Appendix II

GE Testing for Fort Calhoun Station

A team consisting of Alan Wang, Shanlai Lu, Ralph Architzel, Leon Whitney, and Mark Kowal of the NRC staff and Clint Shaffer from ARES Corporation conducted a pilot audit of proposed Fort Calhoun Station (FCS) strainers. The audit included a visit on August 29 - September 1, 2005 to observe head loss testing being performed by GE Energy (GE) at the Continuum Dynamics, Inc. (CDI) test facility in Ewing, NJ. This test facility audit was part of the FCS volunteer pilot plant audit. During this test facility visit, GE conducted several tests of a strainer module of the design planned for implementation at FCS. The audit team had the opportunity to watch the installation of several disks of the test module, the filling of the test tank, the introduction of the debris, the post-test tank conditions and partial disassembly of the strainer with the final accumulation of debris. The audit team was provided the following documents for review:

1. CDI Test Plan 05-05, Rev. 0, "Sector Test Plan for Fort Calhoun Debris Mixtures," Proprietary.
2. Pages 20-37 of GE Proposal No. 172 4-JXDA7-TP1, Rev. 8, Proprietary, May 1, 2005.
3. CDI Procedure T133-01-RV0, "Insulation Fiber Processing," Proprietary, August 17, 2005.
4. CDI Procedure T133-02-RV0, "In-Situ Paddle Wheel Flow Meter Calibration," Proprietary, August 17, 2005.
5. CDI Procedure T133-03-RV0, "Debris Preparation," Proprietary, August 17, 2005.
6. CDI Procedure T133-04-RV0, "Main Sector Test," Proprietary, August 17, 2005.
7. CDI Procedure T133-05-RV0, "Data Acquisition Verification," Proprietary, August 17, 2005.
8. CDI Procedure T133-06-RV0, "Microporous Debris Generation," Proprietary, August 17, 2005.
9. CDI Procedure T133-07-RV0, "Insulation Fiber Processing with Blender," Proprietary, August 17, 2005.
10. GE-NE-0000-0045-0254, Rev 1, "GE Passive Containment Sump Strainers: Scaling Equation for Sector Tests," Proprietary, August 2005.
11. GE-OPPD-CSS-010, “Information Requested in Support of Fort Calhoun Pilot Plant Audit,” Proprietary, September 12, 2005.

Head Loss Test Observed

The test observed by the audit team involved Temp-Mat, Kaowool, and Nukon® fibrous insulation debris, calcium silicate particulate insulation debris, simulated paint particulate debris, and latent particulate debris. Debris was prepared according to CDI procedures. It should be noted that the primary calcium silicate implemented at FCS has asbestos fibers in it and therefore could not be used in the head loss tests, i.e., the calcium silicate tested is not the same as the primary plant calcium silicate. However, the licensee did study available supplies of non-asbestos calcium silicate and procured calcium silicate for testing from a source they determined to have similar properties to the insulation in the plant.

The audit team was not able to observe the actual head loss testing for the first test because the pump motor would not start due to a malfunctioning starter motor resulting in that test being conducted later in the evening after the motor was repaired. Actual head loss testing was observed for the second test. However, debris accumulation could not be observed in either case, because the paint particulate rendered the tank water opaque. The time-dependent traces for head loss and flow were made available to the team the following morning and the team observed partial examination of the post-test debris bed. The test head loss appeared to be still increasing somewhat when the primary test was completed. The NRC audit team questioned whether the test should have been continued for a longer period before being declared complete.

The post-test examination demonstrated that a large portion of the debris had settled to the test tank floor rather than accumulating on the test strainer module. The audit team speculated that perhaps only about 30% of the debris was on the strainer. As such, the test involved both debris transport and head loss issues in the same test.

The debris accumulation on the strainer had a rather uniform appearance; however objective thickness measurements were not attempted. The glossy appearance of the outer debris surface suggested a layer of particulate with the color of the paint particulate. Prying loose some of the debris illustrated fibrous/particulate debris underneath the outer particulate. This debris accumulation appeared to be a classic thin-bed debris accumulation.

GE provided the NRC a proprietary sample of the debris bed and photos of the first day's testing observed by the NRC through OPPD following the visit (document 11 above).

Transport Issues Associated with GE Head Loss Testing

The debris loads introduced into the test tank in the GE head loss tests were based on FCS debris transport analyses performed by Alion Science and Technology (Alion). The transport analyses assumed that these debris loads accumulate on the plant sump screens but the GE head loss testing is taking credit for additional "near-sump" debris transport. Therefore the audit team considers that a number of issues need to be addressed by GE, which include:

- Do the hydraulic flow conditions of velocity and turbulence in the CDI test tank represent the FCS recirculation sump conditions in regards to debris transport?
- Do the debris introduction procedures employed by GE in the CDI tank represent the transport of debris into the recirculation sump area at FCS?
- How should the GE head loss testing effective debris transport be implemented with GR/SE debris transport methodology?
- How does the inherent transport from the head loss testing scale in the proposed GE scaling equation?

The flow conditions between the CDI tank and FCS recirculation sump could be substantially different with respect to debris transport, but GE has not provided any comparative information with which to form a judgment;

In the CDI tank, the procedure is to distribute the particulate uniformly around the strainer but the reality is that the debris is poured from buckets into the water with an attempt at uniform distribution. Under these conditions, agglomerations of initially dry particulate may be forming that rapidly settle to the tank floor as sludge where it is difficult to get the particles back into suspension when stirred, especially at colder water temperatures. Note that the agglomeration of particles into sludge is far less likely at the higher water temperatures characteristic of the FCS sump pool. When the particulate was added to the water in the CDI tank, the water became completely opaque so that there was no visual method of verifying that settled particulate became suspended again upon stirring, therefore it is possible that the lack of particulate debris transport in the CDI tank during the GE head loss testing is not representative of FCS transport following a LOCA. Without some form of verification that the particulate actually becomes suspended during stirring in the CDI tank, the head loss transport fraction may not be representative of FCS. Alternate methods of introducing particulate into water include introducing as wet slurry or spreading the particulate over the water surface in a manner that precludes agglomeration. Gaining an understanding of particulate settling within the GE tank would benefit from linear flume separate-effects testing where the particulate in introduced at one end and water overflows a weir at the other end. The fraction of particulate settled within the flume, correlated to flow velocity and turbulence, and transport distance, could form a basis for believing the particulate settling within the test tank.

A realistic near field effect that applies to settled pieces of fibrous debris, RMI debris, and coatings debris is the lift velocity required to lift debris from the pool floor onto the screens. For the test witnessed, the strainer module circumferential approach velocity was considered by the staff to be relatively low. Experimental test data [NUREG/CR-6772] demonstrates that it takes a flow velocity of about 0.28 ft/s to start lifting Nukon™ shreds over a 6-inch curb. Therefore, it is not surprising that Temp-Mat shreds do not appear to lift from the GE tank floor onto the module once the shreds settled to the floor. In all likelihood, the fibrous debris accumulated on the strainer of the observed test was due to fibrous debris that remains suspended with very little turbulence. The important issue with fibrous debris transport is to ensure the fraction of ZOI debris that is destroyed or eroded finely enough that it transports as suspended fiber is conservatively evaluated and represented in the head loss testing. The audit team questioned whether the quantity of fibrous debris accumulating on the GE test strainer modules scaled was equivalent to a conservative representation of the bounding potential to generate fine fibrous debris in the plant following the postulated LOCA.

The licensee and their vendor also noted that a set of sector tests had also been conducted for the FCS strainer. The audit team did not review the records of these tests in detail. Discussions with the licensee indicated that these tests did result in significantly less debris not reaching the screen and resulted in somewhat higher head loss for formula quantities of debris.

The FCS transport methodology appears to have adapted the GR baseline methodology, as illustrated by the transport chart shown in ALION-REP-OPPD2522-003, Figure 4-5 that is based on 60% small fines and 40% large piece debris for fibrous debris, despite the CFD refined analyses presented in ALION-REP-OPPD2522-002. The 100% transport (except for the inactive pool fraction) of the small fine fibrous debris along with 100% transport of particulate debris is essentially the GR baseline methodology. Piggy-backing a head loss test transport fraction onto the baseline methodology raises a question regarding acceptance of the baseline methodology. The baseline methodology was accepted as a whole. Once the evaluation deviates from the baseline methodology, then the non-conservative assumptions inherent in the baseline need to be addressed. This means that the transport of the large piece debris and erosion of debris in the sump need to be adequately addressed. It is noted that FCS assumed some transport of large piece fibrous debris. However, the issue of whether or not Temp-Mat debris will water-saturate in a time frame less than the time for activating the recirculation cooling has not been settled to the staff's satisfaction. That is, if Temp-Mat remains buoyant for longer periods, then floatation transport dominates and the transport of large pieces debris could become a much larger fraction. Even with analytical refinements, double accounting for debris transport is not valid without supporting validation. Regarding this point the licensee noted that the plant actually has wire screen doors that would tend to minimize the transport of floating debris; although there is an opening at the base of the door that would be covered sometime during flood-up before recirculation started.

The GE scaling equation (discussed below) does not adequately scale transport processes between the CDI tank tests and the FCS recirculation sump. The audit team considered that either experimental data or perhaps CFD analyses are needed to resolve this issue.

Head Loss Testing Procedure

The observed test involved a test procedure of introducing all debris into the test tank prior to starting the recirculation pump. If this same procedure is used throughout, there is a concern that potentially important aspects of head loss testing could be missed. Although, some of the debris in a LOCA scenario would in fact accumulate in the sump prior to operating the recirculation pumps, substantial quantities of debris would enter the sump pool after recirculation started; e.g., (1) small and fine debris blown into the upper containment levels could take a while to be washed back down to the sump; (2) erosion of fibrous debris and calcium silicate in the pool would occur over the long term; and (3) failure of unqualified coatings is likely a long term process. Such alternate time-dependent accumulations could be explored by altering test procedures; e.g., (1) introducing debris with the pump running, as well as, with the pump off; and (2) introducing the fibrous debris separate from the particulate debris; i.e., allowing the fibrous debris to fully accumulate prior to introducing the particulate. Since much of the particulate could arrive after the fibrous debris bed is completely or nearly completely formed, a possibility of forming a stratified bed exists. If stratification is an issue, it would apply to the maximum fibrous debris beds rather than thin-beds. Stratification can be investigated by introducing the particulate well after accumulating the fibrous debris.

The procedure of introducing the silicon carbide, zinc filler, and sand particulates into the test tank is a concern. Common experiences of introducing bulk dry powders into cold water illustrate the potential to form agglomerates (sludge) that becomes difficult to subsequently entrain as individual suspended particles. Other observed head loss testing procedures typically create wet slurry to ensure such agglomeration does not occur. Although, the CDI procedures included stirring with a fire hose, the water in the tank becomes so opaque that the success of this stirring cannot be visually verified. Conducting comparable tests that introduce the particulate as wet slurry would provide evidence of whether or not this concern is a valid concern. This alternate test procedure should be conducted as additional validation of the near field effect.

The testing observed indicates that the thin-bed debris accumulation will likely cause the most severe head loss. Therefore, the head loss testing needs to focus on ensuring the worst case thin-bed tests are achieved. This means varying the relative thickness of the fiber bed that forms the thin-bed starting from about 1/8-inch to a thickness that the resultant porosity does not cause the particulate porosity to control head loss. The thickness of the fibrous bed affects the filtration efficiency; i.e., how fine of a particulate can be filtered. If the bore hole phenomena persists for the design basis head loss tests, a thorough investigation of this behavior is needed to ensure the behavior is understood. Does the bore hole phenomena tend to govern the maximum head loss?

The audit team raised a concern that the test termination criterion might not allow the test head loss to achieve a relative steady state. The test results reviewed illustrate the head loss could increase if the test were allowed to continue.