August 22, 2016

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SUBJECT: STAFF OBSERVATIONS OF TESTING FOR GENERIC SAFETY ISSUE-191 DURING A JUNE 28 TO JUNE 30, 2016 TRIP TO THE ALDEN TEST FACILITY FOR PERFORMANCE CONTRACTING INC. STRAINER TESTS

On June 28 through 30, 2016, three members of the U. S. Nuclear Regulatory Commission (NRC) staff traveled to the Alden Research Laboratory (Alden) in Holden, Massachusetts to observe testing associated with the resolution of Generic Safety Issue-191. The objective of the trip was to observe an Emergency Core Cooling System strainer head loss test including chemical effects precipitates for Callaway Unit 1 and to ensure that testing is being conducted consistent with NRC staff guidance. The participating NRC staff members were Andrea Russell, Marioly Diaz-Colon and Steve Smith of the Office of Nuclear Reactor Regulation.

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The NRC staff members interacted with personnel from the Callaway licensee along with vendor personnel from Alden and Alion Science and Technology Corp.

The enclosure summarizes the NRC staff's visit on June 28-30, 2016.

Members of the NRC staff have previously visited Alden on March 17 to 18, 2005, January 18 to 19, 2006, March 8, 2006, January 16 to 18, 2008, February 12 to13, 2008, July 29 to 31, 2008, July 12 to 14, 2010, and August 4 to 5, 2015, to observe testing. Summaries of NRC staff observations from these visits are available in the Agencywide Document Access and Management System (Accession Nos. ML052060337, ML060750340, ML061280580, ML081830645, ML080920398, ML08470317, ML102160226, and ML15240A154).

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As stated

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ENCLOSURE:
As stated

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DATE	8/15/2016	8/15/2016	8/16/2016
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DATE	8/17/2016	8/16/2016	8/22/2016

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OBSERVATIONS OF TESTING AT ALDEN RESEARCH LABORATORY

JUNE 28 TO 30, 2016

Trip Summary

This trip was conducted to observe the Emergency Core Cooling System (ECCS) strainer head loss testing including chemical effects precipitates for Callaway Unit 1, and more generally to evaluate the methodology used at Alden Research Laboratory (Alden) for strainer head loss and penetration testing. The U.S. Nuclear Regulatory Commission (NRC) staff considered the test observations necessary because the testing is being used to support a risk-informed evaluation of strainer performance. The NRC staff has not observed a significant number of tests being used to support risk-informed analyses for strainers. In addition, Alden developed a new strainer test facility that will be used for testing several strainers in the near future. The trip allowed the NRC staff to gain confidence that testing is being conducted in a manner consistent with staff guidance. The test protocol is designed to minimize near-field settling. The test tank includes flow distribution intended to provide turbulence sufficient to effectively ensure all debris transports to the test strainer. A long-term NRC staff concern is that debris surrogates used in the testing may not be adequately fine to ensure transport to the strainer or to represent the fine material likely to transport to a strainer. NRC staff observations during testing did not identify any significant concerns with the test facility or methodology.

Testing and Facility Overview

On June 28 through 30, the NRC staff observed a thin-bed head loss test with chemical effects precipitates for Callaway at Alden Labs. Alden has the capability to perform tests in several facilities. Alden has been conducting testing of ECCS strainers with technical assistance from strainer vendors and other engineering consultants for several years. Callaway, in conjunction with Wolf Creek Generating Station, Unit 1, had previously conducted testing at Alden, but the NRC staff determined that the testing was potentially non-conservative. The new test loops and methods were developed to remove the potential non-conservatisms. Alden has previously performed testing deemed to be acceptable by the staff, but the testing for Callaway had not been redone until the current round of testing.

The test observed by the NRC staff was performed in a large test tank. Figures 1 and 2 show the tank geometry and schematic of the test loop. The test loop is comprised of a large tank, pumps, piping, and a tank level control system that includes an additional large tank (transition tank). The system also has the ability to heat the tank water. The test loop contains valves necessary to isolate or throttle flow, and fill and drain the tank. The pump is driven by a variable-speed motor to assist in controlling flow rate. Instrumentation for reading flow, pressure differential, and temperature are installed in the loop. Some of the instrumentation is connected to a desktop computer for display, trending, and data collection. Grab samples were taken to determine pH and conductivity, and concentrations of circulating silicon particles and precipitates in the water throughout the test. The test loop also has sample ports for taking samples to determine the amount of debris that bypasses the strainer.

The test facility also incorporates a parallel loop for the introduction of some of the debris sources. The loop diverts some of the primary loop pump discharge to a hopper. Debris is poured into the hopper and mixed with turbulent water flow to dilute and break up the debris. The debris then flows out of the hopper and gravity drains into the test tank.

The test tank contains the test strainer modules as shown in Figure 1. The return flow to the tank creates significant turbulence in the upstream portion of the test tank. This maintains debris in suspension to ensure that it reaches the strainer.

The draft test procedure and technical data were provided for review by the NRC staff prior to the testing. The staff did not perform a detailed review of the procedures, but agreed, based on a limited review, that they were likely to result in a test that bounds the head loss for the strainers installed at Callaway for the debris loads being evaluated.

The NRC staff also observed other test facilities at Alden Labs including a mock up to determine the potential for Loss-Of-Coolant Accident (LOCA) generated debris to block refueling pool drain lines. The test facility for this study is designed to provide prototypical flow conditions as they would occur in the refueling pool and its drainage system to determine if debris can transport to the drains, and if so, whether the debris will block the drains such that significant holdup of water could occur.

<u>Test Setup and Strainer Details</u>

The test tank contained two stacks of Performance Contracting Inc. (PCI) strainer modules connected to an outlet plenum. The outlet plenum was connected to the suction header for the test loop pump. The strainer array was contained within the steel and Plexiglas walls of the tank (Photo 1). Callaway has two large strainer arrays located in the basement of containment, each in a deep sump pit with only a small amount of the strainer projecting above the floor. The plant arrays are composed of 16 stacks of strainer modules. Some stacks are taller than others to allow for structures in the pit. The total strainer area in the plant for each strainer array is about 3,311 square feet (ft^2). The test tank walls surrounding the strainer on three sides form a rectangular area with spacing between the walls and strainer test modules intended to model the distance between strainer modules and walls of the sump pit as installed in the plant. The modules used in the test are the same height as the shorter strainer module installed in the plant.

The test strainer was typical of the PCI design which includes flow control to distribute flow more evenly among modules and within each module. The strainer modules were the same design as the modules installed at Callaway. The area of the test module was about 348 ft^2, which represented about 11.014% of the total strainer area for one strainer installed at Callaway considering 150 ft^2 of sacrificial area. Flow in the plant is 8,750 gallons per minute (gpm) per train maximum. Test debris amounts and flows were scaled based on the ratio of the area of the plant strainer (minus sacrificial area) to the test strainer.

The NRC staff arrived at Alden around 07:30 am on Tuesday, June 28, 2016. The NRC staff met with representatives from Callaway, Alden, and Alion to discuss the overall test procedure and the results from a previous full-load head loss test performed for Callaway.

Discussions with the Licensee and Test Personnel

During the first day of the visit, the NRC staff received a presentation showing the results from a prior week's "full-load" head loss test. Test personnel stated that the full-load head loss test resulted in acceptable head loss with the largest target fiber load (300 pounds (lbs.)) on a single strainer. The target load was determined to ensure that the risk from all breaks that may produce that amount of fiber is very low. The test included the full particulate and chemical precipitate loads that could be produced by limiting design basis breaks within containment. The test simulated the maximum velocity through the strainer surface that could occur in the plant. The velocity included spray flow and accounted for potential higher Diesel Generator frequency which can result in higher pump speed, and therefore flow rate. The maximum possible generated total fiber with no intact blankets "or latent fiber" is 986.75 pound-mass (lbm) with a maximum volume of 410.80 cubic feet (ft^3). This condition was used to determine calcium phosphate generation. Based on the results of the full-load test it appears to the staff that the increase in risk due to the breaks that cannot be shown to pass deterministic criteria based on the testing being conducted will be very low.

The full-load head loss test was conducted by adding particulate and fibrous debris in mixed batches. Eight equally sized batches of particulate and fibrous debris were added. Each batch included a fiber quantity that would result in a theoretical bed of approximately 1/16 inch. The particulate load for Callaway is very high because of a large quantity of unqualified coatings that are assumed to fail as particulates.

During the full-load test, no bridging of fiber between strainers or the walls of the test tank was observed. This indicates that fiber was not prevented from transporting to the strainer due to being held up due to deposition in these locations. The strainer appeared to be coated with chemicals. No settling of debris was observed near the strainers. A very small amount of settling was observed upstream of strainer. The amount of settling was judged to be insignificant. Some open areas between strainer modules were noted. It appeared that there were cavities between disks that led to potential open areas on the strainer. Similar observations were made during the thin-bed test and are discussed further below.
The licensee provided graphs of the full-load test. The head loss increased with each chemical precipitate debris addition, but most of the head loss was a result of the particulate and fiber load on the strainer. The full-load test head loss at 120°F was less than required for Net Positive Suction Head (NPSH) margin at 212°F. During the full-load test no vortexing was observed at the design basis Large-Break Loss-Of-Coolant Accident (LBLOCA) submergence level.

The full-load test included only 30 lbs. of latent particulate debris. The NRC staff noted that if 30 lbs. of latent particulate is used as the design basis the licensee may need to justify that level of cleanliness on a relatively frequent periodicity because 30 lbs. is much lower than the NRC guidance value for latent particulate, which is 170 lbs.

The full-load test included different sizes of silicon dioxide as a surrogate for both acrylic/epoxy and zinc coatings. The appropriate size distribution was used for each coating type and surrogate quantities were adjusted for density. Three different commercially available silicate surrogates were used to attain the appropriate size distribution.

The chemical precipitate debris for Callaway's full-load test was based on Westinghouse Commercial Atomic Power (WCAP)-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to support GSI-191". The WCAP-16530-NP-A chemical model predicted an unscaled chemical load of 25 kilograms (kg) of calcium phosphate and 213 kg of sodium aluminum silicate. The licensee based the chemical load for testing on 25 kg of calcium phosphate and 215 kg aluminum oxyhydroxide. The full-load test scaled amount of chemical precipitate debris added to the test loop was 2.75 kg of calcium phosphate and 23.68 kg of aluminum oxyhydroxide. The chemical precipitates were added as one batch of calcium phosphate and five batches of aluminum oxyhydroxide. The chemical precipitate debris additions in the full-load test did not result in large head loss increases. The increases were relatively gradual and relatively small for each batch. This behavior may have been due to the large amount of particulate already captured in the debris bed.

The licensee discussed plans for the thin-bed test. For the thin-bed test, all particulate will be added before any fibrous debris. The fiber will be added in 1/16 inch theoretical bed thickness increments. The licensee noted that shake down tests indicates that greater than 1/8 inch of fiber is required to get a filtering bed. Each test increment of fiber will be 4.36 lbs. which is equal to 1/16 inch.

The thin-bed particulate load is the same as the full-load test, but will include 170 lbs. of latent particulate (scaled down to the test amount) instead of 30 lbs. which is what was included in the full-load test. The actual (scaled) amount of particulate in the test was greater than 600 lbs. The scaling factor for the thin-bed test is 0.11014. This is the same as for the full-load test. Therefore, the flow and debris scaling are the same as the full-load test.

The licensee plans to perform strainer penetration testing in the week following the thin-bed test. This testing will determine how much fiber may pass through the strainer to aid in evaluating how equipment downstream of the strainer may be affected.

<u>Thin-Bed Test Performance</u>

The thin-bed test was run to determine whether the plant specific debris load and strainer configuration can result in a relatively high head loss resulting from the full particulate load and a relatively small fibrous debris load. The Callaway plant has the potential for a large amount of particulate debris to be generated because of the large amount of unqualified coatings that have been applied within the containment.

The NRC staff observed the preparation of debris prior to its addition to the test. The particulate debris was mixed in trash cans with a large amount of water. The mixtures were stirred well until added to the debris addition hopper which further diluted and agitated the debris mixture.

The fibrous debris was created from large sheets of Nukon fiberglass that has been heated on one side to simulate being installed on hot piping. The sheets were cut into smaller pieces using a large paper cutter, then further reduced in size by hand tearing. This fibrous debris is then placed into a large tank. The tank contains a manifold fed from a high pressure pump. The discharge of the pump exits the manifold through small nozzles. The high pressure and high velocity fluid renders the fiber into fine pieces. The tank is manually stirred during the process to ensure that all of the fiber is exposed to adequate jet forces to attain the desired size distribution. The method produces fine fiber of the desired characteristics. The system is capable of preparing about 2 lbs. of fiber (one five gallon bucket of dry cut up fiber) at a time. The NRC staff noted that the fiber could agglomerate into larger clumps after preparation, but that stirring, or adding via the hopper resulted in the agglomerations breaking apart. A small amount of the resulting fiber fines were photographed on a light table to document the debris characteristics.

Debris additions for the thin-bed test began in the morning on June 28, 2016. The water was at about 122°F, and the water level was about 8 inches above the top of the strainer at approximately the design basis LBLOCA submergence level. The level was expected to increase due to the addition of the debris slurries. Clean Strainer Head Loss (CSHL) was about 2.65 to 2.7 pounds per square inch (psi). Flow was at the design scaled flow rate of about 1,100 gpm. The fluid in the test was buffered and borated demineralized water to simulate plant conditions following a LOCA.

All particulate debris was added first. Most of the particulate debris was added through the hopper system. The latent particulate, which contains some larger particles was sprinkled on the surface of the water just upstream of the strainer. This is intended to prevent the larger particulate from settling in the tank upstream of the strainer or in the debris addition system. The addition of particulate debris had no effect on head loss. As expected, the temperature began to decrease with the addition of the cooler debris laden water and the tank level rose. Temperature was controlled around 120°F manually. Once the particulate debris was added it was no longer possible to see the strainer because of the cloudiness of the water. A flow sweep was performed after the particulate debris addition was complete.

After the flow sweep, the first batch of fiber was added. Each 1/16 inch batch was about 4.36 lbs. At the conclusion of fiber preparation, each batch was contained in three trash cans of 35 gallons total capacity each. The total liquid volume was about 90 gallons. This equals about 1977 grams in 340 liters and corresponds to about 6 grams of fiber per liter of water. This dilution ratio is adequate to assist in preventing agglomeration.

The first batch of fiber made almost no difference in head loss. The second batch resulted in about a 0.10 psi increase. The third batch resulted in about 0.10 psi increase. At a 3/16 inch theoretical bed thickness, the head loss increase was less than about 0.5 psi. The fourth batch of fiber resulted in about half the head loss increase of the two previous batches, or about 0.05 psi. The rate of head loss increase was also slower than the previous two batches. The test team determined that adequate fiber had been added to form a thin bed.

In the afternoon of June 28, 2016, after the fiber addition was completed, the transition tank contents were recirculated into the test tank so that debris in the transition tank could be captured on the strainer. After the fiber additions, the recirculation pump for the transition tank started leaking and had to be secured. A temporary pump was installed to maintain mixing in the tank. The failed pump was replaced to allow the tank to be recirculated. The pump failure was caused by the suction line becoming clogged with particulate. The contents of the tank were recirculated into the test loop and it was verified that no debris remained in the transition tank. The recirculation of the transition tank may have resulted in a slight increase in head loss although the increase may have been a result of the previous debris addition. The test team determined that the amount of lost particulate was not significant to the results of the test. After all of the fiber had been added to the test, the NRC staff left the test facility. The head loss was allowed to stabilize and then temperature and flow sweeps completed.

Chemical Preparation and Additions

The chemical precipitate debris for Callaway's thin-bed test was based on WCAP-16530 NP-A. The unscaled chemical load was calculated incorporating plant specific data such as assuming 30-day operation of all containment spray pumps, LBLOCA pH, worst case Final Safety Analysis Report temperature profile, minimum water volume and a maximum amount of Tri-Sodium Phosphate (TSP) into the chemical precipitate spreadsheet based on WCAP-16530-NP-A. The chemical model predicted 25 kg of calcium phosphate and 213 kg of sodium aluminum silicate. The licensee based the chemical load for testing on 25 kg of calcium phosphate and 215 kg of aluminum oxyhydroxide. The test scaled amount of chemical precipitate debris added to the test loop was 2.75 kg of calcium phosphate and 23.68 kg of aluminum oxyhydroxide.

The thin-bed test procedure included one batch of calcium phosphate (400 gallons) and six batches of aluminum oxyhydroxide. The batches of aluminum oxyhydroxide consisted of five batches of 500 gallons and one batch of approximately 480 gallons. In general, the chemical precipitate debris addition to the test loop consisted of first adding the batch of calcium phosphate and then adding the batches for aluminum oxyhydroxide. The test procedure required that a stable head loss be attained prior to each chemical precipitate batch addition. The NRC staff had the opportunity to observe the preparation of several batches of chemical precipitate debris for both calcium phosphate and aluminum oxyhydroxide. During the first day of the NRC staff visit, Alden Laboratory personnel began preparing chemical precipitate debris for later addition to the test. The laboratory had the chemicals and necessary equipment for generating large quantities of both calcium phosphate and aluminum oxyhydroxide precipitates using the methodology outlined in WCAP-16530-NP-A. The addition of the chemical precipitates debris took place during the second day of the NRC staff visit.

The NRC staff observed the preparation of a 400 gallon batch of calcium phosphate and a 500 gallon batch of aluminum oxyhydroxide precipitates executed by Alden personnel. For calcium phosphate, the preparation consisted of dissolving calcium acetate into approximately 400 gallons of deionized water and then adding TSP. The ingredients were added slowly and mixing was maintained for one hour to allow chemical reactions to continue. Approximately one hour after the batch of calcium phosphate was prepared, the laboratory staff began a settlement test in a graduated cylinder. The one-hour precipitate settlement was approximately 6.0 milliliters (mL) out of 10 mL. In other words, the cloudy portion of the precipitate covered up to the 6.0 mL mark with 4.0 mL of clear fluid from the 6.0 mL mark to the 10 mL mark. The objective of this measurement was to ensure suspension of the chemical precipitate so it will transport to the test strainers. The final concentration of the calcium phosphate batch resulted in 1.82 grams/liter. The batch of calcium phosphate met the one-hour settlement measurement and concentration criteria specified in WCAP-16530-NP-A. Photo 2 shows parts of the procedure for the preparation of calcium phosphate.

The preparation of the first batch of aluminum oxyhydroxide consisted of dissolving aluminum nitrate into approximately 500 gallons of deionized water and then adding sodium hydroxide. The ingredients where added slowly and mixing was maintained for one hour to allow chemical reactions to continue. Approximately one hour after the aluminum oxyhydroxide was prepared; the laboratory staff began the settlement test in a graduated cylinder. The one-hour aluminum oxyhydroxide precipitate settlement test resulted in approximately 9.1 mL out of 10 mL. The final concentration of the first batch of aluminum oxyhydroxide resulted in 2.1 grams/liter. These results met the settlement and concentration criteria specified in WCAP-16530-NP-A. Photo 3 shows various points in the preparation of an aluminum oxyhydroxide chemical precipitate batch.

During the second day (June 29, 2016) of the NRC staff visit, an issue arose before the addition of chemical precipitate debris. Alden personnel informed the NRC staff that foreign material was found inside the calcium phosphate tank. The material was determined to be a result of the tank mixing-propellers contacting a piece of the tank lid that had fallen into the tank overnight. Photo 4 shows the material found in the calcium phosphate tank and the broken propeller. Alden personnel addressed the situation by replacing the existing calcium phosphate batch with a new one. The new calcium phosphate batch resulted in a one-hour precipitate settlement test of approximately 5.4 mL out of 10 mL and a concentration of 1.82 grams/Liter. These results met the criteria specified in WCAP-16530-NP-A.

Alden personnel reviewed the head loss test data before starting the addition of chemical precipitate debris on June 29, 2016. Based on a review of the data, it appeared that the head loss increased slowly after the initial increase from the final 1/16 inch fiber addition made the previous afternoon. The increase was less than another 0.05 psi. Head loss then became relatively stable. The flow sweep and temperature sweep conducted overnight appeared to have the expected response. The temperature sweep from about 120 to 130°F resulted in a slight decrease in head loss. The flow sweep resulted in a significant response in head loss, although a significant portion of this response was due to the clean strainer contribution. The flow sweep was completed just prior to NRC arrival. The head loss appeared to stabilize following the flow sweep.

Alden personnel obtained test-loop solution samples for pH, turbidity and particle size prior to the start of the chemical precipitate debris addition. The 400-gallon batch of calcium phosphate was added first. The transition tank setup allowed the addition of a large volume calcium phosphate batch while maintaining the required strainer submergence. Flow from the test tank was drained into the transition tank at about the same rate that the calcium phosphate batch was added to the test tank although the submergence level of the strainer was not considered critical during this portion of the test. Once the calcium phosphate batch addition was finished, the contents of the transition tank were recirculated back to the main test tank until a stable head loss was established. Then the transition tank was isolated from the system and drained through a filter bag to capture any debris contained in the transition tank at the time of draining. The calcium phosphate addition resulted in about 0.02 psi increase. During the full-load test the addition of the same amount of calcium phosphate resulted in about 0.03 psi increase in head loss.

The first batch of aluminum oxyhydroxide precipitate was introduced after a stable head loss response was achieved following the calcium phosphate addition. The head loss resulting from each batch of chemicals was allowed to stabilize prior to the addition of the next batch. The first batches of aluminum oxyhydroxide had some effect on head loss. The head loss increase was very slow. The chemical additions were completed overnight. Each chemical addition resulted in a small increase in head loss. The first batch of aluminum oxyhydroxide resulted in about a 0.055 psi increase. The second batch resulted in about 0.1 psi increase. The third and fourth batch resulted in about the same 0.025 psi increase. The fifth and sixth batch resulted in about the same 0.125 psi increase. These values are approximate, from raw data obtained at the time of the test. An interesting aspect of the chemically induced head loss during this thin-bed test is that the later aluminum oxyhydroxide additions resulted in more head loss than the first two additions. A flow sweep was completed at temperature, temperature was reduced to about 90^{o}F, and a flow sweep at reduced temperature was completed. The final head loss was about 3.45 psi at about 90^{o}F.

Pump Stop and Drain Down

When NRC staff arrived at the test facility on June 30, 2016, the chemical precipitate debris addition portion of the test had been completed. The final flow sweeps had been completed and the loop was ready for drain down. The loop was slowly drained to the LBLOCA design basis level and no air core vortices occurred. There were some minor dimples on the water surface that were not sustained.

When the pumps were secured gasses were released from the strainer. Upon drain down it appeared that the gas was released from the top of the core tube as there was some disturbance of the bed in that area (Photo 5). During drain down, the bed tended to fall off of the strainer in some places. The bed appeared to be less stable than the bed from the full-load test. Full-load test photos appeared to show the bed adhering more tenaciously to the strainer.

A debris pile on top of the strainer appeared to be mostly particulate with some chemical precipitate. There was no evidence of fiber on top of the strainer, likely due to the extremely high particulate to fiber ratio included in the test.

Cavities, or bore holes, were observed in the debris bed following the thin-bed test. These cavities looked similar to those in the full-load test. Observation of these cavities after the thin-bed test showed obvious fiber coloration around the edges indicating that during the drain down the debris bed may have fallen off of the strainer and flowed out of the perimeter of the strainer creating the "cavity" in at least some of the cases (Photo 6).

Inspection of the strainer after drain down did not allow the NRC staff to conclude that the cavities that are seen as potential open areas in the debris bed are present during the test. However, it appears likely that some cavities existed prior to drain down. Inspection of the debris bed showed an extremely thin layer of fiber next to the perforated plate with a large amount of particulate on top of the fiber (Photo 7). The debris bed formation indicates that the particulate did not start accumulating on the strainer until the fiber created a matrix to capture it. This appears to be a classical thin bed where the flow is passing through a particulate bed with very little fiber. Head loss may be limited by flow passages or cavities through the bed as discussed above.

The thin-bed test had about half the fiber of the full-load test and all of the particulate. Also, for the full-load test, particulate and fiber were mixed together prior to addition and for the thin-bed test the particulate was all added before the fiber. These two combinations provide a good basis for the response of the strainer under different loading conditions.

<u>Strainer Disassembly</u>

Upon disassembly of the strainer it was observed that there were open areas on the strainer disks and areas where the debris bed appears to be thinner or have passages through it. It is hard to tell whether these cavities were there prior to drain down, or caused by the drain down. It is possible that some of the debris from between the strainers is pulled out when the support wires are removed. Observation of the debris bed between disks indicates that there are areas that have less debris, like worm holes and open caverns within the debris bed. As with other observed open areas in the debris bed it is difficult to tell if these were created during drain down. Some of the strainer surfaces were observed to have several square inches of clean area (Photo 8). It is not clear that these areas are clean during the test. The debris bed may have pulled off during disassembly or fallen off during drain down. Likely at least some debris covered the entire strainer. When the disks were turned vertically, in general, the entire bed slid off as a single piece. Also, when the disks were removed from the stack, most of the debris fell off the bottom side of the disk onto the disk below. Occasionally some of the debris bed adhered to the bottom side of the strainer.

A lot of the volume between disks appeared to be completely filled with debris when viewed from the edges (Photo 9). The debris that is on the periphery of the strainer was observed to have some fiber in it (Photo 10). After completing observations of both strainer stack disassembly procedures it appears there are some areas between the disks that have less debris than other areas. The disks are likely completely covered with some amount of debris, but the thickness of the bed varies, being thinner where the passages or cavities exist. It appeared that about (very rough estimate) 90 gallons of debris was removed from the strainers during cleaning.

During the disassembly of the strainer after previous tests it was observed that some small pieces of fiber that pass through the perforated plate remain trapped inside the disk. The fragments of fiber do not transport further downstream in the strainer. The fiber becomes trapped within the wire matrix that provides support to the disks (Photo 11). Observation of the disk and wire support system show that the support wires have a gap between them to allow flow. The fiber becomes trapped in low flow areas near the wires. The NRC staff observed a disk after being washed off and observed that fiber had bypassed the perforated plate and stayed within the disk, similar to observations from previous tests (Photo 12).

This test had a very large amount of particulate to fiber ratio. About 610 lbs. of particulate and 17 lbs. of fiber were added to the test. The total fiber added to the test resulted in a 1/4 inch theoretical bed thickness. However, some fiber passed through and was captured inside the strainer and some was captured on the peripheral bed. Therefore, there was not 1/4 inch of fibrous debris on the strainer surface as some was deposited in these locations. The actual thickness of the bed on the strainer cannot be determined.

The NRC staff conducted a short exit meeting with the licensee and other test personnel from Alion and Alden. The NRC staff expressed appreciation for the opportunity to observe the testing. The NRC staff noted that the test methods used by Alden, and the inputs for test parameters provided by the licensee and Alion, resulted in testing that meets staff guidance (Agencywide Document Access and Management System Accession No. ML080230038).

Test Results

The test results are summarized as follows.

1) The strainer head loss for the thin-bed test was measured to be about 3.4 psi. for the test strainer at 120°F, including CSHL. CSHL was about 2.7 psi.
2) The water temperature at the start of the thin-bed test was 120°F. The temperature decreased slightly during the test due to the addition of colder water with the debris, but was controlled close to the desired temperature.
3) The head loss associated with the full debris load including chemical precipitates was reported to have margin to NPSH limits without scaling to temperatures higher than the test temperature.
4) The thin-bed head loss was less than the reported full-load head loss. Therefore, the full-load test is limiting for Callaway.

Observations

The NRC staff considered the results of the observed test to be of significant interest. The major points are as follows:

1) Testing appeared to be conducted per the staff guidance on head loss testing.
2) All debris, except for an insignificant amount, transported to the strainer.
3) Some particulate remained in the fluid and did not filter out on the debris bed. This may have been due to the very high particulate to fiber ratio for this test.
4) The addition of chemical precipitate debris for both the full-load test and the thin-bed test did not result in a large head loss increase above the conventional debris head loss. Also, the addition of subsequent chemical precipitate debris batches had some effect on head loss. In the past the staff has observed decreasing effects from later chemical batches.
5) Observation of the debris bed indicates that there may be areas of lesser debris deposition in some locations.
6) Some fiber was observed to be trapped within the strainer disks.
7) The test resulted in a thin-bed effect with a very high particulate to fiber ratio bed on the strainer.

Summary

The NRC staff observed ECCS strainer performance testing conducted for the licensee, Callaway, by Alden and Alion at the Alden Research Laboratory. Debris surrogates used in the test were representative of a those expected following a LOCA. The thin-bed test which included the full particulate debris load and all of the chemical precipitate debris load resulted in a filtering bed and some head loss. The maximum head loss attained was about 3.45 psi including CSHL. This head loss was less than the head loss reported for the full-load test that had been completed prior to the NRC staff visit. At the conclusion of the NRC staff visit, the licensee planned to continue testing to attempt to determine the amount of fiber that may penetrate the strainer and affect downstream components. The testing observed by the NRC staff and the full-load test conducted previously provide confidence that the licensee has identified a head loss that is bounding for the conditions in the plant within the evaluation bounds. Breaks that produce debris quantities less than or equal to the amount of debris tested will be evaluated deterministically by the licensee. Breaks that produce debris quantities in excess of the amount of debris tested will be evaluated using a risk-informed approach. Note that higher head losses may occur but this test was intended to identify a fiber amount that provides acceptable risk metrics. The NRC staff will continue to engage the licensee and vendors as sump strainer testing progresses and is incorporated into their evaluations.

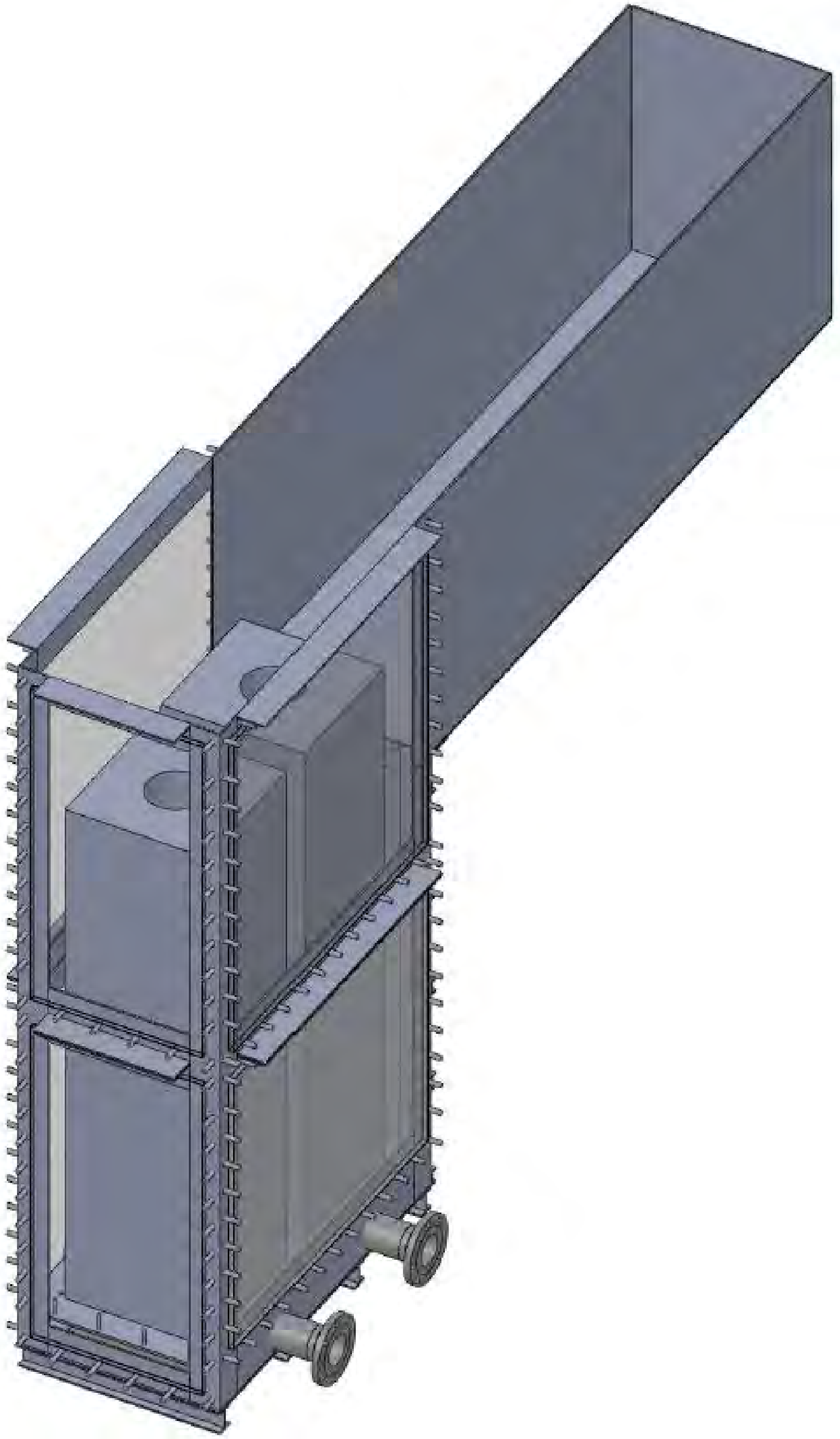

Figure 1 - Test Tank and Strainer Layout

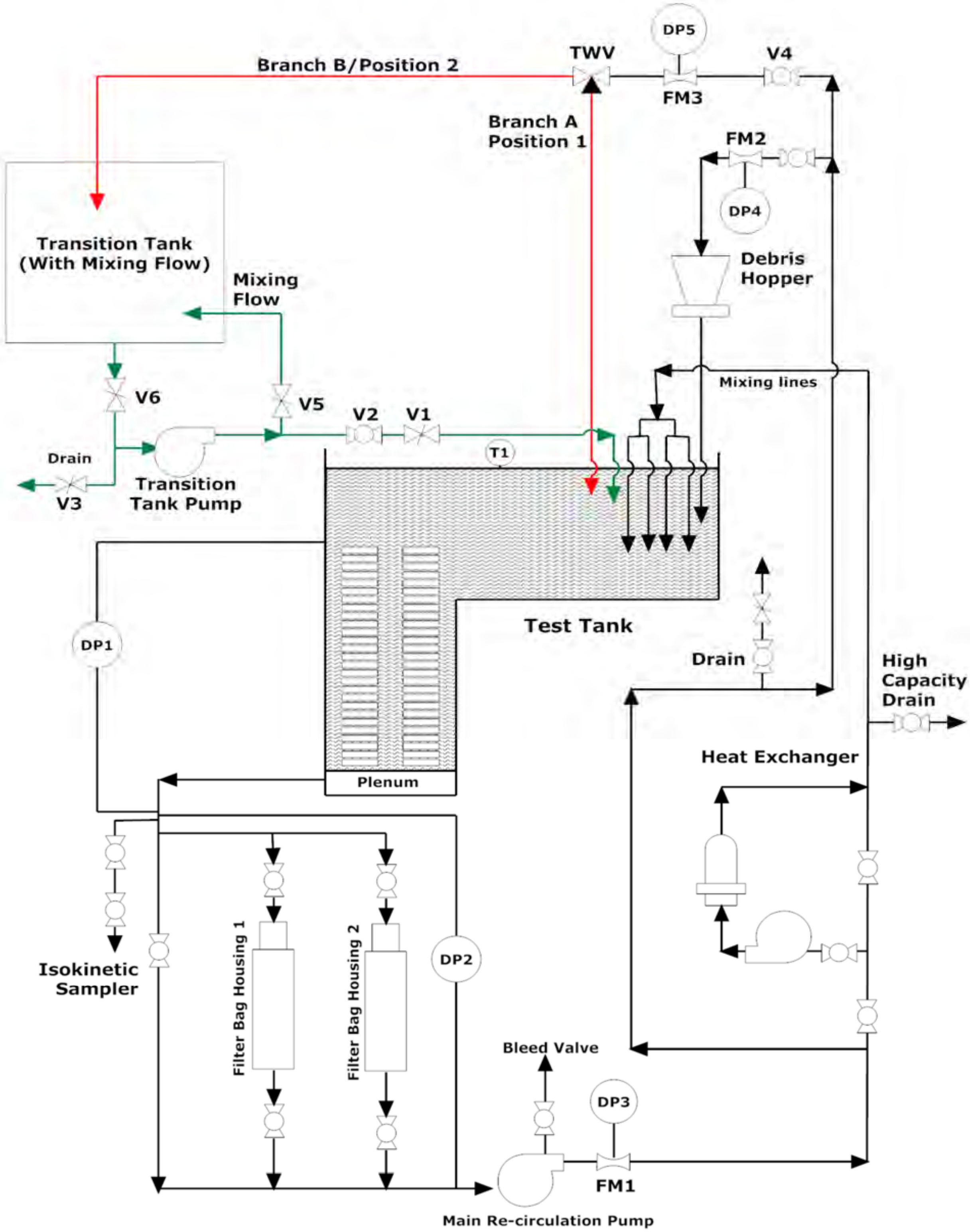

Figure 2 - Test Facility Schematic

Photo 1 – Strainer in Test Tank

Photo 2 – Preparation of calcium phosphate chemical precipitate debris

Photo 3 – Preparation of aluminum oxyhydroxide chemical precipitate debris

Photo 4 – Issue with calcium phosphate tank – additional debris found, as a result, of contact between the mixing-propeller and the tank lid

Photo 5 – Debris bed disturbed by gas release

Photo 6 – Fiber around cavity

Photo 7 – Thin layer of fiber that captured the particulate

Photo 8 – Open area on strainer

Photo 9 – Entire strainer stack showing most of strainer engulfed in debris

Photo 10 – Fiber in peripheral bed

Photo 11 – Wire support structure for disks

Photo 12 – Fiber captured within disk