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ATTACHMENT 1

HOLISTIC OVERVIEW OF GSI-191 RESOLUTION FOR KEWAUNEE POWER STATION

DOMINION ENERGY KEWAUNEE, INC.
KEWAUNEE POWER STATION

HOLISTIC OVERVIEW OF GSI-191 RESOLUTION FOR KEWAUNEE POWER STATION

Dominion Energy Kewaunee (DEK) has been aggressively pursuing resolution of GSI-191 for several years. Numerous physical and programmatic changes have been implemented, and several evaluations and recirculation strainer flume tests have been performed to support the Kewaunee Power Station (KPS) design. With the new commitments described in this response, DEK has addressed the requirements of Generic Letter 2004-02 regarding the potential for recirculation system strainer blockage and related effects at KPS.

An overview of KPS and the activities performed in support of GSI-191 resolution follows.

1. Plant Description

KPS is a two-loop pressurized water reactor (PWR) with a maximum licensed power level of 1772 MW thermal. The containment diameter is 105 ft, height is 192 ft, and free volume is 1,320,000 ft^3. The primary system and components are insulated with reflective metal insulation (RMI).

NOTEWORTHY: The primary system and components are insulated with reflective metal insulation (RMI).

2. Strainer Design

In 2006, the original two recirculation strainer modules, with a combined effective surface area of approximately 39 ft^2, were replaced with a strainer manufactured by Performance Contracting, Incorporated (PCI). The PCI strainer is a horizontal stacked disc strainer consisting of 14 modules with an effective surface area of 768.7 ft^2. The strainer has 0.066 inch perforations to limit the size of debris that can bypass the strainer.

The strainer modules and associated components are designed for a maximum allowable head loss of 10 ft of water at 4000 gpm. The design basis recirculation flow through the strainer is less than 2000 gpm, resulting in structural margin.

The recirculation strainer and debris interceptors, C8x18.75 channel placed strategically along the floor to surround the strainer, are structurally designed to prevent damage or failure from jet impacts and operating basis and design basis loads, including debris accumulation.

CONSERVATISM: The recirculation strainer is designed for an allowable head loss of 10 ft of water; significant margin is available (see Section 8 below).

CONSERVATISM: The recirculation strainer is designed for 4000 gpm flow through the strainer. The maximum design basis flow is less than 2000 gpm.

NOTEWORTHY: Debris interceptors (structural steel channels surrounding the strainer) limit debris from reaching the strainer's perforated material.

3. Debris Generation

The postulated reactor coolant system (RCS) breaks resulting in the worst combination of quantity and types of debris have been determined using the Zone of Influence (ZOI) sizes prescribed in NEI 04-07 (reference 1). Select qualified epoxy coating systems utilize a ZOI of 4D.

KPS currently has mostly RMI in containment. As described in Attachment 2, there is some fibrous insulation in the reactor coolant pump and steam generator compartments that will be removed and replaced with nonfibrous material. Although the recirculation strainer was designed to handle the quantity of fiber currently in containment, due to concerns with the testing protocol used by Kewanee and its vendors, the fibrous material will be removed in order to support final resolution of GSI-191. Consequently, the remaining fiber at any postulated break location combined with latent debris fiber will be maintained sufficiently low to prevent formation of a filtering bed of fiber on the recirculation strainer.

The quantity of latent debris in containment will be monitored and maintained below a specified quantity. Although Kewaunee does not have Nukon insulation in containment, the density of Nukon (2.4 lbs/ft^3) is used to determine the total quantity of allowable latent debris. Using the density of Nukon as opposed to other representative materials with a larger fiber diameter, such as human hair, results in a conservatively low allowable quantity of latent debris. A filtering/thin bed is specified as greater than or equal to 1/16 inch fiber thickness.

Monitoring and maintaining containment cleanliness prevents accumulation of latent debris and is an important element of the Kewaunee GSI-191 program.

NOTEWORTHY: Monitoring and maintaining containment cleanliness is key element for maintaining measured latent debris below the newly-specified allowable value.

NOTEWORTHY: Fiberglass insulation on the pressurizer surge line pipe whip restraints and on service water piping in the reactor coolant pump and steam generator vaults will be removed.

NOTEWORTHY: The remaining fibrous material (insulations, latent fiber) in containment will be maintained at a low volume to prevent formation of a filtering bed of fiber on the recirculation strainer.

CONSERVATISM: The density of Nukon is used to determine the allowable volume of fibrous latent debris in containment.

4. Debris Transport

Implementation of the activities described in Attachment 2 will result in Kewaunee no longer having sufficient fiber in containment from a postulated break to create a filtering bed of fiber on the strainer. Following implementation of those activities, it will be assumed that 100% of the fiber from a postulated break (fibrous insulation, latent fiber) will become Fines (no Smalls, Larges or Intact pieces) and will transport to the recirculation strainer. Transport to the inactive sump pool will not be credited. This approach is conservative because strainer flume tests conducted for Kewaunee show that with Kewaunee's low strainer approach velocity, and the use of debris interceptors, very little fiber is actually expected to reach the strainer's perforated surface. See strainer flume tests (Section 10 below) for additional information.

CONSERVATISM: It will be assumed that 100% of fibrous material (insulations, latent fiber) will become Fines.

CONSERVATISM: It will be assumed that 100% of fibrous material (insulations, latent fiber) will transport to the recirculation strainer.

CONSERVATISM: No credit is taken for debris becoming trapped on equipment, grated surfaces or intervening floor levels.

CONSERVATISM: Transport of debris to the inactive Sump C below the reactor vessel during pool fill will not be credited.

NOTEWORTHY: With Kewaunee's low strainer approach velocity and the use of debris interceptors, little fiber is expected to reach the strainer's perforated material.

5. Upstream Effects

The containment drainage paths will not prevent undetermined quantities of water from reaching the recirculation sump. Drainage paths and holdup volumes are known and are accounted for in the evaluation of sump water level and volume.

Programmatic controls have been established which ensure future modifications in containment will not unknowingly create new holdup volumes (see Programmatic Controls in Section 12).

The containment refueling cavity drain currently has a standpipe with a 1 inch x 1 inch grid recessed in the top of the standpipe. The 1 inch x 1 inch grid will be removed to provide additional assurance that the standpipe will not become clogged with debris.

NOTEWORTHY: The 1 inch x 1 inch grid will be removed from the containment refueling cavity drain standpipe to provide additional assurance that the standpipe will not become clogged with debris.

6. Downstream Effects

Samples of water downstream of the recirculation strainer were collected during strainer flume testing. The samples were sent off for analysis to determine the length, diameter and quantity of fiber that will bypass the strainer. It was determined that 0.2% of fiber in the sump pool will bypass the strainer. The current quantity of fiber in containment is insufficient to form a thin bed of fiber on the fuel that will prohibit core cooling. Furthermore, upon completion of the insulation removal activities described in Attachment 2, the remaining quantity of fiber that could bypass the recirculation strainer is insignificant and would have no adverse impact on the nuclear fuel.

With the 0.066 inch strainer perforation size, the size of particulate material that could bypass the strainer will not result in system or component blockage downstream of the strainer.

NOTEWORTHY: There is insufficient fiber in containment to bypass the recirculation strainer and form a thin bed of fiber on the nuclear fuel support grid.

NOTEWORTHY: The recirculation strainer perforation size, 0.066 inch, will preclude system and component blockage downstream of the strainer.

7. Chemical Effects

The quantity of chemical precipitants formed in the post-accident sump pool was calculated using WCAP-16530-NP (reference 2). The subject calculation determined Kewaunee's primary chemical constituent is sodium aluminum silicate ($NaAlSi_3O_8$). The quantity of chemical precipitants is 8.286 mg/l. Strainer flume testing was performed with as much as 200% of the design basis quantity of chemical debris in the test flume and strainer head loss remained well below the allowable head loss with significant margin available. Fiberglass insulation contributes to the formation of $NaAlSi_3O_8$. Therefore, upon removal of the fiberglass material (as described in Attachment 2), the quantity of chemical precipitation will be lower than currently calculated. The absence of a thin bed of fiber and reduced chemical precipitants results in a significant reduction in the head loss across the recirculation strainer and additional head loss margin when compared to what is currently available. (See Head Loss and Vortexing discussion below.)

CONSERVATISM: Strainer flume testing and head loss measurement was performed with 200% of the design basis quantity of chemical debris in the test flume.

CONSERVATISM: Upon the removal of fiberglass insulation as noted in Attachment 2, chemical precipitation will be significantly lower than currently calculated.

NOTEWORTHY: With the absence of a filtering bed of fiber on the recirculation strainer and reduced chemical precipitants, there will be a reduction in the head loss across the recirculation strainer and additional head loss margin when compared to what is currently available. Current strainer head loss testing indicates almost seven (7) feet of margin is available.

8. Strainer Head Loss and Vortexing

The recirculation strainer is designed for a maximum head loss of 10 ft of water. Several strainer flume tests were conducted and the maximum recorded head loss was 3.28 ft of water (debris bed losses and clean strainer losses combined). Therefore, significant strainer head loss margin is available.

Upon removal of the fiberglass insulation as described in Attachment 2, and including the reduction in chemical precipitation due to the silicon (fiberglass) reduction, even more margin will become available to the recirculation strainer.

The recirculation strainer height is 37.25 inches and the minimum recirculation sump water level at the onset of recirculation is 43.44 inches, which equals 6.19 inches of water above the top surface of the strainer. The strainer was tested with two inches of submergence and no vortexing was observed. An evaluation was conducted that determined the recirculation strainer is not subject to vortexing, air ingestion, void formation or flashing with gas evolution.

CONSERVATISM: The strainer was tested and evaluated for two inches of submergence. The minimum submergence is actually greater than six inches.

9. Net Positive Suction Head (NPSH)

The Residual Heat Removal (RHR) Pump takes suction from the containment sump during the recirculation phase of an accident. There is 14.1 ft of water NPSH available to the pump. Eight (8) ft of water NPSH is required at the design flow rate of 2000 gpm. Therefore, 6.1 ft of water NPSH margin is available. Several conservatisms are used in this evaluation including, but not limited to, the recirculation strainer is assumed to be debris-laden with the maximum 10 ft of water head loss, the RHR pump is assumed to be operating at the pump manufacturer's 2000 gpm design flow rate which is greater than the design basis accident flow rate, and no credit is taken for containment overpressure. The calculated design basis flow rate assumes the RHR throttle valve is failed full open. If this valve is not failed full open, plant procedures specify throttling RHR flow to 1500 gpm in the recirculation mode.

CONSERVATISM: When calculating RHR pump NPSH margin in the recirculation mode, the recirculation strainer is assumed to be debris-laden with the maximum 10 ft of water head loss.

CONSERVATISM: When calculating RHR pump NPSH margin in the recirculation mode, the RHR pump is assumed to be operating at the pump's design flow rate which is greater than the calculated design basis flow through the pump.

CONSERVATISM: When calculating RHR pump NPSH margin in the recirculation mode, no credit is taken for containment overpressure.

CONSERVATISM: The design basis flow calculated through the RHR pump in the recirculation mode assumes the RHR throttle valve is failed full open.

10. Strainer Flume Tests

On three separate occasions strainer flume testing was conducted to validate Kewaunee's strainer design. The maximum allowable head loss across the debris-laden strainer is 10 ft of water.

In 2006, DEK performed KPS strainer flume tests at Alden Research Laboratories (ARL). The tests included a clean strainer head loss test, 1/8 inch thickness Nukon fiber bed head loss test, and design basis debris load test. The pump flow rate used in the tests was equivalent to 4000 gpm, more than two times the design basis flow rate through the strainer. The design basis debris load test included manual mixing of the debris in the flume and water agitation by overhead sprays to maximize the debris transport to the strainer. The maximum strainer head loss measured during these tests was 3.15 ft of water (strainer debris bed losses and clean strainer losses combined).

In 2007, fiber transport tests were conducted at ARL. A debris interceptor, C8x18.75 channel, was placed in the flume upstream of the strainer. Fibrous material was placed in the flume and the recirculation pump was run at flow rates equivalent to 2000 and 4000 gpm. The fiber transported downstream of the interceptor was collected, weighed and measured. The tests confirmed that Kewaunee's strainer low approach velocity and the presence of a debris interceptor will minimize transport of fiber to the strainer.

In 2008, large scale flume tests were conducted at ARL. A clean strainer head loss test, a design basis debris inventory test, and an additional test with more than the design basis debris inventory and 200% quantity of chemical precipitant were conducted. The chemical debris was generated using the methodology in WCAP-16530-NP (reference 2) and its final Safety Evaluation Report issued by NRC, WCAP-16785-NP (reference 3) and PWROG Letter OG-07-270 (reference 4). The recirculation pump was run at a flow rate equivalent to 1950 gpm, which exceeds the design basis flow through the recirculation strainer.[1] The test flume water depth was conservatively low, 40.5 inches as opposed to 43.44 inches minimum sump level (compare to the strainer height of 37.25 inches). The maximum measured head loss occurred with the beyond-design-basis debris quantities and equaled 3.28 ft of water which is significantly less than the allowable head loss of 10 ft of water.

Upon removal of the fiberglass insulation as described in Attachment 2, and including the chemical precipitation reduction due to the silicon (fiberglass) reduction, additional strainer head loss margin will be achieved.

NOTEWORTHY: Strainer flume testing was performed at Alden Research Laboratories on three separate occasions, in 2006, 2007 and 2008.

CONSERVATISM: Strainer flume tests used conservatively high flow rates through the recirculation strainer.

CONSERVATISM: Strainer flume tests used conservatively low water levels.

CONSERVATISM: The computational fluid dynamics model used as input to the flume design uses a conservatively low sump water level to increase turbulence and velocity in the sump pool (see RAI 15).

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[1] Note that RHR pump flow mentioned in the NPSH section above is greater than flow rate through the strainer due to pump recirculation flow which is routed from the pump outlet to the downstream side of the strainer.

11. Licensing Basis

KPS is currently transitioning to Improved Technical Specifications (ITS). The ITS will include a new surveillance requirement for a visual inspection of the strainer and debris interceptors every 18 months. The new surveillance will verify no debris restrictions or structural distress. The new surveillance also requires a visual inspection to ensure no abnormal corrosion, even though the strainer and debris interceptor components are constructed from stainless steel materials. The new surveillance requirements have been incorporated into plant procedures.

NOTEWORTHY: New recirculation strainer visual inspection requirements were incorporated into plant procedures prior to issuance of the corresponding new Technical Specification surveillance requirement.

12. Programmatic Controls

Programmatic controls designed or redesigned as a result of GSI-191 resolution include, but are not limited to the following.

a. Dominion has established a Fleet GSI-191 program with specific individuals designated to ensure the nuclear sites' GSI-191 design and licensing basis and technical documents are maintained. Fleet and individual site procedures have been created to implement the program.

b. Station processes, including the Design Change Process, consider the effect on the post-accident containment recirculation system due to station changes potentially affecting debris generation, debris transport and downstream or other effects.

c. The KPS containment is cleaned each refueling outage for housekeeping and contamination control. This cleaning maintains a low quantity of latent debris in the containment. Latent debris sampling and quantification will occur going forward during every other refueling outage.

d. The Dominion Fleet and DEK have established procedures for the qualified coating program. The program covers application, inspection, and maintenance of qualified coatings in containment and maintains an inventory of unqualified coatings in containment.

NOTEWORTHY: Dominion has created a Fleet GSI-191 Program and assigned designated responsible individuals at the corporate and plant sites to implement the program.

Summary of Holistic View

In summary, DEK's activities for GSI-191 resolution at KPS have addressed the maximum postulated quantity of debris generated as a result of a loss of coolant accident (LOCA). Numerous analyses have been performed to evaluate the debris effects. Physical changes have been made to the plant and additional changes are committed to in this response. These activities ensure the containment post-accident recirculation system will not become blocked as a result of post-accident debris in the containment recirculation sump pool.

The maximum quantity of debris that can be generated by a LOCA at KPS will not create a thin bed of fiber on the recirculation strainer. The quantity of fiber and particulate debris generated post-accident will remain sufficiently low such that head loss across the recirculation strainer remains within the design basis allowance. Fibrous insulation removal activities planned for the upcoming refueling outages will further reduce the quantity of fibrous and chemical particulate debris generated in the recirculation sump pool.

Over the course of 3.5 years, several recirculation strainer flume tests were conducted at ARL to prove the adequacy of Kewaunee's design and validate that large head loss margins are available for both the recirculation strainer and the RHR pump while operating in the recirculation mode.

Programmatic controls have been implemented to ensure long-term maintenance of the containment post-accident recirculation system within its licensing and design basis.

References:

1. NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology," Revision 0, December 2004.
2. WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," Revision 0.
3. WCAP-16785-NP, "Evaluation of Additional Inputs to the WCAP-16530-NP Chemical Model," Revision 0.
4. OG-07-270, Letter from Reginald R. Dulaney (Westinghouse PWR Owners Group) to PWR Owners Group Systems and Equipment Engineering Subcommittee and GSI-191 Points of Contact, "New Settling Rate Criteria for Precipitates Generated in Accordance with WCAP-16530-NP," dated June 7, 2007.

ATTACHMENT 2

SUMMARY OF PLANNED CHANGES AND IMPLEMENTATION SCHEDULE

DOMINION ENERGY KEWAUNEE, INC.
KEWAUNEE POWER STATION

SUMMARY OF PLANNED CHANGES AND IMPLEMENTATION SCHEDULE

Following a series of teleconferences between members of the DEK and NRC staff regarding the resolution of Generic Letter 2004-02, DEK has elected to remove fibrous insulation material from the containment building in the limiting break location. Removal of the insulation, along with other specified changes outlined below, will ensure the fibrous materials remaining in the containment will not form a filtering bed of fiber on the recirculation strainer as a result of post-LOCA generated debris. A filtering bed of fiber on the recirculation strainer, along with particulate and chemical debris, has the potential to cause high head loss across the strainer and challenge the operability of the containment sump recirculation system.

The changes outlined below will address the remaining debris generation and testing concerns and will prevent the need to retest Kewaunee's recirculation strainer system. The planned changes and the impacts of those changes are presented below, along with a schedule for implementation.

A. SUMMARY OF PLANNED CHANGES

Debris Generation and Transport

1. Remove the following insulations from the RCS Loop Vaults.
    a. The fibrous insulation (TempMat) on the pressurizer surge line pipe whip restraints will be removed and replaced with a nonfibrous material.
    b. The fibrous insulation on the Service Water piping that passes through the top of the "B" reactor coolant pump vault will be removed.
2. The JM Thermobestos insulation (calcium silicate insulation with asbestos fibers) in the "A" steam generator vault will be secured with stainless steel banding, similar to that performed in the "B" vault (opposite train) to enable use of a Zone of Influence (ZOI) size equal to 5.45D. (RAI 2)
3. The remaining fibrous material in containment will be assumed to be Fines and subject to transport to the recirculation strainer.
4. The containment refueling cavity drain standpipe will be modified to remove the 1 inch x 1 inch grid/grating recessed in the top of the standpipe to eliminate the potential for debris to be captured on the drain opening. (RAI 40)
5. The calculation of the minimum containment sump level at the start of recirculation will be revised to identify a postulated break at the top of the pressurizer as a non-limiting case for evaluating the recirculation system performance, or that scenario will be removed from the calculation. (RAI 32)

Allowable Latent Debris Quantity to Prevent a Filtering Bed of Fiber

6. The allowable quantity of latent debris (dirt, dust) in containment will be limited to 51 lbm to prevent formation of a filtering bed of fiber on the recirculation strainer when combined with the remaining fiber in containment. (RAI 8)
7. A thin/filtering bed of fiber on the recirculation strainer will be defined as greater than or equal to 1/16 inch thickness.
8. The Dominion fleet latent debris sampling and evaluation procedure will be revised to require a sampling frequency of every other refueling outage for low-fiber plants that are dependent upon plant cleanliness (i.e., Kewaunee) to prevent formation of a filtering bed of fiber on the recirculation strainer. The procedure will specify the sampling frequency may be relaxed after several consecutive sample results (outages) that identify minimal or no increasing volume of measured latent debris and ample latent debris inventory margin. (RAI 8)

B. ISSUE RESOLUTION AS A RESULT OF THE PLANNED CHANGES

The goal of the fibrous insulation removal and Thermobestos insulation banding activities, in combination with revising/reducing the maximum allowed latent debris in containment, is to reduce the overall quantity of fibrous material that could be generated by a LOCA and prevent formation of a thin or thick bed of fiber on the recirculation strainer.

Eliminating the potential for a filtering bed of fiber will address NRC concerns regarding PCI strainer testing performed for Kewaunee. The concerns included the quantity and preparation of fibrous material for testing, and the pre-test transport evaluation (e.g., TempMat tumbling velocity applied and computational fluid dynamics model results at the wall opening near the center of the recirculation strainer).

Debris Generation and Transport

Removal of the fibrous material from the pressurizer surge line pipe whip restraints and from the Service Water piping in RCS Loop B reactor coolant pump vault will eliminate the majority of the fibrous material in the limiting postulated LOCA break locations.

The JM Thermobestos insulation (calcium silicate insulation with asbestos fibers) on the steam generator blowdown piping in the "A" steam generator vault will be secured with stainless steel banding (similar to what was previously done in the "B" steam generator vault (opposite train)) to enable use of a ZOI size equal to 5.45D for both trains. The steam generator blowdown piping outside the RCS Loop Vaults may also be banded, if necessary to minimize the ZOI size for other non-limiting break locations. The use of banding, in addition to the current insulation fasteners which consists of a combination of stainless steel bands, rivets and screws, ensures the calcium silicate lagging configuration is equal to or better than the Ontario Power Generation test configuration referenced in NEI 04-07 that resulted in a ZOI size determination of 5.45D. The quantity of Thermobestos material generated in the RCS Loop A Vaults following banding activities, is equal to 3.7 ft^3. Ten percent (10%) of this material is fibrous (0.37 ft^3) and 90% is particulate (see response to RAI Question 2). The quantity of Thermobestos material in the RCS Loop B Vaults is 2.3 ft^3 (0.23 ft^3 fibrous).

Since the changes above resulted in a revised debris inventory, the RCS postulated break locations were re-evaluated to determine if the location of the limiting debris generating break had changed. Table B-1 provides a summary of the postulated break locations and associated debris generation for all materials. The re-evaluation determined that the limiting break remains the RCS Loop B hot leg break at the steam generator.

The new debris inventory assumes all of the noted fibrous material is Fines (no Smalls, Larges or Intact Pieces). This is conservative because all the fibrous material is subsequently assumed to transport to the recirculation strainer. Furthermore, none of the fibrous, particulate or chemical debris generated will be credited as entering the inactive sump below the reactor vessel. The volume of water in Sump C, below the entry point into the sump, is 3,500 ft^3 (see response to RAI Question 34) which is $\geq$ 15% of the recirculation sump water volume at the onset of recirculation (22,550 ft^3).

Table B-1 identifies the limiting postulated RCS break (i.e., generates the most fibrous debris and detrimental mixture and quantity of debris) as the RCS Loop B hot leg break at the steam generator. A break at the same location on the opposite train, RCS Loop A hot leg break, would create a larger quantity of particulate debris, but there would be less fiber on the strainer to filter the particulate. For either train location, the total quantity of fibrous debris will be insufficient to create a filtering bed of fiber on the recirculation strainer.

TABLE B-1: BREAK CASES

BREAK	THERMO-BESTOS FIBER(1)	THERMO-BESTOS PARTIC.(1)	OKOTHERM FIBER(2)	CERA-BLANKET FIBER	LATENT FIBER(3)	UNQUALIFIED COATINGS	MAX QUALIFIED COATINGS
RCS Loop A Cold Leg	0 ft^3	0 ft^3	0 ft^3	0 ft^3	3.21 ft^3	3.91 ft^3	Note 4
RCS Loop A Intermed. Leg	0 ft^3	0 ft^3	0 ft^3	0 ft^3	3.21 ft^3	3.91 ft^3	Note 4
RCS Loop A Hot Leg	0.37 ft^3	3.37 ft^3	0 ft^3	0 ft^3	3.21 ft^3	3.91 ft^3	Note 4
RCS Loop B Cold Leg	0 ft^3	0 ft^3	0 ft^3	0 ft^3	3.21 ft^3	3.91 ft^3	0.53 ft^3
RCS Loop B Intermed. Leg	0 ft^3	0 ft^3	0.56 ft^3	0 ft^3	3.21 ft^3	3.91 ft^3	0.62 ft^3
RCS Loop B Hot Leg (6)	**0.23 ft^3**	**2.11 ft^3**	**0.56 ft^3**	**0 ft^3**	**3.21 ft^3**	**3.91 ft^3**	**1.28 ft^3**
Rx Vessel Nozzle Cold Leg	0 ft^3	0 ft^3	0 ft^3	0.5 ft^3	3.21 ft^3	3.91 ft^3	Note 5
Rx Vessel Nozzle Hot Leg	0 ft^3	0 ft^3	0 ft^3	0.26 ft^3	3.21 ft^3	3.91 ft^3	Note 5

Notes:

1. Thermobestos material, calcium silicate with asbestos fibers, 10% fiber, 90% particulate.
2. Pressurizer heater cables fibrous insulation material.
3. Allowable based on 1/16 in. fiber bed thickness, latent debris 15% fibrous (see discussion below) (1/16 x 0.08333 ft/in x 768.7 ft^2 strainer surface area = 4.003 ft^3 – 0.79 ft^3 non-latent fiber = 3.21 ft^3).
4. Not calculated, however values are assumed to be equivalent to Loop B data due to mirror image coated structures.
5. Not calculated. However, due to the location of this break being mainly contained within the reactor vessel shield wall, the majority of the debris generated, including failed qualified coatings, would be deposited into the inactive sump below the reactor vessel.
6. Limiting break, RCS Loop B hot leg break at the steam generator.

Allowable Latent Debris Quantity to Prevent Thin Bed Effect

Limiting the quantity of allowable latent debris (dirt, dust) in containment will prevent the formation of a thin bed of fiber on the recirculation strainer when combined with other fibrous material remaining in the postulated break locations. A limit of 51 lbm will be set for the maximum allowable latent debris in containment (see Table B-2).

Historically, a bed of fiber equal to 1/8 inch was believed to cause detrimental strainer head loss when particulate is present in the debris mix. Industry strainer head loss testing has identified that higher head losses can occur at lesser fiber bed thicknesses, especially when calcium silicate is present in the debris mix.[2]

Kewaunee's recirculation strainer has an effective surface area of 768.7 ft^2. A maximum fiber bed thickness of 1/16 inch is selected to ensure high head loss does not occur from a thin bed of fiber filtering particulate debris. The source of fiber for Kewaunee is from latent debris and small quantities of fibrous materials noted in Table B-1 above. The quantity of calcium silicate particulate debris in Kewaunee's containment is low (2.1 ft^3 in the limiting break location). The containment recirculation sump volume at the onset of recirculation is 22,550 ft^3. This is the volume at the minimum sump water level of 43.44 inches (see RAI Question 32). This results in a calcium silicate concentration of 9.3 E-05 by volume, which is sufficiently low that it would be expected to have a negligible impact on strainer head loss.

Using the fibrous debris load from the limiting RCS hot leg break at the steam generator, and using a maximum fiber bed thickness of 1/16 inch, the maximum allowable latent debris is determined to be 51 lbm.

TABLE B-2: STRAINER BED THICKNESS FOR 768.7 FT^2 STRAINER

STRAINER FIBER BED THICKNESS		1/8 IN	1/10 IN	1/12 IN	1/14 IN	**1/16 IN**
Bed Thickness	IN	0.125	0.100	0.083	0.071	**0.063**
Bed Thickness	FT	0.010	0.008	0.007	0.006	**0.005**
Bed Volume	FT^3	8.007	6.406	5.338	4.575	**4.003**
Non-Latent Fiber (1)	FT^3	0.790	0.790	0.790	0.790	**0.790**
Allowable Latent Fiber	FT^3	7.217	5.616	4.548	3.785	**3.213**
Allowable Latent Fiber (2)	LBM	17.321	13.477	10.915	9.085	**7.712**
Allowable Latent Debris (3)	LBM	115.472	89.849	72.768	60.567	**51.416**

(1) Thermobestos fiber, Okotherm
(2) 2.4 lbm/ft^3
(3) Assumes 100% of generated fibrous material is placed on the strainer surface

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[2] NRC Staff Review Guidance Regarding Generic Letter 2004-02, "Closure in the Area of Strainer Head Loss and Vortexing," dated March 2008.

Revised Debris Load – Comparison to Strainer Flume Tests

The results of the strainer head loss tests are presented in Enclosures F-2, I-2 and I-3 in this letter. The minimum specified quantity of Fine fiber and other debris materials used during strainer flume tests is presented in Table B-3 below, in comparison to the revised debris load for the limiting break location. The following is noted:

- Small fiber pieces (Smalls) are not used in the comparison since very few pieces were observed to have transported to the recirculation strainer when the test flume was drained down (see Enclosure I-4). Additionally, the new debris inventory will not include fibrous material larger than Fines.
- TempMat Fines are not used in the comparison since NRC staff has questioned the debris preparation used for the tests. TempMat Fines were questioned as not being prepared with sufficient individual fibers.

TABLE B-3: TESTED CONFIGURATION VS. LIMITING BREAK

DEBRIS	U/M	TEST 3 (ENCL. I-2)	TEST 9 (ENCL. I-3)	LIMITING BREAK REVISED DEBRIS LOAD (2)
Thermobestos Fiber Fines	FT^3	0	0	0.23
Okotherm Fiber Fines	FT^3	0.23	0.23	0.56
Latent Fiber Fines	FT^3	4.69 (3)	4.69 (3)	3.21
Owens Corning Pipe Cover Fines	FT^3	0.44	0.88	0
Total Fines	**FT^3**	**5.36**	**5.8**	**4.0**
Thermobestos Particulate	FT^3	0.49	0.49	2.11
Latent Particulate	LBM	85	100	43.35 (85% of 51 lbm)
Zinc Coating Particulate	FT^3	0.84	0.84	5.19
Epoxy/Enamel Coating Particulate	FT^3	4.68	4.68	
Epoxy Coating Chips	FT^3	0.09	0.09	
Chemical Precipitant	LBM	12.51 (100% of design)	25.02 (200% of design)	12.51
TOTAL HEAD LOSS(1) (including clean strainer losses)	FT	1.10	3.29	

(1) Maximum allowable strainer head loss is 10 ft of water
(2) Assumes 100% transport of generated material
(3) Quantity added AFTER the test pump was started

The data shown in Table B-3 indicates the debris inventory used in the large scale strainer head loss flume tests conducted by PCI at the Alden Research Laboratory facility in 2008 bounds the revised debris inventory. This conclusion is based on the following:

- The quantity of fibrous Fines in the revised debris inventory is bounded by the quantity used in the flume tests, and includes only those fiber Fines added after the recirculation pump was started.
- A thin bed of fiber was not formed on the recirculation strainer during the tests as can be seen from the flume draindown photos that show bare strainer surfaces (Enclosure I-4) and by the low strainer head loss achieved during the tests, even with 200% chemical debris addition to the test flume.

Conclusion

DEK believes that the Kewaunee recirculation system will not be challenged by the generation and transport of post-accident debris based on the following:

1. The holistic overview in Attachment 1.
2. The new commitments and information provided in Attachment 2.
3. The responses to the individual RAI questions in Attachment 3.
4. Previous Generic Letter 2004-02 submittals.

C. IMPLEMENTATION SCHEDULE

The revision to the Dominion fleet latent debris sampling and evaluation procedure will be issued prior to the next refueling outage scheduled to commence in February 2011.

The remaining changes listed in Part A above will be implemented no later than two refueling outages following the current operating cycle's refueling outage. This will afford the time necessary to conduct additional plant walkdowns, perform design activities, order materials and plan and perform the installation to minimize personnel dose and the impact on plant operation.

Following implementation of these changes, the Kewaunee Updated Safety Analysis Report will be updated to reflect the revised recirculation system design basis, including the maximum allowable fibrous debris in containment.

ATTACHMENT 3

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION GENERIC LETTER 2004-02

DOMINION ENERGY KEWAUNEE, INC.
KEWAUNEE POWER STATION

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION KEWAUNEE POWER STATION

Dominion Energy Kewaunee (DEK) responded to GL 2004-02 by letters dated March 7, 2005, July 6, 2005, September 1, 2005, February 29, 2008, May 21, 2008, and December 18, 2008. On August 14, 2009, the NRC staff transmitted a request for additional information (RAI) (reference 1) regarding the response to GL 2004-02 for Kewaunee Power Station (KPS). Revised Questions 5, 6, 7, and 12 to the RAI (reference 2) were received from NRC on October 14, 2009.

The RAI questions and associated DEK responses are provided below. One additional clarification was verbally requested during a teleconference with NRC staff on March 4, 2010.

CLARIFICATION - ZONE OF INFLUENCE SIZE FOR INORGANIC ZINC COATINGS

NRC Request

Please clarify that the Zone of Influence (ZOI) size for qualified inorganic zinc coatings remains as 10D.

Response

Kewaunee's response dated February 29, 2008 (refer to Tables 3.B-2 and 3.H-2 in response), indicates that Kewaunee implemented a reduced ZOI equal to 4D for the epoxy coating systems listed in the table below. This ZOI reduction was based on evaluating Kewaunee's use of Florida Power & Light's coating test report, JOGAR-06-001, Revision 0 (reference 3).

SUBSTRATE	COATING SYSTEMS PRIMER / TOPCOAT(S)
Concrete	• Carboline 195 / Phenoline 305 • Phenoline 305 / Carboline 195 / Phenoline 305 • Phenoline 305 / Phenoline 305
Steel	• Carboline Carboguard 890 / Carboguard 890 • Carboline Carbozinc 11 / Phenoline 305

A ZOI equal to 10D is applied to all other qualified coatings not shown in the table above. In addition, 100% of unqualified coatings are assumed to fail.

A. BREAK SELECTION

NRC Question 1

Please provide the following additional information regarding the break selection evaluation:

a. *the systematic method used in the break selection evaluation,*
b. *the specific locations of the selected breaks along their respective piping component,*
c. *specification of which reactor coolant loop contains the pressurizer,*
d. *justification for not having a reactor vessel nozzle break in the list of break selections.*

Response

The systematic method used to determine Kewaunee's break selection was provided in our responses dated September 1, 2005 (Attachment 1, page 6 of 19) and February 29, 2008 (Attachment, pages 3 and 4 of 42).

Three reactor coolant system (RCS) breaks in Loop (Train) B were evaluated. Those breaks were: RCS hot leg break at the steam generator, RCS cold leg break at the reactor coolant pump (RCP), and RCS intermediate leg break at the steam generator. The RCS hot leg break at the steam generator was determined to be the limiting break. The pressurizer is attached to RCS Loop B and therefore, the RCS breaks in Loop B result in the most types and quantities of debris.

Due to the large zone of influence (ZOI) for the debris types present in these areas (see Enclosure A), additional RCS loop breaks were not analyzed as the debris source term would not change. The insulation debris materials involved in the RCS Loop B break include:

- Reflective metal insulation (RMI) (ZOI 28.6D)
- TempMat encased in 24 gauge stainless steel panels (ZOI 17D)
- Thermobestos (calcium silicate with asbestos fibers) (ZOI 5.45D)
- Fiberglass pipe cover (ZOI 17D)
- Pressurizer heater fibrous cable insulation (ZOI 17D)

A ZOI of 17D or larger encompasses the entire Loop B vaults/compartments (includes reactor coolant pump, steam generator, and pressurizer compartments – see Enclosure A). The limiting break, RCS Loop B hot leg at the steam generator, results in the most detrimental mixture of insulation debris. This break creates additional debris due to its location near the pressurizer, such as Reflective Metal Insulation (RMI) debris from the pressurizer and pressurizer heater fibrous cable insulation debris.

The RCS break at a reactor vessel nozzle will not result in the most detrimental debris generation. This break was initially not analyzed as a limiting debris generation location due to its location outside the RCS Loop B vaults. The nozzles are located within the reactor vessel shield wall, and shielded by overhead "sand plugs" each weighing 3,800 lbs.

The reactor vessel nozzles are insulated with reflective metal insulation (RMI). In 1980, reactor vessel nozzle pipe restraints were installed in the shield wall penetrations between the RCS Loop vaults and the reactor vessel sump. The pipe restraints were insulated with 0.032 inch thick stainless steel Type 304 sheet metal panels encapsulating 3 inch thick Johns Manville cerablanket. The volume of cerablanket insulation in the RCS Loop B hot leg shield wall penetration is calculated as 0.26 ft^3. The volume of cerablanket insulation in the RCS Loop B cold leg shield wall penetration is calculated as 0.5 ft^3.

Debris generated due to a RCS pipe break at the reactor vessel nozzle would cause the RMI to blow down to the bottom of inactive Sump C below the reactor vessel. Some small pieces of RMI and the cerablanket material would blow into the RCS Loop B vault/compartment and could potentially wash down to the containment sump (basement) by blowdown or containment spray washdown. However, a break at this location would not produce any other fibrous debris, other than latent fiber, and would result in minimal coating debris. Further, the debris that would blow down to Sump C below the reactor vessel would stay in this location and not transport to the recirculation strainer as the water in this location does not freely recirculate with the containment basement sump pool. An RCS pipe break in the RCS Loop vault/compartment would blow the restraint insulation in the shield wall penetration(s) into the void below the reactor vessel.

Pictorial views of the analyzed breaks are provided in Enclosure A.

As stated in Attachment 2, Kewaunee plans to remove the fibrous TempMat material from the pressurizer surge line pipe whip restraints and the fibrous insulation on the service water piping in Vault B. Due to these changes, the postulated break locations were re-evaluated, including the reactor vessel nozzle break. The limiting break remains as a RCS Loop B hot leg break at the steam generator. Refer to Attachment 2, Table B-1.

B/C. DEBRIS GENERATION/ZONE OF INFLUENCE/CHARACTERISTICS

NRC Question 2

Please justify adopting the safety evaluation-approved 5.45D zone of influence for calcium silicate insulation for the Thermobestos installed at Kewaunee by comparing the respective jacketing/banding systems to ensure that the Thermobestos is as well-protected as the Ontario Power Generation-tested calcium silicate insulation.

Response

The calcium silicate insulation (Johns Manville Thermobestos) on the steam generator blowdown lines in containment was judged to be similar to the calcium silicate insulation tested by Ontario Power Generation (NEI 04-07, Volume 1, Table 3-1). The calcium silicate insulation tested by Ontario Power Generation (OPG) was clad with 0.016 inch alloy 1100 aluminum jacketing with stainless steel (SS) bands (reference 3). Kewaunee's calcium silicate insulation is wrapped in Type 304 stainless steel jacketing, 0.010 inch minimum thickness, and is fastened with a combination of SS rivets, SS bands and SS screws.

Kewaunee's Type 304 stainless steel jacket on the steam generator blowdown lines has more strength than the aluminum jacket tested by OPG. The tensile strength of aluminum alloy 1100, as cited in the OPG report (reference 3) is 13,000 psi. The tensile strength of Type 304 stainless steel is 73,200 psi. The Ontario Power Generation test utilized 0.5 inch wide by 0.02 inch thick stainless steel bands to fasten the jacketing. Kewaunee's insulation jacketing is fastened with a combination of SS rivets, SS bands and SS screws. In lieu of evaluating the strength of the OPG configuration against Kewaunee's various configurations, Kewaunee added 0.5 inch wide by 0.02 inch thick SS bands, 6 inches on center on the Thermobestos insulation in the limiting debris generation break locations (Vault B, RCS Loop B). The addition of these SS bands ensures Kewaunee's insulation configuration is bounded by the OPG test configuration. As indicated in Attachment 2 to this letter, the Thermobestos insulation in Vault A, RCS Loop A, will also be banded to allow utilization of a ZOI of 5.45D for the opposite train as well.

Additional Verbal NRC Request

Provide the basis for assuming Thermobestos is 10% fibrous.

Response

The Johns Manville Thermobestos material installed at Kewaunee is assumed to be 10% fibrous material. Material specification datasheets are not available for this material as it is no longer made and could not be provided by the vendor. Consequently, the material is assumed to be similar to a current Johns Manville product, Thermo-12, calcium silicate insulation with cellulose fiber. Thermo-12 has less than 10% fibrous material as indicated on the Material Safety Datasheet for this product (Enclosure A-1).

NRC Question 3

Please describe the repairs that were made to the calcium silicate (Thermobestos) and fiberglass insulation systems that justify reducing the amounts of debris generated by these two insulation types. State the zones of influence used for these materials in the *updated debris generation evaluation. Provide the bases and assumptions for the bases for the zones of influence if they differ from those in the staff safety evaluation (SE) on the NEI Guidance Report 04-07.*

Response

As reported in our February 29, 2008 letter (reference 4), jacketed calcium silicate (Thermobestos) insulation that could become submerged post-accident was repaired to eliminate gaps in the jacketing. The location of this insulation is on the steam generator blowdown piping in the containment basement elevation. This insulation is not located in a large break loss of coolant accident (LOCA) worst case debris-generating zone of influence (not inside the RCS Loop Vaults). Therefore, the insulation is not counted in the debris source term. To ensure the insulation remains in place while submerged and does not create calcium silicate insulation debris in the recirculation pool, the gaps in the insulation jacketing exposing the calcium silicate insulation were closed by adding, adjusting or replacing the jacketing, bands and rivets, as required.

Repairs were also made to jacketed fiberglass insulation on the service water lines that supply the reactor vessel shroud cooling coils. This insulation is located on the upper elevation of containment, above and to the south of the reactor vessel. This insulation is subject only to containment spray impingement. It is not in a debris-generating zone of influence. This insulation was identified as having many dents and gaps in the 0.010 inch thick stainless steel jacketing which exposed the underlying fiberglass material. Consequently, a work order was implemented that replaced entire sections of the insulation and jacketing and eliminated gaps in the jacketing that could allow the release of individual fibers into the refueling cavity pool when wetted by containment spray.

The repaired insulation is not within the scope of insulation planned for removal as described in Attachment 2 because it is not in a worst-case break location for debris generation.

NRC Question 4

Please verify that all latent debris is assumed to be Fines or provide a justification for any different classification. Specify separately the amount of latent particulate and latent fiber assumed in the evaluation.

Response

All of Kewaunee's latent debris is assumed to be Fines. The debris is assumed to be 15% fibrous debris and 85% particulate debris (reference 4; Section 3.D, Attachment page 9 of 42) in accordance with NEI 04-07.

The latent fiber surrogate selected for strainer flume testing was NUKON processed through a shredder. The latent particulate selected for strainer flume testing was the Performance Contracting Incorporated (PCI) Pressurized Water Reactor (PWR) Dirt

Mix. PWR Dirt Mix consists of various sizes of silica sands, ranging from < 75 microns to 2000 microns.

Kewaunee's GSI-191 analyses currently assume a total of 100 lbm latent debris in containment. However, as noted in Attachment 2, this value will be reduced to 51 lbm. The quantity of latent debris used in Kewaunee's large scale flume testing was 100 lbm (in the design basis case, Test 3) and 115 lbm (in the supplemental design basis case, Test 9). See also the response to Questions 8 and F.19.c.ii.

NRC Revised Questions 5, 6, 7, and 12

Please provide the following information regarding debris generation, debris transport, and erosion of debris so that the NRC staff can verify that the amounts and size distribution of debris added to the strainer test were appropriate. Please provide this information for fiberglass, TempMat, and Thermobestos.

a. *The amount of each debris type generated by the limiting break(s), including the size categorization of the debris as it is initially generated by the LOCA blowdown. Include the bases for this information, such as approved guidance or test data.*

b. *The amounts of TempMat, fiberglass pipe cover, and Thermobestos that are considered to erode into fine debris over the entire sump mission time and the basis for the amounts provided. Include information regarding how the initial size distribution of the debris affected the erosion results for each type of debris.*

c. *Describe how debris that was considered to reach the strainer by the transport calculation and was added to the head loss test flume, but settled prior to reaching the strainer, was treated with respect to erosion. Did the strainer test include a sufficient quantity of fine debris to account for this source? Debris of interest includes Thermobestos, fiberglass, and TempMat. If a sufficient quantity of fine debris to account for the eroded Fines from these components was not added to the test, provide a justification for not doing so or show that the test was not affected non-conservatively by this issue.*

d. *The amount of each debris type added to the head loss test broken down into the size components fine, small, large, intact. Please include a description of what each debris component represents.*

e. *The scaling factor used during strainer testing and the basis for this factor.*

Response

As noted in Attachment 2 to this letter, Kewaunee will remove the TempMat insulation from the pressurizer surge line pipe whip restraints and will remove the fiberglass pipe cover from the Service Water piping in the RCS Loop B Vaults. Following these two modifications, there will not be any TempMat or fiberglass pipe cover in the limiting break location, a RCS Loop B hot leg break. Therefore, only Thermobestos material will be addressed in this RAI response.

The quantity of Thermobestos material generated by the limiting breaks, a RCS hot leg break at either RCS Loop A or RCS Loop B, and the quantity of material placed in the large scale strainer flume tests is addressed in Attachment 2, Tables B-1 and B-3. For either limiting break location, there will be insufficient fibrous material generated to create a thin bed of fiber on the strainer, that when filtering particulate, would result in the strainer head loss exceeding the maximum allowable loss of 10 ft of water.

The ZOI size used for Thermobestos material, 5.45D, is addressed in response to Question 2, and in Attachment 2 to this letter.

The fibrous portion of the Thermobestos material will be considered as Fine fiber, therefore, erosion of this material is no longer applicable.

The surrogate materials used during the large scale flume tests were:

- 10% fibrous portion: TempMat Smalls - this material should have been Fines and therefore, is not credited in Attachment 2, Table B-3.
- 90% particulate portion: Pulverized calcium silicate powder. A photograph of adding pulverized calcium silicate powder to the test flume can be found in Enclosure B.

The 2008 large scale flume tests were performed with a 7.129% scaling factor. One full-sized strainer module supplied from Kewaunee's inventory was used in the large scale flume tests. The strainer module has a surface area of 54.8 ft^2 when fully submerged, as it was during the tests. Kewaunee's installed strainer has 14 modules with a total surface area of 768.7 ft^2 (includes additional surface area on the last strainer module end cap). Therefore, the test strainer was 7.129% of the size of the installed strainer (54.8 / 768.7) and the debris load for the test was scaled to place 7.129% of the specified material[3] in the flume.

Following the activities stated in Attachment 2, Thermobestos (calcium silicate insulation with asbestos fibers), latent fiber, and pressurizer heater cable fibrous insulation, will remain low enough in quantity to prevent formation of a filtering bed of fiber on the recirculation strainer.

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[3] Specified material was the debris quantity determined to transport to the strainer, plus margin.

Containment cleanliness is a key factor in maintaining a low latent fiber contribution (see RAI 8). All fibrous materials will be assumed to be Fines and will be assumed to transport to the recirculation strainer. Strainer testing with 100% chemical debris, and repeated with 200% chemical debris, included the addition of sufficient fibrous Fines into the test flume after the recirculation pump was started to bound the new fibrous debris inventory. The maximum measured strainer head loss was 3.29 ft of water (clean strainer and debris bed losses combined). This was significantly below the allowable strainer head loss of 10 ft of water.

D. LATENT DEBRIS

NRC Question 8

The staff noted that the licensee provided estimates of the mass of latent fiber and particulate. However, only a brief description of the methodology used to estimate the quantity of the latent debris was provided. The staff determined that the methodology was not presented in sufficient detail to judge its adequacy and conservatism. Similarly the staff noted that although the licensee provided quantitative estimates of the area of tapes, tags, signs and stickers, the procedure used was described insufficiently to judge the adequacy and conservatism of the evaluation. The staff also noted that latent debris quantity (11.3 lbm) is the lowest measured latent debris quantity of any pressurized-water reactor plant (approximately 1/10th the median value), even though the containment sampling was performed during a relatively dirty condition with work in progress. The licensee stated that its strainer head loss analysis and testing assume 100 lbm of latent debris, substantially greater than the 11.3 lbm measured but staff notes, that many plants (including some with low amounts of fibrous and/or particulate insulation), have measured more than 100 lbm of latent debris in containment, so staff needs to have confidence that the licensee's sampling method is sufficiently accurate that the 100 lbm assumed for testing is conservative. Therefore, please describe the surfaces where samples were collected and the number of samples per surface. Please justify that the sample locations were representative of floors, walls, ductwork and equipment surfaces where latent debris could collect. Please summarize the extrapolation/statistical method used to estimate the total latent debris quantity in containment.

Response

Kewaunee is a relatively small PWR (maximum licensed power level of 1772 MW thermal) with a low latent debris load. The containment parameters are as follows:

- 105 ft inside diameter
- 192 ft height – basement floor elevation to dome roof
- 1,320,000 ft^3 free volume
- Four floor elevations
- Reflective metal insulation (RMI) plant

- Coated surfaces

The following latent debris sampling and evaluation procedures were forwarded to the Staff for their review on September 16, 2009 (forwarded by e-mail)[4]:

- NEP-04.23, "Containment Latent Debris Sample Collection," Revision 2.
- NEP-04.22, "Containment Latent Debris Sampling Evaluation," Revision 2.

Initial latent debris sampling and evaluation was performed in October 2004. The evaluation quantified 11.3 lbm latent debris. Fifteen samples were collected. The first three samples were discarded as "practice samples" and one sample with weight loss was not used. The evaluation was based on the eleven remaining samples. With a small number of samples and using statistical analysis, this resulted in a high assumed debris load for some categories. Example:

Floor Surfaces: Sample 12 = 0.021 g/ft^2
Sample 13 = 0.003 g/ ft^2
Sample 4 = 0.187 g/ ft^2
Mean Debris Loading = 0.181 g/ ft^2

The next sample collection and evaluation will be conducted during the 2011 Refueling Outage, which is scheduled to begin in late February 2011.

During the initial sample collection and evaluation, samples were collected from floors, ventilation ductwork, the containment liner and walls. Table 8-1 below displays the data collection and evaluation summary:

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[4] Note that NEP-04.23 and NEP-04.22 were superseded by Dominion fleet procedure CM-AA-CRS-101, Revision 2, and Calculation C11928, Revision 0, in February 2010.

Table 8-1

Sample Identification	Debris (g)	Area (ft^2)	Loading (g/ ft^2)	90% Conf. Upper Limit (g/ ft^2)	Total Area Evaluated (ft^2)	Total Debris (lbs)
Floors						
Sample 12	0.7	33	0.021	0.181	18,575	7.4
Sample 13	0.15	56	0.003			
Sample 4	1.8	9.625	0.187			
Containment Liner						
Sample 7	0.1	51.8	0.002	0.006	41,240	0.6
Sample 9	0.3	72	0.004			
Ventilation Samples						
Sample 6	0.3	3.4	0.088	0.094 (horiz.) 0.059 (vert.)	2,230 (h) 4,667 (v)	1.1
Sample 8	0.8	10	0.08			
Sample 14	0.4	7.6	0.053			
Cable Trays Subject to Containment Spray (1)						
See Note 1	N/A	N/A	N/A	0.094	1,795	0.4
Walls						
Sample 10	0.5	34.9	0.014	0.059	13,738	1.8
Sample 11	0.1	36	0.003			
Sample 15	2.0	45	0.044			
				TOTAL:	**82,245**	**11.3**

(1) Cable tray debris was not sampled due to concerns about employee safety and equipment operation. The debris load for cable trays is assumed to be the same as horizontal ventilation ducts.

The evaluation methodology used for the latent debris quantification is as follows:

- Debris samples were grouped by surface type: floors, containment liner, ventilation ductwork, cable trays subject to containment spray impingement and walls.
- The Sample Mean and the Sample Standard Deviation were determined for the debris mass found per unit area.

$$\bar{x} = \frac{\sum x_i}{n}$$

$$s^2 = \frac{1}{n-1}\left[\sum x_i^2 - \frac{\left(\sum x_i\right)^2}{n}\right]$$

Where:
$\bar{x}$ - mean for group of samples (g/ft^2)
x_i - individual sample mass per area (g/ft^2)
n - number of samples in group
s - sample standard deviation (g/ft^2)

- Assuming the debris is normally distributed, and the number of samples is small relative to the total population, an upper limit on the mean debris loading was determined from the T-distribution. A 90% confidence was selected.

T – DISTRIBUTION VALUES

The upper-tailed t – distribution values provided are at the 90% confidence level (Q = 1 – 0.9 = 0.1), where the degrees of freedom (v) is the number of samples minus 1.

t = 1.886 σ for 3 samples
t = 3.078 σ for 2 samples

v / Q	0.25 (75%)	0.10 (90%)	0.05 (95%)	0.025 (97.5%)
1	1.000	3.078	6.314	12.706
2	0.816	1.886	2.290	4.303
3	0.765	1.638	2.353	3.182
4	0.741	1.533	2.132	2.776
5	0.727	1.476	2.015	2.571
6	0.718	1.440	1.943	2.447
7	0.711	1.415	1.895	2.365
8	0.706	1.397	1.860	2.306
9	0.703	1.383	1.833	2.262

$$\bar{x} - t_{UL}\frac{s}{\sqrt{n}} < \mu < \bar{x} + t_{UL}\frac{s}{\sqrt{n}};$$

$$\mu_{UL} = \bar{x} + t_{UL}\frac{s}{\sqrt{n}}$$

Where: t_{UL} - t distribution value at 90% confidence for sample size *n*
μ_{UL} - upper limit on the mean debris loading at 90% confidence (g/ft^2)

- To estimate the debris mass for a surface type, the upper limit on mean debris loading is multiplied by the total area for that surface type. The total latent debris is the sum of the totals for each surface type.

Recent Programmatic Changes

While preparing the response to this RAI, industry benchmarking was performed that concluded:

- The number of latent debris samples collected by our program is low compared to other plants,
- There are additional surfaces in containment that should be added to our program, and;
- Kewaunee's containment is smaller than many PWRs.

Consequently, the following changes were recently made to Kewaunee's program:

1. The initial latent debris evaluation performed for Kewaunee by a vendor was embedded in the debris generation calculation. A new calculation has been issued that supersedes the latent debris portion of the debris generation calculation. The new latent debris calculation, C11928, Revision 0, is included as Enclosure C-1. The new calculation will be used in concert with Dominion fleet procedure, CM-AA-CRS-101, Latent Debris Collection and Sampling Procedure, Revision 2, which was adopted at Kewaunee in February 2010. The new calculation:

    - Provides guidance on where to collect latent debris samples.

    - Specifies that at least 24 usable samples must be obtained, with samples from each of the surface types.

    - Specifies additional surface area and surface types. Debris loading for the newly identified surfaces in the evaluation was assumed based on sample results from similar surfaces. Additional samples are scheduled to be taken during the next refueling outage in 2011.

The revised quantity of latent debris in containment is 21.903 lbs. The revised quantity is bounded by the 100 lbm latent debris assumed in the GSI-191 analyses, and the 100 lbm latent particulate and 15 lbm latent Fine fiber used in the large scale flume testing.[5]

2. As noted in Item 1 above, the Dominion fleet procedure for latent debris sampling, CM-AA-CRS-101, Revision 2, was adopted at Kewaunee in February 2010. Kewaunee-specific Nuclear Engineering Procedures (NEP), NEP-04.22 and NEP-04.23, were subsequently deleted. Revision 2 of the Dominion fleet procedure, CM-AA-CRS-101, incorporated Kewaunee-specific latent debris sampling and evaluation guidance. The current Dominion fleet procedure, CM-AA-CRS-101, Latent Debris Collection and Sampling Procedure, Revision 2, is included as Enclosure C-2.

   The fleet procedure, when used with Kewaunee's latent debris calculation, provides guidance similar to that found previously in procedures NEP-04.22 and NEP-04.23, with the following exceptions:

   - The fleet procedure allows use of masslin cloth or a vacuum with a high efficiency particulate air (HEPA) filter for sample collection. The previous Kewaunee procedure, NEP-04.23, only specified using a vacuum for sample collection.

   - The fleet procedure specifies a sampling frequency of every fifth refueling outage if cleaning is performed each refueling outage, or every-other-refueling outage if routine cleaning is not performed. Sampling is also required after any invasive or extended maintenance (steam generator replacement, for example), or on any reduced frequency specified by the site GSI-191 Program Owner.

     DEK conducts routine cleaning in containment every refueling outage. However, because Kewaunee is a low-fiber plant and dependent upon plant cleanliness to prevent formation of a filtering bed of fiber on the recirculation strainer, Kewaunee will conduct latent debris sampling and evaluation every other refueling outage. The sampling frequency may be relaxed after several consecutive sample results (outages) that identify minimal or no increasing volume of measured latent debris and ample latent debris inventory margin. This procedure change will be issued prior to the next refueling outage scheduled to commence in late February of 2011.

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[5] Note: As indicated in Attachment 2, the new maximum allowable quantity of latent debris in containment will be limited to 51 lbm to prevent formation of a filtering bed of fiber on the recirculation strainer.

Containment Cleanliness

Kewaunee performs routine cleaning of containment each refueling outage for both cleanliness and contamination control. Routine cleaning will continue to be performed to ensure Kewaunee maintains a low latent debris volume in containment to prevent creating a filtering bed of fiber on the recirculation strainer.

The following activities are performed each refueling outage.

- A containment cleaning activity is placed on the refueling outage schedule that commences approximately upon achieving hot shutdown. Health Physics staff and Controlled Area Maintenance Operators clean floors, walls and equipment as needed. In 2009, nineteen hours was allotted for this activity.
- Separate work activities are scheduled to clean the "A" and "B" train reactor coolant pump vaults. The vaults are pressure washed or steam cleaned.
- Containment Sumps A (waste sump), B (RHR pump suction sump pit) and C (below the reactor vessel) are opened, inspected and cleaned.
- Containment floor drains are flushed and cleaned.

Additionally, the containment is routinely walked-down to identify and remove any miscellaneous debris sources. This activity is routinely scheduled during power operations and is also conducted prior to exceeding 200 °F in the reactor coolant system upon startup from each refueling outage.

E. DEBRIS TRANSPORT

NRC Question 9

Insufficient information was provided in the supplemental response to demonstrate that the debris interceptor testing was conducted in a manner that is prototypical of the expected plant condition. If the interceptor tests are not being used to demonstrate adequate strainer performance, please so state, and the additional questions below need not be addressed. If the interceptor tests are being used to demonstrate adequate strainer performance, then please provide the following additional information concerning the debris interceptor testing:

a. *the basis for adding debris with the test pump stopped.*

b. *a description of the procedure for preparing fine debris.*

c. *a discussion as to whether fine and small debris were prepared and weighed separately to determine the quantities used for testing.*

d. *discussion concerning the concentration in the debris slurries prepared for testing and the potential for debris to agglomerate during preparation and addition in a nonprototypical manner.*

e. *description of the debris addition sequence for all types and sizes of debris used in the test. If particulate debris was not included, then please justify not including it in the testing, since it could result in increased flow restriction at the interceptors, leading to greater flow over the tops of the interceptors, consequently increasing downstream transport.*

f. *description of how far in front of the debris interceptor the debris was added to the test flume and a technical basis.*

g. *description of whether a case considering total blockage at the debris interceptors was considered in the test matrix.*

h. *the technical basis for scaling the debris quantity used for debris interceptor testing to the total debris interceptor area.*

i. *description of the extent to which floating transport was analyzed by the test program, since the debris was likely mixed with water (thereby removing trapped air) prior to the test initiation.*

j. *discussion of any sources of drainage from containment spray, the refueling canal, the pipe rupture, etc., that enter the containment pool near the strainer, and the technical basis for considering the overhead sprays used in the test as representative of the plant condition that would likely involve more concentrated streams of break and spray drainage.*

k. *comparison of the range of velocity and turbulence conditions used for the debris interceptor testing to the computational fluid dynamics calculation for the plant condition and the technical basis for the flow conditions used for the testing.*

l. *discussion of the flume width and water level used for flume testing and whether these parameters are representative of the analogous parameters for Kewaunee.*

m. *description of the physical characteristics of the debris interceptors including at a minimum the height of the interceptors, the size of any openings in the interceptors, and the total surface area of the debris interceptors.*

n. *discussion of the specific individual percentages of the Fines and of small pieces that transported downstream of the debris interceptors.*

o. *the technical basis for using a 40% Fines and 25% small pieces size distribution for Thermobestos and Okotherm debris. Please further describe the form of the remaining 35% of the Thermobestos and Okotherm debris and provide a technical basis for this debris not being considered as transporting to the debris interceptors either in its destroyed form or as eroded Fines.*

p. *description of how the results of the debris interceptor testing are being applied to the Kewaunee strainer performance analysis and identification of the quantities of each type and size of debris assumed to be trapped on the plant debris interceptors.*

q. *description of the methodology used to determine the differential pressure across the debris interceptors due to debris blockage to ensure structural adequacy.*

r. *explanation for why the interceptor tests with less debris added to the flume experienced greater percentages* of debris downstream of the interceptor.

Response

The debris interceptor fiber transport tests reported in our February 29, 2008 letter (reference 4) were performed to model the recirculation system with the debris interceptors in the test flume.

The debris interceptors are sections of C8x18.75 channel placed between the interior and outer containment walls to surround the strainer. The debris interceptors act similar to the existing concrete curb upon which the original recirculation strainer was installed. The debris interceptors can prevent debris that may be traveling along the containment floor from reaching the strainer. The interceptors are 8.375 inches tall (8 inch channel height, mounted on 3/8 inch steel plate). The debris interceptor arrangement is shown in Enclosure D. The lengths of the three debris interceptors are as follows:

- The debris interceptor on south end of the strainer (near end module) is 9 feet 2.6 inches in length.
- The debris interceptor on the west side of the strainer, between the two interior containment basement walls, is six feet in length.
- The debris interceptor on the north end of the strainer (near the strainer exit piping) is 8 feet 3.4 inches in length.

The purpose of the 2007 debris interceptor fiber transport tests was to determine the quantity of fiber that collects on the recirculation sump strainer without artificially placing the debris directly on the strainer as was done during the 2006 tests.

Subsequent to performing the 2007 debris interceptor tests, Kewaunee performed a series of large scale flume tests to measure strainer head loss with the design basis debris load and with an improved chemical debris surrogate. The debris interceptors were modeled in the large flume. The large scale flume tests were conducted in 2008 and they became the credited design basis strainer head loss tests. The debris interceptor tests performed in 2007 provided useful fiber transport information. However, the interceptor tests are not the credited tests and are not used to demonstrate adequate recirculation strainer performance.

Therefore, the additional information requested in items a through r of this NRC question are not addressed.

NRC Question 10

The supplemental response described erosion testing that was used as a basis for the assumption of 10 percent erosion of fiberglass pipe cover and Temp Mat fibrous debris.

a. *Please describe the test facility used and demonstrate the similarity of the flow conditions (velocity and turbulence), chemical conditions, and fibrous material present in the erosion tests to the analogous conditions applicable to the plant condition.*
b. *Please justify taking credit for any erosion tests conducted at a minimum tumbling velocity if debris settling was credited in the test flume for velocities in excess of this value (e.g., in front of the debris interceptor).*
c. *Please identify the duration of the erosion tests and describe how the results were extrapolated to the sump mission time.*

Response

As noted in Attachment 2 to this letter, Kewaunee will remove the TempMat insulation from the pressurizer surge line pipe whip restraints and will remove the fiberglass pipe cover from the RCS Loop B Vault. Following these two modifications, there will not be any TempMat or fiberglass pipe cover in the limiting break locations, a RCS Loop B hot leg break, and all remaining fiber will be assumed to be Fines.

NRC Question 11

Please identify whether erosion of Thermobestos debris in the containment pool was accounted for in the sump performance analysis. Please state the erosion percentage assumed over a 30-day period and discuss the technical basis for the assumed erosion percentage.

Response

See Attachment 2 and response to "NRC Revised Questions 5, 6, 7, and 12".

NRC Question 12

Please describe whether/how erosion of debris that settles in the test flume is accounted for in the sump performance evaluation. If this phenomenon was neglected, please estimate the quantity of eroded fines from large and small pieces of fibrous and Thermobestos debris that would result had erosion of the settled debris in the head loss test flume been accounted for and justify the neglect of this material in the head loss testing program. If this eroded debris is not accounted for in a prototypical or conservative manner, then please provide a basis for the conservatism of the analytical debris erosion results given that the analysis significantly underestimates the total quantity of settled debris (when debris that settled in the test flume is considered).

Response

See Attachment 2 and response to "NRC Revised Questions 5, 6, 7, and 12".

NRC Question 13

Please identify the computational fluid dynamics code used to determine the flow pattern in the containment pool and provide an overview of the simulations run and modeling assumptions. In addition to this general discussion, please also provide the following specific information:

a. *description of how the debris interceptors were modeled in the input deck (e.g., as a porous medium, fully blocked, time-dependent modeling, etc.) and how the flow split between the various interceptors was determined.*
b. *description of the locations where drainage from the break, containment sprays, and any other sources of significant water addition, is assumed to enter the containment pool and how they are modeled in the code.*
c. *description of the size of the computational domain and boundary conditions in the model.*
d. *discussion of the main physical models used in the computational fluid dynamics simulation (e.g., turbulence).*
e. *basis for concluding that the simulations run are bounding with respect to debris transport.*

Response

As indicated in Attachment 2 to this letter, following removal of the fibrous insulation material on the pressurizer surge line pipe whip restraints and the Service Water piping in RCS Loop B Vaults, all remaining fibrous material in containment will be considered Fines and subject to transport to the strainer. Kewaunee is no longer relying on the computational fluid dynamics (CFD) analysis to determine the quantity of debris that will transport to the strainer. The total quantity of fiber from any generated break is limited to prevent the formation of a filtering bed of fiber on the recirculation strainer.

Large scale strainer flume tests performed in 2008 demonstrate significant strainer head loss margin is available to address the combined effects of chemical, (non-thin bed) fiber and particulate debris. The CFD model was used as an input to designing the large scale flume.

Kewaunee's CFD analysis of the recirculation sump pool was performed by Alden Research Laboratories (ARL). ARL utilized the following computer codes in the development of the CFD:

- Fluent, Version 6.1.22 - state-of-the-art general-purpose commercial CFD software for modeling flows involved in complicated geometries. Fluent version 6.1.22 was used to perform the Kewaunee Power Station CFD simulations.
- Gambit, Version 2.1.6 - used to generate the computational mesh and define boundary conditions on surfaces required to perform the CFD simulation. The final

solid model included all pertinent features from floor elevation to the water surface elevation at the start of the recirculation.

- AutoCAD, Version 2008 - used to compute the projected areas where the velocity exceeds the incipient tumbling velocity.
- Microsoft Excel 2007 - used for general spreadsheet calculations.

The objective of the CFD analysis was to model the entire containment basement, determine the sump pool area velocities, and determine the amount of debris, classified by type and size, which could potentially transport to the containment sump strainer or debris interceptor areas during the recirculation phase of a LOCA.

The analytical methodology follows the methodology outlined in NEI 04-07 and in the NRC Safety Evaluation Report (SER) for NEI 04-07. A steady state CFD simulation was performed for the worst-case debris generating break scenario (RCS Loop B hot leg break) to a converged solution. The CFD results were post-processed by plotting three-dimensional (3D) surfaces of constant velocity. The extent of the 3D surfaces were projected onto a horizontal plane to form a flat contour. Closed curves around the projected velocity contour were automatically digitized and the area within the curves was calculated.

The model was created as follows:

- The model was prepared using plant drawings, photographs and dimensions provided from field walkdowns.
- Objects above the defined water surface elevation of 595.375 ft (containment vessel floor elevation 592 ft + water depth 40.5 inches = 595.375 ft) were not included in the model.
- Relatively small individual objects less than six (6) inches in longest dimension were not included in the model.
- Walls, concrete columns and steel support columns are addressed in the model since they are considered to play an important role in restricting flow. Typically, the walls and concrete columns have regular shape and are modeled as shown in the plant drawings. For some steel support columns, the detailed structure, such as the anchor bolts, are not modeled or their shape is simplified.
- The strainer has 14 modules with each having 6 disks. Instead of modeling each disk, each strainer module is simplified as a cubic box with dimensions of 2.25 ft wide, 0.71446 ft long, and 2.89583 ft high and its six faces (top, bottom, north, south, east, west) are open to flow. The cross shape structures on the sides of the strainer modules are not modeled.
- The modules are connected by a pipe with a diameter of 18 inches which is modeled.

- The three debris interceptors at the entrance of the three openings to the strainer area are modeled as solid shapes. The 3/8 inch gap between the interceptor bottom and the floor is ignored and is blocked to flow.
- The refueling cavity filter skid near the strainer assembly is simplified by modeling four cylinders 32 inches high and 10 inches in diameter, and 14 cylinders 32 inches high and 5 inches in diameter. All the cylinders are sitting on a 4-inch high flat slab.
- The reactor coolant drain tank is surrounded by solid walls. The tank is not included in the model, but the walls are included.
- The regenerative heat exchanger is not included in the model. It is assumed not to influence the general flow pattern in the containment sump because it is a relatively long distance from the strainer area and it is located within a rectangular shape cubicle with walls on three sides.
- The service water valve gallery (cluster), out of the main recirculation flow path, was modeled as a solid cube for simplification.

An overview of the CFD simulations follows:

Using the solid model, a body-fitted hybrid (hexahedral and tetrahedral cell topology) three dimensional mesh was constructed in GAMBIT, including objects submerged underneath the selected water surface level in the containment. This geometry was meshed in GAMBIT. The containment was divided into six proximity zones. The mesh was structured according to the division of the zones. Each zone included a few volumes. The meshed volumes in each zone were grouped as one fluid group. Although hybrid mesh topology was used accordingly, hexahedral topology was applied as much as possible. The entire computational domain was meshed and consists of about 2.7 million cells. Finer mesh was distributed in Zones 1 through 5, which are closer to the strainer modules. Inflow and outflow boundaries for the numerical model were specified in GAMBIT. ARL developed a method for introducing the break flow into the pool, at the water surface, which preserved the momentum and vertical trajectory of the break flow but did not require extending the numerical simulation to the elevation of the break. Spray flow into the pool at the water surface was included in this study. The computational mesh and inflow/outflow boundary specifications were exported from GAMBIT and imported into the FLUENT CFD software program. The values for each boundary condition were set in FLUENT as were the properties of the working fluid (water). A two-equation standard turbulence k-ε model with wall functions was used to compute the turbulence kinetic energy, k, and its dissipation rate, ε. The computed k and ε were used to calculate the turbulence viscosity which was used to close the governing equations. Steady-state converged solution was obtained.

A variety of hydrodynamic parameters were available from the steady-state converged results. Among these parameters and which were used in this study for analysis included velocity components in x, y, and z directions. It should be pointed out that beside the velocities, the pressure, kinetic energy and its dissipation rate were used to monitor and control the convergence of solution.

Two flow simulations were modeled:

- The condition at the initiation of recirculation. Flow into the RCS and out of the RCS break is equal to 4456 gpm, which is the maximum RWST injection (2586 gpm, SI and RHR) plus recirculation flow through the strainer (1870 gpm). An additional 1390 gpm containment spray injection flow enters the sump pool. This condition is modeled at the minimum sump level at the initial onset of recirculation and lasts approximately 14 minutes.
- The long-term recirculation condition. This is modeled as 1870 gpm flow through the recirculation strainer that enters the RCS and spills from the RCS back to the sump. For conservatism and simplification, this scenario is modeled at the same minimum sump water level. However, the actual sump water level at this condition would be significantly higher.

Both flow simulations were prepared for the limiting break, a RCS Loop B hot leg break. A break in RCS Loop B not only creates the worst quantity and combination of debris, but RCS Loop B is also physically closer to the recirculation sump strainer. Closer proximity to the strainer results in a more conservative evaluation of turbulence caused by the RCS spill flow as well as debris distance traveled.

See also the Alden presentations from the September 15, 2009, and November 10, 2009, teleconferences, included as Enclosures E-1 and E-2.

See also response to Questions E.15, velocity and turbulence contour plots, and E.16, debris distance traveled.

NRC Question 14

Drainage from the elevation above the containment basement was assumed to reach the containment pool primarily through the south stairwell due to a 2-inch floor collar, weirs, and a toe-rail at the north stairwell. Following a loss of coolant accident, if large pieces of debris are able to settle out on this floor elevation, flow to the south stairwell could be partially restricted, resulting in pooling of water and redirection of part of the drainage through the north stairwell that is closer to the containment sump strainer. Please describe how these phenomena were analyzed in the debris transport calculation, how flow to the containment pool was distributed between the north and south stairwells, and whether any hold up of water on this elevation was considered.

Response

As indicated in Attachment 2 to this letter, Kewaunee will remove the TempMat insulation from the pressurizer surge pipe whip restraints and will remove the fiberglass pipe cover from the Service Water piping in RCS Loop B Vault. These two activities will eliminate any fibrous debris that would be larger than Fines. However, reflective metal insulation, although not transportable in the Kewaunee sump pool, is still a generated debris larger than Fines.

The steam generators, reactor coolant pumps and pressurizer are located inside concrete compartments (referred to as "vaults"). The RCS piping, except immediately adjacent to the reactor nozzles, is located inside the vaults (refer to Enclosure A). Inside the vaults are horizontal steel grate work platforms and solid concrete floor surfaces, and vertical wall partitions. The concrete vault structures are open to the containment on top, above the highest floor elevation (see Enclosure M, page 2), and are open to the containment at the bottom of the vaults, approximately 13 ft above the containment basement floor elevation. Debris generated by a LOCA inside the vaults could wash down to the sump (basement elevation) from the openings in the vaults, or could be ejected into the upper containment elevation. Debris ejection into the upper containment elevation would be minimal or limited to small debris due to the concrete and steel structures and components inside the vaults (see response to RAI Question 40).

Potential LOCA pipe break locations outside the vaults include a break at the reactor vessel nozzle, or piping connected to the RCS with a much smaller diameter than the RCS. A reactor vessel nozzle break is not a limiting debris generation location (see Response to Question 1). There are no breaks outside the vaults that would generate large debris on the containment floor elevations above the basement floor so as to cause a potential for debris blockage of the drainage path down the unobstructed south stairwell.

Containment spray drainage enters the containment basement via the following main paths:

1. Spray into upper vaults that drain to the basement out the bottom of the vaults.
2. Spray into the refueling cavity that drains to the containment basement via the cavity drain.
3. Spray onto solid floor surfaces that drains to lower floor elevations and eventually to the basement via unobstructed floor penetrations (on two upper floor elevations only; the floor elevation above the containment basement has collars around floor penetrations).
4. Down unobstructed stairwells.
5. Through floor drains that lead to an isolated waste sump that overflows into the basement/sump elevation.

There is no containment spray after the RWST injection phase ends for the design basis event (recirculation spray is not used in response to a design basis event).

The calculation of minimum sump water level at the initiation of recirculation assumes water holdup on all floor elevations due to containment spray drainage that has not yet reached the sump (see response to Question 34).

Views of the containment vault configurations are included as Enclosures A, E-3 and M.

NRC Question 15

Please provide contour plots of the velocity and turbulence in the containment pool. Please also provide close-up plots of the velocity and turbulence contours in the region of the strainer and its immediate surroundings. In addition, please provide a table of the head loss test flume (average) velocity as a function of distance from the test strainer and the basis for the velocities chosen. Please identify the turbulence level simulated in the test flume and state the flume width(s) used for testing.

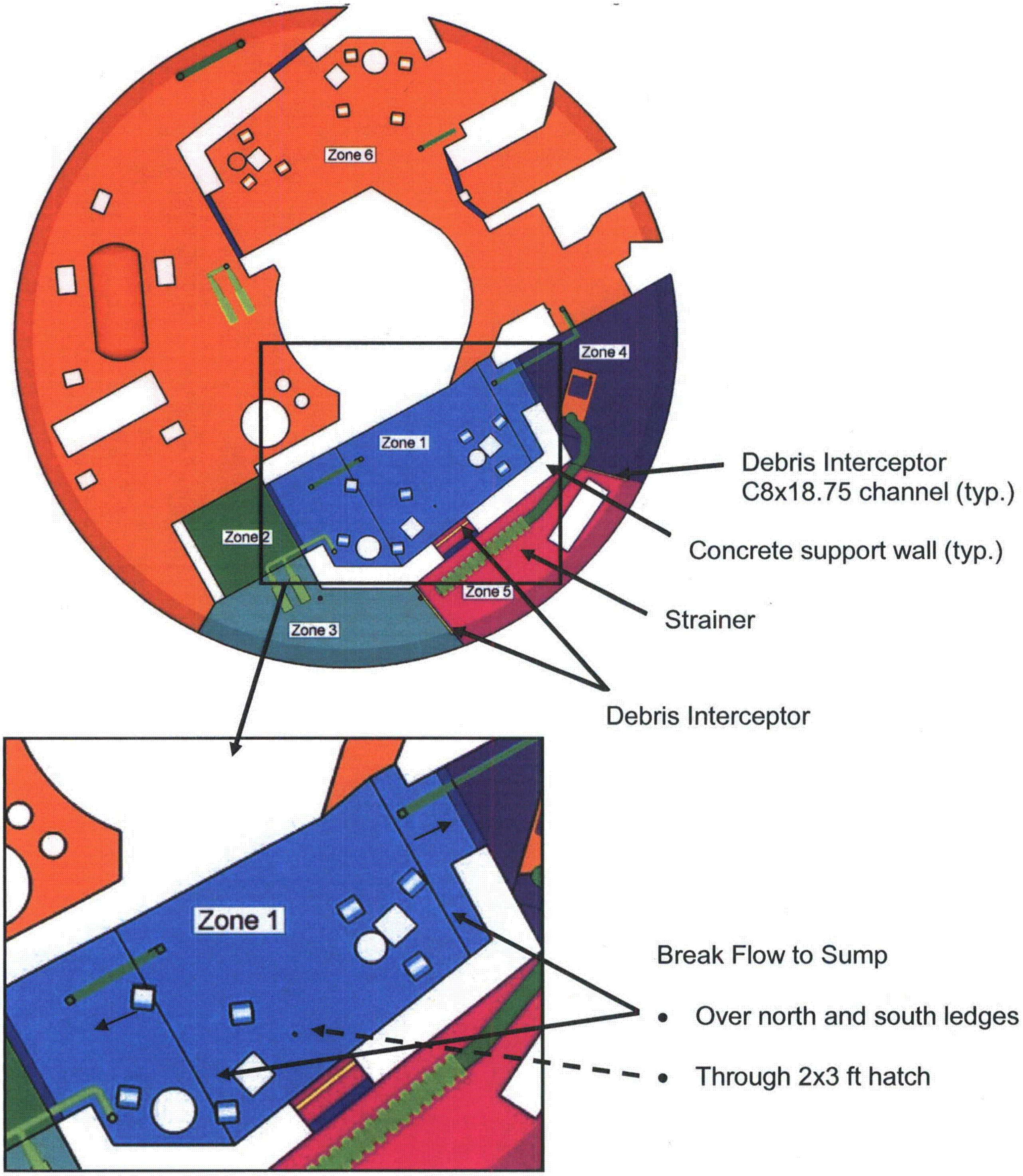
Response

As indicated in Attachment 2 to this letter, and in response to Question 13, following removal of the fibrous insulation material on the pressurizer surge line pipe whip restraints and the Service Water piping in RCS Loop B Vaults, all remaining fibrous material in containment will be considered Fines and subject to transport to the strainer. DEK is no longer relying on the CFD analysis to determine the quantity of debris that will transport to the strainer. The total quantity of fiber from any generated break is limited to prevent the formation of a filtering bed of fiber on the recirculation strainer.

Large scale strainer flume tests performed in 2008 demonstrate significant strainer head loss margin is available to address the combined effects of chemical, (non-thin bed) fiber and particulate debris. The CFD model was used as an input to designing the large scale flume.

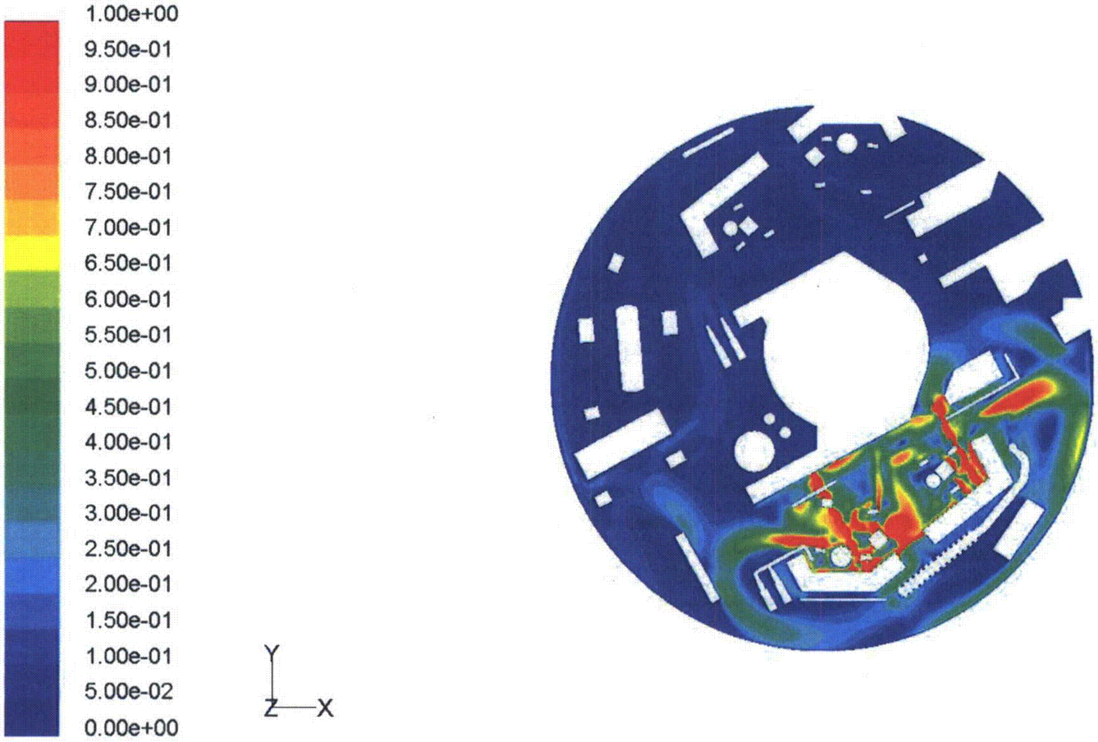
See Enclosure E-2 for the ARL presentation used during the November 10, 2009 telecon between DEK staff, their vendors and the Nuclear Regulatory Commission.

The pictorials on the following page display the layout of the containment sump. For the limiting break, RCS Loop B hot leg break at the Steam Generator (SG), the limiting break location is one elevation above Zone 1. RCS break flow exits the SG/Reactor Coolant Pump (RCP) vault and washes into the sump from three vault openings.

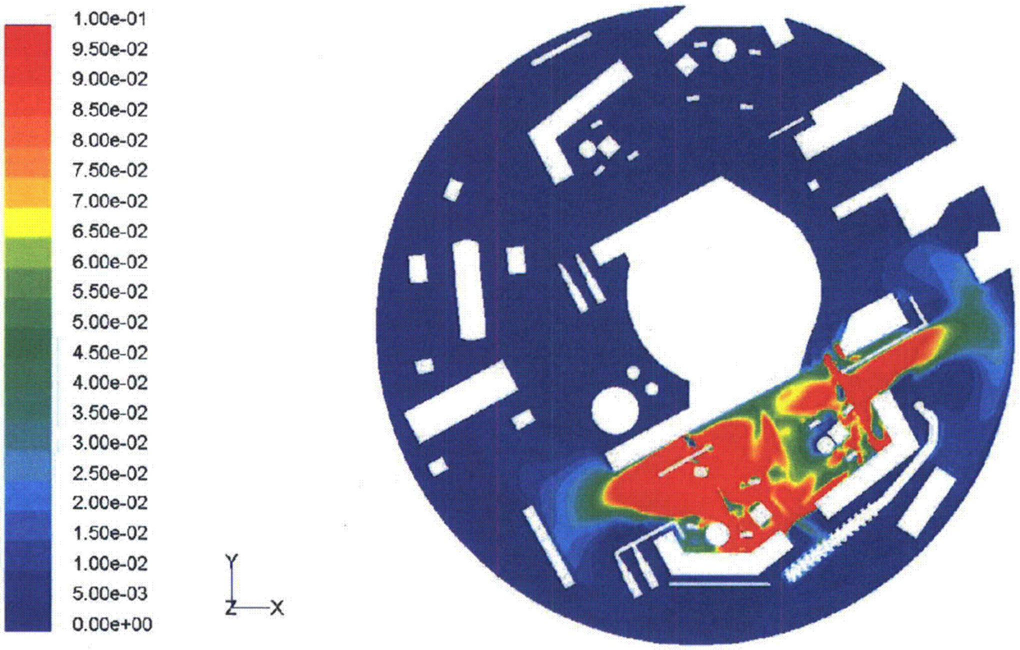


Flow exiting the vault above Zone 1 washes primarily into Zones 2, 4 and 6 during the sump pool fill phase.

Velocity contour plots for the containment sump were prepared. Contour plots are provided below for the debris transport determination, the start of recirculation with combined reactor vessel injection, and containment spray from the RWST and containment sump recirculation in progress. Break flow momentum over the north and south ledges results in higher sump pool turbulence and velocities to maximize debris transport. The plots display the velocity and turbulent kinetic energy distribution at the middle of the water column.

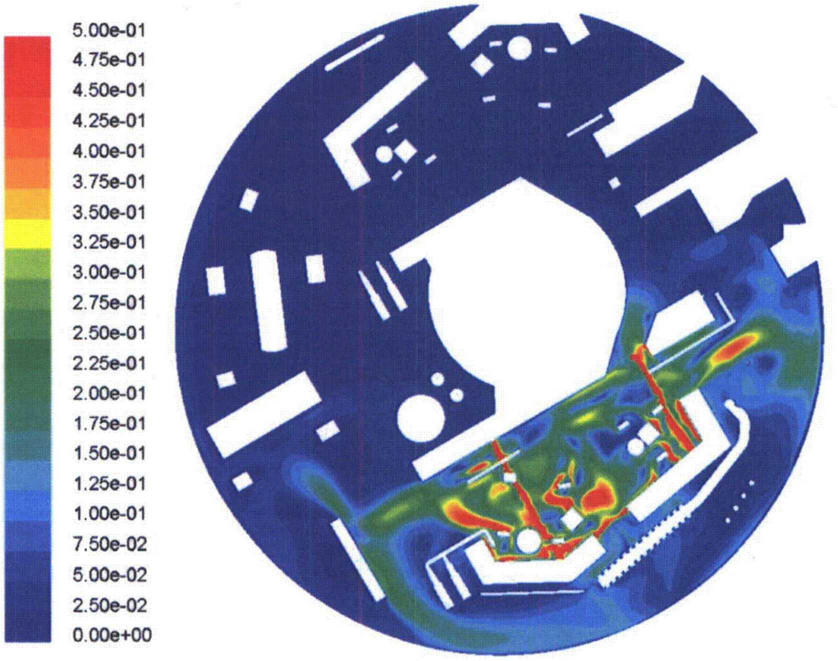


Velocity magnitude (ft/s)

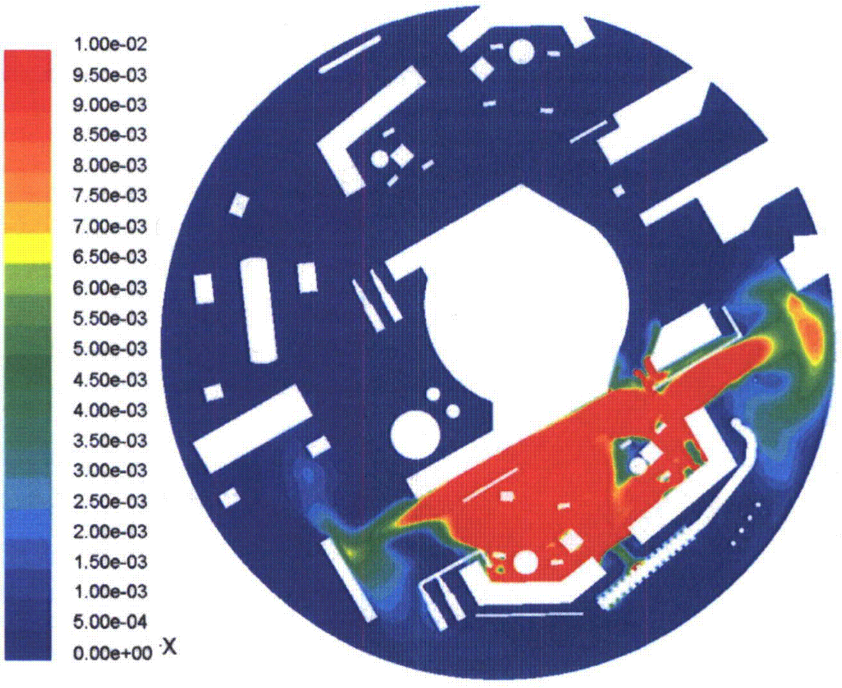


Turbulence (ft^2/sec^2)

Contour plots for the long-term recirculation condition are displayed below (injection phase complete). The contour plots are considered conservative because a low sump pool water level (40.5 inches depth) was used for simplicity when preparing the CFD. The minimum sump water level at the onset of recirculation is calculated as 43.44 inches and the sump water level during long-term recirculation is > 5.75 ft (69 inches). The test flume was constructed to represent the conditions for long-term recirculation, conservatively using the minimum sump pool water level at the onset of recirculation.

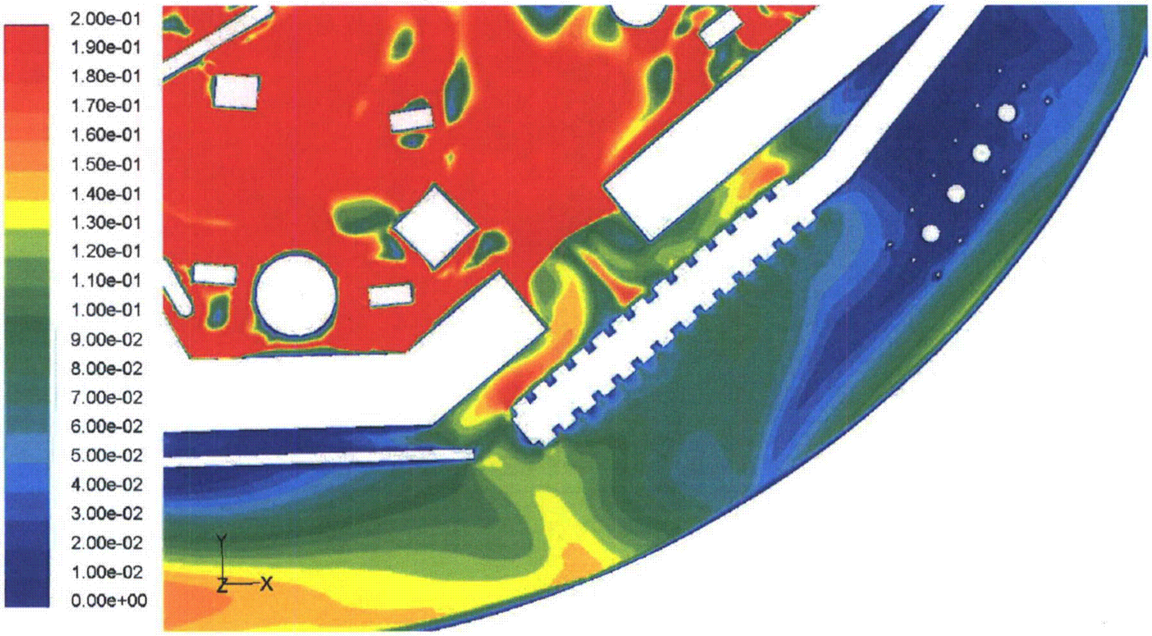


Velocity magnitude (ft/s)

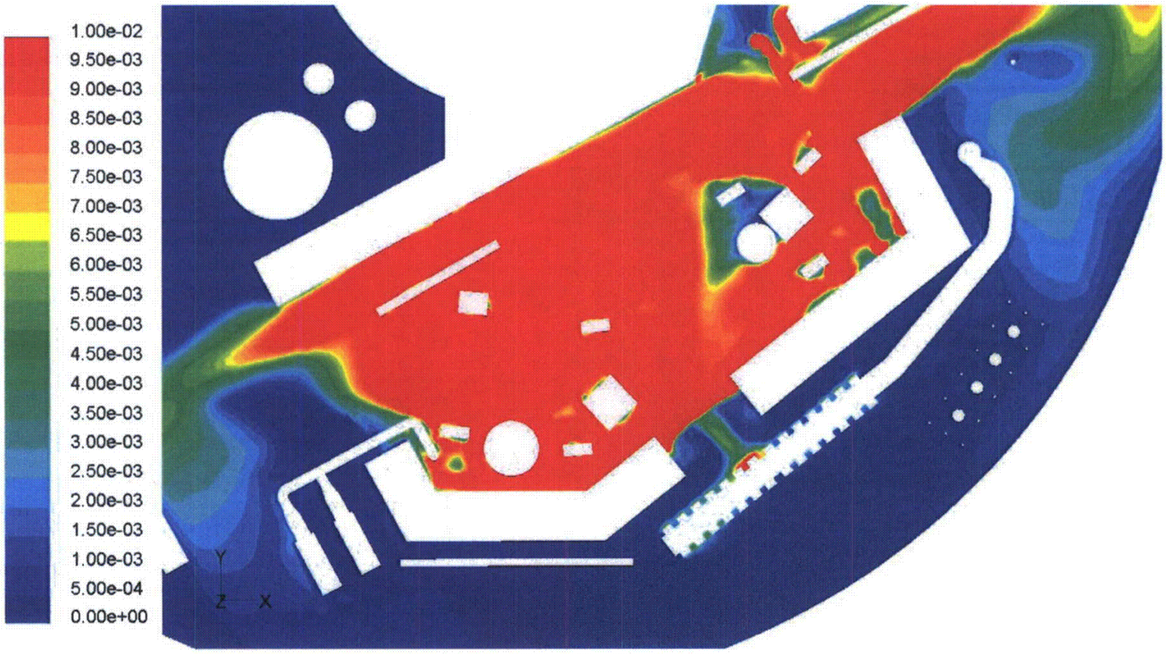


Turbulence (ft^2/sec^2)

Overall, the sump pool is relatively calm in the area of the strainer, as shown below. Velocity and turbulence levels are low, especially in the main transport paths to the strainer, approaching from the North (right side of page) and South (left side of page).

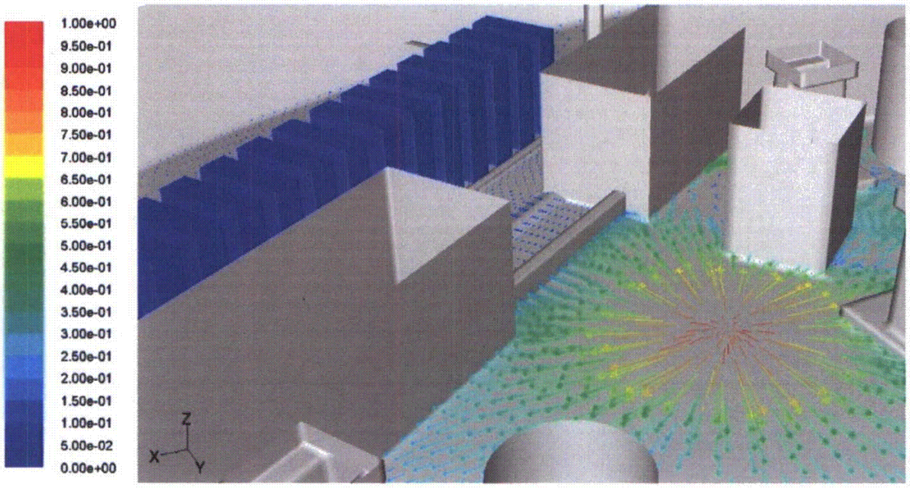


Velocity magnitude (ft/s)

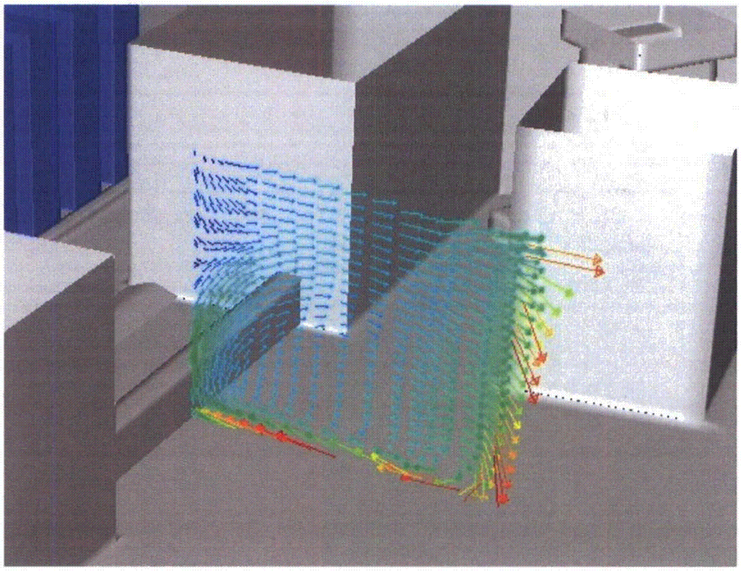


Turbulence (ft^2/sec^2)

The center debris interceptor between the interior support walls (C8x18.75 channel, shown in the first pictorial above) limits flow to the strainer at this location by creating a toroidal flow pattern. Flow exiting the upper elevation falling out of the 2 x 3 ft hatch above Zone 1 (see first pictorial above), penetrates the water column and spreads along the floor of containment. The jet sets up a vortical flow field. When the jet hits the debris interceptor, the water is forced vertically upward and sets up a complex three dimensional flow field that allows only a portion of the flow to penetrate to the strainer side of the debris interceptor. This results in higher approach velocities at the north and south ends of the strainer.



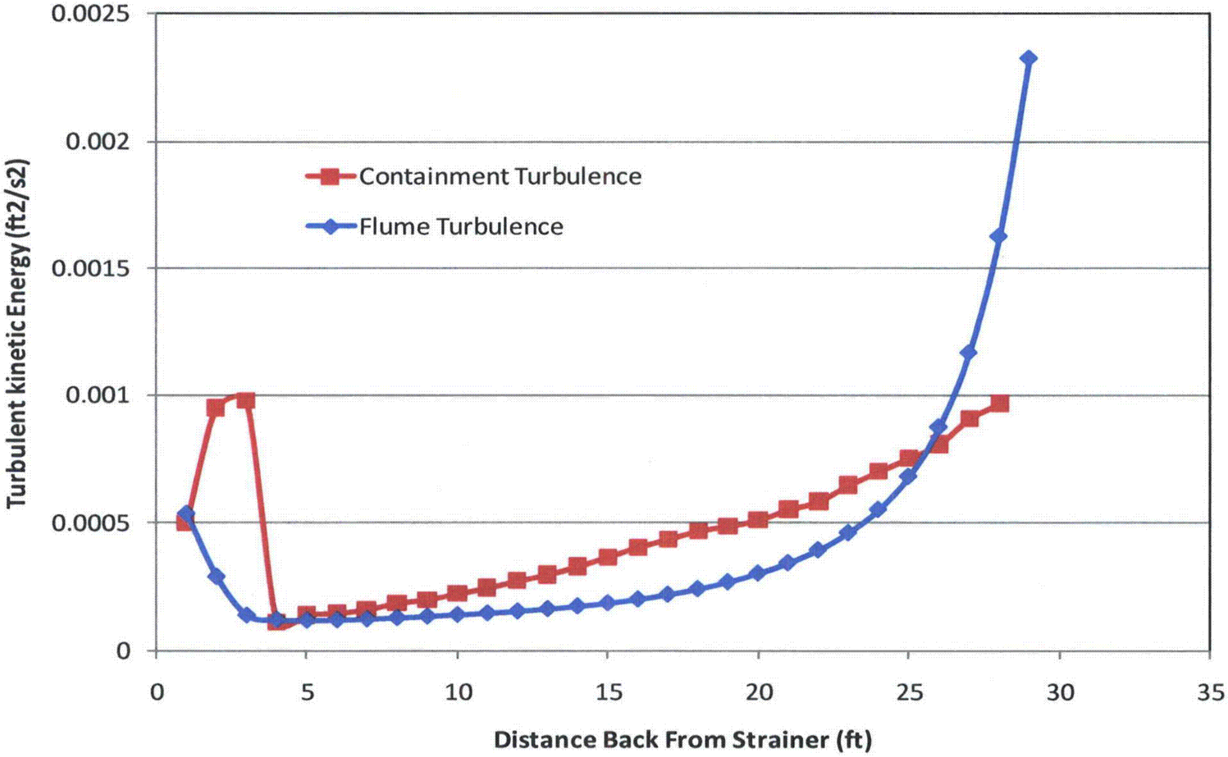
Hatch Flow Spreads Along the Floor



Toroidal Flow Pattern

The velocity field calculated for long-term recirculation was used as the basis to develop the approach velocity to the strainer in the test flume. Three main approaches exist to the strainer, from the left (South), right (North) and center (West) as viewed in the figures. The West approach is limited by the debris interceptor and the toroidal flow field at that location resulting in flow both toward and away from the strainer with little net flow. The average velocities calculated over each of the approaches to the strainer were then averaged again, doubling the weighting of the highest velocity to more conservatively represent the overall approach to the strainer. The approach planes were trimmed to neglect any stagnant areas of flow in the general approach area. The following table shows the approach velocities calculated in this manner as a function of distance away from the strainer. The table also includes the flume width calculated based on the modeled module flow rate and water depth (40.5 in.). Finally, the table also includes the local Reynolds Number obtained at each location in the flume. Although the Reynolds Numbers are low, they are firmly above that required for turbulent free surface flow (2000). The table below compares the turbulence calculated over the same approaches in the containment and in the test flume. The turbulence plotted for the flume represents the effective turbulence level, accounting for the significant difference in viscosity between the test temperature and the containment recirculation temperature (110 °F vs. 200 °F).

DISTANCE FROM STRAINER (FT)	VELOCITY (FT/SEC)	FLUME WIDTH (IN.)	HYDRAULIC RADIUS (FT)	REYNOLDS NUMBER
1	0.10	10.4	0.39	6704
2	0.10	9.9	0.37	6045
3	0.10	11.3	0.41	6644
6	0.08	14.3	0.51	6435
10	0.09	11.7	0.42	6617
21	0.12	8.9	0.33	6821
25	0.13	8.5	0.32	6852
30	0.13	8.4	0.32	6861



NRC Question 16

Please identify the distance from the strainer at which debris was added to the test flume. Please justify the conservatism or prototypicality of this distance based on the transport analysis results for blowdown, washdown, and pool-fill transport.

Response

As indicated in Attachment 2 to this letter, and in response to Questions 13 and 15, following removal of the fibrous insulation material on the pressurizer surge line pipe whip restraints and the Service Water piping in RCS Loop B Vaults, all remaining fibrous material in containment will be considered Fines and subject to transport to the strainer. DEK is no longer relying on the CFD analysis to determine the quantity of debris that will transport to the strainer. The total quantity of fiber from any generated break is limited to prevent the formation of a filtering bed of fiber on the recirculation strainer.

Large scale strainer flume tests performed in 2008 demonstrate significant strainer head loss margin is available to address the combined effects of chemical, (non-thin bed) fiber and particulate debris. The CFD model was used as an input to designing the large scale flume.

Because of the new commitments stated in Attachment 2, the distance from the strainer at which debris was added to the test flume becomes less significant. The new debris inventory will only include fine fiber, chemical debris and particulate debris. Because all debris generated is assumed to transport to the strainer, this question is no longer applicable.

NRC Question 17

Please describe how the potential for debris transport in the vicinity of the strainer via floatation was considered in the head loss tests for Kewaunee.

Response

The large scale flume tests conducted at ARL in August of 2008 measured strainer debris bed head loss. These tests were conducted in a large flume with heated (approximately 120 °F) water. The large scale flume included a heat recirculation loop with a heat recirculation pump and an 800,000 BTU/hr heat exchanger. Use of heated water eliminated trapped air bubbles in the debris and resulted in minimal floating debris. Prior to entry into the flume, non-chemical debris was placed in heated water (approximately 120 °F) and mixed to help eliminate trapped air in the debris.

Additional Verbal NRC Request

Address the potential for debris transport via floatation in the containment.

Response

As indicated in Attachment 2, following removal of the fibrous insulation on the pressurizer surge line pipe whip restraints and the Service Water piping in RCS Loop B, the remaining fibrous material in containment will be considered as Fines and subject to transport to the recirculation strainer. The total quantity of fibrous material will be limited to prevent the formation of a thin bed of fiber on the recirculation strainer that can filter particulates and result in a high strainer head loss. Because all debris generated is assumed to transport to the strainer, this question is no longer applicable.

F. HEAD LOSS AND VORTEXING

NRC Question 18

Please provide the clean strainer head loss (CSHL) methodology for the non-strainer portions of the assembly. Please provide the assumptions used for the CSHL calculation.

Response

PCI calculated Kewaunee's clean strainer head loss. The CSHL value includes losses from the strainer assembly, as well as the exit piping that discharges the strained water into the recirculation sump pit where the RHR pumps take suction. The following presents the CSHL calculation for the strainer assembly, and the non-strainer components (i.e., the attached discharge piping and sump entry).

Strainer Assembly CSHL

The following equation was used to calculate the strainer exit velocities:

$$V_{ex} = Q_{str} / A_{ex}$$

Where; Q_{str} = strainer water flow rate, gpm x 0.002228 to convert to ft^3/sec.
A_{ex} = exit area, or cross section area of the inside of the strainer's core, ft^2.
V_{ex} = Strainer Exit Velocity, ft/sec.

The equation for the strainer only CSHL, i.e., without any pipe and/or fitting losses, is:

$$HL_{strainer} = A + K_1 \nu V_{ex} + K_2 (V_{ex}^2 / 2g)$$

Where; ν = water's kinematic viscosity, ft^2/sec (a function of water temperature).
g = gravitational constant, which is 32.2 ft / sec^2.
A = a constant with a very small value of 0.002205 feet of water ~ 0, and is therefore ignored.
K_1 = a coefficient multiplied by ν to allow adjustment to the water temperature.
K_2 = another coefficient that is multiplied times the dynamic head of the water at the strainer's exit.

Coefficients K_1 and K_2 have the following values (determined by a regression analysis of the PCI test data):

$$K_1 = 1{,}024 \quad \text{and} \quad K_2 = 0.8792$$

With the values of the coefficients determined and utilizing the CSHL equation, the Base Head Loss, HL_{Base} was calculated for different water temperatures where the value of kinematic viscosity, ν is selected based on the design basis water temperature. DEK specified a conservative long-term sump water temperature of 65°F. The actual base CSHL is computed using the value of Exit Velocity, V_{ex} for the particular water flow rate. Selecting a value of ν for the water temperature, the Exit Velocity is computed using $V_{ex} = Q_{str} / A_{ex}$ and the values of specified water flow rate values, respectively, for the Kewaunee strainer. Each strainer's core tube has an 18.00 inch outside diameter and a 0.06 inch wall thickness. Therefore, the value of internal cross sectional area of the core tube is computed by the following equations:

$A_{ex} = \pi D_{ex}^2 / 4$

Where, D_{ex} = inner core tube diameter

D_{ex} = outer diameter – 2 x core tube wall thickness

= 17.88 inches

Therefore, $A_{ex} = 1.744 \text{ ft}^2$

Using the computed value for A_{ex} the Exit Velocity, V_{ex}, for the strainer assembly is computed using the specified flow rate of 1920 gpm (see response to Questions 33 and 19.c for flow rate discussion).

$$\begin{aligned} V_{ex} &= Q_{str} / A_{ex} \\ &= 1920 \text{ gpm} \times 0.002228 \text{ ft}^3 / \text{s} / \text{gpm} / 1.744 \text{ ft}^2 \\ &= 2.453 \text{ ft/s} \end{aligned}$$

The resultant value for V_{ex} was then used to calculate the CSHL from the previously discussed equations as follows:

$$\begin{aligned} HL_{strainer} &= K_1 \nu V_{ex} + K_2 (V_{ex}^2 / 2g) \\ &= (1024)(1.138 \times 10^{-5})(2.453) + (0.8792)(2.453^2 / 64.4) \\ &= 0.02859 + 0.08215 \\ &= 0.111 \end{aligned}$$

The following table provides a summary of the values obtained from the above equations and the resultant Clean Strainer Head Loss for the strainer assembly without the discharge piping.

Summary of Calculated Strainer Only Clean Strainer Head Loss

Parameter	Value
Total Suction Flow (gpm)	1,920
Water Temperature (^oF)	65
Water Kinematic Viscosity (ft^2/sec)	1.138×10^{-5}
Internal Core Tube Outer Diameter (inches)	18.00
Internal Core Tube Thickness (inches)	0.06
Internal Core Tube Inner Diameter (inches)	17.88
Internal Core Tube Cross-Sectional Area (ft^2)	1.744
Design Strainer Exit Velocity (ft/sec)	2.453
Calculated Uncorrected CSHL (feet of water)	0.111

Strainer Discharge Piping and Sump Entrance

The 18.00 inch outside diameter (OD) strainer core tube discharge is attached to the 18.00 inch OD strainer assembly discharge piping. The strainer discharge flow enters a short straight run of pipe where it passes through a horizontal 12° mitered elbow, then enters a straight run of pipe. The flow then enters a horizontal 34.3° mitered elbow, a short straight run of pipe, and a horizontal 55.0° mitered elbow that aligns the strainer discharge pipe to the sump cover. At the sump cover, the strainer discharge flow passes through a 90° short radius elbow that discharges into the sump pit reservoir.

Head loss was calculated for each subcomponent, then summed and added to the strainer assembly head loss to obtain the total clean strainer head loss. The subcomponent calculations are provided below.

Straight Pipe

The piping between the strainer assembly and the sump pit cover plate is 18 inch OD Schedule 10S stainless steel with a 0.25 inch wall thickness. The pipe's inside diameter is slightly less than that of the core tube (i.e., 17.50 inch vs. 17.88 inch). For the pipe, the D_{ID} = OD – 2 x wall thickness = 18.00 – 2 (0.25) = 17.50 inches or 1.458 feet. The cross-sectional area, A_{pipe}, of the pipe is calculated as follows:

$A_{pipe} = \pi D_{ID}^2 / 4$
$= 1.670 \text{ ft}^2$

With the pipe cross-sectional area determined, the flow velocity, V_{pipe} is calculated.

$V_{pipe} = Q_{str} / A_{pipe}$
$= 1920 \times 0.002228 / 1.670$
$V_{pipe} = 2.562 \text{ ft/s}$

The straight pipe runs cumulatively total approximately 156 inches, or 13 feet. Using this length as a bounding value, along with the flow velocity, V_{pipe}, an estimate of the head loss resulting from this straight pipe is determined. The Darcy-Weisbach equation is used for head loss associated with incompressible flow in pipe to calculate the head loss per unit length of pipe.

$$\Delta h_f = f / D (V_{pipe})^2 / 2g \, \Delta L$$

Where, Δh_f = head loss for a straight pipe, ft. water.
ΔL = total pipe length = 13 ft.
V_{pipe} = local water velocity in the pipe, ft/sec = 2.562 ft/s.
f = friction factor, dimensionless.
D = internal diameter of the pipe = 17.50 in = 1.458 ft.
g = gravitational constant = 32.2 ft/sec^2.

The friction factor, f depends on the Reynolds Number (Re), which is dimensionless, and the pipe diameter (D). Any temperature effect is incorporated in ν, the water's kinematic viscosity, which is temperature dependent. Re is then calculated by using the following equation:

$$Re = V D / \nu$$

Where the value of $\nu = 1.138 \text{ ft}^2 \times 10^{-5} / \text{s}$ for the evaluated 65° F water. Re is calculated to be 3.282×10^5. Utilizing the Moody Diagram results in a conservatively determined friction factor value, f of 0.013.

The value of f is then used to calculate head loss for water flow through the total 13-foot length of straight pipe.

$HL_{str\ pipe} = (0.013/1.458)(2.562^2) / (2 \times 32.2) \times 13$
$= 0.0118$ feet of water

Increasing this value by 10% for conservatism results in a total straight pipe head loss, $HL_{str\ pipe}$, of 0.0130 feet of water.

Mitered Elbows

The mitered elbows consist of three (3) different miters: 12°, 34.3°, and 55°. Each of these requires consideration for head loss, as detailed in the following sections.

For a mitered elbow, the head loss can be calculated utilizing the following generalized equations:

$$HL_{fitting} = K_{fitting} V^2 / 2g$$

and

$$K_{fitting} = \alpha \times f$$

12° Mitered Elbow

The 12° miter elbow is bound by a 15° mitered elbow for which the value of $\alpha = 4$. With the friction factor, $f = 0.013$, the value of $K_{12\ miter}$ can be determined as follows.

$$K_{12\ miter} = \alpha_{12} \times f = 4 \times 0.013 = 0.052$$

34.3° Mitered Elbow

The 34.3° mitered elbow is bound by the α value for a 45° mitered bend, $\alpha = 15$.

$$K_{34.3\ miter} = \alpha_{34.3} \times f = 15 \times 0.013 = 0.195$$

55° Mitered Elbow

The 55° mitered elbow is bound by the α value for a 60° mitered elbow, $\alpha = 25$.

$$K_{55\ miter} = \alpha_{60} \times f = 25 \times 0.013 = 0.325$$

The sum of the coefficients associated with the three (3) mitered elbows is 0.572 feet.

90° Short Radius Elbow

The head loss for the 90° short radius elbow is determined, where $\alpha = 20$ and $f = 0.013$ for a smooth inside surface on a 18 inch pipe elbow.

$$K_{90\ el} = \alpha_{90\ elbow} \times f = 20 \times 0.013 = 0.260$$

Mitered and 90° Short Radius Elbow Head Loss

With the individual K value established for the subject mitered and 90° short radius elbows, the head loss is then calculated for the subject fittings.

$$K_{fittings} = K_{12\ miter} + K_{34.3\ miter} + K_{55\ miter} + K_{90\ el}$$
$$= 0.052 + 0.195 + 0.325 + 0.260 = 0.832$$

Utilizing a generalized equation and the velocity value, V_{pipe} = 2.562 ft/s, the head loss contribution from the four fittings, $HL_{fittings}$ can be determined.

$$HL_{fittings} = K_{fittings} \times V_{pipe}^2 / 2g$$
$$= 0.832 \times 2.562^2 / 64.4$$
$$= 0.0848 \text{ feet of water.}$$

Increasing this value by 10% for conservatism results in a head loss associated with the fittings of 0.0933 feet of water.

Water Entering Sump Pit Head Loss

The head loss associated with the strainer discharge flow entering vertically downward into the sump pit is addressed. There is a final head loss resulting from the expansion of that flow into a "reservoir" (i.e., sump pit). For this configuration, K_{exit} = 1.00 and V_{pipe} = 2.562 ft/s.

$$HL_{exit} = K_{exit} \times V_{pipe}^2 / 2g$$
$$= 0.102 \text{ feet of water.}$$

Increasing this value by 10% for conservatism results in a HL_{exit} of 0.112 feet of water.

The table below summarizes the bounding values of head loss discussed above. All head losses are in feet of water.

Calculated Clean Strainer Subcomponent Head Loss	
Parameter	**Value (feet of water)**
Uncorrected CSHL	0.111
6% Uncertainty Correction of the CSHL	0.007
Strainer Length HL Corrections	0.020
Strainer Module to Module Transition (+10% conservatism)	0.0085
Attached Piping Head Loss (+10% conservatism)	0.0130
Fitting Head Loss (+10% conservatism)(Elbows)	0.0933
Entering Sump Water Head Loss (+10% conservatism)	0.112
Total Corrected CSHL with Attached Piping	0.365

NRC Question 19

Very little head loss and vortexing information was included in either submittal. Please provide information on the testing conducted on the strainer including the following, along with other relevant information:

19.a. *Identify the maximum debris head loss measured during testing. Identify the test clean strainer head loss portion of the total separately. Provide the temperature at which the head loss was measured.*

Response

As reported in our December 18, 2008 response (reference 5), the following data was provided:

The August 2008 large scale flume tests were conducted with one full size strainer module, as compared to a smaller-scale strainer module used in February 2006. For conservatism, the original calculated 40.5 inch recirculation sump level was maintained. The strainer head loss test results verified that significant strainer head loss margin is available. The maximum strainer head loss allowed is 10 ft of water.

Test (Note 1)	**Temp-Corrected Clean Head Loss (ft. of water)**	**Debris Bed Head Loss (ft. of water)**	**Temp-Corrected Debris Bed Head Loss (ft. of water)**	**Total Temp-Corrected Losses (ft. of water)**
Maximum design basis debris load, with margin (Note 2)	0.365	0.51	0.83	1.10
Maximum design basis debris load, with additional debris load margin (Note 3)	0.365	1.67	3.01	3.28

Notes:

1. Test results are temperature-corrected, where noted, to 65 °F.
2. The first head loss test in August 2008 included the following debris load margin:
   a. TempMat test quantity included 10% margin above the transported quantity.
   b. Fibrous cable insulation included 10% margin.
   c. Thermobestos/calcium silicate insulation included 10% margin.
   d. Latent debris included 785% margin based on original measured value; or 357% margin based on current latent debris calculation.
   e. Inorganic zincs included 107% margin.
   f. Phenolic Epoxies included 7% margin.
   g. Enamel and factory coatings included 8% margin.
3. A supplemental head loss test was conducted. The debris load margin was increased as follows (see table above):
   a. TempMat test quantity included 20% margin above the transported quantity.
   b. Chemical debris was doubled, providing 100% margin.
   c. Fiberglass pipe cover included 83% margin.
   d. Latent debris included 918% margin based on original measured value; or 425% margin based on current latent debris calculation.

The maximum measured head loss across the debris-laden recirculation strainer, 3.28 ft of water, which includes debris load margin and clean strainer losses, is significantly less than the maximum allowable strainer head loss of 10 ft of water.

19.b. *Provide information that clearly shows how the debris head loss was extrapolated to temperatures other than the test temperature. If plant CSHL was adjusted for temperature, please provide the CSHL at the various temperatures that were considered. Provide the plant CSHL and debris head loss separately for each temperature.*

Response

Clean Strainer Head Loss (CSHL) and debris bed head loss was determined for the given test temperature, then corrected to a conservative long-term sump water temperature of 65 °F. Head loss values at intermediate temperatures were not calculated. The maximum allowable strainer head loss (debris bed and clean strainer losses combined) is 10 ft of water.

The following data summarize the CSHL and debris bed losses at the temperature-corrected values.

	COL. A	COL. B	COL. C	COL. D	COL. E	COL. F
TEST (Note 1)	**CSHL STRNR AND DISCHARGE PIPING (ft of water)**	**CSHL STRAINER ONLY (ft of water)**	**TEST CSHL (ft of water)**	**DEBRIS BED HEAD LOSS (ft of water)**	**DEBRIS BED HEAD LOSS (ft of water)**	**TOTAL LOSSES (ft of water)**
Maximum design basis debris load, with margin (Test 3)	0.365	0.111	0.01807	0.51	0.83	1.10
Maximum design basis debris load, with additional debris load margin (Test 9)	0.365	0.111	0.01807	1.67	3.01	3.28

Notes:

1. Columns A, B, C, E and F values are temperature-corrected to 65 °F.
2. Column A – calculated CSHL, strainer modules plus discharge piping losses.
3. Column B – calculated CSHL, strainer modules only.
4. Column C – measured CSHL by test, strainer modules only.
5. Column D – measured debris bed losses by test.
6. Column E – debris bed losses temperature-corrected to 65 °F.
7. Column F – total head loss; strainer, discharge piping and debris bed losses [Col. A – Col. B + Col. C + Col. E = Col. F].

The CSHL (Col. A) temperature-correction was calculated using the kinematic viscosity of water at 65 °F. The debris bed head loss temperature correction (Col. E) was calculated using the dynamic viscosity of water at the test temperature(s) and the long-term temperature (65 °F). Excerpts from the Clean Head Loss and Total Head Loss calculations are included as Enclosures F-1 and F-2. The test plots are provided in response to Question 23.

19.c. *Provide the head loss test methodology including details of the following, for each test:*

- i. *debris introduction sequences.*
- ii. *if any debris additions, including latent debris surrogate, were made at less than the scaled 100% flow rate, provide the flow rate at which the debris was added.*
- iii. *debris preparation methodology and resulting surrogate size distributions.*
- iv. *debris characteristics for all debris surrogates used during testing.*
- v. *general procedure/steps for conducting the tests.*
- vi. *description of the test facility.*
- vii. *description of debris introduction techniques including the debris mixtures and concentration (with respect to water) for each debris addition.*
- viii. *thin bed incremental amounts of fibrous debris added (theoretical thickness and the basis) and the type(s) of fiber added.*
- ix. *the amounts (volume or mass) of each size (fine, small, etc.) of all debris that was added to the test flume for each debris addition, and the location of the debris addition with respect to other equipment within the test flume.*
- x. *scaling factors.*
- xi. *flow rates.*
- xii. *verification that particulate debris surrogate amounts were density-corrected so that the required volume of surrogate was used during testing.*
- xiii. *statement as to whether stirring was used, and if used, whether the stirring affected the debris bed (either by forcing larger debris onto the bed or washing debris from the bed).*
- xiv. *the amounts of debris that settled in the test apparatus.*
- xv. *information that justifies that excessive agglomeration of debris did not occur due to higher than prototypical debris concentrations within the flume or higher than expected concentration during debris addition.*

RESPONSE

Test Overview

The 2008 large scale flume tests for Kewaunee were performed by PCI and AREVA at Alden Research Laboratories (ARL). The flume layout was configured for Kewaunee's test to include varying widths from 8.375 to 14.25 inches. Water depth was 40.5 inches. Flume length was 45 feet. A CFD analysis was performed by ARL and used as input to the test flume wall design. A debris interceptor was placed across the width of the flume, upstream of the strainer. The debris interceptor was a replica of the plant design, a steel C8x18.75 channel. The debris interceptor was mounted on 3/8 inch steel plate to model installation in the containment.

Debris introduced into the flume included all debris types, fibrous, particulate and chemical debris. Head loss tests were performed at the design basis flow rate of 1920 gpm (1870 gpm flow through the strainer, plus an additional 50 gpm for conservatism).

Scaling Factor **(F.19.c.x)**

A full size strainer module from Kewaunee's inventory was used for the tests. The strainer module has a surface area of 54.8 ft^2. The surface area of the strainer installed in the plant is 768.7 ft^2. The flume test conditions (flow rate and debris quantities) were scaled down to 7.129% for the test strainer size.

54.8 ft^2 / 768.7 ft^2 plant strainer = 7.129% scale

Description of Test Facility **(F.19.c.vi)**

Flume design layout and photographs are included in Enclosure G.

The ARL test apparatus consisted of a steel flume measuring 10 ft wide, 5 ft deep and 45 ft long. Inside the steel flume, plywood was used to contour the flume wall to simulate the containment approach velocities. The upstream end of the flume was used to introduce flow into the flume, resulting in a 30.59 ft long test section. The flume was equipped with two flow systems designated as the Strainer Flow Loop and the Heat Recirculation Loop. To reduce the hydrostatic forces on the plywood walls, water was added on both sides of the flume testing section in order to prevent the flume wall from collapsing due to high pressures from the water inside the flume. The flume was filled with city water using a two-inch diameter hose and was drained into waste water storage tanks using the elevation head of the flume.

The Strainer Flow Loop was constructed from four-inch and eight-inch diameter schedule 40 PVC piping and utilized a 20 HP variable speed centrifugal pump with a rated capacity of 1500 gpm at 40 ft of head. During testing, flow from the strainer was discharged to the upstream end of the flume through an orifice meter. The loop was designed to provide strainer flow rates from 75 gpm to 210 gpm and measure pressure differentials across the test strainer ranging from 0.02 ft of water to 20 ft of water.

The Heat Recirculation Loop was used to heat and maintain the flume water temperature at approximately 120 °F, with a variance of approximately 20 °F. The loop contained a heat recirculation pump and an 800,000 BTU/hr heat exchanger. A secondary closed loop system, consisting of a separate pump and a boiler, supplied the heat input for the heat exchanger. Once the water temperature reached approximately 120 °F, the boiler was shut down and the Heat Recirculation Loop isolated. Water temperature was maintained during the tests using immersion heaters installed in the upstream end of the test flume.

Flow meters used in the testing were calibrated using the weight time method in the ARL meter calibration facility, which is traceable to the National Institute of Standard and Technology (NIST). Calibration curves for each flow meter were used in the data recording to calculate flows in gallons per minute. The calibration interval for flow meters was in accordance with ARL's calibration procedures.

An automated data recording system was able to read the output of four differential pressure cells to record the flow through the flow meters and the pressure differential across the strainer. Each cell was calibrated using a NIST traceable dead weight tester. Each cell used during a test was checked against a micro-manometer at two deflections before the test was started. The cell calibration interval was in accordance with ARL's calibration procedures.

Water temperature measuring devices were checked against a NIST traceable temperature device using a controlled temperature bath adjusted to provide temperatures over the range encountered during the strainer study.

A 200-lb capacity scale was used for weighing debris in a dry state.

Test Conditions and Flow Rates **(F.19.c.xi)**

The test flume volume was 238.1 ft^3 (1781 gal) and the piping volume was 30.79 ft^3 (230 gal) for a total liquid volume of 268.89 ft^3 (2011 gal).

The water level for the tests was 40.5 inches (3.375 ft) with 3.25 inch strainer submergence. This was more conservative than plant conditions: minimum sump level of 43.44 inches and strainer height of 37.25 inches with 6.19 inch submergence.

The flume width was determined by a flume wall calculation performed by ARL. The flume was constructed with varying widths to obtain the average approach velocities to the strainer at distances to the strainer up to 30 ft. This included the increased velocity over the debris interceptor.

Flow through the strainer module in the test flume was 136.9 gpm (0.305 ft^3/sec). This flow rate is equivalent to 1920 gpm through the actual strainer in the containment during the design basis event (1870 gpm, plus 50 gpm added for margin). The velocity through the strainer module was 0.0056 ft/sec.

Debris Preparation **(F.19.c.iii)**

As indicated in Attachment 2, following removal of the fibrous insulation on the pressurizer surge line pipe whip restraints and the Service Water piping in RCS Loop B Vaults, the remaining debris inventory applicable to the tested materials are: Thermobestos, Okotherm cable insulation, latent debris, coatings and chemical debris (see Attachment 2, Table B-3). However, all materials tested are included in this table for completeness.

The following table displays the test materials, surrogates and how they were processed for the tests.

MATERIAL/SIZE	TEST SURROGATE	HOW PROCESSED
TempMat - Fines	TempMat raw fibers from manufacturer prior to needling	Dry shredded with food processor or similar
TempMat - Smalls	TempMat blanket	Cut into pieces sized to fit through 1x4 opening
Fiberglass Pipe Cover - Fines	Owens Corning fiberglass	Dry shredded with food processor or similar
Fiberglass Pipe CoverSmalls	Owens Corning fiberglass	Processed through leaf shredder; pieces small enough to pass through 1x4 grid
Okotherm cable insulation - Fines	TempMat raw fibers from manufacturer prior to needling	Dry shredded with food processor or similar
Okotherm cable insulation - Smalls	TempMat blanket	Cut into pieces sized to fit through 1x4 opening
Thermobestos (Calcium silicate w/asbestos fibers) - Fibrous portion (10%)	TempMat blanket	Cut into pieces sized to fit through 1x4 opening (see Response to Revised Questions 5, 6, 7 and 12)
Latent fibers - Fines	Nukon	Dry shredded with food processor or similar
Thermobestos (Calsil w/asbestos fibers) - particulate portion (90%)	Calcium silicate	Pulverized powder
Latent particulate	PCI PWR Dirt Mix	Small < 75 microns (37%) Medium 75 to 500 microns (23%) Large 500 to 2000 microns (40%)
Coatings - Zinc	Tin Powder	Powder form
Coatings - Epoxy, Enamels	Acrylic Powder	Powder form
Coatings - Epoxy outside ZOI	Acrylic Chips	1/64" to 1/4" chips
Chemical Debris	Sodium Aluminum Silicate	WCAP-16530-NP AlOOH

Surrogate Debris Characteristics **(F.19.c.iv., F.19.c.xii)**

Actual debris materials were used where possible. A description of the surrogate materials used is documented in SFSS-TD-2007-004, "Sure-Flow Suction Strainer – Testing Debris Preparation & Surrogates," Revision 0. This proprietary document was submitted previously by PCI to NRC in accordance with 10 CFR 2.390.

Surrogate debris was density-corrected. Weight conversions were applied to the surrogates (e.g., lbs/ ft^3). The debris quantities were then scaled to the test volume.

Tin Powder

PCI's review of tin powder found it to be stable, not easily oxidized in air, and resistant to corrosion and incompatibilities (i.e., halogens, halogen trifluorides, nitric acid, sodium peroxide, sulfur, copper nitrate, hydrochloric acid, tin chloride, sodium peroxide, and potassium peroxide). PCI also found tin powder is slow reacting when heated in air, has no reaction with cold water or when heated in steam, has a very slow reaction rate with dilute hydrochloric acid, and a very slow reaction rate with diluted sulfuric acid.

Owens-Corning®

Fiberglass pipe insulation (pipe cover) with an original manufactured density of 3.5 – 5.5 lb/ ft^3 was used as the surrogate material for fiberglass since it has a higher density than other types of fiberglass.

Latent Fiber

Latent fiber debris exists primarily in the form of Fines from unknown sources, but may include fiberglass insulation, fiberglass cloth, fibrous cloth, and protective clothing, among other similar type materials. Although Kewaunee does not have NUKON® insulation in containment, NUKON® insulation was used as the surrogate material for latent fiber since it has similar debris characteristics. NUREG/CR-6877 indicates that NUKON® fibers are comparable to plant latent fiber samples.

Calcium Silicate Powder

IIG® Thermo-12® calcium silicate insulation was procured by PCI from the manufacturer. The product is standard thermal calcium silicate insulation block material that meets ASTM C533-95 and has a density of 14.5 lb/ ft^3. The product was purchased directly from the manufacturer in a pulverized form.

Acrylic Chips

Coating debris specified as chips was formed from Carboline® Carboguard® 890 dry film coating. Chips used in Kewaunee testing were sized between 1/64" and 1/4".

Sodium Aluminum Silicate

The chemical precipitate formed in Kewaunee's sump pool is sodium aluminum silicate ($NaAlSi_3O_8$). Because $NaAlSi_3O_8$ is considered a hazardous material, aluminum oxyhydroxide (AlOOH) was used in lieu of $NaAlSi_3O_8$ for the tests. This surrogate is acceptable as indicated in Section 7.3.2 of WCAP-16530-NP, Revision 0. The chemical precipitates were generated using the methodology in WCAP-16530-NP and the final

Safety Evaluation Report, WCAP-16785-NP, and PWROG letter OG-07-270. The chemical materials were generated in mixing tanks and introduced into the test flume within the parameters provided in the PWROG letter OG-07-270.

PWR Dirt Mix (Latent Particulate)

PCI blended three different silica sand products and achieved:

Small:	< 75 microns (37%)
Medium:	75 to 500 microns (23%)
Large:	500 to 2000 microns (40%)

Procedure Steps **(F.19.c.v)** and Debris Introduction Sequence **(F.19.c.i)**

Prior to conducting the strainer debris head loss tests, a clean strainer head loss (CSHL) test was conducted. Upon obtaining the CSHL test data, a transport test of select miscellaneous debris materials was performed. The materials that were found to not transport were not placed in the test flume during the debris bed head loss tests to preclude the non-transportable debris from capturing other debris, such as fibrous debris, and interfere with its movement toward the strainer. The CSHL and transport test procedure steps were as follows:

CSHL and Debris Transport Tests

1) Verify flume and piping have been cleaned and are free of residual debris.
2) Fill flume to designated water level and heat to 120 °F.
    - document water level.
    - manually verify strainer submergence depth.
    - record water level and strainer submergence.
3) Start recirculation pump and obtain 75 gpm flow rate.
4) Maintain the strainer flow rate and monitor head loss through the strainer.
5) Manually record on 2 minute intervals.
    - flow rate
    - water temperature
    - differential pressure (dp) across strainer
6) Measure and record the pH of the flume water; observe strainer for vortexing.
7) Increase strainer flow to next incremental value (target flow rates: 75, 136.9, 175, 200 and 215 gpm).
8) Repeat steps 4 through 7; end of CSHL test.
9) Adjust flow to design basis flow rate (136.9 gpm).
   Note: Debris drop zone was located ~ 29 ft upstream of leading edge of strainer

10) Add miscellaneous debris samples at the upstream end of the flume (1/4" x 1/4" RMI, 1/2" x 1/2" RMI; 1" x 1" RMI, 3 inch strip of 1/2" width Dymo label, 7 inch strip of ½" Dymo label, 3/4" plastic decal, ~12 in. piece of plastic decal, ~3 in. piece of plastic decal, 3/4" x 3/4" piece of electrical tape, 7 inch tie wrap, ~3.5 inch tie wrap, 1" x 4" paper labels, 1" x 2.5" Brady labels).
11) Run the test for at least one full pool turnover or until debris settles on flume floor.
12) Document the miscellaneous debris location in relation to the drop zone.
13) Terminate the test.

The following procedure was used for the strainer debris bed head loss design basis case (labeled "Test 3"). The duration of Test 3 was just over 30 hours. The test was repeated a second time at design basis conditions with additional debris added to the flume for debris inventory margin (labeled "Test 9"). The duration of Test 9 was also approximately 30 hours.

Debris Bed Strainer Head Loss Tests

1) Verify flume and piping have been cleaned and are free of residual debris.
2) Prepare debris (see response to **F.19.c.iii**)
    - Non-chemical debris is weighed dry.
    - Separate non-chemical debris by type and size into individual batches.
    - Combine each batch with hot water (120 °F).
    - Fine fibrous debris:
        - o Mix with 3 parts water to 1 part fibrous (by volume)
        - o Fill 5 gallon bucket w/3 gallon hot water
        - o Place 1 gallon of pre-mixed fine fiber into 5 gallon bucket
        - o Remix 5 gallon bucket with paddle mixer or similar
        - o Repeat until all fine fibrous is diluted
3) Fill flume to designated water level and heat to 120 °F.
    - Document water level
    - Manually verify strainer submergence depth
    - Record water level and strainer submergence
    - Check immersion heaters periodically for debris accumulation
4) Prior to starting pump, add 25% of latent fine fibrous; this debris is evenly distributed throughout the length of the test flume by pouring from its mixing container; rinse container with city water to ensure all debris entered into flume.
5) Wait 5 minutes.
6) Start recirculation pump (at design basis flow rate).
7) Measure and record pH of flume water; observe strainer for vortexing.
8) Manually record on 2 minute intervals.
    - Flow rate

- Water temperature
- Differential pressure across strainer
- Observation for vortexing
- Observation for bore-hole formation
- Additional information as appropriate

9) Insert all fine particulate debris.

10) Insert all/remaining fine fibrous.
Note: Debris in the test flume was not manually or mechanically stirred. **(F.19.c.xiii)**

11) Wait at least one pool turnover.

12) Insert all small particulate.

13) Insert all small fibrous.

14) Wait at least one pool turnover.
    - maintain flow rate
    - monitor head loss

15) Measure and record pH; observe for vortexing.

16) Insert chemical debris; 51 batches inserted incrementally over 24 hours.
    - 33% of base chemical concentration was added in increments. pH of the flume water is measured and recorded when approximately 25%, 50%, 75% and 100% of this debris is added. Head loss is monitored for at least two pool turnovers.
    - The process is repeated for the next two batches (66%, 99% of base chemical concentration).
    - At this point, the flume volume concentration is essentially met.
    - An additional 20% of the base chemical concentration is added to the flume to compensate for chemical debris that may have settled or captured in the debris bed to ensure the flume volume chemical concentration is maintained. These 20% additions continue until the full amount of chemical is added.
    - The chemical debris storage tanks and lines are rinsed and flushed to ensure the total chemical debris is added into the flume.

17) Terminate the test when the change in head loss is less than 1% in the last 30 minute time interval, and a minimum of 15 flume turnovers have occurred after all the tested debris is inserted into the test flume.

Debris Introduction Techniques **(F.19.c.vii)**; Latent Debris (initial flume introduction) **(F.19.c.ii)**

Twenty five percent (25%) of the latent fibrous debris, represented using fine Nukon fibers, was added to the test flume prior to starting the recirculation pump. This debris was evenly distributed throughout the length of the test flume by pouring from its mixing container. Prior to placement into the flume, the latent fibers (Fines) were mixed in hot 120 °F water, three parts water to one part fibrous debris by volume. The container was then rinsed with tap water and emptied into the flume to ensure all debris entered the flume. After a hold-time of five minutes, the flume recirculation pump was started.

RAI F.19.c.ii, and a follow up teleconference with NRC staff on September 15, 2009, questioned whether adding 25% latent fiber prior to starting the pump would allow the fiber to settle and limit its transport to the strainer. RAI F.19.c.ii is no longer applicable since the new debris inventory described in Attachment 2 to this letter specifies a new maximum allowable latent debris quantity that is bounded by the quantity of latent debris added to the test flume after the recirculation pump was started. No other debris was placed in the flume prior to starting the recirculation pump, or at a reduced flow rate.

Other Non-Chemical Debris **(F.19.c.xv)**

Non-chemical debris was retained in separate containers, segregated by both debris type and size. 120 °F water was added to each container to aid in removing trapped air bubbles. The debris was mixed using a mechanical paddle mixer.

In accordance with the procedure, the debris was introduced into the flume at the "drop zone", approximately 29 ft upstream of the leading edge of the strainer module. The containers were rinsed with tap water and emptied into the flume to ensure all debris entered the flume.

Agglomeration of the debris was prevented by preparing and maintaining the debris in separate containers (by size and type) until addition to the flume (see F.19.c.iii). Adding debris to the flume was sequenced, allowing time between addition of the contents of each debris container to prevent agglomeration. There was one full pool turnover between adding fine debris and small debris, and another full pool turnover between adding small debris and beginning chemical debris addition. See also available photos of the debris preparation (Enclosure B, Questions 5/6/7/12) and debris addition (Enclosure H).

Chemical Debris

The base chemical concentration for Kewaunee "Test 3" (design basis debris load) was 12.51 lbm sodium aluminum silicate ($NaAlSi_3O_8$) (AlOOH surrogate). Using a 7.129% scaling factor, 0.93 lbm at 11 grams/liter was placed in the test flume.

As directed by procedure, the chemical debris was introduced as follows:

Fifty one (51) batches were inserted incrementally over 24 hours:

- 33% of the base chemical concentration was added in increments. The pH of the flume water was measured and recorded when approximately 25%, 50%, 75% and

100% of this debris was added. Head loss was then monitored for at least two pool turnovers.

- The process was repeated for the next two batches (66%, 99%).
- At this point, the flume volume concentration was essentially met.
- An additional 20% of the base chemical concentration was added to the flume to compensate for chemical debris that may have settled or captured in the debris bed and to ensure the flume volume chemical concentration was maintained. These 20% additions continued until the full amount of chemical was added.
- The chemical debris storage tanks and lines were rinsed and flushed to ensure all the chemical debris was added into the flume.

The strainer debris bed head loss test was repeated "Test 9" (design basis debris load with additional debris for margin) and 200% chemical addition was used for this test. Therefore, the chemical concentration was 25.02 lbm sodium aluminum silicate ($NaAlSi_3O_8$) (AlOOH surrogate). Using a 7.129% scaling factor, 1.86 lbm at 11 grams/liter was added into the test flume using the same chemical debris introduction sequence as listed above.

Chemical concentration worksheets for Test 3 and Test 9 are included as Enclosure J.

Quantity of Debris Added to the Test Flume **(F.19.c.ix)**

The following table displays the quantity of debris added to the test flume during the design basis tests.

MATERIAL	SIZE	TEST 3 QTY (Design Basis Test)	TEST 9 QTY (DB Test w/add'l debris)
TempMat	Fines	4.95 ft^3	5.4 ft^3
TempMat	Smalls	5.95 ft^3	6.5 ft^3
Fiberglass Pipe Cover	Fines	0.44 ft^3	0.88 ft^3
Fiberglass Pipe Cover	Smalls	1.56 ft^3	3.12 ft^3
Okonite Cable Insulation	Fines	0.23 ft^3	0.23 ft^3
Okonite Cable Insulation	Smalls	0.33 ft^3	0.33 ft^3
Calsil fiber	Fines	0.054 ft^3	0.054 ft^3
Latent fiber	Fines	6.25 ft^3	6.25 ft^3
Calsil particulate	Pulverized powder	0.486 ft^3	0.486 ft^3
Latent particulate	Small: < 75 microns (37%) Medium: 75 to 500 microns (23%) Large: 500 to 2000 microns (40%)	85 lbm	100 lbm
Zinc coatings	Tin powder	0.8424 ft^3	0.8424 ft^3
Epoxy coatings	Acrylic Powder	1.3 ft^3	1.3 ft^3
Epoxy coatings	Chips	0.09 ft^3	0.09 ft^3
Enamel coatings	Acrylic Powder	3.3783 ft^3	3.3783 ft^3
AlOOH	WCAP	12.51 lbm	25.02 lbm

Debris Quantity Added per Each Debris Addition

- Latent Fines – 25% added prior to pump start (see F.19.c.ii).
- Chemical Debris – administered in 51 batches (see F.19.c.vii).
- All other debris additions – total/remaining debris quantity added (not in increments) – see F.19.c.v and F.19.c.i above.

Location of Debris Addition with Respect to Other Equipment

With the exception of 25% of the latent Fines addressed in F.19.c.ii, the debris was introduced into the flume through the "drop zone", approximately 29 ft upstream of the leading edge of the strainer module. A debris interceptor (C8x18.75 channel) was present in the flume, 1.4 ft upstream of the leading edge of the strainer. There was no other equipment in the flume.

Thin Bed of Fiber **(F.19.c.viii)**

A thin bed test was not performed in the large scale flume in 2008. Instead, the large scale flume tests were used to determine the actual debris transport and strainer head loss at the design basis flow rate. A thin bed of fiber did not form during these tests.

In 2007, fiber transport tests were performed in the 20' 11" x 27" ARL flume. A debris interceptor was modeled in the flume. The flow rate was equal to the maximum flow rate over the debris interceptors as determined by a CFD. In this test, a thin bed of fiber did not form on the strainer.

In 2006, a thin bed flume test was performed in the 20' 11" x 27" ARL flume by placing enough Nukon Fines into the flume to form a 1/8" bed of fiber on the strainer. The pump flow rate was equivalent to 4000 gpm, more than two times the design basis flow rate through the strainer. All particulate debris was placed in the flume. Chemical debris in powder form was inserted, equivalent to 665 mg/L $NaAlSi_3O_8$. Measured head loss was 2.3 ft of water (temperature corrected to 65 °F). Total head loss was 2.3 ft + 1.45 CSHL = 3.75 ft, which is well below the 10 ft allowable head loss.

Results **(F.19.c.xiv)**

The results of the clean strainer losses plus strainer debris losses show total head loss was well below the 10 ft of water allowable total head loss. See response to Questions 19.b and 23 for the quantitative results.

The CSHL test plots (raw data, prior to temperature correction) are included in Enclosure I-1.

The miscellaneous debris items placed in the test flume to document their transport (labels, etc.), were all found to settle in the flume between 4 ft and 14 ft past the drop zone. Therefore, these debris items were excluded from the strainer debris bed head loss tests. Little or no miscellaneous debris will reach the recirculation strainer due to the low strainer approach velocity, the use of debris interceptors that surround the strainer, the elevated containment sump temperature, and density of the materials which cause them to sink.

The strainer debris bed head loss tests included fibrous, particulate and chemical debris.

- The test plot for "Test 3", with the design basis debris load, is included in Enclosure I-2.
- The test plot for "Test 9", with additional debris load for added margin, is included in Enclosure I-3.

Similar to the CSHL plot, the Test 3 and Test 9 plots depict raw test data (without temperature correction).

After draining the test flume it was observed that nearly all debris, with the exception of chemical debris and suspended fibers, settled in the test flume well upstream of the debris interceptor. Small and Fine TempMat debris was found near the drop zone, other fibrous debris was found a few feet beyond the drop zone, and some Fine fiber was found on the upstream side of the debris interceptor. See photos in Enclosure I-4.

NRC Question 20

Please provide a vortexing evaluation including test conditions, assumptions, and their basis. Include any additional vortexing evaluation that was conducted not based on test observations.

Response

During the large scale flume tests conducted in August 2008, the flume test procedure specified observing the strainer at regular intervals during the test for signs of vortexing (see response to F.19.c.v.). No vortices were observed during the debris bed head loss tests.

Additionally, PCI performed a vortex evaluation for the Kewaunee strainer design. The evaluation is included as Enclosure K. The largest opening for water to enter the recirculation sump pit where the RHR pumps take suction is 0.066 inch diameter holes in the strainer assembly. The size of the perforated plate holes will preclude formation of a vortex. The strainer module internal design includes wire stiffeners with small openings inside the strainer that directs flow to the core tube and ultimately the sump pit. These obstructions and small clearances will also prevent vortex formation.

NRC Questions 21 & 22

Please provide the conditions assumed for the voiding evaluation and their bases. Please include an evaluation for the potential of degasification of the sump fluid as it passes through the debris bed.

Provide the conditions assumed for the evaluation of flashing in the strainer and their bases. Please provide the margin to flashing for each condition considered.

Response

Void formation is the result of the pressure of a fluid being reduced below its saturation pressure. Voids are formed by the flashing of the liquid phase. Air does not need to be present to create significant voiding.

Evaluation TDI-6008-07, Revision 6 (Enclosure K), includes an evaluation for air ingestion. Air ingestion is evaluated and results in a Froude Number for the Kewaunee strainer that is substantially less than the guidance provided in Regulatory Guide 1.82, Revision 3. Air ingestion is not expected to occur in Kewaunee's strainer due to having a low Froude Number, a lack of an air entrainment mechanism (no vortex formation), and complete strainer submergence.

TDI-6008-07, Revision 6 (Enclosure K) also evaluates for void formation. The evaluation uses a conventional hydraulic and fluid flow calculation and concludes 0% void fraction in the strainer discharge flow.

TDI-6008-07, Revision 6 (Enclosure K) also evaluates for flashing at the strainer debris bed and gas evolution (deaeration) downstream of the strainer. The evaluation concludes any void fraction that could occur at the strainer debris bed would be very minimal and the voids caused by flashing at the strainer will have collapsed before they enter the recirculation pump inlet lines. It also concludes that due to the significant elevation difference between the sump outlet and recirculation pump inlet, re-initiating void fraction downstream of the sump outlet is not possible.

NRC Question 23

Please provide head loss plots for the testing including annotations of relevant steps in the tests.

Response

Head loss plots are included as Enclosures I-1, I-2 and I-3. The test plots provide the raw test data prior to temperature correction. See response to Question 19.b for a tabulation of the strainer losses.

- Enclosure I-1 provides the clean strainer head loss test plot.
- Enclosure I-2 provides the strainer debris bed head loss test plot at the design basis flow rate and with the design basis debris load.
- Enclosure I-3 provides the strainer debris bed head loss test plot at the design basis flow rate and with the design basis debris load supplemented by revising the chemical debris load to 200% of the design basis value, and with additional insulation and latent debris for additional debris load margin.

For all cases, the more conservative temperature-corrected strainer head loss (clean strainer and debris bed losses combined) remained well below the allowable 10 ft of water loss.

NRC Question 24

Please provide information on whether the strainer is vented.

Response

The recirculation strainer is self-venting by design. The strainer is located on the containment basement floor elevation. The strainer empties into the sump pit where the RHR pumps take suction. The containment basement will flood during the LOCA event. The sump pit begins to fill when the containment basement water elevation reaches 9.5 inches above the basement floor elevation, when water begins to enter the strainer's inner core tube and empty into the sump pit. The strainer core tube has a slotted design around its circumference that allows air to escape out of the upper half of the core tube and strainer as the pit and strainer exit piping fills. The strainer is fully submerged prior to the RHR pump being started in the recirculation mode.

NRC Question 25

Please provide the head loss test termination criteria. Include test data that verifies the criteria were met.

Response

The PCI test protocol specified terminating the test when:

1. The change in head loss was less than 1% during the last 30 minute time interval, and;
2. A minimum of 15 flume turnovers had occurred after all the tested debris has been inserted into the test flume.

In both strainer head loss tests (Test 3 with design basis debris load, Test 9 with additional debris load – see F.19.c), the maximum measured strainer head loss occurred at or just after 28 hours of flume operation. The test termination criteria was met approximately two hours later during each test and the strainer head loss was decreasing at the time of test termination (see Test 3 and Test 9 plots in Enclosures I-2 and I-3).

NRC Question 26

Please provide any extrapolation of head loss test results to the plant strainer mission time and the methodology used. Please provide adequate data that the staff can verify that the extrapolation was performed conservatively.

Response

At 26 hours and 49 minutes after the start of the Design Basis Test (Test 3), the last chemical debris batch was inserted into the flume. The test continued for another three hours and 49 minutes (from 26:49 to 30:38). After inserting the final chemical batch, the head loss climbed slightly as expected, then leveled off and began to slowly decrease over the last three hours of the test. With the full debris load in the recirculation sump and head loss continually decreasing, an extrapolated decrease in head loss was not calculated. The design basis test with additional debris load (Test 9) had similar results. Test 3 and Test 9 plots are included as Enclosures I-2 and I-3.

NRC Question 27

Please provide a schematic representation of the test flume that includes relevant measurements and articles within the flume.

Response

Kewaunee's large scale flume arrangement is shown in Enclosure G. Debris introduction occurred approximately 29 ft upstream of the leading edge of the strainer module. A debris interceptor, C8x18.75 channel, was mounted 3/8 inch off the flume floor to replicate containment conditions, and was placed 1.396 ft upstream of the strainer.

NRC Question 28

Please state whether any debris interceptors were included in the head loss testing. If debris interceptors were included in the testing, please provide details of how the debris interceptors are installed in the plant and how the interceptors were installed in the test flume. Please provide adequate details so that the staff can evaluate the prototypicality of the test setup against the plant.

Response

See response to Question F.27 for the flume design, including placement of the debris interceptors in the flume. See Enclosure D for a pictorial layout of the debris interceptors as they are installed in the containment basement (sump).

The debris interceptors installed in the plant are constructed from C8x18.75 channel and are mounted on 3/8 inch steel plate. The same material and mounting was used in the flume design.

The flume wall calculation evaluated the placement of the debris interceptor in the flume and determined the flume wall width necessary to achieve the desired flow velocity, 0.138 ft/sec, over the debris interceptor. Considering the debris interceptor placement in the flume 1.396 ft upstream of the strainer module, and an effective water height above the debris interceptor equal to 2.677 ft, a required flume width of 0.829 ft at the debris interceptor was determined. Therefore, the flume wall width contracted slightly at the debris interceptor placement to achieve the desired flow velocity at that location.

The flow rate over the flume debris interceptor, 0.138 ft/sec, is the weighted average flow velocity over the three debris interceptors installed in the plant. However, the CFD flow patterns indicate the majority of the flow towards the strainer approaches the strainer from the south, over the south debris interceptor. The average flow velocity over the south debris interceptor is 0.111 ft/sec. Therefore, the flume design was conservative. See also response to Question 15.

G. NET POSITIVE SUCTION HEAD (NPSH)

NRC Question 29

The basis for the stated design flow rates for the residual heat removal (RHR) pumps was not provided. Please provide the methodology and assumptions for the calculation of these flow rates.

Response

One RHR pump operates when the plant is in the recirculation mode. This results in a flow rate through the recirculation strainer of 1870 gpm and a flow rate through the pump of 1990 gpm (includes pump recirculation flow). A flow rate of 1920 gpm through the strainer (1870 gpm, plus 50 gpm margin) was specified as the flow rate for the large scale flume tests.

Fluid flow analysis program PROTO-FLO, Version 4.5, was used to model the recirculation system and determine these flow rates. The maximum flow rate through the recirculation strainer was determined conservatively assuming the RHR pump discharge throttle valve (RHR-8A/B) is failed in the full open position. A high sump level of 6 ft is used in the analysis to provide a conservative high flow rate. The containment temperature and pressure are assumed to be 210 °F and 35 psia, respectively. Pressure drop through the sump strainer is assumed to be negligible which results in a higher RHR flow rate. The RHR pump is assumed to be operating on the vendor's shop test (certified) pump curve, rather than in a degraded condition. The reactor vessel/RCS pressure is assumed to be the same as the containment pressure which maximizes RHR flow. An additional 10% conservatism (uncertainty) is applied to the calculated flow rate. As indicated in our December 18, 2008 response, the resultant flow rate through the recirculation strainer with one RHR pump taking suction from the sump is 1870 gpm. The flow through the RHR pump was conservatively calculated as 1990 gpm, which includes flow through the strainer plus pump recirculation flow. The flow rate through the strainer, 1870 gpm, was conservatively increased to 1920 gpm for conducting the 2008 large scale flume tests.

NRC Question 30

The basis for the NPSH required for the RHR pumps at the design flow rate was not provided. Please provide the basis for the RHR pump NPSH required, including any assumptions or acceptance criteria used by the pump vendor.

Response

Kewaunee's RHR pumps are Byron Jackson, Type 6 x 10 x 18 Vertical V-DSM.

The NPSH required (NPSHR) for the RHR pumps is 8 ft of water at 2000 gpm. This was determined from the original manufacturer pump curves, Byron Jackson Tests T-32129 and T-32130. The vendor pump tests were performed at 1770 RPM and 2000 gpm. Total developed head was 280 ft of water at 80% pump efficiency.

2000 gpm is greater than the design basis flow rates through the RHR pumps. The design basis flow rate through the RHR pumps is 1990 gpm when supplying the reactor vessel in the containment sump recirculation mode (see response to Question 29). One RHR pump operates in the recirculation mode in response to the design basis event.

NPSH margin for the RHR pumps, based on the most recent tests and calculations is as follows:

PARAMETER	HEAD (FT)	COMMENT
NPSH Available	24.108	Total water height at the onset of recirculation, minus piping friction losses [26.224 – 2.116]
Maximum measured debris laden strainer head loss	3.28	Includes clean strainer head loss, strainer discharge piping losses and debris bed losses combined (Notes 1, 2)
NPSH Required	8	At design flow rate 2000 gpm
NPSH Margin	12.828	

Notes:
1) The ECCS recirculation strainer design is limited to 10 ft head loss at 4000 gpm, unless the structural integrity of the strainer is analyzed to exceed that value.
2) The maximum measured head loss through testing is 3.28 ft of water (see response to Question 19.b).

NRC Question 31

The methodology for the calculation of suction line friction head losses for the NPSH calculations was not provided. Please provide the NPSH calculation methodology along with the calculation's assumptions and the bases for these assumptions.

Response

Piping friction losses were calculated using the Darcy-Weisbach formula. The losses were calculated for the RHR pump suction line from containment to the pump suction. The suction piping includes the inlet pipe bell, suction piping, containment isolation valves, and pipe fittings.

In the calculation, the sump water temperature is assumed to be 70° F. Although the sump water temperature would be much greater than 70° F when the RHR suction supply is switched over from the RWST to the containment sump, using a lower fluid temperature resulted in greater piping head losses due to friction in the suction piping. This assumption is conservative in that it results in lower NPSH available (NPSHA) at the RHR pumps because of the higher calculated friction losses.

The friction losses were calculated with an assumed flow rate of 2000 gpm, which is the design flow point for the RHR pump. This assumption is conservative because the maximum flow through the suction piping is less than 2000 gpm (see response to Question 33).

The relative roughness of the suction piping is assumed to be consistent with new clean commercial steel pipe. The RHR system piping is stainless steel which is not readily susceptible to corrosion.

The following equation expresses the frictional losses term (h_{fs}):

$$h_{fs} = h_{strainer} + \sum h_{pipe}$$

Where,

$h_{strainer}$ = head loss across the strainer (in feet)

$\sum h_{pipe}$ = sum of friction losses through piping, valves, and fittings at rated flow (in feet)

The general equation for frictional losses through a pipe (pressure drop), known as Darcy's formula and expressed in feet of liquid, is:

$$h_L = f \cdot \frac{L}{D} \cdot \frac{V^2}{2 \cdot g}$$

Where,

f = friction factor

L = equivalent length of pipe (in feet)
V = mean velocity (in feet per second)
D = internal diameter of pipe (in feet)
g = acceleration of gravity = 32.2 feet/sec^2

The friction factor (f) is a function of Reynold's Number (Re) and the character of the pipe wall (relative roughness). Reynold's Number is defined as (dimensionless):

$$Re = \frac{\left(\frac{\rho \cdot V \cdot D}{\mu}\right)}{g}$$

Where,

$$\rho = 62.3 \frac{lb}{ft^3} \quad @\ 70\ °F$$

V = velocity of fluid (feet/sec)

D = inside pipe diameter (feet)

$$\mu = 2.05 \cdot 10^{-5} \frac{lbf \cdot sec}{ft^2} \quad @\ 70\ °F$$

g = acceleration of gravity = 32.2 feet/sec^2

The relative roughness of the pipe is defined in Crane Technical Paper 410 as:

Relative Roughness = ε / D

Where,

ε = 0.00015 ft [for commercial steel pipe]

D = inside pipe diameter (feet)

When Reynold's number and relative roughness are known, the friction factor (f) is read from the Moody chart published on page A-25 of Crane Technical Paper 410.

The RHR pump suction piping from the containment sump is segregated into three sections for the purposes of calculating friction losses. Those sections are:

- From the suction pipe end bell in the sump pit to the first isolation valve (14-inch diameter; called RUN 1).
- From the first isolation valve through the second isolation valve to a reducer (12-inch diameter; called RUN 2).

- The pipe from the second isolation valve to the RHR pump suction (10-inch diameter; called RUN 3).

The results of the calculated friction losses for RUN 1 are as follows:

RUN 1

$$\mathrm{Re}_{1S} = \frac{\left(\dfrac{\rho \cdot Q \cdot D_{1S}}{A_{1S}\,\mu}\right)}{g}$$

$$\mathrm{Re}_{1S} = \frac{\left(\dfrac{62.3\,\dfrac{\mathrm{lbf}}{\mathrm{ft}^3} \cdot 4.465\,\dfrac{\mathrm{ft}^3}{\mathrm{sec}} \cdot 1.1042\mathrm{ft}}{0.9576\mathrm{ft}^2 \cdot 2.05 \cdot 10^{-5}\,\dfrac{\mathrm{lbf}\cdot\mathrm{sec}}{\mathrm{ft}^2}}\right)}{32.2\,\dfrac{\mathrm{ft}}{\mathrm{sec}^2}}$$

$\mathrm{Re}_{1S} = 4.86 \times 10^5$

Relative Roughness = ε / D_{1S}

Relative Roughness = 0.00015 / 1.1042

Relative Roughness = 1.358×10^{-4}

Using the Moody Chart on page A-24 of Crane Technical Paper 410, the friction factor corresponding with the Reynold's Number and relative roughness is:

$f_{1S} = 0.0147$

The results of RUN 2 equal 0.0148. The results of RUN 3 equal 0.0149.

The overall calculated friction losses from the sump suction to the RHR pump suction are:

$$\sum h_{pipe} = f_{1S} \cdot \frac{L_{1S}}{\left(D_{1S} \cdot A_{1S}{}^2\right)} \cdot \frac{Q^2}{2 \cdot g} + f_{2S} \cdot \frac{L_{2S}}{\left(D_{2S} \cdot A_{2S}{}^2\right)} \cdot \frac{Q^2}{2 \cdot g} + f_{3S} \cdot \frac{L_{3S}}{\left(D_{3S} \cdot A_{3S}{}^2\right)} \cdot \frac{Q^2}{2 \cdot g}$$

$$\sum h_{pipe} = 0.0147 \cdot \frac{106.488\ \mathrm{ft}}{\left(1.1042\mathrm{ft} \cdot \left(0.9576\mathrm{ft}^2\right)^2\right)} \cdot \frac{\left(4.465\,\dfrac{\mathrm{ft}^3}{\mathrm{sec}}\right)^2}{2 \cdot 32.2\,\dfrac{\mathrm{ft}}{\mathrm{sec}^2}} + 0.0148 \cdot \frac{56.299\ \mathrm{ft}}{\left(0.995\mathrm{ft} \cdot \left(0.778\mathrm{ft}^2\right)^2\right)} \cdot \frac{\left(4.465\,\dfrac{\mathrm{ft}^3}{\mathrm{sec}}\right)^2}{2 \cdot 32.2\,\dfrac{\mathrm{ft}}{\mathrm{sec}^2}} + 0.0149 \cdot \frac{65.740\ \mathrm{ft}}{\left(0.835\mathrm{ft} \cdot \left(0.548\mathrm{ft}^2\right)^2\right)} \cdot \frac{\left(4.465\,\dfrac{\mathrm{ft}^3}{\mathrm{sec}}\right)^2}{2 \cdot 32.2\,\dfrac{\mathrm{ft}}{\mathrm{sec}^2}}$$

$\sum h_{pipe} = 2.116\ \mathrm{ft}$

NRC Question 32

Differences between the conditions and assumptions for the small- and large-break loss of coolant accident cases were not provided. Please provide any differences in conditions for the small- and large-break loss of coolant accident cases or demonstrate one case to be limiting.

Response[6]

The NPSH evaluation for the RHR pumps operating in the recirculation mode is prepared for the bounding large break LOCA (LBLOCA) case.

Recirculation is assumed to be initiated at the 37% RWST level (tank 63% depleted). This is the soonest recirculation can be initiated and is based on having two ECCS trains available. The 37% RWST level switchover to recirculation results in the lowest (most conservative) containment sump water level. Additional details are provided below.

NPSH required is based on the RHR pump design flow rate of 2000 gpm. This is a conservatively high flow rate for either the LBLOCA or small break LOCA (SBLOCA) case.

Containment atmospheric pressure is assumed to be equal to the vapor pressure of the sump water. This assumption is conservative in that it does not credit containment pressurization to assist in the available NPSH to the RHR pumps during a transient and bounds both the SBLOCA and LBLOCA cases.

The head loss across the debris laden recirculation strainer is assumed to be at the maximum allowable 10 feet of water and bounds both the SBLOCA and LBLOCA cases.

Sump Level

The minimum containment water level at the start of recirculation is an input in determining the NPSH margin for the RHR pumps in the recirculation mode. Kewaunee's minimum recirculation sump water level calculation evaluated two scenarios.

Scenario 1 assumed a pipe break with a diameter greater than or equal to two inches, at or below the elevation of the Reactor Coolant System (RCS) loops. The scenario is postulated to be a small break with minimum safety injection. It was conservatively

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[6] See also the response to Questions 29 and 33 regarding recirculation flow paths and RHR pump flow rates.

assumed that the accumulators do not discharge during this scenario. This scenario bounds the sump level for a LBLOCA where the accumulators would discharge, and it bounds a SBLOCA where the RCS pressure is assumed to remain above the accumulator pressure preventing their discharge. The safety injection flow rate during the switchover to recirculation is assumed to be conservatively low at 200.4 gpm. This limits the volume of RWST water injected during the switchover to recirculation and results in a conservatively low sump level. Containment spray is assumed to actuate and is conservative for response to a SBLOCA or LBLOCA (see discussion below).

Scenario 1 Details and Sump Level Results

This scenario models a two-inch or greater pipe break at or below the elevation of the RCS loops. Following the break, the containment volume begins to fill with pressurized steam, steam begins to condense on the containment heat sinks, and a portion of the RCS water inventory spills to the containment basement floor. The spilled RCS water contracts when it reaches the cooler sump. The contraction is equal to the ratio of the two water densities. The safety injection system takes suction from the RWST and delivers it to the reactor vessel. At the same time, the (internal containment spray) ICS system takes water from the RWST to provide spray to containment. The injected water spills out of the break onto the containment basement floor and begins to fill containment (waste) Sump A and (recirculation) Sump B. The sprayed water initially accumulates on the upper containment floors before cascading down to the basement floor. In Scenario 1 it is conservatively assumed that the safety injection accumulators do not discharge and the water in them is not added to the containment sump level. This was conservatively assumed because there may be some SBLOCA scenarios where the RCS pressure does not drop below the accumulator pressure. The accumulators have a nitrogen cover charge and are maintained at approximately 750 psig. The minimum accumulator pressure allowed by plant Technical Specifications is 700 psig and minimum volume is 1225 ft^3 (2450 ft^3 total for two accumulators).

Scenario 1 assumes a conservatively low safety injection flow rate of 200.4 gpm. This flow rate is used to determine the additional volume of RWST water contributing to the sump volume during the time to perform the manual switchover to recirculation. Using the Kewaunee SBLOCA analysis, and assuming an RCS pressure equal to 1800 psig, just below the 1815 psig safety injection actuation value, the corresponding safety injection flow rate is 200.4 gpm. Containment spray is assumed to actuate and the flow rate for one spray train operating during the time to perform the switchover to recirculation is assumed as 1148 gpm (design flow rate and recalculated flow rate is 1300 gpm per train). The assumed containment spray flow rate is conservatively low for the purpose of determining the quantity of additional water accumulation in the sump pool during the time to perform the manual switchover to recirculation.

After Sump A and Sump B RHR pump suction pit (below the basement floor elevation) are filled, the water level above the containment basement floor elevation begins to rise. When the water level reaches 2' 5" above the floor elevation, water spills into the inactive Sump C below the reactor vessel. As Sump C fills, there is no change in the containment basement sump water level until Sump C water level reaches the level in the basement. Then the water level in the containment basement and Sump C (below the reactor vessel) rises as additional water is supplied from the RWST.

When the RWST is depleted to the switchover setpoint of 37% RWST level, the transfer to containment sump recirculation begins. There is a delay before recirculation begins due to operator response time required to perform the manual switchover actions. During the switchover procedure, one ICS pump and one RCS injection pump are shut down. The remaining operating ICS and RCS pumps continue to deplete the RWST to lower than 37% during the switchover to recirculation. Eight minutes of operator response time is assumed for completion of the switchover function. This is a conservatively short response time.

Containment hold-up volumes are credited for limiting the volume of RWST water that will reach the recirculation sump. The hold-up volumes are described and quantified in response to Question 34.

At the start of recirculation, the minimum sump water level calculated is as 43.44 inches which results in 6.19 inches of recirculation strainer submergence.

SCENARIO	MIN. SUMP LEVEL ABOVE BASEMENT FLOOR ELEV. (IN.)	STRAINER HEIGHT (IN.)	WATER LEVEL ABOVE STRAINER (IN.)
Scenario 1	43.44	37.25	6.19

Scenario 2 Details

Scenario 2 was created to simplistically model a RCS refill scenario that takes RWST inventory and refills the RCS, rather than placing that inventory in the containment sump.

Scenario 2 in the minimum sump water level calculation was assumed to be a two-inch diameter pipe break that occurs at the top of the pressurizer. It was assumed that no water from the RCS inventory spills to the containment floor. Instead, the volume of the pressurizer normally filled with steam becomes water solid. The accumulators were assumed to discharge into the RCS. The safety injection flow rate assumed during the switchover to recirculation was 533 gpm, taken from an existing Kewaunee SBLOCA analysis. Containment spray was conservatively assumed to actuate.

The NRC staff questioned whether the accumulators would fully discharge during Scenario 2. Consequently, a revised Scenario 2 that does not achieve accumulator injection was considered and is described below:

- To achieve an RCS refill scenario, one containment spray pump is assumed to be failed in order to lengthen the time to reach 37% RWST level which requires switchover to recirculation. With one spray pump assumed to failed, the flow rate out of the RWST is reduced resulting in a longer time duration for RWST injection. This allows time to refill the RCS after the initial blowdown and steaming out the break. Otherwise, the RCS would not have sufficient time to refill prior to the start of recirculation.

- RCS pressure is assumed to remain at approximately 1000 psia to prevent accumulator injection. Core injection is provided by the high head safety injection (HHSI) pumps. Two HHSI pumps are assumed to provide injection flow.

- Pressurizer level is normally at the 46.7% level during full power operation. Following the blowdown phase of the event and the time of minimum RCS inventory, the RCS is assumed to refill by HHSI injection flow to 22% of pressurizer level (22% pressurizer level is identified in ES-1.2, Post-LOCA Cooldown and Depressurization, as an input for terminating safety injection), or more conservatively to go water solid (100% pressurizer level). If 22% of pressurizer level is used as the refill volume, some RCS contents would be credited as spilling to the sump (the difference between 46.7% pressurizer level at the start of the event and the postulated 22% level at the start of recirculation). If the pressurizer goes solid, some RWST inventory is used to fill the RCS and does not contribute to the sump level.

- During the time between the start of the LOCA and the onset of recirculation (the time of interest) the RCS inventory remains hot due to the energy stored in the RCS, in the nuclear steam supply system steel, and in the fuel. Therefore, RCS shrinkage that could result in additional RWST inventory not reaching the sump is not applied. If appreciable RCS cooling occurs before recirculation begins, such as in response to a SBLOCA which occurs over a long period of time, then recirculation would not be required.

- The contribution to the sump level during the time to perform the manual switchover to recirculation is minimized. During the switchover, when one HHSI pump is shut down to be realigned to the containment sump, the other HHSI pump continues to inject RWST inventory into the core. However, the water from the HHSI injection train is assumed to primarily refill the RCS and is not credited for spilling to the sump for the time it takes to manually switchover. With one spray pump assumed as failed, only one spray pump is injecting into containment during the manual switchover process and this spray flow contributes to the rising sump level.

- Holdup of water on the upper containment floors is reduced due to operating only one spray pump in the injection mode, and the volume of spray in the atmosphere not yet reaching the sump is reduced due to the reduction in spray volume.

- RCS shrinkage due to RCS cooldown after the start of recirculation is ignored because the continuing RWST depletion from containment spray injection and/or flow out of the RCS break will exceed any shrinkage and results in a rising sump level.

The net effect of this revised Scenario 2 is a sump level equal to approximately 40 inches if the pressurizer refills to 22% level at the start of recirculation, or 38 inches if the pressurizer goes solid. In both cases, the resulting sump water level will fully submerge the recirculation strainer (strainer height is 37.25 inches) at the onset of recirculation.

As described in the above revised Scenario 2, it is possible to refill the RCS following a small break LOCA scenario and maintain RCS pressure above the accumulator discharge pressure. However, even though it can be shown that this RCS refill scenario will result in the recirculation strainer being fully submerged, a refill scenario without accumulator discharge is not a limiting case for evaluating the recirculation system's capabilities. This is primarily due to the low flow rate through the recirculation system due to use of HHSI. Flow through the recirculation strainer for this event would be approximately 350 gpm (one HHSI pump providing reactor vessel injection) as opposed to nearly 2000 gpm during the design basis event where the low head residual heat removal (RHR) pump is used for vessel injection. Furthermore, a break at the top of the pressurizer, or any elevated RCS break, will not result in a more detrimental debris generation inventory than the limiting RCS Train B hot leg break. This is due to an elevated small break having a much smaller Zone of Influence, resulting in less debris generation and the absence of fibrous insulation material at the top of the pressurizer. The limiting RCS Train B hot leg break will generate some fibrous debris from calcium silicate insulation on the steam generator blowdown piping and will generate fibrous debris from pressurizer heater cable insulation.

Scenario 2 in the current calculation was modeled simplistically in order to conservatively prevent spilling RCS contents into the sump and achieve a low sump level. However, it is recognized that the scenario as written in our current calculation provides a conservative analysis for sump level but does not accurately describe the RCS refill scenario. Therefore, the minimum sump level calculation will be revised and Scenario 2 will be identified as a non-limiting case for evaluating the recirculation system performance, or Scenario 2 will be removed entirely. Scenario 1 will remain the limiting sump level case for evaluating the recirculation system performance for both SBLOCA and LBLOCA.

Debris Generation SBLOCA vs. LBLOCA

It is recognized that the amount of debris generated during a small break LOCA (SBLOCA) and large break LOCA (LBLOCA) will be different, i.e., a LBLOCA will generate more debris (have a larger ZOI) than a smaller pipe break. However, KPS analyses assume the maximum debris generation (RCS Loop B hot leg break) and the minimum sump water level (which corresponds to a break of any size two inches or greater at or below the elevation of the RCS loops).

SBLOCA RCS Cool Down

Emergency Operating Procedures specify performing a RCS cool down as fast as possible (but less than 100 °F/hr) following a LOCA. Therefore, in response to a SBLOCA, it is quite feasible that the RCS could be cooled and depressurized during the RWST injection phase of the accident and containment sump recirculation may not be required.

NRC Additional Review Question: Containment Spray Actuation Effect

The NRC reviewer questioned whether the containment spray setpoint would realistically be reached for a two inch (small) break and the impact if containment spray does not actuate.

Containment spray is actuated at a nominal containment pressure of 21 psig. A SBLOCA may or may not actuate containment spray. It is conservatively assumed that containment spray is actuated.

Regardless of whether containment spray is actuated or not, the switchover to recirculation does not commence until the RWST drains down to the 37% level (most conservative assumption with two ECCS trains available).

If containment spray does not actuate in response to a SBLOCA, the RWST injection time is significantly extended and may result in cool down and depressurization of the RCS, preventing the need for recirculation.

In the event that containment spray does not actuate and recirculation is initiated, the volume of water in the sump would be greater than the volume that is currently calculated due to elimination of some hold up volumes. Hold up volumes, such as spray in the refueling cavity, on the floors, in the ICS piping, and from falling spray droplets not yet in the sump, along with the steam/condensate mass assumed to be in the atmosphere, are RWST inventory that does not contribute to the sump level at the onset of recirculation (see response to Question 34). The hold up volumes more than exceed the quantity of sprayed water that was credited for contributing to the rising water level during the switchover to recirculation.

Additionally, if containment spray does not actuate there is no transport mechanism for latent debris and failed coatings on the upper containment elevations. Containment spray and condensation drainage are the mechanisms for transporting these debris items to the containment sump. Furthermore, a SBLOCA will have a relatively small Zone of Influence for creating debris and the overall quantity of debris generated is reduced resulting in less head loss across the recirculation strainer.

NRC Question 33

Please discuss the potential for differences between hot-leg and cold-leg injection flow rates and NPSH margins. Alternatively, please demonstrate that the evaluated case is limiting or that other cases are not required at Kewaunee.

Response[7]

In response to a LBLOCA with a depressurized RCS, the RHR pumps will feed the reactor core via the upper plenum (reactor vessel) injection line. In the recirculation mode, design basis flow through the RHR pump for this scenario is calculated as 1990 gpm. Therefore, the NPSH required (NPSHR) 8 ft of water at 2000 gpm used in the NPSH evaluation is bounding. (The design basis flow rate through the recirculation strainer is calculated as 1870 gpm. The flow rate through the RHR pump includes pump recirculation flow. Pump recirculation flow discharges to the pump suction, downstream of the strainer.)

In response to a LOCA with RCS pressure at greater than 150 psig, the safety injection pumps will deliver flow to the RCS via cold leg injection. The maximum Safety Injection flow to the core when piggybacked on a RHR pump is approximately 1265 gpm. This value, plus approximately 115 gpm RHR pump recirculation flow, is well below the NPSHR of 8 ft of water at 2000 gpm used in the evaluation.

Kewaunee's emergency operating procedures do not specify use of hot leg injection.

In the NPSH margin evaluation, containment atmospheric pressure is assumed to be equal to the vapor pressure of the sump water. This assumption is conservative in that it does not credit containment pressurization to assist in the available NPSH to the RHR pumps during a transient.

The containment sump water elevation is assumed to be 595.62 feet (43.44 inches of water above the containment basement floor). This is the calculated minimum containment sump water elevation at the start of recirculation. The RHR pump suction elevation is 569.396 feet, resulting in a difference of 26.224 feet. RHR pump suction friction losses are calculated as 2.116 feet of water, resulting in 24.108 feet of head available.

The head loss across the debris laden recirculation strainer is assumed to be 10 feet of water, the maximum allowable.

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[7] See response to Question 32 for the evaluation of LOCA events used for determining the minimum containment sump water level, which is an input to the NPSH margin evaluation.

The NPSH margin for operating the RHR pump in the containment sump recirculation mode with the assumed maximum allowable strainer head losses was reported in our December 18, 2008 response (reference 3) and is re-stated below:

PARAMETER	HEAD (FT OF WATER)	COMMENT
NPSH Available	24.108	Total water height at the onset of recirculation, minus piping friction losses.
Maximum allowable debris laden strainer head loss	10 (Note 1)	Includes clean strainer head loss and debris bed head loss combined.
NPSH required	8	At design flow rate 2000 gpm/pump.
NPSH margin	6.108	

Note 1: See also table in Question 30 response.

NRC Question 34

Please identify the water sources and hold up volumes considered in the minimum water level calculation and provide quantitative values for each hold up volume for the limiting water level for the small- and large-break loss of coolant accident cases.

Response

Question 32 above describes the scenarios analyzed for determining the minimum recirculation sump water level, including a description of the water sources.

The following table displays the hold up volumes that are included in the minimum recirculation sump water level calculation. All hold up volumes listed below were applied to both evaluated scenarios.

DESCRIPTION OF HOLD UP VOLUME	VOLUME (CU. FT.)
Waste Disposal Containment Sump A. The sump is below the 592' containment basement floor (sump) elevation. It fills and remains filled during the LOCA response scenario.	112.6
Sump B recirculation pit. The pit is below the 592' containment basement floor (sump) elevation. The RHR pumps take suction from the Sump B recirculation pit. Although not a true hold up volume because this water is part of the recirculation sump, the sump is assumed to be empty at the start of the LOCA event. It fills with water as Sump B (basement level) fills. Included in this volume is the initial fill of the RHR suction piping up to the second isolation valve (SI-351A/B).	464.2
Containment Sump C. This sump is located under the reactor vessel. Assuming the LOCA event does not occur at a reactor vessel nozzle (which is not a limiting break for debris generation), this sump will remain empty until the water level on the containment basement floor reaches elevation 594'-5" or 2'-5" above the containment basement elevation. At that time, Sump C begins to fill via the opening in the sump manway hatch. After Sump C is filled to elevation 594'-5", the water level in containment and Sump C will continue to rise in response to additional water supplied from the RWST. The volume of this sump at the point where the water level reaches the opening into Sump C is 3,764 cu. ft., less the volume of the flooded portion of the bottom of the reactor pressure vessel. At this point, the hold up volume is approximately 3,500 cu. ft.	3,500
Hold up in the lowest elevation of refueling cavity due to the presence of a standpipe in the floor drain.	74.2
RWST volume to fill the normally empty portion of Internal Containment Spray (ICS) piping and the ring header.	233
The volume of water from containment spray water droplets falling that have not reached the containment sump.	41.1
Water held up at upper elevations of containment on horizontal surfaces due to containment spray or condensation drainage.	1238.1
The steam and condensate mass in containment as a result of the LOCA.	1008.1
TOTAL HOLD UP VOLUME (CU. FT.):	6,600

NRC Question 35

Please identify whether the emergency operating procedures would allow operators to manually operate two trains of RHR in recirculation mode. If this configuration is allowed, quantify its impact on the pumps' NPSH margin. Please provide similar information regarding the operation of the internal containment spray system in recirculation mode.

Response

The emergency operating procedures specify running one RHR pump in the recirculation mode in response to the design basis LOCA event.

The emergency operating procedures allow starting a second RHR pump in the recirculation mode to provide recirculation spray in response to a beyond-design basis event (i.e. an event resulting in increasing containment pressure and less than two fan coil units operating). The beyond-design-basis event is not addressed in this response.

H. STRUCTURAL ANALYSIS

NRC Question 36

In accordance with the first portion of Section 3.k of the Revised Content Guide for Generic Letter 2004-02 Supplemental Responses, licensees were requested to provide the design code of record used in the structural qualification of their replacement strainer components. The licensee did not provide this information in the supplemental responses. Please provide the applicable code(s) of record for the qualification of the strainer modules, piping, piping supports, Sump B pit cover, Sump B pit maintenance hatch strainer, and any other applicable components.

Response

The strainer modules are mounted to the containment basement floor elevation. The discharge of the strainer is piped to the recirculation sump pit where the residual heat removal pumps take suction. Adjacent to the piping sump pit entrance, a maintenance hatch strainer is positioned on the top of the sump pit. The maintenance hatch strainer is not credited in the design basis accident strainer surface area.

The strainer modules and maintenance hatch strainer, including the strainer mounting tracks and support channels that span across the sump pit, were evaluated using a combination of manual calculations and finite element analyses using the GTSTRUDL computer program, Version 25, and the ANSYS computer program, Version 5.7.1.

The strainer discharge piping and pipe supports, and sump cover plate (pipe entry into Sump B, recirculation sump pit), were evaluated using a combination of manual calculations and computerized analysis using the AutoPIPE Program, Version 8.50.

The strainer and related components were designed, fabricated and evaluated to USAS(ANSI) B31.1, Power Piping, 1967 Edition.

NRC Question 37

In accordance with the second portion of Section 3.k of the Revised Content Guide for Generic Letter 2004-02 Supplemental Responses, licensees were requested to provide the design margins for the strainer components which were analyzed for structural adequacy. Please provide and summarize, in tabular form, the design margins and/or interaction ratios for the strainer components analyzed for resolution of GL2004-02.

Response

The requested information is included as Enclosures L-1 and L-2, with photos of the strainer assembly included to aid the review.

Enclosure L-1 is from the structural evaluation of the strainer modules and maintenance hatch strainer, including the strainer mounting tracks and support channels that span across the sump pit.

Enclosure L-2 is from the structural evaluation of the strainer discharge piping, pipe supports and sump cover plate (pipe entry into Sump B, recirculation sump pit).

The strainer modules and associated components are designed for a maximum allowable head loss of 10 ft of water at 4000 gpm. Head loss less than 10 ft and reduced flow rates (such as the recalculated 1870 gpm design basis flow through the strainer; see response to Questions 33 and 19.c) results in additional structural margin.

NRC Question 38

The third portion of item 3.k of the revised content guide for the GL 2004-02 supplemental responses requests that the licensees "Summarize the evaluations performed for dynamic effects such as pipe whip, jet impingement, and missile impacts associated with high-energy line breaks (as applicable)." Please provide a detailed summary along with any additional supporting information regarding the assessment that the strainer modules are not subject to the aforementioned dynamic effects.

Response

An evaluation was performed to verify that the recirculation strainer and debris interceptors would not be impacted by a LOCA jet. The recirculation strainer is located at the East side of the containment basement, between 3' 2" feet thick concrete support walls and the outer containment wall (see Enclosures D and E-2 for pictorials). There are no postulated pipe breaks between the support walls and the outer containment wall where the strainer is located. Postulated pipe breaks on the West side of the interior basement walls (West of the strainer), were evaluated and determined not to cause jet impingement or pipe impact on the strainer or debris interceptors. The nearest lines evaluated included:

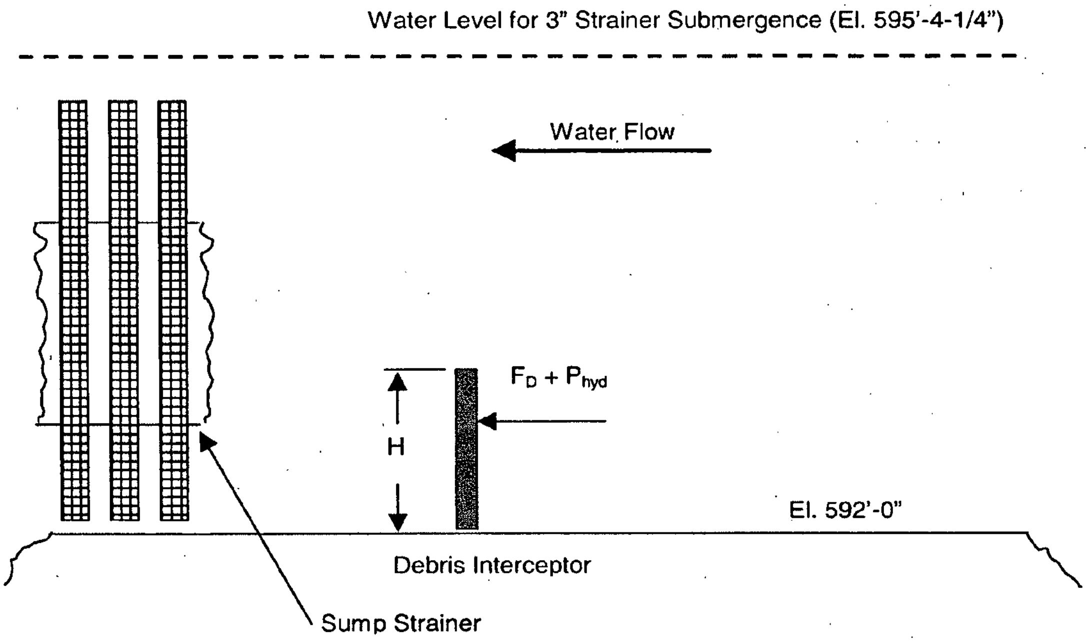
Piping	Pipe Outside Diameter (in.)	Comments
RHR outlet from RCS Loop B hot leg	8	No impact. A postulated guillotine break at valve RHR-1B would result in a jet parallel to the RHR pipe axis and would not impinge on the debris interceptors (D.I.) or strainer. A jet from a longitudinal break would impact the inside of the east shield wall but not the D.I. or strainer.
Pressurizer surge line	10	No impact. This line is located inside the Loop B vaults and is one floor above the containment basement (sump) elevation.
Accumulator injection 1B (SI-22B to RCS)	12	No impact. This line is located within the Loop B RCP vault and is located above the containment basement (sump) elevation.
Safety Inject to RCS cold leg (SI-13B to RCS)	6	No impact. This line is located within the Loop B RCP vault and is located above the containment basement (sump) elevation.
Charging line to cold leg (CVC-12 to RCS)	2	No impact. This line enters Loop B RCP vault from the north side of containment, west of the strainer area. A postulated break in the containment basement elevation would impinge on the RCP B support steel beams.
CVC letdown off the crossover leg	2	No impact. This two inch line is located 8' 6" above the 592' floor elevation. A guillotine break at valve RC-200B would result in a jet parallel to the pipe run and to the inside of the shield wall. A guillotine break at the tee upstream of RC-200B would result in a circular jet with an approximately 3' 6" radius which would not reach the D.I. or strainer.
RTD lines	1, 2 & 3	No impact. These lines are located within the Loop B vaults above the containment basement (sump) elevation.
Cold leg to pressurizer	2 & 3	No impact. This line is located within the Loop B vaults and is located above the containment basement (sump) elevation.
Low head safety injection (SI-304A(B) to Rx Vessel)	4 & 6	No impact. These lines are located one elevation above the containment sump elevation.

NRC Question 39

Figure 4 of the licensee's February 2008 supplemental response indicates that three debris interceptors were installed as part of Dominion Energy Kewaunee, Inc.'s GL 2004-02 resolution efforts. However, these components were not mentioned in Section 3.k of the supplemental response. Please provide additional information regarding the structural adequacy of these components including a description and summary of the structural analyses that were performed to demonstrate the ability of these components to maintain their structural integrity during a design basis accident.

Response

The debris interceptors, C8x18.75 channel, were structurally evaluated for consideration of drag and hydrostatic loads, deadweight and seismic loads, including the inertia effects of the hydrodynamic mass during a seismic event. There are no dynamic loads on the debris interceptors from a postulated pipe break (no jet impingement or pipe impact).



The debris interceptors were evaluated for a minimum water level of 40.5 inches which bounds the minimum water level at the start of recirculation. Evaluation assuming minimum water level provides a more conservative drag load.

The debris interceptors were conservatively evaluated assuming a sump flow rate of 4000 gpm. However, the actual design basis flow rate through the strainer was subsequently calculated as 1870 gpm.

The three design load combinations for the debris interceptors' steel structure are:

Condition	Load Combination	Allowable
Normal	DL + LL (Note 1)	AISC allowable
Operating Basis Earthquake (OBE)	DL + LL + DBA + OBE (Note 2)	AISC allowable
Design Basis Earthquake (DBE)	DL + LL + DBA + DBE (Note 2)	1.5 x AISC allowable but no greater than $0.9F_v$

Notes:
1. By comparison of Normal Condition and OBE, and since each has the same allowable, OBE is the bounding combination. Therefore, the Normal Condition was not evaluated.
2. Each load combination containing DBA and seismic is divided into two sub-combinations. One sub-combination assumes the water level reaches the total height of the debris interceptor on the upstream side of the barrier and has no fluid on the downstream side (this condition maximizes hydrostatic head). The other sub-combination assumes water level reaches a steady state head of 40.5 inches and the interceptor is completely submerged.

The following is a summary of lateral loads associated with each critical load combination.

Condition	Hydrostatic	Drag	Dynamic	Hydrodynamic	Combined Loads
OBE water depth = 9"	0.0 psf (top) 46.8 psf (bottom)	2.0 psf	23.0 psf	38.20 psf	110.00 psf
OBE water depth = 40.5"	N/A	2.0 psf	23.0 psf	44.78 psf	69.78 psf
DBE water depth = 9"	0.0 psf (top) 46.8 psf (bottom)	2.0 psf	46.0 psf	76.40 psf	171.20 psf
DBE water depth = 40.5"	N/A	2.0 psf	46.0 psf	89.56 psf	137.56 psf

Notes:
1. Dynamic and hydrodynamic loads for DBE are twice OBE loads.
2. Hydrostatic pressure is conservatively treated as a uniform pressure with base pressure applied over the entire height of the debris interceptor.
3. Sub-combinations OBE water depth = 9" and DBE water depth = 9" are bounding pressures within each combination.

The debris interceptors were initially evaluated for use of C9x13.4 channel. Subsequent to the evaluation, C8x18.75 channel was selected based on material availability and the C8x18.75 channel was evaluated and found to be acceptable. The evaluation included structural adequacy of the channel material, structural posts, welds between the channel and base plate, base plate material, and expansion anchors.

I. UPSTREAM EFFECTS

NRC Question 40

Please describe the size of the refueling cavity drain line, the minimum flow restriction in this line, and any line losses associated with the drain line. Please also describe the types and quantities of debris that could transport to the refueling cavity, and the basis for concluding that debris blockage or partial blockage will not occur at the cavity drain. The evaluation should account for the potential for some types of debris to remain buoyant following a loss of coolant accident, transport toward the cavity drain due to surface currents, and potentially sink on top of the cavity drain as water gradually displaces the air trapped in the debris material's pores. Please quantify the holdup volume assumed for the refueling cavity in the containment pool minimum water level calculation.

Response

The refueling cavity drain is located at the lowest cavity elevation, 608' 0", at the north end of the cavity (see Enclosure M). The drain opening is eight inches in diameter, connected to a four-inch diameter drain line. The refueling cavity drain line enters containment Sump A, below the containment basement floor (recirculation sump) elevation. Containment Sump A drains to the Sludge Interceptor Tank in the Auxiliary Building. However, this line is isolated upon a containment isolation signal. Containment Sump A, when filled, overflows onto the containment basement floor (recirculation sump).

The refueling cavity drain is located directly under the fuel transfer lifting frame. The drain has a removable standpipe that is eight inches in diameter, six inches high and has a 1 inch x 1 inch grid recessed in the standpipe top. Installation of the standpipe is controlled by a plant procedure which requires the standpipe to be in place during plant operation. The standpipe prevents non-suspended debris in the refueling cavity from entering the drain.

The minimum containment sump water level calculation for the start of recirculation credits a hold up volume in the refueling cavity equal to 8.25 inches of water height in the lower canal, or 74.2 ft^3 (555 gal.). This is the height of water held up by the presence of the standpipe. Ultimately, the cavity will drain to 6-inches of water height when containment spray stops. Containment spray duration is approximately 55 minutes. Clean water enters the cavity from containment spray (RWST injection mode). Kewaunee does not credit the use of recirculation spray for the LOCA event.

For the limiting hot leg break in the RCS Loop B Steam Generator Vault, large debris is not postulated to exit the top of the Steam Generator or Reactor Coolant Pump vaults and land directly on top of the refueling cavity drain line standpipe. This is based on the following:

- The vertical vault walls will direct uplifted debris vertically into containment.

- The refueling cavity drain standpipe is located horizontally approximately 57 ft from the break location. The break location is recessed in the Steam Generator Vault at the 617' 10" elevation. The top of the Steam Generator Vault walls are at the 666' and 660' elevation. The operating floor elevation is 649'. The refueling cavity drain is located at the 608' elevation.

- There are multiple obstructions between the RCS hot leg piping and the standpipe which would prevent large debris from reaching the upper containment or the refueling cavity standpipe. These obstructions could also stop or deflect the transport of small debris. The obstructions include the following:
    - Steel grate work platforms that surround the Steam Generator at the 624' 1" elevation.
    - Steel handrails and work platforms that surround the Steam Generator above the 660' elevation vault wall tops (shown in Enclosure M).
    - In the adjacent/adjoining Reactor Coolant Pump Vault, steel grate work platforms that are located at the 620' 3" and 633' 2" elevations.
    - Many other obstructions that are located between the break location and the refueling cavity drain, such as but not limited to, permanent ladders, handrails, equipment, ventilation ductwork, structural steel, reactor vessel internals lifting rig, refueling cavity bridge crane and the fuel assembly transfer equipment.

- A piece of debris would need to be at least eight inches wide, planar, and transportable or land horizontally and directly over the standpipe to block the drain line. The debris would need to maintain this position as the refueling cavity pool fills. There is no credible scenario for this type of debris, trajectory and behavior during pool fill.

- A crumpled piece of sheet metal, if one were to land in the cavity, would not land directly over the drain opening due to the fuel assembly lifting frame located above the drain. In addition it would not transport towards the drain due to the weight of the material, and would not seal a drain opening due to its shape.

- Any fibrous insulation entering the refueling cavity pool would not land directly over the drain opening due to the fuel assembly lifting frame located over the drain. In addition it would not be of sufficient size and density to block an eight-inch diameter opening, and would not transport to the drain opening due to the high temperature of the pool water and low transport velocity in the pool.
    - The post-accident containment atmosphere will be approximately 210 °F. The water sprayed into the refueling cavity and onto containment structures will therefore be hot, which will aid in sinking debris and prevent or eliminate air bubbles from being trapped in the debris. Small fibrous insulation debris

that may have entered the refueling cavity would enter during the initial phase of the break blowdown, which allows time for the debris to settle in the refueling cavity. During the time the cavity fills to above the drain standpipe opening the debris will settle in the refueling cavity. NUREG/CR-6808, Section 5.2.1, states, "Fiberglass insulation readily absorbs water, particularly hot water, and sinks rapidly (...from 20 to 30 seconds in 120 °F water)." The revised debris inventory described in Attachment 2 to this letter indicates fibrous debris size will be limited to Fines after the described insulation removal activities are complete. Calcium silicate debris would be expected to sink and not be buoyant.

- Floating debris would likely consist of Fines and small debris such as coatings that would pass through the drain opening.
- The transport velocity around the drain, greater than 17 inches from the drain centerline, is calculated to be less than 0.1 fps. Any debris that transports over the cavity ledge into the lower cavity falls into an area where the transport velocity is less than 0.1 fps. NUREG/CR-6808, Section 5.2.1, states, "Water velocities needed to initiate motion of sunken insulation are on the order of 0.2 ft/s for individual shreds, 0.5 to 0.7 ft/s for individual small pieces (up to 4 in. on a side), and 0.9 to 1.5 ft/s for individual large pieces (up to 2 ft on a side)."

Therefore, any debris that may enter the pool other than Fines will not transport down the standpipe drain.

In addition to the limiting debris generation RCS hot leg break, other breaks are considered:

- A break in the RCS Loop A piping (hot leg, cold leg, or intermediate leg) would not generate any fibrous insulation debris, with the exception of fibers contained in calcium silicate (Thermobestos) insulation on the steam generator blowdown lines. The fibrous portion of calcium silicate insulation is limited to Fines. There is no TempMat or Okotherm insulation in the RCS Loop A vaults.

  The refueling cavity drain standpipe is closer in proximity to the "A" Steam Generator Vault. However, similar to the RCS Loop B configuration, between the postulated RCS Loop A piping and the refueling cavity drain there are several steel grating work platforms, structural steel shapes, equipment, piping, ladders and handrails that will deflect, distort and limit the size of reflective metal debris exiting the top of the vault. Additionally, due to the drain pipe location being below the fuel assembly lifting frame, an eight-inch diameter planar piece landing directly on top of the drain pipe is not credible.

- An RCS Loop B cold leg or intermediate leg break, similar to the limiting hot leg break, would be at an elevation within the vault below several steel work platform grating elevations. A cold leg break would not generate any calcium silicate

(Thermobestos) debris. The cold leg and intermediate leg are located between the TempMat and Okonite cable insulation materials and the refueling cavity drain. Therefore, it is postulated that this debris would likely be blown in the opposite direction from the cavity drain location. (Recall that the TempMat insulation will be removed. See Attachment 2.)

- The reactor vessel top head is insulated with reflective metal insulation. A non-isolable leak or break at this location will not result in large fibrous debris in the refueling cavity.

To provide further insurance that the refueling cavity drain will not become blocked by debris, the 1 inch x 1 inch grid/grating on the recessed top of the standpipe will be removed. This will provide an unobstructed eight inch diameter drain opening for the four-inch drain line.

As noted above, 555 gallons of hold up water volume is assumed to exist in the refueling cavity at the initiation of recirculation when the containment sump water level is at its lowest during the recirculation phase. 555 gallons equates to approximately 0.22 inch sump water level at that time (containment elevation) during the sump fill. At the onset of recirculation, the minimum sump water level is calculated at 43.44 inches and the strainer height is 37.25 inches. Therefore, the sump water level is 6.19 inches above the strainer surface. The strainer is analyzed for a minimum submergence equal to two inches above the top of the strainer. Therefore, the refueling cavity holdup volume accuracy is not critical to strainer submergence. However, blockage of the refueling cavity drain and accumulation of additional holdup at this location is not postulated.

J. DOWNSTREAM EFFECTS/IN-VESSEL

NRC Question 41

The NRC staff considers in-vessel downstream effects to not be fully addressed at Kewaunee as well as at other pressurized water reactors. The licensee's submittal refers to draft WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid." The NRC staff has not issued a final safety evaluation (SE) for WCAP 16793-NP. The licensee may demonstrate that in-vessel downstream effects issues are resolved for Kewaunee by showing that the licensee's plant conditions are bounded by the final WCAP-16793-NP and the corresponding final NRC staff SE, and by addressing the conditions and limitations in the final SE. The licensee may also resolve this item by demonstrating without reference to WCAP-16793 or the staff SE that in-vessel downstream effects have been addressed at Kewaunee. In any event, the licensee should report how it has addressed the in-vessel downstream effects issue within 90 days of issuance of the final NRC staff SE on WCAP-16793.

Response

Kewaunee uses Westinghouse 422V+ nuclear fuel in the reactor.

DEK has performed a nuclear fuel blockage and nuclear fuel support grid fiber bed thickness evaluation using the guidance from WCAP-16406-P, Revision 1. The evaluation shows no potential for internal reactor blockages and minimal formation of a thin bed of fiber (0.010 inch thickness) on the nuclear fuel top support grid.

DEK also performed a post-accident nuclear fuel decay heat removal evaluation using the guidance in WCAP-16793-NP, Revision 0. The evaluation shows the maximum fuel deposition to be approximately 90 microns, well below the acceptance criteria of 1270 microns. The evaluation shows fuel clad temperature is approximately 160 °F, well below the acceptance criteria of 800 °F.

The results of these evaluations will remain bounding following the removal of fibrous material described in Attachment 2.

Upon issuance of the SE for WCAP-16793-NP, DEK will re-evaluate the nuclear fuel decay heat removal evaluation and revise the evaluation if necessary. An updated response will be submitted within 90 days of issuance of the final SE on WCAP-16793-NP, as required.

K. Chemical Effects

NRC Question 42

Please identify and justify all plant-specific refinements made to the WCAP-16530-NP base chemical model predictions and indicate how much each refinement reduced the predicted amount of precipitate compared with the October 2006 analysis. For example, if silicate inhibition was credited, please provide justification. Please provide any relevant bench-top testing and analysis that support reduction of the Kewaunee-specific chemical precipitate loading. Discuss why the overall plant-specific chemical effects evaluation remains conservative when crediting reductions to the WCAP-1530-NP base chemical model. Additional information concerning staff expectations for the use of plant-specific refinements to WCAP-16530 is available in Section 9 of the Chemical Effects Review Guidance available at ML080380214.

Response

No plant-specific refinements were made to the WCAP-16530-NP base chemical model predictions. No bench-top testing was performed. Chemical precipitate loading was not reduced.

NRC Question 43

The licensee's February 29, 2008 supplemental response states that the minimum pH range calculation assumes end of cycle, minimum boron concentration. Likewise, the maximum pH is based on beginning of cycle maximum boron concentration. The staff would expect the maximum boron concentration to result in the minimum sump pool pH and the minimum boron concentration to result in the maximum sump pool pH. Please explain the basis for the pH calculations with respect to boron concentration at the beginning and end of cycle. Also, please explain if the volume and concentration of sodium hydroxide is adjusted during the operating cycle.

Response

The following table was provided in our February 29, 2008 (reference 4) response, as Table 3.O-1 in Section 3.O, "Chemical Effects." The text description in the "Input" column for the Low pH Range and High pH Range was transposed in reference 4.

The table below shows the corrected information. The transposition in reference 4 was a typographical error and does not affect our chemical precipitation analysis.

We do not adjust the volume or concentration of sodium hydroxide in the caustic standpipe during the operating cycle.

	START OF LOCA (0 SEC.) pH	**1,000,000 SECONDS (11.5 DAYS) pH**	**INPUT**
Low pH Range	4.66	7.5	Maximum RWST and Accumulator Boron Concentration; RCS at 1514 ppm boron (beginning of cycle)
High pH Range	5.13	7.8	Minimum RWST and Accumulator Boron Concentration; RCS at 0 ppm boron (end of cycle)

K. LICENSING BASIS

NRC Question 44

Please describe any surveillance requirements applicable to the emergency core cooling recirculation strainer installed at Kewaunee to ensure that the strainer is not restricted by debris and that there is no evidence of structural distress or abnormal corrosion.

Response

There currently are no Technical Specification surveillance requirements for the Emergency Core Cooling recirculation sump strainer. However, Kewaunee is currently in the process of transitioning to Improved Technical Specifications (ITS). The ITS will include a new surveillance requirement for a visual inspection of the strainer and debris interceptors every 18 months. The ITS submittal was submitted to NRC on August 24, 2009 (reference 6).

The new surveillance will verify no debris restrictions and no structural distress for the strainer and debris interceptor. The requirement also includes visual inspection to ensure no abnormal corrosion (the strainer and debris interceptor components are constructed from stainless steel materials).

The new surveillance requirement has already been incorporated into plant procedures OP-KW-OSP-CCI-003, Cold Shutdown Containment Inspection, and OP-KW-OSP-CCI-002, "Containment Inspection During Power Operation."

References:

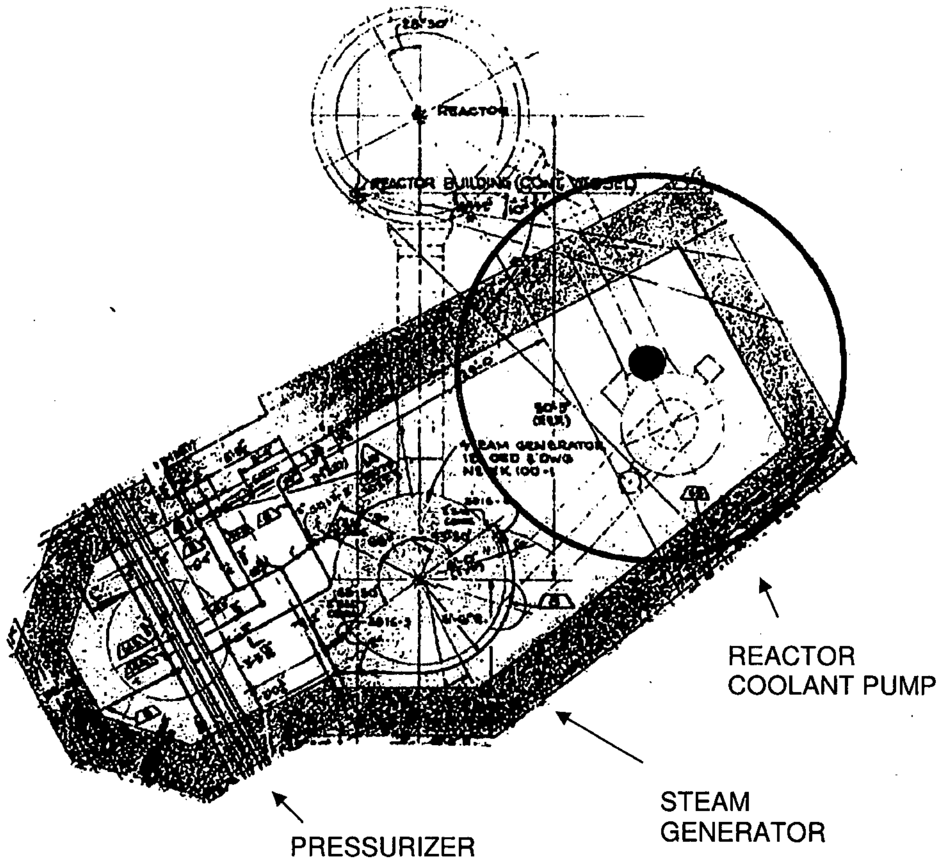
1. Letter from Peter S. Tam (NRC) to David A. Heacock (DEK), "Kewaunee Power Station - Request for Additional Information Regarding Response to Generic Letter 2004-02 (TAC No. MC4691)," dated August 14, 2009.
2. Email from Peter S. Tam (NRC) to Jack Gadzala, Thomas Breene and Craig Sly (DEK), "Kewaunee - Revised Questions 5, 6, 7, and 12 of the 8/14/09 RAI (TAC MC4691)," dated October 14, 2009.
3. Ontario Hydro Report N-REP-34320-10000-R00, "Jet Impact Tests – Preliminary Results and Their Applications," Ontario Power Generation, April 2001.
4. Letter from Gerald T Bischof (DEK) to Document Control Desk (NRC), "NRC Generic Letter 2004-02 Supplemental Response - Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated February 29, 2008.
5. Letter from J. Alan Price (DEK) to Document Control Desk (NRC), "NRC Generic Letter 2004-02 Updated Supplemental Response - Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated December 18, 2008.
6. Letter from Leslie N. Hartz (DEK) to Document Control Desk (NRC), "License Amendment Request 249: Kewaunee Power Station Conversion to Improved Technical Specifications (TAC No. ME02467)," dated August 24, 2009. [ADAMS Accession No. ML092440426]

ATTACHMENT 4
LIST OF ENCLOSURES

Enclosure	Description	No. of Pages
A	(RAI 1) Analyzed LOCA Pipe Breaks for Debris Generation	4
A-1	(RAI 2) MSDS for Thermo-12 (Page 1 of 5)	1
B	(RAI 5/6/7/12) Photos of TempMat, Fiberglass, Thermobestos	3
C-1	(RAI 8) Latent Debris Calculation C11928, Revision 0	44
C-2	(RAI 8) Latent Debris Procedure CM-AA-CRS-101, Revision 2	11
D	(RAI 9) Debris Interceptors Installed in the Plant	2
E-1	(RAI 13/15/16) ARL Presentation from 9/15/09 Teleconference with NRC	8
E-2	(RAI 13/15/16) ARL Presentation from 11/10/09 Teleconference with NRC	14
E-3	(RAI 14) Containment Layout Cut-Away View	3
F-1	(RAI F.19.a) Excerpt from Clean Strainer Head Loss Calculation	4
F-2	(RAI F.19.a) Excerpt from Total Head Loss Calculation	4
G	(RAI F.19.c.vi) Flume Design Layout and Photographs	4
H	(RAI F.19.c.xv) Photos of Debris Addition During Large Scale Tests	5
I-1	(RAI 23 & F.19.c.xiv) Clean Strainer Head Loss Test Data	2
I-2	(RAI 23 & F.19.c.xiv) Test 3 Design Debris Load Head Loss Test Data	1
I-3	(RAI 23 & F.19.c.xiv) Test 9 Supplemental Debris Load Head Loss Test Data	1
I-4	(RAI F.19.c.xiv) Photos of Flume Drain down	3
J	(RAI F.19.c.xv) Chemical Concentration Worksheets	2
K	(RAI 20/21/22) Vortex Calculation TDI-6008-07, Revision 6	33
L-1	(RAI 37) Photos and Excerpts from Strainer Module Structural Evaluation	8
L-2	(RAI 37) Photos and Excerpts from Strainer Piping Structural Evaluation	6
M	(RAI 40) Refueling Cavity Drain Location	4

ENCLOSURE A
(RAI 1) ANALYZED LOCA PIPE BREAKS FOR DEBRIS GENERATION

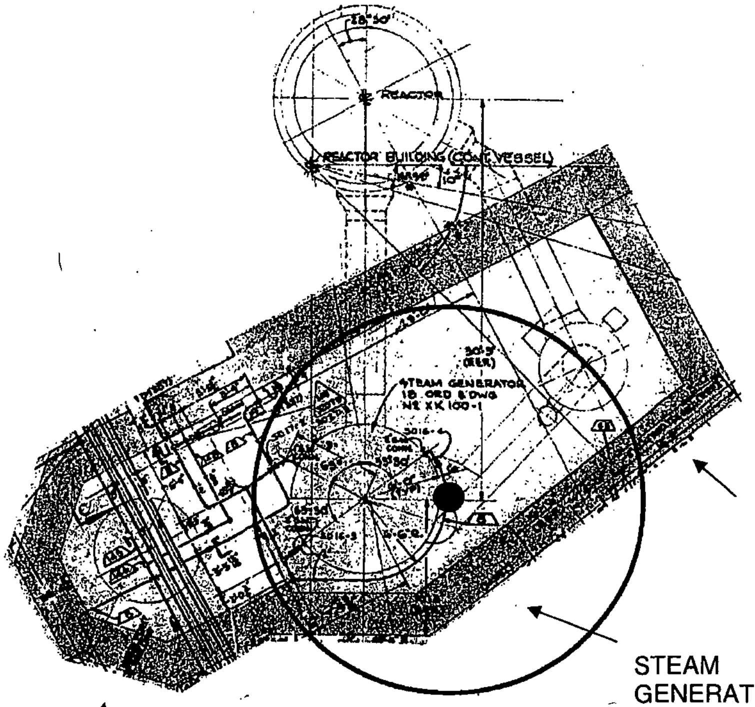
ANALYZED RCS COLD LEG BREAK – NOT LIMITING BREAK



BREAK S1 RCS COLD LEG
ZOI = 5.45D R = 12' – 6" ———

ENCLOSURE A
(RAI 1) ANALYZED LOCA PIPE BREAKS FOR DEBRIS GENERATION

ANALYZED RCS INTERMEDIATE LEG BREAK – NOT LIMITING BREAK



REACTOR
COOLANT PUMP

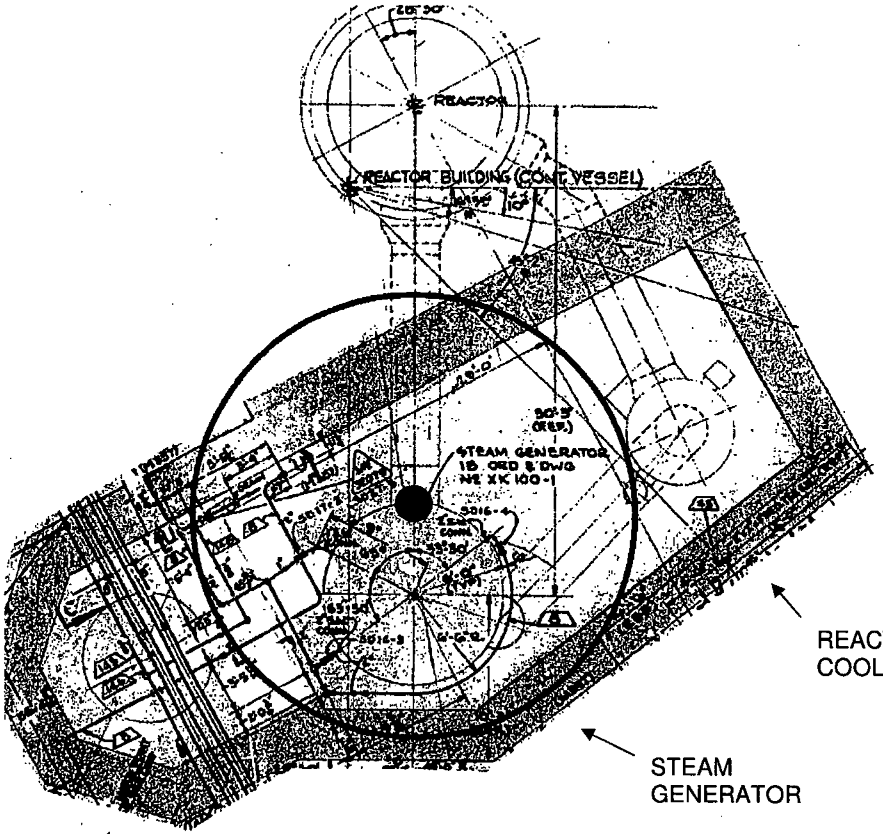
STEAM
GENERATOR

BREAK S2 RCS CROSSOVER LEG
ZOI = 5.45 D R = 14'-1"

PRESSURIZER

ENCLOSURE A
(RAI 1) ANALYZED LOCA PIPE BREAKS FOR DEBRIS GENERATION

ANALYZED RCS HOT LEG BREAK –**LIMITING BREAK**



REACTOR COOLANT PUMP

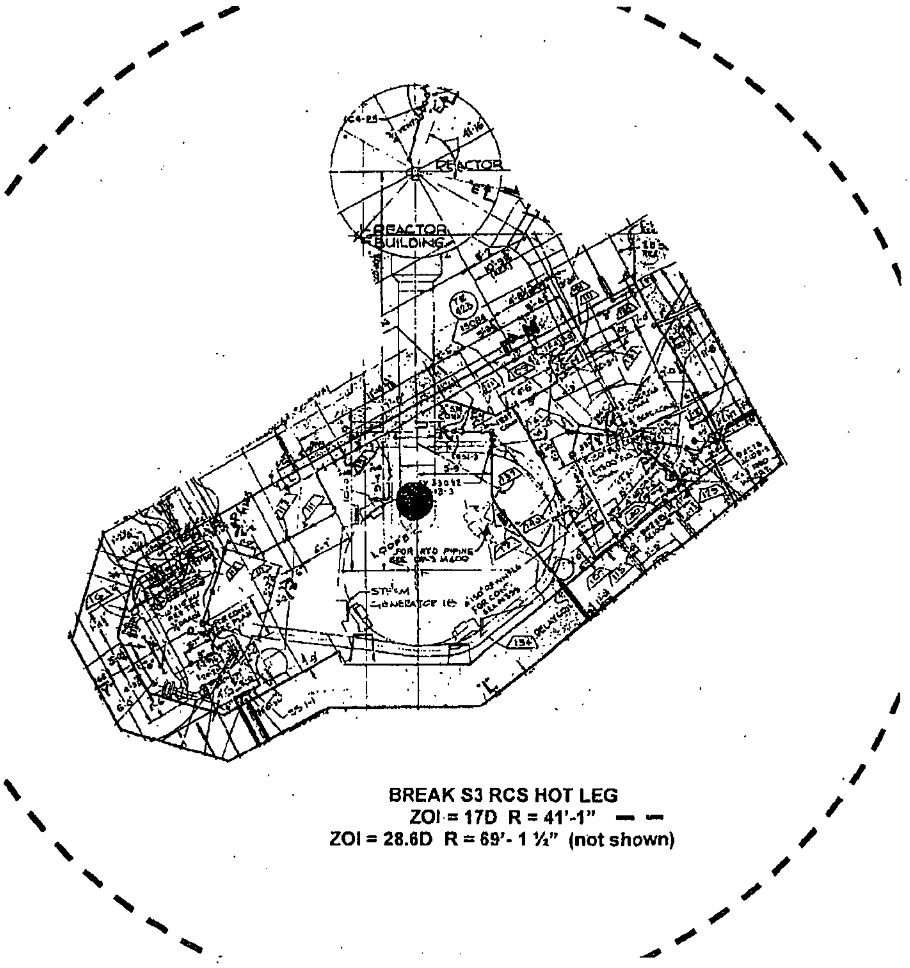
STEAM GENERATOR

PRESSURIZER

BREAK S3 RCS HOT LEG
ZOI = 5.45 D R = 13'-2"

ENCLOSURE A
(RAI 1) ANALYZED LOCA PIPE BREAKS FOR DEBRIS GENERATION

ANALYZED RCS HOT LEG BREAK –**LIMITING BREAK**



BREAK S3 RCS HOT LEG
ZOI = 17D R = 41'-1" — —
ZOI = 28.6D R = 69'- 1 ½" (not shown)

ENCLOSURE A-1
(RAI 2) FIBER COUNT FOR JM THERMO-12 (PG 1 OF 5 ONLY)
FOR THERMOBESTOS COMPARISON ONLY

IIG
Industrial Insulation Group
A Calsilite/Johns Manville Joint Venture

Date: 8/31/2005
MSDS ID: 20501
Rev: 1.0.4
Replaces: 10/6/2003

Material Safety Data Sheet

Material Name: Calcium Silicate Insulation

Section 1— Chemical Product and Company Identification

Product Name: Thermo-12® Gold Calcium Silicate Insulation
CAS# Mixture/None Assigned
Generic Name: Insulation (Calcium Silicate)
Formula: Mixture
Chemical Name: Synthetic Calcium Silicate

Manufacturer Information
Industrial Insulation Group
2100 Line Street
Brunswick, GA. 31520

Phone number for Health and Safety Information: 970.858.6211 (M-F, 7:00a.m. to 4:00p.m., Mountain Time)

Trade Name: Thermo-12 Gold

Section 2 — Composition and Information on Ingredients

CAS #	Component	Percent	OSHA PEL	ACGIH TLV	NIOSH REL	UNITS
1344-95-2	Synthetic Calcium Silicate	> 93	15(T) 5(R)	10	10(T) 5(R)	mg/M^3
51274-00-1	Iron-based color	< 1	15(T) 5(R)	10	NE	mg/M^3
65997-17-3	Synthetic Vitreous Fiber	0 - 2	15(T) 5(R)	5	5	mg/M^3
9004-34-6	Cellulose Fiber	0 - 2	15(T) 5(R)	10	10(T) 5(R)	mg/M^3
1344-09-8	Sodium Silicate	0 - 6	15(T) 5(R)	10	NE	mg/M^3

NE = Not Established
ACGIH TLVs are 2003 values. OSHA PELs are those in effect on the date of preparation of this MSDS. The listed PELs, TVLs and RELs are time weighted average exposure limits.
Component Related Regulatory Information
This product may be regulated, have exposure limits or other information identified as the following:
Nuisance particulates.

Section 3 — Hazards Identification

Emergency Overview
APPEARANCE AND ODOR: Odorless, Yellow semi-circle or block insulation with coloring throughout as a visual marker to indicate this is an asbestos-free product.

This product is an article and under normal conditions of use, this product is not expected to create any unusual emergency hazards. However, cutting, sawing, or abrading may increase the risk of personnel exposure.

Inhalation of excessive amounts of dust created when fabricating, cutting, or other mechanical alterations of the product may cause temporary upper respiratory irritation and/or congestion— remove affected individuals to fresh air.

Skin irritation may be treated by gently washing affected area with soap and warm water.

Eye irritation may be treated by flushing eyes with large amounts of water. If irritation persists, contact a physician.

Prolonged contact with dust from this product may cause Dermatitis.
In the event of fire, use normal fire fighting procedures to prevent inhalation of smoke and gases.

ENCLOSURE B
(RAI 5/6/7/12) PHOTOS OF TEMPMAT, FIBERGLASS, THERMOBESTOS

TempMat Fines

TempMat Smalls

ENCLOSURE B
(RAI 5/6/7/12) PHOTOS OF TEMPMAT, FIBERGLASS, THERMOBESTOS

Owens Corning Fines

Owens Corning Smalls

ENCLOSURE B
(RAI 5/6/7/12) PHOTOS OF TEMPMAT, FIBERGLASS, THERMOBESTOS

Nukon (Latent) Fines

Pulverized Calsil Powder