condition until the coolant temperature reaches the temperature where a calculated crack-tip metal temperature exceeds the minimum temperature requirement of Reference 1 and Table 2-1. The minimum required temperatures are subsequently determined at 1285 psig and at 2325 psig (full power, steady-state condition). The resulting closure head limit curves are included in Figure 6-1 and Figure 6-2 for heatup and cooldown, respectively.

For plant heatup, the closure head limit curve lower bounds both the beltline region and the nozzle corner limit curves. As noted, the closure head limit does not change throughout the lifetime of the plant. In the case of normal cooldown from steady-state conditions, as shown in Figure 6-2, the beltline P-T limit is controlling until it intersects with the closure head limit curve. At 635 psig, which corresponds to 20 percent of the preservice hydrostatic test pressure, the allowable temperature corresponds to the minimum temperature requirement of RT_{NDT} +120°F per item 2.b of Table 2-1. The P-T limit curve for the (inlet and outlet) nozzle corner region is not a controlling P-T limit region at any time during normal plant heatup or cooldown.

The P-T limits thus calculated are “uncorrected P-T limits,” meaning that measurement uncertainty due to instrument error or sensor location adjustment is not included. The sensor location adjustment is necessary due to the difference in sensor readings (pressure and temperature) at the measurement location compared to the corresponding pressures and temperatures at the controlling P-T limit region. Sensor location adjustment includes the effect of pump operation. These corrections are made to the uncorrected P-T limits and the resultant corrected P-T limits are presented in

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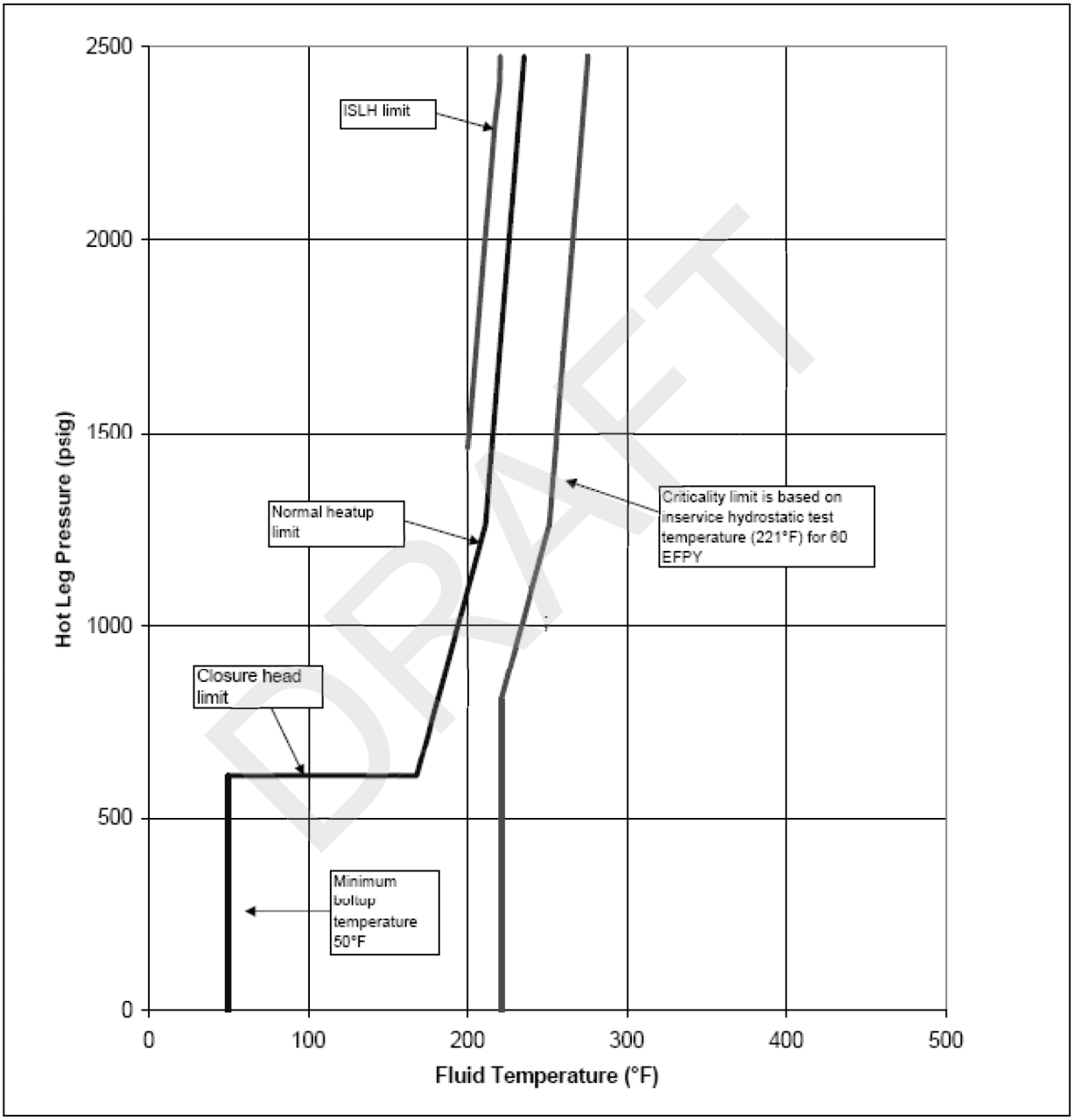
Figure 6–1 U.S. EPR RCS P-T Limits – Normal Heatup with ISLH and Criticality Limit Curves Applicable to 60 EFPY



Note:

1. P-T limit curves do not include margin for instrument uncertainty.

Note:

1. P-T limit curves do not include margin for instrument uncertainty.

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Table 6–2 Adjusted Reference Temperature for the U.S. EPR Reactor Vessel Materials through 60 EFPY

Material Description		Initial RT_{NDT} (°F)	ART, °F at 60 EFPY(1)	
Reactor Vessel	Type		1/4t Location	3/4t Location
Nozzle Shell	SA-508, Grade 3, Class 1	-4	8.0	1.2
Upper Core Shell	SA-508, Grade 3, Class 1	-4	63.4(3)	40.2(3)
Lower Core Shell	SA-508, Grade 3, Class 1	-4	63.4(3)	40.2(3)
Transition Ring	SA-508, Grade 3, Class 1	-4	57.8	32.0
Weld #1	Low Alloy Steel Weld	-4	15.4	4.2
Weld #2	Low Alloy Steel Weld	-4	126.5(3)	93.4(3)
Weld #3	Low Alloy Steel Weld	-4	95.4	53.8
Closure Head	SA-508, Grade 3, Class 1	-4	-4(2)	N/A
Closure Head	Closure Head Weld	-4	-4(2)	N/A

Notes:

1. The margin term in the RG 1.99 Revision 2 expression for adjusted reference temperature is calculated according to RG 1.99 Revision 2, Equation 4. The standard deviation for initial RTNDT is 0°F because the initial RTNDT is specified as a maximum limit for vessel manufacture. The standard deviation for ΔRTNDT is the lesser of 28°F for welds and 17°F for base metals and 0.50 times the mean value of ΔRTNDT calculated from the chemistry factors and fluences in Table 6-1.
2. The projected fluence to the RPV head is insufficient to cause any measurable shift in RTNDT.
3. Limiting beltline ART values and materials used in the generation of the P-T Limits.

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Table 6–6 RCS Heatup Limits at 60 EFPY

Normal Heatup		Criticality Limit		ISLH Test Limit	
Fluid Temp. (°F)	Hot Leg Press. (psig)	Fluid Temp. (°F)	Hot Leg Press. (psig)	Fluid Temp. (°F)	Hot Leg Press. (psig)
50	0	221	0	200	1457
50	611	221	807	205	1705
55	611	225	868	210	1953
60	611	230	943	215	2202
65	611	235	1019	217	2301
70	611	240	1095	220	2400
75	611	245	1170	220.53	2476
80	611	250	1246		
85	611	251	1261		
90	611	255	1459		
95	611	260	1707		
100	611	265	1954		
105	611	270	2202		
110	611	272	2301		
115	611	275	2457		
120	611	275.37	2476		
125	611				
130	611				
135	611				
140	611				
145	611				
150	611				
155	611				

Table 6–6 RCS Heatup Limits at 60 EFPY

160	611				
165	611				
168	611				
170	641				
175	717				
180	792				
185	868				
190	943				
195	1019				
200	1095				
205	1170				
210	1246				
211	1261				
215	1459				
220	1707				
225	1954				
230	2202				
232	2301				
235	2457				
235.37	2476				

Note:

The tabulated heatup limits do not include margin for instrument uncertainty.

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Table 6–7 RCS Cooldown Limits at 60 EFPY

Fluid Temperature (°F)	Hot Leg Pressure (psig)
50	0
50	611
52	611
57	611
62	611
67	611
72	611
77	611
82	611
87	611
91	611
96	611
101	611
106	611
111	611
116	611
116	1468
121	1527
122	1680
123	1704
128	1830
133	1970
138	2099
143	2200

Table 6–7 RCS Cooldown Limits at 60 EFPY

148	2312
153	2435
158	2572

Note:

The tabulated cooldown limits do not include margin for instrument uncertainty.

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