## ArevaEPRDCPEm Resource

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|---|---|
| **From:** | Pederson Ronda M (AREVA NP INC) [Ronda.Pederson@areva.com] |
| **Sent:** | Friday, June 05, 2009 10:38 AM |
| **To:** | Getachew Tesfaye |
| **Cc:** | BENNETT Kathy A (OFR) (AREVA NP INC); DELANO Karen V (AREVA NP INC); WELLS Russell D (AREVA NP INC) |
| **Subject:** | Response to U.S. EPR Design Certification Application RAI No. 199, FSAR Ch. 5, Supplement 1 |
| **Attachments:** | RAI 199 Supplement 1 Response US EPR DC.pdf |

Getachew,

AREVA NP Inc. (AREVA NP) provided responses to 4 of the 6 questions of RAI No. 199 on April 23, 2009. The attached file, "RAI 199 Supplement 1 Response US EPR DC.pdf" provides technically correct and complete responses to the remaining 2 questions.

The following table indicates the respective pages in the response document, "RAI 199 Supplement 1 Response US EPR DC.pdf," that contain AREVA NP's response to the subject questions.

| Question # | Start Page | End Page |
|---|---|---|
| RAI 199 — 05.02.03-17 | 2 | 7 |
| RAI 199 — 05.02.03-19 | 8 | 13 |

This concludes the formal AREVA NP response to RAI 199, and there are no questions from this RAI for which AREVA NP has not provided responses.

Sincerely,


*Ronda Pederson*
ronda.pederson@areva.com
Licensing Manager, U.S. EPR Design Certification
**AREVA NP Inc.**
An AREVA and Siemens company
3315 Old Forest Road
Lynchburg, VA 24506-0935
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**From:** Pederson Ronda M (AREVA NP INC)
**Sent:** Thursday, April 23, 2009 3:42 PM
**To:** 'Getachew Tesfaye'
**Cc:** BENNETT Kathy A (OFR) (AREVA NP INC); DELANO Karen V (AREVA NP INC); WELLS Russell D (AREVA NP INC)
**Subject:** Response to U.S. EPR Design Certification Application RAI No. 199, FSAR Ch. 5

Getachew,

Attached please find AREVA NP Inc.'s response to the subject request for additional information (RAI). The attached file, "RAI 199 Response US EPR DC.pdf" provides a technically correct and complete response to 4 of the 6 questions.

Appended to this file are affected pages of the U.S. EPR Final Safety Analysis Report in redline-strikeout format which supports the response to RAI 199 Questions 05.02.03-15, 05.02.03-16, 05.02.03-18.

The following table indicates the respective pages in the response document, “RAI 199 Response US EPR DC.pdf,” that contain AREVA NP’s response to the subject questions.

| Question # | Start Page | End Page |
|---|---|---|
| RAI 199 — 05.02.01.02-2 | 2 | 2 |
| RAI 199 — 05.02.03-15 | 3 | 3 |
| RAI 199 — 05.02.03-16 | 4 | 4 |
| RAI 199 — 05.02.03-17 | 5 | 6 |
| RAI 199 — 05.02.03-18 | 7 | 7 |
| RAI 199 — 05.02.03-19 | 8 | 8 |

A complete answer is not provided for 2 of the 6 questions. The schedule for a technically correct and complete response to these questions is provided below.

| Question # | Response Date |
|---|---|
| RAI 199 — 05.02.03-17 | June 12, 2009. |
| RAI 199 — 05.02.03-19 | June 12, 2009. |

Sincerely,

*Ronda Pederson*

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**From:** Getachew Tesfaye [mailto:Getachew.Tesfaye@nrc.gov]
**Sent:** Tuesday, March 24, 2009 3:07 PM
**To:** ZZ-DL-A-USEPR-DL
**Cc:** Robert Davis; Jeffrey Poehler; David Terao; Tarun Roy; Joseph Colaccino; ArevaEPRDCPEm Resource
**Subject:** U.S. EPR Design Certification Application RAI No. 199 (794, 2243,2309), FSAR Ch. 5

Attached please find the subject requests for additional information (RAI). A draft of the RAI was provided to you on March 6, 2009, and discussed with your staff on March 19, 2009. RAI Questions 05.02.01.02-2, 05.02.03-16, 05.02.03-18, and 05.02.03-19 were modified as a result of that discussion. The schedule we have established for review of your application assumes technically correct and complete responses within 30 days of receipt of RAIs. For any RAIs that cannot be answered within 30 days, it is expected that a date for receipt of this information will be provided to the staff within the 30 day period so that the staff can assess how this information will impact the published schedule.

Thanks,
Getachew Tesfaye

Sr. Project Manager
NRO/DNRL/NARP
(301) 415-3361

**Hearing Identifier:** AREVA_EPR_DC_RAIs
**Email Number:** 543

**Mail Envelope Properties** (5CEC4184E98FFE49A383961FAD402D31F80D64)

**Subject:** Response to U.S. EPR Design Certification Application RAI No. 199, FSAR Ch. 5, Supplement 1
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**Received Date:** 6/5/2009 10:38:16 AM
**From:** Pederson Ronda M (AREVA NP INC)

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**Response to**

**Request for Additional Information No. 199 (749, 2243, 2309), Supplement 1, Revision 0**

**3/24/2009**

**U. S. EPR Standard Design Certification**
**AREVA NP Inc.**
**Docket No. 52-020**
**SRP Section: 05.02.01.02 - Applicable Code Cases**
**SRP Section: 05.02.03 - Reactor Coolant Pressure Boundary Materials**
**Application Section: 5.2**

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

**Question 05.02.03-17:**

In RAI 05.02.03-6, the staff requested that the applicant modify FSAR Section 5.2.3.4.1 to include the stabilizing heat-treatment temperature for stabilized grades of stainless steels, and the basis for its selection including a discussion on verification testing that AREVA has performed to determine that its stabilizing heat treatment is adequate for material in the RCS environment to prevent stress-corrosion cracking. In addition, the staff requested that the applicant modify FSAR Section 5.2.3.4.1 to include corrosion-testing requirements for stabilized grades of stainless steels and a basis for the adequacy of the testing requirements selected.

The applicant responded on November 10, 2008 and provided the following response:

1. The material specifications for the U.S. EPR state that the designer must minimize the sensitization of austenitic stainless steels. The designer meets this specification by selecting the time and temperature for a stabilization heat treatment that reduces sensitization susceptibility for stabilized steels.
2. U.S. EPR FSAR, Tier 2, Section 5.2.3.4.1 will be modified to include the following sentences: 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.

   The applicant's response does not fully address the staff's question. The staff understands that stabilized austenitic stainless steel used in the RCPB will be solution annealed and rapidly cooled but the staff's RAI sought information related to the applicant's stabilizing heat-treatment temperature, including the adequacy of the stabilizing heat treatment. The only stabilized stainless steel material (Grade 347) identified by the staff that is part of the RCS pressure boundary is used to fabricate the CRDM pressure housing. The staff notes that some of the welding performed on Grade 347 material will involve dissimilar-metal welds-to-F6NM material as shown in the applicant's response to RAI 05.02.03-12, in which the applicant provided additional information to the staff on November 10, 2008. The staff also notes that the applicant has stated, in RAI responses, that the EPR CRDM is based on a proven German design with several years of operating experience. The staff requests that the applicant provide the following information:

1. Identify the stabilizing heat treatment temperature, for stabilized grades of stainless steels, and a basis for its selection including a discussion on verification testing that has been or will be performed to determine that the stabilizing heat treatment is adequate for material in the RCS environment to prevent stress corrosion cracking.
2. If the dissimilar-metal welds between F6NM and Grade 347 material will not be performed by first applying a buttering layer to the F6NM followed by PWHT before joining F6NM to Grade 347 material, provide a basis for performing a PWHT on the Grade 347 austenitic stainless steel. The staff notes that PWHT of Grade 347 after the stabilizing heat treatment is performed may degrade the material's resistance to degradation mechanisms such as stress-corrosion cracking. In addition, please include corrosion-testing requirements for weld-procedure qualifications involving stabilized grades of stainless steels that receive a subsequent PWHT.

3. Given that the applicant has stated that the EPR CRDM is based on a proven German design, the staff requests that the applicant describe any differences between the German and EPR design of the dissimilar-metal weld, including materials processing requirements and PWHT. Identify any service-related degradation issues that have occurred that were associated with the pressure housing in German plants. If degradation has occurred in German plants, describe what steps have been taken to address these issues in the EPR CRDM pressure housing design.

**Response to Question 05.02.03-17:**

1. No stabilizing heat treatment will be performed for Grade 347 used for the control rod drive mechanism (CRDM) pressure boundary. Stabilization heat treatment has not been performed on CRDM martensitic stainless steel pressure boundary components for current U.S. plants and will not be performed for the U.S. EPR CRDMs.

2. Grade 347 is joined to the Type 415 material with nickel-based filler metal, and the entire lower pressure housing is subject to a two-stage postweld heat treatment (PWHT) (twice for four hours each with a cool down to 176°F in between) at a temperature between 1050°F and 1076°F to reestablish satisfactory toughness in the heat-affected zone (HAZ) of Type 415 base metal. Between the two stages, there is an intermediate cooldown to a range from 176°F to room temperature. The sensitization concern due to PWHT is eliminated by the composition requirement in Table 05.02.03-17-1—Chemical Composition of Type 347 CRDM Pressure Boundary Material (Ladle Analysis) and additional testing during welding procedure qualification.

   As discussed in the Response to Item 1, a stabilizing heat treatment will not be performed for Grade 347 for the CRDM pressure housing. The only heat treatment performed in the course of steel manufacturing is solution annealing with a maximum temperature not exceeding 2012°F, followed by quenching in water or equivalent rapid cooling in air to prevent grain boundary carbide precipitation. This provides a homogeneous microstructure free of detrimental precipitates with a relatively fine grain matrix.

   The carbon content is limited to a maximum of 0.04 percent. The minimum stabilization ratio of niobium to carbon (Nb/C) is specified as 13 for Grade F347, which is subject to PWHT, and 10 for Grade TP347, which is not subject to PWHT. Additionally, the minimum allowable chromium content is increased to 18 percent. Table 05.02.03-17-1 summarizes the chemical composition for Grade 347 materials used for U.S. EPR Class 1 pressure boundary applications.

   The modified chemical composition verifies that the amount of free carbon is lower than the free carbon levels found in “low carbon” (maximum 0.03 percent) grades of non-stabilized austenitic stainless steels. Typical bulk carbon content of Grade 347 ranges from 0.02 percent to 0.03 percent. Therefore, grain boundary precipitation of chromium carbides is virtually suppressed. The behavior of Grade 347 stainless steel with respect to intergranular attack and SCC is described in Reference 1 and Reference 2. Figure 05.02.03-17-1—Time-Temperature Sensitization Diagram for Titanium Stabilized (Type 321) and Niobium Stabilized (Type 347) Stainless Steel (Reference 3) displays the time-at-temperature regimes necessary to cause any thermal sensitization for a regular Grade 347.

As required by the material specification, Grade 347 is corrosion tested according to ASTM A 262 Practice E after being subject to sensitizing heat treatment. For Grade 347 components not subject to PWHT, the sensitizing heat treatment prior to A 262 Practice E is 1202°F for 30 minutes, which is a time-at-temperature regime suitable for detecting any improper solution annealing in Grade 347. For Grade 347 which will be subject to PWHT during fabrication, the A 262 Practice E test is performed after a sensitizing heat treatment for 12 hours at 1076°F, acting as a conservative, simulated PWHT. In any ASTM A 262 tests, intergranular attack is not permitted regardless of depth.

Welding procedure qualification is based on ASME Code Section III and ASME Code 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 at the transition between the nickel-based weld metal and Grade 347 base metal.

3. Regarding Grade 347 materials processing and fabrication, the CRDM pressure housing design has remained identical for more than 30 years. The current U.S. EPR design for the pressure housing is not different from the German nuclear power plants. Therefore, the design of the dissimilar welds between martensitic stainless steel and Grade 347 and the PWHT has remained unchanged.

   Manufacturing and inservice experience is available for Grade 347 (Reference 4, Reference 5, and Reference 6). In Siemens/KWU-designed PWR plants, Grade 347 stainless steels were utilized in large amounts for nuclear components. Common product forms such as plates, forgings, welded and seamless piping, and numerous welded joints were fabricated with Grade 347. Table 05.02.03-17-2—Operating Experience with Siemens/KWU PWR Plants Using Grade 347 summarizes the operating experience of German-built PWRs that have no reported degradation issues with Grade 347.

   The current CRDM design with Grade 347 has been in service for more than 30 years without any reported degradation issues associated with CRDM pressure housing.

**References for Question 05.02.03-17:**

1. M. Widera, R. Kilian, R. Bartsch, H. Hoffmann, G. König, O. Wachter: Characterization of stabilized stainless steels welds of PWR piping systems; Proc. $9^{th}$ Int. Symp. on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, TMS, 1999, pages 667 – 674.
2. R. Kilian.: "Characterization of Sensitization and Stress Corrosion Cracking Behavior of Stabilized Stainless Steels under BWR Conditions"; Proc. 7th Int. Symp. on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, NACE, 1995, pages 529-538.
3. Berthold Lundqvist, Steel Research Center, Sandvik: Welding Stainless Steels Part I; Canadian Welder and Fabricator – January 1983.
4. E. Weiß; M. Erve: Stabilized austenitic stainless steel for light water reactors; Independent Journal for Nuclear Engineering, Energy Systems and Radiation; Carl Hanser Verlag, Munich 1990

5. H. Muesch; Mannesmann Anlagenbau AG: Welding of Material Grade TP 347mod; Nuclear Engineering and Design 85 (1985), page 155 – 161.
6. E. Weiß, J. Schmidt, M. Erve: High Reliability and Low Maintenance; Stainless Steel Europe, September 1992; page 43 – 48.

**FSAR Impact:**

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

**Table 05.02.03-17-1—Chemical Composition of Type 347 CRDM Pressure Boundary Material (Ladle Analysis)**

| C (wt percent) | Si (wt percent) | Mn (wt percent) | P (wt percent) | S (wt percent) | Cr (wt percent) | Nb (wt percent) | Ni (wt percent) | Co (wt percent) |
|---|---|---|---|---|---|---|---|---|
| ≤ 0.04 | ≤ 1.00 | ≤ 2.00 | ≤ 0.030 | ≤ 0.015 | 18.00 - 19.00 | 10x( percentC)1 - 0.65 | 9.00 - 12.00 | ≤ 0.06 |

Notes:

1. For parts subject to PWHT; Nb ≥ 13 x ( percentC).

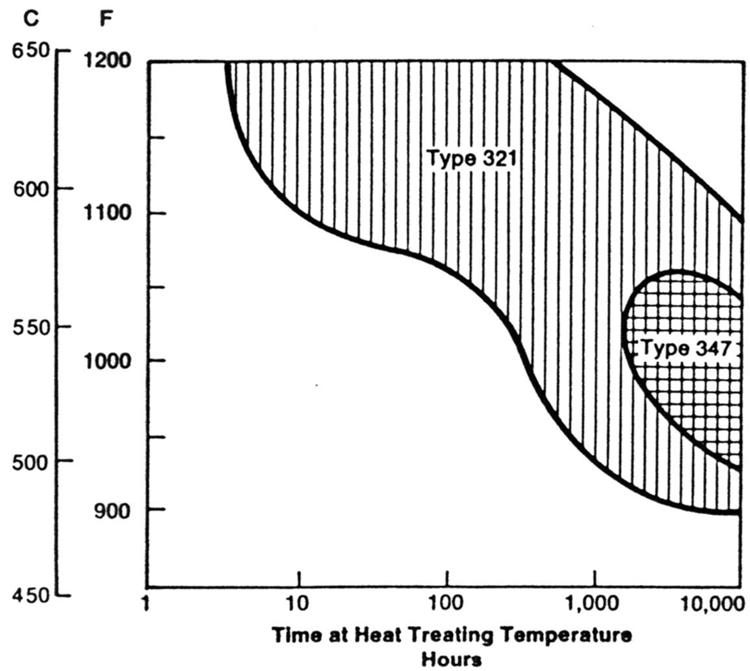
**Table 05.02.03-17-2—Operating Experience with Siemens/KWU PWR Plants Using Grade 347**

| Plant | | Country | Output MW | Start of Commercial Operation (Year) |
|---|---|---|---|---|
| Obrigheim | KWO[1] | Germany | 340 | 1968 |
| Stade | KKS[1] | Germany | 640 | 1972 |
| Biblis A | KWB A | Germany | 1167 | 1975 |
| Biblis B | KWB B | Germany | 1240 | 1977 |
| Borssele | KCB | Netherlands | 449 | 1973 |
| Unterweser | KKU | Germany | 1345 | 1979 |
| Neckarwestheim 1 | GKN 1 | Germany | 785 | 1976 |
| Neckarwestheim 2 | GKN 2 | Germany | 1305 | 1989 |
| Gösgen | KKGg | Switzerland | 970 | 1979 |
| Grafenrheinfeld | KKG | Germany | 1275 | 1983 |
| Grohnde | KWG | Germany | 1360 | 1985 |
| Phillipsburg 2 | KKP 2 | Germany | 1392 | 1980 |
| Brokdorf | KBR | Germany | 1487 | 1986 |
| Emsland | KKE | Germany | 1329 | 1988 |
| Isar 2 | KKI 2 | Germany | 1400 | 1988 |
| Trillo | CNT 1 | Spain | 1000 | 1988 |
| Angra 2 | | Brazil | 1275 | 2000 |

Notes:

1. Decommissioned.

**Figure 05.02.03-17-1—Time-Temperature Sensitization Diagram for Titanium Stabilized (Type 321) and Niobium Stabilized (Type 347) Stainless Steel**



**Question 05.02.03-19:**

Background

The applicant is proposing to use SA-479 (UNS S41500) or SA 182 Grade F6NM (UNS S41500), in the quenched and tempered condition, for a portion of the control-rod-drive-mechanism pressure housing. UNS S41500 is a martensitic stainless steel. In operating reactors, there has been a history of environmentally induced cracking (stress-corrosion cracking or service-induced hydrogen embrittlement) in martensitic stainless steels (References 1-3), although not in control-rod-drive-mechanism applications. Many of these incidents have been attributed to improper heat treatment, specifically tempering at a lower-than-optimal temperature resulting in excessive strength and hardness, thereby rendering the material susceptible to environmentally induced cracking. In Reference 1, it was concluded based on several cracking incidents that the susceptibility of martensitic stainless steels to stress-corrosion cracking increased if the Rockwell hardness exceeded 26 HRC. For Grade F6NM, SA-182 imposes a maximum Brinell hardness of 295 HB, and SA-479 imposes a maximum hardness of 293 HB for UNS S41500 - both of which equate to a Rockwell hardness of approximately 31 HRC. Martensitic stainless steels with higher nickel content (> 2 percent) can also be susceptible to thermal aging embrittlement in the operating temperature range of PWR reactor coolant systems. (S41500 has a nickel content of 3.5-5.5 weight percent)

Requested Information

1. Describe measures to be taken during manufacture of the UNS S41500 material and fabrication of the CRDM pressure housing to minimize the material susceptibility to environmentally induced cracking.

2. Describe the operating experience or other information used as the basis for concluding UNS S41500 stainless steel will be compatible with the reactor coolant system environment, particularly with regard to its resistance to environmentally induced cracking (either stress-corrosion cracking or service-induced hydrogen embrittlement) and its resistance to thermal aging embrittlement.

References

1. NRC Bulletin No. 89-02: Stress Corrosion Cracking of High-Hardness Type 410 Stainless steel Internal Preloaded Bolting in Anchor-Darling Model 350W Swing Check Valves or Valves of Similar Design, July 19, 1989
2. NRC Information Notice 94-055: Problems With Copes-Vulcan Pressurizer Power-Operated Relief Valves, August 4, 1994
3. NRC Information Notice 95-26: Defect in Safety-Related Pump Parts Due to Inadequate Heat Treatment, May 31, 1995

**Response to Question 05.02.03-19:**

1. Measures taken during the manufacture of the UNS S41500 material and fabrication of the control rod drive mechanism (CRDM) pressure housing to minimize the material susceptibility to environmentally-induced cracking are described for each of the following categories:

- Steelmaking and further processing to semi-finished products.
- Material properties.
- Heat treatment during steel manufacturing.
- Welding and post-weld heat treatment (PWHT).
- Weld procedure qualification.
- Environmental cracking, including intergranular stress corrosion cracking (IGSCC), transgranular stress corrosion cracking (TGSCC), hydrogen embrittlement, and thermal aging.

Steelmaking and Further Processing to Semi-Finished Products

The Type 415 martensitic stainless steel for the CRDM pressure housings is produced by primary melting in an electric arc furnace in combination with AOD or VOD refining. The melting and refining practices verify the minimization of residual and trace elements, such as sulfur and phosphorous, for achieving optimal toughness properties.

In accordance with Reference 1, the manufacturer takes into account the tendency for the grains to grow in the Type 415 martensitic stainless steel at temperatures above 2012°F and the hot working temperature range for Type 415; the temperature range for hot working operations is set from 1562°F to 2102°F (Reference 2).

Material Properties

In addition to ASME SA-479/ASME SA-182 requirements, further controls are defined for Type 415 martensitic stainless steel.

- Chemical composition:
  - Restriction of S to ≤ 0.010 percent and P to ≤ 0.020 percent.
  - Minimum Cr ≥ 12.6 percent.
  - For long-term service temperature above 300°C (572°F), the ratio of the Chromium-Equivalent (%Cr+%Mo+1.5x%Si) to the Nickel-Equivalent (%Ni+30x (%C+ %N) +0.5%Mn) is below 2.2.
- Mechanical Properties:
  - Yield strength ≥ 685 MPa (99 ksi).
  - Tensile strength limited to 980 MPa (142 ksi).
  - Elongation ≥17 percent.
  - Reduction of area ≥50 percent.
  - The ratio yield strength to tensile strength does not exceed 0.90.
  - Tensile testing at an elevated temperature of 662°F.
- Toughness properties
  - The impact energy determined on longitudinal specimens at room temperature is at least 90 J (average) and 70 J (lowest individual value).

- The lateral expansion is ≥ 1.10 mm.

Heat Treatment during Steel Manufacturing

During manufacturing, the bars are austenitized in a temperature range between 1721°F and 1922°F, followed by quenching in a suitable liquid by immersion or in air. The quenching is followed by tempering between 1050°F to 1112°F for a minimum time of eight hours. This tempering is performed in two four-hour sessions, with a cooldown to 176°F between sessions, for the magnetic properties to be achieved. Heat treatment actions are continuously monitored and documented at least on one part per lot.

Welding and PWHT

Welding of the dissimilar welds is accomplished with gas tungsten arc weld (GTAW) in the flat position with the pressure housing rotating. Preheating of the martensitic stainless steel must be performed, and in order to establish a sufficient toughness state on the heat-affected zone (HAZ) of the martensitic stainless steel, the welded joint must be subject to PWHT. Based on manufacturing experience with CRDMs, the preheating temperature is between 212°F to 248°F, and the interpass temperature is between 212°F to 284°F. This reflects experience with nickel base filler metals and the width of the HAZ, which is kept narrow.

After welding, the parts are cooled down to a temperature in the range of room temperature and 176°F to verify a full martensitic transformation in the HAZ. The welded parts are subsequently heat treated with a minimum holding time of eight hours between 1050°F and 1076°F. The PWHT is performed in two sessions (two four-hour sessions for a total of eight hours). Between the two sessions, there is an intermediate cooldown to a range from 176°F to room temperature.

Welding Procedure Qualification

A satisfactory welded joint with sufficient material properties is demonstrated during testing in the context of welding procedure qualification based on ASME Code Section III and Section IX, complemented by additional testing reflecting the operating experience. These tests include impact and hardness testing to verify the soundness of the joint in the postweld heat treatment (PWHT) condition.

The hardness testing involves both macro and micro hardness with the requirement that in the HAZ, 350 HV hardness is not exceeded in any case. The 350 HV limit provides sound weldments and excellent operational behavior. Typical hardness values are in the range of 290 to 330 HV10 in the HAZ of Type 415.

In addition to ASME Section III requirements, HAZ impact energy numbers are verified during procedure qualification. To ensure a satisfactory toughness in the HAZ (as close as possible to the fusion line) a minimum energy of 72 J (average) and 56 J (minimum individual value) is required at room temperature.

Environmental Cracking

An assessment of the susceptibility of UNS S41500 stainless steel to environmental cracking, including intergranular stress corrosion cracking (IGSCC), transgranular stress corrosion cracking (TGSCC), hydrogen embrittlement, and thermal aging, is discussed as follows:

IGSCC

According to Reference 3, martensitic stainless steel X3CrNiMo13-4 (ASME equivalent: Type 415) has less tendency to form carbide precipitations compared to other types of martensitic stainless steels because of its reduced carbon content. At higher temperatures, carbon is completely dissolved in the austenitic structure. After transformation to martensite, carbon remains in solution. During welding operation, carbides precipitate in the HAZ on the grain boundaries in more coarse carbides but mostly within the grains in fine $M_{23}C_6$ together with carbon nitrides. This prevents chromium depletion near the grain boundaries therefore preventing intergranular attack, and IGSCC. Based on the operating experience of Type 415 used for the CRDMs in German nuclear power plants for a time period of 19 years, Type 415 is not susceptible to intergranular corrosion under PWR primary water chemistry conditions.

TGSCC

Martensitic stainless steels may be adversely affected by TGSCC in oxygenated water and in the presence of chloride. Stress corrosion tests on Type 415 material have been performed at 599°F using pre-stressed, electrically isolated four-point bending specimens in static autoclaves. The environmental conditions of the tests simulated primary water conditions according to the specification of conventional German PWRs. One hundred seventy seven specimens have been subjected to these test conditions. No incipient cracking observed on any of the specimens after a total exposure of up to 4200 hours.

In order to force incipient cracking, the test conditions were made more aggressive:

a) 1750 ppm $H_3BO_3$ + 10ppm chloride/$N_2H_4$ for a duration of 880 hours.

b) 1750 ppm H3BO3+ 100ppm chloride/N2H4 for a duration of 984 hours.

c) Deionized water, air-saturated, 100 ppm chloride.

For these tests, the four-point bend specimens are pre-stressed up to 90 percent of the room temperature yield strength.

Samples of the test series a) and b) are free of incipient cracking. The test conditions in series c) either cracked or were broken. However, the test conditions in series c) are not relevant to primary water applications because during operation, concentrations of chloride are not present in the primary circuit of PWRs.

Additionally, a critical threshold potential has to be reached before TGSCC initiation occurs. In high temperature water, this threshold potential is controlled by the concentration of dissolved oxygen. Because of the reducing water chemistry of the primary coolant, those critical threshold values will not to be reached. Therefore, TGSCC is not expected for the U.S. EPR lower pressure housing of the CRDM made from Type 415.

Based on the operating experience of Type 415 used for the CRDMs in German nuclear power plants for a time period of 19 years, Type 415 is not susceptible to TGSCC under PWR primary water chemistry conditions.

Hydrogen embrittlement

For hydrogen-induced stress corrosion cracking (SCC), a criterion for the susceptibility of low alloyed steels is provided in Reference 4. Low alloy steels with hardness equal to or lower than 350 HV (tensile strength of approximately 1200 MPa) are not susceptible to hydrogen-induced SCC. This criterion is also used for the assessment of the susceptibility of martensitic stainless steels to hydrogen-induced SCC. Hardness of the HAZ of Type 415 and the base material after final PWHT is limited to a maximum of 350 HV.

The presence of atomic hydrogen in the area of the martensitic stainless steel is unlikely because atomic hydrogen is not able to penetrate the passive oxide layers due to the electrostatic field inside the oxide.

Thermal Aging

Martensitic stainless steels are, depending on the operating temperature, susceptible to thermal aging by precipitation of chromium enriched $\alpha$'-phase. This embrittlement is a shift of the impact energy versus temperature curve to higher temperatures, and a decrease of the upper shelf energy (USE) level.

In the case of the pressure housing, the operating temperature for the Type 415 is lower than 572°F and closer to 482°F; therefore, the aging effect is lower for the Type 415 for the CRDM housing than would be if exposed to the reactor coolant system (RCS) outlet temperature.

A thermal aging model was developed initially by Framatome (now AREVA NP), then refined by EdF in the 1980s (Reference 5). Based on the chemical composition, the microstructure, the tempering heat treatment, and the initial mechanical properties of the material, the model allows evaluation of the effect of the aging. For the Type 415 CRDM housing part conditions (estimated: 54 years at 482°F and 6 years at 536°F), this model predicts a shift of the transition temperature $\Delta TT_{½USE}$ of 73.4°F and a decrease of $\Delta$USE of 2J for Type 415. This aging embrittlement effect is insignificant, taking into account the initial upper shelf level well above 100J and the initial transition temperature of -148°F.

2. Type 415 martensitic stainless steel has been used for the CRDM pressure housings in the German Konvoi PWRs for 19 years. During 19 years of operation, no crack indications or leakages on pressure housings including parts made from the Type 415 martensitic stainless steel have been reported.

   In several German plants, non-destructive testing on the CRDM pressure housings, including the upper dissimilar metal weld, has been performed utilizing different methodologies, such as eddy-current examination from the inside and ultrasonic examination and liquid penetrant examination from the outside. In German nuclear power plants, the pressure housings are spot-checked by eddy-current method. As noted in Item 1 above, no intergranular corrosion attack, cracking (such as due to IGSCC, TGSCC, or thermal embrittlement), or leakages have been detected on the CRDM pressure housings by these inservice testings.

**References for Question 05.02.03-19:**

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2. Schmidt + Clemens Edelstahlwerk: Soft-martensitic CrNi Stainless Steels Märker Irrubigo 4313 (X 5 CrNi 13 4) Märker Irrubigo 4405 (X5 CrNiMo 16 5), Data Sheet.
3. Folkhard: Metallurgie der Schweißung nichtrostender Stähle Springer Verlag 1984.
4. Hickling, J.: Hydrogen-induced Stress Corrosion Cracking in Low Alloyed Steels, 4th MPA Seminar, Stuttgart, 1978.
5. Meyzaud, Y., R. Cozar: “Design of Aging-Resistant Martensitic Stainless Steels for PWR” AIME-Conf. On Ferritic Alloys for Use in Nuclear Energy Technologies, Snowbird (USA), June 12-14, 1983.

**FSAR Impact:**

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