LOS ALAMOS TECHNICAL EVALUATION REPORT

On-Site Audit of Dresden Nuclear Power Plant Emergency Core Cooling System Strainer Blockage Resolution

by

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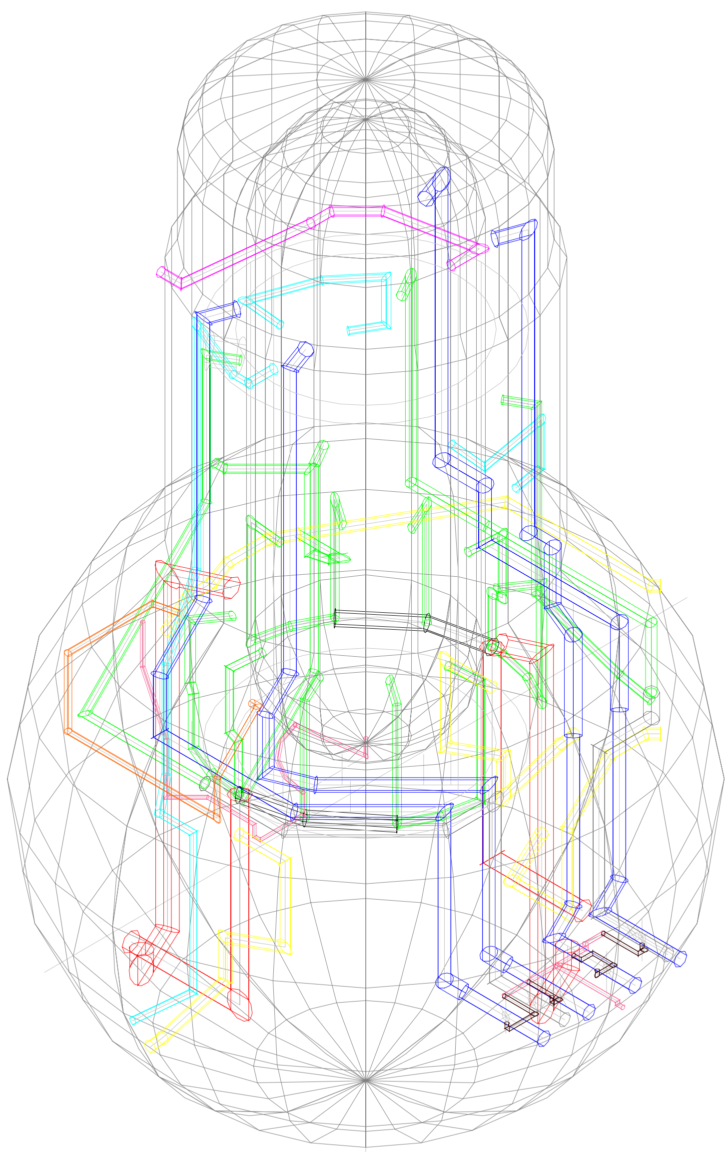

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ACRONYMS

ARL	Alden Research Laboratories, Inc.
BWROG	Boiling Water Reactor Owner's Group
DES	Duke Engineering Services
DPSC	Diamond Power Specialty Company
ECCS	Emergency Core Cooling System
EPRI	Electric Power Research Institute
FME	Foreign Matter Exclusion
ITS	Innovative Technology Solutions
LANL	Los Alamos National Laboratory
LOCA	Loss-of-Coolant Accident
LPCI	Low-Pressure Core Injection
LPCS	Low-Pressure Core Spray
LSL	Loop Select Logic
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
PCI	Performance Contracting, Inc.
PP&L	Pennsylvania Power and Light
RG	Regulatory Guide
RMI	Reflective Metal Insulation
RWCU	Reactor Water Clean-Up
SER	Staff Evaluation Report
SPCP	Suppression Pool Cleanliness Program
TPI	Transco Products, Inc.
URG	Utility Resolution Guidance
ZOI	Zone of Influence

INTRODUCTION

Dresden Units 2 and 3 are BWR/4 plants with Mark I containments. In response to US Nuclear Regulatory Commission (NRC) Bulletin 96-03, replacement strainers were installed at Dresden Units 2 and 3. The NRC staff performed an on-site audit at Dresden of the analyses that formed the basis for the design and installation of replacement strainers. Included in the audit were the licensee's [Commonwealth Edison (ComEd)] implementations of programs related to the general issue of emergency core cooling system (ECCS) strainer blockage, namely, the Foreign Material Exclusion (FME) Program and the Suppression Pool Cleanliness Program (SPCP). Los Alamos National Laboratory (LANL) scientists assisted NRC in this effort.

Dresden Units 2 and 3 are very similar in layout and ECCS design, including the dimensions of the replacement strainers. Both units primarily use reflective metallic insulation (RMI) for insulating primary piping. Small quantities of fibrous insulation are present in the drywells of both units. Appendix A provides a complete list of fibrous debris locations in Units 2 and 3. A significant difference between Units 2 and 3 relevant to this audit is that Unit 3 contains approximately 8 ft^3 of calcium-silicate insulation. The on-site audit reviewed documents related to the design and installation of replacement strainers at both units. Appendix B provides the completed checklist used by the LANL and NRC staffs during the on-site review. This report documents the supporting analyses conducted by LANL scientists during the on-site review.

1.1 PLANT FAMILIARIZATION

Dresden Units 2 and 3 predominantly use 2.5-mil stainless-steel, 2-mil stainless-steel, and 6-mil aluminum RMI cassettes[1] for insulating the primary piping and reactor vessel. Limited quantities of Nukon™ mats[2] are used around special components and certain piping segments. The plant estimates that between 90 and 100 ft^3 of Nukon™ insulation is present in the drywell of Units 2 and 3. Most of the Nukon insulation is protected by stainless-steel jackets with normal J-hooks. The flued head penetrations are insulated with asbestos (14 ft^3 per flued head penetration) and a small quantity of nonencapsulated Nukon (1.93 and 2.67 ft^3 in Units 2 and 3, respectively). Amaflex closed-cell foam insulation was used on the chilled water pipes. Additionally in Unit 3, small quantities of calcium-silicate insulation (8.24 ft^3) are used on the reactor water clean-up (RWCU) pipes located in the mid-regions of the drywell. Using qualitative rationale, the licensee eliminated Amaflex foam insulation and asbestos from the analyses.

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[1] RMI cassette construction consists of metallic foils of a certain type and thickness encapsulated by 304 stainless-steel sheaths that are approximately 0.028 in. thick. The actual type and thickness of the foils varies depending on the manufacturer. Diamond Power Specialty Company (DPSC) uses 2.5-mil stainless-steel and 6-mil aluminum foils, whereas Transco Products, Inc. (TPI) uses 2-mil stainless-steel.

[2] Nukon is a trademark insulation manufactured and marketed by Performance Contracting, Inc. (PCI). It is a low-density (2.3 lbm/ft^3) fiberglass mat.

The Dresden Units 2 and 3 ECCS configuration includes an ECCS ring header circumscribing the torus with connecting piping to four inlet penetrations. In the torus, each connecting line is fitted with a flanged surface for mating to the ECCS strainer flange. The original suction strainers (i.e., pre- NRCB 96-03 strainers) were truncated cone strainers. The base of the strainer where it mates the flange was about 18.3 in. in diameter and gradually decreased to 14.5 in. in diameter over its 10-in. length. The net surface area of each strainer was 4.7 ft^2. The design flow for the low-pressure core injection (LPCI) and low-pressure core spray (LPCS) pumps are 5000 and 4500 gal./min, respectively, for the short term and 2500 and 4500 gal./min for the long term (t > 10 min). This results in a design net ECCS flow of 29,000 gal./min for the short term and 19,000 gal./min for the long term. During the short term, the licensing-basis flow is different from the design-basis flow because of considerations such as single failure. Total, licensing-basis, ECCS flow through the four strainers combined during the short term is 32,200 gal./min. This flow corresponds to an assumed failure of the LPCI Loop Select Logic (SF-LSL), which causes all four LPCI pumps to inject into a broken reactor recirculation loop at 5150 gal./min each[3] and core decay heat removal to be achieved by two LPCS pumps operating at 5800 gal./min each. The Dresden licensee's $NPSH_{margin}$ estimates were obtained subject to the following assumptions: (a) the operator would throttle the ECCS flow after 10 min and (b) the wetwell would be at a pressure higher than the atmospheric pressure by up to 9 psig during the short term and 2.5 psig over the long term. The Office of Nuclear Reactor Regulation (NRR) staff reviewed and approved the licensee calculations regarding $NPSH_{margin}$ for the pre-NRCB 96-03 plant configuration.

The plant's resolution of the potential strainer-blockage issue is installation of *passive, large-capacity* suction strainers designed and manufactured by PCI. The strainer sizing and performance analyses were performed by Innovative Technology Solutions, Inc. (ITS) and Duke Engineering Services (DES). The replacement strainers have a combined surface area of 475 ft^2 (an increase of approximately 2500% compared with the pre-NRCB 96-03 design). The plant estimated the debris loading on the strainer following a postulated loss-of-coolant accident (LOCA) using methods and calculations developed and performed by the contractors. In many instances, these methods varied significantly from those discussed by the Boiling Water Reactors Owners Group (BWROG) in the Utility Resolution Guidance (URG) document (Ref. 1). Estimates for quantities of fibrous debris generated were evaluated on a plant-specific basis using Method 2 of the URG. No debris generation calculations were performed for RMI. Instead, the analyses assumed that sufficient RMI debris would be generated to form a "saturation bed" around the strainer. The quantity of sludge used to size the strainer was 370 lb based on conservative interpretation of "actual plant measurements."[4] Reportedly, this quantity corresponds to sludge generated during one power cycle; in other words, the licensee has committed to clean up the suppression pool during every outage. Other particulate debris included in the design basis were qualified paint chips, rust from unpainted structures, dust and dirt, and unqualified or indeterminate coatings. The FME Program and the SPCP were implemented to limit the quantities of foreign materials and suppression pool sludge (e.g., clothing or plastic sheet) in the drywell.

The licensee provided several documents for review during this onsite audit. These documents did not present the design criterion used to size the replacement strainers. Contradictory statements often were made regarding the design criterion and the licensing bases. The anecdotal evidence suggests that the licensee intended the strainer design to be such that new strainers loaded with LOCA debris

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[3] This flow is not equal to the LPCI pump run-out flow. Instead, the Dresden licensee estimated fractional losses in the LPCI piping and Recirculation line. These losses then were coupled with pump curves to estimate the actual flow out the break assuming free release into the drywell.

[4] This value of 370 lb was based on one worst-case measurement with large uncertainties. The licensee believes that the actual sludge volume would be significantly lower than this value.

would result in a net head loss equal to or less than the clean strainer head loss estimated for pre-NRCB 96-03 strainers. However, neither the licensee nor the contractors clearly documented the design criterion and how the strainers meet that criterion.

1.2 OBJECTIVES AND SCOPE OF ANALYSES

The primary objective of LANL on-site audit is to independently confirm adequacy of the strainer size and independently evaluate performance of the replacement strainers under LOCA conditions. In addition, the audit also focused on reviewing the supporting documentation to identify any concerns relative to the licensee's strainer design criteria and strainer performance analyses. In particular, the review of licensee strainer design analyses was to do the following.

1. Evaluate how the licensee estimated the quantity of debris used for sizing the strainer. Determine if the process used for selecting the breaks is consistent with the guidance in Regulatory Guide (RG) 1.82, Rev. 2, and if the methods used by the licensee were consistent with that of the NRC and therefore were considered to provide reasonable estimates for debris generation and transport.

2. Evaluate the licensee's proposed strainer design criteria and strainer performance.

During the plant audit, LANL scientists undertook a detailed review of the documentation provided by the licensee. To substantiate various findings, the LANL staff performed several independent calculations. This report presents the various analyses performed by the licensee (and its contractors) followed by LANL staff comments and the results of LANL independent analyses.

1.3 LIST OF LICENSEE SUPPORTING DOCUMENTS REVIEWED

The following is a list of engineering calculations provided for review by the licensee.

1. DE&S Calc. No. DRE98-0018, "ECCS Strainer Head Loss Estimates for Dresden Station Units 2 and 3," Duke Energy and Services, Prepared by Innovative Technology Solution Corporation (1999).

2. ComEd Calc. No. DRE97-0010, "Dresden LPCI/Core Spray NPSH Analysis Post-DBA LOCA: Log-Term Design Basis," (1997).

3. ComEd Calc. No. DRE97-0012, "Dresden LPCI/Core Spray NPSH Analysis Post-DBA LOCA: Short-Term Design Basis," (1997).

4. DE&S Calc. No. DRE99-0018, "Methodology for Dresden 2 and 3 Insulation Debris Generation and Transport Assessment," Duke Energy and Services (1999).

5. DE&S Calc. No. DRE98-0056, Rev. 1, "Sources of Debris in the Unit 2 Drywell Considered for Clogging of the ECCS Strainers, (1999).

6. PCI, Head Loss Calculations for Bare Sure-Flow Suction Strainers at Quad Cities 1, 2 and Dresden 2, 3 Nuclear Units, PCI-NPD-CE01, Performance Contracting, Inc., (1997).

LANL REVIEW FINDINGS

2.1 SELECTION OF THE BREAK

The NRC regulatory guidance recommends that the licensee should analyze a sufficient number of breaks to demonstrate that the limiting break would maximize the estimated head loss across the ECCS strainer. Of particular concern are the medium LOCAs that may result in the highest sludge-to-fiber ratio but not necessarily the highest fiber volume.

The postulated breaks analyzed by the licensee can be broadly divided into the following categories.

1. *Breaks postulated in the open drywell volume*. The licensee identified all of the weld locations in pipes larger than 12-in. in diameter and treated them as possible break locations. Appendix A provides a list of weld locations in the 28-in. Recirculation line that were considered by the licensee. The licensee treated these breaks as "unrestrained breaks," thus allowing for maximum separation and maximum offset. The licensee performed analyses to establish that the limiting break (which generates the maximum amount of fiber) also results in the maximum head loss. The diverse break locations coupled with large zones of influence give a reasonable assurance that the limiting break was selected by the licensee for analysis. Therefore, LANL concluded that the process used by the licensee to identify the limiting break in the open drywell volume is reasonable.

2. *Breaks postulated inside the bio-shield*. The licensee analyzed a break postulated inside the bio-shield wall. That break resulted in a large volume of shredded RMI and approximately 1.43 ft^3 of Nukon insulation. The licensee stated that no transport path is available out of reactor cavity to the suppression pool and hence screened out this break. An equally supporting rationale for screening out this break is that it does not form the limiting break; several breaks postulated in the open drywell volume generate and transport larger quantities of fibrous insulation (approximately 20 ft^3). LANL staff concluded that it is appropriate for the licensee to screen out breaks located inside the bio-shield because the head loss impact of these breaks would be bounded by the limiting break postulated in the open drywell volume.

3. *Breaks postulated to occur in the flued head penetrations*. The licensee treated breaks located in the flued heads differently from the breaks located in the drywell open volume because of their potential to generate asbestos insulation. Anecdotal evidence (also a cursory review of CAD drawings) suggests that between 10 and 15 welds are located either inside or very close to the flued head penetrations.

The licensee concluded that the limiting break for analysis is a large break in the open drywell vlume. Based on the review, the LANL staff concurs with the licensee and concludes that the licensee selection of the limiting break in the open drywell volume is reasonable and would provide a bounding estimate of the amount of debris generated as well as the resulting head loss. It meets the intent of guidance provided in RG 1.82, Rev. 2.

2.2 DEBRIS GENERATION

Discussions about debris generation are provided below for each insulation type.

Reflective metal insulation. The RMI insulation present in the plant consists of three types of foils: 2-mil stainless steel, 2.5-mil stainless steel, and 6-mil aluminum. The plant did not perform debris-generation calculations. Instead, it used a saturation thickness method to estimate the head-loss contribution of RMI. This method is based on the BWROG observation that RMI debris beds reach a saturation point beyond which drag induced by strainer flow is not sufficient to retain RMI debris on the strainer surface. Use of this method eliminates the requirement to perform debris-generation and -transport calculations. The NRC staff reviewed this method and accepted it as indicated in the NRC SER (Ref. 1).

The saturation thickness method for Dresden resulted in an assumed RMI foil debris loading of 4637 ft^2 corresponding to unthrottled ECCS operation. This is approximately equal to the foil surface area contained in RMI cassettes used to insulate approximately 125 linear feet of Recirculation line piping (28-inch in diameter). Considering that Transco RMI has been observed to withstand damage pressures in excess of 150 psig and the drywell transport factor for Transco RMI is less than 0.5, it is reasonable to conclude that licensee's treatment of RMI resulted in a very conservative estimate of the quantity of RMI foil that could reach the strainer. This is a voluntary conservatism[5] introduced into the analyses by the licensee. In theory, the licensee could have used debris-generation models in lieu of saturation thickness models to estimate the quantity of RMI debris generated. This would have resulted in lower volume of RMI being transported and thus lower head loss across the debris bed.

Nukon™ insulation. The licensee used Method 2 of the URG to estimate the zone of influence and the quantity of fibrous Nukon™ debris generated by the jets. The general assumptions for estimating the quantity of debris generated are (1) no shielding of targets by intervening structures, (2) no pipe restraints at the break location so that maximum separation and maximum offsets apply, and (3) no credit for special jacketing or bands on some of the insulation. For unjacketed Nukon, the destruction pressure recommended by the URG is 10 psi, which leads to a spherical zone of influence (ZOI) with a radius R_{ZOI} equal to 10.4 x D_{pipe}, where D_{pipe} is the diameter of the broken pipe. For the limiting break (28 in. in diameter), R_{ZOI} is 24.2 ft or a sphere approximately 48 ft in diameter. As shown in Fig. 1, the postulated ZOI encompasses almost one-half of the Dresden drywell and thus is judged to be very conservative.

The licensee (and its contractor) automated Nukon debris-generation calculations using a proprietary program called PIPES. NRC did not review the PIPES program either before or as part of this audit. It appears that the program input included the locations and quantities of Nukon insulation present in the drywell. Using that information, the program estimates the quantities of Nukon insulation located in the ZOI of each postulated break location, as well as the relative location of the generated debris with respect to the lowest grating. Obviously, the accuracy of the program output depends on the accuracy of the input data regarding the locations of the Nukon insulation. According to the licensee calculations, the limiting break postulated in the Unit 3 open drywell volume would generate approximately 80 ft^3 of Nukon insulation debris. All of this debris would be located above the lowest grating (the reference location of the lowest grating is 515 ft). Independent calculations performed by

5 "Voluntary conservatism" refers to the fact that the licensee has deliberately chosen the most conservative option provided in the URG, as opposed to other options that would yield lower estimates for the quantity of debris generated. Even the other options have built-in conservatism.

the LANL staff verified the licensee estimates. The LANL scientists' independent calculations are summarized in Appendix A.

Calcium-silicate insulation (Cal-Sil). The only location in which Cal-Sil insulation is present is on the Unit 3 RWCU piping. The estimates of Cal-Sil volume in Unit 3 varied between[6] 5.05 and 8.24 ft^3. The licensee analyses assumed that 100% of the Cal-Sil insulation would be destroyed (either during blowdown or during spray washdown). This is a very conservative assumption because (a) the Cal-Sil blankets are encapsulated by aluminum jackets with stainless-steel bands (failure of that jacket is necessary to expose Cal-Sil to erosion caused by blowdown and washdown) and (b) it is unlikely that any single postulated break has a ZOI large enough to encompass the entire length of the RWCU lines on which Cal-Sil insulation was used. Further discussions are provided in Appendix A. It is our conclusion that the licensee's treatment of Cal-Sil is conservative and is voluntary on the part of the licensee.

Asbestos. The only known locations where asbestos is present are the flued head penetrations, where asbestos is used in conjunction with Nukon. The maximum amount of asbestos contained in any penetration is about 14 ft^3. The licensee assumed that breaks postulated in the flued head penetrations would result in destruction of 100% of this insulation. The licensee however screened out asbestos insulation based on their findings: (1) very small quantities of asbestos insulation debris would reach the strainer and (2) it's head loss impact would be negligible give that asbestos is not expected to form an uniform bed. LANL staff concurs with the licensee rationale and further notes that (a) the inherent design of the penetration minimizes the potential for significant radial and axial separation (which would reduce the ZOI), (b) the break would cause non spherical jet directed at close-by walls where it would dissipate without impinging on the large quantities of adjacent insulation, (c) the insulation contained in the penetration would be destroyed, but by itself it will not induce large pressure drop, and (d) there are very few flued head penetrations in the drywell (thus low likelihood of a break in the flued head penetrations).

Based on the review, it is concluded that the licensee's estimate of insulation debris generated by postulated breaks is reasonable (and conservative) and meets the intent of RG 1.82, Rev. 2, and the NRC staff evaluation report (SER) on the URG (URG SER).

The debris-generation estimates are based on following assumptions: (a) no credit is taken for shielding of target insulation by the intervening structures and (b) no credit is taken for special jackets and bands that are present on some insulation blankets (e.g., Cal-Sil). These assumptions highlight the conservatism built into the URG debris-generation methods. The following assumptions further enhance the margin of conservatism: (a) the licensee used the saturation thickness method for estimating the quantity of RMI debris generated/transported to the strainer and (b) the licensee assumed that all of the Cal-Sil located in the drywell would be destroyed and transported to the suppression pool. These two assumptions are "voluntary" on the part of the licensee.

The LANL review revealed one flaw in the licensee's configuration controls related to updating and documenting the current estimate of the nonmetallic insulation present in the drywell of Units 2 and 3. There have been several instances where the licensee's "most recent" estimates of Nukon inventories in the containment are different from estimates in other documents (supposedly outdated) and even CAD drawings. Both the licensee analyses and the LANL independent review relied on these "most recent" licensee estimates of Nukon despite the fact that they are substantiated by anecdote only. These discrepancies can be traced to the licensee's recent practice of removing Nukon insulation and replacing

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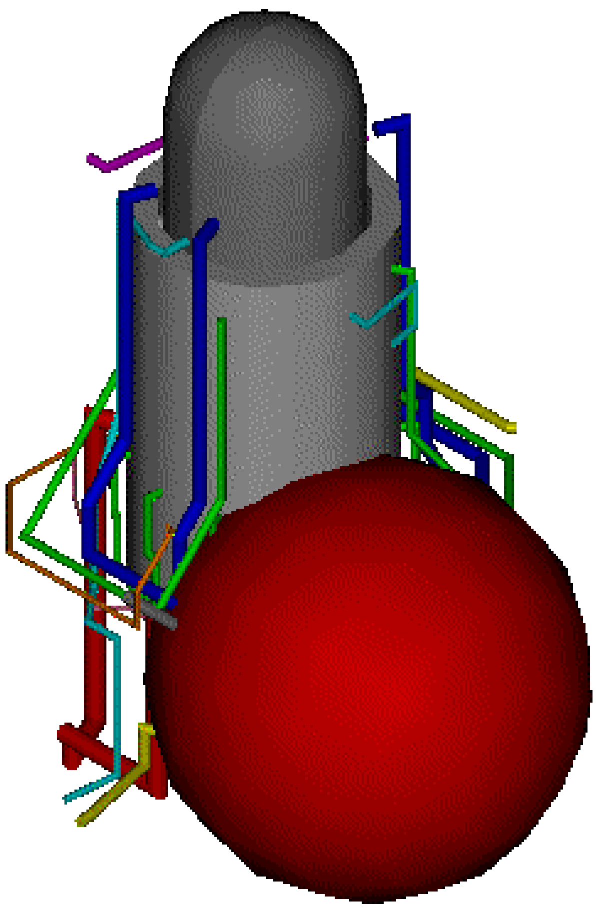
[6] A range was provided because, as explained in Appendix B, there appears to be some confusion about the exact quantity of Cal-Sil in Unit 3.

it with RMI. Although this practice may enhance plant safety with respect to this issue, it leaves some ambiguity about the actual quantity of nonmetallic insulation located in the drywell. This may also lead to violation of design basis fiber leading; i.e., unknowingly the drywell may contain more fibrous insulation than assumed in the strainer design basis. It is recommended that the licensee update and document the

Legend of Colors
Red is the Zone of Influence
Gray is the RX Pressure Vessel (Shield)
Color lines represent primary pipes



(a)

Fig. 1-A. Vertical view of AutoCAD Illustration of the ZOI for Nukon insulation and comparison with the drywell volume (see Appendix-A for more information).

Legend of Colors
Red is the Zone of Influence
Gray is the RX Pressure Vessel (Shield)
Color lines represent primary pipes

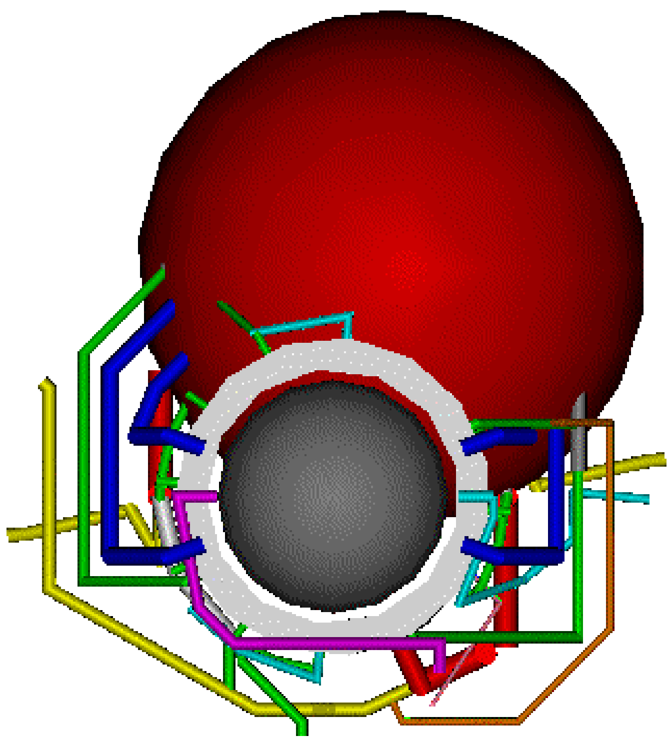


Fig. 1-B. Cross-Sectional view of AutoCAD Illustration of the ZOI for Nukon insulation and comparison with the drywell volume (see Appendix-A for more information).

current locations and quantities of nonmetallic insulation and implement more rigorous configuration control.

2.3 DEBRIS TRANSPORT

2.3.1 Drywell Transport

Discussions related to drywell transport for each insulation type are provided below.

RMI. No transport calculations were performed for RMI, which is consistent with the saturation thickness method being used for evaluating the effect of RMI on strainer head loss.

Nukon insulation. The licensee used a drywell debris transport factor[7] of 0.28 for Nukon insulation debris generated above the lowest grating and 0.78 for that generated below the lowest grating. These transport fractions are consistent with the values suggested in the BWROG URG (Ref. 1). These numbers account for transport of "fine" and "large" debris fragments as a result of air-borne transport during blowdown and erosion during washdown. The NRC staff reviewed and accepted these values for Nukon.

Cal-Sil. The licensee used a transport factor of 1.0 for debris generated from the destruction/erosion of Cal-Sil insulation during the blowdown and washdown phases. This is a very conservative treatment of Cal-Sil debris generation and transport.

Asbestos. The licensee used a drywell debris transport factor of 0.24 for asbestos insulation debris generated above the lowest grating and 0.54 for that generated below the lowest grating. These numbers have not been reviewed by the NRC staff. LANL staff agrees that considerable portion of Asbestos may be captured in the drywell, but the licensee has not made a convincing case as to why they believe up to 75% of asbestos insulation may be captured in the drywell. This is not a very important issue because (a) asbestos is part of the source-term only for breaks postulated at the flued head penetrations, and (b) the licensee demonstrated that limiting break generates and transports significantly larger quantities of fibrous debris.

Drywell debris (other than insulation). For all other postulated drywell debris (e.g., dust and dirt and paint chips), a drywell transport factor of 1.0 was assigned.

The drywell transport factors used by the licensee for Nukon, and drywell debris were obtained based on methods previously reviewed and accepted by the NRC staff. For Cal-Sil the URG does not provide guidance that was approved by the NRC. Therefore, the licensee used a drywell transport factor of 1 and LANL recognizes that the licensee approach is very conservative . For Asbestos also the URG does not provide any guidance. Therefore, the licensee used engineering judgement (without further substantiation). Although LANL disagrees with the licensee engineering judgement, it is inconsequential because (a) this issue is only important for breaks postulated at or in the flued head penetrations, and (b) both LANL and the licensee concluded that head loss impacts of the flued head penetration breaks can be bounded by the limiting break which generates and transports significanty larger quantities of fibrous insulation.

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[7] The drywell transport factor is the ratio of volume of debris transported to the suppression pool to the volume of debris generated. This factor takes into consideration debris size distribution and the location of debris with respect to the lowest grating.

2.3.2 Suppression Pool Transport

The LANL staff comments about the licensee's (or its contractors) treatment of suppression pool transport are substantial and sometimes complex. To facilitate comprehension, the paragraphs below provide a brief overview of the guidance provided in the URG and the staff's position on suppression pool transport. The regulatory overview is followed by a review of licensee analyses/assumptions and LANL comments.

Guidance on Suppression Pool Transport Evaluation.

The suppression pool transport evaluation is an assessment of how much debris in the suppression pool ultimately is transported and deposited on the suction strainers. The BWROG guidance for evaluating suppression pool transport is provided in Sec. 3.2.5.2 with the basis for guidance provided in Sec. 3.2.5.1. In Section 3.2.5 of the URG SER, NRC staff concurred with the BWROG guidance.

High-Energy Phase. The BWROG URG recommends that licensees not take credit for settling of debris in the suppression pool during the high-energy phase, where the pool undergoes chugging and/or condensation oscillations. The BWROG position is based on results of research conducted as part of the NUREG/CR-6224 study, which revealed that intense chugging causes nearly complete mixing of the debris.

ECCS Recirculation Phase. The URG gave the licensee an option to either completely ignore settling of debris in the pool even during the low-energy phase (which is conservative) or to estimate fraction settling using the data and results from Appendix B to NUREG/CR-6224 [Ref. 2]. However, the URG cautioned licensees intending to take credit for gravitational settling that supporting analyses should explicitly evaluate the plant-specific turbulence levels created by the recirculating flows[8]. The BWROG recognized that such plant-specific analyses would be complex and recommended that licensees intending to take credit for settling discuss the approach in detail with the NRC before adopting this. The NRC staff concurred with the BWROG URG position but with a caution that the NUREG/CR-6224 data were obtained for selected insulations and plant conditions. Therefore, the NUREG data should not be generalized for use. The rationale for the NRC staff position is as follows.

- Gravitational settling in the suppression pool is possible after cessation of chugging, but the magnitude of settling is strongly influenced by such phenomena as turbulence and recirculation flow patterns.
- NUREG/CR-6224 did not study settling in the suppression pool mechanistically, instead it relied on engineering judgment (coupled with sensitivity analyses). Such models should not be used without proper justification.

Retention in the Primary System. NUREG/CR-6224 first postulated that a fraction of the debris approaching the ECCS strainer may pass through it and enter the primary system. In the primary system, the debris can settle out (either in entirety or a fraction) at different locations where low flow velocities exist. No models were developed to quantify the fraction that would be retained in the primary system. Instead, NUREG/CR-6224 used parametric analyses to explore importance of this issue. Since then, this issue did not receive much attention either from the BWROG or from the NRC. As a result, neither the BWROG URG nor NRC RG 1.82, Rev.2, provide any guidance on this matter. It was assumed that licensees intending to take credit would perform supporting analyses and discuss them with NRC staff *a priori*.

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[8] Including those induced by operation of ECCS in the suppression pool cooling mode.

Licensee Treatment of Suppression Pool Transport

The licensee reported to have used data and models described in NUREG/CR-6224 [Ref. 2] to model the transport of debris in the suppression pool. The analysts used the following modeling assumptions.

High-Energy Phase. No credit was taken for gravitational settling during the high-energy phase. This was accomplished by artificially setting the turbulence factor to 0.0. This is consistent with the URG guidance.

ECCS Recirculation Phase. The licensee's assumptions on gravitational settling varied depending on the type of insulation.

Nukon Insulation. No credit was taken for gravitational settling of Nukon insulation during this phase. A filtration efficiency of 1.0 was used to estimate the quantity of Nukon insulation accumulating on the strainer. For the limiting break, these assumptions would lead to 18 ft^3 of Nukon insulation deposited over the strainer.

RMI Insulation. No sedimentation calculations were performed for RMI, which is consistent with the saturation thickness method.

Particulate Debris. Significant credit was taken for gravitational settling of debris other than Nukon insulation and RMI. Calculations were performed using the BLOCKAGE 2.5R code [Ref. 3],[9] which requires that information on the settling velocity, turbulence factor, filtration coefficient, and primary system retention factor be provided as input by the analyst.

Settling velocity, also known as the terminal velocity, refers to the velocity at which debris would settle out in a calm pool of water. The licensee estimated terminal velocities using analytical models for several debris types. Table 1 lists the settling velocities used in these analyses. The settling velocities varied from 0.3 ft/s to 0.01 ft/s, depending on the debris type. A settling velocity of 0.3 ft/s for a particular debris type (e.g., rust flakes) would mean that in approximately 30 s, all debris of that type would settle out in a suppression pool about 10 ft high. Therefore, the licensee assumption of settling velocity can influence the outcome significantly.

Turbulence factor is a correlative factor used to account for retardation of settling by turbulence induced by ECCS recirculation. Both the BWROG and the NRC recognized that the flow patterns established by ECCS recirculation would be complex and the resulting turbulence influence on settling would be difficult to quantify. The licensee used a turbulence factor of 0.5 but did not provide any analytical or experimental support for the chosen value. A turbulence factor of 0.5 would simply reduce the settling velocity by half. In the above example, debris would now settle out in 60 s instead of 30 s. In other words, after about 1 min, all rust flakes would have settled, and none would be available for transport to the strainer. Once again, the licensee's assumptions can completely alter the outcome. It is for this reason that the BWROG recommended that licensees intending to take credit for settling should perform supporting analyses.

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[9] BLOCKAGE does not incorporate any values pre-approved by NRC for use; analysts must develop the input and provide support for their assumptions

Filtration coefficient refers to the fraction of the approaching debris type that would be filtered by the strainer (either by itself or as a result of debris bed buildup). A filtration coefficient of 1.0 was used for rust flakes and paint chips. A maximum filtration coefficient of 0.5 was applied for the rest of the debris (e.g., sludge and paint powder). A filtration coefficient of 0.5 would mean that one-half of the debris approaching the strainer would be transported through the strainer.

Retention factor refers to the fraction of debris entering the primary system that would settle out in the primary system. The licensee used a value of 1.0 for this factor. This means all the debris entering the primary system would settle out some where in the primary system. The licensee did not provide a rationale for this assumption nor did they perform any supporting analyses. This is particularly important considering that a Dresden single failure results in significant quantities of the ECCS water completely bypassing the core.

The results of licensee calculation are summarized in Table 1. These values correspond to a Nukon debris loading of 18 ft^3 (which is equal to the volume of Nukon debris estimated to reach the strainer). These analyses effectively suggest that only a quarter of the particulate debris (the fraction is as low as 5% for some of the debris) would be retained on the strainer; the rest will either settle out in the pool or be retained somewhere in the primary system. These results reflect the assumptions made by the licensee regarding pool turbulence level, filtration efficiency, and retention of particulate debris in the primary system.

Table 1
ITS BLOCKAGE 2.5R Simulation Results for Dresden (V_{Nukon} = 18 ft^3)

Debris Type	Settling Velocity (ft/s)	Fraction Settled to the Pool Floor	Fraction Retained in the Primary System	Fraction Deposited on the Strainer
Rust Flakes	0.3	0.877	0.000	0.123
Early Paint Chips	0.3	0.879	0.000	0.121
Late Paint Chips	0.3	0.949	0.000	0.051
Calcium Silicate	0.01	0.451	0.274	0.276
Early Paint Powder	0.01	0.451	0.275	0.275
Late Paint Powder	0.01	0.452	0.184	0.364
Dirt/Dust	0.01	0.450	0.273	0.277
Sludge	NUREG[10]	0.471	0.258	0.272

LANL Comments

[10] Data provided in the NUREG for settling velocities measured in the chugging tank after cessation of chugging

Based on the review, it is LANL's opinion that the licensee analyses do not present a defensible rationale for the methods and data used to model suppression pool transport. This comment is particularly important considering that licensee was able to eliminate significant quantities of insulation and other debris from consideration. Specifically, note the following.

- The licensee did not conduct any analyses to justify the turbulence factor of 0.5 used in their analyses. Sludge concentration measurements conducted by the BWROG and the strainer vendors have shown that very little turbulence was needed to keep the sludge particles in suspension (same is probably true for other particulate debris). If the licensee (or the contractor) has reasons to believe that such high levels of settling are possible, they should have performed either small experiments or analyses to provide the supporting rationale. The licensee's attempt to take credit for gravitational settling without providing supporting analyses is not consistent with either URG or NRC regulatory guidance.

- The licensee used a primary system retention factor of 1.0, which implies that all the debris entering the strainer would settle out (or plate out) somewhere in the primary system. This assumption is nonconservative, especially considering that Dresden single failure (SF-LSL) results in all LPCI pumps bypassing the core altogether and discharging directly into the containment.

LANL undertook a simple review of the existing literature to identify what our estimates would be for the fraction of debris that may be accumulated on the strainer surface. Table 2 compares the LANL estimates for the fraction of debris deposited on the strainer with those of the licensee. Clearly LANL values are conservative, but the conservatism is necessitated by the fact that neither LANL nor the licensee has a good understanding of the level of residual turbulence or its impact on debris suspension.

Table 2
Comparison of LANL and Licensee Estimates for Fraction Deposited on the Strainers

Debris Type	Settling Velocity (ft/s)	ITS Value	LANL Value	Rationale for LANL Selection
Rust Flakes	0.3	0.123	0.25	The strainer circumscribed velocities are 0.6 ft/s. The LANL-estimated suppression pool linear velocities are about 0.2 ft/s. At such low velocities, interpretation of Alden Research Laboratory (ARL) results suggest a low likelihood of paint chips and rust flakes being in suspension, in spite of turbulence.
Paint Chips	0.3	0.121	0.25	Same as above.
Sludge	0.01	0.272	0.70	NRC measurements have shown that 0.5-in.-thick debris would have a cumulative filtration efficiency in the range of 0.7. The likelihood of sludge settling down is very low (URG Testing).
Calcium Silicate	0.01	0.276	0.80	Same as sludge except an efficiency of 0.8 to account for particle size.

Paint Powder	0.01	0.275	0.80	Inorganic zinc (IOZ) Filler. Arbitrarily increased filtration to account for paint powder size.
Dirt/Dust	0.01	0.277	0.80	Same as Cal-Sil above.

In conclusion, the suppression pool transport factors used by the licensee (for debris other than Nukon and RMI) have no justification and as such are not defensible. The methods used by the licensee (or its contractor) are not consistent with the guidance provided in the BWROG URG. In particular, the BWROG URG specifically recommended the utilities to perform plant-specific turbulence evaluations before using BLOCKAGE; the licensee did not perform such an analysis. It is the opinion of the LANL staff that the licensee should reevaluate debris settling and document these analysis if they wish to take credit for gravitational settling in the suppression pool before finalizing the design basis.

2.4. Debris Loading on the Strainer

Table 3 compares the debris loadings used by the licensee for the strainer design basis with the debris loadings independently estimated by LANL and the maximum possible debris loading. The comparison highlights the magnitude of difference between various estimates. LANL head loss estimates were obtained using values listed under column “LANL Value”. It is worthy to note that LANL values are consistently higher than the licensee estimates

Table 3
Comparison of the Debris Loading Used by the Licensee with the LANL Estimates

Debris Type	Plant Value	LANL Value	Max. Value	Comments
Nukon (ft^3)	5 to 48	18.5	18.5	Licensee calculations varied Nukon volume over a wide range. The value of 18.5 ft^3 used by LANL was obtained using independent estimates.
RMI (ft^2)	18, 548 Sat. Thickness	Sat thick (12")	18, 548	Based on the saturation thickness concept. LANL estimates are from the BWROG equation and licensee estimates are from a modified form. Differences have an insignificant effect on head loss.
Calcium Silicate (ft^3)	2.4	6.8	8.5	LANL used total value of Cal-Sil. LANL does not give credit for settling as assumed by ITS.
Asbestos (ft^3)	None	None	14 ft^3	The limiting break postulated by LANL does not generate any asbestos debris. Breaks postulated in the penetrations are not the limiting breaks.
Rust Flakes (lb)	6	12.5	50	The strainer circumscribed short time velocities are 0.6 ft/s. The LANL-estimated suppression pool linear velocities are lower than 0.2 ft/s. At such low velocities, interpretation of Pennsylvanic Power and Light (PP&L)/ARL results suggests a low likelihood of paint chips and rust flakes being in suspension.
Paint Chips (lb)	34 to 140	170 - 700	170-700	The licensee parametrically examined impact of unqualified paints on head loss. LANL also examined it.

Sludge (lb)	100 (226)	259 (583)	370 (833)	In the closed-loop head-loss testing, NRC measurements have shown that 0.5-in.-thick debris would have a cumulative filtration efficiency in the range of 0.7.
Dirt/Dust (lbm)	41	120	150	Same as sludge above.

2.5 Strainer Design Considerations

The NRC and the URG guidance recommends that the licensee should carry out the following steps at a minimum to establish a design basis for the ECCS strainer.

E. Estimate the ECCS operating parameters, such as flow through each strainer following a postulated LOCA. These estimates should consider factors such as the most limiting single failure and the licensing bases previously reviewed and approved by the NRC.

F. Estimate head loss resulting from accumulation of debris on the replacement strainer and size the strainer such that head loss is acceptable as determined by the $NPSH_{Margin}$ calculations.

G. Estimate the $NPSH_{margin}$; which represents the operational margin. These evaluations should take into consideration factors such as the licensing basis (or NRC approved) containment overpressure that can be credited in the NPSH evaluations.

Below is a summary of the analyses performed by the licensee and LANL comments on those analyses.

2.5.1 Licensee Evaluations/Analyses

ECCS Operating Parameters

Dresden Units 2 and 3 have four LPCI pumps, each with design flow of 5000 gal./min and a run-out flow of up to 5800 gal./min, and four LPCS pumps, each with a design flow of 4500 gal./min and a run-out flow of up to 5800 gal./min. All LPCI and LPCS pumps are connected to the ring header with four ECCS strainers (see Fig. 2).

For ring-header plants, the most limiting single failure with regard to the LPCI/LPCS pumps' NPSH is failure of the LPCI LSL (SF-LSL). The worst-case SF-LSL results in all four LPCI pumps injecting into broken loop at a rate of 5150 gal./min. The LPCS pumps alone inject into the core at a rate of 5800 gal./min. Corresponding to this situation, the net flow through the ring header immediately following a LOCA is 32,200 gal./min (vs a design flow rate of 29,000 gal./min). During this time frame ($t_{LOCA} < 600$ s), the pool temperature is estimated to remain at less than 150^oF.

During long-term operation (i.e., after 10 min), the Dresden Units 2 and 3 licensing basis allows the licensee to take credit for operator throttling of the LPCI pumps. The throttled LPCI flow is 2500 gal./min as compared with the design flow of 5000 gal./min. The LPCS pump would not be throttled and continues to operate at its design flow of 4500 gal./min. The licensee calculations indicate that the suppression-pool temperature can reach as high as 170 ^oF.

Figure 2 shows the locations where the ECCS strainers are connected to the ring header. As shown here, four strainers are used to process the inlet flow. The pre NRCB96-03 licensing basis assumes that the strainer closest to the most limiting pump would be lost, and the three remaining strainers would be available. During short-term operation, this results in an estimated flow of 10,733 gal./min through each

strainer following a LOCA and SF-LSL failure and in a flow of 6333 gal./min during long-term. The licensee used these flow rates in the $NPSH_{Margin}$ calculations performed for the pre-NRCB 96-03 strainer/plant configuration.

The licensee analyses/assumptions relative to the ECCS operating parameters appear reasonable. The NRC staff reviewed these ECCS operating parameters and approved them for use in pre-NRCB 96-03 $NPSH_{margin}$ evaluations. The licensee retained the same values.

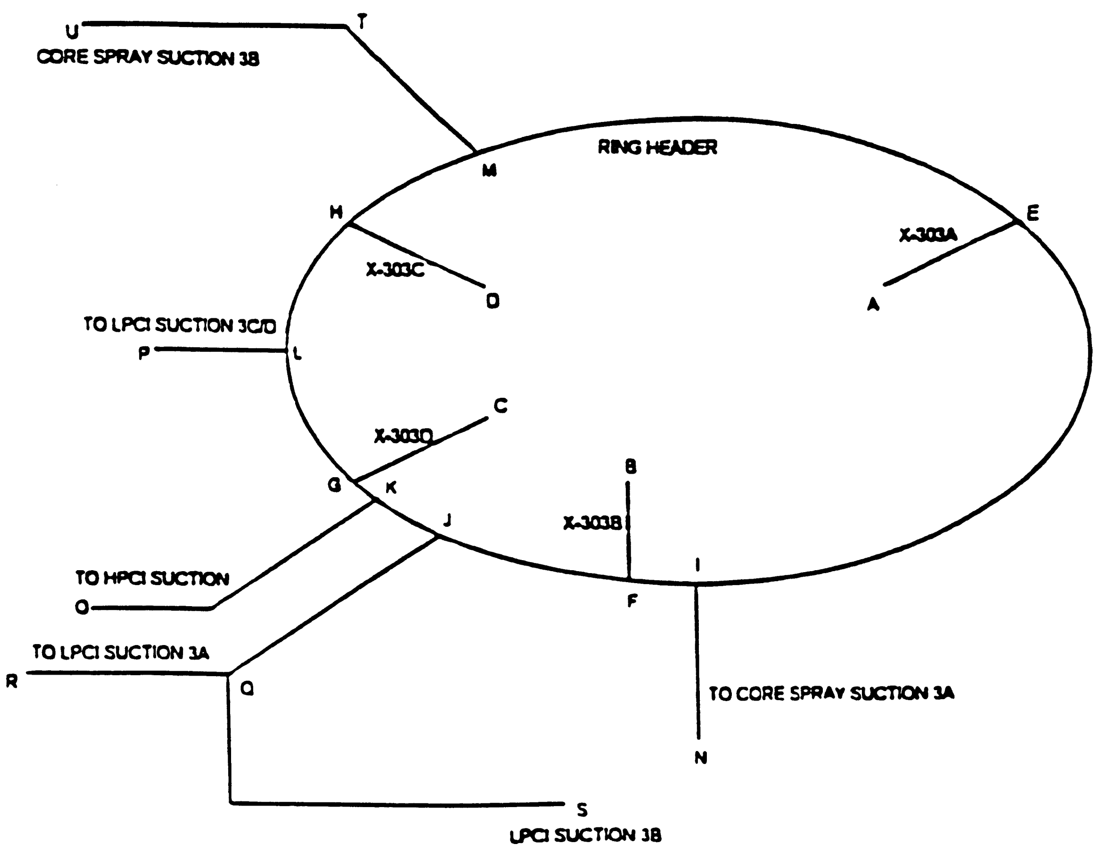


Figure 2. Dresden ECCS Pump and Ring-Header Arrangement. (Ref. Licensee Documents)

Licensee $NPSH_{Margin}$ evaluations

$NPSH_{Margin}$ refers to the difference between $NPSH_{available}$ and $NPSH_{required}$. The $NPSH_{Margin}$ calculation on record corresponds to the pre-NRCB 96-03 plant configuration and pre-NRCB 96-03 licensing basis. In those calculations, the $NPSH_{Margin}$ was estimated using the following equation:

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

where
$P_{wetwell}$ = containment pressure in the wetwell (psia),
P_{vp} = vapor pressure of water at $T_{wetwell}$ (psia),
ρ = density of water at 212°F (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),
$\Delta H_{strainer}$ = frictional losses in the strainer (ft-water), and
$NPSH_{required}$ = NPSH required for pump operation (ft-water).

Table 4 lists the values of various parameters used in the licensee evaluations (Ref. 3). The following assumptions were made by the licensee in the NPSH evaluations.

- $\Delta H_{strainer}$ was calculated based on the old (pre-NRCB 96-03) strainer geometry assuming that one of the strainers would be rendered inactive due to debris plugging. The clean strainer head loss for old strainers was given as 5.8 ft-water at a flow rate of 10,000 gal./min.
- $P_{wetwell}$ was used from the licensing-basis curve (see Figure 3). The Dresden Units 2 and 3 licensing basis allows the licensee to take credit for wetwell pressures in excess of the atmospheric pressure (14.7 psia). The magnitude of over-pressure ($P_{wetwell}$ -P_{atmos}) varies with time as follows: 9.5 psig (22 ft-water) between 0 and 240 s, 2.9 psig (6.8 ft-water) between 240 and 450 s, 1.9 psig (4.5 ft-water) between 450 s to 2.5 h, and 2.5 psig (5.9 ft-water) for time beyond 2.5 h.
- $NPSH_{req}$ was estimated using manufacturer-provided information.
- The ECCS flow rate was assumed to be 32, 200 gal./min during short term and 19, 000 gal./min over long term. These values are consistent with the licensing basis case reviewed and approved by the NRC.

Table 4
Parameters Derived for Dresden NPSH Margin Calculations

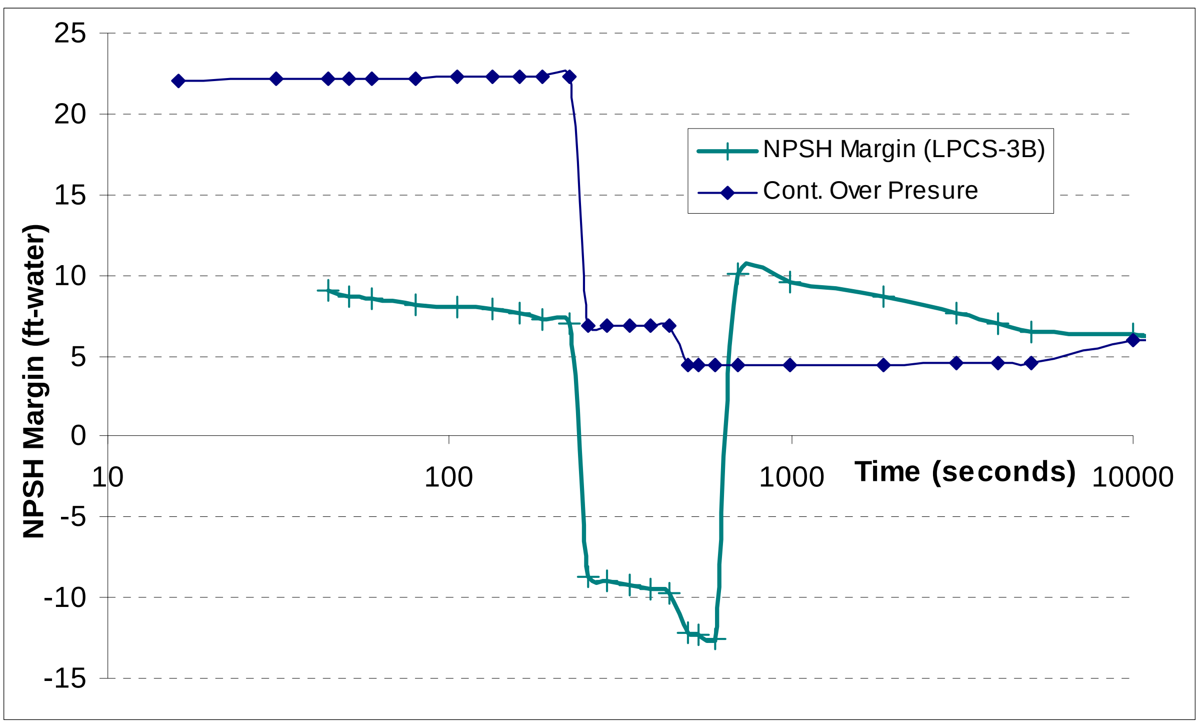
System # pumps	Flow Rate (gal./min)	$NPSH_{req}$ (ft-H_2O)	ΔH_{static} (ft-H_2O)	ΔH_{Line} (ft-H_2O)	$\Delta H_{sstrainer}$ (ft-H_2O)	$NPSH_{Margin}$ (ft-H_2O)	T_{pool} °F
SF-LSL (32,000 gal./min) through three strainers; short-term (at 600 s)							
LPCI (4)	5150	31.5	13.3	11.99	6.68	-6.3	149
LPCS (2)	5800	38.5	13.3	11.22	6.68	-12.5	149
SF-LSL (19,000 gal./min) through three strainers; long-term (at 5000 s)							
LPCI(4)	2500	25	14.4	3.39	2.33	10.9	164
LPCS (2)	4500	27	14.4	5.37	2.33	6.5	164

The LANL staff performed several spot-checks to ensure that the licensee estimates for friction losses in the piping sections are accurate. Based on these calculations, it is our impression that the licensee NPSH evaluations for the pre-NRCB 96-03 configuration are reasonable. The NRR staff reviewed and approved the licensee calculations regarding $NPSH_{margin}$. Figure 3 presents the $NPSH_{margin}$ as approved by the NRC staff for the limiting pump (LPCS-3B). In this report, we refer to that curve as the licensing-basis curve.

The limiting LPCI and LPCS pumps are LPCI-3B and LPCS-3B, respectively, attached to nodes S and U in Fig. 2. For these and possibly other LPCI/LPCS pumps during short-term operation (i.e., before the operator throttles the ECCS), the $NPSH_{margin}$ as calculated by the licensee was less than 0. This negative margin was projected to occur between 4 and 10 min after the LOCA and was calculated to be as high as -12 ft-water. There are two primary reasons for the estimated negative $NPSH_{margin}$.

- The analyses were based on old strainer geometries, which resulted in head losses in excess of 6 ft-water because of flow through a small screen area. The analyses also assumed that only three strainers (connected to nodes A, B, and C) of Fig. 2 are operational, which maximized head loss across the clean strainer as well as head loss caused by piping that connects the strainers to the ring header (i.e., nodes A, B, and C to nodes E, F, and G, respectively)
- The $NPSH_{required}$ values for the LPCI and LPCS pumps are large. This is a characteristic of the pumps in service.

Fig. 3. $NPSH_{margin}$ estimated for LPCS-3B for pre NRCB 96-03 strainer configuration. (These values were reviewed and approved by the NRC staff)



The NRC staff approved operation of Dresden under negative $NPSH_{Margin}$ for a limited time (<10 min) because (a) the Quad Cities and Dresden plants have shown that their ECCS pumps can operate under cavitation for 1 h without significant loss of functionality, and (b) the Dresden EOPs call for pump throttling even at times shorter than 10 min if cavitation effects are observed.

Dresden decided to resolve the ECCS strainer blockage issue by installing large suction strainers. Strainer replacement affects $NPSH_{Margin}$ in three ways.

- *Increased strainer surface area would mean a reduction in clean strainer head losses*. In the case of Dresden Units 2 and 3, this effect is very significant because the strainer surface areas have been increased by 2500%. This means reductions in strainer velocities and in clean-strainer head losses. Estimates for clean-strainer ΔH for replacement strainers is approximately 1.27 ft-water at a flow rate of 8000 gal./min. This value is much lower than the 5.8 ft-water estimated for pre-NRCB 96-03 strainers.

- *Implementation of FME and SPCP programs effects plant licensing basis*. In the past (i.e., pre-NRCB 96-03), the licensee assumed that one of the four strainers is blocked completely, presumably to account for strainer plugging by containment debris as well as foreign materials left behind in the containments. This assumption resulted in increased flow through each operating strainer (to 10,733 gal./min). Such assumptions were used commonly at all the plants as a means for sizing strainers before NRCB 96-03. Because NRCB 96-03 resolution includes stricter controls on the suppression cleanliness (SPCP) and foreign materials left behind in the containments (FME), all plants audited by NRC relaxed this licensing basis assumption. Whether a licensee chooses to relax this assumption is up to an individual utility (Table 5 can be consulted to fully comprehend the impact of this assumption). Relaxation of this assumption and taking credit for the availability of all four strainers would (a) reduce licensing basis flow through each strainer, which would result in lower clean-strainer head loss estimate (b) increase the surface area for debris accumulation that can be used in the NPSH evaluations, which also would result in lower head loss estimate for the fouled strainer, and (c) shorten the distance water has to flow to reach the limiting pump, which would result in lower line loss estimate . In our opinion the licensee made no rational argument for retaining past licensing basis. It is probably more appropriate for the licensees to take credit for availability of all four strainers.

- *Accumulation of debris on strainers may cause overall head loss to go up.* The debris generation and strainer loading calculations are used to estimate the resulting head loss.

No calculations related to how replacement strainers and mechanistic treatment of debris would affect the $NPSH_{margin}$ were presented for review. During the on-site audit, LANL scientists were informed that Dresden did not update the NPSH calculations to reflect NRCB 96-03 resolution and that Dresden intends to retain the “existing licensing basis.” For example, a Dresden representative told us that (1) Dresden would continue to take credit for operation of three strainers only and that (2) head loss impact of debris accumulation on the three operating strainers would still be lower than the head loss calculated for clean pre-NRCB 96-03 strainer. This also is reflected in the checklist prepared by the licensee to facilitate this audit in which flow through each strainer was listed to be 10,733 gal./min during short-term operation and the corresponding head loss was listed as 5.8 ft-water. On the other hand, many of the calculations performed by the contractor (ITS) clearly credited continued operation of all four strainers (which results in full single-failure strainer flow of 8050 gal./min.). The licensee needs to resolve this inconsistency and state the bases for their head- loss estimates.

Based on this review, the following are LANL comments on the licensee $NPSH_{Margin}$ evaluations:

- The calculational approach followed by the licensee to estimate the $NPSH_{Margin}$ is logical and is similar to the procedures adopted by every other plant audited as part of this audit.
- The procedure has two major inconsistencies. The first one relates to the number of strainers credited to be operational in the licensee NPSH evaluations.The licensee stated that Dresden intends to take credit for continued operation of three ECCS strainers, where as the strainer head loss analyses carried out by the contractor (ITS) clearly credited all four strainers being operational. The licensee should resolve this inconsistency and update the NPSH calculations.
- The licensee stated that licensing basis long-term ECCS flow is 19, 000 gal./min. This is also the ECCS flow used in the licensing basis approved by NRC. However, the licensee head loss

calculations are based on a net ECCS flow of 29, 000 gal./min. At these higher ECCS flow rates, the NPSHMargin would be negative even with replacement strainers and no debris deposited on the strainer. NRC did not approve ECCS operation at 29, 000 gal./min, and it is not clear why the licensee proposed to use this higher flow rate in the head loss calculations.

Strainer Design and *Performance Analysis*

Strainer Design Details

Dresden's 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 PCI. The strainers use disks stacked along the length of the strainers to extend the plate area and thus reduce the approach velocity at the plate. The design was tested and demonstrated by PCI at the Electric Power Research Institute (EPRI) facility (Ref. 4). The strainer testing program consisted of clean-strainer head loss measurement.

Four equal-size strainers are connected to the ring header at nodes A, B, C, and D of Fig. 2. Geometric details of an individual strainer are provided in Table 5. Each strainer has a plate surface area of 119 ft^2 and a circumscribed surface area of 48 ft^2, an increase of 2500% and 1000%, respectively, compared with pre- NRCB 96-03 strainers. Table 6 presents combined surface areas and flow parameters as a function of the number of strainers credited to operate following a LOCA. This comparison highlights the importance of licensee assumptions related to the number of strainers assumed to operate following a LOCA.

Table 5
Geometric Details of Replacement ECCS Strainers

Specification	**Value**
Module Length*	54 in.
Outer Diameter*	32.5 in.
Inner Diameter*	24.25 in.
Circumscribed Area**	38.3 ft^2
Circumscribed + Ends Area**	48.0 ft^2
Holding Volume Between**	6.4 ft^3
Surface Area **	119 ft^2

* Dimensions given in the drawings provided during audit.
**Estimated by LANL staff from drawings. Confirmed using ITS/PCI-derived numbers.

The following are deficiencies in the sizing/design criteria.

- *No documented or articulated strainer design criterion.* In the documentation provided by the licensee (and that prepared by the contractors), there was no mention of the design criterion used to size the strainers. In fact, one of the contractor's (ITS) calculation sheet clearly states that there is no acceptance criterion for the strainer. It appears that the strainers were sized based on other factors (perhaps hydrodynamic loads), and analyses were conducted, after the fact to ensure that head losses resulting from debris buildup on the replacement strainers are

"acceptable." During the audit, a representative of the licensee stated that the strainer design criterion is that head losses resulting from debris buildup on the replacement strainers do not exceed the licensee estimate of head loss for an old (pre-NRCB 96-03) clean strainer at the same flow. The licensee has gone through several iterations of replacing fibrous insulation by RMI or other such insulation to ensure that head loss estimates for the replacement strainer. As such, there is nothing wrong with such an iterative approach. The major drawback of the approach appears to be that it resulted in a discontinuity in documentation between the licensing- basis documents provided by the licensee.

Table 6
Geometric Details of Strainer

Specification	Licensing Basis	Actual
Short Term (Unthrottled with SF-LSL)		
Number of Strainers	3	4
Flow Rate (gal./min)	32,200	32,200
Flow Rate per Strainer (gal./min)	10733.	8050
Total Circumscribed Area (ft^2)	115	143
Total Holding Volume (ft^3)	19.2	25.6
Total Surface Area (ft^2)	356	475
Velocity at Screen (ft/s)	0.201	0.151
Circumscribed Velocity(ft/s)*	0.625	0.469
Long Term (Throttled with SF-LSL)		
Flow Rate (gal./min)	19,000	19,000
Velocity at the Plate (ft/s)	0.11	0.089
Circumscribed Velocity (ft/s)*	0.37	0.277

*Circumscribed velocity is calculated using a circumscribed area without the area of the ends as suggested by BWROG URG. This maximizes the velocity and the RMI "saturated bed thickness.'

Strainer Head-Loss Performance Analysis

URG Guidance for RMI and Fiber Beds. As noted in the URG, estimation of head loss across debris bed composed of a mixture of RMI and fibrous debris is somewhat complex. In Appendix K to the URG

SER, the NRC staff stated that head loss resulting from mixed fiber and RMI beds should be (a) based on vendor-provided head-loss data obtained for that strainer design or (b) obtained by adding the contribution of individual constituents (i.e., fiber and RMI contributions). While the URG SER was in the draft form, LaSalle issued a report[11] that provided experimental head loss data for PCI stacked disk strainers loaded with mixed debris beds. LaSalle report concluded that head loss caused by mixed debris beds could not be predicted by simply adding the head loss contribution of individual constituents and that a synergism exists between RMI and fibrous debris that made the mixed beds head loss higher than the sum of individual contributions. After analyzing the LaSalle data, NRC concluded that higher head loss is a reflection of the strainer geometry rather than existence of a synergism. To demonstrate this point, the URG SER guidance was applied to the PCI strainer in a manner that accounted for the difference in the location where fibrous debris might accumulate on the strainer surface when there is no RMI compared to when there are significant quantities of RMI. As supported by the pictorial evidence presented in the LaSalle report, when no RMI is present the fibrous debris would accumulate in the strainer gaps where it would be subjected to flow velocities. When significant quantities of RMI are present, however, the fibrous debris tends to accumulate on the circumscribed surface where it would be subjected to higher flow velocities. Once these differences were accurately accounted for, then, as shown in Appendix-K, the URG SER guidance (that head for mixed RMI and fiber beds can be obtained by adding the contribution of individual constituents) was found to predict LaSalle head loss reasonably well (the agreement was with in the experimental uncertainty). These analyses were presented in the URG SER to further clarify NRC regulatory guidance.

Licensee Head Loss Calculations. The strainer head-loss calculations were performed by ITS under the DES quality assurance program. The licensee did not have experimental data. Therefore, the licensee calculations are based on head-loss methodology developed by the contractors. This methodology recognizes that head loss across Dresden strainer would be caused by buildup of RMI, fibrous and particulate mixed bed on the surface of the replacement strainer. The licensee estimated the total head loss as an algebraic sum of three components: (1) head loss caused by flow through the clean strainer, (2) head loss caused by buildup of fibrous and particulate debris (with out any regard for simultaneous presence of RMI) and (3) head loss caused by buildup of RMI debris to saturation thickness. The licensee (or the contractor) did not provide any experimental data that validated their approach, either in its generic form or in the way it was applied to Dresden. The following paragraphs provide brief description of the licensee evaluations and LANL review comments.

*Clean-strainer head loss***.** The vendor (PCI) provided the head-loss correlation used for estimating clean-strainer head loss. PCI tested a prototype strainer at the EPRI facility. The LANL staff reviewed the PCI data base for the correlation and determined that the clean-strainer head-loss correlation used by the licensee is reasonable.

The licensee (or the vendor) estimated clean strainer head loss assuming a water flow rate of 8,050 gal./min during short term and 7, 250 gal./min during long term. These flow rates correspond to the situation when all four strainers are operational. Further comments on the selection of flow rates used in the head loss analyses are provided below. The calculated head losses for the clean strainers are 1.28 ft-water at a strainer flow rate of 8, 000 gal./min and 1.03 ft-water at 7, 250 gal./min. As expected the clean strainer head losses for the replacement strainer are much smaller than the pre-NRCB 96-03 strainers. A sensitivity analysis was performed to examine the impact of variability in core pipe dimensions on the head loss.

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[11] LaSalle is a ComED plant. The tests were conducted by ITS Corporation. The report was also prepared by ITS Corporation.

Based on the review LANL concluded that clean strainer head loss estimates are reasonable for use in NPSH evaluations.

Head loss resulting from the buildup of fibrous and particulate debris. As previously noted the licensee intended to estimate head loss caused by fibrous and particulate debris without any regard to presence of RMI debris in the bed. To achieve this the licensee used a computer code named HLOSS,[12] which estimates head loss induced by accumulation of fibrous and particulate debris on the strainer surface. 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 methodology using experimental data from (a) pure fiber beds and (b) fiber and sludge beds. Since LANL did not undertake a detailed review of the HLOSS program (and LANL was not presented with validation of HLOSS methodology in conjunction with miscellaneous debris), LANL has reservations about using the HLOSS analytical correlation to estimate head loss resulting from miscellaneous debris in lieu of URG bump-up factors. LANL was only able to verify adequacy of the strainer design using URG bump-up factor.

The licensee used HLOSS to calculate head loss caused by accumulation of non-metallic debris loading on the strainer surface. These estimates were obtained for eight different combinations of fibrous and particulate debris. Table 7 presents each of these combinations. As shown in Table 7, in all the cases analyzed a Nukon debris volume ranging between 6 and 48 ft^3. This volume is less than the total holding volume of all four strainers combined (when accounted for compression). As a result, the calculated head losses are small. LANL reservations about licensee approach are as follows:

1. The licensee used HLOSS methodology in lieu of URG bump-up factors to estimate head los caused by the accumulation of miscellaneous debris.
2. The licensee estimated head loss impact of fibrous debris with out taking into consideration the effect of RMI. Further comments on this issue are provided below.
3. The licensee head loss calculations exhibit little (if any) dependence on the quantity of fibrous debris deposited on the strainer surface after the debris volume exceeds a critical value of about 14 ft3. This finding is inconsistent with any data reviewed so far by LANL scientists. This is most likely a reflection of various assumptions made by the licensee.

Based on the review, LANL concluded that the licensee approach to estimation of fibrous debris contribution towards head loss is not consistent with the guidance provided in the NRC SER. The licensee should account for the fact that RMI would displace some of the fibrous debris (out of the gap on to the circumscribed surface). This would likely result in higher head loss as demonstrated by LaSalle experiments. The URG SER Appendix-K provides more guidance on how the licensee could account for this effect.

Head-loss effect of RMI debris buildup. The 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:

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[12] HLOSS was developed and owned by ITS Corporation. It is a proprietary code and was not reviewed or approved by LANL or NRC staff.

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

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 the URG review. This equation was found to explain all the 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 to calculate RMI ΔH is reasonable considering that the RMI used in Dresden is primarily 2-mil stainless steel, 2.5-mil stainless steel, and 6-mil aluminum.

The calculations suggest that RMI contribution (by itself) is very small. The licensee calculations suggest that head loss impact of RMI accumulation up to saturation thickness is about 1.0 ft-water at a strainer flow rate of 7, 250 gal./min. This is expected because 2-mil SS RMI foils were known to result in modest head losses.

Based on the review LANL concluded that the licensee approach to estimating head loss caused by the RMI debris accumulation on the strainer up to saturation thickness is reasonable.

Net head-loss estimates. The licensee simply assumed that head loss caused by mixed beds is an algebraic 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 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). Specifically, Appendix K reviewed the head loss experimental data from LaSalle (another ComEd plant) and used it to point out the significance of this impact. From this viewpoint, it is our conclusion that the licensee methodology for estimating head loss resulting from the mixed beds does not ensure that the resulting head loss is either bounding or best-estimate.

The licensee did not provide any calculations that explicitly stated (a) the design-basis debris loading on the strainer surface and (b) the resulting head loss across the strainer. Instead, they provided a series of head-loss predictions for various assumed strainer debris loadings. No effort was made to come up with a finalized (or design-basis) head-loss estimate. In the plant data sheet provided to us, the licensee simply stated that the design-basis head loss is 5.8 ft-water at a strainer flow rate of 10,700 gal./min (or a net flow of 32, 200 gal./min). There is no documented licensee calculation in support of that number.

LANL Evaluations/Calculations

Because of the deficiencies stated above, LANL performed independent calculation to verify adequacy of strainers installed at Dresden Units 2 and 3. These calculations were used to draw conclusions regarding adequacy of ECCS strainers installed at Dresden Units 2 and 3.

LANL $NPSH_{Margin}$ evaluations for Clean Replacement Strainers

The $NPSH_{Margin}$ refers to the difference between $NPSH_{Available}$ and $NPSH_{Required}$. LANL calculated $NPSH_{Margin}$ for the clean replacement strainer to examine the effect of the strainer replacement on the $NPSH_{margin}$. Figure 4 presents the estimated $NPSH_{margin}$ for each LPCI/LPCS pump as function of time assuming single failure and replacement strainers. The $NPSH_{margin}$ estimates presented in Fig. 4 are for the case of clean replacement strainers only. They were obtained assuming that all four strainers are operational and there is an ECCS flow of 32,200 gal./min over the first 10 min and 19,000 gal./min after 10 min. These calculations accounted for (a) reduction in head losses caused by replacement strainers, and (b) reduction in frictional line losses due to the assumption that all four strainers are operational.

As evident from Fig. 4, in spite of installing large stacked-disk strainers, the estimated $NPSH_{margin}$ for one of the LPCS pumps (LPCS-3B) is less than 0, and for two other pumps (LPCS-3A and LPCI-3B), the $NPSH_{margin}$ is close to 0. After the operator throttles the ECCS to 19,000 gal./min, the $NPSH_{margin}$ returns to being positive (in excess of 10 ft-water). Therefore, during long-term operation, it appears that up to 10 ft-water $NPSH_{margin}$ exists to accommodate the head loss resulting from debris accumulation. However, during the short term, a very limited margin exists for debris accumulation, and the overall success of LPCS operation depends to a great extent on the operator response to pump cavitation.

LANL Evaluation of Dresden Strainer Performance

The LANL staff performed independent calculations using guidance provided in URG SER Appendix-K. These evaluations differ from the licensee evaluations in the following manner:

1. LANL scientists assumed that a fraction of the fiber would accumulate on the circumscribed surface, where it would be subjected to circumscribed velocities and result in higher head loss. This is the major difference between the LANL analyses and those of ITS. ITS assumed that all the fiber would accumulate in the cavity region and that the RMI would build on the circumscribed surface. The LANL assumption is supported by information provided by LaSalle plant (another ComED Plant) ECCS head loss experiments, and confirmed by other industry groups. In other words, assumptions are not made to simply make the analyses more conservative, rather they have defensible bases.
2. LANL used throttled ECCS flow rates to estimate head loss during long-term operation. This flow rate is 19, 000 gal./min (and per strainers this corresponds to flow rate of 4750 gal./min).
3. LANL assumed that all four strainers are operational.
4. LANL used URG bump-up factors to account for the impact of miscellaneous debris.
5. LANL used debris loadings given in column 3 of Table 3, instead of ITS estimates. LANL estimates for debris loading are larger than ITS estimates.

Under the assumptions stated above, LANL obtained head loss estimates for eight cases described in Table 7. These cases are the same as those analyzed by the licensee. These cases explore the impact of the following parametrics.

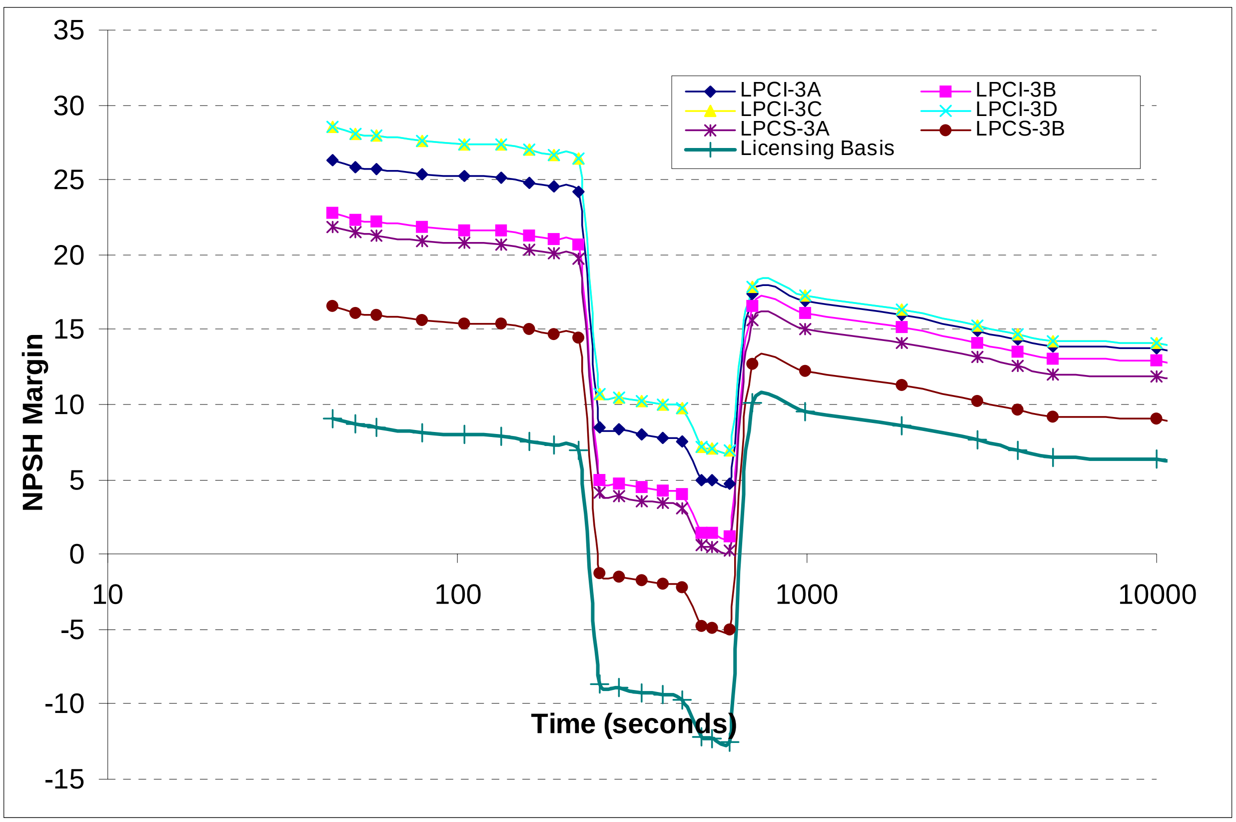
- The licensee estimated that 370 lb of sludge is generated from one cycle of operation, whereas the amount of sludge from two cycles is 833 lb. A series of parametrics were run to explore this impact.
- The licensee also estimated that approximately 500 lb of unqualified paint coatings exist in the drywell, above and beyond the paint debris expected to be generated by a LOCA. A series of parametrics were run to explore this impact.
- The most limiting case is Case #8, which corresponds to Unit 3.

Cases 1 and 3 are the base cases for Units 2 and 3. The difference between these two cases is the quantity of calcium-silicate used in the strainer head loss calculations. These cases are of importance

to this review because the licensee anticipates cleaning the suppression pool after each outage until they have reasonable assurance that continued operation beyond that does not result in a sludge mass in excess of 370 lb. And impact of unqualified coatings is unknown at this time. Cases 2 and 4attempt to bound the impact of unqualified paints, by assuming that they would all fail and transport to the suppression pool. These results are only important if the ongoing program concludes to that effect. Cases 6 through 8 are of some interest in that they can provide some insight into the head-loss margin.

The head loss estimate for each case are provided in Appendix-B. Figure 5 presents the resulting $NPSH_{margin}$ for LPCS-3B corresponding to Cases 1 through 5 described above. Note that LPCS-3B is the most limiting pump (due to the fact line losses in the connecting piping are very large compared to the other pumps). Figure 6 presents $NPSH_{Margin}$ values as a function of time for all the pumps corresponding to Case 1 (Unit-2, Base Case).

Fig. 4. Clean Strainer $NPSH_{margin}$ for all the ECCS Pumps in Dresden Unit 3. Replacement strainers. All four strainers Operational. Based on LANL analyses.



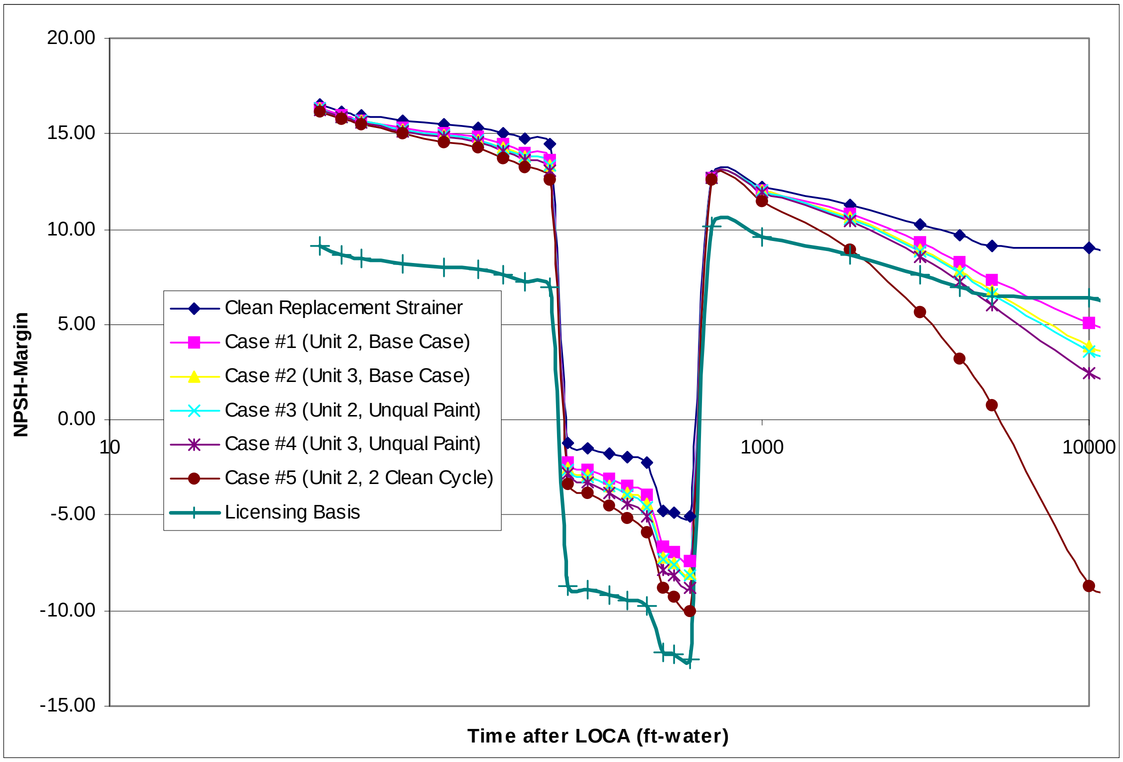


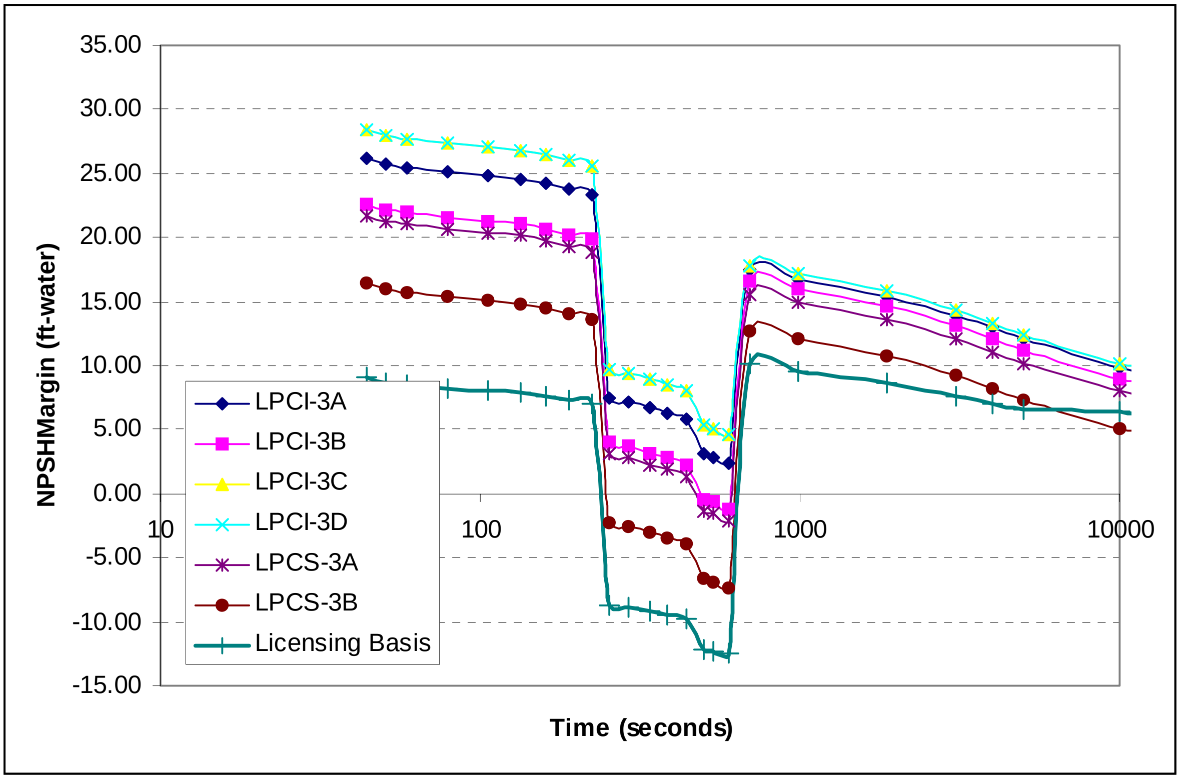
Fig. 5. Fouled Strainer $NPSH_{margin}$ for the Limiting ECCS Pump (LPCS-3B). Replacement Strainers. All four strainers Operational. Based on LANL analyses.

Table 7
List of Various Cases Analyzed to Examine the Adequacy of Dresden Strainers

Case ID	Nukon	Sludge	Paint	Rust	Dust	Cal-Sil
	ft^3	lbm	lbm	lbm	lbm	ft^3
1: Unit 2, Normal Paint, 1 Cycle	18.6	370	170	50	150	0.0
2: Unit 2, Unqual Coats, 1 Cycle	18.6	370	700	50	150	0.0
3: Unit 3, Normal Paint, 1 Cycle	18.6	370	170	50	150	8.5
4: Unit 3, Unqual Coats, 1 Cycle	18.6	370	700	50	150	8.5
5: Unit 2, Normal Paint, 2 Cycle	18.6	833	170	50	150	0.0
6: Unit 2, Unqual Coats, 2 Cycle	18.6	833	700	50	150	0.0
7: Unit 3, Normal Paint, 2 Cycle	18.6	833	170	50	150	8.5
8: Unit 3, Unqual Coats, 2 Cycle	18.6	833	700	50	150	8.5

Based on our calculations, it is our view that the strainers are reasonably sized for debris loadings under Cases 1 through 4. The strainers are not properly sized to handle Cases 5 through 8. However, we recognize that our calculations are associated with several conservative assumptions. These calculations demonstrate that the strainers can handle (1) higher debris loadings estimated by LANL and (3) the impact of differences in head loss methodology. This conclusion, however, is only valid if the licensing basis long-term flow is 19, 000 gal./min. Note that at flow rates higher than 19, 000 gal./min, even the clean strainers would result in negative NPSHMargin; and the debris accumulation makes the case even worse.

Fig. 6. Fouled Strainer $NPSH_{margin}$ for all the ECCS Pumps in Dresden Unit 2, Base Case.



Replacement Strainers. All four strainers Operational. Based on LANL analyses.

DEFICIENCIES AND RECOMMENDATIONS

LANL concerns relate to the lack of clearly defined licensing basis for the replacement strainer at Dresden. Licensee does not have an analysis that answers three questions related to verification of adequate ECCS Pump $NPSH_{Margin}$ accurately: (a) What is the design-basis debris loading on the strainer(s)? (b) What is the head loss caused by debris accumulation on the strainers? and (c) What is the overall effect on the $NPSH_{margin}$? Although numerous analyses were performed, no single document (or series of documents) that comprehensively answered these questions was produced. Specific deficiencies are given below by subject matter.

Debris Loading on the Strainer. The licensee analyses did not provide a rational basis for suppression pool transport of debris. The licensee simply used a value of 0.5 for the turbulence factor to account for the effect of turbulence on debris settling in the pool. This is completely contrary to guidance provided in the URG, as well as NRC staff comments in the URG SER. This issue is particularly important considering that the licensee through these analyses concluded that only a small fraction of debris would actually accumulate on the strainer (and the rest would sediment). Auxiliary to this issue, LANL also disagrees with the licensee assumption that a significant portion of the debris would enter the primary system and be captured in it.

ECCS Operating Parameters. The most important ECCS operating parameter of interest is ECCS flow through each strainer, which is inversely proportional to the number of strainers assumed to be operational following a LOCA. Licensee statements and documents suggest that only three of the four strainers would be operational following a LOCA. On the other hand, the licensee analyses assumed that all four strainers would be operational. This has a significant effect on the estimated head loss. The licensee has not provided any rationale as to why they believe that only three strainers would be operational following a LOCA.

The licensee performed all the head loss calculations assuming a net ECCS flow of 29, 000 gal./min during long-term (i.e., for times greater than 10 minutes after LOCA). The licensee own calculations (as well as LANL independent calculations) clearly show that $NPSH_{Margin}$ at 29, 000 gal./min ECCS flow would be negative, without any regard to debris related concerns (i.e., $NPSH_{Margin}$ would remain negative for clean replacement strainers). During on-site audit, the representative clearly stated that the approved licensing basis assumes throttled ECCS operation at a net flow of 19, 000 gal./min during long-term. The NRC representative also confirmed that the licensing basis for long-term operation is 19, 000 gal./min. Given that, it not clear why the licensee head loss calculations were performed at an ECCS flow rate of 29, 000 gal./min.

Treatment of Head Loss Caused by Particulate Debris. The licensee adapted a new method for predicting head loss caused by particulate and miscellaneous debris in lieu of the BWROG URG bump-up factors[13]. The URG bump-up factors were reviewed by NRC and approved for use. The licensee approach to handling the effect of miscellaneous debris has not been reviewed by the NRC staff. Neither did the licensee present evidence in support of it.

Quantification of the Effect of RMI Debris Accumulation on Mixed-Bed Head Loss. The licensee did not have any experimental data on head loss caused by accumulation of RMI and fibrous debris at the debris loadings of interest to Dresden. Therefore, they relied completely on analytical means.

[13] The NRC staff reviewed the use of bump-up factors and concluded that bump-up factors result in conservative (some times severely conservative) estimates of head loss (NRC SER, Sec. 3.2.6).

Specifically, they estimated the mixed-bed head loss to be an algebraic sum of head loss caused by RMI accumulated on the circumscribed surface and head loss caused by fibrous debris accumulated in the strainer cavity. This approach does not address the possibility that some of the fibrous debris may actually accumulate on the circumscribed surface and that there they would be subjected to higher flow velocities. The approach adopted by the licensee is different from that approved by the NRC staff and discussed in the URG SER (Ref. 1). Please note that in Appendix-K to URG SER, NRC explained how mixed bed head loss data from LaSalle tests (which was obtained by ComED and ITS for debris loadings and strainer geometry typical of Dresden) can be predicted by accounting for the location where fibrous debris is expected to accumulate

$NPSH_{margin}$ Calculations. The licensee ECCS pump $NPSH_{margin}$ calculations for the pre-NRCB 96-03 strainers are logical and defensible. They should be revised because as a result of replacement strainers several factors have changed. Important changes are as follows:

•The long-term ECCS flow rate used in $NPSH_{Margin}$ calculations should be 19, 000 gal./min, not 29, 000 gal./min which was used in the licensee head loss calculations. At 29, 000 GPM the line head losses are such that postive $NPSH_{Margin}$ can not be assured even without any regard to strainer head losses.

•The licensee $NPSH_{Margin}$ should take credit for continued function of all strainers. This assumption was already used in the licensee head loss calculations, but not in the licensee calculations to estimate line head losses. This assumption would have considerable impact on the line loss estimates also.

Treatment of Asbestos. The ITS analyses went through an exhaustive review of the various effects that asbestos (and to some degree Cal-Sil) can have on head loss but finally concluded that because no data are available, they would eliminate it from consideration (or treat Cal-Sil in a more conventional way as a source of particulate debris). This argument is illogical and is not consistent with the URG or the URG SER guidance. If ITS felt that asbestos and Cal-Sil can have very deleterious effect, then they (ITS and the licensee) should have studied it and resolved it. Please note that it falls on the licensee to address plant-specific issue(s) and concerns, including collecting data for which data is not otherwise available.

CONCLUSIONS

It is our view that the Dresden strainer is adequately sized to handle the debris loading expected to reach the strainer following a LOCA. This conclusion was reached based on independent analyses performed by the LANL staff during the on-site audit. The licensee analyses do not model associated phenomena in a consistent manner to lead to that conclusion. The general conclusions are recommendations are as follows:

- LANL believes the strainers for Dresden are adequately size to perform their safety function.
- Inconsistencies such as NPSH calcs not reflecting the new strainers & licensing basis calcs showing one strainer failed while the licensee's contractor is assuming all strainers are operational need to be resolved. Further inconsistencies are presented and discussed in the previous section.
- Dresden's approach is not consistent with the URG or the staff's SER on the URG in two areas: (1) the Dresden suppression pool transport calculations do not follow NRC/URG guidance and (2) the Dresden head loss estimates do not follow NRC/URG guidance. The licensee should resolve these deficiencies.
- The licensee should better document the actual drywell inventory of insulation. At the time of on-site audit much of that information was in the form anecdotal evidence. This could have major impact on assuring that plant debris inventory is within the licensing basis calculation assumptions.

REFERENCES

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3 US Nuclear Regulatory Commission, “BLOCKAGE v2.5, LOCA Induced BWR ECCS Strainer Blockage Analysis Tool,” NUREG/CR-6370 (1996).

4. PCI, Head Loss Calculations for Bare Sure-Flow Suction Strainers at Quad Cities 1, 2 and Dresden 2, 3 Nuclear Units, PCI-NPD-CE01, Performance Contracting, Inc., (1997).