VERMONT YANKEE
NUCLEAR POWER CORPORATION

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December 29, 1999
BVY 99-164

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D.C. 20555

Reference: (a) NRC Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling Water Reactors," dated May 6, 1996.

(b) Safety Evaluation for NEDO-32686, Rev. 0, "Utility Resolution Guidance Document for ECCS Suction Strainer Blockage," dated August 1998

(c) NEDO-32686, Rev. 0, "Utility Resolution Guidance Document for ECCS Suction Strainer Blockage," dated November 1996

Subject: Vermont Yankee Nuclear Power Station
License No. DPR-28 (Docket No. 50-271)
Notification of the Installation of Larger Emergency Core Cooling System (ECCS)
Suction Strainers In Accordance With NRC Bulletin 96-03

In accordance with the requested actions of Reference (a), Vermont Yankee is informing the staff of completion of our actions.

During our 1998 Refueling Outage, Vermont Yankee installed large, passive, ECCS strainers under the provisions of 10CFR50.59. A description of how design inputs were chosen in our design of the strainers is provided in Attachment 1.

Part of the design inputs for our strainers included the performance of plant-specific testing for behavior of coating debris. A proprietary description of this testing and the results is included in Attachment 2. Attachment 2 of the enclosed information is considered proprietary information by Duke Engineering and Services (DE&S). In accordance with 10CFR2.790(b)(1), an affidavit attesting to the proprietary nature of the enclosed information is attached. A non-proprietary version of the testing and results is included in Attachment 3.

In addition to the installation of new, high debris capacity strainers, the Torus inner surface, from the waterline and below, was re-coated with a qualified coating. Also, the drywell was cleaned and confirmed free of foreign material following an inspection in accordance with our drywell close-out procedure. The Torus was confirmed to be clear of foreign material following our replacement of strainers and re-coating project. The drywell vents and downcomers were likewise inspected and verified to be free of foreign materials.

change: NRC PDC Ltr encl 1 1w/o prop A001 1/1

PDR ADOCK 05000271

The change in design/licensing basis as a result of the requested actions of Reference (a) will be incorporated into the Vermont Yankee procedures and calculations as soon as practicable following receipt of your review of the attached information.

We trust that the information provided is acceptable. However, should you have any questions or require additional information concerning this submittal, please contact Mr. Jeffrey T. Meyer at (802) 258-4105.

Sincerely,

VERMONT YANKEE NUCLEAR POWER CORPORATION

Don M. Leach
Vice President, Engineering

STATE OF VERMONT)
)ss
WINDHAM COUNTY)

Then personally appeared before me, Don M. Leach, who, being duly sworn, did state that he is Vice President, Engineering of Vermont Yankee Nuclear Power Corporation, that he is duly authorized to execute and file the foregoing document in the name and on the behalf of Vermont Yankee Nuclear Power Corporation, and that the statements therein are true to the best of his knowledge and belief.

Sally A. Sandstrum, Notary Public
My Commission Expires February 10, 2003

Attachments

cc: USNRC Region 1 Administrator
USNRC Resident Inspector - VYNPS
USNRC Project Manager - VYNPS
Vermont Department of Public Service (w/o proprietary section, Attachment 2)

SUMMARY OF VERMONT YANKEE COMMITMENTS

BVY NO.: 99-164

The following table identifies commitments made in this document by Vermont Yankee. Any other actions discussed in the submittal represent intended or planned actions by Vermont Yankee. They are described to the NRC for the NRC's information and are not regulatory commitments. Please notify the Licensing Manager of any questions regarding this document or any associated commitments.

COMMITMENT	COMMITTED DATE OR "OUTAGE"
None	N/A

Attachment 1

Vermont Yankee Nuclear Power Station

Design Inputs for Larger ECCS Suction Strainers

This attachment describes methods that are deemed acceptable to Vermont Yankee for implementing requirements with respect to suppression pools performing the functions of water sources for emergency core cooling, containment heat removal, or containment atmosphere cleanup.

Debris generation, early debris transport, long-term post-LOCA transport, were evaluated to ensure that the ability of the emergency core cooling systems (ECCS) to provide long-term post-LOCA core cooling was not jeopardized. All potential debris sources were evaluated, including but not limited to insulation materials (e.g., fibrous, and metallic), corrosion material, foreign materials, and paints or coatings. Relevant information for such evaluations were retrieved from Reference (c) and have been reviewed and approved by the NRC Staff in Reference (b).

The following summarizes actions taken by Vermont Yankee:

<u>Selection of Breaks, Debris Generation, and Drywell Transport</u>:

A calculation was performed of the quantity of insulation debris that would be available in the suppression pool as the result of a LOCA event. The calculation follows the Utility Resolution Guidance (URG) methodology for determining the quantity of debris and applies the URG recommended transport and destruction factors for that debris based on location relative to the lowest level of grating in the drywell. However, instead of performing a break location specific analysis of the zone of influence of destruction as allowed by the URG, a more conservative approach was employed. Because the largest quantity of fibrous insulation in the drywell is NUKON insulation which is located only on the recirculation system piping, it is assumed that the rupture of the largest recirculation line (28 inch) would produce the largest zone of influence and therefore the largest quantity of debris. In lieu of performing a break location specific analysis using the methodology provided in the URG for the zone of influence, it is conservatively assumed that the zone of influence will encompass all of the insulation on either the A or B recirculation loop. This is a conservative approach but not excessive given that the URG methodology would calculate a spherical zone of influence approximately 44 feet in diameter which is sufficiently large to encompass a large fraction of the insulation on the recirculation loop.

In Reference (b), the Staff noted that the methodology for the selection of break locations should include locations in the drywell where the highest density of fibrous insulation is installed. The Staff goes on to say that either Method 1 or 2 provide a conservative bounds for the volume of debris generated. Vermont Yankee has chosen to conservatively use the largest pipe located in the drywell as a basis for determining the zone of destruction and has arbitrarily expanded that zone to include an entire half of the drywell for the purposes of determining the quantity of debris generated. Vermont Yankee used the URG transport factors for a Mk I containment when determining the amount of debris that would be transported to the suppression pool. These transport factors were acceptable to the Staff in Reference (b).

<u>Other Sources of Debris</u>:

A plant specific sludge generation rate for Vermont Yankee has been established. As a conservative measure, an additional amount of sludge is assumed to be in the suppression pool to accommodate the amount of sludge that cannot be completely removed during torus cleaning. As recommended in URG Section 3.2.2.2.1, an additional amount is added to the sludge source term. This is to accommodate the dirt and dust which may be present in the drywell and above the water level in the torus which are washed into the suppression pool as a result of a LOCA. This term also addresses the debris which could result from a LOCA jet impacting a concrete surface.

As recommended in URG Section 3.2.2.2, a debris source term of rust flakes is considered to be available in the suppression pool. This source term accommodates the amount of rust which may be removed from unpainted steel surfaces in the drywell and torus (e.g., unpainted miscellaneous structural components, drywell surfaces, main vents/downcomers, etc.).

As recommended in URG Section 3.2.2.2.1.1, a debris source term of inorganic zinc top coated with epoxy is considered to be available in the suppression pool. This is the maximum amount of debris which would result from direct impact of the LOCA jet on a surface covered with a qualified coating. Where a LOCA jet impacts a surface it is assumed the coating will be removed without regard to whether or not the coating is qualified.

With respect to the balance of the coatings (indeterminate/unqualified) within the Vermont Yankee Primary Containment, tests to evaluate generic strainer performance under Vermont Yankee conditions were performed at Alden Research Labs (ARL) in Holden, Massachusetts. The purpose of the testing was to investigate the effect of paint chips and fiber debris on the performance of the ECCS strainers. The proprietary version of this testing program and its results are contained in Attachment 2. A non-proprietary version is included in Attachment 3. These tests were performed in a modified 'Chugging Facility". This facility, which is a scale model of a section of the BWR Mk I torus, uses pistons to simulate the turbulence induced by the downcomers. Previously, this facility had been used to investigate debris sedimentation under various levels of turbulence. A modification to this facility added a small cylindrical strainer in the pool along with the associated piping and a variable speed pump. This facility was then used to investigate the effect of varying degrees of pool turbulence on the rate of debris buildup on the strainer. This was done to simulate debris removal behavior from a pool for the very low strainer approach velocities representative of the Vermont Yankee strainers. During the performance of the tests, when paint was added to the debris mixture, both paint and fiber could only be removed from the pool and deposited on the strainer under high flow and high turbulence conditions. For the expected DBA flowrates for Vermont Yankee, no fiber or paint was collected on the strainer. Under post-DBA/IBA conditions of recirculation flow for Vermont Yankee, only fiber was collected. After the chugging period is over and the turbulence in the pool is driven by recirculation flow, only fiber could be removed from the pool and deposited on the strainer. Based on these tests, at no time was paint able to be removed from the pool and deposited on the strainer. Therefore, no specific source term of unqualified / indeterminate coatings debris is used.

In Reference (b), the Staff concluded that the generic values provided in the URG for other sources of debris were acceptable. Vermont Yankee follows the URG methodology for determining these values. With respect to coatings, licensees were encouraged to use test data to support their evaluation of coatings. This test data is considered acceptable to Vermont Yankee and is being presented to the Staff in this submittal so that they may review the results.

Suppression Pool Transport:

Vermont Yankee follows the URG recommendations with respect to not crediting settling in the suppression pool during the high-energy phase of the LOCA. After the high-energy phase, some settling is credited.

In Reference (b) the Staff found the URG acceptable with no comment.

Head Loss:

NUREG/CR-6224 models, with respect to head loss, were implemented by the NRC in the BLOCKAGE 2.5 computer code, which is publicly available from the Oak Ridge National Laboratory code center. Vermont Yankee utilized a code developed by the ITS Corporation (HLOSS 1.0) to provide a computational tool that could be used to assess stacked-disk strainer performance under varying fiber loads with particulate debris when calculating head loss across the strainer. This code was developed by ITS to minimize the limitations in BLOCKAGE 2.5. HLOSS 1.0 incorporates the following features:

- Head loss estimates based on the head loss correlation presented in NUREG/CR-6224,
- Time-dependent debris build-up on the strainers that may be input by the user based on strainer flow rate and pool water volume as in BLOCKAGE 2.5 (with all debris assumed to be suspended in the suppression pool at time zero),
- Filtration efficiencies and sedimentation fractions that may be input by the user,
- Use of the full strainer surface area for debris deposition until the gaps between the stacked disks are filled with debris,
- Use of the strainer circumscribed area for further debris deposition after the gaps are filled,
- Calculation of debris thickness on the outside of the circumscribed area that accounts for the surface curvature, and
- Use of the algorithm for the debris-specific surface area that eliminates potential non-conservative results associated with a volume-weighted average in cases of large quantities of particles with low specific surface area.

It was felt that there was a much better basis for using the NUREG/CR-6224 correlation because there is a much more extensive database to demonstrate the validity of that correlation. In addition, all-important phenomena are treated explicitly in a semi-theoretical manner, which is much easier to argue as conservative in a particular circumstance.

In Reference (b), the Staff recommends that licensees use test data to support the head loss used in their plant. As stated above, Vermont Yankee relies on the NUREG/CR-6224 model, which relies on fundamental characteristics of the debris bed composition. Its results have been extensively validated for debris beds composed of fiberglass and simulated suppression pool sludge, as well as mineral wool fibrous materials. The NUREG/CR-6224 model was also extensively validated in support of the OECD/CSNI International Task Group. In all cases, as reported in NEA/CSNI/R (95)11, 'Knowledge Base for Emergency Core Cooling System Recirculation Reliability', the NUREG/CR-6224 model consistently predicted the experimental results within an acceptable error band. More recently, an experiment was performed at EPRI for the PCI stacked disk strainer using Tempmat rather than Nukon fibrous debris. Comparison of the measured head loss with that predicted using the HLOSS 1.0 code showed agreement to within 20%, with the predicted result conservatively higher than that measured.

Docket No. 50-271
BVY 99-164

Attachment 3

Vermont Yankee Nuclear Power Station

Technical Report for the Testing and Results from Vermont Yankee Specific Paint Debris

Non-Proprietary Information Enclosed

ANALYSIS OF TESTS FOR INVESTIGATING THE EFFECT OF COATINGS DEBRIS ON ECCS STRAINER PERFORMANCE FOR VERMONT YANKEE

NON-PROPRIETARY ISSUE

DUKE ENGINEERING & SERVICES
COMPANY DISCLAIMER STATEMENT

Please Read Carefully

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Executive Summary

Two series of tests were conducted at the Alden Research Laboratories (ARL) to investigate the effect of paint chips and fibrous debris on the performance of the new ECCS suction stacked-disks strainers at the Vermont Yankee plant. The two series of tests were: 1) tests to determine head losses due to a mixture of different types of fibrous debris and paint chips, hereafter denoted as L-Series because they were conducted in the same closed-loop facility used for earlier head loss tests sponsored by the USNRC [Zigler, *et al*, 1995], and 2) tests conducted to investigate the effects of suppression pool turbulence on the debris bed formation, hereafter designated as the C-Series because they were conducted in the same suppression pool segment chugging facility previously used for the debris settling tests, sponsored by the USNRC [Souto and Rao, 1996].

<u>L-Series Tests</u>: The specific objective of the L-series tests (loop test facility) was to estimate the head losses due to a mixture of fibrous insulation debris (0.35 lb in mass), composed of 75% (by mass) of NUKON™, 20% of FiberMat, and 5% of Temp-Mat®, and simulated paint chips (cured epoxy) of given shape (flat pieces) and size distribution, i.e., 50% (by mass) of small (1/8"×1/8" to ½"× ½"), 25% of medium (1/2"×1/2" to 1"×1"), and 25% of large (1"×1" to 2"×2") paint chips. Additionally, some tests included 168 g of simulated suppression pool sludge. The quantities of these materials and their ratios to each other were representative of the worst-case debris loading (on a per strainer surface area basis) predicted to result from a hypothetical DBA LOCA at Vermont Yankee. The range of approach velocities tested (0.01 to 0.06 ft/s), encompassed the expected approach velocities for the Vermont Yankee strainers (0.02 to 0.04 ft/s). Significant findings of this series of tests are summarized as follows:

1. Debris was deposited non-uniformly over the strainer, with the bed thickness being higher in the center than at the edges of the strainer. Non-uniform distribution of debris on the strainer indicates that deposition of debris on the strainer surface was significantly impacted by gravitational settling and wall effects. This situation (i.e., gravity and wall effects dominating debris deposition) is not expected for the Vermont Yankee stacked-disks strainers. In this context, note that these approach velocities were significantly lower than those approach velocities previously tested in this facility (i.e., 0.15 to 1.5 ft/s) [Zigler, *et al*, 1995] and, therefore, these gravity related effects were never observed before.
2. The head losses measured were significantly lower than those calculated before the tests using the HLOSS 1.0 computer code. This over-estimation in the computer code calculations is mainly attributed to the intrinsic assumption of uniform debris distribution on the strainer made in the pre-test analysis.
3. One test was conducted with a representative quantity of shredded Armaflex insulation material, also included as part of the debris mixture. This sample of shredded Armaflex remained floating on the water surface, without reaching the strainer and, therefore, was not further tested. This behavior suggests that Armaflex insulation debris would not contribute to the head loss due to postulated post-LOCA debris collecting on the Vermont Yankee stacked-disks strainers.

C-Series Tests: The specific objective of the C-series tests (chugging facility tests) was to investigate the effect of varying levels of turbulence on debris deposition and retention on a cylindrical strainer at the relatively low approach velocities typical of the Vermont Yankee stacked-disks strainers. To this effect, two bounding strainer approach velocities, i.e., 0.06 and 0.12 ft/s, and four levels of turbulence, i.e., high, medium, low and no simulated chugging, were investigated. Note that the high level of turbulence was estimated to be representative of suppression pool turbulence occurring late in time during a medium LOCA blowdown. The same fibrous debris composition and paint chips used for the L-series were investigated in the C-series tests. Significant findings of this series of tests are summarized as follows:

1. The C1 tests, conducted with fibrous debris only, showed that at an approach velocity of 0.12 ft/s, strainer suction forces were dominant over gravity or turbulence related forces, for all of the turbulence levels tested. Note that this approach velocity, 0.12 ft/s, is at least 3 times higher than the highest approach velocity expected at the Vermont Yankee stacked-disks strainers (about 0.04 ft/s). For an approach velocity of 0.06 ft/s, the fibrous debris remained suspended in the water at the high and medium turbulence levels, indicating than turbulence-related forces were dominant over strainer suction and gravity related forces.
2. The C2 tests, conducted with fibrous debris and paint chips, showed that both types of debris (i.e., fibers and paint chips) can only be deposited on the strainer at an approach velocity of 0.12 ft/s and the high level of turbulence required to fully suspend all debris materials. For the medium and low levels of chugging-induced turbulence tested, very few paint chips were deposited on the strainer, suggesting that gravity related forces (i.e., sedimentation onto the pool floor) dominated the behavior of paint chips. At the approach velocity of 0.06 ft/s, these tests clearly indicated that neither fiber or paint chips can be suctioned by the strainer at the high and medium chugging-induced turbulence levels. After the simulated chugging was stopped, only a small quantity of fibrous debris was deposited on the strainer.
3. Overall, the C-series tests indicate that paint chips do not contribute to the head loss due to post-LOCA debris for the strainer approach velocities and suppression pool turbulence conditions calculated for Vermont Yankee.
4. As in the case of the L-series tests, the head loss measurements for the C-series tests were lower than those head losses calculated with the HLOSS 1.0 computer code before the tests. Again, this over-estimation in the pre-test head loss calculations is partially related to the non-uniform distribution of debris on the cylindrical strainer that was observed during the C-series tests.
5. An indirect result from this series of tests was the estimation of the density and characteristic fiber diameter of the fibrous debris mixture for use in the Vermont Yankee ECCS strainer performance analysis. Based on a characteristic debris bed thickness estimated from video tapes of the C-series tests, a density of 2.1 lb/ft^3 is proposed for the mixture of fibrous debris types postulated to occur during a DBA. Based on the head loss measurements, a characteristic fiber diameter of 8.3 μm is proposed for the Vermont Yankee ECCS stacked-disks strainer performance analysis under DBA conditions.

1.0 Introduction

During a loss-of-coolant accident (LOCA) in a Boiling Water Reactor (BWR) nuclear power plant, pipe insulation in the drywell may be dislodged by the force of the LOCA jet and be transported to the suppression pool. This insulation debris, along with corrosion products and other miscellaneous debris can block the strainers on the suction lines supplying the emergency core cooling system (ECCS) pumps. Consequently, this could result in a sufficiently large pressure drop across the strainer surface that would degrade pump performance. For the Vermont Yankee (VY) nuclear station, strainers have been designed to accommodate worst-case debris loading such that the resulting head loss across the debris bed does not degrade pump performance. This design effort involved predicting the debris head loss at the strainer surface for a specified set of assumptions, which included:

- fibrous insulation debris transported to the strainers,
- corrosion products and other miscellaneous debris in the suppression pool,
- pump flow rate, and
- paint chip debris in the suppression pool.

For this design effort to be valid, it is necessary to have confidence that the correlation used to predict head loss is applicable and conservative for the insulation type and other conditions relevant to Vermont Yankee.

The methodology used to calculate fibrous debris head loss as part of the Vermont Yankee strainer sizing activity is based on that developed by the Nuclear Regulatory Commission (NRC) as documented in NUREG/CR-6224 [Zigler, et. al., 1995]. This methodology is implemented in the HLOSS code developed by Innovative Technology Solutions (ITS) Corporation [Mast, P. K. and Souto, F. J., 1997]. The validation effort conducted for the HLOSS code demonstrated the applicability of the code for calculating debris head loss across NUKON fibrous debris, with and without the presence of corrosion products. The primary fibrous insulation found at Vermont Yankee, however, is a mixture of fibers rather than just NUKON. While all the fibrous insulation types are blankets of fibers, they have somewhat different densities, and the size of the individual fibers is also different. Because the NUREG/CR-6224 head loss correlation is based on the actual physical parameters of the fibrous debris material (i.e., fiber diameter, density, and porosity), it is expected to be valid for fiber mixtures as well. However, limited data on mixed fiber bed head loss is available to confirm this expectation.

Tests to evaluate generic strainer performance under the specified Vermont Yankee conditions were performed at Alden Research Labs (ARL) in Holden, Massachusetts [Johnson, 1998]. The purpose of the testing was to investigate the effect of paint chips and fiber debris on the performance of new ECCS suction strainers to be installed at the Vermont Yankee plant. Two separate sets of tests designated as L tests and C tests were planned and executed [Copus, January 15, 1998]. These tests are summarized as follows:

- L-Series Tests: These tests were designed to quantify the effect of known quantities of paint chips (with known size distribution) in a fibrous debris bed on strainer head loss at low approach velocities prototypic to the Vermont Yankee ECCS flow under accident conditions.

- C-Series Tests: These tests were designed to investigate the effect of varying levels of pool turbulence on paint chip deposition on the strainer surface at low approach velocities prototypic to the Vermont Yankee ECCS flow under accident conditions.

Both test series represented previously untested conditions unique to the Vermont Yankee ECCS performance expectations under accident conditions [Betti, 1997]. Previous head loss[1] and turbulence[2] testing has been performed, but not at the debris loading conditions specified for Vermont Yankee Design Basis Accident (DBA) and Intermediate Break Accident (IBA) scenarios and not at the low approach velocities that would be prototypic for the new ECCS strainers.

This report summarizes the results of the ARL tests performed for Vermont Yankee, along with analysis of the tests using HLOSS 1.0 and BLOCKAGE 2.5. The results can be used to apply the HLOSS code to Vermont Yankee strainer design/evaluation efforts.

1. Head loss Test series database – Tests at flow velocities of .15 - 1.5 ft/sec & fibrous/sludge (no paint) debris loadings, see NUREG-6224, App. E., Figure E-24, Tables E1-E9 [Zigler, et al, 1995].

2. Chugging Test series database – Tests which measured concentration ratios after set times, 10 & 15 min., for generic fiber (NUKON class 3&4, class 5&6) and iron oxide particles, see NUREG-6224 App. B, Fig. B6-B9 [Zigler, et al, 1995].

2.0 L-Series Tests

These tests were performed in the "Head Loss Loop Facility", which consists of a 100 gallon flow loop with a flat disk strainer of approximately 0.8 ft^2 in area. Flow through the loop can be closely controlled via variable speed pumps so that values of head loss versus (steady-state) velocity can be generated for a known debris bed on the strainer. Values of head loss at representative VY flow velocities were generated for a range of debris quantities/composition. The important parameters that were varied were:

- *Fiber quantity*: A mixture of 75% (by mass) NUKON, 20% Fibermat, and 5% Tempmat representative of the insulation mix in the Vermont Yankee VY containment was used for 6 of the 7 tests. Two quantities of shredded fiber were used:
  - 0.35 lb., which is representative of the fiber loading per unit area expected from a DBA, was used in tests L-1, L-2, L-3, L-4, and L-5,
  - 0.05 lb., which is representative of the fiber loading per unit area expected from an IBA, was used in test L-14.

- *Sludge*: All of the tests were run initially without sludge. Four tests included 168 g of (BWROG simulant, NUREG/CR-6224- iron oxide mixture) sludge at the end of the test to quantify the impact of combined sludge and paint chip particulate in the debris bed.

- *Paint Chip Size*: The shape and size distribution of unqualified coatings debris is highly uncertain. Thus, a mix of VY specified sizes [Betti, 1997] was explored as shown in the following table. In most cases, a thickness of 7.5 mils was used, with one comparison test (L-5) at a thickness of 15 mils.

Table 1. VY Paint Chip Size Distribution

Size	Size Range
Small	1/8" x 1/8" to ½" x ½"
Medium	½" x ½" to 1" x 1"
Large	1" x 1" to 2" x 2"
Mix	50% small, 25% medium, 25% large

- *Paint Chip Quantity*: The quantity of paint coatings that would be expected to be destroyed during a LOCA is also highly uncertain. Thus, a range of values for the quantity of coatings debris was explored. Note that the largest quantity specified (20 ft^2) represents slightly more than 20 ft^2 of coatings debris per square foot of strainer surface area.

- *Strainer approach velocity:* The Vermont Yankee strainer is expected to operate under ECCS flow conditions of 7400 - 14200 gpm for the 800 ft^2 RHR system strainer and 4000 - 4600 gpm for the 430 ft^2 CS system strainer. The range of approach velocities (0.01 - 0.06 ft/s) which encompasses these conditions was applied for each of the debris loading cases.

Table 2 summarizes the L series matrix of tests, varying the relative quantities of each of the above debris types. These tests were performed in January 1998.

Table 2. L Series Test Matrix

Test	Fiber Type	Fiber Mass (lb.)	Sludge Mass (lb.)	Paint Size (thickness - mil)	Paint Amount (ft^2)	Flow Velocity (ft/s)
L-1	Mix	0.35	-	-	0.0	0.01-0.06
L-2	Mix	0.35	0.4	-	0.0	0.01-0.06
L-3	Mix	0.35	-	Mix (7.5)	5.0	0.01-0.06
L-4	Mix	0.35	0.4	Mix (7.5)	5.0	0.01-0.06
L-5	Mix	0.35	0.4	Mix (15)	5.0	0.01-0.06
L-11	-	-	-	Mix (7.5)	20.0	0.01-0.06
L-14	Mix	0.05	0.4	Mix (7.5)	20.0	0.01-0.06

2.1 Qualitative Results from the L Tests

The L tests effectively met their designed goal of covering the parametric space, which included low flow conditions and the individual and combined debris constituents of paint, sludge, and fiber. Tests L-1 and L-3 provided a baseline head loss comparison between fibrous debris with and without paint chips at the relatively low flow velocities representative of VY strainer conditions. Results of these two tests indicated that head losses were less than pretest predictions [Copus, January 19,1998] using theoretical input values or the extrapolated results from the high flow velocity database as indicated by Appendix E of NUREG/CR-6224. Tests L-2 and L-4 repeated the comparison between fiber and paint debris beds when sludge is also present. These tests indicated that sludge was a significant contributor to total head loss and that the total head loss was still less than pre-test predictions based on the high velocity database. Tests L-4 and L-5 compared 15 mil thick paint debris to 7.5 mil paint debris. These tests indicated that paint of either thickness produced similar results, both having head losses less than pretest prediction values. As an option, a small amount of Armaflex insulation was to be added to the test loop during Test L-3. The purpose for this additional point for Test L3 was to determine the transportability of the Armaflex insulation type. Due to its closed-cell construction, Armaflex was found to be highly buoyant, was not transportable, and could not be added to the debris bed. This test confirmed that Armaflex debris would not contribute to head losses across the strainer surface.

All of the above tests were for a fiber loading representative of DBA conditions. Tests L-11 and L-14 repeated the investigation of low flow conditions for paint alone and a fiber loading representative of IBA conditions. The L-11 test investigated the separate effect of a large paint loading (20 ft^2 vs. a strainer area of less than 1 ft^2) without a fiber or sludge component. The test indicated that paint alone could not completely block flow and that head losses would be relatively low at low flow velocities. The L-14 test combined the effects of a small fiber bed, a large paint loading, and sludge. This test indicated that the addition of fiber and sludge would increase the head loss due to large paint loadings alone.

The general data trend is that head losses across a generic strainer for the VY loading conditions and flow velocities have been lower than predicted. Also, fiber bed densities have been much less than the theoretical values used for input to the pretest calculations.

2.2 L Series Tests – Quantitative Results

Seven tests (L1, L2, L3, L4, L5, L11, & L14) were performed, which resulted in ten separate data sets and 69 separate data points at conditions that are applicable to VY specifications. A summary of this data is given in Table 3.

Table 3. L Series Data Sets & individual points

VY fiber mix	2 data sets	12 pts	0.01-0.06 ft/s flow range
VY fiber + paint	3 data sets	21 pts	0.01-0.12 ft/s flow range, 7.5 & 15 mil paint
VY fiber + sludge	1 data set	6 pts	0.01-0.06 ft/s flow range
VY fiber, sludge & paint	3 data sets	21 pts	0.01-0.12 ft/s flow range, 7.5 & 15 mil paint, DBA & IBA loading
VY paint	1 data set	6 pts	01-0.06 ft/s flow range, highest load

2.2.1 L Series Data

A range of pressure drop values in terms of inches of water was measured for each type of debris over the expected range of VY ECCS flow velocities. The results for two of the flow velocities are reported below in Table 4 by debris type.

Table 4. L Series Head Loss results

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2.2.2 Density Estimate for fiber bed in the L Tests

All but one of the tests formed thick 0.35 lb fiber beds on the 0.8 ft^2 flat plate strainer. Visual observations indicated non-uniform loading densities due to large fiber fragments and a dominant settling velocity (vs. flow velocity) force with debris thicknesses estimated at 2-6 inches and slightly different behavior from test to test. These thicknesses can be estimated/verified perhaps to within 0.5 inch using the filmed results of the tests [ARL, 1998]. The debris was thickest in the center of the strainer and thinnest at the edge position, with the difference being about a factor of two. Turning off the flow resulted in expansion of the fiber debris bed by as much as 1 or 2 inches. The thickness was measured during the L4 test at 3-3.5 inches at the edge and 5-5.5 inches in the center of the strainer. All of the debris was estimated to be on the strainer at that time, and using a density of 1.5 lb/ft^3 would yield an average thickness on the strainer of about 3.7 inches. The approach velocity was 0.02 ft/s for these initial bed thickness measurements. For 100% deposition of the 0.35 lb fiber mass at a density of 2.77 lb/ft^3, the fiber would form an average fiber bed of ~2 inches. Accordingly the apparent density of the fiber debris bed could range from 1.8 lb/ft^3 to 0.9 lb/ft^3 depending on the flow velocity, location on the strainer, and time of debris bed measurement. Based on an average fiber debris depth of 3.7 inches, a nominal L test density for head loss estimates would be ~1.5 lb/ft^3 with an uncertainty factor of 30%.

2.2.3 Fiber Diameter Estimate for the L tests

Pretest predictions were performed using a density of 2.77 lb/ft^3 and an effective fiber diameter of 7.1 μ m based on a weight percent averaging of the manufacturer as-fabricated data. These values produced estimated head losses of approximately 6 inches of water (vs. 1.5 inches actually measured) at 65F and an approach velocity of 0.04 ft/s. Both the average fiber diameter (which is used to estimate the average surface-to-volume ratio for the entire debris bed) and the debris bed average density are dependent on specific debris loading conditions, and different input values for both values are indicated in order to analytically match the observed results. First, different densities were clearly observed. Based on an observed average fiber debris depth of 3.7 inches, the L test density for head loss estimates would more appropriately be 1.5 lb/ft^3. Second, very non-uniform debris loading was seen in the L tests, indicating non-uniform flow through the strainer. Head loss measurements from the L tests can be conservatively matched using a density of 1.5 lb/ft^3 and an effective fiber diameter of 10.7 μm. Table 5 summarizes this information.

Table 5. Hloss vs. L Series Test Values

<PROPRIETARY INFORMATION REMOVED>

3.0 C-Series Tests

These tests [Ripp, January 1998] were performed in the (modified) "Chugging Facility." This facility, which is a scale model of a section of the BWR Mark I torus, uses pistons to simulate the turbulence induced by the downcomers. Previously this facility had been used to investigate debris sedimentation under various levels of turbulence [Souto and Rao, 1995]. A modification to this facility added a small (2.8 ft^2) cylindrical strainer in the pool along with the associated piping and a variable speed pump. This facility was then used to investigate the effect of varying degrees of pool turbulence on the rate and amount of fiber and paint chip debris buildup on the strainer (as inferred from the time-dependent head loss across the strainer). No sludge debris was used in these tests. This was done to observe the fiber and paint chip debris behavior in the suppression pool for the relatively low strainer approach velocities (0.02 - 0.04 ft/s) representative of the Vermont Yankee strainers.

The fiber and paint chip debris quantities used in these tests were scaled (on a per square foot of strainer surface area basis) to those specified for an IBA and DBA at Vermont Yankee. The cylindrical strainer mockup used in these tests had approximately 1/400 times the surface area of the stacked disk strainers in the VY facility.

Four levels of pool turbulence were investigated in these tests:

<u>HI</u> - Stroke of 2 ft and a frequency of 57 strokes per minute for four downcomer tubes each with an area of 0.5 ft^2. This was estimated to be representative of suppression pool turbulence energy level occurring late in time during a Medium LOCA blowdown which relates roughly to a hypothetical 900 s VY IBA in a Mark I torus. A discussion of the chugging phenomena expected during a LOCA, the scaling analogy used to design the ARL test facility, and some previous results for fiber and sludge materials may be found in the NUREG/CR-6368 report [Souto and Rao, 1995]. The HI turbulence level used in the C test series resulted in a turbulence level that suspended both paint and fiber debris.

<u>MED</u> - Stroke of 2 ft and a frequency of 27 strokes per minute. This resulted in a turbulence energy level at 22% of the HI turbulence level. This level begins to suspend paint debris in addition to fiber debris.

<u>LO</u> - Stroke of 2 ft and a frequency of 13 strokes per minute. This resulted in a turbulence energy level at 5% of the HI turbulence level. This level was sufficient to keep fiber debris suspended off floor, but could not suspend any paint.

<u>Zero</u> - No stroke, recirculation flow only at 75 and 150 gpm through a 1 ft^2 splash plate at the pool surface. This results in a turbulence energy level of less than 1% of the HI turbulence level. This level was sufficient to partially circulate fiber and extend its settling time (relative to the quiescent pool settling time), but had no effect on paint settling times.

Two strainer approach velocities were investigated in these tests:

V = 0.06 ft/s - nominal approach velocity (based on total surface area) for VY strainers

V = 0.12 ft/s - high approach velocity (based on circumscribed surface area) for VY strainers

The fiber and the paint debris used for pool loading was the same as that used in the L test series. For fiber debris, the mixture of NUKON/Tempmat/Fibermat described in Section 2 was used. This material is representative of the materials in Vermont Yankee and also compares reasonably to the generic reactor materials used to develop the database found in NUREG/CR-6224. For paint chip debris, a cured epoxy paint (K&L 7575) in the sizes and size distribution shown in Section 2 was supplied by Keeler and Long which was similar to epoxy paint found in the VY plant. This paint debris had an approximate thickness of 7.5 mils and the weight per square foot was about 31.2 g/ft^2. This material is reasonably representative of reactor paint materials in terms of size, density, and settling velocity based on test results documented in the BWROG URG. Although the actual coatings in the VY drywell vary in thickness (7.5 mil to 15 mil range considered in the L-series tests), the 7.5 mil paint debris was used for these tests, since the thinner debris would have a lower settling velocity and thus would be more likely to transport to the strainer. The use of the thinner paint debris is considered conservative for that reason.

The parameters varied in the test matrix for the C series tests, shown in Table 6, are the pool turbulence level, the strainer approach velocity, and the debris loading in the pool. Of these parameters, both the material parameters and the turbulence parameters were intended to be relatively generic due to their high degree of uncertainty, with the key parameter being the relatively well defined Vermont Yankee specific approach velocity (0.02 ft/s on average for the VY CS system and 0.04 ft/s on average for the VY RHR system) to the ECCS strainers. This approach velocity would be representative of the fluid velocity at the debris surface prior to filling of the gaps between the strainer disks. After the gaps are filled with debris, the fluid velocity at the debris surface would be determined by considering the total strainer flow through the circumscribed area of the strainer. This velocity ranges from 0.06 ft/s for the CS system to 0.11 ft/s for the RHR system. As can be seen in Table 6, the strainer approach velocities actually tested ranged from 0.06 ft/s to 0.12 ft/s. Thus, this is somewhat higher than actually expected, for conservatism (higher surface velocities would tend to favor debris deposition on the strainer).

Table 6. C Series Test Matrix

Test	Strainer Approach Velocity	Pool Turbulence	Pool Debris Load
C0	0.06 - 0.12 ft/s	HI, MED, LO & ZERO	None – clean plate
C1a-0.12	0.12 ft/s	LO	Fiber only (1 lb mixed)
C1c-0.06-1Hz	0.06 ft/s	HI	
C1c-0.06-0Hz	0.06 ft/s	ZERO	
C1d-0.12	0.12 ft/s	LO	
C1b-0.06	0.06 ft/s	MED	
C1b-0.12r	0.12 ft/s	MED	
C2a-0.06	0.06 ft/s	LO	DBA load (1 lb fiber, 170 ft^2 paint)
C2b-0.06	0.06 ft/s	MED	
C2b-0.12	0.12 ft/s	MED	
C2c-0.12	0.12 ft/s	HI	
C2c-0.06-1Hz	0.06 ft/s	HI	
C2c-0.06-0Hz	0.06 ft/s	ZERO	

For a given test run (C-2, for example), a comparison of the time dependent head loss at the four pool turbulence levels was designed to demonstrate how pool turbulence and debris settling affect deposition of (especially paint chip) debris on the strainer surface. If turbulent forces are dominant, then head losses would remain low during the turbulent period and a large fraction of debris would still be suspended in the pool when the turbulence ends. Head losses would then be expected to remain low if settling forces are dominant late in time, as a larger fraction of the paint chip debris would then be subject to settling to the floor of the suppression pool. If strainer suction forces are dominant, then head losses could increase steadily throughout both the turbulence and the settling phases in the pool as debris continues to collect on the strainer.

Prior to the C tests, three possible scenarios were postulated:

1) Turbulence keeps all debris suspended in the pool, but does not impact the rate of debris buildup on the strainer. In this case, one would expect a combination of fiber and paint debris to build up on the strainer during the blowdown phase of the accident. Following the end of blowdown, relatively rapid sedimentation of paint debris would occur such that the debris buildup on the strainer would be primarily fiber. (This is the default set of assumptions used to develop prior estimates of debris buildup on the strainers.)

2) Turbulence not only keeps the debris suspended in the pool during the blowdown phase of the accident, but also impedes the deposition of (especially paint) debris on the strainer. In that case, there is no period of time during which significant paint debris is deposited, and the overall debris deposition on the strainer is very similar to what would be expected for fibrous debris only.

3) The level of turbulence in the pool following the blowdown phase is sufficiently high that there is a long-term impact on both paint chip and fiber deposition on the strainer surface. In that case, the ultimate head loss is reduced because of the reduction in both paint chip and fibrous debris deposition.

A comparison of results at different pool turbulence levels and a comparison between the results of the C-1 series (fiber only) and the C-2 series (fiber with paint) determined which of the above scenarios is a closer description of reality.

The C tests were run during the week of February 16-20, 1998. The measured parameter was the head loss (in inches of water) as a function of time, approach velocity, and turbulence (chug) level. Key results from these tests are summarized in Table 7. The entrainment values are estimates of the debris fraction initially suspended or entrained in the pool based on observation.

Table 7. C Series Test Results

Designator	Head Loss @ time (in. @ min)	Chug level	Flow vel level	Fiber entrained	Paint entrained
C0		All	All	-	-
C1b-0.12r		Med	Hi	All	-
C1a-0.12 C1d-0.12		Lo	Hi	All	-
C1c-0.06-1Hz		Hi	Lo	All	-
C1b-0.06		Med	Lo	All	-
C1c-0.06-0Hz		Zero*	Lo	All	-
C2c-0.12		Hi	Hi	All	80%
C2b-0.12		Med	Hi	All	10%
C2c-0.06-1Hz		Hi	Lo	All	80%
C2b-0.06		Med	Lo	All	10%
C2a-0.06		Lo	Lo	All	1%
C2c-0.06-0Hz		Zero*	Lo	All	80%

* The zero chugging-induced turbulence follows an initial period of high turbulence that was required to initially suspend the debris.

3.1 Qualitative Analysis of the C Tests

Test C0 was a baseline test series without any debris in the pool. Data was taken at three chugging levels and two flow velocities. These tests demonstrated that the chugging turbulence levels had a negligible impact on head loss across a clean strainer.

The C1 test series was performed with only fibrous debris in the pool. At the higher strainer approach velocity of 0.12 ft/s, complete deposition on the strainer of all fibrous debris initially in the pool was observed at both the medium and low pool turbulence level. As would be expected in that case, the final measured head loss was approximately the same in both cases (independent of pool turbulence level). This indicates that for these flow versus pool turbulence conditions, the strainer suction forces were dominant relative to the pool turbulence forces for fibrous debris.

At the lower strainer approach velocity, both the medium and high pool turbulence levels were sufficient to keep all fibrous debris in suspension and prevent its deposition on the strainer. This indicates that for these flow versus pool turbulence conditions, the pool turbulence forces dominated the strainer suction forces for fibrous debris. In the final fiber-only test run at this lower flow rate, debris was initially suspended in the pool through induced chugging turbulence. The piston chugging was then terminated such that the only source of pool turbulence was the recirculation of the flow through the strainer. At this very low turbulence level, fibrous debris was collected on the strainer. However, significant fiber sedimentation was also observed, thereby limiting the total quantity of debris collected on the strainer and hence the final head loss value.

The C2 test series was performed with both fiber and paint debris in the pool. At the higher strainer approach velocity, the degree of paint debris deposition on the strainer was a strong function of pool turbulence. The high pool turbulence level (Test C2c-0.12) was sufficient to keep most of the paint debris suspended in the pool rather than settling to the pool floor, and this suspended paint debris was then readily deposited on the strainer along with the fibrous debris. Thus, the strainer suction forces dominated the pool turbulence forces for both paint and fibrous debris under these conditions. At the medium pool turbulence level (Test C2b-0.12), most of the paint debris settled to the pool floor, and little remained suspened where it could be ultimately depsoited on the strainer surface. Hence, the measured head loss in this case was only slightly higher than the corresponding result from the fiber-only tests. This indicates the dominance of the settling forces for paint debris even at the medium pool turbulence level.

At the lower strainer approach velocity, one observed similar results with respect to paint debris sedimentation. Thus, at the high pool turbulence level (Test C2c-0.06-1Hz), most of the paint debris did not settle to the pool floor, whereas at the medium pool turbulence level (Test C2b-0.06), significant sedimentation was observed. However, at this lower approach velocity, the pool turbulence in both cases was also sufficiently high to keep all debris (both paint chip and fiber) in suspension and prevent its deposition on the strainer. Thus, as was the case in the fiber only tests conducted at this flow rate, no measurable head loss was observed. This indicates that for these conditions, the pool turbulence forces dominate the strainer suction forces for both debris types. At the low pool turbulence level (Test C2a-0.06), deposition of fiber on the strainer was observed. However, paint debris sedimentation was sufficiently complete such that no more than a negligible quantity of such debris was deposited on the strainer. This same effect was observed in Test C2c-0.06-0Hz, wherein the debris was initially fully suspended through high chugging turbulence, with the piston chugging then terminated such that the only source of pool turbulence was the recirculation of the flow through the strainer. As in Test C2a-0.06, little or no paint debris deposition on the strainer was observed. Also as in the fiber-only test conducted in this manner, significant settling of even fibrous debris was obsserved. Thus, at the lower strainer approach velocity of 0.06 ft/s, significant paint debris deposition on the strainer was not observed under any pool turbulence conditions. Figures 1A and 1B illustrate the critical debris deposition results from the C series tests.

Based on the results of these tests as summarized above, one can draw several qualitative conclusions relative to the expected behavior of the actual Vermont Yankee strainers during a postulated LOCA. During the initial stages of a LOCA, either DBA or IBA, little debris will have built up on the strainers, and the gaps between the strainer stacked disks will be open (not filled with debris). During that initial time period, the flow velocity at the strainer/debris surface is determined by the total strainer surface area and ranges from 0.02 ft/s to 0.04 ft/s as previously stated. This surface velocity is the important parameter for characterizing the relative importance of the strainer suction force relative to the force of the random bulk turbulence in the pool. Visual interpretation of the test video obtained during the C-series testing demonstrated that the key factor in determining whether debris was deposited on the strainer was not whether the debris impacted the strainer surface, but whether the flow rate was sufficient to keep that debris on the surface. At both approach velocities, debris was observed to continually impact the strainer surface. However, for certain combinations of approach velocity and pool turbulence, the random bulk fluid velocity was sufficiently high to reentrain the debris into the pool. Thus, the expected behavior of the actual Vermont Yankee strainers prior to gap closure is best represented by the results of the testing done at the lower strainer approach velocity of 0.06 ft/s. For that approach velocity, it was demonstrated that no significant deposition of paint debris on the strainer could occur. The paint debris either rapidly settled to the pool floor at low turbulence, or remained in suspension at medium to high turbulence. In fact, at this approach velocity, even fibrous debris deposition on the strainer was inhibited by the turbulence. Thus, during the early stages of a DBA LOCA and during all phases of an IBA LOCA (during which insufficient debris is generated to fill the gaps), no paint debris deposition on the strainer is expected.

During the later stages of a DBA LOCA, after the gaps have essentially filled with debris, the flow velocity at the debris surface is determined by the circumscribed strainer surface area and ranges from 0.06 ft/s to 0.11 ft/s as previously stated. Thus, for the CS strainer (0.06 ft/s velocity), the conclusions drawn from the low velocity tests summarized above are still valid, even after gap closure. For the RHR strainer (0.11 ft/s velocity), the testing done at 0.12 ft/s is most directly relevant. Those results would suggest that paint debris suspended in the pool at the time of gap closure could subsequently be deposited on the strainer surface, causing a significant head loss increase. However, the timing of debris deposition on the strainers is such that pool turbulence is significantly diminished by the time gap closure occurs. The results of the C-2 tests done at medium to low pool turbulence demonstrate that rapid settling of the paint debris is then expected to occur. Thus, a negligible quantity of paint debris remains suspended in the pool by the time gap closure occurs, and negligible paint debris deposition on the strainer is expected.

These qualitative arguments on paint debris behavior suggest that paint debris does not impact Vermont Yankee strainer head loss under any relevant DBA or IBA LOCA conditions. These arguments are based on best-estimate anticipated debris quantities, pump flows, and strainer sizes. However, these arguments should be revisited as part of the final Vermont Yankee strainer head loss performance assessment to confirm that the preliminary conclusions reached herein are valid.

C2a - lo chug lo v

<PROPRIETARY INFORMATION REMOVED>

Figure 1A. Head loss results for test C2a-0.06

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C2b - med chug lo v

<PROPRIETARY INFORMATION REMOVED>

Figure 1 B. Head loss results for test C2b-0.06

3.2 Quantitative Analysis for the C Tests

3.2.1 C tests – Density Estimate for fiber bed in the C Tests

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3.2.2 Fiber Diameter Estimate for the C tests

<PROPRIETARY INFORMATION REMOVED>

Table 8. Comparison of test results and HLOSS calculations for different fiber diameters (The debris density used is 2.1 lb/ft^3)

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3.2.3 Debris Deposition Analysis using the ARL C tests

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3.2.3.1 Test C2a-.06 (C2a)– Low flow and the lowest chugging energy. Fiber plus paint, but very little paint on strainer.

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3.2.3.2 Test C1c-.06-0Hz (C1c) – Low flow and zero chugging. Fiber debris.

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3.2.3.3 Test C2c-0.06-0Hz (C2f)– Low flow and zero chugging. Fiber debris plus paint but very little paint on strainer.

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3.2.4 Comparison to Blockage Calculations

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Table 9. Blockage Results vs. C Series Test Values

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4.0 Summary and Conclusions

Tests to evaluate generic strainer performance under the specified Vermont Yankee conditions were performed at Alden Research Labs in Holden, Massachusetts [Johnson, 1998]. The purpose of the testing was to investigate the effect of paint chips and fiber debris on the performance of new ECCS suction strainers to be installed at the Vermont Yankee plant. Two separate sets of tests described as L (Loop facility) tests and C (Chugging facility or pool facility) tests were planned and executed. Both test series represented previously untested conditions unique to the Vermont Yankee ECCS performance expectations under accident conditions. The results of these tests can be used to apply the HLOSS code to Vermont Yankee strainer design/evaluation efforts.

The L tests were performed in the "Head Loss Loop Facility", which consists of a 100 gallon flow loop with a flat disk strainer of approximately 0.8 ft^2 in area. The purpose of the testing was to investigate the effect of VY specific debris on a generic strainer in a loop geometry. Flow through the loop can be closely controlled via variable speed pumps so that values of head loss versus (steady-state) velocity can be generated for a known debris bed on the strainer. Values of head loss at representative VY flow velocities were generated for a range of debris quantities/composition.

All but one of the L tests formed thick 0.35 lb. fiber beds on the 0.8 ft^2 flat plate strainer. Visual observations indicated non-uniform loading across the strainer due to wall effects and a dominant settling velocity (vs. flow velocity) force with debris thicknesses estimated at 2-6 inches and slightly different loading behavior from test to test. These thicknesses can be estimated/verified perhaps to within 0.5 inch using the filmed results of the tests [ARL, 1998]. The debris was thickest in the center of the strainer and thinnest at the edge position with the difference being about a factor of two. Turning off the flow resulted in expansion of the fiber debris bed by as much as 1 or 2 inches. The thickness was measured during the L4 test at 3-3.5 inches at the edge and 5-5.5 inches in the center of the strainer. All of the debris was estimated to be on the strainer at that time and using a density of 1.5 lb/ft^3 would yield an average thickness on the strainer of about 3.7 inches. The approach velocity was 0.02 ft/s for these initial bed thickness measurements. For 100% deposition of the 0.35 lb. fiber mass at a reference density of 2.77 lb/ft^3, the fiber would form an average fiber bed of 2 inch. Accordingly the apparent density could range from 1.8 lb/ft^3 to 0.9 lb/ft^3 depending on the flow velocity, location on the strainer, and time of debris bed measurement. Based on an average fiber debris depth of 3.7 inches, a nominal L test density for head loss estimates would be 1.5 lb/ft^3 with an uncertainty factor of 30%.

Pretest predictions for the L tests were performed using a reference density of 2.77 lb/ft^3 and an effective fiber density of 7.1 micron based on a weight percent averaging of the manufacturer as-fabricated data. These values produced estimated head losses of approximately 6 inches (vs. 1.5 inches actually measured) at 65F and a flow velocity of 0.04 ft/s. Both the effective fiber diameter (which is used to estimate the average surface-to-volume ratio for the entire debris bed) and the debris bed average density are dependent on specific debris loading conditions and different input values for both values are indicated in order to analytically match the observed results. Based on an observed average fiber debris depth of 3.7 inches, the L test density for head loss estimates would more appropriately be 1.5 lb/ft^3. Head loss measurements from the L tests can then be conservatively matched using a density of 1.5 lb/ft^3 and an effective fiber diameter of 10.7 μm.

The C tests were performed in the (modified) "Chugging Facility." This facility, which is a scale model of a section of the BWR Mark I torus, uses pistons to simulate the turbulence induced by the downcomers. Previously, this facility had been used to investigate debris sedimentation under various levels of turbulence. A modification to this facility added a small (2.8 ft^2) cylindrical strainer in the pool along with the associated piping and a variable speed pump. This facility was then used to investigate the effect of varying degrees of pool turbulence on the rate of debris buildup on the strainer (as inferred from the time-dependent head loss across the strainer). This was done to simulate debris removal behavior from a pool for the very low strainer approach velocities (0.02 ft/s on average for the CS system and 0.04 ft/s on average for the RHR system) representative of the Vermont Yankee strainers.

The C1 test series was performed with fiber debris in the pool. Fiber debris was suctioned from the pool completely in tests C1a-0.12, C1d-0.12, and C1b-0.12r. over a period of thirty minutes and deposited on the strainer this indicated that the strainer suction forces were dominant at the higher approach velocity of 0.12 ft/s regardless of turbulence level. Fiber debris remained suspended in the pool indefinitely in tests C1c-0.06-1Hz and C1b-0.06, which were performed at the expected VY DBA flowrate. These tests showed that turbulent forces dominated the strainer suction force at the HI and MED turbulence levels for the lower approach velocity of 0.06 ft/s Fiber debris was partially suctioned from the pool in the C1c-0.06-0Hz test over a 60 minute period and deposited on the strainer, indicating that settling forces were a factor which limit fiber debris deposition on the strainer under the condition of recirculation only.

The C2 test series was performed with both fiber and paint debris in the pool. When paint was added to the debris mixture, both paint and fiber could only be suctioned from the pool and deposited on the strainer under the higher approach velocity and the HI turbulence level as indicated by test C2c-0.12. Fiber with small amounts of paint were suctioned from the pool and deposited on the strainer under MED turbulence levels in the C2b-0.12 test performed at the higher flow velocity which was very similar to the fiber only result seen in C1b-0.12r. For the postulated VY DBA approach velocity of 0.06 ft/s, no fiber or paint was collected on the strainer as indicated by the C2b-0.06 and C2c-0.06-1Hz tests. Under post DBA/IBA conditions of recirculation flow, only fiber was collected as indicated by the C2c-0.06-0Hz test. Comparison of the data taken at the 0.06 ft/s approach velocity (C2a-0.06, C2b-0.06 and C2c-0.06 tests) clearly indicate that neither fiber or paint can be suctioned from the pool and deposited on the strainer during for turbulent conditions in excess of turbulence driven by recirculation flow alone at the initial Vermont Yankee approach velocities of 0.02 ft/s and 0.04 ft/s. For conditions where pool turbulence is driven by recirculation flow, only fiber can be suctioned from the pool and deposited on the strainer and only a fraction of the fiber is deposited with the remainder settling to the bottom of the pool.

The qualitative results from the C-series tests concerning paint debris deposition on the strainer suggest that paint debris does not impact Vermont Yankee strainer head loss under any relevant DBA or IBA LOCA conditions. At pool turbulence levels that are sufficient to keep paint debris suspended in the pool (rather than settling to the pool floor), the turbulence is also sufficient to prevent deposition of the paint debris on the strainers. Once turbulence levels are reduced so as to allow the deposition of debris on the strainers, the turbulence is no longer sufficient to prevent rapid settling of the paint debris. In no case was it possible to observe a measurable impact on strainer head loss due to coatings debris.

For the C tests, depending on the flow velocity and time of debris bed measurement, the density of the debris bed could range from 1.4 lb/ft^3 to 4 lb/ft^3. Based on an observed average fiber debris thickness of 2 inches from test C1a at the 0.12 and 0.06 ft/s approach velocities, a nominal C test density for head loss estimates would be 2.1 lb/ft^3 with an uncertainty factor of 50% due to non-uniform deposition and the uncertainty in the thickness measurement

Head loss measurements from the C tests which suctioned fiber from the pool and deposited it on the strainer were lower than would be predicted using extrapolated values from the high velocity database found in NUREG/CR-6224. Pretest predictions for the C tests were performed using a density of 1.5 lb/ft^3 and an effective fiber diameter of 10.7 μm based on results of the L series tests. These values produced estimated head losses of approximately 5 inches (vs. 10 inches actually measured) for 100% debris deposition. Both the effective fiber diameter (which is used to estimate the average surface-to-volume ratio for the entire debris bed) and the debris bed average density are dependent on specific debris loading conditions and different input values for both values are indicated in order to analytically match the observed results. Head loss measurements from the C tests can be reasonably matched using the observed average density of 2.1 lb/ft^3 and an effective fiber diameter of 8.3 μm.

Comparison of the BLOCKAGE calculations to the settling results seen in the C tests [156 ft^3 pool, 75 gpm flow, 0.35 ft^3 fiber] indicates agreement somewhere between the tau=1 case where quiescent pool debris settling velocities are used and the tau=0.5 case where the settling velocity for the debris is one half the quiescent pool settling velocity. The tau=1 case indicates approximately 75% fiber deposition on the strainer in 60 minutes and the tau=0.5 case indicates approximately 80% deposition in 60 minutes vs. a 75% removal in 50-60 minutes for the C tests. The C tests indicated near complete settling in 40-50 minutes where BLOCKAGE indicates that about 10% of the fiber would still be in the pool at that time. This seems to indicate that the settling times are slightly faster and the settling fraction is slightly higher in the C cases than what would be predicted using the default (NUREG/CR-6224) settling velocities found in BLOCKAGE

Comparison of the results of the L series tests and the C series tests indicates that the average debris density was lower and the effective surface to volume ratio was higher in the L tests which were conducted on a flat plate and in a flow loop system vs. the C tests which were conducted using a cylindrical strainer in a pool system. Tests under both conditions produced head loss values lower than those, which would be extrapolated from the database, found in NUREG/CR-6224.

5.0 References

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Attachment A

The following is an HLOSS Output File used in the analyses to estimate the head loss across the cylindrical strainer under the conditions of the C1a-.I2 test.

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