ENCLOSURE 5

APP-GW- GLR-079, Revision 5

"AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA"

(Non-Proprietary)

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I. INTRODUCTION

This technical report provides the information for closing the following Combined Operating License (COL) Information Item from APP-GW-GL-700, AP1000 Design Control Document (DCD), Revision 15:

COL Information Item	Design Control Document Section and Title	Description
6.3-2 Verification of Containment Resident Particulate Debris Characteristics	6.3.8.2 Verification of Water Sources for Long Term Recirculation Cooling Following a LOCA	The Combined License applicants referencing the AP1000 will perform an evaluation consistent with Regulatory Guide 1.82, revision 3, and subsequently approved NRC guidance, to demonstrate that adequate long-term core cooling is available considering debris resulting from a LOCA together with debris that exists before a LOCA. As discussed in DCD subsection 6.3.2.2.7.1, a LOCA in the AP1000 does not generate fibrous debris due to damage to insulation or other materials included in the AP1000 design. The evaluation will consider resident fibers and particles that could be present considering the plant design, location, and containment cleanliness program. The determination of the characteristics of such resident debris will be based on sample measurements from operating plants. The evaluation will also consider the potential for the generation of chemical debris (precipitants). The potential to generate such debris will be determined considering the materials used inside the AP1000 containment, the post-accident water chemistry of the AP1000, and the applicable research/testing.

In addition, this technical report presents an additional requirement to COL Information Item 6.3-1, shown here as it currently appears in DCD Revision 15:

COL Information Item	Design Control Document Section and Title	Description
6.3-1 Containment Cleanliness Program	6.3.8.1 Containment Cleanliness Program	The Combined License applicants referencing the AP1000 will address preparation of a program to limit the amount of debris that might be left in the containment following refueling and maintenance outages. The cleanliness program will limit the storage of outage materials (such as temporary scaffolding and tools) inside containment during power operation consistent with COL item 6.3.8.2.

The additional requirement is that the containment cleanliness program must provide cleanliness conditions consistent with the conditions used for this evaluation.

Based on this report, the NRC should consider the above COL Information Item closure to be acceptable and generally applicable to COL applications referencing the AP1000 design certification.

This technical report has been updated to include information from the following three sources:

1. Head loss testing that was done specifically for AP1000.
2. A downstream effects evaluation of the impact on the Passive Core Cooling System (PXS) equipment.
3. A downstream effects evaluation of the chemical deposition on the fuel following a LOCA.

Specific Containment Recirculation and In-Containment Refueling Water Storage Tank (IRWST) screen design information is contained in Technical Report 147 (Reference 2). The head loss test results are reported in WCAP-16914-P (Reference 9).

II. REFERENCES

1. Nuclear Regulatory Commission Regulatory Guide 1.82, Rev.3, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," November 2003
2. APP-GW-GLN-147, Revision 2, Technical Report 147, "AP1000 Containment Recirculation and IRWST Screen Design," February 2008
3. Nuclear Regulatory Commission Generic Letter GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," September 2004
4. NEI 02-01, Rev. 1, "Condition Assessment Guidelines: Debris Sources Inside PWR Containments," September 2002
5. NEI 04-07, Revision 0, "Pressurized Water Reactor Sump Performance Evaluation Methodology," December 2004
6. NUREG-1793, "Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design," September 2004
7. WCAP-16530-NP, Revision 0, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," February 7, 2006
8. NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," October 1995
9. WCAP-16914-NP, Revision 2, "Evaluation of Debris Loading Head Loss Tests for AP1000 Recirculation Screens and In-containment Refueling Water Storage Tank Screens," March 2008
10. WCAP-16914-NP, Revision 2, "Evaluation of Debris Loading Head Loss Tests for AP1000 Recirculation Screens and In Containment Refueling Water Storage Tank Screens," July 2009
11. WCAP-16406-P, Revision 1, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191," September 2007
12. U.S. Nuclear Regulatory Commission Safety Evaluation on WCAP-16406-P, Revision 1, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191," September 2007
13. WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," June 2007
14. APP-GW-GLE-002, Revision 4, "Impacts to the AP1000 DCD to Address Generic Safety Issue (GSI)-191," March 2008
15. NEI 04-07, Revision 0, "Pressurized Water Reactor Sump Performance Evaluation Methodology," December 2004
16. WCAP-17028-NP, Revision 2, "Evaluation of Debris Loading Head Loss Experiments Across AP1000 Fuel Assemblies During Post-Accident Recirculation," February 2009
17. WCAP-17028-NP, Revision 2, "Evaluation of Debris Loading Head Loss Tests for AP1000 Fuel Assemblies During Loss of Coolant Accidents," July 2009
18. "Thermal Conductivity of Wet Fabrics," Saburo Naka and Yoshinobu Kamata, Members, TMSJ, Journal of the Textile Machinery Society of Japan, Transaction, Vol. 29, No. 7, T100-106 (1976)
19. APP-PXS-GLR-001, Revision 2, "Impact on AP1000 Post-LOCA Long Term Cooling of Postulated Containment Sump Debris," May 2009.
20. NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology", Revision 0, Volume 1.
21. NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology", Revision 0, Volume 2, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02, Revision 0," December 2004.

22. APP-GW-GL-700, AP1000 Design Control Document, Revision 17.

III. TECHNICAL BACKGROUND

The AP1000 Nuclear Power Plant uses natural recirculation for cooling the core following a loss of coolant accident (LOCA). This capability of the AP1000 plant is presented in the design control document (DCD).

The containment recirculation sump for the AP1000 is the loop compartment. Screens are provided in strategic areas of the loop compartment to remove debris that might migrate with the water in containment and adversely affect core cooling. Accordingly, it must be assured that the screens themselves are not susceptible to plugging.

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There are three major sections of this report. The first section describes the AP1000 post-LOCA screen performance evaluation. The second section describes the head loss testing that was performed specifically for the AP1000. The final section describes the "downstream effects" calculations that were performed for AP1000. Two different evaluations were performed. The first described the "ex-vessel" effects, i.e., those that occur in the piping and valves of AP1000's long term recirculation flow path. The second evaluated the "in-vessel" effects and determined the amount of chemical deposition that can occur on the fuel rods during long term core cooling.

IV. AP1000 SCREEN DESIGN

The AP1000 has two Containment Recirculation Screens and two IRWST Screens. Consistent with the response of the nuclear industry to NRC guidance on the evaluation of sump screens, the AP1000 screen sizes have been made significantly larger. This increase is judged to be prudent because of the standardized approach for the AP1000 design, the potential for additional industry testing and regulatory guidance, and the reduced impact of incorporating larger screens at this time.

The AP1000 screen designs have complex geometries which provide greater screen areas in a given volume and which allow the screens to tolerate larger debris loads with acceptable head losses; the design of these screens is described in detail in Reference 2.

V. AP1000 POST-LOCA SCREEN DEBRIS EVALUATION

Introduction

The AP1000 containment building is designed both to contain radioactive material releases and to facilitate long term core cooling in the event of a LOCA. Water discharged from a break is collected in the lower portion of the containment for recirculation to the core by the PXS as described in DCD Section 6.3.2.1.3. Steam is also condensed on the containment vessel and drains back into the in-containment refueling water storage tank (IRWST). The IRWST has screens that protect the inlets to discharge lines that drain this water back into the RCS as described in DCD Section 6.3.2.1.3. The AP1000 Containment Recirculation Screens and IRWST screens protect the flow paths and components of the PXS from debris that is generated by a postulated pipe break and any debris that is being transported in the recirculating water.

The NRC identified its concern regarding maintaining adequate long-term core cooling in Generic Safety Issue 191 (GSI-191) "Assessment of Debris Accumulation on PWR Sump Performance" and Generic Letter (GL) 2004-02 (Reference 3), issued in September 2004, identified actions that utilities must take to address the sump blockage issue. The NRC position is that plants must be able to demonstrate that debris transported to the sump screen or into the reactor coolant system (RCS) after a LOCA will not lead to unacceptable head loss for the recirculating flow. For the AP1000, this requirement is interpreted as demonstrating that debris transported to containment recirculation screens, IRWST screens, or fuel assemblies will not significantly impede flow through the PXS and will not adversely affect the long-term operation of the PXS.

Applicability to the AP1000 Design

The AP1000 design minimizes the potential for a LOCA to generate debris that might challenge the recirculation flow path:

- Because passive safety systems are used and because there is no containment spray system used during a design basis accident (DBA) LOCA, the recirculation flow velocities are low, thus minimizing the potential for debris transport. The AP1000 does have a non-safety containment spray capability (injection only) which is provided for use in a severe accident. This capability is manually actuated (requiring a locked closed manual valve to be opened). Operating procedures prevent its use during a DBA.
- The flow velocities have been reduced further by the increase in face area of the screens (approximately 55% larger for containment recirculation).
- There is no fibrous debris generated by the LOCA blowdown.
  - Metal reflective insulation (MRI), which contains no fibrous material, is used on components that may be subjected to jet impingement loads; MRI is not transported to the AP1000 Containment Recirculation Screens with these low flow rates.
  - Other sources of fibrous debris that might be generated post LOCA include fire barriers and HVAC filters. Such sources are required to be located outside the zone of influence (ZOI) and above the maximum containment flood level during recirculation conditions.
- Other insulation inside containment outside the ZOI is jacketed or not submerged (below the maximum containment flood level during recirculation conditions).
- Protective plates, described in detail in Reference 2, guard the Containment Recirculation Screens against coatings and other debris from falling onto or just in front of the Containment Recirculation Screens and being transported to the screens. Coatings applied to structures or to engineered components are required to have a minimum density (≥100 lbm/ft^3) such that if they become detached they will settle out and not be transported to the AP1000 screens. Inorganic zinc (IOZ) applied to components in the containment is required to be safety – Service Level I.
- The coatings located within a LOCA jet impingement will be assumed to fail according to the following criteria:

The spherical equivalent radius of the zone of influence (ZOI) used by AP1000 for generation of coatings debris is:

Coating	Spherical Radius
For untopcoated inorganic zinc (IOZ)	5 x Break Diameter (5D)
For epoxy coatings	4 x Break Diameter (4D)

Applying this ZOI criteria and by comparison of existing plants the amount of coatings assumed to fail within the LOCA ZOI for AP1000 is conservatively estimated to be 50 pounds of a combination of epoxy and IOZ.

- Other potential sources of transportable material, such as caulking, signs, or equipment tags installed inside the containment below the maximum flood level or where there is sufficient water flow to transport these components are designed so that they do not produce debris that will be transported to the containment recirculation screens, IRWST screens, or into a cold leg LOCA or direct vessel injection (DVI) break location that is submerged during recirculation. Tags and signs in these locations are made of materials that are dense enough that they would not be transported to these screens.
- Screen area is exceptionally large to provide for the collection of debris on the screens without impacting recirculation flow.
- The materials that might corrode and produce large quantities of chemical precipitates have been greatly reduced. The amount of aluminum located inside containment that is located below the post-LOCA flood-up level is limited to 60 pounds. Note that there are some larger sources of aluminum located below the flood level; however, they are enclosed in stainless steel or titanium such that the aluminum is not susceptible to the post accident containment fluids.

Three sources of potential debris are therefore evaluated for impact to the AP1000 recirculation flow path. These sources are:

1. Latent containment debris - Latent containment debris, or resident containment debris as it is sometimes called, is dirt, dust, lint, and other miscellaneous materials that might be present inside containment at the initiation of a LOCA. The concern is that latent debris might be present in large enough quantities to collect on screen-like surfaces and inhibit flow through them.
2. ZOI coatings - Coatings located within the ZOI of a LOCA are assumed to fail as fines (small particles) and to transport to the screens or a flooded break.
3. Post-accident chemical effects - Post-accident chemical effects are the result of containment sump fluid reacting chemically with materials inside containment and producing chemical products (precipitants). The concern is that chemical products might be generated in sufficient quantities to collect on screen-like surfaces or on fiber beds and challenge their ability to pass flow.

The following is an evaluation of both the latent containment debris and chemical products that may be present inside the AP1000 containment in the unlikely event of a LOCA.

Evaluation Approach

The evaluation was performed in two steps:

1. [

   ]a,c A limit on the amount of ZOI coating fines has been established using information from operating plants.

2. The post-accident chemical products were estimated using a tool generated by the PWR Owners Group and design features and materials of the AP1000.

The following summarizes the evaluations performed for each of the above steps.

Latent Containment Debris Evaluation

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- Specific consideration of "resident" debris - both fiber-form and particulate debris that accumulates on surfaces during plant construction, testing, and operations.
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- The percentage of the total resident debris that is fiber was determined by laboratory analysis of debris taken from four plants and test results showing the debris tolerance of the AP1000 fuel assembly.
- The potential for the generation of chemical debris (precipitants).
- A containment cleanliness program that limits the types and amounts of resident debris in the AP1000. This report adds that the containment cleanliness program must limit resident debris to be consistent with this evaluation.

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Because AP1000 uses MRI insulation systems or a suitable equivalent, it is expected that the AP1000 fibrous debris would be a small fraction of the total latent containment debris. For conservatism, the amount of latent containment debris defined for the AP1000 is based on the containment debris found in operating plant walkdown data.

Operating PWRs have performed walkdowns in order to determine the amount of latent debris that may exist in their containment as a part of Generic Letter 2004-02 'Supplemental Responses and Close-Out' responses. This information is summarized in Table 1 and has been evaluated for its applicability to the AP1000. Several factors were considered, including the size of the containment and the type of insulation used inside containment.

Table 1 – Operating PWR Latent Debris Amounts

			Total Latent debris (lb)	
Plant	Dominant Insulation	Containment ID (ft)	Walkdown	Analysis
ANO	RMI	116	122.4	150.0
BVPS 1/2	?	126	159.0	?
		126	184.0	?
Byron 1/2	RMI	140	67.3	150.0
		140	124.6	150.0
Braidwood 1/2	RMI	140	126.0	150.0
		140	72.8	150.0
Calvert Cliffs	?	130	150.0	?
Catawba	High fiber / Replace	127	90.0	200.0
Comanche	?	135	91.0	200.0
DCPP	Low fiber / RMI	140	60.0	100.0
Farley	Low fiber	130	125.0	200.0
Ginna	High fiber	105	77.0	100.0
Kewaunee	Low fiber / RMI	105	11.3	100.0
McGuire 1/2	High fiber	125	140.0	200.0
		125	90.0	200.0
Palo Verde 1/2/3	RMI	146	101.2	200.0
		146	119.2	200.0
		146	105.8	200.0
Point Beach 1/2	High fiber	105	19.0	150.0
		105	30.0	150.0
Prairie Island	Low fiber / RMI	105	30.2	?
Salem	High fiber	140	33.0	200.0
San Onofre	RMI	150	155.0	200.0
Seabrook	High fiber	140	40.7	200.0
Sequoyah	RMI	125	24.5	200.0
South Texas	RMI	150	160.0	200.0
St Lucie	High fiber	120	67.4	134.7
Surrey 1/2	?	126	121.0	121.0
		126	51.0	121.0
Turkey Point 3/4	High fiber	116	77.2	77.2
		116	154.4	154.4
Vogtle	High fiber	140	60.0	120.0
Fort Calhoun	?	110	15.7	159.0
		Averages	89.9	161

Latent Containment Debris, Containment Size Evaluation – It is considered possible that larger containments might have more latent debris. Table 1 lists the containment inside diameter which is taken as a figure of merit for the containment size. The containment IDs vary from 105 feet to 150 feet. The total amount of latent debris reported for each of these plants is plotted against their ID. Figure 1 shows this plot. The figure shows a large amount of plant-to-plant variation for each containment size. It appears that other factors, possibly variations in the utility cleanliness programs / practices, are of more importance than containment size.

However, it is noted that there does seem to be a slight dependency of containment size as shown with the trend line displayed on the figure. As shown on Table 1, the average for all these plants is about 90 pounds of latent debris. The trend line indicates the latent debris varies from about 60 pounds for the smallest containments (105-foot ID) to about 120 pounds for the largest containments (150-foot ID). The AP1000 has a 130-foot ID containment which the trend lines indicates would have about 92 pounds, which is close to the average for all of the containments.

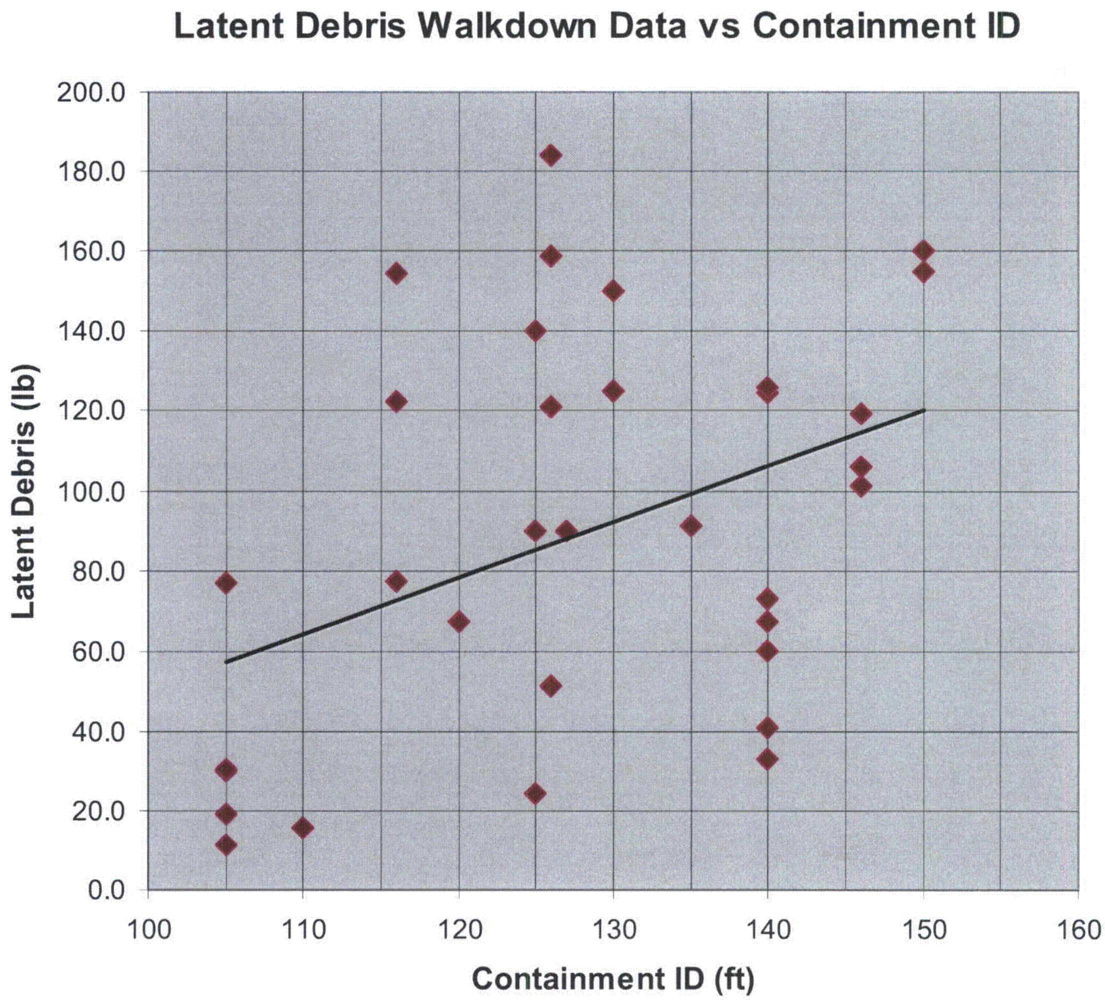

Figure 1- Operating PWR Latent Debris vs Containment Size

Latent Containment Debris Insulation Type Evaluation – It is possible that the type of insulation used inside containment might affect the amount of debris because of the possibility of generating some latent debris as insulation is removed and re-installed during shutdown maintenance. Table 1 lists the dominant insulation used inside containment. For 7 of the plants, this information is not listed. 15 plants are indicated to be low fiber and 12 are indicated to be high fiber. The average for the low fiber plants is 94 pounds and the average for the high fiber plants is 73 pounds. It appears that other factors, possibly variations in the utility cleanliness programs / practices, are more important than the type of insulation used in containment.

Total Latent Debris Amount for AP1000 - The conclusions from the evaluation of this walkdown data are:

- Plants can maintain low total amounts of latent debris
  - Average total amount is 90 pounds
  - 8 plants have less than 50 pounds
- The licensing commitment for these plants is
  - 17 plants use less than 200 pounds
  - 15 plants use 150 pounds or less
- The latent debris walkdown data is applicable to the AP1000
  - The containment size and type of insulation used do not obviate the use of the data on the AP1000

As a result of this evaluation, the AP1000 will assume that the containment may have as much as 130 pounds of latent debris inside containment; additional coating fines from the ZOI will be added as discussed below.

ZOI Coating Fines – For current operating plants coatings composed of IOZ within a sphere of diameter equal to 5 ID of the broken pipe will fail as fines (small particles) and as a result will transport along with the latent debris. Also, epoxy coatings within a sphere of diameter equal to 4 ID of the broken pipe will be assumed to detach and add to the total latent debris.

- With an epoxy coating thickness of 6 mils and a dry film density of 125 lb/ft^3, there would be 31.7 lb of epoxy debris from a CL pipe with ID of 22 inches.
- The amount of IOZ is approximated differently than the epoxy because the amount of IOZ allowed in the AP1000 (other than the containment vessel) is being limited to hot surfaces on components (where epoxy coatings are not practical). As a result, it is assumed that the amount of IOZ is 10 lb.
- The total amount of coating debris inside the ZOI is then 31.7 lb + 10 lb = 41.7 lb. This amount is conservatively assumed to be 50 pounds.

This amount of ZOI coating fines will increase the total debris in containment to 180 pounds, considering the 130 lb of from latent debris.

Amount of Latent Fiber - The data provided in NUREG/CR-6877, "Characterization and Head-Loss Testing of Latent Debris from Pressurized-Water-Reactor Containment Buildings", supports the position that the amount of latent fiber that is found in operating plants that have performed latent debris walkdowns is small, as opposed to the generic 15% provided in the SER on NEI 04-07. Both NUREG/CR-6877, and the data in the Generic Letter 2004-02, "Supplemental Responses and Close-Out", support the fact that the mass of latent debris calculated for the AP1000 (APP-PXS-M3C-053, Revision 0) is in line with debris masses found and reported in operating plants.

Using the data provided in Table 2 of NUREG/CR-6877, it is seen that 3 of the 4 plants evaluated in the manner described in the NEI 04-07 SER have less than 7.5 percent fiber in their latent debris totals. The data in table 2 of NUREG/CR-6877 illustrates that the average fibrous debris load of the four plants is 7 % and two of the four plants had less than 4 % fiber. Of 34 plants sampled for responses to Generic Letter 2004-02, "Supplemental Responses and Close-Out", only one has proposed a fiber content less than 15%. This plant performed a debris characterization per the NEI 04-07 SER and concluded that an appropriate latent fiber fraction should be 2.7%. Observations from other plant walkdowns included statements such as "dust with no fiber", "visual inspection showed very little fiber content", and "visual examination of the debris showed very little fiber", further indicating that the assumption of 15% latent fiber is extremely conservative.

The amount of fiber proposed for the AP1000 [

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Table 2 – Operating PWR Latent Debris Fiber Concentration

	Plant A		Plant B		Plant C		Plant D	
NUREG/CR-6877								
Particle	5.06 g	83%	2479 g	90.8%	14.77 g	95%	151.2 g	93.3%
Fiber	1.04 g	17%	252 g	9.2%	0.77 g	5%	10.88 g	6.7%
Total	6.1 g	100%	2731 g	100%	15.54 g	100%	162.08 g	100%
NUREG/CR-6877								
Particle	5.06 g	69%	2479 g	74.2%	14.77 g	52%	151.2 g	55.2%
Fiber	1.04 g	14%	252 g	7.5%	0.77 g	3%	10.88 g	4.0%
Other*	1.25 g	17%	611 g	18.3%	12.74 g	45%	111.93 g	40.8%
Total	7.35 g	100%	3342 g	100%	28.28 g	100%	274.01 g	100%

*Los Alamos removed larger / heavier particles from the plant samples in their work for NUREG/CR-6877 because they thought they would not transport. This debris (OTHER) is shown added in the lower set of values. Separating out such debris is not anticipated to be done by the utilities; it also does not reduce the amount of fibers, only the percentage.

Latent Debris Transport

Debris present on the various containment surfaces and components can be transported within the AP1000 containment by different mechanisms including, immersion in a pool of slowly-moving water, jetting of steam/water mixtures expelled through the break, wetting from liquid drops (caused by condensation and not by containment spray) falling from the containment dome (center region) and water film flowing down the containment walls during passive containment cooling system (PCS) operation. It is important to note that, during an accident, the majority of condensation is returned to the IRWST via filming on the walls and not through drops from the dome onto the operating deck. For different postulated break locations, the total mass of latent containment debris divides into three categories: debris that can migrate to the Containment Recirculation Screens, debris that can migrate to the IRWST Screens, and debris that does not transport to either set of screens. It is noted that the Westinghouse AP1000 design differs from the current PWR designs in that there is no containment spray that can be used during a LOCA.

In order to provide a simple, bounding set of conditions for evaluating the transport of debris to the AP1000 screens, the following conservative assumptions are made:

- All of the latent debris located inside containment is assumed to transport and none is assumed to settle out. Several different cases are considered that provide the maximum debris transport to the different screens / core, as follows
    - Max CR screen case: CR screen 100%, break 0%, IRWST 0%
    - Max CR screen bypass case: CR screen 10%, break 90%, IRWST 0%
    - Max IRWST screen case: CR screen 50%, break 0%, IRWST 50%
- 100% of the total latent debris located inside the AP1000 containment is assumed to be transported to the containment recirculation screens.
- 90% of the debris that could transport to the containment recirculation screens is assumed to be able to be transported into the RCS through a flooded LOCA break. This split in debris is based on an analysis of how much recirculation flow returns to the RCS through the break and through the PXS recirculation lines. Details of this analysis are provided below.
- 50% of the total latent debris located inside the AP1000 containment is assumed to be able to be transported to the IRWST screens. This assumption is considered very conservative because :
    - The IRWST is a closed tank and the only way for latent debris to be transported into the tank is

via the IRWST gutter. During normal plant operation, the gutter drains to the normal containment sump and not into the IRWST.

- The IRWST gutter is designed to return steam condensate flowing down the containment shell to the IRWST in an accident. The vertical surface of the containment shell will have a relatively light load of debris.
- The IRWST gutter is located at the operating deck elevation and much of the latent debris will be located below this elevation and therefore cannot be transported to the gutter.
- For the most part, latent debris located on the operating deck will be transported down to the lower parts of the containment and not into the gutter. Reasons for this are:
  - The operating deck is flat.
  - There is a several inch high lip around the operating deck that prevents water lying on the operating deck from draining to the gutter.
  - The operating deck has many openings that allow water on the deck to spill down to the lower parts of the containment. The edges of these openings do not have lips.
  - Some latent debris could be transported to the gutter by the discharge of flow from a break located above the operating deck. Such a break would only affect a small portion of the total operating deck area.

The industry has provided guidance in Reference 5 for the selection of break locations within a PWR and the selections effect on debris generation and composition. Westinghouse has reviewed Reference 5 and determined that, considering the design features of the AP1000 and the conservative transport assumptions made above, this reference is not applicable to the AP1000. It should be noted that many of the criteria in Reference 5 are intended to determine the break locations that produce limiting amounts and compositions of debris that can be generated and transported to the screens. The situation is different for the AP1000 because of its design.

In the AP1000, different LOCA break locations do not generate different amounts and compositions of debris to be transported to the screens. The reason for this is that AP1000 does not use the types of insulation (such as fiberglass) or other materials that can be damaged by a LOCA jet and transported to the screens. Therefore, debris generated by LOCA jets is not a consideration in this analysis, as stated in NUREG-1793 (Reference 6). AP1000 uses MRI insulation or suitable equivalent in the locations where insulation may be damaged by LOCA jets. The density of the MRI material combined with the low recirculation velocities ensures that any debris generated by the damage of this insulation material will settle to the containment floor and not be transported to the screens or to a flooded break.

The requirement to use high density coatings inside containment, together with the other AP1000 features (including low water flows / velocities and shield plates over the recirculation screens), results in no coating debris being transported to the screens.

The requirement to use signs and tags made from high density materials results in none of this debris being transported to the screens.

Debris Split (Break vs PXS) – For the AP1000, some LOCA break locations will be flooded during long term recirculation operation because of the relatively high containment flood-up elevation. During such operation, a portion of the recirculation flow will enter the RCS through the break and will not be screened. The limiting break is a DECL LOCA.

The determination of the percentage of the debris that might be transported into the RCS without screening by the containment recirculation screens is determined by integrating the relative recirculation flows through the break and the PXS. Table 3 illustrates the process used to determine the flow split. This table shows the break flow back into the RCS and the PXS recirculation flow as a function of time as well as their integration. The event analyzed is a DVI LOCA in the loop compartment.

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For LOCA scenarios the DECLG in the loop compartment is the most limiting with regards to debris loading on the fuel assemblies (debris loading on the screens have already been tested and analyzed which showed the DP was acceptable). Item i.) provides the explanation for the CL flow split and how it is bounding with regards to debris transport:

i.) For a DECLB, the flow split between the PXS recirculation flow path and through a double ended rupture of a cold leg pipe is calculated to result in less than 85% of the flow through the CL and 15% through the PXS. This split is calculated with the containment at its final flooded level. As is observed for DVI LOCAs, recirculation starts through the break before the PXS recirculation begins, so that the integrated split over the time required to pass one containment volume through the RCS is a few percentage points higher. So the integrated flow split for a DECLB will be 90% through the break and 10% through the PXS.

ii.) For a hot leg breaks up to and including a DEHLB, the location of the break makes these breaks less limiting. There are several reason for this including:

- Such a break location will not result in spill of IRWST injection so that the start of recirculation will be later, with lower decay heat.
- The flow that enters the core through the downcomer from the DVI injection lines will tend to exit through the HLs as well as the ADS lines. There could also be inflow through the HL break especially for the break of a HL itself. This would result in a counter-current flow path within the HL due to the competing effects of inflow from the break and outflow from the core. Any debris brought into the RCS through the HL would tend to be deposited in the top portion of the fuel assemblies which would not create the concentrated debris bed formation seen in the tests conducted with debris entering the bottom of the fuel. In any case, the PXS injection flow path would still be available to support core cooling.
- For the core, a HL LOCA will potentially allow fiber to be transported into the RCS but in this case it will at worst settle on top of the fuel assembly. In this sequence, no fiber will be transported to the core inlet and challenge the head loss across the core. For this reason the added particles that could be generated by a HL LOCA (as compared to a CL LOCA) would not increase the limiting FA debris head loss.
- The containment recirculation screens could see extra ZOI generated particle debris however, the surface area of these screens is so large that the addition of some extra particles will not cause its head loss to be greater than the test results which were based on the IRWST screen conditions. The following provides a comparison of the limiting CR and IRWST screen conditions.

	CR	IRWST
Number Screens Operating	2	1
Surface Area, Total (ft2)	5000	500
Debris Load, Fiber (lb) / (ft2/lb)	6.6 / 758	3.3 / 151
, Particles (lb) / (ft2/lb)	173 / 29	173 / 2.9
, Chemicals (lb) / (ft2/lb)	57 / 88	57 / 8.8
Flow Rate (gpm)	827	410
(ft2/gpm)	6.0	1.2

  From this comparison, it can be seen that the increase in particles caused by a HL LOCA as compared to a CL LOCA would still leave the IRWST with a larger particle load per area and the other parameters (fibers, chemicals and flows) would still make the IRWST screen head loss larger than the CR screens. The extra ZOI generated particles will not result in the CR screen head loss being increased above the test results.
- The IRWST screens will have less fiber transported to them than the assumed 50% fiber because a HL LOCA will wash less of the operating deck to the gutter / IRWST than a LOCA such as one on top of the Pressurizer. In addition, both IRWST screens will be operable in a HL LOCA such that the fiber load per screen will be less than ½ of what has been tested. The extra ZOI generated coating particles will not affect the limiting IRWST screen head loss.

Based on the previous discussions, Table 4 shows the latent debris amounts for the AP1000 for the case where maximum debris is transported to the core. This table lists the total latent debris, how much is fiber, and how much is transported where. This table is based on the limiting LOCA case, a DECL LOCA. The total latent debris in containment is assumed to be 130 lbs based on the results of previous plant walkdown data (Table 1). It is assumed that 100% of latent debris is transported (does stay in place and does not settle). The composition of the latent debris is listed in Table 4 as 130 lbm particulate debris with 6.6 lbm of that being fiber (distribution of particulates and fiber is described above in Table 2). In addition to the latent debris, there is 50 lb of ZOI coating fines, all of which are assumed to transport. 100% of latent debris and ZOI coating fines are assumed to transfer to the loop compartments. With the limiting flow split for the DECL LOCA of 90%/10% the amount of fiber transported to the core is 6 lbm.

Table 4 – AP1000 Maximum Fiber and Particle Debris Amounts

	Fiber	Particle	Total
Latent Debris	6.6 lb	123.4 lb	130 lb
ZOI Coating Fines	0.0 lb	50.0 lb	50 lb
Total Latent and ZOI	6.6 lb	173.6 lb	180 lb
Transported	100%	100%	100%
Settles	0%	0%	0%
Transported to Loop Compartment	100%	100%	100%
Transported to Core	90%	100% (1)	-
Transported to IRWST	50%	100% (1)	-

Note (1) 100% of the particles eventually transport to the core and to the IRWST because the particles are assumed to pass through the CR screen since there may not be a fiber bed across it.

Post-Accident Chemical Effects

A consideration in evaluating the effects of the debris transported to the sump after a LOCA is the chemical products which may form in the post-LOCA sump environment. Materials present in containment may dissolve or corrode when exposed to the reactor coolant. This reaction would result in oxide particulate corrosion products and the potential for the formation of precipitants due to changes in temperature and reactions with other dissolved materials. These chemical products could become another source of debris loading and impact sump screen performance and recirculation flow.

An analysis was performed to determine the type and quantity of chemical precipitants which may form in the post-LOCA recirculation fluid for the AP1000 design. The analysis evaluated these post-LOCA chemical effects using the methodology developed in WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191" (Reference 7). The purpose of the bench testing and calculation methods documented in WCAP-16530-NP was to characterize the type and quantity of precipitates formed using a chemical model evaluation, and to support the downstream effects evaluation using the chemical precipitates predicted in the chemical effects model. These data and methods have been used to evaluate post-accident chemical affects and support sump screen performance testing for operating PWRs. These data and methods are applicable to the AP1000 for the following reasons:

1. The base chemical composition of the containment materials in the AP1000 was determined to be consistent with the classification groups listed in WCAP-16530-NP.
2. The sump temperature transient is within the bench test temperature range of 140 °F to 270 °F for more than 99.5% of the 30 days evaluated.
3. The sump pH transient for the AP1000 is within the range of 4.1 to 12.0 evaluated in WCAP-16530-NP.
4. The buffering agent for the PXS in the AP1000 plant is trisodium phosphate dodecahydrate (TSP), which was one of the buffering agents included in the bench testing.

Therefore, considering the above, the data and calculation methods described in WCAP-16530-NP are clearly applicable to the AP1000 design.

Table 5 lists the predicted precipitants for the AP1000 chemical model evaluation using conservative containment material amounts. The results have been calculated using the minimum post-accident recirculation volume of coolant for the AP1000. Table 5 also lists the chemical precipitants in terms of a mass concentration using the minimum recirculation water volume.

Table 5: AP1000 Predicted Chemical Precipitate Formation

Precipitants	kg	lbm	ppm
$NaAlSi_3O_8$	1.54	3.4	0.65
AlOOH	23.60	51.99	9.97
$Ca_3(PO_4)_2$	0.52	1.14	0.22

Note that the AP1000 has several features that significantly reduce the amounts of materials that could contribute to the formation of chemical precipitants. The AP1000 containment has little concrete that can come in contact with the post-accident water as a result of the use of structural steel module construction. The only identified aluminum in the AP1000 containment is in the excore detectors. These detectors are enclosed in stainless steel so that post-accident containment water will not circulate against the aluminum. The AP1000 DCD Tier 1 Table 2.2.3 item 8c) xiv) requires inspection of the excore detectors and ensures that they are enclosed in stainless steel or titanium. In addition, the amount of exposed aluminum that is located below the maximum containment flood-up level is limited to 60 pounds. This requirement is contained in DCD subsection 6.1.1.4.

A sensitivity evaluation was also performed to determine the additional precipitant generation that might occur from zinc materials in containment being exposed to the sump liquid. This sensitivity evaluation determined that less than 1 kg of zinc is released into solution when the limiting case with contingency was considered. This amount is relatively small and is determined to be negligible to the overall precipitant generation.

This evaluation shows that the potential amount of chemical precipitants available in the AP1000 containment is significantly lower than in current plants.

VI. AP1000 HEAD LOSS TESTING

Head loss experiments were conducted for AP1000 as part of the response for the AP1000 design to GSI-191 and Generic Letter (GL) 2004-02 (Reference 3). References 9, 10, 16, and 17 provide a detailed description of the head loss testing. The performance of the Containment Recirculation Screens and an AP1000 fuel assembly was demonstrated under a bounding set of AP1000 specific debris loadings that included chemical effects. This debris loading included particulates, fibrous materials, and chemical precipitates that may form in the containment water pool. As discussed in section V, AP1000 has reduced the potential for a LOCA to generate debris that will challenge long-term core cooling.

Screen Testing Discussion

This report documents recirculation screen head loss experiments that were conducted for AP1000 as part of the response for the AP1000 design to Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR Sump Performance" and Generic Letter (GL) 2004-02 (Reference 3). The performance of the recirculation screens must be confirmed and demonstrated under debris loading conditions (including chemical effects) that address the bounding set of AP1000 specific debris loadings. Debris loadings for the containment screens include particulates and fibrous materials, as well as chemical precipitates that may form in the containment water pool.

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The data from this test program demonstrates the ability of the Recirculation screens and the In-Containment Refueling Water Storage Tank screens to successfully perform their design functions under debris loading conditions expected for the AP1000 following a postulated LOCA. Four head loss tests were performed that investigated a spectrum of debris inventories, debris staging, chemical effects, and flow rates. The design basis test demonstrates that the head loss across the screens is acceptable when considering the design basis latent and chemical debris load. The chemical surrogate was mixed outside of the flume and added to the flume water following the WCAP-16530-NP-A approved method for particulate generation.

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

The results of the design basis test demonstrate that, for the latent debris and post-accident chemical debris load included in the test program, the head loss is less than that which has been shown to be allowable for acceptable long term core cooling.

Screen Flashing Concerns

For the CR screens the water level at the time recirculation is initiated is well above the top of the screen such that the minimum pressure downstream will be sub-cooled and flashing will not occur.

The following discussion addresses concerns regarding the pressure drop across the IRWST screen being greater than the submergence of the IRWST screen, so flashing may be expected per item 14 of "NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing."

The water in the IRWST is normally subcooled throughout most of a LOCA transient. For larger LOCAs the PRHR HX does not operate very long, if any, prior to ADS actuation and ADS 1/2/3 does not fully saturate the IRWST. In addition, in the long term the steam condensate returning from the containment shell is subcooled by 30 to 40F. However, for smaller LOCAs (< 1") there will be extended operation of the PRHR HX (for ≥ 2 hours) prior to the actuation of ADS which can result in heatup of the IRWST water to saturation. Even in this case, the IRWST water will not remain saturated during long term recirculation because the subcooled steam condensate returning to the IRWST through the gutter will reduce the IRWST temperature. Therefore for smaller LOCAs, it is possible for the water in the IRWST to be saturated for a limited period of time such that it is necessary to consider the potential of steaming of the saturated water as it flows through the IRWST screen.

The minimum water level in the IRWST occurs during recirculation operation. This level can vary from several feet above the top of the IRWST screen to just at the top of the screen. In addition, after a couple weeks the IRWST level might drop lower (below the top of the IRWST screens) if the three unflooded rooms (two PXS rooms and the CVS room) eventually flood due to leakage. The following considers two different water level conditions that bound the operation over these different levels. One case is with the water level below the top of the IRWST screen and another is with the water just above the IRWST screen top.

Case 1

With a saturated water level below the top of the screen enclosure, there will be no flashing since the flow will be in an open flume and not in a closed pipe - in this case the water level will decrease behind the screen relative to the level in front of the screen (as it does in the screen tests). The limiting case is considered to be with a level just below the top of the top of the screen early after start of recirculation with the highest passive system recirculation flow rates through the IRWST screen; this flow is higher than would occur in the wall-to-wall case because of the higher decay heat.

Case 2

For this case it is assumed that saturated water is at a level just above the top of the screen enclosure. This level seals off the air/steam atmosphere of the IRWST gas space from entering into the top of the screen enclosure and allowing the level behind the screen to decrease. In this situation steam bubbles might form in the top 14" of the screen since that is the maximum pressure loss that can occur in across the screen. Bubbles that form in this part of the screen will tend to rise up to the surface and escape into the IRWST.

A calculation was made of the steam bubble rise velocity and the water down flow velocity. This calculation shows that the steam bubble rise velocity is much higher than the water down flow velocity such that the bubbles will not be entrained into the PXS injection flow. Instead they will rise up the top of the IRWST screen and leak out into the IRWST gas space.

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

- The minimum bubble size is equal to the screen hole size (1/16") and the bubbles are assumed not to agglomerate. This bubble size is appropriate for this low velocity and DP.
- The lowest level where bubbles can occur is 7.5" below the top of the screen. This assumption is based on:
  - The water in the IRWST is saturated
  - The water level is at the top of the IRWST screen
  - The flow rate is equal to the recirculation flow rate at the start of recirculation (410 gpm), the maximum IRWST screen flow with passive system operation as shown in WCAP-16914-P, in Table 5.2.
  - The maximum screen head loss is 7.5" of water with the maximum debris loading; this pressure loss is calculated from a head loss of 14" of water at 75 lb/sec vs the 55 lb/sec at 7.5" loss. A flow squared relation is used because COBTA-TRAC uses that assumption.

The bubble rise velocity is calculated to be at least 15 cm/sec. This calculation is based on test data contained in "Bubbles, Drops, and Particles", R. Clift et al., Dover Publications, 2005 (Figure 7.3, "Terminal Velocity of Air Bubbles in Water at 20C).

The water flow is calculated at the lowest level behind the screen where steam bubbles might form. That level is 7.5" below the IRWST top. Since the screen is 50" high, the downward flow at this elevation will be 410 gpm * 7.5" / 50" = 62 gpm. The downward flow area behind the screen is the distance between the back of the screen (1' 10") times the width of the screen (7' 8") = 14.1 ft2. The downward flow velocity is then 0.30 cm/sec.

This water flow is much lower than the steam bubble rise velocity of 15 cm/sec and as a result the steam bubbles will not be drawn into the IRWST injection line.

Screen Testing Summary

The testing performed for the AP1000 Containment Recirculation screen design demonstrates that the collection of debris during post LOCA recirculation operation on the pocket-design screens of the Containment Recirculation screens and the In-Containment Refueling Water Storage Tank screens will not develop head losses that will challenge long-term core cooling or the ability to maintain a coolable core geometry under the expected AP1000 debris loading conditions.

Note that these tests were performed with debris loads based on a total of 150 lbm of debris (particles and fibers). Since the total debris load in the plant has been increased to 180 lbm, additional screen tests will be performed to demonstrate acceptable performance with the increased amount of debris. The results of the additional confirmatory tests will be delineated in WCAP-16914 Rev. 3.

Fuel Assembly Testing Discussion

Westinghouse has performed a series of experiments to quantify the effect of resident debris and containment chemical effects on the head loss across the fuel assemblies of an AP1000 during a postulated loss of coolant accident (LOCA). This report documents the fuel assembly head loss experiments that were conducted for the AP1000 design in consideration of Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR Sump Performance" (Reference 1).

The experiments, performed at the Westinghouse Science and Technology Center (STC) in Churchill, PA, used a fuel assembly design that is consistent with the fuel assembly design described in Section 4.2.2.2 of the AP1000 Design Certification Document (DCD) (Reference 2). The flow rates and debris loadings were selected to conservatively bound those conditions expected following a postulated LOCA for the AP1000 as defined in Reference 2. The debris load for the AP1000, both particulate and fiber as well as chemical effects, has been significantly reduced by design.

The data from this test program demonstrates the ability of the AP1000 to provide assurance of long term core cooling under debris loading conditions expected for the AP1000 following a postulated LOCA. Sixteen head loss experiments were performed that investigated a spectrum of fibrous and particulate debris loads and chemical effects. Data from these experiments indicate that the design basis amount of debris that might exist in an AP1000 containment resulted in [

]^{a,c} In addition, the data from all of the experiments that investigated sensitivities to [

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The experiments demonstrate that with the expected AP1000 fibrous and particulate debris loading conditions, long term core cooling is assured. That is, head losses due to fibrous and particulate debris collection within the fuel assemblies will not challenge either long-term core cooling or the maintaining of a coolable core geometry.

As noted above, these experiments demonstrate that the AP1000 design provides for [ ]^{a,c} of fibrous and particulate debris within fuel assemblies with respect to long term core cooling. The long-term cooling analysis of the AP1000 (Reference 3) has shown that the plant can withstand at [ ]^{a,c} of head loss across the core, higher than the experimental results, and still provide adequate core cooling.

Fuel Assembly Testing Summary

The testing performed for the AP1000 fuel assembly demonstrates that the collection of debris during post LOCA recirculation operation will not develop head losses that will challenge long-term core cooling or maintaining a coolable core geometry under the expected AP1000 debris loading conditions.

Note that these tests were performed with debris loads based on a total of 150 lb of debris (particles and fibers). Since the total debris load in the plant has been increased to 180 lb, additional fuel assembly tests will be performed to demonstrate acceptable performance with the increased amount of debris. These tests will also address uncertainties related to the how the flow rates change in the AP1000 as the debris head loss builds up. The results of the additional confirmatory tests will be delineated in WCAP-17028 Rev. 3.

VII. AP1000 DOWNSTREAM EFFECTS EVALUATION

The term "downstream effects" refers to effects of debris that enters the RCS directly or is ingested through the recirculation screens on systems, structures and components located downstream of the recirculation screens. These effects are evaluated for operating plants to support closure of GSI-191 using data and methods developed by the PWR Owners Group. Two evaluations were performed for the AP1000 downstream effects evaluation:

- The first evaluation describes the effects of debris on the system and components outside the core. This evaluation looks specifically at the disruption of the long term core cooling flow path (outside the core) by debris. A separate part of this evaluation addressed the operation of the non-safety shutdown cooling system.
- The second downstream effects evaluation performed for AP1000 conservatively calculated the amount of chemical deposition that can occur on the fuel rods following a LOCA and subsequent boiling in the core. The AP1000 is unique in the fact that throughout a LOCA the ADS stage 4 lines will vent significant quantities of water as well as steam. This venting of water significantly reduces the concentration of chemicals (boron, TSP, etc.) in the core. AP1000 DCD Tier 2 Section 15.6.5.4C.4 captures this effect as it has been applied to boron buildup following a LOCA. As a result of this characteristic, hot leg recirculation is not provided in the AP1000.

Ex-Vessel Downstream Effects Evaluation Method

The data and methods used to evaluate ex-vessel downstream effects are outlined in Revision 1 of WCAP-16406-P (Reference 11). The evaluation methods identified in WCAP-16406-P Revision 1 that are applicable to long-term core cooling recirculation flow paths associated with the AP1000 passive core cooling system design include:

- The fuel blockage evaluation as described in Section 5. This particular downstream effects evaluation method addresses the core evaluation from the NRC comment.
- Valve evaluations for plugging and erosive wear as described in Sections 7 and 8 and Appendix F. The screening criteria for valves that are identified in Revision 1 of WCAP-16406-P are applicable to valves in the long-term core cooling recirculation flow path of PWRs. Only the explosively actuated (squib) valves in the post-LOCA flow path are not covered by the screening criteria. Once the squib valves are open they exhibit, very closely, the characteristics of a standard gate valve.

Some AP1000 design features eliminate the need for downstream effects evaluations of components that are included in Revision 1 of WCAP-16406-P. Evaluations excluded by the AP1000 design include:

- Pump evaluations, including hydraulic performance, disaster bushing performance, and vibration analysis. There are no safety related pumps in the AP1000 passive core cooling flow paths to evaluate.
- Heat exchanger evaluations for both plugging and erosive wear. There are no safety related heat exchangers in the AP1000 passive core cooling flow paths.
- Orifice evaluations for plugging and erosive wear as described in Sections 7 and 8 and Appendix F. There are no orifices in the post-LOCA recirculation flow path of the AP1000 design.
- Settling of debris in instrumentation lines as described in Section 8. No instrumentation lines used in the AP1000 post-LOCA containment recirculation flow path design are required to support a safety related function.
- Containment Spray System (CSS). The AP1000 does not have a conventional CSS. The non-safety containment spray function is not permitted to be used during a DBA. Therefore, this system is excluded from consideration of the AP1000 design.

Thus, where applicable design features exist in the AP1000, the data and methods identified in Revision 1 of WCAP-16406-P are applied to evaluate ex-vessel downstream effects for the AP1000 design.

The Normal Residual Heat Removal System (RNS) is not a safety-related system, but may also be used to accomplish post-accident long-term core cooling at the discretion of the plant operators if the system and its components are operable; it is a redundant system that provides for "defense in depth" for long-term core cooling.

In the DCD Chapter 15 safety analysis, RNS operation is not assumed to be available post-accident because the system is not safety-related. Without RNS operation, the PXS provides the necessary core cooling using natural circulation driven by decay heat and hydrostatic pressure heads.

If the RNS is available, the RNS pumps can be used to inject / recirculate water into the RCS and provide cooling via heat exchangers. During this operation, containment isolation capability of the RNS lines is maintained.

As was done for the PXS, the screening criteria for pumps and valves identified in Revision 1 of WCAP-16406-P that are applicable to valves in the long-term core cooling recirculation flow path of PWRs were applied to the AP1000 RNS to address the performance of systems, structures, and components within the RNS in the presence of debris ingested into the RNS with the post-LOCA recirculating coolant when the RNS is assumed to be operating.

- Based upon the evaluation criteria of Reference 11, the majority of the valves used in the RNS met the screening criteria and required no further evaluation for wear, abrasion, erosion, and plugging. This evaluation demonstrated that the RNS containment isolation valves would not be susceptible to plugging or erosion damage that would prevent them from performing their containment isolation function should that become necessary during RNS operation. However, four of the AP1000 RNS valves utilized in the post-LOCA RNS recirculation required further plugging and wear evaluations. These evaluations showed that these four valves, throttle globe valves V006A/B and V008A/B, are not susceptible to plugging or failure by erosive wear, confirming that their RNS throttling function would not be compromised

- For the two RNS pumps, the effect of debris ingestion was evaluated on three aspects of operability including hydraulic performance, mechanical shaft seal assembly performance, and mechanical performance (vibration). The hydraulic and mechanical performances of the AP1000 RNS pumps were determined to not be affected by the recirculating sump debris. The mechanical shaft seal assembly performance evaluation resulted in a change to the procurement specification so that the RNS pumps' backup seal bushings use a more wear resistant material, such as bronze.

- The AP1000 RNS heat exchangers and orifices were evaluated for the effects of erosive wear for a mission time of 30 days. The erosive wear on these components was determined to be insufficient to affect the system performance. The smallest clearance found for the AP1000 heat exchangers and orifices is 0.620 inches for the heat exchangers; therefore, no blockage of the RNS flow paths is expected with the current sump screen hole size of 0.0625 inches.

- There is no instrumentation tubing or reactor vessel level instrumentation system (RVLIS) in the AP1000 RNS, so no evaluation for potential debris collection in either instrumentation tubing or RVLIS was performed. The RNS flow lines were evaluated for debris settlement and it was determined that the minimum flow through the RNS greatly exceeded the minimum flow that would allow settlement.

Ex-Vessel Downstream Effects Evaluation of AP1000 Recirculation Flow Paths

The evaluation included each valve and associated piping in the recirculation path of the PXS. The methodology and acceptance criteria used are described in WCAP-16406-P, Reference 11, consistently with the applicable amendments, limits, and conditions of the NRC SE on WCAP-16406-P, Reference 12.

The equipment in the post-LOCA flow path was identified using current P&IDs for the AP1000 PXS. The AP1000 PXS P&IDs show no pumps, heat exchangers, orifices, or spray nozzles in the PXS. Therefore, although included in the method of WCAP-16406-P, the evaluation performed for the AP1000 PXS does not address pumps, heat exchangers, orifices, spray nozzles, or instrumentation tubing because these components and features are not included in the design of the AP1000 PXS. The following two tables show the components that are in the AP1000 long term core cooling flow path. Table 7 describes the containment recirculation flow path and Table 8 describes the IRWST injection flow path.

Table 7: Containment Recirculation Flow Path				
	Description	Size and Schedule (Piping / Valves)	Minimum Diameter (inches)	Note
1	Recirc Screens	N/A	0.0625	
2	Cross-Over Duct	7" x 10" (Rectangle)	N/A	1
3	Recirculation Pipe	10" / 8" Sch 40S	10.02 / 7.981	2
4	Gate Valve	8"	≥ 5.1	3
5	Check Valve	8"	≥ 5.1	3
6	Squib Valve	8"	≥ 5.1	4
7	DVI Pipe	8" Sch 160	6.813	
8	Venturi	N/A-	4.00	5

Notes:

1. Two ducts connect the A and B screens each duct is 7" x 10".
2. The piping changes from 10" to 8" just before the containment recirculation squib valves in the PXS B subsystem.
3. The piping has two paths for each recirculation subsystem: each path travels through the following valves: check or gate, squib, gate, check, and squib.
4. A squib valve, when open, has characteristics similar to those of a standard straight through gate valve.
5. This venturi represents the smallest passage in the recirculation piping. The venturi is used to choke reverse flow during an RCS blowdown and has no flow limiting function during recirculation.

Table 8: IRWST Injection Flow Path				
	Description	Size and Schedule (Piping / Valves)	Minimum Diameter (inches)	Note
1	IRWST Screen	-	0.0625	
2	IRWST Injection Pipe	10" Sch 40S	10.020	1
3	Reducer	10" x 8"	7.981	1
4	IRWST Injection Pipe	8" Sch 40S	7.981	2
5	Gate Valve	8"	≥ 5.1	
6	Check Valve	8"	≥ 5.1	
7	Squib Valve	8"	≥ 5.1	3
8	DVI Pipe	8" Sch 160	6.813	2
9	Venturi	N/A	4.00	4

Notes

1. IRWST injection pipe begins as 10" schedule 40S and reduces into 8" schedule 40 pipe.
2. The piping changes from Sch 40S to 160 downstream of the squib valves. A squib valve, when open, has internal flow paths similar to those of a
3. standard gate valve.
4. This venturi represents the smallest passage in the recirculation

piping. The venturi is used to choke reverse flow during an RCS blowdown and has no flow limiting function during recirculation.

In order to apply erosive and abrasive wear rate models, the debris size and concentration was first assessed. Identification of the debris types indicates that the debris appears to be made up of mostly latent debris. The latent debris is mostly particulate material, with a small amount of fibrous debris. Although the AP1000 design precludes transport of coatings to the Containment Recirculation screens, a small amount of coatings debris was included in the mix for conservatism.

Each identified valve in the PXS was evaluated for plugging and wear against the applicable initial screening criteria in Reference 11. The PXS consists of open gate, check, and squib valves, all of which are greater than 1 inch in size based on their individual flow line diameters. Therefore, according to the initial screening criteria, the valves do not need further evaluation for plugging or wear. The squib valve design was not directly addressed in the screening criteria of Reference 11. However, the squib valves were treated as gate valves because this is the valve the squib valve most closely represents when activated.

All instrumentation sensors in the PXS recirculation lines are strapped to the outside of the piping. Therefore, there are no instrumentation tubes or sensing lines to evaluate for potential debris collection in the tubes or sensing lines. In addition, there is no reactor vessel level instrumentation system (RVLIS) or RVLIS-like system that is required to be operational post-LOCA for long-term core cooling. Therefore, no evaluation was needed.

For completeness, the potential debris collection in the PXS flow lines is evaluated. Based on the minimum flow rates for the PXS flow lines, it has been determined that the transverse velocity is sufficient to prevent debris settlement in the PXS flow lines. Therefore, blockage in PXS flow lines due to settle-out of debris is precluded.

In summary, the evaluation performed using the applicable methods and models in WCAP-16406-P (Reference 11) consistently with the applicable amendments, limits, and conditions of the associated NRC SE on the WCAP (Reference 12) demonstrates that the AP1000 PXS equipment utilized in post-LOCA recirculation is acceptable for the expected debris loading in the recirculating fluid resulting from a postulated LOCA.

Ex-Vessel Downstream Effects Evaluation of AP1000 Refueling Cavity Drain Lines

References 20 and 21 provide the methodology guidance to perform a baseline sump performance evaluation. The types of insulation found in the AP1000 containment dictate the direction in which the evaluation is performed. The AP1000 is a highly compartmentalized and insulated with RMI in the zone of influence (ZOI) and has two 6-inch drain connections (Figure 9.1-6 sheet 1, Reference 22) located in the refueling cavity. The drain line splits into two lines outside the cavity and separately penetrates the refueling cavity wall. Inside the refueling cavity, the lines end with a downward facing 90 degree elbow which prevents debris that might enter the cavity from falling right into the drain lines.

Section 3.4.3.2 of Reference 21 provides a discussion of the debris size distributions that have been used in various studies and specifies a two-size distribution for material inside the zone of influence (ZOI) of a postulated break for the baseline evaluation. These two size groups are small fines (< 4 inches) and large pieces (> 4 inches). Small fines are defined as any material that could transport through gratings, trash racks, and/or radiological protection fences by blowdown, containment sprays, or post-accident pool flows. Furthermore, small fines are assumed to be the basic constituent of the material for latent debris and coatings (i.e., individual fibers, particles, and pigments, respectively). Reference 20, Section 3.4.3.2, assumes the largest openings of the gratings, trash racks, or radiological protection fences to be less than a nominal 4 inches (less than 20 square inches total open area) and classifies the remaining material that cannot pass through gratings, trash racks, and radiological fences as large pieces.

Reference 21, Sections 3.6.3.1, 3.6.3.2, and 3.6.3.3, which address the highly compartmentalized, the mostly uncompartmentalized, and the ice condenser containments, respectively, primarily contain compartmental-specific debris transport assumptions. Table 3-4 of Reference 21 summarizes these assumptions for the small fines debris generated within the ZOI. The baseline guidance recommends that all debris generated outside the ZOI be treated as small fines debris that is subsequently transported to the sump screens (i.e., 100% transports to the sump pool and no transport into the inactive pools). The baseline guidance recommends the assumption that all of the large piece debris deposits onto the containment bottom floor where it stays. The Reference 20 guideline adopts the value of 75 percent for small fines and 25 percent for large pieces as the size distribution of any type of RMI inside a pipe break ZOI. For highly compartmentalized containments such as the AP1000, 25% of the RMI debris generated is large pieces and 75% of the RMI debris generated is in the form of small fines. 25% (~18% of the total RMI destroyed) of the small fines is assumed to be ejected to upper containment and 75% (~56% of the total RMI destroyed) of the small fines are deposited directly to the sump pool floor.

In-Vessel (Core) Downstream Effects Evaluation Method

With respect to downstream effects associated with the core, the potential for deposition of post-LOCA chemical products on the fuel cladding and the consequential effects on clad temperatures can be addressed using the methods developed and documented in WCAP-16793-NP (Reference 13). This evaluation method was developed to be generically applicable to all PWRs.

There is a concern that debris could also collect at the fuel assembly grids. The Nuclear Regulatory Commission (NRC) identified its concern regarding maintaining adequate long-term core cooling in GSI 191. Generic Letter (GL) 2004-02 (Reference 3), issued in September 2004, identified actions that utilities must take to address the sump screen blockage issue. The NRC's position is that plants must be able to demonstrate that debris transported to the sump screen after a LOCA will not lead to unacceptable head loss for the recirculation pumps, will not impede flow through the ECCS and CSS, and will not adversely affect the long-term operation of either the ECCS or the CSS.

To demonstrate acceptable AP1000 long term core cooling performance, an evaluation was performed to account for chemical reactions within the coolant that could lead to deposition of material within the core. The evaluation for the AP1000 accounted for the unique features of the AP1000 design. These features include those that significantly reduce the amounts of materials that could contribute to the formation of chemical precipitants, as well as the absence of containment spray during a LOCA or safety injection pumps to provide long term core cooling.

As noted in this report, the AP1000 has several features that significantly reduce the amounts of materials that could contribute to the formation of chemical precipitants. The AP1000 containment has little concrete that can come in contact with the post accident water as a result of the use of structural steel module construction. The only identified aluminum in the AP1000 containment is in the excore detectors. These detectors are enclosed in stainless steel so that post accident containment water will not circulate against the aluminum. Therefore, this mass of aluminum is excluded from the post-LOCA chemical reaction. However, for conservatism, a aluminum mass of 60 lbm is used in the post-LOCA chemical reactions.

The calculation method of the LOCADM spreadsheet is described in WCAP-16793 (Reference 13). The evaluation makes some simplifications to the required inputs that are conservative for this evaluation. These data and methods are applicable to the AP1000 for the following reasons:

- This evaluation effectively increases the aluminum surface area to conservatively account for the zinc release from galvanized steel. It is conservative to increase the aluminum amounts because the aluminum release rate is greater than that of any other material used in this evaluation. Although rate of core deposition for both aluminum and zinc are different, a bounding thermal conductivity for the chemical deposition on the fuel cladding is evaluated regardless of the material being deposited in the core.
- This evaluation uses what is called "The Pre-Filled Reactor and Sump Option". Use of this option assumes that the entire sump volume is present in the sump at time t = 0, precluding the need to specify individual break flow rates. This is also conservative, because modeling the sump as full at

the start of the transient allows the chemical reactions to begin at time t = 0 and provides for the calculation of a greater amount of precipitate deposition on the fuel.

- Although the AP1000 design precludes large amounts of aluminum from making contact with post accident containment recirculation fluids, a mass of 60 lbm of aluminum is used for conservatism.
- This evaluation uses a modified aluminum release method to satisfy NRC requirements in the draft Safety Evaluation prepared for WCAP-16793-NP. Including this requirement effectively doubles the release rate during the initial portion of the event as required by the NRC, yet holds fixed the total aluminum mass release. This is also conservative, because the release rate of aluminum is increased early in the transient when the deposition on the fuel is greatest due to high core decay heat rates and the boiling associated with the removal of that decay heat.
- This evaluation determines the impact of chemical precipitate deposition on fuel rods resulting from the formulation of chemical precipitates in the post-LOCA recirculation pool environment.

  The LOCADM calculation method conservatively assumes that all of the chemical precipitates generated in the post-LOCA environment are transported into the core and that the chemical precipitates produced can only be depleted via core deposition over the thirty day length of the calculation. The calculation conservatively assumes that there is no deposition of chemical precipitates anywhere else in the recirculation pool, such as on the recirculation screens.

  In addition to the chemical precipitates, the fibrous debris that may transport into the core are also considered in the LOCADM calculation. This consideration is done through a "bump-up" factor which adds crud buildup on the fuel related to the amount of fiber transported into the core. The bump-up factor in LOCADM is 'independent of the type, diameter, or length of the fiber' and independent of the source of the fiber whether it be screen pass-through or break bypass. The bump-up factor is set such that total mass of deposits on the core after 30 days is increased by the best estimate of the 'mass' of the fiber that may reach the core.

  It is conservative to use the "bump-up" factor that was developed for current operating plants to address the possibility that fiber glass debris may bypass the sump screens and be available for deposition on the fuel cladding.

  Including fibers in the AP1000 LOCADM evaluation provides for a plant-specific effect that is based on the screen design and debris mix of that plant. The application of the bump-up factor to the AP1000 is consistent with its application for current operating plants and accounts for fibrous material in the recirculating coolant that may reach the fuel. The bump-up factor was not established, and was not used, to account for additional chemicals added to the core inlet because of unfiltered flow through the break because those chemicals are already included in the calculation.

  The AP1000 plant design precludes the use of fiberglass insulation and therefore it does not have a source of post-accident generated fiberglass debris. A quantitative estimate of the effect of the latent fibrous debris on chemical deposit thickness and fuel temperature is accounted for in AP1000 LOCADM calculation by use of the bump-up factor applied to the initial debris inputs. The bump-up factor is set so that total release of chemical products over 30 days is increased by the estimate of the mass of the latent fibrous debris in the AP1000 containment. The use of the bump-up factor in the AP1000 LOCADM calculation is appropriate because, although the amount of fibrous and particulate debris is small and the fibrous component of that amount is smaller still, it is possible that some of the fibrous debris in the AP1000 containment may bypass the fuel bottom nozzle and protective grid and enter the core.

  The bump-up factor accounts for this postulated bypass of latent fibrous debris by increasing the mass of chemical precipitates that may be deposited on the fuel. In effect, the mass of latent fibrous debris bypass is treated as post-accident chemical precipitates for the purpose of evaluating deposition in the core. This allows the bypassed material to be deposited on the fuel in the same manner as the chemical reaction products with the same low thermal conductivity as those chemical reaction products.

The bump-up factor is implemented in the LOCADM calculation on a mass basis. The basis for the bump-up factor is the assumption that all of the latent fibrous debris mass will pass through the bottom nozzles and protective grids of the fuel and enter the core. To implement the bump-up, all materials that contribute to the formation of chemical precipitates are increased by a uniform percentage so that the resulting precipitates available for deposition have increased by approximately the amount of latent fibrous debris assumed for the AP1000. This conservative method is independent of the type, diameter, or length of the fiber.

Typical types of fibers that might be found inside a currently operating reactor containment building include fiberglass, cotton, nylon, polyester, and human hair. The thermal conductivity of dry natural fibers such as cotton (0.02 BTU/ft-h-°F) and manmade fibers such as nylon and polyester (0.144 and 0.13, BTU/ft-h-°F) is compromised when the fibers become saturated with water, as is the case in a post-LOCA environment. The thermal conductivity of these saturated fibers rises significantly, trending towards the value of water at the ambient conditions saturating the fibrous material (~0.40 BTU/ft-h-°F) (Reference 18). The conclusion is that these fibers have a heat conductivity when wet that is much higher than the heat conductivity used for the chemical scale in the LOCADM evaluation (0.11 BTU/ft-h-°F).

The latent fiber in the AP1000 containment may include a variety of fiber materials that may be longer and thicker than fiberglass fibers. Since the bottom nozzle and the protective grid present a limiting hole size similar to the six of the mesh holes in the recirculation screens, it is expected that the fiber capture capability of the bottom nozzle and the protective grid would allow fewer longer and thicker fibers to penetrate the "strainer" than the shorter thinner fibers.

Long fibers would tend to be captured and retained by the debris filter bottom nozzle and protective grid of the fuel located at the core entrance. Thus, the fuel design inhibits the passage of long fibers into the active core itself.

Short small diameter fibers are considered more conservative than the thick large diameter fibers that are the constituents of fibrous debris for the following reasons:

- A given fiber, regardless of diameter, has only one point of contact. NUREG/CR-6877 suggests that the diameter of latent fibrous debris is greater than that of fiberglass by as much as 2 to 1.
- A single fiber, in and of itself, will not impact heat transfer from the fuel. Therefore groups of fibers must be considered to evaluate their potential to impact heat transfer.

Consider first that the fibers configure themselves in a parallel orientation to the fuel rod with square or hexagonal packing (these are the most efficient packing configurations, allowing the least amount of space between fibers).

The packing ratio for these configurations will be equal to the ratio of "occupied" cross-sectional area to total cross-sectional area for a given configuration. As the fiber diameters increase, the area of unoccupied space must also increase. As the area of unoccupied space increases, the amount of water available to fill in the unoccupied space also increases, allowing for greater heat transfer. The larger the fiber diameter, the greater the interstitial free space, and the greater the heat transfer.

Longer, thicker fibers will tend to be trapped in the fuel assembly inlet nozzle and not be transported to the fuel rods. For smaller thinner fibers transported to the fuel rods, the best packing of the fibers would result in significant voids that would result in better heat transfer than the amount assumed in the LOCADM code.

- This evaluation accounts for the AP1000 plant design, which has automatic depressurization system (ADS) stage 4 valves in the hot-leg that, once actuated, vent significant quantities of water along with steam from the core to the containment throughout the LOCA event. This behavior was modeled in the LOCADM spreadsheet by defining core injection flow rates that exceeded the boiloff rate by an amount that was less then the amount calculated in the AP1000 long term core cooling accident analysis (DCD Tier 2 Section 15.6.5.4C). LOCADM tracks the chemical concentrations in the core region based on the relative water injection and steam/water venting.

In-Vessel (Core) Downstream Effects Evaluation of AP1000

The evaluation was performed with the LOCADM spreadsheet using AP1000 plant specific data. The purpose of this evaluation was to use the LOCADM spreadsheet to predict the growth of fuel cladding deposits and to determine the clad/oxide interface temperature that results from coolant impurities entering the core following a LOCA. Three scenarios were evaluated with LOCADM for the AP1000 design:

1. Maximum sump volume – maximum water volume results in lower concentrations of post-accident chemical products.
2. Minimum sump volume – minimum water volume results in higher concentrations of post-accident chemical products.
3. Minimum sump volume with fibrous debris "bump-up" – minimum water volume and implementation of a "bump-up" factor results in the highest concentration of post-accident chemical products.

Limiting for AP1000

The AP1000 is expected to have results similar to or less severe than those of operating plants with similar post-accident chemical loading, chemical concentrations, flow rates, and core power profile. The large amount of water carryover from the ADS stage 4 lines significantly reduces the chemical concentration buildup in the core relative to operating plants.

Acceptance Criteria

As noted in Section A4 of Reference 13, the stated acceptance criterion is that the maximum cladding temperature maintained during periods when the core is covered will not exceed a core average clad temperature of 800°F [426.7°C]. This acceptance basis is applied after the initial quench of the core and is consistent with the long-term core cooling requirements stated in 10 CFR 50.46 (b)(4) and 10 CFR 50.46 (b)(5)."

An additional acceptance criterion is to demonstrate that the total debris deposition on the fuel rods (oxide + crud + precipitate) is less than 50 mils [1270 μm]. This acceptance criterion is based on Reference 4, which states that:

"The 50 mil [1270 μm] thickness is the maximum acceptable deposition thickness before bridging of adjacent fuel rods by debris is predicted to occur."

The results of this evaluation are presented in Table 9 below and discussed in the following text.

Maximum sump volume

For the maximum sump water volume case, use of the LOCADM spreadsheet predicted a maximum LOCA scale buildup of 0.4858 mils (12.34 microns). When added to the pre-accident oxide thickness of 5.984 mils (152 microns) and pre-accident crud thickness of 5.512 mils (140 microns), this yields a total of 11.98 mils (304.34 microns). This predicted deposition is significantly less than the acceptance criteria of 50 mils (1270 microns).

Minimum sump volume

For the minimum sump water volume case, use of the LOCADM spreadsheet predicted a maximum LOCA scale thickness of 0.5578 mils (14.17 microns). When added to the pre-accident oxide thickness of 5.984 mils (152 microns) and pre-accident crud thickness of 5.512 mils (140 microns), this yields a total of 12.05 mils (306.17 microns). Again, this predicted deposition is significantly less than the acceptance criteria of 50 mils (1270 microns).

Limiting Case - Minimum sump volume with fibrous debris "bump-up"

For the minimum sump water volume case, the LOCADM spreadsheet was also run with increased quantities of debris – in accordance with the "bump-up factor" methodology described in Reference 13. For the limiting case, the LOCADM spreadsheet predicted a maximum LOCA scale thickness of 1.03 mils (26.19 microns). When added to the pre-accident oxide thickness of 5.984 mils (152 microns) and pre-accident crud thickness of 5.512 mils (140 microns), this yields a total of 12.53 mils (318.19 microns). Again, this predicted deposition is significantly less than the acceptance criteria of 50 mils (1270 microns).

For conservatism, the "bump-up factor" considered 22.5 pounds (12.5% of 180 pounds) of fibrous material and neglected any screen capture. The 22.5 pounds of latent fiber was uniformly distributed to each of the materials contributing to chemical precipitate generation. The bump-up factor had a minor impact on the total deposition thickness as shown in Table 9.

Cladding Temperatures

In all three cases evaluated, the maximum temperature calculated for the outside diameter (OD) of the fuel cladding at the onset of recirculation was 304. 23°F [151.24°C]. In all three cases evaluated, the temperature of the fuel clad OD was calculated to then decrease throughout the remainder of the event.

Table 9 – Results of All Cases

Case	LOCA Scale Thickness mils (microns)	Pre-Accident Deposition Thickness mils (microns)	Total Deposition Thickness mils (microns)	Max Clad Temperature °F [°C]
Maximum sump volume	0.4858 (12.34)	11.50 (292)	11.98 (304.34)	304.23 [151.24]
Minimum sump volume	0.5578 (14.17)	11.50 (292)	12.05 (306.17)	304.23 [151.24]
Minimum sump volume and "bump-up"	1.03 (26.19)	11.50 (292)	12.53 (318.19)	304.23 [151.24]

The LOCADM calculations performed for the AP1000 demonstrate that both acceptance criteria for long-term core cooling identified previously in this report are achieved. Specifically, for the three cases evaluated:

1. The maximum clad OD temperature calculated for the AP1000 of 304.23°F (151.24 °C) is significantly less than the acceptance value of 800°F (426.7 °C).
2. The total thickness of deposition calculated for the AP1000 fuel cladding is significantly less than the 50 mil (1270 μm) thickness at which bridging of deposited debris between adjacent fuel rods by debris is predicted to occur.

Thus, the conservative calculation of deposition of post-accident chemical products on the fuel clad surface does not challenge long-term core cooling for the AP1000 design.

VIII. REGULATORY IMPACT

Design Function

The changes to the DCD presented in Reference 14 do not represent an adverse change to the design function or to how design functions are performed or controlled. The changes to the DCD do not involve revising or replacing a DCD-described evaluation methodology, nor do they involve a test or experiment not described in the DCD. The DCD change does not require a license amendment per the criteria of VIII.B.5.b of Appendix D to 10CFR Part 52.

Severe Accident Change Criteria

The DCD changes do not result in a negative impact on features that mitigate severe accidents. There is therefore no increase in the probability or consequences of a severe accident.

Security

The closure of the COL Information Items will not alter barriers or alarms that control access to protected areas of the plant. The closure of the COL Information Items will not alter requirements for security personnel. Therefore, the closure of the COL Information Item does not have an adverse impact on the security assessment of the AP1000.