Westinghouse

Westinghouse Electric Company
Nuclear Power Plants
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
ATTENTION: Document Control Desk
Washington, D.C. 20555

Direct tel: 412-374-6206
Direct fax: 412-374-5005
e-mail: sisk1rb@westinghouse.com

Your ref: Docket No. 52-006
Our ref: DCP/NRC2443

April 22, 2009

Subject: AP1000 Response to Request for Additional Information (SRP 6)

Westinghouse is submitting a response to the NRC request for additional information (RAI) on SRP Section 6. This RAI response is submitted in support of the AP1000 Design Certification Amendment Application (Docket No. 52-006). The information included in this response is generic and is expected to apply to all COL applications referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application.

Enclosure 1 provides the response for the following RAI(s):

RAI-SRP6.2.2-SRSB-01 R1
RAI-SRP6.2.2-SRSB-02 R1
RAI-SRP6.2.2-SRSB-03 R1
RAI-SRP6.2.2-SRSB-04 R1
RAI-SRP6.2.2-SRSB-05 R1
RAI-SRP6.2.2-SRSB-07 R1
RAI-SRP6.2.2-SRSB-10 R1
RAI-SRP6.2.2-SRSB-11 R1
RAI-SRP6.2.2-SRSB-15 R1

Questions or requests for additional information related to the content and preparation of this response should be directed to Westinghouse. Please send copies of such questions or requests to the prospective applicants for combined licenses referencing the AP1000 Design Certification. A representative for each applicant is included on the cc: list of this letter.

Very truly yours,

D. A. Lindgren /FOR

Robert Sisk, Manager
Licensing and Customer Interface
Regulatory Affairs and Standardization

Enclosure

1. Response to Request for Additional Information on SRP Section 6

DO63
NRO

cc: D. Jaffe - U.S. NRC 1E
E. McKenna - U.S. NRC 1E
P. Donnelly - U.S. NRC 1E
C. Proctor - U.S. NRC 1E
T. Spink - TVA 1E
P. Hastings - Duke Power 1E
R. Kitchen - Progress Energy 1E
A. Monroe - SCANA 1E
P. Jacobs - Florida Power & Light 1E
C. Pierce - Southern Company 1E
E. Schmiech - Westinghouse 1E
G. Zinke - NuStart/Entergy 1E
R. Grumbir - NuStart 1E
D. Behnke - Westinghouse 1E

ENCLOSURE 1

Response to Request for Additional Information on SRP Section 6

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP6.2.2-SRSB-01
Revision: 1

Question (Revision 0):

In the AP1000 DCD Section 6.3.2.2.7.3, Westinghouse stated that:

> "When the recirculation lines initially open, the water level in the IRWST is higher than the containment water level and water flows from the IRWST backwards through the containment recirculation screen. This back flow tends to flush debris located close to the recirculation screens away from the screens."

The back flow of water through the recirculation screens may cause a significant amount of water to be injected into the sump cavity. Although this flow through both recirculation screens causes the materials to be flushed from the screens, the backflow could cause enough turbulence in the cavity to lift up the debris from the bottom of the cavity, which collects during the early part of the LOCA, and once the water flow reverses into the screens this debris is available to be collected on the screens.

a. Describe the potential for blockage with the addition of uplifted debris.
b. Identify whether or not the addition of the zinc coatings or the higher density epoxy coatings, that were assumed to be collected at the bottom of the cavity, provide a source of blockage to the screens.
c. Identify whether these coatings add to the chemical impurities that could enter the core region.

Additional Question (Revision 1):

The responses to SRP-6.2.2-SRSB-01 and SRP-6.2.2-SRSB-02 indicate that the back flow velocity through the containment recirculation screen to be 0.006 ft/sec and 0.0132 ft/sec, respectively. Explain the difference. What is the assumed flow area used in the calculation.

Westinghouse Response: (Revision 0 with Revision 1 markup)

a. The initial calculated reverse velocity is very low, ~~less than~~ranging from approximately 1560 to ~~650~~ 4600 gpm (3.48 to 10.25 ft^3/sec) depending on the conditions assumed. These maximum values are both based on the elevation corresponding to the IRWST switchover level of 112.56 ft and the containment water evaluation of 104.65 ft. at the time of switchover to containment recirculation. The 1560 gpm value is based on the conditions assumed in the DCD Chapter 15 long-term cooling analysis of one IRWST line injecting with maximum resistances. The 4600 gpm value assumes two lines injecting with minimum line resistances. The frontal face area of each recirculation screen is 105 ft^2 (ITAAC Table 2.2.3-4, item 8.C). These flow rates result in a velocity range of 0.0166 to 0.0488 ft/sec initially across the front face of the recirculation screens. ~~This flow rate results in a velocity of less than 0.006 ft/sec across the front face of the recirculation screen.~~ Note that the reverse flow is elevated 2 feet above the floor due to the curb that is located in front of the recirculation screens. All of the resident debris that is involved with post accident flows is assumed to be transported to the screens; none of this debris is assumed to settle out. As a result, the only debris that may be on the floor in front of the recirculation screens is MRI and high density coatings. This high density debris will not be uplifted by the very low velocity / elevated reverse flow through the recirculation screens.

b. The zinc coating material is elemental zinc having a density of 457 lbm/ft3. Due to the high density of the zinc coating material and the low velocity of flows in the reactor containment building pool, the zinc coatings will not transport to the recirculation screens.

   By the requirements of the DCD, epoxy coatings have a density of 105 lbm/ft3. Calculations of paint debris chip transport have been performed and demonstrate that chips of the size necessary to block the recirculation screens will not transport to the screens. These calculations are available for NRC review.

   Therefore, these coatings are not considered a source of blockage to flow through the recirculation screens.

c. The zinc and epoxy coatings used inside the AP1000 reactor containment building are the same Design Basis Accident Qualified (DBA-Qualified) coatings materials currently used inside reactor containment buildings of operating PWR's. The dissolution and leaching of DBA-Qualified coatings resulting in chemical impurities in the post-accident recirculation fluid was evaluated by the PWR Industry in WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191" and determined to not be subject to dissolution, and to be an insignificant source of chemical impurities .Therefore, these coatings are not a significant source of chemical impurities.

Design Control Document (DCD) Revision: None

PRA Revision: None

Technical Report (TR) Revision: None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP6.2.2-SRSB-02
Revision: 1

Question:

In TR 26, Revision 3, on page 8, in the "Applicability to the AP1000 Design" subsection, Westinghouse states that:

> "The flow velocities have been reduced further by the increase in face area of the screens (approximately 55% larger for containment recirculation)."

Since Westinghouse credits the low flow velocities in minimizing the potential for a LOCA to generate debris challenging the recirculation flow path, the staff requests additional information to assess the velocities during every phase of the transient.

Identify the calculated flow velocities through the IRWST screens (leading to the intact and broken DVI lines, respectively), the containment recirculation screens, and the reactor vessel during all phases of the transient including the reverse flow through the recirculation screens when the IRWST is switched to recirculation. For example, when recirculation flow starts, identify the velocity of the initial reverse flow through the recirculation screens and the velocity variation across the screens once all water has filled the recirculation sump cavity.

Additional Question:

The responses to SRP-6.2.2-SRSB-01 and SRP-6.2.2-SRSB-02 indicate that the back flow velocity through the containment recirculation screen to be 0.006 ft/sec and 0.0132 ft/sec, respectively. Explain the difference. What is the assumed flow area used in the calculation.

Westinghouse Response: < The original response has been revised as shown below to address the additional questions. >

The sensitivity study performed to evaluate effect of increased head loss caused by post accident debris was based on the DCD Chapter 15.6.5.4C analysis. This DCD case is a double ended DVI LOCA that results in flooding of PXS room B and reduces the final containment floodup level. The IRWST injection line associated with the faulted DVI line is assumed to open early in the event when the CMT connected to the faulted DVI line blows down to the ADS 4 actuation setpoint. This assumption is made to maximize the IRWST draindown flow rate and reduce the time when switch to recirculation occurs. When recirculation is actuated on a low IRWST level signal, it is assumed that the recirculation squib valves located in the flooded PXS room fail because they are not qualified to operate under water, this assumption minimizes the number of recirculation lines in operation. The recirculation squib valves located in the unflooded PXS room provide for recirculation; the limiting single failure is one ADS 4 squib valve. Note that the operating recirculation line draws water from both recirculation screens because the screens are cross connected. In the final long-term cooling configuration, water recirculates from the containment through one recirculation line and from PCS condensate that is collected and drained into the IRWST.

Each of the two IRWST injection lines are separated from each other and are connected to opposite sides of the tank. As described above IRWST flow into the intact DVI line is zero until the RCS pressure is significantly reduced. The flow through the IRWST line associated with the faulted DVI line starts as soon as the IRWST squibs open.

In the injection phase, the volumetric flow in the IRWST injection line associated with the intact DVI line reaches a maximum of 1260 gpm and decreases to the long term recirculation flow shown below as the IRWST drains. At this flow, the IRWST screen face velocity is 0.~~070~~ 14 ft/sec.

The IRWST spill flow (volumetric) through the broken DVI line reaches a maximum as soon as the IRWST injection valves open and decreases as the IRWST drains and the PXS valve room floods. The maximum initial flow in this line is 2700 gpm. This flow decreases quickly to 2220 gpm as the PXS valve room floods due to RCS blowdown and IRWST spill. The face velocit~~y~~ies in the IRWST screen at these flow rates ~~is~~are 0.~~150~~ 301 and 0.~~124~~ 245 ft/sec respectively.

The initial calculated reverse flow and velocity ranges from approximately 1560 to 4600 gpm (3.48 to 10.25 ft^3/sec) depending on the conditions assumed. These values are based on the elevation corresponding to the IRWST switchover level of 112.56 ft and the containment water elevation of 104.65 ft at the time of switchover to containment recirculation. The 1560 gpm value is based on the conditions assumed in the DCD Chapter 15 long term cooling analysis of one IRWST line injecting with maximum resistances. The 4600 gpm value assumes two lines injecting with minimum line resistances. The frontal face area of each recirculation screen is 105 ft^2 (ITAAC Table 2.2.3-4, item 8.C). This flow rate results in a velocity range of 0.0166 to 0.0488 ft/sec initially across the front face of the recirculation screens.
~~When the IRWST level has dropped to about 112 ft, the recirculation squib valves automatically open. At this time the IRWST level is about 6 ft above the containment water level which results in a brief period of flow from the IRWST into the containment. This flow rate will be less than 650 gpm and will flow through one recirculation line (associated with the intact DVI line) and through both recirculation screens. At this flow rate, the velocity through the front face of the recirculation screens is 0.0132 ft/sec.~~

During the long-term cooling analysis recirculation phase, flow from the IRWST maintains the water level in the PXS room such that it serves as a reservoir for the broken DVI line injection into the vessel. The IRWST level is maintained by steam condensate return from the IRWST gutter and back flow from the intact PXS recirculation line. The containment recirculation line connected to the intact DVI line provides flow to the reactor vessel through the intact DVI line as well as some flow back through the IRWST to the faulted DVI line.

The following table shows the calculated flow velocities through the IRWST screens, the containment recirculation screens, and the reactor vessel during the containment recirculation phase. Note that because of the cross-–connection between the two containment recirculation screens, both of these screens share the flow, which reduces the velocity. The IRWST screen flows and velocities listed below are for the screen associated with the faulted DVI line; the other IRWST screen sees a lower flow rate. The reactor vessel velocity is calculated at the fuel assembly inlet.

	IRWST screen (one screen)	Recirculation screen (both screens)	Reactor Vessel
Time [sec]	6800 to 10,000	6800 to 10,000	6800 to 10,000
Flow Rate [gpm]	540	755	1042
Velocity [ft/s]	0.06~~3~~0	0.008	0.0313
Frontal Area [ft^2]	20	210	74.28

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Technical Report (TR) Revision:

None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP6.2.2-SRSB-03
Revision: 1

Question:

In TR 26, Revision 3, on page 8 in "Applicability to the AP1000 Design" subsection, Westinghouse states that metal reflective insulation (MRI) is used on components that may be subjected to jet impingement loads; MRI is not transported to the AP1000 Containment Recirculation Screens with low flow rates; and as a result, there is no fibrous debris generated by the LOCA blowdown. On page 11 in "Break Selection Criteria" subsection, Westinghouse states that the density of the MRI material ensures that any debris generated by the damage of this insulation material to settle in the containment sump and not be transported onto the screens.

The staff notes there is a significant amount of MRI in the AP1000. In the SER for NEI 04-07, on page 7, the staff stated that MRI is assumed to degrade to 75 percent small fines and 25 percent large pieces.

a. Describe testing or evaluations that show that this type of insulation, once it has been damaged by the LOCA jet, will not become debris that will cause potential plugging of the screens.
b. Verify that the same degradation for the MRI as described in the NEI 04-07 SER exists in the AP1000 or identify what the degradation would be. Describe the impact of the degradation on the debris loading.
c. Was an evaluation performed showing that the MRI material under AP1000 break conditions will not migrate to the containment sump and screens? If so, provide the reference or detailed information in the reference.
d. Is there any chemical residual associated with the MRI that could impact the screen blockage or the downstream blockage in the core? If so, what is the impact to the screens and to the core blockage?
e. Are there any other objects in the zone of influence that can be damaged by jet impingement and contribute to the debris (e.g., cable insulation, instrumentation, hot/cold leg temperature instrumentation, nuclear instrumentation, signs, caulking…)?
f. Is there any fiber insulation encased in MRI that could contribute to the debris? If so, are the configurations qualified for jet impingement? Provide the qualification details.
g. How will lack of debris generating materials in the zone of influence be verified?

Additional Question:

a. Westinghouse's response implied that this RAI regarding MRI is satisfied since NEI 04-07 provides information on the transport of MRI and is accepted by the NRC SER on NEI 04-07. However, though NEI 04-07 indicates that small fines from MRI could be transported to the sump, in AP1000 the small fines from MRI could be transported directly to the open unfiltered flow going into the broken DVI pipe leading to the reactor vessel. This evaluation was not provided by Westinghouse.

b. The RAI response states that the thermal hydraulic conditions associated with a postulated break for the AP1000 are the same as those for current operating PWRs. However, the break conditions for AP1000 may be significantly different especially for a DVI break. What is the velocity of the break when water is flowing into the reactor vessel through the break? Will this be larger than .2 ft/sec, which is the velocity that Westinghouse referred to from NUREG/CR-6808?

Westinghouse Response: < The original response has been revised as shown below to address the additional questions. >

a. Information regarding the generation of debris from MRI is given in NUREG/CR-6808, “Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance.” Information regarding the transport of MRI is given in NEI 04-07, “Pressurized Water Reactor Sump Performance Evaluation Methodology” and has been accepted in the associated NRC Safety Evaluation on NEI 04-07. The liquid velocities evaluated for the AP1000 recirculation flows are lower that the values listed for MRI in Section 4.0 of NEI 04-07.

b. NEI 04-07 and its associated NRC Safety Evaluation are applicable to current operating PWR’s. The thermal hydraulic conditions associated with a postulated break for the AP1000 are the same as those for current operating PWR’s. Therefore, the degradation or damage characteristics for MRI described in NEI 04-07 and its associated Safety Evaluation for current operating plants are also applicable to the AP1000.

c. MRI is constructed of stainless steel. Tests reported in NUREG/CR-6808, “Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance,” have been performed that demonstrate that MRI damaged by LOCA tests will settle and require more velocity to transport than will occur in AP1000. These tests indicate that a velocity of 0.2 ft/s is required to move ½” x ½” crumpled foil MRI debris; larger velocities are required to move larger MRI debris. The AP1000 will have a liquid velocity less than 0.072 ft/s available to move MRI toward the containment recirculation screens.

d. MRI is constructed of stainless steel and contains no substances that would contribute to the post accident chemical precipitants.

e. Damage due to jet impingement is dependant upon the material of interest. Based on a review of the AP1000 design, there are no other materials that that would be affected by jet impingement loads associated with a high energy pipe break that would become debris.

f. As stated in TR 26, on page 8, MRI contains no fibrous material.

g. Tier I ITAAC Table 2.2.3-4, item ix, addresses this issue. The ITAAC requires the inspection of the "insulation used inside the containment on ASME Class 1 lines and on the reactor vessel, reactor coolant pumps, pressurizer and steam generators". The acceptance criteria are that "the type of insulation used on these lines and equipment is a metal reflective type or a suitable equivalent". Also note that the DCD (Section 6.3.2.2.7.1, item 3) also requires metal reflective insulation or a suitable equivalent be used where LOCA jet impingement damage insulation and generate debris.

Additional Reponse:

a. The density of MRI (stainless steel) is much greater (about 8 times) than water density, such that it will settle out readily when the water flows / turbulence due to RCS blowdown has decreased. Small fines from MRI would be moved around the room during the initial blowdown, however once ADS 1/2/3 has been actuated the RCS pressure will decrease substantially and allow the MRI fines to settle out. After the flooding level has increased over the break and after RCS pressure is overcome by the static head of flood water, water starts flowing back into the RCS through the break.

   The figure on the following page provides potential break location elevations in comparison with the room floor elevation. Please note that the lowest of these elevations, designated as the accumulator check valve will not exhibit the flow back into the RCS through the break because the IRWST flow will be either spilling or entering the RCS through this line. This can be seen in the Passive Core Cooling sketch provided.

   The AP1000 DCD long-term core cooling analysis reports the following total flow rates into the core

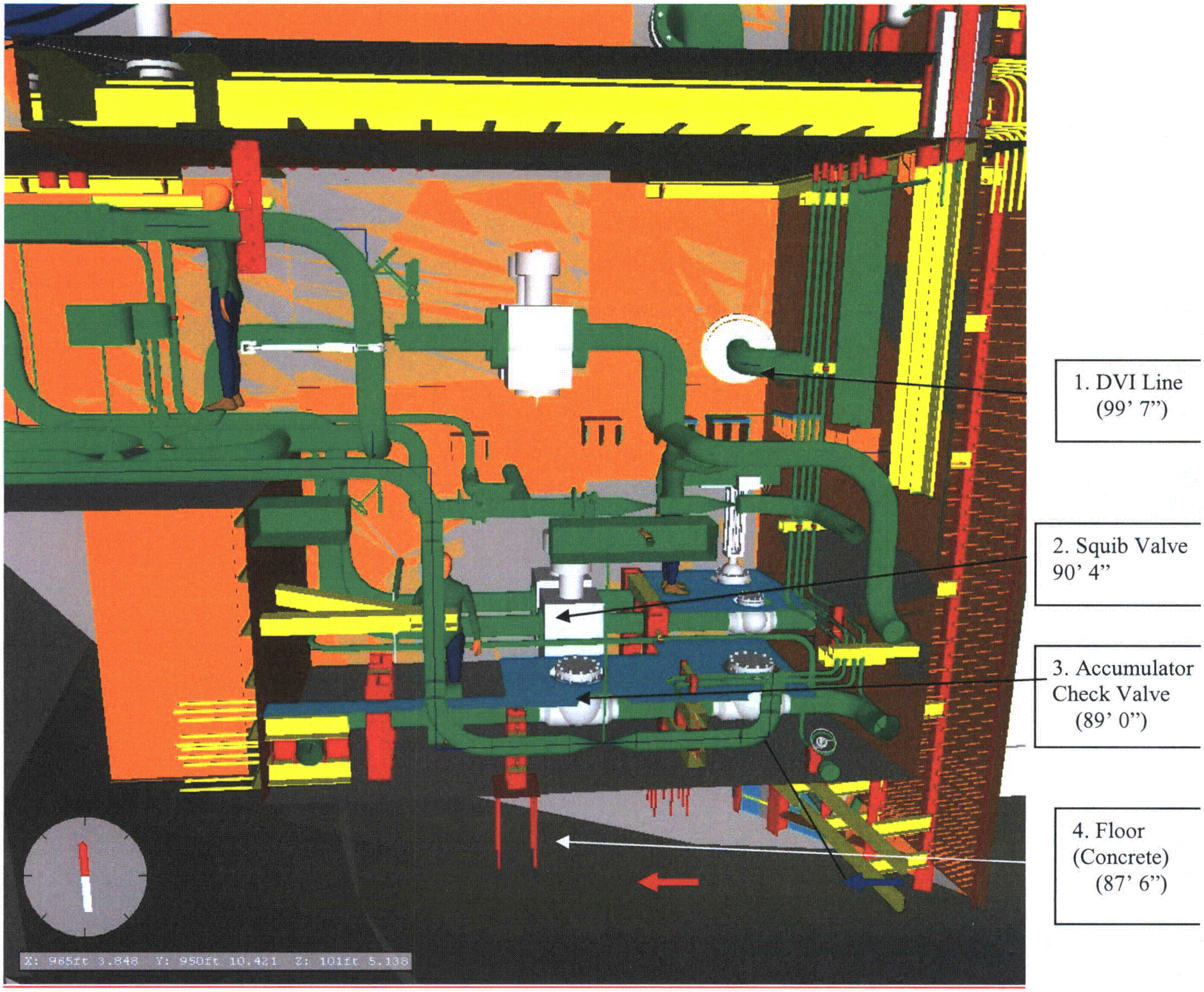
   - At 10000 seconds in the LOCA transient, average flow rate into the core is calculated as 1068 gpm (2.3795 ft^3/s) and the peak flow rate into the core is calculated as 1325 gpm (2.9521 ft^3/s)

   - At 14days into the LOCA transient, average flow rate into the core is calculated as 736 gpm (1.6398 ft^3/s) and the peak flow rate into the core is calculated as 957 gpm (2.1322 ft^3/s)

The associated velocities on the floor can be calculated using the break elevation with a flow area associated with a hemisphere and the maximum core flowrate (60% through the break and 40% through the intact line). Response to RAI-SRP6.2.2-SRSB-10, Revision 1 provides the justification for the flow split through the break DVI line and the intact DVI line.

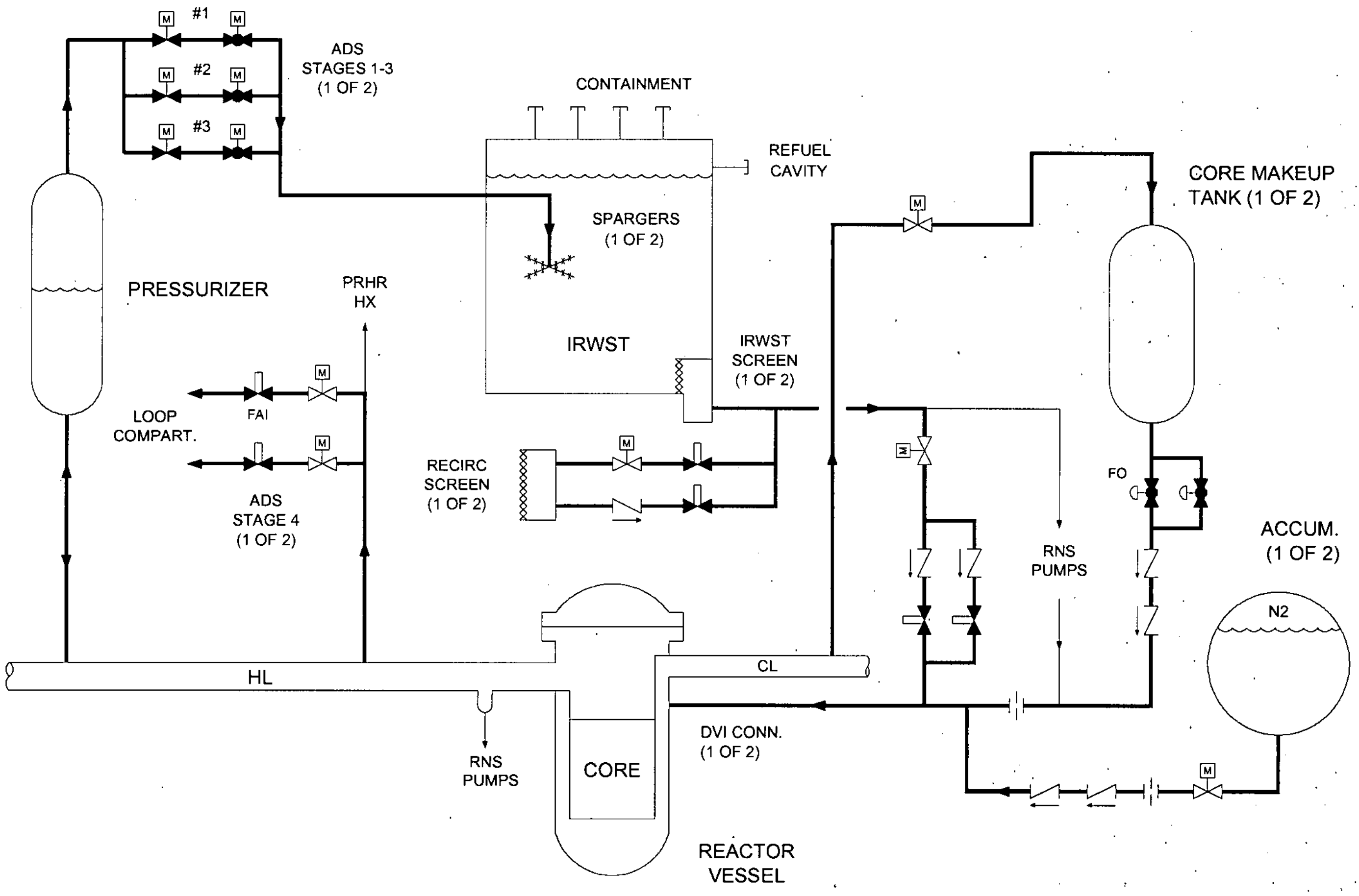
	Break Location	Max. Flow Rate	Flow Area	Velocity at Floor
1	DVI nozzle	1325 gpm * 60% (for One Line) = 795 gpm = 1.771 ft^3/s	917.38 ft^2	0.00193 ft/s
2	Squib Valve	1.771 ft^3/s	50.44 ft^2	0.0351 ft/s
3	Check Valve	1.771 ft^3/s	14.14 ft^2	0.125 ft/s

b. Tests reported in NUREG/CR-6808, “Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance,” have been performed that demonstrate that MRI damaged by LOCA tests will settle and require more velocity to transport than will occur in AP1000. These tests indicate that a velocity of 0.2 ft/s is required to move ½” x ½” crumpled foil MRI debris; larger velocities are required to move larger MRI debris. The response to item a. above shows that there is insufficient water flow to transport MRI fines from the floor location into the break even from the lowest potential break locations. .



View of PXS Room Potential Break Elevations

Passive Core Cooling Sketch



Design Control Document (DCD) Revision:

None

PRA Revision:

None

Technical Report (TR) Revision:

None

RAI Response Number: RAI-SRP6.2.2-SRSB-04
Revision: 1

Question:

In TR 26, Revision 3, on page 9, in the "Evaluation Approach" subsection, Westinghouse states that the post-accident chemical products were estimated using a tool generated by the PWR Owners Group and design features of the AP1000.

Since the amount of post-accident chemical products is an important contributor to plugging, debris build-up and scaling in the core, the software and/or analytical tools used to assess the impact of debris on the AP1000 strainers and core should be identified and validated.

Identify the software and/or analytical tools used to perform these evaluations and describe how the software/tools have been validated to perform chemical evaluations using the design features of the AP1000.

Additional Question:

The AP1000 design basis accident for long-term cooling is the DEDVI break. The DVI (Direct Vessel Injection) line initially releases water out the break, but eventually reverses flow when the AP1000 depressurizes and thereby allows water into the break opening from the containment for natural circulation during long term cooling. The passive recirculation cooling design of the AP1000 is significantly different from all previous PWR designs. With natural circulation flow through the break opening, the water from the containment sump can flow directly to the core bypassing the screens. Because of this aspect of the AP1000 long-term cooling, the debris and chemical loading masses in the containment are significant factors in establishing the reactor safety of the AP1000 since all debris and chemicals suspended in the containment sump water could eventually flow into the core region. The unfiltered debris and chemicals could potentially block flow into the core and cause the fuel to exceed temperature limits and/or cause local heat transfer characteristics of the fuel to be altered allowing some fuel to overheat.

TR 26 Revision 3 described the application of LOCADM for chemical deposition on the fuel cladding and PCT calculations for AP1000. According to TR-26, "A quantitative estimate of the effect of fiber glass on deposit thickness and fuel temperature can be accounted for in LOCADM by use of a 'bump-up' factor. The 'bump-up' factor is applied to the initial debris load and is set such that total release of chemical products after 30 days is increased by the best estimate of the mass of the fiber glass that bypasses the sump screen." Westinghouse performed the Calculation APP-PXS-M3C-057 to provide justification for this bump-up factor. In its review of the calculation APP PXS M3C-057, the staff found that a bump-up factor was established to account for additional chemicals added to the core inlet because of the unfiltered flow through the break, but did not find the justification and basis of the "bump-up" factor. Provide the justification and basis for using the "bump-up" factor identified in the calculation.

Westinghouse Response: < The original response has been revised as shown below to address the additional questions. >

The discussion on page 9 of TR 26, Revision 3, is directed at the prediction of chemical products in the post-accident liquid pool in the reactor containment building floor of the AP1000. The tool used to perform the chemical evaluations is the spreadsheet that was developed to accompany WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191." The spreadsheet was validated as part of the effort to publish and support the NRC review of WCAP-16530-NP-A. The applicability of the spreadsheet to the AP1000 design is stated at the bottom of page 13 and the top of page 14 of TR 26, Revision 3.

Additional Response

Westinghouse performed the LOCADM* calculation for AP1000 (APP-PXS-M3C-057) to determine the impact of chemical precipitate deposition on fuel rods resulting from the formulation of chemical precipitates in the post-LOCA recirculation pool environment.

In its review of the calculation APP PXS M3C-057, the staff found that a bump-up factor was established to account for additional chemicals added to the core inlet because of the unfiltered flow through the break, but did not find the justification and basis of the "bump-up" factor.

The bump-up factor was developed to account for the effect of postulated fiberglass that may bypass the sump strainers and enter the core and adhere to the fuel cladding when evaluating current operating plants. Including the fibers in LOCADM fuel clad deposition predictions 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 the application for current operating plants and accounts for fibrous material in the recirculating coolant that is provided to 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 since those chemicals are already included in the calculation.

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 a "bump-up factor" applied to the initial debris inputs. The bump-up factor is set such that total release of chemical products over 30 days is increased by the estimate of the mass of the latent fibrous debris that may bypass the recirculation screens. The use of the bump-up factor in the AP1000 LOCADM calculation is appropriate since, although the amount of resident debris is small and the fibrous component of that amount is smaller still, it is possible that some of the resident 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 on 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 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 anywhere else in the recirculation pool such as on the recirculation screens.

The bump up factor is implemented in the LOCADM calculation, APP-PXS-M3C-057, on a mass basis. The basis for the bump-up factor is the assumption that all of the mass of bypassed latent fibrous debris 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 to bypass the recirculation screens. This conservative method is independent of fiber diameter and length.

Based on the calculated amount of chemical deposition, it is expected that an increase in the latent fibrous debris load would have a minimal impact on the current result.

* See WCAP-16793, Revision 0, “Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid” for a description of the LOCADM calculation.

The following discussion addressed the potential impact of the fibers entering the core being material than fiberglass with a different heat conductivity.

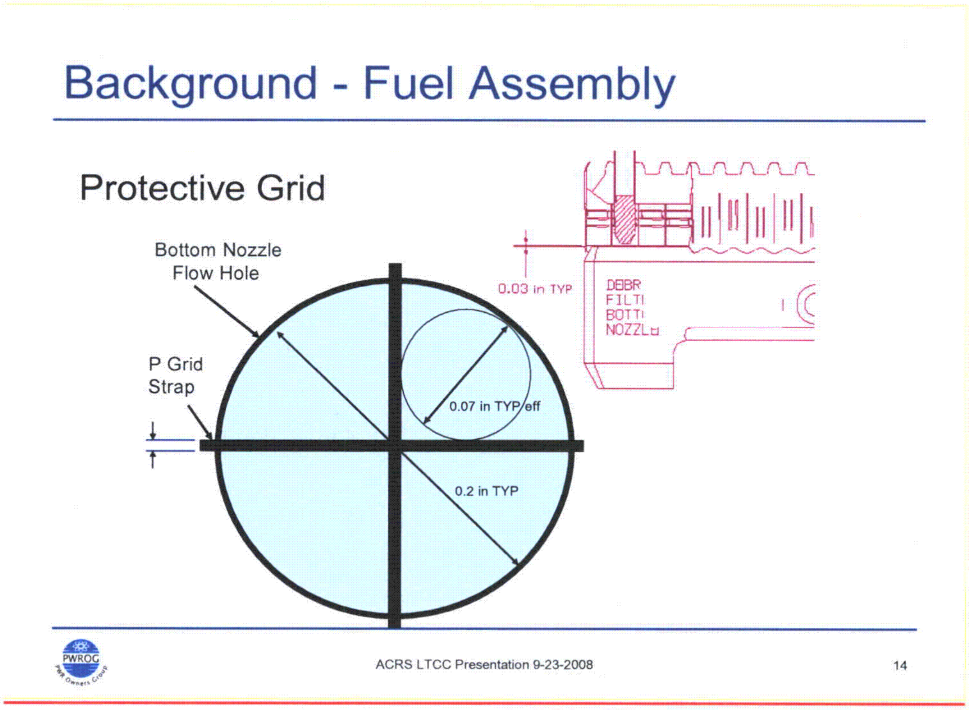
By design, the AP1000 provides for no source of fiberglass being generated following a LOCA. The bulk of resident latent fiber must be composed of fibers brought into containment by human activity. This fiber must be composed of fibers from clothing and rags, cellulose fiber from paper, hair (should be very little since workers must wear gloves and head gear [hoods, hard hats] of some sort at all times), and other miscellaneous fibers of unknown origin; assuming that the bulk of the fibrous debris is from clothing sources. Currently, the predominate type of protective clothing (PC) worn by workers in the nuclear industry is launderable woven textile garments. Among these, 65/35 polyester/cotton and 100% synthetics (nylon and tyvek) dominate use at U.S. nuclear facilities, although dissolvable PCs (such as OREX) are becoming more prevalent.

Typical diameters of various 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, 0.13, BTU/ ft h °F) is compromised when the fibers become saturated with water, as in 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 1). The conclusion is that these fibers have a heat conductivity when wet that is much higher than the heat conductivity of the chemical scale used in LOCADM (0.11 BTU/ft h °F).

Reference 1. 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)

The following discussion addresses the potential impact of the fibers entering the core being longer and thicker than that of fiberglass fibers. Sump strainers have been shown in testing that they are very effective at catching longer fiber and only the shortest are able to bypass. Similar to sump strainers, the fuel nozzle and protective grid are also expected to catch the longer fibers such that few of them would transport into the fuel rod area. However, following discussion assumes that they do.

The recirculation screens that will be installed in the AP1000 have a maximum hole size of 0.0625 inch. The maximum hole size in the bottom nozzle/protective grid in the proposed AP1000 fuel provides for a maximum particle diameter of 0.07 inch.



Background - Fuel Assembly

Protective Grid

ACRS LTCC Presentation 9-23-2008

14

Since the bottom nozzle and the protective grid result in a limiting hole size similar to the recirculation screens, it is expected that the fiber capture capability of the two 'strainers' would be similar, i.e., fewer longer and thicker fibers would penetrate the "strainer" than would shorter thinner fibers.

From NUREG/CR-6877,

> "Qualitative photomicrograph observations of fibers show fiber diameters ranging from 1 to 20 μm, with shapes including straight cylinders; single tortuous, flexible strands; and twisted, flat, ribbon-like strips. Some fibers appear to be interwoven, forming large clusters similar to the fibrous debris shape classification shown in NUREG/CR-6224.

> Most of the fibers, regardless of the shape and size, appear to have debris particles attached to them. The attached particle diameters range from ~1 µm to >50 µm. Fiber diameters were measured, and the bulk of the fibers had a diameter between 12 and 14 µm."

The NUREG/CR-6877 goes on to state;

> "The fibrous surrogate fraction should be prepared such that the length-to-diameter ratio is large (latent fibers are very long compared with their diameter)."

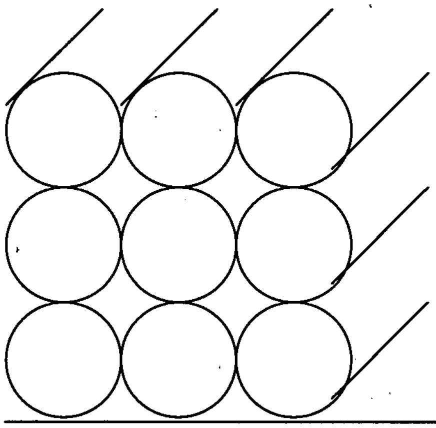
The typical fiber diameters of various types of fibers that might be found inside a currently operating reactor containment building are listed below:

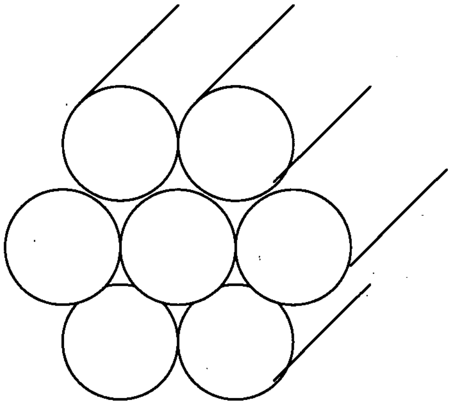
Fiberglass	7 µm
Cotton	10 µm
Nylon	13 µm
Polyester	14 µm
Human hair	60 to 80 µm

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. As noted above, the thermal conductivity of fibers saturated with water trends to that of water.

Short small diameter fibers are considered more conservative than the thick large diameter fibers that are the constituents of resident 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 resident 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).



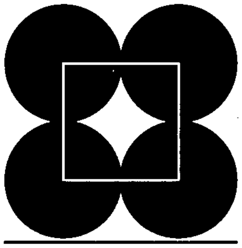


Like this…………… or this

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.

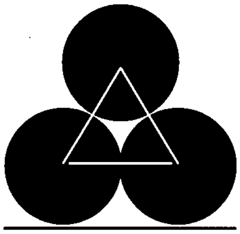
Calculations

To determine the packing ratio for a given configuration, determine the smallest representative figure that, when repeated, will generate the configuration of interest.



$$\text{Area Ratio} = \frac{\sum A_{circle\_sectors}}{A_{square}} = \frac{\left(\frac{1}{4}\pi * r^{2}\right) * 4}{(2r)^{2}} = \frac{\pi}{4} = 0.785$$

For fibers packed in this configuration, doubling the diameter approximately quadruples the amount of free space in the lattice.



$$\text{Area Ratio} = \frac{\sum A_{circle\_sectors}}{A_{triangle}} = \frac{\left(\frac{1}{6}\pi * r^2\right) * 3}{\frac{1}{2} * base * height} = \frac{\left(\frac{1}{2}\pi * r^2\right)}{\frac{1}{2} * 2r * r\tan 60^\circ} = \frac{\pi}{2\tan 60^\circ} = 0.91$$

For fibers packed in this configuration, doubling the diameter approximately quadruples the amount of free space (water filled) in the lattice. Based on local conditions in the core, if boiling were to occur within the bundled fibers, the greater volume of steam would be disruptive to these packing configurations.

Depending on the packing configuration, 7-μm diameter fibers (fiberglass) provide 1.9-μm^2 to 10.52 μm^2 of free space while fibers of 14-μm diameter (latent) provide ~7.6 μm^2 to 42.06 μm^2, indicating that collections of small diameter fibers (such as fiberglass) are more conservative than collections of larger diameter fibers (such as latent fibers). Hence the longer thicker fibers postulated for latent debris would not have a detrimental impact on heat transfer in the core.

Conclusion: The latent fiber may include a variety of fiber materials and may be longer and thicker than fiberglass fibers. Longer, thicker fibers will tend to be trapped in the fuel assembly inlet nozzle and not be transported to the fuel rods. Even if it is 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.

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Technical Report (TR) Revision:

None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP6.2.2-SRSB-05
Revision: 1

Question:

In TR 26, Revision 3, on page 10, Westinghouse states that debris samples removed from operating plants and visual observations during plant walk-downs provide the basis for the debris composition as particulate material (85% by volume), coatings (5% by volume) and fiber (10% by volume).

a. Provide the references or sources of the operating plant walkdowns and debris samples. Confirm that the percentages of various debris types are based on total volume, as reported, and not total mass (NRC SE of NEI 04-07 recommends that fiber be 15% of total mass).
b. Explain why these references and data are representative of the AP1000.
c. Describe whether there could be other types of latent materials in the AP1000 that are different from the operating plants.
d. Explain how actual as-designed and operated AP1000 will be verified to be consistent with this data both prior to start-up and during the life of the plant? Propose appropriate surveillance testing and/or programmatic controls that will be necessary to ensure the actual plant is operated consistent with the analysis assumptions.

Additional Question:

The NRC staff reviewed the Westinghouse calculation files APP-PXS-M3C-053, "Latent Debris Calculation." Westinghouse identifies that only the Almaraz containment walkdown was used in the determination of the distribution of the containment latent debris types. Based on 'observations' at the Almaraz Unit 2 containment, visual identification of the debris types indicated that the debris volume appears to be made up of mostly particulate matter (85% assumed to be mostly dirt, welding slag, rust and grindings) with lesser amounts of coatings (5% paints) and fiber (10%, assumed to be composed of dust fabric and insulation). Therefore, the containment latent debris composition does not appear to have a sound basis.

Also, the debris contribution from vertical surfaces, small pipes and break jet impingement was essentially discounted. Only 10% of the dust on the vertical surfaces was considered and the debris on small bore pipes was ignored. There are a significant number of small pipes throughout the containment that collect debris such as dust. The total top-half surface area of these pipes could contain a substantial amount of debris mass, and adding it to the total could lead to a significant bump in the mass of the debris in the containment.

Westinghouse Response: < The original response has been revised as shown below to address the additional questions. >

Please note the original response provided below relates to the previously proposed debris composition in containment. It has been retained for historical purposes only. The debris and fiber content has been modified as described in the "Additional Response" section.

a. A debris composition of 85% particulates, 14% coatings and 1% fiber by mass is used in the calculation note (APP-PXS-M3C-053, Revision 0) that documents the AP1000 resident debris loadings. This data is based on walk-downs performed at three plants. The walk down data is proprietary; the calculation note is available for review by the NRC. It is noted that rounding the fiber debris upward to 1% fiber by mass added conservatism to the assumed amount of fibrous debris considered in the calculations.

b. The three plants whose latent containment debris walkdown data was used to assess latent debris loading for the AP1000 were evaluated to have containment cleanliness programs that ~~the AP1000~~ might serve as a model for the AP1000 containment cleanliness program. The AP1000 DCD section 6.3.8.1 requires that the AP1000 cleanliness program be consistent with cleanliness programs used in the evaluation of debris loadings for the AP1000. Given this requirement, the walkdown data from the three plants is applicable to the AP1000 design. It is the responsibility of the AP1000 licensee to define and implement the COL containment cleanliness program to assure that the actual latent containment debris loads are less than or equal to those determined by evaluation and used in testing the recirculation screens.

c. The total amount of latent debris is limited by the COL cleanliness program. So the only question is whether the types of debris that might be found in an AP1000 containment could be different such that the resulting head loss across AP1000 screens would be increased.

   Some of the resident debris found in the walk-downs was transported into the containment by people that enter the containment during shutdown activities. This source of debris is expected to be reduced because the simplifications in the AP1000, and the reduced maintenance resulting from the use of canned motor reactor coolant pumps, will result in fewer people entering the containment during shutdowns.

   The materials used in the AP1000 containment are similar or less likely to create resident debris than those used in the plants where the walk-downs were performed. An example of an improved material is the use of MRI instead of fiberglass insulation; removing and re-installing fiberglass insulation can create small amounts of latent debris.

   One area where AP1000 might have an increase in a specific type of resident debris is in the area of coatings. The AP1000 uses qualified coatings inside containment;~~,~~ however, they are not applied, inspected, and maintained as safety coatings. As a result, the latent debris found in an AP1000 could have a greater percentage of coatings debris. Since these coatings are required to be high-density, they could not be transported to the screens.

In summary, the AP1000 latent debris is expected to be made up of similar materials; ~~and~~ if anything it would form a mixture that would result in less pressure loss (less fiber and more [high density] ~~(high density)~~ coatings).

d. The AP1000 DCD contains a COL item (6.3.8.1) that requires the COLA to provide a cleanliness program that is consistent with the assumptions used in determining the AP1000 latent debris amounts. In addition, sensitivity studies have been performed that demonstrate that the AP1000 long-term cooling operation can tolerate much higher head loss than was shown to occur in the debris testing performed for the AP1000 screens and core.

Additional Response:

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 28 plants sampled for the Generic Letter 2004-02, 'Supplemental Responses and Close-Out', responses, 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.

Of the 28 plants sampled from the Generic Letter 2004-02 'Supplemental Responses and Close-Out' responses (see Table 1), 17 have reported latent debris loads less than 100 pounds. Of those 17 plants reporting latent debris loads less than 100 pounds, seven report latent debris loads less than 50 pounds. It should also be noted that of the 28 plants sampled, ten used latent debris loads of 150 pounds or less when performing their downstream evaluations. Trending based on the containment inside diameter is shown in Figure 1. There is a small trend for more debris for a larger containment inside diameter; however, there is a large amount of scatter. This indicates that other factors are more important, such as the utilities cleaniness programs.

Using the data in NUREG/CR-6877 and the Generic Letter 2004-02 'Supplemental Responses and Close-Out' responses, it is proposed that the AP1000 will assume 150 pounds of resident debris of which six pounds are fiber which has the potential to transport to the screens. This resident debris mix is supported by both the plant responses in the Generic Letter 2004-02 'Supplemental Responses and Close-Out' (resident debris mass) and NUREG/CR-6877 (fiber content).

Westinghouse will provide updates to the Design Control Document (DCD) Section 6.3 (including COL item) which will provide the total latent debris limited to 150 lb and the total latent fiber debris limited to 6 lb. These updates will be provided in APP-GW-GLE-002, Revision 2, by May 8, 2009.

Table 1: Operating PWR Debris Amounts

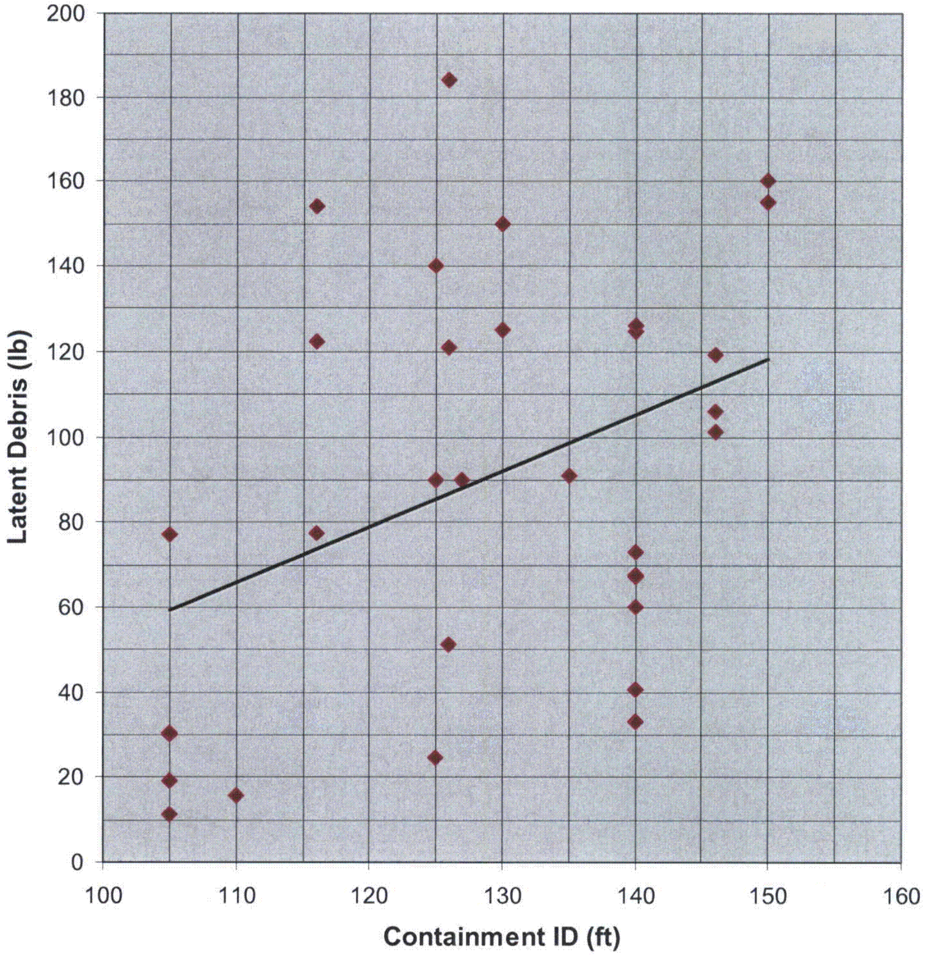
Plant	Dominant Insulation	Containment ID (ft)	Total Latent Debris (lb)	
			Walkdown	Analysis
ANO	RMI	116	122.4	150.0
BVPS 1/2	?	126	184.0	200.0
		126	184.0	200.0
Byron 1/2	RMI	140	67.2	150.0
		140	124.6	150.0
Braidwood 1/2	RMI	140	126.0	150.0
		140	72.8	150.0
Calvert Cliffs	?	130	150.0	150.0
Catawba	High fiber	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	140	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	154.0	154.4
Vogtle	High fiber	140	60.0	200.0
Fort Calhoun	?	110	15.7	159.0
		Averages	90.6	165.7

Table 2 from NUREG/CR-6877

	Plant A		Plant B		Plant C		Plant D	
NUREG/CR-6877								
Particles	5.06 g	83.0%	2479 g	90.8%	14.77 g	95.0%	151.20 g	93.3%
Fiber	1.04 g	17.0%	252 g	9.2%	0.77 g	5.0%	10.88 g	6.7%
Total	6.1 g	100.0%	2731 g	100.0%	15.54 g	100.0%	162.08 g	100.0%
NUREG/CR-6877								
Particles	5.06 g	68.8%	2479 g	74.2%	14.77 g	52.2%	151.20 g	55.2%
Fiber	1.04 g	14.1%	252 g	7.5%	0.77 g	2.7%	10.88 g	4.0%
Other*	1.25 g	17.0%	611 g	18.3%	12.74 g	45.0%	111.93 g	40.8%
Total	7.35 g	100.0%	3342 g	100.0%	28.28 g	100.0%	274.01 g	100.0%

NOTE: * 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 back in in the lower set of values. Separating out such debris is not anticipated to be done by utilities; it also does not reduce the amount of fibers, just the percentage.

Figure 1: Containment ID Trends



Design Control Document (DCD) Revision:

Westinghouse will provide updates to the Design Control Document (DCD) Section 6.3 (including COL item) which will provide the total latent debris limited to 150 lb and the total latent fiber debris limited to 6 lb. These updates will be provided in APP-GW-GLE-002, Revision 2 by May 8, 2009.

PRA Revision:

None

Technical Report (TR) Revision:

None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP6.2.2-SRSB-07
Revision: 1

Question:

In TR 26, Revision 3, in the "Break Selection Criteria" subsection on page 12, Westinghouse states:

> "As the tables show, approximately 24 lbm of latent debris would be expected to be transported to the AP1000 Containment Recirculation Screens through direct impingement, immersion or from being washed down during a high energy line break."

As stated in NUREG-1793, Section 6.2.1.8.3, "Pool Transport and Head Loss Evaluation of the Containment Recirculation Screens, the staff noted that Westinghouse's analysis assumed a mass of resident debris in the containment of 227 kg (500 lb) and that was consistent with estimates made with current generation PWRs in the GSI 191 parametric study (NUREG/CR-6772). In TR-26, Revision 3, on page 16, Westinghouse identified 200 lbm of latent containment debris based on an NRC safety evaluation performed on NEI 04-07. The staff, in its review of the NRC safety evaluation performed on NEI 04-07 (ML043280007), does not find the reference of 200 lbm that Westinghouse identifies in TR-26. Further, the staff notes that the total debris of 24 lbm and .24 ft^3 that were referenced in Table 1 of TR-26 is a very small amount of mass and volume from the whole containment (500 lbs) that may accumulate at the recirculation screens.

a. | Explain the apparent discrepancy between the mass of resident debris in the containment of 227 kg (500 lb) in NUREG-1793 Section 6.2.1.8.3 and the 90.8 kg (200 lb) identified in TR-26, and justify the TR-26 number, as it is not included in the referenced SER.
b. Explain how the volumetric values of debris presented in Tables 1 & 2 were derived. For example, how was the .01 cubic foot of epoxy coatings derived given all of the coatings in the containment that can flow into the sump region? Provide a basis for each of the volumetric values given. Include identification of areas assumed for each break path by type of surface (horizontal, walls, equipment or piping), area of surface, and average volume of debris from operating plant. Identify the operating plant walkdown and actual debris values used to determine the average volume of debris for each area. Identify how and where the "25% conservatism" identified in TR 26 is added.
c. The epoxy density is given as 94 lb/ft^3 in Tables 1 and 2, but as 105 lb/ft^3 in DCD Rev. 16, Table 6.2.1.1-8. Explain the difference between these two values.
d. Section 3.6 of the NRC safety evaluation on NEI 04-07 discusses debris transport methodology. Provide the criteria and methodology used in TR 26, including debris transport factors and flow velocities. Identify model for debris transport off the protective plates and the basis for associated calculations and assumptions.

Additional Question:

Where is the 200 lb referenced in the SER for NEI 04-07?

Westinghouse Response: < The original response has been revised as shown below to address the additional questions. >

a. As discussed in TR 26, the total amount of latent debris in the AP1000 was calculated based on operating plant walk-down debris loading data and AP1000 surface areas. This calculation was performed for two cases. One case was a best estimate case and one was a bounding case. The bounding case resulted in a total of about 100 pounds of latent debris in the containment. This is about 50% more debris than is typically seen in operating plants based on walk-down data. This response is based on APP-GW-GLR-079 (TR26), Rev. 3. APP-GW-GLR-079 is being revised to incorporate 150 lb of latent debris based on the response in RAI-SRP6.2.2-SRSB-05, Rev. 1.

   To demonstrate that there is not a “cliff” near the bounding case, a sensitivity case was defined that used 200 pounds of latent debris. As discussed in TR 26, the 200 pounds was based on NEI 04-07 ~~the NRC recommended value for latent debris in their safety evaluation~~Section 3.5.2.2, “Evaluate Resident Debris Buildup”~~of NEI 04-07~~. A value of 500 pounds of latent debris was not assumed in the AP1000 long-term cooling evaluations.

b. The general description of how the values listed in Tables 1 & 2 were calculated are given at the bottom of page 9 and the top of page 10 of TR 26. The details of how the values were calculated are documented in a calculation note. This calculation note is based on information that is proprietary, including operating plant names, but can be made available for review by NRC representatives at the Westinghouse Washington Office.

c. The use of 94 lb/ft^3 in Tables 1 and 2 is a conservatively low density for epoxy coatings. The use of a lower density was used in conjunction with maximizing the potential for transporting the coatings debris to the recirculation screens.

d. All latent debris in areas that could communicate with the recirculation screens was conservatively assumed to be transported to the recirculation screens. Therefore, in TR 26, the transport factors for latent containment debris, both fibrous and particulate, were taken to be “1.0”.

Additional Response:

The prior response was incorrect;~~,~~ the stated value of “200lb” was not from the SER for NEI 04-07. It is referred to in NEI 04-07 in Section 3.5.2.2, “Evaluate Resident Debris Buildup”:~~.~~

"...recent sampling of surfaces inside containment at a number of plants indicated that it is likely that the maximum mass of latent debris inside containment is less than 200 pounds..."

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Technical Report (TR) Revision:

None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP6.2.2-SRSB-10
Revision: 1

Question:

In TR 26, Revision 3, in the "Break Selection Criteria" subsection on page 13, Westinghouse states:

> "Note that the debris reaching the core is based on a DVI LOCA in the loop compartment. For this event the containment water level rises above the break so that some water can enter the reactor coolant system (RCS) directly and thereby bypass the Containment Recirculation Screens. It is calculated for such an event that no more than 60% of the total recirculation flow will bypass the screens. As a result, the core debris is set at 60% of the Containment Recirculation Screen amount."

The staff notes that in Table 3 the best estimate total mass bypass to the core is 14.35 lbm, and requests the following information.

a. Clarify, since the amount of bypass debris is significant for determining the effect on the core, the basis for the 60% number.
b. Describe how this relates to the total residue mass in the containment of 227 kg (500 lb) that you assumed, as documented in NUREG-1793, Section 6.2.1.8.2.
c. Clarify whether the total mass number to the core includes bypass debris from the recirculation and IRWST screens.

Additional Question:

In its review of part a. to the response to RAI-SRP-6.2.2-SRSB-10, the staff asked Westinghouse to identify if the 60% bypass flow assumption was based on low water level in the containment, which would limit the recirculation flow, or was based on a high water level, which could drive a bigger percentage of unfiltered debris through the DVI break location? On review of the calculation APP-PXS-M3C-049 Rev. 0, the staff found that the 60% number was based on integrated flow through the break divided by the total integrated flow into the core region, but time periods during the transient changes this percentage significantly. Describe the variations you expect in this percentage split with respect to time. Also, using the flow percentage splits between the break and the recirculation screens is not an adequate representation of the debris split because sump recirculation screens are protected from debris by barriers such as the large protective shelves above the screens. On the other hand, there are no protective barriers for the break location and it is completely open to all suspended debris in the containment sump area. Clarify how this bias accounted for in the calculation?

Westinghouse Response: < The original response has been revised as shown below to address the additional questions. >

Page 13 of TR 26 discusses the basis for 60%. The basis is that for the limiting break location (a DVI break), the long-term cooling analysis shows that less than 60% of the integrated RCS flow will enter through the break. The other 40% will pass through the recirculation screens. As a result, the recirculation screens will collect 40% of the latent debris and the remaining 60% will enter the core through the break.

a. The AP1000 did not assume 500 lb of debris were inside the containment. Refer to the response to RAI 6.2.2-SRSB-07 for an explanation of how the AP1000 latent debris was calculated. The 60% value is the percentage of the recirculation screen debris that could be transported to into the core.
b. The AP1000 did not assume 500 lb of debris were inside the containment. Refer to the response to RAI SRP 6.2.2-SRSB-07 for an explanation of how the AP1000 latent debris was calculated.
c. The amount of bypass debris that might pass through the AP1000 screens will be very small considering the low debris loading of these screens and is bounded by the 60% value.

Additional Reponse:

The 60% bypass flow is based on the low water level in the containment because this limits the recirculation flow which is conservative for long term cooling of the cool. However if the water level in the containment were increased, the flow fraction for bypass would remain constant since the flowrate is proportional to the elevation head and the elevation of the DVI lines injectioning the flow are the same.

No settling of the resident debris is assumed in the calculations. Settling would reduce the amount of debris available to be deposited on the screens or to enter the break. The resident debris is assumed to be divided at the same ratio as the flow fraction between the recirculation and broken loop flows.

The figures on the following pages show the calculation of the flow ratio calculated through the break. Figure 1 provides the intact DVI line flows following recirculation. Figure 2 provides the flow into the reactor vessel from the break location. Figure 3 provides the instantaneous flow ratio in the core from the break location to the total core flow (flow through break to the reactor vessel / total flow to reactor vessel) following recirculation. At all times after recirculation the instantaneous flow through the break ratio is less that 60% of the total core flow.

The integral ratio shown in Figure 4 for recirculation flow represents the fraction of the integrated recirculation flow entering the reactor vessel through the broken DVI line The broken DVI line exhibits (negative) flow outward into containment for the first ~3800 seconds in

WCOBRA/TRAC as indicated until the water level in the loop compartment has risen to the point that flow into the reactor vessel can begin. This ratio is 1.0 for the time interval from 3800 seconds prior to the start of containment recirculation flow passing through the intact DVI line and its sump screen.

As shown in Figure 3, once recirculation is established, the instantaneous flow split through the break is always less than the 60% value. From Figure 4, after 10,300 seconds (approximately 1 hour after recirculation is initiated) the integrate flow ratios are less than the 60% value assumed. This 1 hour time is much less than the time required to "turn over" the entire containment water volume (6 to 8 hours).

The WCOBRA/TRAC time scale is such that zero seconds on the x-axis corresponds to 2500 seconds after the initiation of the DEDVI break. Containment recirculation begins at 6800 seconds (9300 seconds after the initiation of the DEDVI break) and is fully established at 7000 seconds WCOBRA/TRAC time.

Figure 1: Intact Loop DVI Recirculation Flow

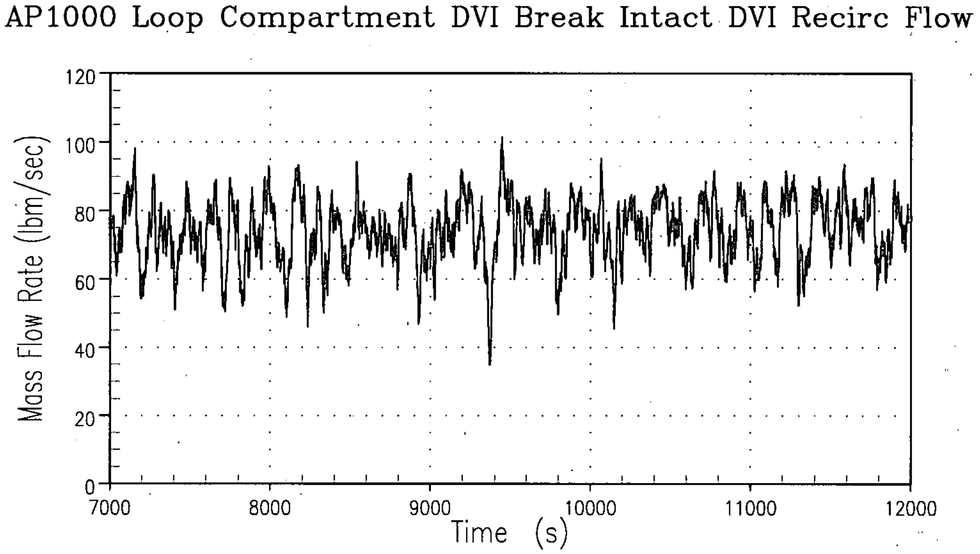


Figure 2: Broken Loop DVI Recirculation Flow

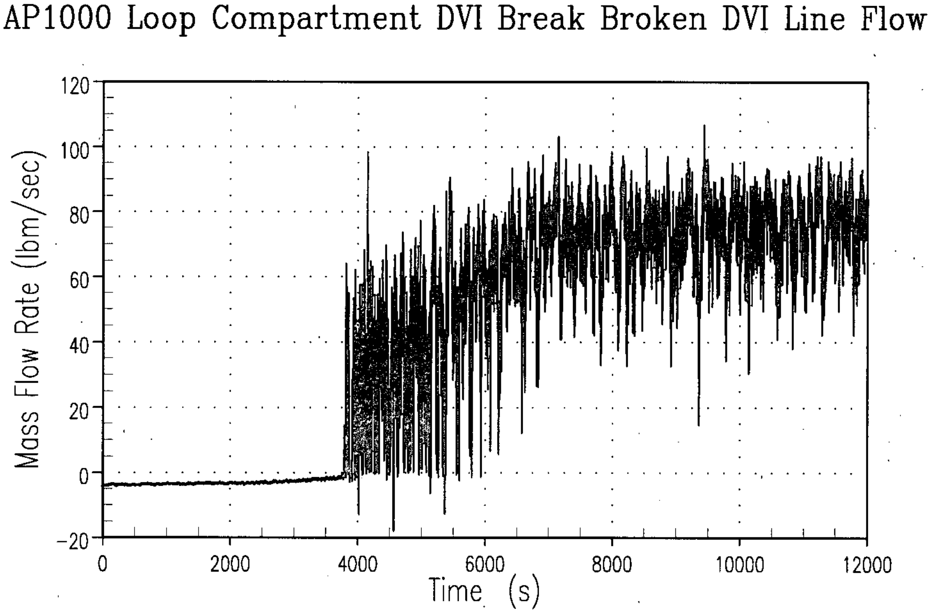


Figure 3: Instantaneous Flow through Break Ratioed to Total Core Flow

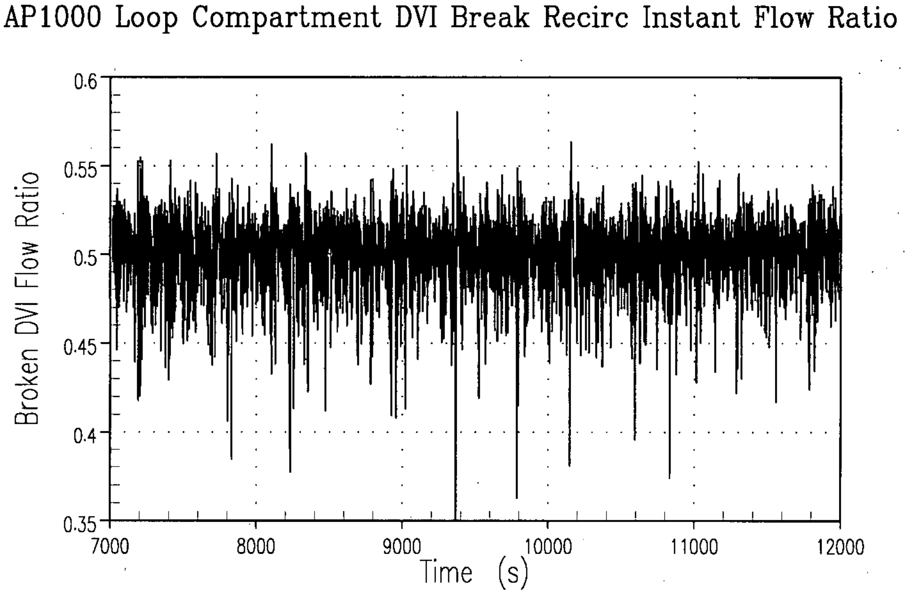
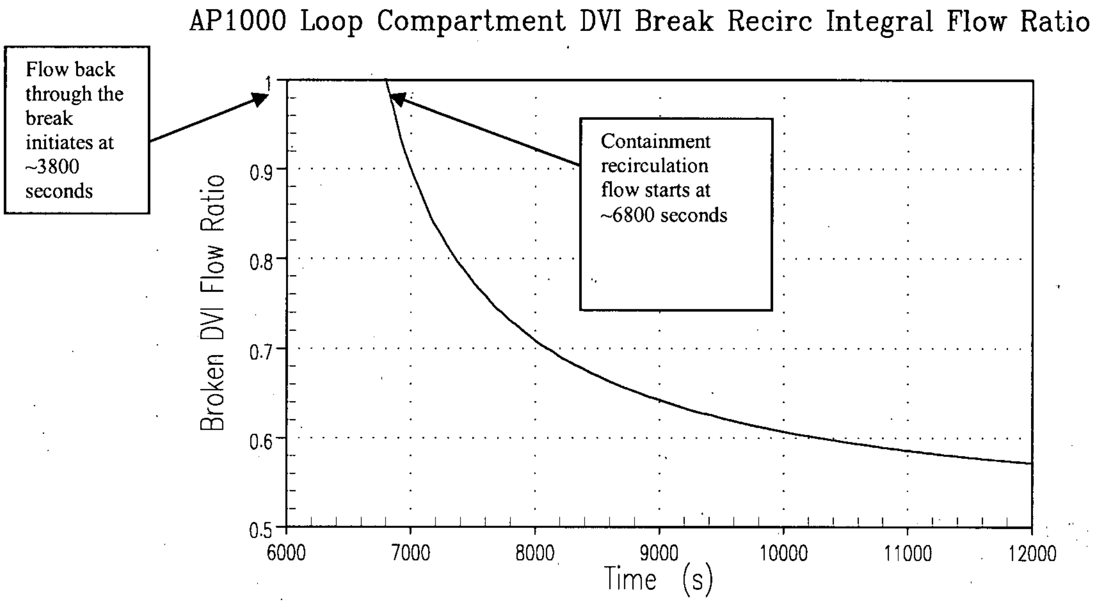


Figure 4: Integrated Flow Ratio (Int. Flow Through Break / Integrated Recirc Flow)



Flow back through the break initiates at ~3800 seconds

Containment recirculation flow starts at ~6800 seconds

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Technical Report (TR) Revision:

None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP6.2.2-SRSB-11
Revision: 1

Question:

Provide responses to the following questions related to APP-PXS-GLR-001, Revision 0, "Impact on AP1000 Post-LCOA Long Term Cooling of Postulated Containment Sump Debris," issued April 28, 2008:

a. In the DEDVI break cases, it is noted that the containment water level exceeds the elevation of the break so that water can flow directly into the reactor pressure vessel bypassing the sump screens. For each of the cases analyzed, including the two sensitivity cases, provide the debris and chemical loading for the water bypassing the sump screens and that taken downstream of the sump screens.

b. Provide the hydraulic head of the IRWST, and the hydraulic head (i.e., water elevation in the containment) over the DVI break location and the recirculation screens with respect to time, the losses in the broken DVI line, and the core inlet resistance for each case analyzed, including the two sensitivity cases.

c. Provide plots of the integrated core boiloff rate and integrated core inlet flow rate for each of the cases analyzed, including the two sensitivity cases.

d. Figure 2-2 indicates the core collapsed level is decreasing. Explain why the level with the unblocked core inlet would decrease while those for the sensitivity cases, Figures 3.1-2 and 3.2-2, decrease for approximately 1500 seconds, then level off for the remainder of the transient. Also explain why the core collapsed liquid levels in the two sensitivity cases are generally higher than the base case.

e. Considering the differences in the core inlet flow rates between the base case and the sensitivity cases as shown by the intact and broken DVI line mixture flow rates (Figures 2-13, 2-14, 3.1-13, 3.1-14, 3.2-13, and 3.2-14), explain why the upper plenum collapsed liquid levels remain almost the same between the base and sensitivity cases (Figures 2-8, 3.1-8 and 3.2-8).

f. Discuss the local heatup effects due to capture of the debris and potential precipitates on fuel rods within the spacer grids and between the spacer grids. The discussion should also consider maximum pre-existing cladding oxide and crud. Justify the amount of oxide and crud assumed for the analysis.

g. On page 1 of APP-PXS-GLR-001, the staff notes that credit is taken for cooling the core from the bypass flow through the broken DVI line from the containment to the downcomer. In DCD Section 15.6.5.4B.3.1, on page 15.6-39, Westinghouse stated that a venturi was inline to limit the flow out the break is located in the DVI line. The bypass flow that flows to the core carries debris through this venturi.

Confirm that the plugging of this venturi has been factored into the cooling flow for the core. If not considered or factored in, please provide an evaluation.

h. In Section 1, “Introduction,” Westinghouse provides five reasons or considerations for selecting the DCD long-term cooling case [DVI line break] as the base for the sensitivity study. The first bullet describes the amount of debris bypassing the containment recirculation screens and being transported to the core for cold leg and hot leg breaks. The second bullet describes a DEDVI break in a PXS room would make available only a small portion of the debris that would be available for a loop break. Explain how these two bullets justify the DEDVI break being the limiting break for long-term cooling sensitivity study. Explain why the DEDVI break chosen is the limiting case from a head-loss standpoint for the IRWST screens, recirculation screens and the core. Also explain when the analyses were begun and why debris would not be present prior to the analysis.

Additional Question:

a. The RAI requested the debris and chemical loading for water bypassing the sump screen and Westinghouse’s response refers to TR 26, Revision 3, Table 5 for the latent debris. Table 5 does not provide the answer for a.

b. When does the reverse flow into the DVI break line occur? What is the time dependent water level in the containment? How is % bypass factor determined from these flows? What is the % bypass during the transient, not the average integrated bypass, but the time dependent % bypass.

c. Why are the integrated core boiloff for the sensitivity cases (Figures RAI-SRP 6.2.2 – SRSC-11c-5 and -7) lower than that of the DCD base case (Figure RAI-SRP 6.2.2 – SRSC-11c-2) having the same decay heat?

Westinghouse Response: < The original response has been revised as shown below to address the additional questions. >

a. Technical Report 26 ,APP-GW-GLR-079, Revision 3, “AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA”, March 2008 provides this information in Table 4~~5~~ for the latent debris.

The results have been calculated using the minimum post-accident recirculation volume of coolant for the AP1000. Table 4 also lists the chemical precipitants in terms of a mass concentration using the minimum recirculation water volume

Table 4: AP1000 Predicted Chemical Precipitate Formation

Precipitants	kg	lb	ppm
$NaAlSi_3O_8$	1.5	3.3	0.6
AlOOH	19.7	43.4	8.3
$Ca_3(PO_4)_2$	0.5	1.1	0.2

b. The hydraulic head of the IRWST, expressed as its liquid level elevation inside the containment during the IRWST injection phase, and the liquid level in containment during the recirculation phase are as follows in the DCD Revision 17 Chapter 15.6.5.4C DEDVI break analysis. The same values apply to the two containment debris sensitivity cases analyzed using the WCOBRA/TRAC AP1000 long-term cooling methodology.

IRWST hydraulic head, then containment hydraulic head			DEDVI LOCA, long-term cooling
Transient Time (time after break occurs) (sec)	Analysis Time (WC/T time) (sec)	IRWST level: then Sump Level during Recirculation (ft)	Level relative to IRWST injection line location, @ 97.0 ft (ft)
~~3000.00~~	~~0.00~~	~~125.96~~	~~28.96~~
3000.00	500.00	125.96	28.96
5232.53	2732.53	117.81	20.81
6486.28	3986.28	113.79	16.79
7390.81	4890.81	111.16	14.16
7820.00	5320.00	110.00	13.00
9098.65	6598.65	110.00	13.00
9300.00	6800.00	110.00	13.00
9400.24	6900.24	106.86	9.86
9450.47	6950.47	106.93	9.93
9701.15	7201.15	107.80	10.80
10654.80	8154.80	107.80	10.80
11257.40	8757.40	107.80	10.80
12666.80	10166.80	107.80	10.80
14377.50	11877.50	107.80	10.80

← Sump injection switchover time

For restart run

At the initiation of switchover, a reduced value of the level is assumed for recirculation to accommodate any dynamic effects from the draining the IRWST into the sump that might slightly affect the static head available for flow into the reactor vessel. The equilibrium containment floodup level of 107.80 ft. is established over the recirculation screens that feed the intact DVI line once 400 seconds have elapsed in the WCOBRA/TRAC restart problem, and this value is maintained thereafter. The 400 second time frame is the period between 'Sump injection switchover time (6800.00 sec)' and '7201.15 sec' in the analysis time (WC/T time column).

The hydraulic head of water in the PXS room with the broken DVI pipe, expressed as the liquid level elevation inside the containment, is identical to the above table values from 6900.24 seconds onward in WCOBRA/TRAC. During the IRWST injection phase of the DEDVI transient, the value is 107.1 ft. from WCOBRA/TRAC analysis time zero until 6598.65 seconds. A value of 106.61 ft. @ 6800 seconds is the sole intermediate input value between the 6598.65 and 6900.24 second points in the DCD Revision 16 Chapter 15.6.5.4C analysis and also in the sensitivity cases.

Consistent with the 107.8 ft. containment floodup level value in the above table being specified for flow from the IRWST, the design value of hydraulic resistance for the broken DVI line input into WCOBRA/TRAC is increased to include an additional loss coefficient (K-factor) of 1.5 to conservatively represent the exit loss for flow from the severed pipe into the PXS room and the subsequent entrance loss from the room into the pipe segment connected to the DVI nozzle.

In sensitivity case 1, the resistance at the core entrance due to postulated blockage equals 2.4*10-6 ft/gpm2; this value is approximately five orders of magnitude greater than the (unblocked) AP1000 core entrance resistance value used in the DCD long-term cooling case. In sensitivity case 2, the resistance at the core entrance due to postulated blockage is double that of sensitivity case 1.

c. The plots of integrated core boiloff rate and integrated core inlet flow rate are provided for the DCD long-term cooling analysis presented in Chapter 15.6.5.4C for both the IRWST injection and the containment recirculation segments of the DEDVI break transient, and for the two sensitivity cases, during the containment recirculation phase.

Each containment recirculation phase case is a window mode computation that begins at 6500 seconds WCOBRA/TRAC problem time and ultimately reflects the quasi-steady-state containment floodup level. The core inlet flow rate integrals show less liquid enters the core in Sensitivity Case 1 than in the DCD analysis, and that less liquid enters the core in Sensitivity Case 2 (the higher resistance sensitivity case) than Sensitivity Case 1. Thus, lower core inlet flow results from the reduced DVI flow rates that are predicted for containment recirculation as a consequence of the postulated sump screen blockages.

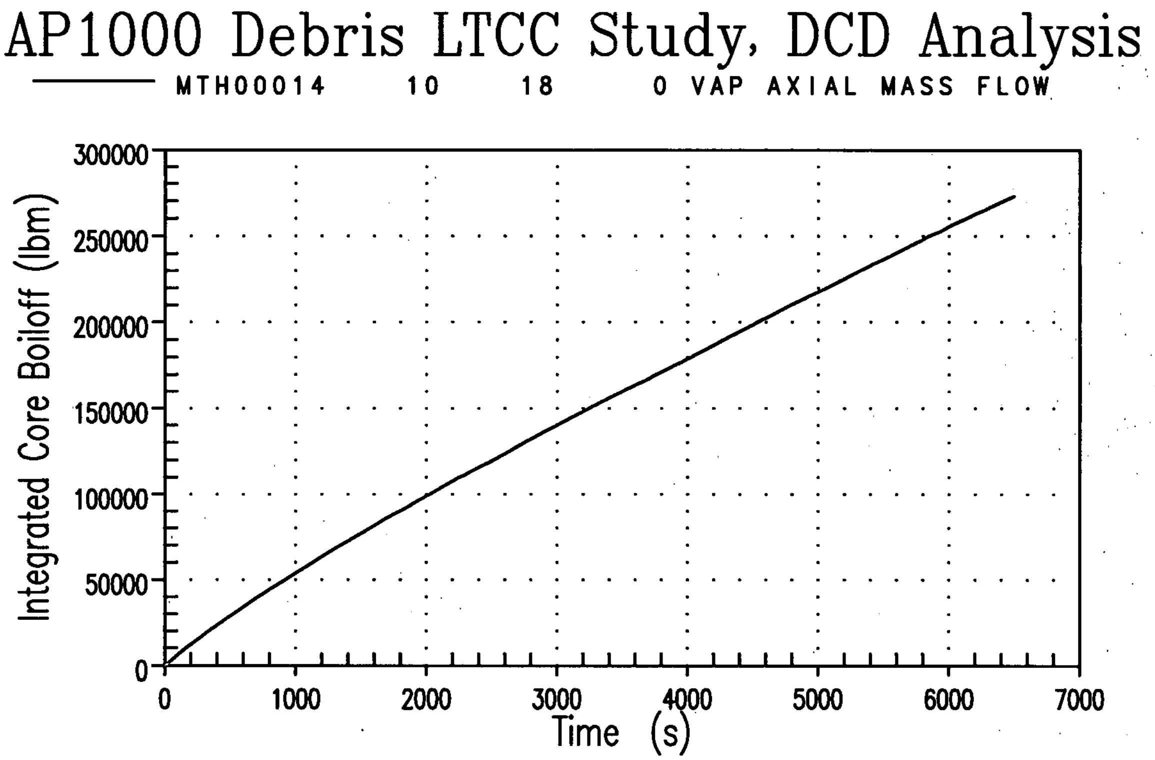


Figure RAI-SRP 6.2.2-SRSB-11c-1: DCD Chapter 15.6.5.4C Analysis Integrated Core Boiloff Rate, IRWST Injection Phase

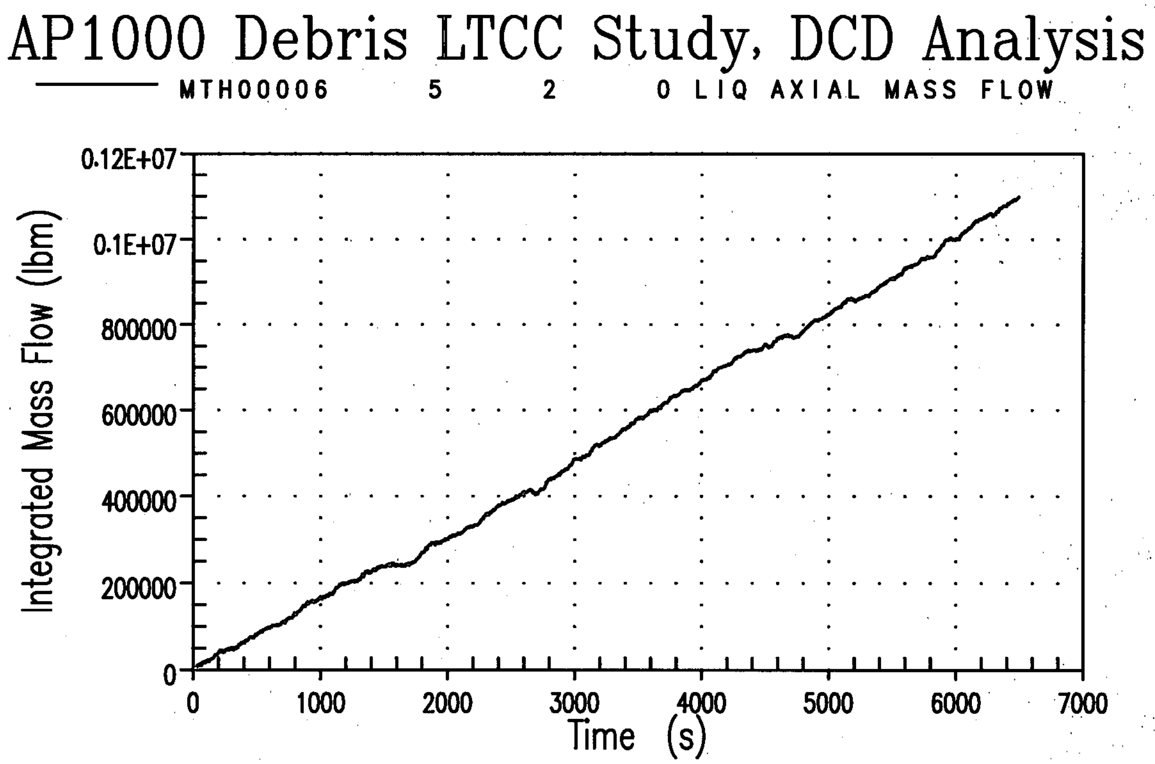


Figure RAI-SRP 6.2.2-SRSB-11c-2: DCD Chapter 15.6.5.4C Analysis Integrated Core Inlet Mass Flow Rate, IRWST Injection Phase

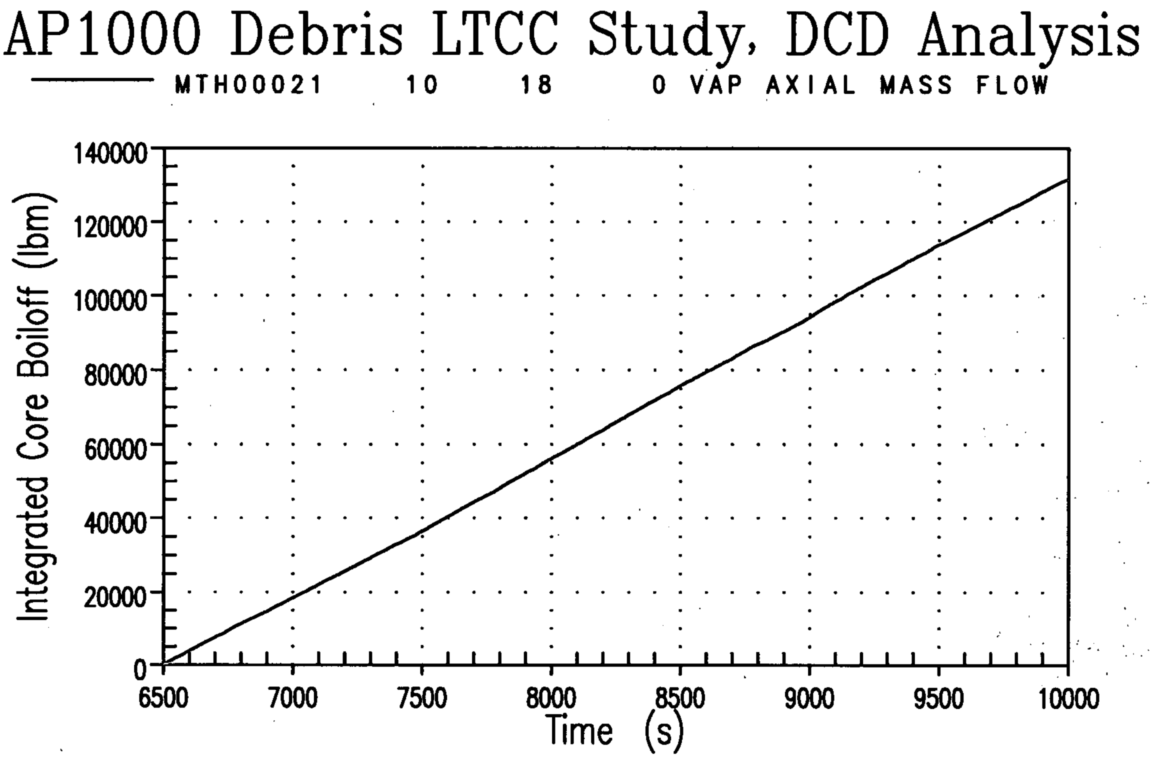


Figure RAI-SRP 6.2.2-SRSB-11c-3: DCD Chapter 15.6.5.4C Analysis Integrated Core Boiloff Rate, Containment Recirculation Phase

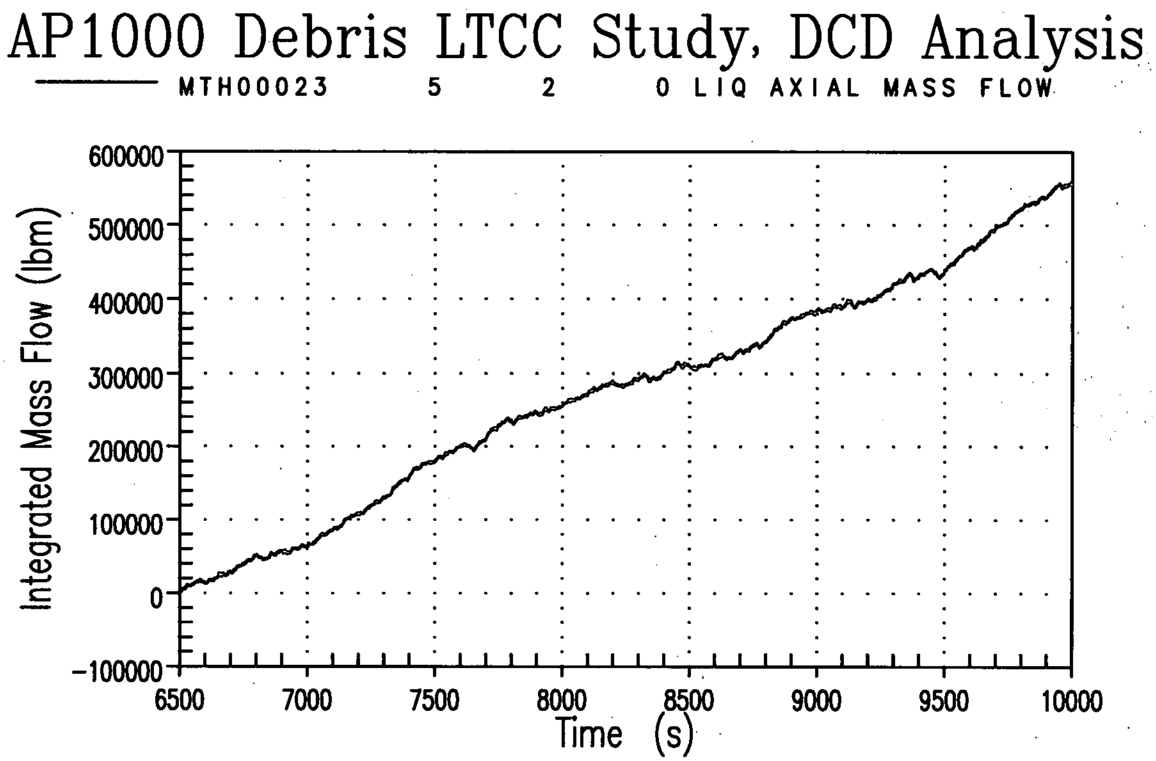


Figure RAI-SRP 6.2.2-SRSB-11c-4: DCD Chapter 15.6.5.4C Analysis Integrated Core Inlet Mass Flow Rate, Containment Recirculation Phase

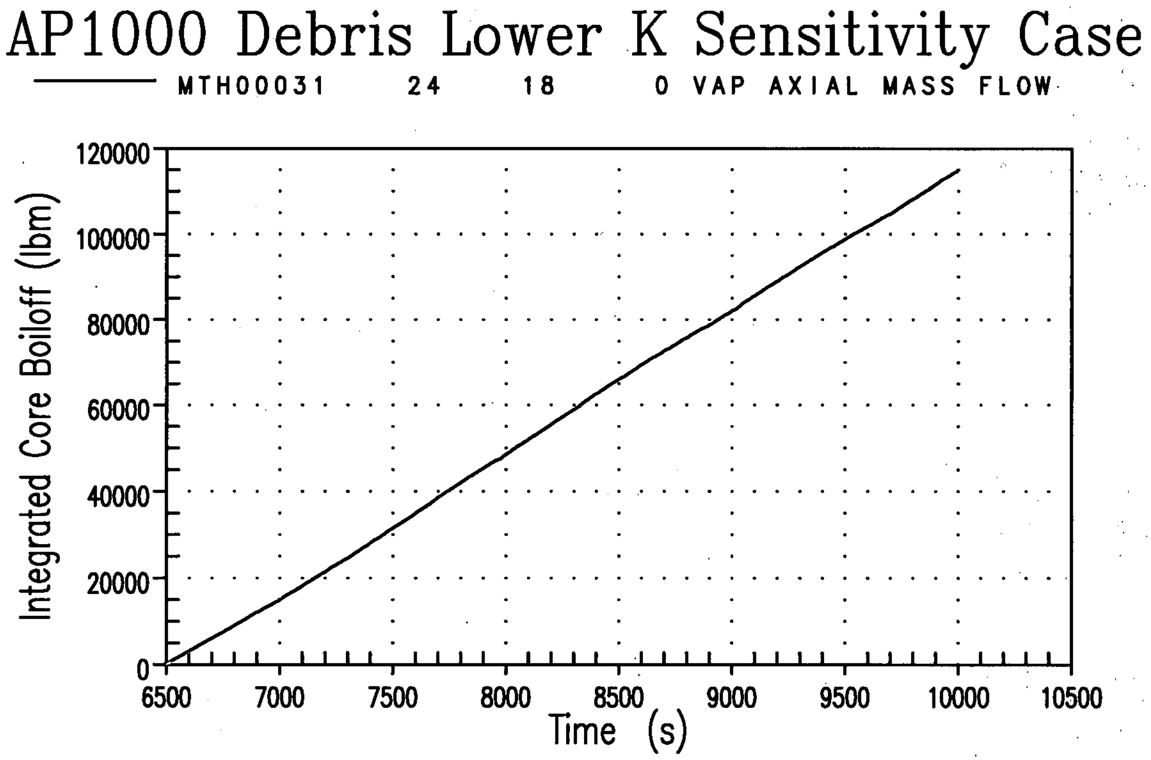


Figure RAI-SRP 6.2.2-SRSB-11c-5: Containment Recirculation Sensitivity Case 1 Integrated Core Boiloff Rate, Containment Recirculation Phase

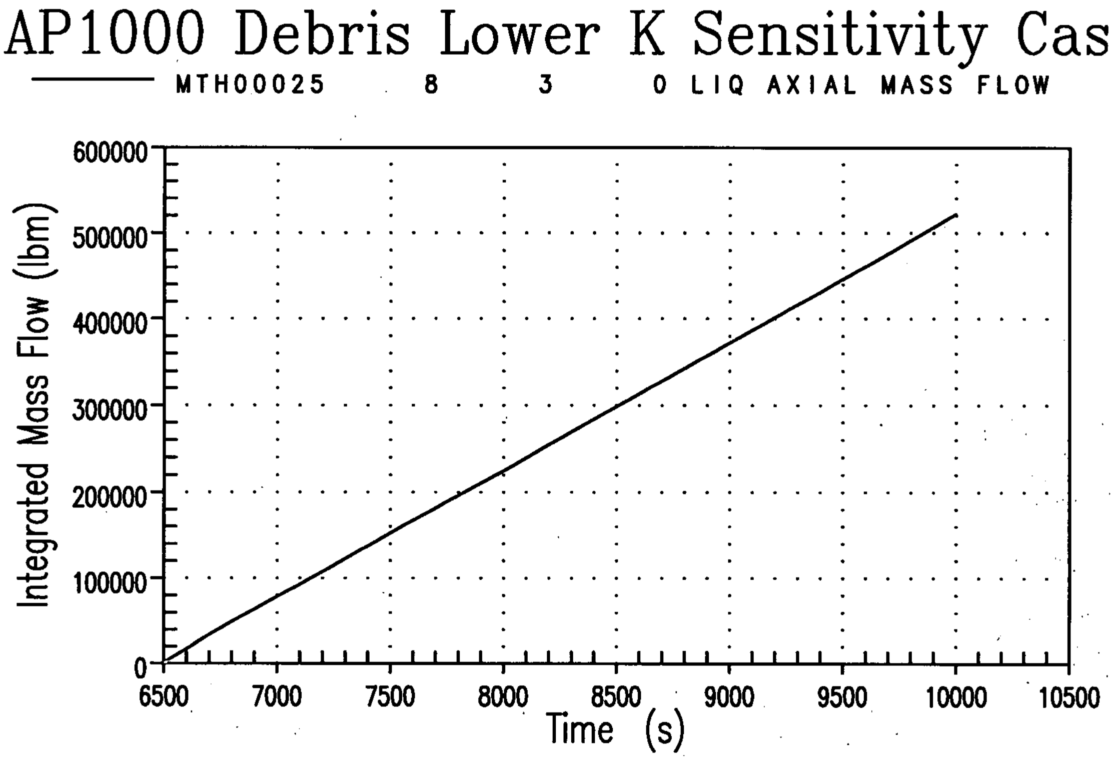


Figure RAI-SRP 6.2.2-SRSB-11c-6: Containment Recirculation Sensitivity Case 1 Integrated Core Inlet Flow Rate, Containment Recirculation Phase

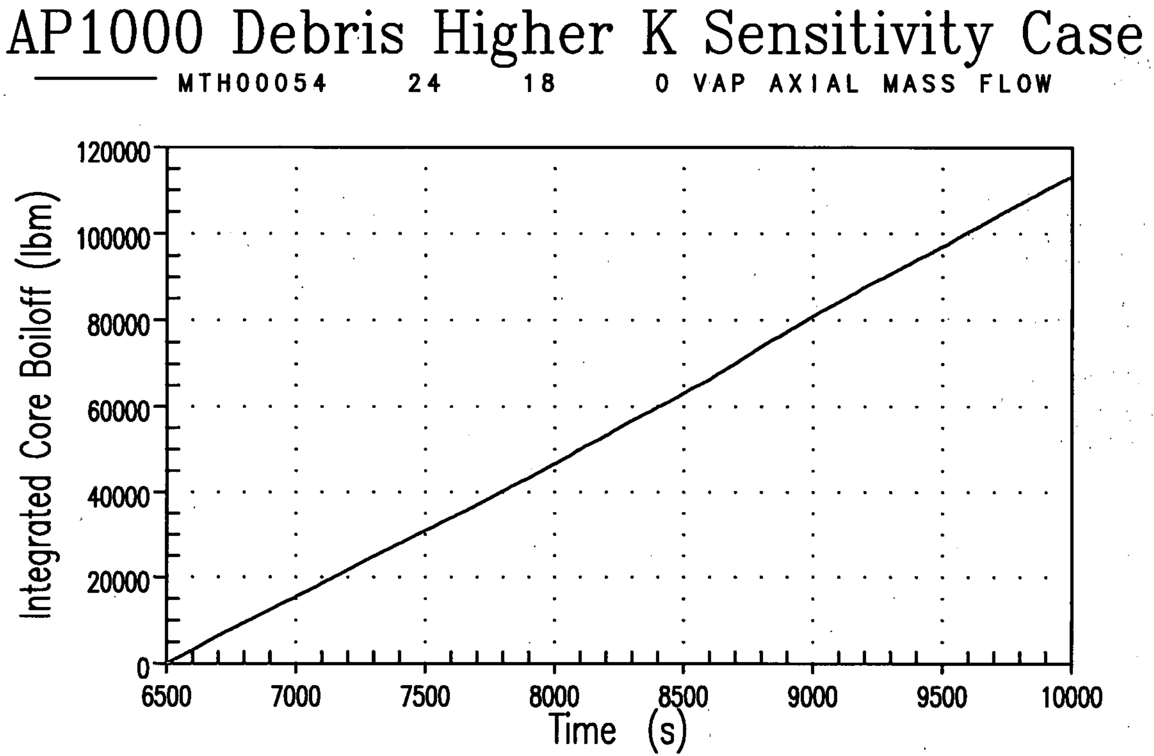


Figure RAI-SRP 6.2.2-SRSB-11c-7: Containment Recirculation Sensitivity Case 2 Integrated Core Boiloff Rate, Containment Recirculation Phase

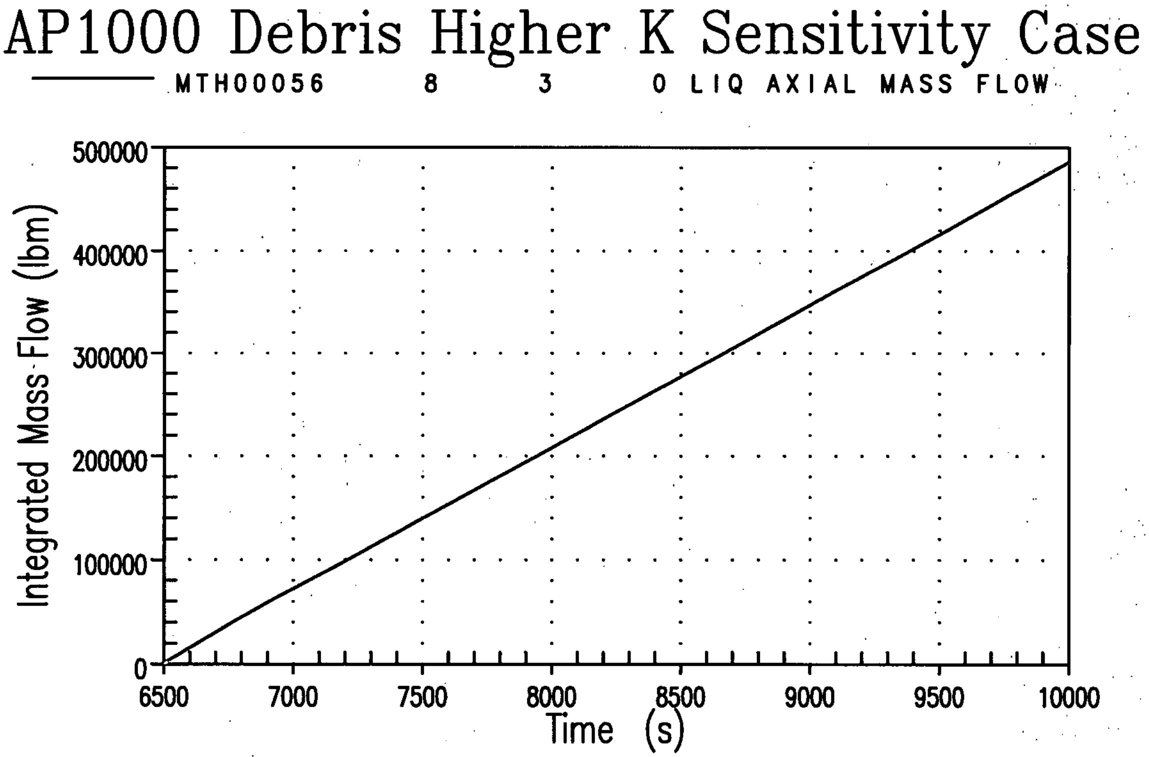


Figure RAI-SRP 6.2.2-SRSB-11c-8: Containment Recirculation Sensitivity Case 2 Integrated Core Boiloff Rate, Containment Recirculation Phase

d. The DCD analysis collapsed liquid level in Figure 2-2 is actually essentially constant over the final 1800 seconds of the calculation, as are the corresponding levels in the two sensitivity cases. In both the DCD analysis and the sensitivity cases, the core level decreases at the start of containment recirculation in response to the containment water level boundary condition presented in the part (b) response. Once the containment water level boundary condition becomes constant, the core collapsed liquid level reaches an equilibrium with it.

The long-term cooling behavior within the reactor vessel is a manometric phenomenon in which liquid in the vessel downcomer proceeds into the core on a net flow basis, as shown in the part (c) response. However, on a microscopic time scale, the flow at the core inlet can fluctuate back and forth, reversing direction when the downcomer and core collapsed liquid levels ebb and flow back and forth due to boiling heat transfer effects in the core. In the design basis (DCD) case, with a small resistance at the core inlet, the manometric flow direction can readily change as core boiling continues. However, in the sensitivity cases the core entrance resistance is orders of magnitude higher, making it much more difficult for reversals in flow to occur due to the manometric effects. The core entrance flow is much more stable in the sensitivity cases because the manometer fluctuations between core and downcomer are damped while the core inlet flooding rate decreases only minimally. The downcomer level in these cases increases to provide the liquid driving head necessary to overcome the increased resistance postulated at the core inlet with little reduction in flow rate.

The continuous manometric perturbations predicted at the core inlet in the DCD case cause fluctuations in flow within the core which impact its predicted collapsed liquid level. The void fraction in the core is higher in the DCD case due to the impact of the inlet flow fluctuations, so the predicted collapsed liquid level is lower in the DCD case with equivalent decay heat removal.

e. During AP1000 long-term cooling, abundant liquid is continuously available in the reactor vessel during the containment recirculation quasi-steady-state process. With abundant liquid present, the predicted upper plenum collapsed liquid level is not directly related to the core inlet flow rates.

The upper plenum two-phase mixture level is a level swell phenomenon that is a function of the core boiloff flow rate and the interfacial drag prediction. Since the containment recirculation phase decay heat values are the same in all cases, the core boiloff rates are almost the same; therefore, the predicted interfacial drag in the upper plenum is about the same in every case, and the predicted upper plenum void fractions are about the same. The presence of the hot legs establishes the same maximum height of two-phase mixture in the upper plenum for every case. Because the same two-phase mixture level and approximately the same void fraction are present in the upper plenum in each case, it follows directly that the collapsed liquid level values are also approximately the same.

f. Technical Report 26 ,APP-GW-GLR-079, Revision 3, “AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA”, March 2008 provides this information on pages 22-26. Additional information on head loss across the core due to debris (latent and chemical) is provided in the report (APP-FA01-T2R-001, Revision 0, “Evaluation of Debris Loading Head Loss Tests for AP1000 Simulated Fuel Assembly During Post-Accident Recirculation”, August 2008.) that provided the results of testing performed for an AP1000 simulated fuel assembly.

g. The venturi line has a 4 inch inside diameter. It has been included in the plugging effects analysis, and was shown to have no impact on flow.

h. A DEDVI LOCA located in a PXS room results in the limiting long-term cooling thermal hydraulic conditions as noted in the five bulleted discussion points. It is also why this case was selected for the limiting case analyzed in the DCD for long-term core cooling. The comment in the second bullet about there being less debris available for injection in this case just points out the conservatism of the sensitivity study performed. The head losses assumed in the sensitivity studies are not based on specific debris loadings for the AP1000.

Rather they demonstrate the capability of the AP1000 to operate with significant head losses even with the most limiting LOCA break location. If the LOCA was not located in a PXS room then the thermal hydraulic conditions would be more favorable and the plant could tolerate higher head losses.

Per the methodology documented in WCAP-14857, Figure 4-2, the initial segment of the AP1000 DCD DEDVI break transient analysis is performed with the NOTRUMP code. This LOCA break is analyzed with NOTRUMP from inception until continuous injection from the IRWST into the reactor vessel has been established. The transient is then continued into long-term cooling with the WCOBRA-TRAC code, which is initialized consistent with the final NOTRUMP-predicted system condition; the WCOBRA/TRAC long-term cooling results are presented in DCD Section 15.6.5.4C. As indicated in the response to part (b), the initial 500 seconds of the WCOBRA/TRAC problem are used to allow the code to equilibrate to the end-of-NOTRUMP condition.

Additional Responses:

b. Response to this additional question can be found in RAI-SRP6.2.2-SRP-10, Rev. 1.

c. All of the referenced cases are performed using the 1971 ANS Infinite +20% decay heat function, according to 10CFR50 Appendix K. The difference in core boiloff observed is a consequence of the lower plenum liquid enthalpy being calculated.

Oscillations in flow direction at the bottom of the core in the DCD base case calculation cause hot liquid present in the core bottom cell(s) to be sent into the lower plenum, increasing the enthalpy. When large resistances are modeled at the core inlet to simulate postulated sump debris in the sensitivity cases, these oscillations diminish, and the lower plenum node is the donor node for flow through the core bottom flow path(s) throughout the calculation. Therefore, the subcooling of liquid present in the lower plenum relative to saturation temperature in the sensitivity cases is not affected by the introduction of any core fluid. The lower plenum subcooling prediction in the sensitivity case modeling the lower core entrance flow resistance increase is compared with the DCD base case prediction in the attached Figure 1. Because more of the core decay power in the sensitivity case(s) is needed to heat to the saturation temperature the more highly subcooled fluid being introduced from the lower plenum, the calculated core boiloff is a bit lower in the sensitivity cases.

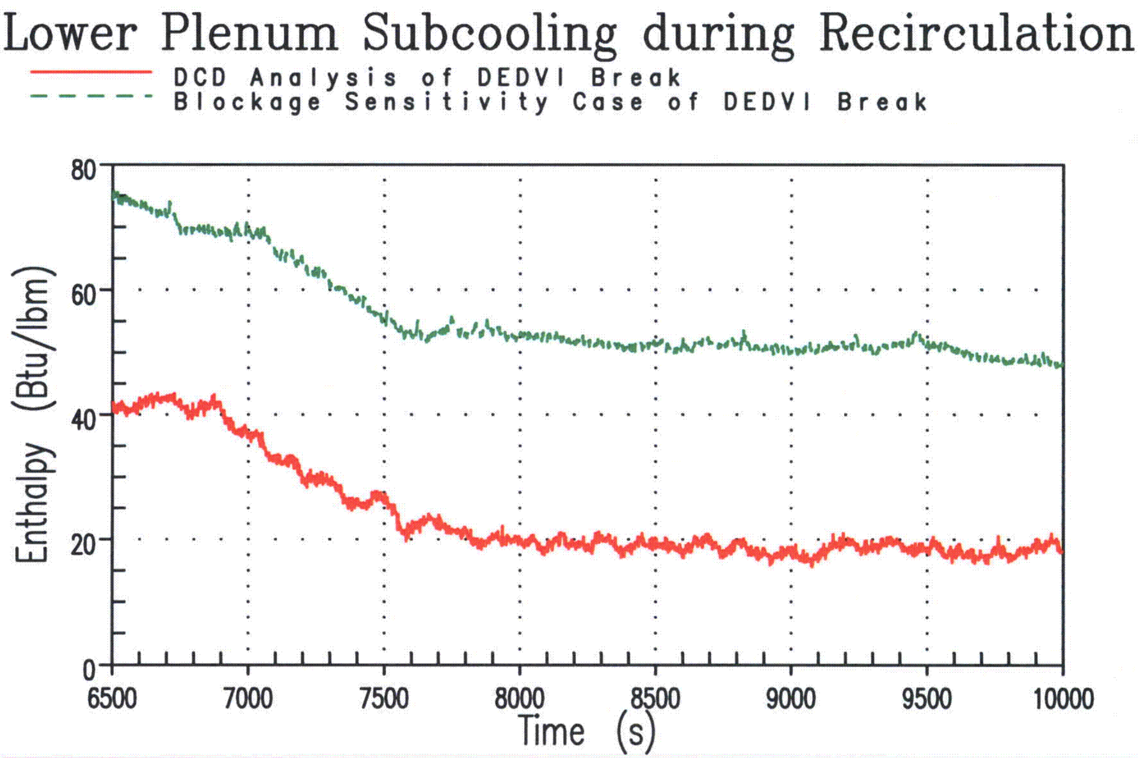


Figure 1: Lower Plenum Subcooling Comparison

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Technical Report (TR) Revision:

None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP6.2.2-SRSB-15
Revision: 1

Question:

In APP-PXS-GLR-001, Revision 0, "Impact on AP1000 Post-LOCA Long-Term Cooling of Postulated Containment Sump Debris," Westinghouse states, on page 2, the following:

> "Also note that during recirculation, water from the IRWST continues to flow into the PXS room and maintains its level; the water flow from the IRWST passes through the IRWST screen, which would remove the debris that would be in the water."

In TR-26 evaluations, all velocities through the screens were considered to be low. The break in the PXS room causes the velocity through the IRWST screen to increase significantly. Additionally, with this significantly higher velocity through the screen, the latent debris in the IRWST has a greater probability of being swept away and into the IRWST screens, which causes a greater chance of debris passing the screens and directly into the core through the break.

Provide the analysis for this additional debris bypass concern and the impact on core cooling and chemical deposits on the fuel. Discuss, in the analysis, the potential for scaling build-up on the fuel from the new chemical products from the AP1000, and if they could impede the heat transfer characteristics of the fuel.

Additional Question:

Westinghouse's response indicates the results of the analysis, but does not provide the analysis. It includes a bumpup factor for the effect of fiber on the chemical deposition, but does not include other chemical debris, does not answer the question concerning the added possibility of more debris passing the screens during the initial part of DVI break.

Westinghouse Response: < The original response has been revised as shown below to address the additional questions. >

The results of the three clad heat-up evaluations performed for the AP1000 are listed in Table 9 on page 26 of Technical Report 26 ,APP-GW-GLR-079, Revision 3, "AP1000 Verification of Water Sources for Long-Term Recirculation Cooling Following a LOCA", March 2008. The third case in Table 9 provides for a minimum recirculation pool volume (resulting in maximum chemical product concentration and therefore chemical deposition on cladding) and an adder (bump-up factor) that models all latent containment debris fiber to be deposited on the clad. The results of this case demonstrate that the total chemical buildup is less than 50 mils, and the resulting calculated clad temperature is unaffected and remains nearly 500°F below the acceptance temperature identified in TR 26. This result is documented in a calculation note that can be made available for review by NRC personnel.

Additional Response:

"Westinghouse's response indicates the results of the analysis, but does not provide the analysis."

The LOCADM calculation is provided in calculation APP-PXS-M3C-057. This calculation will be revised based on the revised amount of fiber and the results will be provided in a revision to APP-GW-GLR-079.

"It includes a bumpup factor for the effect of fiber on the chemical deposition, but does not include other chemical debris"

The LOCADM calculation considers all materials that can form chemical precipitates in the post-LOCA environment. Additionally, the LOCADM calculation conservatively assumes that all of the chemical precipitates generated in the post-LOCA environment (over 30 days) are transported into the core and are available for plate out in the core. In this analysis. none of these chemical precipitates are assumed to be trapped elsewhere (for example, on the containment recirculation sceens).

"does not answer the question concerning the added possibility of more debris passing the screens during the initial part of DVI break"

All the potential chemical precipitates are already assumed to be transported into the core. To account for the possibility that the resident fibrous debris bypasses the recirculation screens and directly enters the RCS and the fuel, a "bump-up" factor is applied on a mass basis to all of the materials contributing to the formation of chemical precipitate. In the case of the AP1000, the mass increase of chemical precipitates is equivalent to the mass of the resident fibrous debris evaluated for the AP1000 containment and assumed in calculation APP-PXS-M3C-053.

For additional information on LOCADM please see the response to **RAI-SRP-6.2.2-SRSB-04.**

Design Control Document (DCD) Revision:

None

PRA Revision:

None

Technical Report (TR) Revision:

None