Watts Bar Unit 1 Nuclear Power Plant Corrective Actions for Generic Letter 2004-02

Acronym List

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ARL	Argonne Research Laboratory
BS	building spray
BWST	borated water storage tank
BTP	Branch Technical Position
BWR	boiling water reactor
BWROG	Boiling Water Reactor Owners' Group
B&W	Babcock and Wilcox
B&WOG	Babcock and Wilcox Owners' Group
CSS	Containment spray system
CFD	Computational Fluid Dynamics
WBN	Watts Bar Nuclear Power Plant
DBA	design basis accident
DDTS	Drywell Debris Transport Study
DP	differential pressure
EC	Engineering Change
ECCS	emergency core cooling system
EEQ	electrical equipment qualification
EOP	emergency operating procedure
EPRI	Electric Power Research Institute
GL	Generic Letter
GR	Guidance Report
GSI	Generic Safety Issue
HELB	high-energy line break
HPI	high-pressure injection
HPSI	high-pressure safety injection
ICET	integrated chemical effects tests
ICM	interim compensatory measure
IOZ	inorganic zinc
LANL	Los Alamos National Laboratory
LBLOCA	large break loss of coolant accident
L/D	length/diameter
LDFG	low density fiberglass
LOCA	loss-of-coolant accident
LPI	low-pressure injection
NEI	Nuclear Energy Institute
NPSH	net positive suction head
NPSHA	net positive suction head available
NPSHR	net positive suction head required
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
PWR	pressurized water reactor

RAI	Request for Additional Information
RB	reactor building
RBES	reactor building emergency sump
RCS	reactor coolant system
RG	Regulatory Guide
RMI	reflective metal insulation
SBLOCA	small break loss of coolant accident
SEM	scanning electron microscope
SE	Safety Evaluation
SRP	Standard Review Plan
TKE	turbulence kinetic energy
TSP	trisodium phosphate
TVA	Tennessee Valley Authority
UFSAR	updated final safety evaluation report
UNM	University of New Mexico
WOG	Westinghouse Owners Group
ZOI	zone of influence

1.0 BACKGROUND

1.1 Introduction

In response to NRC Generic Letter 2004-02 [1], PWR licensees are designing and implementing new strainers in their plants in order to resolve GSI-191 sump performance issue by December 31, 2007. WBN Nuclear Power Station, which is operated by Tennessee Valley Authority (TVA), has proceeded to design and install new strainers in the Fall of 2006. The plant was selected by the staff as the first audit plant because a major part of the design, analyses and testing of the new strainer had been completed. The audit is intended to help enable the NRC staff to (1) evaluate the adequacy of WBN new strainer design and analysis, (2) identify and resolve potential issues that arise when employing the approved methodology, (3) improve the audit process to examine industry-wide implementation of GL 2004-02.

The audit is intended to yield benefits to both the NRC and industry. For the NRC these include:

> The NRC staff will determine the adequacy of the new design and the contractor resources needed for future reviews, audits, and/or inspections.
>
> The NRC staff can identify generic GSI-191 issues that need to be further addressed and clarified through future interactions with strainer vendors and PWR Owner's Group.

Benefits envisioned for the licensee and industry include:

> Feedback from the audit will assist TVA in resolving the GSI-191 PWR sump issue.
>
> Lessons learned from the audit will help enable the industry identify, focus and prioritize the issues impacting resolution of GSI-191.

On March 2, 2006, staff launched the official audit with an early observation trip to the licensee's vendor head loss testing site in December 2005. The following NRC staff, licensee and contractors, and NRC consultants attended the March 2 meeting and were major participants in the audit:

Table 1. WBN Audit Kick-off Meeting (March 2, 2006)

Name	Affiliation
Licensee	
Marie Gillman	TVA
Paul Pace	TVA
Frank Koontz	TVA
Bob Bryan	TVA
Peter Mast	Alion
Timothy Sande	Alion
Lee Willams	Alion
Paul Pyle	Westinghouse
Ann Lane	Westinghouse
NRC	
Shanlai Lu	
Mathew Yoder	
Leon Whitney	
Richard Lobel	
Paul Klein	
Hanry Wagage	
Douglas Pickett	
Ralph Architzel	
Ruth Reyes-Maldonado	
John Lehning	
David Cullison	
Michael Scott	
Steven Unikewicz	
NRC Contractor	
Clint Shaffer	ARES Corporation

The audit meeting provided an opportunity for the NRC to: (1) review the basis, including the detailed mechanistic analysis and design documents, for the proposed new strainer design (2) identify areas that may need clarification or generic resolution. The following categories of the submittal were reviewed and discussed:

Debris generation
Coatings
System head loss
NPSH for ECCS pumps
Modifications
Debris transport
Debris characterization
Chemical head loss
Upstream and downstream effects

Based on the one-day meeting with TVA engineers and their contractors, staff reviewed the design documents submitted to the staff and developed requests for additional information (RAIs) on May 10, 2006 (Appendix III). Responding to these RAIs, TVA issued a letter (Appendix IV) on June 31, 2006, and provided additional information. Based on this information, staff performed a thorough review of major aspects of the design and analysis.

On August 31, and, subsequently on September 7, 2006, the audit team and its management held two telephone debrief conferences with the licensee at the end of the audit. During the course of the audit, staff concluded that the WBN new strainer design provides ample NPSH margin but also identified issues related to the licensee's implementation and plans that need to be assessed as part of the licensee's closure of GL 2004-02. These are discussed throughout the audit report and were communicated to the licensee during the audit meetings and telephone conferences. The licensee is expected to address and document resolution of these issues in conjunction with its efforts to respond to GL 2004-02.

1.2 Bulletin 2003-01 Responses

Overall, the WBN Bulletin 2003-01 response [3], dated August 8, 2003, was clear, comprehensive and of higher than average quality. It specifically addressed the six interim compensatory measure (ICM) categories of Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Press`urized-water Reactors:"

Bulletin 2003-01 discussed six categories of ICMs: (1) operator training on indications of and responses to sump clogging; (2) procedural modifications if appropriate, that would delay the switchover to containment sump recirculation (e.g., shutting down redundant pumps that are not necessary to provide required flows to cool the containment and reactor core, and operating the containment spray system (CSS) intermittently; (3) ensuring that alternative water sources are available to refill the refueling water storage tank (RWST) or to otherwise provide inventory to inject into the reactor core and spray into the containment atmosphere; (4) more aggressive containment cleaning and increased foreign material controls; (5) ensuring containment drainage paths are unblocked; and (6) ensuring sump screens are free of adverse gaps and breaches.

WBN has the following design features in place as identified at the time the bulletin response was submitted to NRC:

1. The absence by design of fibrous material except in locations where it would not be damaged by high energy pipe breaks and be a potential source of debris that could reach the sump screens;

2. Minimal post-construction use of Min K (encapsulated hydrophobic) and 3M M20 mat so that during any one high energy pipe break these materials would not be expected to challenge the relatively large surface area of the containment sump screens;

3. Two designed entry points to the inner sump area which would require any debris from a break near one sump screen to travel around to the other side of containment to collect on the opposite sump screen; and

4. Various sump pit and screen mesh configurations causing relationships between size restrictions and injection path size which would make damage to ECCS and CSS pumps, or clogging of containment spray nozzles, to be of little or no concern.

In response to Bulletin 2003-01, WBN had implemented the following ICMs:

1. Revision of the applicable emergency operating procedure to provide guidance on sump blockage - ICM category #1;

2. Licensed operator training (including a simulator scenario) on a new sump blockage shift order by October, 2003 - ICM category #1;

3. A revision to the transfer-to-sump recirculation procedure to enhance monitoring of the sump for indications of sump blockage and compensatory actions if sump blockage occurs post-LOCA - ICM category #1;

4. Anew post-accident technical considerations instruction to guide Technical Support Center (TSC) personnel concerning sump blockage - ICM category #1;

5. Capability to refill the RWST once safety injection recirculation capability has been lost, or if necessary direct reactor coolant system (RCS) makeup via normal charging from the volume control tank - ICM category #3;

6. A technical instruction which provides guidelines and criteria for entering and exiting containment, including acceptance criteria for housekeeping/cleanliness to ensure no loose debris is left in containment and for storage of materials inside containment during Mode 4 and higher operations - ICM category #4;

7. Aprotective coatings procedure which provides the programmatic requirements for planned preventive maintenance and the performance of coatings inspections, repair and stabilizations each outage, with emphasis on the sump “Zone of Influence” in lower containment Quadrants 3 and 4 inside the crane wall - ICM category 4;

8. The use of an ice condenser loose debris log to ensure that debris found in the ice condenser system cannot adversely impact sump operation - ICM category #4;

9. A containment refueling canal drain procedure which ensures these drains are not blocked, and an ice condenser flow drain visual inspection procedure to ensure these drains are not blocked and their associated valve seats are free of any corrosion, pitting or cracking - ICM category #5;

10. A revision to the accumulator room floor drain procedure to verify them clear and free flowing every outage instead of every other outage - ICM category #5; and

11. A containment pump suction pit inspection procedure conducted each outage which checks for foreign material and sump components for degradations such as corrosion or other physical damage - ICM category #6.

On November 19, 2004, the licensee responded to the September 21, 2004, NRC request for additional information (RAI) related to the licensee’s response to Bulletin 2003-01 . Based on the RAI responses, the NRC staff evaluated the WBN Option 2 response for compensatory measures that were or were to have been implemented to reduce the interim risk associated with potentially degraded or nonconforming ECCS and CSS recirculation functions. Based on WBN response summarized above, the NRC staff considered WBN to be responsive to the intent of Bulletin 2003-01.

1.3 Generic Letter 2004-02 September 2005 Responses

In response to GL2004-02, WBN provided answers to all the NRC requests on September 1, 2005 [4]. WBN indicated that actions have been identified and are planned to ensure ECCS and containment spray system recirculation functions under debris loading conditions will meet all NRC criteria when all modifications are completed. The licensee stated that WBN will be installing a PCI Sure Flow strainer during Cycle 7 refueling outage in Fall of 2006. The licensee intends to make necessary hardware changes to address downstream effects before December 2007.

WBN stated in its response that it had performed containment walkdowns using the guidelines provided in NEI 02-01, "Condition Assessment Guidelines, Debris Sources inside Containment" Revision 1 [5]. The licensee stated that the methodology of the new strainer design complies with NEI 04-07 "Pressurized Water Reactor Sump Performance Evaluation Methodology" and the associated staff Safety Evaluation. According to WBN, all the baseline analyses (debris generation, ZOI, debris characteristics, transport) had been performed before September 1, 2005. The head loss testing was to be conducted in December 2005. The minimum NPSH margin with the current strainer would be 3.76 feet and the new strainer total flow area was estimated to be 2000 - 6000 ft^2.

Regarding chemical effects, the licensee stated that WBN uses sodium tetraborate as the buffering agent for the boric acid in the RCS and from the licensee stated that refueling water storage tank. Because of the fiber in the WBN containment, TVA will add a 50% margin to the new strainer area to compensate for any additional head loss from chemical effects.

WBN planned to install a new sump strainer with perforations of 0.085 inch round holes. WBN performed a downstream effects evaluation based on the debris mix present with a 1/8-inch open dimension. The debris mix included particulate, coating debris and fiber in quantities consistent with the amount assumed to be present during steady state ECCS recirculation. The evaluation included erosive wear, abrasion, and potential blockage of flow paths. The smallest clearance found for the WBN heat exchangers, orifices, and spray nozzles in the recirculation flow path is 0.375 inches. Therefore, WBN concluded in its Septembar 1, 2005 response, that no blockage of the ECCS flow paths will occur. In addition to ECCS and containment spray paths, WBN also evaluated downstream effects on instrumentation tubing, ECCS valves including throttle valves and reactor vessel internals. The evaluation concluded that the HPCI throttle valves may be subject to clogging. As stated in the licensee's September 2005 GL 2004-02 response, no other flow path blockages were identified.

In order to ensure that potential quantities of post-accident debris are maintained within the bounds of the analyses and design bases that support ECCS and CSS recirculation functions, WBN stated that it maintains a suite of procedures and engineering specifications which constitute the containment material control and inspection requirements.

The staff reviewed the WBN September 1, 2005, GL response in early 2006 and found it to be responsive to GL 2004-02. The staff issued RAIs regarding the response to the licensee in April 2006. The licensee elected to respond to these RAIs in conjunction with addressing RAIs from the audit. The staff found the responses supportive of addressing GL 2004-02, with the exceptions identified in this report as open items.

2.0 DESCRIPTION OF PLANNED CHANGES

The current WBN Residual Heat Removal (RHR) containment sump is located in the containment floor below the refueling canal. To prevent debris from entering the sump, an outer trash rack covered with a 1/4-inch mesh screen is provided on each side of the sump inlet. The trash racks extend from the reactor shield wall to the divider wall from floor to ceiling. Connecting the two trash racks is a horizontal grating located one foot below the ceiling to eliminate vortexing. Between the two containment sump outer trash racks is the containment sump suction pit. This pit is surrounded by a six-inch high curb which is used to prevent sediment from entering the pit. Atop the six-inch curb is a metal cruciform which serves to assist in vortex suppression. A fine mesh (1/4-inch) screen located in the containment sump suction pit provides additional filtering and is used to divide the sump into two suction volumes.

In response to NRC GL 2004-02, WBN will remove the trash racks and cruciform and will install a new Sure-Flow® PCI strainer. The design of the new strainer was based on a mechanistic debris generation and transport analysis performed by ALION and testing specific to WBN. The new strainer has an available flow area of 4600 ft^2 compared to the current screen area of approximately 200 ft^2. The new strainer openings are 0.085 inches in diameter compared to the 0.25 inch mesh for the current configuration. The current screens have a flat vertical configuration, while the Sure-Flow® strainer is an advanced configuration intended to be much more resistant to potential blockage. The new strainers, along with the Emergency Core Cooling System (ECCS- including RHR, Safety Injection (SI), and Chemical and Volume Control System (CVCS)) and Containment Spray (CS) pumps, help mitigate the consequences of the following accidents: all LOCAs, rupture of a Control Rod Drive Mechanism causing a Rod Cluster Control Assembly ejection accident, and secondary side pipe breaks inside the containment. The flow area and design of the strainers are intended to ensure that pressure drop across the strainer is sufficiently low and that adequate NPSH margin is available for the RHR and CS pumps. The diameter of the strainer holes is intended to ensure that any debris that can pass through the strainer will not cause blockage or excessive wear to components in the ECCS flow path or the containment spray system. This includes pumps, valves, nozzles, and the nuclear fuel. The new strainer is a passive component, and the only identified failure mode is structural failure. The strainer assembly is designed specifically for WBN and is intended to provide both debris filtering and vortex suppression.

During the review of impacts associated with the containment sump strainer modification, WBN determined that the throttling valves (1 THV-63-582 through -585) on the Charging Injection Line, formerly the Boron Injection Line, were throttled to a barely open position (3/4 turn open or less). The limiting valve has a clearance of approximately 0.04 in, which is less than the 0.085 in hole diameter of the replacement containment sump strainer. WBN identified the potential that during recirculation mode, debris small enough to pass through the containment sump strainer could be large enough to block one or more of these valves. These valves are required for balancing the flow in the 4 Cold Leg Injection lines and to prevent Centrifugal Charging Pump (CCP) runout during injection and recirculation modes. Therefore, WBN decided to set the valves more open to increase the clearance while maintaining CCP runout protection. Once these valves openings are adjusted, the flow balance needs to be re-adjusted. WBN will replace the orifice plate with one that produces a higher pressure drop (i.e., smaller bore diameter), thus increasing system resistance through the cold leg charging injection line header. This will allow the throttle valves to be set further open, thus increasing the clearance between the valve disc and seat while maintaining adequate system resistance to prevent CCP runout. The flow element FE-63-170 is located in the safety injection path, rather than the normal charging line, and therefore, resizing the orifice has no impact on the function of the CVCS during normal plant operation. Due to the increased pressure drop across the orifice plate, the flow transmitter, 1 FT-63-170, will also be replaced. The new transmitter has a 10-50ma output which is the same as the existing transmitter's output; therefore, the existing flow indicator in the main control room does not require replacement.

WBN has contracted Westinghouse to update the WBN ECCS flow model from the obsolete PEGISYS code to the current FLOMAP code. The new model is expected to optimize the flow balance using the latest set of WBN test data. This updated flow model will then be used to size the plate-type orifice to be installed at 1 FE 63 170 (includes hole size, plate thickness, and cavitation check).

All this design change information has been documented in Appendix V based on two white papers submitted by the licensee. The staff understands that WBN will finalize the strainer design report and the downstream effects evaluation report before December 31, 2007. The staff has focused the audit effort on the design, analysis and testing documents which establish the basis for these two reports.

3.0 BASELINE EVALUATION AND ANALYTICAL REFINEMENTS

3.1 Break Selection

The objective of the break selection process is to identify the break size and location that presents the greatest challenge to post-accident sump performance. Sections 3.3 and 4.2.1 of the NEI GR [6] and the associated staff SE approving the evaluation methodology [2] provide the criteria to be considered in the overall break selection process in order to identify the limiting break. In general, the criterion used to define the most challenging break is the estimated head loss across the sump screen. Therefore, all phases of the accident scenario must be considered for each postulated break location, including debris generation, debris transport, debris accumulation and sump screen head loss. Two attributes of break selection which are emphasized in the approved evaluation methodology and can contribute to head loss are (1) the maximum amount of debris transported to the screen, and (2) the worst combinations of debris mixes that are transported to the screen. Additionally, the approved methodology states that breaks should be considered in each high-pressure system that relies on recirculation, including secondary side system piping if applicable.

Section 4.2.1 of the SE discusses a proposed refinement which would allow considering only break locations which are consistent with Branch Technical Position (BTP) MEB 3-1, “Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment” [7] and Standard Review Plan (NUREG-0800) [8] Section 3.6.2, “Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping.” The proposed application of BTP MEB 3-1 for PWR sump analyses was intended to focus attention on high-stress and fatigue break locations such as at the terminal ends of a piping system and intermediate pipe ruptures at locations of high stress. However, as discussed in Section 4.2.1 of the SE, the staff rejected the application of this proposed refinement for PWR sump analyses.

WBN Calculation No. ALION-CAL-TVA-2739-03, “WBN Reactor Building GSI 191 Debris Generation Calculation,” [9], documents the assumptions and methodology the licensee applied as part of the overall break selection process, and to determine the limiting break for WBN. WBN Calculation Nos. ALION-CAL-TVA-2739-04, “WBN Reactor Building GSI 191 Debris Transport Calculation,” [10], and Calculation No. ALION-CAL-TVA-2739-05, “WBN Unit 1 Containment Sump Debris Accumulation and Head Loss,” [11] provide assumptions and methods applied for debris transport, accumulation and head loss calculations. Together, these calculations support and inform the limiting break selection process.

Staff Evaluation

The staff reviewed the licensee’s overall break selection process and the methodology applied to identify the limiting break. Specifically, the staff reviewed Calculations ALION-CAL-TVA-2739-03, ALION-CAL-TVA-2739-04 and ALION-CAL-TVA-2739-05 [9,10,11] against the approved methodology documented in Sections 3.3 and 4.2.1 of the staff’s SE. The staff concluded that the licensee’s break selection evaluation is acceptable, with one open item, and that the evaluation was generally performed in a manner consistent with the approved GR methodology [6]. Deviations from the staff approved methodology were judged by the staff to be acceptable based on the technical basis provided by the licensee (with one open item).

The staff’s review found that the licensee evaluated a number of break locations and piping systems, and considered breaks in each high-pressure system that relies on recirculation to mitigate the event. As a minimum, the following break locations were considered:

Break Location No. 1 - Breaks in the RCS with the largest potential for debris.

Break Location No. 2 - Large breaks with two or more different types of debris.

Break Location No. 3 - Breaks with the most direct path to the sump.

Break Location No. 4 - Large breaks with the largest potential particulate debris to insulation ratio by weight.

Break Location No. 5 - Breaks that generate a “thin-bed” - high particulate with 1/8" fiber bed.

This spectrum of breaks is consistent with that recommended in the staff-approved methodology and is also consistent with regulatory position 1.3.2.3 of Regulatory Guide 1.82, Revision 3 [13].

The licensee considered breaks in the primary reactor coolant system piping, secondary system piping, and other high-energy line break piping systems having the potential to rely on ECCS sump recirculation. The licensee reviewed accident analysis scenarios as described in the WBN UFSAR to determine which accidents and piping systems may require sump recirculation. The licensee concluded that a large-break loss of coolant accident and certain small-break LOCAs would require sump recirculation.

During the March 2, 2006 audit meeting, the licensee stated that LOCAs are the only break scenarios which may require sump recirculation and that secondary side piping system breaks (main steam or feedwater lines) do not*.* The staff questioned whether WBN required analyses of recirculation flow using containment sprays to maintain equipment qualification following a main stream line break. The licensee responded to the question in a July 3, 2006 letter, Response to Request for Additional Information (Appendix III and IV). The licensee response noted that a main steam line break would result in a smaller ZOI than an RCS break due to main steam pressure being less than half of RCS pressure, and the licensee therefore concluded that a LOCA bounds a main steam (or feedwater line) break with respect to debris generation. Following a secondary side break, containment sprays will eventually be required to maintain temperatures within equipment qualification limits following ice-melt. However, operators are not required to restart lower compartment cooler fans, used in conjunction with the sprays to remove heat, for at least 1.5 hours after the event. In addition, the containment spray is only required to remove ambient heat loss from the RCS so that periodic use of only one train of containment spray is required. Therefore, there is less flow to transport debris, less debris to transport, and only intermittent flow. Thus the licensee concluded that a main steam line break was bounded by a LOCA and was not required to be analyzed. The audit team agrees with the licensee's response that a secondary line break is bounded by a LOCA for recirculation performance concerns relating to equipment qualification.

The licensee evaluation identified a double-ended guillotine break of the RCS intermediate crossover piping near the steam generator nozzle as the limiting break. This break generates the largest amount and also the worst combination of debris. The licensee evaluated all phases of the accident scenario for this break, including debris generation, debris transport, debris accumulation and sump screen head loss.

Section 3.3.5 of the staff's SE describes a systematic approach to the break selection process which includes beginning the evaluation at an initial location along a pipe, generally a terminal end, and stepping along in equal increments (5-ft increments) considering breaks at each sequential location. However, the WBN break selection process did not apply such a systematic approach. Based on the magnitude of the ZOI applied, the staff agrees that performing the analysis by considering 5-ft increments is not necessary. The licensee stated that because the quantity of RMI is not a significant contributor to head loss, and the quantity of Min-K would be similar for each break, the bounding case for each loop is the RCS break which would destroy the most coatings. The licensee indicated that a thorough analysis showed that a break in each of the crossover legs near the steam generator nozzle yielded the most coating debris due to the size of the ZOI applied in the analyses. The staff determined that such an analysis was not clearly documented in the calculations and information provided initially for the staff's audit.

The licensee addressed this issue in a July 3, 2006 letter responding to the staff's RAIs (Appendix IV). As a result of the questions raised during the audit, ALION revised and expanded the WBN debris generation calculation (revision 2). The licensee stated that the calculation no longer makes reference to undocumented analyses for the paint calculations. The revised analyses result in revised debris quantities, including increased fiber quantities for min-K and 3M fire wrap with respect to that tested in WBN's strainer test. The licensee stated that it is looking at several options to reduce these quantities to within the tested configuration. These include credit for addtional jet shielding from robust barriers, material testing under jet impingement loading to reduce the ZOI for encapsulated fiber, removal of material and/or sump strainer retesting. The licensee stated that the final debris generation calculation would be provided as a part of a supplemental response for the audit open items. The staff will review the final calculation to verify the impact of the revised debris quantities has been adequately addressed. This is identified as an **OPEN ITEM.**

The licensee also addressed breaks that could generate a “thin bed.” Many possible high-energy line breaks at WBN can be postulated where a small quantity of fibrous debris is generated and transported to the sump, followed by washdown of particulate latent debris, potentially resulting in the thin-bed effect. Rather than analyzing specific HELBs, the licensee specifically assumed the presence of a thin bed in the WBN head-loss calculation. The staff finds this to be acceptable because this methodology ensures that the new WBN sump screen is designed to accommodate formation of a thin bed of fiber and its associated head-loss effects.

In accordance with the staff’s SE, the licensee did not apply the optional refinement of Section 4.2.1 of the SE which would allow considering only break locations which are consistent with Branch Technical Position MEB 3-1, “Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment,” and Standard Review Plan (NUREG-0800) Section 3.6.2, “Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping.”

In conclusion, based on the above considerations, the staff finds the licensee’s evaluation of break selection to be acceptable. The evaluation was generally performed in a manner consistent with the approved SE methodology. Deviations from the staff-approved methodology were judged by the staff to be acceptable based on the technical basis provided by the licensee (with one open item).

3.2 Debris Generation/Zone of Influence

The objective of the debris generation/zone of influence (ZOI) process is to determine, for each postulated break location, the zone within which the break jet forces will be sufficient to damage materials and create debris, the amount of debris generated by the break jet forces and the need to determine the characteristics of the debris. Sections 3.4 and 4.2.2 of the GR [6] and the safety evaluation of the methodology [2] provide the methodology to be considered in the ZOI and debris generation process. In general, the baseline methodology for determining ZOI is based on the ANSI/ANS 58.2 1988 standard [14]. The baseline methodology incorporates spherical ZOIs based on material damage pressures and the corresponding volume-equivalent spherical ZOI radii. Debris generation is then calculated based on the amount of materials within the ZOI. Other sections of the GR and SE provide guidance on particle size distribution and characterization of the debris types.

Section 4.2.2 of the SE discusses optional refinements which would allow application of debris specific spherical destruction zones (ZOIs) and direct jet impingement modeling. WBN Calculation No. ALION-CAL-TVA-2739-03, “WBN Reactor Building GSI 191 Debris Generation Calculation,” [9], documents the assumptions and methodology the licensee applied to determine the ZOI and debris generated for each postulated break.

Staff Evaluation

The staff reviewed the licensee's ZOI and debris generation evaluations and the methodology applied. Specifically, the staff reviewed WBN Calculation No. ALION-CAL-TVA-2739-03 [9] against the approved methodology documented in Sections 3.4 and 4.2.2 of the staff's SE. The staff concluded that the licensee's evaluation is acceptable. The first step in evaluating the debris generated following a HELB is to determine the appropriate ZOI for each HELB considered. Once the ZOI is established, potential debris sources within the ZOI can be identified and the quantity of each debris sources can be calculated. The types and locations of potential debris sources (insulation, coatings, dirt/dust, fire barrier materials) can be identified using plant-specific drawings, specifications, walkdown reports or other such reference materials.

The staff's review concluded that the licensee correctly applied the approved methodology [16] to determine the ZOI to be used for debris generation. The licensee applied the ZOI refinement discussed in Section 4.2.2.1.1 of the staff SE, which allows the use of debris-specific spherical ZOIs. This refinement allows the use of a specific ZOI for each debris type identified. Using this approach, the amount of debris generated within each ZOI is calculated and the individual contributions from each debris type are summed to arrive at a total debris source term. The staff concluded in its SE that the definition of multiple, spherical ZOIs at each break location that correspond to the damage pressures for potentially affected materials is an appropriate refinement for debris generation.

The licensee credited robust barriers and "shadowing" effects in its ZOI evaluation. Section 3.4.2.3 of the SE states that, "[f]or the baseline analysis, the NRC staff position is that licensees should center the spherical ZOI at the location of the break. Where the sphere extends beyond robust barriers, such as walls, or encompasses large components, such as tanks and steam generators, the extended volume can be truncated. This truncation should be conservatively determined with a goal of +0/-25 percent accuracy, and only large obstructions should be considered. The shadow surfaces of components should be included in this analysis and not truncated, as debris generation tests clearly demonstrate damage to shadowed surfaces of components."

As discussed in Sections 3.1 - 3.4 of WBN calculation ALION-CAL-TVA-2739-03 [9], the licensee credited the reactor annulus and refueling canal as robust barriers in the analysis. The staff agrees that the reactor annulus and refueling canal can be credited as robust barriers and can be used a basis for truncating the ZOI. The staff finds this methodology to be acceptable and consistent with the approved methodology.

During the initial phase of the audit, the team questioned how the licensee assessed the quantity of debris in the various ZOIs. The licensee stated that a spreadsheet had been developed using information obtained during debris inventory walkdowns performed in 2004. The team examined WBN calculation ALION-CAL-TVA-2739-03 [9] and noted that it did not clearly show the extent to which the licensee credited truncation due to robust barriers.
The licensee addressed this issue in a July 3, 2006 letter responding to the staff's RAIs (Appendix III). The licensee provided for audit team review the WBN Unit 1 Containment Walkdown Report [11] that was conducted in 2004 to identify debris sources and types among other objectives related to emergency sump strainer issues. The team examined selected

walkdown data sheets and noted that they were thorough and represented a significant effort to identify and quantify all debris sources. Nonetheless, it would be difficult to verify the quantities of debris that were considered shielded by robust barriers using the walkdown reports and the WBN calculation ALION-CAL-TVA-2739-03 [9] spreadsheets alone. However, as a result of the questions raised during the audit, ALION revised and expanded the WBN debris generation calculation (revision 2). The calculation also was revised to show the shielding that was credited (for robust barriers) and to document which of the line items from the insulation spreadsheet were included for each break location. The licensee stated that the final debris generation calculation would be provided as a part of a supplemental response for the audit open items. The staff will review the final calculation to check the documentation of debris shielding by robust barriers that was creditied. This is identified as an **OPEN ITEM.**

In conclusion, the staff finds the licensee's ZOI evaluation to be acceptable, with one open item. The evaluation was performed in a manner consistent with the approved SE methodology. The licensee applied the ZOI refinement discussed in Section 4.2.2.1.1 of the SE, which allows use of debris-specific spherical ZOI's. The licensee applied material-specific damage pressures and corresponding ZOI radius/break diameter ratios as shown in Table 3-2 of the staff SE. The staff found that the licensee provided an adequate level of technical justification with respect to ZOI analyses, with one open item.

3.3 Debris Characteristics

The staff reviewed the debris characteristics presented in the licensee's debris generation report [9], debris transport report [10], and debris head loss report [11]. The staff also reviewed presentation materials provided by the licensee during an audit meeting on March 2, 2006.

Several types of debris are present in the Watts Bar containment, including stainless steel reflective metallic (RMI) insulation, Min-K insulation, 3M-M20C fire barrier, various types of coatings, latent fibrous and particulate debris, and miscellaneous debris such as tags, tape, and labels.

3.3.1 Stainless Steel Reflective Metallic Insulation

The licensee conservatively assumed that the debris size distribution over the entire ZOI was equivalent to the experimental size distribution for the single NRC-sponsored Siemens steam-jet impact test, where an RMI cassette was located directly over the break, such that the cassette was completely destroyed (NUREG/CR-6808 [15], Figure 3-7). In reality, most of the RMI debris within a large ZOI (in this case, 28.6 L/D) would be expected to be destroyed into large pieces, including dislodged cassettes. This point is further elaborated in Appendix II to the NRC staff's Safety Evaluation (SE). The licensee used transport data from NRC-sponsored separate effects testing (NUREG/CR-6772) [16] that is accepted in the staff's SE to demonstrate that (1) a flow velocity in excess of approximately 0.28 ft/s is necessary to move small pieces of stainless steel RMI debris along the containment pool floor (significantly faster velocities are necessary to move large pieces of stainless steel RMI debris) and (2) the terminal settling velocity is approximately 0.37 ft/s for ½-inch pieces of stainless steel RMI debris and 0.48 ft/s for 2-inch pieces. These characteristics for stainless steel RMI are acceptable as applied to the Watts Bar transport analyses.

The licensee assumed a leading coefficient of 0.108 in the head loss equation for RMI (ALION-CAL-TVA-2739-05 [5], Equation 4.1), which is appropriate for a mix of small and large pieces of debris, as noted in NUREG/CR-6808, Section 7.3.1.2. For RMI debris distributed predominately into small pieces, as the licensee assumed, the leading coefficient accepted by the staff would be 0.156, corresponding to an inter-foil gap thickness of 0.01 ft (NUREG/CR-6808 [15], Table 7-2). Although the smaller coefficient assumed by the licensee may be nonconservative in general, this potential nonconservatism does not affect the Watts Bar sump performance evaluation because the licensee did not rely upon this equation for the design and qualification of the replacement sump strainer.

3.3.2 Min-K Insulation

Min-K has a significant potential to impact head loss that is comparable to or worse than calcium silicate. Like calcium silicate, Min-K contains both particulate and fibrous materials that may contribute to the formation of a thin debris bed on a fine strainer without the presence of additional fibrous debris.

Min-K is considered to be readily damaged at a low destruction pressure (2.4 psi in the SE). From an analytical transport standpoint, pulverized Min-K is considered capable of completely transporting to the strainers as suspended debris. Larger pieces of Min-K could settle to the pool floor, but due to a lack of data concerning erosion and dissolution in the containment pool, Min-K has generally been conservatively treated as 100% pulverized transportable debris.

The analytical estimation of head loss depends significantly upon the specific surface area of the debris upon the strainer surface. The specific surface area, in turn, can be directly related to the size distribution of particulate or fibrous debris. The licensee treated Min-K debris as consisting of three materials: fiber (20%), SiO_2 particulate (65%), and TiO_2 particulate (15%). Table 2.5.1 in ALION-CAL-TVA-2739-03 provides the assumed size distributions and densities used in the licensee's head loss evaluation for each of the three constituents of Min-K. Several of the physical properties assumed in Table 2.5.1 for the constituents of Min-K were noted as having been adapted from Microtherm insulation due to a lack of data specific to Min-K. Although Min-K and Microtherm are described in ALION-CAL-TVA-2739-03 [12] as having similar compositions, a thorough substantiation for the substitution of these material properties for characterizing Min-K was not provided. Furthermore, ALION-CAL-TVA-2739-05 [11] included a description of the constituents of Min-K provided by the manufacturer (i.e., Thermal Ceramics) that cited constituent properties that differed significantly in some aspects from the properties in Table 2.5.1 of ALION-CAL-TVA-2739-03 [9]. This information is summarized below:

Table 2: Assumed Physical Properties for Min-K Debris

Constituent	Weight Percent	Particle/Fiber Size (ALION-CAL-TVA-2739-03)	Particle/Fiber Size (Thermal Ceramics)
Fiber	20%	6 µm	mainly 2.5 – 10 µm
Fumed Silica (SiO_2)	65%	Varies, centered at 20 µm	0.01 – 0.015 µm
Titanium Dioxide (TiO_2)	15%	2.5 – 10 µm	< 5 µm

ALION-CAL-TVA-2739-05 [11] states that the composite characteristic size assumed for Min-K in the analytical calculation of head loss was 2.5 µm. It is not clear whether the computation of this composite-specific surface was performed using the accepted methodology discussed in Appendix V to the SE (i.e., using an exponent-weighted average as opposed to simple averaging). The licensee noted that the GR [6] indicates that the characteristic size for Min-K should be assumed to be less than 0.1 µm. The licensee indicated that the value in the GR is not consistent with manufacturer data, and that the value of 2.5 µm was obtained from manufacturer data. However, the basis for the apparent discrepancy between the manufacturer's data and the values from ALION-CAL-TVA-2739-03 [9] is not clear to the staff. Although a brief discussion of general agglomeration theory was provided, the staff concluded that there does not appear to be a substantive basis for the characteristic size distribution assumed by the licensee for Min-K.

A diameter nearer the smaller elementary particle sizes may be more appropriate, due to the associated uncertainty, but precisely determining the appropriate value of specific surface area could be difficult. In light of the potential for submicron-sized particulate, the measured specific surface area may be a function of the degree to which the finest particles can be generated, introduced into the test apparatus, and filtered by the strainer debris bed. Thus, to definitively determine the specific surface area for a material like Min-K, testing may be necessary under applicable filtration conditions. However, as (1) Watts Bar has very small amounts of Min-K inside containment and (2) the analytical head loss calculation was not intended to support the design basis of the replacement strainer, the staff did not consider an accurate determination of the specific surface area of Min-K to be necessary for Watts Bar.

3.3.3 3M-M20C Fire Barrier Material

Beyond its basic physical properties, the licensee generally lacks data concerning 3M-M20C fire barrier debris that is pertinent to important strainer performance phenomena including debris generation, hydraulic transport, strainer accumulation, and head loss.

In ALION-CAL-TVA-2739-03, the licensee's analysis refers to the 3M-M20C material as being a "felt-like" material having a bulk density of 39 lbm/ft^3. As a result of the lack of available data, the licensee assumed the destruction pressure for the 3M-M20C fire barrier to be 2.4 psi. The licensee further assumed that the 3M-M20C material would be completely destroyed into individual fibers, thereby losing its felt-like characteristics in the manner of fragmented high-density fiberglass insulation. The licensee further made an unverified assumption in ALION-CAL-TVA-2739-03 [9] that the 3M-M20C insulation debris could be treated as an equivalent mass of Nukon™ low-density fiberglass insulation with a bulk density of 2.4-lbm/ft^3.

The NRC staff considers the licensee's characterization of the 3M-M20C material to be conservative for the purpose of analytically evaluating debris generation and transport because the 3M-M20C material was assumed to have a conservatively low destruction pressure and to be broken into fines with a conservatively high potential for transporting to the sump. However, in evaluating the accumulation and head loss resulting from the 3M-M20C material, the licensee performed scaled flume testing with surrogate debris that was not consistent with the characterization assumed above. For the scaled flume test, the 3M-M20C material was processed through a shredder prior to being deposited into the flume. The staff's examination of the surrogate test debris showed that the shredding process had created fragments that had partially retained the as-manufactured structure (i.e., the test debris had generally not been destroyed into individual fibers, as had been analytically assumed). Justification was not presented for the size distribution chosen for the surrogate debris fragments. Coupled with the non-prototypical conditions in the test flume (described subsequently in Section 3.6), the preparation of the 3M-M20C surrogate debris in fragments, as opposed to individual fibers, appeared to contribute to significant quantities of the surrogate debris artificially settling to the floor of the flume, rather than reaching the test strainer.

In lieu of obtaining detailed information concerning the characteristics of debris, making defensibly conservative assumptions may generally be an acceptable alternate strategy. However, in this case, the staff is concerned that a conservative set of properties has not been consistently maintained for the 3M-M20C debris through all stages of the replacement strainer performance evaluation. Although the licensee made conservative analytical characterization assumptions that led to 100% of the 3M-M20C debris being considered as individual fibers analytically transporting to the replacement strainers, the preparation of this debris in larger fragments for head loss testing under non-prototypical conditions where the majority of this debris appeared to settle to the floor of the flume represents a nonconservatism of uncertain magnitude that may exceed the conservatism added by the analytical transport assumptions. While the staff believes that the overall treatment of 3M-M20C may still be appropriate, the licensee has not documented sufficient information in the material submitted for audit review to support this conclusion. Since the nonconservative aspects of the licensee's treatment of 3M-M20C are associated with its preparation for head loss testing (discussed subsequently in Section 3.6) the staff will consider this issue to be subsumed under the Open Item discussed in Section 3.6.4 of this report.

3.3.4 Latent Fiber

The licensee adapted the recommendations from the NRC-sponsored study of containment latent debris collected from four PWR containments [NUREG/CR-6877 [17]). This study concluded that it was conservative to assume that latent fibers have similar hydraulic properties to those of low-density fiberglass. The study examined dry bulk densities for collected latent fibers and specifically recommended assuming a bulk density of 2.4 lbm/ft^3, which is the nominal bulk density of Nukon™ low-density fiberglass insulation. Based on the recommendations of NUREG/CR-6877[17], the staff finds the characteristics assumed by the licensee for latent fiber to be acceptable.

3.3.5 Latent Particulate

The licensee adopted recommendations from the NRC-sponsored study of containment latent debris collected from four PWR containments (NUREG/CR-6877[17]), which were further examined in Appendix V to the staff's SE. In this study, a surrogate latent particulate was formulated from sand and dirt to simulate the density and particle size distributions of samples of containment latent particulate debris. This surrogate particulate was tested in a closed loop head loss test apparatus to determine a specific surface area for the mixture. The specific surface area identified for the debris was 106,000/ft, which corresponds to an equivalent particle diameter of 17.3 microns. The licensee adapted this diameter and the solid density of 168 lbm/ft^3 but did not specify a particulate bulk density, which is required in thin-bed calculations; rather the licensee relied upon the Alion HLOSS code, which assumed a solidarity for bulk particulate of 20%. It is not clear to the staff that this assumption is valid, since bulk solidarity is debris-type dependent, and a specific justification was not presented. Otherwise, the licensee's characteristics for latent particulate are acceptable. Furthermore, as the licensee's strainer qualification for head loss is based upon testing rather than analysis, the staff does not consider the resolution of the issue concerning the assumed value of latent particulate bulk solidarity to be necessary for demonstrating the acceptability of the Watts Bar replacement strainer design.

3.3.6. Miscellaneous Debris

The debris generation calculation (ALION-CAL-TVA-2739-03 [9], Table 2.5.1) described ice condenser debris that includes a wide variety of miscellaneous debris. This document states that ice condenser debris will be analyzed for transport in the debris transport calculation and will be addressed through a reduction in strainer area in the head loss calculation. However, the transport document (ALION-CAL-TVA-2739-04[10]) does not appear to acknowledge ice condenser debris explicitly. The head loss document (ALION-CAL-TVA-2739-05[11]) assumed a debris quantity of 1000 ft^2 for tags and tape (with 100% transport) as an unverified assumption, which may also include miscellaneous transportable ice condenser debris. Subsequently 75% of this area was used in estimating the required strainer area. In the head loss tests, 0.35 ft^2 of paper or fibrous tags and 2.31 ft^2 of adhesive tags (corresponding to plant debris quantities of 90 ft^2 of paper or fibrous tags and 653 ft^2 of adhesive tags) were included among the test debris in lieu of a strainer area reduction.

The treatment of miscellaneous debris is somewhat inconsistent among the licensee's sump analysis calculation reports, and it was not clear from the material presented for the audit review that the licensee has subsequently verified the characteristics of the assumptions concerning this debris. In particular, it was not clear from the licensee's head loss and transport evaluations that the miscellaneous ice condenser debris identified in ALION-CAL-TVA-2739-03 [9] is included in the assumed quantities of tags and tape. While it appears likely that the transportable fraction of the ice condenser debris listed in the licensee's debris generation calculation would be bounded by the licensee's assumptions, sufficient information to support this conclusion was not clearly and consistently documented in the material presented for the staff's audit review. As a result, the staff considers it appropriate for the licensee to confirm that (1) any miscellaneous transportable ice condenser debris is included in the quantity of debris assumed for tags and tape, and (2) a defensible basis exists to justify that the quantity of debris for tags and tape is bounding. However, the licensee does not need to submit the confirmation for staff to review. Therefore, this is not an OPEN ITEM.

Table 3 summarizes the WBN treatment of debris characteristics.

Table 3: Summary of Debris Characteristics

Debris Type	Analytical Size Distribution	Transport Characteristics	Head Loss Characteristics
Stainless Steel RMI Insulation	Conservative debris size distribution from NRC-sponsored test	Per accepted test data	No significant head loss expected due to RMI
Min-K Insulation	Fines (conservative)	100% transport (appropriate)	- Microtherm data substituted for Min-K - Assumed particle size may substantially underestimate head loss
3M-M20C Fire Barrier Material	Fines (conservative)	100% transport used due to lack of data (conservative)	No head loss characteristics provided
Coating Chips	Laboratory evaluation of chips manufactured for head loss testing (conservatism unknown)	Applied NUREG/CR-6772 data (conservatism unknown)	No head loss characteristics provided
Coatings Particulate	GR recommended 10-micron diameter	100% transport (conservative)	Specific surface area equivalent to six divided by 10 microns
Latent Fibers	Individual fibers (appropriate)	100% transport (appropriate)	Nukon™ characteristics (accepted)
Latent Particulate	SE Appendix V recommended size distribution (appropriate)	100% transport (conservative)	Followed SE Appendix V recommendations, but bulk density was not specified
Miscellaneous	Miscellaneous ice condenser debris (realistic)	100% (conservative)	Treated as 1000 ft^2 of tags and tape (unverified)

3.4 Latent Debris Evaluation

The objective of the latent debris evaluation process is to provide a reasonable approximation of the amount and types of latent debris existing within the containment, and its potential impact on sump screen performance. Section 3.5 of the NEI GR and the approved staff Safety Evaluation [2] provide the methodology to be considered for evaluation of latent debris. In general, the GR outlined the following five generic activities to quantify and characterize latent debris inside containment: (1) Estimate horizontal and vertical surface area; (2) Evaluate resident debris buildup; (3) Define debris characteristics; (4) Determine fractional surface area susceptible to debris buildup; and (5) Calculate total quantity and composition of debris. The Safety Evaluation (SE) provided alternate guidance for sampling techniques and analysis to allow licensees to more accurately determine the impact of latent debris on sump-screen performance.

Section 4.2.3 of the SE did not provide any additional refinements to the methodology for evaluation of latent debris. Watts Bar Document No. ALION-CAL-TVA-2739-03 [9], Rev.1 documents the assumptions the licensee used in its evaluation for amounts and types of latent debris.

Staff Evaluation

The staff reviewed the licensee's latent debris evaluation. Specifically, the staff reviewed Watts Bar Document No. ALION-CAL-TVA-2739-03 against the approved methodology documented in Section 3.5 of the SE. The licensee has not performed an evaluation for latent debris in accordance with the SE-approved methodology. Rather, a perceived conservative value was chosen for sump strainer design considerations. Characterization of the Latent Debris source term was done in accordance with the NRC SE. In the Watts Bar Nuclear Plant Generic Letter 2004-02 response [4], the licensee committed to performing a qualitative latent debris walkdown in accordance with the guidance in the GR and SE during the Cycle 7 refueling outage. This walkdown is expected to provide the confirmation necessary to ensure that the value and characterization assumptions used are accurate or conservative. Because the licensee has not yet performed the walkdown or confirmatory analysis to show that the amount and characteristics of latent debris used for design of the new sump strainer are realistically conservative, this is an **OPEN ITEM**.

3.5 Debris Transport

Due to the favorable debris and ECCS conditions at WBN and its intention of replacing current strainers with a conservatively large passive strainer, the licensee could afford to perform a very conservative debris transport analysis, which assumed 100% transport with two exceptions. This conservative analysis was documented using logic charts that illustrate the various debris transport processes. Computational fluid dynamics (CFD) analyses were performed to support the development of the logic charts and to demonstrate the conservativeness implemented into these charts. The conservative estimates of debris were used to specify the debris quantities used in the head loss testing, but debris settling within the test flume was extremely pronounced and shown to be non-prototypical on the non-conservative side.

The conservative transport analyses basically assumed that this debris once transported to the strainer would accumulate on the strainer. However, in reality, the height of the replacement strainer is such that most floor transport debris is not likely to lift from the floor onto the strainer. The following transport discussions are grouped into: (1) a discussion regarding the conservativeness of the logic charts, (2) the supporting CFD analyses, and (3) the debris settling within the head loss testing (briefly because this subject is discussed in detail in the head loss section). Following each of these discussions, a staff evaluation is provided.

3.5.1 Conservatisms in Debris Transport Analysis

The staff reviewed the licensee's debris transport analysis documented in ALION-CAL-TVA2739-04 [10]. The various transport processes (e.g., blowdown, washdown, sump pool recirculation) were captured at a high level in simple logic charts that are in agreement with the GR guidance. The quantification of these charts results in tables (Tables 4.1 and 4.2 of [10]) that show 100% of each debris type is transported to the strainer with two exceptions. These exceptions are: (1) the SS RMI debris; and (2) for analytical debris generation Cases 3 and 4, the latent fiber transport was reduced by 6%. The RMI debris that did not transport was determined to reside in slower regions of the sump pool and the latent debris that did not transport was assumed trapped in pool sediments.

Staff Evaluation

The logic chart approach and the resultant transport results are acceptable to the staff with the minor exception of the reduction to the transport of the latent fibers. Certainly, assuming 100% transport is conservative. Although a 6% reduction in the transport of latent fiber does not seem like much, this reduction was based on an analysis that contradicts testing experience. At the pool turbulence levels generally seen in transport tests and that would be likely in a post-LOCA sump pool, individual fibers have not been seen to settle within the pool. This suggests the settling model used in the licensee's CFD analyses is over predicting the settling of the fibers. An over prediction could be the result of either the analytical model, which the licensee did not validate against experimental data, or it could be the result of using too high terminal settling velocity in the analysis. Transport analyses should always assume 100% of latent fibers transport to the strainer unless entrapment in an inactive pool can be justified. However, one of the head loss test cases shown that even with 100% more fiber debris added on the strainer testing module, the head loss was much less than the NPSH margin. Therefore, this %6 reduction is not considered significant to affect the final strainer sizing. The reduction to the RMI debris transport was based on CFD analysis, which is discussed in the next section. The issue of erosion of 3M-M20C and Min-K debris was automatically addressed with the 100% transport assumption.

3.5.2 Supporting Computational Fluid Dynamics Analysis

The staff reviewed the licensee's CFD analysis as documented in ALION-CAL-TVA2739-04 [10] and presented at the Phase 2 audit meeting on March 2, 2006**.** The CFD analysis was used by the licensee to estimate the transport of SS RMI, to demonstrate the transport of paint chips to the recirculation strainers, and to verify the appropriateness of assuming 100% transport for fine debris such as particulates. The staff used these CFD results to ascertain the prototypicality of the flow conditions within the head loss testing flume.

The CFD analysis evaluated sump pool flow conditions of velocities and turbulence in three dimensions. Implementing debris-specific tumbling velocities into the graphical displays show regions of the sump pool where that particular type of debris could be expected to transport. The directionality of the velocity vectors demonstrate regions where debris would move towards the strainers. Implementing debris-specific terminal settling velocities into the model for turbulent kinetic energy needed to suspend debris causes the graphical displays to show the pool regions where that particular type of debris could be expected to become suspended rather than settling on the pool floor.

Staff Evaluation

In reviewing the GR, the staff accepted the CFD analysis method as a means of estimating debris transport within the sump pool if the analysis is correctly performed. The primary sources of uncertainty in CFD transport results include:

1. Numerical aspects of setting up the CFD models, such as the fineness of the nodalization scheme or the method used to source water into the calculation.

2. The suspension model that estimates whether or not a specific type of debris would become suspended due to CFD predicted levels of turbulence.

3. The debris-specific transport data used to gauge whether or not debris would transport (i.e., the tumbling, lift, and terminal settling velocities).

4. The debris entrance assumptions made regarding where and when debris enters the sump pool.

<u>Numerical Aspects</u> The staff reviewed the CFD analysis performed by Alion and finds the numerical aspects of the analysis to be acceptable. The staff notes that the Alion analytical technique has undergone a continual improvement regarding the modeling detail and that Alion has responded to previous staff comments [37] regarding the modeling technique .

<u>Suspension Model</u> The suspension model correlates the minimum turbulent kinetic energy (TKE) necessary to suspend debris with the terminal settling velocity for that debris. Both the CFD code estimation of the TKE and its correlation to the settling velocity are analytical developments that should be validated against experimental data to reduce the uncertainty associated with the application of the model but no validation has been provided. As discussed above, the analysis predicted that about 6% of the individual latent fiber would settle, whereas testing experience indicates that no significant settling occurs at sump pool turbulence levels. This result indicates that the model or its application could be non-conservative. The most important application of this model in the WBN resolution is its application to paint chip suspension near the location of the replacement strainer because such suspension is required for these chips to accumulate on the strainer even if the chips would transport along the floor to the base of the strainer. The staff is not requiring that this validation be performed for the WBN implementation of GL 2004-02 corrective actions since the strainer can be qualified without this particular part of the analysis provided the quantities of the chips are realistically limited. However, if future application of this model becomes more important to an issue resolution, then requiring such a validation may become necessary.

<u>Transport Data</u> The CFD analysis for the transport of the SS RMI debris applied tumbling, lift, and settling velocities from the NRC-sponsored separate effects transport tests [NUREG/CR-6772] that the staff finds acceptable. The settling velocities for very fine particulate and fiber debris listed in the Alion report were based on the application of Stokes Law, which provides

approximate settling rates but lacks the precision of experimental data. Note that the Stokes equation requires specific input such as the shape factor, which is difficult to specify with precision. For WBN , this precision was not needed since 100% transport was generally assumed.

The CDF analysis for the transport of the paint chips was based on data from the NRC sponsored transport tests (NUREG/CR-6772 [16]). In these tests, only one sampling of paint chips was tested and a single incipient tumbling velocity of 0.4 ft/s was documented. In addition, a range of terminal settling velocities of 0.08 to 0.19 ft/s was provided. The coating debris that could form within WBN ranges in density and chip thickness, as well as in chip shapes. Adapting the NUREG/CR-6772 data for all of the WBN coatings chip debris has substantial uncertainty that could lead to non-conservative transport predictions. The staff accepts the licensee CFD analysis for paint chips as acceptable for demonstrating the trends, but the analysis is not definitive enough to predict the quantities of chips that could accumulate on the strainer.

<u>Debris Entrance Assumptions</u> Once the CFD code is used to predict the sump pool flow conditions, the distribution of the debris within the pool must be overlaid to evaluate transport fractions. This distribution requires some kind of evaluation of the chaotic nature of the blowdown, washdown, and recirculation pool fill debris transport processes. As such, the assumptions regarding where and when debris enters the recirculation sump pool probably represent the largest uncertainty associated with the transport estimates. The Alion transport document ALION-CAL-TVA2739-04 [10] was not clear on the assumptions made for debris entering the sump pool.

The staff finds this issue can be a real concern in estimating the transport for paint chips if credit is taken from CFD analysis to reduce the transport fraction. It would also be a concern for RMI debris except that the RMI debris cannot effectively accumulate on the strainer so the CFD transport of RMI debris becomes relatively unimportant. For coatings chips, the Alion CFD analysis apparently focused on chips returning to the sump pool by way of the ice condenser drainage, which may be appropriate for chips generated in the lower compartment. But for chips generated in the upper compartment, such as paint peeling from the dome liner, these chips would preferentially transport to the sump pool by way of the large-diameter refueling pool drain lines, which exit near the location of the replacement strainer. As such, if the licensee assumes all the coatings fail, then a rather large quantity of chips would enter the sump pool adjacent to the replacement strainer, which also coincides with turbulence caused by the falling spray drainage. However, as one of the head loss test cases performed for the staff (Appendix II) concluded that burying an entire strainer module with coating chips did not cause unacceptable head loss, the staff does not treat this as an open item.

3.5.3 Debris Settling During Head Loss Testing

On November 29-30, 2005, NRC staff audited head loss testing at ARL conducted by Framatome AREVA for WBN on the scaled-down strainer module provided by PCI. In the head loss tests nearly all of the debris except for suspended fibers and particles quickly settled to the flume floor and effectively remained there. The test transport results were drastically different than the conservative analytical predictions. Analytically, most of the debris was conservatively accumulated on the strainer, but experimentally very little debris accumulated. Debris settling within a head loss test flume or tank has been referred to as the near field effect.

Staff Evaluation

The staff's review of the head loss testing determined that the debris settling within the test flume was related to the transport flows within the flume that were highly non-prototypical on the non-conservative side. Had the flume flows been prototypical of the CFD predicted flows, more of the debris would have transported to the test strainer. Staff acceptance of the near field effect debris settling requires evidence that the conditions of the test are prototypical of those that would actually occur in the licensee sump pool following a LOCA. Therefore the licensee flume debris transport results are not valid for strainer qualification. For WBN, due to the lack of fiber to form a thin bed, this testing methodology deficiency does not have an impact on the overall strainer sizing. Therefore, it is not an open item.

3.5.4 Debris Transport Audit Conclusion

The highly conservative analytical transport estimates disagree with the experimental debris transport within the head loss tests. The non-prototypical transport observed in the head loss tests means that the debris accumulation and head losses of those tests did not necessarily represent either expected plant conditions or the head losses associated with the highly conservative debris transport analyses. Although the staff notes the disconnect between the transport evaluation and head loss testing, the overall transport evaluations presented in the vendor reports are considered conservative because the licensee assumed most debris to be 100% transportable.

The licensee transport evaluation did not take credit for the inability of the flows approaching the replacement strainer design to somehow lift floor transported debris from the floor onto the strainers. With the tops of these strainer modules reaching more than 5-ft above the sump floor, it is unreasonable to postulate the floor debris becoming suspended unless the water becomes quite turbulent near the strainer modules. Note that for SS RMI, it takes a flow velocity greater than 1 ft/s to lift a small piece of debris over a 6-inch curb. The CFD flow velocities and turbulence levels are much too low to effectively lift the RMI debris from the floor onto the strainer; therefore the RMI cannot threaten the WBN replacement strainer design.

3.6 Head Loss

The staff reviewed both experimental and analytical head loss results provided by the licensee. Documents reviewed included an analytical head loss calculation (ALION-CAL-TVA-2739-05 [11]), the strainer qualification test plan [18], the strainer head loss test report [19], and presentation materials provided by the licensee during an audit meeting held on March 2, 2006.

The Watts Bar replacement strainer design is supplied by Performance Contracting, Inc. (PCI), and consists of an array of vertically stacked, horizontally oriented disks arranged in modules. The head loss qualification testing for the stacked-disk strainer was performed by Framatome AREVA at the Alden Research Laboratory (ARL) in Holden, MA. PCI supplied a scaled-down test strainer module to support the testing. The analytical head loss calculation was performed by Alion.

3.6.1 Staff Observation of Head Loss Testing

The licensee plans to use head loss testing to develop the design basis of the replacement strainer. On November 29–30, 2005, the NRC staff observed head loss testing conducted by Framatome AREVA at ARL for the Watts Bar replacement strainer design. The staff evaluated the test facility design, test procedures, and test matrix, as well as the test debris, data collection, and downstream sampling for two head loss tests. The staff additionally held technical discussions with licensee and vendor personnel.

In support of the head loss testing observation, the staff reviewed the licensee's test plan, which was supplied by Framatome AREVA [18]. Test procedures covered debris preparation, its introduction into the test flume, the setup and preparation of the test flume, the measurement of clean strainer head loss, data acquisition, and downstream sampling. The staff observed the execution of key steps in the test procedures.

The test strainer was a scaled-down module from the modular array used for the replacement strainer design. The test strainer was prototypical of the replacement strainer in that both were constructed of an arrangement of horizontal stacked disks; however, the width of the four square disks of the test module was only about 2/3 the width of the replacement strainer disks. The reduced scale of the stacked disks could have been an issue for Watts Bar had the debris accumulation been significantly non-uniform (e.g., had debris accumulated preferentially at the centers of the disks' interstitial areas); however, for the relatively uniform debris accumulations observed by the staff during the head loss tests, this nonprototypicality of the strainer disk dimensions would not appear to have a significant impact on the Watts Bar replacement strainer design.

The head loss testing at ARL was conducted in a linear flume. The test strainer prototype was mounted at one end of the flume. A recirculation loop pumped water from the flume through the strainer and reintroduced the water into the flume at the end opposite the strainer. A branch of the discharge piping led to overhead nozzles, which were used to add water to the flume in preparation for the test. Procedurally, all debris was added to the flume with the recirculation pump off, and then the debris was manually stirred in an attempt to bring it into suspension at the beginning of the test.

The test debris was generally comprised of surrogates representing the actual plant materials. Reflective metallic insulation (RMI) debris was manufactured from stainless steel metal foils. Coatings debris was obtained by fracturing paint dried onto a flexible surface. Tin was substituted for inorganic zinc to simplify waste disposal requirements. The plant materials, surrogate debris materials, and the rationales for substitution are summarized in the table below.

Table 4: Head Loss Test Surrogate Debris

Plant Material	Surrogate Test Debris	Rationale
3M-M20C fibrous fire barrier	3M-M20C debris	Actual material
Latent fibers	Shredded Nukon™	NUREG/CR-6877 indicated Nukon™ fibers comparable to plant samples analyzed
Latent particulate	Blended silica sands	NUREG/CR-6877 characterization
RMI	RMI foils	Actual material
Inorganic zinc coatings	Tin particulate 50% as 1-5 microns 50% as 10-44 microns	Zinc hazardous material in Massachusetts Tin has comparable density
Other coatings (phenolic, alkyds, silicone)	Either as 10-micron silicone carbide particulate or Amerlock 400 NT chips	Actual plant coatings no longer commercially available
Min-K	Min-K Debris	Actual material
Chemical precipitates	Aluminum hydroxide Calcium carbonate	Licensee determination of similarity to ICET Test 5
Tags and labels	Plastic and paper tags and labels, paper squares	Comparable material

The licensee conducted the four formal head loss tests identified below (note that five head loss tests were originally planned, but that Test No. 4 was considered unnecessary and eliminated based on the results of preceding tests). The licensee intended to demonstrate adequate replacement strainer performance under all 4 test conditions.

1. Test No. 1: Design Basis Case The test debris was based on plant walkdown results and debris generation and transport analysis. All coatings debris was represented with a powder of fine particulate. The strainer pass-through fraction for downstream effects was measured during this test. No chemical surrogate was used. The head loss from debris was determined to be 0.011 ft.

2. Test No. 2: Limited Coatings Size Case This test used the same quantities of debris as the design basis case, but the phenolic, alkyd, and silicone coatings debris was assumed to fail as chips. Inorganic zinc was represented with a powder of fine particulate. The head loss from debris was determined to be 0.016 ft.

3. Test No. 3: Maximum Paint Loading This test assumed a complete failure of all coatings in the containment. Phenolic, alkyd, and silicone coatings were assumed to fail as chips, and inorganic zinc was represented as a powder of fine particulate. The test also included a surrogate to simulate the expected chemical precipitates. The remainder of the debris was as in Test Nos. 1 and 2. The head loss from debris was determined to be 0.049 ft.

4. Test No. 5: Limiting Coatings Size Case This test was the same as Test No. 2 except that the 3M-M20C insulation debris was not included and chemical effects particulate was added. The head loss from debris was determined to be 0.019 ft.

In addition to these formal tests, two informal experiments were conducted to address concerns the staff raised on the lack of debris transport prototypicality in the flume:

1. The staff was concerned that the shredded Nukon™ low-density fiberglass (LDFG) insulation being used to simulate latent fibrous debris was not sufficiently fragmented to simulate the transport and accumulation of individual fibers. Therefore, at the conclusion of Test No. 2, an additional batch of the Nukon™ used to simulate latent fibers was added to the test flume. The additional batch was first manually separated into finer fragments than the machine-shredded pieces used in the formal tests. The additional batch was introduced into the flume near the test strainer to enhance its capability for accumulating on the test strainer. Head loss was subsequently measured at the normal flow rate (with an observed head loss of 0.101 ft) and double the normal flow rate (with an observed head loss of 0.27 ft).

2. The staff was concerned that nonprototypical velocities in the test flume were preventing transportable debris from reaching the test strainer. Therefore, at the conclusion of Test No. 3, debris that had settled to the floor of the flume was manually piled around and on top of the test strainer. Head loss was subsequently measured at the normal flow rate (with an observed head loss of 0.03 ft) and double the normal flow rate (with an observed head loss of 0.2 ft).

The apparent goal of the head loss tests was to create conditions in the test flume prototypical of the conditions expected in the vicinity of the plant replacement strainer following a postulated LOCA. A prototypical module of the replacement strainer design was used for the test in an attempt to achieve a measured head loss that could be shown to be prototypical of the plant replacement strainer, after potentially adjusting for the difference in water temperature (i.e., the water in the tests varied around approximately 50 °F, whereas the post-LOCA sump pool was conservatively considered to be 120 °F for calculating the plant replacement strainer head loss). However, the staff noted that significant aspects of the head loss test setup were not prototypical of the Watts Bar replacement strainer design, which resulted in the staff generally considering the head loss test results to be nonconservative. The staff's discussion below describes these concerns with the licensee's head loss tests, which include the following:

- Nonrepresentative preparation of the latent fiber debris surrogate
- Potentially nonrepresentative preparation of the 3M-M20C test debris
- Nonprototypicality of the test flume flow conditions
- Nonprototypicality of the strainer circumscribed velocity
- Potentially nonconservative debris concentration effects on flume transport
- Potentially nonconservative head loss test termination criteria
- Potentially nonconservative downstream sampling procedures

None of these concerns resulted in open items for the reasons identified in Section 3.6.4 of this audit report.

3.6.1.1 Nonrepresentative Preparation of Latent Fiber Surrogate Debris

The staff identified a concern that the shredded Nukon™ used to simulate containment latent debris did not transport in a prototypical manner in the test flume. Latent fibers represent miscellaneous fibers washed into the containment pool by containment sprays and other flows from various locations. As such, latent fibers may realistically transport predominantly as individual fibers with nearly 100% transport to the strainer. The licensee used large, nonrepresentative pieces of shredded Nukon™ as a surrogate for loose latent fibers in the formal head loss tests observed by the staff. Contrary to the expected behavior of actual latent fibrous debris, the bulk of the shredded Nukon™ surrogate appeared to sink to the flume floor and remain there for the duration of the formal tests. The observed nontransportability of the Nukon™ surrogate debris under the nonprototypical linear flume average transport velocity of 0.04 ft/s is consistent with the previously documented transport incipient tumbling velocity of 0.12 ft/s for Nukon™ shreds.

Thus, as a result of nonprototypicalities in the licensee's procedures for preparing surrogate debris and for simulating hydraulic transport conditions in the actual plant, the accumulation of latent fibers on the strainer appeared to be significantly underrepresented. Since (1) a key objective of the Watts Bar head loss testing was demonstrating that there is insufficient fiber in the Watts Bar containment to result in the formation of a fibrous debris layer on the replacement strainer that is capable of effectively filtering particulate (i.e., incapable of forming a thin-bed accumulation) and (2) latent fiber could be a significant potential contributor to that layer, the lack of prototypicality in the preparation and transport of the latent fiber surrogate debris appeared to have added substantial nonconservatism to the four formal head loss tests.

The staff stated these concerns to licensee and vendor personnel during Test No. 2., and, in response, an informal follow-on experiment was conducted upon the completion of the formal test. For the follow-on experiment, a second batch of shredded latent fiber surrogate debris (i.e., Nukon™ LDFG) was manually separated into finer pieces and introduced into the test flume in the vicinity of the strainer module to enhance debris transport and accumulation. The measured head loss subsequently increased by a factor of approximately 6, apparently a direct result of some of the smaller pieces of hand-shredded fibrous surrogate debris accumulating on the strainer. At the conclusion of the informal experiment, the flume was drained, and the strainer became visible. The debris that had accumulated on the strainer appeared to consist of only very small fines, with small fibers thinly covering the strainer perforations individually, such that bare metal remained visible in between. As a result of these observations, the staff concluded that the measured head loss values had significant sensitivity to the preparation of the latent fibrous debris into adequately representative fine fibers.

Furthermore, while the manual separation of the Nukon™ shreds for the informal experiment appeared to generate a more representative surrogate as compared to the unseparated shreds used in the formal test procedure, it was not demonstrated that the hand-separated shreds were sufficiently fine to adequately represent the transport of individual fibers under the conditions in the test flume. The staff also noted that the test procedure was not conducted according to quality assurance standards, and that the method of introducing the debris from above the test strainer likely influenced the uniformity of the accumulation, resulting in preferential accumulation on the strainer's upper surfaces. A formal test procedure would have ensured that sufficiently fine fibrous debris had been generated to represent the expected transport behavior of latent debris, and that this debris would have approached the strainer as suspended fiber at a relatively uniform concentration in the flow stream to ensure prototypically uniform accumulation.

Despite the concerns described above, the staff considered the informal experiment to have limited value in demonstrating that a fiber layer that is capable of efficiently filtering particulate would not accumulate on the Watts Bar replacement strainer. Although the head loss increased by a factor of 6 during the informal experiment, the value of the head loss remained low (0.101 ft at the design flow). Furthermore, when the flow was increased to twice the design flow, the head loss only increased to 0.27 ft. While the staff considers these head loss values to be potentially nonconservative, they still provide indication that the overall magnitude of the actual head loss likely would remain low compared to the net positive suction head (NPSH) margin of 3.76 ft.

3.6.1.2 Potentially Nonrepresentative Preparation of the 3M-M20C Fire Barrier Debris

In Section 3.3.3 of this audit report, the staff observed that, due to a lack of information concerning the characteristics of 3M-M20C fire barrier material, the licensee had analytically assumed that any debris generated from 3M-M20C would be completely destroyed into individual fibers. Such an analytical treatment was consistent with the staff’s position in the SE on the NEI GR, which generally recommended that conservative assumptions be made in lieu of obtaining applicable data or analysis. However, for the strainer qualification head loss testing observed by the staff, the licensee’s debris preparation process did not conform to the analytical assumption that predominately individual fibers of 3M-M20C would be generated. Instead the shredding process used by the test vendor generally resulted in debris fragments that maintained the as-manufactured material structure. It is possible that the debris size distribution used in the licensee’s testing was representative or conservative with respect to the actual size distribution of LOCA-generated 3M-M20C debris. However, an adequate technical basis supporting the size distribution chosen for the 3M-M20C debris used in the licensee’s testing was not presented during the course of the staff’s audit review to validate this position. Without adequate justification for the size distribution of the 3M-M20C test debris, the staff cannot reach the conclusion that the licensee’s head loss test results are conservative.

3.6.1.3 Nonprototypicality of Test Flume Flow Conditions

The staff was concerned that the lack of prototypicality with respect to the flume flow conditions during the licensee’s head loss tests had significant nonconservative effects on debris transport. During the two tests observed by the staff, the majority of the test debris settled to the floor of the flume rather than accumulating on the strainer. Therefore, the staff evaluated whether the settling observed in the test flume would also occur in the Watts Bar containment.

Using the flume width, water level, and flow rate stated in the head loss test plan, the staff calculated a linear flume average transport velocity of less than 0.04 ft/s for the Watts Bar test conditions. Given that a velocity of about 0.12 ft/s is necessary to move Nukon™ shreds along the floor, and even faster flows are necessary to move RMI and coating debris, the observed settling in the test flume did not contradict the results of previous separate-effects transport experiments.

However, there was no underlying basis to demonstrate the prototypicality of the average transport velocity in the test flume with the velocities in the containment pool in the vicinity of the replacement strainer. The flume average transport velocity of 0.04 ft/s achieved during the tests was simply a side effect of producing a prototypical strainer surface approach velocity. In comparing the flume average transport velocity to the computational fluid dynamics (CFD) results in ALION-CAL-TVA-2739-04 [10] and the CFD results presented at the Phase 2 audit meeting held on March 2, 2006, the staff identified the flume average transport velocity as nonconservatively nonprototypical with respect to the Watts Bar containment pool flow velocities in the vicinity of the current sump strainer. One CFD figure showed flows at some locations approaching the current strainer with velocities exceeding 0.5 ft/s. Another figure showed that a significant region around the sump experienced flow velocities exceeding 0.28 ft/s, which is the accepted threshold tumbling velocity for stainless steel RMI. Although these CFD simulations were performed based upon the current strainer design, the staff expects that a CFD simulation of the replacement strainer design would also predict flow velocities significantly faster than the ARL flume average transport velocity for a significant fraction of the containment pool surrounding the replacement strainer based on the fact that the most dominant parameters for determining the general containment pool flow field (e.g., the sump flow rate and overall containment floor geometry) would remain essentially unchanged.

The staff also noted that refueling cavity drain lines terminate in the vicinity of the recirculation sump. In the ice condenser design, containment spray droplets only reach the upper containment atmosphere. A primary path for containment spray drainage to return to the recirculation sump in the lower containment is through the refueling cavity drain lines. As a result of significant quantities of spray drainage potentially entering the containment pool near the recirculation sump, considerable turbulence may be generated. This turbulence may be sufficient to keep certain types and sizes of debris in suspension, which could influence debris transport in the vicinity of the replacement strainer. However, the fluid conditions in the test flume did not appear to account for this potentially significant effect.

Therefore, the staff concluded that the ARL flume transport environment was nonprototypical with respect to that of the Watts Bar containment pool. As a result of this nonprototypicality and the large quantities of debris that settled during the flume tests, the staff considered the measured head losses from the ARL tests to be nonconservatively low. The staff further notes that the nonprototypicality of the flume debris transport conditions likely also affected the measurements of debris pass-through for downstream effects, since, under more representative conditions, it is likely that a greater quantity of debris would have transported to and passed through the test strainer.

3.6.1.4 Nonprototypicality of Strainer Circumscribed Velocity

The staff identified a nonprototypical condition affecting only the second informal experiment described above, during which the test debris was manually piled around the test strainer. During this experiment, the form of the debris bed changed from a thin, uniform covering over the entire strainer surface to a circumscribed accumulation that engulfed the majority of the strainer module.

Based upon observations at various vendor facilities, the staff has found that the strainer circumscribed velocity (i.e., the volumetric flow rate through a strainer divided by its circumscribed area) and the strainer surface approach velocity (i.e., the volumetric flow rate through a strainer divided by its total surface area) may not be capable of being prototypically scaled simultaneously for all replacement strainer designs. A schematic diagram highlighting the distinction between circumscribed area and total surface area for a conceptual stacked disk strainer module similar to the Watts Bar design is provided below for clarity:

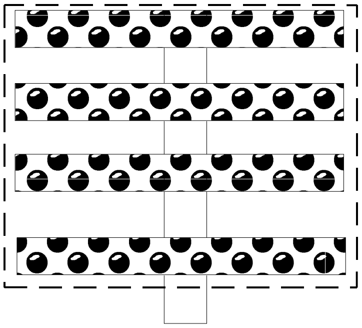

Figure 1: Schematic Diagram of a Stacked Disk Strainer Module

In the diagram above, the horizontal rectangles with dark circles represent square-faced disks of perforated plate. The vertical rectangle represents an unperforated pipe that collects the flow that has passed through each strainer disk. The total strainer area of this module is the total surface area of the square disks of perforated plate. For the given module geometry, the total circumscribed area is considered to be the surface area of an imaginary box drawn around the stack of perforated disks, represented by a dotted line in the above figure.

As stated above, the strainer circumscribed velocity and strainer surface approach velocity may not be simultaneously scalable for all designs. As a result, the appropriate strainer velocity scaling for the overall prototypicality of a head loss measurement depends upon the pattern of debris accumulation on the strainer. For measuring head loss properly, the quantity that must be preserved is the velocity of the fluid as it passes through the accumulated debris. Thus, under the condition where a debris accumulation engulfs the entire strainer (i.e., covers the surface represented by the imaginary box in the figure above), the appropriate velocity for establishing head loss prototypicality would be the strainer circumscribed velocity, rather than the strainer surface approach velocity.

Instead of being scaled according to the circumscribed velocity, the second informal experiment was scaled based upon the strainer surface approach velocity, as had been appropriately done for determining the head loss across the thin, uniform accumulation during the formal part of Test No. 3. As a result, the strainer circumscribed velocity essential for prototypicality during the second informal experiment was approximately a factor of 6 smaller than the expected circumscribed velocity of the actual replacement strainer at the baseline flow rate. When the test flow was subsequently doubled, the strainer circumscribed velocity was nonprototypically low by a factor of 3.

In light of substantial conservatisms in the second informal experiment (e.g., the assumption of a complete failure of all containment coatings) and the actual velocities in many parts of the containment pool at Watts Bar being relatively low, the staff does not consider the formation of a circumscribed accumulation of RMI and limited amounts of paint chips to be realistic for the replacement strainer. Therefore, the nonconservative circumscribed velocity in the second informal experiment does not detract from the design adequacy of the Watts Bar replacement strainer assuming that the currently existing qualified coatings program remains in place. However, as a result of the nonprototypical velocity conditions and a lack of quality-assured test procedures for the second informal experiment, among other concerns, the staff does not consider the licensee’s head loss tests with maximum coatings to be adequate for demonstrating that a complete failure of the coatings in containment could not result in a challenge to the replacement strainer.

Furthermore, although the staff did not perform a detailed review of the licensee’s proposaed elimination of the Watts Bar qualified coatings program, several additional observations were made in the course of the audit review that could impact such a plan:

- Failed coatings from the upper containment, including the dome liner, could transport preferentially to the refueling cavity and then directly to the sump pool near the replacement strainer where the two drain pipes exit. This drainage could be a significant source of turbulence, keeping light chips in suspension near the strainer.

- The licensee’s CFD analyses indicated that 5-mil chips would be suspended by turbulence in the vicinity of the replacement strainer.

- The model used to estimate debris suspension in the licensee’s CFD analysis has not been validated against experimental data; therefore, significant uncertainty is associated with its use.

- Nonprototypical aspects of the licensee’s head loss tests resulted in a large fraction of the test debris settling. Adequate justification was not presented to demonstrate that this settling would occur in the actual plant containment pool. Thus the staff considers the observed debris settling to be nonconservative.

- Head loss data for paint chip accumulations is very limited and no data is available that is specific to the conditions at Watts Bar. In addition, no head loss correlation has been developed to simulate head loss associated with paint chip accumulations.

- Recent NRC-sponsored testing has indicated that relatively significant velocities are necessary to transport various types of coating chips in the absence of significant turbulence.

Although the consideration of these points is not necessary for the Watts Bar strainer qualification provided that the qualified coatings program remains intact, additional consideration of these points and other related concerns may be necessary to ensure adequate replacement strainer performance if the qualified coatings program is eliminated. Without additional analysis to demonstrate that a complete failure of coatings will not impair the functionality of the replacement strainer, the licensee should be able to ensure that coatings failures are limited to an acceptable fraction of the overall quantity present in containment.

3.6.1.5 Potentially Nonconservative Effects of Debris Concentration on Flume Transport

The staff noted three effects associated with high concentrations of debris in the test flume that tended to influence the observed transport behavior of test debris, but which had not been explicitly analyzed to ensure prototypicality with respect to the actual plant conditions. These effects were (1) the tendency for any debris floating on the surface of the flume to be submerged due to the large quantity of additional debris subsequently added to the flume or the impact of water falling from overhead nozzles, (2) the tendency for large quantities of settled debris to pile up and form an insurmountable barrier to debris with the potential for transporting along a clean flume floor, and (3) the tendency for large pieces of debris to agglomerate with small, transportable pieces of debris and prevent them from transporting to the test strainer.

During the Watts Bar head loss tests, significant fractions of several types of debris were noted as remaining on the surface of the flume immediately after being added, including uncrumpled RMI foils, tags and labels, and paint chips (during Test Nos. 2, 3, and 5). These types of debris were generally added to the flume by pouring them out over the length of the flume surface from large trash cans or buckets. The addition of large amounts of debris over the limited surface area of the flume resulted in the layer of debris floating on the flume surface being submerged by the impact of the debris subsequently added. After the debris addition was completed, overhead spray nozzles were used to fill the test flume with water. The impact of this water falling onto the surface of the flume further tended to submerge the debris remaining on the surface. Although experience suggests that the types of debris that floated on the flume surface during the Watts Bar tests may have a limited potential for adverse accumulation and head loss under the expected replacement strainer service conditions, the staff was concerned that the observed test procedures may not generally be sufficient to address modeling the transport of debris with the potential for floatation.

Large quantities of debris were also noted as settling onto the test flume floor during the Watts Bar head loss tests. As noted in Section 3.6.1.1 of this report, the abundance of settled debris appeared partially to result from the nonprototypical flume average transport velocity. Furthermore, a significant quantity of debris that was predominately nontransportable at the flow conditions in the test flume had been added, such as RMI foils and large pieces of various types of debris. (Note, however, that some of the debris that would not have been expected to transport in the nonprototypical transport conditions in the flume may actually be expected to transport in the plant containment pool near the existing sump screen, according to the predictions of CFD simulations.) As expected, such debris tended to pile up and act as a barrier to the transport of any debris that may have been transportable along a relatively clean flume floor at the flume average transport velocity.

Although debris was added to the flume in a specified order to limit agglomeration and other debris interactions that could reduce the potential for transport, prior to the start of the tests, the debris in the flume was manually stirred into suspension. Through this stirring process, the potential was increased for agglomeration interactions between pieces of debris, as well as for transportable pieces of debris to be trapped by large pieces of nontransportable debris resettling to the flume floor. These concerns were exacerbated by the fact that the concentration of debris in the flume appeared to be nonprototypically higher than the concentration of debris that would be expected in the plant containment pool, which could have nonconservatively magnified agglomeration-induced debris settling.

The staff notes that, although these three issues appeared to affect the results of the Watts Bar head loss tests, it was not clear that the behavior of the debris in the test flume with respect to these issues was prototypical or conservative with respect to the plant design.

3.6.1.6 Potentially Nonconservative Head Loss Test Termination Criteria

The staff identified a concern with the licensee's head loss test termination criteria. These criteria permit a head loss test to be concluded once (1) the rate of increase of the measured head loss is less than 1% in 5 minutes and (2) the flume volume has been recirculated at least 5 times during the test. The staff's concern is that, even if these criteria are satisfied, the head loss could still be increasing at a slow but possibly significant rate. Thus, if the observed rates of increase in head loss were to remain steady, a significant increase in total head loss could result, even if plant operators were to throttle or secure pumps as soon as several hours after the switchover to sump recirculation. One potential contributor to a steady increase in head loss over time is the slow erosion of fibrous debris on the containment pool floor (or test flume floor) by flowing water, which has been demonstrated to occur to some extent (refer to Appendix III.3.3.3 to the staff's SE).

The information provided to the staff for the audit review did not address this concern. However, from the licensee's generic letter response, the staff identified that the minimum NPSH margin for Watts Bar is 3.76 ft. Following this minimum value, an additional 5 ft of NPSH margin is added by the time the containment spray pumps finish draining down the refueling water storage tank (RWST). As the ice in the ice condenser baskets continues to melt, additional water inventory would be added to the containment pool. With the addition of this inventory, even if the head loss continued to increase at a slow rate, it does not appear credible that the cumulative head loss increase could exceed the large increase in NPSH margin provided by this additional water inventory. For completeness, the staff believes the licensee should verify and document this conclusion in its analysis.

3.6.1.7 Potentially Nonconservative Downstream Sampling Procedures

During the head loss test designed to represent design-basis conditions for maximizing head loss, the licensee performed strainer pass-through testing. The collected pass-through samples were subsequently analyzed to determine the concentration and characterization of debris in the downstream flow. Collecting pass-through samples during tests designed to maximize head loss may not provide conservative results with respect to downstream effects, since the objective of maximizing head loss implies that the filtration efficiency at the strainer surface will also be maximized. Other accident conditions may not achieve maximum filtration efficiency, and a higher concentration of debris could be experienced downstream of the strainer.

The results of the head loss measurement indicate that a high-filtration-efficiency fibrous bed had not formed on the Watts Bar test strainer. The sequential pass-through samples taken at ten-minute intervals indicated that both the quantity and size of the collected debris were noticeably reduced as the debris bed accumulated on the test strainer, as expected. However, neither the licensee nor its strainer vendor demonstrated that the sample process and analysis techniques utilized verified conservatism for what would be expected for the peak pass-through of debris expected for the plant.

The licensee's downstream effects analysis is evaluated in detail in Section 4.3 of the staff's audit report.

3.6.2 Head Loss Test Temperature Scaling

Although the head loss test plan [18] included a head loss temperature scaling equation based strictly on the difference in viscosity between the room-temperature water in the test flume and water at the elevated temperature conditions analyzed as bounding for the Watts Bar containment pool, the head losses in the test report [19] were not scaled. As room-temperature water has a greater viscosity than hot post-accident sump fluid, applying a viscosity-based temperature scaling approach would have allowed the head losses measured at room temperature to be reduced to account for physical changes in the properties of water at elevated temperatures. However, the licensee's test report conservatively did not credit this phenomenon. Therefore, the staff considers the licensee's methodology to be acceptable.

In the general case that a head loss scaling approach such as that outlined in the test plan were used, however, the staff notes that head loss scaling could involve more than simply viscosity, and ignoring other temperature-dependent phenomena might lead to nonconservative results under certain conditions, such as when the debris bed structure undergoes significant perturbation. As noted above, these concerns do not apply to Watts Bar since scaling of the measured head loss test results was not actually carried out.

3.6.3 Analytical Head Loss Calculation

The staff reviewed the licensee's analytical head loss calculation ALION-CAL-TVA-2739-05 [11]. This evaluation focused first on estimating the minimum strainer area that would preclude the formation of a fibrous layer of sufficient thickness to create a thin bed. In estimating this quantity of fibrous debris, the licensee assumed a minimum thickness of 3/8 inch was necessary for thin-bed formation. The licensee justified the use of 3/8 inch as the minimum thin-bed thickness, as opposed to the 1/8-inch thickness recommended in the Nuclear Energy Institute (NEI) Guidance Report (GR), based on the assumption that an advanced strainer design would promote a non-uniform accumulation of debris that would preclude a high-filtration-efficiency bed covering the entire strainer surface area until a 3/8-inch equivalent bed of fibrous debris could form. The analysis also included the result of a single head loss calculation performed with the Alion HLOSS code. The head loss analysis assumed that the 3M-M20C fire barrier material could be treated as an equivalent mass of low-density fiberglass (LDFG) insulation.

The staff found the analytical assumption that a 3/8-inch-thick layer of fibrous debris is necessary to form a thin bed on the Watts Bar replacement strainer to be unacceptable because it has not been adequately verified. The licensee did not support this assumption with data specific to Watts Bar, such as the replacement strainer design, applicable flow conditions, debris types, and debris size distributions. Visual observations made by the staff during the Watts Bar head loss tests also did not provide a clear justification for assuming the formation of a non-uniform debris bed. Although detailed bed thickness measurements were not conducted, based upon visual post-test examination, a relatively uniform accumulation of fine, suspended debris appeared to have accumulated over all test strainer surfaces. Therefore, rather than attributing the low measured head loss to debris bed non-uniformity, the cause may have instead been the debris bed's being too thin to effectively filter the majority of the suspended particulate. Although the nonprotoypical conditions in the test flume raise concerns about the effect of debris settling in artificially reducing the quantity of fiber that accumulated upon the test strainer, the debris generation calculations show that the quantity of fibrous debris at Watts Bar is somewhat less than the amount necessary to create a 1/8-inch thin bed. This observation supports the adequacy of the Watts Bar replacement strainer design, since experience has generally shown that a fibrous layer of approximately 1/8 inch in thickness is necessary to efficiently filter suspended particulate and induce large head losses.

The staff considers the licensee's treatment of the 3M-M20C debris as an equivalent mass of LDFG insulation debris to be an unverified assumption. With respect to debris generation and transport, in lieu of accepted data, the licensee conservatively assumed a 28.6 L/D ZOI and that destruction into individual fibers would lead to complete transport of all 3M-M20C debris. However, the analytical treatment of 3M-M20C with respect to head loss was not adequately justified. First, the NUREG/CR-6224 [20] correlation has not been validated for a 'felt-like' material. In particular, the NUREG/CR-6224 correlation includes an equation that predicts the compression of an LDFG bed under a differential pressure created by head loss; it is not clear whether the compression equation is applicable to a fibrous bed composed of high-density 3M-M20C debris. Second, the single analytical calculation presented by the licensee in ALION-CAL-TVA-2739-05 [11] considered a maximum debris loading. However, the maximum loading case appears to be less limiting to the strainer design than the thin-bed case, for which a detailed analysis was not presented (although the licensee's calculation noted that a large head loss could be achievable analytically for such cases). Table 8.1 in ALION-CAL-TVA-2739-05 [11] further indicates that, to avoid a 3/8-inch thin bed (as noted above, the staff does not consider this assumption to be justified), a minimum strainer area of 5,160 ft^2 would be necessary to address the 3M-M20C under the assumptions that it is in the form of individual fibers of LDFG, that it fully transports, and that it uniformly accumulates upon the strainer surface. However, this sizing calculation, as well as the head loss calculation described above, tend to significantly overestimate the influence of the 3M-M20C fire barrier material through the artificial assumption that it can be treated as an equivalent mass of low-density fiberglass insulation. As a result, the existing analytical treatment of 3M-M20C appears to be nonphysical and overly conservative.

Furthermore, the staff notes that the strainer area assumed in the analytical calculation (2,400 ft^2) was significantly lower than the value used for the final design and head loss testing (4,565 ft^2). Debris quantities assumed in the analysis were also found to vary somewhat from the quantities used to support the strainer head loss testing.

As a result of the concerns and inconsistencies identified above, the staff considers the single head loss calculation and associated analysis in ALION-CAL-TVA-2739-05 [11] as having limited relevance to the design of the Watts Bar replacement strainer. The staff understands that the licensee intends to use the results of the head loss testing, rather than the analytical head loss calculation, for developing the replacement strainer design basis.

3.6.4 Head Loss Audit Conclusions

The staff identified deficiencies in the methodology used for both the head loss tests and the analytical evaluations that limit their value for demonstrating the design adequacy of the replacement strainer. However, despite these deficiencies, the staff has deduced sufficient specific points that, taken as a whole, lead the staff to conclude that expected debris accumulations (not including chemical effects) would not be sufficient to threaten the adequacy of the Watts Bar replacement strainer design. These points include the following:

1. The large strainer area and relatively small quantities of fibrous material in containment

make it very unlikely that an effective layer of fiber can form uniformly across the entire strainer surface area. The analysis submitted for the staff's audit review indicates that an insufficient quantity of fibrous debris has the potential to reach the sump strainer to form a 1/8-inch thin bed by a reasonable margin. Experience has shown that a fibrous layer of approximately 1/8 inch has generally been necessary to create high head losses across flat-plate strainers. To generate significant head losses across strainer designs having complex geometry (such as the Watts Bar replacement strainer design), even thicker theoretical accumulations of fibrous debris could be necessary if non-uniform accumulation is achieved. As an additional conservatism, the audit review material provided by the licensee, combined with the staff's experience with similar types of insulation, suggests that a significant fraction of the 3M-M20C fiberglass debris might realistically be destroyed into shreds and/or larger pieces of debris (as opposed to individual fibers) that would not transport to the sump strainer as readily as would individual fibers. Furthermore, if less than 100% of the latent fibrous debris accumulates uniformly upon the sump strainer, then additional margin to the formation of a thin bed would be available.

2. The minimum calculated NPSH margin of 3.76 ft is substantially larger than the head losses predicted by the licensee's strainer testing, which were generally on the order of small fractions of a foot. The staff expects the minimum NPSH margin to be conservative, since, as noted in Section 9.2.7.1 of the Watts Bar Final Safety Analysis Report, the NPSH margin calculation does not credit the static head of water above the containment floor level. Following the switchover to containment sump recirculation, NPSH margins will substantially increase, due to contributions from containment sprays and melted ice from the ice condenser baskets. At that time, the NPSH margins for pumps taking suction on the recirculation sump would be expected to exceed 10 ft. The staff has noted that the very low head losses predicted by the licensee's strainer tests are considered to be underestimations, since they are based upon nonprototypical and nonconservative test conditions. However, based upon the facts that (1) head loss testing experience has shown that a fibrous layer with a thickness of approximately 1/8 inch is necessary to induce a large head loss across a strainer and (2) an insufficient quantity of fibrous debris exists in the Watts Bar containment to create a 1/8-inch-thick layer, the staff considers it very unlikely that more prototypical conditions could increase the strainer head loss to an extent that it would exceed the NPSH margin.

3. As the top of the strainer is over 5 ft above the containment floor, it is very unlikely that significant quantities of floor-transported debris, such as RMI foils, could be lifted in sufficient quantity to block the upper strainer surfaces. One possible exception to this statement could be lighter debris (e.g., thin paint chips) entering the containment pool in a relatively turbulent region near the strainer, such as in the vicinity of the refueling cavity drains.

4. Although CFD results show a turbulent region capable of suspending 5-mil paint chips partially encompassing the region of the containment pool where the replacement strainer is to be located, other considerations limit the concern that currently existing quantities of paint chip debris could significantly affect the replacement strainer. These considerations include:

    a. Only a portion of the available paint chips would be light enough and thin enough to become effectively suspended.

b. The portion of the replacement strainer outside the turbulent zone would be less vulnerable to paint chip accumulation.

c. The replacement strainer approach velocities may not be sufficient to keep a large fraction of paint chips attached to the strainer's vertical or downward-facing horizontal surfaces. Thus, to create a possible head loss concern, paint chips would likely need to completely engulf the replacement strainer.

d. The quantity of coatings predicted to fail under the existing qualified coatings program is insufficient to engulf the strainer.

However, when the failure of all coatings in the containment is assumed, the total volume of available paint chips is several times larger than the amount needed to engulf the replacement strainer. As a result of the nonprototypicality of the licensee's head loss tests, the staff does not consider the licensee's maximum coatings test (Test No. 3) or the informal follow-on experiment where debris was piled onto the strainer to be adequate for demonstrating that the replacement strainer design is capable of tolerating a complete failure of all containment coatings. Since the material provided for the staff's audit review did not include additional testing or analysis to demonstrate that strainer functionality would not be unacceptably degraded by the complete failure of containment coatings, the staff concludes that there is currently insufficient basis to support the licensee's proposed elimination of the Watts Bar qualified coatings program.

In conclusion, the staff expects the design and sizing of the Watts Bar replacement strainer to be adequate for ensuring a head loss from currently existing quantities of containment debris (not including chemical precipitates) that will not exceed the NPSH margin for pumps taking suction from the containment recirculation sump. (The staff's review of chemical effects is discussed separately in Section 5.4 of this report and includes one Open Item.) However, due to the presence of significant nonconservatisms in the licensee's test procedures and analytical methodology, the staff does not consider the results of the head loss tests or analytical head loss calculations presented for the audit review to be bounding values acceptable for formulating the replacement strainer design basis and establishing design margin. The staff considers it an **OPEN ITEM** for the licensee to develop a technically defensible design basis that demonstrates an acceptable head loss performance for the replacement strainer. If the licensee plans to use additional head loss testing to resolve this Open Item, the staff further expects that the testing will address the comments identified in Section 3.6.1 of this report, as well as any open items associated with the head loss induced by chemical precipitates.

3.7 Net Positive Suction Head for Containment Sump Recirculation

The licensee provided a table of NPSH margins in calculation ALION-CAL-TVA-2739-05 [9], along with reference documents containing the NPSH calculations and system descriptions. Further, the licensee provided methodology and assumptions that justified its using a sump pool temperature of 190°F in its NPSH evaluations for both the containment spray and RHR pumps. The reported NPSH margins are 3.76 and 4.17 ft of water for the containment spray and RHR pumps, respectively.

Staff Evaluation

The staff reviewed the analytical assumptions used to determine that the maximum sump pool temperature and accepts the estimated maximum temperature of 190°F as conservatively high. The staff noted that this maximum temperature was used in both the containment spray and RHR pump NPSH evaluations.

The staff reviewed the NPSH calculations as documented in the following reports:

1. Westinghouse Calculation FSDA-C-597, dated 11/6/94 – RHR Pump NPSH [21]

2. WBN Calculation EPM-RCP-120291, Rev. 2, Containment Spray Pump Net Positive Suction Head (NPSH) Calc.[22]

3. WBN System Description N3-72-4001, R15 – Containment Spray System [23]

4. WBN System Description N3-74-4001, R12 – RHR System [24]

The staff noted the key conservatisms for these NPSH calculations were the conservatively high sump pool temperature of 190°F and no credit for containment overpressure. The staff did not verify the detailed aspects of the piping friction losses and the required NPSH values quoted in the reports.

This review noted an inconsistency in calculating pressures in terms of feet of static water. To specify a pressure in static water head, both the depth of the water and either the density of the water or the water temperature are required. Typically, water static head is converted to water at the standard temperature of 60°F so that only the water depth is needed in feet. Note that the standard textbook unit conversion factor (2.3092 ft/psi) for converting pressure in psi to head in feet is based on 60°F water. Pump manufacturers most likely convert required NPSH pressures into feet at 60°F since the manufacturers supply pumps that work in a variable temperature environment.

In the licensee calculation for the NPSH available for the RHR pumps (FSDA-C-597) [21], all of the head numbers appeared to be based on 190°F. For example, the atmospheric pressure in feet was 35.07 feet, which was based on a water density of 60.343-lbm/ft^3 (i.e., 190°F). The resultant NPSH available of 23.17 ft appears to be in terms of feet of water at 190°F; however the pump required NPSH is likely in terms of feet of water at 60°F, which is inconsistent. Therefore, the NPSH available of 23.17 ft should have been temperature adjusted to 60°F (i.e., 60.343/62.36 x 23.17 = 22.42 ft) before subtracting the 19 ft of required NPSH to get the NPSH margin. With this correction, the NPSH margin is reduced from the reported 4.17 ft to 3.42 ft (at 60°F).

In the licensee calculation for the NPSH available for the containment spray pumps (EPM-RCP-120291 [22]), the atmospheric pressure, vapor pressure, and the piping friction losses were all calculated assuming the standard 60°F water temperature (i.e., using the unit conversion factor of 2.31 ft/psi). However, the static water height of 50.2 ft was not temperature corrected. Effectively, the calculation added a static water depth based on 190°F water to other pressures based on 60°F water. Correcting the static water depth to 60°F water would result in a depth of 48.6 ft (i.e., 60.343/62.36 x 50.2 = 48.6 ft). That is, the static pressure associated with a water depth of 50.2 ft at 190°F is equivalent to a depth of 48.6 ft at 60°F. This correction would reduce the available NPSH by 1.6 ft, resulting in 15.36 ft rather than 16.96 ft of available NPSH. Upon subtracting the required NPSH of 13.2 ft from 15.36 ft, results in an NPSH margin of 2.16 ft rather than 3.76 ft. This potential inconsistency should be further evaluated by the licensee. However, even if this inconsistency is further confirmed, the 2.16 ft NPSH margin is still substantially greater than the maximum head loss measured in head loss testing. Therefore, this is not an open item.

3.8 Coatings Evaluation

3.8.1 Coatings Zone of Influence

The licensee applied a coatings ZOI with an equivalent radius of 10 length/diameter (L/D). Inside the ZOI, the qualified coatings were assumed to fail as pigment sized particles (10 μm). No credit was taken for shadowing effects arising from large components or equipment within the ZOI.

Staff Evaluation

For determining coatings destruction for WBN 1, the basic approach used by the licensee of a spherical approximation for the ZOI is consistent with that provided in the SE. The licensee applied a ZOI with an equivalent radius of 10 L/D, and treated the debris generated within the ZOI as fine particulate. Therefore, the staff finds that the licensee's treatment of the ZOI for coatings is acceptable. The ZOI used by the licensee conservatively approximates the amount of debris and the debris characteristics that would be generated by a two-phase jet associated with a pipe break in a LOCA scenario.

3.8.2 Coatings Debris Characteristics

As discussed in section 3.8.1 of this report, the licensee applied a ZOI of 10 L/D, in which all coatings were assumed to fail as 10 μm particulate.

For coating debris outside of the ZOI, the licensee analyzed cases with particulate coating debris as well as cases in which the coating debris was assumed to be in chip form. Particulate debris was used for analysis in which the selected break generated fibrous debris. For postulated breaks that did not result in a significant amount of fibrous debris, coating chips were used. The replacement strainer design was tested for both cases during head loss testing. Coating particulates were modeled as 10 μm fines. Inorganic zinc coatings were always modeled as fine particulates. A range of coating chip sizes were tested in the flume during the strainer proof testing. Coating chip sizes ranged from less than 1/32 inch to greater than ½ inch.

The licensee also performed testing which modeled 100% failure of the coatings inside containment. This test modeled 50,545 lb of coating debris (42,419 lbs of phenolic epoxy, 7,900 lbs of inorganic zinc, 44 lbs of alkyds, and 182 lbs of silicone based coatings). Debris was introduced in chip form for all the coating debris except the inorganic zinc, which was represented as particulate in the form of tin powder. The licensee stated that the test involving 100% failure of coatings resulted in only a small increase in head loss when compared to the base case.

Staff Evaluation

The staff's SE addresses two distinct scenarios for formation a fiber bed on the sump screen surface. For a thin bed case, the SE states that all coatings of debris should be treated as particulate and assumes 100% transport to the sump screen. For the case in which no thin bed is formed, the staff's SE states that the coating debris should be sized based on plant-specific analyses for debris generated from within the ZOI and from outside the ZOI, or that a default chip size equivalent to the area of the sump screen openings should be used. WBN considered each of these cases. Although WBN is a relatively low fiber plant, the licensee's strainer testing treated coating debris as particulate for the break location generating the highest amount of fibrous debris. For other scenarios tested by WBN, coating chips with a density conservatively less than the actual plant coatings were used. The coating chips used in the testing were generally larger than the holes in the strainer, and would therefore be expected to block flow if they were transported to the strainer surface and remained on the surface.

During interaction with PWR licensees for resolution of GSI-191, the NRC staff has questioned the current industry method of assessing qualified coatings. The staff has asked licensees to either prove that their assessment techniques can accurately identify the amount of degraded qualified coatings in containment, or assume all of the coatings fail. For one scenario, WBN has opted to assume that all of the coatings inside containment fail. The staff has raised concerns about the large quantity of coating debris created by assuming 100 percent failure of coatings inside containment. The staff's concerns are related to head loss testing, debris transport, and chemical effects and are addressed in Sections 3.5, 3.6, and 4.4 of this report.

Conclusion for WBN

The staff finds that the licensee's treatment of the coatings debris acceptable. The licensee models their coating debris in a manner consistent with the methodology provided in the Staff's SE.

Conclusion for General Methodology Applied by Vendor

Because WBN does not have a sufficient amount of fiber to form a thin bed, the staff agrees with modeling the coating debris as chips for the scenario in which all coatings are assumed to fail. For a plant in which a fiber bed is expected to form, the staff expects that the coating debris would be treated as particulate unless the licensee can provide adequate justification for the use of chips. Such justification may include testing of the actual plant coatings to determine the manner in which they fail. Licensees should perform analysis of the debris characteristics for all coating types within containment. Certain coating types may fail as chips under design basis accident conditions, while others (i.e. inorganic zinc, and unqualified coatings) may fail as particulate.

4.0 ADDITIONAL DESIGN CONSIDERATIONS

4.1 Sump Structural Analysis

General guidance for considerations to be used when performing a structural analysis of the containment sump screen is contained in Section 7.1 of the NEI GR [6] and the staff SE [2]. General items identified for consideration include (1) verifying maximum differential pressure caused by combined clean screen and maximum debris load at rated flow rates, (2) geometry concerns, (3) sump screen material selection for the post accident environment, and (4) the addition of hydrodynamic loads from a seismic event. Analysis of dynamic loads imposed on the sump screen structures due to break-jet impingement were not required for WBN because no break locations have been identified to cause direct jet impingement. No other refinements were provided in other sections of the SE.

Staff Evaluation

The presentation of the structural design of the strainer and the support system during the audit indicated that the licensee adhered to concepts embodied in the Standard Review Plan (SRP) section 3.8.4 [38]. The lateral restraint of the screen assemblies individually and collectively was discussed. The staff stated that a more rigid system of lateral bracing may be more appropriate than the cable bracing being used on the test assembly. If the bracing was required to be extended to the wall, then the wall would need to be evaluated for the additional loads from the bracing. The issue of interaction between individual screen modules was raised, and this effect is expected to be addressed in the detailed structural analysis. The presentation revealed no significant issues in the structural qualification of the screen and support system. Because the licensee did not provide the final strainer structural design report, staff is unable to review and comment in detail on the structural design. Therefore, the licensee is required to complete the report. This is an **OPEN ITEM.**

4.2 Upstream Effects

The objective of the break selection process is to evaluate the flowpaths upstream of the containment sump for holdup of inventory which could reduce flow to and possibly starve the sump. Section 7.2 of the GR [6] and the SE [2] provide the guidance to be considered in the upstream effects process to evaluate holdup or choke points which could reduce flow to and possibly cause blockage upstream of the containment sump. The GR identifies two parameters important to the evaluation of upstream effects: (1) containment design and postulated break location, and (2) postulated break size and insulation materials in the ZOI.

Staff Evaluation

WBN Unit 1, Document ALION - 2739 - 02 [25], “WBN Unit 1: Characterization of Events that may lead to ECCS Sump Recirculation,” was used in the review for this section. The staff reviewed this document to ascertain whether the licensee evaluated the flow paths from the postulated break locations and from containment spray washdown to identify and take measures to alleviate potential choke points in the flow field upstream of the sump. The staff also reviewed the above document and interviewed licensee personnel to verify whether the licensee considered water holdup in the placement of any curbs or debris racks intended to trap debris before reaching the sump. The staff concluded that the licensee’s upstream effects evaluation is acceptable because it was performed in a manner consistent with the approved methodology in Section 7.2 of the GR and SE.

In the containment evaluation section, the licensee determined the water level at the sump after certain accidents like large break LOCA (LBLOCA), small break LOCA (SBLOCA), and other high energy line breaks (HELB). Minimum water level cases were calculated for input to the

ECCS and NPSH calculations. Also, minimum water level for large break LOCA (LBLOCA) cases was calculated for input to the debris transport and head loss calculations.

The staff reviewed the containment evaluation to determine that reasonable assumptions were used regarding flow path clearance or blockage specifically for the minimum flood elevation cases. The staff found that assumptions were based on conservative judgements about the flow paths leading to the sump which result in the minimum volume.

Based on discussions with the licensee and review of the above indicated documents, the staff concludes that the licensee has adequately reviewed the flow paths leading to the emergency sump screen for choke points, has considered the entrapment of debris upstream of the sump screen with regard to the holdup of water, and has considered the effect of holdup in planned modifications. Accordingly, the staff finds the licensee's treatment of upstream effects to be acceptable.

4.3 Downstream Effects

4.3.1 Downstream Effects - Core Heat Transfer Evaluation

Staff Evaluation

The acceptance criteria for the performance of a nuclear reactor core following a loss of coolant accident (LOCA) are found in Section 10 CFR 50.46 of the Commission's regulations. The acceptance criterion dealing with the long-term cooling phase of the accident recovery is as follows:

> Long-term cooling: After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

Following a large break in the reactor system after the core has been recovered with water, long-term cooling will be accomplished by the low pressure ECCS pumps. These pumps initially take suction from a storage tank containing borated water. When that source of water becomes depleted, the suction to the low pressure pumps will be switched to the containment sump. At that time the containment sump will contain all the water spilled from the reactor system and that added by the containment spray. The core cooling mode by which water from the containment sump is continually added to the reactor system and is recirculated as it spills from the break may be required for an extended period of time. During this long-term cooling period any debris which is washed into the containment sump and which is passed through the sump screens will have a high probability of being pumped into the reactor system.

Generic Letter 2004-02 requires that holders of operating licenses for pressurized-water reactors perform evaluations of the ECCS and the containment spray recirculation functions. These evaluations are to include the potential for debris blockage at flow restrictions within the ECCS recirculation flow path downstream of the sump screen. Examples of flow restrictions which should be evaluated are the fuel assembly inlet debris screens and the spacer grids within the fuel assemblies. Debris blockage at such flow restrictions could impede or prevent the recirculation of coolant to the reactor core leading to inadequate long term core cooling. WBN provided evaluations for the purpose of demonstrating that debris blockage of the reactor core during the long-term cooling period is not of concern for WBN [27]. The NRC staff review of this material is described herein.

NRC staff concerns for debris blockage of the reactor core are primarily related to the recovery following the largest postulated reactor system piping breaks. For smaller break sizes the goal of plant operators would be to fill the reactor system and establish closed loop cooling using the decay heat removal system. Recirculation of sump water might not be required for small break sizes and if recirculation were needed, the requirements would be less than for large breaks. The amount of sump debris following a small break is expected to be less than that which would be generated following a large break. This evaluation will therefore emphasize long-term cooling following large piping breaks.

Following a large break LOCA at WBN, the ECCS pumps are aligned to inject into the reactor cold legs. If the break were in a reactor system hot leg, the ECCS water would be forced through the reactor core toward the break. Core flow, including a small amount of core bypass flow, during the long term cooling period would be equal to the total ECCS flow. If all ECCS pumps were assumed to operate, ECCS flow into the reactor system through the reactor vessel and into the core would be maximized. The maximum flow condition is evaluated since it provides the greatest potential for debris transport to the reactor core and subsequent lodging within flow restrictions.

Following a large cold leg break with injection into the reactor cold legs, water will flow into the core, but the rate of core flow will be limited by the pressure needed to overcome the flow resistance of steam generated by the core in reaching the break and by the static head of the water in the core. Eventually the rate of ECCS water reaching the core will be limited to that needed to replenish that boiled away. The excess will be spilled out of the break, including that water injected into the intact cold legs which will flow around the upper elevations of the downcomer and reach the break without passing through the core. The long-term cooling period following a large cold leg break represents a minimum core flow condition. Core blockage by debris under these conditions would add to the resistance which must be overcome for the ECCS water to reach the core and lead to additional spillage from the break. Continued boiling in the core will act to concentrate the debris in the core and might lead to reduced heat transfer from the fuel. Heat transfer might be affected by direct plate out of debris on the fuel rods and by accumulation of material within the fuel element spacer grids. Chemical reaction of the debris with the containment spray buffering agents and boric acid from the ECCS water and reactor coolant might affect the plate out and accumulation processes.

For the evaluation of potential core blockage following a hot leg or a cold leg break, the licensee used the methodology of WCAP-16406-P [26]. The WCAP describes how particulate debris with a density that is heavier than water will settle in the reactor vessel lower plenum and not be passed into the core for a sufficiently low flow velocity. The WCAP also describes how fibrous debris with a density approximately the same as water would be carried along with the recirculated sump water but would be filtered by the sump screens and by screens located at the inlet to the fuel bundles. WCAP-16406-P [26] was recently submitted as a topical report for NRC review. Staff plans to complete the review of this topical report by April 2007. During a meeting with the PWR owners group April 12, 2006, to discuss issues associated with downstream effects on reactor fuel, Westinghouse presented plans to develop another topical report with a more detailed fuels evaluation methodology. Conclusions from the review of both these topical reports may affect the staff’s conclusions regarding WBN ’s corrective actions for Generic Letter 2004-02.

The licensee provided a generic methodology for the amount of particulate debris which might flow into the reactor vessel with the ECCS water ([27] starting at page 43). The generic methodology discussed the settling potential for RMI, concrete debris, latent containment debris and coating paticulates. The licensee believes that any small particles of RMI, concrete debris, latent containment debris and all but the smallest coating paticulates that pass through the sump screen and reach the reactor vessel will settle in the lower plenum of the reactor vessel. In the discussion of the generic methodology, the licensee referred to a study which was reported to show that paticulates with a characteristic length of 0.07 inches and a thickness of 0.005 or greater will settle.

The licensee has performed an evaluation which determined that the total volume of particulate and coatings debris which may pass into the reactor vessel to be approximately 16 cubic feet [28]. The licensee has further calculated that the volume of the reactor vessel lower plenum below the core support plate is 612 cubic feet. Thus the licensee concludes that there is insufficient particulate and coating debris at WBN to cause lower plenum blockage (Appendix III). The NRC staff reviewed the licensee’s calculation and agrees with the licensee’s conclusion.

The licensee states on page 47 of reference [27] that coating debris no larger than 0.02 inches is expected to be transported through the fuel. Although this statement may be true for hot leg breaks, it would not be true for large cold leg breaks where the boiling process would cause this material to congregate in the core. The licensee believes that very little particulate material would be available to be transmitted to the core. The quantity of chemical compounds formed at three hours into the accident was calculated to be less than 1.5 pounds, and the amount of alkyd coating was calculated to be 44 pounds [27]. The staff’s evaluation of chemical compounds is contained in Section 4.4 of this evaluation. The PWR owners group is evaluating the effect on core heat transfer of materials concentrated within the reactor core in the long-term cooling period following a loss of coolant accident. The licensee has not provided a plant-specific analysis for the concentration of the various particulate and chemical compounds within the reactor core during the post-LOCA period, including chemical reactions under the effect of ionizing radiation, to demonstrate that the condition of the core remains within acceptable LOCA limits. This is a generic issue to be addressed by the licensee once the new PWR Owners Group study is completed; the staff has identified this as an **OPEN ITEM**.

The licensee determined that 148.7 cubic feet of 3M fibrous debris might be formed within the containment of a WBN unit following a large LOCA. The licensee conservatively assumes that 100% of the fibrous debris would be transported to the containment sump. Most of the fibrous debris would be retained on the sump screens. The licensee assumes that all debris which is passed through the screen would reach the core.

Using the methodology of WCAP-16406-P [26], the licensee has provided calculations for the size of a debris bed which might form at the core entrance. The licensee used an acceptance criteria of a fibrous debris bed of no more than 0.125 inches across the core inlet. This acceptance criterion is based on pressure drop studies for BWR strainer blockage concerns in NUREG/CR-6224 [20]. Using the methodology of WCAP-16406-P, the licensee calculated a fiber bed thickness at the core inlet of 0.06839 inches following a postulated cold leg break and between 0.2780 and 0.8666 inches following a hot leg break [27]. The hot leg break fiber bed thicknesses were calculated using combinations of sump screen efficiencies of 97% and 95% and for core inlet screen efficiencies of 95% and 50%. The calculated bed thickness exceeded the licensee's acceptance criterion of 0.125 inches. The licensee needs to evaluate the effect on core cooling for this condition. This is an **OPEN ITEM**. The staff notes that the sump screen hole size (0.085 inches) is smaller than the fuel inle t screens by a factor of two. Therefore, for the purpose of calculating core inlet blockage, the licensee's assumptions for fuel inlet screen filtration efficiency are conservative.

Reference [27] discusses the fuel assembly support grids as a possible location for core blockage by debris. In particular if sufficient debris were to form between the support grid and a fuel rod, local heat transfer would be affected and excessive fuel cladding temperatures might be encountered. The staff notes that the spacing between the fuel rods and the support grids is larger than the holes of the containment sump screen. The staff would therefore not expect debris that is passed through the sump screen to be lodged within the fuel assembly support grids unless this material were concentrated within the core as a result of long-term boiling. The licensee noted that the effects of potential debris collection behind spacer grids is currently being considered generically in a program by the PWR owners group. WBN needs to address this issue once the generic methodology is developed by PWROG. This is an **OPEN ITEM**.

As part of its review, the staff performed confimatory calculations of core inlet blockage using the RELAP5 and TRACE computer codes. The staff used generic input descriptions which were modified to incorporate plant-specific data for the reactor core and reactor vessel internals for WBN which was supplied by Westinghouse the nuclear fuel vendor. The staff evaluations concluded that following a break of a reactor system cold leg, adequate core cooling would still be maintained for an excess of 99% core blockage during the long-term cooling period. The staff analyzed cold leg breaks since this condition is limiting for entry of ECCS water into the reactor core. The staff did not evaluate the effect on core cooling from complete blockage of the core by a fiber bed thicker than the licensee's acceptance criterion of 0.125 inches such as was calculated by the licensee in the long-term cooling period following a hot leg break. As discussed above, this condition needs to be evaluated by the licensee.

To prevent excessive concentration of boric acid within the core following a large cold leg break, the existing emergency procedures at WBN instruct operators to manually align the low pressure injection pumps to redirect water to the hot legs three hours after a loss of coolant accident. If sufficient water is added to the hot legs, a net down flow will be established in the reactor core which will flush out the concentrated boric acid and prevent further concentration from occurring. Since the location of the break will not be known to the plant operators, hot leg recirculation would begin three hours after the accident at WBN regardless of break location.

The PWR Owners Group is evaluating the effect on core heat transfer of materials concentrated within the reactor core in the long-term cooling period following a loss of coolant accident. At the completion of this study the NRC staff will require that WBN provide a plant-specific analysis for the concentration of the various particulate and chemical compounds within the reactor core during the post-LOCA period including chemical reactions under the effect of ionizing radiation and to demonstrate that the condition of the core remains within acceptable LOCA limits. The licensee's evaluations should include the effect on core heat transfer of plate out of material on to the surface of fuel rods during long term boiling and the effect of any debris trapped between the fuel element spacer grids and the adjacent fuel rod in the production of local hot spots.

The initiation of flow to the reactor hot legs may be a source of debris to the top of the core. Since hot leg injection will not begin until three hours after the pipe break occurs, there is the opportunity for a considerable amount of the debris to be filtered out or to settle from the water that flows to the top of the core. The licensee has provided an analysis [27] based on the methodology of WCAP-16406-P [26], which concludes that after a time of three hours, the concentration of fibrous debris in the recirculating fluid will be essentially zero. The NRC staff has not approved the methodology in WCAP-16406-P. The staff notes, however that flow restrictions at the top fuel nozzle are considerably larger than the containment sump screen hole size. It is therefore unlikely that any significant blockage will occur at the top of the core at WBN following initiation of hot leg recirculation.

The licensee continues to evaluate the post-LOCA consequences of debris ingestion into the reactor system and its effect on long-term core cooling. The licensee is working with the PWR Owners Group to complete evaluations for the effects of ingested debris on long-term reactor core cooling. The licensee believes that when the evaluations are completed, the effect of debris ingestion will be shown to be small. However, as previously noted, the staff identified several open items to be addressed.

4.3.2 Downstream Effects - Component Evaluation

The staff reviewed the Westinghouse generic reference document WCAP-16406-P [26] and plant-specific calculations to determine if the licensee had adequately addressed the evaluation of downstream effects in regard to system components outside the reactor vessel.

Prior to the March 2, 2006 audit kick-off meeting, the staff had requested the licensee to address certain topics that would be subject to the audit, including general issues and specific concerns relative to the reference documents, in addition to a general overview of downstream effects. These downstream topics include methodology and plant specific issues such as ingested debris characteristics, physical changes required, validation of wear models, as well as plant specific evaluations of pumps, heat exchangers and valves. During the kick-off meeting, the licensee presented an overview of the downstream evaluation and identified that ECCS throttle valves are being modified to allow larger clearance. However, the information provided by the licensee addressing important methodology and criteria used in the evaluation, including the bases for assumptions and techniques used in the calculations and testing, did not allow the staff to perform a detailed review of all aspects of downstream effects for WBN , as discussed below.

The NRC staff recognizes that, due to the WBN use of primarily reflective metallic insulation (RMI) inside containment, there is relatively little fibrous and particulate debris. However, there is a significant amount of ingested coating debris that must be evaluated. In regard to the licensee's evaluation, the staff identified that the NRC has not yet accepted the Westinghouse topical report WCAP-16406-P [26], which the licensee references for various wear and clogging evaluations.

By letter dated April 11, 2006, the NRC staff issued several RAIs to obtain additional information in regard to these issues. By letter dated July 3, 2006, the licensee submitted responses to these RAIs, which the staff also considered in making the audit findings discussed below.

The NRC staff is currently reviewing the Westinghouse Owners Group (WOG) topical report WCAP-16406-P [26]. The WCAP references related to downstream effects have also not yet been approved by the staff. Overall, the staff believes the licensee's evaluation of downstream effects of components outside the reactor vessel is generally conservative, but is based, in part, on this topical report. Once the topical report is approved, the licensee should identify any analysis methods, assumptions, and downstream components, which may be affected and need to be revisited, and verify the components still meet applicable criteria. This is an **OPEN ITEM**.

Specific Audit Items

In addition to the specific subject areas identified in the kick-off meeting, the NRC staff reviewed certain general audit elements of the downstream evaluation for components outside the reactor vessel, which are discussed below.

Component Clogging

The staff reviewed the vulnerability of the high pressure safety injection throttle valves to clogging. Calculation CN-CSA-05-10 concludes that there is no concern for plugging, sedimentation and erosion at WBN Unit 1 for valve downstream effects for GSI-191. The response to RAI Question 3a. indicates that the final calculation has not been issued since it is impacted by the revised debris generation results and the final results of the downstream effects calculation will be provided in a supplemental response. The licensee understands that the results of NRC-sponsored throttle valve tests and IN 96-27 show that high-pressure throttle valves may be susceptible to clogging by typical debris within containment. In regard to NRC-sponsored bypass tests showing that significant debris can pass through sump strainers under certain conditions, the WBN new strainer designs have low approach velocities and smaller holes than assumed in the NRC-sponsored tests, and the licensee considers that only fines will pass through the strainers and be ingested. The licensee's response to NRC question 3.b indicates that, if the debris is small enough to pass through the .085 inch diameter hole in the sump strainers, the debris will also pass through the throttle valves. This is contingent on the development of an additional acceptance criteria for valve position, which will affect the minimum valve flow opening. The recently submitted ECCS analysis report LTR-SEE-06-118, Rev. 1 [30] shows that the throttle valves must be open 1-1/2 turns to pass expected debris, but the corresponding valve clearances are not identified. This analysis has not yet been reviewed by the NRC nor has the modification been completed; however, the licensee's acceptance criterion is that the minimum opening must be at least 1.15 times the screen hole size, which the staff agrees is acceptable.

However, there are several other potentially non-conservative assumptions related to clogging or the absence of clogging that should be shown to be realistically conservative or otherwise validated. For example, a potential non-conservative assumption that the licensee has not addressed is the potential for slender debris to pass through the strainers axially, as addressed in RG 1.82 Rev. 3 [31]. Since there is minimal fibrous ingested debris, this effect is not expected to be significant. The licensee's assessment of the potential for clogging of throttle valves appears to be adequately conservative. However, until completion of the staff review of WCAP-16406-P [26], some assumptions in the methodology identified in calculation CN-CSA-05-14 [28], such as homogeneous distribution of debris and no interaction of debris downstream, could not be validated to confirm that matting and subsequent clogging from chemical effects do not occur at flow obstructions.

Debris Characterization

The staff reviewed the licensee's characterization and properties of ECCS post-LOCA fluid (abrasiveness, solids content, and debris characterization). Calculation CN-CSA-05-7 identifies debris size and concentration. Calculation CN-CSA-05-14 [28] also includes major assumptions that impact the ingested debris characterization, including the conservative assumption that 100% of the coatings and particulate matter are small enough to pass through the sump screens. A total concentration of 593 ppm is calculated on the basis of fiber, particulate, and coating screen penetration. The staff agrees that a realistically conservative concentration value should be used as an initial concentration in the wear analysis. Coatings, representing a concentration of 482 ppm, are the predominant downstream debris contributor, and fiber represents only 5 ppm. The latent fiber concentration is based on 5% screen penetration for Nukon LS. However, as discussed in NUREG/CR-6885 [32], screen penetration for Nukon BP is significantly higher than Nukon LS. Therefore, the licensee should re-evaluate the basis for the estimate of latent fibrous screen penetration to ensure that the estimate is adequately conservative. This is an **OPEN ITEM**.

The ingested debris size, type, and concentration significantly affect the amount of wear. Calculation CN-CSA-05-7 [33] shows that 94% of the coatings are greater than 400 μm, but the maximum size is not shown. However, the predicted debris characterization appears to be consistent with the information in WCAP-16406-P and appears to be acceptable, pending the results of the staff review of this topical report.

Material Wear

The staff reviewed the materials of certain wetted downstream surfaces such as wear rings, pump internals, bearings, throttle valve plug, and seat materials. Calculation CN-CSA-05-7 [33] identifies materials and hardness values for pump wear rings, impellers and seal bushings. Calculation CN-CSA-05-10 [29] identifies that the globe throttle valve plugs are all Stellite #6. Although most of the materials identified in the calculations are considered corrosion and wear resistant, certain materials may not be suitable and replacement may be required. Wear rings and impellers for the RHR and CS pumps with a BHN less than 400 were further evaluated for wear. Calculation CN-CSA-05-7 [33] also identifies spray nozzles as stainless steel which are wear and corrosion resistant.

Section 7 of WCAP 16406-P [26] summarizes the wear and analysis models used in the evaluation of components. It is important that the wear model be validated by correlation to test data that is representative of the specific debris and pump type. The licensee's calculation referenced the methodology in WCAP 16406-P [26] and appeared to be adequately conservative, pending the results of the staff review of this topical report.

Calculation CN-CSA-05-7 [33] also shows that all of the WBN pumps use carbon/graphite material for the disaster bushing and that replacement of this material with a more wear resistant material such as bronze is recommended. The response to NRC Question 1 does not identify that this material is to be replaced. However, in a discussion with the staff, the licensee clarified that replacement of the bushings is not necessary, because WBN has an Engineered Safety Feature atmospheric filtration system in its auxiliary building. The licensee also indicated that a revision to the above calculation will be made to reflect that changing the bushings is not necessary.

System Vibration

The staff reviewed specific information in the WCAP-16406-P [26] topical report and the licensee's submitted calculations to assess whether the system piping vibration response changed for any of the above reasons. Should excessive wear occur in certain critical wear surfaces of the ECCS pumps, this may contribute to increased vibration levels. Wear rates depend on a number of factors that must be correlated to testing data. The licensee's assessment of increased vibration due to material wear appeared to be adequately conservative. However, until completion of the staff review of WCAP-16406-P [26], the vibration modeling and acceptance criteria for the pumps could not be completely verified.

Air Entrainment

The staff attempted to review the extent of air entrainment and its effect on downstream component performance. The WCAP topical report and calculations submitted by the licensee do not address air entrainment. However, air entrainment effects on downstream components is not expected to be significant at WBN due to the small head loss across the strainer.

Opening Size

The staff reviewed the opening sizes and running clearances in pumps, valves, and other restricted openings. In pumps, wear rather than blockage is the primary concern. Calculation CN-CSA-05-7 [33] indicates that blockage of pumps due to debris ingestion is not a concern for a number of reasons, including the fact that none of the pumps at WBN are equipped with hydrostatic bearings or cyclone separators. Calculation CN-CSA-05-10 [29] evaluates the plugging impact for ECCS valves. As discussed above, valves having the smallest openings are high pressure throttle valves and are not expected to be susceptible to clogging. As identified in calculation CN-CSA-05-7 [33], the clearances of spray nozzles and orifices is greater than the expected size of the debris and plugging is not expected to be a concern.

Heat Exchangers

The staff reviewed heat exchangers to determine if any have small (i.e., 3/8" or less) tubes and whether the ECCS is on the shell side. Calculation CN-CSA-05-7 [33] shows that the smallest tube inner diameter is 0.527 inches. Therefore, tube plugging is not expected to be a concern. However, the performance of heat exchangers is susceptible to fouling. WCAP-16406-P [26] indicates that based on the debris definition, no plugging of tubes is expected, but the report also indicates that the maximum length of fibers could be up to 4 inches and that chemical effects have not been considered. The possibility of chemical effects fouling or blockage occurring from a fiber mat forming on the tube sheet has not been evaluated. As a result, the staff could not validate that tube plugging or loss of heat transfer due to chemical fouling is not a concern. The staff expects that, following NRC approval of WCAP-16406-P [26] and qualification testing by the screen manufacturer, the calculation will be revised to show that the largest particle to pass through the screen will not significantly affect the performance of the heat exchangers and that adequate heat transfer is assured with respect to fouling from chemical effects and blockage.

Downstream Effects Component Evaluation Conclusions

Due to the use of primarily RMI insulation in containment with little fibrous debris and no calcium silicate, WBN has minimal fibrous and particulate debris. However, there is a significant amount of ingested coating particles which could affect downstream components. The licensee has made significant progress in resolving concerns identified in GL 04-02 related to downstream effects for components other than reactor pressure vessel internals and fuel. To evaluate various degradation mechanisms for downstream components, the licensee has prepared calculations based on Westinghouse topical report WCAP-16406-P [26]. Since this topical report has been recently revised and is not yet approved by the NRC, the licensee cannot finalize the evaluation of downstream effects and the evaluation cannot be validated at this time. The licensee has indicated that in addition to the screen modifications, throttle valve positions are being changed to pass debris, and flow orifices are being modified. Modifications to pumps or other equipment have not been identified by the licensee.

4.3 Chemical Effects

The NRC staff reviewed the licensee's chemical effects evaluation consistent with the information outlined in Section 7.4 of the GSI-191 SE. The staff observed a flume test at Alden Laboratory in which particulate debris, intended to represent chemical precipitate, was added to the debris during head loss testing of a strainer section. Representatives from WBN provided an overview of the licensee's chemical effects evaluation during the March 2, 2006, audit kick-off meeting with NRC staff.

The WBN containment materials include mostly reflective metallic insulation (RMI) with relatively low amounts of fiber. Flume testing debris included 3M-M20C Fire Wrap, Min-K, and shredded NUKON fiberglass to simulate latent fiber. Surrogate materials were used for coating debris, including tin powder that was used to simulate inorganic zinc (IOZ) particulate and silicon carbide particles to simulate failed coating particulate. Plant-specific flume testing for WBN was performed prior to the PWR Owners Group sponsored chemical effects bench top testing. Since sodium tetraborate is used to buffer a postulated post-LOCA containment pool at WBN, the licensee used the preliminary results from Integrated Chemical Effects Test (ICET) 5 as the basis for selecting the type and quantity of particulate to simulate chemical effects. Specifically, the licensee added aluminum hydroxide (55 mg/L) and calcium carbonate (35 mg/L) to the other debris to simulate an added chemical product loading during flume testing. The flume test fluid was ambient temperature tap water.

The licensee has not justified the ambient temperature, tap water, flume environment with additions of calcium carbonate and aluminum hydroxide particulate to be a sufficient test to address chemical effects. The staff recognizes the licensee used the information available at the time from the ICET program and viewed the added particulate to be an additional debris source rather than a "chemical effects" test. Based on calcium carbonate solubility reference material provided by the licensee during the March 2, 2006 meeting, the calcium carbonate powder added to the flume would be expected to dissolve at the test temperature.

The staff has a number of generic concerns about the test methodology where particulate is added to an ambient temperature tap water environment to simulate chemical effects, including:

- Verification is needed that the particulate is representative of the chemical precipitate that may form in a post-LOCA containment pool.

- The potential participation of boron in the formation and properties of aluminum hydroxide in representative environments that would not be present in simulated particulate added to a tap water environment needs to be addressed.

- The chemical behavior of debris materials in the flume environment relative to a representative post-LOCA containment pool is not clear with respect to influences on reaction kinetics, chemical precipitate agglomeration, precipitate density, chemical reactivity, filterability, and particle size distribution.

- Potential interactions between intended chemical precipitate and flume debris, including other flume test surrogate materials (e.g., tin and silicon carbide particulate) are not known.

- Simultaneous addition of chemical precipitate with other plant-specific debris does not seem to be consistent with a time-dependent formation of chemical precipitate in the sodium tetraborate environment.

- Addition of particulate simulating chemical precipitate at the same time as other debris results in an inability to understand the behavior of this particulate (e.g., dissolution, time to form a representative hydrated amorphous precipitate) after addition to the flume and complicates understanding of the influence of chemical precipitate on head loss.

Subsequent to flume testing, WBN performed a plant-specific determination of the chemical products formed with the chemical model developed in WCAP-16530-NP [34]. This model predicted a total of 10 mg/L of precipitate. The NRC staff is currently reviewing WCAP-16530-NP. As part of this review, the staff will be requesting additional information from the PWR Owners Group to resolve technical questions about the chemical model and particle generator contained in the WCAP.

Although the staff questions the technical adequacy of the non-representative flume test methodology employed for addressing chemical effects, WBN has many plant attributes that are favorable with respect to potential chemical effects. WBN has a relatively large available pump net positive suction head margin and low amounts of fiber such that a continuous fiber bed does not form on the new strainer surface. Compared to the scaled amount of aluminum tested in ICET 5, WBN has much less aluminum in containment; less than 5% of the submerged aluminum area and less than 1% of the spray zone area. Therefore, the plant-specific amount of aluminum containing precipitate is expected to be much less than the amount that would be projected based on the ICET 5 results. During ICET 5, with a sodium tetraborate buffer, no precipitate was observed at the constant 140°F test temperature. Precipitate formed some time after the test solution had cooled to room temperature. From a NPSH margin standpoint, delays in precipitate formation are favorable compared to immediate precipitate formation, since pump NPSH margin increases significantly with time following the onset of recirculation after a large break LOCA. In addition to ICET, NRC-sponsored vertical loop head loss testing performed at Argonne National Lab included a test in a sodium tetraborate environment. The sodium tetraborate test showed no significant head loss increase across a NUKON fiber bed with a

50 ppm dissolved aluminum concentration. Finally, WBN increased the total sump strainer area by 50% to provide margin that accounts for uncertainties in head loss associated with chemical effects.

WBN's analysis and consideration of eliminating the qualified coatings program raises the possibility that a significant amount of coatings could arrive as debris in a post-LOCA containment pool. Inorganic zinc coatings were included within the ICET program. The WBN assessment concludes the phenolic epoxy is not chemically active in the post-LOCA containment environment and that the total amount of alkyd coatings would not affect the head loss due to chemical effects. The licensee needs to provide justification for the conclusion that epoxy phenolic coating is resistant to leaching in the WBN post-LOCA environment. This is an **OPEN ITEM**. In addition, although the WBN alkyd coatings are already considered in the debris term, the evaluation of alkyd coating should include an understanding of how this coating interacts with the projected post-LOCA environment. Potential interactions could include the leaching of chemicals from the alkyd coatings, softening, or other changes to the coating (e.g., become gelatinous) that could produce greater head loss compared to an alkyd coating tested in ambient temperature water. This is an **OPEN ITEM**.

In summary, the staff has identified issues with the chemical effects test methodology used for WBN. Considering the low amount of fiber at WBN , the low amount of expected chemical precipitate, and favorable test results at Argonne National Laboratory using a greater amount of chemical precipitate in an environment similar to WBN , the staff concludes WBN has adequately addressed potential chemical effects, except for the open items identified above.

5.0 Alden Research Laboratory Head Loss Test Facility Audit

WBN sponsored head loss testing performed by Framatome Areva at the Alden Research Laboratory test facility in their flume head loss test loop located at Worcester, MA. Staff audited the test, and an audit report is attached in Appendix II.

6.0 Conclusions

WBN has responded to NRC's bulletin and generic letter GL 2004-02 according to the required schedule. The new strainer with 4600 ft^2 surface area will be installed during the 2006 Fall outage. This makes WBN one of the first plants to make strainer changes fourteen months before the December 2007 deadline. Although the licensee needs to resolve several remaining open items, the staff concludes that the new sump design appears to be robust with ample design margin. The staff review conclusions are summarized below.

Break Selection

The staff finds the licensee evaluation of break selection to be acceptable in general. The evaluation was generally performed in a manner consistent with the approved SE methodology. Deviations from the staff approved methodology were judged by the staff to be acceptable based on the technical basis provided by the licensee, with one open item.

Open Item 1:

The licensee should submit the final debris generation calculation to verify that the impact of the revised debris quantities has been adequately addressed.

Debris Generation/Zone of Influence

The staff finds the licensee's ZOI evaluation to be acceptable in general. The evaluation was performed in a manner consistent with the approved SE methodology. The licensee applied the ZOI refinement discussed in Section 4.2.2.1.1 of the SE, which allows use of debris-specific spherical ZOIs. The licensee applied material-specific damage pressures and corresponding ZOI radius/break diameter ratios as shown in Table 3-2 of the staff SE. The staff found that the licensee provided an adequate level of technical justification with respect to ZOI analyses, with one open item.

Open Item 2:

The licensee should submit the final debris generation calculation that addresses crediting debris shielding by robust barriers.

Debris Characteristics

The licensee generally used accepted guidance in characterizing potential debris sources. Several exceptions to this conclusion, described in detail in Section 3.3 of this report, include the licensee's treatment of Min-K and the 3M-M20C fire barrier. Although the unverified assumptions made regarding Min-K were not considered to be significant with respect to demonstrating the adequacy of the replacement strainer design, the staff concluded that the licensee should provide confirmation that the overall treatment of 3M-M20C debris is conservative with respect to demonstrating adequate replacement strainer performance. The staff also concluded that the licensee should provide confirmation that the assumptions made regarding miscellaneous debris (e.g., ice condenser debris, tags, and labels) are conservative. This confirmation does not need to be submitted for staff's review. Therefore, it is not an open item.

Latent Debris

The licensee used an assumed value for the amount of latent debris for the sump strainer evaluation. The licensee has not yet performed a walkdown or confirmatory analysis to show that the amount and characteristics of latent debris used for design of the new sump strainer are realistically conservative. In the WBN Generic Letter 2004-02 response, the licensee committed to performing a qualitative latent debris walkdown during the Cycle 7 refueling outage. Therefore, WBN needs to complete the walkdown and the confirmatory analysis to show that the assumptions regarding the amount of latent debris are valid.

Open Item 3:

The licensee should complete the walkdown and the confirmatory analysis to show that the assumptions regarding the amount of latent debris are valid.

Debris Transport

The licensee's analytical treatment of transport for non-coating debris is considered conservative. For coatings, the analytical results are acceptable given the source terms based on the licensee's coating maintenance program. However, these analytical results are not sufficient that the licensee can justify not having a coatings maintenance program. In terms of the CFD debris transport analysis, the staff finds it acceptable. Alion followed the methodology described in the NEI GR as modified by the staff's SE for geometry, assumptions.

Head-Loss Testing and Analysis

The staff identified deficiencies in the methodology used for both the head loss tests and the analytical evaluations that limit their value for demonstrating the design adequacy of the replacement strainer. However, despite these deficiencies, the staff has concluded that, taken as a whole, the licensee has demonstrated that expected debris accumulations would not be sufficient to threaten the WBN replacement strainer design. Therefore, the staff considers the design and sizing of the WBN replacement strainer to be adequate for ensuring a head loss from currently existing quantities of containment debris that will not exceed the NPSH margin for pumps taking suction from the containment recirculation sump. However, due to the presence of significant nonconservatisms in the strainer vendor's test procedures and analytical methodology, the staff does not consider the results of the head loss tests or analytical head loss calculations presented for the audit review to be bounding values acceptable for formulating the only replacement strainer design basis and establishing design margin.

Open Item 4:

The licensee should provide additional justification for the conclusion that the maximum head loss across the new strainer is less than the NPSH margin available.

Net Positive Suction Head

The staff reviewed the WBN NPSH calculation and found substantial NPSH margin. However, the staff noted that the NPSH available calculations may have mixed units, i.e., ft-water at standard water density and ft-water at elevated temperatures in same equation. It is not clear to the staff why this approach is used. However, the staff does not believe this would alter the final screen design. WBN needs to evaluate the impact of this possible inconsistency if it is confirmed.

Coatings Debris Generation/Zone-of-Influence

The staff finds that the licensee's treatment of the coatings debris acceptable. The licensee models their coating debris in a manner consistent with the methodology provided in the Staff's SE.

Sump Structural Analysis

Final sump design, structural analysis and installation documentation has not been provided to the staff. No review was performed in this area. The licensee needs to complete the document as part of GL closure package.

> **Open Item 5**:
>
> The licensee should to provide the final structural analysis report for the replacement strainer.

Upstream effects

The licensee's evaluation was generally performed in a manner consistent with the approved GR methodology. The staff concludes that the licensee has adequately reviewed the flow paths leading to the emergency sump screen for choke points. Therefore, the upstream effects evaluation is acceptable.

Downstream Effects (Core Heat Transfer)

The staff reviewed the downstream effects core evaluations submitted by the licensee. At this point, the industry wide generic downstream effects evaluation methodology is being developed. The licensee plans to continue to evaluate the post LOCA consequences of debris ingestion into the reactor system and its affect on long- term core cooling. The following items remain open in the staff's review.

> **Open Item 6:**
>
> Upon the completion of PWROG generic methodology development and NRC's approval, the licensee should evaluate the effects of plate out or local deposition of materials concentrated within the reactor core on core heat transfer during the long-term cooling period and submit the results for staff's review.
>
> **Open Item 7:**
>
> The licensee should address the fact that following a large hot leg break, a debris bed might form at the entrance to the core which would be greater than the licensee's acceptance criterion of 0.125 inches and evaluate the impact on the core heat transfer.

Downstream Effects (Component)

Overall, the staff believes the licensee's evaluation of downstream effects of components outside the reactor vessel is generally conservative, but is based, in part, on a topical report that has not yet been approved by the NRC. Therefore, if there are new issues identified through the review of the generic topical report, the licensee needs to verify the affected components and demonstrate that they still meet the applicable criteria.

As part of the debris ingestion evaluation, the coatings and particulate debris screen penetration mass amount have been conservatively estimated. However, the fibrous debris ingestion estimate for latent debris is based on screen penetration test results for Nukon LS (leaf shredded). Based on NUREG/CR-6885, leaf shredded Nukon appears to clump, and therefore is less likely to penetrate screens than actual latent debris would be. WBN needs to re-evaluate the basis for the estimate of latent fibrous screen penetration to ensure that the estimate is adequately conservative.

Open Item 8:

The licensee should identify any analysis methods, assumptions, and downstream components, which may be affected by changes to WCAP-16406-P and need to be revisited, and verify the components still meet applicable criteria.

Open Item 9:

The licensee should re-evaluate the basis for the estimate of latent fibrous screen penetration to ensure that the estimate is adequately conservative.

Chemical Effects

The staff has identified issues with the chemical effects test methodology used for WBN. Considering, however, the lack of a continuous fiber bed at WBN, the low amount of expected chemical precipitate, and the large margin in strainer area available to account for uncertainties in chemical effects, the staff concludes WBN has adequately addressed potential chemical effects, except for the following open items:

Open Item 10:

The licensee should provide justification for the conclusion that epoxy phenolic coating is resistant to leaching in the WBN post-LOCA environment. In addition, although the WBN alkyd coatings are already considered in the debris term, the evaluation of alkyd coating should include an understanding of how this coating interacts with the projected post-LOCA environment.

Open Item 11:

WBN indicated that the WCAP-16530-NP chemical model spreadsheet contained an error that affected the amount of chemical precipitate for WBN. The licensee should provide an evaluation of the plant specific impact of any changes to the WCAP chemical model in the WBN GL 2004-02 response supplement.

Note: In addition to the open items identified in this report, the report notes two items that the licensee should confirm, but for which the staff does not need information to be submitted. These items can be found on pages 16 and 38 of this report.

Appendix I References

1. GL 04-02 NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004.

2. GSI-191 SE, Revision 0, "Safety Evaluation of NEI Guidance on PWR Sump Performances," dated December 6, 2004.

3. MEMO from W.R.Lagergren to Document Control Desk " WATTS BAR NUCLEAR PLANT (WBN) UNIT 1 - RESPONSE TO BULLETION 2003-01 - POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY SUMP RECIRCULATION AT PRESSURIZED-WATER REACTORS." ML0322305100. August 8, 2003.

4. MEMO from W.R.Lagergren to Document Control Desk " WATTS BAR NUCLEAR PLANT (WBN) UNIT 1 - NRC GENERIC LETTER (GL) 2004-02: POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY RECIRCULATION DURING DESIGN BASIS ACCIDENTS AT PRESSURIZED WATER REACTOR (PWR) - SECOND RESPONSE" ML0524903470. September 1, 2005.

5. NEI 02-01, "Condition Assessment Guidelines: Debris Sources Inside PWR Containments," Revision 1, dated September 2002.

6. NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology," dated December 2004.

7. NRC Branch Technical Position (BTP) MEB 3-1, "Postulated Rupture Locations in Fluid System Piping Inside and Outside Containment"

8. Standard Review Plan (NUREG-0800) Section 3.6.2, "Determination of Rupture Locations and Dynamic Effects Associated with the Postulated Rupture of Piping."

9. WBN Reactor Building GSI-191 Debris Generation Calculation. ALION-CAL-TVA-2739-03 Rev. 1.

10. WBN Unit 1 Reactor Building GSI-191 Debris Transport Calculation. ALION-CAL-TVA-2739-04 Rev. 0.

11. WBN Unit I Containment Sump Debris Accumulation and Head Loss. ALION-CAL-TVA-2739-05.

12. WBN GSI-191 Debris Generation/Transport and Sump Screen Testing. ALION-CAL-TVA-2739-03 Rev. 1.

13. Regulatory Guide 1.82, "Water Sources for Long-Term Recirculation Following a Loss-of-Coolant Accident," Revision 3, dated August 2003. Section 1.3.2.3.

14. ANSI/ANS Standard 58.2, "Design Basis for Protection of Light Water Nuclear Power Plants Against the Effects of Postulated Pipe Rupture," dated 1988.

15. NUREG/CR-6808, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance," dated February 2003.

16. NUREG/CR-6772, "GSI-191: Separate-Effects Characterization of Debris Transport in Water," dated August 2002.

17. NUREG/CR-6877, "Characterization and Head-Loss Testing of Latent Debris from Pressurized-Water-Reactor Containment Buildings," dated July 2005.

18. Test Plan for SURE-FLOW STRAINER (Prototype) Headloss Evaluation for Watts Bar Containment Sump.Framatome Areva. 51-9005676-001.

19. Test Report for SURE-FLOW STRAINER Performance Test For WBN .

20. NUREG/CR-6224, “Parametric Study of the potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris,” October 1995.

21. Westinghouse Calculation FSDA-C-597, dated 11/6/94 – RHR Pump NPSH

22. WBN Calculation EPM-RCP-120291, Rev. 2, Containment Spray Pump Net Positive Suction Head (NPSH) Calc.

23. WBN System Description N3-72-4001, R15 – Containment Spray System

24. WBN System Description N3-74-4001, R12 – RHR System

25. Document ALION - 2739 - 02, “WBN Unit 1: Characterization of Events that may lead to ECCS Sump Recirculation”

26. WCAP-16406-P, “Evaluation of Downstream Effects in Support of GSI-191,” June 2005.

27. Calculation Note CN-CSA-05-36, “WBN GSI-191 Downstream Effects Debris Fuel Evaluation,” Westinghouse Electric Company LLC.

28. Calculation Note CN-CSA-05-14, “WBN GSI-191 Down Stream Effects Debris Ingestion Evaluation,” Westinghouse Electric Company LLC.

29. Calculation Note CN-CSA-05-10, “WBN Sump Debris Downstream Effects Evaluation for ECCS Valves”

30. TVA ECCS analysis report LTR-SEE-06-118, Rev. 1

31. Regulatory Guide 1.82, "Water Sources for Long-Term Recirculation Following a Loss-of-Coolant Accident," Revision 3, dated August 2003

32. NUREG/CR-6885, "Screen Penetration Test Report," dated October 2005.

33. Westinghouse CN-CSA-05-7. “WBN Sump Debris Downstream Effects Evaluation For ECCS Equipment.”

34. WCAP-16530-NP. “ Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to support GSI-191". Revision 0. Feburary, 2006

35. WBN GSI-191Downstream Effects-Vessel Blockage Evaluation. Westinghouse.CN-CSA-05-2.

36. WBN Unit 1:Characterization of Events That may lead to ECCS Sump ALION-REP-TVA-2739-02.

37. Memo from R.Architzel to Thomas Martin “ REPORT ON RESULTS OF STAFF PILOT AUDIT-FORT CALHOUN STATION ANALYSES REQUIRED FOR THE RESPONSE TO GENERIC LETTER 2004-02 AND GSI-191 RESOLUTION.” ML053101940. January 26, 2006.

38. NUREG-0800 “ Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants”

Appendix II. WBN Head Loss Test Observation Trip Report

Summary

On November 29-30, 2005, NRC staff members and a NRC consultant visited Alden Research Laboratory (ARL) to observe the head loss tests conducted by Framatome Areva for the TVA WBN power station. The replacement strainer design for WBN will be supplied by Performance Contracting Inc. (PCI). The staff evaluated the testing facility design, testing procedures, test matrix, test debris including chemical by-products and coatings debris, and the sampling of the flow downstream of the strainer. The near field debris settlement phenomenon and its modeling were discussed with the licensee and the vendor. For the WBN new sump design, it appears that the new sump design is conservative and has significant margin to accommodate uncertainties but several generic testing issues were identified during the testing.

This audit visit to ARL was the first phase of the audit. The first phase audit team consisted of five NRC staff including David Solorio (Branch Chief of NRR/DSS/SSIB), Shanlai Lu (Team Leader), John Lehning, Martin Murphy, Matthew Yoder, and one NRC consultant, Clint Shaffer from ARES. A second phase of the audit is tentatively scheduled for February 2006 after the licensee completes their final design package, at which time the staff will review the licensee's debris generation, debris transport, chemical effects, upstream and downstream effects, and NPSH analyses. This report serves as both a trip report and an interim audit report to be issued to the licensee as part of the audit correspondence.

Background

Based on the staff's review of GL-2004-02 responses from all PWR licensees, the staff selected WBN as one of our audit plants on the new sump design for the following reasons:

1. The ice melt from the WBN ice condenser feature would significantly affect the sump water temperature during the early time period of a postulated loss of coolant accident.

2. Because the WBN plant also generates Tritium in addition to power, the staff is particularly interested in the licensee's approach for evaluating the downstream effects on the WBN reactor core.

3. The head loss tests for WBN were the first series of design basis head loss tests conducted by Framatome Areva/ARL/PCI. Staff intends to interact with each vendor early on to ensure proper testing procedures and, particularly, the treatment of near field debris settlement.

4. WBN plant is one of several plants which proceeded early in response to GL2004-02 and a significant portion of the design documents was available to the staff.

The staff decided to perform the WBN audit in two phases to coordinate with the ongoing Oconee audit. The first phase consisted of auditing the licensee's design basis head loss testing by Framatome Areva for TVA WBN nuclear power station at ARL in Holden, MA and a second phase is tentatively scheduled in February 2006 as resources become available from the Oconee audit. The team observed two head loss tests and interacted with the licensee and the vendor regarding the following areas:

1. Test debris (including fibrous, metallic, coatings, and chemical byproducts)
2. Test facility
3. Head loss testing procedures
4. Test matrix
5. Near field debris settling referred to as the near field effect

This interim audit report primarily documents the staff initial observations of the head loss tests.

Audit Initial Observations

The team's initial observations were made from the following:

1. A draft copy of the licensee's testing procedure that was provided prior to the audit. At the site, the team was subsequently provided with a marked up revision to that procedure that reflected corrections and recent changes.

2. High level discussions of calculational reports for accident event characterizations, debris generation, debris transport, and downstream effects. Electronic copies of calculational reports were provided shortly before the visit to ARL but not in time for the team to review the reports prior to visiting the site.

3. The team observed two head loss tests including debris preparation and data collection, which constituted the primary source of these initial observations. The team held technical discussions with licensee and vendor personnel throughout the course of these tests.

These observations are organized by overall impressions of licensee's approach to the sump blockage resolution, the characterization of the debris tested, the similitude of the test apparatus, the debris transport and accumulation within the test flume, downstream sampling, test procedures and test matrix.

Overall Impressions The WBN plant is insulated primarily with RMI but has lesser quantities of fibrous insulation and/or fire barriers and Min-K insulation. Other debris sources include potential failed coatings, latent debris, and chemical byproducts. The plant has a relatively deep sump and reasonably large NPSH margin, and plans to replace the existing recirculation sump screens with a large, complex, and submerged stacked disk strainer having a total area of 4550 ft^2. The licensee has assumed 200 lbm of latent debris, which the licensee considered highly conservative due to their improved housekeeping maintenance program. Their sources of fibrous debris (not yet reviewed) do not appear substantial enough to completely cover the proposed replacement strainer with a layer of fibrous debris sufficient to effectively filter particulate. A team calculation of the licensee stated sources of fibrous debris and the replacement strainer screen area indicates a fibrous layer with a thickness of about 0.06-in (assuming 100% transport), which is about half the 1/8-in considered to be a nominal minimum thickness to form a fibrous/particulate debris. Even if Min-K and/or chemical byproducts can be filtered without a fibrous bed, the quantities of these materials are generally not substantial enough to form a threatening layer of debris. If substantiated in the follow up audit review, the expected conclusion is that a significant bed of fibrous particulate debris cannot form at WBN .

Conversely, substantial quantities of RMI debris and coatings debris in paint chip form could potentially be generated following a LOCA. It currently appears that the transport of this debris in sufficient quantity to threaten the NPSH margin is not likely but this conclusion has not been adequately substantially at this time. The licensee testing at ARL was conducted in a linear flume that supposedly has conservative similitude with the licensee sump but the team's comparison of the flume transport velocity with licensee sump CFD results strongly suggests otherwise. This testing similitude includes what is being referred to as the near field effect.

Overall, it appears that the licensee has a reasonable resolution to the strainer blockage issue but needs to provide more supporting justifications to ensure no adverse effect has been overlooked. These justifications could include revisions to their testing program to counter audit criticisms. From an auditing standpoint, the staff needs to require completeness in the resolution submittals that includes justifications for near field settling and test material characterizations. More detailed discussions are now provided.

<u>Debris Characterization</u> The materials tested at ARL were not samples of actual plant materials rather substitutions were made for key materials as shown in Table 1. For example, the licensee 3M M20C fibrous insulation is no longer in production so a similar insulation was substituted. Testing with inorganic zinc is problematic in Massachusetts so Tin was substituted. Represented coating debris was substituted.

Table II-1. Test Debris Materials

Plant Material	Surrogate Test Debris	Rationale
3M M20C Fibrous Fire Barrier	3M Interam I-10 Mat 3/16-in	M20C No Longer in Production Similar Material Substituted
Latent Fibers	Shredded Nukon™	NUREG/CR-6877 Indicated Nukon™ Fibers Comparable to Plant Samples Analyzed
Latent Dirt	Blended Silica Sands	NUREG/CR-6877 Characterization
RMI	RMI Foils	
IOZ Coatings Inorganic	Tin	Zinc Hazardous Material in Massachusetts Tin Has Comparable Density
Other Coatings (Phenolic, Alkyds, Silicone)	Either Silicone Carbide or Amerlock 400 NT	Actual Plant Coatings No Longer Commercially Available
Min-K	Commercial Samples of Min-K Insulation	Comparable Material
Chemical Byproducts	Aluminum Hydroxide Calcium Carbonate	ICET Test 5
Tags and Labels	e.g., Paper Squares	

It is important that the surrogate debris tested have similar (or conservative) characteristics to the postulated LOCA generated debris in the plant. Ideally, the licensee should characterize the postulated plant debris and that characterization should include all of the key generation, transport, accumulation, and head loss parameters. The characteristics of the surrogate material should be characterized and compared to the postulated plant debris to demonstrate that each transport and head loss process is adequately represented. The licensee, for example, provided the bulk density of the 3M fibrous debris (39-lbm/ft^3) but not its porosity or fiber diameter or glass density. It is interesting to note that this 3M fibrous debris must have a relatively low porosity for fibrous insulation (i.e., 1 – 39/175 = 0.78, assuming the same glass density as Nukon™), if fact, its porosity is on par with the porosity of fine particulate. As such, if a significant layer of this 3M fibrous debris were to accumulate, it could be quite effective at causing head loss. The licensee needs to evaluate the pertinent characteristics of all potential debris types and make comparisons with surrogates for staff review to ensure adequacy of the substitutions but this was not generally available for the audit.

The staff noted that the Nukon™ surrogate for latent fiber was not appropriately prepared to represent latent fibers and this was communicated to the licensee representatives. Latent fibers represent miscellaneous fibers washed into the sump by containment sprays from various locations within containment. As such latent fibers may realistically (and conservatively speaking) transport as predominantly individual fibers with nearly 100% transport. The problem is that the licensee used shredded Nukon™ to represent the latent fibers but the shredded Nukon™ transports predominately along the test flume floor. The test flow velocities in the ARL flume were well below the documented transport velocity for Nukon™ shreds of 0.12 ft/s; therefore most of the Nukon™ probably did not reach the strainer. Therefore, the accumulation of latent fibers on the strainer was highly underrepresented. In response to this staff observation, the licensee subsequently tore by hand the Nukon™ used to simulate latent debris for subsequent testing, which increased the observable presence of fibers accumulating on the strainer but still does not necessarily represent individual fiber transport and probably also did not qualify as a quality assured procedure.

Coating chips were used in the tests observed by the staff. The licensee stated that the chips had been generated by painting a plastic sheet and that was subsequently crumpled up after the paint had dried to form chips. The licensee did not identify a target size for the paint chips and indicated that the size distribution of the chips was not known. Unlike paint chips in an actual plant, which may tend to be brittle due to aging or thermal cycling, the paint chips used during the test appeared quite flexible. There was an apparent lack of standardization on the preparation of surrogate coatings debris.

The staff noted a concern that debris premixed in water could have been settling and agglomerating within the respective containers prior to their addition to the test flume. The concern was raised when staff heard larger than expected debris entering the flume water than was expected that appeared to occur as the last of the container was emptied. Although test technicians subsequently stirred up the debris in the test tank, it was not clear whether their efforts were capable of breaking up these agglomerated clumps of debris into more-representative individual pieces.

The staff observed that the surrogate chemical by-products were used by the vendor as part of the debris addition during the tests. Although it was indicated by the licensee that the amount of chemical by-product added was determined based on the ICET Test 5 results, the staff did not find any supporting documents. In addition, the vendor has not addressed the applicability of this testing procedure considering the PH, temperature and other chemical concentrations. Overall, the staff has concerns with the general testing approach which is adopted by the vendor to address the chemical effects.

<u>Test Apparatus</u> The licensee head loss testing was conducted in a linear flume at ARL. A prototype of the licensee proposed replacement strainer was mounted inside the flume at one end. A recirculation loop pumped water from the flume through the strainer and reintroduced the water into the flume at the far end. A secondary recirculation loop simulated downcomers with the intended purpose of introducing turbulence to stir up settled debris. During the visit, dimensional and flow data was accumulated as shown in Table 2. The test prototype strainer consisted of four square disks 18-in to a side compared to a total of 504 disks (6 x 4 x 3 x 7) 28-in to a side for the replacement strainer. The ratio of the circumscribed area to the total screen area for the test strainer was 0.43 compared to 0.067 for the replacement strainer. Although the test flow rate was specified so that the screen approach velocities would be essentially identical, their respective circumscribed velocities, as tested, were quite different.

Table II- 2. Test Apparatus Data

Parameter	Values
ARL Flume	
Dimensions	27-in wide, 39-in height, and 20-ft-9-in long
Water Depth (as Tested)	22.5-in
Flow Cross Section	27-in x 22.5-in = 4.2 ft^2
Linear Flow Velocity	**0.036 ft/s**
Test Strainer	
Total Screen Area	16.1 ft^2
Test Flow Rate	67.6 GPM
Approach Velocity	**0.0094 ft/s**
Strainer Disks	18-in square
Between Each Disk	1-in
Inside Each Disk	0.5-in
Plate Thickness	0.06-in
Height	4 (0.5 + 2(0.06)) + 3(1) = 5.48-in
Circumscribed Area	(2(18)^2 + 4(18)5.48 - π (~7.1)^2/4) /144= 6.97 ft^2
Circumscribed Velocity	**0.022 ft/s**
Water Over Strainer	~1-ft
Clearance Below	~ 5-in
Proposed Replacement Strainer	
Total Screen Area	4550 ft^2
Scenario Flow Rate	19100 GPM
Approach Velocity	**0.0094 ft/s**
Strainer Disks	28-in square
Strainer Array	7 x 3 = 21 (vertical stacks)
Modules	4 per stack
Modules Disks	6 per module
Total Strainer Disks	21 x 4 x 6 = 504
Height of 4 Modules	46.25-in
Underneath Clearance	3-in
Height of Plenum Box	9-in
Floor to Strainer	3+9 = 12-in
Diameter of Holes	0.085-in
Open Fraction of Holes	0.322
Circumscribed Area	[7(3)(28)^2 + 2(7+3)(28)(46.25+3)]/144 = 305.9 ft^2
Circumscribed Velocity	**0.14 ft/s**

Debris Transport and Accumulation During the two tests observed by the audit team, the majority of the debris settled to the floor of the test flume rather than accumulate on the strainer. The licensee is taking credit for this substantial debris settling within the test flume but the licensee did not provide comparative analyses between the licensee sump and the ARL test apparatus that validates the debris settling within the test flume as being realistic for the licensee sump. This debris settling within the test tank is being referred to by the vendors as the near field effect and defended as being prototypical of the respective licensee sumps under investigation. The licensee based the validity of the near field settling on the screen approach velocities (based on the entire screen area) being the same between the licensee proposed replacement strainers and the test strainer.

Using the dimensions and flow rate provided during the ARL visit, the team calculated a net linear flume flow velocity of 0.036 ft/s, which is quite slow. In fact, the staff observed internal circulation patterns within the flume where surface flow appeared to go in the reverse direction. Noting that it takes a floor level flow velocity of about 0.12 ft/s to move Nukon™ shreds along the floor and even faster flows to move RMI and coating debris, it is not surprising that the majority of the debris simply settled to the flume floor and remained there. However, the CFD results presented to the staff in ALION-CAL-TVA2739-04 clearly indicate that the sump pool flow velocities are substantially faster. One figure shows flows approaching the current strainer with velocities exceeding 0.5 ft/s at some locations and another figure shows that most of the sump region flow exceeds a velocity of 0.28 ft/s, which is the accepted threshold velocity to move stainless steel RMI. Although, the CFD analyses simulated the existing strainer instead of the replacement strainer, a comparable CFD result simulating the replacement strainer, with or without debris accumulation, would certainly predict significantly faster approach velocities than the ARL flume test velocity. Therefore, it must be concluded that the ARL flume transport environment is not comparable to the licensee sump; therefore the test transport results cannot be directly applied to the plant.

In addition to the lack of similitude in the near field transport velocities, the velocities approaching the strainer also are substantially different. This approach velocity is referred to as the circumscribed velocity and is calculated by dividing the volumetric flow by the circumscribed area, which is outer perimeter area of the strainer. The circumscribed velocity for the prototype strainer was 0.022 ft/s compared to 0.14 ft/s for the replacement strainer, i.e., the average circumscribed approach velocity for the replacement strainer would be about 6.4 times the prototype circumscribed approach velocity, as tested. This lack of similitude affects circumscribed accumulation, which for WBN likely consists of RMI and paint chips piled against or on top of the replacement strainer. The head loss through such a debris bed is a function of the circumscribed velocity, which typically consists of a combination of linear dependency and the square of the velocity. This means the head loss at the replacement velocity would be somewhere between 6.4 and 40 times that measured on the prototype, as tested. Upon completion of a scheduled test, the licensee's vendor conducted an unplanned extension to the test where technicians artificially relocated the debris settled on the flume floor which effectively piled the debris over and around the prototype strainer to scope the effect of a circumferential accumulation of RMI and coatings debris. Basically, the head loss approximately doubled leading the vendor to conclude that the head loss from such an accumulation was still inconsequential, although the vendor considered this an unrealistic accumulation. The audit team, however, notes two problems with this conclusion. First, the circumscribed velocity in the test was too low by a factor of about 6.4, and secondly it could not be ascertained with any certainty that the strainer circumscribed perimeter was fully covered in debris and it seemed likely that the rear portion of the strainer may have been relatively exposed.

The staff learned that in the actual plant, large-diameter drain lines from the refueling cavity terminate in the vicinity of the sump strainer, which could create turbulence and/or channels of increased flow velocity. The staff also observed from CFD results that there may be flow obstructions in the vicinity of the sump that could cause significant flow channeling with associated increased flow velocity, which would tend to increase debris transport along those channels. It was not clear that neglecting these two potentially significant phenomena would lead to a conservative model of near-field debris transport in the test flume setup.

The staff noted a significant quantity of the coatings chips, tags, and labels, and a few smaller pieces of uncrumpled RMI tended to float upon the surface of the water rather than sink. The coatings chips seem to float like small boats and a close examination of a few individual chips indicated that imperfections in the chip surface may hold residual air causing buoyancy. Pushing these chips underwater by hand or turbulence from water streams from above the surface of the flume caused a lot of these chips to sink. Concentrations of floating debris also contributed to sinking. However, the staff noted that for WBN , these effects may not be significant since relatively small quantities of such debris sinking directly onto the plant replacement strainer would not likely have a significant impact on head loss since only the upper horizontal surface would be directly affected.

The floor transport of debris would have been affected by the high concentration of debris if the flow velocities had been in the transportable range. The large pieces of RMI would have impeded the movement of paint chips and fibrous shreds and so on. If, for example, the flow velocity was increased greater than 0.12 ft/s to move Nukon™ shreds but less than 0.28 ft/s to move RMI, the RMI could prevent the movement of the Nukon™. It is not clear at this time that the floor debris concentrations inside the ARL flume represented the corresponding concentrations in the plant sump.

The accumulation of fibrous debris on the prototype strainer was not uniformly distributed over the entire sump strainer surface. Minor variations in the screen approach velocities could account for this observed accumulation behavior. It is most likely that had there been sufficient fibrous debris in suspension, the accumulation would have evolved towards relative uniformity. Further, it was observed that fibrous debris was accumulating predominately over the individual strainer flow holes, leaving the surrounding structural metal generally uncovered, which is consistent with the initial formation of a debris bed. Although, the individual holes were filing with fibers, the thickness of such accumulations did not appear to be able to effectively filter particulate.

<u>Downstream Sampling</u> The sampling of debris-laden fluid downstream of the prototype sump strainer was performed primarily during the design-basis head loss test which occurred prior to the staff's arrival at the test facility. The staff was informed that downstream sampling had been performed at 10-minute intervals during the first hour of the design-basis test, and at 20-minute intervals thereafter. During a later flume test observed by the staff, two downstream samples of debris-laden fluid were taken to demonstrate the sample collection process. The staff observed that the downstream samples were collected via taps from the suction line just downstream of the sump strainer. The staff observed technicians measuring the sample collection time, the purpose for which was explained as assuring that the water velocity in the sample collection taps would support the collection of a representative fluid sample.

In subsequent discussions with the licensee, the staff noted that the Safety Evaluation (SE) regarding the NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology," Revision 0, recommends that no credit be taken for the filtering effect of a debris bed when determining the quantity/concentration of debris that might pass through a suction strainer. The licensee's downstream sampling apparently relied upon, to some degree, the filtration of the debris bed, since there appeared to be a very thin coating of debris over flow holes on the front and sides of the strainer prototype. In response to licensee questions, the staff further elaborated that variations from the SE should be justified, and that one possibility for demonstrating that a given amount of debris bed filtration is conservative would be to show that the debris bed being credited would form under all presumable accident conditions requiring sump recirculation. Along similar lines, performing downstream sampling during tests with the design-basis debris loading for head loss generally may not be conservative with respect to downstream effects, since there may be a number of accidents for which reduced debris loadings may decrease the filtration capability available from the sump strainer debris bed.

Test Procedures Test procedures include steps for debris preparation and debris introduction, flume setup, clean strainer head loss, data acquisition, and downstream sampling. The staff observed the execution of key test procedures during the visit. Concerns were raised regarding debris preparation, downstream sampling, and the termination criteria. The debris preparation procedure concerns were discussed under debris characteristics, specifically the simulation of latent fibers. The downstream sampling procedure concerns were discussed under downstream sampling.

The head loss testing procedures specify maintaining recirculation flow rate and monitoring the head loss through the suction strainer until the head loss stops increasing more than 1% in 5 minutes or until the pool volume has recirculated at least 5 times by calculation from the start of the test, whichever takes longer to achieve. The staff concerns are: (1) the head loss could still be increasing significantly when 5 pool turnovers is reached, and (2) an acceptable termination rate of 1% increasing could potentially be sustained, which could result in 12% per hour until the increase actually ceases. The mission time for the strainers is 30 days. Even if the plant throttles back on the flow after several hours or after the first day, the potential exists for a 1% to amount into a significant increase in head loss. One potential source of a steady increase in head loss over time is the slow erosion of fibrous debris on the sump floor (or test flume floor) by the flow, which has been demonstrated to occur at least to some extent but potential very substantially. The staff would be more comfortable with the test continuing until an asymptotic condition became much more pronounced, at least for key design basis tests.

Procedurally, all debris was added to the flume at the beginning of the test and then mixed together in the flume using manual stirring and/or the injection of water flow from the vertical downcomers. After mixing, further mixing ceases and the head loss test procedure was initiated. The staff is concerned that introducing all the debris in this manner could cause agglomeration effects that would not be present if the debris were introduced much more slowly with the recirculation suction operating. In a realistic scenario, debris will arrive in the sump pool over a period of time that reflects washdown debris transport and delayed failure of some materials such as failed coatings. An alternate test procedure of slow introduction in conjunction with the current procedure would clarify whether or not this concern is important.

Test Matrix The test document provided for staff review included 5 tests. The staff observed two of these tests and one test was canceled due to its similarity to another test, i.e., similar head losses were expected. No tests were specified to demonstrate repeatability. Each of these tests included a mixture of debris types. Matrix parameters included: with and without 3M fibrous debris, with and without chemical particulate, substantial variations in quantities of coatings debris, and a lesser variation in the quantity of RMI debris. In one test, the coatings debris was all introduced as powder whereas in the other tests only the IOZ was introduced in the powder form. The quantities of latent and Min-K debris remained constant in the matrix.

Once it is recognized that RMI and coatings paint chips essentially would not transport within the flume at the tested flow rate and there was insufficient fiber to form a continuous layer of fibrous debris sufficient to effectively filter particulate, the head loss results from all of the tests conducted should be similar in magnitude. A more effective test matrix would have focused on satisfying the different aspect of similitude one at a time since these aspects apparently cannot be satisfied simultaneously for this strainer in the ARL flume.

The flow rate, as tested, would have satisfied the thin uniform layer accumulation if the appropriate quantity of fibrous debris had accumulated on the strainer, which includes all of the latent fiber. If a test was conducted with fiber only, then a debris preparation procedure and a stirring procedure could be developed to ensure complete accumulation of fibrous debris and with fibers only, the accumulation should be visible. Such a test could be definitive in determining that there is insufficient fiber to effectively filter particulate if a second phase of the test (after completion of the fiber accumulation) slowly added the particulate debris.

A circumscribed accumulation test could be conducted where RMI and coatings debris was introduced around and over the prototype strainer in a manner that ensured a reasonably uniform layer of such debris had completely engulfed the strainer. But in this test, the flume flow rate would be increased so that the prototype circumscribed approach velocity was the same as the plant replacement strainer circumscribed approach velocity. In this manner, the flow through such a debris bed and its corresponding head loss should have similitude between the prototype test strainer and the replacement strainer.

To conduct near field debris transport in the ARL flume, the flow velocities have to be those predicted for the plant sump. Here a CFD result that simulated the replacement strainer is needed to determine what those velocities should be. A transport test matrix should consider the transport of individual debris types independently, as well as, a realistic mixture. However, the above two definitive tests (thin and circumscribed accumulations) could alleviate the need to substantiate near field debris transport.

Staff Position Statement on the WBN Head Loss Testing

The audit team finds that the formal head loss tests audited are not directly applicable to qualifying the licensee replacement strainer because the debris transport environment within the ARL flume does not adequately represent the licensee sump pool transport environment shown in the licensee's CFD sump pool analyses. The linear transport velocity in the ARL flume of about 0.036 ft/s is so much slower than the CFD sump pool velocities, which appear to be greater than 0.28 ft/s over perhaps two-thirds of the sump pool, that there is no comparison. Further, the ARL flume velocity is much slower than the near field velocity of the replacement strainer, as indicated by its circumscribed velocity of 0.14 ft/s. Therefore, the extensive debris settling within the ARL flume likely would not represent corresponding post-LOCA recirculation conditions within the licensee sump pool. Since the debris transport within the ARL flume, including the fibrous debris, was underrepresented, the corresponding head losses were likely also underrepresented. This finding applies to all of the formal tests in the licensee test matrix.

In response to concerns raised by the audit team, the licensee conducted two post-test exploration tests to address these concerns. In one post-test test, fiberglass shreds were further broken down and added to the flume directly over the prototype strainer in attempt to enhance the accumulation of fibers on the strainer to show that the incomplete transport of surrogate latent fiber would not make much difference to the head loss. In another post-test test, the settled RMI and coatings debris was relocated to surround and cover the strainer to demonstrate the low magnitude of head loss associated with such debris. Although both of these post-test tests were enlightening, the tests were spontaneous and lacked the disciplined test procedure needed for a test to qualify the replacement strainer. However, these two post-tests tests do indicate their value if the tests were to be formally repeated with test procedures focused to achieve the test objectives. To fully make this point, the staff has developed suggested procedures to accomplish the test objectives. Consider the following procedures for formally repeating the post-test tests:

1. A fiber/particulate debris test focused to demonstrate that there in not sufficient fiber to form a fiber layer on the replacement strainer that can effectively filter particulate. In this test, the maximum quantity would be introduced first slowly without particulate with the pump operating and the downcomers providing turbulence to keep the fibers in suspension. The test would benefit from much more fully breaking down the fibrous shreds before introducing them into the flume so that the fibers behave more like individual fibers and the accumulation on the strainer approaches completeness. The resultant incomplete layer of fiber likely can be visually validated and photographed. Once the fiber accumulation has reached completion, a second phase of this test could introduce the particulate; again slowly with the pumps and downcomers operating.

2. An RMI/coatings debris test focused to demonstrate that a significant layer of such debris will not form a threatening head loss on the replacement strainer. Consider a layer of such debris with a thickness corresponding to the spacing between the prototype strainer and the flume wall where the layer is fully encompassing including the top surface; perhaps held in place by an artificial screen upstream of the debris. The pump flow rate would be set to achieve a circumscribed velocity on the test strainer equivalent to the replacement strainer (0.14 ft/s). This data likely could be scaled to alternate bed thicknesses.

If additional tests are not conducted to address the concerns raised by the audit team, the second phase will necessarily focus entirely on the analytical aspects of the resolution to determine acceptability of the replacement strainer. The analytical evaluation will focus on the maximum fiber layer that could accumulate on the strainer and compare that thickness to existing data regarding whether or not particulate would be effectively filtered. It would also evaluate the potential thickness of RMI and coating debris on the replacement strainer including the possibility of completely covering the strainer. There may be sufficient margin at WBN to make an analytical determination.

Staff Position Statement on the Vendor Head Loss Testing

This head loss testing audit, as well as, other audits has found vendors taking into account near-field debris settling without validating this settling as representative of the licensee sump. Clearly, in this case the test flume settling may not be representative of the licensee sump. Further, the prototype circumscribed velocity was not representative of the replacement strainer. Vendor testing needs to consider a complete set of similitude parameters include debris surrogates, total screen and circumscribed approach velocities, and transport velocities and turbulence. It may be that all of the similitude parameters cannot be achieved simultaneously but perhaps the test matrix could be designed to achieve the important similitude objectives piecemeal.

Appendix III Staff Request For Additional Information

REQUEST FOR ADDITIONAL INFORMATION

WBN NUCLEAR PLANT, UNIT 1

NRC AUDIT OF CONTAINMENT SUMP MODIFICATIONS

RESULTING FROM GENERIC LETTER 2004-02

DOCKET NO. 50-390

Break Selection and Zone of Influence Analysis

1. Tennessee Valley Authority (TVA, the licensee) stated that because the quantity of reflective metallic insulation is not a significant contributor to head loss, and the quantity of fibrous material, Min-K, would remain relatively unchanged for each break, the bounding case for each loop is the reactor coolant system break which would destroy the most coatings. The licensee indicated that a thorough analysis showed that a break in each of the crossover legs near the steam generator nozzle yielded the most coating debris due to the size of the zone of influence (ZOI) applied in the analyses. The Nuclear Regulatory Commission (NRC) staff (the staff) determined that such an analysis was not clearly documented in the calculations and information provided for the staff's audit. Please provide the referenced analysis to verify that the limiting break is at the base of the steam generator.

2. As discussed in Sections 3.1 - 3.4 of WBN calculation ALION-CAL-TVA-2739-03, the licensee credits the reactor annulus and refueling canal as robust barriers in the analysis. As stated, the licensee's analysis showing that a break in each of the crossover legs near the steam generator nozzle yielded the most coating debris was not clearly documented in the calculations and information provided for the staff's audit. Therefore, WBN calculation ALION-CAL-TVA-2739-03 does not clearly show the extent to which the licensee credited truncation due to robust barriers. Using the response to question 1 above, please show the extent to which truncation is credited.

3. Steam line breaks in the debris generation calculation are ruled out because recirculation is not required for cooling the core following a steam line break. However, recirculation using spray flow for environmental qualification of equipment is required. Please explain why this scenario was not analyzed.

Debris Generation

1. Please provide the complete walk-down report, “Report on WBN Unit 1 Containment Building Walkdowns for Emergency Sump Strainer Issues,” TVAW001-RPT-001, Revision 0.

Chemical Effects

1. Please provide the amounts of various WBN containment materials (I) submerged and (ii) in the containment spray zone for the following materials: aluminum, zinc (from galvanized steel and inorganic zinc (IOZ) coatings), copper, carbon steel, and uncoated concrete. These amounts should include any scaffolding material or metallic-based paints (e.g., aluminum-based paints used on pressure vessels).

2. Provide a discussion concerning the post loss-of-coolant accident (LOCA) containment pool pH, including the range of pH values possible. The values discussed by the licensee at the audit meeting were more refined than the licensee's response to the NRC Generic Letter (GL) 2004-02. Please clarify.

3. If possible, provide the containment pool temperatures as a function of time during the emergency core cooling system (ECCS) mission time for the limiting combination of conditions that would produce (I) the highest pool temperatures with time, and (ii) the lowest pool temperatures with time.

4. Provide the WBN plant-specific chemical effects analysis. Indicate if any more chemical effects related testing is planned.

5. During the integrated chemical effects testing (ICET), in certain chemical environments such as sodium tetraborate, precipitates formed as the solution cooled from the 140°F test temperature. These products could interact with other downstream debris to cause clogging in narrow passages of downstream components such as valves and pump internals, or affect internal surfaces of heat exchangers or the reactor vessel. Describe your evaluation of potential downstream effects related to interaction with chemical products and the criteria used to determine that performance of downstream components is acceptable for your plant-specific chemical products and debris combination.

6. If all the coatings are assumed to fail, justify why this large additional debris loading would not increase the analyzed amount of chemical effects, or add another unanalyzed chemical product.

Net Positive Suction Head / Loss-of-Coolant Accident

1. Section 2.3 of ALION-REP-TVA-2739-02, Revision 0, notes that the maximum containment sump temperature used to establish the available net positive suction head (NPSH) for the containment spray pumps during the recirculation phase was 190°F. Please provide the temperature used to establish the available NPSH for the residual heat removal (RHR) pumps during the recirculation phase, and justify if it is different from that used for the spray pumps during recirculation.

2. Please summarize the methodology and assumptions used to determine the maximum sump pool water temperature at the initiation of sump recirculation. Please justify if there is a deviation of this temperature from the calculated maximum containment temperature following a LOCA. If such calculation assumptions were used to maximize containment pressure, please explain the effect of such assumptions on containment temperature.

3. Please provide copies of the following calculation reports referenced in Section 2.5 of ALION-REP-TVA-2739-02, Revision 0:

   - N2-72-4001, R-15 - Containment Spray System
   - N3-74-4001, R12 - RHR System
   - WBN calculation EPM-RCP-120291 Revision 2, Containment Spray Pump Net Positive Head (NPSH) Calculation.
   - Westinghouse calculation FSDA-C-597 dated 11/6/94 - RHR Pump NPSH.

Debris Transport

1. Please provide ALION's FLOW-3D Version 9 executable and the corresponding input deck for the WBN analysis.

Downstream Effects (Core)

These questions refer to the WBN downstream effects calculations found in calculation CN-CSA-05-36, Fuel Evaluation:

1. Page 5 states that a fiber bed of less than 0.125 inch at the core inlet is acceptable. Page 40 states that a 7-foot head loss is predicted for a 1/8-inch fiber bed. What head loss would be produced at the core inlet following a large cold leg break? Please explain and justify whether adequate flow to the core would be provided with this head loss.

2. Page 7 states that 95 percent of fibrous material would be trapped in the bottom fuel nozzle and that the remaining 5 percent is assumed to be returned to the sump. This assumption is stated to be based on the similarity of the dimensions of the flow path through the sump screen and the dimensions through the screen at the bottom of the fuel.

   a. Please provide drawings of the fuel element inlet screens showing the dimensions of the flow path into the fuel.

   b. Provide comparisons of the dimensions of the sump screen holes to the debris screen at the inlet at the fuel elements.

3. Page 10 lists the volume concentration for 3M fiberglass passing through the sump screens as 2.351e-3 and the total fibrous concentration to be 2.559e-3. Page 5 of calculation CN-CSA-05-14 lists the fibrous concentration passing through the sump screens as 5 parts per million. Please relate these quantities.

4. Page 10 states that decay heat is based on American Nuclear Society (ANS) Standards 79 with 2σ. Since this is a LOCA calculation, please explain why the decay heat was not calculated using ANS Standard 71 + 20 percent to be consistent with Appendix K to *Title 10 Code of Federal Regulations* Part 50.

5. Page 17 shows that following a hot leg break, the fiber bed at the core inlet will exceed the 1/8-inch acceptance criterion within the first hour of recirculation. Please explain the effect of this condition on the core. Describe alternate flow paths for water to reach the core. Describe the transport and deposition of debris through these alternate flow paths.

6. The staff plans to perform audit calculations using the TRACE code to evaluate flow of water to the core through alternate flow paths in the event that the core inlet becomes blocked. Please provide the staff with the location and dimensions of any alternate flow paths through which water could reach the core under these circumstances. Provide the height of flow holes above the bottom of the core as well as their radial distribution about the core periphery.

7. Pages 18 and 19 show the depletion of fibrous material in the recirculating water for hot and cold leg breaks. A range of 97 percent to 95 percent depletion on the sump screens and a range of 95 percent to 50 percent depletion on the fuel screens is assumed. The depletion fraction is assumed to remain constant with time for each cycle as the recirculating water passes the screens. Please explain whether a fiber so short or a particle so small that it can pass through the sump screen and the fuel inlet screens once, will also pass through the sump screens and fuel inlet screens for sequent recirculation passes. Please justify your assumptions.

8. Pages 36 and 37 state that the fuel assembly support grids typically have flow dimensions of 0.04 to 0.115 inches. How do these dimensions compare with those of the WBN fuel? Page 37 further states that the support grids may cause a fiber bed to form across a given elevation to resemble a bed forming across a flat plate. Please explain how the trapping of debris within the support grids and the resulting effect on core heat transfer has been evaluated for WBN . In particular, consider the possibility that a layer of debris and steam forms between a fuel rod and the adjacent support grid so as to prevent water from contacting the fuel rod surface within the support grid. Please explain whether excessive local temperatures would be encountered in this scenario.

9. Pages 43 through 47 evaluate the potential of particulate material such as reflective metal fragments, concrete, latent containment debris and paint chips to flow into the core. It is generally concluded that this material will not reach the core, but will settle out in the lower plenum of the reactor vessel. Please provide an evaluation of the potential to clog the core inlet due to filling the lower reactor vessel with a volume of debris.

10. Page 43 refers to recent internal studies using disk-like particulates of various shapes with a specific gravity of 1.6. These studies were reported to have shown that particulates having a characteristic length of about 70 mils and thickness of 5 mils or greater would settle out in a reactor vessel lower plenum. Please provide documentation for this study describing the test apparatus and procedures. What vertical velocities were used?

11. Page 47 states that coating debris no larger than 0.02 inch are expected to be transported through the fuel. Although this statement may be true for hot leg breaks, it would not be true for large cold leg breaks where the boiling process would cause this material to congregate in the core. Please provide the results of an evaluation of the effect of paint debris on core boiling heat transfer, including the effect of reaction

products from the mix of chemicals which would be concentrated in the core by the boiling process following a cold leg break. The effect of the high-radiation field within the core on the chemical and physical nature of the mixture within the core needs to be considered. The potential for heat transfer loss from a chemical film that might form or be plated out by the boiling process needs to be evaluated. Please justify that adequate heat transfer will be maintained during the long-term cooling period.

12. Please provide an evaluation of the concentration of various materials that would occur following a large cold leg break under the conditions that water enters the bottom of the core and is boiled leaving all dissolved and suspended material behind. Consider that hot leg injection begins at 3 hours after the accident. Consider all the constituents within the ECCS water including boric acid, containment spray buffering agents, paint and fibrous debris.

    a. Provide graphs showing the concentration of each constituent as a function of time.

    b. Concentration of material within the reactor core will depend on the water volume that is assumed to be available for mixing. Since the core will be boiling at low pressure it will be in a highly voided condition as will the upper plenum. Please provide and justify the values used for core void fraction and upper plenum void fraction used in the concentration analysis. Provide justification for the fraction of the lower plenum volume, which is included, as well as for any other contribution to the total mixing volume.

    c. Provide the flow rates into the reactor system as a function of time during cold leg recirculation and during hot leg recirculation.

    d. Provide and justify the concentrations flowing into the reactor core as a function of time for each constituent in the ECCS water for both cold leg and hot leg recirculation. Consider boric acid, containment spray buffering solution, paint debris, and fibrous debris.

13. Following the initiation of hot leg recirculation, material which passes through the sump screen will be available to flow to the reactor core from the top. Please provide a comparison of flow restrictions at the top of the core including the fuel elements to that of the sump screens.

Head Loss Testing

1. Please provide the Sequoyah head loss test report that may provide validation that the paint chips would not have transported in the WBN tests had the flow velocities been more prototypical.

2. Please provide the paint chip specification parameters used in the cell floor drain analyses, specifically the floor tumbling velocity and the settling velocity for the turbulence model.

3. Please provide an evaluation of the 3M fiber glass insulation to justify why other fiber surrogate material can be used to represent the 3M fiber glass in the head loss test.

Downstream Effects (Component)

1. Please provide the downstream component hardware change plan, design and completion report.

2. Chemical Considerations

   a). During the ICET, in certain chemical environments such as sodium tetraborate, precipitates formed as the solution cooled from the 140°F test temperature. These products could interact with other downstream debris to cause clogging in narrow passages of downstream components such as valves and pump internals, or affect internal surfaces of heat exchangers or the reactor vessel. Describe your evaluation of potential downstream effects related to interaction with chemical products and the criteria used to determine that performance of downstream components is acceptable for your plant-specific chemical products and debris combination.

   b). Explain how the interaction of downstream chemical effects combined with debris will be evaluated.

3. Throttle Valves

   a). The TVA response to NRC GL 2004-02 dated September 1, 2005, indicated that an updated evaluation will be performed following final selection of strainer design and that the conclusions will be provided in a supplemental response. Describe the approach, including testing program, and schedule to finalize throttle valve positions/openings.

   b). Explain how NRC Information Notice 96-27, and the recent NRC Throttle Valve Testing (NUREG/CR-6902), when available, will be considered in the throttle valve evaluation.

4. Methodology

   a). The TVA response to GL 2004-02 dated September 1, 2005, indicated that the evaluation of downstream effects is consistent with the Westinghouse Commercial Atomic Power (WCAP) Report, WCAP-16406-P, and during the audit the licensee confirmed that they are not taking any exceptions to the WCAP-16406-P methodology. The NRC staff has outstanding questions (NRC letter dated October 27, 2005) on the WCAP-16406-P methodology, and has recently been requested by the Westinghouse Owners Group to formally review WCAP-16406-P as a topical report. Explain how you plan to address comments that result in a revision or addendum to the methodology for topics such as:

      - Validation of potential non-conservative assumptions,

- Conservatism to account for uncertainties,
- Wear rates correlated to testing data,
- Debris adhesion to solid surfaces, and
- Downstream matting effect.

Sump Structure

1. Please provide the strainer final design and structure analyses report. If it is not available now, please indicate when it will be available.

Appendix IV Licensee’s Response to Staff’s RAIs

Appendix IV WBN Planned Sump Modifications (White Paper Submitted by Licensees)

Modifications to Containment Sump Strainer (DCN 51940)

The Residual Heat Removal (RHR) containment sump is located in the containment floor below the refueling canal. To prevent debris from entering the sump, an outer trash rack covered with 1/4-inch mesh screen is provided on each side of the sump inlet. The trash racks extend from the reactor shield wall to the divider wall from floor to ceiling. Connecting the two trash racks is a horizontal grating located one foot below the ceiling to eliminate vortexing. Between the two containment sump outer trash racks is the containment sump suction pit. This pit is surrounded by a six-inch high curb which is used to prevent sediment from entering the pit. Atop the six-inch curb is a metal cruciform which serves to assist in vortex suppression. A fine mesh (1/4-inch) screen located in the containment sump suction pit provides additional filtering and is used to divide the sump into two suction volumes.

DCN 51940 removes the trash racks and cruciform; and installs a Sure-Flow® strainer. The horizontal grating (near the ceiling) and the fine mesh screen located in the sump both remain in place. The current WBN sump screen was designed to conform to the requirements of Regulatory Guide 1.82 R0. This RG assumed a non-mechanistic 50% screen blockage to account for post-LOCA debris in the sump pool. The design of the new strainer was based on a mechanistic debris generation and transport analysis performed by ALION and testing specific to WBN. This type of analysis was mandated by NRC GL 04-02 and the methodology used was based on NEI 04-07 which is endorsed by the NRC. The new strainer has an available flow area of 4600 ft^2 compared to the current screen area of approximately 200 ft^2. The new strainer openings are 0.085 inches compared to the 0.25 inch mesh for the current configuration. The current screens have a flat vertical configuration where the Sure-Flow® strainer is an advanced configuration to be much more resistant to potential blockage when compared to a flat configuration.

The mechanistic analysis in conjunction with a walkdown determined the type and amount of debris expected during accident conditions. This was input into a transport analysis to determine the amount of debris expected at the strainers. This input was then used to calculate the expected head loss under the calculated debris load. This was also used to determine the weight of the debris expected to be on the strainer. This weight was then used to qualify the structure for all conditions. The debris transport analysis was also used as input to the test procedures to ensure that the strainer tests simulated accident conditions.

The strainers along with the Emergency Core Cooling System (ECCS- including RHR, Safety Injection (SI), and Chemical and Volume Control System (CVCS)) and Containment Spray (CS) pumps help mitigate the consequences of the following accidents: all LOCAs, rupture of a Control Rod Drive Mechanism causing a Rod Cluster Control Assembly ejection accident, and secondary side pipe breaks inside the containment. The flow area and design of the strainers ensure that pressure drop across the strainer is sufficiently low and that adequate NPSH margin is available for the RHR and CS pumps. The diameter of the strainer holes ensures that any debris that can pass through the strainer will not cause blockage or excessive wear to components in the ECCS flow path or the containment spray system. This includes pumps, valves, nozzles, and the fuel. This is a passive component and the only failure mode is structural failure. The strainer assembly is designed specifically for WBN and will provide both debris filtering and vortex suppression.

Modifications to CVCS System (DCN 52057)

During review of impacts associated with the containment sump strainer modification (reference DCN 51940), it was determined that the throttling valves (1-THV-63-582 through -585) on the Charging Injection Line, formerly the Boron Injection Line, were throttled to a barely open position (3/4 turns open or less).

The limiting valve has a clearance of approximately 0.04″, which is less than the 0.085″ hole diameter of the replacement containment sump strainer. Thus the potential exists that during recirculation mode, debris that is small enough to pass through the containment sump strainer could be large enough to block one or more of these valves.

These valves are required for balancing the flow in the 4 Cold Leg Injection lines and to prevent Centrifugal Charging Pump (CCP) runout during injection and recirculation modes. Therefore, it is necessary to set the valves more open to increase the clearance while maintaining CCP runout protection.

Flow element 1-FE-63-170 is located upstream of the THVs, in the 4″ common header. The flow element measures the total injection line flow rate upstream of the Boron Injection Tank (BIT). DCN 52057 will replace the orifice plate with one that produces a higher pressure drop (i.e., smaller bore diameter), thus increasing system resistance through the cold leg charging injection line header. This will allow the throttle valves to be set further open thus increasing the clearance between the valve disc and seat while maintaining adequate system resistance to prevent CCP runout. The flow element FE-63-170 is located in the safety injection path, rather than the normal charging line, and therefore, resizing the orifice has no impact on the function of the CVCS during normal plant operation.

Due to the increased pressure drop across the orifice plate, the flow transmitter, 1-FT-63-170, will also be replaced. The new transmitter has a 10-50ma output which is the same as the existing transmitter's output; therefore, the existing flow indicator in the main control room does not require replacement.

The minimum turns open for the THVs was determined from data from the valve drawing, vendor information, and DCN 51940. From the valve drawing, the full open to full closed range is 1.62 inches. The vendor supplied the number of turns to full open as 9.5 turns and the valve seat and disc angle of 30°. The clearance per turn can be calculated as follows:

$$\boxed{\sin(30) * \frac{1.62in}{9.5turns} = 0.085 {}^{in}\!/_{turn}}$$

From DCN 51940, the maximum strainer hole diameter is 0.085 inches. Therefore, the minimum turns open for each THV is 1 turn. For conservatism, 1.5 turns has been considered the minimum turns open.

Westinghouse was contracted to update the Watts Bar ECCS flow model from the obsolete PEGISYS code to the current FLOMAP code. The new model was optimized using the latest set of Watts Bar test data. This updated flow model was then used to size the plate-type orifice to be installed at 1-FE-63-170 (includes hole size, plate thickness, and cavitation check). A drawing, containing fabrication details for the plate-type orifice was provided. Westinghouse also performed the calculations necessary to determine the instrumentation span for the associated flow transmitter. In addition, the ECCS Analysis Report was revised to reflect this change.