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U. S. Nuclear Regulatory Commission
ATTENTION: Document Control Desk
Washington, DC 20555

BRUNSWICK STEAM ELECTRIC PLANT, UNIT NOS. 1 AND 2
DOCKET NOS. 50-325 AND 50-324/LICENSE NOS. DPR-71 AND DPR-62
SUPPLEMENTAL RESPONSE TO NRC BULLETIN 96-03, "POTENTIAL PLUGGING OF EMERGENCY CORE COOLING SUCTION STRAINERS BY DEBRIS IN BOILING-WATER REACTORS"

Gentlemen:

On May 6, 1996, the NRC issued Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors." During the Boiling Water Reactors Owners' Group (BWROG) meeting on February 19, 1997, the NRC stated that review of the proposed strainer replacements would be aided if additional plant specific information were supplied. Enclosure 1 supplies additional plant specific information for the Brunswick Steam Electric Plant, Unit Nos. 1 and 2. No new regulatory commitments are contained in this letter.

Please refer any questions regarding this submittal to Mr. Mark Turkal, Supervisor - Licensing at (910) 457-3066.

Sincerely,

Keith R. Jury

Keith R. Jury
Manager – Regulatory Affairs
Brunswick Steam Electric Plant

GMT

IE73/1

Enclosure

1. Brunswick ECCS Suction Strainer Replacement Project Summary

pc (with enclosure):

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ENCLOSURE 1

BRUNSWICK STEAM ELECTRIC PLANT, UNIT NOS. 1 AND 2
NRC DOCKET NOS. 50-325 & 50-324
OPERATING LICENSE NOS. DPR-71 & DPR-62

SUPPLEMENTAL RESPONSE TO NRC BULLETIN 96-03, "POTENTIAL PLUGGING OF EMERGENCY CORE COOLING SUCTION STRAINERS BY DEBRIS IN BOILING-WATER REACTORS"

Brunswick ECCS Suction Strainer Replacement

Project Summary

Brunswick ECCS Suction Strainers Replacement Project Summary

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1.0 Introduction

The NRC issued Bulletin 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling Water Reactors," on May 6, 1996. The initial response report was provided in Carolina Power and Light (CP&L) Letter, No. BSEP 96-0364, dated November 1, 1996. During the Boiling Water Reactors Owners' Group (BWROG) meeting with the NRR, on February 19, 1997, the NRC verbally indicated additional plant specific information would be required to support their review. This report presents the details of: 1) the approach CP&L intends to implement to resolve the potential Emergency Core Cooling System (ECCS) suction strainer blockage issue identified in Bulletin 96-03; and 2) the criteria CP&L plans to meet in the design and evaluation of the replacement strainers; and 3) the methodology CP&L plans to employ for the evaluation of the replacement strainers and demonstration of the long term ECCS recirculation capability.

As described in Section 2, CP&L's primary action for resolution of the potential ECCS suction strainer blockage issue is the replacement of the currently installed suction strainers with large, passive strainers. CP&L is proceeding with the design, engineering and fabrication of the replacement strainers. CP&L, together with Duke Engineering and Services, Inc. (DE&S), Innovative Technology Solutions Corporation (ITS) and Performance Contracting, Inc. (PCI), will perform the necessary design, engineering and fabrication services.

Detailed design and engineering activities for the Brunswick Steam Electric Plant (BSEP) Unit No. 2 are currently underway. Fabrication of the strainers is expected to be initiated in June. The replacement strainers are scheduled for installation in Unit 2 during its next refueling outage (B213R1), which is scheduled to start on September 13, 1997. For BSEP Unit No 1, engineering activities are expected to be initiated in November of this year, with fabrication activities to be initiated in December. The refueling outage for Unit 1 (B112R1) is scheduled to start on April 25, 1998.

2.0 Potential ECCS Suction Strainer Blockage Issue Resolution Approach

CP&L's planned approach for resolution of the potential ECCS suction strainer blockage issue involves three actions:

- Replace the existing ECCS suction strainers on the Residual Heat Removal (RHR) and Core Spray (CS) systems, with larger, passive strainers.
- Perform periodic suppression pool and ECCS suction strainer inspections and cleanings, based on the predicted sludge generation rate.
- Perform reviews of data obtained during the quarterly Technical Specification surveillance of the ECCS pumps.

These three actions are presented in more detail below.

2.1 Suction Strainer Replacement

CP&L intends to replace the existing suction strainers on the RHR and CS Systems with large, passive strainers. CP&L has selected PCI's Sure-Flow™ suction strainers, a stacked disk strainer design, for the replacement strainers (see Appendix B). The main design features of the Sure-Flow™ suction strainers are as follows:

- The disks are fabricated from perforated plate. The holes in the perforated plate are selected such that a maximum particle size that can pass through the strainer are less than the minimum orifice size in the RHR and CS systems. The perforated plate is easy to clean.

- The disks are attached to an internal core tube that provides flow control capabilities. Holes are cut in the core tube and are designed such that the uniform flow is achieved along the entire strainer length and the flow across the perforated plate is laminar, thereby reducing head loss.

- The core tube also acts as a structural backbone, capable of resisting the large submerged structure hydrodynamic loads that are postulated in BWR suppression pools. Use of the core tube allows relatively long strainer lengths to be installed. Supports can also be attached to the core tube, if required.

- The strainers are designed to prevent vortexing. This has been confirmed by prototype testing.

The Sure-Flow™ strainers have been tested to demonstrate the hydraulic performance of the strainers. These tests were conducted at the Electric Power Research Institute (EPRI) NDE Center in Charlotte, NC. The tests included low and high fiber quantities, with and without particulates. Testing of mixed fiber and reflective metal insulation beds was also performed. These tests demonstrate the ability of the Sure-Flow™ strainers to perform under various debris loadings, and also demonstrate that the analytical methods developed to evaluate strainer performance provide acceptable results. The reports documenting the tests performed and the results obtained are attached to this submittal.

The replacement strainers have been sized to provide sufficient surface area to ensure that the head loss through the fouled strainers, for all design basis events, is acceptable. The currently planned strainer sizes for each system penetration, in terms of strainer diameter and length and surface area, are provided in the table shown below. Also shown is the approximate increase in surface area, as compared to the existing strainers.

System	Approx. Replacement Strainer Diameter x Length*	Approx. Replacement Strainer Surface Area*	Approx. Increase in Surface Area*
RHR	45"∅ × 16'-9"	529 ft^2	1,550%
CS	45"∅ × 6'-0"	245 ft^2	1,530%

- \- length is the total values per torus penetration

2.2 Suppression Pool and ECCS Strainer Cleanliness

CP&L has a long term program for inspecting and cleaning the BSEP suppression pools and ECCS suction strainers. This program has been developed and is documented in Preventive Maintenance (PM) Routes APUH 001 and APUL 001, for Unit Nos. 1 and 2, respectively. These routes require periodic inspection of the suppression pool for sludge accumulation. If the sludge accumulation limit specified in the routes is reached, then suppression pool cleaning is performed in accordance with guidelines given in the routes. The routes also require periodic physical condition inspections of the ECCS suction strainers, at the same interval as the suppression pool inspections. The strainers are cleaned, if required.

The sludge accumulation limit specified in the PM routes was selected to ensure that the maximum sludge accumulation in the suppression pool does not exceed the design value used in the strainer performance evaluation (refer to Section 3). The sludge accumulation limit was established based on sludge generation rates determined from data obtained from previous BSEP suppression pool inspections/cleanings and from review of other industry data. These sludge generation rates will be reviewed as additional data is obtained from upcoming suppression pool inspections and the inspection intervals and sludge accumulation limit may be adjusted accordingly.

CP&L maintains foreign material exclusion and cleanliness administrative procedures to ensure the cleanliness of the suppression pool. These procedures are 0AI-125, "System Cleanliness/Foreign Material Exclusion", and 0AI-127, "Primary Containment Inspection and Closeout". These procedures control materials in the drywell, suppression pool, and systems that interface with the suppression pool, and ensure that materials that could potentially impact ECCS operations are properly controlled and prevented from entering the suppression pool.

2.3 ECCS Pump Technical Specification Surveillance Data Review

CP&L continues to collect and review pump suction data obtained during the quarterly Technical Specification surveillances. This collection and review of the Technical Specification surveillance data will insure continued operability of the ECCS pumps during the period between the inspections.

3.0 Plant Configuration and Design Parameters

3.1 Containment Design

3.1.1 Containment System Design

Both BSEP units have Mark I containment designs. The Mark I containment consists of the following:

- Drywell
- Pressure suppression chamber (torus)
- Vent system between the drywell and torus
- Isolation valves

- Vacuum breakers

In the event of a process system piping failure within the drywell, reactor water and steam are released into the drywell atmosphere. The resulting increased drywell pressure then forces a mixture of drywell atmosphere, steam, and water through the vent system, which opens beneath the surface of the suppression pool water in the torus. The water quenches the steam, thereby controlling the pressure rise in the drywell. The drywell steam-air atmosphere, which is transferred to the torus, pressurizes the torus. In the event that the drywell pressure drops below the torus pressure, the torus is vented to the drywell through vacuum breakers to equalize the pressure between the two vessels.

Cooling systems are provided to remove heat from the reactor core, the drywell, the water in the torus, and from the air in the vapor space above the water. This provides continuous cooling of the primary containment under accident conditions to maintain the pressure suppression capabilities and containment integrity.

3.1.2 Pressure Suppression Chamber (Torus) Mark I Design

The pressure suppression chamber (torus) is a hollow, reinforced concrete shell encircling the lower portion of the drywell containment structure. The concrete shell encloses a continuous 16-sided steel torus liner of circular cross sections. The major centerline diameter of the torus is 109 feet and the cross-sectional diameter of the circular liner is 29 feet. A paper joint is provided between the bottom of the torus and the mat foundation, to allow radial expansion of the torus. Vertical keys are provided along the outside perimeter of the drywell pedestal to allow independent, unrestrained radial expansion of the torus, when subjected to symmetric loadings. Under asymmetric loads, the keys force the drywell and torus to respond as a single unit.

The pressure suppression vent system connects the drywell and torus together. Eight circular vent pipes, equally spaced around the periphery of the drywell, connect the drywell to a vent header contained within the air space of the torus. Projecting downward from the header are 96 downcomer pipes, which terminate approximately 3 feet below the water level of the torus. Jet deflectors are provided at the inlet of each vent pipe to prevent possible damage to the vent line and header due to jet forces and/or missiles which might accompany a pipe break inside the drywell. Steam discharged into the torus causes the pool to swell and surge upward. Vent header deflectors are provided to deflect this surge away from the vent header toward the torus liner.

Steam discharged through the safety relief valves (SRV's) enters the torus through T-quenchers. The T-quenchers contain numerous orifices through which the steam exits into the suppression pool.

3.2 ECCS Design

The ECCS Systems include the RHR System, operating in the Low Pressure Coolant Injection (LPCI) mode, Core Spray, High Pressure Core Injection (HPCI), and the Automatic Depressurization System (ADS). The combination of these systems is designed to satisfy the 10CFR50.46 ECCS Acceptance Criteria. The RHR and CS Systems are the ECCS Systems utilized for long-term cooling. These systems take suction from the suppression pool, and, as such, are potentially impacted by the suction strainer plugging issue. Therefore, the RHR and

CS suctions strainers are planned to be replaced. As the HPCI System is not utilized for long-term cooling, its suction strainer will not be replaced.

A brief description of the RHR and CS Systems is provided below.

3.2.1 RHR System

The RHR system consists of two essentially complete and independent loops, identified as Loop A (Division I) and Loop B (Division II), with each loop containing two pumps and the necessary piping, valves and controls to support the various modes of operation. The suction piping of each pump on a loop ties into a common header (24" diameter pipe) which singly penetrates the torus. The suction strainer is attached to a flanged connection immediately adjacent to the torus penetration.

The RHR system is designed for the following six modes of operation:

- LPCI
- Shutdown Cooling
- Containment (Drywell and Suppression Pool) Spray
- Suppression Pool Cooling
- RHR Service Water Injection
- Fuel Pool Cooling Assist

The LPCI mode of operation of the RHR System is the only mode providing an emergency core cooling function. This mode of operation provides a low pressure source of core cooling for the entire range of postulated break sizes. If the break is small, yet high pressure systems are unable to recover level, ADS will depressurize the Reactor Vessel, thus allowing LPCI injection. For larger breaks, the Reactor Vessel depressurizes via the break which allows almost immediate (approximately 20 sec) LPCI injection. The LPCI mode injects via the Reactor Recirculation System discharge piping to provide a volume of water to flood the Reactor core. Automatic initiation of the system occurs from low reactor vessel water level or high drywell pressure (approximately 1.8 psig) "coincident" with low reactor vessel pressure (approximately 410 psig).

Once the core is flooded to at least two-thirds core height, one RHR or Core Spray Pump is normally required to make up for Jet Pump throat to diffuser slip joint leakage. The other pumps are stopped so that the emergency power (if there is a loss of offsite power) that was being used by these pumps may be shifted to other plant loads including RHR Service Water Booster Pumps. One RHR Pump and Heat Exchanger are typically placed in the Containment Cooling Mode after a line break in the drywell as per the Emergency Operating Procedures (EOPs).

Upon automatic initiation of the A(B) Loop of LPCI, the associated pumps should start approximately 10 seconds after the initiation signal is received. If a loss of power has occurred resulting in the Emergency Diesel Generators powering the pumps, the pumps will start 10 seconds after the associated diesel ties onto the emergency bus.

The A(B) and C(D) RHR Pumps take suction from the Suppression Pool through the normally open motor operated Suppression Pool Suction Valve, E11-F020A(B), and the associated motor-operated RHR Pump Suppression Pool Suction Valve, E11-F004A(B) or E11-F004C(D), and discharge through the Pump Discharge Check Valve, E11-F031A(B) or E11-F031C(D). The

discharge check valves are designed to prevent backflow through the pump and to maintain a water leg in the discharge piping.

With the RHR and CS Pumps running on minimum flow or dead headed, indicated pump discharge pressure on CS should increase to approximately 305 psig and RHR should be 202 psig. As reactor pressure decreases to approximately 410 psig, the LPCI Inboard Injection Valve, E11-F015A(B), should automatically open. As reactor pressure continues to decrease, the discharge of the RHR Pumps should overcome reactor pressure below approximately 200 psig, allowing the flowpath to continue from the RHR Pumps' discharge check valve directly into the Reactor Vessel through the normally open LPCI Outboard Injection Valve, E11-F017A(B), the LPCI Inboard Injection Valve, E11-F015A(B), the LPCI Injection Line Check Valve, E11-F050A(B), the locked open LPCI Manual Injection Valve, E11-F060A(B), and into the Reactor Recirculation System discharge lines. Once reactor pressure is reduced to approximately 20 psig, RHR flow should reach approximately 17,000 gpm per operating loop with two pumps.

The LPCI Outboard Injection Valve, F017A(B), is a throttle valve which may be adjusted to control flow into the vessel, whereas the Inboard Injection Valve, E11-F015A(B), is designed for either full open or full close service. E11-F017A(B) is normally open, but with a LPCI initiation signal present, this valve cannot be closed or throttled for 5 minutes to ensure a discharge path exists from the pumps to the vessel. E11-F015A(B), cannot be closed as long as the LPCI initiation signal is present. In addition, the RHR heat exchanger is automatically bypassed via the RHR Heat Exchanger Bypass Valve, E11-F048A(B), for the first three minutes to ensure that flow gets to the reactor through the most direct route. During the interval of time when the RHR pumps are operating to restore the reactor vessel level, heat removal is not necessary.

Each LPCI loop is provided with a minimum flow line to the Suppression Pool to protect the pumps from damage due to overheating as a result of low or no-flow operation. This feature allows the pumps to operate with a closed discharge valve, without overheating, by recirculating Suppression Pool water through the minimum flow bypass line.

After the core has been flooded to at least two-thirds core height, only one Core Spray or one RHR pump is required to maintain this level.

The two separate loops of RHR, in the Suppression Pool Cooling (SPC) mode, provide the primary source of containment cooling. Following a LOCA, SPC is manually initiated to limit Suppression Pool temperature and Containment pressure within design limits.

The RHR pumps receive power from the 4160V emergency auxiliary buses. For each loop, the RHR pump motor and associated automatic motor valves receive AC power from different buses.

3.2.2 Core Spray System

The Core Spray System provides a low pressure source of core cooling for the entire range of postulated break sizes. If the break is small, yet high pressure systems are unable to recover level, ADS will depressurize the reactor vessel, thus allowing Core Spray injection. For larger breaks, the reactor vessel depressurizes via the break which allows immediate Core Spray injection. The Core Spray System injects via a dedicated set of spray spargers (one per loop) in a

spray pattern directly over the reactor core.

The Core Spray System consists of two redundant and independent loops. Each loop contains one 100% capacity pump and the necessary piping, valves, and controls. The suction piping (14" diameter pipe) on each loop independently penetrates the torus. Currently, the suction strainer attaches to a flanged connection immediately adjacent to the torus penetration.

The Core Spray System controls support vessel injection when reactor pressure is reduced below the injection permissive. Automatic initiation of the system occurs from low reactor vessel water level or high drywell pressure coincident with low reactor vessel pressure.

The two loops are designated as "A" and "B", with the "A" Loop assigned to ESF Division I and the "B" Loop assigned to ESF Division II. Water from the suppression chamber is discharged into the reactor pressure vessel via the Core Spray spargers. An alternative water supply to the Core Spray loops is available from the Condensate Storage Tank, via a manual valve.

The Core Spray System relies upon station AC power sources to power the pumps. Pump power is supplied from the associated station emergency 4160 VAC Bus. Each pump is powered from an independent bus with each emergency bus capable of being powered from one of three sources of AC power. Normally during plant operation, the buses will be powered from the Main Generator output via the Unit Auxiliary Transformer (UAT). During plant shutdown conditions, and in the event this power source is lost, the emergency buses are automatically or manually transferred to the unit's Startup Auxiliary Transformer (SAT). Should both of the above fail, the station Emergency Diesel Generators automatically power the buses.

Failure of a single loop of the Core Spray System is backed up by the other loop. Failure of both loops is backed up by the LPCI Mode of RHR.

3.2.3 Limiting Conditions for Strainer Performance

The specific, limiting (i.e., worst case) conditions that are to be used in the evaluation of the strainer performance are provided below. These conditions are associated with a LOCA and loss of one emergency power system. For the governing case for RHR, this results in two RHR pumps on one loop operating at run-out conditions, and one CS pump operating at minimum Technical Specification flow. For the governing case for CS, one CS pump is operating at run-out conditions, with one RHR operating at minimum Technical Specification flow. Run-out flow is assumed to continue until up to ten minutes into the accident, when coolant level in the reactor is reestablished. Operator action is taken at that time to reduce RHR and/or CS flows, as any single RHR or CS pump is able to maintain water level in the reactor. This action is required to change the RHR mode of operation to containment cooling and/or containment spray and also assures adequate steam condensation capability by limiting suppression pool temperatures.

- Worst case RHR flow of 21,000 gpm through one loop, coincident with total CS flow of 4,625 gpm, until ten minutes into the accident. At ten minutes, the total RHR flow is reduced to 11, [illegible] pm, which is the nominal, single pump RHR flow.

- Worst case CS flow of 6,700 gpm, coincident with total RHR flow of 7,700 gpm, until ten minutes into the accident. At ten minutes, the CS flow is reduced to 4,725 gpm, which is the nominal CS flow.

3.2.4 NPSH Required

The RHR Loops A and B (2 pumps and one strainer per loop), and Core Spray Loops A and B (one pump and one strainer per loop) Net Positive Suction Head (NPSH) margins were determined with the existing installed strainers. The pump NPSH is affected by the wetwell pressure, suppression pool temperature, and fouled or clean suction strainer and line losses. The BSEP NPSH evaluation does not take credit for wetwell pressure increases, so the pressure is held at 14.7 psia.

At ten minutes into the accident, the available NPSH margins are as follows:

- RHR @ 21,000 gpm, 161.8°F, 14.7 psia;
  - Clean Strainer: 3.3 ft. head
  - 50% Clogged Strainer: 1.2 ft. head
- Core Spray @ 6,700 gpm, 162.5°F, 14.7 psia
  - Clean Strainer: 4.9 ft. head
  - 50% clogged strainer: 4.3 ft. head

After ten minutes into the accident, the available NPSH margins are as follows:

- RHR @ 11,500 gpm, 189°F, 14.7 psia;
  - Clean Strainer: 7.2 ft. head
  - 50% Clogged Strainer: 6.6 ft. head
- Core Spray @ 4,725 gpm, 189°F, 14.7 psia
  - Clean Strainer: 6.6 ft. head
  - 50% clogged strainer: 6.3 ft. head

With the losses due to the existing strainer head losses removed, the RHR pump NPSH margin is 9.4 ft. water and the Core Spray pump NPSH margin is 10.9 ft. water at ten minutes into the accident. After ten minutes, with the losses due to the existing strainer head losses removed, the NPSH margins are 9.0 ft. for RHR and 9.6 ft. for CS.

These NPSH margins are based on the maximum predicted suppression pool temperatures. As the head loss through the fibrous debris increases with decreasing temperature, the NPSH margins at minimum predicted temperatures will be reviewed to ensure the acceptability of the design.

3.3 Drywell Insulation

The insulation systems used in the drywell include both fibrous and reflective metal insulation. The specific types and approximate quantities are summarized below:

Type	Approx. Quantity	
	Unit 1	Unit 2
Fibrous Insulation (quantities in ft^3)		
NUKON - Jacketed	1,406	1,232
NUKON - Unjacketed	1,145	1,036
Temp Mat	46	58
Reflective Metal Insulation (quantities in ft^2)		
Transco RMI (1 mil Al)	33,021	44,609
Diamond Power RMI (2 mil SS)	44,320	44,320
Other (quantities in ft^3)		
Calcium Silicate	4	4
Micro Therm	2	2

3.4 Other Potential Drywell Debris Sources

The other potential drywell debris sources can be divided into three categories. These categories are defined in Section 3.2.2 of NEDO-32686, "Utility Resolution Guidance for ECCS Suction Strainer Blockage," (URG), Revision 0, dated November 1996.

3.4.1 Fixed Debris

Fixed debris is material that is part of the permanent plant that becomes a debris source only after exposure to the effects of a LOCA. This includes material that is blown or stripped off as a result of impingement forces. Material in this category are listed in Section 3.2.2.2.2 of the BWROG Utility Resolution Guidance (URG).

The other potential drywell debris applicable to BSEP are as follows.

Debris Type	Quantity (lbm)	Reference
LOCA generated dirt/dust	150	URG, Section 3.2.2.2.3.2
Qualified paint/coatings (100 % epoxy)	71	URG, Section 3.2.2.2.2.1.1
Rust flakes from unpainted steel	50	URG, Section 3.2.2.2.3.6
Other Drywell fixed debris	15	Contingency (assumed to be paint)
Total	286	

3.4.2 Latent Debris

Latent debris is debris that would not be present until later in the LOCA event progression after prolonged exposure to a LOCA environment. For example, unqualified coatings (not directly impacted by the LOCA jet) have the potential to detach from the surface where applied, but only

after prolonged exposure to the LOCA environment and after containment pressure is reduced later in the event. This type of debris is discussed in detail in Section 3.2.2.3 of the URG.

For each BSEP unit, the latent debris is approximately 2,000 ft^2 of unqualified paint/coatings. This equates to 314 lbm of debris.

3.4.3 Transient Debris

Transient debris is non-permanent plant material brought into the drywell, typically during an outage (e.g., tools, rags, sheets, plastic bags, temporary filters, dirt/dust, etc.). Transient debris is principally controlled through FME and housekeeping programs. This type of debris is described in more detail in Section 3.2.2.2.1 of the URG.

CP&L maintains an effective FME and housekeeping program. Dirt/dust debris is included in the fixed drywell debris and wetwell sludge quantities. A contingency of an additional 4 ft^3 of fibrous debris is included in the strainer design to account for fibrous transient debris.

3.5 Potential Wetwell Debris Sources

Potential wetwell debris sources are rust particles (sludge) from the carbon steel, including the torus liner and interior surfaces of torus attached piping systems, and unqualified paint.

Based on limited BSEP specific data, with comparisons to other industry data, the sludge generation rate is currently being conservatively set at 100 lbm (dry) per year. A total sludge quantity of 600 lbm (dry) is to be used in the strainer evaluation, based upon an assumption of three, 24 month cycles of sludge generation before cleaning. It should be noted that the last sludge measurement at BSEP Unit No. 1 showed a sludge generation rate of 33 lbm per year. The quantity of unqualified paint in the wetwell is included in the quantity of unqualified paint specified in Section 3.4.2.

4.0 Replacement Strainer Design Requirements

4.1 Strainer Functional Requirements

The functional requirements for the suctions will be as follows:

- The suction strainers shall screen out debris particles greater than 0.095".

  This particle size limit will ensure that any particle passing through the strainer will be smaller than the orifices associated with the cyclone separators, and all other small flow restrictions in the pump seal flush piping. This requirement is consistent with the General Electric Company Service Information Letter No. 323, which provided recommendations for sizing the strainer hole size.

- The suction strainers, including the strainer elements itself, the collected debris and any interconnecting piping components, shall produce a total head loss not to exceed:

- For the first ten minutes into the LOCA:
  - 8.4 ft. water at 21,000 gpm at 162°F for RHR
  - 9.9 ft. water at 6,700 gpm at 162°F for CS

- After ten minutes:
  - 8.0 ft. water at 11,550 gpm at 189°F for RHR
  - 8.6 ft. water at 4,725 gpm at 189°F for CS

These total head loss values will provide an available NPSH that exceeds the required NPSH for all ECCS modes of operation for RHR and CS. The debris generation, transport and head loss determinations shall be in accordance with Bulletin 96-03 and Regulatory Guide 1.82, Revision 2, unless otherwise justified. The head loss due to the strainer elements and other interconnecting piping components shall be determined and justified.

4.2 Strainer Code Requirements

The strainer code requirements shall be in accordance with the requirements listed below. These code requirements are considered appropriate for the intended applications and function of the suction strainers. The code edition and addenda to be utilized are to be consistent with those specified in the UFSAR.

- Quality Assurance
  - 10CFR50 Appendix B
  - ASME Certificate not required

- Materials
  - Conform to ASTM material specifications
  - Certified Material Test Reports (CMTRs) are to be provided for all materials (except where ASME Section III Code would permit Certificates of Compliance)

- Design
  - Qualified to ASME Section III, Nuclear Power Plant Components, Subsection NC

- Welding
  - Weld procedures and personnel qualified to ASME Section IX.

- NDE
  - Critical structural welds examined by liquid penetrant per ASME Section III
  - All other welds visually examined per ASME Section III

- Stamping
  - NPT Stamp is not required

The RHR and CS piping systems are classified as ASME Class 2 piping systems. The suction strainers are components which attach to these piping systems. As the suction strainers are non-pressure boundary components, the suction strainers are not required to be constructed to the requirements of the ASME Code (refer to Paragraphs NCA-1130(b) and NC-2121, 1986 Edition). In fact, no code and standards have been developed or adopted that specifically define the requirements for the construction of the strainers for this application. Therefore, the above

requirements have been developed and are being specified for the construction of the strainers. These requirements rely on good engineering practice and have adopted appropriate sections of the ASME Code to assure the fabricated strainers are robust and of high quality.

Suction strainers constructed to the above requirements will be of a quality and reliability that are appropriate and commensurate with their intended application and function.

4.3 Strainer and Strainer Support Structural Requirements

The strainers and strainer supports shall be qualified for the loads, load combinations and acceptance criteria established under the Mark I Containment Reevaluation Program. The governing documents for these requirements are as follows:

- NEDO-21888, "Mark I Containment Program Load Definition Report," (LDR) Revision 2, November 1981, including Addenda, Sheet 1, April 1982.
- NEDO-24583-1, "Mark I Program, Structural Acceptance Criteria, Plant Unique Analysis Application Guide," (PUAAG), October 1979.
- NUREG-0661, "Safety Evaluation Report, Mark I Containment Long-Term Program, Resolution of Generic Technical Activity A-7," July 1980, including Supplement 1, August 1982.

Supports for the strainers, if any, shall also be qualified to the requirements contained in the above governing documents.

5.0 Replacement Strainer/ECCS Long Term Recirculation Evaluation Methodology

This section presents the methodology planned to be used to evaluate the replacement strainers and ECCS long-term recirculation. This methodology is intended to meet the replacement strainer design requirements discussed in Section 4. This methodology is based on information contained in NUREG/CR-6224, in the URG and in other published literature. In some instances, the information in these publications is modified to provide appropriate application to this evaluation for BSEP.

5.1 Drywell Debris Generation

The types and quantities of debris in the drywell generated as a result of a LOCA is a function of:

- Postulated pipe break locations
- Break blast/jet shapes, sizes and intensities (i.e., Zone of Influence)
- Insulation debris types and quantities within the Zone of Influence
- Other debris types and quantities

Each of these items can be evaluated explicitly for each postulated pipe break location to determine the quantity of debris generated by that break. Alternately, simplified, but conservative evaluations can be made that provide bounding debris quantities to be utilized for the strainer and ECCS long-term recirculation evaluation.

CP&L is performing a more simplified evaluation of the bounding debris quantities generated as a result of a LOCA. This simplified evaluation approach is described below.

- Determine the type, thickness and application (i.e., the piping systems and pipe sizes) of the insulation systems utilized in the drywell. (Note that this information, as well as the general condition of the insulation, has been confirmed through the performance of field walkdown conducted during the last two refueling outages.)

- Determine the Zone of Influence for each insulation type by pipe break size using Method 3 of the URG (refer to Section 3.2.1.2.3.3).

  The URG uses a spherical Zone of Influence (hemispherical for single-ended guillotine breaks), which is consistent with guidance given in Regulatory Guide 1.82, Revision 2. As defined in the URG, the volume of the sphere is determined for each insulation type based on the pipe diameter where the break is postulated, the amount of break separation, and the destruction pressure for that insulation type. All breaks will be conservatively assumed to be unrestrained (i.e., having a radial offset greater than 3D/2). Destruction pressures are provided for most insulation types. Characteristics of other fibrous insulation types not given in the URG will be determined through literature review or microscopic examination, and then given a destruction pressure of a similar insulation material. Once the volume of the sphere is know, the equivalent sphere radius is calculated.

- Determine the routing of the high energy piping and their location relative to the majority of the piping insulation in the drywell using the plant composite piping drawings.

- Identify potentially controlling pipe breaks using the above information.

  This step involves inspecting the composite piping drawings, and with the knowledge of the Zones of Influence for various pipe break sizes, selecting break locations which would generate large volumes of debris. The location of the insulation debris relative to platforms and grating is also accounted for due to different transport factors being applied (see Section 5.2). As BSEP is mostly homogeneous in its fiber-type insulation, this identification of potentially controlling pipe breaks from visual inspection of the composite drawings is possible.

- Determine the insulation debris types and quantities associated with each potentially controlling pipe break, and associated RHR/CS demand (i.e., flow rates).

- Select the break location(s) that results in the bounding debris volumes to be utilized in the strainer performance evaluation. More than one break location may be required to be evaluated to address all insulation types and corresponding RHR/CS demand.

The reactor vessel is insulated with RMI. Any pipe breaks inside the bioshield wall would be bounded by the drywell pipe break quantities of RMI, since there are guard pipes installed on the reactor vessel nozzles which direct 85% of the pressure out through the bioshield walls.

Other non-insulation drywell debris is generated as a result of the LOCA. This debris and the quantities generated for each are provided in Section 3.4.

5.2 Drywell Debris Transport

The drywell insulation debris transported as a results of a LOCA will be determined using the combined generation and transport factors given Section 3.2.3.2.5, Tables 5 and 6, of the URG. The basis for these combined generation and transport factors are also provided in the URG, and provide the justification for utilizing transport factors less than 100%.

All particulate debris generated in the drywell is assumed to be transported to the suppression pool with 100% efficiency, and in the suppression pool at time zero into the accident.

5.3 Wetwell Debris Transport

The suppression pool is highly turbulent during the blowdown phase of a LOCA. However, after the first several minutes of the transient, the degree of turbulence is significantly reduced. The key phenomenon that can occur at that time is settling of debris to the bottom of the suppression pool. The fibrous debris is typically too light for settling to be important, and thus fiber settling will not be considered.

Particulate debris, especially larger particulate species, such as paint chips and rust flakes, have been shown to settle very rapidly. The key parameters for calculating settling, other than the particulate sizes and densities, are the suppression pool volume, the volumetric flow rate through the suppression pool, and the effective particulate settling velocities (based on degree of pool turbulence). For conservatism, this settling is not included in the strainer head loss analysis. However, it will be considered in the strainer margin assessment performed as described in Section 5.5.

5.4 Suction Strainer Blockage and Head Loss

The strainer head loss, given the deposition of a certain amount (and type) of fibrous debris and a certain amount (and type) of particulate debris on the strainer, will be calculated using a modified NUREG/CR-6224 head loss model. The head loss model in NUREG/CR-6224 was modified by our consultants, ITS, to provide a correlation for strainers having different geometries and for strainers with a heavy fiber loading. This modified head loss model explicitly treats the effects of:

- arbitrary strainer geometry (stacked disks) for both light fiber loads, when the entire stacked disk surface area is accumulating debris, and for heavy fiber loads, when the fibrous debris is simply building up on the outside of a cylindrical shape;
- debris deposition on the outside of a cylinder rather than a flat surface (resulting in a reduced bed thickness);

- different fibrous debris constituents;
- different types and quantities of particulate debris constituents;
- overall bed porosity (e.g., compression); and
- the effect of different fluid temperature and flow rate.

It should be noted that the last four items listed above are also explicitly treated in the original NUREG/CR-6224 head loss model.

The model was developed to represent the physics and fluid flow behavior expected for thick fiber beds (with particulates) on large passive strainers. A comparison of model predictions to the results of the PCI strainer tests performed at EPRI has been performed. This comparison showed agreement to within ~10% for a wide range of fiber quantities, and sludge to fiber mass ratios.

A complete description of the modified head loss model is presented in Appendix A. This modified head loss model and a comparison of the model predictions with results from tests performed at EPRI were presented to the NRC Staff by ITS on February 18, 1997.

A copy of the PCI Test Reports is included in Appendix B.

As discussed in Appendix A, the strainer head loss will be calculated considering the time-dependent debris build-up on the strainer. This buildup of debris on the strainers, which occurs over a finite time interval, is primarily determined by the volumetric flow rate through the strainer as compared to the suppression pool volume

The strainer head loss, due to the deposition of Reflective Metallic Insulation (RMI) across the strainer surface, will be calculated using RMI head loss model presented in Appendix B to the URG.

5.5 ECCS Pumps NPSH Margin Assessment

The existing NPSH margin calculations will be revised to incorporate the head loss through the debris, calculated as described above, the head loss through the strainer itself, and the head loss through any interconnecting piping components required to connect the strainer to the existing ECCS pipe connections. The revised NPSH margins will then be determined and shown to be acceptable.

An assessment will also be made as to the conservatisms contained in the NSPH margins calculated above and the additional margins that would be shown to exist, without these conservatisms included. This will include consideration of other time-dependent aspects of strainer performance, including:

- the efficiency with which the fibrous debris can trap particulate debris while the debris build-up is occuring and prior to the development of very thick beds; and

- the settling of particulate in the suppression pool, which occurs during the finite time of debris build-up on the strainer.

The BLOCKAGE computer program will be utilized to quantify this debris bed efficiency and particulate sedimentation.

This assessment will provide additional assurance that RHR and CS systems can perform their intended functions.

The potential for air/steam ingestion into the strainers during an SRV T-Quencher discharge and the potential for vortexing will also be assessed.

5.6 Suction Strainer Structural Evaluation

The suction strainers, and any required supports, will be qualified for the Mark I submerged structure loads defined in the LDR, and other applicable loads acting on the strainer (i.e., deadweight, thermal expansion and seismic). This qualification will utilize methods and parameters that are similar to those used in the qualification of other BSEP submerged structures, as documented in the BSEP Plant Unique Analysis Report (PUAR) and in the UFSAR.

5.7 Other Plant Structural, Systems and Components Evaluation

The installation of the replacement strainers may affect the qualification of other existing structures, systems and components. The items that may be affected are:

- the RHR and CS torus penetrations;
- the torus attached RHR and CS piping;
- the strainer support attachment points on the torus liner;
- other torus internal structures and systems in close proximity to the replacement strainers; and
- torus water level.

The requalification of torus penetration, liner, internal structures and piping components will utilize methods and parameters that are similar to those used in the original qualification of these items, as documented in the BSEP PUAR and UFSAR.

6.0 Licensing Amendment Request

CP&L's preliminary assessment is that the replacement strainers can be installed, and acceptability of the strainers and the ECCS long-term recirculation capability can be evaluated under the 10CFR50.59 process.

A Technical Specification change, to address the change in suppression pool water volume due to the replacement strainers installation, will be required to support the strainer installation or evaluation. No other Technical Specification change is contemplated at this time. CP&L does not plan to include torus and suction strainer surveillance requirements. As discussed in Section

2, these surveillance requirements are already contained in the appropriate BSEP maintenance procedures (routes). Placing these surveillance requirements in the maintenance procedures provides the appropriate level of control to insure that adequate inspection and cleaning is performed.

APPENDICES

Appendix A

A Modified NUREG/CR-6224 Head Loss Correlation

Table of Contents

1. Background and Objectives

There is a concern that during a design basis loss of coolant accident (LOCA) in a Boiling Water Reactor (BWR), the strainers at the suction inlet to the Emergency Core Cooling System (ECCS) could become sufficiently clogged with debris generated during the LOCA as to cause cavitation and failure of the ECCS pumps. This debris consists of drywell piping insulation (fibrous or metallic) loosened as a result of the LOCA forces and transported to the suppression pool, sludge that has built up in the suppression pool during the reactor's steady-state operation, and other particulate debris sources such as dirt and dust, loosened paint chips, and loosened rust. In order to assess the performance and adequacy of such strainers, one must be able to predict the head loss across those strainers during the accident as a function of the time dependent debris buildup and the time-dependent ECCS flow and coolant temperature. At the present time no single tool exists that can predict such head loss under the full range of potential strainer debris loading conditions.

1.1 Background

The most comprehensive assessment of the phenomenological issues that impact strainer head loss and the potential computational models that could be used to predict such head loss was conducted by the Nuclear Regulatory Commission (NRC) and documented in the NUREG/CR-6224 report entitled "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris" [Zigler, 1995]. The correlations presented therein were shown to be applicable to a wide variety of situations involving head loss due to flow through a fibrous debris layer. The BLOCKAGE computer code [Rao, 1996] was subsequently developed to implement the modeling approaches recommended in NUREG/CR-6224.

The BLOCKAGE code provides a very comprehensive assessment of

- the time-dependence of debris transport from the BWR drywell to the suppression pool,
- the buildup of debris on the strainers as a function of pump flow rate and pool water volume,
- the potential reduction in debris buildup as a result of sedimentation to the floor of the suppression pool,
- the potential reduction in the buildup of particulate debris as a result of less than perfect filtration of such particulate by the fibrous debris,
- and the head loss resulting from the flow through the deposited debris.

However, the BLOCKAGE code was developed under the assumption that the surface area of the strainer could be treated as a constant, user-supplied input to the analysis, with the debris buildup being calculated as though the strainer could be represented as a flat surface with the same surface area. This simplifying assumption is very valid in the case where one has a large surface area relative to the debris volume, such that only a thin debris layer would be calculated. However, in the case where one has a large volume of debris, with a complex strainer geometry

involving stacked disks and curved surfaces, the BLOCKAGE approach to debris deposition is no longer valid. There are two principal reasons for this:

1. A stacked disk strainer has a very large surface area relative to the overall strainer volume. With large volumes of fibrous debris, the interstitial gaps between the disks can become filled with debris. When that occurs, the effective surface area of the strainer for additional debris deposition is reduced to the circumscribed area of the strainer.
2. For thick layers of debris on the outside of a cylindrical shape, the debris thickness relative to the debris volume is a function of the surface curvature, and is less than the thickness that would result from deposition on a flat surface of the same area.

The NUREG/CR-6224 methodology accounts for the head loss due to particulate material trapped within a fibrous debris bed through a decrease in the bed porosity as well as through the use of a modified ("average") debris bed surface to volume ratio. A suggested approach to determining the average surface to volume ratio is not provided. However, the BLOCKAGE code allows for the use of either a simple volume averaged value, or simply the fiber value. For a particulate material such as sludge, whose surface to volume ratio is not too different from that of NUKON insulation fiber, these two approximations do not have a large impact on the calculated result.

This is not the case, however, for a small surface to volume ratio particulate species such as paint chips. In this case, the approximation of keeping the surface to volume ratio fixed at the value for fiber has the effect of treating the paint chips as though it were simply more fiber. This tends to significantly over predict the impact of paint chips on head loss. Even worse, however, is the use of a simple volume average. It can be shown that because of the form of the NUREG/CR-6224 head loss correlation, the use of simple volume averaging actually leads to the non-physical result that the addition of a small surface to volume ratio particulate such as paint chips actually reduces the calculated head loss. This is clearly an unacceptable, non-conservative result. It had not been identified as a problem previously, because the NUREG/CR-6224 correlation had not previously been applied to paint chip particulate.

1.2 Objectives of the Analysis

In light of the limitations in BLOCKAGE identified above, and the fact that no near-term revision of the BLOCKAGE code has been publicized, a modified NUREG/CR-6224 head loss correlation was developed that could be used to assess stacked-disk strainer performance under heavy fiber load with significant quantities of arbitrary particulate (including small surface to volume ratio material such as paint chips). This methodology incorporates the following features:

- head loss estimates based on the identical basic head loss correlations used in BLOCKAGE,

- time-dependent debris build-up on the strainers based on strainer flow rate and pool water volume as in BLOCKAGE (with all debris assumed to be suspended in the suppression pool at time zero),
- use of the full strainer surface area for debris deposition until the gaps between the stacked disks are filled with debris,
- use of the strainer circumscribed area for further debris deposition after the gaps are filled,
- a calculation of debris thickness on the outside of the circumscribed area that accounts for the surface curvature, and
- implementation of an averaging algorithm for the debris surface to volume ratio that is consistent with the basic head loss correlations.

1.3 Assumptions

The methodology relies on the same basic head loss correlation documented in NUREG/CR-6224 and implemented in the BLOCKAGE code. Validation of that correlation as documented in NUREG/CR-6224 and in the BLOCKAGE Code validation report [Shaffer, 1996] is assumed to be applicable herein.

A detailed discussion of stacked disk strainers is not provided herein. The reader who is not familiar with the basics of that strainer geometry is referred to the PCI report discussing the performance characteristics of their stacked disk strainer design [Hart, 1996].

2. Methodology Description

As discussed in the section on objectives, this methodology is based on the identical head loss correlation described in NUREG/CR-6224. Any enhancements are implemented exclusively in the calculation of certain terms in that correlation. The methodology is set up to perform the strainer performance assessment for one strainer at a time. Thus, if multiple strainer designs are being evaluated (RHR and Core Spray, for example) a separate analysis would need to be performed for each one.

2.1 Basic Head Loss Correlation

The NUREG/CR-6224 head loss correlation is described in detail in Appendix B to that report and is a semi-theoretical head loss model. The correlation is based on the theoretical and experimental research for the pressure drops across a variety of fibrous porous media carried out since the 1940s. This head loss model, proposed for laminar, transient and turbulent flow regimes through mixed debris beds (i.e., debris beds composed of fibrous and particulate matter) is given by:

$$\Delta H = \Lambda \left[3.5\, S_v^2\, \alpha_m^{1.5} (1 + 57\, \alpha_m^3)\, \mu\, U + 0.66\, S_v\, \alpha_m/(1-\alpha_m)\, \rho\, U^2 \right] \Delta L_m$$

where,

ΔH is the head loss,
S_v is the average surface to volume ratio of the debris,
μ is the dynamic viscosity of water,
U is the fluid approach velocity,
ρ is the density of water,
α_m is the mixed debris bed solidity (one minus the porosity),
ΔL_m is the mixed debris bed thickness, and
Λ is a unit conversion factor ($\Lambda = 1$ for SI units).

The mixed debris bed solidity is given by:

$$\alpha_m = \left(1 + \frac{\rho_f}{\rho_p}\eta\right)\alpha_o \frac{\Delta L_o}{\Delta L_m}$$

where,

α_o is the as fabricated fiber bed solidity,
ΔL_o is the theoretical fibrous debris bed thickness,
$\eta = m_p/m_f$ is the particulate to fiber mass ratio in the debris bed,
ρ_f is the fiber density, and
ρ_p is the average particulate material density.

For N_p classes of particulate materials, m_p and ρ_p are defined by:

$$m_p = \sum_{i=1}^{N_p} m_i$$

and

$$\rho_p = \frac{\sum_{i=1}^{N_p} \rho_i V_i}{\sum_{i=1}^{N_p} V_i}$$

where m_i, ρ_i and V_i are the mass, density and volume of a particulate material i.

Compression of the fibrous bed due to the pressure gradient across the bed is also accounted for. The relation that accounts for this effect, which must be satisfied in parallel to the previous equation for the head loss, is given by (valid for $(\Delta H/\Delta L_o) > 0.5$ ft-water/inch-insulation):

$$\Delta L_o = 1.3\ \Delta L_m\ (\Delta H\ /\ \Delta L_o)^{0.38}$$

For very large pressure gradients, the compression is limited such that a maximum solidity is not exceeded. In the NUREG/CR-6224, this maximum solidity is defined to be

$$\alpha_m = 65\ \text{lb/ft}^3/\rho_p$$

which is equivalent to having a debris layer with a density of 65 lb/ft^3. Note that 65 lb/ft^3 is the macroscopic density of a granular media such as sand or gravel and clay [Baumeister, 1958]. In this methodology, α_m is considered to be a user-specified input parameter.

It should be noted that there are indications that this formulation for debris bed compression may over predict compression significantly in the case of very thick debris layers. As such, it is possible to ignore compression in this analysis if so desired.

The NUREG/CR-6224 model assumes that the debris is uniformly distributed on the strainer surface. For flat-disk strainers and thin layer beds ($\Delta L_o \leq 0.125$ inches), that correlation is known to over-predict the results [Zigler, *et al*, 1995]. Thus, a minimum debris thickness equal to the strainer perforated plate hole diameter is assumed to be necessary to result in any measurable head loss.

In the above formulation, three parameters have as of yet not been specified; the approach velocity, U, the theoretical (uncompressed) fibrous debris bed thickness, ΔL_o, and the average surface to volume ratio, S_v. The approach velocity is a function of the user specified volumetric flow rate through the strainer of interest and the effective strainer surface area. The debris bed thickness is a function of the volume of debris on the strainer, the effective strainer surface area, and the strainer surface curvature.

2.2 Calculation of Effective Strainer Surface Area and Approach Velocity

The fluid approach velocity, U, is given simply in terms of the volumetric flow rate and the effective surface area as

$$U = \frac{Q}{A}$$

where,

Q is the volumetric flow rate through the strainer, and
A is the effective strainer surface area.

The effective area, A, is a function of the debris bed thickness, ΔL_m. While the debris bed thickness is calculated to be less than half the width of the gaps between the disks (a user-defined input parameter), the effective area is simply set equal to the full (perforated) surface area of the strainer, A_s. This area is calculated based on simple geometrical considerations of the strainer dimensions. Once the debris thickness exceeds half the gap width, the effective surface area is reduced to the circumscribed area of the strainer, A_c (i.e., ignoring the surface area within the gaps between the disks). Note that in both cases, this area calculation accounts for the perforated surfaces on the ends of the strainer.

2.3 Calculation of Debris Deposition on the Strainer

The total quantities of fibrous debris and particulate assumed to be suspended in the pool at time zero must be specified. In order to calculate the rate at which this debris accumulates on the strainer being analyzed, one has to specify the volumetric flow rate through the strainer, Q, the total volumetric flow rate through all strainers, Q_{tot}, and the total pool water inventory, V_{pool}.

If the flows are constant, the fractional debris deposition on the strainer at any given time, t (user input), into the accident can be calculated assuming that

- all debris in the pool stays uniformly distributed in the pool,
- debris is removed from the pool (deposited on all strainers) in proportion to the rate at which water is removed from the pool, and
- debris is deposited on the strainer being analyzed in proportion to the flow rate through that strainer versus the total flow rate.

This results in the following equation to describe the fractional debris buildup on the strainer of interest:

$$FRAC = \left(\frac{Q}{Q_{tot}}\right)\left(1 - \exp(-\frac{Q_{tot}}{V_{pool}} * t)\right)$$

This fraction is applied uniformly to the total quantity of each debris constituent (fiber and all particulate species) initially in the pool.

In the case where a time-dependent (but step-wise constant) flow is specified in the input, each time interval of constant flow (out to the user-specified problem time) must be treated separately. The fractional deposition during an interval is applied to the total debris quantity in the pool at the start of the interval. These deposition quantities can then be summed to yield the total deposition for the problem time of interest.

2.4 Debris Thickness Calculation - Effective Surface Area Consideration

As a rough approximation, it would be expected that the theoretical fibrous debris bed thickness on the strainer would be given by the volume of fibrous debris divided by the strainer surface area. This is in fact the approach taken in the BLOCKAGE code. In the case of a stacked-disk strainer, however, it is clear that the debris thickness would be under predicted by such an approximation once the gaps between the disks are filled. Thus, the calculation of theoretical fibrous debris bed thickness is accomplished in two steps.

Step 1 - It is first necessary to calculate a theoretical debris thickness using the entire strainer surface area, A_s. Thus, for a total fiber volume on the strainer of V_f, the thickness would be calculated as

$$\Delta L_o = V_f / A_s.$$

If following the correction for bed compression, the debris bed thickness, ΔL_m, is less than half the width of the gaps between the disks, the calculation of theoretical debris bed thickness is complete.

Step 2 - If the thickness calculated in step 1 exceeds the maximum allowable, a correction must be made. To do this it is necessary to first calculate the volume of fiber in the gaps between the disks. This is simply given by

$$V' = V_{gap} * \Delta L_o / \Delta L_m$$

where,

V_{gap} is the total volume associated with the interstitial gaps between the disks. This quantity is calculated explicitly based on the strainer geometry.

The theoretical thickness of the fibrous debris on the outside of the strainer circumscribed surface is then given by

$$\Delta L_o = (V_f - V') / A_c$$

where,

A_c is the circumscribed surface area of the strainer.

2.5 Debris Bed Thickness Calculation - Surface Geometry Considerations

The discussion on fibrous debris bed thickness above is only qualitatively correct. Simply dividing the fiber volume by the strainer surface area would accurately predict theoretical

thickness if the surface geometry were planar. This is a good approximation when one is dealing with the entire strainer surface area (step 1 above), since much of the disk area is associated with the flat surfaces of the disks. However, once the gaps are filled, most of the deposition effectively occurs on the outside of a cylinder, and the debris bed thickness is less than that predicted above.

To account for this effect, the debris bed thickness can be calculated assuming that the thickness of the fiber is the same on the ends of the strainer (flat surfaces) as on the outside of the circumscribed cylindrical surface. With this assumption, it is a simple matter to calculate the total volume of a debris layer of thickness ΔL_o, equate this to the known volume of the fiber (reduced by the fiber in the interstitial gaps), and solve the resulting quadratic equation for the debris bed thickness. This result is given by:

$$\Delta L_o = \frac{\sqrt{(\pi DH + A_{flat})^2 + 4(V_f - V')\,\pi H} - (\pi DH + A_{flat})}{2\pi H}$$

where,

D is the outer diameter of the strainer disks (assumed to be uniform axially),
H is the active length of the strainer, and
A_{flat} is the flat surface area of the ends of the strainer (calculated automatically).

This equation is used in lieu of the simpler expression previously presented in Section 2.4 under step 2.

2.6 Consideration of Impact of Strainer Supports

For relatively small strainers, the only connection to the strainer is the inlet tube to the strainer. However, for larger strainers, it may be necessary to provide additional supports for structural reasons. Depending on the details of these supports, they can have a small impact on the effective strainer total surface area, ΔAs, circumscribed area, ΔAc, and interstitial gap volume, ΔV_{gap}. To account for this effect, it is necessary to quantify these reductions. These reductions are then taken into account in the calculation of theoretical debris bed thickness by setting

$$A_s \rightarrow A_s - \Delta A_s$$

in the equation describing the debris thickness over the entire strainer surface area (Section 2.4, Step 1), and setting

$$H \rightarrow H * \frac{\pi DH}{\pi DH - \Delta A_c}$$

$$V' \rightarrow V' * \frac{V_{gap} - \Delta V_{gap}}{V_{gap}}$$

in the equation describing the debris thickness once the interstitial gaps have been filled (Section 2.5).

2.7 Calculation of Average Debris Surface to Volume Ratio

The intuitive choice for the average surface to volume ratio is to use a volume weighted average, which is equivalent to defining the average by the total surface area divided by the total volume. Unfortunately, such a choice is inconsistent with the formulation of the basic head loss correlation and can lead to non-physical results. Presented below is a simple derivation of an alternate averaging scheme that provides consistency with the basic form of the correlation.

Consider a fixed volume V that contains a mixture of two types of fiber, 1 and 2. We take

S_i = the surface to volume ratio of fiber type i, and
q_i = the quantity (microscopic volume) of fiber type i.

If we consider the dominant terms in the relationship for the pressure drop, ΔP, we have

$\Delta P \sim \langle S\rangle^2 * \alpha^{1.5}$

where,

<S> is the average surface to volume ratio, and
α is the total solidity which is $(q_1 + q_2)/V$.

We now consider the following argument for determining the average <S>. Rather than having the two fiber types well mixed in region V, consider that the fibers are separated into adjacent regions V_1 and V_2 (with the constraint that the sum of the two volumes be V), with part of the flow going through each region (in parallel rather than in series). We now postulate that the flow velocity through each of these two regions is the same, and that the pressure drop across the two regions is also the same. This allows us to solve for the relative volumes V_1 and V_2. One form of this relationship can be expressed as

$$\frac{V}{V_1} = 1 + \frac{q_2}{q_1}\left(\frac{S_2}{S_1}\right)^{4/3}.$$

If we once again consider the two fiber constituents to be well mixed, and again postulate the pressure drop to be unchanged and the flow velocity to be unchanged, we can equate the pressure drops calculated from the two different viewpoints to yield

$$\langle S\rangle^{4/3} = S_1^{4/3}\left(\frac{q_1}{q}\right)\left(\frac{V}{V_1}\right).$$

Substituting for the volume ratio, we are left with

$$\langle S\rangle = \left[\frac{q_1}{q}S_1^{4/3}+\frac{q_2}{q}S_2^{4/3}\right]^{3/4}.$$

It is obvious how this result could be extended to more than two such fiber species. We further make the assumption that the same formulation can be applied when some of the species are particulate rather than fiber.

3. References

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Hart, G., "*The Development and Testing of Performance Contracting, Inc.'s Sure-Flow™ Stacked Disk Suction Strainer*", Performance Contacting, Inc., February 1, 1996.

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Zigler, G., J. Brideau, D.V. Rao, C. Shaffer, F. Souto, and W. Thomas, "*Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris*", NUREG/CR-6224, U.S. Nuclear Regulatory Commission, October 1995.

Appendix B

Sure-Flow™ Strainer Performance Test Reports

Reports:

1. **Performance Contracting, Inc. Report, "Summary Report on Performance of Performance Contracting, Inc.'s Sure-Flow Suction Strainer with Various Mixes of Simulated Post-LOCA Debris," Revision 0, dated February 14, 1997**

2. **Continuum Dynamics, Inc. Report, "Performance Contracting, Inc. ECCS Sure-Flow™ Strainer Data Report," No. WO4536-01, dated December 1996**