June 12, 2007

MEMORANDUM TO: Michael L. Scott, Chief
Safety Issues Resolution Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

FROM: Stephen J. Smith, Reactor Systems Engineer ***/RA/***
Safety Issues Resolution Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

SUBJECT: STAFF OBSERVATIONS OF TESTING FOR GENERIC SAFETY ISSUE 191 DURING MARCH 8 AND MARCH 9 TRIP TO THE ALION HYDRAULICS LABORATORY

On March 8 and 9, 2007, four NRC staff members traveled to the Alion Science and Technology Hydraulics Laboratory in Warrenville, Illinois, to observe testing associated with the resolution of Generic Safety Issue 191 (GSI-191). The objective of the trip was to observe chemical effects tests being conducted for the Three Mile Island (TMI) Unit 1 strainer modification. The participating Nuclear Regulatory Commission (NRC) staff members were John Lehning and Steve Smith of the Safety Issues Resolution Branch in the Division of Safety Systems, and Paul Klein and Matthew Yoder of the Steam Generator Tube Integrity and Chemical Engineering Branch in the Division of Component Integrity. The staff interacted with personnel from the TMI licensee (Exelon) along with vendor personnel from Alion Science and Technology and Enercon.

The enclosure summarizes the staff’s visit on March 8-9, 2007.

Members of the NRC staff have previously visited the Alion Hydraulics Laboratory on February 24, 2006, on April 28, 2006, and on August 17 to 18, 2006 to observe testing. Summaries of staff observations from these visits are available in ADAMS (Accession ML060750467, ML061720514, ML063110561).

Enclosure:
Trip Report

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OBSERVATIONS OF TESTING

AT ALION SCIENCE AND TECHNOLOGY HYDRAULICS LABORATORY

MARCH 8 AND 9, 2007

Overview of Facility

On March 8 and 9, the staff observed a chemical effects head loss test for TMI Unit 1 at Alion Labs. The Alion Hydraulics Laboratory has the capability to perform tests in several facilities including (1) a large tank test loop for performing integral head loss testing of modular strainer arrays or strainer prototypes, (2) a small-scale vertical head loss test loop, (3) a small-scale multi-function test loop with temperature control capability, and (4) a small-scale transport flume. The staff observed a chemical effects head loss test for Three Mile Island (TMI) Unit 1 that was performed in the large test loop. The large test loop is comprised of a large clear-sided tank, a pump, a mechanical mixer, piping, and a diffuser. The test loop contains valves necessary to isolate or throttle flow. The pump is driven by a variable-speed motor to assist in controlling flow rate. Also installed is instrumentation for reading flow, pressure differential, temperature, and turbidity. Some of the instrumentation is connected to a desktop computer for trending and data collection. Grab samples are taken to determine the pH of the water throughout the test. The large test loop also has a bypass loop for filtering particulate. The filter loop was not used for this test. The test tank has a relatively large capacity and contained about 2200 gallons of water at the start of the test. In addition, the test loop has separate heating and cooling loops. For the test observed on this trip, the heating loop was used to bring the temperature up to the desired test specification, and then isolated during the test. The cooling loop was not used for this test. The hydraulics laboratory also has the chemicals and equipment needed for generating precipitates using the methodology outlined in WCAP-16530-NP, “Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191.”

Test Setup and Filter Details

The test tank contained a two by two array of Enercon “top hat” strainers connected to an outlet plenum. The outlet plenum was connected to the suction header for the test loop pump. The strainer array was contained in a plywood enclosure that fully surrounded three sides of the array and left the top half of the array exposed on one side. This arrangement was intended to model the TMI containment pool in which the strainers are installed in a sump below floor level. See Figures 1 and 2 (in the test results section) for an idea of how the strainers were contained in a plywood enclosure.

The top hats were of the single type and were about 42 inches tall. The test strainers were similar to the strainers designed for TMI. However, the test strainers were shorter and the annulus in the strainers had a slightly different dimension than the strainers installed in the plant. Dimensions for the plant strainers were not documented in the test procedure. The test plan explained that the shorter test strainers were likely to load more uniformly than the installed strainers. More uniform loading was considered to be conservative by the test plan. The difference in annulus size was considered to be negligible by Alion. The test array was scaled to account for expected debris loading including latent tag blockage. Scaling also attempted to account for inactive or dead screen area.

ENCLOSURE

The strainers contained a fiber bypass prevention material which consisted of layers of metallic mesh. This is a feature currently employed on Enercon strainers to reduce the amount of fiber bypassing the strainer and is termed a “bypass eliminator.” The bypass eliminator was previously reported as being somewhat effective in removing debris that had bypassed the perforated plate in an NRC Alion Laboratory trip report dated June 27, 2006, (ML061720514). Figure 4 (in the test results section) shows some of the mesh removed from the strainers that were used in the test that is the subject of this report. There is some debris apparent on the mesh.

The technical approach employed by Alion to evaluate TMI chemical effects consisted of several test steps. The plant-specific amount of chemical precipitate was determined with the chemical model spreadsheet contained in WCAP-16530-NP. These precipitates were prepared in the Alion Hydraulics Laboratory using the directions provided in WCAP-16530-NP, with the exception that reverse osmosis water was used to generate the precipitates instead of potable water. At the appropriate point in the test procedure, the chemical precipitates were transferred to the test loop, which was filled with potable water. It is estimated that approximately 200 gallons of precipitate solution was generated for use during the test. For TMI Unit 1, only calcium phosphate and sodium aluminum silicate precipitates were predicted to form for the case that was tested. No aluminum oxyhydroxide was added to the loop as none of this type of precipitate was predicted to form for the scenario being tested.

The debris loading for the case tested included Nukon insulation, qualified epoxy coatings (based on a 5D zone of influence [ZOI]), unqualified coatings, Thermolag fire barrier, latent particulate, and latent fiber. The Nukon insulation was shredded and then boiled to remove the binder. Ground silica was used as the coating debris surrogate. The average size of the ground silica representing failed coatings was 10 microns. The latent particulate surrogate was ground silica sand with sizing representative of the guidance in the NRC Safety Evaluation Report on Nuclear Energy Institute (NEI) 04-07 (ML043280641). Ground silica was also used as the Thermolag particulate surrogate. In addition, Thermolag also contains some fiber. Nukon was used as a surrogate for the Thermolag fiber. The staff did not perform a detailed review to ensure the licensee’s surrogate properties were similar to actual plant debris. All plant-specific debris loadings were scaled from the net plant screen area (2280 ft^2) to the net test loop screen area (62.3 ft^2). Both numbers are net screen areas and include allowances for latent tags, tape, or labels, or screen areas obstructed by stiffener rings, etc. The actual gross area of the plant strainer is 2835 ft^2. It is likely that there is some small scaling error related to the gross-to-net screen conversion. The scaling considered that bridging of fiber over solid portions of the strainer would not occur. It is likely that some bridging will occur, potentially resulting in a thinner fiber bed on the test strainer than would be the case in the real plant. However, any error from this issue should be minor. The theoretical bed thickness for this test was 1.4 inches and was based on the amount of debris that is expected to transport to the sump strainer. The ratio of total particulate mass to total fiber mass for the test was approximately 3.7.

For the test observed during this trip, the debris loading was intended to be equivalent to that expected for TMI’s limiting debris case (east D-ring hot leg break) following the 2009 TMI refueling outage (RFO). TMI will be replacing their steam generators (SG) in 2009. This modification will facilitate removal of a significant amount of fibrous insulation on the steam generators and reactor coolant system and allow its replacement with reflective metal insulation (RMI). The fibrous debris added for this test was significantly less than the amount that would be expected prior to the SG replacement.

Test Performance

Prior to the introduction of debris and chemical precipitates to the test loop, the test fluid temperature was increased to about 85°F and the clean strainer head loss was determined. Alion had prepared the required precipitates using the WCAP procedures as guidance within a few days before the staff arrived at the lab. After precipitates were mixed as specified in the WCAP, the solutions were diluted to specific concentrations. Settling rates were measured in standard centrifuge tubes and verified to meet WCAP acceptance criteria for precipitate settling. With the test loop temperature at 85°F, the scaled amount of non-chemical debris (i.e., fiber and particulate) from a postulated loss of coolant accident (LOCA) was introduced into the test tank. The particulate surrogate and Nukon were divided relatively equally and placed into five-gallon buckets with water. The mixtures were then stirred in an attempt to create a homogeneous slurry. The buckets were then poured into the test tank.

Alion personnel used a small sump pump to agitate the debris in an attempt to prevent it from settling to the tank floor. This process required several hours. Agitation was also provided by a mechanical stirrer and by the discharge of the pump through a diffuser. Despite this agitation, the staff observed that significant settling of the debris occurred in the large test loop. The staff considers this settling to be nonprototypical because the test tank geometry was atypical of the plant's sump. In the TMI sump, the top hat strainers are installed in a pit that has a floor about 7½ feet below the containment floor level. The strainers extend about 2 ½ feet above the containment floor. In the plant configuration, debris capable of moving across the containment floor could reach the strainer array by falling into the sump pit. In the test configuration, the debris was more likely to settle on the floor because the plywood barrier extended 2 to 3 feet above the base of the tank. In order to reach the strainers, the debris had to be lifted over the plywood barrier.

Despite utilizing a similar tank geometry, previous testing observed by NRC staff in the large test tank at Alion did not exhibit excessive settling of debris. The most likely reason for the increase in settling during the chemical effects testing is the lower flow rate used during the test. The previous tests used a 3-by-3 strainer array (9 top hats). The chemical effects test used a 2-by-2 array (4 top hats) in order to reduce the amount of chemical precipitates required for the test. In order to maintain the velocity of flow through the strainers at the design rate, the volumetric flow rate was reduced to about 44 percent of the previous tests. The lower flow rate appeared to reduce the velocity and turbulence in the tank sufficiently to allow more settling of the debris.

The baseline head loss for the fiber and particulate loading was established at about 0.35 feet of water. This is very close to a previous test that was run with a 3-by-3 strainer array with similar (scaled) debris loading.

After the baseline head loss for debris only was established and documented, incremental percentages of chemical precipitate were introduced to the test loop and the head loss associated with these precipitate additions was measured. Timing of precipitate addition was intended to be consistent with the WCAP-16530-NP chemical model predictions of precipitate formation following a LOCA. The predictions are site-specific based on the materials present in the post-LOCA environment at the plant being evaluated. The test measured the amount of chemical precipitate it took to reach the limiting net positive suction head (NPSH) margin. The margin is 1.35 ft at 208.8°F (with clean strainer head loss already subtracted) which equates to about 3.8 feet at 85°F. TMI will use the information from the test to determine the best actions to take to ensure that strainer head loss will remain acceptable. These actions may include removal of precipitate-forming materials or fiber from the containment zones of influence (ZOI). The results of this test may also lead to further testing or changes to the test plans for TMI.

The flow rate in the test loop was set to achieve between 0.008 and 0.009 ft/sec strainer approach velocity (target value of 241 gpm). As strainer head loss increased, flow decreased, so the flow had to be increased back to the target point by opening the test loop throttle valve. The maximum calculated approach velocity for TMI Unit 1 is 0.0086 ft/sec.

Test Results

The results and other information regarding the testing observed by the staff during the March 8 and March 9 testing are presented in this section. After all non-chemical debris had been added to the test tank, the test vendor stated that several hours were spent in an attempt to agitate fibrous debris onto the strainers. The staff observed some of the attempts to move the debris to the strainers. Because the test started much later than planned, NRC personnel were not present when it was decided to stop the effort to get the fiber onto the strainers. When NRC staff personnel left the test site the first day, there was a large quantity of debris on the floor of the test tank. When NRC personnel arrived at the lab on the second day, it was apparent that a significant portion of the fiber remained on the floor of the tank. However, the majority of the debris that had been on the tank floor the previous day had been agitated sufficiently to reach the strainers. Because the water was cloudy it was difficult for the staff to determine how the debris was distributed over the strainers and exactly how much remained on the test tank floor. However, from the portions of the strainers that were visible, it did appear that the entire strainer active area was covered with some thickness of fiber. It appeared possible that there was additional fiber buildup at the one open side of the wooden strainer enclosure. However, the staff noted that for previous tests a reasonably even accumulation had been achieved with a similar configuration. The staff requested photos after drain down to help evaluate the strainer coverage in the test configuration. The pictures provided (see Figures 1-5) did not provide conclusive evidence to support or reject a conclusion about the debris accumulation on the strainers.

Three batches of chemicals were added during the night shift prior to NRC personnel arrival at the Alion Lab for the second day of testing. After three batches of chemicals had been added pressure drop was about 1.6 to 1.7 feet and slowly increasing. The three batches of chemicals totaled 2.4 percent (0.314 lbs) of the total sodium aluminum silicate load, and 1.5 percent (0.026 lb) of the total calcium phosphate load for the test case. The quantity of chemical precipitates used in the test was scaled to the actual plant quantity by the ratio of the test strainer area to the plant strainer area (roughly 1:36.6). Observation of the water covering the strainers revealed that there were small surface dimples above the rear two strainers. These dimples were very small and barely perceptible. The dimple on the water surface above the strainer closer to the discharge diffuser was often absent or not observable. These minor pre-vortex indications were first identified by Alion personnel performing the test. It is estimated that a full vortex was not near forming at any time during the test observed by the staff.

Since meeting head loss stabilization criteria after chemical precipitate addition required long time periods, chemical additions occurred later than chemical model predictions. Therefore, the procedure was changed to allow the precipitates to be added after five tank volume turnovers. The test director determined whether the rate of change in head loss was acceptable prior to the next addition of precipitates.

The fourth batch of chemicals was added at about 1055 on Friday, March 9, 2007. Prior to the addition of this batch of precipitates, the strainer head loss was about 1.82 ft. Batch 4 consisted of 2.2 percent (0.294 lb) of the total sodium aluminum silicate and 1.5 percent (0.026 lb) of the total calcium phosphate precipitate. After addition of the precipitates, head loss began to increase almost immediately. Flow was increased about 3 to 4 gpm to reach the target of 241 gpm. By about 1115 head loss was about 2.35 feet.

The fifth batch of precipitate was added at about 1215. This batch consisted of 1.9 percent (0.255 lb) of the sodium aluminum silicate and 1.4 percent (0.025 lb) of the calcium phosphate. By 1250 the differential pressure had reached about 2.94 feet.

At about 1315, the sixth batch of precipitate was added. This batch consisted of 8.2 percent (1.075 lb) of the total sodium aluminum silicate and 7.8 percent (0.138 lb) of the total calcium phosphate. Prior to the addition of this batch of chemicals the head loss was about 2.96 feet. Flow was increased slightly to maintain the desired rate just after the chemicals were added. By 1345 head loss was about 3.34 feet and by 1355 head loss was 3.62 feet. NRC personnel had to leave the Alion Labs prior to the addition of the next batch of precipitate due to travel plans. At this point, the head loss across the strainer was very close to the maximum NPSH acceptance criteria for the test.

The total chemical precipitate loading prior to reaching the test acceptance criteria (after the sixth batch was added) was 1.938 lb of sodium aluminum silicate and 0.215 lb of calcium phosphate. This represented about 14.8 percent of the sodium aluminum silicate and 12.2 percent of the calcium phosphate loading predicted by the WCAP for the scenario being tested.

Alion and Exelon personnel stated that they would allow the head loss to significantly exceed the plant acceptance criteria prior to securing the test. The maximum loss expected prior to test termination was 15 feet of head loss. The licensee planned to observe the behavior of the strainers at these higher head losses. NRC personnel inquired as to whether the pump would be stopped and restarted to determine if this would effectively reduce strainer head loss. Test personnel responded that this would be done.

The pH of the test loop was taken about every 30 minutes during the test via grab samples. The pH started at a value of approximately 7 and increased slowly as the test proceeded by approximately 0.5 pH units due to the chemical additions. The temperature of the fluid in the loop was about 85^{o}F at the beginning of the test and increased to about 87^{o}F by the sixth chemical addition, probably due to pump heat.

Figure 1-Strainer in Plywood Enclosure

Figure 2-Strainers in Plywood Enclosure

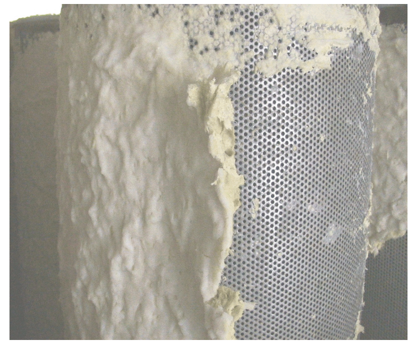

Figure 3-Strainer Surface with Debris

Figure 4-Bypass Eliminators

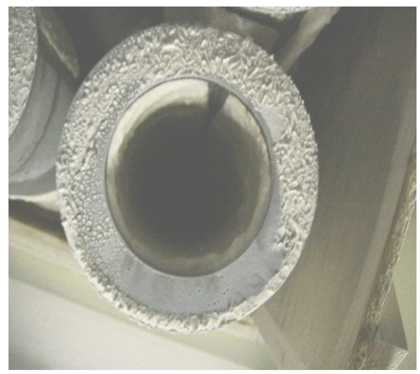

Figure 5-Debris on top of Strainer

Follow-Up Information from Licensee and Alion

In support of a follow-up phone call on April 3, 2007, the licensee provided some photographs of the test tank and strainers following drain down of the test solution. These photos are included above. The conditions shown in the photos are as drained. The filters and debris bed were not disturbed prior to the photos being taken (except for the photo of the bypass eliminator, Figure 4).

Figures 1 and 2 show the installation of the strainers in the tank. Figure 3 shows a closeup of the perforated strainer surface. All three figures are post-test and show some debris on the strainers' surfaces. Some debris has apparently fallen off of the strainers following the test and subsequent drain down of the tank. Figure 4 shows the bypass eliminator that has been removed from the strainer internals following the test. Figure 5 shows the top surface of a strainer with some debris settled on it.

During the April 3 conference call, the licensee and the test vendor provided additional information regarding some details of the test setup, the strainer installation at the plant, and observations from the completion to the staff. The staff had several questions about the results and other information provided. A summary of the information discussed during the conference call is provided below.

The TMI strainers are installed in a pit about 12 feet by 15 feet by 7.5 feet deep. The strainers extend above the containment floor by about 2.5 feet; however, they remain below the predicted LOCA minimum water level in the containment. There are 81 top hat strainers installed with a total surface area of about 2580 ft^2.

The head loss following the addition of the first 6 batches of chemical precipitates was about 3.6 feet at test temperatures. This head loss is equivalent to about 1.5 feet of head loss at the design temperature of 208°F. The first six batches of chemicals represented about 15 percent of the total precipitate load for the test case.

Following the departure of NRC personnel, the test was continued. After 100 percent of the precipitates were added the head loss was measured at about 4.6 feet. Therefore, the first 15 percent of chemical precipitate addition resulted in about 78 percent of the total head loss. The staff noted that this behavior was not consistent with previous chemical tests observed by the staff. The previously observed pattern is for the head loss to increase more steeply as more chemicals are added due to increased filtration efficiency. The licensee and test vendor were asked if they had any idea as to why the observed head loss behavior occurred in this test. It was unclear to those on the call as to why this test result appeared different than previous chemical tests observed by the staff.

The staff questioned whether there was an increase in precipitates settling out on the floor of the test tank during the later parts of the test because the results indicated the possibility that transport of the precipitates to the strainer may have become less efficient as the test progressed. It was stated by test personnel that the water was too cloudy to make a determination on the amount of precipitates on the floor. However, both from direct observation and from the photographs provided by the licensee, the staff concluded that settling of the precipitate had occurred. It was not clear that the observed settling is prototypical of the expected plant behavior.

During the call, the licensee noted that using the WCAP guidance for chemical precipitate predictions results in significantly more precipitate when NUKON insulation is installed in its current configuration at TMI. With NUKON insulation, the model predicts about 850 pounds of precipitate at TMI. With the NUKON removed, the model predicts about 185 pounds of precipitate.

After the entire chemical load had been added to the test tank and head loss had become relatively stable at about 4.6 feet, the pump was stopped, restarted, run for about 5-10 minutes, and then stopped. At the end of this run, the head loss was measured at about 0.27 feet. The staff inquired as to the mechanism that provided the reduction in head loss. It was stated that generally, air that builds up inside the strainer is released when the pump is stopped, assisting some of the debris bed in sloughing off of the strainer. It was also questioned as to whether the head loss measured at the termination of the pump stop/restart evolution was stable. The test personnel did not determine whether the head loss was stable following the pump restart.
The licensee discussed plans to run integrated 30-day tests in May of this year. The tests would be conducted in small-scale test loops at an overseas lab. There is also the possibility of conducting an additional large-scale chemical effects test at the Alion lab in Warrenville, Illinois.

Observations

During the test, the licensee and test vendor discussed the efforts being performed at TMI in response to GSI-191, which include both test programs and plant modifications.

Among the areas briefly discussed during the staff's visit were the following: The licensee noted that work had been done with respect to debris generation, debris transportation, latent debris, chemical effects, break selection, and head loss testing. The staff considered the results of this test to be of significant interest. In addition to actions that will be taken prior to the end of 2007, TMI will be replacing steam generators (in 2009) and plans to remove a majority of fibrous insulation in the ZOI for several breaks as part of this effort. Among the most interesting findings from the test observed is that the head loss atypically leveled off after a relatively small fraction of the precipitate was added.

Based on the staff's observations during the trip, issues or questions that may require further resolution were identified:

- Non-prototypical debris settling (including chemical precipitates) occurred during the test. As explained previously, the test tank geometry was significantly less conducive to transport than actual plant conditions. The test personnel made a dedicated effort to get the entire debris load entrained on the strainers. However, the attempts were not fully successful. Due to the cloudiness of the water, it was not possible for the staff to quantify the amount of debris that was not transported to the strainers. The effects of debris settling should be addressed during the evaluation of this test.

- The head loss associated with the addition of chemical precipitates increased most dramatically at first and more slowly as more precipitate was added. The first 15 percent of precipitate resulted in about 78 percent of the total head loss. Addition of the final 85 percent of chemical precipitates resulted in the remainder of the head loss for the test. The staff has observed other tests where chemical precipitates were added that resulted in exponential increases in head loss as additional precipitates were added to the test loop. An explanation for this atypical behavior would add to the understanding of filtering chemical precipitates.

- It was noted that there may be some scaling issues with active filtering areas vs. "dead" areas on the strainer. The issue involves the subtraction of strainer sections that do not contain holes (and therefore do not allow flow) from the total strainer area under the assumption that they will not have debris covering them. Bridging of debris across the "dead" areas may occur. However, observation of the photos taken following drain down showed that at least some of the areas of the strainer that were considered "dead" had no debris on them, indicating that the assumption may have been reasonable. This issue is minor compared to the debris settling issue described above.

- After generating the chemical precipitates, the precipitate settling rate was measured and compared to the WCAP 16530-NP acceptance criteria. In some cases, however, it was several days before the precipitates were used for testing. The staff recommended that the settling rates be tested again just prior to addition to the test loop to verify that the precipitate properties had not changed significantly since the precipitates were generated.

- Some of the latent fiber surrogate may not have been shredded completely into individual fibers. This issue is probably a minor effect for this test since there was a significant load of insulation-based fibrous debris on the strainers. However, if a test is conducted for a case where all, or most, fibrous insulation has been removed from the ZOI, and only latent fiber is predicted to reach the strainer, the test fiber should be shredded into very fine pieces to ensure representative transport and accumulation behavior.

- The configuration of the wooden enclosure around the strainers may have resulted in preferential loading of the front two top hats/modules and more likely the front surfaces of these two top hats. Based upon previous staff experience, this may have been a small effect for this test and may even be typical of loading of the outside strainers in the plant. However, this effect should be considered in the design of the test protocol.

- Due to the large amount of precipitant solution added during the head loss test, the water level above the strainers varied during the test. The addition of a relatively large volume of fluid (on the order of 10 percent of the initial volume) increases the height of water above the strainers and changes the flow characteristics within the test tank. This effect should be considered during development of the test protocol.

Summary

In summary, the staff observed chemical effects testing conducted for TMI Unit 1 at the Alion Hydraulics Laboratory. Simulated plant debris in the test observed by the staff were representative of a break location that produced a fiber bed and particulate loading expected following the removal of a significant amount of fibrous insulation from the plant. Introduction of a fraction of the total chemical precipitates predicted by the WCAP-16530-NP chemical model produced a pressure drop equal to the acceptance criteria for the test. The test confirmed that chemical precipitates can produce a high pressure drop across a pre-existing debris bed. The addition of the final 85 percent of the chemical precipitates produced an unexpected response. That is, only about 25 percent of the head loss occurred with the addition of the final 85 percent of the precipitates. This test was atypical when compared to staff observations during previous chemical effects testing. The NRC staff will continue to engage various licensees and vendors as chemical effects testing progresses. The staff expects these tests will provide additional understanding of plant-specific chemical effects.