Summary Report and Analysis of Data from Operating Experience Smart Sample, OpESS 2018/01, "Evaluation of Licensee Actions Taken in Response to 10 CFR Part 21 Notification of the Potential Existence of Defects Related to Control Rod Drive Mechanism (CRDM) Thermal Sleeves"

1. Introduction and Background

During a spring outage in 2014, a control rod drive mechanism (CRDM) thermal sleeve wear issue was identified at a U.S. plant when a single thermal sleeve fell from the reactor vessel (RV) closure head at an unrodded CRDM during an inservice inspection. Examination of the fallen sleeve confirmed that the upper flange of the thermal sleeve, which rests inside the CRDM head adapter tube, had worn through. Industry determined that the wear could be correlated to a change in elevation of the bottom of the thermal sleeve (guide funnel) when compared to the as-designed condition. Dimensional measurements of CRDM thermal sleeve elevations demonstrated that significant but acceptable wear had occurred, and all rodded locations had low-to-moderate wear.

In December 2017, Unit 2 at Belleville nuclear power plant in France experienced a complete wear through and separation of one thermal sleeve at a rodded CRDM location. Belleville is a four-loop, 1300-MW Électricité de France plant. During low-power physics testing and rod drop testing, the plant had difficulty stepping the rod into the core. The rod was freed by exercising the drive rod but was then stopped prior to full insertion during the rod drop test. The failure to insert the rod was caused by the worn thermal sleeve flange remnant. Investigation of the Belleville incident showed the same wear behavior as was discovered in 2014 at the U.S. plant.

In response to this operational experience, and pursuant to the requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 21, "Reporting of Defects and Noncompliance," Westinghouse notified the NRC of this defect. The notification states that while there was no immediate safety concern, a substantial safety concern may be possible in the unlikely event that there is interference with the movement of more than one control rod.

In July 2018, Westinghouse published a nuclear safety advisory letter NSAL-18-1, "Thermal Sleeve Flange Wear Leads to Stuck Control Rod," [1] that provides details on the thermal sleeve flange issue and inspection recommendations. The technical evaluation in this letter suggests that the inspections and evaluations of prior industry guidance may not be sufficiently conservative, and the lack of conservatism could result in a substantial safety hazard. The Nuclear Energy Institute (NEI) later published the inspection guidance in Westinghouse's nuclear safety advisory letter as interim NEI-03-08, "Needed," inspection guidance under MRP 2018-033.

In September 2018, the NRC staff finalized a technical evaluation and a safety assessment of this issue [2]. The staff investigated the probability of multiple failed thermal sleeves and the safety impact of multiple stuck rods. Analyses conclusions include:

- Using past NRC staff positions on the mitigation of anticipated transients without scram (ATWS) events, the staff estimated five stuck rods as the conservative limit where loss of shutdown capability would occur. Incorporating this scenario into a Standardized Plant Analysis Risk (SPAR) model analysis, the staff estimated that the increase in core damage frequency would be less than 1E-5 and does not surpass the criteria documented in Regulatory Guide (RG) 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing

Basis." In addition, other accidents, such as a steam line break, were considered, but low initiating event frequencies coupled with the CRDM thermal sleeve failure probabilities, suggest very low changes in core damage frequency.

- These risk numbers increase with time if no inspections and mitigation occur.
- The NRC staff's recommended path forward was to conduct a smart sample for the most susceptible plants to request information to determine on a plant-specific basis if an adequate degree of conservatism is present in this analysis and the corresponding industry analyses.

In November 2018, the NRC published an operating experience smart sample (OpESS) titled OpESS 2018/01 [3], "Evaluation of Licensee Actions Taken in Response to 10 CFR Part 21 Notification of the Potential Existence of Defects Related to Control Rod Drive Mechanism (CRDM) Thermal Sleeves," which supplements sample selection for Inspection Procedure (IP) 71152, "Problem Identification and Resolution." The NRC developed this supplemental inspection to sample plant-specific information related to the thermal sleeve measurements of wear recorded at domestic plants that were identified in the Westinghouse nuclear safety advisor letter (NSAL-18-1).

This report provides a high-level summary of the smart sample, the analysis results, and the impact of the analysis results on the conclusion in the NRC technical assessment of this issue.

2. OpESS 2018/01 CRDM Smart Sample Summary

While smart samples are voluntary, because of the generic implication of the CRDM thermal sleeve flange wear issue, its emergent nature, and the potential for becoming a significant safety issue, OpESS 2018/01 received good participation from the regions. The NRC staff completed the comment resolution summary for OpESS and issued OpESS 2018/01 on November 20, 2018 [3]. In a relatively short period of time, headquarters staff were provided with thermal sleeve wear data from five domestic pressurized-water reactors (PWRs). The table below provides a summary of plants that have performed the NSAL-18-1 examinations, along with the sites where NRC regional inspectors performed OpESS 2018/01 inspections.

Plant	Region	Unit	Years Operating	Performed NSAL-18-1	Performed OpESS 2018/01
A. W. Vogtle	2	1	31	Yes	Yes
		2	29	No	NA
Braidwood	3	1	30	No	NA
		2	30	Yes	Yes
Byron	3	1	33	Yes	Yes
		2	31	No	NA
Catawba	2	1	33	Yes	Yes
		2	32	Yes	Yes
McGuire	2	1	37	Yes	No
		2	34	Yes	Yes
Millstone	1	3	32	Yes	Yes
Seabrook	1	1	28	Yes	Yes
Sequoyah 1 & 2	2	1	37	No	NA
		2	36	Yes	Yes

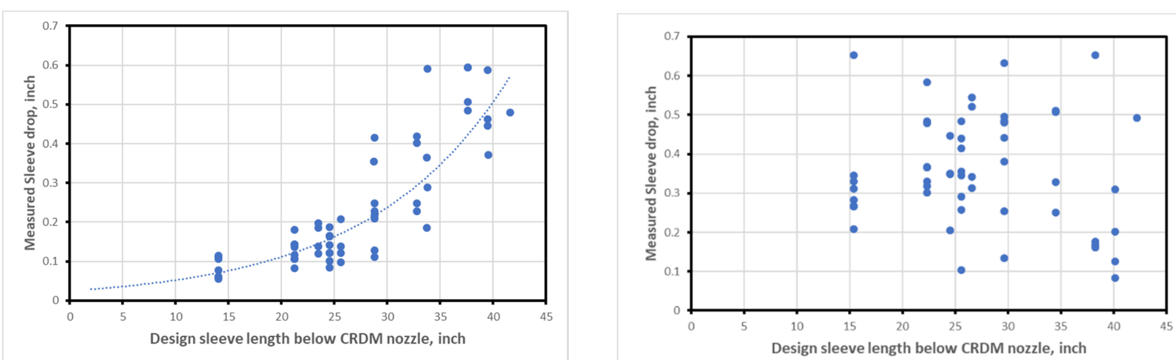
Plant	Region	Unit	Years Operating	Performed NSAL-18-1	Performed OpESS 2018/01
Shearon Harris	2	1	31	Yes	Yes
Wolf Creek	4	1	33	Yes	No

Out of the population of 16 units which were deemed most susceptible, to date the NRC has performed OpESS 2018/01 inspections on 10 units. Additionally, all the sites that have susceptible thermal sleeve have either performed the recommended inspections or are scheduled to perform them during the next upcoming outage. While there are several different vendors that can perform these inspections, the inspections themselves are very similar. Specifically, these inspections consist of determining the relative change in the distance between the end of the thermal sleeve and the top of the guide tube by using a laser scanning technique after the vessel head is removed. The measured values are used to calculate the wear rate, which is then used to determine if the thermal sleeve can remain in service as well as to plan for the next subsequent inspection. Subsequent followup inspections will ultimately provide a more accurate wear rate.

One unit in Region 4 will be doing followup inspections during their next scheduled outage, which is currently scheduled for spring of 2019. Furthermore, by fall of 2019, all the plants in table above will have performed at least one examination.

3. Analysis of Results from OpESS 2018/01

Through the smart sample, the staff obtained CRDM thermal sleeve measurement data. This data includes either design or as-built CRDM thermal sleeve elevation measurements and to-date elevation measurements for each CRDM thermal sleeve in the units. The regional inspection team supplied this data to headquarters in tabular form. Using this data, staff investigated the trends of wear relative to the location of the wear. From the sample of 10 Tier 1 plants, the NRC staff recognized two different trends in the data. Figure 1 illustrates these two trends:



(a) Plant A **(b) Plant B**

Figure 1 Thermal sleeve wear measurements

Note that the thermal sleeves near the top of the head have a greater portion of the thermal sleeve exposed to cross flow than the thermal sleeves on the periphery of the head. The "design sleeve length," on the above graphs corresponds to the length of the thermal sleeve that is exposed. In some cases, a clear trend with location is seen—more wear occurred near the center of the head. In other cases, the wear appeared location independent. It is currently unknown why these differences occurred.

Even though this data only represents one point in time, a wear rate can be estimated from this data and the design or as-built conditions. These wear rates can then be displayed as a cumulative distribution function and compared against what was used in the LIC-504 analyses [2] as shown in Figure 2. In this figure, the different color circles represent the data[1] from the sampled plants, while the solid red line represents the distribution assumed in the LIC-504 analyses [2]. Data that falls above and to the left of the red line is considered conservative and data that falls below and to the right is considered nonconservative. It is suspected that the nonconservative values would produce probabilities of failure that are higher than those calculated in the LIC-504 analyses.

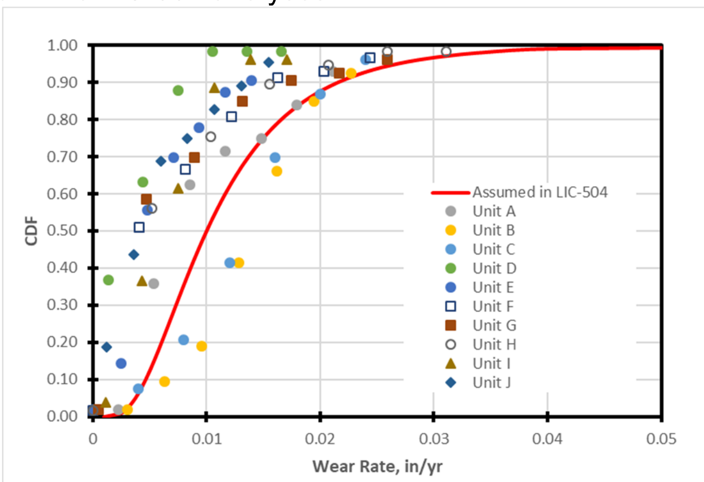
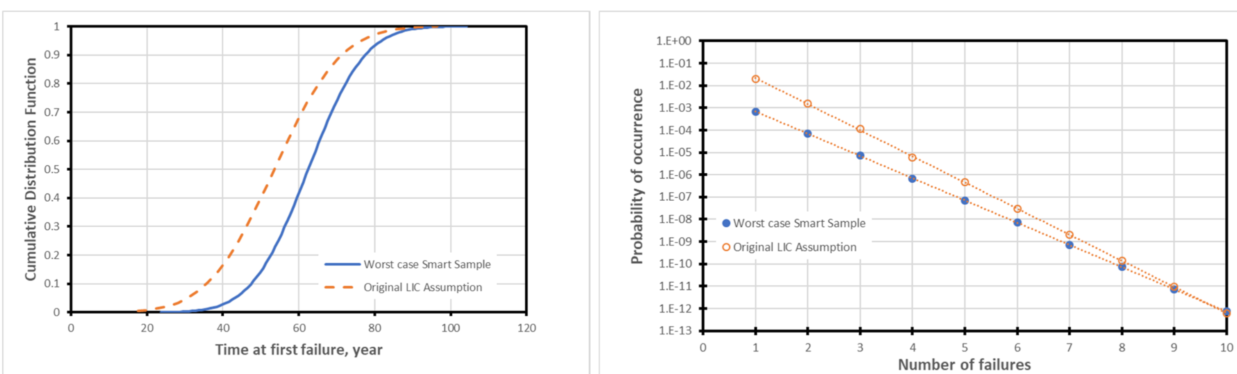


Figure 2 Comparison of smart sample wear rates and assumption in LIC-504 analysis

From Figure *2*, most of the collected data falls above the assumption used in the LIC-504 analyses. Of the two plants that fall below the curve, the difference is relatively small.

Taking the worst-case wear data, the staff conducted an analysis to compare the probability of failure results with those in the LIC-504 analysis. Using the same analysis procedure as in the LIC-504 [2], staff calculated the probability of failure shown in Figure *3*.



(a) First thermal sleeve failure **(b) Multiple sleeve failure**

Figure 3 Probability of failure comparison

[1] Only the data for rodded thermal sleeves was included.

In these figures, the orange open circles represent the results presented in the LIC-504 analysis, while the blue solid circles represent the results using the worst-case wear rate in Figure *2*. Surprisingly, even though the wear-rate data appears to be nonconservative, the probability of failure numbers are conservative compared to those in the LIC-504 analyses. The reason for this behavior becomes clear when the worst-case data is investigated more closely. See Figure *4*.

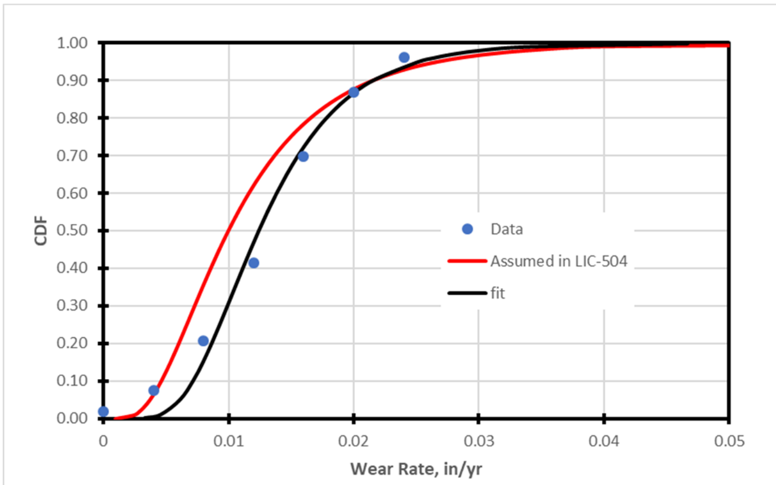


Figure 4 Comparison of worst case wear rate data with LIC-504 assumption

Figure 4 shows the worst-case wear data and its fit compared with the assumption used in the LIC-504 analyses. While most of the data is nonconservative with respect to the LIC-504 assumption, the data at the high wear rates are conservative (i.e., the data above 90 percent probability falls above the assumption in the LIC-504 analyses). Since the probability of first thermal sleeve failure is driven by the upper tail of the wear rate distribution, the data and fit shown in Figure *4* would produce probability a first failure greater than that from the LIC-504 analyses. In looking at the data in Figure *2*, the maximum measured wear rate was 0.030 inches/year with all of the high wear rate data falling above the assumption made in the LIC-504 analyses.

4. Impacts on CRDM Thermal Sleeve LIC-504 Results

From the sample of 10 out of 16 most susceptible domestic plants, the CRDM thermal sleeve wear data obtained suggests that the assumptions made in the LIC-504 analyses [2] are conservative and reasonable for making a safety determination. More than 62 percent of the most susceptible plants were sampled. The trends are consistent even though the level of conservatism is small.

The smart sample results also suggest that the licensees are following the details of the Westinghouse nuclear safety advisory letter appropriately and have taken steps to perform additional measurements at future outages and/or repair CRDM thermal sleeves as needed.

Using the results generated in this effort, the staff recommends that no further smart sample inspections are needed.

5. Summary

Based on the potential for the thermal sleeve wear resulting in a nuclear safety concern, Westinghouse recommended in its nuclear safety advisory letter (NSAL-18-1) that the most susceptible plants (T-cold) perform inspections during the first refueling outage following issuance of the NSAL, if the plants have exceeded 25 effective full-power years. Westinghouse recommended establishing acceptance criteria to prevent thermal sleeve separation, and perform baseline inspection, and establish a reinspection frequency based on the observed wear. Based on the results of the operating experience smart sample, it appears that the domestic T-Cold plants are performing the Westinghouse NSAL-recommended inspections. Consequently, the NRC staff is satisfied that the affected plants are properly addressing the thermal sleeve flange wear issue. Therefore, the NRC requires no further action at this time. The NRC staff will continue to monitor industry operating experience.

6. REFERENCES

[1] NSAL-18-1, “Thermal Sleeve Flange Wear Leads to Stuck Control Rod,” July 9, 2018 (ADAMS Accession No. ML18198A275).

[2] LIC-504 Technical Assessment of Potential Control Rod Drive Mechanism Thermal Sleeve Failure, September 27, 2018 (ADAMS Accession No. ML18249A081).

[3] Operating Experience Smart Sample (OpESS) 2018/01, “Evaluation of Licensee Actions Taken in Response to 10 CFR Part 21 Notification of the Potential Existence of Defects Related to Control Rod Drive Mechanism (CRDM) Thermal Sleeves,” November 19, 2018 (ADAMS Accession No. ML18263A261).