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LTR-NRC-20-12

March 2, 2020

Subject: NSAL-20-1 Revision 0, "Reactor Vessel Head Control Rod Drive Mechanism Penetration Thermal Sleeve Cross-Sectional Failure"

Westinghouse Letter LTR-NRC-19-79 (ML19346H873), dated December 12, 2019, provided notification of the potential existence of a defect pursuant to 10 CFR Part 21. The notification was related to operating experience with a cross-sectional thermal sleeve fracture and/or crack-like indications in the flange collar region. As a result, Westinghouse provided additional information on the issue to our utility customers in Nuclear Safety Advisory Letter (NSAL) NSAL-20-1, "Reactor Vessel Head Control Rod Drive Mechanism Penetration Thermal Sleeve Cross-Sectional Failure". This document was shared with the industry soon after its issue date of February 14, 2020 and is attached for your information.

Camille T. Zozula, Secretary
Westinghouse Safety Review Committee

Attachment: NSAL-20-1

cc: Kate Lenning (NRC)
Leslie Fields (NRC)
Dave Rudland (NRC)

Nuclear Safety Advisory Letter

1000 Westinghouse Drive, Cranberry Township, PA 16066

Subject: **Reactor Vessel Head Control Rod Drive Mechanism Penetration Thermal Sleeve Cross-Sectional Failure**	Number: **NSAL-20-1**
Basic Component: Thermal Sleeve in CRDM Reactor Head Penetration	Date: February 14, 2020
Substantial Safety Hazard or Failure to Comply Pursuant to 10 CFR 21.21(a) Transfer of Information Pursuant to 10 CFR 21.21(b) Advisory Information Pursuant to 10 CFR 21.21(d)(2)	Yes ☒ No ☐ N/A ☐ Yes ☐ Yes ☐

SUMMARY

New operating experience (OE) has shown that Westinghouse nuclear steam supply system (NSSS) plants that operate in a T-cold configuration and have control rod drive mechanism (CRDM) thermal sleeves with a collar below the flange (Figure 2), are potentially susceptible to cracking and separation of the flange from the sleeve. This separated condition, when combined with the type of flange wear discussed in NSAL-18-1 [1], can potentially impede control rod movement and RCCA insertability. To date, two plants at the same site identified crack-like indications. One plant experienced complete flange separation at one location; however, the separation did not impede control rod motion.

In December 2019, in accordance with 10 CFR Part 21, Westinghouse reported this issue as a potential defect [2] due to the possibility for this type of degradation to impact control rod insertion and ultimately plant shutdown. This NSAL discusses the thermal sleeve failure, provides the potentially affected licensees with a basis for limited continued plant operation, and offers inspection recommendations.

The OE involves a new thermal sleeve failure mechanism. However, the safety significance of this issue is associated with the conditions discussed in NSAL-18-1. As a result, the recommendations captured in NSAL-20-1 should be considered in addition to those provided in NSAL-18-1.

Additional information, if required, may be obtained from Bryan Wilson, (412) 374-3281

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ISSUE DESCRIPTION

During a planned 2019 refueling outage at a Westinghouse NSSS plant, a thermal sleeve (Figure 1) was observed to be fractured and resting upon an upper internals upper guide tube (UGT). The OE showed that a mechanical failure of the thermal sleeve had occurred across its cross-section. The failure mechanism was different from the thermal sleeve flange wear discussed in NSAL-18-1 and TB-07-2, Revision 3 [3]. The fracture occurred beneath the "collar" (illustrated in Figure 2) which is present on a subset of thermal sleeves supplied by Westinghouse (The affected plant was operating with its original reactor vessel closure head [RVCH] and CRDM thermal sleeves.)

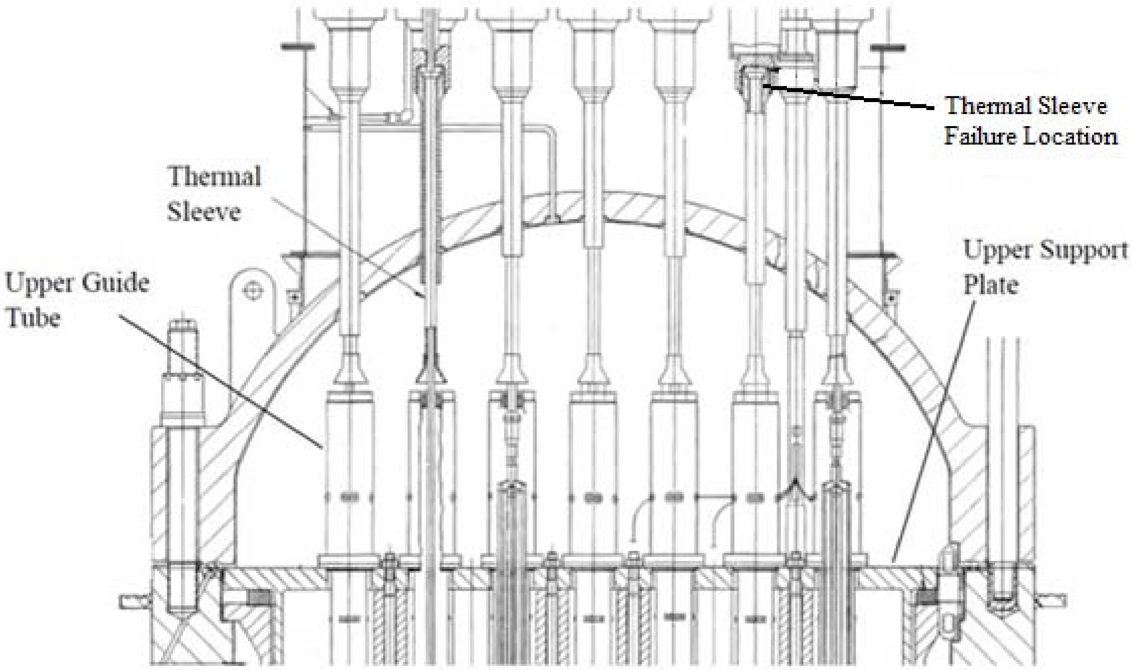

Figure 1 Thermal Sleeve Location in the RVCH

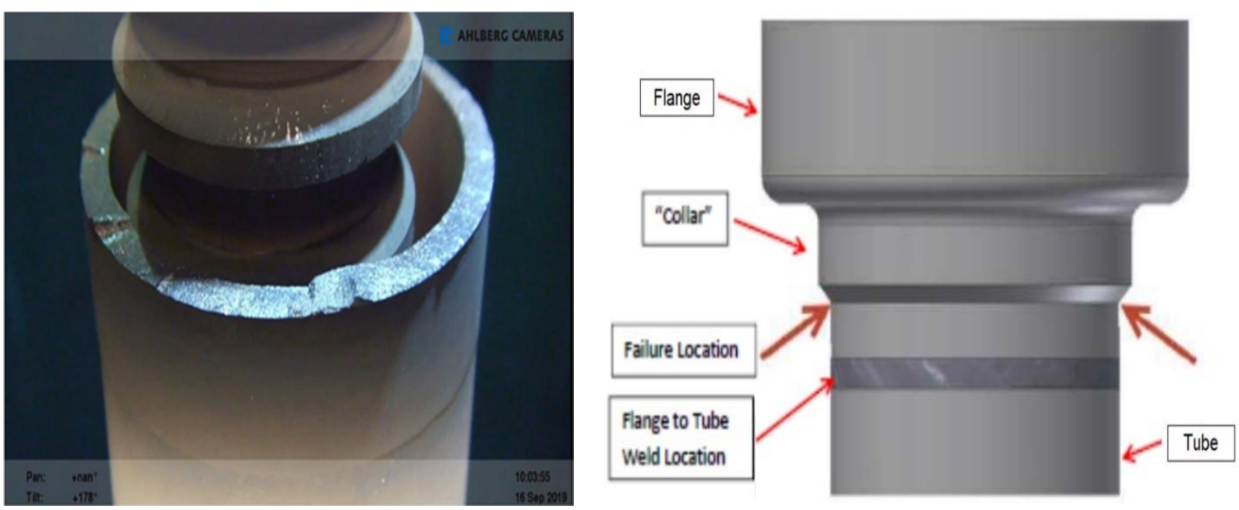

Figure 2 Thermal Sleeve Flange Failure Location

The utility performed extent of condition inspections on the remaining thermal sleeves at the affected plant as well as on a second plant at the same site. Both plants have the same thermal sleeve design. The inspections were performed via visual examination of the inner surface of the thermal sleeve. A total of thirteen thermal sleeve locations (Unit 1 – twelve, Unit 2 – one) had visible crack-like indications, as shown in Figure 3. No additional locations had failed. The locations of the affected sleeves were distributed throughout the RVCH, with a higher concentration of cracked sleeves toward the center of the head. Crack-like indications of varying lengths were identified with no correlation to the amount of flange wear experienced. The affected utility did not identify any issues associated with drive rod movement during operation prior to identifying the failure.

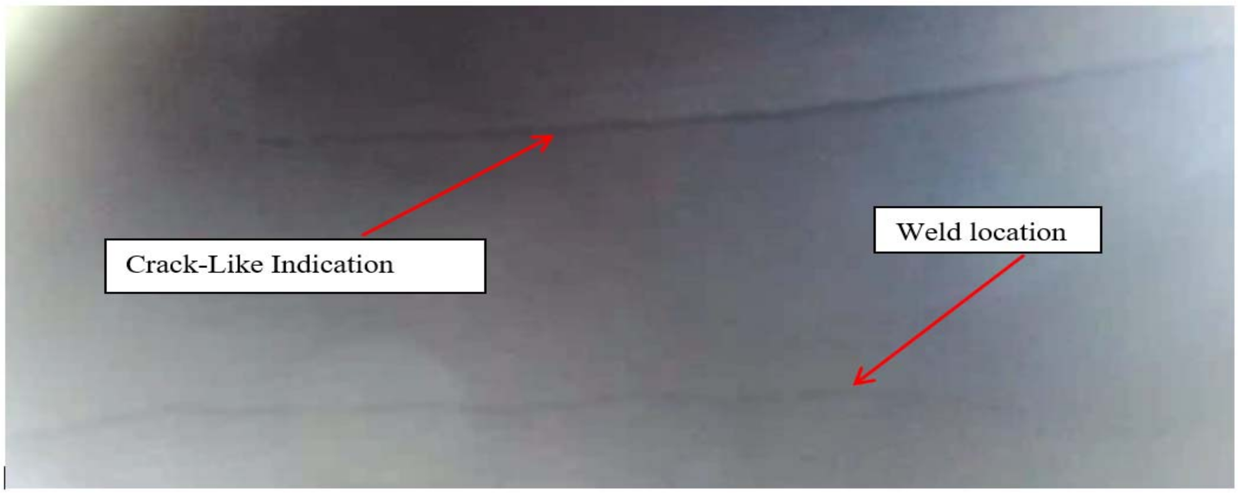

Figure 3 Crack-Like Indication Identified by Visual Inspection

TECHNICAL EVALUATION

In response to this OE, the affected utility performed a causal analysis with support from Westinghouse. Based on metallurgical examination of the separated sleeve, the analysis concluded that the most likely cause of failure was fatigue crack propagation. The analysis identified the transition between the collar and the tubular section on the outer diameter of the thermal sleeve to be a potential contributor, due to the stress concentration resulting from the tube wall thickness transition and potentially sharp transition radius in this location; however, this was not substantiated through the identification of a crack initiation site. Thermal sleeve designs without the collar have a large controlled transition radius between the tubular section and the flange. This transition results in a much lower stress concentration, which is less susceptible to this failure mechanism. Therefore, plants operating with thermal sleeve designs without a collar below the flange are not included in Table 1.

The causal analysis also identified the loading, more specifically flow-induced vibration (FIV), as a potential contributor to the cracking and failure. Plants with higher head bypass flow, referred to as "T-cold" head plants, tend to produce more significant FIV loads on the thermal sleeves as compared to plants with lower head bypass flow, referred to as "T-hot" head plants. This is evidenced by T-cold head plants consistently experiencing a greater amount of thermal sleeve wear [3]. As such, it is anticipated that T-cold head plants will have much greater susceptibility to this issue than T-hot head plants.

In certain conditions in which the CRDM housing is worn (as discussed in NSAL-18-1) and the thermal sleeve flange is separated from the sleeve, the flange remnant can move from its normal position and potentially wedge between the drive rod and the pocket worn into the CRDM housing as is shown in Figure 4. The minimum amount of combined thermal sleeve flange and CRDM housing wear required for this to potentially occur is approximately 0.80 inches. This wear, measured in terms of the gradual "lowering" of the thermal sleeve from its as-installed position, is referred to as the flange wear lowering criterion. Wedging of the drive rod is unlikely if this flange wear lowering criterion is not exceeded.

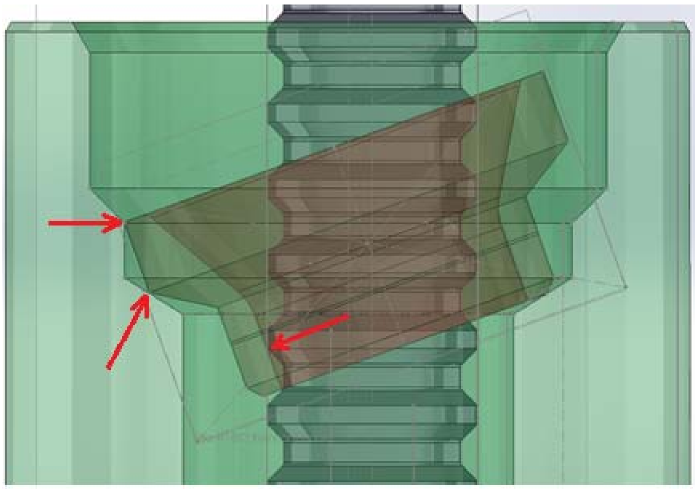

Figure 4 Potential Flange Wedging Scenario

SAFETY SIGNIFICANCE

A potential defect was identified that is associated with a previously unseen form of thermal sleeve degradation (i.e., mechanical fatigue and fracture that leads to flange separation). RCCA insertability could become adversely impacted not only due to the flange wear reported in LTR-NRC-18-34 [4], but also due to the additional coincident fracture and separation of the thermal sleeve tube from its flange. This condition could exist prior to reaching the flange wear criteria established in PWROG-16003-P, Revisions 1 and 2 [5] (note that PWROG-16003-P, Revision 0 set the wear criteria at less than 0.80 inch). The information provided in PWROG-16003-P, Revisions 1 and 2 and NSAL-18-1 does not address this new OE. If no action is taken to monitor and/or correct this condition and if more than one RCCA fails to insert following a reactor trip, this could result in a substantial safety hazard.

Inactive CRDM locations and unrodded thermal sleeve locations do not contain drive rods which can be impeded by separation of the thermal sleeve. A fractured and separated thermal sleeve at one of these locations does not create a condition that impacts adjacent or nearby rodded locations. Sleeve separation at one of these locations does not have the potential to result in a substantial safety hazard.

OPERABILITY ASSESSMENT

As discussed in NSAL-18-1, thermal sleeve flange wear is an aging mechanism that affects most operating Westinghouse plants (see Tables 1 and 2 of NSAL-18-1). Most of these plants have recently performed thermal sleeve flange wear inspections in response to MRP 2018-027 [6] industry guidance. The following assessments take into consideration the information in NSAL-18-1 and the new operating experience:

- All but three of the affected plants, which have performed flange wear measurements, will remain below the flange wear lowering criterion at a single thermal sleeve location by the next refueling outage following the issuance of this NSAL. However, should one control rod fail to insert during plant operation, the safety analyses demonstrate that the reactor can be safely shut down with the highest worth control rod stuck in its fully withdrawn position.

- One of the affected plants that has performed flange wear measurements has the potential to exceed the flange wear lowering criterion for up to two rods by the next refueling outage following issuance of this NSAL. In addition to this plant, there are a few other plants that have not yet performed flange wear measurements. For these plants, the wear distribution from the as-measured plants provides an adequate assessment of the probability that more than one thermal sleeve location might potentially exceed the flange wear lowering criterion before the next refueling outage. Reviewing the wear distribution across the as-measured locations shows that the probability for five locations to exceed the wear criterion by the next refueling cycle is on the order of 10^{-8}. This is well below the probability of a typical anticipated transient without scram (ATWS) analysis,[1] considers fewer impacted rods[2], and conservatively neglects both the probability of a mechanical flange failure occurring at a location that has exceeded the wear criterion and the probability of an anticipated operational occurrence (AOO, or ANS Condition II event) occurring at the same time.

- It is reasonable to conclude, based on the flange wear condition alone, that the affected plants are bounded by the current ATWS analysis conclusions until at least the next refueling outage. Individual flange wear conditions may be used on a plant-specific basis to show that the time to reach the 0.80 inch wear criterion is greater than one refueling cycle.

If a thermal sleeve mechanical failure were to occur, it is unlikely to go unnoticed during a refueling outage and be left uncorrected. The separated lower section of the thermal sleeve would be observed during head removal and reinstallation activities prior to RVCH reinstallation. Furthermore, inspections of the remaining degraded sleeves show a distribution to the observed size of the crack-like indications, suggesting that the crack growth rate (CGR) is finite and the time from crack initiation to flange separation is likely greater than one fuel cycle. Additionally, there is no clear correlation between locations experiencing significant flange wear and locations where crack-like indications were observed. While it is possible that failure of more than one thermal sleeve could occur during an operating cycle, it is anticipated that the number of failures would be minimal (likely less than five). Furthermore, it is not considered credible that more than one failure would occur at locations that have exceeded the flange wear lowering criterion and involve remnants that interfere with rod insertion. Therefore, it is reasonable to expect that during the operating time until the next refueling outage that this issue would not result in more than one control rod failing to insert. Even if multiple control rods failed to insert, which is a low probability event, this is not an unanalyzed condition that is beyond the ATWS analysis.

On the basis provided, the plants identified herein can continue to operate until at least the next refueling outage following the issuance of this NSAL.

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1 ATWS analyses demonstrate that the AMSAC accident mitigation system adequately addresses a common mode failure of all control rods failing to insert. Because of the low expected frequency of an ATWS event, the analyses use best estimate assumptions. Deterministic analyses have been performed for AOOs to demonstrate that, although the applicable safety analysis acceptance criteria may not be met, core coolability would be maintained, the reactor coolant system pressure boundary integrity would be maintained, and the radiological consequences would not exceed the applicable acceptance limits. The analyses assume an ATWS mitigation system has been implemented, as required by 10 CFR 50.62, the ATWS Rule.

2 NUREG/CR-5500 considers the failure of ≥ 10 control rods to insert with a loss of shutdown capability.

AFFECTED PLANTS

The potentially affected Westinghouse NSSS plants listed in Table 1 are those that:

- Operate with higher upper head bypass flow conditions, known as T-cold head plants.
- Operate with thermal sleeves containing a collar just below the flange (see Figure 2).

Table 1: T-cold Plants Susceptible to Thermal Sleeve Cracking and Flange Wear

Asco 2	Comanche Peak 1 & 2	Seabrook
Braidwood 1 & 2	Doel 4*†	Sizewell B*
Byron 1 & 2	Hanbit 1 & 2	Tihange 3*†
Callaway*	Kori 3 & 4	Vogtle 1 & 2
Catawba 1 & 2	Maanshan 1 & 2	Wolf Creek

(*) Replacement RVCH is not designed by Westinghouse. The thermal sleeves supplied with the original RVCH featured the collar design. If a like-for-like replacement of the thermal sleeves was performed, it is possible that the issue described in this NSAL could apply. It is recommended that these plants contact their replacement head supplier to evaluate applicability.

(†) T-hot head but T-cold capable. These plants are a hybrid of T-hot and T-cold due to some head spray cooling nozzles being plugged and some being open. In this configuration it is uncertain whether the local flow conditions are similar to those of a T-cold head; therefore, these plants are conservatively assumed to have a higher susceptibility to this issue than a standard T-hot plant.

NRC AWARENESS

The NRC was informed of this issue by Westinghouse [2].

RECOMMENDED ACTIONS

Due to the potential for this issue to result in control rods failing to insert, it is recommended that the affected plants perform the following initial inspections:

- Examination Method:
  - Visual examination (quality similar to a VT-3)
- Location:
  - Inner diameter surface of the thermal sleeve in the region shown in Figure 5.
- Coverage and Timing:
  - For plants that <u>have not</u> performed flange wear measurements per NSAL-18-1:
    - Inspect 100% of the sleeves at rodded locations at the next refueling outage following issuance of this NSAL.
    - Alternatively, during the next refueling outage following issuance of this NSAL, flange wear measurements as recommended by NSAL-18-1 could be conducted first and used to inform the inspection coverage and timing based on the recommendations given below for plants with flange wear inspection measurements. Locations that exceed the 0.80-inch flange wear lowering criterion or are projected to exceed this criterion over the next cycle will require inspections during this same outage.
  - For plants that <u>have</u> performed flange wear measurements per NSAL-18-1:
    - Inspect thermal sleeves at rodded locations at least one cycle prior to projecting to reach the 0.80-inch flange wear lowering criterion.
- Acceptance criteria:
  - Predictive CGR and acceptable crack length acceptance criteria are not currently available. It is conservative to assume that any sleeve containing crack-like indications has the

potential for failure within the next operating cycle and that some action should be taken. This action could include thermal sleeve replacement or justifying continued operation based on the extent of cracking and degree of flange wear. Should a predictive CGR and/or acceptable crack length acceptance criteria be developed, these may be used to justify a new re-inspection interval for rodded locations exceeding the flange wear lowering criteria.

- Re-inspection:
  - Until such time that a more refined flange wear lowering criterion or predictive CGR and acceptable crack length can be established (either on a plant-specific basis or generically), any rodded locations exceeding the 0.80-inch flange wear lowering criteria should be inspected at each refueling outage to monitor for cracking.

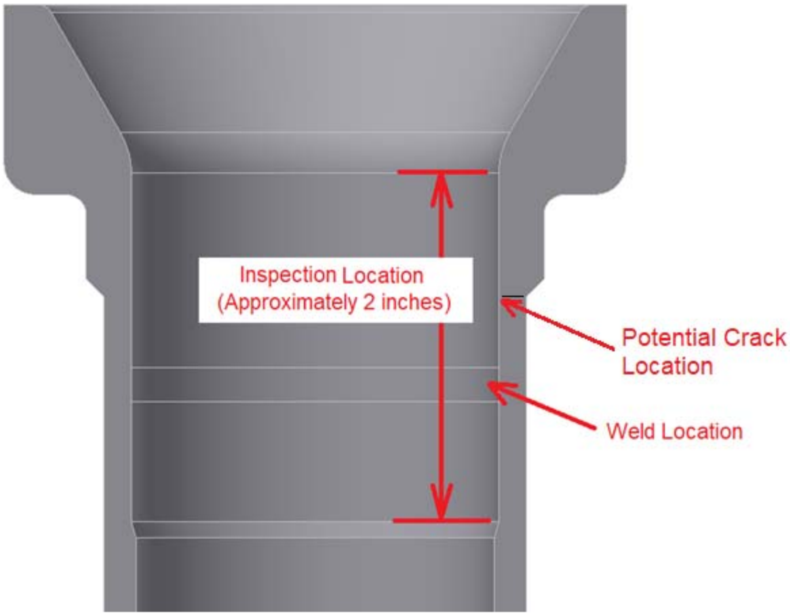

Figure 5 Recommended Visual Inspection Zone

There are alternative, proactive asset management approaches that could be taken to increase the probability of detecting cracking before flange separation presents a risk of causing a stuck rod at any sleeve location. These include scheduling inspections well in advance of reaching the 0.80-inch thermal sleeve flange wear lowering criterion, expanding the inspection coverage to 100% of the sleeves, and using more advanced inspection techniques such as ultrasonic inspection. As a minimum, during each refueling outage, personnel at the affected plants should verify that no thermal sleeves are resting on a UGT. Furthermore, while flange separation does not result in a substantial safety hazard for thermal sleeves at inactive CRDM locations and unrodded thermal sleeve locations, it may be prudent to include these locations in the scope of inspection as a means of proactive asset management.

REFERENCES

1. Westinghouse Nuclear Safety Advisory Letter NSAL-18-1, “Thermal Sleeve Flange Wear Leads to Stuck Control Rod,” July 9, 2018.
2. Westinghouse Letter LTR-NRC-19-79, “Notification of the Potential Existence of Defect Pursuant to 10 CFR Part 21,” December 12, 2019 [NRC Accession Number ML19346H873].
3. Westinghouse Technical Bulletin TB-07-2, Rev. 3, “Reactor Vessel Head Adapter Thermal Sleeve Wear,” December 7, 2015.

4. Westinghouse Letter LTR-NRC-18-34, "Notification of the Potential Existence of Defects Pursuant to 10 CFR Part 21," May 23, 2018 [NRC Accession Number ML18143B678].

5. Pressurized Water Reactor Owners Group Report PWROG-16003-P, Rev. 2, "Evaluation of Potential Thermal Sleeve Flange Wear," May 2019.

6. EPRI Letter MRP 2018-027, "NEI 03-08 Needed Inspection Guidance for PWR CRDM Thermal Sleeve Wear," August 31, 2018.