September 8, 2000

Mr. Oliver D. Kingsley, President
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Downers Grove, IL 60515

SUBJECT: QUAD CITIES - CONTRACTOR REVIEW OF HEAD LOSS CALCULATIONS ASSOCIATED WITH REQUEST FOR LICENSE AMENDMENT (TAC NOS. MA5043 AND MA5044)

Dear Mr. Kingsley:

On July 28, 2000, the U.S. Nuclear Regulatory Commission (NRC) staff held a conference call with Mr. Rod Krich, of your staff, to discuss the Commonwealth Edison Company's (ComEd) January 29, 1999, request for a license amendment for Quad Cities Nuclear Power Station, Units 1 and 2. The amendment would take credit for containment overpressure to provide adequate net positive suction head for the emergency core cooling system (ECCS). During the conference call, the NRC staff explained why the method used was unacceptable for determining the head loss across the ECCS suction strainers. Your staff and the NRC staff agreed to the following: (1) ComEd would revise the calculations of suction strainer head loss and make any necessary changes to the January 29, 1999, submittal; (2) the NRC would suspend its review of the submittal until the revised calculations were submitted; and (3) the NRC would provide ComEd the technical evaluation report (TER) developed by Los Alamos National Laboratory documenting the detailed review of your head loss calculations.

The TER is enclosed. If you have any questions about the review of your submittal, please contact me at (301) 415-1321.

Sincerely,

/RA/

Stewart N. Bailey, Project Manager, Section 2
Project Directorate III
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket Nos. 50-254 and 50-265

Enclosure: Technical Evaluation Report

cc w/encl: See next page

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Technical Review of ComEd Calculations

Quad Cities Station Units 1 and 2: ECCS Strainer Head Loss Estimates

May 24, 2000

Performed by

Dasari V. Rao
Probabilistic Risk and Hazards Analysis Group
Technical and Safety Assessment Division
Los Alamos National Laboratory
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Performed for

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Office of Nuclear Reactor Regulation
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Rockville, Md.

ENCLOSURE

Table of Contents

1.0 INTRODUCTION

In response to US Nuclear Regulatory Commission Bulletin 96-03 (NRCB 96-03), "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling Water Reactor," the Commonwealth Edison Company (ComEd) replaced existing truncated-cone ECCS suction strainers at Quad Cities Station Units 1 and 2 with large-capacity stacked-disk strainers. The replacement strainers were designed to minimize the head loss resulting from the accumulation of loss-of-coolant accident (LOCA)-related debris. Estimates of head loss resulting from debris accumulation are provided in ComEd calculations QDC-1600-M-0545 and QDC-0010-M-0396 [Refs. 1 and 2] for Quad Cities Station Units 1 and 2, respectively.

These calculations are part of the licensee submittal(s) in support of their request for containment overpressure credit in the $NPSH_{Margin}$ calculations. Los Alamos National Laboratory scientists (LANL) were tasked by NRC to review the head-loss calculations.

1.1 Summary of Information Provided in the Licensee Submittals

The licensee calculations [Refs. 1 and 2] provided the following information for each unit.

1. A summary of types of insulation materials present in the drywell of each unit and an approximate inventory of selected types of insulations (e.g., Nukon and calcium-silicate)
2. The calculation methods used by the licensee to estimate the quantity of each type of insulation that would accumulate on the ECCS strainer and the head loss resulting from debris accumulation
3. The results of the calculations for each unit, including estimates for quantity of debris generated, quantity of debris transported to the strainers, and the resulting head loss.

Although, the information contained in these calculations is not complete (e.g., they did not include piping isometrics), it is sufficient to perform this review. Where necessary, the information provided in the calculations was supplemented by the licensee response to NRC Request for Additional Information. Some important information from the licensee submittal is provided below.

Quad Cities Station Units 1 and 2 are boiling water reactors operated by Commonwealth Edison Company. Originally, both units were primarily insulated with 6-mil reflective metal insulation (RMI). Over time, a portion of the 6-mil aluminum RMI insulation was replaced with 2-mil or 2.5-mil stainless-steel RMI. Thus, the majority of the piping and other equipment in Quad Cities Station Units 1 and 2 currently are insulated primarily by 2/2.5-mil stainless-steel RMI and 6-mil aluminum RMI. A small portion of the piping is insulated with low-density fiberglass insulation (Nukon) and calcium-silicate insulation encapsulated in aluminum sheaths. The licensee estimated that approximately 114 ft^3 of Nukon and 7.8 ft^3 of calcium-silicate insulation are present in the drywell of Unit 1 [Ref. 1]. Although Ref. 2 does not list the exact quantity of Nukon and calcium-silicate insulation present in the Unit 2, it does suggest that significantly smaller quantities of Nukon insulation is present in Quad Cities Unit 2. From the discussions provided in the submittal(s), it appears that Quad Cities Unit 1 provides the limiting case of the two units (as related to the quantity of fibrous insulation present in the drywell).

The licensee estimated debris loading on the strainer following a postulated 'worst-case' break using methodology provided by the Boiling Water Reactors Owners Group (BWROG) in the Utility Resolution Guidance (URG) document [Ref. 3]. The quantity of RMI accumulating on the strainer was estimated using the saturation thickness approach. The quantity of Nukon debris transported to the suppression pool and subsequently to the strainer was estimated for Unit 1 by applying combined generation/transport fractions listed in the BWROG URG for the entire drywell inventory. This means the utility used Method 1 for mapping out the zone of influence (ZOI) and combined generation/transport factors of 0.28 and 0.78 for estimating the quantity of "fine" and "large" pieces that would be transported to the suppression pool. In the case of calcium-silicate, the licensee used Method 1 in conjunction with a combined generation/transport factor of 0.1.

The licensee used the BLOCKAGE v2.5 computer code for estimating the quantity of debris settling in the suppression pool. The analysis made several assumptions regarding the settling characteristics of the debris that have not been approved by the NRC Staff Evaluation Report (SER) on the URG. For example, the analysis credited that more than 50% of the finer particulates (e.g., sludge, and dust/dirt) would pass through the strainer and settle out in the primary system. This assumption is inconsistent with URG guidance as approved by the NRC SER.

The licensee used a modified version of the NUREG/CR-6224 head-loss correlation for estimating the head-loss effect of fibrous and particulate debris accumulation on the strainer surface. This contribution then was simply added to the RMI contribution to estimate the total head loss caused by a mixed bed of RMI and fibrous debris. The head-loss analyses credited the following aspects of ECCS performance.

1. The net ECCS flow through the strainers for the first minutes following a LOCA would be 33,400 gal./min. This includes flow from both the low-pressure core injection (LPCI) and low-pressure core spray (LPCS) pump flows. The operator would throttle the flow to 29,000 gal./min after 10 min (600 s). The licensee representatives have suggested that the throttled flow used in the head-loss calculations is much larger than the licensing-basis long-term flow.
2. The suppression pool temperature varies from an initial value of 106^{o}F to 176^{o}F during a period of several hours.

The licensee stated that the head-loss calculations were performed and the strainers were designed and installed before BWROG URG was finalized. Presumably as a result, the licensee analyses in some areas did not adhere to the URG guidance.

1.2 Scope of LANL Review

The LANL staff review of the licensee submittal [Refs. 1 and 2] and the supporting documentation focused on the following.

1. *To assess the adequacy/accuracy of the debris loading used by the licensee to size the strainer*. In particular, LANL reviewed the calculation methods used in the licensee calculations to estimate the quantity of debris generated and to estimate the fraction that might transport to the ECCS suction strainers.

2. *To perform confirmatory calculations of strainer head loss resulting from build up of design-basis debris loading*. These estimates were used to draw conclusions regarding the adequacy of the strainer and the operational margin.

LANL did not devote any effort to examining the validity of the licensee's assumption related to types of insulation present in the drywell or the quantity of debris that might be generated by a postulated break. It is assumed that the licensee ZOI and debris generation-calculations are sufficiently accurate. A cursory review was performed to identify various conservative assumptions made by the licensee in estimating the debris generated by a limiting break.

Upon a preliminary review of the licensee calculations, LANL prepared a draft request for additional information (RAI). Appendix A provides this list as prepared by the LANL staff. NRR forwarded these questions, in a modified form, to the licensee. In the subsequent conference calls, the licensee provided some of the additional data.

1.3 References

1. Zigler, G., and P. Mast, *Quad Cities Station Unit 1: ECCS Strainer Head Loss Estimates*, Innovative Technology Solutions Calculation Note No. QDC-1600-M-0545, Rev. 7, 1998.

2. Souto, F., and J. Bostelman, *Quad Cities Station Unit 2: ECCS Strainer Head Loss Estimates*, Innovative Technology Solutions Calculation Note No. QDC-0010-M-0396, Rev. 7, 1997.

3. General Electric Company, Utility Resolution Guidance for ECCS Suction Strainer Blockage, Boiling Water Owners Group, NEDO-32686, Rev. 0, 1996.

4. Rao, D. V., et al., BLOCKAGE V2.5 User's Manual, NUREG/CR-6370, US Nuclear Regulatory Commission, 1996.

5. Zigler, G., et al., Parametric Study of the Potential for BWR ECCS Strainer Blockage due to LOCA Generated Debris, NUREG/CR-6224, US Nuclear Regulatory Commission, 1995.

6. Mast, P., and F. Souto, HLOSS 1.0: A Code for the Prediction of ECCS Strainer Head Loss, Innovative Technology Solutions, Inc., ITS/ITS-97-01, 1997.

7. Mast, P., G. Zigler and F. Souto, A Modified NUREG/CR-6224 Correlation Methodology for Head Loss Estimation for PCI Stacked Disk Strainers, Presentation to US NRC, Innovative Technology Solutions, Inc., 1997.

8. Performance Contracting, Inc. Report, "Summary Report on Performance of PCI Sure-Flow Strainer with Various Mixes of Simulated Post-LOCA Debris," Revision 0, 1997.

9. Brown, S., Test Evaluation Report on LaSalle Strainer Fiber and RMI Debris Tests, TPP-VL0400-006, ComEd LaSalle County Station, Commonwealth Edision Company, 1998.

10 Hyvarinen, J., and O. Hongisto, "Metallic Insulation Transport and Strainer Clogging Tests," STUK, Finnish Center for Radiation and Nuclear Safety, 1994.

2.0 CONTRACTOR FINDINGS

2.1 Debris Loads used in the Head Loss Estimates

The licensee performed debris-generation calculations and provided the following values for the quantity of debris used to size the ECCS strainers. The calculation note does provide some of the details and supporting documentation necessary to derive the information summarized in Table 1. LANL did not perform independent calculations because (a) the licensee assumptions are transparent and (b) in most cases, the licensee assumptions are consistent with the BWROG URG guidance.

Table 1. Inventory of Debris and the Quantities Estimated to Reach the Suppression Pool.

Debris Type	Utility Estimate[1]			Calculation Basis
	Inventory	TF	str.	
Fibrous	114 ft^3	0.28 0.78	37	The licensee used Method 1 for determining the ZOI and applied the URG-suggested combined generation/transport factors.
RMI	14,360 ft^2	Sat	Sat	The RMI debris saturation quantities were estimated using BWROG URG approach assuming 2-mil s/s foils.
Cal-Sil	8 ft^3	0.1	0.8	The licensee used Method 1 for the ZOI mapping and a combined generation/transport factor of 0.1.
Paint Dust	85 lb	1.0	85	URG-suggested number.
Rust	50 lb	0.33	17	URG-suggested number was used as the original inventory for these debris. However, took credit for sedimentation in the wetwell because they are heavy. They assumed that 67% of rust flakes/paint-chips would settle.
Paint-Chips (IOZ-Chips)	85 lb	0.33	28	
Dirt/Dust	150 lb	0.5	75	URG-suggested number of 150 lbs for dirt. Plant-specific number of 443 lb was used for sludge inventory in the suppression pool. However, the licensee assumed that a fraction of these entering the primary (because of the low filtration coefficient) will be retained in the primary system
Sludge	443 lb	0.5	225	

[1] *Inventory* refers to the total inventoy in the drywell as stated by the licensee. *TF* refers to the combined drywell/wetwell transport factor (fraction of inventory assumed to be transported to the strainer), and *str* refers to the total quantity of debris assumed by the licensee to have accumulated on the strainer.

2.1.1 Debris Load Evaluations for Nukon

The Quad Cities licensee estimated that Unit 1 contains approximately 114 ft^3 of Nukon in the drywell. The licensee noted that approximately 6 ft^3 of this insulation is below the lowest grating and the remaining 108 ft^3 is above the lowest grating.

The licensee used Method 1 for mapping the ZOI coupled with the BWROG URG specified combined generation/transport fractions. This method assumes that all the fibrous debris in the containment (114 ft^3) will be subjected to jet effects. Depending on the location of insulation with respect to the lowest grating, 28% or 78% of that debris will be transported to the suppression pool. This resulted in 37 ft^3 of fibrous insulation being transported to the suppression pool.

The licensee did not take credit for any sedimentation of fibrous debris in the suppression pool. The quantity of debris transported to each strainer was estimated in proportion to the flow rates of the corresponding ECCS pumps.

It is concluded that the licensee followed BWROG guidance to estimate the bounding value of Nukon debris that may be transported to the ECCS suction strainer. This approach is conservative because (a) the licensee assumed that the entire containment inventory of fibrous insulation would be subjected to the blast effects of a postulated break, which is very unlikely, and (b) the licensee did not take credit for any capture of debris in the wetwell (either as a result of sedimentation or deposition on structures). Some of the conservatism is "voluntary" in that the licensee chose the most conservative of various calculational methods described in the BWROG URG. For example, the licensee could have used Methods 2 or 3 to lower the quantity of Nukon insulation that may be generated.

2.1.2 Debris Load Evaluations for Particulate Insulations (Calcium-Silicate and Asbestos)

The licensee estimated that there is approximately 8 ft^3 of calcium-silicate insulation in the drywell. The calcium-silicate insulation is located on the head vent lines in the reactor cavity area above the drywell bulkhead. The calcium silicate is shielded from any postulated break by the 1" plate bulk head which separates the drywell from the reactor cavity. There were no potential break locations that could subject the calcium-silicate insulation to the direct jet impingement. Nevertheless, the licensee assumed that a limiting large LOCA would generate and transport approximately 10% of the total inventory to the ECCS strainer (the licensee did not take credit for sedimentation of calcium-silicate in the wetwell). This assumption was made to maintain "conservatism" in the head-loss estimates.

During one of the conference call(s), LANL enquired about the rationale for selecting the 10% transport factor. The licensee acknowledged that the only basis for that number is a previous version of the BWROG URG and that they are aware that BWROG URG has since been revised. The licensee also agreed that there exists no possible path by which calcium-silicate can be either destroyed by postulated breaks or be transported to the suppression pool (because it is located inside the reactor cavity). If this explanation is true, the licensee should document it and may screen out calcium-silicate from further consideration. Such a simplification would address several of the comments below related to head-loss estimates.

2.1.3 Debris Load Evaluations for Reflective Metallic Insulation

The type of reflective metallic foil originally installed at Quad Cities Station Units 1 and 2 is 6-mil aluminum. In the last few years, the replacement cassettes (wear- and tear-type replacements) apparently have been 2- or 2.5-mil stainless steel. The licensee estimates that only a limited quantity of 2- or 2.5-mil cassettes is located inside the Units 1 and 2 drywells.

The licensee used the BWROG URG saturation thickness approach to estimate the bounding quantity of RMI debris that could accumulate on the stainers. However, they modified the URG equations to better reflect the spheroid debris layer shape they expect to have on the Quad Cities Units 1 and 2 strainers. They calculated the saturation thickness and quantities assuming that all the RMI debris would consist of 2-mil stainless-steel fragments, which are lighter and thus have a higher likelihood of accumulation. The settling velocity and Kt values used for 2-mil stainless steel are same as those described in the BWROG URG.

The licensee estimated that up to 14,360 ft^2 of RMI foil fragments could reach the strainers assuming runout flow through the ECCS. This effective foil area is equal to approximately the foil contained in 450-500 1-ft-long RMI cassettes typically installed on 24-in.-diam recirculation lines. Upon a careful review and rederivation of the equations used by the Quad Cities licensee, LANL concluded that the licensee's approach to estimating RMI debris accumulation on the strainers is conservative and adheres to the technical approach suggested in the BWROG URG.

2.1.4 Debris Load Evaluations for Particulate Debris

The licensee typically followed the URG guidance to estimate the quantity of other particulate debris located in the drywell and suppression pool (e.g., dirt/dust, sludge, etc.) or that generated as a result of LOCA forces (e.g., paint chips). For the sludge, the licensee used a plant-specific number of 443 lbm based on what appears to be licensee sample analyses. As shown in Table 1, the inventory values compare favorably with the BWROG recommendations. The licensee used the following assumptions to estimate the fraction of debris reaching the strainers.

1. All particulate debris was assumed to reach the suppression pool at 0 s after a LOCA.

2. With the exception of inorganic zinc (IOZ) paint chips and rust flakes, the licensee did not credit gravitational sedimentation of debris in the wetwell. For this debris, the licensee assumed that approximately 67% would plate-out in the wetwell. This assumption was justified by the fact that they are heavy and that the residual time is large.

3. The quantity of debris transported to each strainer was estimated in proportion to the flow rates of the corresponding ECCS pumps. With the exception of "smaller particles" (sludge and dirt/dust), all the debris reaching the strainer was assumed to accumulate uniformly on the strainer surface. In the case of sludge, the licensee allowed for a significant portion of the sludge to pass through the fiber bed; the filtration coefficient was varied between 0.0 and 0.5 as the debris bed thickness varied. The maximum filtration was assumed to be 0.5, which means even after all the Nukon accumulates on the strainer, up to 50% of the sludge passes through the strainer and enters the primary system The fraction of the sludge that passed through the filter bed was assumed to plate-out in the primary system. This amounted to 50% of the total sludge mass and 50% of total dust and dirt mass. Thus, the

licensee head-loss calculations only credited 225 lb of sludge and 75 lb of dust/dirt in the head-loss evaluations.

In general, the licensee's treatment of particulate debris generation (i.e., inventory), transport, and accumulation is consistent with BWROG URG guidance. The exceptions are the licensee's treatment of (a) sedimentation of IOZ paint chips and rust flakes in the suppression pool and (b) filtration modeling of sludge and dirt/dust on the strainer surface. Assumptions related to IOZ paint chips and rust flakes appear to be reasonable considering that both the BWROG data and NRC data have shown that they are very likely to settle out in the water pools (the densities are 150 and 300 lb/ft^3 for IOZ and rust flakes, respectively). Besides, the head-loss implications of the IOZ chips and rust flakes is minimal. (See the BWROG URG bump-up factor data.) The licensee's assumption about filtration of sludge and dirt/dust by the fibrous debris bed is inconsistent with the BWROG URG guidance. Although it is possible that once-through filtration of sludge by the debris beds is low, repeated pass-through improves the capture efficiency as demonstrated in the BWROG/Electric Power Research Institute (EPRI) testing. The licensee assumption that only 50% of the sludge and dirt/dust would be captured is not appropriate.

2.1.5 LANL Conclusions Regarding Debris Load Estimates

In general, the LANL staff concluded that the licensee's estimates of the quantity of fibrous and particulate debris accumulating on the strainer were obtained using methods that have large conservatism. In many cases, the conservatism is voluntary on part of the licensee in that the NRC SER approved other methods described in the URG that could have resulted in less conservative estimates for the debris loading.

The only exception is in regard to the licensee's treatment of the quantity of sludge and dust/dirt that would be deposited on the strainer. The licensee assumed that only 50% of the sludge would accumulate on the strainer. While it is possible that some of the sludge may in fact pass through the debris bed, the URG did not propose nor did NRC approve that up to 50% of the sludge and dust/dirt may not accumulate on the strainer surface.

2.2 Description of Quad Cities Strainers

Quad Cities replaced all four strainers attached to the ring-header that feeds all the ECCS pumps. For the sake of clarity, we refer to these strainers as Quad-A through Quad-D. They are identical, each with a plate area of 202 ft^2, a circumscribed surface area of 63 ft^2, and a gap volume of 13 ft^3. Table 2 provides the geometric details of the strainers. These strainers are slightly larger than the Performance Contracting Incorporated (PCI) prototype strainers used in the BWROG head-loss tests.

Assuming that ECCS flow goes through each strainer equally (approximately true in the case of Dresden, which is also a ring-header plant), Table 3 provides the debris loading on each strainer during long-term ECCS cooling. The debris loadings given in Table 3 were the estimates obtained by LANL using the debris inventory given in Table 1. They differ from the licensee estimates as follows:

1. The licensee assumed that 50% of the sludge and dust/dirt passes through the strainer (and possibly settles out in the primary system). LANL assumed that all the sludge would be deposited on the strainer. The LANL assumption is consistent with the BWROG URG guidance

and probably has some conservatism associated with it.

2. The licensee assumed that 0.8 ft^3 of calcium-silicate would be available for deposition on the strainers. LANL assumed that no calcium-silicate would be generated/transported to the suppression pool.

Table 2. Geometric Descriptions of Each of the PCI Stacked-Disk Strainers at Quad Cities Units 1 and 2.

Parameter	Quad A	Quad B	Quad C	Quad D
Outer Diameter (in.)	45	45	45	45
Inner Diameter (in.)	24.5	24.5	24.5	24.5
Length (in.)	42	42	42	42
Number of Disks	11	11	11	11
Gap Thickness (in.)	2	2	2	2
Disk Width (in.)	1.5	1.5	1.5	1.5
$A_{circ+end\text{-}plate}$ (ft^2)	63.3	63.3	63.3	63.3
A_{circ} (ft^2)	41.2	41.2	41.2	41.2
A_{disk} (ft^2)	18.1	17.0	17.0	17.0
V_{disk} (ft^3)	1.29	1.29	1.29	1.29
Strainer Total				
A_{plate} (ft^2)	202.1	202.1	202.1	202.1
V_{gap} (ft^3)	12.9	12.9	12.9	12.9

Table 3. Estimated Debris Loading on Each Strainer Following a LOCA.

Debris Type	Strainer ID Number				Total
	Quad-A	Quad-B	Quad-C	Quad-D	
Fibrous (ft^3)	9	9	9	9	37
RMI (ft^2)	3950	3950	3950	3950	14360
Calcium-Silicate (ft^3)	0.0	0.0	0.0	0.0	0.0
Paint Dust (lbm)	21	21	21	21	85
Rust (lbm)	13	13	13	13	50
Paint-Chips (lbm)	7	7	7	7	28
Dirt and Dust (lbm)	38	38	38	38	150
Sludge (lbm)	111	111	111	111	443

In relative terms, the Quad Cities Units 1 and 2 strainers are comparable in size to strainers installed at primarily RMI plants (for example, they are larger than the Dresden strainers). But, it is not clear that they are large enough to handle the Quad Cities Unit 1 “design basis” fibrous debris loads, which were obtained using bounding assumptions. This may be just a manifestation of licensee assumptions rather than the strainers being inadequate.

2.3 Description of ECCS Performance Assumptions Made in the Quad Cities Analyses

The Quad Cities head-loss estimates are based on the assumptions (see Table 4a) regarding the ECCS performance described below. They were retained in our calculations. According to these assumptions, the total ECCS flow immediately following a double-ended quillotine break (DEGB) would be 33,400 gal./min. The water temperature during this time would be equal to or less than 149^{o}F. After 10 min, the operator would throttle the flow to 29,000 gal./min. And the pool water temperature ultimately reaches 175 ^{o}F. These values were shown in Table 2 of the Quad Cities Unit 1 calculation (QDC-1600-M-0545, Page No. 18).

During one of the conference calls, the NRC Technical Manager, (Ms. K. Kavanagh) stated that the long-term licensing flow would be lower than the assumed flow. This value was assumed to be about 9500 gal./min, not the 29,000 gal./min used in the licensee calculations. This is a major difference and could have a significant effect on the head-loss estimates. The licensee stated that they have used 29,000 gal./min because it is conservative and would obviously bound the licensing-based flow. NRC directed the LANL staff to perform head-loss calculations using both flow rates. Table 4(b) provides the additional flow rates used in the LANL head-loss calculations in response to the NRC request. As shown in Table 4(b), the long-term licensing basis flow would result in velocities at the circumscribed surface being lower than 0.2 ft/s, which was minimum velocity required to accumulate significant amounts of RMI debris on the strainer surface. Considering that licensing basis flow can be credited for time periods after 10 minutes, it is reasonable to assume that majority of the RMI accumulation would occur in the first ten minutes. After that there would be minimal RMI accumulation.

Table 4(a). Licensee Assumptions Regarding ECCS Performance Cited in the Head-Loss Calculations.

	Quad-A	Quad-B	Quad-C	Quad-D
Flow Rate Data Obtained from the licensee submittal(s)				
Net Flow Rate (GPM)				
Full Design	**8,350**	**8,350**	**8,350**	**8,350**
Throttle Design	**7,250**	**7,250**	**7,250**	**7,250**
Plate Velocity (ft/s)				
Full Design	**0.092**	**0.092**	**0.092**	**0.092**
Throttled Design	**0.080**	**0.080**	**0.080**	**0.080**
CircumScribed Velocity (ft/s)				
Full Design	**0.451**	**0.451**	**0.451**	**0.451**
Throttled Flow	**0.392**	**0.392**	**0.392**	**0.392**

Table 4(b). Licensing-Basis ECCS Performance Used in Selected LANL Head-Loss Calculations.

	Quad-A	Quad-B	Quad-C	Quad-D
Flow Rate Data Obtained from the licensee submittal(s)				
Licensing Flow Rate (GPM)	2375	2375	2375	2375
Licensing Plate Vel. (ft/s)	0.026	0.026	0.026	0.026
Licensing Circ. Vel. (ft/s)	0.12	0.12	0.12	0.12

2.4 Head-Loss Estimates

2.4.1 Licensee Evaluations

The licensee used their contractor-provided head-loss correlation and sizing methodology (Refs. 1, 2, 6, 7, and 8). The head-loss analyses were performed by ITS Corporation (ITS). The following sections summarize the licensee calculations and LANL comments.

*Clean strainer head loss***.** The licensee did not provide any discussion regarding the clean strainer head- loss estimates. It is possible that the licensee used PCI clean strainer head-loss data to estimate the clean strainer head loss and add it to the piping head losses to estimate the total dynamic head losses. This approach is followed by some licensees, and we have found it to result in inconsistent assumptions regarding $NPSH_{Margin}$ estimates. However, this approach may ultimately yield conservative estimates.

Head loss resulting from the buildup of fibrous and particulate debris. ITS has developed a computer code named HLOSS to estimate head loss induced by accumulation of fibrous and particulate debris on the strainer surface [Ref. 6]. HLOSS is a proprietary code and was not made available for review/use by LANL staff. From the discussions, it appears that HLOSS basically relies on the head-loss correlation reported in NUREG/CR-6224, although in a modified form to account for stacked-disk strainer design. It calculates the total head loss as a sum of three factors: (1) head loss caused by debris accumulation in the holding volume (or gap volume) of the strainer, (2) head loss caused by the region immediately outside the gap, and (3) head loss caused by debris accumulated on the circumscribed surface of the strainer. ITS has validated the HLOSS method using experimental data from (a) pure fiber beds and (b) fiber and sludge beds. The LANL reservation about this method relates to the fact that ITS relied on an HLOSS analytical correlation in lieu of bump-up factors to estimate the head loss resulting from miscellaneous debris (paint dust, dirt/dust, calcium-silicate, and rust flakes). The analytical correlation models miscellaneous debris through the use of user-selected specific surface area values. To the best of our knowledge, this approach has never been validated and its use without such a validation posed a difficulty in our review. An easier and more direct approach would have been for ITS to use BWROG URG bump-up factors because they have been reviewed and accepted by the Staff. Alternately, the licensee (or the contractor) should have established how well HLOSS predictions compare with the bump-up factors (or a similar experimental database).

Head loss effect of reflective metallic insulation debris buildup. Head-loss contribution of pure RMI debris build-up on the strainer surface was calculated by assuming that RMI builds up to the saturation thickness. The saturation thickness was estimated using a method developed by ITS. The resulting head loss was estimated using the following equation:

$$\Delta H = 0.108 U^2 A_{foil} / A_c$$

where,

ΔH	Head loss (ft-water)
A_{foil}	Surface area of the RMI foils accumulated on the screen (ft^2)
A_C	Strainer circum-scribed surface area (ft^2)
U	Approach velocity based on A_c (ft/s)

This equation was first proposed by NRC in the URG SER (Appendix K, Equation K.5a) to correlate the head-loss data available to NRC at the time of URG review. This equation was found to explain all the 2.5-mil stainless-steel RMI data to within 35%; it was never validated for use with other RMI types. Test data documented in the URG suggest that this equation may result in a conservative estimate for head loss in the case of 6-mil aluminum. Hence, its use by the licensee is reasonable.

The effect of RMI is some what complex when significant quantities of fibrous debris is present, as in the case of Quad Cities Unit 1. In Appendix K to the URG SER, the NRC staff stated that head loss resulting from mixed fiber and RMI beds should be based on either (a) vendor-provided head-loss data obtained for that strainer design or (b) analytical results, only after accounting for strainer shape and debris buildup on that strainer surface. The licensee did not have experimental data (at least, no experimental data were provided in the calculation note). Instead, the licensee relied completely on an analytical model. This model simply assumes that head loss resulting from mixed beds is a simple sum of head loss caused by RMI build-up to saturation thickness and head loss caused by fiber build-up on the strainer surface. Although this may appear to be in conformance with the NRC SER recommendation, it has one serious flaw. Their approach, as implemented, does not account for the difference in the location where fibrous debris might accumulate when there is no RMI vs when there are significant quantities of RMI. As explained in Appendix K, when sufficiently large quantities of RMI and fiber are involved, the fiber may build up on the circumscribed surface of the strainer as opposed to the plate surface (which is the case when there is no RMI). Appendix K explained the effect such a difference could have on head loss based on the experimental head-loss data from LaSalle (another ComEd plant). From this viewpoint, it is our conclusion that the ITS method for estimating head loss resulting from the mixed beds does not ensure that the resulting head loss is either bounding or best-estimate.

Net head-loss estimates. The net head-loss estimates provided for Quad Cities Unit 1 are as follows.

1. The head loss resulting from the fibrous and particulate debris accumulation on the strainer plate is 0.65 ft-water, assuming long-term throttled flow of 29,000 gal./min. This reflects the following assumptions: (a) approximately 9 ft^3 of fibrous debris accumulates on each strainer and filters the particulate debris to the efficiencies described in Table 1 and (b) all the debris would be located within the gaps of the stacked-disk design and would be subjected to velocity in the proximity of 0.08 ft/s.

2. The head loss resulting from the RMI debris buildup on the strainer circumscribed surface is 0.30 ft-water, assuming long-term throttled flow of 29,000 gal./min. This reflects the licensee's assumption that approximately 2410 ft^2 of RMI debris would accumulate on the strainer surface and that it would be subjected to water velocities in the proximity of 0.4 ft/s.

3. The net head loss is approximately 1 ft-water. This is a simple sum of 0.65 ft-water from fibrous debris and 0.4 ft-water due to RMI saturation bed formation. No effort was made to examine the effect of the fibrous debris accumulation on the circumscribed surface of the strainer.

2.4.2 LANL Evaluations/Calculations

Because of deficiencies stated above, LANL performed independent calculations to evaluate the Quad Cities Units 1 and 2 strainer head loss. These calculations examined the effect of the following differences.

1. *Higher quantity of sludge and dust/dirt filtered on the strainer surface*. As previously discussed, the licensee assumed that only 50% of the sludge and dirt/dust would be filtered by the debris bed, which is not consistent with URG guidance. LANL calculations used a value that varied between 80-100%.

2. *Difference in the location where fibrous debris may accumulate*. The licensee implicitly assumed that all the fibrous and particulate debris would accumulate within the gaps of the stacked-disk design. This artificially subjects all the fibrous debris to a lower water velocity and thus minimizes the head-loss contribution of the fibrous debris. One can easily envision circumstances in which sufficient quantities of RMI fragments would (along with some fiber) fill the gaps first. This allows for oncoming fiber to deposit on the circumscribed surface, which would result in higher head losses. To account for this, LANL assumed that a fraction of the fibrous debris would accumulate on the strainer circumscribed surface and that not all of it would deposit inside the gaps. Figure 1 captures the differences in the LANL approach and that of the licensee.

3. *Difference in the ECCS flow rate*. The licensee calculations assumed a throttled flow of 29,000 gal./min. This apparently is different from the licensing basis flow of 9500 gal./min. LANL performed head-loss calculations assuming both flow rates.

4. *No calcium-silicate*. The licensee stated that there is little support for assuming that any calcium-silicate would be transported to the suppression pool. Hence, the LANL calculations eliminated this from the potential debris.

2.4.3. LANL Estimates of Head Loss

The LANL staff performed independent calculations to obtain approximate estimates of head loss. Table 5(a) and 5(b) list all the cases run by Los Alamos.

Total ECCS Flow of 29,000 gal./min. Table 5(a) provides the head-loss estimate obtained by LANL for Quad Cities Unit 1. The flow rate per strainer is 7250 gal./min, which is one-quarter of the total ECCS flow.

Table 5(a) Head-Loss Estimate for Quad Cities Station Unit 1 Strainer.

Strainer geometry	**Table 2**	
Total fiber per strainer	**9**	**ft^3**
Fiber outside gaps	**6.7**	**ft^3**
Other debris	**Table 3**	
Flow	**7250**	**gal./min**
Head loss	**3.2**	**ft-water**

This head loss evaluations assumed that fibrous debris deposits uniformly both within and outside the gap. This resulted in approximately 6.7 ft^3 of Nukon debris being accumulated on the strainer circumscribed surface(which included ends). The BWROG recommended bumpup factors were used to estimate the head loss impact of miscelleneous particulate debris (e.g., dust/dirt and rust flakes). The resulting head loss is 3.2 ft-water. This head loss estimate does not include head loss caused by clean strainer, which would be approximately another 1 ft-water.

Total ECCS Flow of 9, 500 GPM. Table 5(b) provides the head loss estimate obtained by LANL for Quad Cities Unit 1. The flow rate per strainer is 2375 gal./min, which is quarter of what was believed to be the throttled licensing basis flow[2].

Table 5(b) Head Loss Estimate for Quad Cities Station Unit 1 Strainer.

Strainer geometry	**See Table 2**	
Fibrous debris per strainer	**9**	**ft^3**
Fibrous out side the gap	**5**	**ft^3**
Other debris	**See Table 3**	
Flow	**2375**	**gal./min**
Head loss	**1.2**	**ft-water**

The estimated head loss is 1.2 ft-water, which is about same as that predicted by the licensee for long-term strainer head loss. However, the assumed ECCS flow in our case is significantly different from that used in the licensee calculations to arrive at this number.

[2]Recently, the licensee stated that the long-term licensing basis flow is lower than 9500 gal./min,; more like 7500 gal./min. However, the licensee did not know if the long-term meant 10 min or much later into the accident.

2.5 Conclusions

LANL independent calculations suggest that during long-term recirculation, a reasonable upper bound for head loss across the Quad Cities Station Unit 1 ECCS strainers would be approximately 1.2 ft-water, assuming that

- The debris loading is as described in Table 3.
- The long-term recirculation flow is 9500 gal./min or lower at a suppression pool temperature of 175°F or higher.

The Quad Cities Unit 2 ECCS strainer would have a lower head loss because the licensee estimates for strainer Nukon loading for Unit 2 are much lower (35 ft^3 for Unit 1 vs 6.74 ft^3 for Unit 2).

Although the LANL independent calculations also resulted in approximately same long-term estimates for strainer head loss, they are based on significantly different assumptions related to the total ECCS flow through the strainer and the debris accumulation on the strainer. Some of these differences are summarized below.

Difference in the Long-Term ECCS Flow. The licensee calculations assumed that long-term ECCS flow through the strainers is 29, 900 gal./min, which is significantly higher than the licensing basis flow. When LANL used this flow the resulting head losses are actually in the proximity of 3.2 ft-water, which is significantly higher than the corresponding licensee estimate. Licensee stated that flow rate of 29, 900 gal./min was used because it is conservative. While it may be so, it significantly impacts head loss estimates. First, a net ECCS flow rate of 29, 900 GPM (or 7250 gal./min per strainer) would induce circumscribed velocities in the proximity of 0.4 ft/s. This would allow for significant accumulation of RMI debris on the circumscribed surface (up to formation of saturation thickness). Instead, if the calculations were to be performed at an ECCS flow rate of 9500 gal./min, the corresponding strainer circumscribed velocity of 0.12 would not be sufficient to retain very large quantities of RMI. This would have significant impact on how the debris bed builds up on the strainer surface. Although, not addressed here the lower ECCS flow rate would also impact (a) the clean strainer head loss and (b) the frictional head losses in the piping. It is not clear that the licensee factored in these issues into the $NPSH_{Margin}$ evaluations.

Difference in the Technical Approach for Estimating Head Loss Caused by Mixed Beds. The licensee assumed that head loss caused by mixed beds is a simple sum of (a) head loss caused by equal amount of fiber accumulating on the strainer (independent of any RMI) and (b) head loss caused by RMI buil-up to saturation thickness. Implicitly the licensee approach assumes that the fibrous debris would builup on the strainer plate surface where very small flow velocities exist and the RMI would build-up on the circumscribed surface where higher velocities exist. As noted by ComEd and its contractor (ITS), the LaSalle and European data clearly established that such an assumption is inappropriate [Reference 9 and 10]. LaSalle data is important because it is the only data that was obtained for mixed RMI and fibrous debris beds that can be characterized as thick beds built on PCI stacked disk strainer. LaSalle data basically consisted of three tests: (a) Head Loss caused by 9 lbs (approx 4 ft^3) of Nukon that accumulated on the strainer, (b) Head loss caused by 2250 ft^2 of RMI debris accumulated on the strainer and (c) Head loss caused by

9 lbs of Nukon and 2250 ft^2 of RMI debris simultaneously accumulated on the strainer. As stated by ITS and ComEd, this testing has shown that simple addition of individual contributions of RMI and Fibrous debris is not sufficient, because the head loss measured for mixed beds was far in excess of the estimate obtained by simple addition. In Appendix-K to the NRC SER on BWROG URG, the NRC independently analyzed the LaSalle data. In the reanalysis of LaSalle data, NRC assumed that the debris buildup would be uniform in that both RMI and fiber would approach the strainer simultaneously in proportion to their relative concentrations. This would mean that fiber would accumulate both within and outside the gaps (or interstitial volumes) as dictated by the total volume of the debris in comparison to the combined gap volume. This formulation was well supported by LaSalle photographs. By properly accounting for this difference, NRC was able to successfully explain the head loss data. During this analysis, NRC noted that simple addition of individual contributions is inappropriate and that care should be given to adequately account for where the debris might accumulate on the strainer. Quad Cities calculations did not take into account the insights gained from the LaSalle data or NRC review/comments on the LaSalle data. This is a major deficiency in the licensee analyses.

Difference in Debris Transport Assumptions. The licensee made several assumption related to debris transport and filtration that are not consistent with URG guidance.

Overall Assessment. Based on the analysis and review of similar plants, it is LANL conclusion that the Quad Cities strainers are adequately sized to support long-term ECCS operation. Most likely, the actual head losses would be much lower than those predicted by LANL, because the licensee debris generation estimates for Nukon fiber are conservative.

Appendix A
Request for Additional Information

LANL prepared these requests for additional information during earlier stages. This is provided here for a record.

(a) The licensee's treatment of calcium-silicate debris generation/transport is confusing and should be clarified/revised.

Background: Assumption 3.6 states that calcium-silicate is unlikely to transport to the suppression pool as a result of a DEGB. The rationale appears reasonable. As stated in that assumption, it is also reasonable to explore its effect on head-loss if some of the calcium-silicate insulation (for example, 10%of the total insulation inventory) gets to the suppression pool. However, this rationale is not reproduced in Sec. 6.1.3.3, which estimates calcium-silicate source term. In Sec. 6.1.3.3, the contractor (ITS) stated that BWROG guidance was used to estimate the calcium-silicate source term. In this context, please note that use of URG combined generation/ transport fractions for calcium-silicate and Mink-K insulation is inappropriate. This BWROG position was stated in at least two different places in the URG (Vol. 1, Table 4, and Vol. 1, Table 6). The BWROG recommended that individual utilities address this issue on a plant-specific basis.

NRC would like to obtain additional information regarding the contractor's (ITS) analyses in support of the quantity of calcium-silicate debris used in the head-loss calculations. In particular, the licensee should answer four questions at a minimum.

2. Is the calcium-silicate insulation at Quad Cities Units 1 and 2 encapsulated in stainless-steel or aluminum sheaths?
3. Would the calcium-silicate be in any of the postulated break ZOIs?
4. Is it possible that calcium-silicate could be subjected to containment spray flow?
5. What is the total quantity expected to be transported and the rationale for that estimate?

Unless a defensible rationale is provided, the utility should treat the entire calcium-silicate insulation as being "capable" of reaching the suppression pool. This would increase the particulate-to-fiber ratio and thus the head loss.

(b) The contractor's approach for estimating calcium-silicate head loss is deficient and appears to be inconsistent with their observations stated in the submittal and the information provided elsewhere. The contractor should revise their method for estimating calcium-silicate head-loss contribution or provide a better rationale.

Background: In Sec. 2.1.4, the contractor states that the head-loss contribution of calcium-silicate was estimated using the NUREG/CR-6224 correlation and by treating calcium-silicate debris as being fine powder. However, in the sentence immediately following, the contractor states that calcium-silicate debris may not be amenable to being modeled using the NUREG/CR-6224 correlation. In the recent weeks, the contractor has released additional data suggesting that the NUREG/CR-6224 correlation is not "appropriate" for estimating head loss caused by calcium-silicate. Given these uncertainties, the contractor and the utility should provide the following information.

1. How was the NUREG/CR-6224 equation used to estimate head loss caused by calcium-silicate debris?
2. Was their approach validated by comparison with any “valid” experimental data?
3. If the contractor believes that usage of the NUREG/CR-6224 correlation is wrong for estimating calcium-silicate head loss, then why was it used?

Note that it falls on the contractor and the utility to obtain and interpret the head-loss data appropriately to resolve this issue. If the contractor believes that a particular correlation is not appropriate, it should not be used.

(c) The contractor's approach for estimating head loss caused by miscellaneous debris has never been reviewed by the staff. The staff is under the impression that “bump-up” factors will be used to estimate the head-loss contribution by the miscellaneous debris. The contractor should revise or clarify their approach.

Background: The contractor stated that the NUREG/CR-6224 correlation was used. Please provide information on how the correlation was applied, how it was validated, and how the results compare with the “bump-up” factors proposed by the BWROG.

(d) The contractor’s method for estimating head loss caused by fibrous beds is not correct. It does not adhere to the BWROG guidance or that previously reviewed/endorsed by the staff. This deviation from the guidance has a significant effect on the estimated head loss. The contractor should revise the head-loss calculations or provide a rationale for their assumptions.

Background: The contractor assumed a filtration coefficient for the sludge of much less than 1. This resulted in a majority of the sludge entering the core and “settling out” in the core. This assumption has never been approved. The contractor did not provide a defensible rationale for this assumption. Note that neither the BWROG nor the NRC staff provided any direct or implied guidance on this issue. The contractor should revise their calculations, assume that all sludge will be deposited on the strainer, and re-estimate head loss.

(e) The licensee's approach to estimating head loss resulting from mixed beds is erroneous and inconsistent with NRC guidance. Contractor should revise the estimates and account for strainer shape effects.

Background: In the URG, the BWROG recommended that licensees address this issue on a plant-specific basis by confirming that head loss from RMI+fiber+sludge does not exceed that of particulates+fiber. If such a confirmation cannot be provided, appropriate corrections based on plant-specific conditions should be made. The contractor and licensee have performed a series of tests in support of the LaSalle submittal. These results suggested that head loss by mixed debris cannot be bounded by “simple addition” of head loss measured for equivalent amounts of constituents. In the SER, Appendix K, it is stated that simple addition of Test 1 (fiber only test with 9 lb of Nukon) and Test 4 (RMI only test with 2250 ft^2 of RMI) is not appropriate to estimate head loss caused by Test 5 (which has 9 lb of Nukon and 2250 ft^2 of RMI). As explained in the SER, the staff stated that the relative location of the fiber should be evaluated carefully. In spite of this clarification, the contractor performed a simple addition of head-loss contributions, a theoretical equivalent of adding results of Test 1 and Test 4. That is incorrect. The contractor should revise its calculations and examine the effect on head loss if the fiber accumulates outside the crevices (which is the more likely scenario). Note also in this context that the BWROG stated in several meetings that in the presence of significant quantities of RMI, an alternate strainer design behaves very closely to a truncated cone design.

(f) The contractor and the licensee assumed that asbestos is no longer in the containment. The licensee should install proper "configuration" controls to ensure that asbestos is actually removed from the drywell in a timely manner.