November 8, 2007

MEMORANDUM TO: Jared S. Wermiel, Deputy Director
Division of Safety Systems
Office of Nuclear Reactor Regulation

FROM: Michael L. Scott, Chief ***/RA/***
Safety Issues Resolution Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

SUBJECT: STAFF OBSERVATIONS OF ARKANSAS NUCLEAR ONE, UNIT 2, STRAINER TESTING FOR GENERIC SAFETY ISSUE 191 DURING AUGUST 13–14, 2007, TRIP TO FAUSKE AND ASSOCIATES (TAC NOS. MC4663 AND MC4664)

On August 13–14, 2007, the NRC staff traveled to the Fauske and Associates, LLC (FAI), strainer testing facilities in Burr Ridge, IL, to observe containment sump strainer testing for Arkansas Nuclear One, Unit 2 (ANO-2), that is associated with the resolution of Generic Safety Issue 191 (GSI-191). The participating NRC staff members were John Lehning of NRR/DSS/SSIB and Paul Klein of NRR/DCI/CSGB.

The primary objective of the trip was for the staff to observe an integrated chemical effects head loss test performed on a test strainer comprising two pocket strainer modules designed by Control Components, Inc. (CCI). The licensee stated that the test strainer modules are identical to the modules installed in the ANO, Unit 1, strainer array and are nearly identical to the slightly taller ANO-2 modules.

The enclosed trip report describes the staff's head loss testing observations during the trip to FAI, the most significant of which are summarized below:

- In the presence of calcium silicate and chemical precipitates, the thin-bed effect was observed on a complex strainer with fibrous debris quantities significantly less than the amount necessary to create a uniform 1/8-inch-thick debris bed.
- The head loss from the "ultra-thin bed" observed during the test was limited due to the formation of boreholes through the thin debris layer.
- Varying the strainer approach velocity during the test can provide a direct indication of the impact of borehole formation on the measured head loss. Determining whether boreholes are present is significant because boreholes affect the scaling of the measured head loss by viscosity or approach velocity.

Enclosure:
As Stated

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Enclosure:
As Stated

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NRC STAFF TRIP REPORT

HEAD LOSS TESTING FOR ARKANSAS NUCLEAR ONE, UNIT 2

AT FAUSKE AND ASSOCIATES

(TAC NOS. MC4663 AND MC4664)

Background

In June 2007, the Arkansas Nuclear One (ANO) licensee informed the NRC staff that the upcoming integrated chemical effects head loss testing to qualify the ANO strainers would be conducted at Fauske and Associates, LLC (FAI). Since FAI had not previously been involved with strainer head loss qualification testing for the resolution of Generic Safety Issue 191 (GSI-191), the staff requested a teleconference with the licensee to discuss the planned testing procedure and further requested an invitation to observe one of the licensee's head loss tests. This report summarizes key points from the NRC staff's teleconference with the licensee on July 10, 2007, and describes the staff's observations from the integrated chemical effects head loss test conducted at FAI on August 14, 2007.

Test Procedure Discussion

On July 10, 2007, the staff participated in a teleconference to discuss the procedure for the ANO strainer testing. The most significant staff comments on the test procedure follow:

- The licensee should ensure that either (1) debris does not settle in the test flume or (2) debris settling is justified technically. As discussed during the call, debris preparation (including chemical precipitate concentrations), sequencing, flume flow conditions, and flume water level may play a role in settling.

- The licensee should ensure that the worst-case thin bed is addressed by the test program. The staff's safety evaluation (ADAMS Accession No. ML043280641) on Nuclear Energy Institute (NEI) 04-07 provides guidance for thin beds and has additional specific guidance for treating both coating debris and calcium silicate insulation (e.g., less than 1/8th-inch of fiber may contribute to the formation of a thin bed if sufficient calcium silicate debris is present).

- The licensee should ensure that the non-prototypical debris sequencing in the preliminary sensitivity tests (in an attempt to conduct head loss tests for both units at the same time and to investigate the effect of varying quantities of fibrous and calcium silicate debris in a single test) does not adversely affect the selection of the debris loadings chosen for the final strainer qualification tests.

The licensee responded to these and the other staff comments during the teleconference by stating that they would be addressed by the ANO test program. The staff's comments and the licensee's steps to address the comments are discussed further below as part of the staff's head loss testing observations.

ENCLOSURE

Overall Test Program

The licensee's test program included a relatively extensive series of preliminary sensitivity head loss tests, followed by final qualification tests for each of the two units at ANO. Separate strainer qualification tests were considered necessary for ANO-1 and ANO-2 because of plant-specific differences in the design of the emergency core cooling systems, the replacement strainers' surface areas, and post-accident debris quantities. Prior to conducting the final qualification tests, which the licensee planned to run for an extended period of time, the licensee conducted shorter sensitivity tests to identify the quantities of chemical and non-chemical debris that the ANO strainers can accommodate while maintaining an acceptable pressure drop.

As a result of the licensee's desire to use a single sensitivity test to examine different debris loadings for both ANO units, the debris addition sequences for some the sensitivity tests were atypical. For instance, one of the chemical sensitivity tests specified the following debris addition sequence:

Fiber, Particulate, Chemical Precipitate, Fiber, Particulate, Chemical Precipitate, Fiber.

Given the potential for this addition sequence to result in atypical debris bed stratification, the staff questioned whether such a sequence would eventually result in the same head loss as a test that employed a more typical sequencing of debris (e.g., Particulate, Fiber, Chemical Precipitate). The licensee replied that the atypical debris addition sequences specified for some of the sensitivity tests would not be used in the final qualification tests.

Because the sensitivity tests would be used to select which debris loading would be used for the final qualification testing, the staff noted that the licensee should still have confidence that anomalies associated with different debris sequencing procedures do not have a non-conservative impact on these tests. The licensee replied that, prior to the extended-duration final qualification tests, shorter "pre-qualification" tests may be attempted to demonstrate whether sequencing effects are significant.

Since the licensee's actions to address the staff's comment on debris sequencing could not be evaluated based upon the observation of a single test, the staff requested a follow-up phone call with the licensee following the completion of the ANO test program so that the head loss results for similar tests with different debris addition sequences could be compared. The staff considered the licensee's testing as potentially valuable in addressing residual concerns associated with the significance of varying the sequence of debris addition for head loss testing.

ANO Strainer Design

The ANO licensee is installing pocket strainers designed by Control Components, Incorporated (CCI). The strainers were designed with a 1/16-inch perforation size, slightly smaller than the 1/12-inch or 3/32-inch perforations more commonly used in replacement strainer designs. The licensee stated that 1/16-inch perforations were the smallest standard size available and that they had been chosen in an attempt to limit the overall downstream source term. As discussed further below, the licensee suggested that the small size of the strainer perforations was a contributing factor to the observation of the thin-bed effect at fibrous debris thicknesses significantly less than 1/8 inch during the licensee's strainer head loss tests.

The test was conducted in the FAI flume, which was constructed of plexiglass and had dimensions of eight feet tall by eight feet long by two feet wide. The test strainer was mounted approximately 2 feet from the end of the test flume. A plexiglass divider was inserted into the flume around the front of the test strainer, which separated the upstream side of the flume from the downstream side. The difference in the height of water across this divider provided a secondary, visual indication of the differential pressure across the strainer. The tank turnover time for the observed test was approximately seven minutes at the scaled normal test flow rate of 84 gallons per minute (gpm).

Test Observations

For the integrated chemical effects head loss test observed by the staff, the licensee planned to use the debris addition sequence listed in Table 1, below. The staff noted that the addition of calcium silicate after the chemical precipitate could lead to non-prototypical sequencing effects, as discussed above. The licensee stated that most of the calcium silicate was added at the end of the test in order to determine approximately how much calcium silicate the strainer can accommodate prior to reaching the differential pressure limit. The licensee further indicated that the potential for non-prototypical sequencing effects could be addressed subsequently (e.g., through the pre-qualification tests described above).

Table 1: Planned Debris Addition Sequence for Observed Head Loss Test

Plant Debris Type	Surrogate Material	Number of Batches
Latent Fiber	Thermal Wrap	1
Zinc Coatings	Zinc Powder	1
Epoxy Coatings and Latent Particulate	Silicon Carbide Powder	1
Calcium Silicate	N/A	1
Epoxy Paint Chips	N/A	1
Chemical Precipitate (Sodium Aluminum Silicate)	WCAP-16530- NP Surrogate	5
Calcium Silicate	N/A	5

As described subsequently, following the official completion of the test, the licensee added extra batches of calcium silicate and fibrous debris (which are not listed in Table 1) to observe the effect of this additional debris on the measured head loss.

The debris preparation process was completed prior to the staff's arrival at the FAI test site. However, prior to the test, the licensee showed the staff a sampling of the test debris that had been prepared for use. The staff observed that the debris had generally been prepared into small fines that would tend to transport to the test strainer. Although some stray pieces of larger debris may also have been present in the prepared test material, such as a roughly 3-inch chunk of calcium silicate observed on the floor of the flume at one point during the test, the licensee periodically stirred the floor of the test flume to address the potential for debris settling.

The prepared particulate debris was added to the test flume as a dry powder, and the staff noted that the calcium silicate tended to pile up on the surface of the flume prior to being submerged by the weight of the debris above it or by the test technician's stirring of the test flume surface. Although the staff had previously identified the addition of particulate as a dry powder as potentially leading to non-prototypical debris settling, the staff did not identify concerns with this practice for the ANO testing based upon the observed behavior of the initial batch of particulate added to the tank, the relative shortness of the test flume, and the stirring of the test tank. Consistent with staff guidance presented in a public meeting on June 19, 2007, the licensee accounted for the coatings debris at ANO by adding particulate debris, despite having a uniform fiber bed of less than 1/8th inch in thickness. In addition to representing 100% of failed ANO coatings as particulate, the licensee also added some paint chips to the flume to account for the possible presence of larger pieces of failed coatings debris. The staff considered the licensee's approach to be conservative.

The fibrous debris and paint chips prepared for the test had been mixed with water in separate buckets. The staff considered the size distribution of the fibrous debris to be reasonable. The vendor stated that the fibrous debris had been shredded with a dog brush and further broken into fines with a water jet. The staff noted that the concentration of the fibrous debris in the buckets was low relative to the volume of water and that the low concentration of fiber avoided agglomeration of this debris prior to the test. The licensee stated that the practice of maintaining low concentrations in debris slurries prepared for head loss testing was in response to staff comments in a trip report regarding testing conducted at CCI in September 2006. This observation indicated that, although FAI had not previously been involved with strainer head loss testing for Generic Safety Issue 191, the FAI/ANO testing benefitted from lessons learned from head loss testing at other vendor facilities.

Plant-specific chemical precipitate loads for ANO were determined using the WCAP-16530-NP spreadsheet, without refinements. Although ANO-2 currently uses trisodium phosphate to buffer the post-loss-of-coolant accident containment sump fluid, the licensee plans to switch to sodium tetraborate (STB) as a corrective action in response to Generic Letter 2004-02. Therefore, inputs to the WCAP-16530-NP spreadsheet were based upon the future STB environment. For ANO plant-specific conditions, the spreadsheet predicts sodium aluminum silicate as the precipitate. Therefore, sodium aluminum silicate was prepared at a maximum 11 g/L mixing tank concentration in accordance with the procedure in WCAP-16530-NP. This solution was diluted to a precipitate concentration of 9.7 g/L in order to measure the settlement properties. Precipitate settlement was determined to meet the acceptance criteria.

Based upon the staff's observations during the testing, the chemical precipitate preparation appeared adequate overall. However, the staff observed several small, white clumps in the test tank during the addition of the chemical precipitate. Although the presence of these few clumps did not appear to have a significant effect on the test results, the staff suggested that the licensee investigate this phenomenon and follow up as necessary to prevent non-prototypical precipitate agglomeration.

The addition of debris in accordance with the sequence prescribed in Table 1 began at approximately 8:20. By approximately 8:30, all debris up to the epoxy paint chips had been added to the flume. Between about 8:45 and 9:00 the five batches of chemical precipitate were added to the flume, and the head loss increased from essentially zero to approximately two to three inches. Around 9:30, the flow rate was reduced from 152 gpm to 84 gpm, which represents the normally expected sump flowrate for ANO-2 during recirculation after scaling to the test strainer area. The licensee stated that the higher flowrate of 152 gpm represents the single failure of a low-pressure safety injection pump to trip after the switchover to sump recirculation. The licensee performed part of the testing at this increased flowrate in response to open items associated with this issue that were identified by the staff during audits for other Combustion Engineering plants. The remaining five batches of calcium silicate in Table 1 were added between approximately 10:00 and 11:30. During the addition of this debris, the head loss slowly but steadily increased, eventually reaching a value over 0.8 ft. Because the measured head loss had been relatively steady over the previous hour, the test was officially declared complete at approximately 13:00.

Prior to shutting down the test pump, the licensee decided to add additional debris to the flume to observe the measured head loss response. An additional batch of calcium silicate was added to the test, which resulted in the head loss exceeding one ft. Next, two additional batches of fibrous debris were added, which resulted in head losses of approximately 1.5 ft and slightly over two ft, respectively.

At these head losses, the water level in the downstream section of the flume was sufficiently reduced as to uncover the upper portion of the test strainer, clearly revealing the presence of boreholes in the debris bed. As has been previously observed in other staff test observations (e.g., observations of Diablo Canyon testing at Alion on July 28, 2005), under certain conditions, the differential pressure across a debris bed may poke holes through the bed, resulting in water jetting through these open holes at high velocity. Subsequently, debris would gradually reclog these boreholes, while other boreholes would form at different locations to relieve the increasing pressure. Previous testing experience suggests that conditions which tend to favor borehole formation include very thin debris beds without a substantial fibrous layer.

Following the addition of these extra debris batches, the licensee decided to experiment with stopping and restarting the test pump with a one-minute delay. The staff observed that the debris bed largely seemed to remain on the screen after the stopping of the pump. Although the restart of the test pump resulted in a puff of particulate being released from the bed, five minutes later, the staff observed that the measured head loss, which was still slowly rising, had increased to approximately 85% of its value prior to the pump being stopped.

<u>Significant Test Observations</u>

1. In the presence of calcium silicate and chemical precipitates, the thin-bed effect was observed with fibrous debris quantities significantly less than the amount necessary to create a uniform 1/8-inch-thick debris bed. Specifically, in the test observed by the staff, the theoretical uniform thickness of fibrous debris added to the test flume (excluding the fibers from the calcium silicate binder) for the official portion of the test was approximately 0.018 inch (1/56th of an inch). The subsequent two extra batches of fibrous debris raised the theoretical uniform bed thickness to approximately 0.028 inch

(1/36th of an inch) and 0.038 inch (1/26th of an inch), respectively. In recognition of the very small quantities of fibrous debris needed to form a thin bed in the presence of calcium silicate and chemical precipitates, the licensee referred to debris beds such as that formed in the observed test as “ultra-thin beds.”

Given the small amount of fibrous debris and the considerable quantity of calcium silicate comprising the debris loading for the observed test, the fibrous binder that typically comprises several percent of calcium silicate insulation by weight appeared to be an important contributor to the formation of the debris bed. Based upon a rough calculation performed by the NRC staff, the binder in the calcium silicate debris may have constituted between roughly one to four times the amount of fiber in the batch of fibrous debris added during the official portion of the test. However, even with the calcium silicate binder included, the total amount of fibrous debris added for the official test appeared to remain somewhat less than 1/8th of an inch.

As reflected in the staff’s safety evaluation on NEI 04-07, previous vertical loop head loss testing had already shown that, with little or no added fibrous debris, calcium silicate debris is capable of forming a debris bed on a small, flat screen. The significance of the FAI/ANO testing was its demonstration that a similar outcome (in the presence of chemical precipitates and a small amount of fiber) can occur for a larger strainer module with a complex geometry.

2. The head loss from the "ultra-thin bed" observed during the test was limited due to the formation of boreholes through the thin debris layer. When the extra debris batches were added following the official completion of the test, the increase in head loss resulted in the uncovering of the downstream side of the test strainer, which allowed visual observation of boreholes forming in the debris bed. However, the licensee also conducted flow variations when the downstream side of the strainer was submerged. The unexpectedly small changes in head loss associated with the flow variations indicated that borehole formation was occurring, even though the presence of boreholes was not visually identifiable. The licensee further stated that during one test, after the flow was cut in half, the measured head loss recovered to approximately 90 percent of its original value. The licensee’s test observations are significant in suggesting that, in a flow regime where borehole formation limits the head loss across a debris bed, reducing the flowrate through the debris bed (i.e., throttling or shutting off pumps) may result in only minor reductions in the measured head loss, as compared to a debris bed for which the head loss is not borehole limited (for which the head loss generally varies with flow slightly more than linearly in the regime of interest to most pressurized-water reactor replacement strainers). An idealized diagram illustrating this phenomenon is provided below as Figure 1.

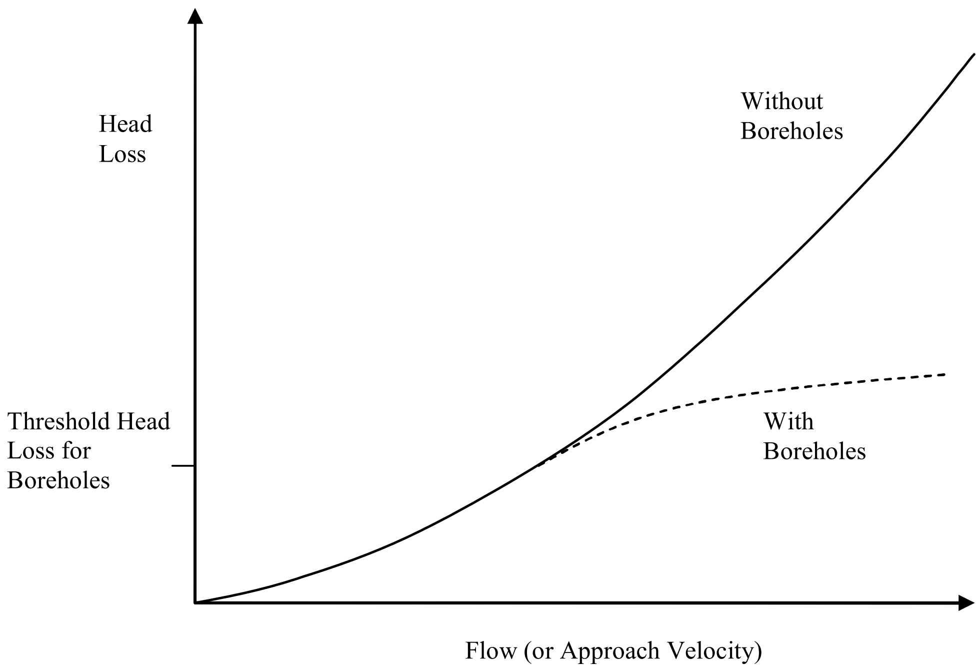

Figure 1: Idealization of the Impact of Boreholes on Measured Head Loss

3. As noted by the staff in several GSI-191 public meetings, the presence of boreholes in a debris bed presents significant difficulties for scaling a head loss test's results by viscosity or approach velocity. For this reason, the determination that boreholes (or other differential-pressure-based effects that disrupt the bed structure) are not present is critical to the justification for scaling the head loss test results. The licensee understood the staff's concerns with respect to borehole formation and planned to scale head loss test results for viscosity or approach velocity only if borehole formation was demonstrated not to occur.

   Although visual post-test examinations of the debris bed can provide limited evidence as to whether or not borehole formation occurred during the test, this method is subject to uncertainties because of the opacity of the test fluid, disturbances to debris beds after the test pump is shut down, and the challenge of estimating the significance of any observed borehole indications. Therefore, in addition to a post-test visual examination, the staff considered the FAI/ANO practice of varying the test flowrate and observing the measured head loss response to be a relatively direct way of determining the potential impact of borehole formation on the measured head loss. The staff further suggested to the licensee that flow variations should be conducted gradually to avoid bed disruptions that could impact the measured head loss.

4. In light of the observed formation of the ultra-thin debris beds discussed above, the licensee suggested that the 1/16th-inch-diameter perforations of the ANO strainers may have contributed to the capability of a very thin layer of debris to result in a measured

head loss. The staff agreed with this assessment and noted that the commonly accepted threshold for thin-bed formation with Nukon shreds and iron oxide particulate was based on a 1/8th square mesh screen. A reduction in the size of the strainer perforations would lead to an increased filtration efficiency for fine debris, which could tend to reduce the minimum threshold thickness for thin bed formation.

5. During the testing, in the downstream section of the test flume, the licensee and staff observed that an agglomeration of fibrous debris and chemical precipitates had formed and become attached to the flume wall. The agglomeration was a thin strip (approximately 3/4 inch by 1/4 inch) that did not appear to be strongly bound together. The observation of this agglomeration suggested that, while the majority of the debris source term downstream of the strainers would be smaller than the strainer perforation size, the source term could include occasional stray pieces of agglomerated debris larger than the strainer perforations.

Potential Outstanding Issues

Overall, the NRC staff concluded that the observed head loss test conducted by the ANO licensee appeared reasonable. However, based on the NRC staff's test observations and discussions with licensee representatives, several technical issues were identified as having the potential for further resolution. It should be noted that these items were identified based on limited staff observations during the trip and a previous phone call to discuss the test procedure; therefore, the potential outstanding issues stated below may not fully represent the NRC staff's concerns on all parts of the licensee's testing program and associated analyses. Furthermore, the licensee may have adequately addressed some of the staff's concerns but may not have had an opportunity to clarify these points fully during the staff's visit.

In light of the above qualifications, potential outstanding issues for the licensee to address with regard to strainer testing include the following:

- Ensuring that the non-prototypical debris sequencing used in some of the sensitivity tests does not affect the selection of tests for the final strainer qualification runs. In response to the staff's concern, the licensee tentatively planned to perform pre-qualification tests to assure that sequencing effects are not significant.

- Ensuring that flow changes and flume stirring are carried out in a manner that minimizes bed disruption and allowing time for disruptions in the debris bed to heal. The staff considered the licensee's practices of varying flow to determine the behavior of the head loss as a function of approach velocity and stirring the flume to prevent debris settling to be appropriate, and noted that these practices should be controlled to minimize disruption to the debris bed structure.

- Ensuring adequate termination criteria for the final strainer qualification tests. Although a documented test plan was not available, the licensee tentatively stated that the final strainer qualification tests would not be terminated until the slope of the measured head loss versus time was no longer increasing (or the 30-day mission time of the recirculation sump was exceeded). The staff would consider this approach to be acceptable, provided that the licensee documents the approach in the test procedure and establishes an acceptable minimum number of flume turnovers prior to test termination to ensure that suspended debris is given adequate opportunity to be filtered out by the strainer debris bed.

Conclusions

While several potential outstanding issues remain, the staff was generally impressed with the licensee's head loss testing program. The licensee personnel present during the observed head loss test appeared attentive to detail, displayed a questioning attitude, and seemed generally knowledgeable of sump performance issues. The staff also appreciated the licensee's invitation to observe testing, as well as the licensee's willingness to discuss additional test results with the staff. The NRC staff plans to follow up with the licensee concerning lessons learned from sensitivity testing related to debris sequencing.