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Operated by Nuclear Management Company, LLC

November 2, 2000
NG-00-1853

Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Mail Station 0-P1-17
Washington, DC 20555-0001

Subject:	Duane Arnold Energy Center Docket No: 50-331 Op. License No: DPR-49 Proprietary Review of NRC Staff Audit of Resolution of Issues Identified in NRC Bulletin 96-03
Reference:	Letter from B. Mozafari (NRC) to M. Sellman (Nuclear Management Company, LLC), dated September 22, 2000
File:	A-100

In the referenced letter, the NRC Staff transmitted their report on an audit of the Duane Arnold Energy Center's (DAEC's) resolution of issues identified in NRC Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors." The report consisted of an NRC memorandum and a Los Alamos National Laboratory report. The Staff requested a review of these documents to identify proprietary information pursuant to 10 CFR 2.790. This review has been completed.

The review identified proprietary information. A copy of the report, with the proprietary information "blacked out" is attached. Affidavits concerning the proprietary nature of this information have previously been provided to the Staff with NEDC-32721P, Application Methodology for General Electric Stacked Disk ECCS [Emergency Core Cooling System] Suction Strainer, Revision 1, dated November 1997, and associated supplements.

Should you have any questions regarding this matter, please contact this office.

Sincerely,

M Mcnell for

Kenneth E. Peveler
Manager, Regulatory Performance

Attachment
cc: B. Mozafari (NRC-NRR) (w/a)
J. Dyer (Region III) (w/a)
NRC Resident Office (w/a)
M. Sellman (w/o)
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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

MEMORANDUM TO: Gary M. Holahan, Director
Division of Systems Safety and Analysis

Thru: John N. Hannon, Chief
Plant Systems Branch
Division of Systems Safety and Analysis

Thru: George T. Hubbard, Chief
Balance of Plant and Containment Systems Section
Plant Systems Branch
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FROM: Robert B. Elliott, Reactor Systems Engineer
Balance of Plant and Containment Systems Section
Plant Systems Branch
Division of Systems Safety and Analysis

SUBJECT: REPORT ON RESULTS OF STAFF AUDIT CONDUCTED ON OCTOBER 4-6, 1999, OF DUANE ARNOLD ENERGY CENTER'S RESOLUTION OF ISSUES IDENTIFIED IN NRC BULLETIN 96-03 (TAC NUMBER MA0704)

On October 4-6,1999, the staff conducted an audit of IES Utilities, (IES, the licensee) resolution for NRC Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris" (NRCB 96-03), for Duane Arnold Energy Center (DAEC). The purpose of the audit was to verify the implementation of NRCB 96-03. Specifically, the staff:

A- assessed the adequacy of the licensee's resolution, and
B- evaluated the need for additional review on a generic basis of licensees resolutions through the NRC inspection program.

1.0 Background

Title 10, Section 50.46 of the *Code of Federal Regulations* (10 CFR 50.46, the ECCS rule) requires that nuclear power plant utilities design their ECCS systems to meet five criteria. Criterion 5 of this rule requires the ECCS to provide long-term cooling capability following a loss-of-coolant accident (LOCA). To meet this criterion, the system should be designed to provide sufficient cooling to maintain the reactor core temperature at an acceptably low value. In addition, the ECCS should continue to remove decay heat for the extended period of time required by the long-lived radioactivity in the core. The ECCS is designed to meet this criterion, assuming the worst case single failure of any piece of equipment or system. However, experience gained from operational events and detailed analyses of BWR designs has demonstrated that excessive buildup of debris from thermal insulation, corrosion products, and

ENCLOSURE 1

other particulates on ECCS pump strainers is likely to occur during a LOCA. This creates the potential for a common-cause failure of the ECCS, which could prevent the ECCS from providing long-term cooling following a LOCA. Based on this information, the NRC decided that BWR licensees should take adequate steps to prevent strainer clogging in order to ensure that the ECCS can perform its safety function during a LOCA.

On May 6, 1996, NRCB 96-03 was issued requesting BWR licensees to implement appropriate procedural measures and plant modifications to minimize the potential for clogging of ECCS suppression pool suction strainers by debris generated during a LOCA. Regulatory Guide 1.82, Revision 2, (RG 1.82) was issued in May 1996 to provide guidance on evaluating plants for compliance with the ECCS rule. On November 20, 1996, the Boiling Water Reactor Owners Group (BWROG) submitted NEDO-32686, "Utility Resolution Guidance for ECCS Suction Strainer Blockage" (also known as the URG) to the NRC for review. The purpose of the URG is to give BWR licensees detailed guidance for complying with the requested actions of NRCB 96-03. The staff approved the URG in a safety evaluation report (SER) dated August 20, 1998. In response to NRCB 96-03, all affected BWR licensees have installed new large-capacity passive strainers to resolve the issue. Licensees have typically concluded that installation of the new strainer designs does not create an unreviewed safety question as defined in Title 10, Section 50.59 of the *Code of Federal Regulations* (10 CFR 50.59). This means that NRC approval of the new strainers is not required. As a result, we have not performed a comprehensive formal review of licensee resolutions for this issue. Therefore, we decided to conduct 4-6 plant audits to verify adequate implementation prior to closing out this generic issue for BWRs. DAEC is the fourth of these audits. Appendix A to this report provides the staff's plan for the conduct of these audits. The audit plan also provides a more detailed description of the background on this issue.

2.0 DISCUSSION

The audit team was a four person team including Robert Elliott and Kerri Kavanagh from the Plant Systems Branch of the NRC's Office of Nuclear Reactor Regulation, and D.V. Rao and Bruce Letellier from the Los Alamos National Laboratory (LANL). The audit covered two areas involving the DAEC's resolution of issues identified in NRCB 96-03. In addition, the audit covered issues identified in NRCB 95-02, "Unexpected Clogging of Residual Heat Removal (RHR) Pump Strainer While Operating in Suppression Pool Cooling Mode," dated October 17, 1995. These three areas are:

A- DAEC's strainer modification documentation and associated 50.59 safety evaluation,

B- DAEC's analyses performed in response to NRCB 96-03, including
  1- strainer performance and design calculations
  2- hydrodynamic load calculations

C- DAEC's suppression pool cleanliness program (NRCB 95-02). While not specifically addressed in the audit plan objectives, suppression pool cleanliness and NRCB 95-02 were included in the audit scope because of the potential adverse impact that foreign debris could have on ECCS strainer operability.

As noted above, Appendix A to this audit report provides our plan for conducting plant audits of NRC Bulletins 96-03 and 95-02. For conciseness, the blank plant data spreadsheets normally attached to the audit plan have been left out of this appendix. Detailed descriptions of LANL's review related to strainer performance, associated confirmatory calculations, and the audit plan plant data spreadsheets filled in with the details of DAEC's strainer designs are provided in LANL's technical evaluation report (TER). LANL's TER is included as Appendix B to this audit report.

At the time of the audit, DAEC had completed the strainer hardware installation. They installed new strainers designed by the General Electric (GE) Company. The new strainers are of a stacked disk design. GE prepared a licensing topical report (LTR) on their strainers which was submitted to the NRC for review. The report is NEDC-32721P, "Application Methodology for GE Stacked Disk ECCS Suction Strainer," Revision 1, dated November 1997. The report received partial approval from the NRC in an SER dated February 3, 1999. This approval was for calculating strainer performance (i.e., the head loss across the strainer with debris on the strainer surface). However, some issues related to the calculation of hydrodynamic loads remain open for GE strainers because the hydrodynamic loads portion of the GE LTR is still undergoing staff review. As a result, these hydrodynamic load issues also remain open for DAEC, and could not be resolved at the time of the audit. When we complete our review of the GE topical report, we will assess the impact on the DAEC design and determine if further followup is required at that time. This review will be accomplished separately from this audit. For the purposes of the audit, we limited our hydrodynamic load review to assessing if DAEC's calculations were consistent with the GE methodology.

The following sections describe the reviews performed at the site and our findings for each area audited.

2.1 The Licensee's Strainer Modification Documentation and Associated Safety Evaluation (10 CFR 50.59)

In order to ensure that the implementation of the strainer resolution did not adversely impact other plant systems in such a way as to create a new or previously unidentified safety concern, we reviewed the licensee's strainer modification package and safety evaluation for the ECCS strainer modification, Modification Number ECP-1588. The documents reviewed included the Safety Evaluations SE-99-012 and SE-98-029, as well as Engineering Specification BECH-MRS-M471. We performed a technical review to ensure that DAEC adequately considered the potential impacts of the strainer modification on plant safety. In addition, we evaluated DAEC's safety evaluation to ensure that the potential impacts of the new strainers on the licensee's accident analyses were adequately considered.

The following provides a brief overview of the main design and operational considerations addressed by DAEC in the implementation of the strainer modification:

- The ECCS configuration for DAEC consists of two trains of low pressure coolant injection (LPCI) and two trains of low pressure core spray (LPCS). Each train of LPCI has two pumps that take suction off a common strainer. Each train of LPCS has one pump that takes suction from its own dedicated strainer.

- The licensee ensured that the basic ECCS functions remained unchanged by the

strainer replacement. For instance, the strainers are designed to screen out objects larger than 0.125 inches in size. This requirement is the same as the old strainers.

- The new strainers were designed to have a maximum head loss equal to or less than the existing net positive suction head (NPSH) margin for the ECCS pumps (14.67 feet of water (ft H_2O) for LPCI with two pumps operating, 8 ft H_2O for LPCI with one pump operating, and 4.48 ft H_2O for LPCS when loaded with debris).

- The strainer specification limits the maximum strainer weight to less than 3000 pounds (lbs).

- All materials, design, fabrication, examination and testing for the ECCS strainers was specified to be in accordance with Section III, Subsection NC, NF, and/or NG of the 1977 edition (including Summer 1977 addenda) of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Regulatory Guide 1.82, Revision 2, and NUREG/CR-6224. The strainers were also designed, fabricated and installed as Seismic Category I, Nuclear Safety Related Equipment. All welds were 100% visually examined in accordance with the ASME Code, Section V. Structural welds requiring liquid penetrant (PT) examination were 100% PT tested in accordance with the ASME Code, Section V using the appropriate acceptance criteria specified in the ASME Code, Section III.

- The strainers were structurally analyzed to withstand the hydrodynamic and inertial loads calculated using the analysis methodologies specified in the Mark I Containment DAEC Plant Unique Analysis Report (PUAR) and Mark I Application Guides.

- The design of the strainers considers the worst case single failure. Different single failures were considered for the LPCI and the LPCS to ensure that each was design for its worst cased debris loading.

Licensee Safety Evaluation of Strainer Modification (10CFR50.59): The licensee conducted two 50.59 evaluations. The first (SE-98-029 for Mod Number ECP-1588, "ECCS Suction Strainer Replacement") was performed before the URG and the GE topical report were reviewed by the staff. DAEC could not complete updating their licensing basis for the strainers because these two documents were still being reviewed by the NRC. So they performed their first safety evaluation for replacing the strainer with a larger stacked disk strainer design while still retaining their existing licensing basis. In this safety evaluation, they concluded that the replacement of the strainers does not constitute an unreviewed safety question because:

1) The strainer replacement does not increase the probability of occurrence of an accident evaluated previously in the Safety Analysis Report (SAR) because the design meets the design, material, and construction standards applicable to the residual heat removal (RHR) system, core spray (CS) system, and suppression chamber. No instrumentation

is affected by the modification, and the modified systems will not be operated outside their design or testing limits. The modification does not affect primary containment integrity or its ability to perform its safety functions. All applicable ASME Code design requirements are met for the strainer modification design to ensure that the primary containment safety function is not inhibited.

2) The modification does not increase the consequences of an accident evaluated previously in the SAR because the new strainer design does not change, degrade or prevent any actions described or assumed in an accident analysis. No assumptions used in the evaluation of radiological consequences in the Updated Final Safety Analysis Report (UFSAR) were changed. The new strainers do not prevent the RHR or CS systems from performing their functions, and their initiation signals, system interfaces, interlocks, and flow rates are also unchanged. The modification does not affect any fission product barrier. The containment's capability to withstand the pressures and temperatures resulting from a postulated accident is unchanged. Structural stresses are all calculated to be within ASME Code allowables.

3) The modification does not increase the probability of a malfunction of equipment important to safety previously evaluated in the SAR. The new strainers perform the same function as the old strainers, but have better head loss characteristics, and they meet or exceed the materials/construction design specifications for the original strainers. The strainer modification does not otherwise affect the operating characteristics of the supported ECCS systems. For instance, no protection feature or support system is adversely affected by the new strainers, and there is no reduction in system or equipment redundancy/independence resulting from the modification. The frequency or severity of system test requirements are not increased by the modification. All seismic and hydrodynamic load requirements are met, and the calculated loads for the containment penetrations and piping system do not exceed ASME Code allowables (with modifications to the penetrations). The strainers, associated penetration attachments, and torus interfaces were designed to current applicable structural loads, including hydrodynamic, seismic, thermal, pressure, and deadweight. Therefore, DAEC concluded that the containment integrity and functional capability are maintained.

4) The modification does not increase the consequences of a malfunction of equipment important to safety previously evaluated in the SAR. The modification does not change the accident response or safety function of any of the systems or components that could be affected by the change (i.e., the RHR system, the CS system, the strainers, and the torus). The new strainers meet or exceed the original design specification for the old strainers for materials and construction, and they have significantly better performance capability with debris. The strainer modification also meets all applicable ASME Code requirements, and as a result, will not adversely impact containment integrity.

5) The modification does not create the possibility of an accident of a different type than any previously evaluated in the SAR. The strainer function is unchanged. The modification only affects the size and surface area. The new strainers are passive with no active components. And for the reasons indicated above, the strainers will not adversely impact primary containment integrity or the containment's ability to perform its safety function.

6) The modification does not create the possibility of a malfunction of equipment important to safety of a different type than any evaluated previously in the SAR. The new strainers do not affect the RHR or CS systems except to increase their overall performance margin. The strainers do not introduce any new failure modes. Equipment is not being relocated and the function and operation of the equipment remains unchanged. All design requirements of the RHR, CS and suppression chamber are met. Since the strainers, their associated penetration attachments, and the torus interfaces are designed to withstand all applicable structural loads (i.e., hydrodynamic, seismic, thermal, pressure, and deadweight), the possibility of containment structural failure is not created.

7) The modification does not reduce the margin of safety as defined in the basis for any Technical Specification (TS). The modification does not change the required actions or surveillance requirements in the TS for the ECCS or the containment. The LPCI and CS flow rates and test frequencies are unchanged. The impact of the strainers on torus water level was reviewed and determined to have a negligible effect. The required minimum water levels for the torus and the condensate storage tank and the frequency of their verification are not changed by the modification. The modification does not change the average suppression pool temperature. The bases for the operability limits and surveillance requirements specified are not affected by the strainer design change. The net impact of the change is an increase in the margin of safety because the new strainers provide acceptable operation with significantly higher debris loadings than the old strainers.

- The second safety evaluation is SE 99-012 dated August 26, 1999. This evaluation was performed to evaluate the revision of the licensing basis for the strainers and ECCS net positive suction head (NPSH) margin. These revisions incorporated updated analyses in the licensing basis based on the new strainers, including analyses for ECCS NPSH margin, containment minimum pressure, debris generation, and strainer head loss, as well as, revisions to the UFSAR and other documentation. In this safety evaluation, they concluded that the licensing basis revision does not constitute an unreviewed safety question because:

1) The revision to the strainer licensing basis does not increase the probability of the occurrence of an accident evaluated previously in the SAR because the licensing basis changes are related to events that happen after a LOCA has already occurred. These changes do not affect or modify operating conditions or initiators previously analyzed in the SAR. The changes are to the containment pressure/temperature analysis, debris generation calculations, debris transport calculations, strainer debris load calculations, strainer performance calculations, and NPSH analysis.

2) The revision to the strainer licensing basis does not increase the consequences of an accident previously evaluated in the SAR because the changes do not alter or degrade

any actions assumed in an accident to mitigate the event. All changes to the design inputs for the modified calculations and analyses are in accordance with methodologies previously approved by the NRC, such as the DAEC TS, the URG, and the GE LTR. No assumptions used in evaluating the radiological consequences of any accident are changed, and no fission product barriers are affected. The revision does not affect LPCI or CS system initiation signals, system interfaces/interlocks, and pump flow rates. The primary containment's ability to withstand temperatures, pressures, or hydrodynamic loads resulting from postulated accidents is unchanged. Suppression pool structural loads were evaluated in accordance with the Mark I program and the suppression pool's original design requirements. The pressure and temperature analysis changes are bounded by the design basis accident LOCA case.

3) The revision to the strainer licensing basis does not increase the probability of a malfunction of equipment important to safety previously evaluated in the SAR. The strainer design assumptions are significantly more conservative than those used in the original SAR analysis. As a result, the ECCS suction strainer hardware will reduce the probability of a malfunction of the ECCS systems due to increased reliability in a post-LOCA environment. The methods used to size the strainer and demonstrate adequate ECCS pump NPSH margin are acceptable because they have been reviewed and approved by the NRC. Reliance on containment pressure to demonstrate adequate NPSH margin for the ECCS pumps has been reduced, increasing the margin of safety.

4) The revision to the strainer licensing basis does not increase the consequences of a malfunction of equipment important to safety previously evaluated in the SAR. The only systems or components that could be affected by the revision are the LPCI and CS systems, the torus and the strainers. The safety functions of these systems/components are unchanged, and their capabilities to perform their safety functions have not been reduced by the revision. As noted above, the methods used to size the strainer and demonstrate adequate ECCS pump NPSH margin are acceptable because they have been reviewed and approved by the NRC.

5) The revision to the strainer licensing basis does not create the possibility of an accident of a different type than was previously evaluated in the SAR. Both the old and new strainers are passive devices that support operation of the LPCI and CS systems. Since they are passive devices, they cannot initiate an accident of a different type than previously analyzed. In addition, the changes made to analyses for debris generation, NPSH margin and containment pressure/temperature were based on existing operating conditions and TS. The operating conditions of the existing systems were not changed from the required design conditions currently listed in the UFSAR.

6) The revision to the strainer licensing basis does not create the possibility of a different type of malfunction of equipment important to safety than was previously evaluated in the SAR. No new failure modes are created since no equipment is being relocated, and system functions and operation are not changed. The new strainers perform the same function as the old, and all design requirements fo the LPCI, CS and the suppression chamber are met. The structural design margins specified in the ASME Code are maintained. As noted above, the methods used to size the strainer and demonstrate adequate ECCS pump NPSH margin are acceptable because they have been reviewed and approved by the NRC. Specific changes to containment pressure/temperature

analysis inputs were evaluated by benchmarking and comparison analysis to ensure the adequacy of the new analysis.

7) The revision to the licensing basis does not reduce the margin of safety as defined in the basis for any TS. The revision does not change the required actions for the conditions specified and the ECCS surveillance requirements are not changed. The LPCI and CS pump flow rates and test frequencies were not changed, and analysis by DAEC demonstrates that the revision does not degrade their capabilities. The required water levels in the suppression pool and condensate storage tank are unchanged as are the requirements for verification of these levels. The revision does not affect average suppression pool temperature.

In performing these safety evaluations, the licensee considered a number of different documents to ensure that they fully captured the potential impacts of the modification in their safety evaluations. For instance, DAEC considered relevant background information provided in various generic communications such as NRCBs 95-02 and 96-03, as well as DAEC's responses to those generic communications. Relevant requirements of the DAEC licensing basis as defined in their UFSAR were considered for the residual heat removal (RHR), LPCI, primary containment, suppression pool, suppression pool cooling, containment spray, CS, and high pressure coolant injection systems. The impact of the strainer modification on these systems under different plant operating modes was considered based on the plant's Nuclear Safety Operational Analysis (NSOA) to ensure that the new strainers did not adversely impact the capabilities of these systems under the various required operating conditions for these systems. The NSOA defines the operating modes or states that these systems are expected to be capable of performing their functions. DAEC also evaluated the requirements for the LPCI, CS, and primary containment specified in the design basis documents (DBDs) for these systems. The DBDs for the LPCI and CS were updated to reflect the new strainer criteria relative to the overall size; however, other criteria such as strainer hole size was maintained to ensure that the new strainers did not adversely impact system performance.

DAEC also performed an evaluation of the HPCI and reactor core isolation cooling (RCIC) systems to determine if there would be a significant safety benefit to installing new strainers for these systems. The results of DAEC's "Risk-informed Evaluation of Torus Suction Strainers for HPCI and RCIC" was transmitted in IES memo NG-99-0443 to the DAEC Project Manager for NRCB 96-03 on March 24, 1999. In this memo, DAEC concluded that there would be negligible safety benefit to installing new strainers on these systems. For a large break LOCA, the LPCI and CS systems would provide core cooling. For medium and small breaks, if clogging of the high pressure system strainers were to occur, the reactor vessel could be depressurized via the safety relief valves (either automatically or manually) so that cooling could be provided by the low pressure systems which have the new improved strainers. They also note that the smaller breaks would generate less debris making it less likely that the strainers would be clogged. They further stated that the "combined core damage frequency (CDF) for large, medium, and small break LOCAs is 4.1% of the CDF for all internal events, and damage cutsets involving torus strainer clogging comprise only 3% of this 4.1%. As such, the contribution to core damage of LOCA induced torus strainer clogging as currently modeled in the DAEC PSA is relatively small." Although not stated in the DAEC evaluation, we noted in reviewing the UFSAR that both the HPCI and RCIC systems preferentially draw suction from the CST before before switching to the suppression pool. For medium and small break LOCAs, this would allow more time for debris to settle before the HPCI or RCIC would switch over to the suppression pool,

thereby further minimizing the potential for clogging the suction strainers for these systems.

Staff Evaluation: We reviewed DAEC's engineering packages described above to determine if DAEC had fully considered the systems potentially affected by the strainer modification. In addition, we evaluated these packages to ensure that DAEC made appropriate engineering, procedural, or documentation changes to ensure that plant safety is adequately maintained during the installation of the new strainers and in normal operation with the new strainers. Based on our review, we concluded that DAEC's engineering package and associated safety evaluation were adequate in scope, evaluating the potential impacts of the strainer replacement. We did not identify any systems or components that would be impacted by the strainer replacement that were not addressed by the licensee. Therefore, we conclude that appropriate steps were taken by DAEC to safely install the new strainers and to ensure that the installation improved overall plant safety.

We also reviewed DAEC's evaluation of the HPCI and RCIC systems to determine if there would be a significant safety benefit to installing new strainers for these systems. We agree with DAEC's conclusion that there would be a negligible safety benefit to upgrading the strainers for these systems.

2.2 Plant-specific Analyses, Strainer Performance and Design Calculations, and Hydrodynamic Loads

Strainer Performance and Design Calculations: We evaluated DAEC's strainer analyses and design calculations through a series of confirmatory calculations. These calculations were performed by LANL. LANL's confirmatory analyses focused on two objectives:

1) Confirm DAEC's estimated debris loadings for the new strainers.
2) Confirm the performance of the strainer design based on the strainer design criteria and DAEC's calculated accident conditions.

These calculations are designed to confirm that the strainers will function as intended during a LOCA. LANL conducted two sets of calculations to achieve these objectives. First, they independently estimated the debris loadings for the strainers using the methods approved by the NRC. Second, they estimated the head loss across the strainers using (a) the debris loadings calculated by DAEC in their analyses, and (b) the debris loadings independently estimated by LANL. LANL's report is included in Appendix B of this report. Their report includes a description of their analyses, their analyses results, and calculation summary tables. LANL's overall

conclusion in their report is that the "DAEC strainer replacement strategy is sound and their analyses provide reasonable assurance that the ECCS strainers are adequately sized to support long-term ECCS operation following a LOCA." LANL further states that any uncertainties in DAEC's analyses are compensated for by conservative assumptions factored into the analysis.

Staff Evaluation: We have reviewed LANL's findings relative to the performance of the DAEC strainer design and agree with their results. The audit's confirmatory analyses demonstrate that the DAEC's strainers are adequately sized. We did not identify any weaknesses in DAEC's analyses and documentation that we believe need to be addressed.

Hydrodynamic Loads: We met with members of the DAEC's staff to discuss their evaluation of the submerged loads on the strainer. In preparation for the audit, we reviewed the GE LTR. Our review of the hydrodynamic loads portion of this topical report was not complete at the time of the DAEC audit. Open issues still remained with the GE LTR on hydrodynamic loads. As such, no conclusions on the adequacy of the hydrodynamic loads on the DAEC's strainer were made during the audit or in this report. The review of the hydrodynamic load portion of the GE LTR is currently still ongoing. We will assess the need to address any open items regarding the adequacy of the DAEC design relative to hydrodynamic loads upon the completion of our review of the LTR.

The data from tests conducted by GE was available at the time of the audit. The detailed methodology of how the submerged structure hydrodynamic masses and acceleration drag volumes were calculated was provided in the GE LTR.

GE provided the values of the hydrodynamic masses and the acceleration drag volumes (ADV) for the GE stacked disk suction strainers installed at Duane Arnold. According to the GE LTR, the procedure for calculating the design acceleration drag volume for the GE strainers consists of:

(1) determining the geometry factor and the hole factor, and
(2) calculating the acceleration drag volume for the crossflow and longitudinal directions.

The geometry factor can be determined using Table 2 in Appendix C of the LTR. Table 2 presents the predictions for the proprietary fast-panel analysis. The GE methodology uses the fast panel analysis to predict the hydrodynamic mass coefficients of three GE stacked disk strainer designs (i.e., three different ratios of diameter to length, referred to as D/L) placed in an inviscid flow field. These results are then used to compare the predicted mass coefficients for solid surfaced cylinders of the same corresponding dimensions. According to the LTR, Table 2 can be used to determine the longitudinal and crossflow geometry factors for any given GE strainer with a specified D/L. However, the fast panel analysis cannot directly model the complex configuration of the stacked disk geometry with perforated plates. As such, a hole reduction factor was required.

The values to be used for the hole factors were provided in Appendix I of the LTR. According to Appendix I, the acceleration drag volume values were determined from the fast panel analysis and the test results of GE's prototype strainer. Since the strainer perforated plate (or

holes) was the only difference between the analytical model and the tested strainer, the ratio of these ADV values represented the hole reduction factor to be applied to the hydrodynamic mass coefficient for the GE strainers. [redacted]

The acceleration drag volume is the volume of the strainer straps added to the product of the geometry factor, hole factor, and the circumscribed cylinder volume of the stacked disk strainer. Based on the procedure described in the GE LTR, GE provided the crossflow and axial direction acceleration drag volumes for the Duane Arnold LPCI and CS system suction strainers. The acceleration drag volumes were then used as an input to the calculation of the submerged structure loads and their effect on the containment penetrations. DAEC documented the their efforts to address the requirements originally defined by NUREG-0661, "Safety Evaluation Report MARK I Containment Long-Term Program Resolution of Generic Technical Activity A-7," for the strainer modification in ECP-1588 and in DDC-3741, "DAEC, Plant Unique Analysis Report, Volume 7 - Residual Heat Removal and Core Spray Strainer Modifications for NRC Bulletin 96-03." We reviewed these documents as part of our audit.

While our main concern was centered on the methodology used to calculate the acceleration drag coefficient (C_m), we were also interested in the value of the standard drag coefficient, C_d. Standard drag is generally considered to be small in comparison with C_m but it can represent about 10 percent of the combined load, C_m and C_d. Similar to C_m, GE felt that it could be demonstrated by analysis and test that the original value of 1.2 for C_d was too conservative for the new strainer application. [redacted]

Although the audit was not focused on the structural aspects of the new strainer design, we were able to obtain a brief summary of the criteria used in the design. As expected, the loads associated with the new strainer design did increase the penetration loads. The increased penetration loads required modifications to the LPCI and CS containment penetrations. The modifications are described in Volume 7 of the DAEC PUAR. With these modifications and the supporting re-analysis, the design was able to meet all ASME code requirements.

Staff Evaluation: The staff performed confirmatory calculations of the acceleration drag volumes and hydrodynamic masses for the Duane Arnold suction strainers. Our calculation followed the procedure described above. Our confirmatory calculations demonstrated that values provided by GE were consistent with the values that would be calculated using procedure in the GE LTR. However, since the review of the GE LTR is not complete, we cannot provide an evaluation of the adequacy of the design acceleration drag volumes and hydrodynamic masses used in the calculation of the submerged structure loads. For the standard drag coefficient, C_d, we believe that the standard drag is not a significant contributor to the overall hydrodynamic load on the strainer. Therefore, we have concluded that the recommended values in the LTR for the standard drag coefficient are reasonable for load recalculation purposes.

2.3 Suppression Pool/Strainer Cleanliness

Consistent with the requested actions of NRCB 95-02, DAEC has established a suppression pool cleaning program to ensure operability of the ECCS and to prevent the design basis for the new strainers from being exceeded. The program consists of a combination of foreign material control procedures and cleaning activities. We reviewed DAEC's suppression pool/strainer cleanliness program to ensure that the program is adequate to maintain ECCS operability during normal operation. Specifically, we interviewed the station personnel regarding the suppression pool cleanliness and reviewed selected procedures and work orders from the program including:

- Surveillance Test Procedure (STP) 3.6.1.1-01, "Suppression Chamber and Drywell Visual Inspection."
- Administrative Control Procedure (ACP) 1408.20, "Foreign Material Control."
- Integrated Plant Operating Instruction (IPOI) 7, "Special Operations."
- Pre-planned Maintenance Action Request (PMAR) 99-0285, dated April 6, 1999.

Foreign Material Control: ACP 1408.20 provides guidelines for implementing foreign material control. As a minimum, foreign material exclusion areas (FMEAs) or system closure shall be required on all work activities requiring foreign material exclusion (FME). Formal accountability of the entry and exit of tools, parts, grinding particles, and other items that could affect the intended operation of a system or component is maintained in FMEAs using material accountability logs (MALs). An FMEA is established when a system closure inspection to verify removal of all foreign material is not feasible. Guidance to the work planner provided in this procedure states that FME control requirements should be defined based on work activity considerations such as the size of the system opening, the potential effects of foreign material on system reliability, the effects of restricting access to the work zone, the ease with which tools dropped into the system can be readily retrieved, the cleanliness of adjacent areas, the potential detrimental effects of work activities in adjacent areas, the potential for introduction of foreign material via the ventilation system, the ease of cleaning and inspecting the system or component upon completion of the work, and the need for quality control inspections. The work planner must also balance the need for FME barriers with ease of retrieval. If an FMEA is implemented, then the following is implemented:

1- A custodian is assigned to control and account for tools and materials, and a MAL is implemented.
2- All personal objects are removed prior to entering the FMEA, or they are taped inside clothing pockets. In addition, badges, dosimetry, and glasses shall be taped or otherwise secured.
3- Lanyards shall be used to ensure the ability to retrieve objects, if dropped.

ACP 1408.20 provides guidance on many other potential methods the work planner can use to control foreign material. Examples include roping off the work area, temporary ventilation filters, temporary coverings for areas where recovery of dropped items would be difficult, cleaning adjacent areas, rescheduling work to avoid overlap with potentially detrimental activities in adjacent work areas, vacuuming the open system or component prior to closure, or flushing the system upon completion of the work.

ACP 1408.20 also describes the responsibilities of the worker and the Custodian. Prior to

beginning work, the worker shall review, understand and adhere to the FME requirements. He shall also inspect the work area for loose tools, parts and materials. If an FMEA is established, he will verify that materials smaller than the planned system opening are formally accounted for or removed from the FMEA. The worker shall perform the work activities in a manner that reduces the possibility of introducing foreign material into the system (e.g., remove foreign material following maintenance, ensure components removed from the field are sealed to prevent foreign material intrusion, prevent metal shavings from entering electrical components, etc.). The worker is also responsible to notify supervision if FME control is lost and to balance the MAL before the system closure inspection is completed. Custodian responsibilities are also defined in ACP 1408.20. The Custodian controls the access to the FMEA and maintains the records for material accountability using the MAL.

The procedure defines the actions necessary when tools, parts or materials are lost. If they cannot be accounted for, a Supervisor is notified promptly and an Action Request initiated. If a loose parts analysis is preferable to physical recovery, the necessary evaluations/actions shall be completed and documented in the AR system prior to the system closure inspection.

The final parts of ACP 1408.20 include system cleanliness classifications and the definitions of the acceptance criteria for cleanliness. Reactor core isolation cooling and ECCS systems are class B. The acceptance criteria states that metal chips, filings, and grindings are unacceptable. Small particles and atmospheric dust that will be removed during flushing is acceptable.

Suppression Pool Cleaning: PMAR 99-0285 establishes a schedule of every other refueling outage for desludging the suppression pool to ensure that sludge quantities are maintained below the analyzed value of 500 lbs.

Suppression pool cleaning is accomplished through the work order system. The suppression pool cleaning is tracked as a Pre-planned Work Order (PWO). These work orders are in the computer with a defined schedule. Prior to the refueling outage, the PWO's are printed out and integrated into the outage work schedule.

Surveillances: STP 3.6.1.1-01 requires visual inspection of the interior and exterior of the suppression chamber, vent lines, vent header and downcomers, and the interior surface of the drywell for evidence of deterioration. This procedure also includes the inspection of the ECCS strainers and the suppression pool coatings. This procedure is primarily structural inspection, but includes an inspection of the ECCS strainers for debris. It provides a comment space in the procedure checklist, but no success criteria. This surveillance is typically performed every outage. The surveillance schedule is not to exceed 24 months.

IPOI2 provides procedures for primary containment entry and closeout, as well as torus closeout. The procedure provides instructions to ensure that the drywell and torus are free of debris although some engineering judgement is allowed in assessing the need to remove materials from the drywell. In cases where the suppression pool has been drained, the strainers are inspected and verified free of debris as part of the torus closeout.

Maintenance Rule: We reviewed IES Maintenance Rule Memorandum NG-98-2021, "Core Spray and RHR Strainer Monitoring." This memorandum provides a discussion on the new ECCS strainers and their relationship to the DAEC Maintenance Rule Program. Specifically, the strainers are included in the licensee's maintenance rule activities because they are captured as an integral component of the ECCS systems to which they are attached. DAEC maintains programs for component-specific predictive maintenance, preventive maintenance, surveillance and inspection activities separate from the Maintenance Rule Program. DAEC's Maintenance Rule Program provides the performance-based mechanism for tracking the effectiveness of these programs in maintaining the reliability and availability of key plant functions. Using their Maintenance Rule Program, DAEC tracks the ability of the Containment Spray, LPCI and CS systems to deliver rated flow. They are tracked both on failure rate and unavailability. If the a strainer related problem caused a failure of these systems, then it would be captured in the reliability and unavailability criteria. The Maintenance Rule Program also captures past unavailability identified at a later date. For instance, if, based on an inspection of the strainers or the torus, the inspector concludes that an ECCS system or train would not have been able to perform its function after a certain period of time, then the past unavailability would be applied to the system/train in the Maintenance Rule database. In addition, DAEC also has a Structure Monitoring Program within their Maintenance Rule program which has performance criteria regarding discovery of structural conditions, which without repair, could reasonably be expected to cause a system/train failure prior to the next scheduled assessment of the structure. The memorandum further notes that the NRC's baseline Maintenance Rule inspection conducted at DAEC in October 1997 concluded that DAEC's program acceptably monitored equipment performance and met the requirements of the Maintenance Rule.

Staff Evaluation: DAEC has implemented a program of suppression pool cleaning every other refueling outage. We conclude that this cleaning interval is appropriate based on the conservative assumptions in DAEC's strainer analysis relative to the amount of sludge in the suppression pool, and on the foreign material controls utilized in the torus and drywell to prevent foreign material from being inadvertently dropped in the suppression pool. Cleaning the suppression pool every other refueling outage means that the torus will be desludged approximately every three to four years. In addition, STP 3.6.1.1-01 requires strainer visual inspections as part of the Primary Containment Leakage Rate Testing Program required visual examinations. As part of this program, the strainers are visually examined and verified free of debris every refueling outage. Inspection of the strainers every outage minimizes the potential for unrecognized buildup of debris on the strainer surface. Similarly, cleaning the suppression pool every other refueling outage ensures that debris buildup in the suppression pool beyond the strainer design basis will not occur. The level of inspection and cleaning performed by DAEC is a conservative approach to ensuring adequate strainer availability; therefore, we conclude that DAEC's cleaning and surveillance intervals are acceptable.

We reviewed several work orders from previous refueling outages involving work in an around the torus. These work orders included activities such as coating inspections, torus cleaning (desludging), and containment leak rate testing. Our review determined that the work orders included appropriate foreign material controls that was consistent with the guidance in ACP 1408.20. For instance, for local leak rate testing of the torus hatch, the torus was declared an FMEA and a MAL was established. A Quality Control (QC) hold point was included for verification of compliance with ACP 1408.20 and the establishment of the MAL. A second QC verification was included for verifying that the MAL was balanced at the conclusion of the work.

Based on our review, we conclude that DAEC's foreign material exclusion procedures provide an appropriate level of protection from foreign material for the ECCS strainers.

We agree with DAEC's assessment that their Maintenance Rule Program would capture ECCS performance problems (both reliability and unavailability) related to the ECCS strainers. The Maintenance Rule performance data should ensure that DAEC would address strainer issues appropriately with their preventative or predictive maintenance programs, as required.

Overall, our review and interviews with Duane Arnold's staff have shown that DAEC has a good focus on maintaining adequate cleanliness in the suppression pool, the drywell, and on the strainer surfaces. We also conclude that they have implemented appropriate programs and procedures to ensure operability of the ECCS strainers and availability of suppression pool water for ECCS injection during a LOCA. Therefore, we conclude that Duane Arnold has adequately addressed the issues raised in NRCB 95-02.

3.0 CONCLUSIONS

As shown by the audit team's confirmatory calculations, we believe that Duane Arnold has adequately designed their ECCS strainers to withstand the high debris loads anticipated during a LOCA. In addition, they have implemented an appropriate inspection program to ensure the operability of the ECCS (relative to strainer and suppression pool cleanliness), and they have also implemented a suppression pool cleanliness program and foreign material control procedures to limit the potential for clogging the ECCS with materials brought into the drywell or wetwell during outage operations. The licensee was well prepared for the audit. All requests for additional information were addressed quickly and efficiently. As a whole, it was a successful site visit.

This audit was seen as the starting point for the closure of hydrodynamic load open issues related to the new strainer installation. However, actual closure cannot be made until we complete our review of the GE LTR. During the exit meeting, we restated that no conclusions on the hydrodynamic loads on the Duane Arnold ECCS strainers will be made at this time. Our major focus of this audit was understanding the application of the GE methodology to the new ECCS strainers. Since our review of the hydrodynamic load portion of the GE LTR is currently still ongoing, we will assess the need to address any open items regarding the adequacy of the DAEC design relative to hydrodynamic loads upon the completion of our LTR review.

APPENDIX A

AUDIT PLAN

Implementation of NRC Bulletin 96-03 Resolutions

Applicability: The staff plans to audit the following sites:

1- Duane Arnold (Mark I, GE Bolt-on, NUKON Fibrous Insulation)
2- Dresden (Mark I, PCI Bolt-on, RMI Insulation)
3- Limerick (Mark II, ABB, NUKON Fibrous Insulation)
4- Grand Gulf (Mark III, Enercon, Calcium Silicate and Kaowool Insulation)

After performing the above audits, the staff will evaluate the need for additional audits. If additional audits are needed, the staff would most likely select from the following plants:

- Susquehanna (Mark II, GE Bolt-on, RMI)
- Fitzpatrick (Mark I, PCI Ring Girder, Various Fibrous Insulations)
- Peach Bottom (Mark I, ABB, NUKON Fibrous Insulation)
- Perry (Mark III, Enercon, NUKON Fibrous Insulations)

The choice of any additional plants to be audited will be assessed by the staff based on findings from the initial four audits. If the initial audits identify any safety issues, then additional sites may be selected to determine if the issues are vendor-specific, plant-specific, or generic in nature.

Objective: To verify the implementation of NRC Bulletin 96-03 (NRCB 96-03), "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris." Specifically, the staff will:

1) assess the adequacy of licensee resolutions,
2) identify if additional evaluation of licensee resolutions through the NRC inspection program is necessary, and
3) if additional inspection effort is needed, identify areas to be inspected and guidance needed to support inspection effort (i.e., a Temporary Instruction).

Background: On July 28, 1992, an event occurred at Barsebäck Unit 2, a Swedish boiling-water reactor (BWR), which involved the plugging of two containment vessel spray system (CVSS) suction strainers. The strainers were plugged by mineral wool insulation that had been dislodged by steam from a pilot-operated relief valve that spuriously opened while the reactor was at 435 psig. Two of the three strainers on the suction side of the CVSS pumps that were in service became partially plugged with mineral wool. Following an indication of high differential pressure across both suction strainers 70 minutes into the event, the operators shut down the CVSS pumps and backflushed the strainers. The Barsebäck event demonstrated that the potential exists for a pipe break to generate insulation debris and transport a sufficient amount of the debris to the suppression pool to clog the ECCS strainers.

Similarly, on January 16 and April 14, 1993, two events involving the clogging of emergency

core cooling system (ECCS) strainers occurred at the Perry Nuclear Power Plant, a domestic BWR. In the first Perry event, the suction strainers for the residual heat removal (RHR) pumps became clogged by debris in the suppression pool. The second Perry event involved the deposition of filter fibers on these strainers. The debris consisted of glass fibers from temporary drywell cooling unit filters that had been inadvertently dropped into the suppression pool, and corrosion products that had been filtered from the pool by the glass fibers which accumulated on the surfaces of the strainers. The Perry events demonstrated the deleterious effects on strainer pressure drop caused by the filtering of suppression pool particulates (corrosion products or "sludge") by fibrous materials adhering to the ECCS strainer surfaces. This sludge is typically present in varying quantities in domestic BWRs, since it is generated during normal operation. The amount of sludge present in the pool depends on the frequency of pool cleaning/desludging conducted by the licensee.

On September 11, 1995, Limerick Unit 1 was being operated at 100-percent power when control room personnel observed alarms and other indications that one safety relief valve (SRV) was open. The licensee implemented emergency procedures. Attempts by the reactor operators to close the valve were unsuccessful, and a manual reactor scram was initiated. Prior to the opening of the SRV, the licensee had been running the "A" loop of suppression pool cooling to remove heat being released into the pool by leaking SRVs. Shortly after the manual scram, and with the SRV still open, the "B" loop of suppression pool cooling was started. The reactor operators continued their attempts to close the SRV and reduce the cooldown rate of the reactor vessel. Approximately 30 minutes later, operators observed fluctuating motor current and flow on the "A" loop of suppression pool cooling. Cavitation was believed to be the cause, and the loop was secured. After it was checked, the "A" pump was successfully restarted and no further problems were observed. After the cooldown following the blowdown event, the licensee sent a diver into the Unit 1 suppression pool to inspect the condition of the strainers and the general cleanliness of the pool. The diver found that both suction strainers in the "A" loop of suppression pool cooling were found to be almost entirely covered with a thin "mat" of material, consisting mostly of fibers and sludge. The "B" loop suction strainers had a similar covering, but less of it. Analysis showed that the sludge primarily consisted of iron oxides and the fibers were polymeric in nature. The source of the fibers was not positively identified, but the licensee has determined that the fibers did not originate within the suppression pool, and contained no trace of either fiberglass or asbestos. This event at Limerick demonstrated the need to ensure adequate suppression pool cleanliness. In addition, it re-emphasized that materials other than fibrous insulation could clog strainers.

In response to the Limerick event, the staff issued NRCB 95-02, "Unexpected Clogging of Residual Heat Removal (RHR) Pump Strainer While Operating in Suppression Pool Cooling Mode," on October 17, 1995. The bulletin requested that licensees (1) assess the operability of their ECCS on the basis of the cleanliness of their suppression pool and ECCS strainers, (2) verify the operability of the ECCS through an appropriate pump test and strainer inspection within 120 days from the date of the bulletin, (3) establish a pool cleaning program, (4) review their foreign material exclusion (FME) practices and correct any identified weaknesses, and (5) implement any additional appropriate measures for ensuring the availability of the ECCS.

Title 10, Section 50.46 of the *Code of Federal Regulations* (10 CFR 50.46) requires that licensees design their ECCS systems to meet five criteria, one of which is to provide long-term cooling capability following a successful system initiation for a sufficient duration so that the core temperature is maintained at an acceptably low value and decay heat is removed for the extended period of time required by the long-lived radioactivity remaining in the core. The ECCS is designed to meet this criterion, assuming the worst single failure. However, experience gained from operating events and detailed analyses has demonstrated that excessive buildup of debris from thermal insulation, corrosion products, and other particulates on ECCS pump strainers is highly likely to occur. This creates the potential for a common-cause failure of the ECCS, which could prevent the ECCS from providing long-term cooling following a LOCA. The staff has concluded, therefore, that licensees must take adequate steps to prevent strainer clogging in order to ensure compliance with the regulations.

As a result, NRCB 96-03 was issued on May 6, 1996, requesting BWR licensees to implement appropriate procedural measures and plant modifications to minimize the potential for clogging of ECCS suppression pool suction strainers by debris generated during a LOCA. Regulatory Guide 1.82, Revision 2, (RG 1.82) was issued in May 1996 to provide non-prescriptive guidance on performing plant-specific analyses to evaluate compliance with 10CFR50.46. On November 20, 1996, the Boiling Water Reactor Owners Group (BWROG) submitted NEDO-32686, "Utility Resolution Guidance for ECCS Suction Strainer Blockage" (also known as the URG) to the staff for review. The purpose of the URG is to give boiling-water reactor (BWR) licensees guidance for complying with the requested actions of NRCB 96-03. The staff approved the URG in an safety evaluation report (SER) dated August 20, 1998. In response to NRCB 96-03, all affected BWR licensees have installed (or will install during their next refueling outage) new large-capacity passive strainers to resolve the issue. These installations have typically been conducted under 10CFR50.59 with the licensees concluding that no unreviewed safety question exists due to the installation of the new strainer designs. As a result, no detailed review of licensee resolutions for this issue has been performed by the staff. Therefore, the staff will conduct 4-6 plant audits to verify implementation prior to closing out the generic issue for BWRs.

Audit Requirements: The following analyses and programs will be included in the audit scope:

1) the licensee's 50.59 safety evaluation,
2) the licensee's plant-specific analyses performed in response to NRCB 96-03,
3) the licensee's strainer performance and design calculations, and
4) the licensee's ongoing suppression pool cleanliness program (NRCB 95-02).

Audit Guidance

1) Licensee's 50.59 safety evaluation

   Purpose: to perform a technical review to ensure that implementation of the strainer resolution did not create new safety concerns (e.g., hydrodynamic loads), as well as to ensure that the licensee's safety evaluation is sufficiently comprehensive to ensure that no additional safety concerns were caused by the strainer resolution.

Specifically, the auditor will review the licensee's 10CFR50.59 safety evaluation performed in response to its NRCB 96-03 resolution to assess the:

- affect of any changes to strainer hydrodynamic load calculations on plant safety
- affect of the increased strainer size (and associated supporting structure) on suppression pool inventory/accident analyses
- adequacy of scope of resolution (e.g., is change only required to low pressure ECCS pumps)
- potential for new failures not previously evaluated being created by the resolution
- potential for an increase in the probability of a failure previously evaluated

The staff will perform a technical review of the 10CFR50.59 safety evaluation to confirm that the licensee's resolution adequately addressed the potential impacts of the new strainer design on plant safety.

2) Plant-specific analyses performed in response to NRCB 96-03

Purpose: Evaluate plant-specific application of the URG in plant analyses to determine if the calculated strainer debris loadings are appropriate.

Specifically, the auditor will review the licensee's plant-specific strainer analyses:

- to assess the overall application of the URG to the plant
- to confirm consistent interpretation of the URG and the staff's SER
- to evaluate licensee analyses of areas where the URG did not provide detailed guidance (e.g., evaluation of debris generation and transport inside the bio-shield wall)

Limited confirmatory calculations will be performed, as necessary, to confirm consistency in the application of the URG methodologies.

3) Strainer performance and design calculations

Purpose: To confirm that the strainer has been adequately designed and constructed to meet its safety function.

Specifically, the auditor will review the licensee's strainer design calculations to confirm:

- the adequacy of the licensee's basis for determining their strainer head loss
- the adequacy of the licensee's basis for calculation of their NPSH margin
- the adequacy of the strainer structural design and construction (e.g., ASME code requirements)

In addition, the auditor will compare calculated clean strainer head losses with results of post-implementation testing performed by the licensee.

4) Ongoing suppression pool cleanliness program (NRCB 95-02)

Purpose: To confirm that the licensee's program to ensure appropriate levels of suppression pool and ECCS suction strainer cleanliness is adequate to ensure operability of the ECCS.

Specifically, the auditor will review the licensee's suppression pool cleanliness program to confirm:

- the licensee has established an adequate suppression pool cleaning program including:
  1) procedures to evaluate pool cleanliness
  2) criteria for cleaning pool/strainers
  3) frequency of pool evaluation and cleaning
  4) basis for cleaning frequency and criteria
- the licensee has established adequate administrative controls on the program (e.g., included in the plant maintenance program)

The appendices to this audit plan (not included herein) provide spreadsheets detailing the specific information which will be evaluated by the auditors. The auditors will review plant drawings, calculations, strainer specification and other design documentation, as appropriate. The licensee's documentation will be used to fill in the attached spreadsheets. Confirmatory calculations will be performed by the team as shown on the spreadsheets. The completed spreadsheets will be included in the trip report for each plant.

Reporting Requirements: The results of this audit will be documented in a routine trip report. The trip report will be addressed to the Director, Division of Systems Safety and Analysis, NRR (mail stop O-8E2). A copy of the trip report will be forwarded to the Project Manager for the audited plant. A summary report of the staff's findings on all the audits will be published following completion of the audits.

Completion Schedule: These audits should be completed by May 31, 1999.

Contact: Questions regarding this audit plan should be directed to Rob Elliott at 301-415-1397.

Statistical Data Reporting: Hours expended for this audit, including preparation time, should be reported under TAC number MA0704.

Originating Organization Information

Organization Responsibility: This audit plan was initiated by the Containment Systems and Severe Accident Branch (SCSB).

Resource Estimate: It is estimated that each audit will require approximately 240 hours per audit (120 hours per auditor, with two NRR representatives on each audit). The staff estimates approximately 40 hours at each audit site.

Other: It is anticipated that each audit team will consist of two members of SCSB and two contractor personnel.

Training: No specific training is associated with this audit.

References:

NRC Bulletin 93-02, "Debris Plugging of Emergency Core cooling Suction Strainers," dated May 11, 1993.

NRC Bulletin 93-02, Supplement 1, "Debris Plugging of Emergency Core cooling Suction Strainers," dated February 18, 1994.

NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," dated October 1995.

NRC Bulletin 95-02, "Unexpected Clogging of Residual Heat Removal (RHR) Pump Strainer While Operating in Suppression Pool Cooling Mode," dated October 17, 1995.

NRC Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors," dated May 6, 1996.

Regulatory Guide 1.82, Revision 2, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," dated May 1996.

GL 97-04, "Assurance of Sufficient Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal Pumps," dated October 7, 1997.

APPENDIX B

Los Alamos

Technical Evaluation Report

LA-CP-99-346

ON-SITE AUDIT OF DUANE ARNOLD ENERGY CENTER'S EMERGENCY CORE COOLING SYSTEM STRAINER BLOCKAGE RESOLUTION

Based on our review, we conclude that DAEC's foreign material exclusion procedures provide an appropriate level of protection from foreign material for the ECCS strainers.

We agree with DAEC's assessment that their Maintenance Rule Program would capture ECCS performance problems (both reliability and unavailability) related to the ECCS strainers. The Maintenance Rule performance data should ensure that DAEC would address strainer issues appropriately with their preventative or predictive maintenance programs, as required.

Overall, our review and interviews with Duane Arnold's staff have shown that DAEC has a good focus on maintaining adequate cleanliness in the suppression pool, the drywell, and on the strainer surfaces. We also conclude that they have implemented appropriate programs and procedures to ensure operability of the ECCS strainers and availability of suppression pool water for ECCS injection during a LOCA. Therefore, we conclude that Duane Arnold has adequately addressed the issues raised in NRCB 95-02.

3.0 CONCLUSIONS

As shown by the audit team's confirmatory calculations, we believe that Duane Arnold has adequately designed their ECCS strainers to withstand the high debris loads anticipated during a LOCA. In addition, they have implemented an appropriate inspection program to ensure the operability of the ECCS (relative to strainer and suppression pool cleanliness), and they have also implemented a suppression pool cleanliness program and foreign material control procedures to limit the potential for clogging the ECCS with materials brought into the drywell or wetwell during outage operations. The licensee was well prepared for the audit. All requests for additional information were addressed quickly and efficiently. As a whole, it was a successful site visit.

This audit was seen as the starting point for the closure of hydrodynamic load open issues related to the new strainer installation. However, actual closure cannot be made until we complete our review of the GE LTR. During the exit meeting, we restated that no conclusions on the hydrodynamic loads on the Duane Arnold ECCS strainers will be made at this time. Our major focus of this audit was understanding the application of the GE methodology to the new ECCS strainers. Since our review of the hydrodynamic load portion of the GE LTR is currently still ongoing, we will assess the need to address any open items regarding the adequacy of the DAEC design relative to hydrodynamic loads upon the completion of our LTR review.

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LOS ALAMOS TECHNICAL EVALUATION REPORT

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

by

D. V. Rao and B. Letellier
Probabilistic Risk and Hazard Analysis Group
Technology and Safety Assessment Division
Los Alamos National Laboratory

December 1999

THIS REPORT CONTAINS INFORMATION THAT IS PROPRIETORY TO THE DUANE ARNOLD ENERGY CENTER.

ENCLOSURE 2

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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

PROPRIETARY

LOS ALAMOS TECHNICAL EVALUATION REPORT

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

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[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.

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 202°F 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.

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 instrument piping penetrations

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.

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., $R_{ZOI} + 10.4 \times D_{RCA} = 17.11$ 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 on the periphery of the ZOI (i.e., only a small part is actually in 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.

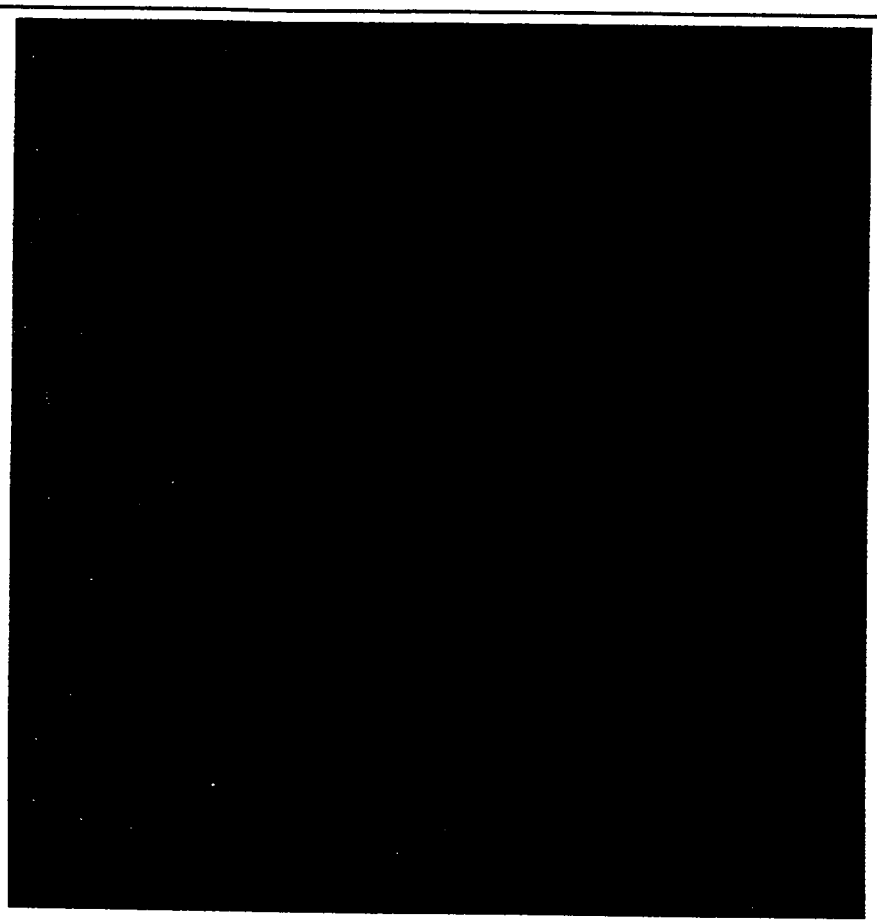

Fig. 1. Plan view of ZOI (magenta) superimposed on affected piping systems (yellow) within the drywell (red).

Note: Piping layout and insulation information was obtained from the piping and instrumentation drawings provided by the licensee.

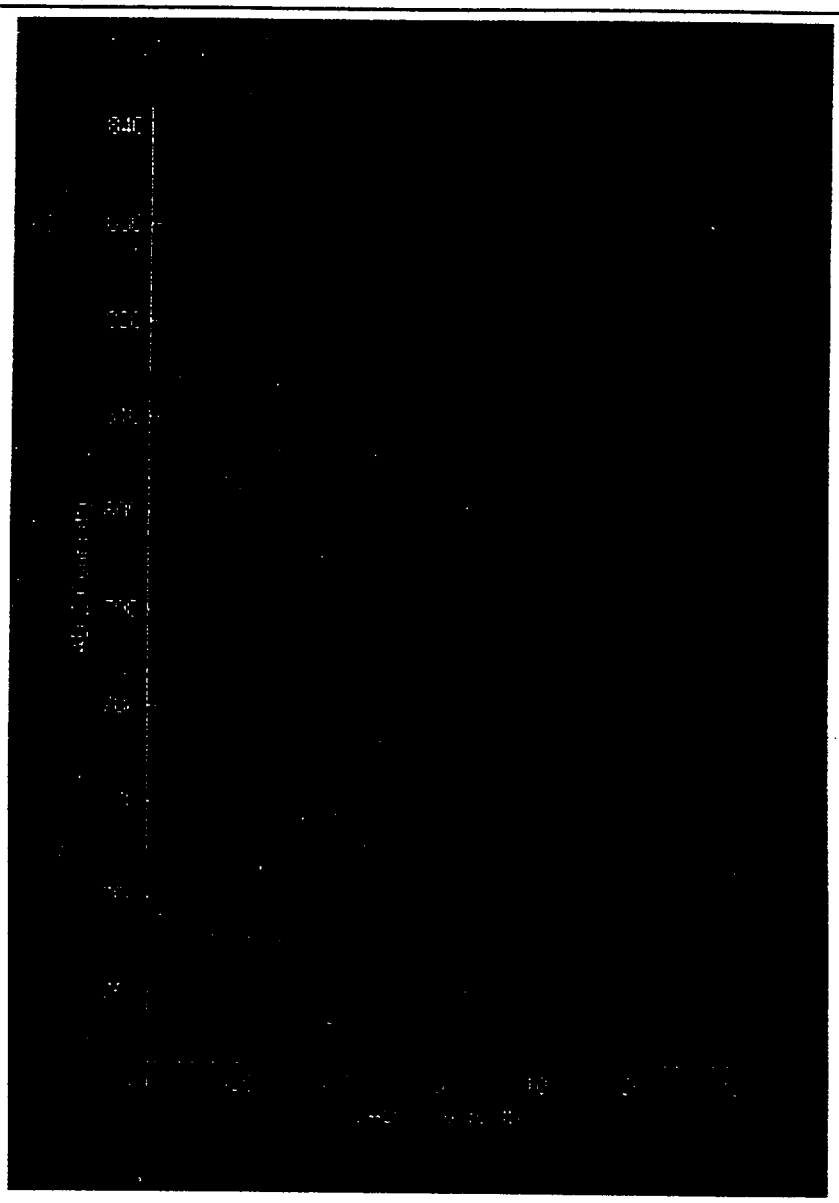

Fig. 2. Elevation view of ZOI (magenta) superimposed on major piping systems (yellow) within the drywell (red).

Note: Piping layout and insulation information was obtained from the piping and instrumentation drawings provided by the licensee.

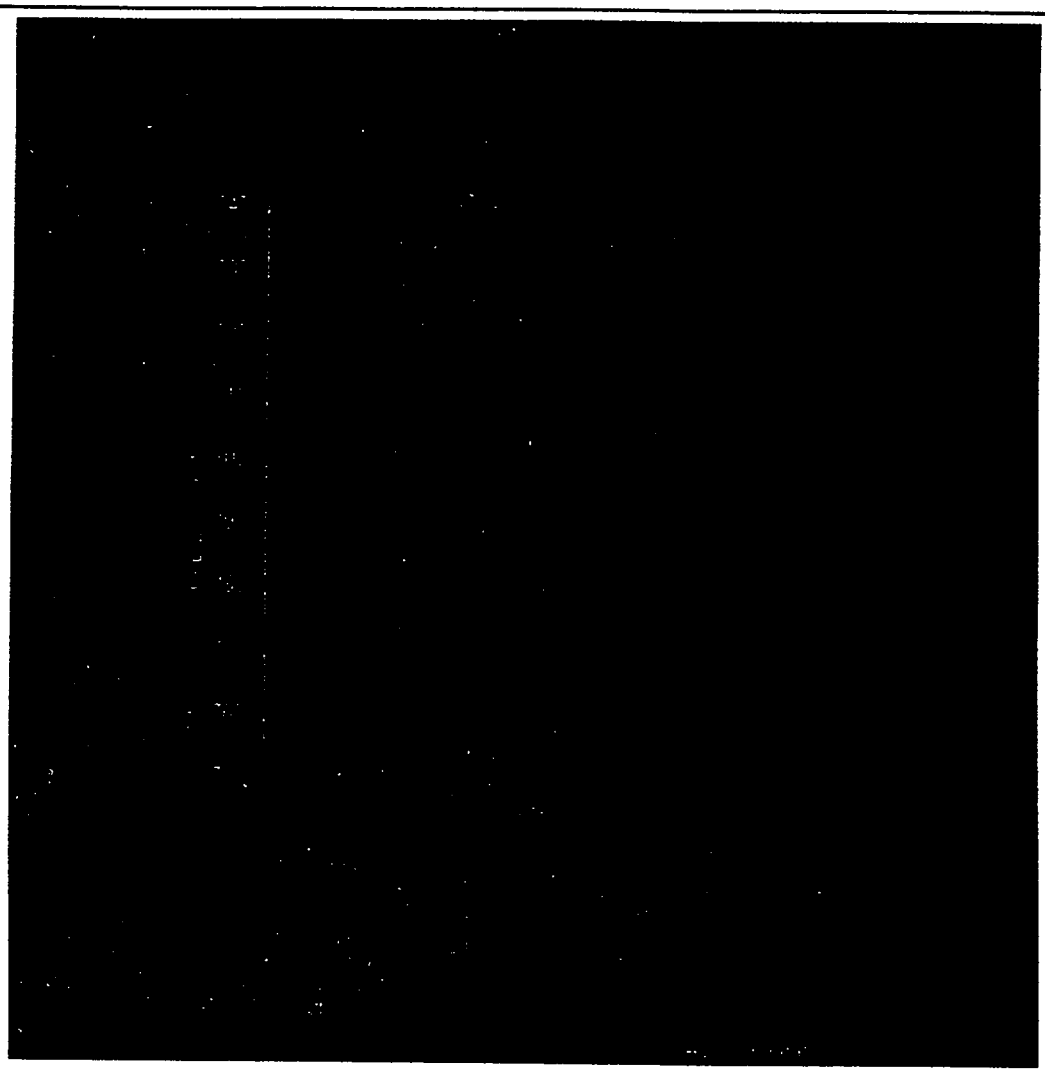

Fig. 3. Perspective view of ZOI (magenta) superimposed on major piping systems (yellow) within the drywell (red).

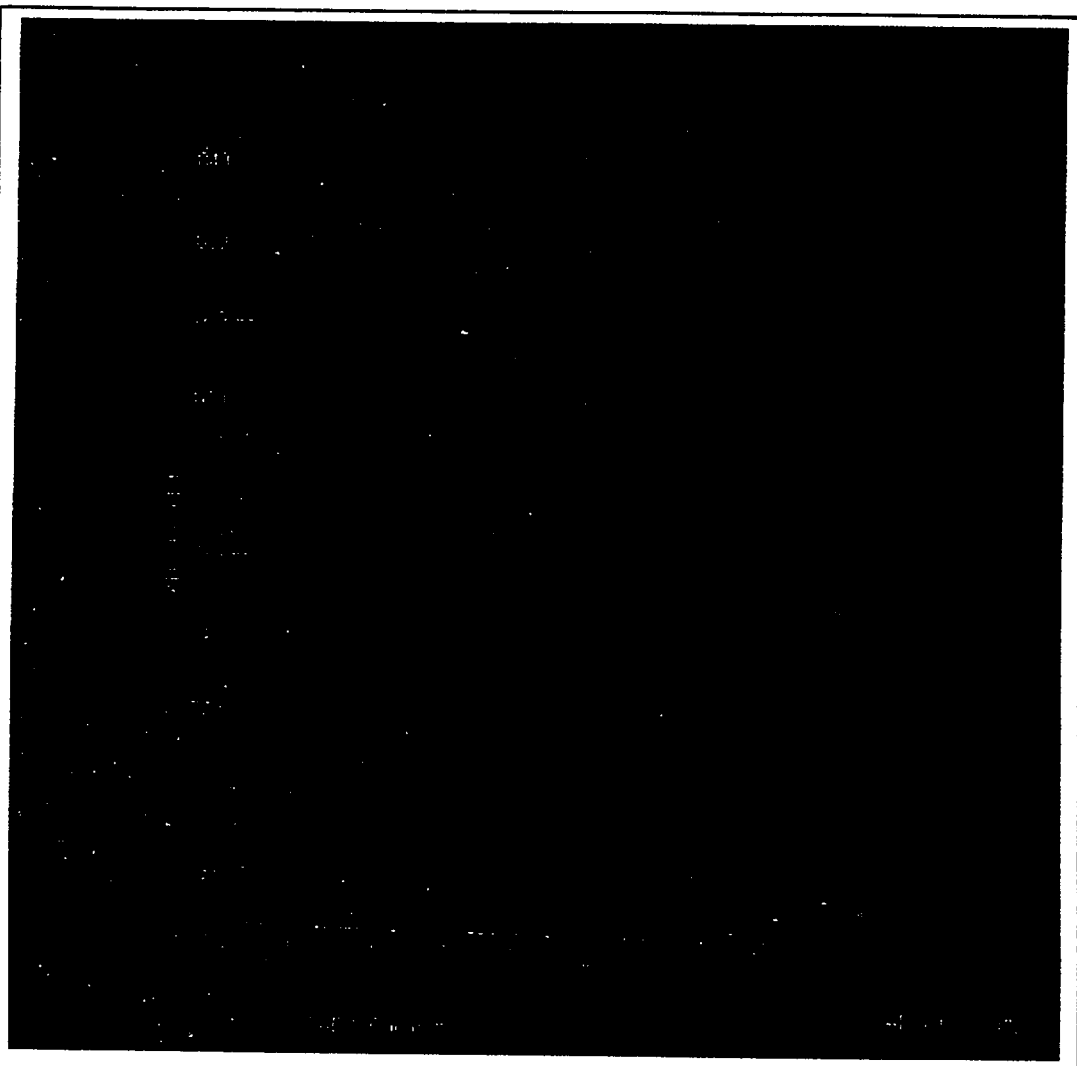

Fig. 4. Perspective view of ZOI (magenta) superimposed on major piping systems (yellow) within the drywell (red).

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

Figure 5 is a picture of calcium silicate/asbestos insulation used in the drywell piping penetrations. Each penetration contains less than 14 ft^3 of cal-sil/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 penetrations and (b) the net head loss effect of such debris is well bounded by the limiting break that was estimated 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. The cal-sil is incapsulated and is not subject to containment spray water. Therefore, 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 quantity of lead wool insulation per penetration is less than 10 ft^3 (see Fig. 6). 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 licensee's assumptions.

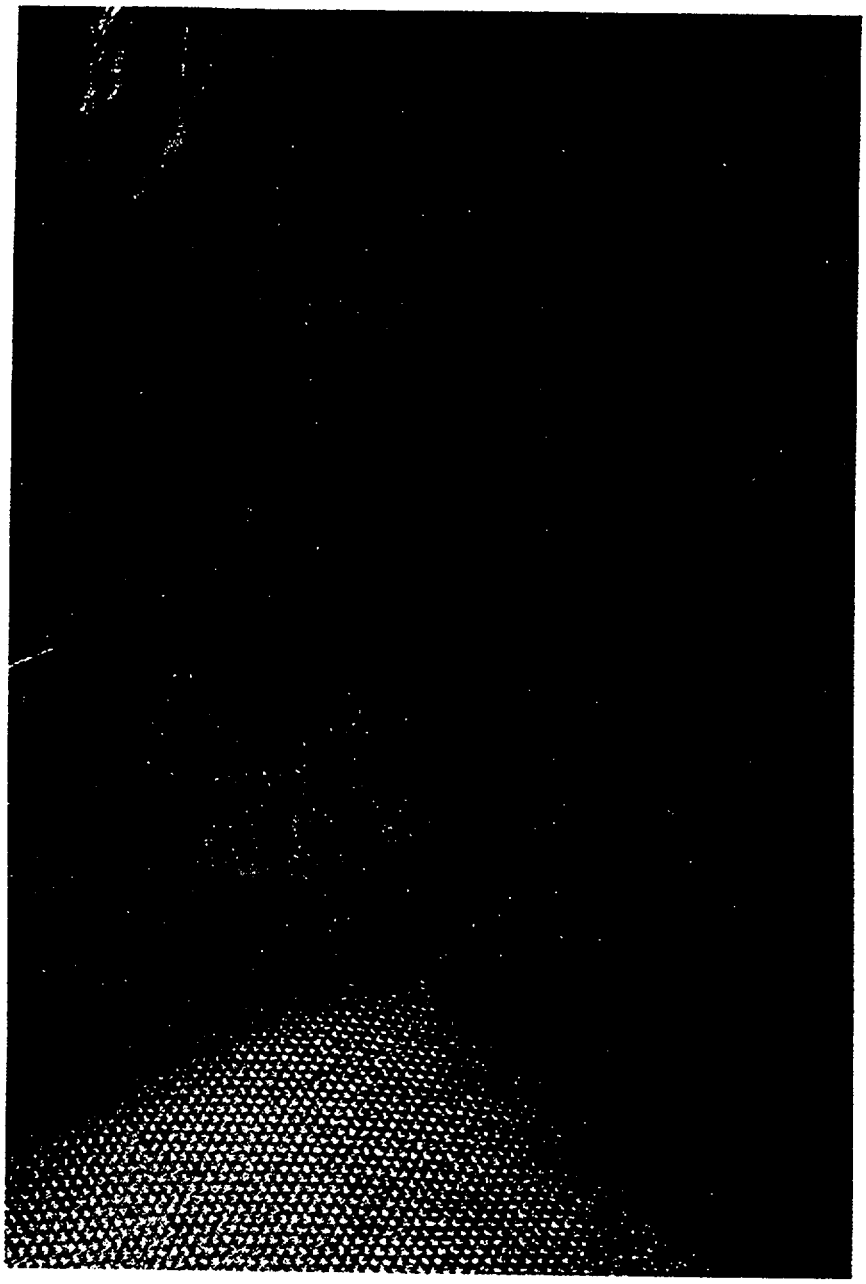

Fig. 5. Photograph of calcium-silicate/asbestos insulation in the drywell piping penetrations.

Fig. 6. Photograph of lead wool insulation in the instrument pip penetrations.

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™)	182.5 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 licensing-basis, 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 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 160ºF during the first 10 min and 202°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.

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.

Licensee Estimates for Strainer Head Loss

The licensee used the vendor-provided strainer sizing methodology (Ref. 4). 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

Table 4. Parameters used in the 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

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[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

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 is referred to in the licensee document as "RMR Pumps Two Pumps Running." This case assumes that single failure results in loss of one LPCI train and one LPCS train. Over the first 10 min, the remaining LPCI and LPCS trains inject water at the runout flow of 13,000 and 4500 gal./min, respectively. After 10 min the operator would throttle the LPCI and LPCS flows to 9600 and 3100 gal./min. Corresponding to this case, approximately 75% of the debris would deposit on the RMR strainer attached to the operating LPCI train. The second case is referred to in the licensee document as "RMR Pumps One Pump Running." This assumes that single failure results in loss one LPCI train and one LPCS train. Similar to the previous case, both of the operating LPCI and LPCS trains inject at the runout flow. After 10 min, however, the operator would throttle the LPCI pumps and shut off one of the LPCI pumps. Corresponding to this case approximately 60% of the debris would be deposited on the operating RMR strainer.
- 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 not creating any operator action. 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 pressure, 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 off 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.

Case D. This case is a variation of Case A. Unlike Case A, this case assumes that 10 min into the accident the operator would do the following: (a) throttle ECCS flow to design flow and (b) switch off one LPCI pump on each of the operating LPCI trains. The EOPs direct the operator to follow these steps. LANL simulations found that strainers are adequately sized to handle this configuration.

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 conservatisms are (a) the licensee accommodated sufficient margin while estimating the quantity of debris generated by the break jets, (b) the licensee did not take credit for settling of debris in the suppression pool, and (c) the licensee estimated strainer load factors assuming very conservative ECCS response.

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 (°)	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 (°F)	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

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
Clean ΔH (ft-water)	**Not Provided in the Submittal**			

37.6

[redacted]

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**	**-**	**-**	

[redacted]

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 t**
Substantial changes in methods	**No**

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Author(s): Venkateswara Dasari (D.V. Rao) , TSA-11
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Submitted to: Programmatic Distribution

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