ENCLOSURE 4

WCAP-16914-NP Revision 5 "Evaluation of Debris Loading Head Loss Tests for AP1000 Recirculation Screens and In-Containment Refueling Water Storage Tank Screens"

Westinghouse Non-Proprietary Class 3

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Evaluation of Debris Loading Head Loss Tests for AP1000™ Recirculation Screens and In-Containment Refueling Water Storage Tank Screens

Westinghouse

WCAP-16914-NP
APP-MY03-T2C-003
Revision 5

Evaluation of Debris Loading Head Loss Tests for AP1000 Recirculation Screens and In-Containment Refueling Water Storage Tank Screens

K. F. McNamee*
T. S. Andreychek
Systems & Equipment Engineering

T. L. Schulz*
Y. J. Song*
AP1000 Nuclear Systems Engineering

C. L. Rocco*
AP1000 Plant Engineering – Plant Integration

D. D. Stefanczyk
Fauske and Associates, LLC

June 2010

Approved: **J. S. Monahan***
AP1000 Plant Engineering – Plant Analysis Integration

*Electronically approved records are authenticated in the electronic document management system.

Westinghouse Electric Company LLC
P.O. Box 355
Pittsburgh, PA 15230-0355

RECORD OF REVISIONS

Revision	Date	Description
0	March 2008	Original issue
1	July 2009	Revision bars are not included in this document because this revision supersedes the original document in its entirety.
2	September 2009	Revision bars are included to indicate changes to Revision 1 resulting from NRC RAIs related to the tests. Note: All changes to Revision 2 Accepted
3	December 2009	Revision bars are included to indicate changes to Revision 2 resulting from performing more Design Basis Tests based on the current IRWST design.
4	February 2010	Accepted all changes from Revision 3 Revision bars are not included for editorial and grammatical/punctuation changes which do not affect content. Revision bars are included in the margin to indicate the following design parameter changes to Revision 3: 1. Flow rates for CR and IRWST screens 2. Corrected AlOOH concentrations 3. Corrections to flow rates in Appendix A Test Plan 4. Additions of Appendices B and C to further clarify AlOOH concentrations

5	June 2010	Accepted all changes from Revision 4 Revision bars are not included for editorial and grammatical/punctuation changes which do not affect content. Revision bars are included in the margin to indicate the following changes to Revision 4: 1. Change to particulate debris loading and minimum flow rate in Table 5-2 2. Changes to vent quality, containment pressures and flow rates for LTC Case 3 in Section 5.2 3. Adjustment of fibrous, particulate and chemical debris totals in Table 6-1 to match Table 7-2. Addition of Note 3 to Table 6-1. 4. Corrected particle size of Silicon Carbide (particulate debris) in Sections 3.1.1, 5.1 and 5.3.1 5. Changes to Instrumentation List in Table 4-1 6. Added explanation of DP limits at various flow rates for tests WE213-4W and WE213-5W in Section 6.1. 7. Added reference to Figure 7-8 in Section 7.1, and added reference to Figure 7-18 in Section 7.2. 8. Added Note 1 to Table 8-1 for clarification 9. Change to Reference 12 10. Moved Reference 14 to Appendix B 11. Changed Title of Figure 7-27 to Top instead of Bottom

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EXECUTIVE SUMMARY

This report documents recirculation screen head loss experiments that were conducted for the AP1000™[1] pressurized water reactor (PWR) as part of the response for the AP1000 design to Generic Safety Issue 191 (GSI-191), "Assessment of Debris Accumulation on PWR Sump Performance" (Reference 1), and Generic Letter (GL) 2004-02 (Reference 2). The performance of the recirculation screens must be confirmed and demonstrated under debris loading conditions (including those involving chemical effects) that address the bounding set of AP1000 specific debris loadings. Debris loadings for the containment screens include particulates and fibrous materials, as well as chemical precipitates that may form in the containment water pool.

[

]a,c

The data from this test program demonstrates the ability of the CR and the IRWST Screens to successfully perform their design functions under debris loading conditions expected for the AP1000 following a postulated LOCA. Eight head loss tests were performed that investigated a spectrum of debris inventories, debris staging, chemical effects, and flow rates. These test results demonstrate acceptable head loss for the hydraulic and debris loading conditions of interest, including the design basis debris load case. The design basis tests demonstrate that the head loss across the screens is acceptable when considering the design basis latent and chemical debris load. The chemical surrogate was mixed outside of the flume and added to the flume water following the WCAP-16530-NP-A (Reference 9) approved method for chemical particulate generation.

Three tests were performed as engineering evaluations to examine the sensitivity to the manner in which the chemical constituents might enter the water. For the engineering evaluation tests, water solutions of the ions assumed to be created in solution were added and the influence on the resulting screen pressure differential was recorded. As expected, these engineering evaluation runs showed that the design basis tests provide the most conservative manner of loading the recirculation screens and the tests showed acceptable results.

The testing also demonstrates that the [ ]a,c screens will perform as required under the expected AP1000 debris loading conditions. That is for the AP1000 design, the screens will not develop head losses due to debris collection that will challenge either long-term core cooling or maintaining a coolable core geometry.

1. AP1000 is a trademark of Westinghouse Electric Company LLC.

The testing shows that the AP1000 design provides for considerable margin in screen performance for the following reasons:

- The AP1000 design eliminates the generation and transport of fibrous debris to the screens or to the core;
- The AP1000 design reduces the generation of post-accident chemical effects debris;
- The good housekeeping practices required by COL item 6.3.8.1 will limit the amount of resident containment debris;
- The AP1000 design [ ]^{a,c}
- The AP1000 design provides for increased time [ ]^{a,c}
- The AP1000 requires the use of [ ]^{a,c}
- The AP1000 requires [ ]^{a,c} and
- The AP1000 incorporates large, advanced screen designs.

1 BACKGROUND

In response to Nuclear Regulatory Commission (NRC) Generic Safety Issue 191 (GSI-191) (Reference 1), Westinghouse has performed a series of screen head loss experiments for the AP1000. The purpose of this test program was to quantify the head loss for both the CR Screens and the IRWST Screens with debris loadings (including containment chemical effects) applicable to the AP1000.

[

]^{a,c}

The performance of the screens must be confirmed and demonstrated under debris loading conditions (including chemical effects) that include a spectrum of plant specific debris characteristics for a range of LOCAs up to and including a Large Break LOCA Design Basis Accident (DBA) in order to satisfy GSI-191. The debris included latent fibers and particulates, as well as chemical precipitates that may form in the containment water pool. AP1000 containment latent or resident debris loadings and chemical precipitate loadings were determined by Westinghouse in Reference 4.

Clean screen head loss behavior was tested over a range of flow rates that bound the flow rates of the AP1000 design for both the IRWST and the CR screens. Eight head loss tests, designated as WE213-1W though WE213-5W and WE213-1 through WE213-3, were performed that investigated a spectrum of debris inventories, debris staging, chemical effects, and flow rates. Two tests, WE213-4W and WE213-5W, are the current design basis tests. These two tests account for the increase in IRWST screen area by a factor of 2. From the two current design basis tests (WE213-4W and WE213-5W), [

]^{a,c} All head loss tests were performed under the Westinghouse Quality Management System (QMS) requirements.

2 OBJECTIVE

The objective of this project was to perform tests under the Westinghouse QMS program for debris loading on the recirculation screens. These tests were carried out in conformance with the test procedure steps in the approved Test Plan (References 6 and 12). A multiple phase testing program was used to qualify the performance of the [ ]^{a,c} for a set of defined debris loadings that are characteristic of a Design Basis Accident (DBA) conditions as specified in Reference 4.

3 APPROACH

The specified debris loadings were tested in the hydraulic flume #2 at Fauske & Associates, Inc (FAI), located in Burr Ridge, Illinois. The debris loadings included [

]^{a,c} The screen module was made of a pair of full height, full depth, and full width [

]^{a,c} The test was conservative in this regard because the water level for the AP1000 [

]^{a,c}

The manner in which the debris is added had been observed in prior industry testing programs to make a difference in the overall head loss through the fuel assembly. [

]^{a,c} This approach to sequencing the introduction of debris into the test loop is consistent with the NRC guidance issued on March 31, 2008 (Reference 11).

The IRWST and the CR screens can accept the design basis debris loads (particulate, fiber, and chemical) in any order and still perform with acceptable pressure drop. The chaotic nature of debris generation and transport following a pipe break, the variety of post-LOCA debris types, and the extensive variation of break types and locations make it difficult to accurately determine debris quantities and arrival sequences. In general, licensees determine the maximum debris quantities that could be produced for various breaks. For screen testing, these maximum quantities are scaled down to the size of the test screen and either the actual plant material or a suitable surrogate is used to create prototypical debris for the head loss test.

The following sequence of debris addition was used for the design basis test.

- The desired assembly flow rate was obtained and allowed to stabilize until a steady state condition was verified.

1. NUKON® is a registered Trademark of Performance Contracting, Incorporated.

- The particulate was added per the test plan as dry powder at the water surface near the sparger. The particulates sank immediately after being introduced into the flume. Stirring was used as a means of re-suspending any particulates that might have settled on the bottom of the flume. The flume was allowed to turn over five times after the particulate addition to assure thorough mixing.

- The fiber was added per the test plan by thoroughly wetting the fibers in a bucket of water prior to their introduction to the flume. The wetted fibers were added into the flume by pouring in the solution near the sparger as was done for the particulate addition. Stirring was used as a means of re-suspending any fibers that might have settled on the bottom of the flume. The flume was allowed to turn over five times after the fiber addition to assure thorough mixing.

- Surrogates for chemical reaction products were added to the test loop after all of the fiber and particulate had been added. As defined in the Test Plan, the chemical precipitate for the design basis case was mixed outside the test loop per the Reference 9 methodology and then added to the test loop in measured batches.

The design basis tests were performed with all of the chemical constituents formed outside of the flume as a precipitate; this precipitate was then added to the flume water on the upstream side of the screen modules. Specifically, the surrogate chemical reactant products were formed outside the test loop according to the instructions in Reference 9. When the AlOOH is formed in this manner, the concentration in the mixing volume is far in excess of that typical of a saturated solution and therefore a precipitate of AlOOH is formed. The design basis tests were performed to further document that the AP1000 screen designs are sufficient to accept the design basis latent and chemical debris loadings and have a total head loss across the screens that is within the design tolerance.

All three of the engineering evaluation tests were performed with the chemical reactants added to the flume as water solutions that provided the calculated concentrations of the chemical reaction products (ions) as they are considered to exist in the containment recirculating coolant volume. To provide the necessary ions, water solutions of (1) aluminum nitrate non-hydrate ($Al(NO_3)_3 \cdot 9H_2O$) crystals and (2) a 50% concentration of NaOH were added to the flume. As dictated by the respective concentration of the ions, AlOOH precipitate can form in the flume water.

3.1 DEBRIS SELECTION

Photographs and video evidence of the [ ]^{a,c}. The following sections describe the selection of debris used for the tests.

3.1.1 Particulate Debris

The particulate used in the AP1000 screen tests is silicon carbide (SiC) with a 14 μm median particle size. This material was used to simulate the particulate component of the containment latent debris. The size of the SiC provides for it to be readily transportable and is comparable to that of fine grit such as might be found as dirt. Based on the above, the particulate used in the AP1000 screen head loss tests is applicable to the AP1000 plant.

3.1.2 Fibrous Debris

[

]a,c Based on the above, the fibrous material used in the AP1000 screen head loss tests is applicable to the AP1000 plant.

3.1.3 Chemical Debris

The chemical surrogate used in the AP1000 screen was made [

]a,c Based on the above, the chemical surrogate used in the AP1000 screen head loss tests is applicable to the AP1000 plant.

3.2 TERMINATION CRITERIA

Test termination was determined when one of the following criteria was met or exceeded:

- If the equilibrium pressure drop (ΔP); criterion, determined by calculating the slope in differential pressure across the screen assembly [

  ]a,c

- If the pressure differential limit established for the test was exceeded, the test could be terminated.

- [

  ]a,c

All tests in this series had a termination criterion based on a pressure drop limit across the test screen at the test flow rate. The test could be terminated at any time if the pressure drop across the screen exceeded the limiting pressure drop at the test flow rate. The pressure drop limit was calculated from the resistances used in the WCOBRA-TRAC as a function of the velocity squared $(\Delta P \propto \text{Flowrate}^2)$. The flow/ΔPs that were used in the last test were based on the results of the limiting WCOBRA-TRAC (WC/T) analysis (i.e., on the flow rates and screen pressure drops calculated in the analysis).

4 DESCRIPTION OF EXPERIMENTAL APPARATUS

A description of the test flume used in the conduct of the head loss testing is included in Section 2.0 of Reference 6 and will not be repeated here. Summarized in this section are those items considered important to facilitate the overall understanding of the testing process.

4.1 COMPONENTS USED IN HEAD LOSS TESTING

4.1.1 Physical Components

See Figures 4-1 through 4-4 for the flume layout. For additional information on the physical arrangement of the test flume, see Reference 6. [ ]a,c

- [ ]a,c
- [ ]a,c
- [ ]a,c
- [ ]a,c
- [ ]a,c
- [ ]a,c
- [ ]a,c

a,c

Figure 4-1 Flume Test Facility (Side View): Single Pump Configuration (Reference 6)

a,c

Figure 4-2 Flume Test Facility (Top View): Single Pump Configuration (Reference 6)

a,c

Figure 4-3 Supply Line Sparger (Reference 6)

a,c

[ ]

Figure 4-4 Screen Cartridge Assembly (Reference 6)

4.1.2 Instrumentation

Table 4-1 contains a listing of test instrumentation that was used for the tests. The following parameters were monitored and/or recorded during the head loss tests:

- [ ]a,c
- [ ]a,c
- [ ]a,c
- [ ]a,c

Table 4-1 Instrumentation for Debris Loading Head Loss Testing (Reference 7)[3]

a,c

5 DEBRIS SURROGATES AND SCALING CONSIDERATIONS

5.1 DEBRIS SURROGATES

The debris materials selected for testing the AP1000 containment sump screens, and the basis for their selection, are as follows:

- [ ]a,c
- [ ]a,c
- [ ]a,c

The use of typical plant materials and conservative surrogates provides for a conservative head loss test for the AP1000 recirculation screens.

Table 5-1 lists the debris types applicable to the AP1000, as well as what materials were used to represent them in the test.

Table 5-1 Debris Loads for Head-Loss Testing a,c

5.2 SCALING RATIONALE

The screens used in the test flume [

]a,c

The flow rate used for testing was scaled based on [

]a,c

The amount of fibrous, particulate, and chemical debris used in a test was scaled based on [

]a,c

[

]a,c

The AP1000 CR and IRWST screen flow and debris loadings are shown in Table 5-2. This table also shows the test flow/debris loadings selected to bound the CR and IRWST loadings. These test loadings were used in test number WE213-4W. Test WE213-5W used the same loadings but the final flow was increased.

Table 5-2 AP1000 CR and IRWST Screen Loadings vs Test Screen Loadings

a,c

The debris loads listed for the CR Screens represent 100% of the debris that could exist in the AP1000 containment as discussed in Reference 4. The debris loadings for the IRWST Screens also represent 100% of the debris that could exist in the AP1000 containment except for the fibrous debris which represents 50% of the total (Reference 4). Note that the chemical debris load applicable to the IRWST is expected to be [

]a,c

The minimum screen flows were changed to be consistent with the long-term cooling analysis from Case 3 from APP-PXS-GLR-001 (Reference 13). This case is being used for the design of the screens because head loss across the screens was assumed in the analysis. Note that Case 10 is still bounding for the core DP because it maximizes the fiber that transports to the core; since so much of the fiber in the containment transports to the core (90%) there will not be enough to form a bed on the screens. Therefore, the screens would have no DP in this case. There are other situations where more debris can transport to the screen (and less to the core) and Case 3 is used to bound those cases.

The basis for the flow rates listed in Table 5-2 is as follows:

- CR Screen, max flow – For the maximum screen flows, operation of the RNS will be considered. [

  ]a,c

- CR Screen, min flow – This flow is a minimum flow rate [

]^{a,c}

- IRWST Screen, max flow – The maximum IRWST screen flow [

]^{a,c}

- IRWST Screen, min flow – This flow is a minimum flow rate [

]^{a,c}

The basis for the allowable DP across the screens is:

- CR Screen: This flow is a maximum flow rate [

]^{a,c}

- IRWST Screen: This flow is a maximum flow rate [

]^{a,c}

The debris and flow loadings used for the test screen are shown in Table 5-2. These conditions were selected to bound the conditions seen by the CR and IRWST screens. Test WE213-4W uses these conditions. Test WE213-5W used the same conditions except that the minimum flow was 38 gpm which demonstrates that a higher flow does not affect the debris bed formation and DP. The debris and flow loadings used in the previous screen tests were larger because they were based on smaller IRWST screens without a cross-connection. For the IRWST maximum flow, the flow loading is slightly above the loading that was tested. This is considered acceptable because:

- The difference between the maximum plant loading and what was tested is small, [ ]^{a,c}

- The screen debris and flows have been scaled in a very conservative way by using screen face area instead of the normal actual screen area. If the actual screen area scaling was used, [ ]^{a,c}, and by the photos taken after tests WE213-4W and WE213-5W.

- The DP observed [ ]^{a,c}

5.3 DEBRIS PREPARATION

Photos and videos of the debris preparation and introduction of debris into the flume are not available for the licensing basis test. The following sections describe the debris preparation procedures for the tests.

5.3.1 Particulate Preparation

The particulate used in the AP1000 screen tests, [ ]^{a,c}

5.3.2 Fiber Preparation

[ ]^{a,c} As previously noted, the fibrous material used in the AP1000 screen head loss tests is applicable to the AP1000 plant.

5.3.3 Chemical Preparation

The chemical surrogate used in the AP1000 screen was [

]a,c

6 INITIAL CONDITIONS AND TEST MATRIX

6.1 INITIAL CONDITIONS

The initial conditions for each test included the following:

1. A clean screen cartridge module was installed in the flume.

2. The flume was filled with water to an initial water depth of approximately [

   ]^{a,c} bottom mounting flange (see Figure 6-1).

3. An initial five minute steady state run providing head loss over a clean screen cartridge. This was always the first step after initiation of each test.

4. The flume water temperature was at ambient conditions at approximately 63°F (17°C).

The test flow rate depended on the AP1000 specific recirculation screen area and flow rate delivered by its source of recirculation coolant volume. The test flow was established. A chiller unit was used during each test to keep the flume water temperature constant. The length of the tests caused the flume water temperature to increase by a few degrees. Thus, using the chiller kept the flume water temperature relatively constant for the entire duration of the test.

The debris loads for the different experiments were determined by AP1000 evaluations documented in Reference 4. The scaled amount of each debris type to be added to the test loop for each test was defined in the Test Plan (References 6, 7 and 12). Table 6-1 provides the test matrix with the parameter values used in the tests.

Engineering Tests WE213-1, WE213-2, and WE213-3 were designed to investigate [

]^{a,c}

Tests WE213-1W through WE213-5W were designed to demonstrate the head loss over the screen cartridges for extended durations with the design basis particulate, fibrous, and chemical debris load. These tests support the technical basis for reasonable assurance of long-term cooling following a postulated LOCA in the AP1000. Tests WE213-4W and WE213-5W reflect an [

]^{a,c}

a,c

Figure 6-1 Screen Filter Cartridge Assembly

a,c

Table 6-1 AP1000 Screen Test Matrix

[

]^{a,c} This is explained as follows:

- [

  ]^{a,c}

- [

  ]^{a,c}

- [

  ]^{a,c}

[ ]^{a,c}

6.2 TERMINATION CRITERIA

Test termination can be accomplished in three ways:

- By meeting the equilibrium criterion determined by calculating the [

  ]^{a,c}, the test may be terminated.

- If the [ ]^{a,c} established for the test is exceeded, the test may be terminated.

- The [

  ]^{a,c}

7 TEST RESULTS

The Test Report, Reference 7, provides complete details of test runs, debris loading, and test velocities. This section provides a summary of the experiments performed. Table 7-1 provides a matrix of the tests performed. The matrix is summarized in Table 7-1 and includes all eight tests. Table 7-2 summarizes the total debris amounts added during each test. For each of the eight tests a clean head loss over the screen cartridges was measured during the first five minutes (minimum) of the test per each flow rate intended for the test. Time zero of each test was defined when the desired initial flow rate through the loop was reached and steady-state. Initial flow rate in this case means any one of the intended flow rates to be used during the test for which an initial clean head loss needs to be measured.

All eight tests were run with an initial flume water depth of about [ ]^{a,c} The mean depth of the fluid in the loop increased slightly by [ ]^{a,c} into the flume. The volume increase was mainly due to the fibrous debris, because the fiber was wetted (for all tests except WE213-3W to WE213-5W) in a bucket of water prior to being introduced into the flume. The wetting was performed so the fiber would sink rapidly. Adding dry fiber resulted in the fiber floating on top of the water and sinking at a very slow rate. The particulate was added as dry powder, which sank on the order of seconds after being introduced into the flume. The chemical debris also contributed to an increase in the overall volume of the loop.

For the design basis tests, where the AlOOH was prepared based on the WCAP methodology (Reference 9), the debris was added as a solution. The procedure required [ ]^{a,c} The net effect on the mean flume water level by adding the debris and chemicals was small, about 2 inches, because the water was distributed on both sides of the screen cartridges.

The initial flume water temperature for each test was about 17°C (63°F) as dictated by the supply. The water used during the testing was well water, which was demineralized (Chlorides and Fluorides were not present) prior to being used. The temperature of the water was kept constant to within a couple of degrees Celsius by the chiller unit controlling the loop water temperature. The temperature was recorded for each test and the plots are available in Appendix A.

The loop flow rate was kept constant at [ ]^{a,c} for four of the eight tests (WE213-1W, WE213-1, WE213-2, and WE213-3) conducted as part of this investigation. For the second (WE213-2W) and third (WE213-3W) design basis tests, the flow rate was kept constant at [ ]^{a,c} for the chemical additions. For the fourth (WE213-4W) and fifth (WE213-5W) design basis tests the same procedure of flow variation was followed, however the flow rate for particles and fiber was [ ]^{a,c} in test WE213-5W for chemical addition.

Each test was initiated and the clean head loss data collection completed, the particulate debris was introduced into the flume as dry power. The material was weighed out and the powered material "sprinkled" onto the surface of the flume water level. In WE213-3W to WE213-5W the particulate debris was added at a much slower rate. This addition was near the sparger (away from the cartridge) making sure that the debris was well distributed in the water volume prior to being transported to the screen cartridges.

"Termination" as used above refers to the data acquisition system and the pump being turned off. A few more activities were carried out once the test was terminated. First, [

]a,c Documentation of the debris bed for each test is provided in the subsequent sections.

a,c

Table 7-1 AP1000 Head Loss Tests Matrix as Performed (Reference 7)

Table 7-2 provides the debris loads for each test performed.

a,c

Table 7-2 AP1000 Screen Test Debris Load (Reference 7)

7.1 DESIGN BASIS TEST #1 (WE213-1W)

This first design basis test was performed to qualify the performance of the AP1000 recirculation screen cartridges. Figure 7-1 shows the head loss history across the screen cartridges, Figure 7-2 shows the flow rate during the test and Figure 7-3 shows the clean screen head loss prior to introduction of debris. The debris loads and flow rates for this test were based on conditions that would be seen by the IRWST screens, which bound the conditions that would be seen by the CR screens. [ ]^{a,c}

The test was initiated by first obtaining a clean flume configuration head loss reading for about five minutes once a steady-state, [ ]^{a,c} A single particulate debris addition occurred at twelve minutes into the test. The particulate was introduced near the sparger by "sprinkling" the material near the surface of the water over a period of about ten seconds. Any particulate debris that remained in the bucket was rinsed out with flume water and poured into the flume to ensure that all of the particulate debris was deposited in the flume.

Within tens of seconds of the particulate debris being added, the entire flume volume turned gray in color. The debris did not settle, but remained suspended in the water medium. Figure 7-4 shows the particulate debris homogenously distributed throughout the flume. Stirring was used during these turnovers to assure that most of the debris remained suspended in the flume or was deposited in the screen cartridges as intended instead of settling out on horizontal surfaces in the flume outside of the screens.

The flume volume was allowed to turn over a minimum of five times before additional debris could be added. At 32 minutes into the test, [ ]^{a,c} Stirring was used as necessary to re-suspend any debris that settled outside of the screen cartridges.

The particle debris was observed to stay suspended in the flume, so the flume was allowed to turn over for a few hours to provide sufficient time for the debris to deposit in the screens. Since a sufficient number of turnovers were provided and a steady-state pressure drop was observed, the first addition of chemical debris was made. The chemical debris was prepared based on the WCAP methodology (Reference 9); thus, precipitated AlOOH was added to the flume. [ ]^{a,c}

A steady-state head loss was observed within about 1 hour after the first chemical addition, so a second AlOOH addition was made, equal in quantity to the first. [ ]^{a,c}

Five hours into the test, the third chemical addition [ ]^{a,c} This addition had a [ ]^{a,c} as seen in Figure 7-1. [

]^{a,c} Stirring was used to re-suspend the debris, which turned the flume water gray.

[

]^{a,c} However, changes in the flow rate were minor, as could be observed in Figure 7-2.

Approximately four hours after the last chemical addition, the flume was inspected and it was observed that all the debris had settled out and the water had become clear. The settled debris was again a small film on the order of a couple of millimeters in thickness. Stirring was conducted as an effort to deposit the settled debris into the screen cartridges. The stirring induced a significant increase in head loss as seen in Figure 7-1. After the stirring, the flume was left uninterrupted. The next observation of the flume showed that the head loss had recovered since the last chemical addition and had reached a steady-state value. The flume water had turned clear and it should be noted that there was no significant amount of debris settled outside of the screen cartridges, making stirring unnecessary. A chemical addition of [

]^{a,c}

For the remainder of the experiment, chemicals were added if a steady-state head loss was attained and at least five turnovers were allowed. Starting at approximately 34 hours into the test, the chemical additions [

]^{a,c} However, [ ]^{a,c} It is important to note that the [

]^{a,c} This step change and recovery was not so pronounced with the [

]^{a,c}

After termination of the test, the flume was left stagnant overnight to enable any suspended debris to settle out. The water was drained and the end panels removed. The screen cartridges were inspected and documented. Pictures of the screen cartridges following this test are provided as Figures 7-6 through 7-8.

Water samples were collected at various times during the test. The samples were analyzed to determine the amount of aluminum in solution in each sample. The tested samples contained only the solution portion of the collected sample after it had been allowed to settle for at least 48 hours. Based on the results of the analysis presented in Reference 7, the amount of aluminum dissolved in the samples is very low and therefore solubility does not play a significant role in the experiments that were conducted in the flume.

In addition to the data presented and discussed above, the pH was also measured during the experiment.
[

]a,c

[

]a,c

The information provided above was summarized from Reference 7.

a,c

Figure 7-1 Head Loss History for AP1000 – WE213-1W (Reference 7)

a,c

Figure 7-2 Flow Rate History for AP1000 – WE213-1W (Reference 7)

a,c

Figure 7-3 Clean Screen Head Loss During the First Five Minutes of WE213-1W Test (Reference 7)

a,c

Figure 7-4 SiC in Flume AP1000 – WE213-1W (Reference 7)

a,c

Figure 7-5 AlOOH Milky Appearance AP1000 – WE213-1W (Reference 7)

a,c

Figure 7-6 Screen Cartridge Following Test for AP1000 – WE213-1W (Reference 7)

a,c

Figure 7-7 Screen Cartridge Following Test for AP1000 – WE213-1W (Reference 7)

a,c

Figure 7-8 Screen Cartridge Following Test for AP1000 – WE213-1W (Reference 7)

7.2 DESIGN BASIS TEST #2 (WE213-2W)

The second design basis test was performed in a very similar manner to the first design basis test. Figure 7-15 shows the head loss history across the screen cartridges, Figure 7-16 shows the flow rate during the test, Figure 7-17 shows the head loss history during the flow variation, and Figure 7-18 shows the flow rate history during the flow variation. The purpose of the test was to investigate the behavior of the system if [

]a,c

After the clean head loss was measured, the fiber was added into the flume. A mass of [

]a,c

Figures 7-9 and 7-10 are included to show the fibers shortly after being introduced into the flume and the settled debris upstream of the filter, respectively. Particulate debris was added next the same way as in WE213-1W. Just as with all the other tests, the flume water turned completely gray within a minute after this debris was added. The flume was stirred to aid the distribution of the particle debris in the flume making sure it got deposited in the screens. As before, the particulate debris continued to pass through the screen and settled in the flume at a very slow rate. A few hours were provided for the flume to turnover sufficiently allowing time for [
]a,c

The pressure drop in the flume reached about [

]a,c

The pressure drop never increased substantially throughout the entire duration of the test. Towards the later additions a slight increase was observed, but the maximum allowable head loss of [

]a,c

The water in the flume turned milky/cloudy after each AlOOH addition and continued to get more opaque (more milky/cloudy) as more chemical debris was added. This behavior is shown in Figure 7-11. Also, as the flume was allowed to run uninterrupted for hours at time, such as during an overnight run, AlOOH was observed to settle out on horizontal surfaces in the flume. One example of this behavior can be seen in Figure 7-12, where settled out AlOOH is seen to collect on top of the screen cartridge assembly on the downstream side. The picture was taken at the end of the experiment.

Upon completion of the test, the flume water was drained and the end panels removed. The screen cartridges were photographed and three photos are included as Figures 7-12 through 7-14. Figure 7-12 shows the entire screen cartridge, Figure 7-13 shows a close-up view of the bottom and Figure 7-14 shows the very small amount of light being able to pass through the filter when light was shone on the downstream side of it. The lack of passing light demonstrates the amount of debris present in the screens.

Since the total amount of debris intended for this test was not added into the flume and the maximum head loss was not exceed, another termination criterion was used as described in the test plan (Appendix A). The concentration of [ ]a,c

Water samples were collected during the experiment, one sample before each debris (chemical and non-chemical) addition. This allowed for the concentration of AlOOH precipitates in the flowing stream to be determined at different points during the test. An initial sample was also collected at time zero as a reference point. The results for two of the many samples collected are reported here. [ ]a,c respectively. Thus, as could be seen, the concentration of AlOOH was well above the termination criteria and therefore the test could be terminated. Even though Sample 12 showed that the concentration in the flume was greater than [ ]a,c more debris was added to investigate the influence of additional AlOOH on the head loss and behavior of the flume. The concentration results were obtained by boiling off a portion of the collected sample and weighing the amount of residue remaining in the beaker after all the water had been boiled off. Table 7-3 shows the data used for calculating the concentrations.

[ ]a,c Also, the temperature in the flume was held constant by using the chiller unit as could be seen in the results provided in Appendix A. Additional pressure plots are also included in Appendix A along with the head loss and flow rate plots included as Figures 7-15 and 7-16, respectively.

Lastly, two additional plots are included as Figures 7-17 and 7-18, which show the flow variation study conducted at the end of the experiment. The flow rate was [ ]a,c Consequently, the pressure drop increased to [ ]a,c

a,c

Figure 7-9 Fiber Seconds After Being Added in the Flume (Reference 7)

a,c

Figure 7-10 Settled Fiber Upstream of the Screen Cartridges (Reference 7)

a,c

Figure 7-11 Settled AlOOH on the Screen Cartridges Assembly (Reference 7)

a,c

Figure 7-12 View of the Entire Screen Cartridge with Deposited Debris for Test WE213-2W

a,c

Figure 7-13 Close-up View of the Bottom of the Screen Cartridge for Test WE213-2W

a,c

Figure 7-14 Close-up View of the Bottom of the Screen Cartridge for Test WE213-2W

Table 7-3 Concentration of AlOOH in the Flume for WE213-2W (Reference 7)

a,c

a,c

Figure 7-15 Head Loss History for Test WE213-2W (Reference 7)

a,c

Figure 7-16 Flow Rate History for Test WE213-2W (Reference 7)

a,c

Figure 7-17 Head Loss History during the flow Variation for Test WE213-2W (Reference 7)

a,c

Figure 7-18 Flow rate History during the Flow Variation for WE213-2W (Reference 7)

7.3 DESIGN BASIS TEST #3 (WE213-3W)

This test, as well as the following two design basis tests discussed in Section 7.4, was performed differently from the first two design basis tests. The main differences were in terms of fibrous debris preparation and the method of adding debris, especially the chemical debris, into the loop. The purpose of the test was the same as in the second design basis test, WE213-2W, which was to investigate the behavior of the system if [

]^{a,c}

[

]^{a,c} The first step of the test was to obtain a clean loop head loss as a reference point at each flow rate intended for the test. This initial step lasted at minimum of ten minutes, with about five minutes for each flow rate. Following the measurements of the clean screen head loss, the particulate debris was added first over a period of few minutes as noted in Figures 7-19 and 7-20. Overall, the method was the same as in the design basis tests WE213-1W and WE213-2W, except that the debris was introduced more slowly with the powdered debris "sprinkled" near the surface of the water and in close proximity of the sparger.

As expected, within tens of seconds after the addition of the debris, the flume water turned completely gray both upstream and downstream of the screen. In other words, the particulate debris had no difficultly passing through the screens. No head loss was observed following the particulate addition. As outlined in the procedures, the flume was then allowed to turn over five times prior to the next debris addition. During the turnover period the flow rate remained steady and no increase in head loss was observed. Furthermore, no settling of particulate debris was noticed, but stirring was used to mix the debris to ensure that it passed through the screens.

The fiber was added next using a different procedure than for the previous tests. The goal was to introduce the fiber in the form of fine individualized fibers. As shown in Figure 7-9 and 7-10, some fiber agglomeration was observed during the fibrous debris addition in earlier tests. As the fibrous debris settled, the flume was stirred to encourage capture of the fibrous debris by the screens. However, fiber clumps were not adequately separated for WE213-1W and WE213-2W. To address this condition, the fiber was prepared in [

]^{a,c} above was implemented in tests WE213-3W through and including WE213-5W.

Early additions of the fibrous debris caused no observable increase in head loss. . However, shortly after the fiber was introduced, a small increase in head loss was observed followed by a large increase as seen in Figure 7-19. The head loss continued to increase with subsequent fiber additions eventually reaching a peak value just under [ ]^{a,c} Following the completion of all the fiber additions, the flume was stirred to make sure that any settled debris (mainly concentrating on fibrous debris, because the particulate debris was readily in suspension) would be re-suspended and deposited into the screen cartridges. Then, the flume was run until the next day at steady-state, allowing the head loss to stabilize. The particulate debris was allowed to settle, which was required in order to extract a good reference sample for chemical testing.

Chemical debris was added the following day. First, a solution sample was collected, which was used as a reference sample for chemical testing needed later in the test, as is discussed below, and the flow rate was decreased to about [ ]^{a,c} Then, the chemical debris was added in small batches differently than during the previous two design basis tests. Unlike previously, the AlOOH was added very slowly to the flume, over at least a few minutes per batch) as outlined in Figures 7-19 and 7-20 (see the legends in the figures). During the first few additions, corresponding to the first few hours over which the chemical was added into the loop, the rate of addition was closely followed (equal to or greater than) along the predicted rate of chemical production in the AP1000 scaled to the flume size and then doubled for conservatism. The scaled predicted rate of production of AlOOH in the AP1000 is shown in Table 7-4 as well as in Figure 7-22 which compares the rate of chemical addition to the flume to the predicted rate of AlOOH production in the AP1000).

This third design basis test was the only design basis test that resulted in the head loss exceeding the allowable limit of [ ]^{a,c} . The head loss limit was exceeded very early into the chemical addition phase of the experiment) (see Figures 7-20 and 7-23 for more information). As seen in Figure 7-20, almost immediately following the addition of the first batch of AlOOH, the head loss started to increase and continued to increase significantly. The allowable head loss limit was exceeded after a small amount of chemical debris being added [ ]^{a,c} Note that the initial head loss prior to the start of chemical addition was not zero, but about [

]^{a,c} Once the allowable head loss was exceeded, conditions were met that allowed for the test to be terminated, since that was one of the two criteria necessary for test termination. The other termination criteria stated that the test could be terminated once the concentration of AlOOH inside the loop exceeded [

]^{a,c}

Even though [

]^{a,c}

After the sensitivity study, the loop was allowed to run steady-state overnight to allow the head loss to stabilize and reach a final value and also allow the debris to settle. It was observed, and expected from previous tests, that the particulate debris would settle out during an overnight run, but the chemical debris would not settle out completely with the water still being cloudy/milky the next morning. Nevertheless, a large amount of AlOOH did settle out on the horizontal surfaces within the loop just as observed in previous tests. After noting the last set of observations, the flow rate was dropped to zero and the test terminated. The following day the loop was drained and the end panels removed which allowed access for cleaning and photographs to be taken of the screen cartridges. Three photographs are included for this test, which show an overall view of the cartridges (Figure 7-25) and two close-up views (Figures 7-26 and 7-27).

[

]^{a,c} Also, the temperature in the flume was held constant by using the chiller unit as could be seen in the results provided in Appendix A.

a,c

Figure 7-19 Head Loss History for Test WE213-3W (Reference 7)

a,c

Figure 7-20 Flow Rate History for Test WE213-3W (Reference 7)

a,c

Figure 7-21 Fine and Individualized fiber for Test WE213-3W (Reference 7)

Table 7-4 Rate of Chemical Production in the AP1000 Scaled to the Flume and Doubled for Conservatism for the WE213-3W Test (FAI/Westinghouse, 2009b) (Reference 7)

a,c

a,c

Figure 7-22 Rate of AlOOH Addition for Test WE213-3W

a,c

Figure 7-23 Head Loss History for Test WE213-3W after the Start of Chemical Debris Additions

a,c

Figure 7-24 Flow Rate History for Test WE213-3W Test after Chemical Debris Additions

a,c

Figure 7-25 View of the Entire Screen Cartridges with Deposited Debris for the Test WE213-3W

a,c

Figure 7-26 Close-up View of Debris Deposited at the Bottom of the Screen for Test WE213-3W

a,c

Figure 7-27 Close-up View of Debris Deposited at the Top of the Screen for Test WE213-3W

7.4 DESIGN BASIS TEST #4 AND TEST #5 (WE213-4W AND WE213-5W)

The last two design basis tests (WE213-4W and WE213-5W) conducted as part of this program are discussed together due to the almost identical conditions under which the tests were run and the very similar results that were obtained. [

]^{a,c} including the data presented in Table 7-2.

Both tests were initiated similarly to the previous tests, in which the clean screen configuration head loss was first measured at each intended flow rate to be used during the tests for a minimum of five minutes at each flow rate. [
]^{a,c} for WE213-4W and WE213-5W, respectively. Once the clean screen head loss was measured, the particulate debris was added using the same procedure as in WE213-3W, in which the particulate debris was "sprinkled" slowly near the water surface in the flume. Following the addition, the flume was run at steady-state for five turnovers. Stirring was done to distribute the particulate throughout the flume making sure that it was transported to the screen cartridges.

The addition of the particulate debris resulted in the same behavior observed in all other tests, in which shortly after the addition of the debris the flume water turned gray and the particulate debris was distributed throughout the loop, both upstream and downstream of the screen cartridges. Additionally, as expected based on previous tests, no head loss increase was observed following the addition of this debris even after a minimum of five turnovers. The head loss and flow rate plots for the entire duration of both tests are included as Figures 7-28 and 7-29 for WE213-4W and as Figures 7-30 and 7-31 for WE213-5W. These figures indicate the points of the particulate debris addition to the loop along with a note stating the length of time over which the particulate was added.

Following the addition of the particulate debris, the flume was allowed to turnover five times, which was the usual procedure that has been followed in the previous tests. No considerable head loss increase was observed in both of the tests.

The fiber was added next using the same procedure as in the third design basis test (WE213-3W), [

]^{a,c} in Figures 7-28 and 7-30 for WE213-4W and WE213-5W, respectively. Stirring was done to mix and resuspend any debris, mostly fiber, which might have settled on the bottom of the flume. It was difficult to see whether any debris had actually settled due to the water being gray from the particulate debris, so stirring was conducted for the one minute period typically used in previous tests. Next, the flume was allowed to run steady-state until the next day when the chemical debris was added.

The addition of chemical debris was also conducted using the same procedure as in the WE213-3W test in which early additions closely followed the predicted production rates of AlOOH in the AP1000. However, for these two tests a larger IRWST screen was assumed, hence the rate of chemical addition presented in Table 7-4 was [ ]^{a,c} The new values are presented below in Table 7-5. Also, the rates at which the AlOOH was added into the flume for both tests are presented graphically in Figure 7-32 along with head loss and flow histories during those times represented in Figures 7-33 through 7-37. A total of [ ]^{a,c} was added to the flume during each test, but all this debris had no affect on the head loss. The pressure remained very close to zero for the entire duration of both tests. However, the chemical did cause the water in the flume to turn milky/cloudy, which was expected based on previous test results. Once all the debris was added, the flume was stirred for about one minute per the usual procedure and then allowed to run steady-state until the next morning during both tests.

The following day a chemical sample was collected and analyzed for the concentration of AlOOH in solution using the same procedure as described in Section 7.2 for test WE213-2W. A portion of the sample was boiled off and the remaining solid debris was measured on an electronic balance. Any mass that needed to be subtracted from the reference sample, which was collected just prior to any chemical additions, was accounted for and then the number was converted to a concentration. [ ]^{a,c}

The large uncertainty was considered based on the sensitivity of the equipment, which was observed to measure the data with a ± 0.06 gm tolerance. [ ]^{a,c} The data collected and used in the calculation of the concentrations presented here is included as Table 7-6 for Test WE213-4W and Table 7-7 for Test WE213-5W, respectively.

Since one of the [ ]^{a,c} Before either of the tests was terminated, a flow variation study was conducted to observe the behavior of the system in response to an increase in flow rate. In both tests, the increase followed by a decrease in flow rate did not have an impact on the head loss, which remained very close to zero psi. An expanded view of the data collected during the flow variation flow studies is presented in Figures 7-37 and 7-38 for WE-2134W and Figures 7-39 and 7-40 for WE213-5W.

Upon completion of the flow variation studies, the tests were terminated. Then, the flume was drained and the screen cartridges photographed. Two figures are included, one for each test, that show a large portion of the screen cartridges. Figure 7-41 shows the screen cartridges following test WE213-4W and Figure 7-42 following test WE213-5W. Additionally, a close-up view of some of the screen pockets is included in Figures 7-43 and 7-44 for tests WE213-4W and WE213-5W, respectively. On the other hand, if the fibers were observed to still be "clumpy," the mixture was shaken more and the fiber content inspected once again. This procedure was repeated until the desired fiber consistency was obtained. Photographs of the type of final fiber debris that was introduced into the loop are provided in Figure 7-45 and Figure 7-46.

Finally, [ ]^{a,c} Additionally, the temperature in the flume was held relatively constant by using the chiller unit as is seen in the results provided in Appendix A.

a,c

Figure 7-28 Head Loss History for the Test WE213-4W

a,c

Figure 7-29 Flow Rate History for the Test WE213-4W

a,c

Figure 7-30 Head Loss History for the Test WE213-5W

a,c

Figure 7-31 Flow Rate History for the Test WE213-5W

a,c

Figure 7-32 Rate of AlOOH Addition during the Tests WE213-3W and WE213-4W

a,c

Figure 7-33 Head Loss History for Test WE213-4W after Chemical Debris Addition

a,c

Figure 7-34 Flow Rate History for Test WE213-4W after of Chemical Debris Addition

a,c

Figure 7-35 Head Loss History for Test WE213-5W after Chemical Debris Addition

a,c

Figure 7-36 Flow Rate History for Test WE213-5W after Chemical Debris Additions

a,c

Figure 7-37 Head Loss History during the Flow Variation Study at the End of Test WE213-4W

a,c

Figure 7-38 Flow Rate History during the Flow Variation Study at the End of Test WE213-4W

a,c

Figure 7-39 Flow Rate History during the Flow Variation Study at the End of Test WE213-5W

a,c

Figure 7-40 Flow Rate History during the Flow Variation Study at the End of Test WE213-5W

Table 7-5 Rate of Chemical Production in the AP1000 Scaled to the Flume And Doubled for Conservatism for the WE213-4W and WE213-5W Tests (FAI/Westinghouse, 2009b) (Reference 7)

a,c

Table 7-6 Concentration of AlOOH in the flume during the WE213-4W (FAI/Westinghouse, 2009b) (Reference 7)

a,c

Table 7-7 Concentration of AlOOH in the flume during the WE213-5W (FAI/Westinghouse, 2009b) (Reference 7)

a,c

a,c

Figure 7-41 Flow View of Multiple Pockets with Deposited Debris for Test WE213-4W

a,c

Figure 7-42 View of Multiple Pockets with Deposited Debris for Test WE213-5W

a,c

Figure 7-43 Close-up View of Deposited Debris for Test WE213-5W

a,c

Figure 7-44 Close-up View of Deposited Debris for Test WE213-5W

a,c

Figure 7-45 Fine and Individual Fiber for Test WE213-4W

a,c

Figure 7-46 Fine and Individual Fiber for Test WE213-5W

7.5 ENGINEERING EVALUATION TEST #1 (WE213-1)

WE213-1 is the first of three engineering evaluation tests performed. This test was conducted to investigate the behavior of the screen cartridges, the flume, and the head loss to different debris loads. [

]^{a,c}

As in the design basis test, clean flume head loss was measured for the first five minutes, then the particulate debris was added. [ ]^{a,c} As in the design basis test, the addition of the particulate debris turned the flume water gray until the first chemical addition. [

]^{a,c}

The chemicals were introduced [

]^{a,c}

The following two reactants [

]^{a,c}

During the first two additions [

]^{a,c} The precipitates resembled the appearance of snow/milk. Figure 7-49 shows the gray flume water with precipitates distributed throughout the flume volume.

After the addition [ ]^{a,c} After five volume turnovers with no appreciable change since the last addition, the test was terminated. [

]^{a,c} A view of the debris bed in the screen cartridges is included in Figure 7-50.

a,c

Figure 7-47 Head Loss History for the Test WE213-1 (Reference 7)

a,c

Figure 7-48 Flow Rate History for the Test WE213-1 (Reference 7)

a,c

Figure 7-49 View of Precipitated AlOOH in the Flume for Test WE213-1 (Reference 7)

a,c

Figure 7-50 Debris Bed in the Screen Cartridges Following the Test WE213-1 (Reference 7)

7.6 ENGINEERING EVALUATION TEST #2 (WE213-2)

The second engineering evaluation test was very similar to WE213-1 in terms of results and debris addition steps. The difference was the [

]^{a,c} The chemical debris was added in the same manner as in test WE213-1 [

]^{a,c}

The head loss and flow rate data for this test is presented in Figure 7-51 and Figure 7-52. As seen in the figures, [ ]^{a,c} The debris bed formed during the test is shown in Figure 7-53. The pH of the flume water [

]^{a,c} No further discussion is necessary for this test, because it was similar in results to the first engineering evaluation test and any differences have already been discussed.

a,c

Figure 7-51 Head Loss History for the Test WE213-2 (Reference 7)

a,c

Figure 7-52 Head Loss History for the Test WE213-2 (Reference 7)

a,c

Figure 7-53 Debris Bed in the Screen Cartridges Following the Test WE213-2 (Reference 7).

7.7 ENGINEERING EVALUATION TEST #3 (WE213-3)

The last of the engineering evaluation tests investigated a loading that corresponded to [ ]^{a,c} The procedures for this test were similar to those of the first two engineering evaluation tests. The main difference for this test [ ]^{a,c} The results are shown in Figure 7-54 and Figure 7-55 in terms [ ]^{a,c}

The resultant [ ]^{a,c}

Except for the [ ]^{a,c}

a,c

Figure 7-54 Head Loss History for the Test WE213-3 (Reference 7)

a,c

Figure 7-55 Flow Rate History for the Test WE213-3 (Reference 7)

a,c

Figure 7-56 Debris Bed in the Screen Cartridges Following the Test WE213-3 (Reference 7)

7.8 VORTEX FORMATION UPSTREAM OF THE SCREEN CARTRIDGES

One of the concerns during each of the head loss tests was the potential for vortex formation upstream of the screen cartridges. Once a significant head loss forms across the screens, a water level difference develops thus causing the downstream end of the screens to be exposed. This provides an opportunity for the water entering the screens to entrain air along with it and result in a vortex. However, no vortex formation and air entrainment into the screens was observed in any of the tests. [

][a,c] Finally, Figure 7-57 through Figure 7-59 are included to show the level difference in the flume [
][a,c]

a,c

Figure 7-57 Visible Level Difference Across the Screen Cartridges (Reference 7)

a,c

Figure 7-58 Downstream Level Across the Screen Cartridges (Reference 7)

a,c

Figure 7-59 Upstream Level Across the Screen Cartridges (Reference 7)

8 CONCLUSIONS

8.1 TEST DATA SUMMARY

Eight head loss tests were conducted as part of the AP1000 containment recirculation screen test program, including the five design basis tests conducted to demonstrate the performance of the AP1000 recirculation screen cartridges with a design basis debris load of particulate, fibrous, and chemical debris. The design basis tests results indicate that for the design basis loading induced during the tests, the maximum head loss will not be exceeded across the screens. Looking for indications of vortexing was also included as part of the program. No vortexing was observed over the screens even when conditions favorable to initiation of vortex generation were purposefully induced by exposing the upstream side of the screens.

Three of the test conducted, referred to as engineering evaluations, used different debris loads and recorded the resulting head loss response of the screens. In the engineering evaluations, the chemical addition procedure was varied between the design basis and engineering evaluations to test for the effect of the chemical addition methods on the head loss over the screens.

Table 8-1 lists a summary of head loss test observations for the design basis test and three engineering evaluations.

Table 8-1 Test Summary

a,c

8.2 APPLICABILITY OF TESTING TO AP1000 DESIGN

[

]a,c

a,c

Figure 8-1 Screen Pocket

a,c

Table 8-2 Dimensions of Screen Pocket		

[

]a,c

As can be observed from the data from design basis tests WE213-4W and WE213-5W (including photographs), the amount of debris that can be transported to the AP1000 recirculation screens is very small and is not sufficient to form a contiguous debris bed. This is also true for two of the sensitivity cases with much higher debris amounts. The resulting head loss in these four screen debris loading tests was insignificant.

The design basis screen debris tests were conducted at flows that were as [

]^{a,c}

As [ ]^{a,c} bounded the conditions for both the Containment Recirculation and the In-Containment Refueling Water Storage Tank Screens, the data collected from this program is applicable to both screens. Therefore, the data from this test program is directly applicable to the AP1000 [ ]^{a,c}

9 SUMMARY

Head loss experiments were conducted for the AP1000 in response to Generic Safety Issue 191 (GSI-191) for the AP1000 design. The data from this test program demonstrate the ability of both the CR and the IRWST screens to successfully perform their design functions under the debris loading conditions expected for the AP1000 following a postulated LOCA.

Eight head loss tests were conducted as part of this AP1000 containment recirculation screen test program, including the five design basis tests conducted to demonstrate the performance of the AP1000 recirculation screen cartridges with a design basis debris load of particulate, fibrous, and chemical debris. The design basis tests results indicate that for the design basis loading induced during the tests, the maximum head loss will not be exceeded across the screens.

Tests WE213-4W and WE213-5W demonstrate the performance of the recirculation screens under design basis debris loading conditions, including chemical effects is acceptable, when considering the design basis debris loadings that include latent particulates, latent fibrous materials, and the chemical precipitates that may form in the containment water pool.

Tests WE213-4W and WE213-5W also demonstrate that the [ ]^{a,c} screens will perform as required under the expected AP1000 debris loading conditions. That is, the design basis screens will not develop head losses due to debris collection that will challenge long-term core cooling and will therefore provide for maintaining a coolable core geometry.

Furthermore, the test conditions bound the flow and debris conditions that both the CR and the IRWST screens would experience in the recirculation mode following a postulated LOCA. The data applies to both of those screens.

10 REFERENCES

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3. Technical Report TR-147, Revision 3, "AP1000 Containment Recirculation and IRWST Screen Design," AP1000 Document Number APP-GW-GLN-147, November 2009.

4. APP-GW-GLR-079, Revision 7, "AP1000 Verification of Water Sources for Long Term Recirculation Cooling Following a LOCA," February 2010.

5. FAI/08-10, Revision 0, "Test Report for Debris Loadings Head Loss Tests for AP1000 Recirculation Screens," 2008.

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9. WCAP-16530-NP-A, Revision 0, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," April 2008.

10. Letter from H. K. Nieh (NRC) to G. Bischoff (PWROG), "Final Safety Evaluation for Pressurized Water Reactor Owners Group (PWROG) Topical Report (TR) WCAP-16530-NP, 'Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191' (TAC No. MD1119)," December 2007.

11. Revised Guidance for Review of Final Licensee Responses to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors," March 2008. [ML080230234]

12. FAI/09-210, Revision 0, "Test Plan for AP1000 Debris Loading Head Loss Test 8," August 2009.

13. APP-PXS-GLR-001, Revision 4, "Impact on AP1000 Post-LOCA Long-Term Cooling of Postulated Containment Sump Debris," February 2010.

APPENDIX A
TEST PLAN

This Appendix is proprietary in its entirety.

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APPENDIX B
BOIL-OFF TEST CALIBRATION

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APPENDIX C
CALCULATION OF ALOOH CONCENTRATION FROM BOIL-OFF TESTS

This Appendix is proprietary in its entirety.

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