July 31, 2006

MEMORANDUM TO: James E. Dyer, Director
Office of Nuclear Reactor Regulation

THRU: Thomas O. Martin, Director ***/RA/***
Division of Safety Systems
Office of Nuclear Reactor Regulation

Michael L. Scott, Branch Chief ***/RA/***
Safety Issues Resolution Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

FROM: John Lehning, Reactor Systems Engineer ***/RA/***
Safety Issues Resolution Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

SUBJECT: FOREIGN TRAVEL TRIP REPORT—NRC STAFF VISIT TO CHALK RIVER LABORATORIES TO OBSERVE SUMP STRAINER HEAD LOSS TESTING PERFORMED BY ATOMIC ENERGY OF CANADA, LIMITED

Three Nuclear Regulatory Commission (NRC) staff members traveled to the Chalk River Laboratories located in Chalk River, Ontario, on June 26–30, 2006, to observe head loss testing performed by Atomic Energy of Canada, Limited (AECL), and to discuss related technical issues associated with containment sump strainer testing and qualification. AECL is one of five vendors supplying sump strainers to U.S. pressurized-water reactors (PWRs) in conjunction with PWR licensees' efforts to respond to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation at Pressurized-Water Reactors," by resolving the sump performance issues associated with Generic Safety Issue 191.

The testing observed by the staff consisted of both reduced-scale and large-scale head loss tests of AECL's Finned Strainer design to support its installation at three PWR units operated by Dominion Energy (Surry Power Station, Units 1 and 2, and Millstone Power Station Unit 2). Although the tests could not be observed in their entirety due to their extended durations and unforeseen travel delays, the staff was able to observe the performance of key steps in the test procedures. On the basis of these observations, the staff concluded that AECL's test procedures and setup were generally conducive to generating conservative results. However, as discussed further in the enclosed trip report, a number of potential concerns related to the head loss test procedures and their interface with other areas of the sump strainer performance analysis were identified and discussed with AECL and Dominion during the visit.

CONTACT: John Lehning, NRR/DSS/SSIB
301-415-1015

In addition to observing head loss testing, the staff discussed several technical issues with AECL and Dominion representatives, including chemical effects, containment coatings, and downstream sampling. The staff's discussions on chemical effects remained general, since AECL had not completed test plans and procedures in this area at the time of the staff's visit. Although, for this reason, the staff could not reach a conclusion on the adequacy of the test program, the trip allowed the staff to provide timely feedback on AECL's general approach prior to the commencement of the testing program. With regard to containment coatings, AECL presented the results of proprietary testing on the performance of various types of coatings under postulated design-basis accident conditions. These test results provided the staff insight into the failure modes of different coatings and the assessment of whether the adhesion of qualified coatings remains adequate for ensuring continued satisfaction of the original qualification requirements. Finally, AECL presented an analysis of several downstream samples of the debris-laden fluid that had passed through a Finned Strainer test module, and the staff provided limited feedback. In part because the application of the downstream samples and associated analysis had not been clearly defined, the staff did not form a definitive conclusion as to the adequacy of these procedures.

In summary, the trip was a valuable and timely opportunity both to (1) interact with and provide feedback to AECL concerning head loss test procedures and other strainer qualification testing and (2) gain insight from previous testing conducted by AECL that is relevant to the NRC's efforts to resolve Generic Safety Issue 191. Detailed observations from the staff's trip are provided in the enclosed NRC Foreign Trip Report.

Enclosure: NRC Foreign Trip Report

cc w/ enclosure:

<u>DISTRIBUTION:</u>
W. Dean, AO/EDO
J. Dunn Lee, OIP
T. Rothschild, OGC
ONSIR/INFOSEC
M. Cullingford, NRR
T. Hiltz, NRR
T. Martin, NRR/DSS
M. Weber, NRR
J. Grobe, NRR/DCI
M. Yoder, NRR/DCI/CSGB
P. Klein, NRR/DCI/CSGB
M. Scott, NRR/DSS/SSIB
S. Lu, NRR/DSS/SSIB
R. Architzel, NRR/DSS/SSIB
J. Golla, NRR/DPR/PGCB
A. Hiser, NRR/DCI/CSGB
T. Hafera, NRR/DSS/SSIB
S. Unikewicz, NRR/DCI/CPTB
DCI RF
SSIB/rf

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ADAMS Accession#: ML062020596 NRR-105

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DATE	07/ 25 /06	07/ 27 /06	07/ 27 /06	07/ 26 /06	07/ 31 /06

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NRC FOREIGN TRIP REPORT

Subject

NRC Staff Visit to the Chalk River Laboratories to Observe Head Loss Testing of the Atomic Energy of Canada, Limited, Finned Strainer Design for Surry Power Station, Units 1 and 2, and Millstone Power Station, Unit 2

Dates of Travel and Countries/Organizations Visited

Dates:
June 26–30, 2006

Organizations:
Atomic Energy of Canada, Limited (AECL)
Dominion Energy (Dominion)

Location:
Chalk River Laboratories
Chalk River, Ontario
Canada

Authors, Titles, and Agency Affiliations

John Lehning, Reactor Systems Engineer, NRC/NRR/DSS/SSIB
Paul A. Klein, Senior Materials Engineer, NRC/NRR/DCI/CSGB
Matthew G. Yoder, Materials Engineer, NRC/NRR/DCI/CSGB

Sensitivity

Non-Sensitive – Subsequent reviews by AECL and Dominion did not identify any proprietary information in this report.

Background/Purpose

In response to Generic Letter 2004-02 (GL 2004-02), “Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors,” PWR licensees are in the process of evaluating the performance of their containment recirculation sumps and making any plant modifications necessary to achieve regulatory compliance according to approved mechanistic sump performance criteria. Atomic Energy of Canada, Limited (AECL), is one of five vendors supplying replacement sump strainers to U.S. PWRs in support of their GL 2004-02 resolution activities.

As part of the regulatory process of verifying that PWR licensees are appropriately addressing GL 2004-02, the NRC staff has been conducting observations of head loss testing at each of the five replacement strainer vendors. These head loss testing observations have provided many benefits, including (1) opportunities for the staff to understand and provide feedback on replacement strainer designs and qualification testing approaches prior to installation, (2) assurance that an acceptable level of quality exists across the spectrum of strainer vendors contracting with U.S. PWR licensees, (3) a source of input to staff audit reports on PWR licensees' GL 2004-02 activities, and (4) a resource for the staff's review of PWR licensees' supplemental responses to GL 2004-02.

In the U.S. market, AECL has contracts to supply replacement sump strainers to 7 PWR units, including Millstone Power Station (MPS), Units 2 and 3; Surry Power Station (SPS), Units 1 and 2; and North Anna Power Station, Units 1 and 2, which are all operated by Dominion, as well as V.C. Summer Nuclear Station, which is operated by South Carolina Electric and Gas. AECL became involved with sump strainer performance issues in the mid-1990s and has since completed the design and testing of sump strainers for reactors located both in Canada and abroad. Through this work, AECL has accumulated significant knowledge of technical issues associated with sump performance that is not easily accessible to the NRC staff due to proprietary controls (in contrast, the significant technical contribution made by the NRC's test programs is publicly available). Therefore, the staff's visit to AECL was a unique and timely opportunity to observe replacement strainer testing for U.S. PWRs, as well as to engage AECL in discussion of historical research findings, particularly those associated with the performance of containment coatings.

<u>Abstract: Summary of Pertinent Points/Issues</u>

The NRC staff spent two days at the Chalk River Laboratories reviewing AECL's strainer testing and qualification program (note that the trip had been shortened by one day due to weather-induced travel delays). The following objectives were met during the staff's visit to AECL: (1) reviewing test plan documentation and observing key procedural steps for a reduced-scale head loss test for SPS 1 and 2, (2) reviewing test plan documentation and observing key procedural steps for a large-scale head loss test for MPS 2, (3) discussing AECL's plans for upcoming chemical effects testing, (4) discussing the results of previous proprietary research conducted by AECL on coatings used in nuclear power plants, (5) discussing the results of AECL's downstream sampling tests, and (6) providing feedback to AECL and Dominion on the staff's observations during the trip.

Overall, the staff had a positive impression of the observed large-scale and reduced-scale head loss tests, since AECL's test procedures and setup generally appeared conducive to generating conservative results. However, the staff did identify a number of potential concerns related to AECL's head loss testing and its interface with other areas of the sump strainer performance analysis; these potential concerns were shared with AECL and Dominion during the trip and are documented in detail in Attachment III.

At the time of the staff's visit, AECL's chemical effects testing had not commenced. Furthermore, test plans and procedures had not been finalized. Therefore, the discussion on chemical effects testing focused on general objectives and concepts rather than specific procedures or detailed information. Although the general testing approach presented by AECL appeared reasonable, without additional information the staff could not reach a conclusion on the adequacy of AECL's chemical effects test program.

AECL also discussed proprietary results of coatings testing performed for Canadian nuclear power plants several years ago. The testing involved exposing coating samples to adverse conditions that could be experienced during a design-basis accident. The discussion provided insight into assessing the adequacy of the adhesion of qualified coatings to ensure that they continue to satisfy their original qualification requirements. During the discussion, the staff was shown a variety of specimens from these coatings tests.

AECL discussed the test methodology and results for several downstream samples taken to quantify the amount of fibrous and particulate debris passing through the strainer. Separate tests were used to measure the fibrous and particulate pass-through. The staff did not provide detailed feedback in this area because (1) the application of the test results to licensees' downstream effects evaluations had not been clearly defined and (2) the primary NRC staff contacts for downstream effects were not present during the trip.

Discussion

See Attachment III.

Pending Actions/Planned Next Steps for NRC

The staff will continue to evaluate the information obtained from AECL and will engage AECL and/or Dominion in teleconferences if any additional clarification or staff feedback is necessary. Further, the information documented in this trip report will constitute a source of input for the staff's review of supplemental responses to GL 2004-02 and in its audit reviews for one or more selected plants that are planning to install AECL-designed replacement strainers.

Points for Commission Consideration/Items of Interest

No items were identified as being of potential interest to the Commission.

Attachments

Attachment I:	Agenda of the NRC Staff's Visit to the Chalk River Laboratories
Attachment II:	List of People Contacted
Attachment III:	Detailed Discussion
Attachment IV:	AECL Strainer Testing Slides

"On the Margins"

AECL presented an overview of the major activities at the Chalk River Laboratories and other company facilities. Notable activities include the development of advanced CANDU pressurized-heavy-water reactor designs, the refurbishment of operating CANDU reactors (including intensive projects such as retubing reactor vessels), and the production of radioactive isotopes for medical applications. The staff also toured selected areas of the Chalk River facility, including several machine shops used for onsite component fabrication.

Attachment I. Agenda of the NRC Staff's Visit to the Chalk River Laboratories

NRC visit to AECL Chalk River Laboratories
Subject: Testing for ECC Strainers
Time: June 27-28, 2006, 8:30am to 5:30pm.

NRC: Matthew Yoder, Paul Klein, John Lehning
Dominion: Marty Badewitz, Bill Faye, Marty Legg, Addison Hall, Rick Redmond
Sargent and Lundy: Bob Gerke, Tom Bartoski

Agenda – June 27, 2006

#	Activity	Location	Lead	Time	Expected Attendees
1.	Welcome, Introductions and AECL/CRL Overview	B456 conference room 212	Shaun Cotnam	8:30 – 9:00 am	NRC staff Dominion Shaun Cotnam Nigel Fisher Buddy Taylor Randy Lovelace Chris Knight David Rhodes
1a.	Agenda finalization	B456 conference room 212	Buddy Taylor	9:00 – 9:30 am	NRC staff Dominion Shaun Cotnam Nigel Fisher Buddy Taylor Randy Lovelace Chris Knight David Rhodes
2.	Tour of Test Facilities - Large Scale tank - Reduced Scale tank - Test modules: hands-on session.	B456	Nigel Fisher	9:45 – 11:30	NRC staff Dominion Nigel Fisher Buddy Taylor David Rhodes Gina Strati
3.	NRC Break out session	B456 small conference room		11:30 – 12:00	NRC staff
4.	Lunch	Cafeteria	Hosted by Shaun Cotnam	12:00-13:00	NRC staff Dominion Nigel Fisher Buddy Taylor Randy Lovelace Shaun Cotnam Chris Knight David Rhodes Gina Strati
5.	Debris preparation and demonstration	B456	Gina Strati	13:00-13:30	NRC staff Dominion Nigel Fisher Buddy Taylor Gina Strati
6.	Start of Reduced Scale Test	B456	Gina Strati	13:30 – 14:30	NRC staff Dominion Nigel Fisher Buddy Taylor Gina Strati
7.	NRC Break out session	B456 small conference room		14:30 – 15:00	NRC staff
8.	Large Scale 3rd fiber addition Reduced Scale 2nd fiber addition	B456	Nigel Fisher	15:00 – 15:30	NRC staff Dominion Nigel Fisher Buddy Taylor Gina Strati
9.	Presentation / Discussion on Coatings approach	B456 conference	Nigel Fisher	15:30 – 16:30	NRC staff Dominion

		room 212			Nigel Fisher Buddy Taylor
10.	Presentation / Discussion on Bypass Testing	B456 conference room 212	Nigel Fisher	16:30 – 17:00	NRC staff Dominion Nigel Fisher Buddy Taylor David Guzonas
11.	Day 1 Closeout meeting and Day 2 Agenda.	B456 conference room 212	Buddy Taylor	17:00 – 17:30	NRC staff Dominion Nigel Fisher Buddy Taylor Randy Lovelace Chris Knight Shaun Cotnam

Agenda – June 28, 2006

13.	Presentation of Chemical Effects approach	B456 conference room 212	Nigel Fisher	8:30 – 9:30	NRC staff Dominion Nigel Fisher Buddy Taylor Randy Lovelace Chris Knight David Guzonas
14.	Large Scale 4rd fiber addition Reduced Scale 3rd fiber addition	B456	Nigel Fisher	As scheduled	NRC staff Dominion Nigel Fisher Buddy Taylor Gina Strati
15.	NRC Break out session	B456 small conference room		As scheduled	NRC staff
16	Lunch	Cafeteria	S. Cotnam	12:00 – 13:00	NRC staff Dominion Nigel Fisher Buddy Taylor Shaun Cotnam David Rhodes Gina Strati David Guzonas
17	Day 2 Closeout meeting	B456 conference room 212	Buddy Taylor	16:00 – 16:30	NRC staff Dominion Nigel Fisher Buddy Taylor

Agenda – June 29, 2006

18.	Large Scale Reduced Scale	B456	Nigel Fisher	As needed?	NRC staff Dominion Nigel Fisher Buddy Taylor Gina Strati

Note that the schedule provided above was devised prior to the staff's visit. Weather-induced travel delays resulted in the agenda items being compressed into the two-day period of June 28–29. Therefore, although the days and times noted in the agenda may not be accurate, all of the above agenda items were completed during the visit.

Attachment II. List of People Contacted

Name	Title / Organization	Nature of Communication
Buddy Taylor	Account Representative Global Nuclear Products AECL	Trip coordination AECL's U.S. strainer contracts
Pamela Kranz	Administrator Global Nuclear Products AECL	Trip coordination
David B. Rhodes	Technical Director Fluid Sealing Technology Unit AECL	AECL's strainer technology, test procedures, and test results
C. H. (Chris) Knight	Branch Manager Project Services Branch AECL	AECL's U.S. strainer contracts
Shaun K. Cotnam	Director Global Nuclear Products AECL	AECL's organizational functions, overview of AECL sump strainer program
Nigel Fisher	AECL	AECL's strainer design, head loss test facilities, test procedures, and test results
Randy Lovelace	AECL	AECL's strainer technology
David Guzonas	AECL	AECL's plans for chemical effects testing
Martin F. Badewitz	Project Engineer Nuclear Engineering Dominion	Dominion replacement strainer projects
Bill Faye	Dominion	Dominion replacement strainer projects
Marty Legg	Dominion	Dominion replacement strainer projects
Addison Hall	Dominion	Dominion replacement strainer projects
Rick Redmond	Dominion	Dominion replacement strainer projects
Bob Gerke	Sargent and Lundy	Sargent and Lundy contract work for Dominion
Tom Bartoski	Sargent and Lundy	Sargent and Lundy contract work for Dominion

AECL

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Attachment III. Detailed Discussion

On June 26–30, 2006, three members of the NRC staff visited Atomic Energy of Canada, Limited's (AECL's), Chalk River Laboratories. The visit included a tour of AECL's strainer testing and debris preparation facilities; observation of reduced-scale and large-scale thin bed testing for the Finned Strainer design; and a discussion of planned and completed testing concerning chemical effects, containment coatings, and strainer pass-through. The head loss testing observed by the staff was performed for two Dominion plants, Surry Power Station, Units 1 and 2 (SPS), and Millstone Power Station, Unit 2 (MPS 2).

AECL's Finned Strainer Design

The AECL Finned Strainer design proposed for SPS and MPS 2 consists of interconnected modules, each having an oblong central suction plenum with fins extending outward from both sides along the lengthwise dimension. Corrugated perforated plate is used to construct the fins, which constitute the available strainer surface area. Perforations of 1/16-inch are planned for all AECL strainers being marketed in the United States. Various structural elements are used for reinforcement.

In contrast to the actual plant strainer modules, the test modules have fins on only one side. Furthermore, as opposed to the actual modules, which have 8 fins per side, the reduced-scale test module has only 3 fins; furthermore, the outer face of the outer fins on the reduced-scale test module is unperforated, in part to prevent turbulence in the tank volume from disturbing the formation of a uniform debris bed. A conceptual diagram (not to scale) of an actual strainer module beside the test strainer modules is provided as Figure 1, below. Photographs of full-scale and reduced-scale test strainer modules are included in Attachment IV.

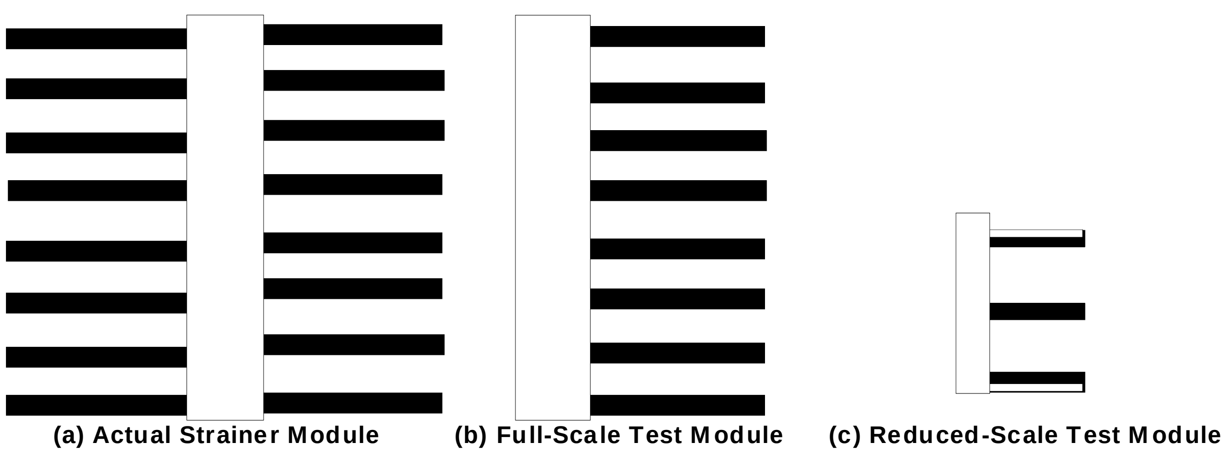


Figure 1: Conceptual Diagram of a Top View of the AECL Finned Strainer Design (Not to Scale)

As described in the head loss test plans reviewed by the staff, qualification of the AECL strainers tested two performance limits: (1) the thin bed case and (2) the full debris loading case. Head loss testing experience has shown that, depending upon the strainer design and the types and quantities of debris involved, the maximum strainer head loss can be achieved by either a thin layer of fibrous debris that effectively filters particulate (i.e., the thin bed case) or by a maximum debris loading configuration that may completely fill the interstitial areas of a complex geometry strainer and form a circumscribed debris bed around the strainer's outer surface (i.e., the full debris loading case). AECL indicated that previous testing has shown that the thin bed case has generally maximized head loss for the Finned Strainer design. However, AECL also stated that head loss can sharply increase when the gaps between the strainer fins become filled. Further, a tradeoff can be made between the two design limits by altering the pitch between adjacent fins. For a given strainer footprint, spacing the fins more closely will increase the total strainer surface area, thereby reducing the significance of the thin bed effect. However, spacing the fins more closely also reduces the strainer interstitial volume, which may increase the head loss resulting from the full debris loading. The staff noted that the fin pitch for the SPS strainer design is 4 inches (which corresponds to a gap of approximately 2 inches between adjacent fins), whereas for MPS 2, the fin pitch is 10 inches.

AECL representatives stated that a sacrificial strainer area of 150 ft^2 would be allocated for miscellaneous debris, such as tags and labels. Dominion representatives indicated that the intent was to add this sacrificial area to the strainer area demonstrated to be acceptable by head loss testing.

The AECL strainers proposed for SPS and MPS 2 are designed to function under fully submerged conditions (i.e., with a complete water seal present over all strainer surfaces). In response to a question from the NRC staff, AECL indicated that there are no vents or penetrations through the strainer that connect its internal volume to the containment atmosphere above the minimum post-accident water level.

Reduced-Scale Head Loss Test Observations

The staff made observations regarding a reduced-scale head loss test for SPS. Both SPS units are Westinghouse 3-loop reactors with the subatmospheric containment design. According to Dominion's response to Generic Letter (GL) 2004-02, during the recirculation phase of a design-basis accident, low-head safety injection (LHSI) pumps and recirculation spray (RS) pumps take suction from the containment recirculation sump. The LHSI pumps provide low-pressure, high-flow-rate cooling to the reactor core and are aligned to the containment sump when the refueling water storage tank (RWST) reaches its low-low level setpoint. The RS system provides long-term containment heat removal by passing sump water through a heat exchanger and then spraying it into the containment atmosphere. Currently, the RS pumps are started after a time delay of several minutes once the containment pressure exceeds its high-high setpoint; however, the NRC staff is currently reviewing the licensee's proposal to change the start signal for the RS pumps to the coincidence of signals for high-high containment pressure and a wide-range RWST level of 60%. The replacement strainer design is based upon obtaining NRC approval for this proposed change to the RS pumps' starting logic.

Each SPS unit has a single recirculation sump that is the common suction for the LHSI pumps and the RS pumps of both trains. AECL personnel described the replacement strainer design as incorporating a horizontal divider plate to hydraulically separate the suction of the LHSI pumps in the upper strainer section from the suction of the RS pumps in the lower strainer section. Hydraulic separation is employed because the RS pumps begin taking suction from the recirculation sump significantly earlier than do the LHSI pumps. Thus, this design allows the RS pumps to take suction through a strainer section that is fully submerged at the time they are actuated while allowing the upper strainer section used by the LHSI pumps to take advantage of the increased water level available at the time their suction is switched to the sump. The design conservatively assumes that 100% of the total plant debris load analyzed as reaching the strainer accumulates upon its lower section (i.e., complete debris transport occurs between the time the RS pumps start and the time the LHSI pumps are switched over to the recirculation sump).

The reduced-scale test tank is a cylindrical water tank roughly 7.5 ft in diameter and 5 ft high. The test fluid was station service water maintained at a temperature of 104 °F by heating elements and cooling coils. AECL stated that a 2-ppm concentration of micron-sized particulate was naturally present in the service water, which was supplied by the Ottawa River. Efforts were made to prevent debris settling in the test tank through the use of a mechanical stirrer and the positioning of the discharge line to induce turbulence along the tank floor.

The reduced-scale test observed by the staff was a thin bed test for the RS portion of the replacement strainer (i.e., the lower strainer section only). To facilitate the test setup, AECL did not prototypically model the tank water level. However, AECL stated that the large-scale demonstration test would simulate the actual containment water level. Each head loss test performed for SPS was considered to be applicable to both units, since the quantity of each type of debris added to the tank was intended to be bounding for both units.

The thin bed test used only fibrous and particulate debris, since the inclusion of reflective metallic insulation (RMI) could lead to nonconservative head loss results. The fibrous debris sources at SPS include Temp Mat, asbestos, Paroc mineral wool, and latent fibrous debris. Based upon the information provided in the test plan, AECL had apparently made efforts to simulate each material with a similar surrogate material; however, the staff did not investigate the appropriateness of the surrogate substitutions in the course of the trip (e.g., asbestos debris was modeled with cerafiber). The test plan indicated that the primary sources of particulate debris for SPS are latent particulate, qualified coatings, unqualified coatings, and calcium silicate. Walnut shell flour with a mean particle diameter of approximately 25 microns was used as the surrogate debris source for latent particulate and coatings debris. The test observed by the staff did not include calcium silicate, which was a small fraction of SPS's total particulate debris by volume. AECL stated that the observed test was a sensitivity case to examine the impact of the calcium silicate debris. AECL indicated that previous testing with this quantity of calcium silicate included had shown that its contribution to the measured head loss was non-negligible. The staff was further informed that some of the insulation categorized as calcium silicate may also contain asbestos. Rather than definitively identifying this potentially hazardous material, Dominion planned to perform separate head loss tests, first assuming that the material is calcium silicate particulate, and then assuming that it is asbestos fibers. The staff did not review this decision in detail as part of the trip.

All of the particulate debris was added at the beginning of the test, with the recirculation pump and mechanical stirrer running. Prior to being added to the tank, the walnut shell surrogate debris was placed into a mixing barrel, mixed with service water, and pressure washed for several minutes. The walnut shell flour was added slowly at the tank surface to promote mixing with the tank volume. The quantity of surrogate debris used during the test was derived by volumetrically scaling the quantity of actual plant debris by the ratio of the test strainer surface area to the proposed replacement strainer surface area. The staff noted that ideally, the surrogate particulate debris would consist of a scaled equivalent number of identically sized particles as the actual plant debris. AECL agreed and believed that, as a result of density differences between the walnut shell flour and some of the actual plant particulate debris, scaling based upon displaced volume would tend to more closely approximate this objective than scaling by equivalent mass. The staff did not review in detail the licensee's volumetric scaling method for particulate debris as part of the trip.

After one tank turnover following the particulate addition (roughly half an hour), the first 1/16-inch batch of fibrous debris was prepared for addition to the test tank. A batch of fibrous debris that had been previously fragmented by a leaf shredder was placed into the mixing barrel, service water was added, and the fibrous debris was then pressure washed for several minutes. Prior to its addition to the test tank, the fibrous debris was visually inspected to assure that large clumps were not present. The fibrous debris was added to the tank in a manner similar to the particulate debris. The second 1/16-inch batch of fibrous debris was added after 3 tank turnovers (roughly 1.5 hours); subsequent batches of fibrous debris were added when the head loss was considered to have stabilized (i.e., was changing by less than 5% or 0.01 psi in 1.5 hours, whichever is greater, and displaying no generally increasing trend). In all, six batches of fiber were added, a sufficient quantity to build a fibrous bed of 3/8-inch theoretical thickness. Any fiber remaining on the test tank surface was skimmed off just prior to the addition of the next batch and subsequently mixed with the incoming batch, pressure-washed, and returned to the test tank. Reprocessing floating fibers obviated justification that debris floatation in the test tank is prototypical of the actual plant containment pool.

In meetings with the five strainer vendors on May 24–25, 2006, the staff raised a general question concerning the conservatism of fibrous debris preparation procedures that do not include boiling to remove the binder material that holds individual fibers together. The basis for the staff's question was that earlier testing had shown noticeable increases in head loss when fibrous debris was boiled to simulate either routine heat exposure or submergence in the hot containment pool following an accident. However, the staff observed during the trip that a large fraction of the unboiled fibrous debris added to the test tank had been broken into fine fragments, with a significant quantity of suspended individual fibers. Although the staff could not examine Dominion's debris characterization and transport evaluations during the trip to confirm that the test debris size characteristics were conservative with respect to the analytical assumptions therein, the size distribution of fibers in the reduced-scale tank appeared reasonably conservative based on visual observation. Since AECL's pressure-washing procedure created a large quantity of fibrous fines, boiling away the binder material did not seem likely to have as significant an impact as it would for larger clumps of fibrous debris that had only been passed through a leaf shredder. AECL further stated that previous tests performed for Canadian plants had shown that boiling fiberglass debris did not have a significant effect on measured head loss.

The test duration was 45 hours. The maximum measured head loss was approximately 1.57 ft. According to the test plan, AECL will scale this value to account for the temperature-driven viscosity difference between the water in the test tank and the plant containment pool. Although the staff did not discuss head loss scaling during the trip, this issue was discussed with AECL and other strainer vendors during the May 24–25 meetings. The staff had noted a potential concern during these meetings that head loss scaling could be more complicated than simple viscosity correction if, for example, bore holes or other debris bed structural changes were to occur. Neglecting these complex structural phenomena could lead to nonconservative scaling results. Although the staff was not able to identify during the trip whether this potential concern was applicable to the observed reduced-scale test, it was noted that AECL is conducting its testing at a higher temperature than many of the other strainer vendors; thus, head loss scaling concerns may generally be less severe.

AECL estimated that the debris distribution at the end of the test was as follows: 75% on the test strainer, 13% settled under the test strainer, and 12% settled away from the test strainer. During the test, the staff had observed debris bridging the 2-inch gaps between the strainer fins. Since the staff did not observe the completion of the test, it was not clear whether the debris described as settling under the test strainer included debris that had bridged the strainer fin gaps while the recirculation pump was running, but subsequently slumped to the tank floor when the pump was stopped or following the draining of the test tank. Also, although several photographs were provided of the debris that settled away from the strainer, the staff could not conclusively determine its composition. Despite these limitations, the debris distribution information provided by AECL was useful in understanding the extent of near-field settling in the reduced-scale test tank.

Large-Scale Head Loss Test Observations

The staff made observations during a large-scale head loss test for MPS 2. MPS 2 is a Combustion Engineering plant with a large-dry containment design. According to Dominion's response to GL 2004-02, when the RWST reaches its low-level setpoint, the realignment of the emergency core cooling system and containment spray system occurs automatically. The low-pressure safety injection pumps are automatically stopped, and the suction of the high-pressure safety injection pumps and containment spray pumps is automatically switched over to the containment recirculation sump. The high-pressure safety injection pumps provide long-term recirculation of water through the reactor core. The containment spray system provides long-term containment heat removal by pumping sump water through a heat exchanger and spraying the cooled water back into the containment atmosphere. As opposed to the testing for SPS, the two PWR units at MPS have sufficiently different designs to prevent the application of a single test for both units.

There are two large-scale test tanks at the Chalk River Laboratories, which are similar in function. The large-scale tanks permit head loss testing with a full-scale test module (Figure 1b). The large-scale tank used for the MPS 2 test measured approximately 6 ft deep, 8 ft wide, and 19 ft long. The test fluid was service water maintained at a temperature of 104 °F by a heating and cooling system. A variable-speed stirrer was used to generate turbulence to aid in keeping debris in suspension in the test tank upstream of the test strainer. Periodically, the tank bottom was also manually stirred, which resulted in additional debris reaching the strainer, thereby increasing the measured head loss.

The large-scale test observed by the staff was a thin bed test with a general procedure analogous to that previously described for the reduced-scale test. That is, the entire load of particulate was first added to the test tank, and 1/16-inch batches of fiber were subsequently added at intervals determined by stabilization criteria provided in the test plan (which were similar to the criteria described for the reduced-scale test) until a theoretical fiber loading of 3/8 inch was added to the test tank. According to the thin bed test procedure, only fibrous debris and particulate debris were added to the test tank (i.e., RMI was not included). The fibrous debris used for the test included Nukon, Knauf pipe insulation, and mineral wool. Walnut shell flour was used as a surrogate for qualified coatings, unqualified coatings, and for latent particulate debris. As for the reduced-scale test, the staff did not review in detail whether the surrogate debris was representative of the actual plant debris.

As a result of weather-induced travel delays and the relatively long and random periods between debris additions, the staff was not onsite during the initiation of the large-scale test or during the addition of subsequent batches of debris. However, AECL showed the staff a video of the debris preparation, which resembled the reduced-scale process on a larger scale. The test debris was placed in a plastic pool and mixed with water that had been pumped out of the test tank. Chunks of debris were fragmented through the action of a hose, by technicians using rakes, and by the operation of a pressure-washer. Once sufficiently small pieces had been created, the debris was pumped back into the test tank with a portable pump, which presumably further reduced the debris size.

Baffle plates were placed in the test tank around the test module to model the boundaries formed by adjacent modules surrounding a centrally located module in the actual plant strainer design. The test plan indicates that the baffle plates will result in water approaching the test module from the tips of the fins, which tends to increase the uniformity of debris bed formation. For the actual plant modules, however, the test plan notes that some flow may also approach from other orientations (e.g., perpendicular to the strainer fins).

Although a cover plate was not installed during the thin bed test, this structure is part of the replacement strainer design and will be in place during the full debris loading test. Removing the cover plate during the thin bed test was done to allow visual observation of the debris bed formation. However, during the full debris load test, the cover plate is installed to properly model the interstitial volume of the actual strainer that can be filled with debris. In the actual plant strainer design, the underside of the cover plate will be positioned at least 9 inches above the tops of the strainer fins to maintain a flowpath along the top of the strainer.

The test duration was 75 hours. The maximum measured head loss was approximately 4.15 ft. According to the test plan, AECL will scale this value to account for the temperature-driven viscosity difference between the water in the test tank and the plant containment pool. As described in more detail in the staff's discussion of reduced-scale testing above, simply scaling head loss based on viscosity could lead to nonconservative results in certain cases (e.g, when significant debris bed structural changes occur). During the trip, the staff did not review the acceptability of AECL's head loss scaling methodology as applied to the observed large-scale test.

Due to the presence of suspended particulate in the tank volume, few observations could be made on the behavior of debris in the test tank. On the second day, the tank volume appeared slightly clearer, and a flashlight was used to see several feet into the tank. The staff noted that clumps of fiber had settled on the suction ductwork leading to the pump. Although such settling was potentially nonprototypical, the staff noted that the quantity of settled fiber was small compared to the total quantity of fiber added to the test tank, and that AECL had been periodically sweeping the tank floor outside the baffle plates in an effort to prevent debris settling. Photographs later provided to the staff appeared to show that relatively small amounts of predominately particulate debris had settled outside the baffle plates, but the actual amount and composition of the debris that settled was not discernible. Quantitative information in this regard was not available. As for the reduced-scale test, post-test photographs showed that a large amount of fibrous debris had settled directly beneath the test strainer. It was not clear to what extent the settling in this area had occurred during the test as opposed to after the recirculation pump had been secured or the test tank had been drained.

Although the staff did not observe vortex testing, the large-scale test plan for MPS 2 included this procedure. The procedure noted that clean strainer head loss would be measured at several flow rates between 50% and 125% of the nominal rated strainer flow. In conjunction with these measurements, the test procedure indicated that the potential for air ingestion would be investigated by gradually reducing the height of water above the top of the strainer while looking for the formation of hollow-core vortices. The procedure stipulated that the submergence depth at which hollow-core vortices form would be noted. AECL personnel stated that vortex formation was not noted in clean strainer tests where the height of water in the tank was essentially reduced to be level with the top of the strainer. In response to a staff question, AECL indicated that the presence of debris could result in air ingestion for very small strainer submergence levels. The staff did not investigate air ingestion in detail during the trip, but noted that the large-scale head loss tests were conducted under representative submergence depths without evidence of adverse air intrusion.

Debris Bed Phenomena

Although the staff's visit concluded prior to the termination of the reduced-scale and large-scale tests, AECL provided photographs of the debris beds formed for both tests. From the photographs, the staff observed that the layers of the debris bed nearest the strainer appeared to have the highest concentration of walnut shell flour particulate. The staff made similar observations of particulate concentration varying along the thickness of the debris bed during a trip to another vendor's head loss test facility (ML060750467) regarding a test that was procedurally similar to the AECL thin bed tests. One noteworthy difference between the two tests was that, at the completion of the test, the suspended particulate concentration remained significantly higher in the other vendor's test; however, it was not clear whether this difference had a significant effect on the resultant debris bed morphology.

The staff asked AECL to discuss the basis for the thin bed test procedure. AECL stated that batching in fibrous debris in 1/16-inch increments had been compared to adding the entire quantity of fibrous debris at once. The two measured head losses were found to be comparable. AECL has also observed that the capability of silicon carbide particulate (with a mean particle size of approximately 10 microns) to migrate through a fibrous debris bed appears greater than that of walnut shell flour particulate (with a mean size of approximately 25 microns). Observations tended to show that the silicon carbide was highly concentrated in the debris bed layers nearest the strainer surface, whereas the distribution of the walnut shell flour along the bed thickness tended to be somewhat more dispersed. These observations of particulate migration through the fibrous debris bed could provide limited evidence that, for sufficiently small particulate, the sequence of debris addition in the formation of a thin bed may not be of primary importance. However, the staff did not review adequate information during the course of the trip to confirm such a conclusion, or to identify the set of conditions for which the conclusion would be applicable.

Chemical Effects

The NRC staff discussed plans for chemical effects testing with AECL and Dominion. At the time of the staff's visit, AECL's chemical effects testing had not yet commenced. Furthermore, test plans and procedures were still under development. Therefore, the discussion on chemical effects testing focused on general objectives and concepts rather than specific procedures or detailed information.

AECL intends to generate chemical precipitates in bench-top tests using the preparation technique described in WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191." AECL will perform analysis (e.g., inductively coupled plasma, x-ray diffraction) to compare the products generated in the bench-top tests with those identified in WCAP-16530-NP. The staff indicated that WCAP-16530-NP is currently being reviewed by the staff and that a request for additional information (RAI) is expected to be issued within the next month. Since the WCAP is being used as a basis for chemical effects testing, the staff recommended that AECL and Dominion review the RAI once it is available.

In addition to bench-top testing, head loss associated with chemical products will be evaluated in the reduced-scale test tank. Sargent and Lundy will be providing technical support by calculating the plant-specific amount of chemical product using the spreadsheet contained in WCAP-16530-NP. A borated water environment with either trisodium phosphate (TSP) or sodium hydroxide (NaOH), depending upon the actual plant buffer material, will be established in the reduced-scale tank. A plant-specific mixture of fiber and particulate will be added to establish a thin bed on the strainer segments in the reduced-scale tank. Once the thin bed head loss has stabilized, a scaled amount of the plant-specific chemical precipitate will be added incrementally until the full quantity of precipitate is in the tank. Head loss across the bed will be allowed to stabilize between incremental chemical precipitate additions.

Chemical effects test termination criteria were discussed with AECL. AECL had not yet established such criteria for its planned testing. The staff discussed some of the results from head loss testing in NaOH environments at Argonne National Laboratory. In particular, significant head loss changes were observed in NaOH environments approximately 4 to 8 days after aluminum nitrate had been added to the test loop. The staff expects that test termination criteria will take into consideration potential time dependency of head loss resulting from chemical precipitates.

In summary, although the general testing approach presented by AECL appeared reasonable, without additional information the staff could not reach a conclusion on the adequacy of AECL's chemical effects test program. The staff will continue to communicate with AECL and Dominion representatives concerning chemical effects testing to obtain additional information about test plans and results.

Coatings

The predominant coating surrogate used in AECL's testing is walnut shell flour. The flour is supplied to AECL after being sifted through a No. 325 mesh. This filtration results in particles that range in size from 2 to 60 microns. The average particle size is approximately 25 microns. The NRC guidance on particulate coating debris calls for 10-micron particulate. However, coating debris generated in a design-basis accident (DBA) will likely range in particle size. The staff believes that the size distribution of the walnut shell flour used in the AECL tests provides a reasonable representation of DBA-generated particulate coating debris.

The density of the walnut shell flour is 81 lb/ft^3, which is less than the density of the majority of containment coatings, with the exception of some unqualified coatings. For reference, epoxy coatings in containments range in density from approximately 90 lb/ft^3 to greater than 100 lb/ft^3, and inorganic zinc primers have densities that may be several times larger than epoxies. Based on density, the staff would expect walnut shell flour to transport to the strainer surface more readily than actual coating debris of an equivalent size and would therefore be a conservative surrogate from the debris transport perspective.

The staff observed the addition of walnut shell flour to AECL's reduced-scale test tank. The debris appeared to disperse throughout the tank and tended to remain suspended. The tank has a clear section of piping on the recirculation loop downstream of the strainer. The staff observed that, shortly after the debris was introduced in the tank, the walnut shell flour was passing through the downstream piping. AECL representatives stated that in previous tests only a small fraction of the particulate debris settled in the tank away from the strainer surface. The staff was unable to observe the completion of the test, but asked AECL representatives to document the amount of debris that settled away from the strainer upon test completion. The staff requested that the same documentation of settled debris be performed for the large-scale test tank.

Earlier tests conducted by AECL used silicon carbide as a surrogate for coating debris. The silicon carbide debris had a density of 196 lb/ft^3 and a particle size of about 10 microns. Representatives from AECL indicated that, in the tests using silicon carbide, a portion of the debris settled out on the bottom of the tank and in other areas of the test setup away from the strainer surface. These early tests also resulted in a lower pressure drop across the strainer surface than the tests using walnut shell flour. Representatives from AECL indicated that the tests using silicon carbide would be repeated using walnut shell flour in order to obtain a more conservative pressure drop that does not rely upon potentially nonprototypical debris settling. The staff position is that, lacking sufficient justification for crediting near-field debris settling, licensees should ensure that all debris analyzed to reach the strainers arrives on the strainer surface during the test.

The staff questioned whether walnut shell flour could absorb water in the test tank and therefore change the size of its constituent particles. Representatives from AECL stated that they had performed some bench-top tests to address this concern, and that the walnut shell flour did not absorb a significant amount of water. The NRC staff was unable to see the results of the bench-top tests during this visit. The staff informed AECL that the bench-top test results would be valuable information for licensees to provide as part of their supplemental responses to Generic Letter 2004-02.

One of the plants for which AECL is performing strainer qualification testing does not have enough fibrous debris in containment to form a thin bed on the strainer surface. For this plant, AECL plans to generate coating chips to represent epoxy debris. They also plan to use zinc particulate to represent inorganic zinc primer. The staff believes that it is reasonable to use zinc particulate for inorganic zinc primer since it will most likely fail as a particulate in a DBA. The staff also agrees with the use of coating chips for cases where a plant does not form a fiber bed on the strainer surface. NRC guidance states that coating chip debris in such cases should be roughly the size of the strainer holes, unless justification is provided for a different debris size. The staff informed AECL that a thorough characterization should be performed on the coating chips they generate. This characterization should include the range of chip size, the chip density, and the chip thickness.

As part of the staff's trip to observe strainer testing at the Chalk River Laboratories, AECL agreed to discuss the results of some of the coatings research that had been conducted as part of past strainer replacement projects. The past coatings testing discussed during this trip included transport testing of coating debris and destructive physical testing of coated coupon samples. The transport testing conducted by AECL included coating debris in chip form. The destructive testing subjected various coatings to simulated DBA conditions including irradiation, temperature, pressure, chemistry, submersion, and spray. These coatings were on concrete or steel coupons and the adhesion values of freshly cured coating samples were compared to those of coupons that experienced the simulated DBA conditions. The insights provided by AECL were helpful to the staff in that they confirmed NRC test results and/or provided additional insight on coating issues.

Downstream Sampling

Although the staff did not observe downstream sampling during the trip, AECL presented the results of three previous strainer pass-through tests. Tests for fiber pass-through and particulate pass-through were performed separately.

Two of the tests were to measure strainer fibrous pass-through. A test strainer with 1/16-inch perforations was used. In conducting the tests, the full load of fiber for the plant was divided into ten batches and added at the beginning of the tests. Grab samples were taken from the pump outlet at various intervals. Due to the presence of background particulate contamination, AECL found it necessary to count fibers rather than measuring the total suspended solids to determine the concentration of fibrous debris in the sample. As a result, the test procedure was subsequently altered to include a step for rinsing the fibers prior to adding them to the test tank to reduce the particulate contamination. Fibrous debris concentrations on the order of tens of mg/L were found in samples collected toward the beginning of the tests; after the tests had run for roughly a half day and a substantial fiber bed had been created, the downstream concentration of fibrous debris appeared to be asymptotically approaching a nonzero value of approximately several tenths of one mg/L at the time the tests were terminated. AECL found that the vast majority of the collected fiber was less than 1 mm (1/25 inch) in length. During the trip, the staff did not examine whether passing the collected fibers through the recirculation pump substantially affected their size distribution.

AECL also presented the results of one pass-through test for particulate debris. Grab sampling of the particulate was performed in a manner similar to that described above for fibrous debris; however the sample location was on the suction piping upstream of the pump. AECL credited the filtration from latent fibrous debris for the particulate pass-through sampling by engineering a debris bed consisting solely of latent fibers. Although latent fibrous debris beds may not be capable of forming a high-efficiency particulate filter for most PWR replacement strainer designs, the staff has previously noted that beds significantly less than 1/8 inch in thickness can noticeably reduce the concentration of debris in downstream samples. The staff informed AECL and Dominion that the staff's safety evaluation on the Nuclear Energy Institute (NEI) sump performance methodology (ML043280641) recommended that a clean strainer be assumed for determining debris pass-through; however the staff also noted that, if a licensee can demonstrate that the debris bed being credited for filtration will form under all conditions, then this practice may be an acceptable alternative approach. After approximately a half day of running the test, the initial concentration of particulate had decreased from over 2000 mg/L to a value less than 200 mg/L. At the time the test was terminated, the particulate concentration appeared to be asymptotically approaching a nonzero value of slightly less than 100 mg/L.

Staff feedback regarding AECL's downstream sampling procedures was limited because the application of the test results had not been clearly identified and because dedicated reviewers in this technical area were not present during the trip. The staff noted that interaction on downstream effects had occurred with AECL and the four other strainer vendors during meetings held on May 24–25, 2006. The staff further noted that dialogue with the Westinghouse Owners Group (WOG) on WCAP-16406-P, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191," was ongoing, encouraged AECL to remain aware of these discussions, and offered AECL the opportunity for additional staff interaction on downstream effects via teleconference. The staff noted that more detailed reviews of licensees' downstream effects approaches would be performed during the sample audit process.

Potential Outstanding Issues

Overall, the NRC staff concluded that AECL's strainer qualification and testing approach appeared reasonable. However, based on the NRC staff's observation of testing and discussions with AECL and Dominion representatives, several technical issues were specifically identified as having the potential to require further resolution. It should be noted that these items were identified based on a limited staff review of the information provided by AECL and Dominion during the trip on the specific topics discussed in this report; therefore, the potential outstanding issues stated below do not fully represent the NRC staff's concerns on all parts of AECL's testing program or Dominion's strainer performance calculations. Also, in the course of the staff's future sample audits and other review efforts on GSI-191, additional issues may be identified. Furthermore, AECL and/or Dominion may have adequately addressed some of the staff's potential concerns but may not have had an opportunity to clarify these points fully during the staff's visit.

In light of the above statements, potential outstanding issues for licensees using AECL strainer qualification testing include the following:

- Ensuring that debris is not settling away from the test strainer in the reduced-scale and large-scale test tanks, or else providing justification for crediting near-field settling of debris. Information provided by AECL suggested that only small amounts of debris had settled away from the test strainer; licensees installing AECL strainers should be capable of providing additional confirmation.

- Verifying whether debris that settles directly beneath the test strainer settles there during the test as opposed to after the recirculation pump is secured or the tank is drained.

- Providing evidence that walnut shell flour is not affected by the test tank environment in a manner that would change its particle size or otherwise impact its head loss or transport properties.

- Providing a characterization of the chip size, density, and thickness for any coating chip debris used for strainer qualification.

- Ensuring an adequate technical basis exists for substituting surrogate debris for actual plant debris. Although it appeared that AECL had generally made efforts to address this potential concern, the staff was not clear on the degree to which similarity had been demonstrated for all of the surrogates chosen (e.g., cerafiber for asbestos).

- Ensuring that a basis exists to demonstrate the conservatism of including or excluding RMI for full debris load tests. For example, debris beds containing RMI generally have higher porosity than those solely containing fiber and particulate. However, if the addition of RMI is necessary to create a circumscribed debris accumulation, its addition may indirectly lead to a higher head loss. Therefore, the effect of RMI debris should be understood and form part of the basis for demonstrating that the full debris load test results are conservative.

- Ensuring that full debris load tests are sufficiently conservative. AECL stated that the full debris load case is determined by choosing the break that maximizes the volume of debris on the strainer. However, the staff noted that simply maximizing the quantity of debris at the strainer may not necessarily represent a worst case head loss test, since head loss is also influenced by the types of debris in the bed, their structure, and other parameters. While the staff recognizes the impracticality of testing all possible debris bed configurations, a defensible basis for the conservatism of the debris source term used for the full load tests is expected.

- Ensuring that thin bed tests are sufficiently conservative. Certain types of debris (e.g., calcium silicate) may have significantly larger influence on head loss than an equivalent quantity of other types of debris. Therefore, maximizing the volume of particulate for the thin bed test may not necessarily represent a worst case head loss test. While the staff recognizes the impracticality of testing all possible debris bed configurations, a defensible basis for the conservatism of the debris source term used for the thin bed tests is expected.

- Ensuring an adequate technical basis is developed for chemical effects testing procedures. Although AECL's general testing approach appeared reasonable, insufficient procedural detail was available for the staff to draw a conclusion as to its technical adequacy. Licensees installing AECL strainers should further be aware that additional issues may be identified in this area as future interactions with the staff proceed.

- Ensuring an adequate technical basis is documented to support the scaling of head loss test results based solely upon viscosity. As noted during the staff's meetings with the five strainer vendors on May 24–25, 2006, at lower temperatures, complex disturbances to the test debris bed structure (e.g., boreholes) could occur. Nonconservative results may be obtained if the results of tests involving disturbed debris beds are scaled to actual plant conditions simply based on viscosity. As a result, the staff expects that licensees relying upon the simple viscosity scaling approach will justify its adequacy based upon their plant-specific conditions and head loss test conditions.

Conclusion

The potential outstanding issues noted above notwithstanding, the staff had a positive overall impression of AECL's strainer qualification program. The staff further appreciated the openness and cooperation of AECL and Dominion during the visit to the Chalk River

Laboratories. The staff informed AECL and Dominion that a report would be generated to document observations made during the trip and further noted that the current GL 2004-02 audit plan proposes to select at least one plant from each strainer vendor for a detailed audit.

Attachment IV. AECL Strainer Testing Slides

AECL ECCS Strainers – Testing

2006 June 27

AECL

US PWR Licensees

Dominion – Millstone 2 and 3
Surry 1 and 2
North Anna 1 and 2

SCEG – V.C. Summer

Strainer Design Parameters

Plant	Debris Mix	Hole Size (in.)	Available NPSH Margin (ft)	Area (ft²)	Approach Velocity (ft/s)
Millstone 2	Fiber/Part.	1/16	2.3	6250	0.0024
Surry 1 & 2	Fiber/Part.	1/16	4 6.4	~6000 ~1500	~0.0047 ~0.0061
North Anna 1 & 2	Fiber/Part.	1/16	~3 ~4	~6000 ~2500	~0.0047 ~0.0049
Millstone 3	Fiber/Part.	1/16	~7.3	~7000	~0.0026
V.C. Summer	RMI	1/16	~6	2490 & 3060	0.0067

Reduced-Scale Testing – Surry RS

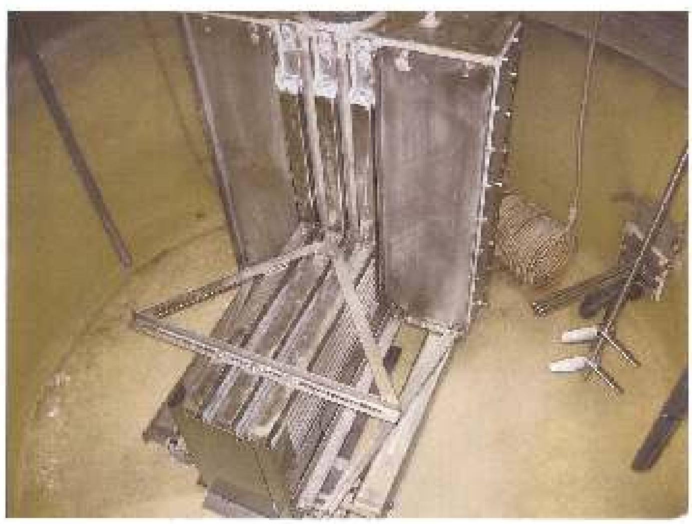
Reduced-Scale Testing – Surry RS

Surry RS strainer sizing

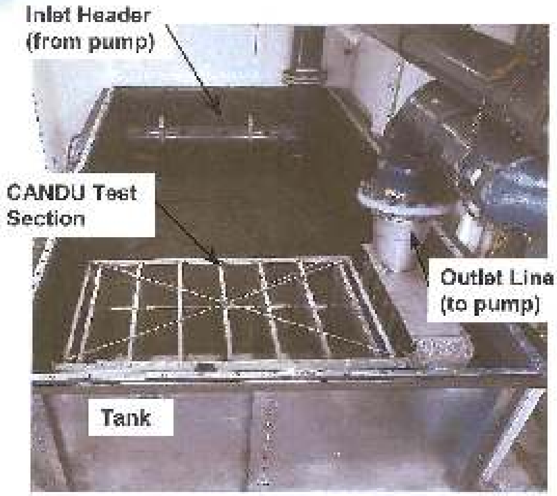
- Thin-bed head loss test
- Strainer = 6000 ft² Test section = 22.5 ft²
- Flow rate = 52.6 gpm
- Water temperature = 104°F
- Particulate = Walnut shell flour (3.1 lb)
- Fiber/(1/16th) = TempMat (0.72 lb), Cerafiber (0.46 lb), Paroc (0.15 lb), Nukon (0.01 lb)

5

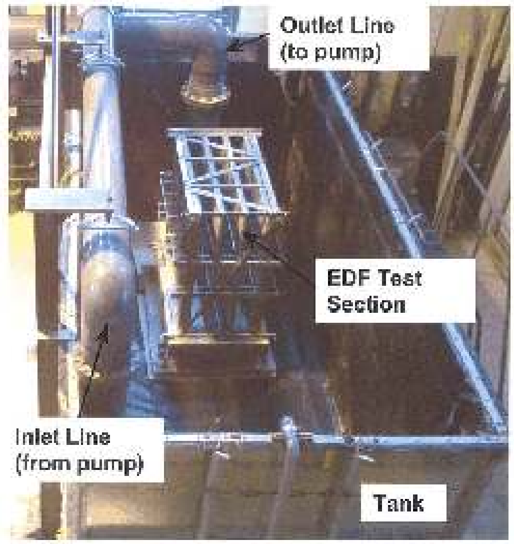
Reduced-Scale Testing – Surry RS



Large-Scale Testing – Millstone 2



"Original" Facility



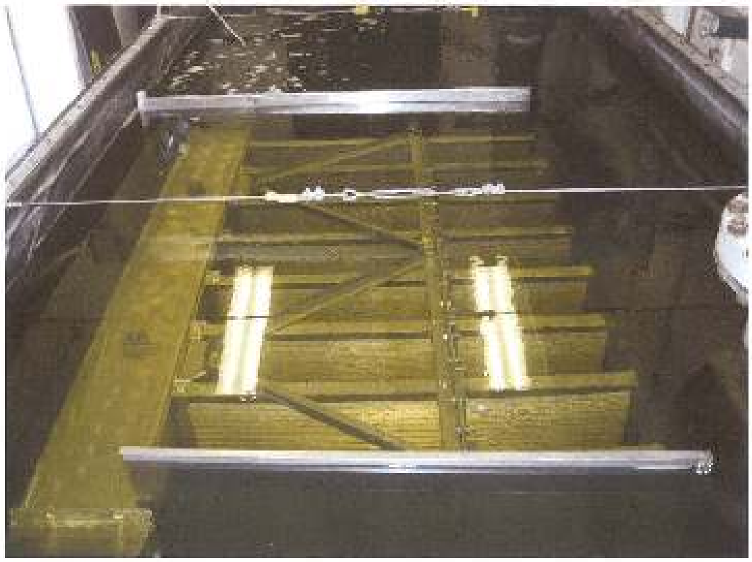
"New" Facility

Large-Scale Testing – Millstone 2

<u>Millstone 2 strainer sizing verification</u>

- Thin-bed head loss test
- Strainer = 5620 ft^2 Test section = 358 ft^2
- Flow rate = 433 gpm
- Water temperature = 104°F
- Particulate = Walnut shell flour (246 lb)
- Fiber/(1/16th) = Knauf (4.37 lb), Nukon (2.86 lb), Fibrex (2.34 lb)

Large-Scale Testing – Millstone 2



Large-Scale Testing – Millstone 2