LOS ALAMOS TECHNICAL EVALUATION REPORT

On-Site Audit of Duane Arnold Energy Center Emergency Core Cooling System Strainer Blockage Resolution

by

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CONTENTS

LIST OF ACRONYMS

BWROG	Boiling Water Reactor Operators Group
CRD	Control Rod Drive
DAEC	Duane Arnold Energy Center
DBA	Design-Basis Accident
DCP	Design Control Package
DEGB	Double-Ended Guillotine Break
ECCS	Emergency Core Cooling System
EOP	Emergency Operating Procedure
EPRI	Electric Power Research Institute
FME	Foreign Material Exclusion
GE	General Electric
HPCI	High-Pressure Core Injection
IOZ	Inorganic Zinc
LOCA	Loss-of-Coolant Accident
LPCI	Low-Pressure Core Injection
LPCS	Low-Pressure Core Spray
LTR	Licensing Topical Report
NPSH	Net Positive Suction Head
NRC	Nuclear Regulatory Commission
PCI	Performance Contracting Inc.
RCA	Recirculation Loop A
RCIC	Reactor Core Isolation Cooling
RFO	Reactor Fuel Outage
RG	Regulatory Guide
RHR	Residual Heat Removal
RMI	Reflective Metal Insulation
RWCU	Reactor Water Clean-Up
SER	Staff Evaluation Report
SPCP	Suppression Pool Cleanliness Program
SRV	Safety Relief Valve
URG	Utility Resolution Guidance
ZOI	Zone of Influence

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ON-SITE AUDIT OF DUANE ARNOLD POWER PLANT EMERGENCY CORE COOLING SYSTEM STRAINER BLOCKAGE RESOLUTION

1.0. INTRODUCTION

Duane Arnold Energy Center (DAEC) is a single BWR/4 unit with Mark I containment. In response to US Nuclear Regulatory Commission (NRC) Bulletin 96-03, replacement emergency core cooling system (ECCS) suction strainers were installed at the DAEC unit in 1997. The NRC staff performed an on-site audit of the analyses that formed the basis for the design and installation of the replacement strainers (Refs. 1–3). Included in the audit were the licensee's (IES Utilities, Inc.) implementations of programs related to the general issue of ECCS strainer blockage, such as the Foreign Material Exclusion (FME) Program and the Suppression Pool Cleanliness Program (SPCP). Los Alamos National Laboratory scientists assisted NRC in this effort.

Appendix A contains the completed checklist used by the Los Alamos and NRC staffs during the on-site review. The checklist provides a brief summary of all aspects of the review. This report documents the supporting analyses conducted by Los Alamos scientists during the on-site review.

1.1. Plant Familiarization

The DAEC unit uses predominantly Nukon™ mats[1] to insulate the primary piping. Limited quantities of 2.5-mil stainless-steel reflective metallic insulation (RMI) cassettes and calcium-silicate insulation (encapsulated in aluminum jackets) were used around some of the piping inside the drywell. In addition, small quantities of calcium-silicate/asbestos and lead-wool insulation were used on the drywell penetrations.

The Nukon insulation is protected by stainless-steel jackets with normal J-hooks. The reactor pressure vessel is insulated by RMI cassettes. However, the plant screened out RMI insulation from the analyses because (a) there are no postulated breaks within the biological shields that could generate and transport debris from the RMI located on the reactor vessel[2] and (b) the RMI located on the process piping will be replaced gradually by fiberglass insulation. The calcium-silicate insulation was screened out because it is located in the higher regions of the containment, where the potential for generation of large quantities of insulation debris is negligible. The calcium-silicate/asbestos and lead wool were screened out because they were present only in the penetrations. Therefore, for the purpose of this audit, the insulation of primary concern at this plant is of fibrous composition (Nukon™).

Before 1998, DAEC used truncated-cone strainers with 1/8-in. perforations to protect against plugging of core-spray nozzles and ECCS pump seals and bearings. The net surface area of the strainers was 38 ft^2. The total, licensing-basis, run-out ECCS flow through the strainers is 35,000 gal./min. The potential for loss of ECCS flow resulting from blockage of old (pre-NRCB 96-03) strainers was analyzed in NUREG/CR-6224 (Refs. 1 and 2). It was found that an insulation volume of only 2 ft^3 in combination with suppression pool sludge was sufficient to induce frictional losses that exceed the $NPSH_{margin}$ within 10 min after a loss-of-coolant accident (LOCA). This finding

[1]Nukon is a trademark insulation manufactured and marketed by Performance Contracting, Inc. (PCI). It is a low-density (2.4-lbm/ft^3) fiberglass mat.

[2]Even if trace quantities of RMI do get transported, their effect on ECCS performance would be bounded by the fibrous debris impact.

formed the basis for issuance of NRCB 96-03 and development of Regulatory Guide (RG) 1.82, Rev. 2.

The plant resolved the potential strainer-blockage issue through (a) installation of *passive, large-capacity* suction strainers designed and manufactured by General Electric Company (GE) and (b) suppression pool cleaning to minimize the amount of sludge. The replacement strainers have a combined surface area of 1359 ft^2 (an increase of approximately 2600% compared with the old design). The plant estimated the debris loading on the strainer following a postulated LOCA using methodologies discussed by the Boiling Water Reactors Owners Group (BWROG) in the Utility Resolution Guidance (URG) document (Ref. 3). Estimates for quantities of fibrous debris generated were evaluated on a plant-specific basis using Method 2 of the URG. The total volume of insulation debris transported to the suppression pool was estimated using the URG drywell transport factor of 0.28 (i.e., 28% of the volume of the generated debris would be transported to the suppression pool as a result of blowdown and washdown). No credit was taken for settling of the debris in the suppression pool. The quantity of sludge used to size the strainer (500 lbm) was chosen to bound the sludge generation rates measured by the licensee. Additional sources of particulate debris were considered in the strainer sizing analyses. This debris included qualified paint chips, foreign material, dust and dirt, rust from unpainted structures, and unqualified or indeterminate coatings. The FME Program and the SPCP were implemented to limit the quantities of foreign materials (e.g., clothing or plastic sheeting) and suppression pool sludge.

Strainers were designed to handle the limiting single failure that resulted in loss of one low-pressure core injection (LPCI) train (or two LPCI pumps) for injection into the core. The strainers also were designed such that sufficient net positive suction head (NPSH) margin exists to accommodate any uncertainties in the estimation of debris volume or head loss. A sensitivity analysis was performed to ensure that a slight variation in the debris quantity would not significantly affect $NPSH_{Margin}$. Estimates of $NPSH_{Margin}$ were based on an assumed suppression pool temperature of 202ºF over the long term. The NRC previously approved a containment overpressure credit of 2.5 psig in calculating the core spray $NPSH_{Margin}$.

1.2. Objectives

The focus of the Los Alamos review of the supporting documentation was to identify any concerns relative to the licensee's strainer design criteria and strainer performance analyses. In particular, the review was to do the following.

- Evaluate how the licensee estimated the quantity of debris used for sizing the strainer. Determine if the process used to select the breaks is consistent with the guidance in RG 1.82, Rev. 2, and whether the method used by the licensee was consistent with the NRC guidance and therefore was considered to provide reasonable estimates for debris generation and transport.
- Evaluate the contractor's (GE) proposed strainer design criteria and performance.

Los Alamos performed two sets of analyses to achieve these objectives. The first set independently calculated the debris loading on the strainer using NRC-approved methods. The second set of analyses used NRC-developed tools to estimate head loss across the strainers using (a) the debris loading used in the licensee analyses and (b) the debris loading estimates calculated independently by Los Alamos. The following sections present and discuss the significant findings of these analyses.

1.3. Licensee Documents Reviewed

The LANL staff used the following licensee calculations and engineering analyses in the on-site audit.

- IES Utilities, "NPSH for Core Spray and RHR Pumps," Duane Arnold Engineering Calculation No. CAL-M97-007 (1997).

- IES Utilities, "Post-LOCA Debris Generation Calculations for ECCS Strainers," Duane Arnold Engineering Calculation No. CAL-M98-002 (1998).

- GE Nuclear Energy, "ECCS Suction Strainer Hydraulic Sizing Report," GENE-E11-00091-01, Duane Arnold Energy Center (1998).

2.0. CONTRACTOR FINDINGS

2.1. Selection of the Break

The licensee selected Method 2 of the URG to estimate the quantity of Nukon insulation targeted by the LOCA jets. This method does not prescribe a rigorous process for selecting the break locations to be analyzed. Instead, it focuses on the breaks located closest to the most densely insulated regions of the drywell. As a result, the licensee postulated an unrestrained double-ended guillotine break (DEGB) in the 19.75-in.-i.d. pipe of Recirculation Loop A (RCA). This is the largest pipe in the drywell, and it was chosen to give the largest possible zone of influence (ZOI). Based on a visual examination of plant drawings, Los Alamos confirmed that the postulated break is located in the area of highest fibrous insulation density and that the location chosen by the licensee includes all major reactor-piping systems. This location is same as the location represented by weld RCA-J006 in the NUREG/CR-6224 study. (Note: The break postulated at RCA-J006 generated the largest quantity of debris in the NUREG/CR-6224 study). The Los Alamos analysts agree with the licensee selection of the break location.

An assumption by the licensee that appeared inconsistent with the guidance of RG 1.82, Rev. 2, is related to medium-sized breaks. Regulatory Position 2.3.1.5 of RG 1.82, Rev. 2, recommends that the licensee consider “the medium and large breaks with the largest potential particulate-to-insulation ratio by weight.” The licensee did not consider medium breaks because they believed that the stacked-disk strainer design is not susceptible to the “thin-bed effect,” and hence, Regulatory Position 2.3.1.5 of RG 1.82, Rev. 2 does not apply. The reason for the RG 1.82, Rev. 2, recommendation is the "thin-bed effect," which has been observed by the BWROG and the NRC in cylindrical and truncated-cone strainers. Specifically, testing has shown that high head losses can occur on cylindrical and truncated-cone strainers with thin beds and a high concentration of sludge. This head loss could be higher than head losses resulting from same sludge concentration and a higher quantity of fibrous debris. In the GE Licensing Topical Report (LTR), a series of tests was conducted by GE in which head loss was measured for small fiber loadings in conjunction with a large sludge concentration. These tests (and the BWROG stacked-disk tests) have provided reasonable assurance that the “thin-bed effect” is not an issue for GE stacked-disk strainers. Note also that the NRC Staff Evaluation Report (SER) noted that this concern may not be applicable to the stacked-disk strainers.

Based on the review, the Los Alamos staff concluded that the break used by the licensee is bounding and meets the intent of the guidance provided in RG 1.82, Rev. 2. The selected break will maximize the estimated head loss across the strainer.

2.2. Debris Generation

Table 1 lists the types of insulation present in the DAEC drywell. Nukon insulation is clearly the predominant insulation type used. Other types of insulation present in the drywell are (a) mirror-type RMI, (b) calcium-silicate, (c) calcium-silicate/asbestos, and (d) lead wool.

The licensee estimated the quantity of Nukon debris generated by the limiting break and presented their rationale for screening out rest of the insulation materials from the head-loss calculation.

Table 1. Types of insulation present on the DAEC drywell piping.

Type	Application
Nukon (fiberglass)	Main steam, recirculation, high-pressure core injection (HPCI), reactor core isolation cooling (RCIC), feedwater, core spray, main steam drains, and residual heat removal (RHR) piping.
Mirror (reflective metallic)	Reactor vessel inside the bioshield, reactor water clean-up (RWCU), control rod drive (CRD) drain, reactor recirculation pumps, and the recirculation pump discharge isolation valve bypass piping
Armaflex (cellular foam)	Well water piping (drywell cooling)
Fiberglass Anti-Sweat	Well water piping (drywell cooling)
Calcium Silicate	Installed on penetration piping (upper drywell elevation)
Calcium Silicate/Asbestos	Installed in some drywell piping penetrations
Lead Wool	Installed in some drywell piping penetrations

Debris Generation Calculations for Nukon

The utility used Method 2 of the URG to estimate the ZOI and the quantity of fibrous Nukon debris generated by the jets. Method 2 is based on estimating the largest ZOI and locating it in the most congested part of the drywell to estimate the maximum quantity of Nukon insulation that would be targeted. A destruction pressure of 10 psi, corresponding to Nukon insulation (Ref. 3) was used by the licensee for estimating the size of the ZOI. Assuming maximum radial and axial separation, the resulting ZOI is a sphere of radius approximately 10 times the inside diameter (19.75 in.) of the largest recirculation loop line, i.e., R_{ZOI} » 10.4 x D_{RCA} = 17.11 ft. This ZOI was superimposed manually on various piping isometrics and drywell section views to determine the location for maximum debris generation and transport. Pipe lengths intersecting the sphere and the corresponding insulation volumes were estimated to arrive at a Nukon debris volume of approximately 544 ft^3. The licensee also undertook an internal independent review of this calculation, which was performed by drawing plan and elevation views of each piping system that included the coordinates of each bend and by calculating pipe-segment intersections with the spherical ZOI. This verification estimated a total Nukon debris volume of approximately 573 ft^3. Summaries of debris volumes by piping system are presented in Table 2.

Los Alamos scientists calculated the volume of Nukon debris using the plan and elevation drawings provided by the licensee. These drawings provided spatial coordinates that could be easily entered into an automated debris generation model that computes piping intersections for spherical ZOI with sizes determined by break diameter. Several stylized views of the piping data within the containment boundaries are provided in Figs. 1–4; a typical 10-psi ZOI for a break in the RCA line also is shown. It should be noted that only piping in the vicinity of the ZOI is included in the model because the region of highest congestion was predetermined by visual inspection. This location is consistent with the observations in NUREG/CR-6224. Break locations were postulated at 1-ft increments along the vertical length of the 22-in.-o.d. RCA line. The maximum debris generated is 427 ft^3, which is lower than the licensee estimate of 544 ft^3. The reason for the difference is that licensee conservatively included piping segments that are not the periphery of the ZOI. LANL included targets that are part of the ZOI.

Table 2. Nukon specifications and debris-generation volumes for three independent analyses.

Piping System	Pipe OD (in.)	Insulation Thickness (inches)	Linear Feet		Insulation-Debris Volume (ft^3)			Transport Factor	Transport Volume (ft^3)	
			Licensee 1	Licensee 2	Lic # 1	Lic # 2	LANL		Licensee 1	Licensee 2
Recirc System	22	3	28	28.4	45.79	46.47	-	0.28	12.82	13.01
	16	3	22	22.0	27.3	27.36	-	0.28	7.66	7.66
	10.75	2.5	37.2	38.2	26.87	27.61	-	0.28	7.52	7.73
Recirc System	22	3	5	3.6	8.18	5.89	-	0.78	6.38	4.59
Main Steam	20	3	190.5	194.0	286.62	292.04	-	0.28	80.25	81.77
Feed Water A side	16	2.5	28	28.05	28.24	28.31	-	0.28	7.91	7.93
	10.75	2.5	27.4	37.2	19.79	26.89	-	0.28	5.54	7.53
Feed Water B side	16	2.5	28	28.05	28.24	28.31	-	0.28	7.91	7.93
	10.75	2.5	27.4	37.2	19.79	26.89	-	0.28	5.54	7.53
HPCI Steam Supply	10.75	2.5	14	13	10.1	9.39	-	0.28	2.83	2.63
HPCI 1-in. drain	1.315	2	31.6	32.7	4.57	4.73	-	0.28	1.28	1.32
HPCI 1-in. drain	1.315	2	4.8	4.8	0.69	0.69	-	0.78	0.54	0.54
RCIC Steam Supply	4.5	2.5	29	28.2	11	10.77	-	0.28	3.10	3.01
RCIC 1-in. drain	1.315	2	17.4	18.4	2.52	2.66	-	0.28	0.70	0.75
RCIC 1-in.drain	1.315	2	5.58	4.8	0.81	0.69	-	0.78	0.63	0.54
Wellwater supply to 1a/1b DW Coolers	3.5	1	63	53.7	6.18	5.27	-	0.28	1.73	1.48
Wellwater supply to 1a/1b DW Coolers	3.5	1	-	7.8	-	0.77	-	0.78	-	0.60
MS 2-in. drains	2.375	2.5	51.9	7.1	13.79	1.89	-	0.78	10.76	1.47
MS 3-in. drains	3.5	2.5	11.1	51.2	3.63	16.76	-	0.78	2.83	13.07
Total					544.11	563.37	427.35		165.94	**171.1**
								110% of Licensee 1 = **182.5**		
							Los Alamos Transport Vol = **122.2**			

Notes: Insulation with a transport factor of 0.28 resides above the lowest level of grating.
Insulation with a transport factor of 0.78 resides below the lowest level of grating.
All piping except the steam line drains and a small portion of the recirculation suction piping is above the first floor grating.

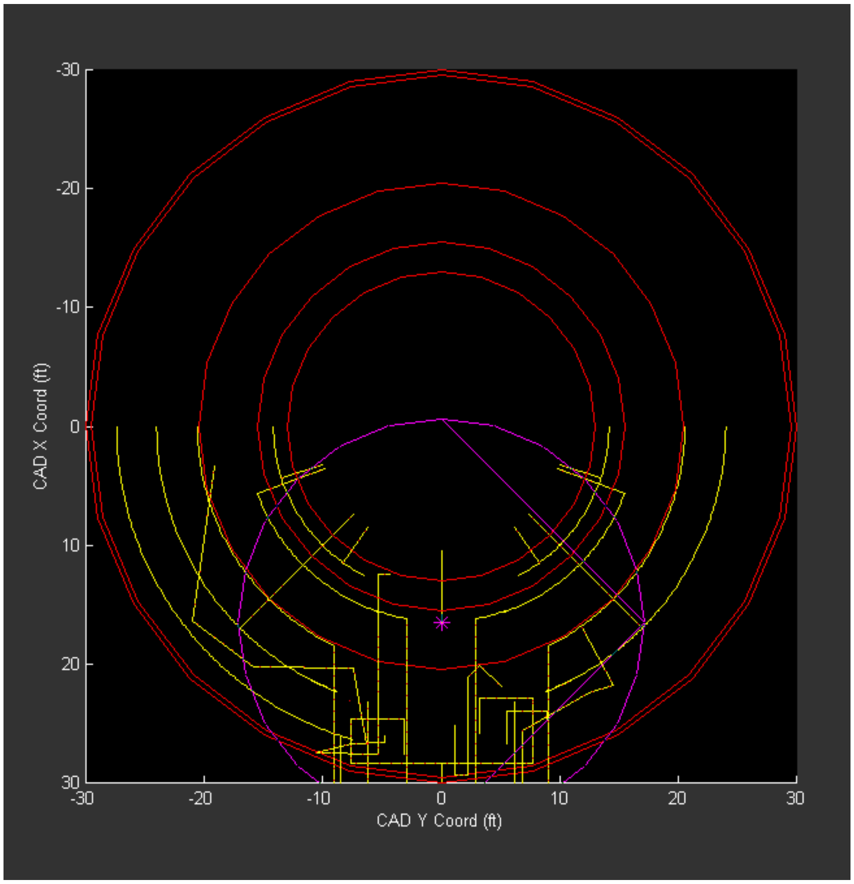

Fig. 1. Plan view of ZOI (magenta) superimposed on affected piping systems (yellow) within the drywell (red).

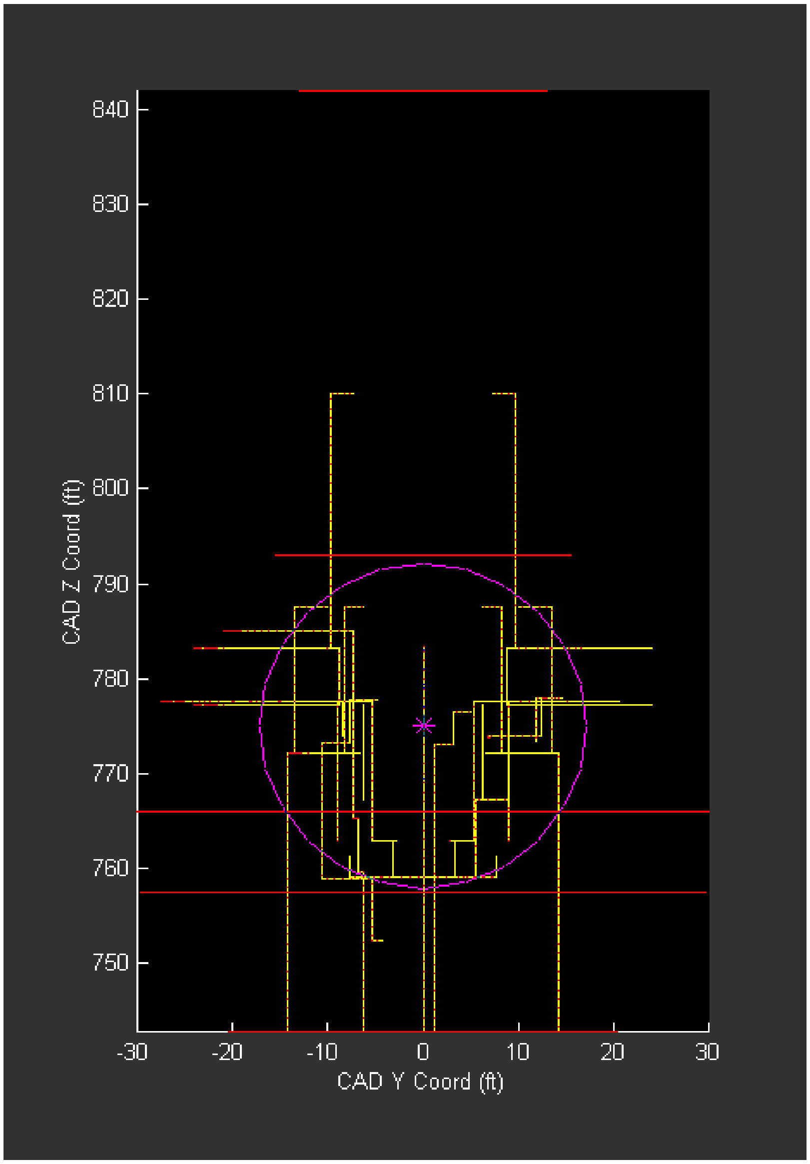

Fig. 2. Elevation view of ZOI (magenta) superimposed on major piping systems (yellow) within the drywell (red).

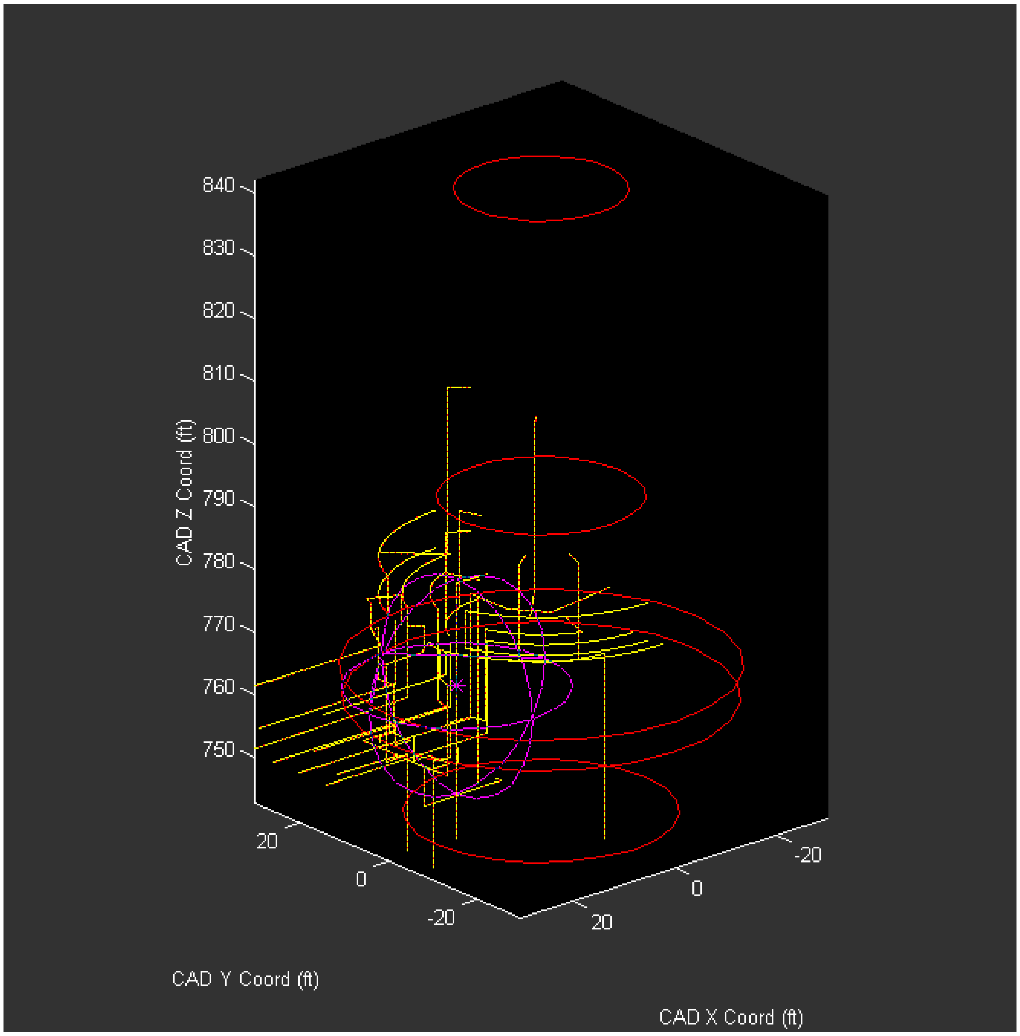

Fig. 3. Perspective view of ZOI (magenta) superimposed on major piping systems (yellow) within the drywell (red).

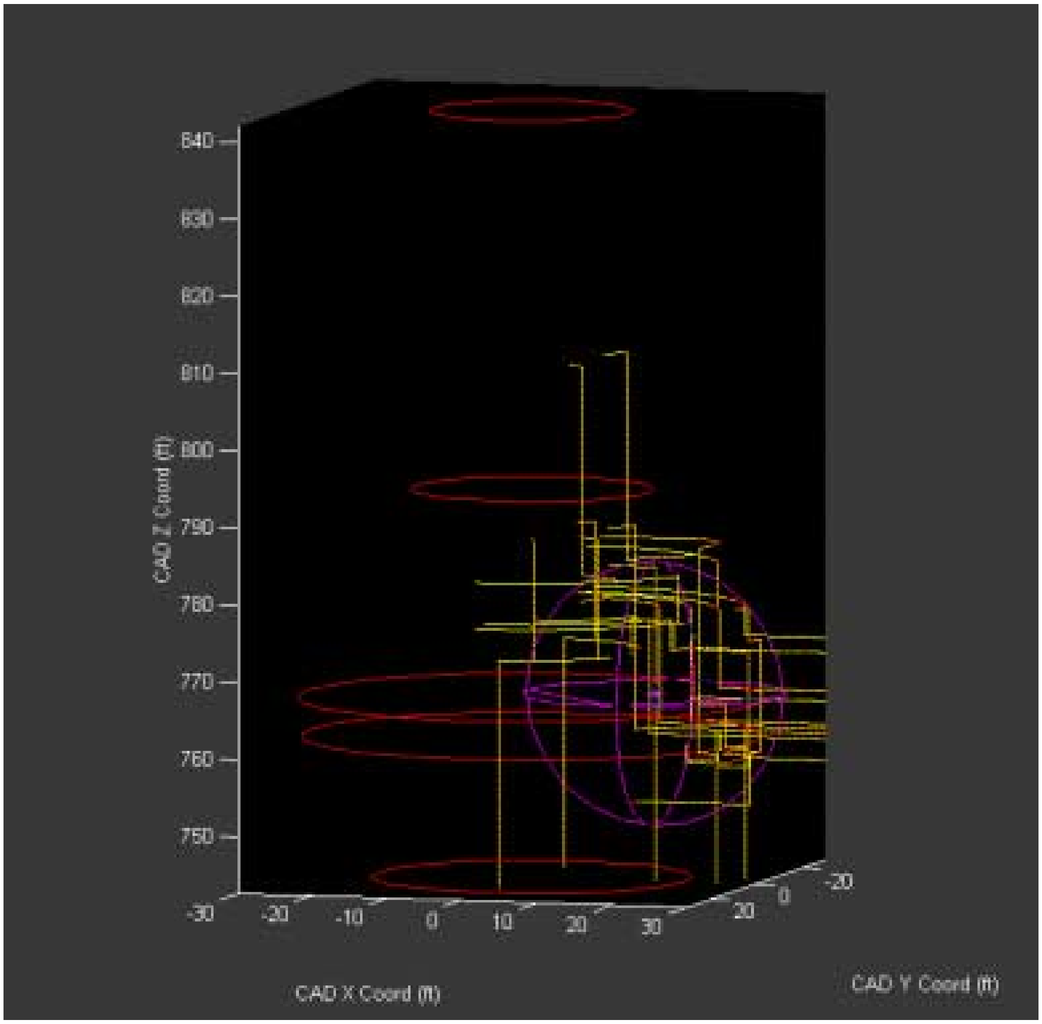

Fig. 4. Perspective view of ZOI (magenta) superimposed on major piping systems (yellow) within the drywell (red).

Both the Los Alamos and licensee calculations have the following built-in conservatism: (a) no credit was taken for shadowing provided by the targets and (b) the break was treated as fully unrestrained resulting in two-sided blowdown.

Rationale for Screening Out Calcium-Silicate/Asbestos Insulation

The licensee presented several arguments for not considering any breaks in high-energy pipe penetrations that contain limited quantities of calcium silicate/asbestos material: (1) the pipes have either check valves or flow-sensing devices/containment isolation valves to prevent significant discharge of fluid; (2) the inherent design of the penetration minimizes the possible radial and axial separation that can occur; (3) the insulation material may be ejected in large pieces that are unlikely to transport through gratings (all penetrations are above the lowest grating); (4) the break would cause a nonspherical jet directed at the biological shield wall, where it would dissipate without impinging on large quantities of adjacent insulation.

Although largely qualitative in nature, these arguments are self-consistent and are typical of those used by other plants to screen out penetration breaks. Los Alamos agrees with this rationale and concludes that screening out calcium-silicate/asbestos insulations is reasonable. The primary reason for the LANL position is that (a) the ZOI for breaks close to the penetrations generated very little debris other than that contained in the penetratons and (b) the net head loss effect of such debris is well bounded by the limiting break that is postulated to generate 550 ft^3 of insulation debris.

Rationale for Screening Out Calcium-Silicate

The calcium-silicate is located in the higher regions of the drywell. There is very little potential for generating large quantities of insulation debris (other than the cal-sil). The head-loss effect of calcium-silicate debris is well bounded by the head loss effect of the limiting break.

Rationale for Screening Out Lead Wool

The instrument penetrations at DAEC are insulated with lead wool. The licensee screened them out for the same reasons as given above. LANL agrees with the licensee rationale because (a) none of the large-break ZOIs include penetrations and (b) the head-loss effect of lead wool by itself is minimal (low inventory and high specific gravity).

Rationale for Screening Out Mirror RMI

This power plant uses 2.5-mil stainless-steel RMI on the reactor pressure vessel inside the biological shield. The licensee did not analyze any breaks with potential for generation and transport of RMI either by itself or in conjunction with fibrous insulation. The licensee screened out RMI because there are no postulated breaks within the biological shields that could generate and transport debris. Los Alamos performed the confirmatory analysis below to examine the validity of the licensees assumptions.

Los Alamos Confirmatory Analysis for Screening Out RMI

The licensee stated that Unit 1 contains large quantities of 2.5-mil stainless-steel RMI on the pressure vessel within the biological shield wall. Los Alamos scientists used the URG methodology to estimate the head loss [see Ref. 6, Vol. I, Page B-1] assuming that break in the biological shield would transport unlimited quantities of RMI to the strainer.

Step 1. The total circumscribed area of the strainers is 59 ft^2 and the ECCS flow is 9600 gal./min.
Step 2. The circumscribed approach velocity is 0.36 ft/s.
Step 3. The URG method results in a saturation thickness of 7.5 in.

Steps 46. The head loss induced by saturation-thickness RMI layer was calculated using
$\Delta H = K_p U^2 t_p$, where
ΔH = head loss (ft-water),
K_p = proportionality constant,
U = approach velocity, and
t_b = bed thickness.

This calculation clearly established that if there were a break in the biological shield and even if all the debris would be transported to the suppression pool, the resulting head loss would be negligible compared with the available $NPSH_{margin}$. Therefore, Los Alamos considers that screening out RMI by the licensee is reasonable.

It is concluded that the licensee estimate of debris used to size the strainers is conservative and meets the intent of RG 1.82, Rev. 2, and the NRC SER on the URG (Ref. 3). It also should be recognized that the current calculations (those of the licensee as well as Los Alamos) resulted in a larger ZOI and a higher volume of insulation debris compared with the NUREG/CR-6224 study (Ref. 1).

2.3. Debris Transport

The URG guidance was used to estimate the quantity of insulation debris transported from the drywell to the wetwell. For Mark I containments, the URG (Ref. 3) recommended drywell transport factors of 28% and 78% for insulation debris generated above and below the lowest grating respectively. These factors account for capture/settling-out of large debris in the drywell.

The licensee determined that for the limiting break (which was described above), about 5% of the Nukon debris volume would be generated below the lowest grating (elevation 757.5 ft). For this portion of the targeted insulation, the licensee applied a drywell transport factor of 0.78. For the remaining portion, a drywell transport factor of 0.28 was applied. The licensee increased this estimate by 10% for added conservatism. An elevation section of the drywell layout (see Fig. 2) suggests that a limited amount of Nukon-insulated piping below the lowest grating may be affected, depending on the exact break location. In fact, the Los Alamos estimate of transported debris does change somewhat depending on the definition of the grating elevation. Although breaks postulated in the mid and low regions of the drywell may not generate the largest total volume of debris, they have the potential of targeting some of the pipes located below the lowest grating and thereby generating the largest volume transported to the suppression pool. The Los Alamos independent analyses confirm that the limiting break analyzed by the licensee will generate and transport the highest amount of insulation debris.

A transport factor of 1.0 also was used for suppression-pool transport. The licensee stated that although some settling is likely, no credit was taken for settling because (a) operation of ECCS in the suppression pool cooling would resuspend the debris and make it available for transport, and (b) the BWROG recommended that licensees not credit debris settling without performing supporting analyses.

The licensee assumptions related to debris transport in the drywell and the suppression pool are reasonable and are in accordance with the guidance provided in the URG. The licensee approach is consistent with the SER on the URG (Ref. 3).

2.4. Debris Loading on the Strainer

Table 3 provides the debris loading used by the licensee for the strainer design basis. Some important observations regarding the rationale used by the licensee are as follows.

- The measured sludge generation rate was ~90 lbm per cycle (57.5 lbm/yr). This rate has been verified by desludging during reactor fuel outages (RFOs) 13–15. The licensee used 500 lbm in the analysis to introduce conservatism and to provide flexibility to operate multiple cycles before desludging. A description of the collection and weighing procedure is included in the licensee documentation reviewed by LANL.
- The licensee cites an aggressive FME program but assumed fixed loadings of the following.
  - 150 lbm of dirt and dust (argued to be conservative)
  - Non-insulation debris including Armaflex insulation (floats and was not of concern)
  - Fiberglass antisweat insulation (included with fiber in Table 2)
- No additional concrete was included because the break location is higher from the floor than the ZOI. The licensee assumed that concrete is covered adequately in the 150 lbm of dirt and dust.
- The licensee assumed that 50 tags (out of 166) and 50 pieces of electrical tape were transported to the strainer. (They applied the 0.28 and 0.78 factors based on location even though there is no testing specific to this material).
- For coatings, the licensee added 71 lbm of phenoline topcoat material, 47 lbm of zinc [inorganic zinc (IOZ)] and 71 lbm of unqualified coating from safety relief valve (SRV) piping within the ZOI.
- No additional suppression pool debris was added as verified by past underwater inspections.

Los Alamos believes that the quantities used for sizing the strainer and the plant's rationale for their use is conservative and conforms to the URG guidance.

Table 3. Debris loading values used by the licensee and the vendor to size the strainer and analyze strainer performance

Type of Debris	Quantity	Remarks
Fibrous Debris (Nukon™)	152 ft^3	Method 2 of URG for Nukon.
RMI¥Stainless Steel	0	RMI was screened out (explained above).
Sludge	500 lb	Measured generation rate of 90 lb/yr.
Dust and Dirt	150 lb	URG Number. Also used in NUREG/CR-6224
Rust	50 lb	URG Number.
Paint		
Inorganic Zinc	47 lb	Qualified paint located outside the conical jet-expansion area was excluded. 26 lb of unqualified paints exist in the drywell.
Unqualified Paint	142 lb	
Transient Foreign Material	0 lb	

2.5. Strainer Design Considerations

ECCS Operating Parameters

DAEC has two independent trains of LPCI[3] systems with two pumps in each train. Each LPCI pump is a single-stage, vertically mounted, centrifugal pump with a rated flow of 4800 gal./min at a discharge head of 390 ft-water. The runout flow for the LPCI pump was conservatively determined (based on pre-operational tests) to be 6500 gal./min. Thus, the run-out flow of each train is 13,000 gal./min, and the design flow is 9600 gal./min.

DAEC has two independent trains of low-pressure core spray (LPCS) systems, with one pump in each train. The LPCS pump is a single-stage, vertically mounted, centrifugal pump with a rated flow of 3100 gal./min at a discharge head of 690 ft-water. The runout flow for the LPCS pump was conservatively determined (based on pre-operational tests) to be 4500 gal./min. Thus, the runout flow for each LPCS train is 4500 gal./min compared with the design flow of 3100 gal./min.

The existing plant licensing basis assumes that both LPCS and LPCI pumps would operate at the runout flow (6500 and 4500 gal./min, respectively) during the first 10 min after a LOCA. At 10 min, the operating pumps would be throttled back to their rated flow (4800 and 3100 gal./min, respectively). The licensee emergency operating procedures (EOPs) direct the plant operators to throttle LPCI/LPCS pump flows and also trip one of the LPCI pumps on each operating train and one of the LPCS pumps.

Limiting Single-Failure Analysis

The limiting single-failure analysis assumes loss of one LPCI train, resulting in continued operation of one LPCI train and two LPCS trains. Even in this situation, the operator would throttle the LPCI/LPCS pumps and trip one of the LPCI pumps on the operating train. The result would be long-term operation of one LPCI pump and one LPCS pump. The net flow is sufficient for decay heat removal.

Design/Licensing Basis ECCS Operating Parameters

The plant representative stated that the ECCS strainers were designed to ensure positive $NPSH_{Margin}$ during the two postulated ECCS system configurations.

1. Assuming no failures in the system, the following ECCS configuration was judged to form the limiting condition from the strainer performance point of view.

    - For the first 10 min, both trains of LPCI and LPCS pumps inject flow at the runout conditions. This results in 13,000 gal./min of LPCI flow through each LPCI strainer and 4500 gal./min of LPCS flow through each LPCS strainer.
    - After 10 min, the operator would throttle LPCS and LPCI pumps to attain their design flow. This results in 9600 gal./min of LPCI flow through each LPCI strainer and 3100 gal./min of LPCS flow through each LPCS strainer.
    - Over the long term, the operator will align one train of LPCI in the suppression pool cooling mode and trip one of the LPCS pumps. The suppression pool cooling mode would operate intermittently.

[3] In the licensee calculations, LPCI is referred to as the RHR system.

2. The limiting case, following the worst-case single failure (i.e., loss of one train of LPCI), involves the following.

   - For the first 10 min, both LPCI pumps attached to the operating train and both the LPCS pumps would operate at the runout flow. This results in an LPCI flow of 13,000 gal./min through the LPCI strainer attached to the operating train and an LPCS flow of 4500 gal./min through each of the LPCS strainers.
   - After 10 min, the operator would (a) throttle LPCS pumps to their design flow of 3100 gal./min and (b) trip one of the LPCI pumps on each of the operating loops and throttle the other one to the design flow. The net result is 4800 gal./min LPCI flow through the strainer attached to the operating LPCI train and 3100 gal./min through each of the operating LPCS pumps.
   - Over the long term, the operator would trip one of the LPCS pumps. This results in long-term decay heat removal by one LPCI pump and one LPCS pump injecting into the core.
   - Upon recovering the lost LPCI train (in case of single failure), the operator may initiate suppression pool cooling.

The licensee considered both these ECCS configurations to estimate the limiting $NPSH_{Margin}$.

Licensee $NPSH_{Margin}$ Evaluations

$NPSH_{Margin}$ refers to the margin for head loss available above and beyond that required to protect against cavitation of the ECCS pumps during long-term operation. The $NPSH_{Margin}$ was estimated by the licensee using the following equation.

$$NPSH_{margin} = (P_{wetwell} - P_{vp})(144/\rho) + \Delta H_{static} - \Delta H_{Line\text{-}losses} - \Delta H_{strainer} - NPSH_{required},$$

where

$P_{wetwell}$ = containment pressure in the wetwell (psia),
P_{vp} = vapor pressure of water (psia),
ρ = density of water (lb/ft^3),
ΔH_{static} = static water height above the pump center line (ft-water),
$\Delta H_{Line\text{-}losses}$ = frictional losses in the piping connecting strainer to pump (ft-water),
$\Delta H_{strainer}$ = head loss at the strainer including the effect of debris buildup (ft-water), and
$NPSH_{required}$ = NPSH requires for pump operation (ft-water).

The licensee calculations clearly described how each parameter in the equation above was estimated. The important assumptions made by the licensee are as follows.

- The licensing basis allows for the licensee to take credit for a containment over-pressure of 2.7 psig to demonstrate that sufficient $NPSH_{Margin}$ is available for LPCS operation at the design flow. However, no credit should be taken for containment over-pressure to demonstrate that sufficient $NPSH_{Margin}$ is available for LPCI operation.
- The liquid vapor pressure was estimated assuming a suppression pool temperature of 160^{o}F during the first 10 min and 202^{o}F after 10 min.
- The static head was calculated based on the suppression pool height listed in the plant Technical Specifications.
- The piping frictional losses were evaluated after accounting for pipe aging effects.
- The strainer head losses were estimated assuming design-basis debris loadings (provided in Table 3 of this report) and the method described in the GE LTR.
- The $NPSH_{Required}$ value was estimated based on the manufacturer's pumping curves.

Table 4 lists each of the parameters used in the licensee $NPSH_{Margin}$ evaluations, with the exception of $\Delta H_{strainer}$ (i.e., sum of clean and fouled strainer head loss). The licensee evaluated $\Delta H_{strainer}$ using methods described in the GE LTR. The strainer was sized to ensure that $NPSH_{Margin}$ remains positive for the ECCS operating conditions described in the licensing basis.

Table 4. Parameters derived for DAEC $NPSH_{Margin}$ calculations.

System # pump	Flow Rate (gal./min)	$NPSH_{req}$ (ft-H_2O)	ΔH_{static} (ft-H_2O)	ΔH_{Line} (ft-H_2O)	$P_{vapor-press}$ (psia)	$P_{containment}$ (psia)	T_{pool} ºF
First 10 min after LOCA (no throttling of pumps assumed)							
RHR (4)	6500	11	10.29	8.92	4.84	15.2	160.9
CS (2)	4500	22	10.63	8.42	4.84	17.9	160.9
After 10 min (throttling of pumps assumed)							
RHR (4)	4800	10.4	10.29	4.05	12.06	15.2	202.2
CS (2)	3100	16.4	10.63	4.00	12.06	17.9	202.2

Strainer Design

The utility solution to potential strainer blockage is based on replacing existing strainers with large-capacity, passive, stacked-disk strainers. These strainers were designed and manufactured by GE Nuclear Energy. The strainers use stacked disks to extend the plate area and thus reduce the approach velocity at the plate. The design was tested and demonstrated by GE at the Electric Power Research Institute (EPRI) facility (Ref. 4). Geometric details of the strainers are provided in Table 5. Each LPCI and LPCS train is fitted with one strainer. Therefore, an LPCI strainer serves two LPCI pumps and a LPCS strainer serves one LPCS pump.

One of the important features of the DAEC replacement strainers is that the gap volume of all four strainers added together is sufficiently large to accommodate all of the debris inside the gaps. This will ensure that debris would be subjected to low flow velocities, and thus, the resulting head loss would be small. Such a condition cannot be ensured when one or more trains are not operational. In this case, it is likely that debris would build up on the circumscribed surface. As a result, it is the single-failure case that forms the most limiting case from the strainer head-loss performance perspective. Therefore, it is not surprising that the emphasis of the licensee calculations is limited to various ECCS operational configurations that result from postulated single failures.

Table 5. Geometric details of strainer

Parameter	RHR#1	RHR#2	CS #3	CS #4	Comment
Outer Diameter (in.)	XXXXX	XXXXX	XXXXX	XXXXX	Provided in the design control package (DCP) drawings
Active Length (in.)	XXXXX	XXXXX	XXXXX	XXXXX	Provided in the DCP Drawings
Flange Diameter (in.)	XXXXX	XXXXX	XXXXX	XXXXX	Provided in the DCP Drawings
Plate Area (Effective)	XXXXX	XXXXX	XXXXX	XXXXX	LANL estimate from geometry
Circumscribed Area (ft^2)	XXXXX	XXXXX	XXXXX	XXXXX	LANL estimate from geometry
Gap Volume (ft^3)	XXXXX	XXXXX	XXXXX	XXXXX	LANL estimate from geometry

Licensee Estimates for Strainer Head Loss

The licensee used the vendor-provided strainer sizing methodology (Ref. 3). This method relies on a head-loss correlation that GE developed based on data obtained by testing a "full-scale" strainer. The range of operating parameters tested by GE does envelop the DAEC operating parameters. GE provided a description of this methodology in the GE LTR, which was submitted for staff review separately. The NRC staff reviewed the GE LTR and approved its application to DAEC. This audit did not focus on further evaluation of the GE strainer sizing methodology. Instead, the focus of the on-site review was to examine how the LTR method was applied in the case of DAEC.

The head-loss calculations were carried out by the strainer vendor (GE) using plant-specific input provided by the licensee. The important aspects of licensee analyses can be summarized as follows.

- Analyses to examine the adequacy of the strainer sizing were performed separately for LPCI and LPCS strainers. This ensured that the LPCI and LPCS strainers individually met their design criteria in a conservative manner.
- For the LPCI strainers, two cases were analyzed. The first case corresponds to a single-failure configuration in which one train of LPCI (with two LPCI pumps operating) and one LPCS train provide ECCS injection. In this case, after throttling, the LPCI strainer flow is 9600 gal./min, and the total ECCS flow is 12,700 gal./min (9600 gal./min of LPCI + 3100 gal./min of LPCS). The second case closely mimics the licensing basis and assumes that one LPCI pump and one LPCS pump would be operational. In this case, the LPCI strainer flow is 4800 gal./min and the total ECCS flow is 7900 gal./min. The first case represents the worst case as regards to the strainer loading and the head loss across the strainer of all possible ECCS configurations. On the other hand, the second case is close to the plant licensing basis.
- Analyses performed to demonstrate the adequacy of LPCS strainers are very conservative. The licensee examined various configurations in which the ECCS may operate after a LOCA and selected the worst case that results in the highest debris loading on the LPCS strainer.

Physically, this case corresponds to a situation where two LPCS pumps are injecting into the core at the design flow (3100 gal./min) and all LPCI pumps together inject 1000 gal./min.

The results of the licensee analyses are summarized in Table 6. These results demonstrate the following.

- The LPCI and LPCS strainers are adequately sized to meet the licensing basis, which assumes that over the long term, one LPCI pump and one LPCS pump would be operated to provide core cooling. The net flow of 7900 gal./min is sufficient for decay heat removal.
- The LPCS strainers are sized to provide sufficient $NPSH_{Margin}$ even assuming worst-case ECCS response. In this case, LPCS operation requires a containment over-pressure of 2.1 psig over the long term. This value is lower than the 2.5 psig over-pressure credit approved by the NRC.
- The LPCI strainers are **not** adequately sized to support the most limiting conditions possible for LPCI operation. This situation corresponds to continued operation of two LPCI pumps on one train and one LPCS pump. For this case to succeed, the licensee needs to credit a containment over-pressure of 4.1 psig. The NRC staff has not approved such high containment over-pressure, although the licensee analyses (performed by GE) show that over-pressure far in excess of 4.1 psig is available following a LOCA.

Los Alamos Confirmatory Estimates for Strainer Head Loss

The Los Alamos staff performed confirmatory calculations using a modified form of the NUREG/CR-6224 correlation to independently estimate upper bounds for head loss across the strainers (Refs. 1 and 2). These analyses did not seek to estimate the most limiting head loss across each strainer (as done by the licensee). Instead, the Los Alamos focus was to simulate each strainer performance for selected cases. Table 7 lists all the cases run by Los Alamos. These cases are as follows.

Case A. Following a design-basis accident (DBA) LOCA, all ECCS trains come on and operate per design. They will operate at run-out flow for the first 10 min and will operate at design flow after 10 min. From the probabilistic point of view, this is the most likely configuration in which the ECCS would operate. LANL simulations found that strainers are adequately sized to handle this configuration. The debris was found to have been accommodated inside the gaps, and as a result, $\Delta H_{strainer}$ is much smaller than the $NPSH_{margin}$.

Case B. LANL assumed that following a DBA LOCA, one LPCI train is disabled. This leaves continued operation of one LPCI train and two LPCS trains. It is assumed that all operating trains would inject run-out flow for the first 10 min and design flow after 10 min. LANL simulations have shown that debris would build up on the circumscribed surface of the LPCI strainer. Coupled with high ECCS flow, this resulted in head loss in excess of the $NPSH_{margin}$. This high head loss occurred approximately 15–20 min into the accident. Therefore, LANL concludes that DAEC strainers are not sized to handle the most limiting single failure. The DAEC representative agreed with this conclusion and stated that (a) this case is not the licensing–basis single failure; (b) upon noticing the higher differential presssure, the operator would switch off one of the LPCI pumps on the operating train to lower head losses; and (c) the LANL conclusions are conservative because they do not credit containment overpressure while estimating LPCI $NPSH_{margin}$. The licensee stated that a more appropriate (licensing–basis) single failure that should be analyzed is the one below.

Case C. This case assumes that following a DBA LOCA, one train of LPCI and one train of LPCS are disabled. This leaves one train of LPCS and one LPCS pump operational. These pumps will operate at run-out flow for the first 10 min. After 10 min, the operator (as directed by the EOPs) would (a) throttle the pumps to their design flow and (b) switch of one of the operating LPCI pumps. For this case, LANL simulations have shown that (a) debris would build up on the circumscribed surface of the LPCI and LPCS strainers and (b) the resulting $\Delta H_{strainer}$ is low because of low approach velocities. Based on these simulations, LANL concluded that the strainers are adequately sized to handle this situation.

Overall, the DAEC strainer replacement strategy is sound and the plant analyses provide reasonable assurance that ECCS strainers are adequately sized to support long-term ECCS operation following a LOCA.

3.0. DEFICIENCIES AND RECOMMENDATIONS

No deficiencies were found.

4.0. CONCLUSIONS

The licensee used NRC-approved methods to estimate the quantity of insulation debris generated in the drywell and transported to the ECCS suction strainer. The licensee□s assumptions for noninsulation debris also are reasonable and conservative. Similarly, the licensee calculation of resulting head loss is conservative and is consistent with independent calculations performed by the Los Alamos staff using BLOCKAGE.

Overall, it is the Los Alamos staff's conclusion that the DAEC strainer replacement strategy is sound and their analyses provide reasonable assurance that ECCS strainers are adequately sized to support long-term ECCS operation following a LOCA. Any uncertainties in licensee analyses are compensated for by the some of the conservatism factored in by the licensee. The most important conservatism is that the licensee did not take credit for settling of debris in the suppression pool.

REFERENCES

1. Science and Engineering Associates, Inc., "Parametric Study of the Potential for BWR ECCS Suction Strainer Blockage Due to LOCA-Generated Debris," US Nuclear Regulatory Commission report NUREG/CR-6224 (October 1995).

2. US Nuclear Regulatory Commission, "BLOCKAGE v2.5, LOCA Induced BWR ECCS Strainer Blockage Analysis Tool," US Nuclear Regulatory Commission report NUREG/CR-6369 (October 1995).

3. BWROG, "Utility Resolution Guidance for ECCS Suction Strainer Blockage," NEDO-32686 (November 20, 1996).

4. GE Licensing Topical Report, "Application Methodology for the General Electric Stacked Disk ECCS Suction Strainer," NEDC-32721P, Revision 1.

Table 6. Licensee estimates for $NPSH_{Margin}$ for each of the ECCS system pumps.

Condition	Flow Rate (gal./min)	Pool Temp (ºF)	NPSH (ft-water)			Containment Overpressure		
			Available	Required	Margin	Available	Required	Margin
LPCS Pump (limiting operating configuration)								
Runout (0–10 min.)	4500	161	33.8	22	11.8	4	-1	5
Design (> 10 min.)	3100	202	35.9	16.4	19.5	10.2	2.1	8.1
LPCI Pump (single pump operating in a train; licensing-basis assumption)								
Runout (0–10 min.)	6500	161	24.2	11	13.2	4	-1.6	5.6
Design (> 10 min.)	4800	202	35.2	10.4	24.8	10.2	-0.1	10.3
LPCI Pump (two pump operating in a train; licensing-basis assumption)								
Runout (0–10 min.)	13000	161	24.2	11	13.2	4	-1.6	5.6
Design (> 10 min.)	9600	202	35.2	10.4	14.7	10.2	4.1	6.1

Table 7. Outcome of confirmatory calculations performed by LANL.

Condition	LPCI Train #1 Flow (gal./min)		LPCI Train #2 Flow (gal./min)		LPCS Train Flow (gal./min)	LPCS Train Flow (gal./min)	Pool Temp (ºF)	Outcome
	RHR-A	RHR-B	RHR-C	RHR-D	LPCS-A	LPCS-B		
Case A (Most Likely Response following a LOCA; All ECCS Trains Operating per design)								
Runout (0–10 min)	6500	6500	6500	6500	4500	4500	161	OK
Design (> 10 min)	4800	4800	4800	4800	3100	3100	202	OK
Case B (Conventional Single-Failure Response; One LPCI Disabled; Rest of the Trains Operating per design)								
Runout (0-10 min)	6500	6500			4500	4500	161	Fail
Design (> 10 min)	4800	4800			3100	3100	202	Fail
Case C (Licensing Basis; Single-Failure LPCI Fails + Operator Trips One of the Operating LPCI Pumps)								
Runout (0-10 min)	6500	6500			4500		161	OK
Design (> 10 min)	4800				3100		202	OK
Case D (Most Likely Response Following a LOCA; Operator Trips One Each of the LPCI Pumps in Each Train)								
Runout (0-10 min)	6500	6500	6500	6500	4500	4500	161	OK
Design (> 10 min)	4800		4800		3100	3100	202	OK

APPENDIX A

Plant Name:	**Duane Arnold Energy Center**
Containment Type:	**Mark I**
Vendor for Strainer:	**GE Nuclear**
Vendor for ΔH Analysis:	**GE Nuclear**
Vendor for Loads Analysis:	**GE Nuclear**

Inventory of Major Insulations In the Plant

	Fibrous	Particulate	RMI	Other
	(Type/ft^3)	*(Type/lbm)*	*(Type/ft^2)*	*(Type/ft^3)*
Primary Piping	**Nukon**	**Cal-Sil**		
Reactor Shielding Cavity			**Mirror- RMI**	
Drywell Penetrations		**Cal-Sil/ Asbestos**		**Lead Wool**
Miscellaneous (Chilled Water)				**ArmaFlex**

(Units: Volume in ft^3 and Foil Area in ft^2)

Debris Generation Model Used in the Study	
Method #1 -- All Debris In the Containment	
Method #2	
Method #3	☒
Method #4 -- Not approved for use by Staff	

Drywell Transport Factors Used in the Study	
Transport Factor is assumed equal to 1	
Used URG Transport Factors	☒
Plant Specific Calculations	

Suppression Pool Transport Factors Used in the Study	
Transport Factor is assumed equal to 1	☒
Used BLOCKAGE Calculations	
Plant Specific Calculations	

Miscellaneous Debris	**Location**	**Basis for Estimates**
Other Fibrous		
Paint (IOZ)	Dry Well	IOZ estimate of 47 lb from URG.
Rust	Sup_Pool	50 lbm from URG
Unqualified Coatings	Drywell	142 lbm fom plant estimate
Dirt and Dust	Drywell	150 lbm rom URG
Sludge	Pool	Measued 90 lb/outage. Assumed 500 lbs.
Other (__FOAM________)		

Head Loss Estimation	
Vendor Correlation and Analysis Used	☒
Vendor LTR Enclosed	**No**
Vendor LTR Previously Reviewed by Staff	**Yes**
Vendor tested Exact Strainers with Insulation	**No**
Plant Specific Analysis (e.g., URG Correlations)	

NPSH Estimation (Comparison with GL 97-04 Response)		
Operator Throttling of ECCS Assumed	**Yes**	
Time at which throttled	**10**	**min**
Percentage Flow Reduction from Rated Flow		
Maximum Pool Temperature	**202 °F**	
Assumed Containment Overpressure	**Yes**	**LPCS**
Staff reviewed the licensing basis (GL 97-04 Res.)	**Yes**	
Reference No:		
Date of Approval:		

Codes and Standards (Comparison with Licensing Basis/UFSAR)	
Quality Assurance Requirements	
10 CFR Appendix-B	☒
ASME Certificate Required	
Materials	
Conform to ASTM Specifications	☒
Certified Material Test Reports are Provided	☒
Design/Fabrication	**Not pressure stamped/pressure tested**
Qualified ASME Section III, Subsection NC	☒
Qualified ASME Section III, Class 2	
Other (Bolts per Sub-section NF_)	☒
Welding	
Qualified to ASME Section IX	☒
Other (Qualified Welder)	☒
NDE per ASME Section III	
Critical welds examined by liquid penetrant	☒
All Other Welds Visually Examined	☒
Other (____________________)	

Structural Evaluation addressed	
Loads on strainer components and welds evaluated	☒
Loads on torus penetrations reevaluated	☒
Added strainer supports to the torus	☒
Effect on structures in close proximity	☒
Effect on increased water level in supp-pool	**Yes (No effect)**
Seismic Loads	**Yes**
Hydrodynamic loads method basis	
Vendor analyses	**Yes**
Methods and Assumptions same as original	**Drag coefficients decreased by 15%**
Substantial changes in methods	**No**

Debris Estimates (Plant and Staff Evaluations)

(If saturation thickness assumption is used got to end)

A) Destruction Pressures Used (in psi)

Insulation Type	Plant	Staff	Comment
Transco RMI			
Cal-Sil with Al Jacket			
K-Wool			
Temp-Mat with ss wire retainer			
Knaupf			
Jacketed Nukon	**10**	**10**	
Unjacketed Nukon			
Koolphen-K			
MIRROR from Diamond			
Min-K			
Other:			
( )			
( )			
( )			
( )			

B) *Volume of Zone of Influence Used (ft^3 or Equivalent L/D Value for Sphere Radius)*

Insulation Type	Break #1		Break #2		Break #3		Break #4	
	Plant	Staff	Plant	Staff	Plant	Staff	Plant	Staff
Transco RMI	--	--	--	--	--	--	--	--
Cal-Sil with Al Jacket	--	--	--	--	--	--	--	--
K-Wool	--	--	--	--	--	--	--	--
Temp-Mat with ss wire retainer	--	--	--	--	--	--	--	--
Knaupf	--	--	--	--	--	--	--	--
Jacketed Nukon	10.1	10.1						
Unjacketed Nukon	--	--	--	--	--	--	--	--
Koolphen-K	--	--	--	--	--	--	--	--
MIRROR from Diamond	--	--	--	--	--	--	--	--
Min-K	--	--						
Other:	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--

C) *Volume of Debris Generated by Break (in ft^3)*

Insulation Type	Break #1		Break #2		Break #3		Break #4	
	Plant	Staff	Plant	Staff	Plant	Staff	Plant	Staff
Transco RMI	--	--	--	--	--	--	--	--
Cal-Sil with Al Jacket	--	--	--	--	--	--	--	--
K-Wool	--	--	--	--	--	--	--	--
Temp-Mat with ss wire retainer	--	--	--	--	--	--	--	--
Knaupf	--	--	--	--	--	--	--	--
Jacketed Nukon	544	427.5						
Unjacketed Nukon	--	--	--	--	--	--	--	--
Koolphen-K	--	--	--	--	--	--	--	--
MIRROR from Diamond	--	--	--	--	--	--	--	--
Min-K	--	--	--	--	--	--	--	--
Other:	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--

If breaks < 2, then

Vendor Data supports screening out rest of breaks ☒

Plant has undocumented analyses reviewed by staff

*D) **Drywell Debris Transport Fractions Used in the Analysis***

Insulation Type	Break #1		Break #2		Break #3		Break #4	
	Plant	Staff	Plant	Staff	Plant	Staff	Plant	Staff
Transco RMI	--	--	--	--	--	--	--	--
Cal-Sil with Al Jacket	--	--	--	--	--	--	--	--
K-Wool	--	--	--	--	--	--	--	--
Temp-Mat with ss wire retainer	--	--	--	--	--	--	--	--
Knaupf	--	--	--	--	--	--	--	--
Jacketed Nukon	0.28/0.78	0.28/0.78						
Unjacketed Nukon	--	--	--	--	--	--	--	--
Koolphen-K	--	--	--	--	--	--	--	--
MIRROR from Diamond	--	--	--	--	--	--	--	--
Min-K	--	--	--	--	--	--	--	--
Other:	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--

*E) **Wetwell Debris Transport Fractions Used in the Analysis***

Insulation Type	Break #1		Break #2		Break #3		Break #4	
	Plant	Staff	Plant	Staff	Plant	Staff	Plant	Staff
Transco RMI	--	--	--	--	--	--	--	--
Cal-Sil with Al Jacket	--	--	--	--	--	--	--	--
K-Wool	--	--	--	--	--	--	--	--
Temp-Mat with ss wire retainer	--	--	--	--	--	--	--	--
Knaupf	--	--	--	--	--	--	--	--
Jacketed Nukon	1	1						
Unjacketed Nukon	--	--	--	--	--	--	--	--
Koolphen-K	--	--	--	--	--	--	--	--
MIRROR from Diamond	--	--	--	--	--	--	--	--
Min-K	--	--	--	--	--	--	--	--
Other:	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--
( )	--	--	--	--	--	--	--	--

F) Net Insulation Debris Volume on the Strainer (ft^3)

Insulation Type	Break #1		Break #2		Break #3		Break #4	
	Plant	Staff	Plant	Staff	Plant	Staff	Plant	Staff
Transco RMI	-	-	-	-	-	-	-	-
Cal-Sil with Al Jacket	-	-	-	-	-	-	-	-
K-Wool	-	-	-	-	-	-	-	-
Temp-Mat with ss wire retainer	-	-	-	-	-	-	-	-
Knaupf	-	-	-	-	-	-	-	-
Jacketed Nukon	**182.5**	**122.5**						
Unjacketed Nukon	-	-	-	-	-	-	-	-
Koolphen-K	-	-	-	-	-	-	-	-
MIRROR from Diamond	-	-	-	-	-	-	-	-
Min-K	**-**	**-**						
Other:	-	-	-	-	-	-	-	-
( )	-	-	-	-	-	-	-	-
( )	-	-	-	-	-	-	-	-
( )	-	-	-	-	-	-	-	-
( )	-	-	-	-	-	-	-	-

G) Miscellaneous Debris

Debris Type	*Plant Estimate*		*URG Recomm.*		*Staff Estimate*		*Units*	*Status*
	Gen	T.F	Gen	T.F	Gen	T.F.		
Other Fibrous							**ft^3**	**O.K.**
Paint (IOZ)	47	1.0	47		47		**lbm**	**O.K.**
Rust	50	1.0	50		50		**lbm**	**O.K.**
Unqualified Coatings	142	1.0			142		**lbm**	**O.K.**
Dirt and Dust	150	1.0	150		150		**lbm**	**O.K.**
Sludge	**500**	**1.0**	150		500		**lbm**	**O.K.**
Other (FOAM)							**ft^3**	**O.K.**
Total	**889**	**1.0**		**1**	**889**	**1**	**lbm**	**O.K.**

ECCS Flow Rate and Design Details

	RHR #1	RHR #2	RHR #3	RHR #4	CS #1	CS #2
Before Throttling						
Flow Rate (GPM)	6,500	6,500	6,500	6,500	4,500	4,500
Pool Temperature (oF)	160.9	160.9	160.9	160.9	160.9	160.9
Wetwell Pressure (psia)	15.2	15.2	15.2	15.2	17.9	17.9
Vapor Pressure (psia)	4.844	4.844	4.844	4.844	4.844	4.844
Piping Frictional (ft-water)	8.92	8.92	8.92	8.92	8.42	8.42
Static-Head (ft-water)	10.29	10.29	10.29	10.29	10.63	10.63
$NPSH_{Available}$ (ft-water)	25.8	25.8	25.8	25.8	33.0	33.0
$NPSH_{Required}$ (ft-water)	11	11	11	11	22	22
$NPSH_{Margin}$ (ft-water)	**14.8**	**14.8**	**14.8**	**14.8**	**11.0**	**11.0**
After Throttling (Time:	**10**	***min)***				
Flow Rate (GPM)	4,800	4,800	4,800	4,800	3,100	3,100
Pool Temperature (oF)	202.2	202.2	202.2	202.2	202.2	202.2
Wetwell Pressure (psia)	15.2	15.2	15.2	15.2	17.9	17.9
Vapor Pressure (psia)	12.061	12.061	12.061	12.061	12.061	12.061
Piping Frictional (ft-water)	4.05	4.05	4.05	4.05	4	4
Static-Head (ft-water)	10.29	10.29	10.29	10.29	10.63	10.63
$NPSH_{Available}$ (ft-water)	13.8	13.8	13.8	13.8	20.6	20.6
$NPSH_{Required}$ (ft-water)	10.4	10.4	10.4	10.4	16.4	16.4
$NPSH_{Margin}$ (ft-water)	**3.4**	**3.4**	**3.4**	**3.4**	**4.2**	**4.2**

Strainer Design Details

	RHR #1	RHR#2	CS#1	CS #2	
Previous Strainer					
Outer Diameter (in.)	24	24	12	12	
Active Length (ft)	2.3	2.3	1.4	1.4	
Flange Diameter (in.)	18	18	8.875	8.875	
Plate Area (ft^2)	14.6	14.6	4.2	4.2	37.6
Clean ΔH (ft-water)	**Not Provided in the Submittal**				
Replacement Strainer					
Outer Diameter (in.)	[redacted]				
Active Length (ft)					
Flange Diameter (in.)					
Plate Area (Effective)					
Circumscribed Area (ft^2)					
Gap Volume (ft^3)					
Clean Head Loss	**Not Provided in the Submittal**				
Strainer Increase					[redacted]
Plate Area Increase	[redacted]				
A_{circ} Increase					
Hole Dimension					
Volume of Gap					

Strainer Debris Loading Analysis Results

Cases Analyzed

Case-A (GPM)	9,600	9,600	3,100	3,100	
Case-B (GPM)	9,600	0	3,100	0	
Case-C (GPM)	4,800	0	3,100	0	
Case-D (GPM)	4,800	4,800	3,100	0	
Run-Out (GPM)	13,000	13,000	4,500	4,500	
Loading (Case-A)					
Load Factor	**0.38**	**0.38**	**0.12**	**0.12**	
Fiber Volume (ft3)	**69**	**69**	**22**	**22**	
Fiber Mass (lbm)	**166**	**166**	**53**	**53**	
Volume Inside Gap	**41.7**	**41.7**	**22.3**	**22.3**	
Gap Occupancy	**FULL**	**FULL**	**0.62**	**0.62**	
Thickness Inside Gap	**0.85**	**0.85**	**0.53**	**0.53**	
Volume Outside Gap	**27**	**27**	**-**	**-**	
Thickness Outside Gap	**5.5**	**5.5**	-	-	
Loading (Case-B)					
Load Factor	**0.76**	**OFF**	**0.24**	**OFF**	**Licensee Case for Two Pumps Running**
Fiber Volume (ft3)	**138**	**OFF**	**45**	**OFF**	
Fber Mass (lbm)	**331**	**OFF**	**107**	**OFF**	
Volume inside Gap	**41.7**	**OFF**	**35.9**	**OFF**	
Gap Occupancy	**FULL**	**OFF**	**FULL**	**OFF**	
Thickness Inside Gap	**0.85**	**OFF**	**0.85**	**OFF**	
Volume Outside Gap	**96**	**OFF**	**9**	**OFF**	
Thickness Outside Gap	**19.6**	**OFF**	**2.2**	**OFF**	
Loading (Case-C)					
Load Factor	**0.61**	**OFF**	**0.39**	**OFF**	**Licensee Case for One Pumps Running**
Fiber Volume (ft3)	**111**	**OFF**	**72**	**OFF**	
Fber Mass (lbm)	**266**	**OFF**	**172**	**OFF**	
Volume inside Gap	**41.7**	**OFF**	**35.9**	**OFF**	
Gap Occupancy	**FULL**	**OFF**	**FULL**	**OFF**	
Thickness Inside Gap	**0.85**	**OFF**	**0.85**	**OFF**	
Volume Outside Gap	**69**	**OFF**	**36**	**OFF**	
Thickness Outside Gap	**14.1**	**OFF**	**9.1**	**OFF**	
Loading (Case-D)					
Load Factor	**0.38**	**0.38**	**0.24**	**OFF**	
Fiber Volume (ft3)	**69**	**69**	**45**	**OFF**	
Fber Mass (lbm)	**166**	**166**	**107**	**OFF**	
Volume inside Gap	**41.7**	**41.7**	**35.9**	**OFF**	
Gap Occupancy	**FULL**	**FULL**	**FULL**	**OFF**	
Thickness Inside Gap	**0.85**	**0.85**	**0.85**	**OFF**	
Volume Outside Gap	**27**	**27**	**9**	**OFF**	
Thickness Outside Gap	**5.5**	**5.5**	**2.2**	**OFF**	
Loading (Run-OUt)					
Load Factor	**0.37**	**0.37**	**0.13**	**0.13**	
Fiber Volume (ft3)	**68**	**68**	**23**	**23**	
Fber Mass (lbm)	**163**	**163**	**56**	**56**	
Volume inside Gap	**41.7**	**41.7**	**23.5**	**23.5**	
Gap Occupancy	**FULL**	**FULL**	**0.65**	**0.65**	
Thickness Inside Gap	**0.85**	**0.85**	**0.55**	**0.55**	
Volume Outside Gap	**26**	**26**	**-**	**-**	
Thickness Outside Gap	**5.3**	**5.3**	-	-	

Strainer Approach Velocities

Plate Velocity (ft/s)				
Case-A (GPM)	[redacted]			
Case-B (GPM)	[redacted]	OFF	[redacted]	OFF
Case-C (GPM)	[redacted]	OFF	[redacted]	OFF
Case-D (GPM)	[redacted]	OFF	[redacted]	OFF
Run-Out (GPM)	[redacted]			
CircumScribed Velocity (ft/s)				
Case-A (GPM)	[redacted]			
Case-B (GPM)	[redacted]	OFF	[redacted]	OFF
Case-C (GPM)	[redacted]	OFF	[redacted]	OFF
Case-D (GPM)	[redacted]	OFF	[redacted]	OFF
Run-Out (GPM)	[redacted]			

Head Loss Estimates for Various Postulated Cases LPCI

Case ID	Nukon	Sludge	Paint	Rust	Dust	Unqual	Temp	#pmps
	ft^3	lbm	lbm	lbm	lbm	lbm	^oF	
1: Plant Estimates (GE)	150	500	47	50	150	142	202	
Design Full								2
Single Fail Full								2
Design Throttled								2
Single Fail Throttled								2
Licensing								1
2: NRC Estimate (BLKG)	150	500	47	50	150	142	202	