August 19, 2010

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 A JULY 12 TO JULY 14, 2010 TRIP TO THE ALDEN TEST FACILITY FOR PCI STRAINER TESTS

On July 12 through 14, 2010, a member of the U. S. Nuclear Regulatory Commission (NRC) staff traveled to the Alden Research Laboratory in Holden, Massachusetts 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 Watts Bar Emergency Core Cooling System strainer and to observe a new test protocol implemented to address staff concerns with previous methods. The participating NRC staff member was Steve Smith of the Office of Nuclear Reactor Regulation, Safety Issues Resolution Branch in the Division of Safety Systems. The staff member interacted with personnel from the Watts Bar licensee along with vendor personnel from the Alden Research Laboratory (Alden), Areva NP Inc. (Areva), and Performance Contracting Inc.

The enclosure summarizes the staff's visit on July 12-14, 2010.

Members of the NRC staff have previously visited the Alden Research Laboratory on March 17 to 18, 2005, on January 18 to 19, 2006, on March 8, 2006, January 16 to 18, 2008, February 12 to 13, 2008, and July 29 to 31 2008, to observe testing. Summaries of staff observations from these six visits are available in ADAMS (Accession ML052060337, ML060750340, ML061280580, ML081830645, ML080920398, ML08470317).

ENCLOSURE:
As stated

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301-415-3190

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Observations of Testing at Alden Research Laboratory
July 12 to 15, 2010

Overview of Facility

This trip was conducted to observe the emergency-core-cooling-system (ECCS) strainer head loss testing for the Watts Bar Plant. The staff considered that the test observations were necessary because the test protocol being used was the first of its kind for a Performance Contracting Inc. (PCI) strainer for operating pressurized water reactors (PWRs). Previous PCI strainer tests at Alden Labs had allowed near-field settling during the tests. The new test protocol is designed to minimize near-field settling. The test tank includes stirrers and flow distribution intended to ensure that effectively all debris transports to the test strainer. In addition, the staff has had concerns in the past regarding the consistency of debris preparation for fine fibrous debris. During previous observations of PCI strainer testing conducted at Alden Labs, the fibrous debris preparation for fine fiber was observed to be too coarse at times. The staff has concluded that using fine fibrous debris results in higher head losses than for more coarse debris and is therefore conservative. The fineness of debris also contributes to its transportability and is therefore a consideration for that aspect of the non-stirred tests as well. Because these tests were stirred and debris was observed to transport to the strainer, the fibrous debris preparation was not a concern from the transportability perspective.

Testing

On July 12 through 14, the staff observed a clean strainer head loss test, debris bypass test, and a thin-bed head loss test with chemical effects for Watts Bar at Alden Labs. The Alden Laboratory has the capability to perform tests in several facilities. These include two large tanks for performing integral head loss testing of modular strainer arrays or strainer prototypes without crediting near-field settling, a small-scale horizontal test loop, a large test facility that models the basket and strainer array for Areva's EPR plant, and a scaled mock up of a portion of a boiling water reactor (BWR) torus for observations of debris behavior during blowdown to the torus (chugging). The test flume that was previously used for testing PWR strainers that credited near field settling has been converted into the two large stirred test tanks mentioned above.

Alden Labs has been conducting testing of PCI strainers with technical assistance from Areva and PCI for several years. Watts Bar had previously conducted testing at Alden Labs, but the staff determined that the testing was non-conservative. The new test loops and test protocol are designed to remove the potential non-conservatisms previously identified by the staff.

All tests observed by the staff were performed in one of the large test tanks. The large test loop is comprised of a large tank, a pump, piping, and a tank level control arrangement. There is also the ability to heat the tank water with an external loop. 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. Also installed are instrumentation for reading flow, pressure differential, and temperature. Some of the instrumentation is connected to a desktop computer for trending and data collection. Grab samples were taken to determine the pH of the water throughout the tests. The large test loop also has sample probes for taking samples to determine the amount of debris that bypasses the strainer.

ENCLOSURE

The test facility also incorporated a parallel loop for the introduction of some of the debris sources. The loop diverts some of the primary loop pump discharge to a volume within a larger hopper. Debris is poured into the volume and mixed with turbulent water flow to dilute and break up the debris. The debris then overflows the internal volume into the hopper and is pumped into the test tank through a distribution manifold.

The test tank is about 14 ft long, 6 ft wide and 6 ft deep. The tank is wider at the end distant from the strainer where the debris is introduced and significant stirring energy is added to the fluid. The walls of the tank narrow as the strainer is approached. The walls surrounding the strainer on 3 sides form a rectangular area with spacing between the walls and strainer module intended to model the distance between strainer modules as installed in the plant. Between the high-turbulence area and the strainer is a perforated plate on the bottom of the tank through which most (about 90%) of the total flow through the strainer is introduced. This feature is designed to add sufficient turbulence to minimize any settling of debris in the tank. See Figure 1 for the test tank arrangement. Note that the drawing states that 75% of the flow is supplied to the low-agitation area, but according to the test personnel, for the Watts Bar test about 90% of the flow was supplied to the low-agitation area.

The draft test procedure and technical data were provided for review by the 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 Watts Bar. For the tests observed on this trip, the external heating loop was used to raise the temperature of the fluid to the desired temperature of about 120^{o}F prior to the initiation of each test. Alden Labs 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."

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

The test tank contained a single Performance Contracting Inc. (PCI) strainer module 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 walls of the tank (Photo 1). Watts Bar has a single large strainer array located in the basement of containment. The array is composed of 23 strainer modules. There are modules with two different areas due to some modules being taller than others. The total strainer area in the plant is about 4675 ft^2.

The test strainer module was typical of the PCI design which includes flow control to distribute flow more evenly among modules and within each module. The module was the same design as the modules installed at Watts Bar. The area of the test module was 216.5 ft^2, which represented about 4.838% of the total strainer area installed at Watts Bar considering 200 sq ft of sacrificial area. Flow in the plant is 19,100 gpm maximum and about 12,000 gpm maximum for the small break loss-of-coolant accident (SBLOCA) case. 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 staff arrived at Alden Labs at about 9:00 am on 7/12/10. The test team was meeting to discuss the overall test procedure and the various tests scheduled to be performed for Watts Bar. The staff observed the discussions and responded to questions from the test team.

Discussions with the Licensee and Test Personnel

Prior to the testing, the licensee, Areva, PCI, and Alden test personnel discussed details of the testing. It was determined that the clean strainer head loss (CSHL) test would be conducted at 700, 800, 924 (design), 1000, and 1100 gpm.

The fiber bypass test was to be conducted by adding 1/16 inch fibrous debris batches and waiting at least 3 pool turnovers prior to adding the next batch. Watts Bar has only about 1/32 inch of fibrous debris which comes from latent fiber. The additional fiber, added as Nukon for this test only, represents an equivalent amount of fiber that is contained in 3M Interam fire barrier material and Min-K insulation. All fiber is considered to be fine for this test (as well as other tests). Grab samples were scheduled to be taken each pool turnover. A pool turnover occurred about every 3.43 minutes at the design flow rate of 924 gpm.

The licensee stated that the thin-bed test for Watts Bar will contain the full debris load. This is due to the very low fibrous debris load at Watts Bar. Fibrous debris sources at Watts Bar are mostly latent fiber. However, both Min-K and Interam materials contain some fibrous constituents, though these materials are generally considered particulate debris types. Watts Bar assumed that there is 30 lb of latent fiber in containment. This equates to a theoretical debris bed of slightly more than 1/32 inch. The debris will be batched into the test facility using the thin-bed addition sequence. The Min-K and Interam will be batched into the test tank after all other particulate surrogates have been added. If the thin bed test results in an acceptable result, it may also be credited for the full-load test. The staff agreed that the batched thin bed test debris addition sequence results in more conservative results than a homogeneous full-load test debris addition sequence and that use of the thin bed results would be acceptable as the full load results for Watts Bar since the fibrous load is very low.

Because Watts Bar strainers are potentially not fully submerged during a SBLOCA, the SBLOCA (low water level) condition needed to be evaluated. The test plan included a placeholder for performing a SBLOCA test. The SBLOCA case has about 25% of the debris of the full load case, and the required flow is about 2/3 of the large-break case. However, if the flow and water level can be reduced to the SBLOCA values following a test that contains the full debris load and acceptable results are obtained, no separate test would be required. The staff agreed that reduction of the flow and water level following a full-load test would provide a conservative evaluation of the SBLOCA condition.

Test Performance

Clean Strainer Head Loss

The CSHL test is run to determine how much head loss is attributed to the clean strainer and the test facility piping. This CSHL loss is subtracted from the debris head losses determined in later tests. The CSHL test was initiated at about noon on 7/12/10. The CSHL in the test facility at the design flow rate was about 4.3 ft. The CSHL test was run at about 130 ^{o}F. The CSHL in the plant is determined via a calculation. The calculated plant CSHL is added to the tested debris head loss for evaluation of various plant scenarios. The calculated CSHL is about 3.6 ft at Watts Bar.

Fibrous Debris Bypass Test

The fibrous debris bypass test is run to determine the amount of fibrous debris that may bypass the strainer and be transported to downstream components including the fuel within the core. The amount of bypass is used to evaluate the potential effects on the downstream components. The fibrous debris bypass test was run immediately following the CSHL test and started at about 2:30 pm on 7/12/10. Fibrous debris was added to the test via the debris addition system. Prior to addition, the fiber batches were placed into 32-gallon trash cans and were diluted with about 16 gallons (½ trash can full) of water. The fiber was then mixed with the water using a drill-driven mixer. The resulting fibrous debris contained some small clumps (photo 2). After being diluted further by the hopper system and pumped to the test tank, the debris was fine with no clumps. (See photos 3 and 4.) The debris as it reached the test tank consisted of single fiber strands and entanglements of several fibers. The staff considered all of the fibrous debris to be easily transportable.

There were five additions of 2.7 lb representing 1/16 inch theoretical fiber beds and one addition of 2.0 lbs representing the remainder of the available fiber. All fiber was considered fine. As discussed above the majority of the fiber represented sources that are constituents of Min-K and 3M Interam. Based on an inspection of the debris, the staff did not believe that the Interam would likely become a significant source of debris if subjected to a LOCA jet because it is relatively robust and covered with a thin steel sheet. However, the Min-K would be more likely to become debris. The amount of fibrous debris used in the debris bypass test was likely conservative because it included the full amount of fibrous debris from the Min-K and Interam, but some amount of these fiber sources would likely not be liberated. Photo 5 shows the test tank with some fibrous debris floating on the water surface during the fiber bypass test.

The flow rate was scaled to the maximum plant ECCS flow rate, and the introduction rate was slow enough to allow relatively prototypical penetration through the strainer. The staff has noted that debris introduction rate can affect the amount of debris that bypasses the strainer, with slower introduction rates resulting in higher bypass. Each debris batch was separated by at least three pool turnovers, and a sample was taken every pool turnover. The amount of debris contained in each sample will be used to quantify the amount of debris that may bypass the strainer and the behavior of the bypass over time. The samples had not been evaluated at the time this trip report was written.

The staff left the test facility prior to drain down of the test tank, but test personnel reported that there was no debris settlement during the test and the strainer had a relatively uniform fluffy bed. The floating fibrous debris was skimmed off of the surface prior to drain down so that conditions in the tank and strainer could be better evaluated. Photographs of the test tank were taken following drain down which validated that little or no settling had occurred and that the debris bed on the strainer was relatively uniform. The head loss did not increase during the fiber bypass test.

Thin-Bed Test

The thin bed test is 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. For Watts Bar, the thin bed test debris load and full load test debris load are the same due to the plant's low fibrous debris amount as described above.

Debris additions for the thin bed test began at about 12:30 pm on 7/13/10. The water was at about 121 ^{o}F, and the water level was about 4 inches below the design submergence level. The level was expected to increase due to the addition of the debris slurries. Clean head loss was about 4.1 to 4.2 ft. Flow was at the design scaled flow rate of 924 gpm.

The debris addition schedule is below. All debris was added through the hopper except for the dirt-dust mixture because it causes damage to the debris introduction pump. A minimum of 3 turnovers was allowed between batches with bypass samples taken every turnover for three turnovers after each debris addition. Head loss was also allowed to stabilize after each debris addition, if required.

Batch 1 – Acrylic Paint – 61.5 lb
Batch 2 – Dirt Dust – 8.3 lb
Batch 3 – Tin Powder – 61.8 lb
Batch 4 through 6 – Min-K – 35.9 lb total
Batch 7 and 8 – Interam - 33 lb total
Batch 9 – Fine Nukon Fiber – 1.5 lb
Batches 10 through 13 – Aluminum Oxyhydroxide – 1.54 lb total (added in dilute form)

When the acrylic paint dust was added at about 12:25 pm there was not significant foaming as had been observed during some earlier tests using a similar debris surrogate. The dirt-dust surrogate was added at about 12:40 pm. It was sprinkled into the tank near the agitators. The tin powder was added at about 1:05 pm. There was no appreciable change in head loss due to the addition of the particulate debris.

The particulate debris, with the exception of the dirt-dust mixture, was placed in trash cans, mixed with water, and poured into the hopper. The addition process ensured that the debris was well mixed throughout the test fluid. The Min-K was also placed in trash cans with water and mixed with a drill driven stirrer. There were coarse strings apparent in the mixture. It was also noted that some of the strings tangled in the mixer during its use (Photo 6). The strings were removed from the mixer and added back into the trash can before spilling it into the hopper. Some of the Min-K at the end of the pour was somewhat clumpy when it came out of the trash can, but the agitation in the hopper broke it up into fine particulate. The Interam was mixed similarly to the Min-K. Both the Min-K and Interam debris were created starting with the actual materials and rendering them into fine particles.

The Min-K addition was commenced at about 1:30 pm. The first addition resulted in the head loss increasing about 2.7 ft. The staff discussed the potential for thin bed formation with the test personnel. It was determined that another addition of Min-K should be made and the head loss response evaluated. The second Min-K addition resulted in a head loss increase of over 2 ft, so the third and final Min-K addition was made at about 3:40 pm. This addition resulted in a similar increase in head loss. After all Min-K was added, the total head loss was about 12 ft, with a clean strainer contribution of about 4.2 ft. Therefore, the debris head loss was about 7.8 ft.

Because head loss was much higher than anticipated for this point in the test, the test personnel met to discuss how to proceed with testing. The licensee determined that the test should be continued to determine the effects of the Interam. The licensee also discussed reducing or eliminating the Min-K source term in the plant and stated that the Min-K was jacketed and banded at relatively small intervals. The current ZOI for the Min-K is 28.6 D, which agrees with the guidance in the staff SE on NEI 04-07. The licensee considered that the ZOI as installed within the Watts Bar containment may be smaller than 28.6 D. The Min-K is installed on relatively small lines that pass within close proximity to electrical cables and is installed in several locations within containment. According to the licensee, the Min-K is jacketed and banded at relatively small intervals. The licensee will consider replacing the Min-K with an alternate material.

The test team discussed whether the current test could be used as a thin bed test and felt that it was likely, but some of the debris had not been added yet. The staff agreed that the test was still valid as a thin bed test and could potentially be used as a full load test. It was noted that the head loss behavior of the Interam material was not well known and that it could act as a particulate. Therefore, the impact of the Interam on the test would have to be considered when determining whether the test could be considered a full load test.

When the first batch of Interam was added at about 5:20 pm head loss increased to about 14 ft. The second addition of Interam at about 5:55 pm resulted in a total head loss of about 14.8 ft.

After the Interam batches were complete, the test team again discussed next steps. The licensee was interested in how much time was left for testing and how many more tests could be completed based on various potential test scenarios. The licensee was interested in the need to perform a SBLOCA test at a level below the top of the strainer. The staff explained that once a strainer becomes partially uncovered or vented, the driving head across the strainer may be decreased and the volume downstream of the strainer may become starved of fluid. The licensee stated that only the tall strainer modules are partially uncovered and that the SBLOCA debris loads are about 25% of the LBLOCA loads. The staff responded that the evaluation of such a configuration would be complex if credit were to be taken for some covered and some uncovered modules. The licensee determined that it was likely that the SBLOCA flood level could be reevaluated to show that all modules are fully covered due to ice melt that was not previously credited.

Test personnel had to stop one of the agitators in the tank, likely due to foreign material interfering with its operation. The agitation in the tank appeared to be adequate, even with one agitator secured.

At about 6:40 pm the batch of Nukon fine fiber was added to the test. Head loss increased to about 16 ft. The staff left the test facility after the final non-chemical debris was added to the test.

Test personnel cleaned out the debris addition hopper, pump, and hoses to collect any debris that was trapped in the debris addition system. This debris was added to the test tank. Head loss fluctuated between 16 and 17 ft, likely due to pump issues. The pump tripped and was restarted several times after all of the non-chemical debris had been added.

Based on a review of the test log and discussions with test personnel, chemical debris was added in four batches beginning at about 9:35 pm and ending at about 10:15 pm. There was no effect on head loss due to the chemicals. The total chemical load for the test was 1.54 lbs.

The differential pressure transmitter sensing lines were vented, and the head loss increased to about 18 to 19 ft.

Flow was reduced to about 565 gpm at 11:10 pm and head loss decreased to about 11 ft.

Test personnel reported that when the tank was drained down that there was very little debris on the floor. The only noticeable debris was metallic particles from the Interam fire barrier material.

Pieces of the debris bed were saved for observation (Photos 7, 8, and 9). The bed was about ¼ inch thick and very dense. The bed behaved like relatively dry clay. Very fine fiber was evident in the bed, as was the coating particulate and larger particulate from the Interam. The fibers mostly appeared to be finer than Nukon. The bed was very uniform.

The staff held an informal exit meeting with the licensee and test personnel and made the following observations about the testing. The staff stated that the debris preparation prior to pouring into the hopper and debris addition system was somewhat clumpy and agglomerated. However, the debris addition system was effective in rendering the debris into fine unagglomerated pieces. The final debris forms were determined to be acceptable. The staff noted that the agitation and transport within the tank appeared to inhibit settling and that almost all debris transported to the strainer. The debris bed did not appear to be affected by the agitation. The staff stated that the venting of the transmitter that resulted in an increase in head loss indication should be investigated and that test practices may need to be changed to include periodic venting of the transmitters to reduce uncertainties during the testing. The staff noted that the treatment of Min-K and Interam as fibrous debris was likely conservative and that the high head losses resulting from Min-K were unexpected. It was noted that the NRC Division of Component Integrity had been consulted and had confirmed that a settled volume of 6 ml was the correct one-hour settling criteria for aluminum oxyhydroxide for stirred tests per the SE for WCAP-16530. The staff stated that overall the test methods appeared to result in a conservative head loss for the Watts Bar plant. The staff stated that they appreciated the opportunity to witness the testing.

<u>Test Results</u>

The test results and physical observations are summarized as follows.

The clean strainer head loss was measured to be about 4.3 ft for the test strainer at 130 ^{o}F.

The results of the fiber bypass test were not available because the samples taken during the test were not evaluated at the time that this report was written.

The water temperature at the start of the thin bed test was 120 ^{o}F. The temperature decreased slightly during the test due to the addition of colder water with the debris.

The head loss associated with the full debris load including chemicals was reported to be about 19 ft. The debris bed appeared to be a thin bed.

The licensee planned to perform at least one additional test to determine a plant configuration that ensures adequate strainer performance. The results of the additional testing had not been reported to the staff at the time that this report was written.

Observations

The 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. The testing was conducted in a facility that did not credit near-field settling so issues with lack of debris transport were not a concern. This is a change in philosophy for testing conducted on PCI strainers at Alden Labs.
2) The debris preparation methodology used a new technique. Although the manual preparation of debris in large buckets resulted in clumpy, agglomerated debris, the use of a debris addition system to further dilute and agitate the debris was adequate to ensure that the debris was rendered into fine pieces prior to being introduced into the test tank.
3) A significant head loss occurred with no debris that is considered fibrous added to the test tank. The majority of the head loss was due to Min-K which has previously been considered to be a particulate debris type. Min-K contains significant amounts of fiber that apparently provide a fibrous bed for particulates to be filtered on.
4) The addition of chemical debris resulted in no effect on head loss.

Summary

The staff observed chemical effects testing conducted for Watts Bar by PCI, Alden Labs, and Areva 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 debris load and all of the chemical debris resulted in a filtering bed and significant head losses. The maximum head loss attained was about 19 ft. At the conclusion of the staff visit, the licensee planned to continue testing to attempt to determine a plant configuration that minimizes head loss across the strainer. The testing observed by the staff indicated that Min-K and particulate debris can produce a thin bed resulting in a high pressure drop across a sump strainer. The staff will continue to engage various licensees and vendors as sump strainer testing progresses. The staff expects these tests will provide a better understanding of plant-specific debris and chemical effects head losses.

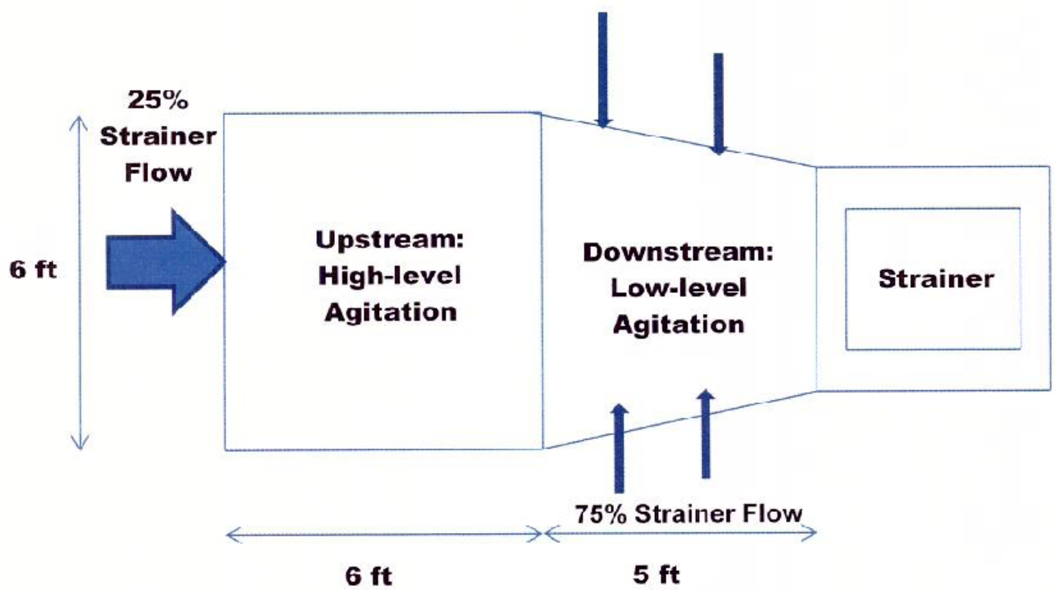

Figure 1 – Test Tank Arrangement

Photo 1-Strainer in Tank

Photo 2-Debris Pour into Hopper

Photo 3-Debris from Hopper

Photo 4-Debris from Hopper

Photo 5-Fiber on Surface of Tank

Photo 6-Min-K Coarse Fiber

Photo 7-Debris Bed

Photo 8-Debris Bed

Photo 9-Debris Bed Cross Section