Dominion Nuclear Connecticut, Inc.
Millstone Power Station
Rope Ferry Road
Waterford, CT 06385

DEC 2 0 2010

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555

Serial No.	10-713
NSSL/WEB	R0
Docket No.	50-423
License No.	NPF-49

DOMINION NUCLEAR CONNECTICUT, INC. MILLSTONE POWER STATION UNIT 3 REMAINING RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION REGARDING GENERIC LETTER (GL) 2004-02

In letters dated March 4, September 1 and November 29, 2005, November 15, 2007, February 29 and December 18, 2008, and July 8, 2010, Dominion Nuclear Connecticut, Inc. (DNC) submitted information in response to GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," for Millstone Power Station Units 2 and 3 (MPS2 and MPS3).

In a letter dated December 17, 2008, the Nuclear Regulatory Commission (NRC) transmitted a request for additional information (RAI) regarding GL 2004-02. Responses to RAI questions for both units were provided to the NRC in a letter dated March 13, 2009.

On February 4, 2010, the NRC issued a second RAI to DNC. Based on review of the RAI responses from the March 13, 2009 letter, the NRC concluded that additional information was needed to assess whether there is reasonable assurance that GL 2004-02 has been satisfactorily addressed at MPS2 and MPS3. The DNC response for MPS2 was provided to the NRC in a letter dated July 8, 2010. The DNC response for MPS3, with the exception of RAI 6 (specifically, items 3, 4, and 6), was provided to the NRC in a letter dated September 16, 2010. This letter contains the remaining RAI responses for MPS3.

A116
NRR

Should you have any questions in regard to this submittal, please contact Wanda Craft at 804-273-4687.

Sincerely,

J. Alan Price
Vice President – Nuclear Engineering
Dominion Nuclear Connecticut, Inc.

STATE OF CONNECTICUT)
)
COUNTY OF NEW LONDON)

The foregoing document was acknowledged before me, in and for the County and Commonwealth aforesaid, today by J. Alan Price, who is Vice President – Nuclear Engineering of Dominion Nuclear Connecticut, Inc. He has affirmed before me that he is duly authorized to execute and file the foregoing document in behalf of that company, and that the statements in the document are true to the best of his knowledge and belief.

Acknowledged before me this 20 day of December 2010.

My Commission Expires: March 31, 2011

WM. E. BROWN
NOTARY PUBLIC
MY COMMISSION EXPIRES MAR. 31, 2011

Notary Public

Commitments made in this letter: None

Attachment:

Millstone Power Station Unit 3, Remaining Response to Request for Additional Information Regarding Generic Letter 2004-02.

cc: U. S. Nuclear Regulatory Commission
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NRC Senior Resident Inspector
Millstone Power Station

ATTACHMENT

MILLSTONE POWER STATION UNIT 3 REMAINING RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION REGARDING GENERIC LETTER 2004-02

DOMINION NUCLEAR CONNECTICUT, INC.
MILLSTONE POWER STATION UNIT 3

MPS3 RAI 6

NRC letter dated December 17, 2008, Request for Additional Information, (ADAMS ML083230469) RAI 6 states, "The staff has been interacting with AECL and Dominion Energy Kewaunee, Inc. Dominion Nuclear Connecticut, Inc. and Virginia Electric and Power Company (collectively Dominion) regarding the current ongoing chemical effects testing for MPS3 and the other Dominion nuclear sites (RIG-89), which starts with a complete non-chemically laden debris bed of fibers and particulates. The NRC staff has noted that the non-chemical head losses (head loss prior to chemical additions) in the current chemical effects tests are significantly lower than for the similarly scaled debris loads in the previous non-chemical large scale and reduced scale tests. Please provide a comparison of the non-chemical head losses determined during the previous large-and-reduced-scale testing to the non-chemical head looses obtained during the current chemical effects testing. Please provide justification for the final chemically laden head loss number used in the strainer evaluation considering that previous non-chemical head losses were significantly higher than the non-chemical head losses determined in association with the recent chemical testing.

RAI 6 Response for Additional Information

The differences in debris-only head loss testing results for the two different test rigs (Rig 33 and Rig 89) were reviewed during the North Anna Chemical Effects Audit performed by the NRC staff in 2008 (Reference North Anna Power Station Audit Report dated February 10, 2009, ADAMS ML090410626). The NRC staff ultimately concluded that, although the reasons for differences in head loss for the two test rigs for North Anna Power Station could not be definitively identified, the significant conservatisms incorporated into the sump strainer performance analysis bound the uncertainties associated with the different test results. A similar case can be made for the MPS3 sump strainer performance. A discussion of the margins and conservatisms associated with the MPS3 sump strainer performance analysis were previously provided in Section 1.C of Attachment 2 of the Millstone Power Station Units 2 and 3 updated supplemental response dated December 18, 2008 (ADAMS ML083650005) which describes the extensive plant conservatisms associated with the design of the MPS3 containment sump strainer. Additional conservatisms were discussed in Section 1.C of the Millstone Power Station Units 2 and 3 supplemental response dated February 29, 2008 (ADAMS ML080650561). An update to these discussions is provided below. The margins and conservatisms described and quantified below support a holistic argument for the acceptability of the strainer installed at MPS3 in light of differences in the Rig 89 and Rig 33 non-chemical head loss results. The conservatisms and margins outweigh the uncertainties introduced by the differences in head loss test results and provide assurance of successful long-term decay heat removal following a design basis Loss of Coolant Accident (LOCA). This discussion is followed by responses to RAI 6 Items 3, 4, and 6 which have not been previously answered.

Conservatisms

- A 5D (5 times pipe diameter) Zone of Influence (ZOI) was used for qualified epoxy coating particulate resulting in a total generation and transport of 10.4 ft^3 of qualified coating particulate to the strainer (ref: CCN 2 to Rev 1 of Calculation GSI-191-ECCS-04149M3). Based on the April 6' 2010 NRC to NEI Letter (ADAMS ML100960495), a 4D ZOI is acceptable for qualified epoxy coatings. Use of a 4D ZOI would result in only 8.0 ft^3 of qualified coating particulate (reference: CCN 1 to Rev. 0 of calculation GSI-191-ECCS-04149M3). Thus, the strainer testing used 23% more (2.4 ft^3) qualified coating particulate than what is expected to occur in containment due to use of the more conservative 5D ZOI for qualified coating.
- A 10% margin was added to the coatings particulate debris quantities generated from the zone of influence (ZOI) and from unqualified coatings (a total of 2.1 ft^3 of coatings margin). Reduction of coating debris, which is all modeled as particulate, would result in a reduction in thin-bed head loss.
- The above two conservatisms result in a total excess of 4.5 ft^3 of coating over what is expected to occur on the strainer in containment. The total particulate coating load on the strainer was calculated to be 23 ft^3. A reduction of 4.5 ft^3 is equivalent to a 20% reduction in coating particulate which would result in a reduction in strainer head loss for a thin-bed from the tested values.
- All unqualified coating was deemed to fail immediately as transportable particulate. This is particularly conservative since unqualified coating makes up 45% of the total tested coating load and 34% of the total particulate load on the strainer. Electric Power Research Institute (EPRI) testing (Reference EPRI Technical Report 1011753 dated September 2005) has shown that less than one-third of unqualified coatings actually failed when subjected to design basis accident (DBA) testing.
- 5% margin was added to the fibrous debris quantities generated from the ZOI (a total of over 60 ft^3 of fiber margin).
- 5% margin was added to the microtherm debris quantity generated from the ZOI (a total of 0.1 ft^3 of microtherm margin).
- In both Rig 33 and Rig 89 testing, all fibrous debris was conservatively prepared as "single fine".
- 100% debris transport was assumed for coatings, microtherm, and latent debris.
- A sacrificial strainer area of 655 ft^2 was installed for MPS3.
- The effective installed strainer area (4544 ft^2) exceeds the tested strainer area (4290 ft^2). The effective installed strainer area does not include the 655 ft^2 of sacrificial area which is also installed in containment. The total strainer area installed is approximately 5200 ft^2.
- Debris load refinements after the Rig 33 testing was completed (and before the Rig 89 test) led to a reduction of about 10% in total particulate which would lead to a reduction of thin-bed head loss.

Non Chemical Testing

Multiple reduced-scale thin-bed tests were conducted in Rig 33 to determine the strainer surface area required for MPS3. Of these tests, two were considered usable for strainer sizing. They are designated as tests M3-2 and M3-16. The peak head loss from these tests, which is higher than the stable, steady-state head loss, is 5.1 psi. Additional tests using the same test module scaled area of 4290 ft^2 were also run in Rig 33. However, the head losses seen in these tests were judged to not be representative of the plant and thus were not used for strainer sizing. Nevertheless, as part of this evaluation, the highest peak head loss from all of the Rig 33 tests (7.8 psi at 104°F) is used (later in this discussion) to show positive margin for Net Positive Suction Head (NPSH) and flashing in even the most extreme case.

Chemical Testing

Rig 89 was designed and built to investigate the influence of chemical precipitates on the debris bed head loss. One test was planned and completed in Rig 89 for MPS3. Prior to the addition of chemicals, the debris bed head loss (0.43 psi) was lower than the Rig 33 head loss with a similar debris bed. After the addition of chemicals, the peak head loss in Rig 89 (2.2 psi) increased approximately 5 times over the non-chemical debris bed head loss, though it remained below the peak Rig 33 result. A detailed analysis report has been prepared to evaluate the different results observed for the non-chemical debris bed head loss tests performed in Rigs 33 and 89. The evaluation focused on the test rig configurations, flow patterns, debris compositions and quantities, debris preparation, air bubble generation, chemical environment, and debris bed formation. Atomic Energy of Canada Limited (AECL) and DNC conclude the Rig 89 test results provide conservative evidence to verify the installed strainer for each unit will function under short-term and long-term design conditions. Rig 89 tests incorporate lessons learned from the earlier Rig 33 testing, such as biological growth, testing fluid impurity, and non-prototypical strainer submergence. Consequently, Rig 89 provides more accurate results.

Aluminum was added to the Rig 89 test to achieve the expected containment concentration of approximately 2 ppm. This low concentration is not expected to add significant chemical precipitant to the debris bed. However, due to head loss increases seen in the Rig 89 testing when aluminum was added, aluminum is considered to have an impact. For the margins presented below, the aluminum is considered to contribute to head loss beginning 12 hours post-LOCA when the sump water temperature is a maximum of 160°F. This is a conservative temperature at which to assume aluminum precipitation occurs in light of the bench-top testing done for MPS3 at AECL. This testing showed that no aluminum precipitated in tests which were run for 30 days at 150°F and at room temperature, both at a pH of 7. Additionally, Argonne National Laboratory (ANL) testing (Technical Letter Report on Evaluation of Long-term Aluminum Solubility in Borated Water Following a LOCA, February 25, 2008, C.B. Bahn, et al) reports that with an aluminum concentration of 40 ppm (much higher than the expected 2 ppm in the MPS3 containment), aluminum precipitation was not observed at a pH of 7.5 (lower than the long-term pH expected in the MPS3 containment), until the test temperature was lowered to 120°F. Both the AECL and ANL tests used sodium aluminate which readily contributes aluminum to solution whereas aluminum in the MPS3 containment is obtained primarily by corrosion of aluminum components. The time of 12 hours assumed for precipitation and transport to the strainer of aluminum precipitates is conservative since corrosion of aluminum is not expected to produce significant precipitate until well after 12 hours post-LOCA.

One preliminary test was conducted in Rig 33 to determine the impact of chemical precipitants while Rig 89 was under construction. The results of this test are not credited in the design of the MPS3 strainer but are included for the purposes of the margin discussion. The Rig 33 chemical effects test had an identical debris bed formation to the non-chemical Rig 33 tests and to the subsequent Rig 89 test. Head loss peaks occurred during the formation of the non-chemical debris bed similar to other Rig 33 tests. The highest peak during the formation of the non-chemical head loss was 6.8 psi. The flowrate in this test was lowered by half following the formation of the non-chemical debris bed to avoid air evolution. Sodium aluminate was added to the test tank over a 7-hour period after formation of the non-chemical debris bed. No head loss impact was observed. Following this, calcium chloride was added to the test tank. The first calcium addition created a peak head loss of 7.2 psi two hours after the addition. This was the highest peak in the test and could have been produced by the formation of calcium phosphate precipitant. Subsequent calcium additions also produced head loss peaks, though each one was lower than the last. The second calcium addition produced a peak of 6.7 psi and the third produced a peak of 5.6 psi. With each of these calcium additions, sufficient aluminum, Trisodium Phosphate (TSP), and boron were added to make up for dilution. The head loss continued to gradually decrease. After the sixth calcium addition, the head loss was 2.3 psi. Flow was returned to full flow upon completion of chemical additions. This flow rate variation renders the final head loss result of the test suspect, due to the non-protypical nature of the test. The final head loss in this test (after addition of all chemicals) was approximately 3.8 psi which is somewhat higher than the peak head loss (2.2 psi) seen in the Rig 89 chemical effects test.

In the Rig 33 chemical test, a head loss peak occurred immediately following the first few calcium additions. These peaks are not a concern for the MPS3 containment, due to the non-protypical nature of the test. The only sources of calcium for the debris bed are calcium leached from degraded concrete or from dislodged fibrous insulation. There is no calcium silicate in the MPS3 debris load and there is no significant source of calcium in the MPS3 containment. Bench-top testing to determine the amount of calcium to use in the chemical effects tests included several significant conservatisms. These tests used a scaled amount of bare concrete which included concrete stripped by the break jet and bare concrete margin for degraded coating. By design, there is no bare concrete in the containment. Bench-top tests were run at a pH of 7 which has higher concrete dissolution than the containment sump water which is expected to be above pH 8. Bench-top tests were run without TSP in the water to maximize the amount of calcium produced. Identical tests run with TSP showed virtually no calcium dissolution in the presence of the same amounts of bare concrete and fiber. Based on these factors, only insignificant amounts of free calcium are expected in containment and formation of calcium phosphate will be negligible. Additional details on these conservatisms are included in the MPS3 response to RAI 16 in DNC letter dated September 16, 2010, Serial No. 10-509. (ADAMS Accession No. ML102640210)

Timing of Debris Bed Formation

Debris bed formation is expected to take at least 6 hours post-LOCA. This is supported by test data from both Rig 33 and Rig 89 tests as well as large scale testing done in Rig 85. Thin bed formation in Rig 89 took approximately 6 hours and in Rig 33 thin bed formation took approximately 24 hours. Thin-bed formation was intended to achieve the highest head loss and so debris additions were widely spaced. This careful fiber addition required a long time for debris bed buildup. Tests were also run in both Rig 33 and Rig 85 to determine the head loss using the full debris load. These tests provide more representative information regarding time for debris bed buildup than the thin-bed tests. In Rig 33, the full debris load tests showed an overall rate of increase less than 1 psi over 12 hours or 0.08 psi/hr. In Rig 85, debris for the full debris load test was added in four increments over a three-hour period. Approximately 36 hours is required to reach the final head loss (1.13 psi) and approximately 2 hours was required to reach 0.4 psi. The containment water level rise following Recirculation Spray System (RSS) pump start is approximately 2 ft/hour. Test tank water turnover for Rig 85 was approximately 10 minutes. Turnover time in containment is a minimum of 48 minutes, indicating a longer time to build a debris bed in containment versus the test rig. Also debris in the test tank was added adjacent to the strainer minimizing transport time. Thus the debris bed formation will lag the increase in containment water level and the positive margins at RSS pump effective time (shown in Table 2 below) will increase as the debris bed is forming.

NPSH/Flashing Margin

The evaluation presented here summarizes the NPSH and flashing margins for the strainer. These margins are listed in Table 2. The margins at RSS effective time (1-2 minutes after RSS pump start) assume a clean strainer, saturated water, and minimum water level. The margins at Refueling Water Storage Tank Empty "(RWST) Empty" and beyond include the maximum non-chemical debris bed head loss seen in Rig 33 (which is higher than the peak head loss in Rig 89), minimum sump water subcooling, and submergence from the remainder of the RWST water. These margins ensure that the strainer design is sufficient to ensure long-term recirculation despite the difference in head loss between the Rig 33 and Rig 89 tests.

Table 1 below compares the strainer debris head loss test results from the credited Rigs 33 and 89 tests. Tests listed in Table 1 used a test module scaled area of 4290 ft^2. The maximum debris bed head loss (5.1 psid at 104°F) from credited Rig 33/89 tests is corrected for the viscosity difference between the test temperature and the applicable temperature for use in Table 2 which quantifies NPSH and flashing margins

Table 1: MPS3 Rig 33 and Rig 89 Strainer Test Results

Rig 33 Record Test Non-Chemical Debris Head Loss (psid) at 104°F	Rig 33 Non protypical test Non Chemical Debris Head Loss (psid) at 104°F	Rig 33 Non Protypical test Head Loss with Chemical Effects (psid) at 104°F	Rig 89 Head Loss with Chemical Effects (psid) at 104°F
5.1 (Test M3-2)	7.8 (Test M3-6)	6.8 (Rig 33 Chemical Test)	2.2 (Test M3-C1)

For MPS3, the four RSS pumps are the recirculation pumps for containment. They start on a RWST level signal when the RWST is approximately half full. The minimum water level in containment on pump start covers the strainer. Quench spray (QSS) pumps continue to pump the remaining volume of the RWST into containment over approximately 3 hours after RSS pump start. Thus the water level in containment is continuously rising for approximately 3 hours following RSS pump start. The final resulting minimum water level is approximately 5 ft above the top of the strainer.

The point for "RWST empty" in Table 2 below is calculated for the time when the QSS pumps stop, when the non-chemical debris bed is conservatively considered to be fully formed, a minimum of approximately 5 ft of additional submergence is on top of the strainer due to RWST water addition, and a minimum of sump water cooling has occurred. The temperature used for the calculation of subcooling margin at "RWST empty" (182°F) is the maximum temperature of the sump water for any large break accident case when the minimum available volume of the RWST has been pumped to containment. The initial temperature for this calculation of subcooling (195°F) is the saturation temperature for the minimum pressure in containment (10.4 psia). For 12-hours post-LOCA the maximum sump water temperature is 160°F, for 24-hours post-LOCA, the maximum sump water temperature is 120°F, and for 30 days the maximum temperature is 100°F.

Table 2: Limiting Margin Summary Using Maximum Credited Rig 33 Test Head Loss of 5.1 psi

Margins	RSS Effective Time (ft H_2O)[1]	RWST Empty (ft H_20)[2,3]	12 hours post-LOCA (ft H_2O)[3]	24 hours post-LOCA (ft H_2O)[3]	30 days post-LOCA (ft H_2O)[3]
NPSH	18.5	23	29.3	32.2	33.2
Strainer Flashing	0.6	4.8	10.4	13.4	14.4
Suction Line Flashing	4.4	9.3	14.9	17.9	18.9

1. RSS pump effective time is the time of minimum sump water level; sump water subcooling is not credited.
2. RWST empty is the time of QSS pump stop (no more water from RWST pumped to containment) and is nominally 3 hours post-LOCA.
3. Margins include maximum credited debris bed head loss from Rig 33 and include credit for sump water subcooling.

Margins include maximum non-chemical debris bed head loss from Rig 33 and include credit for sump water subcooling. Maximum tested chemical effects debris bed head loss from the Rig 89 testing (1.8 psid at 104°F) converts to 4.3 ft of water with no correction for lower viscosity at higher temperatures.

As an additional measure of positive margins, Rig 33 chemical and non-chemical tests for MPS3 were reviewed to determine the peak head loss. This peak head loss was 7.8 psi at 104°F and occurred in test M3-6 in Rig 33. This peak head loss exceeds peaks from the other Rig 33 tests and exceeds the maximum head loss peak seen in Rig 85 (large scale testing). The NUREG/CR-6224 predicted head loss for this debris load and strainer area is 4.4 psi. The high head loss peaks seen in the Rig 33 tests were not considered representative of containment due to suspected effects from air evolution, river water particulate and biological growth which are not prototypical of the MPS3 containment. The head loss peak of 7.8 psi is more than three times the peak head loss seen in the Rig 89 test which was designed and built to simulate the conditions in the MPS3 containment. The margins shown below include the head loss of 7.8 psi at 104°F at the "RWST Empty" and all later points. Table 3 below is the same as Table 2 above, except for the use of the non-protypical test with a head loss of 7.8 psi at 104°F.

Table 3: Limiting Margin Summary Using Rig 33 Head Loss of 7.8 psi

Margins	RSS Effective Time (ft H_2O)[1]	RWST Empty (ft H_20)[2,3]	12 hours post-LOCA (ft H_2O)[3]	24 hours post-LOCA (ft H_2O)[3]	30 days post-LOCA (ft H_2O)[3]
NPSH	18.5	19.6	25.4	27.7	27.0
Strainer Flashing	0.6	1.5	6.6	8.9	8.1
Suction Line Flashing	4.4	6.0	11.1	13.4	12.6

1. RSS pump effective time is the time of minimum sump water level.
2. RWST empty is the time of QSS pump stop (no more water from RWST pumped to containment) and is nominally 3 hours post-LOCA.
3. Margins include maximum non-protypical debris bed head loss from Rig 33 and include credit for sump water subcooling.

Strainer Structural Design

A debris suction load design pressure of 10 psi is used for the structural design of the strainer. The strainer stresses from the governing load combination of: debris suction load; safe shutdown seismic event; and dead weight are compared to the code allowed stresses, at the most limiting temperature, to determine acceptability of the strainer. This design pressure is not exceeded with the credited Rig 33 debris bed head loss of 5.1 psi or the highest head loss peak of 7.8 psi that occurred in the non-prototypical test, at the lowest design temperature for the strainer (100°F).

Summary

The conservatism and margins outweigh the uncertainties introduced by the differences in head loss test results and provide assurance of successful long-term decay heat removal following a design basis LOCA. In addition, the following specific responses are provided to the additional questions related to MPS3 RAI 6 posed in NRC letter dated February 4, 2010 (ADAMS Accession Number ML100070068).

Millstone Power Station Unit 3 (MPS3), Head Loss and Vortexing, RAI 6

Please provide the following additional information to document that the MPS3 strainer evaluation provides adequate assurance that it will perform as required under accident conditions:

MPS3 Head Loss and Vortexing RAI 6, Issue 3

The difference in head loss between the two test methods is about an order of magnitude. The differences in non-chemical head losses between the two types of tests were attributed to contaminants from the use of river water and to air evolution caused by non-prototypically low submergence during the reduced scale tests. It was stated that particulate and biological activity in the river water affected the head loss in the reduced scale testing. Please provide additional details on how the river water particulate and biological activity affected the head loss. Please address the following items:

a. *Provide an evaluation of the degree to which the particulate and biological growth from the river water affected the results of MPS3. It appears that the MPS3 tests were affected to a much greater degree than other AECL tests conducted under similar conditions. Please discuss the reason MPS3 was affected to a greater degree.*
b. *State whether any fiber-only tests were conducted using river water. If such tests were conducted, provide the head losses and other pertinent conditions for those tests.*
c. *Provide an evaluation of the strainer head loss resulting from the particulate that was contained in the river water. Compare the expected test result, when the particulate from the river water and the test debris particulate are present, with the result when only the test debris is considered. Provide the assumptions and the bases for the assumptions used in this evaluation.*
d. *Provide an evaluation of whether the reduced scale testing, which was used as an input for the Rig-89 qualification testing, provided valid input due to the non-prototypical biological growth and particulate from the river water.*

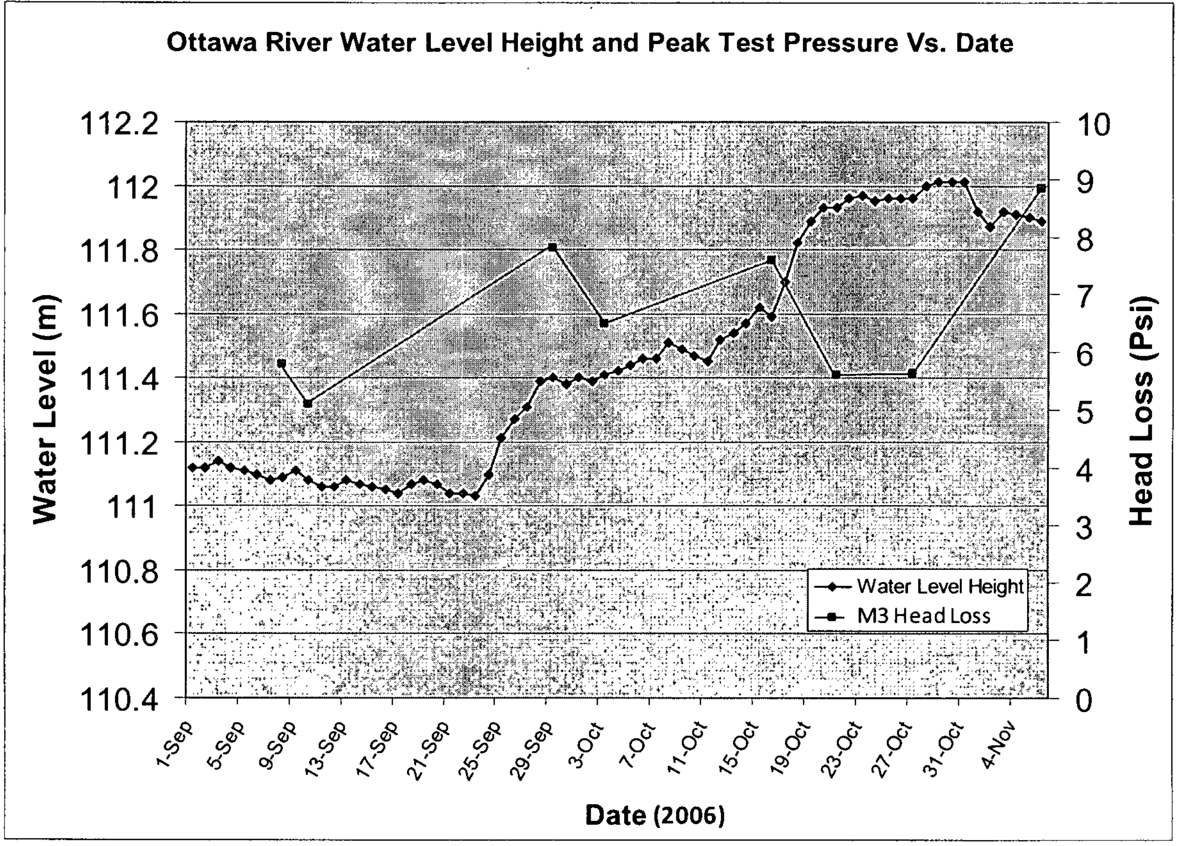
Response to MPS3 Head Loss and Vortexing RAI 6, Issue 3a

Ottawa River water was used in the Rig 33 tests, while distilled water was used in the Rig-89 test. Bacteria growth and the resulting "biological effects" were observed during Rig 33 testing for Surry in May 2006 [1] and for MPS3 in October 2006 [2]. For the affected tests, biological activity prevented head loss from stabilizing after the second fiber addition. Slime formation was believed to be the major mechanism for biological effects. River water particles also contributed to the higher head loss observed in those tests.

According to AECL report (AECL-1124) [3], seasonal slime formation in systems using water from the river has been a problem since 1946. Slime forming micro-organisms have the ability to grow rapidly under favorable environmental conditions. These organisms may be bacteria, fungi, algae or molds and the factors effecting their growth are temperature, pH, nutrients and concentration of electrolytes. These micro-organisms require a source of carbon for growth. (In the Rig 33 tests, walnut shell flour could be the ideal carbon source. The river water particulate could be another carbon source.). Also reported in the AECL Report 1124, a sample of the slime was sent to the National Aluminate Chemicals Company for microbiological identification. The report indicated that it consisted mainly of fungal filaments and "crystalline material". There were occasional bacteria and diatoms (Fragilaria) present.

The water level height of the Ottawa River could also affect the concentration of river particles and slime forming organisms. Higher water level resulted in higher peak head loss as shown in Figure 1.

Figure 1: Ottawa River Water Level High and Peak MPS3 Rig 33 Test Head Loss



Two different water treatment methods were used in MPS3 Rig 33 tests to inhibit biological effects before debris addition. The water treatment method shown to effectively inhibit biological effects observed in Surry testing conducted in late-May 2006 was used for Tests M3-1 to M3-10, which were conducted in September and October 2006. Nitric acid (5-molar) was added to the test water to decrease the water pH to a target value of 5.5 (range of 5.1 to 5.6 pH). The test water was then heated to test temperature. Once the water temperature was stable, sodium hydroxide was added to increase the water pH to a target value of 6.8 (range of 6.5 to 7.0 pH). After debris was added, there was no further biological control.

A more aggressive water treatment was developed in November 2006 following an apparent recurrence of biological effects in October 2006 that affected Tests M3-6 to M3-10. This treatment, consisting of a combination of chlorine additions, heating to a higher water temperature and water filtering, was used for Tests M3-14 and M3-16. Note that filtering was instituted to reduce the quantity of particulate in the test water, not to inhibit bacterial growth. With this treatment, sufficient chlorine was added to the test water to maintain the concentration above 10 ppm during subsequent heating and filtering, as concentrations of this magnitude have been shown to prevent bacterial growth. The water heat-up procedure was changed to heat the water to a higher temperature than used previously (136°F (58°C) versus 122°F (50°C)) before cooling to the test temperature, as water temperatures approaching 140°F (60°C) are sufficient to kill many types of bacteria. Bag type filters located on the discharge side of the pump were used to reduce the quantity of particulate in the water. (This particulate consisted of small quantities of silt and rust in the service water and residual walnut shell flour from the test section and/or piping system.) Two-stage filtering was employed: a 200-µm pore size bag filter was used for the first 10 hours of heat up, and a 10-µm pore size filter was used for the second 10 hours. Chlorine was not added to the test tank after the first debris addition. Three samples of AECL's service water were collected during the test program and analyzed for Total Suspended Solids (TSS). The levels of TSS are shown in Table 4 below.

Table 4: Total Suspended Solids in Service Water

Date	**Point in Test Program**	**TSS (mg/L)**	
		Standard	**Fine***
September 1, 2006	Prior to Program	0.2	n/a
October 13, 2006	Prior to Test M3-8	0.6	n/a
November 1, 2006	Prior to Test M3-14	1.2	3.0

** Note fine TSS measurements not made for samples taken prior to November 1, 2006.*
Standard TSS is measured by drawing the water sample through a 1.5-µm pore Misa filter. The fine TSS reported herein was measured by drawing the water sample through a special 0.1-µm pore filter.

Samples of the debris bed at the end of each test were analyzed for biological activity. This analysis is done using Biological Activity Reaction Tests (BART) for slime-forming (SLYM) and heterotrophic aerobic bacteria (HAB), followed by microbial growth on an agar media and cell counts. Analysis results are shown in Table 5. BART results are shown as positive (+) or negative (-) for microbial growth. Cell counts are shown as colony forming units per mL of water (CFU/mL).

Table 5: Biological Activity Analysis Results

Test	**Sample**	**SLYM**	**HAB**	**CFU/ml**
M3-2	#1	+	+	$4x10^6$
	#2	+	+	$3.7x10^7$
M3-16	#1	+	+	$2x10^7$
	#2	+	+	$2x10^7$

Note SLYM = slime-forming, HAB = heterotrophic aerobic, positive (+) or negative (-) for microbial growth, and CFU/ml = colony forming units per ml of water.

The analysis results show that bacteria were present in the debris bed at the end of Tests M3-2 and M3-16. Therefore, both water treatments did not entirely eliminate biological effects (the treatment method might not be effective for fungi and/or algae). It was postulated that both treatments inhibit the development of biological effects long enough to allow a test to be completed, with the aggressive treatment providing more time and/or being more effective.

Using the cell count results in Table 5, the total colony forming units in the Rig 33 test M3-16 test water would be 1×10^{14} ((2×10^7 /mL) x 5000 L), which is 5 times greater than the number of walnut shell particles (walnut shell particles: 2.0×10^{13}). The test tank volume is 5000 L. Average bacterial cell is 3 to 5-µm in diameter. In the test rig, bacteria growth affecting strainer function would form a bio-film on surfaces that may be one to a few hundred microns thick. It is assumed that each colony forming unit originated from one bacterial cell. The effects of the colony forming unit on the debris bed head loss would be significant, assuming all these colony forming units were separate spherical particles. The mass of each particle was calculated to be 3.3×10^{-11} g. The total mass of the slime particles would be 3.3 kg (7.3 lbm). In order to quantify the head loss influence from the slime particles, the NUREG/CR-6224 correlation was used. The calculation shows that the extra head loss increase from the slime particles could be as high as 1.2 psi.

For the river water particulate influence, an analogous comparison was performed as follows. The actual mass of suspended solids was calculated to be approximately 0.033 lb (3 mg/L × 5000 L). Assuming the increase on head loss from the river water particles were similar to that of Microtherm and the head loss influence was proportional to their mass, the head loss in Rig 33 test could be 0.06 psi higher (head loss impact of river particulate ≈ 4.3 psi × 0.033 lb/2.39 lb ≈0.06 psi). The head loss increase due to Microtherm addition was demonstrated in Test NA-2 [4], where 2.39 lb of Microtherm was added to the test after a bed was formed. The head loss increased immediately by 4.3 psi, to a value six times greater than prior to the Microtherm addition, and the test was aborted before head loss had reached a stable value. However it is not clear that river water particulate and Microtherm have equivalent impact on debris bed head loss. In any case, 0.06 psi is an insignificant head loss impact.

The reason that the MPS3 tests were affected to a much greater degree than other Rig 33 tests was because of the test environments and the air evolution influence. Test environments include the amount of walnut shell flour and slime forming organisms in the test water. Walnut shell flour could provide carbon to slime forming organisms as mentioned before and slime forming organisms concentrations in Ottawa River water fluctuated seasonally and were affected by the water level height. The water level height changed occasionally due to precipitation and/or discharge from the upstream hydro dam. MPS3 tests had the highest walnut shell flour load per unit strainer surface area among the tests conducted for Dominion. As the debris bed head loss exceeded a threshold value, in this case, the static head of water above the fin, air evolution occurred. In the MPS3 Rig 33 tests, air evolution was the dominant factor that contributed to the higher head loss as compared to other Rig 33 tests.

In summary, several factors collectively contributed to the non-chemical head loss differences between the Rig 89 test and the Rig 33 test for MPS3. These factors include:

- Less particulate debris in Rig 89 test than in Rig 33 test due to a refinement of post-LOCA debris load calculation (10% less),
- Distilled water was used in the Rig 89 test, while Ottawa River water was used in Rig 33 test,
- Biological growth in Rig 33 test due to the use of Ottawa River water, while no biological activity in Rig 89 test,
- Debris used in Rig 89 was autoclaved to eliminate biological growth in Rig 89. Rig 33 tests did not use autoclaved debris,
- Debris was conservatively maintained in suspension in Rig 33 in a turbulent flow outside the test section. The turbulent flow was caused by continuous stirring and return flow flushing, and,
- Large amount of air evolution in Rig 33 test, while no air evolution in Rig 89 test.

Response to MPS3 Head Loss and Vortexing RAI 6, Issue 3b

No fiber-only test was performed for MPS3, but a series of fiber-only bypass tests were performed for MPS2, North Anna and Surry. Fiber bypass tests were conducted to determine the quantity and characteristics of fibrous debris that passes through the strainer. The full fibrous debris load was used for these tests. No particulate debris was used. The fibrous debris was "washed" to remove dirt and dust from the fibers. Fibrous debris load was added to the test tank within 30 minutes of the start of the test. For each fiber bypass test, the same test preparation was followed as its corresponding thin-bed and full debris load tests in terms of test water, heating, water treatment and debris preparation. The fiber bypass tests were usually run for several hours because the head loss stabilized very quickly. The highest observed head loss occurred in Test M2-28. The head loss stabilized at 0.1 psi. No water treatment or pre-test water filtering was used for Test M2-28. For North Anna and Surry fiber bypass tests, the head loss was negligible. For example, in Test S2-42 (Surry RS fiber bypass test), the head loss stabilized at 0.034 psi. For Test NA-19 (North Anna RS fiber bypass test) the head loss stabilized at 0.02 psi. Water treatment and pre-test water filtering were used for both North Anna and Surry fiber bypass test. The high head loss observed in Test M2-28 may indicate that particulate from Ottawa River water and biological growth affected debris bed head loss.

Though some head loss effects were observed in Test M2-28, the phenomenon was not representative because the fiber-only debris bed was too porous to catch the minute river particles and the microscopic slime forming organisms. River water particles and slime forming organisms could cause a higher head loss if a more compact thin bed was formed.

Response to MPS3 Head Loss and Vortexing RAI 6, Issue 3c

No test results exist which directly examine the effect of the river water particulate in the absence of other variables. As briefly mentioned in response to RAI 6 Issue 3a, the river water particles could increase the head loss by 0.06 psi. The evaluation was based on the assumption that the minute river water particle would behave the same as that of the Microtherm particles on the debris bed head loss.

The calculated river water particulate mass for Test M3-16 is listed in Table 6. The mass of river particulate (0.03 lb) is insignificant and not expected to cause a measurable impact on head loss.

Table 6: Number of Particles

Test	TSS (fine) [mg/L]	Test Water Volume [L]	Total Mass of River Water Particulate [lb]
M3-16	3.0	5,000	3.3×10^{-2}

Response to MPS3 Head Loss and Vortexing RAI 6, Issue 3d

The impacts of river water particulate and biological effects on Rig 33 head loss results are relatively small.

The inputs that were taken from the Rig 33 tests were debris preparation and addition method for thin bed forming and the specific thin bed thickness. The debris preparation and addition sequence were accepted as conservative.

As shown in the additional information for RAI 6 above, use of Rig 33 test results for the maximum non-chemical head loss leaves adequate margin for pump NPSH, strainer flashing, and suction line flashing to bound the conservative estimate of head loss due to chemical effects.

MPS3 Head Loss and Vortexing RAI 6, Issue 4

Please provide additional details on how the postulated air evolution affected the MPS3 head loss tests considering the following:

a. *Please provide an evaluation of how the air evolution phenomenon affected the MPS3 tests compared to other AECL tests conducted under similar conditions. Please provide information on why air evolution, as a factor in head losses, would only occur for AECL strainers.*
b. *The response to RAI 4 stated that the air evolution began to affect head loss as soon as the fibrous debris was added to the test and that the head loss began to decrease as soon as fibrous debris additions were stopped. Please provide an evaluation of why the air evolution would begin to affect head loss as fiber was added to the test and why it would stop as soon as fibrous debris additions were stopped.*
c. *Please provide an evaluation of why the evolution of air, caused by the addition of fibrous debris with air entrained in it, would result in the highest head loss when a relatively small amount of fibrous debris was added.*

Response to MPS3 Head Loss and Vortexing RAI 6, Issue 4a

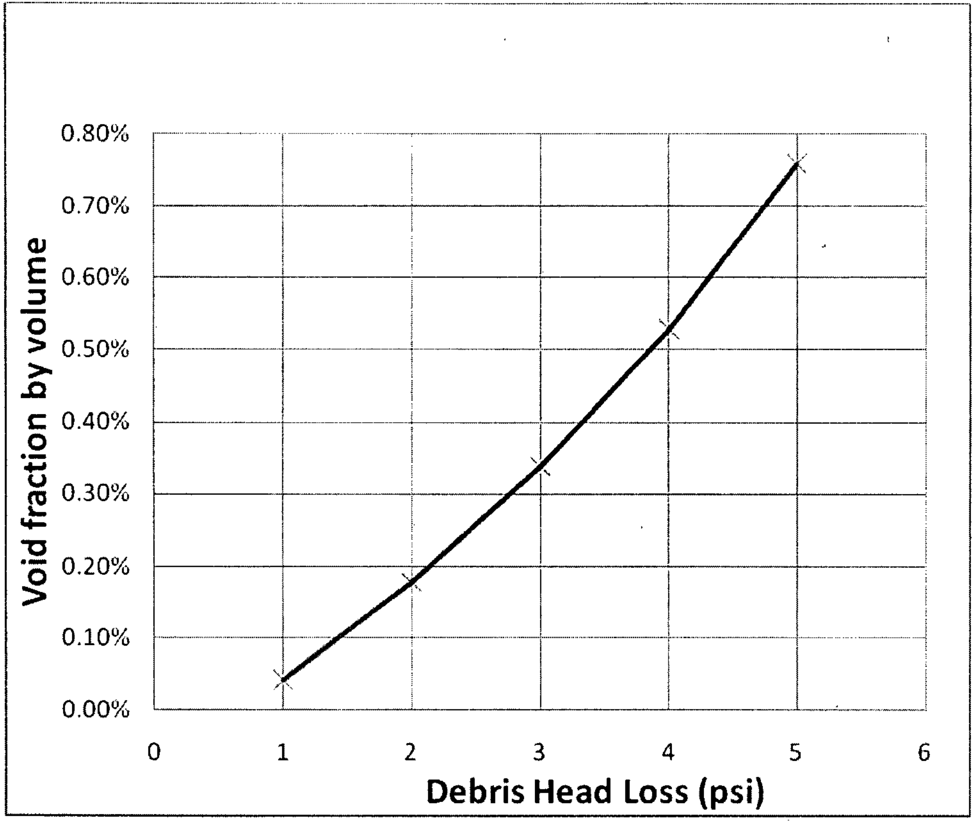
Air solubility in water is proportional to the absolute pressure at the location of interest. The maximum quantity of air that could be dissolved in the water is proportional to the absolute pressure above the water surface. In strainer testing, as the debris bed head loss becomes greater than the static head of water above the fin, dissolved air will evolve from the solution. In MPS3 Rig 33 tests, the water submergence was set to 8 inches. The corresponding static head was 0.29 psi at the top of the submerged fin and 1.4 psi at the bottom of a 30-inch high fin. Once the debris bed head loss exceeded 0.29 psi, air evolution would start to occur along the tops of the fins and air bubbles would start to accumulate within the debris bed. When debris bed head loss exceeded 1.4 psi, air evolution would occur along the entire height of the fins. Air bubbles retained within the debris bed would restrict the flow, increasing debris head loss.

Based on a dissolved air calculation, it was found that air evolution increases significantly as the head loss across the debris bed increases. Figure 2 shows a theoretical plot of how air evolution is affected by debris head. This plot assumes that air will immediately evolve out of solution if it exceeds the saturation concentration. However, it is likely that there is some time delay and the actual air release would be less than indicated. Nevertheless, for a relatively small head loss, air evolution is very low and it starts to become more significant as head loss exceeds approximately 2 psi. The tests performed for other Dominion plants had head losses less than 2 psi, which was not enough to cause significant air evolution.

In a significant head loss situation, if all the air that evolved from solution were to remain within the debris bed, it would take only minutes before the debris bed was completely blocked by air. Since, there is a constant migration of such air bubbles through the debris bed; the bed would never get completely blocked. Under steady state conditions there is equilibrium between air evolution within the bed and air migration through the bed.

Typically, after a fiber addition the head loss increased rapidly to a much higher value, then after a while the head loss dropped and stabilized to a lower value. The air bubbles caught in the debris bed can explain this scenario. It was observed that air bubbles became attached to the fibers during the debris preparation process and were added to the test tank along with the debris, as shown in Figure 6. Shortly after a fiber addition, these air bubbles started to restrict the flow path, which initiated the rise in head loss and then resulted in generation of more air inside the debris bed due to low submergence. Eventually, the rate of air generation became equal to the rate of air migration, and the head loss stabilized at a lower value than the peak value. The air bubble blockage in the debris bed is believed to be the most significant factor for high head loss in MPS3 tests in Rig 33. Since this mechanism is strictly dependent on the water submergence and head loss, it is expected to occur for any strainer design under similar conditions.

Figure 2: Theoretical Air Evolution at a Point on the Strainer Submerged by 26 Inches



A less significant contributing factor to strainer head loss due to air evolution is accumulation of air within the strainer. Because of the test module configuration, this tended to occur in many of the Rig 33 tests.

An equation was developed in Reference [5] to calculate head loss across a strainer that is partially air-filled:

$$\Delta p_{void} = \Delta p_{full} + 1/2\rho g h \qquad \text{Equation 1}$$

Where,
Δp_{void} = pressure drop across the strainer with the same uniform debris bed and flow rate when the strainer is filled with air,
Δp_{full} = pressure drop across the same debris bed when the strainer is filled with water,
h = height of the air void within the strainer.

The extra pressure loss due solely to the presence of air within the strainer is quantified by the last term in Equation 1. This effect is due to the reduction of driving pressure for flow to pass through the upper portion of the strainer as compared to the lower portion of the strainer; thus the upper portion of the strainer loses effectiveness.

The second column from the right in Table 7 quantifies the extra head loss caused solely by air accumulation within the test strainer for Dominion Rig 33 tests. For MPS3, this caused an additional 0.5 psi head loss. Moderate air accumulation was also observed during North Anna tests, which caused approximately 0.3 psi additional head loss.

The two photos below show air bubbles observed in the MPS3 reduced-scale test (Figure 3) and large-scale test (Figure 4).

Figure 3: Air Bubbles Observed Erupting from Fin Channels at Pump Stop in Test M3-16

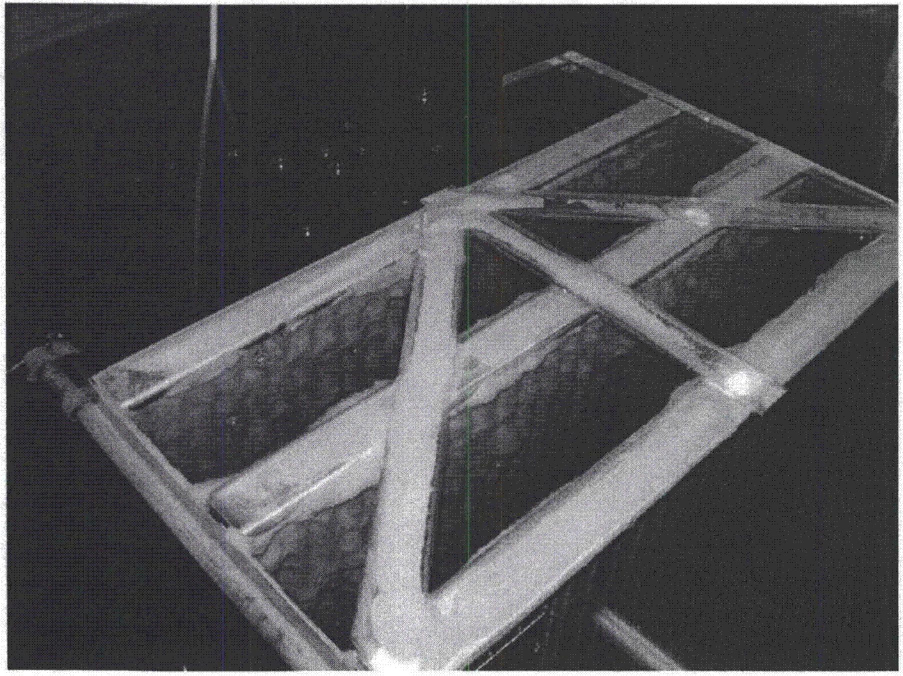
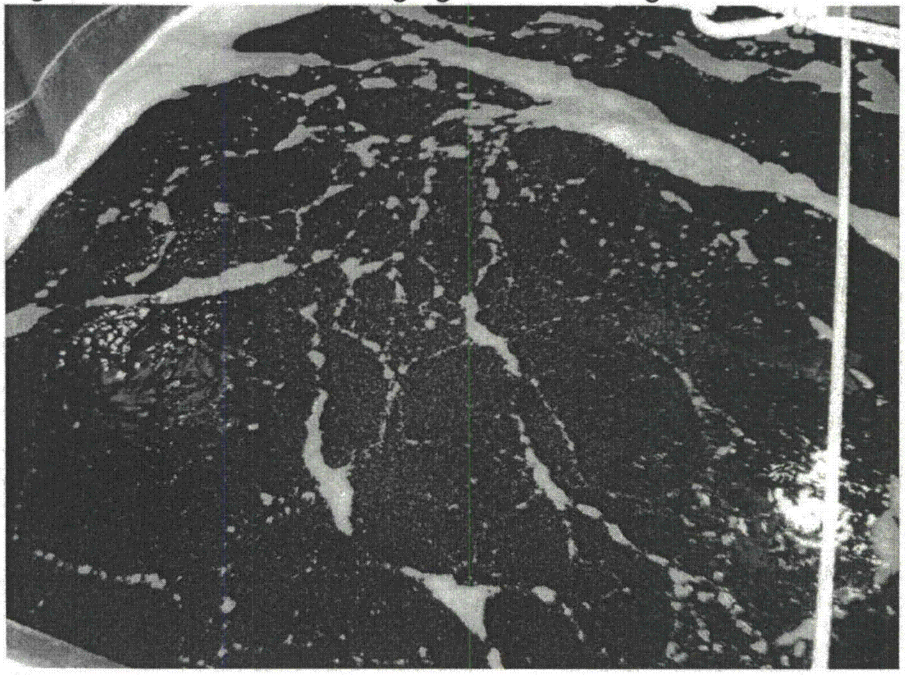


Figure 4: Air Bubbles Emerging from Discharge Header in MPS3 Large-Scale Test



Air evolution was also observed in other Dominion strainer tests performed by AECL, but to a lesser degree. Since the debris bed head loss of these other tests was lower than that of the MPS3 tests, less air would be generated within the debris bed.

Similar air evolution would occur for any strainer under conditions similar to the MPS3 tested conditions.

Table 7: Air Evolution in Rig 33 Tests

Test	Strainer Submergence & Fin Height [inches]	Static Head Top~Bottom of Fins [psi]	Peak Debris Bed Head Loss [psi]	Head Loss Caused by Air Inside Strainer [psi]	Significant Air Evolution?
NAPS LHSI NA-15	7 / 20	0.25~0.97	1.4	0.36	Minor
NA-16	7 / 20	0.25~0.97	1.3	0.36	Minor
NAPS RS NA-10	27 / 15	0.97~1.5	2.1	0.27	Minor
NA-14	27 / 15	0.97~1.5	1.4	0.27	Minor
Surry LHSI S2-33	7 / 20	0.25~0.97	0.53	0.06	No
S2-35	7 / 20	0.25~0.97	0.24	0	No
Surry RS S2-28	27 / 15	0.97~1.5	1.0	0.001	No
S2-30	27 / 15	0.97~1.5	1.3	0.10	Minor
SPS-Rig 33-C1	12 / 15	0.43~0.97	0.39	0	No
MPS2 M2-22	7 / 37.75	0.25~1.6	0.81	0.11	Minor
M2-27	7 / 37.75	0.25~1.6	0.68	0.07	Minor
MPS3 M3-2	8 / 30.38	0.29~1.4	5.1	0.54	Major
M3-16	8 / 30.38	0.29~1.4	3.6	0.54	Major

Response to MPS3 Head Loss and Vortexing RAI 6, Issue 4b

The above mentioned RAI 4 (NRC Request for Additional Information dated December 17, 2008) is quoted as below:

> *The explanation for higher peak head loss that occurred during large-scale strainer performance testing stated that air was released from solution when head loss across the debris bed lowered the pressure in the debris bed below the static pressure of water on top of the debris bed. This air release apparently results in higher peaks in head loss. The explanation of this phenomenon is unclear. It is also unclear as to why this phenomenon would not occur during the reduced-scale testing since the head losses and submergence were similar. Please provide additional details and evaluation of the cause of the peak head loss that occurred during this testing.*

The MPS3 large-scale test M3L-2 was performed in the AECL large-scale strainer testing facility—Rig 85. In that test, many air bubbles were observed emerging from the discharge header after the third fiber addition, as shown in Figure 4. The discharge header was located on the floor of the test tank. During the test, the head loss stabilized at 2.7 psi after the second fiber addition. The third fiber addition increased the head loss to 4.1 psi. Three more fiber additions were added into the test and each addition caused a spike in head loss as shown in Figure 5. DNC's response to RAI 4, dated March 13, 2009, referred to the fourth, fifth and sixth fiber additions. Prior to these fiber additions, air evolution had already reached a significant level due to high debris bed head loss.

The observed head loss spike after the fourth, fifth and sixth fiber addition was due to the air bubbles trapped inside the fibrous debris. Microscopic examination of fibers prepared in a similar fashion (i.e., using a pressure washer to agitate and break up the clumps of fiber) showed that air bubbles were attached to the fibers (see Figure 6). It was the air bubbles that initiated the pressure spikes, not the fibers.

As soon as the fibers reached the debris bed, the bubbles started to migrate into the debris bed, blocking flow area and causing the head loss to increase. The increasing head loss caused the generation of more bubbles within the bed, which, in turn, caused a further increase in head loss. Once the debris addition was completed and no new bubbles were developing at the debris bed, the continuing migration of air bubbles through the debris bed into the fins began to decrease, unblocking flow area and causing further head loss decreases. Eventually, the rate of air generation decreased to become equal to the rate of air migration, and the head loss stabilized at a lower value than the peak value.

Figure 5: Head Losses vs. Debris Addition in MPS3 Large-Scale Thin Bed Test

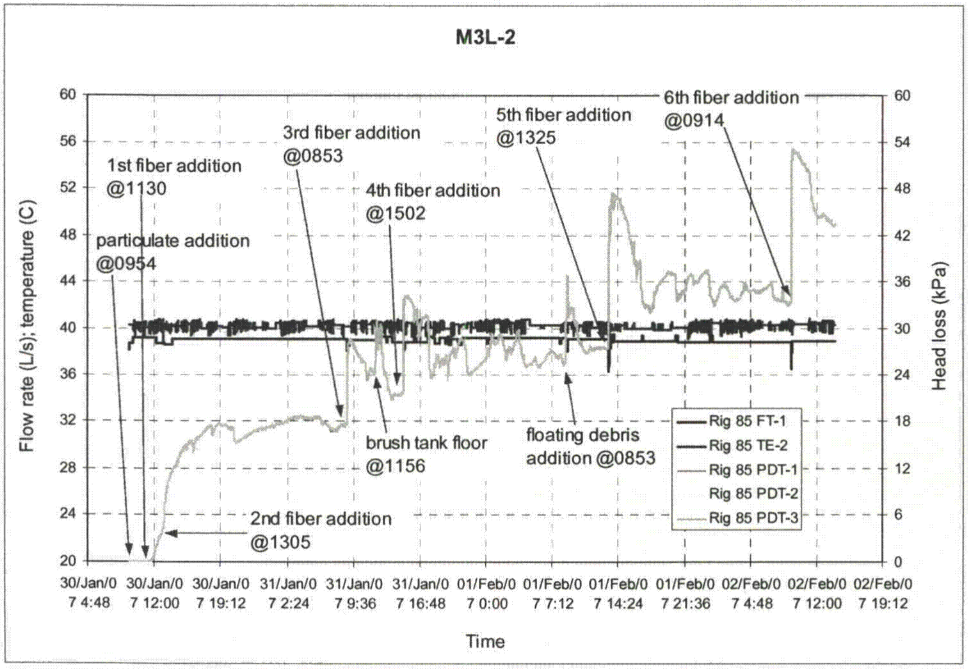
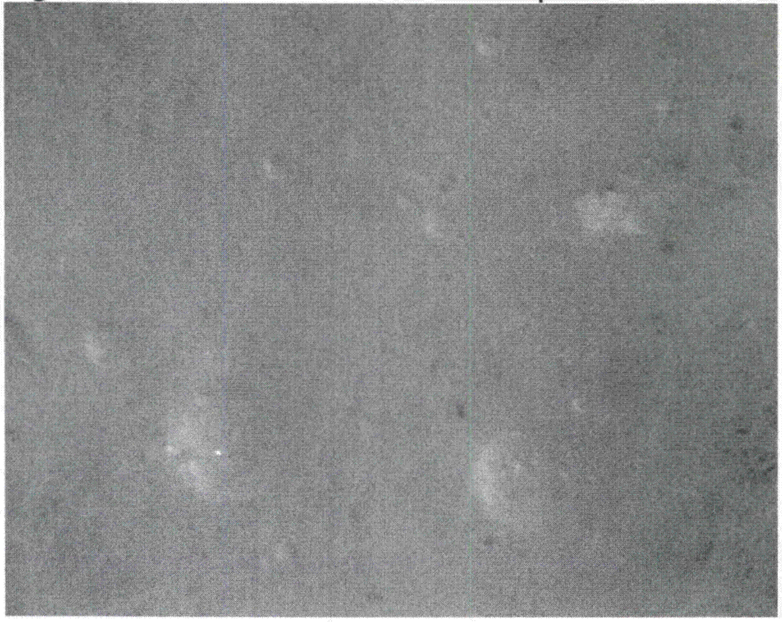


Figure 6: Air Bubbles Attached to Prepared Thermal Wrap Fiber



Response to MPS3 Head Loss and Vortexing RAI 6, Issue 4c

As explained in response to Issue 4b, prior to the last three fiber additions, air evolution already existed in the system due to high debris bed head loss (4.1 psi). Newly added fiber brought entrained air bubbles into the debris bed, blocking flow area and causing the head loss to increase. The increasing head loss caused the generation of more bubbles within the bed, which, in turn, caused a further increase in head loss. Once a debris addition was completed and no new bubbles were arriving at the debris bed, then the continuing migration of air bubbles through the debris bed into the fins began to decrease, unblocking flow area and causing further head loss decreases. Eventually, the rate of air generation decreased to become equal to the rate of air migration, and the head loss stabilized at a lower value than the peak value.

MPS3 Head Loss and Vortexing RAI 6, Issue 6

Please provide an evaluation of the potential for the lower head loss in the Rig-89 testing (versus reduced scale testing) to have been caused by agglomeration of debris, especially fibrous debris.

Response to MPS3 Head Loss and Vortexing RAI 6, Issue 6

The potential for the lower head loss in the Rig 89 testing to have been caused by agglomeration of fibrous debris was very low. Fibrous debris was sprayed as "single fine" by using a high pressure jet flow in a 200 liter plastic barrel. The sprayed fiber was then added into the in-line debris addition tank. The debris addition tank was equipped with a stirrer. After a batch of fibrous debris was added into the tank, the stirrer was activated to suspend the fiber and to avoid debris settling or agglomeration. The debris addition tank was then valved-in to let the fiber flow to the strainer box slowly by adjustment of the in-line control valves. (Figure 7)

Figure 8 and Figure 9 show that after the test, the debris bed was firm and uniform. No fibrous debris clumps were observed. The reasons for lower non-chemical head loss in Rig 89 are unclear, however sufficient margin exists as described above, to account for the higher Rig 33 non-chemical head loss results, along with the head loss due to chemical precipitants found in Rig 89.

Figure 7: Debris Bed at the End of MPS3 Chemical Effects Test

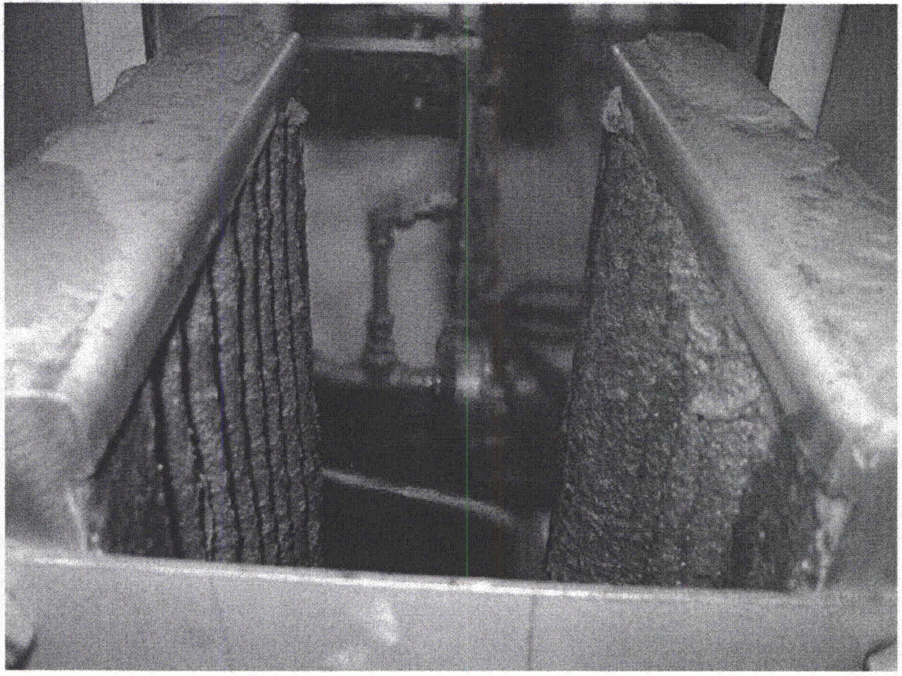
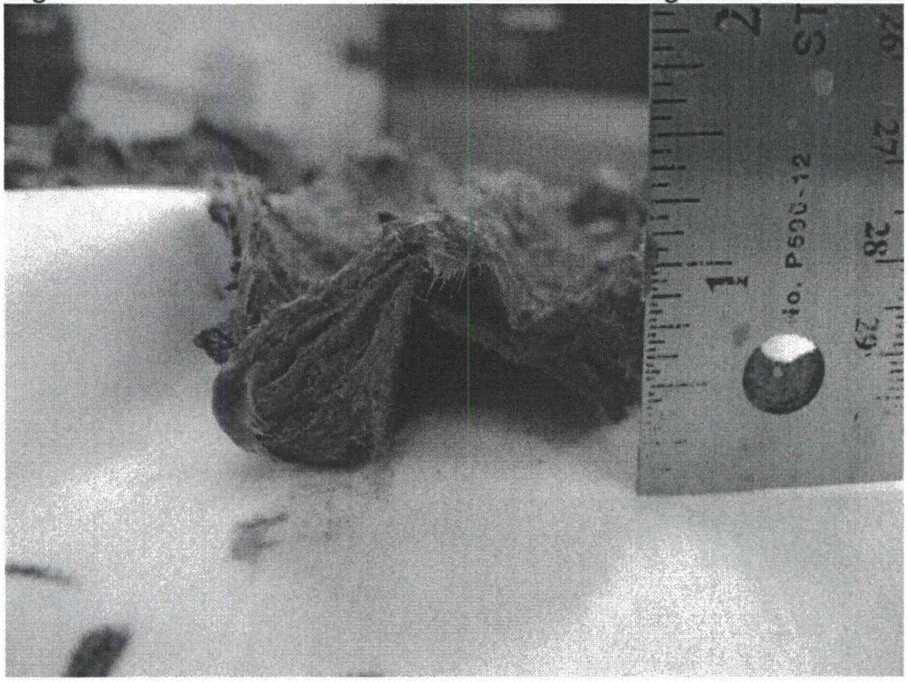


Figure 8: Close-Up of a Piece of Debris Bed Removed from the Strainer Surface

Figure 9: Debris Bed Thickness after MPS3 Rig 89 Chemical Effects Test



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