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November 26, 2019
NOC-AE-19003696
10 CFR 50.55a

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555-0001

South Texas Project Units 1 & 2
Docket No. STN 50-498, STN 50-499
Supplemental Information for Proposed Alternative to ASME Code Requirements for the Repair/Replacement of Essential Cooling Water System Class 3 Buried Piping
(Relief Request RR-ENG-3-24) (EPID: L 2019-LLR-0096)

References:

1. Letter; R. Dunn to U.S. NRC Document Control Desk; "Proposed Alternative to ASME Boiler & Pressure Vessel Code Section XI Requirements for Repair/Replacement of Essential Cooling Water (ECW) System Class 3 Buried Piping in accordance with 10 CFR 50.55a(z)(a) (Relief Request RR-ENG-3-24)"; September 26, 2019; (NOC-AE-19003684) (ML19274C393).
2. Letter; D. Galvin to G. T. Powell; "South Texas Project, Units 1 and 2 – Supplemental Information needed for acceptance of requested licensing action RE: Proposed alternative to ASME code requirements for the repair of essential cooling water system class 3 buried piping (EPID: L 2019-LLR-0096)"; November 13, 2019; (AE-NOC-19003235) (ML19312A096).

By Reference 1, STP Nuclear Operating Company (STPNOC) submitted a proposed alternative to the requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) at South Texas Project Units 1 and 2. The proposed alternative to ASME Code, Section XI, IWA-4000, applies a carbon fiber reinforced polymer system for the internal repair of buried essential cooling water piping. By Reference 2, the NRC staff identified supplemental information that would be needed to complete its review. The STPNOC response providing this supplemental information is in the Enclosure to this letter.

There are no commitments in this letter.

If there are any questions or if additional information is needed, please contact Nic Boehmisch at (361) 972-8172 or me at (361) 972-7743.

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nb
Enclosure: Supplemental Information for Proposed Alternative

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SOUTH TEXAS PROJECT UNITS 1 AND 2
DOCKET NUMBERS 50-498 AND 50-499
SUPPLEMENTAL INFORMATION FOR PROPOSED ALTERNATIVE TO ASME CODE REQUIREMENTS FOR THE REPAIR/REPLACEMENT OF ESSENTIAL COOLING WATER SYSTEM CLASS 3 BURIED PIPING (RELIEF REQUEST RR-ENG-3-24)

By letter dated September 26, 2019 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML19274C393), STP Nuclear Operating Company (STPNOC, the licensee) submitted a proposed alternative to the requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) at South Texas Project, Units 1 and 2. The proposed alternative to ASME Code, Section XI, IWA-4000, applies a carbon fiber reinforced polymer (CFRP) system for the internal repair of buried essential cooling water (ECW) piping.

The U.S. Nuclear Regulatory Commission (NRC) staff has reviewed the application and has determined that the following additional information is necessary for the staff to make an independent assessment regarding the acceptability of the proposed alternative:

1. ASME Code, Section XI, IWA-4221 (b) requires repair/replacement piping to meet the original Construction Code requirements for the ECW piping. However, the applicable Construction Code for South Texas Project does not provide the requirements for the design, fabrication, installation, examination and testing of CFRP in buried piping. The application identifies 12 separate lines to use CFRP (three supply lines each for Units 1 and 2, and three return lines each for Units 1 and 2). Specific analyses or technical evaluations demonstrating structural integrity for these 12 separate lines using CFRP are missing in the submittal. Attachment C in Enclosure 5 of the application provides only a sample calculation. Thus, critical technical analysis information required for the NRC to draw a safety conclusion is missing.

2. The application includes an analysis methodology change from the ASME Code. ASME Codes and Standards for piping analysis are discussed in Title 10 of the Code of Federal Regulations Section 50.55a. Piping analysis for safety-related Class 3 piping in ASME Subsection ND does not utilize the load and resistance factor design (LRFD) method. The application describes using the LRFD methodology for buried aluminum-bronze buried piping in soil.

**<u>NRC Additional Information 1.a.</u>**
Provide a summary of design inputs to include loads, pressures, temperatures, geometrical inputs, length of repair, CFRP layers, thicknesses, bonding length used for the analysis and evaluations of these 12 lines.

**<u>STPNOC response</u>**
The calculation provided in Enclosure 5 is bounding for all supply and return lines. South Texas Project (STP) has one diameter of pipe, 30 in., for all supply and return piping. As a result of this being a single analysis with applicability to all supply and return lines, the results from the analysis are all contained within Enclosure 5, specifically Attachment C. Pages 3 and 62 of 62 of Enclosure 5 describe Attachment C as “Sample Calculations”. Despite this title, the calculation provided as Attachment C is actually a bounding calculation representing all 12 lines (supply and return for three trains in both units). The calculated factors of safety are summarized on the last page of the calculation for all design limit states.

**NRC Additional Information 1.b.**
Provide a summary of the results of all analyses and evaluations to include circumferential design analysis, buckling evaluations, longitudinal design analysis, bond integrity at terminations for the applicable load combinations, corresponding allowable limits, and margins for all 12 of the repairs using CFRP.

**STPNOC response**
Refer to response to 1.a.

**NRC Additional Information 1.c.**
Provide the missing details for Sections E/S-7, H/S-10, and G/S-9 in the piping layout drawings in Enclosure 2, Attachments B1, B2, and B3.

**STPNOC response**
Refer to Figures 6, 7, and 8 contained in Enclosure 5 for CFRP details (Figure 6 is the same as E/S-7, Figure 7 is H/S-10 and Figure 8 is G/S-9).

**NRC Additional Information 1.d.**
Provide an evaluation of the terminations of the repairs considering the effects from both sides (repair side and the other or non-repaired side). Also, describe whether any of the repair terminations interface with piping not buried such as piping in valve pits, piping in buildings, or any other continuations.

**STPNOC response**
At the terminal ends of the CFRP system there is a transition length of pipe between the host pipe and the CFRP system. Over this transition length, the host pipe is a pressure boundary and meets all design requirements, and the CFRP system also meets the design requirements. The most significant longitudinal load in this transition zone is due to the temperature change and conservatively considers that the entire thermal force on the composite section is resisted by the CFRP alone, and the load transfer from the CFRP system onto the host pipe occurs through the bond between the CFRP system and the aluminum bronze substrate, as discussed in Enclosure 5, Limit States 5 and 6.

The buried piping interfaces with continuous aluminum bronze piping in buildings. However, the scope of the relief request is for buried piping only. Repair of non-buried pipe will be in accordance with ASME Section XI Code requirements.

**NRC Additional Information 1.e.**
Provide or include in the evaluations the effect of dissimilar thermal expansion of the repaired aluminum-bronze pipe and the CFRP material on the terminations.

**STPNOC response**
The dissimilar thermal expansion of aluminum bronze and CFRP have been considered in the Enclosure 5 starting on page 27 of 62 (limit states 5 and 6) and the corresponding section in the calculations in Enclosure 5, Attachment C. See in particular the bottom portion of page 28 (beginning with the paragraph above Equation 44), the 2nd and 3rd bullets under section 5A.3.3 and Enclosure 5, Attachment C, page 2, item 3.

**NRC Additional Information 1.f.**
Enclosure 5, Figure 2a, provides a typical design summary sheet for the piping repair. Figure 2a, Column 3, specifies the approximate length of piping repaired with CFRP but the listed value is "TBD". Clarify the reference to "TBD" or provide the associated value.

**STPNOC response**
The analysis considers the entire length of all buried supply and return lines for CFRP repair. CFRP will only be applied to a specific location in the pipeline where the existing pipe is at or below code requirements for pipe minimum wall thickness.

**NRC Additional Information 1.g.**
Enclosure 2, Item 1)c), refers to an Enclosure B. The application does not include an Enclosure B. Clarify the reference to Enclosure B or provide Enclosure B.

**STPNOC response**
The reference to Enclosure B refers to Attachments B1, B2, and B3 of Enclosure 2.

**NRC Additional Information 2.a.**
Provide a discussion of the analysis method used in the original design for ASME safety-related Class 3 ECW piping and any variances between the ASME ND allowable stress methodology and the LRFD methodology.

**STPNOC response**
Calculations provided in Enclosure 5 consider both LRFD and allowable stress design (ASD) methodologies. The LRFD approach is specified in the AWWA C305 Standard and hence was used to determine CFRP system layup for the 30 in. diameter ECW pipelines at STP. The ASD approach is presented as a check of the factors of safety for the limit states, and the factors of safety for the limit states are presented in the calculations in Attachment C of Enclosure 5. The main difference between the two design approaches is in the way the design factors of safety are determined. The LRFD methodology accounts for the variabilities in loads and resistances separately and uses load and resistance factors to achieve particular reliability indices (i.e., probabilities of failure). The ASD methodology does not have a specific correlation to the probability of failure, and the minimum required factor of safety is based on past performance and experience with similar materials and structures. CFRP materials are not currently addressed in ASME Section III; therefore, the factors of safety considered by NRC for the CFRP repairs at the Surry Power Station were used.

This response provides a discussion of the variances between the analysis methods used in the original design of the Class 3 ECW piping and the CFRP system design method presented in Enclosure 5. The original piping system was designed and installed to ASME III, 1974 Edition including addenda through winter 1975. Section III allows use of portions of later Editions and Addenda as well as use of material produced to earlier Editions of the Code by using the provisions of NCA-1140(e). The 2013 Edition of ASME Section III, Division 1 – ND is referred to in this evaluation unless otherwise noted.

**CFRP System Design and ASME Section III, Division 1 – ND Evaluation**
Although CFRP materials are not addressed in the ASME Section III code, the code allows the use of such unlisted materials:

**Paragraph ND-3649, Pressure Design of Other Pressure Retaining Piping Products.**
*Pressure retaining piping products not covered by the standards listed in Table NCA-7100-1 and for which design equations or procedures are not given in this Subsection may be used where the design of similarly shaped, proportioned, and sized components have been proven satisfactory by successful performance under comparable service conditions. Where such satisfactory service experience exists, interpolation may be made to other sized piping products with a geometrically similar shape. In the absence of such service experience, the pressure design shall be based on an analysis consistent with the general design philosophy of this Subsection and substantiated by at least one of the following:*

*(a) proof test as described in ASME B16.9;*

*(b) experimental stress analysis (Appendix II).*

The above requirement is fulfilled by the CFRP system as follows:

- There exists extensive, successful service experience under comparable conditions with similarly proportioned components of the same or similar CFRP repair material as demonstrated in Enclosure 9.
- Proof tests of the representative CFRP layup for repair of pipes were performed to demonstrate water tightness of the CFRP layup to a pressure of 400 psi (limit of the test apparatus), which is more than 6 times higher than the maximum working pressure of 63 psi at STP. (Reference Enclosure 4.)
- Full scale tests of CFRP repaired pipe were performed and documented in the Water Research Foundation (WRF) reports 4352 and 4510.

The evaluations of the applicable design criteria from ASME-III, Division 1 – ND-3600 – *Piping Design* are provided below.

**Paragraph ND-3611.1, Allowable Stress Values**
*Allowable stress values to be used for the design of piping systems are given in Tables 1A, 1B, and 3, Section II, Part D, Subpart 1.*

This paragraph establishes the basis for allowable stress values and refers to the tables in Section II, Part D, Subpart 1. Since CFRP has not been incorporated into ASME, allowable stress values used are based on manufacturer's recommended stress values and the corresponding factors of safety considered by NRC for the CFRP repairs at the Surry Power Station shown below:

| | **Different Load Combinations** | | | | | |
|---|---|---|---|---|---|---|
| | **LS1** | **LS2** | **LS3** | **LS4** | **LS5** | **LS6** |
| Minimum acceptable $FS_{eff}$ for LRFD methodology | 3.5 | 2.25 | 2.33 | 2.33 | 2.25 | 2.33 |

Where,

- LS1 is for protection from tensile rupture of CFRP system in the circumferential direction due to internal pressure.
- LS2 is for protection from buckling of CFRP system in the circumferential direction due to internal negative pressure and external groundwater pressure.
- LS3 is for protection from tensile rupture of CFRP system in the longitudinal direction due to thrust, Poisson effect of internal pressure, and temperature decrease.
- LS4 is protection from shear bond failure of CFRP system at repair terminations.
- LS5 is for protection from buckling of CFRP system in the longitudinal direction due to temperature increase.
- LS6 is for protection from tensile rupture of CFRP system in the longitudinal direction due to radial expansion of pipe in corroded zone of metallic pipe.

AWWA C305 Standard for CFRP repair of pipe uses a reliability based approach to determine load and resistance factors, which can be combined into one factor of safety (i.e., effective factor safety) for the purpose of comparing with the allowable stress design methodology. This approach starts with a target reliability or maximum acceptable annual failure rate and considers load factors and resistance factors separately. Load factors are based on the probability distribution of individual loads anticipated during the life of the structure. Resistance factors are based on material properties, manufacturing process, environmental effects, and analysis methods and accuracy; they are represented by a resistance factor, a time effect factor, and a material adjustment factor. This reliability approach is described in more detail in Enclosure 5, Section 5A.1.2, and the associated references.

The effective factor of safety, $FS_{eff}$, is calculated by dividing the load factors and resistance factors for each limit state: $FS_{eff} = LF/(\lambda*\phi*C)$ where LF and $\phi$ are the effective load factor and resistance factor for the given design limit state, respectively, $\lambda$ is the time effect factor, and C is the material adjustment factor. The typical design calculations presented in Enclosure 5, Attachment C, presented a calculation using load and resistance factors followed by a calculation of the effective factors of safety for each limit state for the actual selected CFRP layup. For all the limit states considered, the effective factors of safety remain above the factors of safety considered by NRC for the Surry Power Station, as summarized on the last page of calculations in Enclosure 5 Attachment C.

**Paragraph ND-3611.2, Stress Limits**
This paragraph provides stress limits for design and service loadings, external pressure, expansion, and non-repeated stresses. The design loads, load combinations, and the corresponding resulting factors of safety are presented in Enclosure 5 and in the calculations in Enclosure 5 Attachment C.

**Paragraph ND-3612, Pressure-Temperature Rating for Piping Products**
**Paragraph ND-3612.2, Piping Products Not Having Specific Ratings**

*Should it be desired to use methods of manufacture or design of components not covered by this Subsection, it is intended that the manufacturer shall comply with the requirements of ND-3640 and ND-3690 and other applicable requirements of this Subsection for design loadings involved. The manufacturer's recommended pressure ratings shall not be exceeded.*

CFRP material does not have specific ratings, so the manufacturer's recommended material properties are used. The manufacturer's recommended pressures and temperature are not exceeded, as documented by the factors of safety for the piping within the scope of the CFRP repairs at STP.

ND-3641.1 determines the minimum thickness of pipe wall required for design pressures at temperatures not exceeding those listed for various materials by the following equations:

$$t_m = \frac{PD_o}{2(SE + Py)} + A$$

$$t_m = \frac{Pd + 2SEA + 2yPA}{2(SE + Py - P)}$$

Where,

| | |
|---|---|
| $t_m$ = | minimum required wall thickness, in. |
| P = | internal design pressure, psig |
| $D_o$ = | outside diameter of pipe, in. |
| d = | inside diameter of pipe, in. |
| SE= | maximum allowable stress in material due to internal pressure and joint efficiency (or casting quality factor) at the design temperature, psi |
| y = | coefficient having value of 0.4, except that for pipe with a $D_o/t_m$ ratio of less than 6, the value of y shall be $d / (d + D_o)$ |
| A = | additional thickness (such as for corrosion allowance), in. |

CFRP laminates currently have no allowable stress values listed in ASME Codes, as discussed above, and the minimum wall thickness equations in the Code cannot be used directly to determine the thickness requirements for CFRP. As a result, the minimum wall thickness of CFRP (obtained by determining the minimum number of layers of CFRP) was determined by using equations similar to those provided in ND-3641.1 except for joint efficiency and allowances. Equations for Limit State 1, presented in Enclosure 5, are expressed in terms of strain or stress and are adapted to the particular features of the CFRP system repair, including considerations of multiple layers, layup sequence, material properties along and across the fiber, and others. Note that for CFRP, additional thickness, A, is not used, but it is typically provided because the number of CFRP layers is rounded up. Margin of safety above the minimum factor of safety (or a combination of load and resistance factors used in calculations) is presented as a strength-to-demand ratio (SDR). As discussed above, the calculated factor of safety for the pressure cases is 8.17 as shown in the design summary on the last page of Enclosure 5 Attachment C.

ND-3690 states that the dimensions of nonstandard products shall be such to provide strength and performance equivalent to standard products, except as permitted in ND-3641. ND-3641.1 is discussed above, and ND-3641.2 is discussed below.

**Paragraph ND-3641.2 Straight Pipe Under External Pressure refers to ND-3133.**
ND-3133 is not directly applicable because the modulus of elasticity and strength for CFRP laminates are not listed in the Code. The piping that is in scope of this repair is buried in soil; therefore, external soil and ground water loads and internal negative pressure were considered. In the calculations provided in Enclosure 5 for Limit State 4, the load combinations are

considered, including external pressures together with internal negative pressure, to determine the worst case load that may result in buckling of the CFRP system. The calculated factor of safety on buckling of the CFRP system is 10.01.

**Paragraph ND-3642 Curved Segments of Pipe**
This Section provides limitations for pipe bends and elbows. The minimum CFRP layup at any point on the bend is at least equal to the layup in the straight pipe and includes one additional longitudinal layer more than calculated number of layers. Some circumferential layers are overlapped in bends, thus providing additional partial hoop layers through the curved segments of pipe.

**Paragraph ND-3643 Intersections**
This Section gives rules governing the design of branch connections to sustain internal and external pressure in cases where the axes of the branch and the run intersect, and the angle between the axes of the branch and of the run is between 45 degrees and 90 degrees, inclusive. It provides guidance on calculating the reinforcement area around the branch connection. The CFRP layup provided has high factors of safety as discussed above. In addition, as discussed in Enclosure 5, CFRP system installation at outlets and other branch connections requires special details consisting of integration of CFRP and Glass Fiber Reinforced Polymer (GFRP) layers from the main pipe and outlet in a particular sequence, including folding of layers from the main pipe into the outlet and vice versa, to satisfy the strength requirements and ensure watertightness at the same time. Several additional layers of CFRP are locally applied in the vicinity of the outlet to replace the amount of material lost in the cross-section, as well as to provide continuity of forces around the outlet. A sample illustration of details at outlets is shown in Figure 8 in Enclosure 5. In addition to such detailing, a longitudinal axial force equal to P∗A (bulkhead thrust force) is considered in the design of the CFRP layups to account for the effects of pressure-induced thrust.

**Paragraph ND-3644 Miters.**
Not applicable to CFRP repair design at STP.

**Paragraph ND-3645 Attachments.**
Not applicable to CFRP repair design at STP.

**Paragraph ND-3646 Closures.**
Not applicable to CFRP repair design at STP.

**Paragraph ND-3647 Pressure Design of Flanged Joints and Blanks.**
Not applicable to CFRP repair design at STP.

**Paragraph ND-3648 Reducers.**
Not applicable to CFRP repair design at STP.

**Paragraph ND-3650 Analysis of Piping Systems.**
*To validate a design under the rules in this paragraph, the complete piping system must be analyzed between anchors for the effects of thermal expansion, weight, and other sustained and occasional loads.*

The calculations provided in Enclosure 5 for Limit State 5, considers strains in the longitudinal direction due to pressure-induced thrust, Poisson effect of internal pressure, and temperature change. The calculations are adapted to the particular features of the CFRP system repair,

including considerations of multiple layers, layup sequence, material and thermal properties along and across the fiber, and others. The calculated factor of safety for CFRP in the longitudinal direction is 4.41 and that due to seismic events is 3.47, which is considered conservative for the repair of ECW piping. Note that this does not consider the contribution of additional CFRP layers installed near elbows, which increases the factor of safety.

Occasional loads are considered as transient loads in both circumferential and longitudinal load cases in the provided calculations.

Cyclic loads are unlikely in buried pipeline applications, as discussed in Enclosure 8. Variation of loads in pipelines is limited to changes in pressures and temperatures at system shut-downs and start-ups, which is typically once a year or once in eighteen months. As a result, the number of cycles during a 50-year design life is not significant. Operating loads are typically steady, and although variations in internal pressure or temperature may occur during operation, such variations are expected to be small, which result in narrow cyclic stress ranges that require a much greater number of stress cycles for failure that are even less likely to occur. For the above reasons, the CFRP system for the ECW pipeline does not need to be designed for fatigue effects, and failure of the CFRP system due to fatigue is not considered an applicable failure mode for the proposed repair technology in this alternative request.

**CFRP Limit States not Considered in ND-3600**
ND-3600 does not consider all failure modes for the CFRP repair of pipe, including the shear at the ends of the repair as discussed above, and localized radial expansion of CFRP in areas of corroded through holes in the host pipe. Failure modes and effects analysis for the CFRP repair at STP is presented in Enclosure 8, and calculations are presented in Enclosure 5.

**NRC Additional Information 2.b.**
Provide a summary of the results of the piping analysis for one limiting case.

**STPNOC response**
Refer to STP response 1.a. A summary exists on the final page of Enclosure 5, Attachment C.