# ENCLOSURE 8

WCAP-16914-NP, Revision 2

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

(Non-Proprietary)

Westinghouse Non-Proprietary Class 3

WCAP-16914-NP
APP-MY03-T2C-001
Revision 2

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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-001**
**Revision 2**

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

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## 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. |

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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 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 Containment Recirculation and the In-Containment Refueling Water Storage Tank Screens to successfully perform their design functions under debris loading conditions expected for the AP1000 following a postulated LOCA. Four 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 values for the hydraulic and debris loading conditions of interest, including the design basis debris loading test. The design basis test demonstrates 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 approved method for particulate generation.

Three additional tests were performed as engineering evaluations to examine the sensitivity to the manner in which the chemical constituents might enter the water. In 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 test provides the most conservative manner of loading the recirculation screens and the tests showed acceptable results, all loadings considered.

The testing also demonstrates the [ ]$^{a,c}$ screens will perform as required under the expected AP1000 debris loading conditions. That is, they 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 recirculation screen head loss experiments for the AP1000. The purpose of this test program was to quantify the head loss for both the Containment Recirculation Screens and the In-Containment Refueling Water Storage Tank Screens with debris loadings including containment chemical effects applicable to the AP1000.

[

]a,c

The performance of the recirculation 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. Four head loss tests, including a design basis test and three engineering tests, were performed that investigated a spectrum of debris inventories, debris staging, chemical effects, and flow rates. From the design basis test, [

]a,c

These 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 silicon carbide as a particulate surrogate, NUKON®[1] fibrous insulation as a resident fiber surrogate and aluminum oxyhydroxide (AlOOH) as the chemical precipitate surrogate. The recirculation 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. Therefore, the following sequence of debris addition was used for the design basis test. 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 desired assembly flow rate was obtained and allowed to stabilize until a steady state condition was verified.
- 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 introduction to the flume. The wetted fibers were added into the flume by pouring 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 WCAP-16530-NP methodology and then added to the test loop in measured batches.

The design basis test was 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 WCAP-16530-NP-A (Reference 9). When the AlOOH is formed in this manner, the

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

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 test was 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 nonahydrate ($Al(NO_3)_3 \cdot 9H_2O$) 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 PREPARATION

Photo and video evidence 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.

### 3.1.1 Particulate Preparation

The particulate used in the AP1000 screen tests, silicon carbide (SiC) with a 9.5-micron median particle size, was used to simulate the particulate component of the containment latent debris. All particulate material was well mixed in a bucket of loop water until completely suspended before being introduced in the test. Based on the above, the particulate used in the AP1000 screen head loss tests is applicable to the AP1000 plant.

### 3.1.2 Fiber Preparation

The fiber used in the AP1000 screen tests, [NUKON® fibrous insulation supplied by PCI, was used to simulate the fibrous component of the containment latent debris. The NUKON® fiber was heat treated prior to processing by PCI. Heat treated "shredded" fiber glass was processed through PCI's Munson shredder and produced fiber glass 'fines' debris. Heat treated "Chipped" fiber glass was processed through a wood chipper and produced fiber glass that is less fine with small clumps of material. A combination of the fibrous materials was wetted in loop water before being introduced in the test. It was observed in screen test WE213-1W that there was a substantial head loss across the screen indicating that there was a contiguous debris bed on the screen. This implies that the fiber was adequately prepared]$^{a,c}$. 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 Preparation

The chemical surrogate used in the AP1000 screen was made outside of the loop according to the approved procedure in WCAP-16530-NP-A prior to introduction into the test loop. The batches of chemical debris were added to the test loop at various rates, depending on the requirements of the particular test. The chemical surrogate was added in a number of batches spaced out to allow at least five turnovers of the fluid in the loop prior to the next addition. 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 can be accomplished in two ways:

- By meeting the equilibrium criterion determined by calculating the slope in differential pressure across the screen assembly [

\ ]$^{a,c}$

- If the pressure differential limit established for the test is exceeded, the test may be terminated.

# 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 flume layout. For additional information on the physical arrangement of the test flume, see Reference 6. [

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- 
- 
- ][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 desired to be monitored/recorded during the head loss tests:

- [
-
-
- ][a,c]

**Table 4-1 Instrumentation for Debris Loading Head Loss Testing (Reference 6)**

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# 5 SCALING CONSIDERATIONS

The scaling rationale provided for the use of conservative latent debris loading for the tests. The basic scaling rationale was:

- [

  ]a,c

- [

  ]a,c

[

]a,c

[

]a,c

The ratio of the frontal areas is given in Table 5-1.

[ a,c

| Table 5-1 Recirculation Screen Frontal Area Scaling | | |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

]

Note that the chemical debris load applicable to the IRWST [

]a,c

The flow rate used in the tests is based on the IRWST [

.]a,c

The nominal "full flow" values for the flume recirculation flow rate [

]a,c.

a,c

**Table 5-2 Test Loop Flow Rate to Conservatively Represent the Recirculation Screens**

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|---|---|---|---|
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| | | | |

Note (1) [

(2)

(3)

][a,c]

# 6 INITIAL CONDITIONS AND TEST MATRIX

The initial conditions and test matrix of the head loss testing, including the design basis test and the three engineering tests, are summarized below.

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

- [

  ]$^{a,c}$

- [

  ]$^{a,c}$

- The post-accident chemical surrogate was evaluated and generated using the method described in WCAP-16530-NP-A (Reference 9). The use of this method has been reviewed and accepted by NRC in their Safety Evaluation dated December 21, 2007 (Reference 10). AlOOH is conservatively used as the surrogate for the other chemical products [ ]$^{a,c}$

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

Table 6-1 lists the debris types applicable to the AP1000, as well as what materials were used to represent them in the test. The scaling used for the test assumed that [ ]$^{a,c}$

**Table 6-1 Debris Loads for Head-Loss Testing**

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The initial conditions for each test included the following:

1. Clean screen cartridge module 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 nominal test flow rate depended on the AP1000 specific recirculation screen area and flow rate delivered by its source of recirculation coolant volume. [

]$^{a,c}$

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 (Reference 6). Table 6-2 provides the test matrix with proposed values to be used in the experiments.

Engineering Tests #4, #5, and #6 were designed to investigate head loss dependence on different debris loads (particulate, fibrous, and chemical) and the method of chemical addition. These tests demonstrate the impact on the screen head loss with different debris loads compared to the design basis test. [
]$^{a,c}$.

Design basis Test #7 was designed to demonstrate the head loss over the screen cartridges for extended durations with the design basis particulate, fibrous, and chemical debris load. This test supports the technical basis for reasonable assurance of long-term cooling following a postulated LOCA in the AP1000.

**Figure 6-1 Screen Filter Cartridge Assembly**

**Table 6-2 AP1000 Screen Test Matrix**

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[

]a,c. The head loss limit was taken

as the pressure loss (in psi) calculated in the limiting LTC sensitivity analysis case at the selected flow rate. This same pressure loss was used as the pressure loss limit in the design basis testing.

# 7 TEST RESULTS

## 7.1 SUMMARY OF TEST RUNS, DEBRIS LOADINGS, AND TEST VELOCITIES

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.

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

a,c

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

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

a,c

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|---|---|---|---|
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## 7.2 DESIGN BASIS TEST (WE213-1W)

This 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 containment recirculation screens. [

]$^{a,c}$

The test was initiated by first obtaining a clean flume configuration head loss reading for about 5 minutes once a steady-state, [ ]$^{a,c}$ A single silicon carbide addition occurred at 12 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 10 seconds. Any residual silicon carbide 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 silicon carbide addition, 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 silicon carbide homogenously distributed throughout the flume. Stirring was used during these turnovers to assure that most of the debris remained suspended in the flume or 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 silicon carbide 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; 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 significant impact on the head loss 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 with efforts to deposit the settled debris into the screen cartridges. [

]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

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. [

]a,c

In addition to the data presented and discussed above, the pH was also measured during the experiment.
[ ][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 5 Minutes of the 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)**

## 7.3 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 silicon carbide was added. [ ]a,c As in the design basis test, the addition of SiC 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. Figure 7-11 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 7-12.

a,c

**Figure 7-9 Head Loss History for the First Engineering Evaluation (WE213-1) Test (Reference 7)**

a,c

**Figure 7-10 Flow Rate History for the First Engineering Evaluation (WE213-1) Test (Reference 7)**

a,c

**Figure 7-11 View of Precipitated AlOOH in the Flume (Reference 7)**

a,c

**Figure 7-12 Debris Bed in the Screen Cartridges Following the WE213-1 Test (Reference 7)**

## 7.4 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 7-13 and Figure 7-14. As seen in the figures, [ ]a,c The debris bed formed during the test is shown in Figure 7-15. The pH of the flume water [

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

a,c

**Figure 7-13 Head Loss History for the Second Engineering Evaluation (WE213-2) Test (Reference 7)**

a,c

**Figure 7-14 Head Loss History for the Second Engineering Evaluation (WE213-2) Test (Reference 7)**

a,c

**Figure 7-15 Debris Bed in the Screen Cartridges Following the WE213-2 Test (Reference 7).**

## 7.5 ENGINEERING EVALUATION TEST #3 (WE213-3)

The last of the engineering evolution tests investigated a loading that corresponded to [ ][a,c] The procedures for this test were similar to those of the first two engineering evolution tests. The main difference for this test [ ][a,c] The results are shown in Figure 7-16 and Figure 7-17 in terms [ ][a,c]

The resultant [ ][a,c]

Except for the [ ][a,c]

a,c

**Figure 7-16 Head Loss History for the Third Engineering Evaluation (WE213-3) Test (Reference 7)**

a,c

**Figure 7-17 Flow Rate History for the Third Engineering Evaluation (WE213-3) Test (Reference 7)**

a,c

**Figure 7-18 Debris Bed in the Screen Cartridges Following the WE213-3 Test (Reference 7)**

## 7.6 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 Lastly, Figure 7-19 through Figure 7-21 are included to show the level difference in the flume [
]a,c

a,c

**Figure 7-19 Visible Level Difference Across the Screen Cartridges (Reference 7)**

a,c

**Figure 7-20 Downstream Level Across the Screen Cartridges (Reference 7)**

a,c

**Figure 7-21 Upstream Level Across the Screen Cartridges (Reference 7)**

## 7.7 FLASHING EVALUATION DOWNSTREAM OF THE SCREEN CARTRIDGES

The water in the IRWST is normally subcooled throughout most of a LOCA transient. For larger LOCAs the passive residual heat removal heat exchanger [

]$^{a,c}$.

The minimum water level in the IRWST occurs during [

]$^{a,c}$.

a,c

[ ]

**Figure 7-22 IRWST Screen Operation With the Water Level Just Below the Screen Top**

The other case considers a [

]a,c as shown in Figure 7-23.

a,c

**Figure 7-23 Screen Operation With the Water Level Just Above the Screen Top**

For the second case, a calculation was made of the steam bubble rise velocity and the water down flow velocity. This calculation shows that the [ ]a,c.

The calculation of the steam bubble rise includes the following assumptions:

- The minimum bubble size is equal to the [ ]a,c. This bubble size is appropriate for this low velocity and DP.
- The lowest level where bubbles can occur is [ ]a,c. This assumption is based on:
  - The water in the IRWST [ ]a,c.
  - The water level is at the [top of the IRWST screen]a,c.
  - The flow rate is equal to the recirculation flow rate at the start of recirculation [ ]a,c.
  - The maximum screen head loss is [ ]a,c.

The bubble rise velocity is calculated to be at least [ ]a,c. This calculation is based on test data contained in Figure 7-3, "Terminal Velocity of Air Bubbles in Water at 20 °C" of Reference 14.

The water flow is calculated at the lowest level behind the screen where steam bubbles might form. That level is [ ]a,c.

As shown above, the downward water flow velocity is much smaller than the steam bubble rise velocity of [ ]a,c, and as a result, the steam bubbles will not be drawn into the IRWST injection line.

# 8 CONCLUSIONS

## 8.1 TEST DATA SUMMARY

Four head loss tests were conducted as part of this AP1000 containment recirculation screen test program, including the design basis test 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 test results indicate that the head loss generated by the design basis debris load would not exceed the design limit and therefore the design basis debris load would not preclude long term cooling.

Three additional experiments were conducted, referred to as engineering evaluations, in which different debris loads were tested and the head loss response over the screens was studied. 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. Finally, vortexing was also included as part of the program, and no vortexing was observed over the screens even when favorable conditions were purposefully induced by exposing the upstream side of the screens.

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

a,c

| **Table 8-1 Test Number** | | | |
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| | | | |

## 8.2 APPLICABILITY OF TESTING TO AP1000 DESIGN

[

]a,c

a,c

**Figure 8-1 Screen Pocket**

**Table 8-2 Dimensions of Screen Pocket**

a,c

| | | |
|---|---|---|
| | | |
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| | | |
| | | |
| | | |

[

]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 containment recirculation and the IRWST screens to successfully perform their design functions under the debris loading conditions expected for the AP1000 following a postulated LOCA.

Four head loss tests were performed that investigated a spectrum of debris inventories, debris staging, chemical effects, and flow rates.

The performance of the recirculation screens was demonstrated under design basis debris loading conditions, including chemical effects. The design basis test demonstrates that the head loss across the screens 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.

Three additional tests were performed as engineering evaluations to examine the sensitivity to the manner in which the chemical constituents might enter the water. In 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 test provides the most conservative and representative manner of loading the recirculation screens.

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

Furthermore, the test conditions bound the flow and debris conditions that both the Recirculation and the In-Containment Refueling Water Storage Tank screens would experience in the recirculation mode following a postulated LOCA. The data applies to both of those screens.

# 10 REFERENCES

1. NRC Generic Safety Issue GSI-191, "Assessment of Debris Accumulation on PWR Sumps Performance," footnotes 1691 and 1692 to NUREG-0933, 1998.

2. NRC Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," September 2004.

3. Technical Report TR-147, "AP1000 Containment Recirculation and IRWST Screen Design," AP1000 Document Number APP-GW-GLN-147, Revision 2, May 2009.

4. APP-GW-GLR-079, Revision 4, "AP1000 Verification of Water Sources for Long Term Recirculation Cooling Following a LOCA," June 2009.

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

6. FAI/09-94, Revision 0, "Test Plan for AP1000 Debris Loading head Loss Tests for Recirculation Screens (Safety Related)," May 2009.

7. FAI/09-99, Revision 0, "Test Report for AP1000 Debris Loading Head Loss Tests for Recirculation Screens," June 2009.

8. NEI 04-07, Revision 0, "Pressurized Water Reactor Sump Performance Evaluation Methodology, Volume 2 – Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02," December 2004.

9. WCAP-16530-NP-A, "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/08-05, Revision 0, "Test Plan for AP1000 Debris Loading Head Loss Tests for Recirculation Screens (Safety Related)," 2008.

13. APP-PXS-GLR-001, Revision 1, "Impact on AP1000 Post-LOCA Long-Term Cooling of Postulated Containment Sump Debris," May 2009.

14. "Bubbles, Drops, and Particles", R. Clift et al., Dover Publications, 2005.

# APPENDIX A
# TEST PLAN

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