Exelon Generation

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RS-16-081

April 15, 2016

10 CFR 50.54(f)

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Braidwood Station, Units 1 and 2
Renewed Facility Operating License Nos. NPF-72 and NPF-77
NRC Docket Nos. STN 50-456 and STN 50-457

Byron Station, Units 1 and 2
Renewed Facility Operating License Nos. NPF-37 and NPF-66
NRC Docket Nos. STN 50-454 and STN 50-455

Subject: Revision to Closeout Documentation for Resolution of Generic Letter 2004-02 (Generic Safety Issue (GSI)-191)

References:

(1) Letter from D. M. Gullott (Exelon Generation Company, LLC) to US NRC, "Plant-Specific Path and Schedule for Resolution of Generic Letter 2004-02," dated May 14, 2013

(2) Letter from S. Bahadur (NRC) to W. A. Nowinowski (PWR Owners Group), "Final Safety Evaluation for Pressurized Water Reactor Owners Group Topical Report WCAP-16793-NP, Revision 2, 'Evaluation of Long-Term Cooling Considering Particulate Fibrous and Chemical Debris in the Recirculating Fluid,'" dated April 8, 2013

(3) Letter from D. M. Gullott (Exelon Generation Company, LLC) to US NRC, "Closeout Documentation for Resolution of Generic Letter 2004-02 (Generic Safety Issue (GSI)-191)," dated October 30, 2015

In Reference 1, Exelon Generation Company, LLC (EGC) stated that the only remaining open issue related to the resolution of GSI-191 was in-vessel downstream effects; and presented a resolution plan to close this issue. In-vessel downstream effects refers to post-accident debris in the recirculated water in containment, bypassing the recirculation sump strainers, and accumulating at the bottom of the fuel assemblies, having potential to reduce cooling flow to the core and degrading long term core cooling.

As noted in Reference 1, to address in-vessel downstream effects, Braidwood Station and Byron Station would use the acceptance criteria of 15 grams of fiber per fuel assembly specified in WCAP-16793-NP Revision 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid." WCAP-16793 documents the results of industry debris head loss testing on a typical Westinghouse fuel assembly and sets acceptance criteria for debris loading to ensure long term core cooling is maintained.

EGC committed to completing the resolution plan by documenting the quantity of fibrous debris that reaches the sump strainers; and verifying compliance with the limitations and conditions specified in the NRC Safety Evaluation (Reference 2) associated with WCAP-16793-NP Revision 2. This information was provided to the NRC in Reference 3.

During the subsequent review of Reference 3, the NRC inquired into the basis for the fiber bypass value used to determine the in-vessel fiber loading (i.e., grams of fiber per fuel assembly). EGC explained that the fiber bypass value was based on the Byron and Braidwood Stations' specific testing that utilized grab samples to determine strainer bypass. Subsequently, due to questions regarding the reliability of this method, EGC elected to utilize a different method to determine a new design basis fiber bypass fraction for Byron and Braidwood Stations.

Based on the similarities in strainer design, debris load, and penetration velocity between Byron, Braidwood, Salem and Palo Verde Stations; bypass testing data for Salem and Palo Verde Stations were used to determine a revised conservative bypass fraction for Byron and Braidwood Stations of 30%. The in-vessel fiber loading was calculated to be 11.9 grams/fuel assembly using a 30% bypass fraction and a transport fraction to the strainer of 75%, meeting the acceptance criteria of 15 grams/fuel assembly specified in WCAP-16793-NP Revision 2. The details of the methodology used to calculate the in-vessel fiber loading are provided in Attachment A, "Fiber Bypass Fraction and Grams of Fiber per Fuel Assembly," of Attachment 1, Braidwood Station and Byron Station, Design Analysis 2014-04466, Revision 1, "Assessment of the NRC Safety Evaluation Limitations and Conditions Associated with WCAP-16793-NP." Note that attached Design Analysis 2014-04466, Revision 1, supersedes Design Analysis 2014-04466, Revision 0, submitted with Reference 3, in its entirety.

If you have any questions or require additional information regarding this submittal, please contact Joseph A. Bauer at (630) 657-2804.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 15th day of April 2016.

Respectfully,

David M. Gullott
Manager – Licensing
Exelon Generation Company, LLC

Attachment: Braidwood Station and Byron Station, Design Analysis 2014-04466, Revision 1, Assessment of the NRC Safety Evaluation Limitations and Conditions Associated with WCAP-16793-NP

cc: USNRC Region III, Regional Administrator
USNRC Senior Resident Inspector, Braidwood Station
USNRC Senior Resident Inspector, Byron Station

ATTACHMENT 1

Braidwood Station and Byron Station

Design Analysis 2014-04466, Revision 1
Assessment of the NRC Safety Evaluation Limitations and Conditions Associated with WCAP-16793-NP

Closeout Documentation for Resolution of Generic Letter 2004-02
(Generic Safety Issue (GSI)-191)

ATTACHMENT 1
Design Analysis Major Revision Cover Sheet
Page I

Design Analysis	**Last Page No.** [6] 15, Attachment D, page D28

Analysis No.: [1] 2014-04466 **Revision:** [2] 1 Major ☒ Minor ☐

Title: [3] Assessment of the NRC Safety Evaluation Limitations and Conditions Associated with WCAP-16793-NP

EC/ECR No.: [4] 405352 (Braidwood), 405357(Byron) **Revision:** [5] 0, 0

		Component(s): [14]	
Station(s): [7]	Byron/Braidwood		
Unit No.: [8]	1 and 2	N/A	
Discipline: [9]	MEDC		
Descrip. Code/Keyword: [10]	M03		
Safety/QA Class: [11]	SR		
System Code: [12]	SI		
Structure: [13]	N/A		

CONTROLLED DOCUMENT REFERENCES [15]

Document No.:	From/To	Document No.:	From/To
WCAP-16793-NP	From	CN-SEE-I-07-38	From
CN-CRA-10-54	From	BRW-06-0016-M	From
WCAP-17057	From	BYR06-029	From

Is this Design Analysis Safeguards Information? [16] **Yes** ☐ **No** ☒ If yes, see SY-AA-101-106

Does this Design Analysis contain Unverified Assumptions? [17] **Yes** ☐ **No** ☒ If yes, ATI/AR#:

This Design Analysis SUPERCEDES: [18] N/A **in its entirety.**

Description of Revision (list changed pages when all pages of original analysis were not changed): [19]
Revision 1 changes the method for calculating the fiber bypass fraction. The fiber load is calculated to be below the limit of 15 g/fuel assembly. Revision 1 also references the results of Revision 3 to design analysis CN-SEE-I-07-38.

	Print Name	Sign Name	Date
Preparer: [20]	H. Kopke	See Sargent & Lundy Document	

Method of Review: [21] **Detailed Review** ☒ **Alternate Calculations (attached)** ☐ **Testing** ☐

	Print Name	Sign Name	Date
Reviewer: [22]	E. DeCristofaro, S. Paarlberg	See Sargent & Lundy Document	

Review Notes: [23] Independent review ☒ Peer review ☐

(For External Analyses Only)

	Print Name	Sign Name	Date
External Approver: [24]	R.Peterson	See Sargent & Lundy Document	
Exelon Reviewer: [25]	See Owner Review Record, page II	See Owner Review Record, page II	See Owner Review Record, page II

Independent 3rd Party Review Reqd? [26] **Yes** ☐ **No** ☒

	Print Name	Sign Name	Date
Exelon Approver: [27]	J. Cunzeman	[signature]	4/14/2016

Exelon Owner Review Record

Design Analysis: 2014-04466 Revision 1

Design Analysis Title: Assessment of the NRC Safety Evaluation Limitations and Conditions Associated with WCAP-16793-NP

Exelon Reviewers:

Print Name	Sign Name	Date
Giovanni Panici (Braidwood)	Giovanni Panici	4-13-2016
Kevin Dhaese (Byron)	K Dhaese	4.14.2016

DESIGN ANALYSIS TABLE OF CONTENTS

Analysis No. 2014-04466 **Rev. No.** 1 **Page No.** IIA

Sargent & Lundy LLC

DESIGN CONTROL SUMMARY

CLIENT:	Exelon	UNIT: 1&2	PAGE NO.: 1
PROJECT NAME:	Byron/Braidwood	S&L NUCLEAR QA PROGRAM	
PROJECT NO.:	11332-194	APPLICABLE ☒ YES ☐ NO	
CALC. NO.:	2014-04466	SAFETY RELATED ☒ YES ☐ NO	
TITLE:	Assessment of the NRC Safety Evaluation Limitations and Conditions Associated with WCAP-16793-NP		
EQUIPMENT NO.:			

IDENTIFICATION OF PAGES ADDED/REVISED/SUPERSEDED/VOIDED & REVIEW METHOD

Initial issue (47 pages). This calculation supplements Calculation Note CN-SEE-I-07-38.

INPUTS/ ASSUMPTIONS
☒ VERIFIED
☐ UNVERIFIED

REVIEW METHOD:	Detailed Review	REV.:	0
STATUS:	☒ APPROVED ☐ SUPERSEDED BY CALCULATION NO. ☐ VOID	DATE FOR REV.:	07/14/2015
PREPARER:	Eric R. DeCristofaro (Signature on file)	DATE:	12/05/2014
REVIEWER:	Matthew M. Ross (Signature on file)	DATE:	12/05/2014
REVIEWER:	Helmut R. Kopke (Signature on file) (Client Comment Incorporation)	DATE:	12/05/2014
APPROVER:	Robert J. Peterson (Signature on file)	DATE:	07/14/2015

IDENTIFICATION OF PAGES ADDED/REVISED/SUPERSEDED/VOIDED & REVIEW METHOD

Calculation revised to update the design basis fiber bypass, and hence the in-vessel fiber loading (grams of fiber per fuel assembly or g/FA).

Changes to main body tracked with revision bars. Attachment A revised in its entirety. Attachments B, C, and D are unchanged.

88 Total Pages.

INPUTS/ ASSUMPTIONS
☒ VERIFIED
☐ UNVERIFIED

REVIEW METHOD:	Detailed Review	REV.:	1
STATUS:	☒ APPROVED ☐ SUPERSEDED BY CALCULATION NO. ☐ VOID	DATE FOR REV.:	4-13-16
PREPARER:	Helmut R. Kopke	DATE:	4-13-2016
REVIEWER:	Eric R. DeCristofaro	DATE:	4-13-2016
REVIEWER:	Stephen J. Paarlberg (2nd Round OAR Comments Only)	DATE:	4/13/16
APPROVER:	Robert J. Peterson	DATE:	4-13-16

IDENTIFICATION OF PAGES ADDED/REVISED/SUPERSEDED/VOIDED & REVIEW METHOD

INPUTS/ ASSUMPTIONS
☐ VERIFIED
☐ UNVERIFIED

REVIEW METHOD:		REV.:	
STATUS:	☐ APPROVED ☐ SUPERSEDED BY CALCULATION NO. ☐ VOID	DATE FOR REV.:	
PREPARER:		DATE:	
REVIEWER:		DATE:	
APPROVER:		DATE:	

Table of Contents

List of Affected Sections

Main body (all pages)	Revision 1
Attachment A (all pages)	Revision 1
Attachment B	Revision 0
Attachment C	Revision 0
Attachment D	Revision 0

1.0 BACKGROUND AND PURPOSE

The current Byron and Braidwood in-vessel effects analysis is documented in Westinghouse Calculation Note CN-SEE-I-07-38, Revision 3, "LOCADM Analysis." This calculation is based on Revision 2 of WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid." The calculation presents the results of the LOCADM analysis (maximum deposition thickness and fuel cladding temperature), but does not address the limitations and conditions presented in Section 4.0 of the NRC Safety Evaluation Report (SER) for WCAP-16793-NP, Revision 2. Also, Appendix B of Calculation Note CN-SEE-I-07-38 contains an assessment of fuel blockage due to fibrous debris which is "no longer applicable" per the verbiage in the appendix.

The purpose of this calculation is to addresses the fourteen limitations and conditions presented in Section 4.0 of the NRC Safety Evaluation Report (SER) for WCAP-16793-NP, Revision 2, for Byron and Braidwood. These limitations and conditions are to be addressed by licensees as part of their response to the NRC to in-vessel long term core cooling concerns. As a part of addressing these limitations the following additional information is determined:

- **Attachment A** calculates the fiber bypass fraction and grams of fiber per fuel assembly.
- **Attachment B** calculates the available driving head.
- **Attachment C** calculates the maximum flow rate per fuel assembly.

Revision 1 of this calculation updates the method used to determine the design basis fiber bypass quantity. The revised fiber bypass results in a change to the in-vessel fiber quantity (grams of fiber per fuel assembly).

2.0 REFERENCES

2.1 Safety Evaluation by the Office of Nuclear Reactor Regulation to WCAP-16793-NP, Revision 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," October 2011 (ADAMS Accession No. ML12084A154). Transmitted via letter from Sher Bahadur (NRC) to Anthony Nowinowski (PWR Owners Group), on April 8, 2013, (ADAMS Accession No. ML13084A152)).

2.2 Drawing 113E977
- 2.2.1 Braidwood Units 1 & 2, Sheet 1, Rev. 5, "4 Loop Reactor Vessel Units 1 & 2."
- 2.2.2 Byron Units 1 & 2, Sheet 1, Rev. 5, "4-Loop 173.000 I.D. Reactor Vessel."

2.3 Drawing M-196
- 2.3.1 Byron Unit 1, Sheet 1, Rev. M, "Reactor Coolant Loop Piping Arrangement and Weld Details."
- 2.3.2 Byron Unit 2, Sheet 2, Rev H, "Reactor Coolant Loop Piping Arrangement"
- 2.3.3 Braidwood Unit 1, Sheet 1, Rev. N, "Reactor Coolant Loop Piping Arrangement Unit 1"
- 2.3.4 Braidwood Unit 2, Sheet 2, Rev. H, "Reactor Coolant Loop Piping Arrangement"

2.4 Calculation Note Number CN-CRA-10-54, Rev. 2 (Braidwood), Rev. 1 (Byron), "Byron/Braidwood Units 1 and 2 LOCA Long-Term M&E and Containment Re-Analysis for IR Issues Identified in 2010."

2.5 ASME Steam Tables, 1967.

2.6 WCAP-17057-P, Rev. 1, "GSI-191 Fuel Assembly Test Report for PWROG."

2.7 Pressurized Water Reactor Owners Group (PWROG), Topical Report (TR) WCAP-16793-NP, Rev. 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," Dated July, 2013.

2.8 Arey, M., PWROG letter to Document Control Desk, NRC, "PWROG Response to Request for Additional Information Regarding Topical Report WCAP-16793-NP, Revision 1, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," (PA-SEE-0312)," August 9, 2010 (ADAMS Accession No. ML102230031).

2.9 Byron/Braidwood UFSAR, Revision 15, Tables 4.1-1 and 5.4-5.

2.10 Steam Generator Support Pad Elevation
- 2.10.1 Braidwood Unit 2 Drawing 2SG-01, Rev. A, "Spec L-2907, Inspection Identification Drawing For Inservice Inspection of Steam Generator No. 2RC01BA Loop #1, Unit 2."
- 2.10.2 Braidwood Unit 2 Drawing 2SG-02, Rev. A, "Spec L-2907, Inspection Identification Dwg. For Inservice Inspection of Steam Generator No. 2RC01BB Loop #2, Unit 2."
- 2.10.3 Braidwood Unit 2 Drawing 2SG-03, Rev. A, "Spec L-2907, Inspection Identification Dwg. For Inservice Inspection of Steam Generator No. 2RC01BC Loop #3, Unit 2."
- 2.10.4 Braidwood Unit 2 Drawing 2SG-04, Rev. B, "Spec L-2907, Inspection Identification Dwg. For Inservice Inspection of Steam Generator No.

2RC01BD Loop #4, Unit 2."

- 2.10.5 Byron Unit 2 Drawing 2SG-1-ISI, Rev. B, Sheet 1, "Inspection Identification Dwg. For Inservice Inspection for Steam Generator No. 2RC01BA."
- 2.10.6 Byron Unit 2 Drawing 2SG-1-ISI, Rev. A, Sheet 3, "Inspection Identification Dwg. For Inservice Inspection for Steam Generator No. 2RC01BB."
- 2.10.7 Byron Unit 2 Drawing 2SG-1-ISI, Rev. C, Sheet 2, "Inspection Identification Dwg. For Inservice Inspection for Steam Generator No. 2RC01BC."
- 2.10.8 Byron Unit 2 Drawing 2SG-1-ISI, Rev. A, Sheet 4, "Inspection Identification Dwg. For Inservice Inspection for Steam Generator No. 2RC01BD."
- 2.10.9 Byron and Braidwood Unit 2, "Vertical Steam Generator Instructions," January 1980.
- 2.10.10 Drawing 7720E001, Rev. 6, "Steam Generator Arrangement"

2.11 Calculation No. BYR06-029 / BRW-06-0016-M, Rev. 5, "SI/RHR/CS/CV System Hydraulic Analysis in Support of GSI-191." Byron currently uses Rev. 5, and Braidwood uses Revs. 5 and 5A. The information used herein is from Rev. 5 and is not impacted by Rev. 5A.

2.12 Braidwood EC 389605, Rev. 1, "Westinghouse 17X17 OFA Fuel Changes; Robust P-Grid and Standardized Debris Filter Bottom Nozzle."

2.13 Byron EC 388707, Rev. 0, "Westinghouse 17X17 OFA Fuel Changes; Robust P-Grid and Standardized Debris Filter Bottom Nozzle."

2.14 CCI Test Specification Q.003.84 748, Revision 3, "Containment Sump Strainer Replacement: Large Size Filter Performance Test."

2.15 TODI NF1200257, Rev. 0, "Byron Unit 2 Cycle 18 Non-MUR Reload Design Initialization."

2.16 TODI NF1100405, Rev. 1, "Byron Unit 1 Cycle 19 Reload Design Initialization."

2.17 TODI NF1300006, Rev 0, "Braidwood Unit 1 Cycle 18 Reload Design Initialization"

2.18 TODI NF1300169, Rev. 0, "Braidwood Unit 2 Cycle 18 Reload Design Initialization."

2.19 Exelon Power Labs Report, "Sump Strainer Particle Loading," 02/01/2006. (see Attachment D)

2.20 CCI Report 680/41134, Rev. 3, "Large Size Filter Performance Test."

2.21 Letter from J. Butler (NEI) to S. Bailey (NRC), Subject: Fibrous Debris Preparation Procedure for ECCS Recirculation Sump Strainer Testing, Revision 1, dated January 30, 2012 (ADAMS Accession No. ML120481052), including Attachment entitled, "ZOI Fibrous Debris Preparation: Processing, Storage and Handling," Revision 1, January 2012, (ADAMS Accession No. ML120481057).

2.22 Calculation Note Number CN-SEE-I-07-38, Rev. 3, "LOCADM Analysis for Byron/Braidwood Units 1 and 2."

2.23 Calculation No. BRW-05-0059-M / BYR05-041, Rev. 2, "GSI-191 Post-LOCA Debris Generation."

2.24 PSEG Letter No. LR-N13-0091 from Carl J. Fricker (Salem) to USNRC, Subject: Final Responses to NRC Questions Regarding Salem Bypass Testing, dated April 22, 2013. ADAMS Accession No. ML13114A048.

2.25 NRC Letter (John G. Lamb) to PSEG (Thomas Joyce), Subject: Salem Nuclear Generating Station, Units 1 and 2 – Close-out of Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors" (TAC Nos. MC4712 and MC4713), dated April 30, 2014. ADAMS Accession No. ML14113A202.

2.26 U.S. Nuclear Regulatory Commission Staff Review of the Documentation Provided by PSEG Nuclear, LLC, for Salem Nuclear Generating Station, Units 1 and 2, Concerning Resolution of Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors." ADAMS Accession No. ML14113A221.

The following Byron/Braidwood drawing and calculation References were verified as current in PASSPORT on 2/10/2016: 2.2, 2.3, 2.4, 2.10, 2.11, and 2.23.

3.0 Limitations and Conditions to the use of WCAP-16793-NP, Rev. 2

Section 4.0 of the SER for WCAP-16793 [Ref. 2.1] lists fourteen limitations and conditions that are to be addressed by licensees as part of their response to in-vessel long term core cooling concerns. These limitations are addressed individually in Sections 3.1 through 3.14 of this calculation.

3.1 Limitation 1

Limitation 1 in Section 4.0 of the SER to WCAP-16793 is repeated below:

> *"Licensees should confirm that their plants are covered by the PWROG sponsored fuel assembly tests by confirming that the plant available hot-leg break driving head is equal to or greater than that determined as limiting in the proprietary fuel assembly tests and that flow rate is bounded by the testing. Licensees should validate that the fuel types and inlet filters in use at the plant are covered by the test program (with the exception of LTAs). Licensees should limit the amount of fibrous debris reaching the fuel inlet to that stated in Section 10 of the WCAP (15 grams per fuel assembly for a hot-leg break scenario).*
>
> *Alternately, licensees may perform plant specific testing and/or evaluations to increase the debris limits on a site-specific basis. The available driving head should be calculated based on the core exit void fraction and loop flow resistance values contained in their plant design basis calculations, considering clean loop flow resistance and a range of break locations. Calculations of available driving head should account for the potential for voiding in the steam generator tubes. These tests shall evaluate the effects of increased fiber on flow to the core, and precipitation of boron during a postulated cold-leg break, and the effect of p/f ratios below 1:1. The NRC staff will review plant specific evaluations, including hot- and cold-leg break scenarios, to ensure that acceptable justification for higher debris limits is provided. (Sections 3.1.2 (c), 3.1.2 (e), 3.3.1, 3.4.2, 3.8, 3.9 and 3.10 of this SE)."*

It is shown in Attachment A of this calculation that the quantity of fibrous debris that could bypass the ECCS screens and reach the core is less than 15 grams per fuel assembly. In addition, the available hot-leg break driving head is calculated in Attachment B to be between 13.2 and 14.2 psi for Byron and Braidwood Units 1 and 2. This is much greater than the maximum measured debris head loss during PWROG fuel assembly testing of 2.7 psi [Bullet 1 on page 6-51 of Ref. 2.6].

The maximum flow rate per fuel assembly during cold-leg injection at Byron and Braidwood is 43.6 gpm (see Attachment C). This flow rate is bounded by the maximum flow rate of 44.7 gpm per fuel assembly used in the Westinghouse and Areva testing [Table G-2 and G-3 of Ref. 2.7]. Thus, the hot-leg break available driving head is greater than the debris head loss measured during the fuel assembly blockage test which is the basis for the 15 gram per fuel assembly limit.

In addition, Byron/Braidwood has Westinghouse fuel with a Robust P-grid design [Refs. 2.15, 2.16, 2.17 and 2.18]. The Robust P-grid design was evaluated in Braidwood EC 389605 [page 14 of Ref. 2.12] and Byron EC 388707 [page 14 of Ref. 2.13] and found by Westinghouse to have similar debris mitigation effectiveness to the standard P-Grid design evaluated in WCAP-16793. In addition, per Braidwood EC 389605 [page 9 of Ref. 2.12] and Byron EC 388707 [page 9 of Ref. 2.13] changing from the current Debris Filter Bottom Nozzle (DFBN) to the Standardized Debris Filter Bottom Nozzle (SDFBN) has "no impact to the debris limits for the fuel assembly due to Generic Safety Issue 191 (GSI-191) Downstream Effects."

Per the above discussion, Limitation 1 is met.

3.2 Limitation 2

Limitation 2 in Section 4.0 of the SER to WCAP-16793 is repeated below:

> *"Each licensee's GL 2004-02 submittal to the NRC should state the available driving head used in the evaluation of the hot-leg break scenario, the ECCS flow rates, and the results of the LOCADM calculations. Licensees should provide the type(s) of fuel and inlet filters installed in their plants, as well as the amount of fiber (gram per fuel assembly) that reaches the core. (Section 3.3.1 and 3.10 of this SE)"*

The available hot-leg break driving head is calculated in Attachment B to be between 13.2 and 14.2 psi for Byron and Braidwood Units 1 and 2. This is much greater than the maximum measured debris head loss during PWROG fuel assembly testing of 2.7 psi [Bullet 1 on page 6-51 of Ref. 2.6]. The maximum flow rate per fuel assembly at Byron and Braidwood is 43.6 gpm (See Attachment C). This flow rate is bounded by the maximum flow rate of 44.7 gpm per fuel assembly used in the Westinghouse and Areva testing [Table G-2 and G-3 of Ref. 2.7]. Thus, the hot-leg break available driving head at Byron / Braidwood is greater than the debris head loss measured during the fuel assembly blockage test which is the basis for the 15 gram per fuel assembly limit.

Byron/Braidwood has Westinghouse fuel with a Robust P-grid design [Refs. 2.15, 2.16, 2.17 and 2.18]. The Robust P-grid design was evaluated in Braidwood EC 389605 [page 14 of Ref. 2.12] and Byron EC 388707 [page 14 of Ref. 2.13] and found by Westinghouse to have similar debris mitigation effectiveness to the standard P-Grid design evaluated in WCAP-16793. In addition, per Braidwood EC 389605 [page 9 of Ref. 2.12] and Byron EC 388707 [page 9 of Ref. 2.13] changing from the current Debris Filter Bottom Nozzle (DFBN) to the Standardized Debris

Filter Bottom Nozzle (SDFBN) has "no impact to the debris limits for the fuel assembly due to Generic Safety Issue 191 (GSI-191) Downstream Effects."

It is shown in Attachment A of this calculation that the quantity of fibrous debris that could bypass the ECCS screens and reach the core is less than 15 grams per fuel assembly. The results of the LOCADM calculations are provided in Calculation Note Number CN-SEE-I-07-38 [Ref. 2.22] and are repeated in Table 3.1.

Table 3.1: LOCADM Results Summary

Parameter	Value	Acceptance Criteria
Maximum Cladding Temperature	< 620°F	< 800°F
Maximum Total Deposition Thickness	< 18 mil	< 50 mil

Per the above discussion, Limitation 2 is met.

3.3 Limitation 3

Limitation 3 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"Section 3.1.4.3 of the WCAP states that alternate flow paths in the RPV were not credited. The section also states that plants may be able to credit alternate flow paths for demonstrating adequate LTCC. If a licensee chooses to take credit for alternate flow paths, such as core baffle plate holes, to justify greater than 15 grams of bypassed fiber per fuel assembly, the licensee should demonstrate, by testing or analysis, that the flow paths would be effective, that the flow holes will not become blocked with debris during a LOCA, that boron precipitation is considered, and that debris will not deposit in other locations after passing through the alternate flow path such that LTCC would be jeopardized. (Sections 3.3.1 and 3.4.2 of this SE)"

Limitation 3 is met because no alternative flow paths through the core are credited.

3.4 Limitation 4

Limitation 4 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"Sections 3.2 and 3.3 of the WCAP provide evaluations to show that even with large blockages at the core inlet, adequate flow will enter the core to maintain LTCC. The staff recognizes that these calculations show that significant head loss can occur while maintaining adequate flow. However, the analyses have not been correlated with debris amounts. Therefore, the analyses cannot be relied upon to demonstrate adequate LTCC. (Sections 3.3.3 and 3.4 of this SE)"

Limitation 4 is met because it is shown in Attachment A of this calculation that the quantity of fibrous debris that could bypass the ECCS screens and reach the core is less than 15 grams per fuel assembly. In addition, the evaluations provided in Sections 3.2 and 3.3 of WCAP-16793 are not used.

3.5 Limitation 5

Limitation 5 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"In RAI Response number 18 in Reference 13, the PWROG states that numerical analyses demonstrated that, even if a large blockage occurs, decay heat removal will continue. The NRC staff's position is that a plant must maintain its debris load within the limits defined by the testing (e.g., 15 grams per assembly). Any debris amounts greater than those justified by generic testing in this WCAP must be justified on a plant-specific basis. (Sections 3.4.2 and 3.10 of this SE)"

Limitation 5 is met because it is shown in Attachment A of this calculation that the quantity of fibrous debris that could bypass the ECCS screens and reach the core is less than 15 grams per fuel assembly.

3.6 Limitation 6

Limitation 6 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"The fibrous debris acceptance criteria contained in the WCAP may be applied to fuel designs evaluated in the WCAP. Because new or evolving fuel designs may have different inlet fittings or grid straps that could exhibit different debris capture characteristics, licensees should evaluate fuel design changes in accordance with 10 CFR 50.59 to ensure that new designs do not impact adequate long term core cooling following a LOCA. (Section 3.4.2 of this SE)"

Limitation 6 is met because the Byron/Braidwood Westinghouse fuel with Robust P-grid design [Refs. 2.15, 2.16, 2.17, 2.18] is evaluated in Braidwood EC 389605 [page 14 of Ref. 2.12] and Byron EC 388707 [page 14 of Ref. 2.13] and found by Westinghouse to have similar debris mitigation effectiveness to the standard P-Grid design evaluated in WCAP-16793. In addition, per Braidwood EC 389605 [page 9 of Ref. 2.12] and Byron EC 388707 [page 9 of Ref. 2.13] changing from the current Debris Filter Bottom Nozzle (DFBN) to the Standardized Debris Filter Bottom Nozzle (SDFBN) has "no impact to the debris limits for the fuel assembly due to Generic Safety Issue 191 (GSI-191) Downstream Effects."

3.7 Limitation 7

Limitation 7 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"Sections 2 and 4.3 of the WCAP establish 800 degrees Fahrenheit as the acceptance limit for fuel cladding temperature after the core has been re-flooded. The NRC staff accepts a cladding temperature limit of 800 degrees Fahrenheit as the long-term cooling acceptance basis for GSI-191 considerations. Each licensee's GL 2004-02 submittal to the NRC should state the peak cladding temperature predicted by the LOCADM analysis. If a licensee calculates a temperature that exceeds 800 degrees Fahrenheit, the licensee must submit data to justify the acceptability of the higher clad temperature. (Sections 3.2, 3.4.3, 3.4.4, and 3.10 of this SE)"

Limitation 7 is met since the LOCADM spreadsheet was used in the Calculation Note Number CN-SEE-I-07-38 [Ref. 2.22] to show that the maximum fuel cladding temperature does not exceed 800 °F. The peak cladding temperature was found using the LOCADM spreadsheet to be less than 620°F [Ref. 2.22].

3.8 Limitation 8

Limitation 8 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"As described in the Limitations and Conditions for WCAP-16530-NP (ADAMS Accession No. ML073520891) (Reference 21), the aluminum release rate equation used in TR WCAP-16530-NP provides a reasonable fit to the total aluminum release for the 30-day ICET tests but under-predicts the aluminum concentrations during the initial active corrosion portion of the test. Actual corrosion of aluminum coupons during the ICET 1 test, which used sodium hydroxide (NaOH), appeared to occur in two stages; active corrosion for the first half of the test followed by passivation of the aluminum during the second half of the test. Therefore, while the 30-day fit to the ICET data is reasonable, the WCAP-16530-NP-A model under-predicts aluminum release by about a factor of two during the active corrosion phase of ICET 1. This is important since the incore LOCADM chemical deposition rates can be much greater during the initial period following a LOCA, if local conditions predict boiling. As stated in WCAP-16530-NP-A, to account for potentially greater amounts of aluminum during the initial days following a LOCA, a licensee's LOCADM input should apply a factor of 2 increase to the WCAP-16530-NP-A spreadsheet predicted aluminum release, not to exceed the total amount of aluminum predicted by the WCAP-16530-NP-A spreadsheet for 30 days. In other words, the total amount of aluminum released equals that predicted by the WCAP-16530-NP-A spreadsheet, but the timing of the release is accelerated. Alternately, licensees may choose to use a different method for determining aluminum release but licensees should not use an aluminum

release rate equation that, when adjusted to the ICET 1 pH, under-predicts the aluminum concentrations measured during the initial 15 days of ICET 1. (Section 3.7 of this SE)"

Consistent with the procedure described in Limitation 8, a factor of 2 increase on the surface area of aluminum is used in this analysis (see Section 5.2.1 in Calculation Note Number CN-SEE-I-07-38 [Ref. 2.22]). Therefore, Limitation 8 is met.

3.9 Limitation 9

Limitation 9 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"In the response to NRC staff RAIs, the PWROG indicated that if plant-specific refinements are made to the WCAP LOCADM base model to reduce conservatisms, the user should demonstrate that the results still adequately bound chemical product generation. If a licensee uses plant-specific refinements to the WCAP-16530-NP-A base model that reduces the chemical source term considered in the downstream analysis, the licensee should provide a technical justification that demonstrates that the refined chemical source term adequately bounds chemical product generation. This will provide the basis that the reactor vessel deposition calculations are also bounding. (Section 3.7 of this SE)"

Limitation 9 is met since an unmodified version of the LOCADM spreadsheet was used in Calculation Note Number CN-SEE-I-07-38 [Ref. 2.22] to compute the maximum fuel cladding temperature and the total debris deposition on the fuel rods.

3.10 Limitation 10

Limitation 10 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"The WCAP states that the material with the highest insulating value that could deposit from post-LOCA coolant impurities would be sodium aluminum silicate. The WCAP recommends that a thermal conductivity of 0.11 BTU/(h-ft-°F) be used for the sodium aluminum silicate scale and for bounding calculations when there is uncertainty in the type of scale that may form. If plant-specific calculations use a less conservative thermal conductivity value for scale (i.e., greater than 0.11 BTU/(h-ft-°F)), the licensee should provide a technical justification for the plant-specific thermal conductivity value. This justification should demonstrate why it is not possible to form sodium aluminum silicate or other scales with thermal conductivities less than the selected value. (Section 3.7 of this SE)"

Limitation 10 is met since an unmodified version of the LOCADM spreadsheet with the default thermal conductivity of 0.11 BTU / (h-ft-°F) was used in

Calculation Note Number CN-SEE-I-07-38 [Ref. 2.22] to compute the maximum fuel cladding temperature and the total debris deposition on the fuel rods.

3.11 Limitation 11

Limitation 11 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"Licensees should demonstrate that the quantity of fibrous debris transported to the fuel inlet is less than or equal to the fibrous debris limit specified in the proprietary fuel assembly test reports and approved by this SE. Fiber quantities in excess of 15 grams per fuel assembly must be justified by the licensee. Licensees may determine the quantity of debris that passes through their strainers by (1) performing strainer bypass testing using the plant strainer design, plant-specific debris loads, and plant-specific flow velocities, (2) relying on strainer bypass values developed through strainer bypass testing of the same vendor and same perforation size, prorated to the licensee's plant specific strainer area; approach velocity; debris types, and debris quantities, or (3) assuming that the entire quantity of fiber transported to the sump strainer passes through the sump strainer. The licensee's submittals should include the means used to determine the amount of debris that bypasses the ECCS strainer and the fiber loading expected, per fuel assembly, for the cold-leg and hot-leg break scenarios. Licensees of all operating PWRs should provide the debris loads, calculated on a fuel assembly basis, for both the hot-leg and cold-leg break cases in their GL 2004-02 responses. (Section 3.10 of this SE)"

At Byron/Braidwood the fibrous debris generated due to a cold-leg break is the same as for a hot-leg break since the only fiber from both breaks is 100% latent fiber [Ref. 2.23]. The fiber bypass is determined using testing performed by CCI (the strainer vendor) for other utilities with a CCI strainer with the same perforation size as Byron/Braidwood, as described in Attachment A. The fiber calculated to bypass the strainers and reach the fuel assembly is 11.9 grams per fuel assembly (See Attachment A). This quantity is less than the WCAP-16793-NP acceptance criteria of 15 grams per fuel assembly and therefore Limitation 11 is met.

3.12 Limitation 12

Limitation 12 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"Plants that can qualify a higher fiber load based on the absence of chemical deposits should ensure that tests for their conditions determine limiting head losses using particulate and fiber loads that maximize the head loss with no chemical precipitates included in the tests. (Section 3.3.1 of this SE) Note that in this case, licensees must also evaluate the other considerations discussed in Item 1 above."

Limitation 12 is met because Byron/Braidwood does not utilize a fiber debris limit greater than 15 grams per fuel assembly (See Attachment A).

3.13 Limitation 13

Limitation 13 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"Licensees should verify that the size distribution of fibrous debris used in the fuel assembly testing referenced by their plant is representative of the size distribution of fibrous debris expected downstream of the plant's ECCS strainer(s). (Section 3.4.2.1 of this SE) "

CCI Report Q.003.83 748 [Ref. 2.14] states the following about fiber preparation "The fibers used in the test should be identical (as far as practical) to that used at Byron/Braidwood Unit 1. The fibers will be decomposed by first cutting with a leaf shredder, manually tearing the shredded fibers into smaller pieces and then soaking the pieces in a water bucket. A water jet is used to separate the fiber in the bucket after it is shredded by the leaf shredder." This fiber preparation method is consistent with CCI's standard method which was found to be substantially consistent with NEI's recommended fiber preparation procedure [Ref. 2.21].

The results of the Byron / Braidwood specific fiber bypass testing show that the fiber size distribution at Byron / Braidwood ranged from 0.1 mm to greater than 21 mm in length, but were generally in the 0.1 mm to 1 mm range [page 6 of Ref. 2.19]. This is consistent with the fiber size distribution in WCAP-16793-NP [Ref. 2.7] which is presented in the table below.

Table 3.2: Fiber Bypass Size Category[(a)]

(0 -0.5 mm)	(0.5-1 mm)	(> 1 mm)
67-87%	8-28%	0-15%

(a) From page G-8 of WCAP-16793-NP, Revision 2 [Ref. 2.7]

Therefore, Limitation 13 is met.

<u>Note</u>: Although the NRC had concerns with the total fiber bypass quantity determined in the Byron/Braidwood specific tests due to the bypass quantity being based on grab samples, it is acceptable and common to use grab samples when determining downstream debris size distributions. The NRC accepted the use of grab samples for determining the downstream size distribution of fiber for another utility [Refs. 2.24, 2.25, and 2.26]. Therefore, the use of the Byron/Braidwood specific fiber bypass testing in the response to this limitation is acceptable.

3.14 Limitation 14

Limitation 14 in Section 4.0 of the SER to WCAP-16793 is repeated below:

"The "Margin Calculator," referenced in References 11 and 12, has not been submitted to the NRC under formal letter, and NRC staff has not performed a detailed review of the document. Therefore, NRC staff expects licensees to base their GL 2004-02 invessel effects evaluations on the information provided in the proprietary test reports and associated RAI responses (References 8, 16, 17, 11 and 12), including the conditions and limitations stated in this SE, and existing plant design-basis calculations and analyses. "

Limitation 14 is met because the "Margin Calculator" is not used.

4.0 CONCLUSIONS

Section 4.0 of the SER to WCAP-16793 lists fourteen limitations and conditions that are to be addressed by licensees as part of their response to in-vessel long term core cooling concerns. This calculation addresses each limitation and shows that Byron and Braidwood meet each limitation.

ATTACHMENT A: FIBER BYPASS FRACTION AND GRAMS OF FIBER PER FUEL ASSEMBLY CALCULATION

Note: This attachment contains its own Reference section. Therefore, References in this attachment do not refer to the main body Reference section unless otherwise stated.

1.0 Background / Purpose

In October 2015, Exelon submitted Revision 0 of this calculation (2014-04466) to the NRC as part of the closure documentation for GSI-191 [Ref. 16]. Subsequent to this submittal, the NRC inquired into the basis for the fiber bypass value used to determine the in-vessel fiber loading (grams of fiber per fuel assembly). Exelon explained that the fiber bypass value was based upon Byron/Braidwood specific testing that utilized grab samples to determine strainer bypass [Refs. 2.14, 2.19, and 2.20 of main body]. The NRC expressed concern with this method, as it has been established since the time of the Byron/Braidwood testing (2005) that the use of grab samples to determine fiber bypass fraction/quantity can be inaccurate. For this reason, Exelon elected to determine a new design basis fiber bypass fraction for Byron/Braidwood.

The purpose of this attachment is to document the design basis fiber bypass fraction and quantity as well as the resulting in-vessel fiber loading (grams of fiber per fuel assembly).

2.0 Methodology

One of the primary reasons that the strainer fiber bypass fraction is important is that it is used to determine the grams of fiber per fuel assembly. The grams of fiber per fuel assembly is required to address the Limitations and Conditions in Section 4.0 of the Safety Evaluation Report (SER) for WCAP-16793-NP, Revision 2 [Ref. 3]. These conditions limit the amount of fiber reaching the fuel to 15 grams per fuel assembly for a hot leg break.

The grams of fiber per fuel assembly is calculated using Equation 1. This equation accounts for the only fiber debris source term at the strainer being latent debris [Refs. 12 and 17].

$$\frac{g}{FA} = \frac{M \cdot F \cdot T \cdot CF \cdot B}{N} \qquad \text{(Eq. 1)}$$

Where:

g/FA grams of fiber per fuel assembly

M mass of latent debris, 150 lb_m [Refs. 12 and 17]

F fraction of latent debris that is fiber, 0.15 [Section 3.5.2.3 of Ref. 8]

N number of fuel assemblies, 193 assemblies [Ref. 7]

T transport fraction to strainer

CF conversion from lb_m to grams, 453.6 grams / lb_m

B strainer fiber bypass fraction

Equation 1 is simplified to Equation 2 by inserting known values.

$$\frac{g}{FA} = \frac{150 \cdot 0.15 \cdot 453.6}{193} \cdot T \cdot B = 52.88 \cdot T \cdot B \qquad \text{(Eq. 2)}$$

It should be noted that the use of 150 lbm of latent debris is conservative relative to the amounts measured in containment as it exceeds the maximum measured amount by more than 20% [Refs. 12 and 17].

2.1 Clean Plant Criteria

On December 22, 2011, a letter containing a simple set of resolution criteria (clean plant criteria) to address GSI-191 PWR sump performance for low fiber plants was issued by NEI [Ref. 1]. The NRC responded to these criteria in a letter dated May 2, 2012 [Ref. 2]. In the response, the NRC clarified the Staff's understanding of the criteria and concluded that "...the criteria, as clarified, provide an acceptable method of closing GSI-191 for operating PWRs."

The clean plant criteria, as applied to in-vessel effects, utilize a fiber bypass fraction of 45% and a debris transport fraction of 75% [Ref. 1]. These values are acceptable to the NRC as demonstrated in the following excerpts from Reference 2.

The highest bypass percentage observed by the staff for a fiber only test conducted for a low fiber plant with a typical complex geometry strainer under relatively conservative conditions is approximately 40% ... the staff considers a bypass fraction of 45% to be conservative for most typical perforated plate strainer installations where flow patterns do not result in fragmentation of debris.

The staff concluded that an assumption of 75% transport to the strainer, as used in NEI's calculation, to be reasonable based on the following:

1. *Inactive volumes: Plants may take credit for debris transport to inactive volumes. NRC staff guidance is that this value be limited to 15% regardless of the actual total inactive volume available for a specific plant. The 15% limit is intended to account for delayed washdown of some debris which may not reach the holdup area before it is filled.*
2. *Fine debris capture: NUREG/CR-6808 noted that there are several methods for fine debris capture. These are inertial impaction, diffusiophoresis, diffusion, settling, and spray washout. For latent debris it is unlikely that inertial impaction, diffusiophoresis, or diffusion would have a significant effect on debris capture. Settling and spray washout are likely to contribute*

to capture of latent debris. Capture by these mechanisms has been evaluated as likely for latent debris, but the effectiveness of the mechanisms has not been demonstrated and is plant specific. It is likely that some latent debris at all plants would be captured by these mechanisms.

3. *Fine debris retention: NUREG/CR-6808 concluded that condensation drainage would leave a majority of fine debris in place, surfaces directly sprayed by containment sprays would have a majority of the fine debris removed, and that the retention of fine debris on surfaces experiencing spray drainage is uncertain.*

The NRC then provided further justification for a 75% transport fraction [Ref. 2].

> *The staff concluded that the use of a lower [transport fraction] (e.g., 75% transport fraction instead of at least 85% based on the SE to NEI-04-07) to calculate in-vessel limits for a clean plant is bolstered by the following unquantified conservatisms: 1) some debris will not transport due to inactive holdup volumes and surface deposition, 2) in-vessel debris limits are determined using conservative test methodology, 3) in-vessel debris limits are determined at limiting values of flow and particulate to fiber ratio, 4) internal currents within the reactor vessel will likely result in nonuniform deposition of debris which is associated with reduced head loss, 5) most plants assume 15% of latent debris is fiber, based on an industry upper bound, but most low fiber plants have reported a significantly lower fraction of fiber in latent debris samples.*

Based on the clean plant criteria values for debris transport fraction to the strainer (T) and strainer fiber bypass fraction (B), the following Byron / Braidwood specific in-vessel debris load is computed using Equation 2:

$$\frac{g}{FA} = 52.88 \cdot T \cdot B = 52.88 \cdot 0.75 \cdot 0.45 = 17.8\ g/FA$$

This value exceeds the 15 grams per fuel assembly acceptance criterion. Therefore, the clean plant criteria cannot be used without modification. In order to use these criteria, a more appropriate fiber bypass fraction is determined based on the conditions expected for Byron/Braidwood.

2.2 Design Basis Fiber Bypass

As discussed in Section 1.0, the NRC had concerns with the Byron/Braidwood plant specific fiber bypass testing. Therefore, the design basis is based on fiber bypass testing performed by CCI for other CCI strainers with the same size perforations [2.1 mm or 1/12 (0.083) inch per Refs. 21 and 22]. This approach is acceptable per Limitation 11 in Section 4.0 of the SER for WCAP-16793-NP, Revision 2 [Ref. 3], which states the following:

Licensees may determine the quantity of debris that passes through their strainers by ... relying on strainer bypass values developed through strainer bypass testing of the same vendor and same perforation size, prorated to the licensee's plant specific strainer area; approach velocity; debris types, and debris quantities ...

2.2.1 Industry Fiber Bypass Comparison

A review of U.S. PWRs that installed CCI strainers was performed to determine an appropriate strainer bypass fraction for Byron/Braidwood. A summary of some of the pertinent information is provided below.

- ***Salem [Refs. 4 and 5]:*** Strainers have the same perforation size. In 2006 (Bypass Test 9b) and 2008 (Bypass Test 3), CCI performed fiber bypass tests using only latent debris for Salem. These latent debris only tests are representative of some of the post-LOCA conditions expected at Byron and Braidwood (see summary in Table 2.1).
- ***Palo Verde [Ref. 6]:*** Strainers have the same perforation size. Fiber bypass tests for Palo Verde, a low fiber plant, closely match limiting Byron / Braidwood conditions (see summary in Table 2.1).
- ***D. C. Cook:*** Fiber bypass of 1.2% was measured and an assumed value of 5% was used by Cook [Table 3n-1 in Attachment 4 to Ref. 10]. Additional details on bypass testing are not publicly available.
- ***Oconee:*** Oconee credits the testing and results of Salem Nuclear Station for strainer bypass data [Item 13 in Enclosure to Ref. 9].
- ***Calvert Cliffs:*** Strainers have a different perforation size [1/16 inch per Response to Issue 3j1 in Attachment 1 to Ref. 11].
- ***ANO 1 & 2:*** Strainers have a different perforation size [1/16 inch per Section A12 of Attachment 1 and Section B18 of Attachment 2 to Ref. 18].
- ***R. E. Ginna:*** Strainer has a different perforation size [1/16 inch per Section 3f.1.3 of Attachment 1 to Ref. 19].
- ***Beaver Valley 1:*** Strainer has a different perforation size [1/16 inch per Section 3.j.1 of Attachment 1 to Ref. 20].

Based on the similarities in strainer design, debris load, and penetration velocity between Byron, Braidwood, Salem and Palo Verde, bypass testing data for Salem and Palo Verde are used to determine a conservative bypass fraction for Byron and Braidwood. Table 2.1 provides a comparison of strainer characteristics for Salem, Palo Verde, and Byron / Braidwood.

Table 2.1: Comparison of Strainer Characteristics

Parameter	Salem [Refs. 4 and 5]	Palo Verde [Ref. 6]	Byron / Braidwood
Strainer Perforation Size	1/12 inch	1/12 inch (0.083 inch)	1/12 inch [2.1 mm; Refs. 21 & 22]
Penetration Velocity [(a)]	Test 9b: 0.0041 ft/s Test 3: 0.0047 ft/s	0.0094 ft/s	0.0047 ft/s before CS switchover; 0.0094 ft/s after CS switchover
Effective Strainer Area	Test 9b: 4,845 ft^2 Test 3: 4,156 ft^2	2,742 ft^2	2,160 ft^2 [(b)]
Flow Rate through Single Strainer Train	Test 9b: 9,000 gpm Test 3: 8,850 gpm	Max. flow rate of 11,600 gpm	Max. before CS [(f)] switchover: 4,557 gpm Max. after CS [(g)] switchover: 9,115 gpm
Debris Type and Quantity	Latent fiber only (both tests used 12.5 ft^3 of Nukon fiber)	Nukon fiber [(c)] (Quantity not available)	Latent fiber only [9.375 ft^3 [(d)]]
Theoretical Bed Thickness [(e)]	Test 9b: 0.031 in Test 3: 0.036 in	Not available	0.052 in

a) Penetration velocity = maximum flow rate through single strainer / effective strainer area [V_{pen} (ft/s) = Q (gpm)*(1 min/60 sec)*(1 ft^3/7.48 gal) / $A_{effective}$ ft^2].

b) Installed area (3059.5 ft^2) less the sacrificial area (900 ft^2) [Ref. 23].

c) Nukon is the only fiber type referred to in Reference 6.

d) Latent fiber as-fabricated volume (ft^3) = latent debris mass [150 lbm, Ref. 17] * latent fiber fraction [0.15; Refs. 8 and 17] / latent fiber as-fabricated density [2.4 lbm/ft^3; p. 52 of Ref. 8]

e) Theoretical bed thickness (in) = latent fiber as-fabricated volume (ft^3) / effective strainer area (ft^2) * (12 in/ft)

f) Maximum strainer flow prior to CS switchover is taken from Case 47B of Reference 14 which maximizes the residual heat removal (RH) pump flow during recirculation. The RH pump flow equals the strainer flow for this case. Case 47B models one RH pump as operating; i.e. there is only flow through one strainer.

g) Maximum strainer flow is taken from Case 7B of Reference 14 [4640 gpm containment spray (CS) flow + 4475 gpm RH flow] which maximizes sump flow during recirculation. Case 7B models a one RH and one CS pump as operating; i.e. there is only flow through one strainer.

2.2.2 Staggered RH and CS Pump Switchover

At Byron and Braidwood, the RH pump suction switchover (referred to as RH switchover herein) from the RWST to the Containment Recirculation Sump (referred to as "sump" herein) begins once the LO-2 level is reached in the RWST while CS pump suction switchover from the RWST to the Containment Recirculation Sump begins once the LO-3 level is reached in the RWST [Ref. 14]. The staggered switchover results in a period of time where the total flow through the Emergency Core Cooling System (ECCS) strainers is not the maximum strainer flow (which occurs following CS switchover). Since fiber bypass is impacted by penetration velocity, it is reasonable to model different fiber bypass fractions during recirculation for the times before and after CS switchover.

To analyze fiber bypass during staggered switchover, the fraction of fiber in the containment sump pool that reaches the strainers between RH and CS switchover is required. The fiber removed from the sump pool is estimated based on the fiber bypass fraction and the assumption that the debris is uniformly distributed in the pool. A uniform distribution of fiber is appropriate for Byron and Braidwood since the only fibrous debris is latent. By modeling the debris as being uniformly distributed throughout the pool, the amount of fiber in the pool at any time after recirculation can be related to pool turnovers. This method conservatively models all fiber that bypasses the strainer as immediately returning to the sump pool (i.e. no debris is retained downstream of the strainer). The equations and method used to determine the transient fiber concentration in the pool are provided below.

The mass of fiber in the pool (m) initially (i=0) is equal to the total mass of fiber (m_{tot}). This results in an initial fiber fraction (f_0) of 1.

$$m_0 = m_{tot} \quad \text{(Eq. 3)}$$

$$f_i = m_i / m_{tot} \,;\, f_0 = 1 \quad \text{(Eq. 4)}$$

The concentration of fiber in the pool (C) is based on the mass of fiber in the pool (m) and the pool volume (V_{pool}). Since the CS pumps continue to drawdown the RWST and supply the spray header in containment following RH switchover, the pool volume increases between RH and CS switchover. For this calculation, the average pool volume during this time is used.

$$C_i = m_i / V_{pool} \quad \text{(Eq. 5)}$$

The volume of water flowing through the strainer (V_{str}) during a given time step is computed using the strainer flow rate (Q) and time step duration from i to i+1 (Δt).

$$V_{str,i\ to\ i+1} = Q * (t_{i+1} - t_i) \quad \text{(Eq. 6)}$$

The number of pool turnovers flowing through the strainer during a time step (n_{TO}) is computed by dividing Equation 6 by the pool volume.

$$n_{TO,i+1} - n_{TO,i} = V_{str,i\ to\ i+1} / V_{pool} \quad \text{(Eq. 7a)}$$

$$V_{str,i\ to\ i+1} = (n_{TO,i+1} - n_{TO,i}) * V_{pool} \quad \text{(Eq. 7b)}$$

The fiber quantity retained on the strainer (removed from the pool) (m_r) in a given time step is computed using the fiber concentration, the water volume flowing through the strainer, and the fiber bypass fraction (f_{bypass}).

$$m_{r,i} = C_i * V_{str,i\ to\ i+1} * (1 - f_{bypass}) \quad \text{(Eq. 8)}$$

By substituting the definitions for fiber concentration (Eq. 4) and flow through the strainer (Eq. 7b) into Equation 8 and dividing by the total fiber mass, an equation for the fraction of fiber removed (f_r) based on the fraction of total fiber in the pool (f), pool turnovers, and fiber bypass fraction is obtained.

$$m_{r,i} / m_{tot} = (m_i / V_{pool}) * [(n_{TO,i+1} - n_{TO,i}) * V_{pool}] * (1 - f_{bypass}) / m_{tot} \quad \text{(Eq. 9)}$$

$$f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1 - f_{bypass}) \quad \text{(Eq. 10)}$$

The total mass of fiber in the pool for subsequent time steps ($i \geq 1$) is based on the fiber mass in the pool in the previous time step and the fiber removed during the previous time step.

$$m_i = m_{i-1} - m_{r,i-1} \quad \text{(Eq. 11)}$$

Dividing by the total fiber mass results in an equation based on fiber fractions.

$$f_i = f_{i-1} - f_{r,i-1} \quad \text{(Eq. 12)}$$

The cumulative amount of fiber removed ($\%_{fiber,removed}$) is:

$$\%_{fiber,removed} = \sum_{i=0}^{i} f_{r,i} \quad \text{(Eq. 13)}$$

The transient fiber fraction in the pool as a function of pool turnovers is determined using Equations 4, 10, 12, and 13 in Attachment A.1 and presented in Figure 2.1. A strainer bypass fraction of 15% (i.e. 85% of debris that transports to the strainer is captured) is used in the computation, consistent with the findings in Section 2.2.5 for the time prior to CS switchover (see Figure 2.2). For the time prior to CS switchover, a bypass fraction of 15% is conservative as it greatly exceeds the expected fiber bypass based on bypass test data for other CCI strainers with a similar configuration to Byron/Braidwood.

2.2.3 Pool Turnovers between RH and CS Switchover

To determine the maximum amount of fiber subject to the higher strainer velocities after CS switchover, the minimum amount of fiber retained on the strainer between RH and CS switchover is determined using Figure 2.1 and the number of pool turnovers between RH and CS switchover. The number of turnovers is determined as follows.

$$n_{TO} = \frac{Q \cdot \Delta t}{V_{pool}} \qquad \text{(Eq. 14)}$$

Where:

n_{TO}	number of pool turnovers between RH and CS switchover
Q	recirculation flow rate between RH and CS switchover (for either 1 or 2 train operation)
Δt	time between RH and CS switchover
V_{pool}	average pool volume between RH and CS switchover

The number of turnovers between RH and CS switchover is determined based on the cases presented in the minimum and maximum flood level calculations [Refs. 24 & 25, respectively] since these design basis documents contain all required information (modeled flow rates, switchover times, and pool volumes) and assess the limiting pool volumes. The minimum flood level calculation includes both 1 and 2 train operation cases, while the maximum flood level calculation includes only 2 train operation cases. Thus, the number of turnovers computed encompasses both 1 and 2 train operation.

Attachment A.2 computes the number of turnovers between RH and CS switchover for each case analyzed in the flood level calculations. Note, Reference 24 refers to ECCS switchover, which includes all ECCS pumps (CV, SI, RH), not just the RH pumps. The timing of ECCS switchover is the same as RH switchover since the RH pumps are part of the Emergency Core Cooling System. The discussion herein refers to RH switchover since the RH pumps are the only ECCS pumps to take suction from the sump following switchover.

The computed number of turnovers for the maximum flood scenarios is based on ATD-0111 [Ref. 25]. However, the maximum flood level analysis models one RH suction valve from the RWST as failing to close at RH switchover which results in an RH pump assisting in the drawdown of the RWST (following RH switchover) and direct gravity feed from the RWST to the sump, both of which reduce the time between RH and CS switchover. Furthermore, the maximum flood level analysis predicts the sump water level assuming that the entire RWST empties, which increases the time between RH and CS switchover. To determine a reasonable number of turnovers, the results from Reference 25 are adjusted in Attachment A.2

as described below to reflect more realistic conditions and to determine the sump volume at CS switchover initiation. Three main adjustments are made.

1) RWST Outflow: The turnovers for the maximum flood scenarios are computed in Attachment A.2 assuming the RWST to RH pump isolation valves both close properly, which results in less RWST outflow following the completion of RH switchover than modeled in Reference 25. This adjustment also results in two RH pumps drawing from the sump following RH switchover. The revised RWST outflow consists of two trains CS, CV, and SI flow and is modeled as continuing until the point of CS switchover initiation [Design Input 4.3 of Ref. 25]. Since the time between RH switchover completion and CS switchover initiation is less than 412 seconds, SI switchover is not complete prior to CS switchover initiation. Thus, the RWST outflow is modeled as constant between RH switchover completion and CS switchover initiation.

2) Sump Volume at CS Switchover: To determine the sump volume at CS switchover, first the RWST volume at CS switchover is determined using the RWST level at CS switchover initiation (LO-3, 12%) and corresponding RWST volume at this point from Reference 26. Once the RWST volume at CS switchover initiation and RH switchover completion (from Ref. 25) are known, the total RWST volume injected between RH switchover completion and CS switchover initiation is computed along with the time to inject this volume using the flow rate from Adjustment 1 above. The sump volume at CS switchover initiation is then computed by subtracting the volume of water remaining in the RWST at CS switchover initiation from the computed sump volume in Reference 25 at a time approximately equal to the time of CS switchover initiation (~1560 seconds). The sump volume at this time in Reference 25 is based on the entire RWST having been injected into the sump (i.e. empty RWST).

3) Sump Flow Rate: The flow rate out of the sump is based on two train operation (i.e. two RH pumps) to be consistent with Adjustment 1 above. For two train operation prior to CS switchover initiation, one RH pump draws from each ECCS sump strainer.

The number of turnovers between RH and CS switchover ranges from 0.26 (for maximum flood scenarios) to 1.0 (for minimum flood scenarios), as shown in Attachment A.2. Given the conservatisms already being used in this assessment (e.g. design latent debris mass and latent fiber fraction) as well as the conservatisms employed in the flood level calculations, the median value of 0.63 turnovers between RH and CS switchover is used. This is consistent with the NRC guidance to treat GSI-191 holistically [Ref. 13]. It should also be noted that the use of 15 grams of fiber per fuel assembly as an in-vessel fiber acceptance criterion is conservative, as acknowledged by the NRC in the SER for WCAP-16793 [p. 36 of Ref. 3], which states:

The NRC staff finds that a 15 gram fiber limit is a conservative value for all plant types included in the WCAP ...

Finally, the bypass fractions chosen for design in Section 2.2.5 below are also conservative and include significant margin over the expected values.

2.2.4 Fiber Retained on Strainer Prior to CS Switchover

Figure 2.1 shows that after 0.63 turnovers a minimum of 42% of the fibrous debris has been removed from the active pool. Note, the fraction of fiber on the screen prior to CS switchover would be slightly higher if the debris transported during pool fill-up were accounted for since some debris reaches the strainer prior to recirculation. Both recirculation sump pits would be filled during pool fill-up regardless of whether one or two ECCS/CS trains are in operation.

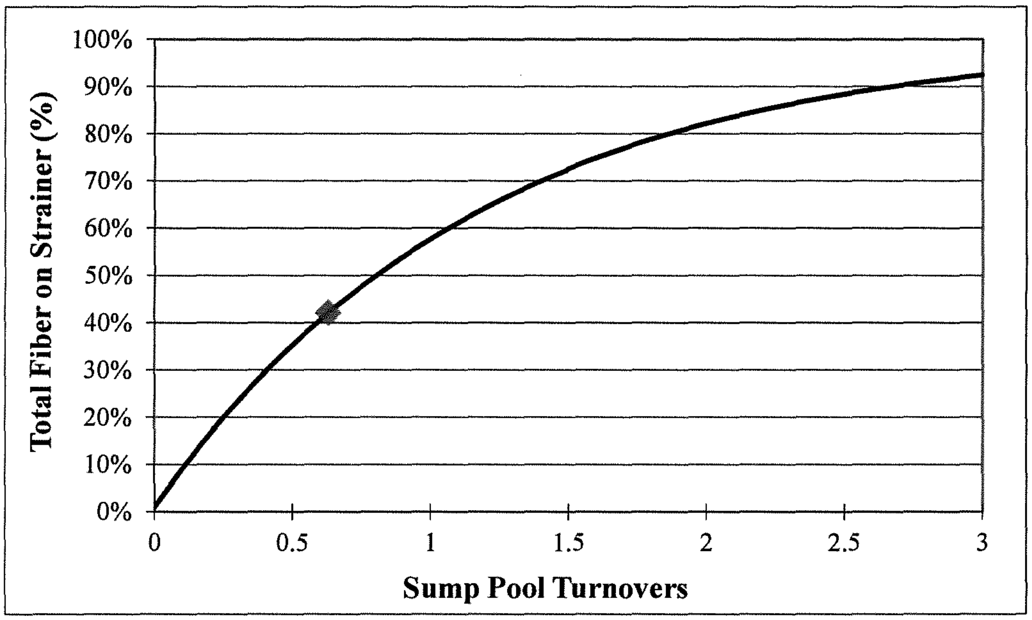

Figure 2.1: Fiber Capture on Strainer

To be conservative, only 40% fiber capture prior to CS switchover is assumed for this analysis. This is conservative as slightly more fiber is subjected to a higher bypass. The plant flow rate, screen penetration velocity and fraction of debris reaching the strainer are provided in Table 2.2 for the time before and after CS recirculation switchover.

Table 2.2: Byron / Braidwood Parameters

	Byron/Braidwood Plant Flow Rate[a]	Penetration Velocity[a]	Fraction of Debris Reaching Strainer
Before CS Switchover	4,557 gpm	0.0047 ft/s	40%
After CS Switchover	9,115 gpm	0.0094 ft/s	60%

a) See Table 2.1 for basis.

2.2.5 Overall Fiber Bypass Fraction

Once the fraction of debris reaching the strainer prior to CS recirculation switchover is determined, an overall fiber bypass fraction (B) can be calculated.

$$B = X_{ECCS} \cdot B_{ECCS} + X_{CS} \cdot B_{CS} = 0.40 \cdot B_{ECCS} + 0.60 \cdot B_{CS} \qquad \text{(Eq. 15)}$$

Where:

X_{ECCS} fraction of debris reaching strainer before CS switchover

X_{CS} fraction of debris reaching strainer after CS switchover

B_{ECCS} fiber bypass fraction for debris reaching strainer before CS switchover

B_{CS} fiber bypass fraction for debris reaching strainer after CS switchover

To determine the appropriate fiber bypass fractions for before and after CS switchover, data from Salem and Palo Verde is utilized.

Table 2.3 and Figure 2.2 present the Salem and Palo Verde fiber bypass test data as bypass percentage versus penetration velocity. The Salem fiber bypass data is computed based on the information presented in References 4 and 5, as explained below. The Palo Verde fiber bypass data (without bump-up) is taken from p. 3-155 of Reference 6.

The fiber bypass for Salem Test 9b in 2006 is 0.25 lbm per 1000 ft^2 [Figure 3f.4.2.2.2-2 of Attachment 1 to Ref. 4]. Given the tested plant strainer area of 4845 ft^2 [Section 3f.4.1.3.2 of Attachment 1 to Ref. 4], this corresponds to 1.21 lbm [=0.25*4845/1000] of fiber bypass. To compute the total fiber added to the test loop for this test, the scale factor (180.8) and added fiber mass (0.0623 kg) are used [Section 3f.4.1.3.4 of Attachment 1 to Ref. 4]. The total fiber added to the test loop for this test was equivalent to 24.83 lbm in the plant [=180.8*0.0623*2.2046]. Thus, the measured fiber bypass percentage for this test is 4.87% [=1.21/24.83*100].

The reason 12.5 ft^3 of latent fiber is not equal to 30 lbm for Salem Test 9b in 2006 is that the measured Nukon density (1.94 lbm/ft^3) was used for the conversion from as-fabricated volume to mass in this test series as explained on p. 10 of Attachment 1 to Reference 5. The measured density is less than the typically used density of 2.4 lbm/ft^3 [p. 52 of Ref. 8]. It is also recognized that 12.5 ft^3 of 1.94 lbm/ft^3 fiber yields 24.25 lbm; the difference between this value and the computed value above (24.83 lbm) is presumably due to truncation errors in the computation (original density was probably in kg/m^3 and then converted to lbm/ft^3).

The fiber bypass for Salem Test 3 in 2008 is 0.68 lbm per 1000 ft^2 [p. 10 of Attachment 1 to Ref. 5]. Given the tested plant strainer area of 4156 ft^2 [Sections 3f.4.1.5.4 and 3f.4.1.6.2 of Attachment 1 to Ref. 4], this corresponds to 2.83 lbm [=0.68*4156/1000] of fiber bypass. The total fiber added to the test loop for this test was equivalent to 30 lbm in the plant [p. 141 of Attachment 1 to Ref. 4]. Thus, the measured fiber bypass percentage for this test is 9.43% [=2.83/30*100].

The amount of bypassed fibers for Salem and Palo Verde is increased by 9% to account for NRC concerns with the fiber bypass capture screen used in the CCI fiber bypass tests [Attachment 1 of Ref. 5]. Specifically, the NRC was concerned that some fiber that bypassed the strainer would then pass through the fiber capture screen due to the capture screen hole size of 0.31 mm [0.012 inch in Ref. 6]. To account for potential capture screen bypass during the tests, an increase factor was developed by Salem and accepted by the NRC [Refs. 27 and 28].

Table 2.3: Salem and Palo Verde Fiber Bypass Test Data

Test Data	Penetration Velocity (ft/s)	Fiber Bypass (%)	Fiber Bypass with Bump-Up (%)
Salem (2006 Test 9b)	0.0041	4.87	5.3
Salem (2008 Test 3)	0.0047	9.43	10.3
Palo Verde (Test 02)	0.0094	8.1	8.8
Palo Verde (Test 03)	0.0094	12.3	13.4

Two points are added to Figure 2.2 to represent the bypass fractions used for Byron and Braidwood before and after CS recirculation switchover. Note that these points are based on the maximum penetration velocities during recirculation before and after CS switchover. This is conservative, as most operating scenarios will experience lower penetration velocities. As noted in Notes 'f' and 'g' to Table 2.1, these penetration velocities are based on single train operation, even though two train operation would be expected [Ref. 15] and two train operation would have lower strainer flow rates/penetration velocities. Two train operation would result in higher flow rates and pressure drop through shared portions of the system (e.g. RCS legs), resulting in less flow rate per pump (and hence per sump strainer) than for single train operation. This is consistent with Section 6.1.5.1 of Reference 14 which describes the system line-up (i.e. single train) for maximum sump flow.

Before CS recirculation switchover a fiber bypass fraction of 15% is used. This conservatively bounds the bypass data at similar penetration velocities with approximately 50% margin.

The maximum penetration velocity after CS recirculation switchover is equal to that used in the Palo Verde fiber bypass tests. To be conservative, a bypass fraction of 40% is used for fiber that reaches the strainer after CS recirculation switchover. This value is consistent with the highest bypass percentage observed by the Staff for a fiber only test for a low fiber plant with a complex geometry strainer [Ref. 2]. As can be seen in Figure 2.2, this value is very conservative relative to the Salem and Palo Verde data.

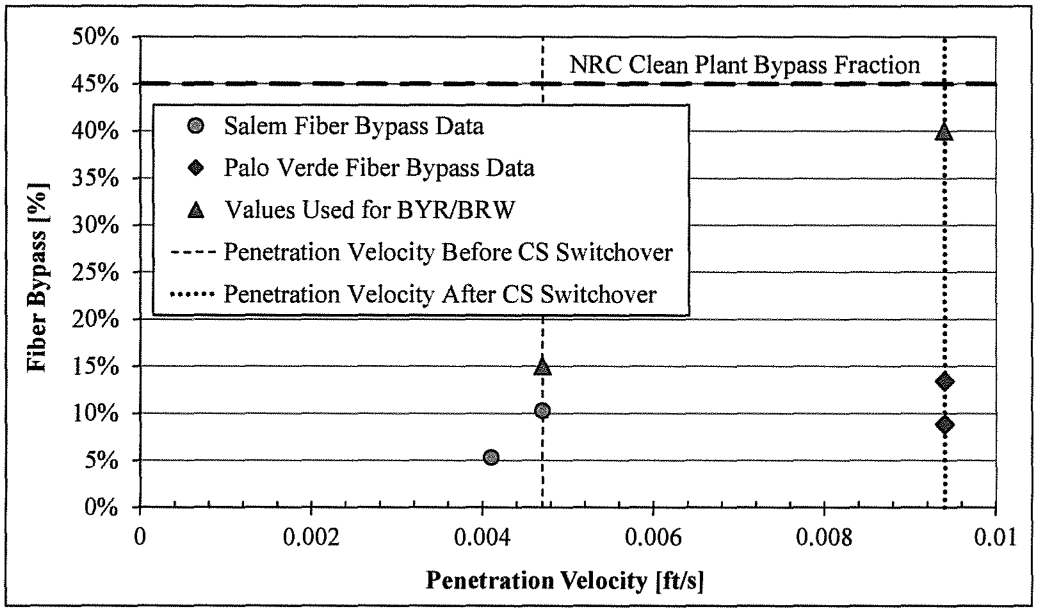

Figure 2.2: Fiber Bypass versus Penetration Velocity

Based on the data in Figure 2.2, the following overall bypass fraction is calculated for Byron and Braidwood using Equation 15.

$$B = X_{ECCS} \cdot B_{ECCS} + X_{CS} \cdot B_{CS} = 0.40 \cdot 0.15 + 0.60 \cdot 0.40 = 0.300 = 30.0\%$$

2.3 In-Vessel Fiber Loading

The quantity of fiber per fuel assembly is calculated below using Equation 2 with a bypass fraction (B) of 30%. The transport fraction to the strainer (T) is maintained at the clean plant criteria value (75%).

$$\frac{g}{FA} = 52.88 \cdot T \cdot B = 52.88 \cdot 0.75 \cdot 0.30 = 11.9 \; g/FA$$

This value is less than the 15 grams per fuel assembly acceptance criterion.

3.0 Conclusions

This attachment determines that an appropriate fiber bypass fraction to use for the CCI strainers at Byron and Braidwood is 30%. This value is based on both testing of other CCI strainers as well as a recognized conservative fiber bypass fraction through complex, perforated plate strainers.

Using the fiber bypass value above, the in-vessel fiber loading is 11.9 grams per fuel assembly.

The in-vessel fiber loading is computed using the clean plant criteria, but with the more appropriate fiber bypass fraction determined herein. This is the only difference between the approach for Byron/Braidwood and the clean plant criteria. The reduced fiber bypass fraction is justified due to the lower penetration velocity before CS recirculation switchover and by adding significant margin to available industry fiber bypass data.

4.0 References

1. Letter from J. Butler (NEI) to S. Bailey (NRC) dated December 22, 2011, "Transmittal of GSI-191 Resolution Criteria for "Low Fiber" Plants." ADAMS Accession No. ML113570229.

2. Letter from W. Ruland (NRC) to J. Butler (NEI) dated May 2, 2012, "NRC Review of Nuclear Energy Institute Clean Plant Acceptance Criteria for Emergency Core Cooling Systems." ADAMS Accession No. ML120730181.

3. Safety Evaluation by the Office of Nuclear Reactor Regulation to WCAP-16793-NP, Revision 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," October 2011 (ADAMS Accession No. ML12084A154). Transmitted via letter from Sher Bahadur (NRC) to Anthony Nowinowski (PWR Owners Group), on April 8, 2013, (ADAMS Accession No. ML13084A152)).

4. PSEG Letter No. LR-N12-0124 from Carl J. Fricker (Salem) to USNRC, Subject: Final Supplemental Response to Generic Letter 2004-02, Including Attachment 1, "Salem Nuclear Generating Station Units 1 and 2 Docket Nos. 50-272 and 50-311 Generic Letter 2004-02 Updated Supplemental Response for Salem," dated April 27, 2012. ADAMS Accession Nos. ML12129A389 & ML12129A390.

5. PSEG Letter No. LR-N13-0091 from Carl J. Fricker (Salem) to USNRC, Subject: Final Responses to NRC Questions Regarding Salem Bypass Testing, dated April 22, 2013. ADAMS Accession No. ML13114A048.

6. APS Letter No. 102-06805-DCM/RKR from John J. Cadogan (Palo Verde) to USNRC, Subject: Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2, and 3 Docket Nos. STN 50-528, 50-529, and 50-530 Revision 2 to Supplemental

Response to NRC Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors, dated December 18, 2013. ADAMS Accession No. ML13357A218.

7. Byron/Braidwood UFSAR, Revision 15, Table 4.1-1.

8. Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02, Nuclear Energy Institute Guidance Report (Proposed Document Number NEI 04-07), "Pressurized Water Reactor Sump Performance Evaluation Methodology." ADAMS Accession No. ML043280641.

9. Duke Energy Letter No. ONS-2014-024 from Scott L. Batson (Oconee) to USNRC, Subject: Oconee Closure Option 1 Response for Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance" in Resolution of Final Issues Related to Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated February 27, 2014. ADAMS Accession No. ML14065A040.

10. AEP Letter No. AEP-NRC-2010-39 from Joel P. Gebbie (AEP) to USNRC, Subject: Updated Final Response to Nuclear Regulatory Commission Generic Letter 2004-02: Potential impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors and a June 2009 Request for Additional Information, dated May 26, 2010. ADAMS Accession No. ML101540527.

11. Constellation Energy Nuclear Generation Group (James A. Spina / Calvert Cliffs) Letter to the USNRC, Subject: Calvert Cliffs Nuclear Power Plant Unit Nos. 1 & 2; Docket Nos. 50-317 & 50-318, Supplemental Response to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors," dated February 29, 2008. ADAMS Accession No. ML080640751.

12. Exelon Letter No. RS-07-161 from Patrick R. Simpson (Exelon) to USNRC, "Supplemental Response to NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated December 31, 2007. ADAMS Accession No. ML080280562.

13. NRC Staff Memorandum from A. L. Bates to L. A. Reyes, Subject: Staff Requirements – Briefing on Resolution of GSI-191, Assessment of Debris Accumulation on PWR Sump Performance, 1:30 P.M., Wednesday, October 25, 2006, Commissioners' Conference Room, One White Flint North, Rockville, Maryland (Open to Public Attendance), dated November 16, 2006, M061025C. ADAMS Accession No. ML063200471.

14. Calculation BYR06-029 / BRW-06-0016-M, Rev. 5, "SI/RHR/CS/CV System Hydraulic Analysis in Support of GSI-191." Byron currently uses Rev. 5, and Braidwood uses Revs. 5 and 5A. The information used herein is from Rev. 5 and is not impacted by Rev. 5A.

15. Byron / Braidwood Procedures

    15.1 1BEP ES-1.3, Rev. 206, "Transfer to Cold Leg Recirculation Unit 1."

    15.2 2BEP ES-1.3, Rev. 206, "Transfer to Cold Leg Recirculation Unit 2."

    15.3 1BwEP ES-1.3, Rev. 203, "Transfer to Cold Leg Recirculation Unit 1."

    15.4 2BwEP ES-1.3, Rev. 203, "Transfer to Cold Leg Recirculation Unit 2."

16. Exelon Letter RS-15-283 from David M. Gullott (Exelon) to USNRC, Subject: Closeout Documentation for Resolution of Generic Letter 2004-02 (Generic Safety Issue (GSI)-191), dated October 30, 2015, Including Attachment "Braidwood Station and Byron Station, Design Analysis 2014-04466, Revision 0, Assessment of the NRC Safety Evaluation Limitations and Conditions Associated with WCAP-1 6793-NP." ADAMS Accession No. ML15303A408.

17. Calculation No. BRW-05-0059-M / BYR05-041, Rev. 2, "GSI-191 Post-LOCA Debris Generation."

18. Entergy Letter No. 0CAN090901 from Kevin T. Walsh (ANO) to USNRC, Subject: Generic Letter 2004-02 Final Supplemental Response Request for Additional Information Arkansas Nuclear One – Units 1 and 2 Docket Nos. 50-313 and 50-368 License Nos. DPR-51 and NPF-6, dated September 24, 2009. ADAMS Accession No. ML092720684.

19. Constellation Energy Nuclear Generation Group (John Carlin / R. E. Ginna) Letter to the USNRC, Subject: Supplementary Response to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated February 29, 2008. ADAMS Accession No. ML080710041.

20. FirstEnergy Nuclear Operating Company (FENOC) Letter No. L-09-152 from Peter P. Sena III (Beaver Valley) to USNRC, Subject: Supplemental Response to Generic Letter 2004-02 (TAC Nos. MC4665 and MC4666), dated June 30, 2009. ADAMS Accession No. ML091830390.

21. CCI Drawing 103.132.173.500, Revision 0, "Side Wall Long Version Seitenwand Lange Version Type 4."

22. CCI Drawing 103.132.174.500, Revision 0, "Pocket Long Version Tasche Lange Version."

23. CCI Report 3 SA-096.018, Revisions 8 (Byron) and 9 (Braidwood), "Head Loss Calculation." The information used herein is the same in Revisions 8 and 9.

24. Calculation SI-90-01, Revision 11, "Minimum Containment Flood Level."

25. Calculation ATD-0111, Revision 15, "Maximum Containment Flood Level."

26. Calculation SITH-1, Revision 8, "Refueling Water Storage Tank (RWST) Level Setpoints."

27. NRC Letter (John G. Lamb) to PSEG (Thomas Joyce), Subject: Salem Nuclear Generating Station, Units 1 and 2 – Close-out of Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors" (TAC Nos. MC4712 and MC4713), dated April 30, 2014. ADAMS Accession No. ML14113A202.

28. U.S. Nuclear Regulatory Commission Staff Review of the Documentation Provided by PSEG Nuclear, LLC, for Salem Nuclear Generating Station, Units 1 and 2, Concerning Resolution of Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors." ADAMS Accession No. ML14113A221.

The following Byron/Braidwood drawing and calculation References were verified as current in PASSPORT on 3/14/2016: 7, 14, 15, 17, 24, 25, and 26.

5.0 Attachments (to Attachment A of 2014-04466)

Attachment A.1:	Transient Fiber Fraction in Sump Pool	(12 pages)
Attachment A.2:	Pool Turnovers Between ECCS and CS Switchover	(12 pages)

	A	B	C	D
1	Strainer Bypass Fraction, f_{bypass}		0.15	
2				
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}\ (i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ *from i=0 to i*
4	0.00	1.00	0.0085	0.9%
5	0.01	0.99	0.0084	1.7%
6	0.02	0.98	0.0084	2.5%
7	0.03	0.97	0.0083	3.4%
8	0.04	0.97	0.0082	4.2%
9	0.05	0.96	0.0081	5.0%
10	0.06	0.95	0.0081	5.8%
11	0.07	0.94	0.0080	6.6%
12	0.08	0.93	0.0079	7.4%
13	0.09	0.93	0.0079	8.2%
14	0.10	0.92	0.0078	9.0%
15	0.11	0.91	0.0077	9.7%
16	0.12	0.90	0.0077	10.5%
17	0.13	0.89	0.0076	11.3%
18	0.14	0.89	0.0075	12.0%
19	0.15	0.88	0.0075	12.8%
20	0.16	0.87	0.0074	13.5%
21	0.17	0.86	0.0074	14.2%
22	0.18	0.86	0.0073	15.0%
23	0.19	0.85	0.0072	15.7%
24	0.20	0.84	0.0072	16.4%
25	0.21	0.84	0.0071	17.1%
26	0.22	0.83	0.0070	17.8%
27	0.23	0.82	0.0070	18.5%
28	0.24	0.81	0.0069	19.2%
29	0.25	0.81	0.0069	19.9%
30	0.26	0.80	0.0068	20.6%
31	0.27	0.79	0.0068	21.3%
32	0.28	0.79	0.0067	21.9%
33	0.29	0.78	0.0066	22.6%
34	0.30	0.77	0.0066	23.3%
35	0.31	0.77	0.0065	23.9%
36	0.32	0.76	0.0065	24.5%
37	0.33	0.75	0.0064	25.2%
38	0.34	0.75	0.0064	25.8%
39	0.35	0.74	0.0063	26.5%
40	0.36	0.74	0.0063	27.1%

	A	B	C	D
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}$ $(i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ from i=0 to i
41	0.37	0.73	0.0062	27.7%
42	0.38	0.72	0.0061	28.3%
43	0.39	0.72	0.0061	28.9%
44	0.40	0.71	0.0060	29.5%
45	0.41	0.70	0.0060	30.1%
46	0.42	0.70	0.0059	30.7%
47	0.43	0.69	0.0059	31.3%
48	0.44	0.69	0.0058	31.9%
49	0.45	0.68	0.0058	32.5%
50	0.46	0.68	0.0057	33.0%
51	0.47	0.67	0.0057	33.6%
52	0.48	0.66	0.0056	34.2%
53	0.49	0.66	0.0056	34.7%
54	0.50	0.65	0.0055	35.3%
55	0.51	0.65	0.0055	35.8%
56	0.52	0.64	0.0055	36.4%
57	0.53	0.64	0.0054	36.9%
58	0.54	0.63	0.0054	37.5%
59	0.55	0.63	0.0053	38.0%
60	0.56	0.62	0.0053	38.5%
61	0.57	0.61	0.0052	39.0%
62	0.58	0.61	0.0052	39.6%
63	0.59	0.60	0.0051	40.1%
64	0.60	0.60	0.0051	40.6%
65	0.61	0.59	0.0050	41.1%
66	0.62	0.59	0.0050	41.6%
67	0.63	0.58	0.0050	42.1%
68	0.64	0.58	0.0049	42.6%
69	0.65	0.57	0.0049	43.1%
70	0.66	0.57	0.0048	43.6%
71	0.67	0.56	0.0048	44.0%
72	0.68	0.56	0.0048	44.5%
73	0.69	0.55	0.0047	45.0%
74	0.70	0.55	0.0047	45.5%
75	0.71	0.55	0.0046	45.9%
76	0.72	0.54	0.0046	46.4%
77	0.73	0.54	0.0046	46.8%
78	0.74	0.53	0.0045	47.3%

	A	B	C	D
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}\ (i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ from i=0 to i
79	0.75	0.53	0.0045	47.7%
80	0.76	0.52	0.0044	48.2%
81	0.77	0.52	0.0044	48.6%
82	0.78	0.51	0.0044	49.1%
83	0.79	0.51	0.0043	49.5%
84	0.80	0.51	0.0043	49.9%
85	0.81	0.50	0.0043	50.3%
86	0.82	0.50	0.0042	50.8%
87	0.83	0.49	0.0042	51.2%
88	0.84	0.49	0.0041	51.6%
89	0.85	0.48	0.0041	52.0%
90	0.86	0.48	0.0041	52.4%
91	0.87	0.48	0.0040	52.8%
92	0.88	0.47	0.0040	53.2%
93	0.89	0.47	0.0040	53.6%
94	0.90	0.46	0.0039	54.0%
95	0.91	0.46	0.0039	54.4%
96	0.92	0.46	0.0039	54.8%
97	0.93	0.45	0.0038	55.2%
98	0.94	0.45	0.0038	55.6%
99	0.95	0.44	0.0038	55.9%
100	0.96	0.44	0.0037	56.3%
101	0.97	0.44	0.0037	56.7%
102	0.98	0.43	0.0037	57.0%
103	0.99	0.43	0.0037	57.4%
104	1.00	0.43	0.0036	57.8%
105	1.01	0.42	0.0036	58.1%
106	1.02	0.42	0.0036	58.5%
107	1.03	0.42	0.0035	58.8%
108	1.04	0.41	0.0035	59.2%
109	1.05	0.41	0.0035	59.5%
110	1.06	0.40	0.0034	59.9%
111	1.07	0.40	0.0034	60.2%
112	1.08	0.40	0.0034	60.6%
113	1.09	0.39	0.0034	60.9%
114	1.10	0.39	0.0033	61.2%
115	1.11	0.39	0.0033	61.6%
116	1.12	0.38	0.0033	61.9%

	A	B	C	D
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}$ $(i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ from i=0 to i
117	1.13	0.38	0.0032	62.2%
118	1.14	0.38	0.0032	62.5%
119	1.15	0.37	0.0032	62.9%
120	1.16	0.37	0.0032	63.2%
121	1.17	0.37	0.0031	63.5%
122	1.18	0.37	0.0031	63.8%
123	1.19	0.36	0.0031	64.1%
124	1.20	0.36	0.0031	64.4%
125	1.21	0.36	0.0030	64.7%
126	1.22	0.35	0.0030	65.0%
127	1.23	0.35	0.0030	65.3%
128	1.24	0.35	0.0029	65.6%
129	1.25	0.34	0.0029	65.9%
130	1.26	0.34	0.0029	66.2%
131	1.27	0.34	0.0029	66.5%
132	1.28	0.34	0.0029	66.8%
133	1.29	0.33	0.0028	67.0%
134	1.30	0.33	0.0028	67.3%
135	1.31	0.33	0.0028	67.6%
136	1.32	0.32	0.0028	67.9%
137	1.33	0.32	0.0027	68.1%
138	1.34	0.32	0.0027	68.4%
139	1.35	0.32	0.0027	68.7%
140	1.36	0.31	0.0027	68.9%
141	1.37	0.31	0.0026	69.2%
142	1.38	0.31	0.0026	69.5%
143	1.39	0.31	0.0026	69.7%
144	1.40	0.30	0.0026	70.0%
145	1.41	0.30	0.0026	70.2%
146	1.42	0.30	0.0025	70.5%
147	1.43	0.30	0.0025	70.7%
148	1.44	0.29	0.0025	71.0%
149	1.45	0.29	0.0025	71.2%
150	1.46	0.29	0.0024	71.5%
151	1.47	0.29	0.0024	71.7%
152	1.48	0.28	0.0024	72.0%
153	1.49	0.28	0.0024	72.2%
154	1.50	0.28	0.0047	72.7%

	A	B	C	D
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}$ $(i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ from i=0 to i
155	1.52	0.27	0.0046	73.1%
156	1.54	0.27	0.0046	73.6%
157	1.56	0.26	0.0045	74.1%
158	1.58	0.26	0.0044	74.5%
159	1.60	0.26	0.0043	74.9%
160	1.62	0.25	0.0043	75.4%
161	1.64	0.25	0.0042	75.8%
162	1.66	0.24	0.0041	76.2%
163	1.68	0.24	0.0040	76.6%
164	1.70	0.23	0.0040	77.0%
165	1.72	0.23	0.0039	77.4%
166	1.74	0.23	0.0038	77.8%
167	1.76	0.22	0.0038	78.1%
168	1.78	0.22	0.0037	78.5%
169	1.80	0.21	0.0037	78.9%
170	1.82	0.21	0.0036	79.2%
171	1.84	0.21	0.0035	79.6%
172	1.86	0.20	0.0035	79.9%
173	1.88	0.20	0.0034	80.3%
174	1.90	0.20	0.0034	80.6%
175	1.92	0.19	0.0033	80.9%
176	1.94	0.19	0.0032	81.3%
177	1.96	0.19	0.0032	81.6%
178	1.98	0.18	0.0031	81.9%
179	2.00	0.18	0.0031	82.2%
180	2.02	0.18	0.0030	82.5%
181	2.04	0.17	0.0030	82.8%
182	2.06	0.17	0.0029	83.1%
183	2.08	0.17	0.0029	83.4%
184	2.10	0.17	0.0028	83.7%
185	2.12	0.16	0.0028	83.9%
186	2.14	0.16	0.0027	84.2%
187	2.16	0.16	0.0027	84.5%
188	2.18	0.16	0.0026	84.7%
189	2.20	0.15	0.0026	85.0%
190	2.22	0.15	0.0025	85.3%
191	2.24	0.15	0.0025	85.5%
192	2.26	0.14	0.0025	85.8%

	A	B	C	D
3	Number of Pool Turnovers n_{TO}	Fraction of Fiber Mass in Pool (Eq. 4 & 12) $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}$ $(i \geq 1)$	Fiber Mass Fraction Removed from Pool (Eq. 10) $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	Percent of Fiber Removed From Pool (Eq. 13) $\%_{fiber,removed} = \Sigma f_{r,i}$ from i=0 to i
193	2.28	0.14	0.0024	86.0%
194	2.30	0.14	0.0024	86.2%
195	2.32	0.14	0.0023	86.5%
196	2.34	0.14	0.0023	86.7%
197	2.36	0.13	0.0023	86.9%
198	2.38	0.13	0.0022	87.2%
199	2.40	0.13	0.0022	87.4%
200	2.42	0.13	0.0021	87.6%
201	2.44	0.12	0.0021	87.8%
202	2.46	0.12	0.0021	88.0%
203	2.48	0.12	0.0020	88.2%
204	2.50	0.12	0.0020	88.4%
205	2.52	0.12	0.0020	88.6%
206	2.54	0.11	0.0019	88.8%
207	2.56	0.11	0.0019	89.0%
208	2.58	0.11	0.0019	89.2%
209	2.60	0.11	0.0018	89.4%
210	2.62	0.11	0.0018	89.5%
211	2.64	0.10	0.0018	89.7%
212	2.66	0.10	0.0017	89.9%
213	2.68	0.10	0.0017	90.1%
214	2.70	0.10	0.0017	90.2%
215	2.72	0.10	0.0017	90.4%
216	2.74	0.10	0.0016	90.6%
217	2.76	0.09	0.0016	90.7%
218	2.78	0.09	0.0016	90.9%
219	2.80	0.09	0.0016	91.0%
220	2.82	0.09	0.0015	91.2%
221	2.84	0.09	0.0015	91.3%
222	2.86	0.09	0.0015	91.5%
223	2.88	0.09	0.0014	91.6%
224	2.90	0.08	0.0014	91.8%
225	2.92	0.08	0.0014	91.9%
226	2.94	0.08	0.0014	92.1%
227	2.96	0.08	0.0014	92.2%
228	2.98	0.08	0.0013	92.3%
229	3.00	0.08	0.0013	92.4%
230	3.02			

	A	B	C	D
1	Strainer Bypass Fraction, f_{bypass}		0.15	
2				
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}$ $(i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ from i=0 to i
4	0	1	=((A5-A4))*B4*(1-$C$1)	=SUM($C$4:C4)
5	=A4+0.01	=B4-C4	=((A6-A5))*B5*(1-$C$1)	=SUM($C$4:C5)
6	=A5+0.01	=B5-C5	=((A7-A6))*B6*(1-$C$1)	=SUM($C$4:C6)
7	=A6+0.01	=B6-C6	=((A8-A7))*B7*(1-$C$1)	=SUM($C$4:C7)
8	=A7+0.01	=B7-C7	=((A9-A8))*B8*(1-$C$1)	=SUM($C$4:C8)
9	=A8+0.01	=B8-C8	=((A10-A9))*B9*(1-$C$1)	=SUM($C$4:C9)
10	=A9+0.01	=B9-C9	=((A11-A10))*B10*(1-$C$1)	=SUM($C$4:C10)
11	=A10+0.01	=B10-C10	=((A12-A11))*B11*(1-$C$1)	=SUM($C$4:C11)
12	=A11+0.01	=B11-C11	=((A13-A12))*B12*(1-$C$1)	=SUM($C$4:C12)
13	=A12+0.01	=B12-C12	=((A14-A13))*B13*(1-$C$1)	=SUM($C$4:C13)
14	=A13+0.01	=B13-C13	=((A15-A14))*B14*(1-$C$1)	=SUM($C$4:C14)
15	=A14+0.01	=B14-C14	=((A16-A15))*B15*(1-$C$1)	=SUM($C$4:C15)
16	=A15+0.01	=B15-C15	=((A17-A16))*B16*(1-$C$1)	=SUM($C$4:C16)
17	=A16+0.01	=B16-C16	=((A18-A17))*B17*(1-$C$1)	=SUM($C$4:C17)
18	=A17+0.01	=B17-C17	=((A19-A18))*B18*(1-$C$1)	=SUM($C$4:C18)
19	=A18+0.01	=B18-C18	=((A20-A19))*B19*(1-$C$1)	=SUM($C$4:C19)
20	=A19+0.01	=B19-C19	=((A21-A20))*B20*(1-$C$1)	=SUM($C$4:C20)
21	=A20+0.01	=B20-C20	=((A22-A21))*B21*(1-$C$1)	=SUM($C$4:C21)
22	=A21+0.01	=B21-C21	=((A23-A22))*B22*(1-$C$1)	=SUM($C$4:C22)
23	=A22+0.01	=B22-C22	=((A24-A23))*B23*(1-$C$1)	=SUM($C$4:C23)
24	=A23+0.01	=B23-C23	=((A25-A24))*B24*(1-$C$1)	=SUM($C$4:C24)
25	=A24+0.01	=B24-C24	=((A26-A25))*B25*(1-$C$1)	=SUM($C$4:C25)
26	=A25+0.01	=B25-C25	=((A27-A26))*B26*(1-$C$1)	=SUM($C$4:C26)
27	=A26+0.01	=B26-C26	=((A28-A27))*B27*(1-$C$1)	=SUM($C$4:C27)
28	=A27+0.01	=B27-C27	=((A29-A28))*B28*(1-$C$1)	=SUM($C$4:C28)
29	=A28+0.01	=B28-C28	=((A30-A29))*B29*(1-$C$1)	=SUM($C$4:C29)
30	=A29+0.01	=B29-C29	=((A31-A30))*B30*(1-$C$1)	=SUM($C$4:C30)
31	=A30+0.01	=B30-C30	=((A32-A31))*B31*(1-$C$1)	=SUM($C$4:C31)
32	=A31+0.01	=B31-C31	=((A33-A32))*B32*(1-$C$1)	=SUM($C$4:C32)
33	=A32+0.01	=B32-C32	=((A34-A33))*B33*(1-$C$1)	=SUM($C$4:C33)
34	=A33+0.01	=B33-C33	=((A35-A34))*B34*(1-$C$1)	=SUM($C$4:C34)
35	=A34+0.01	=B34-C34	=((A36-A35))*B35*(1-$C$1)	=SUM($C$4:C35)
36	=A35+0.01	=B35-C35	=((A37-A36))*B36*(1-$C$1)	=SUM($C$4:C36)
37	=A36+0.01	=B36-C36	=((A38-A37))*B37*(1-$C$1)	=SUM($C$4:C37)
38	=A37+0.01	=B37-C37	=((A39-A38))*B38*(1-$C$1)	=SUM($C$4:C38)
39	=A38+0.01	=B38-C38	=((A40-A39))*B39*(1-$C$1)	=SUM($C$4:C39)
40	=A39+0.01	=B39-C39	=((A41-A40))*B40*(1-$C$1)	=SUM($C$4:C40)

	A	B	C	D
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}$ $(i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ *from i=0 to i*
41	=A40+0.01	=B40-C40	=((A42-A41))*B41*(1-$C$1)	=SUM($C$4:C41)
42	=A41+0.01	=B41-C41	=((A43-A42))*B42*(1-$C$1)	=SUM($C$4:C42)
43	=A42+0.01	=B42-C42	=((A44-A43))*B43*(1-$C$1)	=SUM($C$4:C43)
44	=A43+0.01	=B43-C43	=((A45-A44))*B44*(1-$C$1)	=SUM($C$4:C44)
45	=A44+0.01	=B44-C44	=((A46-A45))*B45*(1-$C$1)	=SUM($C$4:C45)
46	=A45+0.01	=B45-C45	=((A47-A46))*B46*(1-$C$1)	=SUM($C$4:C46)
47	=A46+0.01	=B46-C46	=((A48-A47))*B47*(1-$C$1)	=SUM($C$4:C47)
48	=A47+0.01	=B47-C47	=((A49-A48))*B48*(1-$C$1)	=SUM($C$4:C48)
49	=A48+0.01	=B48-C48	=((A50-A49))*B49*(1-$C$1)	=SUM($C$4:C49)
50	=A49+0.01	=B49-C49	=((A51-A50))*B50*(1-$C$1)	=SUM($C$4:C50)
51	=A50+0.01	=B50-C50	=((A52-A51))*B51*(1-$C$1)	=SUM($C$4:C51)
52	=A51+0.01	=B51-C51	=((A53-A52))*B52*(1-$C$1)	=SUM($C$4:C52)
53	=A52+0.01	=B52-C52	=((A54-A53))*B53*(1-$C$1)	=SUM($C$4:C53)
54	=A53+0.01	=B53-C53	=((A55-A54))*B54*(1-$C$1)	=SUM($C$4:C54)
55	=A54+0.01	=B54-C54	=((A56-A55))*B55*(1-$C$1)	=SUM($C$4:C55)
56	=A55+0.01	=B55-C55	=((A57-A56))*B56*(1-$C$1)	=SUM($C$4:C56)
57	=A56+0.01	=B56-C56	=((A58-A57))*B57*(1-$C$1)	=SUM($C$4:C57)
58	=A57+0.01	=B57-C57	=((A59-A58))*B58*(1-$C$1)	=SUM($C$4:C58)
59	=A58+0.01	=B58-C58	=((A60-A59))*B59*(1-$C$1)	=SUM($C$4:C59)
60	=A59+0.01	=B59-C59	=((A61-A60))*B60*(1-$C$1)	=SUM($C$4:C60)
61	=A60+0.01	=B60-C60	=((A62-A61))*B61*(1-$C$1)	=SUM($C$4:C61)
62	=A61+0.01	=B61-C61	=((A63-A62))*B62*(1-$C$1)	=SUM($C$4:C62)
63	=A62+0.01	=B62-C62	=((A64-A63))*B63*(1-$C$1)	=SUM($C$4:C63)
64	=A63+0.01	=B63-C63	=((A65-A64))*B64*(1-$C$1)	=SUM($C$4:C64)
65	=A64+0.01	=B64-C64	=((A66-A65))*B65*(1-$C$1)	=SUM($C$4:C65)
66	=A65+0.01	=B65-C65	=((A67-A66))*B66*(1-$C$1)	=SUM($C$4:C66)
67	=A66+0.01	=B66-C66	=((A68-A67))*B67*(1-$C$1)	=SUM($C$4:C67)
68	=A67+0.01	=B67-C67	=((A69-A68))*B68*(1-$C$1)	=SUM($C$4:C68)
69	=A68+0.01	=B68-C68	=((A70-A69))*B69*(1-$C$1)	=SUM($C$4:C69)
70	=A69+0.01	=B69-C69	=((A71-A70))*B70*(1-$C$1)	=SUM($C$4:C70)
71	=A70+0.01	=B70-C70	=((A72-A71))*B71*(1-$C$1)	=SUM($C$4:C71)
72	=A71+0.01	=B71-C71	=((A73-A72))*B72*(1-$C$1)	=SUM($C$4:C72)
73	=A72+0.01	=B72-C72	=((A74-A73))*B73*(1-$C$1)	=SUM($C$4:C73)
74	=A73+0.01	=B73-C73	=((A75-A74))*B74*(1-$C$1)	=SUM($C$4:C74)
75	=A74+0.01	=B74-C74	=((A76-A75))*B75*(1-$C$1)	=SUM($C$4:C75)
76	=A75+0.01	=B75-C75	=((A77-A76))*B76*(1-$C$1)	=SUM($C$4:C76)
77	=A76+0.01	=B76-C76	=((A78-A77))*B77*(1-$C$1)	=SUM($C$4:C77)
78	=A77+0.01	=B77-C77	=((A79-A78))*B78*(1-$C$1)	=SUM($C$4:C78)
79	=A78+0.01	=B78-C78	=((A80-A79))*B79*(1-$C$1)	=SUM($C$4:C79)

	A	B	C	D
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}\ (i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ *from i=0 to i*
80	=A79+0.01	=B79-C79	=((A81-A80))*B80*(1-$C$1)	=SUM($C$4:C80)
81	=A80+0.01	=B80-C80	=((A82-A81))*B81*(1-$C$1)	=SUM($C$4:C81)
82	=A81+0.01	=B81-C81	=((A83-A82))*B82*(1-$C$1)	=SUM($C$4:C82)
83	=A82+0.01	=B82-C82	=((A84-A83))*B83*(1-$C$1)	=SUM($C$4:C83)
84	=A83+0.01	=B83-C83	=((A85-A84))*B84*(1-$C$1)	=SUM($C$4:C84)
85	=A84+0.01	=B84-C84	=((A86-A85))*B85*(1-$C$1)	=SUM($C$4:C85)
86	=A85+0.01	=B85-C85	=((A87-A86))*B86*(1-$C$1)	=SUM($C$4:C86)
87	=A86+0.01	=B86-C86	=((A88-A87))*B87*(1-$C$1)	=SUM($C$4:C87)
88	=A87+0.01	=B87-C87	=((A89-A88))*B88*(1-$C$1)	=SUM($C$4:C88)
89	=A88+0.01	=B88-C88	=((A90-A89))*B89*(1-$C$1)	=SUM($C$4:C89)
90	=A89+0.01	=B89-C89	=((A91-A90))*B90*(1-$C$1)	=SUM($C$4:C90)
91	=A90+0.01	=B90-C90	=((A92-A91))*B91*(1-$C$1)	=SUM($C$4:C91)
92	=A91+0.01	=B91-C91	=((A93-A92))*B92*(1-$C$1)	=SUM($C$4:C92)
93	=A92+0.01	=B92-C92	=((A94-A93))*B93*(1-$C$1)	=SUM($C$4:C93)
94	=A93+0.01	=B93-C93	=((A95-A94))*B94*(1-$C$1)	=SUM($C$4:C94)
95	=A94+0.01	=B94-C94	=((A96-A95))*B95*(1-$C$1)	=SUM($C$4:C95)
96	=A95+0.01	=B95-C95	=((A97-A96))*B96*(1-$C$1)	=SUM($C$4:C96)
97	=A96+0.01	=B96-C96	=((A98-A97))*B97*(1-$C$1)	=SUM($C$4:C97)
98	=A97+0.01	=B97-C97	=((A99-A98))*B98*(1-$C$1)	=SUM($C$4:C98)
99	=A98+0.01	=B98-C98	=((A100-A99))*B99*(1-$C$1)	=SUM($C$4:C99)
100	=A99+0.01	=B99-C99	=((A101-A100))*B100*(1-$C$1)	=SUM($C$4:C100)
101	=A100+0.01	=B100-C100	=((A102-A101))*B101*(1-$C$1)	=SUM($C$4:C101)
102	=A101+0.01	=B101-C101	=((A103-A102))*B102*(1-$C$1)	=SUM($C$4:C102)
103	=A102+0.01	=B102-C102	=((A104-A103))*B103*(1-$C$1)	=SUM($C$4:C103)
104	=A103+0.01	=B103-C103	=((A105-A104))*B104*(1-$C$1)	=SUM($C$4:C104)
105	=A104+0.01	=B104-C104	=((A106-A105))*B105*(1-$C$1)	=SUM($C$4:C105)
106	=A105+0.01	=B105-C105	=((A107-A106))*B106*(1-$C$1)	=SUM($C$4:C106)
107	=A106+0.01	=B106-C106	=((A108-A107))*B107*(1-$C$1)	=SUM($C$4:C107)
108	=A107+0.01	=B107-C107	=((A109-A108))*B108*(1-$C$1)	=SUM($C$4:C108)
109	=A108+0.01	=B108-C108	=((A110-A109))*B109*(1-$C$1)	=SUM($C$4:C109)
110	=A109+0.01	=B109-C109	=((A111-A110))*B110*(1-$C$1)	=SUM($C$4:C110)
111	=A110+0.01	=B110-C110	=((A112-A111))*B111*(1-$C$1)	=SUM($C$4:C111)
112	=A111+0.01	=B111-C111	=((A113-A112))*B112*(1-$C$1)	=SUM($C$4:C112)
113	=A112+0.01	=B112-C112	=((A114-A113))*B113*(1-$C$1)	=SUM($C$4:C113)
114	=A113+0.01	=B113-C113	=((A115-A114))*B114*(1-$C$1)	=SUM($C$4:C114)
115	=A114+0.01	=B114-C114	=((A116-A115))*B115*(1-$C$1)	=SUM($C$4:C115)
116	=A115+0.01	=B115-C115	=((A117-A116))*B116*(1-$C$1)	=SUM($C$4:C116)
117	=A116+0.01	=B116-C116	=((A118-A117))*B117*(1-$C$1)	=SUM($C$4:C117)
118	=A117+0.01	=B117-C117	=((A119-A118))*B118*(1-$C$1)	=SUM($C$4:C118)

	A	B	C	D
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}$ $(i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ **from i=0 to i**
119	=A118+0.01	=B118-C118	=((A120-A119))*B119*(1-$C$1)	=SUM($C$4:C119)
120	=A119+0.01	=B119-C119	=((A121-A120))*B120*(1-$C$1)	=SUM($C$4:C120)
121	=A120+0.01	=B120-C120	=((A122-A121))*B121*(1-$C$1)	=SUM($C$4:C121)
122	=A121+0.01	=B121-C121	=((A123-A122))*B122*(1-$C$1)	=SUM($C$4:C122)
123	=A122+0.01	=B122-C122	=((A124-A123))*B123*(1-$C$1)	=SUM($C$4:C123)
124	=A123+0.01	=B123-C123	=((A125-A124))*B124*(1-$C$1)	=SUM($C$4:C124)
125	=A124+0.01	=B124-C124	=((A126-A125))*B125*(1-$C$1)	=SUM($C$4:C125)
126	=A125+0.01	=B125-C125	=((A127-A126))*B126*(1-$C$1)	=SUM($C$4:C126)
127	=A126+0.01	=B126-C126	=((A128-A127))*B127*(1-$C$1)	=SUM($C$4:C127)
128	=A127+0.01	=B127-C127	=((A129-A128))*B128*(1-$C$1)	=SUM($C$4:C128)
129	=A128+0.01	=B128-C128	=((A130-A129))*B129*(1-$C$1)	=SUM($C$4:C129)
130	=A129+0.01	=B129-C129	=((A131-A130))*B130*(1-$C$1)	=SUM($C$4:C130)
131	=A130+0.01	=B130-C130	=((A132-A131))*B131*(1-$C$1)	=SUM($C$4:C131)
132	=A131+0.01	=B131-C131	=((A133-A132))*B132*(1-$C$1)	=SUM($C$4:C132)
133	=A132+0.01	=B132-C132	=((A134-A133))*B133*(1-$C$1)	=SUM($C$4:C133)
134	=A133+0.01	=B133-C133	=((A135-A134))*B134*(1-$C$1)	=SUM($C$4:C134)
135	=A134+0.01	=B134-C134	=((A136-A135))*B135*(1-$C$1)	=SUM($C$4:C135)
136	=A135+0.01	=B135-C135	=((A137-A136))*B136*(1-$C$1)	=SUM($C$4:C136)
137	=A136+0.01	=B136-C136	=((A138-A137))*B137*(1-$C$1)	=SUM($C$4:C137)
138	=A137+0.01	=B137-C137	=((A139-A138))*B138*(1-$C$1)	=SUM($C$4:C138)
139	=A138+0.01	=B138-C138	=((A140-A139))*B139*(1-$C$1)	=SUM($C$4:C139)
140	=A139+0.01	=B139-C139	=((A141-A140))*B140*(1-$C$1)	=SUM($C$4:C140)
141	=A140+0.01	=B140-C140	=((A142-A141))*B141*(1-$C$1)	=SUM($C$4:C141)
142	=A141+0.01	=B141-C141	=((A143-A142))*B142*(1-$C$1)	=SUM($C$4:C142)
143	=A142+0.01	=B142-C142	=((A144-A143))*B143*(1-$C$1)	=SUM($C$4:C143)
144	=A143+0.01	=B143-C143	=((A145-A144))*B144*(1-$C$1)	=SUM($C$4:C144)
145	=A144+0.01	=B144-C144	=((A146-A145))*B145*(1-$C$1)	=SUM($C$4:C145)
146	=A145+0.01	=B145-C145	=((A147-A146))*B146*(1-$C$1)	=SUM($C$4:C146)
147	=A146+0.01	=B146-C146	=((A148-A147))*B147*(1-$C$1)	=SUM($C$4:C147)
148	=A147+0.01	=B147-C147	=((A149-A148))*B148*(1-$C$1)	=SUM($C$4:C148)
149	=A148+0.01	=B148-C148	=((A150-A149))*B149*(1-$C$1)	=SUM($C$4:C149)
150	=A149+0.01	=B149-C149	=((A151-A150))*B150*(1-$C$1)	=SUM($C$4:C150)
151	=A150+0.01	=B150-C150	=((A152-A151))*B151*(1-$C$1)	=SUM($C$4:C151)
152	=A151+0.01	=B151-C151	=((A153-A152))*B152*(1-$C$1)	=SUM($C$4:C152)
153	=A152+0.01	=B152-C152	=((A154-A153))*B153*(1-$C$1)	=SUM($C$4:C153)
154	=A153+0.01	=B153-C153	=((A155-A154))*B154*(1-$C$1)	=SUM($C$4:C154)
155	=A154+0.02	=B154-C154	=((A156-A155))*B155*(1-$C$1)	=SUM($C$4:C155)
156	=A155+0.02	=B155-C155	=((A157-A156))*B156*(1-$C$1)	=SUM($C$4:C156)
157	=A156+0.02	=B156-C156	=((A158-A157))*B157*(1-$C$1)	=SUM($C$4:C157)

	A	B	C	D
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}$ $(i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ from i=0 to i
158	=A157+0.02	=B157-C157	=((A159-A158))*B158*(1-$C$1)	=SUM($C$4:C158)
159	=A158+0.02	=B158-C158	=((A160-A159))*B159*(1-$C$1)	=SUM($C$4:C159)
160	=A159+0.02	=B159-C159	=((A161-A160))*B160*(1-$C$1)	=SUM($C$4:C160)
161	=A160+0.02	=B160-C160	=((A162-A161))*B161*(1-$C$1)	=SUM($C$4:C161)
162	=A161+0.02	=B161-C161	=((A163-A162))*B162*(1-$C$1)	=SUM($C$4:C162)
163	=A162+0.02	=B162-C162	=((A164-A163))*B163*(1-$C$1)	=SUM($C$4:C163)
164	=A163+0.02	=B163-C163	=((A165-A164))*B164*(1-$C$1)	=SUM($C$4:C164)
165	=A164+0.02	=B164-C164	=((A166-A165))*B165*(1-$C$1)	=SUM($C$4:C165)
166	=A165+0.02	=B165-C165	=((A167-A166))*B166*(1-$C$1)	=SUM($C$4:C166)
167	=A166+0.02	=B166-C166	=((A168-A167))*B167*(1-$C$1)	=SUM($C$4:C167)
168	=A167+0.02	=B167-C167	=((A169-A168))*B168*(1-$C$1)	=SUM($C$4:C168)
169	=A168+0.02	=B168-C168	=((A170-A169))*B169*(1-$C$1)	=SUM($C$4:C169)
170	=A169+0.02	=B169-C169	=((A171-A170))*B170*(1-$C$1)	=SUM($C$4:C170)
171	=A170+0.02	=B170-C170	=((A172-A171))*B171*(1-$C$1)	=SUM($C$4:C171)
172	=A171+0.02	=B171-C171	=((A173-A172))*B172*(1-$C$1)	=SUM($C$4:C172)
173	=A172+0.02	=B172-C172	=((A174-A173))*B173*(1-$C$1)	=SUM($C$4:C173)
174	=A173+0.02	=B173-C173	=((A175-A174))*B174*(1-$C$1)	=SUM($C$4:C174)
175	=A174+0.02	=B174-C174	=((A176-A175))*B175*(1-$C$1)	=SUM($C$4:C175)
176	=A175+0.02	=B175-C175	=((A177-A176))*B176*(1-$C$1)	=SUM($C$4:C176)
177	=A176+0.02	=B176-C176	=((A178-A177))*B177*(1-$C$1)	=SUM($C$4:C177)
178	=A177+0.02	=B177-C177	=((A179-A178))*B178*(1-$C$1)	=SUM($C$4:C178)
179	=A178+0.02	=B178-C178	=((A180-A179))*B179*(1-$C$1)	=SUM($C$4:C179)
180	=A179+0.02	=B179-C179	=((A181-A180))*B180*(1-$C$1)	=SUM($C$4:C180)
181	=A180+0.02	=B180-C180	=((A182-A181))*B181*(1-$C$1)	=SUM($C$4:C181)
182	=A181+0.02	=B181-C181	=((A183-A182))*B182*(1-$C$1)	=SUM($C$4:C182)
183	=A182+0.02	=B182-C182	=((A184-A183))*B183*(1-$C$1)	=SUM($C$4:C183)
184	=A183+0.02	=B183-C183	=((A185-A184))*B184*(1-$C$1)	=SUM($C$4:C184)
185	=A184+0.02	=B184-C184	=((A186-A185))*B185*(1-$C$1)	=SUM($C$4:C185)
186	=A185+0.02	=B185-C185	=((A187-A186))*B186*(1-$C$1)	=SUM($C$4:C186)
187	=A186+0.02	=B186-C186	=((A188-A187))*B187*(1-$C$1)	=SUM($C$4:C187)
188	=A187+0.02	=B187-C187	=((A189-A188))*B188*(1-$C$1)	=SUM($C$4:C188)
189	=A188+0.02	=B188-C188	=((A190-A189))*B189*(1-$C$1)	=SUM($C$4:C189)
190	=A189+0.02	=B189-C189	=((A191-A190))*B190*(1-$C$1)	=SUM($C$4:C190)
191	=A190+0.02	=B190-C190	=((A192-A191))*B191*(1-$C$1)	=SUM($C$4:C191)
192	=A191+0.02	=B191-C191	=((A193-A192))*B192*(1-$C$1)	=SUM($C$4:C192)
193	=A192+0.02	=B192-C192	=((A194-A193))*B193*(1-$C$1)	=SUM($C$4:C193)
194	=A193+0.02	=B193-C193	=((A195-A194))*B194*(1-$C$1)	=SUM($C$4:C194)
195	=A194+0.02	=B194-C194	=((A196-A195))*B195*(1-$C$1)	=SUM($C$4:C195)
196	=A195+0.02	=B195-C195	=((A197-A196))*B196*(1-$C$1)	=SUM($C$4:C196)

	A	B	C	D
3	**Number of Pool Turnovers** n_{TO}	**Fraction of Fiber Mass in Pool (Eq. 4 & 12)** $f_0 = 1.0$ $f_i = f_{i-1} - f_{r,i-1}\ (i \geq 1)$	**Fiber Mass Fraction Removed from Pool (Eq. 10)** $f_{r,i} = f_i * (n_{TO,i+1} - n_{TO,i}) * (1-f_{bypass})$	**Percent of Fiber Removed From Pool (Eq. 13)** $\%_{fiber,removed} = \Sigma f_{r,i}$ from i=0 to i
197	=A196+0.02	=B196-C196	=((A198-A197))*B197*(1-$C$1)	=SUM($C$4:C197)
198	=A197+0.02	=B197-C197	=((A199-A198))*B198*(1-$C$1)	=SUM($C$4:C198)
199	=A198+0.02	=B198-C198	=((A200-A199))*B199*(1-$C$1)	=SUM($C$4:C199)
200	=A199+0.02	=B199-C199	=((A201-A200))*B200*(1-$C$1)	=SUM($C$4:C200)
201	=A200+0.02	=B200-C200	=((A202-A201))*B201*(1-$C$1)	=SUM($C$4:C201)
202	=A201+0.02	=B201-C201	=((A203-A202))*B202*(1-$C$1)	=SUM($C$4:C202)
203	=A202+0.02	=B202-C202	=((A204-A203))*B203*(1-$C$1)	=SUM($C$4:C203)
204	=A203+0.02	=B203-C203	=((A205-A204))*B204*(1-$C$1)	=SUM($C$4:C204)
205	=A204+0.02	=B204-C204	=((A206-A205))*B205*(1-$C$1)	=SUM($C$4:C205)
206	=A205+0.02	=B205-C205	=((A207-A206))*B206*(1-$C$1)	=SUM($C$4:C206)
207	=A206+0.02	=B206-C206	=((A208-A207))*B207*(1-$C$1)	=SUM($C$4:C207)
208	=A207+0.02	=B207-C207	=((A209-A208))*B208*(1-$C$1)	=SUM($C$4:C208)
209	=A208+0.02	=B208-C208	=((A210-A209))*B209*(1-$C$1)	=SUM($C$4:C209)
210	=A209+0.02	=B209-C209	=((A211-A210))*B210*(1-$C$1)	=SUM($C$4:C210)
211	=A210+0.02	=B210-C210	=((A212-A211))*B211*(1-$C$1)	=SUM($C$4:C211)
212	=A211+0.02	=B211-C211	=((A213-A212))*B212*(1-$C$1)	=SUM($C$4:C212)
213	=A212+0.02	=B212-C212	=((A214-A213))*B213*(1-$C$1)	=SUM($C$4:C213)
214	=A213+0.02	=B213-C213	=((A215-A214))*B214*(1-$C$1)	=SUM($C$4:C214)
215	=A214+0.02	=B214-C214	=((A216-A215))*B215*(1-$C$1)	=SUM($C$4:C215)
216	=A215+0.02	=B215-C215	=((A217-A216))*B216*(1-$C$1)	=SUM($C$4:C216)
217	=A216+0.02	=B216-C216	=((A218-A217))*B217*(1-$C$1)	=SUM($C$4:C217)
218	=A217+0.02	=B217-C217	=((A219-A218))*B218*(1-$C$1)	=SUM($C$4:C218)
219	=A218+0.02	=B218-C218	=((A220-A219))*B219*(1-$C$1)	=SUM($C$4:C219)
220	=A219+0.02	=B219-C219	=((A221-A220))*B220*(1-$C$1)	=SUM($C$4:C220)
221	=A220+0.02	=B220-C220	=((A222-A221))*B221*(1-$C$1)	=SUM($C$4:C221)
222	=A221+0.02	=B221-C221	=((A223-A222))*B222*(1-$C$1)	=SUM($C$4:C222)
223	=A222+0.02	=B222-C222	=((A224-A223))*B223*(1-$C$1)	=SUM($C$4:C223)
224	=A223+0.02	=B223-C223	=((A225-A224))*B224*(1-$C$1)	=SUM($C$4:C224)
225	=A224+0.02	=B224-C224	=((A226-A225))*B225*(1-$C$1)	=SUM($C$4:C225)
226	=A225+0.02	=B225-C225	=((A227-A226))*B226*(1-$C$1)	=SUM($C$4:C226)
227	=A226+0.02	=B226-C226	=((A228-A227))*B227*(1-$C$1)	=SUM($C$4:C227)
228	=A227+0.02	=B227-C227	=((A229-A228))*B228*(1-$C$1)	=SUM($C$4:C228)
229	=A228+0.02	=B228-C228	=((A230-A229))*B229*(1-$C$1)	=SUM($C$4:C229)
230	=A229+0.02			

	A	B	C	D	E	F	G	H	I
1	Calculation / Case	**SI-90-01, Att. B, Case 1 OSG**				Calculation / Case	**SI-90-01, Att. B, Case 1 RSG**		
2	ECCS Switchover Time	t_{ECCS}	999	sec		ECCS Switchover Time	t_{ECCS}	999	sec
3	CS Switchover Time	t_{CS}	2,736	sec		CS Switchover Time	t_{CS}	2,736	sec
4	t_{CS} - t_{ECCS}	Δt	1,737	sec		t_{CS} - t_{ECCS}	Δt	1,737	sec
5	RH Flow = Recirc Flow	Q_{RH}	4,557	gpm		RH Flow = Recirc Flow	Q_{RH}	4,557	gpm
6	Number of Trains	n_{train}	1			Number of Trains	n_{train}	1	
7	Flow per Strainer	Q_{str}	4,557	gpm		Flow per Strainer	Q_{str}	4,557	gpm
8	Volume on Floor at t_{ECCS}	V_{ECCS}	9,769	ft^3		Volume on Floor at t_{ECCS}	V_{ECCS}	9,823	ft^3
9	Volume on Floor at t_{CS}	V_{CS}	25,787	ft^3		Volume on Floor at t_{CS}	V_{CS}	26,350	ft^3
10	Average Volume on Floor	V_{avg}	17,778	ft^3		Average Volume on Floor	V_{avg}	18,087	ft^3
11	Average Volume on Floor	V_{avg}	132,997	gal		Average Volume on Floor	V_{avg}	135,305	gal
12	Number of Turnovers	n_{TO}	0.99			Number of Turnovers	n_{TO}	0.98	
13									
14	Calculation / Case	**SI-90-01, Att. B, Case 2 OSG**				Calculation / Case	**SI-90-01, Att. B, Case 2 RSG**		
15	ECCS Switchover Time	t_{ECCS}	1,112	sec		ECCS Switchover Time	t_{ECCS}	1,112	sec
16	CS Switchover Time	t_{CS}	2,849	sec		CS Switchover Time	t_{CS}	2,849	sec
17	t_{CS} - t_{ECCS}	Δt	1,737	sec		t_{CS} - t_{ECCS}	Δt	1,737	sec
18	RH Flow = Recirc Flow	Q_{RH}	1,663	gpm		RH Flow = Recirc Flow	Q_{RH}	1,663	gpm
19	Number of Trains	n_{train}	1			Number of Trains	n_{train}	1	
20	Flow per Strainer	Q_{str}	1,663	gpm		Flow per Strainer	Q_{str}	1,663	gpm
21	Volume on Floor at t_{ECCS}	V_{ECCS}	9,874	ft^3		Volume on Floor at t_{ECCS}	V_{ECCS}	9,865	ft^3
22	Volume on Floor at t_{CS}	V_{CS}	25,601	ft^3		Volume on Floor at t_{CS}	V_{CS}	26,188	ft^3
23	Average Volume on Floor	V_{avg}	17,738	ft^3		Average Volume on Floor	V_{avg}	18,027	ft^3
24	Average Volume on Floor	V_{avg}	132,694	gal		Average Volume on Floor	V_{avg}	134,856	gal
25	Number of Turnovers	n_{TO}	0.36			Number of Turnovers	n_{TO}	0.36	
26									

	A	B	C	D	E	F	G	H	I
27	Calculation / Case	**SI-90-01, Att. B, Case 3 OSG**				Calculation / Case	**SI-90-01, Att. B, Case 3 RSG**		
28	ECCS Switchover Time	t_{ECCS}	1,029	sec		ECCS Switchover Time	t_{ECCS}	1,029	sec
29	CS Switchover Time	t_{CS}	2,766	sec		CS Switchover Time	t_{CS}	2,766	sec
30	t_{CS} - t_{ECCS}	Δt	1,737	sec		t_{CS} - t_{ECCS}	Δt	1,737	sec
31	RH Flow = Recirc Flow	Q_{RH}	4,557	gpm		RH Flow = Recirc Flow	Q_{RH}	4,557	gpm
32	Number of Trains	n_{train}	1			Number of Trains	n_{train}	1	
33	Flow per Strainer	Q_{str}	4,557	gpm		Flow per Strainer	Q_{str}	4,557	gpm
34	Volume on Floor at t_{ECCS}	V_{ECCS}	9,676	ft^3		Volume on Floor at t_{ECCS}	V_{ECCS}	9,728	ft^3
35	Volume on Floor at t_{CS}	V_{CS}	25,739	ft^3		Volume on Floor at t_{CS}	V_{CS}	26,308	ft^3
36	Average Volume on Floor	V_{avg}	17,708	ft^3		Average Volume on Floor	V_{avg}	18,018	ft^3
37	Average Volume on Floor	V_{avg}	132,470	gal		Average Volume on Floor	V_{avg}	134,793	gal
38	Number of Turnovers	n_{TO}	1.00			Number of Turnovers	n_{TO}	0.98	
39									
40	Calculation / Case	**SI-90-01, Att. B, Case 4 OSG**				Calculation / Case	**SI-90-01, Att. B, Case 4 RSG**		
41	ECCS Switchover Time	t_{ECCS}	574	sec		ECCS Switchover Time	t_{ECCS}	574	sec
42	CS Switchover Time	t_{CS}	1,490	sec		CS Switchover Time	t_{CS}	1,490	sec
43	t_{CS} - t_{ECCS}	Δt	916	sec		t_{CS} - t_{ECCS}	Δt	916	sec
44	RH Flow = Recirc Flow	Q_{RH}	7,797	gpm		RH Flow = Recirc Flow	Q_{RH}	7,797	gpm
45	Number of Trains	n_{train}	2			Number of Trains	n_{train}	2	
46	Flow per Strainer	Q_{str}	3,899	gpm		Flow per Strainer	Q_{str}	3,899	gpm
47	Volume on Floor at t_{ECCS}	V_{ECCS}	11,125	ft^3		Volume on Floor at t_{ECCS}	V_{ECCS}	11,317	ft^3
48	Volume on Floor at t_{CS}	V_{CS}	24,109	ft^3		Volume on Floor at t_{CS}	V_{CS}	25,338	ft^3
49	Average Volume on Floor	V_{avg}	17,617	ft^3		Average Volume on Floor	V_{avg}	18,328	ft^3
50	Average Volume on Floor	V_{avg}	131,793	gal		Average Volume on Floor	V_{avg}	137,108	gal
51	Number of Turnovers	n_{TO}	0.90			Number of Turnovers	n_{TO}	0.87	

	A	B	C	D	E	F	G	H	I
1	Calculation / Case	**SI-90-01, Att. B, Case 1 OSG**				Calculation / Case	**SI-90-01, Att. B, Case 1 RSG**		
2	ECCS Switchover Time	t_{ECCS}	999	sec		ECCS Switchover Time	t_{ECCS}	999	sec
3	CS Switchover Time	t_{CS}	2736	sec		CS Switchover Time	t_{CS}	2736	sec
4	t_{CS} - t_{ECCS}	Δt	=C3-C2	sec		t_{CS} - t_{ECCS}	Δt	=H3-H2	sec
5	RH Flow = Recirc Flow	Q_{RH}	4557	gpm		RH Flow = Recirc Flow	Q_{RH}	4557	gpm
6	Number of Trains	n_{train}	1			Number of Trains	n_{train}	1	
7	Flow per Strainer	Q_{str}	=C5/C6	gpm		Flow per Strainer	Q_{str}	=H5/H6	gpm
8	Volume on Floor at t_{ECCS}	V_{ECCS}	9769	ft^3		Volume on Floor at t_{ECCS}	V_{ECCS}	9823	ft^3
9	Volume on Floor at t_{CS}	V_{CS}	25787	ft^3		Volume on Floor at t_{CS}	V_{CS}	26350	ft^3
10	Average Volume on Floor	V_{avg}	=(C8+C9)/2	ft^3		Average Volume on Floor	V_{avg}	=(H8+H9)/2	ft^3
11	Average Volume on Floor	V_{avg}	=C10*7.481	gal		Average Volume on Floor	V_{avg}	=H10*7.481	gal
12	Number of Turnovers	n_{TO}	=C5*C4/60/C11			Number of Turnovers	n_{TO}	=H5*H4/60/H11	
13									
14	Calculation / Case	**SI-90-01, Att. B, Case 2 OSG**				Calculation / Case	**SI-90-01, Att. B, Case 2 RSG**		
15	ECCS Switchover Time	t_{ECCS}	1112	sec		ECCS Switchover Time	t_{ECCS}	1112	sec
16	CS Switchover Time	t_{CS}	2849	sec		CS Switchover Time	t_{CS}	2849	sec
17	t_{CS} - t_{ECCS}	Δt	=C16-C15	sec		t_{CS} - t_{ECCS}	Δt	=H16-H15	sec
18	RH Flow = Recirc Flow	Q_{RH}	1663	gpm		RH Flow = Recirc Flow	Q_{RH}	1663	gpm
19	Number of Trains	n_{train}	1			Number of Trains	n_{train}	1	
20	Flow per Strainer	Q_{str}	=C18/C19	gpm		Flow per Strainer	Q_{str}	=H18/H19	gpm
21	Volume on Floor at t_{ECCS}	V_{ECCS}	9874	ft^3		Volume on Floor at t_{ECCS}	V_{ECCS}	9865	ft^3
22	Volume on Floor at t_{CS}	V_{CS}	25601	ft^3		Volume on Floor at t_{CS}	V_{CS}	26188	ft^3
23	Average Volume on Floor	V_{avg}	=(C21+C22)/2	ft^3		Average Volume on Floor	V_{avg}	=(H21+H22)/2	ft^3
24	Average Volume on Floor	V_{avg}	=C23*7.481	gal		Average Volume on Floor	V_{avg}	=H23*7.481	gal
25	Number of Turnovers	n_{TO}	=C18*C17/60/C24			Number of Turnovers	n_{TO}	=H18*H17/60/H24	
26									

	A	B	C	D	E	F	G	H	I
27	Calculation / Case	**SI-90-01, Att. B, Case 3 OSG**				Calculation / Case	**SI-90-01, Att. B, Case 3 RSG**		
28	ECCS Switchover Time	t_{ECCS}	1029	sec		ECCS Switchover Time	t_{ECCS}	1029	sec
29	CS Switchover Time	t_{CS}	2766	sec		CS Switchover Time	t_{CS}	2766	sec
30	t_{CS} - t_{ECCS}	Δt	=C29-C28	sec		t_{CS} - t_{ECCS}	Δt	=H29-H28	sec
31	RH Flow = Recirc Flow	Q_{RH}	4557	gpm		RH Flow = Recirc Flow	Q_{RH}	4557	gpm
32	Number of Trains	n_{train}	1			Number of Trains	n_{train}	1	
33	Flow per Strainer	Q_{str}	=C31/C32	gpm		Flow per Strainer	Q_{str}	=H31/H32	gpm
34	Volume on Floor at t_{ECCS}	V_{ECCS}	9676	ft^3		Volume on Floor at t_{ECCS}	V_{ECCS}	9728	ft^3
35	Volume on Floor at t_{CS}	V_{CS}	25739	ft^3		Volume on Floor at t_{CS}	V_{CS}	26308	ft^3
36	Average Volume on Floor	V_{avg}	=(C34+C35)/2	ft^3		Average Volume on Floor	V_{avg}	=(H34+H35)/2	ft^3
37	Average Volume on Floor	V_{avg}	=C36*7.481	gal		Average Volume on Floor	V_{avg}	=H36*7.481	gal
38	Number of Turnovers	n_{TO}	=C31*C30/60/C37			Number of Turnovers	n_{TO}	=H31*H30/60/H37	
39									
40	Calculation / Case	**SI-90-01, Att. B, Case 4 OSG**				Calculation / Case	**SI-90-01, Att. B, Case 4 RSG**		
41	ECCS Switchover Time	t_{ECCS}	574	sec		ECCS Switchover Time	t_{ECCS}	574	sec
42	CS Switchover Time	t_{CS}	1490	sec		CS Switchover Time	t_{CS}	1490	sec
43	t_{CS} - t_{ECCS}	Δt	=C42-C41	sec		t_{CS} - t_{ECCS}	Δt	=H42-H41	sec
44	RH Flow = Recirc Flow	Q_{RH}	7797	gpm		RH Flow = Recirc Flow	Q_{RH}	7797	gpm
45	Number of Trains	n_{train}	2			Number of Trains	n_{train}	2	
46	Flow per Strainer	Q_{str}	=C44/C45	gpm		Flow per Strainer	Q_{str}	=H44/H45	gpm
47	Volume on Floor at t_{ECCS}	V_{ECCS}	11125	ft^3		Volume on Floor at t_{ECCS}	V_{ECCS}	11317	ft^3
48	Volume on Floor at t_{CS}	V_{CS}	24109	ft^3		Volume on Floor at t_{CS}	V_{CS}	25338	ft^3
49	Average Volume on Floor	V_{avg}	=(C47+C48)/2	ft^3		Average Volume on Floor	V_{avg}	=(H47+H48)/2	ft^3
50	Average Volume on Floor	V_{avg}	=C49*7.481	gal		Average Volume on Floor	V_{avg}	=H49*7.481	gal
51	Number of Turnovers	n_{TO}	=C44*C43/60/C50			Number of Turnovers	n_{TO}	=H44*H43/60/H50	

	A	B	C	D	E
1	**Calculation / Case**	**ATD-0111, App. H, BRW 1 RSG**			
2	ECCS Switchover Initiation Time	t_{ECCS}	928.7	sec	Sht 1 of ATD-0111 Appendix H
3	RH Pumps Switched Over	$t_{RH,f}$	1,156.7	sec	Sht 1 of ATD-0111 Appendix H
4	RWST Volume Remaining at $t_{RH,f}$	$V_{RWST,tRH,f}$	114,151	gal	Sht 1 of ATD-0111 Appendix H
5	RWST Outflow for $t \geq t_{RH,f}$ Assuming RWST to RH Pump Suction Isolation Valves Close	$Q_{RWST,tRH,f}$	8,752	gpm	$= Q_{CS} + Q_{CV} + Q_{SI}$; Backflow and RH pump flow from RWST do not occur if valves operate correctly.
6	RWST Level at CS Switchover Initiation	LO-3	12	%	SITH-1, p. 20
7	RWST Feet per % Level	FpP	0.54833	ft/%	SITH-1, p. 11
8	RWST Gallons per Foot	GpF	8,351.6	gal/ft	SITH-1, p. 14
9	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}$	54,953.2	gal	= LO-3 * FpP * GpF
10	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}'$	7,346.7	ft^3	$= V_{RWST,tCS,i} / 7.48\ gal/ft^3$
11	RWST Volume Injected between RH Switchover Completion and CS Switchover Initiation	$V_{tRH,f\text{-}tCS,i}$	59,197.8	gal	$= V_{RWST,tRH,f} - V_{RWST,tCS,i}$
12	Time between RH Switchover Completion and CS Switchover Initiation	$t_{tRH,f\text{-}tCS,i}$	405.8	sec	$= (V_{tRH,f\text{-}tCS,i} / Q_{RWST,tRH,f})$ * 60 sec/min ; since this is less than 412 sec, CS switchover begins prior to SI switchover completion
13	Time at CS Switchover Initiation	$t_{CS,i}$	1,562.5	sec	$= t_{RH,f} + t_{RH,f\text{-}tCS,i}$
14	Time between RH Switchover Initiation and CS Switchover Initiation	Δt	633.8	sec	$= t_{CS,i} - t_{ECCS}$
15	RH Pump Flow	Q_{RH}	7,797	gpm	Total flow to 2 RH pumps modeled since RWST to RH pump suction valves are assumed to close
16	Number of Trains in Recirc	n_{train}	2		Sht 1 of ATD-0111 Appendix H
17	Flow per Strainer	Q_{str}	3,899	gpm	$= Q_{RH} / n_{train}$
18	Volume on Floor at t_{ECCS}	V_{ECCS}	32,589	ft^3	Sht 12 of ATD-0111 Appendix H
19	Volume on Floor at ~1560 sec in ATD-0111	V_{1560}	59,798	ft^3	Sht 12 of ATD-0111 Appendix H
20	Approximate Volume on Floor at $t_{CS,i}$	V_{CS}	52,451	ft^3	$= V_{1560} - V_{RWST,tCSi}'$
21	Average Volume on Floor	V_{avg}	42,520	ft^3	$= (V_{ECCS} + V_{CS}) / 2$
22	Average Volume on Floor	V_{avg}'	318,051	gal	$= V_{avg}$ * 7.48 gal/ft^3
23	Number of Turnovers	n_{TO}	0.26		$= Q_{RH} * \Delta t / (60\ sec/min * V_{avg}')$
24					

	A	B	C	D	E
25	**Calculation / Case**	**ATD-0111, App. I, BYR 1 RSG**			
26	ECCS Switchover Initiation Time	t_{ECCS}	928.7	sec	Sht 1 of ATD-0111 Appendix I
27	RH Pumps Switched Over	$t_{RH,f}$	1,156.7	sec	Sht 1 of ATD-0111 Appendix I
28	RWST Volume Remaining at $t_{RH,f}$	$V_{RWST,tRH,f}$	114,151	gal	Sht 1 of ATD-0111 Appendix I
29	RWST Outflow for $t \geq t_{RH,f}$ Assuming RWST to RH Pump Suction Isolation Valves Close	$Q_{RWST,tRH,f}$	8,752	gpm	$= Q_{CS} + Q_{CV} + Q_{SI}$; Backflow and RH pump flow from RWST do not occur if valves operate correctly.
30	RWST Level at CS Switchover Initiation	LO-3	12	%	SITH-1, p. 20
31	RWST Feet per % Level	FpP	0.54833	ft/%	SITH-1, p. 11
32	RWST Gallons per Foot	GpF	8,351.6	gal/ft	SITH-1, p. 14
33	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}$	54,953.2	gal	= LO-3 * FpP * GpF
34	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}'$	7,346.7	ft^3	$= V_{RWST,tCS,i} / 7.48\ gal/ft^3$
35	RWST Volume Injected between RH Switchover Completion and CS Switchover Initiation	$V_{tRH,f\text{-}tCS,i}$	59,197.8	gal	$= V_{RWST,tRH,f} - V_{RWST,tCS,i}$
36	Time between RH Switchover Completion and CS Switchover Initiation	$t_{tRH,f\text{-}tCS,i}$	405.8	sec	$= (V_{tRH,f\text{-}tCS,i} / Q_{RWST,tRH,f})$ * 60 sec/min ; since this is less than 412 sec, CS switchover begins prior to SI switchover completion
37	Time at CS Switchover Initiation	$t_{CS,i}$	1,562.5	sec	$= t_{RH,f} + t_{RH,f\text{-}tCS,i}$
38	Time between RH Switchover Initiation and CS Switchover Initiation	Δt	633.8	sec	$= t_{CS,i} - t_{ECCS}$
39	RH Pump Flow	Q_{RH}	7,797	gpm	Total flow to 2 RH pumps modeled since RWST to RH pump suction valves are assumed to close
40	Number of Trains in Recirc	n_{train}	2		Sht 1 of ATD-0111 Appendix I
41	Flow per Strainer	Q_{str}	3,899	gpm	$= Q_{RH} / n_{train}$
42	Volume on Floor at t_{ECCS}	V_{ECCS}	32,655	ft^3	Sht 12 of ATD-0111 Appendix I
43	Volume on Floor at ~1560 sec in ATD-0111	V_{1560}	59,927	ft^3	Sht 12 of ATD-0111 Appendix I
44	Approximate Volume on Floor at $t_{CS,i}$	V_{CS}	52,580	ft^3	$= V_{1560} - V_{RWST,tCSi}'$
45	Average Volume on Floor	V_{avg}	42,618	ft^3	$= (V_{ECCS} + V_{CS}) / 2$
46	Average Volume on Floor	V_{avg}'	318,780	gal	$= V_{avg}$ * 7.48 gal/ft^3
47	Number of Turnovers	n_{TO}	0.26		$= Q_{RH} * \Delta t / (60\ sec/min * V_{avg}')$
48					

	A	B	C	D	E
49	**Calculation / Case**	**ATD-0111, App. J, BRW 2 OSG**			
50	ECCS Switchover Initiation Time	t_{ECCS}	928.7	sec	Sht 1 of ATD-0111 Appendix J
51	RH Pumps Switched Over	$t_{RH,f}$	1,156.7	sec	Sht 1 of ATD-0111 Appendix J
52	RWST Volume Remaining at $t_{RH,f}$	$V_{RWST,tRH,f}$	114,151	gal	Sht 1 of ATD-0111 Appendix J
53	RWST Outflow for $t \geq t_{RH,f}$ Assuming RWST to RH Pump Suction Isolation Valves Close	$Q_{RWST,tRH,f}$	8,752	gpm	= Q_{CS} + Q_{CV} + Q_{SI} ; Backflow and RH pump flow from RWST do not occur if valves operate correctly.
54	RWST Level at CS Switchover Initiation	LO-3	12	%	SITH-1, p. 20
55	RWST Feet per % Level	FpP	0.54833	ft/%	SITH-1, p. 11
56	RWST Gallons per Foot	GpF	8,351.6	gal/ft	SITH-1, p. 14
57	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}$	54,953.2	gal	= LO-3 * FpP * GpF
58	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}'$	7,346.7	ft^3	= $V_{RWST,tCS,i}$ / 7.48 gal/ft^3
59	RWST Volume Injected between RH Switchover Completion and CS Switchover Initiation	$V_{tRH,f\text{-}tCS,i}$	59,197.8	gal	= $V_{RWST,tRH,f}$ - $V_{RWST,tCS,i}$
60	Time between RH Switchover Completion and CS Switchover Initiation	$t_{tRH,f\text{-}tCS,i}$	405.8	sec	= ($V_{tRH,f\text{-}tCS,i}$ / $Q_{RWST,tRH,f}$) * 60 sec/min ; since this is less than 412 sec, CS switchover begins prior to SI switchover completion
61	Time at CS Switchover Initiation	$t_{CS,i}$	1,562.5	sec	= $t_{RH,f}$ + $t_{RH,f\text{-}tCS,i}$
62	Time between RH Switchover Initiation and CS Switchover Initiation	Δt	633.8	sec	= $t_{CS,i}$ - t_{ECCS}
63	RH Pump Flow	Q_{RH}	7,797	gpm	Total flow to 2 RH pumps modeled since RWST to RH pump suction valves are assumed to close
64	Number of Trains in Recirc	n_{train}	2		Sht 1 of ATD-0111 Appendix J
65	Flow per Strainer	Q_{str}	3,899	gpm	= Q_{RH} / n_{train}
66	Volume on Floor at t_{ECCS}	V_{ECCS}	32,144	ft^3	Sht 12 of ATD-0111 Appendix J
67	Volume on Floor at ~1560 sec in ATD-0111	V_{1560}	59,188	ft^3	Sht 12 of ATD-0111 Appendix J
68	Approximate Volume on Floor at $t_{CS,i}$	V_{CS}	51,841	ft^3	= V_{1560} - $V_{RWST,tCSi}'$
69	Average Volume on Floor	V_{avg}	41,993	ft^3	= (V_{ECCS} + V_{CS}) / 2
70	Average Volume on Floor	V_{avg}'	314,105	gal	= V_{avg} * 7.48 gal/ft^3
71	Number of Turnovers	n_{TO}	0.26		= Q_{RH} * Δt / (60 sec/min * V_{avg}')
72					

	A	B	C	D	E
73	**Calculation / Case**	**ATD-0111, App. K, BYR 2 OSG**			
74	ECCS Switchover Initiation Time	t_{ECCS}	928.7	sec	Sht 1 of ATD-0111 Appendix K
75	RH Pumps Switched Over	$t_{RH,f}$	1,156.7	sec	Sht 1 of ATD-0111 Appendix K
76	RWST Volume Remaining at $t_{RH,f}$	$V_{RWST,tRH,f}$	114,151	gal	Sht 1 of ATD-0111 Appendix K
77	RWST Outflow for $t \geq t_{RH,f}$ Assuming RWST to RH Pump Suction Isolation Valves Close	$Q_{RWST,tRH,f}$	8,752	gpm	$= Q_{CS} + Q_{CV} + Q_{SI}$; Backflow and RH pump flow from RWST do not occur if valves operate correctly.
78	RWST Level at CS Switchover Initiation	LO-3	12	%	SITH-1, p. 20
79	RWST Feet per % Level	FpP	0.54833	ft/%	SITH-1, p. 11
80	RWST Gallons per Foot	GpF	8,351.6	gal/ft	SITH-1, p. 14
81	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}$	54,953.2	gal	= LO-3 * FpP * GpF
82	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}'$	7,346.7	ft^3	$= V_{RWST,tCS,i}$ / 7.48 gal/ft^3
83	RWST Volume Injected between RH Switchover Completion and CS Switchover Initiation	$V_{tRH,f\text{-}tCS,i}$	59,197.8	gal	$= V_{RWST,tRH,f} - V_{RWST,tCS,i}$
84	Time between RH Switchover Completion and CS Switchover Initiation	$t_{tRH,f\text{-}tCS,i}$	405.8	sec	$= (V_{tRH,f\text{-}tCS,i} / Q_{RWST,tRH,f})$ * 60 sec/min ; since this is less than 412 sec, CS switchover begins prior to SI switchover completion
85	Time at CS Switchover Initiation	$t_{CS,i}$	1,562.5	sec	$= t_{RH,f} + t_{RH,f\text{-}tCS,i}$
86	Time between RH Switchover Initiation and CS Switchover Initiation	Δt	633.8	sec	$= t_{CS,i} - t_{ECCS}$
87	RH Pump Flow	Q_{RH}	7,797	gpm	Total flow to 2 RH pumps modeled since RWST to RH pump suction valves are assumed to close
88	Number of Trains in Recirc	n_{train}	2		Sht 1 of ATD-0111 Appendix K
89	Flow per Strainer	Q_{str}	3,899	gpm	$= Q_{RH} / n_{train}$
90	Volume on Floor at t_{ECCS}	V_{ECCS}	32,091	ft^3	Sht 12 of ATD-0111 Appendix K
91	Volume on Floor at ~1560 sec in ATD-0111	V_{1560}	59,185	ft^3	Sht 12 of ATD-0111 Appendix K
92	Approximate Volume on Floor at $t_{CS,i}$	V_{CS}	51,838	ft^3	$= V_{1560} - V_{RWST,tCSi}'$
93	Average Volume on Floor	V_{avg}	41,965	ft^3	$= (V_{ECCS} + V_{CS}) / 2$
94	Average Volume on Floor	V_{avg}'	313,896	gal	$= V_{avg}$ * 7.48 gal/ft^3
95	Number of Turnovers	n_{TO}	0.26		$= Q_{RH}$ * Δt / (60 sec/min * V_{avg}')

	A	B	C	D	E
1	**Calculation / Case**	**ATD-0111, App. H, BRW 1 RSG**			
2	ECCS Switchover Initiation Time	t_{ECCS}	928.7	sec	Sht 1 of ATD-0111 Appendix H
3	RH Pumps Switched Over	$t_{RH,f}$	1156.7	sec	Sht 1 of ATD-0111 Appendix H
4	RWST Volume Remaining at $t_{RH,f}$	$V_{RWST,tRH,f}$	114151	gal	Sht 1 of ATD-0111 Appendix H
5	RWST Outflow for $t \geq t_{RH,f}$ Assuming RWST to RH Pump Suction Isolation Valves Close	$Q_{RWST,tRH,f}$	=7085+831+836	gpm	= Q_{CS} + Q_{CV} + Q_{SI} ; Backflow and RH pump flow from RWST do not occur if valves operate correctly.
6	RWST Level at CS Switchover Initiation	LO-3	12	%	SITH-1, p. 20
7	RWST Feet per % Level	FpP	0.54833	ft/%	SITH-1, p. 11
8	RWST Gallons per Foot	GpF	8351.6	gal/ft	SITH-1, p. 14
9	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}$	=C6*C7*C8	gal	= LO-3 * FpP * GpF
10	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}'$	=C9/7.48	ft^3	= $V_{RWST,tCS,i}$ / 7.48 gal/ft^3
11	RWST Volume Injected between RH Switchover Completion and CS Switchover Initiation	$V_{tRH,f\text{-}tCS,i}$	=C4-C9	gal	= $V_{RWST,tRH,f}$ - $V_{RWST,tCS,i}$
12	Time between RH Switchover Completion and CS Switchover Initiation	$t_{tRH,f\text{-}tCS,i}$	=C11/C5*60	sec	= ($V_{tRH,f\text{-}tCS,i}$ / $Q_{RWST,tRH,f}$) * 60 sec/min ; since this is less than 412 sec, CS switchover begins prior to SI switchover completion
13	Time at CS Switchover Initiation	$t_{CS,i}$	=C3+C12	sec	= $t_{RH,f}$ + $t_{RH,f\text{-}tCS,i}$
14	Time between RH Switchover Initiation and CS Switchover Initiation	Δt	=C13-C2	sec	= $t_{CS,i}$ - t_{ECCS}
15	RH Pump Flow	Q_{RH}	7797	gpm	Total flow to 2 RH pumps modeled since RWST to RH pump suction valves are assumed to close
16	Number of Trains in Recirc	n_{train}	2		Sht 1 of ATD-0111 Appendix H
17	Flow per Strainer	Q_{str}	=C15/C16	gpm	= Q_{RH} / n_{train}
18	Volume on Floor at t_{ECCS}	V_{ECCS}	32589	ft^3	Sht 12 of ATD-0111 Appendix H
19	Volume on Floor at ~1560 sec in ATD-0111	V_{1560}	59798	ft^3	Sht 12 of ATD-0111 Appendix H
20	Approximate Volume on Floor at $t_{CS,i}$	V_{CS}	=C19-C10	ft^3	= V_{1560} - $V_{RWST,tCSi}'$
21	Average Volume on Floor	V_{avg}	=(C18+C20)/2	ft^3	= (V_{ECCS} + V_{CS}) / 2
22	Average Volume on Floor	V_{avg}'	=C21*7.48	gal	= V_{avg} * 7.48 gal/ft^3
23	Number of Turnovers	n_{TO}	=C15*C14/60/C22		= Q_{RH} * Δt / (60 sec/min * V_{avg}')
24					

	A	B	C	D	E
25	**Calculation / Case**	**ATD-0111, App. I, BYR 1 RSG**			
26	ECCS Switchover Initiation Time	t_{ECCS}	928.7	sec	Sht 1 of ATD-0111 Appendix I
27	RH Pumps Switched Over	$t_{RH,f}$	1156.7	sec	Sht 1 of ATD-0111 Appendix I
28	RWST Volume Remaining at $t_{RH,f}$	$V_{RWST,tRH,f}$	114151	gal	Sht 1 of ATD-0111 Appendix I
29	RWST Outflow for $t \geq t_{RH,f}$ Assuming RWST to RH Pump Suction Isolation Valves Close	$Q_{RWST,tRH,f}$	=7085+831+836	gpm	$= Q_{CS} + Q_{CV} + Q_{SI}$; Backflow and RH pump flow from RWST do not occur if valves operate correctly.
30	RWST Level at CS Switchover Initiation	LO-3	12	%	SITH-1, p. 20
31	RWST Feet per % Level	FpP	0.54833	ft/%	SITH-1, p. 11
32	RWST Gallons per Foot	GpF	8351.6	gal/ft	SITH-1, p. 14
33	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}$	=C30*C31*C32	gal	= LO-3 * FpP * GpF
34	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}'$	=C33/7.48	ft^3	$= V_{RWST,tCS,i}$ / 7.48 gal/ft^3
35	RWST Volume Injected between RH Switchover Completion and CS Switchover Initiation	$V_{tRH,f\text{-}tCS,i}$	=C28-C33	gal	$= V_{RWST,tRH,f} - V_{RWST,tCS,i}$
36	Time between RH Switchover Completion and CS Switchover Initiation	$t_{tRH,f\text{-}tCS,i}$	=C35/C29*60	sec	$= (V_{tRH,f\text{-}tCS,i} / Q_{RWST,tRH,f})$ * 60 sec/min ; since this is less than 412 sec, CS switchover begins prior to SI switchover completion
37	Time at CS Switchover Initiation	$t_{CS,i}$	=C27+C36	sec	$= t_{RH,f} + t_{RH,f\text{-}tCS,i}$
38	Time between RH Switchover Initiation and CS Switchover Initiation	Δt	=C37-C26	sec	$= t_{CS,i} - t_{ECCS}$
39	RH Pump Flow	Q_{RH}	7797	gpm	Total flow to 2 RH pumps modeled since RWST to RH pump suction valves are assumed to close
40	Number of Trains in Recirc	n_{train}	2		Sht 1 of ATD-0111 Appendix I
41	Flow per Strainer	Q_{str}	=C39/C40	gpm	$= Q_{RH} / n_{train}$
42	Volume on Floor at t_{ECCS}	V_{ECCS}	32655	ft^3	Sht 12 of ATD-0111 Appendix I
43	Volume on Floor at ~1560 sec in ATD-0111	V_{1560}	59927	ft^3	Sht 12 of ATD-0111 Appendix I
44	Approximate Volume on Floor at $t_{CS,i}$	V_{CS}	=C43-C34	ft^3	$= V_{1560} - V_{RWST,tCSi}'$
45	Average Volume on Floor	V_{avg}	=(C42+C44)/2	ft^3	$= (V_{ECCS} + V_{CS}) / 2$
46	Average Volume on Floor	V_{avg}'	=C45*7.48	gal	$= V_{avg}$ * 7.48 gal/ft^3
47	Number of Turnovers	n_{TO}	=C39*C38/60/C46		$= Q_{RH} * \Delta t / (60 \text{ sec/min} * V_{avg}')$
48					

	A	B	C	D	E
49	**Calculation / Case**	**ATD-0111, App. J, BRW 2 OSG**			
50	ECCS Switchover Initiation Time	t_{ECCS}	928.7	sec	Sht 1 of ATD-0111 Appendix J
51	RH Pumps Switched Over	$t_{RH,f}$	1156.7	sec	Sht 1 of ATD-0111 Appendix J
52	RWST Volume Remaining at $t_{RH,f}$	$V_{RWST,tRH,f}$	114151	gal	Sht 1 of ATD-0111 Appendix J
53	RWST Outflow for $t \geq t_{RH,f}$ Assuming RWST to RH Pump Suction Isolation Valves Close	$Q_{RWST,tRH,f}$	=7085+831+836	gpm	$= Q_{CS} + Q_{CV} + Q_{SI}$; Backflow and RH pump flow from RWST do not occur if valves operate correctly.
54	RWST Level at CS Switchover Initiation	LO-3	12	%	SITH-1, p. 20
55	RWST Feet per % Level	FpP	0.54833	ft/%	SITH-1, p. 11
56	RWST Gallons per Foot	GpF	8351.6	gal/ft	SITH-1, p. 14
57	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}$	=C54*C55*C56	gal	= LO-3 * FpP * GpF
58	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}'$	=C57/7.48	ft^3	$= V_{RWST,tCS,i}$ / 7.48 gal/ft^3
59	RWST Volume Injected between RH Switchover Completion and CS Switchover Initiation	$V_{tRH,f\text{-}tCS,i}$	=C52-C57	gal	$= V_{RWST,tRH,f} - V_{RWST,tCS,i}$
60	Time between RH Switchover Completion and CS Switchover Initiation	$t_{tRH,f\text{-}tCS,i}$	=C59/C53*60	sec	$= (V_{tRH,f\text{-}tCS,i} / Q_{RWST,tRH,f})$ * 60 sec/min ; since this is less than 412 sec, CS switchover begins prior to SI switchover completion
61	Time at CS Switchover Initiation	$t_{CS,i}$	=C51+C60	sec	$= t_{RH,f} + t_{RH,f\text{-}tCS,i}$
62	Time between RH Switchover Initiation and CS Switchover Initiation	Δt	=C61-C50	sec	$= t_{CS,i} - t_{ECCS}$
63	RH Pump Flow	Q_{RH}	7797	gpm	Total flow to 2 RH pumps modeled since RWST to RH pump suction valves are assumed to close
64	Number of Trains in Recirc	n_{train}	2		Sht 1 of ATD-0111 Appendix J
65	Flow per Strainer	Q_{str}	=C63/C64	gpm	$= Q_{RH} / n_{train}$
66	Volume on Floor at t_{ECCS}	V_{ECCS}	32144	ft^3	Sht 12 of ATD-0111 Appendix J
67	Volume on Floor at ~1560 sec in ATD-0111	V_{1560}	59188	ft^3	Sht 12 of ATD-0111 Appendix J
68	Approximate Volume on Floor at $t_{CS,i}$	V_{CS}	=C67-C58	ft^3	$= V_{1560} - V_{RWST,tCSi}'$
69	Average Volume on Floor	V_{avg}	=(C66+C68)/2	ft^3	$= (V_{ECCS} + V_{CS}) / 2$
70	Average Volume on Floor	V_{avg}'	=C69*7.48	gal	$= V_{avg}$ * 7.48 gal/ft^3
71	Number of Turnovers	n_{TO}	=C63*C62/60/C70		$= Q_{RH} * \Delta t$ / (60 sec/min * V_{avg}')
72					

	A	B	C	D	E
73	**Calculation / Case**	**ATD-0111, App. K, BYR 2 OSG**			
74	ECCS Switchover Initiation Time	t_{ECCS}	928.7	sec	Sht 1 of ATD-0111 Appendix K
75	RH Pumps Switched Over	$t_{RH,f}$	1156.7	sec	Sht 1 of ATD-0111 Appendix K
76	RWST Volume Remaining at $t_{RH,f}$	$V_{RWST,tRH,f}$	114151	gal	Sht 1 of ATD-0111 Appendix K
77	RWST Outflow for $t \geq t_{RH,f}$ Assuming RWST to RH Pump Suction Isolation Valves Close	$Q_{RWST,tRH,f}$	=7085+831+836	gpm	$= Q_{CS} + Q_{CV} + Q_{SI}$; Backflow and RH pump flow from RWST do not occur if valves operate correctly.
78	RWST Level at CS Switchover Initiation	LO-3	12	%	SITH-1, p. 20
79	RWST Feet per % Level	FpP	0.54833	ft/%	SITH-1, p. 11
80	RWST Gallons per Foot	GpF	8351.6	gal/ft	SITH-1, p. 14
81	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}$	=C78*C79*C80	gal	= LO-3 * FpP * GpF
82	RWST Volume at CS Switchover Initiation	$V_{RWST,tCS,i}'$	=C81/7.48	ft^3	$= V_{RWST,tCS,i} / 7.48\ gal/ft^3$
83	RWST Volume Injected between RH Switchover Completion and CS Switchover Initiation	$V_{tRH,f-tCS,i}$	=C76-C81	gal	$= V_{RWST,tRH,f} - V_{RWST,tCS,i}$
84	Time between RH Switchover Completion and CS Switchover Initiation	$t_{tRH,f-tCS,i}$	=C83/C77*60	sec	$= (V_{tRH,f-tCS,i} / Q_{RWST,tRH,f})$ * 60 sec/min ; since this is less than 412 sec, CS switchover begins prior to SI switchover completion
85	Time at CS Switchover Initiation	$t_{CS,i}$	=C75+C84	sec	$= t_{RH,f} + t_{RH,f-tCS,i}$
86	Time between RH Switchover Initiation and CS Switchover Initiation	Δt	=C85-C74	sec	$= t_{CS,i} - t_{ECCS}$
87	RH Pump Flow	Q_{RH}	7797	gpm	Total flow to 2 RH pumps modeled since RWST to RH pump suction valves are assumed to close
88	Number of Trains in Recirc	n_{train}	2		Sht 1 of ATD-0111 Appendix K
89	Flow per Strainer	Q_{str}	=C87/C88	gpm	$= Q_{RH} / n_{train}$
90	Volume on Floor at t_{ECCS}	V_{ECCS}	32091	ft^3	Sht 12 of ATD-0111 Appendix K
91	Volume on Floor at ~1560 sec in ATD-0111	V_{1560}	59185	ft^3	Sht 12 of ATD-0111 Appendix K
92	Approximate Volume on Floor at $t_{CS,i}$	V_{CS}	=C91-C82	ft^3	$= V_{1560} - V_{RWST,tCSi}'$
93	Average Volume on Floor	V_{avg}	=(C90+C92)/2	ft^3	$= (V_{ECCS} + V_{CS}) / 2$
94	Average Volume on Floor	V_{avg}'	=C93*7.48	gal	$= V_{avg}$ * 7.48 gal/ft^3
95	Number of Turnovers	n_{TO}	=C87*C86/60/C94		$= Q_{RH} * \Delta t$ / (60 sec/min * V_{avg}')

ATTACHMENT B: AVAILABLE DRIVING HEAD

1.0 Purpose

Per Limitation 1 in Section 4.0 of the Safety Evaluation to WCAP-16793 [Ref. 2.1] "Licensees should confirm that their plants are covered by the PWROG sponsored fuel assembly tests by confirming that the plant available hot-leg break driving head is equal to or greater than that determined as limiting in the proprietary fuel assembly tests." Therefore, the purpose of this attachment is to calculate the hot-leg break available driving head and compare it to the proprietary fuel assembly tests.

2.0 Design Input

2.1 Hot-Leg Centerline Elevation

Per Drawing M-196 [Ref. 2.3] the hot-leg centerline is at an elevation of 393 feet for Byron Units 1 and 2 and Braidwood Units 1 & 2.

2.2 Elevation of the Bottom of the Core

Per Drawing 113E977 [Ref. 2.2] for Byron Units 1 & 2 and Braidwood Units 1 & 2 the bottom of the active core is 206.625 inches (62.625"+144") below the center of the hot-leg (393 feet, Design Input 2.1). Therefore, the elevation of the bottom of the active core is 375.78 feet (393 – 206.625/12).

2.3 Elevation of Bottom of the Hot-Leg

The hot-leg centerline is at an elevation of 393 feet (Design Input 2.1). The hot-leg piping has an inner diameter of 29 inches [Table 5.4-5 of Ref. 2.9]. Therefore, the elevation of the bottom of the hot-leg is equal to the hot-leg centerline elevation minus half the inner diameter of the hot-leg which is equal to 391.79 feet (393-29/12/2).

2.4 Steam Generator Tube Spillover Elevation

The minimum steam generator tube spillover elevation for Byron and Braidwood Unit 1 is 431.8 feet [Ref. 2.10.10]. The minimum steam generator tube spillover elevation for Byron and Braidwood Unit 2 is determined by adding the elevation of the top of the steam generator pedestals [396.5 feet, Refs. 2.10.1-2.10.8] to the distance from the steam generator pedestal to the spillover elevation of the lowest tube [greater than 28.5 feet, Ref. 2.10.9]. This results in a steam generator tube spillover elevation of 425 feet for Byron and Braidwood Unit 2. Very minor differences in dimensions were noted across all of the steam generators across each station; however, the numbers used were selected to bias the steam generator tube spillover elevation lower which is conservative. For conservatism the lowest steam generator tube spillover elevation is used for all units.

2.5 Maximum Core Temperature Analyzed

The maximum core temperature does not have a significant impact on the available driving head; therefore, a bounding temperature of 300°F is used for this analysis. The saturation pressure at a temperature of 300°F is 67 psia which bounds the computed post-LOCA containment pressures in CN-CRA-10-54 [Ref. 2.4].

2.6 Minimum Core Temperature Analyzed

A minimum Post-LOCA sump temperature of 120°F is used which is consistent with WCAP-17057-P [Section 6.7.1 of Ref. 2.6]. The use of a lower sump temperature (i.e. 60°F) would not change the conclusions of this analysis.

3.0 Methodology

The hot-leg break available driving head is calculated using the methodology in Section 10.3.2.3 of Attachment 1 to LTR-SEE-I-10-23, Rev. 1, which is included as Attachment K to WCAP-16793-NP, Rev. 2 [Ref. 2.7]. The methodology is provided in response to RAI #18 in the PWROG Response to Request for Additional Information Regarding Topical Report WCAP-16793-NP [Ref. 2.8]. According to the SE to WCAP-16793, "if licensees maintain the 15 gram debris limit established for hot-leg breaks, the cold-leg break may be bounded by the hot-leg break," [page 15 of Ref. 2.1]. Therefore, because Byron/Braidwood meets the 15 gram per fuel assembly debris limit (see Attachment A) the cold-leg break driving head is not calculated herein.

The available hot-leg break driving head equals the elevation head in the downcomer and steam generator tubes up to the spillover elevation minus the elevation head in the core.

$$dP_{avail} = \frac{(Z_{so} - Z_{core-in})\rho_{DC}}{144} - \frac{(Z_{brk} - Z_{core-in})\rho_{core}}{144}$$

Where:
dP_{avail} = Available driving head (psi)
Z_{so} = Steam Generator tube spillover elevation (ft)
$Z_{core-in}$ = Elevation of the bottom of the core (ft)
Z_{brk} = Elevation of the bottom of the hot-leg (ft)
ρ_{DC} = density in downcomer and steam generator (lb_m/ft^3)
ρ_{core} = density in core (lb_m/ft^3)

Since it is expected that the lowest density, hottest water would be in the core, it is conservatively assumed that the density in the core is equal to the density in the downcomer and steam generator tubes (i.e. $\rho_{DC} = \rho_{core}$).

The post-LOCA water temperature in the core can range from 120°F (Design Input 2.6) to 300°F (Design Input 2.5). The density of water at the minimum and maximum analyzed temperatures is 61.7 lb_m/ft^3 and 57.3 lb_m/ft^3, respectively [Ref. 2.5].

4.0 Results

The available hot-leg break driving head therefore ranges from 13.2 to 14.2 psi.

$$dP_{avail} = \frac{(425 - 375.45)*57.3}{144} - \frac{(391.79 - 375.45)*57.3}{144} = 13.2\ psid\ at\ 300^oF$$

$$dP_{avail} = \frac{(425 - 375.45)*61.7}{144} - \frac{(391.79 - 375.45)*61.7}{144} = 14.2\ psid\ at\ 120^oF$$

The above calculation is conservative since the core density is less than the downcomer density.

5.0 Conclusions Regarding Available Driving Head

According to WCAP-17057-P [Bullet 1 on page 6-51 of Ref. 2.6], the testing with 15 grams of fiber per fuel assembly resulted in a maximum debris head loss of 2.7 psi. Therefore, Byron/Braidwood, which has less than 15 grams of fiber per fuel assembly (see Attachment A) will have an available driving head that is greater than the debris head loss.

In addition, Section 10.2 of Reference 2.7 states the following: "The AREVA testing conducted in support of this program demonstrated that 15 g of fiber/FA does not cause a blockage that will challenge LTCC, the maximum pressure drop due to debris (dP_{debris}) was very small and all plants have an available driving head (dP_{avail}) that is considerably greater. Therefore, all PWROG plants can demonstrate LTCC is not impeded if the plant-specific fibrous debris load is less than or equal to 15 g of fiber/FA."

ATTACHMENT C: MAXIMUM FLOW RATE PER FUEL ASSEMBLY

The maximum cold-leg recirculation flow is 4,212 gpm per Section 8.3 and Table 6.2 of Calculation No. BYR06-029 / BRW-06-0016-M [Ref. 2.11]. Based on 2 train operation the maximum flow rate would be 8,424 gpm (=4,212*2). The maximum flow rate per fuel assembly is calculated to be 43.6 gpm / fuel assembly and is found by dividing the maximum cold-leg recirculation flow (8,424 gpm) by the number of fuel assemblies [193 fuel assemblies, Ref. 2.9].

Note, the hot-leg recirculation flow rate in Calculation No. BYR06-029 / BRW-06-0016-M [Ref. 2.11] is slightly higher than the cold-leg recirculation flow rate. However, per page 64 of the SE for WCAP-16793-NP, Rev. 2, the potential for core blockage during hot-leg recirculation is bounded by cold-leg recirculation; therefore, using the maximum flow rate during cold-leg recirculation is appropriate. Also, the cold-leg recirculation flow is based on non-erosion cases since the erosion cases are representative of times further into the LOCA transient beyond hot leg switchover.

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Project Number: **EXE-82632**

Subject: **Sump Strainer Particle Loading**
Water samples taken during Tests 3 and 6 of Control Components Inc. (CCI) Large-Scale Performance Testing of Containment Sump Strainers November, 2005

Reference: CCI specification Q.003.84748, Rev. 2, dated 11/10/05.

Date: **02/01/2006DRAFT**

DESCRIPTION

Exelon is involved with purchasing new strainers for the containment sumps at the Exelon PWRs. This is being driven by an NRC Generic Safety Issue (GSI) 191, which involves post-LOCA debris blockage of the containment sump screens. For Byron & Braidwood the strainer manufacturer is Control Components Inc. (CCI).

Part of the testing of the replacement strainers involves determining the amount of fibrous & particulate debris which can get through the sump strainer as these contaminants can impact analysis for components downstream of the strainer (e.g. reactor fuel). This has been referred to as "strainer bypass" or efficiency. During CCI large scale strainer testing, provisions were made to take water samples of the downstream flow to assist in determining the strainer bypass efficiency for various debris constituents.

Water samples of the flow stream were shipped to the Exelon Power Labs at Wilmington, IL for assistance with determining the amount of fibers and particulate debris contained in samples of the water downstream of the new strainer. The samples were taken during performance of Tests 3 and 6 of the referenced CCI large-scale performance tests in November 2005. CCI also took downstream samples concurrently during all of the test cases. The results of this Exelon determination of fiber and particulate bypass will be used for further analysis input and as a comparison to the CCI test data.

CONCLUSIONS

1. The mg/L solids data found in Tables 1 & 2 were reported on December 2, 2005.
2. None of the material in all the Test 3 water samples was classified as large (greater than 0.083 inches).
3. Most of the particulates present in Tests 3 and 6 were non-fibrous based upon visual examination of the filters.
4. The fiber mass calculated from the estimated total fiber volume of the selected Test 6 samples indicated that most of the solids reported in Table 1 are due to non-fibrous material.

REQUIREMENTS

1. Measure the mass per volume of material on the water samples submitted. There are two sets; a fiber only set (Test # 6) and a fiber plus particulate set (Test # 3). Provide preliminary results on the first twenty samples from each set by December 8^{th} (depending on the sample receipt date). Provide preliminary results on the first twenty samples within 1 week after receipt. The balance of the results within 2 weeks.
2. Measure the fiber dimensions from selected Test 6 filter samples, so that an estimate of the mass of the fibers can be calculated.
3. Take representative photographs from the feed stock material used for Test 3, all Test 3 Filters, and selected Test 6 Filters.

TEST PLAN

TEST PLAN ON MEASURING THE AMOUNT OF DEBRIS IN STRAINER WATER SAMPLES

I. **Scope:** <u>Measure the mass per volume of debris in the downstream water samples passing through the strainer.</u>

1. Rinse all glassware with DI water before proceeding with each filtration.
2. Shake each bottle vigorously just before filtering to suspend all fiber and debris that may have settled.
3. Using a matched weight Millipore 0.8-micron filter, assemble the filtering apparatus.
4. Filter an appropriate volume of water. Record the sample bottle's weight before transferring to the filter apparatus and after filtering. The difference of the sample bottle weighings is the volume of water filtered. For very lightly loaded water, this volume might be the complete 500 ml sample.
5. If the entire bottle contents are used, rinse the bottle with DI water and add that to the filtering apparatus to be filtered.
6. Rinse the filter assembly with DI water.

7. Carefully removed each of the matched weight filters and transfer each set to glass Petri dishes.
8. Dry in an oven at 95 C (+/-3 C) for 30 minutes (ref: ASTM D2276).
9. Allow the filters to cool in a desiccator.
10. Weight both the blank filter and the sample filter on an analytical balance to 0.0001 g.

11. Calculate the PPM (mg/l) as follows:

PPM (MG/L) =(W2-W1)/V

Where W2 = Sample Weight in g
W1= Blank Weight in g
V= Volume Used in mL (assumes density of water = 1.00 g/mL)

II. **Scope:** Estimate the Relative Size of the Fibers on the filters from the Fiber Set (Test # 6). Note that this will be a visual volume estimate under a stereoscope. The longest dimension of the fiber (bundle) will be used. Use this data to calculate the mass of fiber present.

1. Verify the reticule markings with a secondary standard of known dimensions at various magnifications.
2. Photograph typical fields as necessary.
3. The particulate population consists of fiberglass, and possibly "stone flour, typically greater than 60 microns" particulate and "zinc powder, approximately 30 to 40 micron" particulate, and glass.
4. On selected samples (based on discussions with Mr. Davenport) perform length measurements of the fiberglass on the filter membrane. Verify the fiberglass fibers' diameter.
5. Under a stereoscope, examine fields of view and classify the fiberglass fiber dimensions. Measure the length of the fibers. For the purpose of this study particles are classified as follows:

Large: >/= 0.083 inches + 10 %
(0.0913 " = 2320 microns, 0.083" = 2110 microns)
Small: < 0.083 inches.

Note: Because of the magnifications used, particulate/fibers under approximately 20 microns are excluded.

6. After the total sum the numbers of fiberglass fibers and their lengths are known, their mass can be calculated using the fiberglass's density of 159-lbs/cubic foot, the measured lengths, and the measured diameters.
7. Enter the data from the fiber counting / sizing in an Excel spreadsheet for final calculations.

The assigned technician(s) are certified to perform the Project Test Plan.
Applicable Specification: ____NA________ Year/Revision: __________ N/A: ________
Test Plan Approved for Start of Work by: W. Treasurer_________________01/10/2006revised

OBSERVATIONS and DATA

AMOUNT OF DEBRIS IN STRAINER WATER SAMPLES

Tables 1 & 2 summarize the gravimetric determination of the total mass in the submitted water samples. The total volume of the submitted water samples (ranged from 450 to 480 mL) was used for these measurements to maximize the test's sensitivity. It should be noted that the number of filter sets per sample varied from 1 to 8 depending on the particulate density. All the Test 6 samples and Nos. 13-30 Test 3 samples were weighed on single sets of filters. Test 3 Nos. 7-12 was weighed on 2 filter sets, Nos. 5 & 6 used 3, No. 4 used 4, No. 3 used 5, No. 2 used 7 and Test 3 No. 1 used 8 filter sets. This sub sampling was performed to provide an opportunity for subsequent visual particle counting.

Table 1
Test 6, November 15, 2005

Time	Number	Solids mg/L		Time	Number	Solids mg/L
16:30:00	1	9		17:07:30	16	<1
16:32:30	2	37		17:10:00	17	2
16:35:00	3	12		17:12:30	18	3
16:37:30	4	36		17:15:00	19	4
16:40:00	5	6		17:17:30	20	4
16:42:30	6	13		17:20:00	21	4
16:45:00	7	7		17:22:30	22	6
16:47:30	8	6		17:25:00	23	4
16:50:00	9	4		17:27:30	24	4
16:52:30	10	5		17:30:00	25	5
16:55:00	11	4		17:32:30	26	5
16:57:30	12	2		17:35:00	27	5
17:00:00	13	2		17:37:30	28	4
17:02:30	14	<1		17:40:00	29	5
17:05:00	15	1		17:42:30	30	5

Table 2
Test 3, November 17, 2005

Time	Number	Solids mg/L		Time	Number	Solids mg/L
8:45:00	1	852		10:00:00	16	10
8:50:00	2	356		10:05:00	17	7
8:55:00	3	262		10:10:00	18	5
9:00:00	4	137		10:15:00	19	6
9:05:00	5	84		10:20:00	20	4
NA	6	65		10:25:00	21	5
9:15:00	7	53		10:30:00	22	2
9:20:00	8	39		10:35:00	23	3
9:25:00	9	28		10:40:00	24	2
9:30:00	10	21		10:45:00	25	1
9:35:00	11	19		10:50:00	26	1
9:40:00	12	23		10:55:00	27	3
9:45:00	13	17		11:00:00	28	4
9:50:00	14	14		11:05:00	29	1
9:55:00	15	12		11:10:00	30	<1

CALCULATION OF MASS OF FIBERGLASS FIBERS IN TEST 6 SAMPLES

Based on the reported values in Table 1, it was agreed to calculate the mass of fiberglass fibers in Samples 1, 2, 3, 5, 8, 11 and 14 from Test 6.

Determination of Fiberglass Fiber Diameter

Fifteen random fibers were measured (from filters 6-8, 6-11, & 6-14) on the scanning electron microscope (SEM) for their diameters. The diameters ranged from 4.99 to 13.1 microns, with an average diameter of 8.45 microns. There were also some fibers coated with a zinc crystalline compound. This phenomenon was only on the fibers from the actual test samples. The sample of fiberglass used in Tests 3 and 6 did not have the zinc coating.

The following are samples of photographs taken on the SEM of various fibers (see Photographs 1-5 and Spectrum 1 & 2). The average diameter of 8.45 microns and maximum diameter of 13.1 were both used to calculate the estimated mass of fiberglass present.

Counting and Measuring Fiberglass Fibers

The counting and measuring of the fiberglass fibers was performed with a stereomicroscope at 110X. One hundred percent of the fibers were counted for all the selected Set 6 samples except for Sample 1. For Sample 1 the uniform fiber distribution and density permitted that random fields of views could be used. The fibers were long rods, varying from straight to curved. Individual fibers lengths were measured. Many fibers bundled (typically bundles of 2 to 5 fibers). In these cases an effort was made to measure each fiber of the bundle. When the fibers were curved the lengths were a best estimate.

It should be noted that there were many more non-fibrous particles than the fiberglass.

Photograph 6 is of a graticle at the 110X magnification. Each division is 10 microns longs. The fibers counted ranged from 100 to greater than 21,000 microns in length, but were generally in the 100 to 1000 micron range.

Calculation of the Estimated Mass of Fiberglass Fibers in Test 6 Samples

Table 3 summarizes the calculated mg/L density based on the provided fiberglass density (159 # / ft^3), the measured fiber lengths, and the average fiber diameter or the maximum fiber diameter. Test 6 was performed on 11/15/2005.

In performing this type of testing various errors are possible. There is an uncertainty due to the variability of the fiberglass fiber's diameter. Because of this the mass calculation based on the mean and maximum fiber diameter was provided. There are also inaccuracies in determining fiber lengths due to the non-linear nature of many of the fibers, and miss-counting fibers due to that are hidden under other solids. There is a potential of missing or double counting fibers as the filter surface is scanned.

Table 3 – Calculated Mass from Estimated Fiber Volume Measurements

Test # 6 (11-15-05)	6-1	6-2	6-3	6-5	6-8	6-11	6-14
Time	1630	1632:30	1635	1640	1647:30	1655	1702:30
# of Fibers Counted	98*	1158	261	233	88	93	35
mg/L Fiberglass, using average diameter	1.0	0.71	0.14	0.13	0.06	0.06	0.01
mg/L Fiberglass, using maximum diameter	2.5	1.7	0.34	0.31	0.14	0.13	0.05
Total Suspended Solids from gravimetric measurements, mg/L	9 (9.1)	37 (36.7)	12 (11.6)	6 (5.8)	6 (5.5)	4 (3.6)	<1 (0.4)

* Because of uniform distribution and high fiber density, only ten areas of view (approximately one thirtieth of the total filter area) were counted. The factor of 29.7 was then used to calculate the fiber concentration.

PHOTOGRAPHS OF FEED STOCK MATERIAL and FILTERS

Fields of view of selected Test 6 and all Test 3 filters were taken.

Photographs 7 to 22 are of the Test 6 samples that were counted in Table 3. All Photographs were taken at 110X. What should be noted in these pictures is that with the exception of Sample 6-1, there are many more non-fibrous particles present than the fiberglass fibers.

Photographs 23 to 26 were taken at 110X of the feedstock that was used for Test 3. The feedstock was fiberglass, pieces of glass, zinc powder (IOZ) and stone flour.

Photographs 27 through 89 were taken to document the material collected on the filters for Test 3. There are photographs at both 18 and 110 X of each filter.

COMMENTS

Data was provided to Mr. Davenport as it became available.

STATEMENT OF QUALITY

Testing was performed with standards and/or equipment that have accuracies traceable to nationally recognized standards or to physical constants, by qualified personnel, and in accordance with the **Exelon** PowerLabs Quality Assurance Program revision 17 dated 08/30/2005.

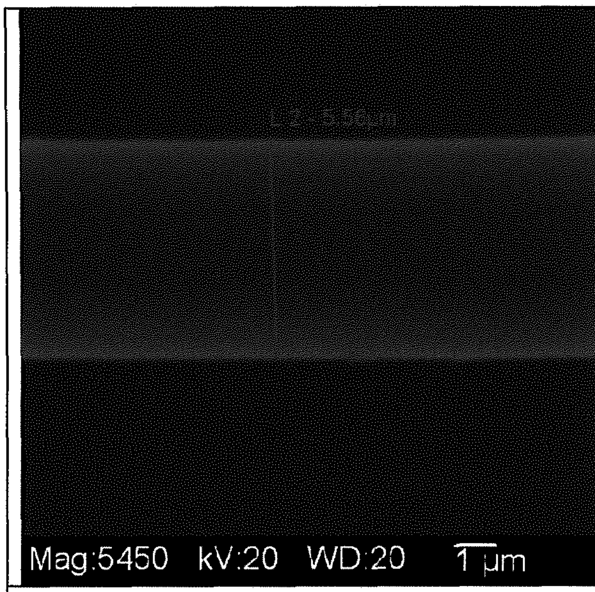
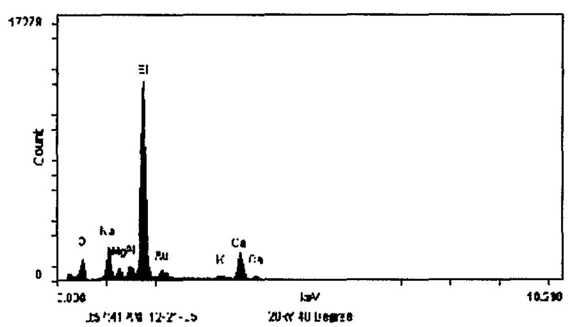
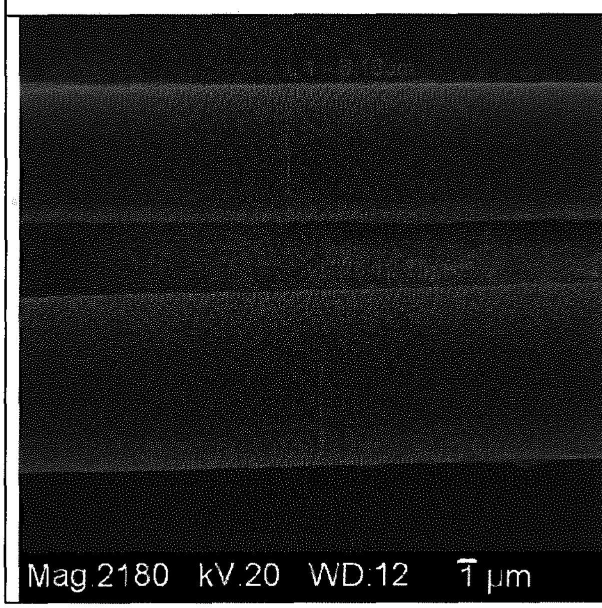
Technician(s): W. Treasurer

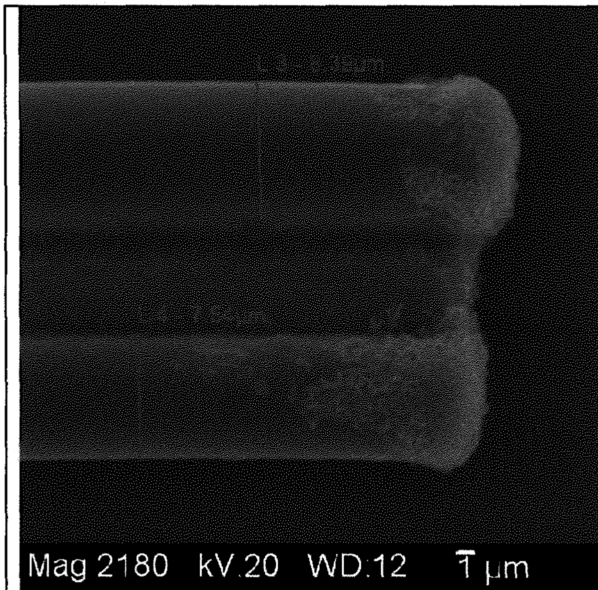
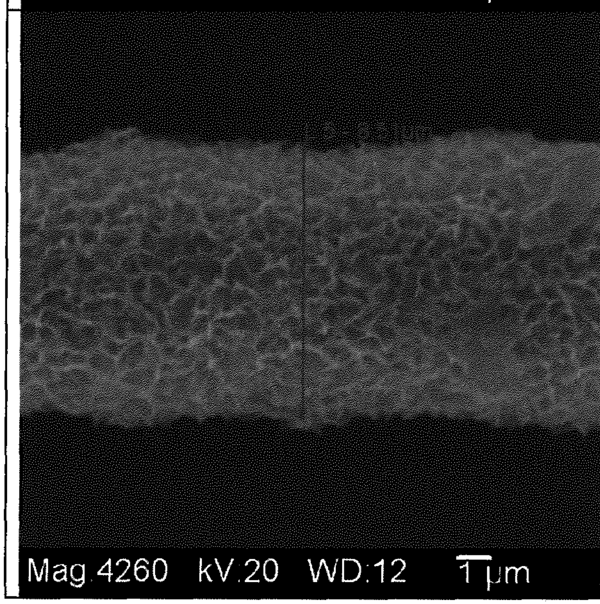
Prepared by: ______________(signed original in file)

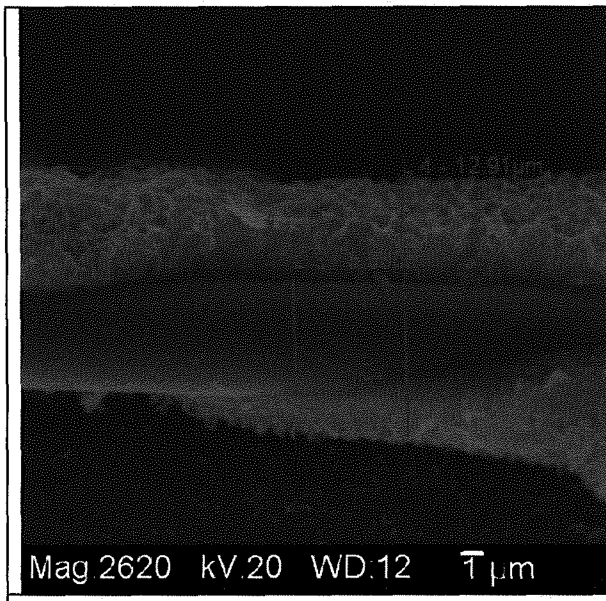
Approved by: ______________(signed original in file)
Title xx/xx/2005

cc: J. Panici, Mod Design, Braidwood
K. Dhaese, Mod Design, Byron.
I. Garza, Sargent Lundy
B. Davenport, Mechanical/Structural Engineering, Cantera

Fiber Diameter Characterization

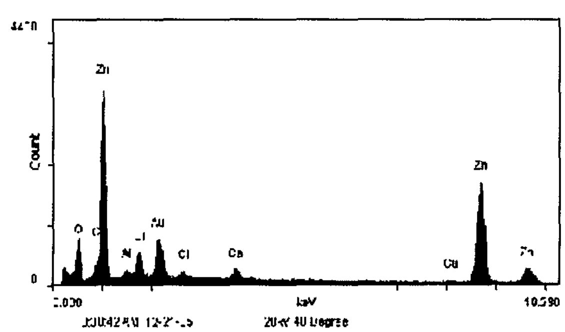
	**Photograph 1** **Fiberglass Feedstock used in Test 6. The diameters varied from 5 to almost 10 microns. No zinc deposition was seen. The length to width ratio was in excess of 10:1.**
	**Spectrum 1** **Typical EDXA spectrum of fiberglass; it is primarily silicon with lesser amounts of sodium, calcium, oxygen, aluminum, magnesium and potassium. There is a small gold peak because the fibers were gold-coated as part of the SEM preparation.**
	**Photograph 2** **Some fibers from 6-11**

	**Photograph 3** **More fibers from 6-11, note that they are joined (bundled) along the axis**
	**Photograph 4** **Close-up of a fiber that has been coated with a zinc compound from 6-11**



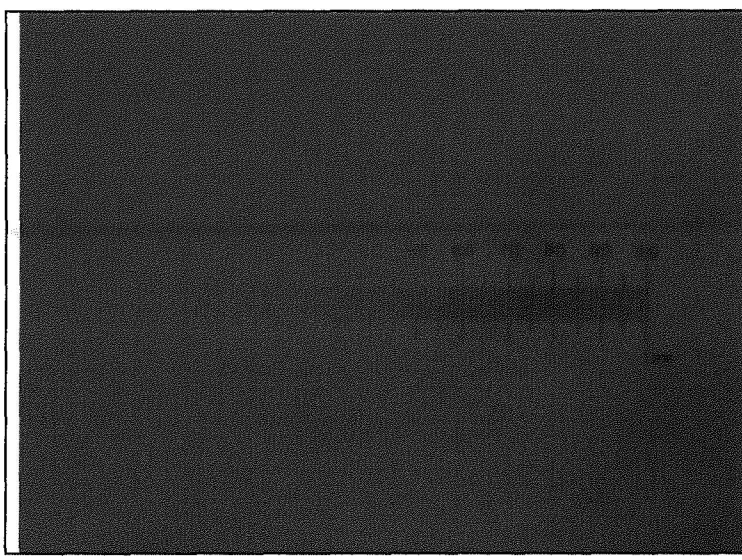
Photograph 5

Coated fiber showing fiberglass core and zinc coating



Spectrum 2

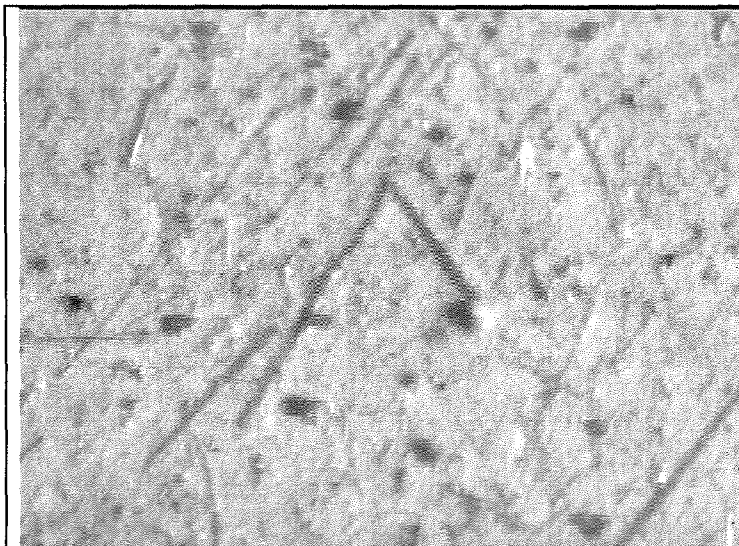
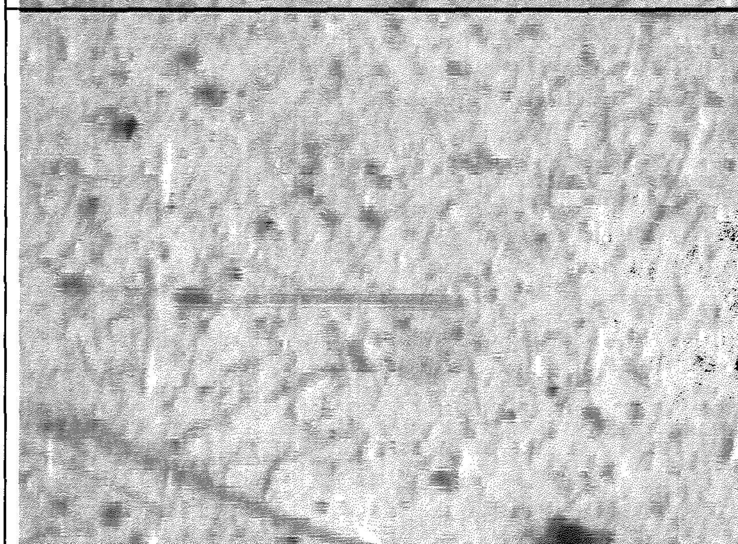
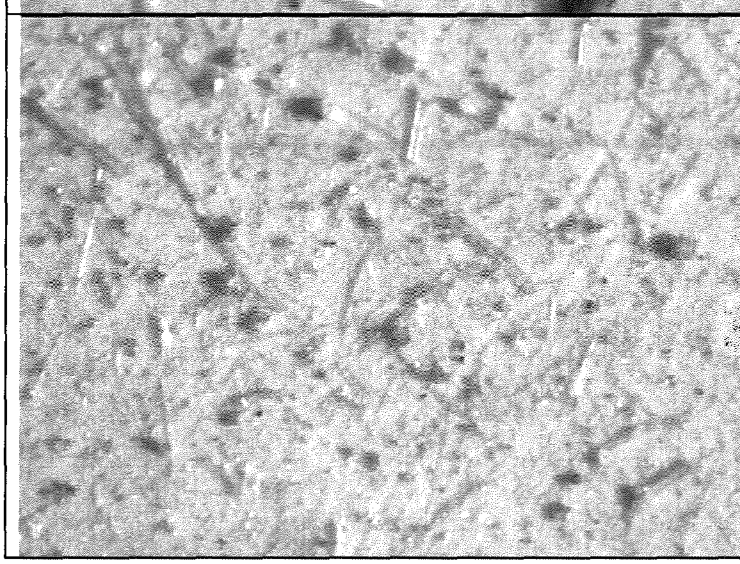
EDXA of the zinc coating on the fiber

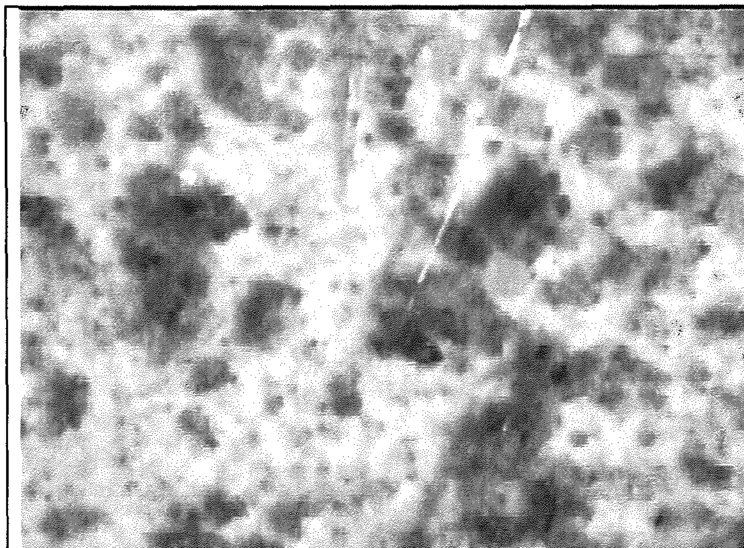
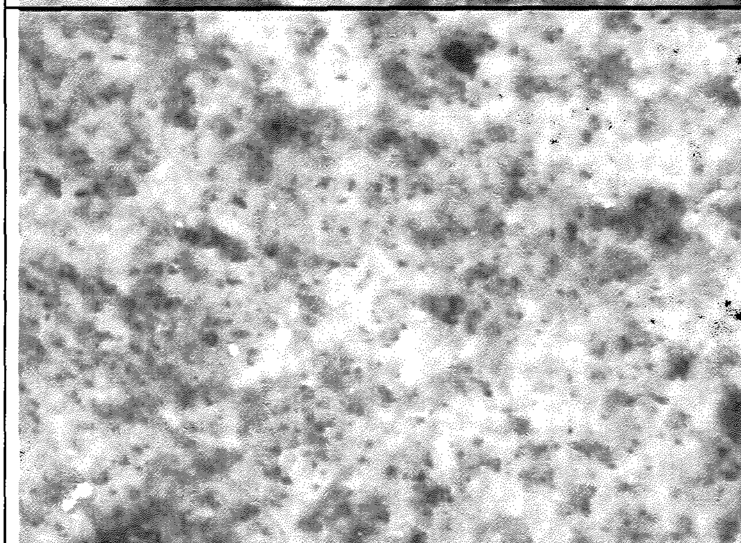
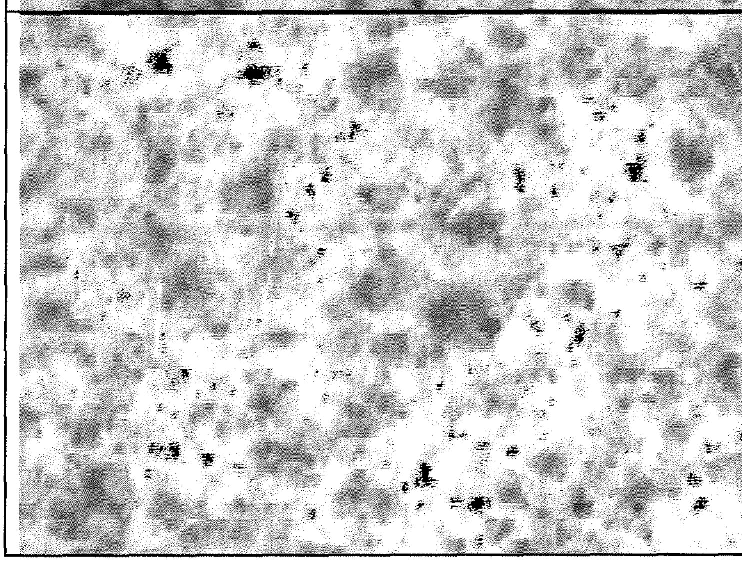


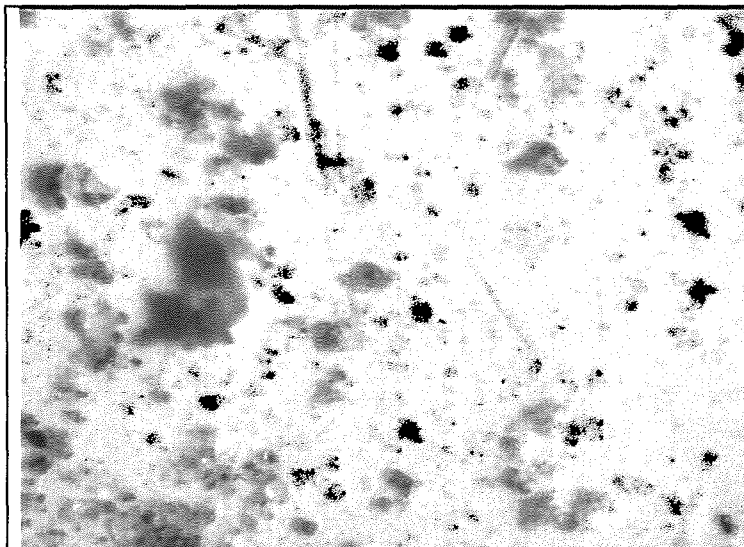
Photograph 6

This is a photograph of a graticle scale at approximately 110 X. Each division is 10 microns; the entire length is 1000 micron.

Photographs of the Filters at 110X

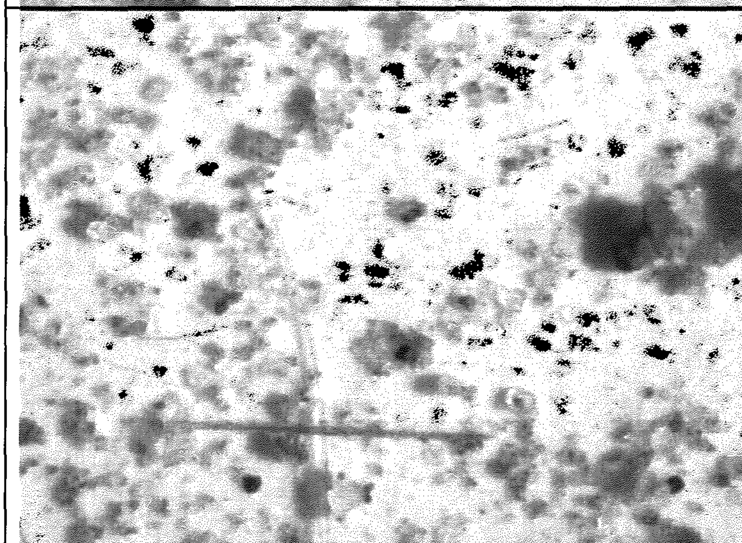
	**Photograph 7** **Filter 6-1, View 1**
	**Photograph 8** **Filter 6-1, View 2**
	**Photograph 9** **Filter 6-1, View 3**

	**Photograph 10** **6-2, View 1**
	**Photograph 11** **6-2, View 2**
	**Photograph 12** **6-2, View 3**



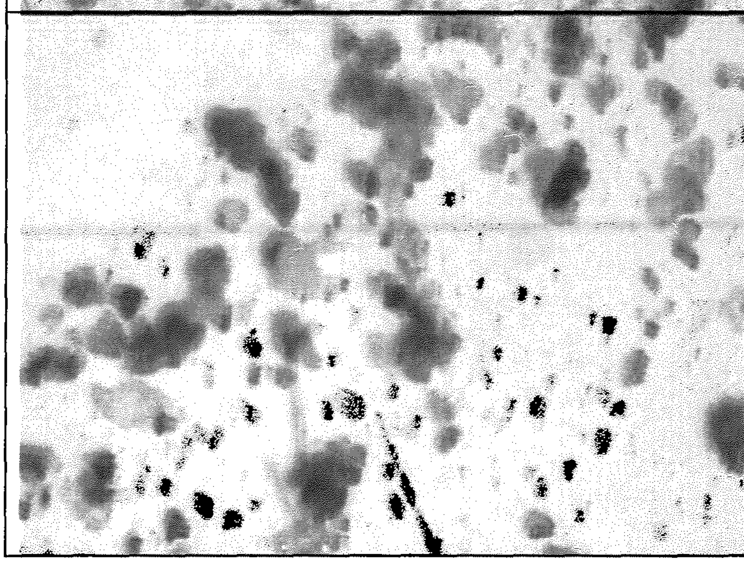
Photograph 13

Filter 6-3, View 1



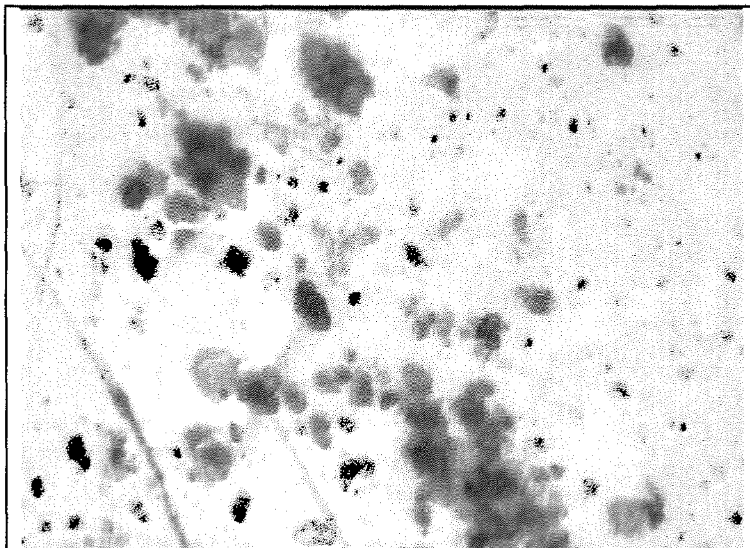
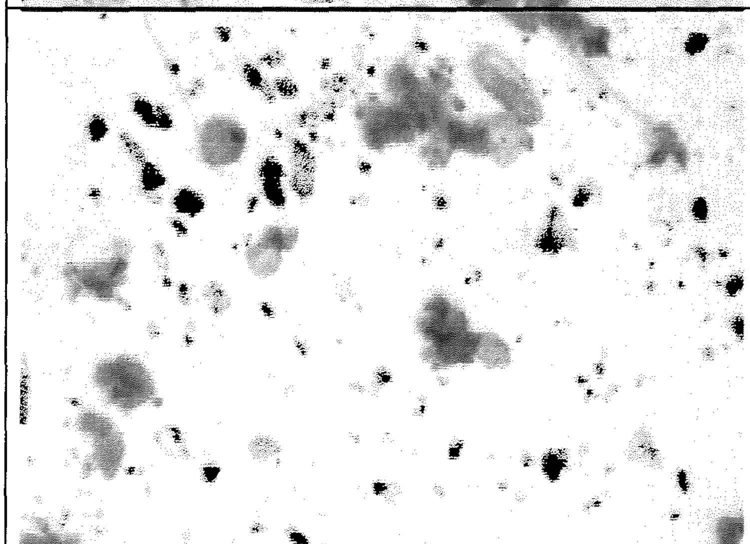
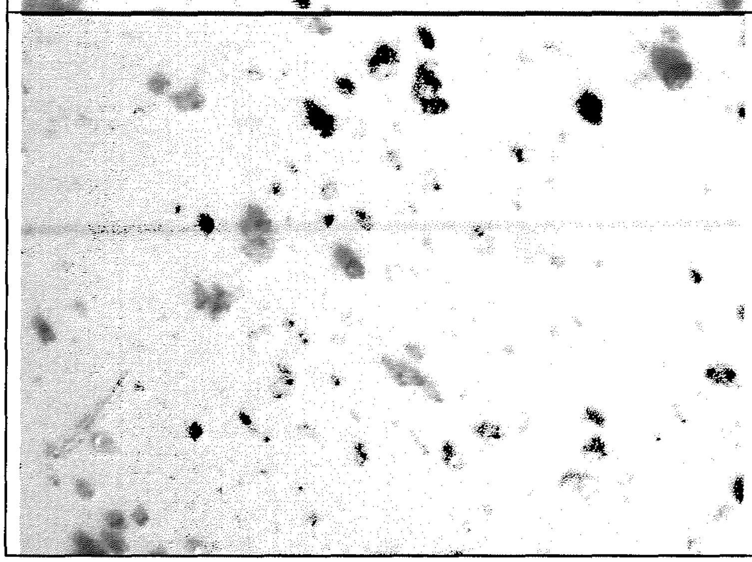
Photograph 14

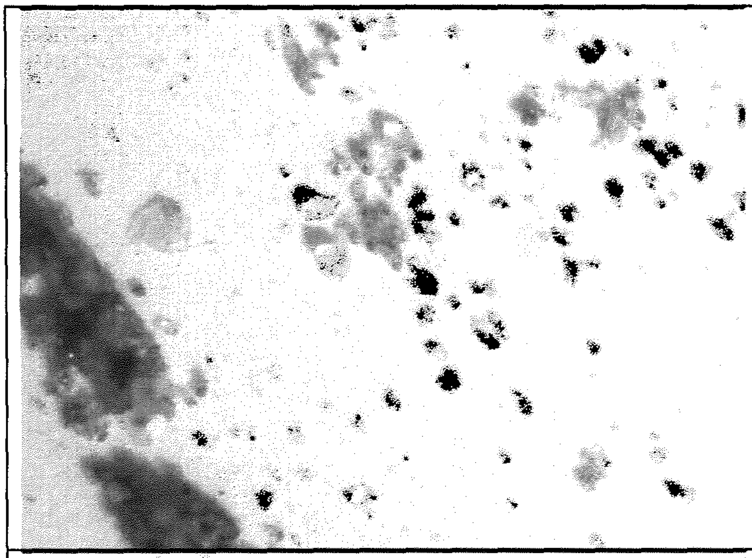
Filter 6-3, View 2



Photograph 15

Filter 6-5, View 1

	**Photograph 16** **Filter 6-5, View 2**
	**Photograph 17** **Filter 6-5, View 3**
	**Photograph 18** **Filter 6-8, View 1**

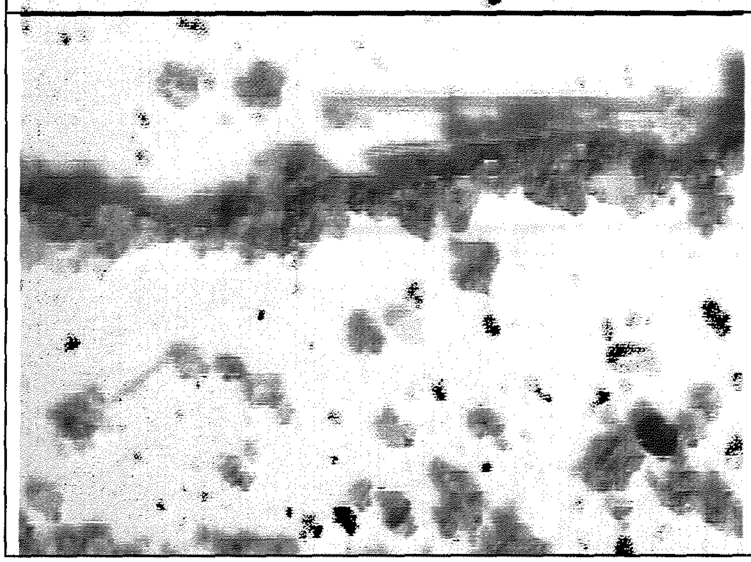


Photograph 19

Filter 6-8, View 2

Photograph 20

Filter 6-11, View 1



Photograph 21

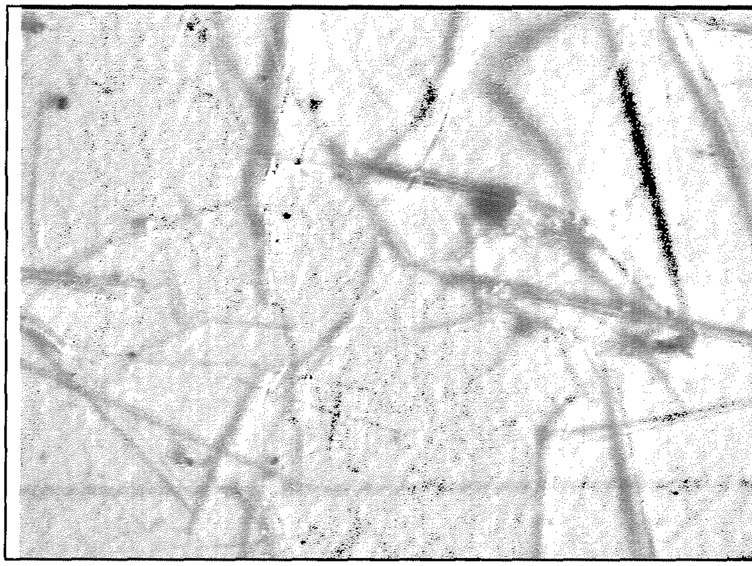
Filter 6-11, View 2

Photograph 22

Filter 6-14, View 1

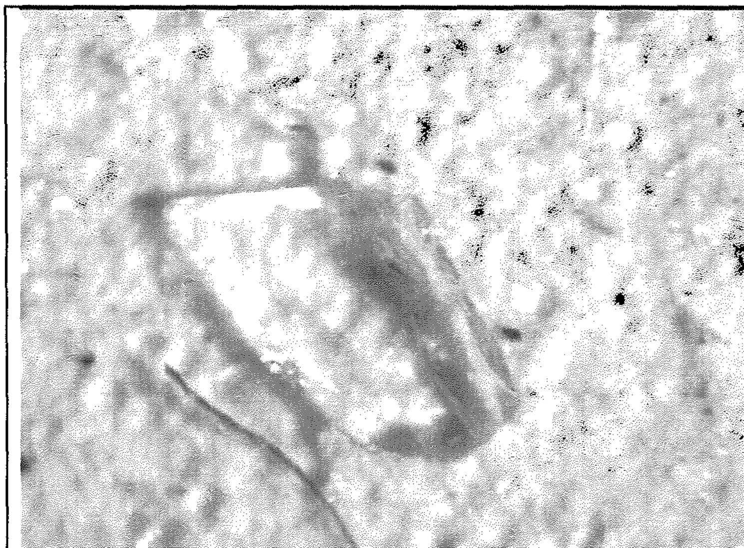
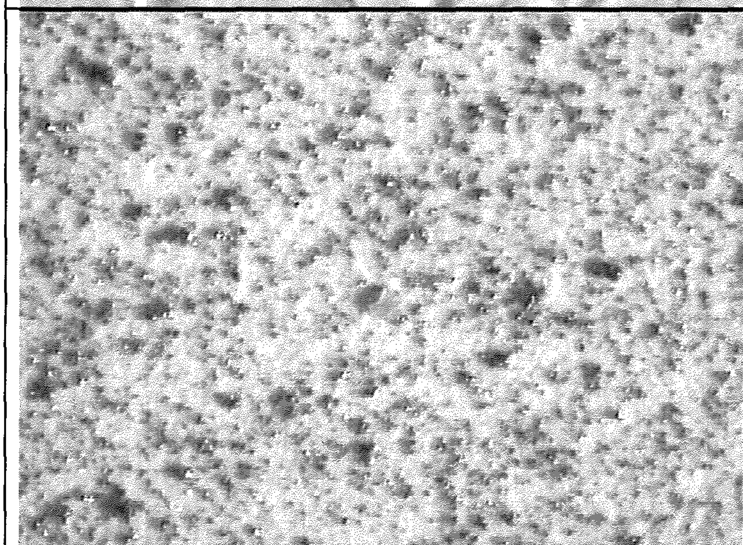
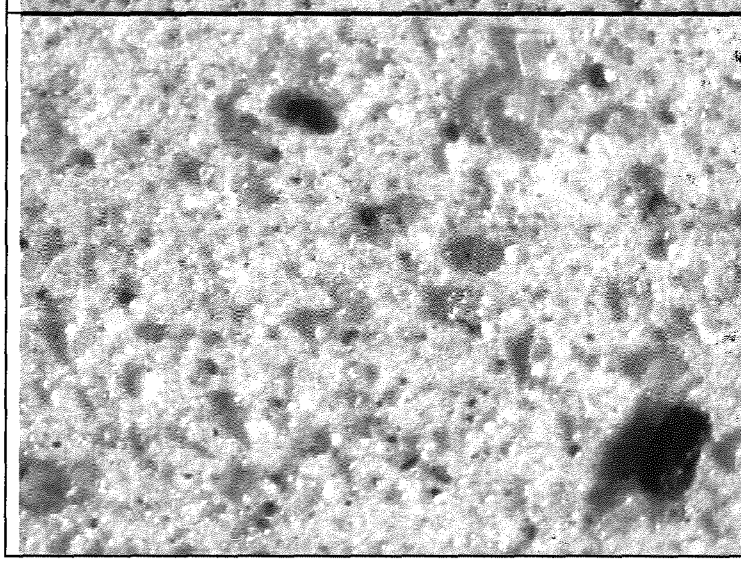
Photographs of the Feed Stock Materials at 110X

The following are photographs of the materials used for Test 3 taken with the stereomicroscope at 110X.

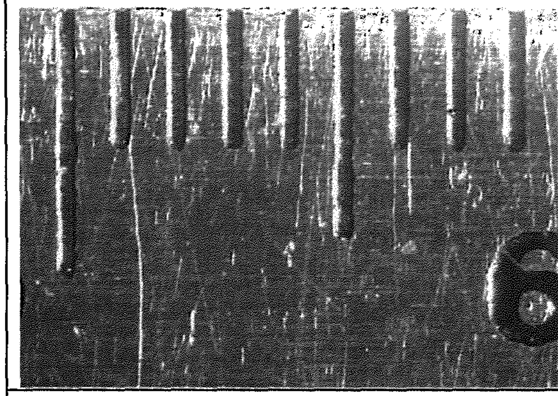
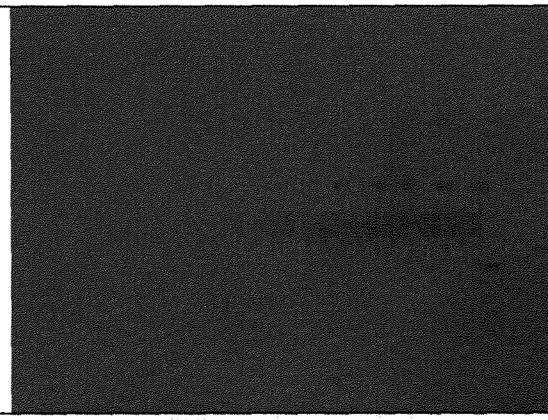
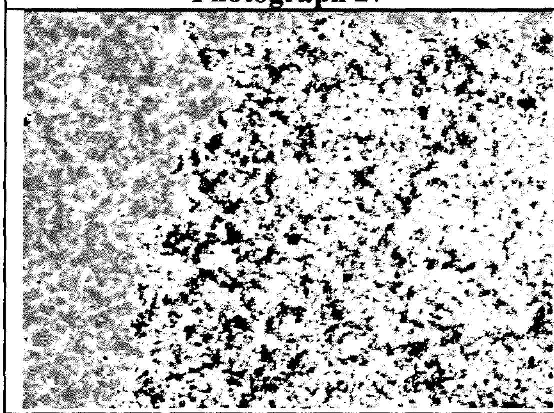
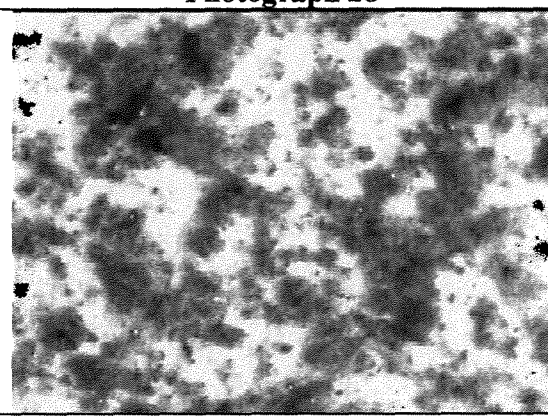
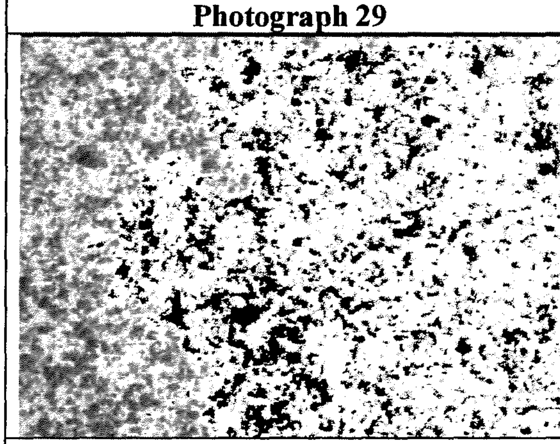
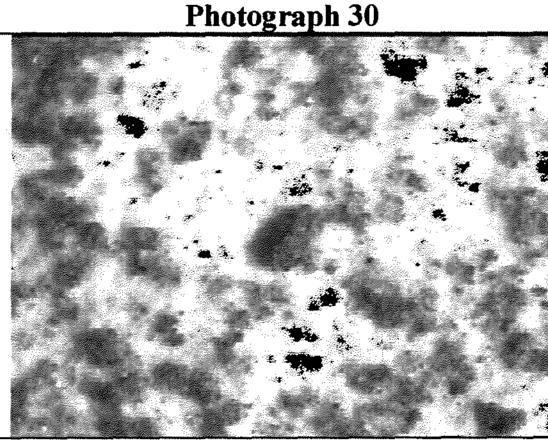


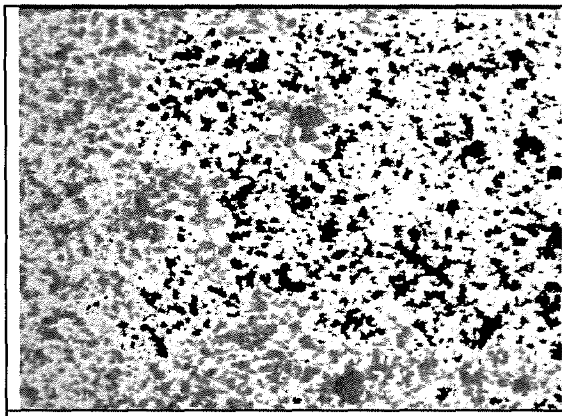
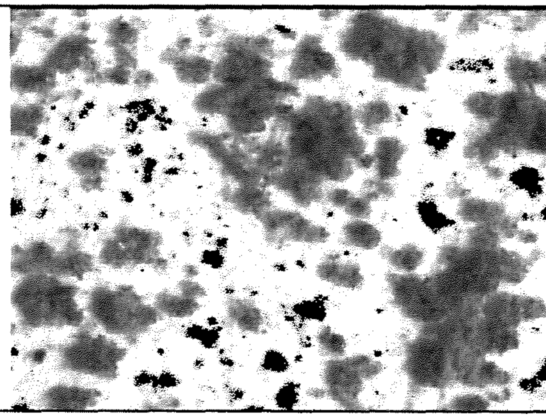
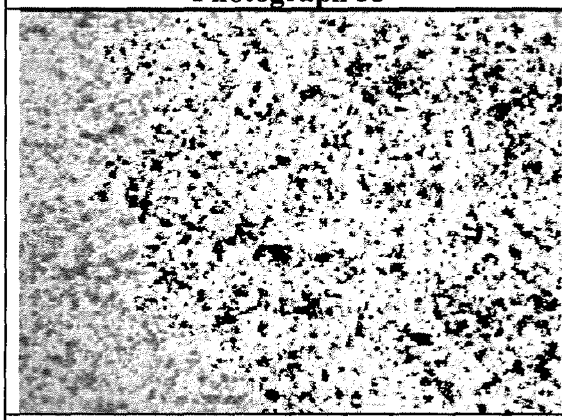
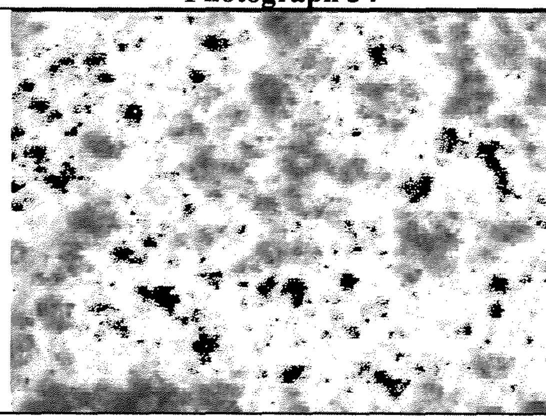
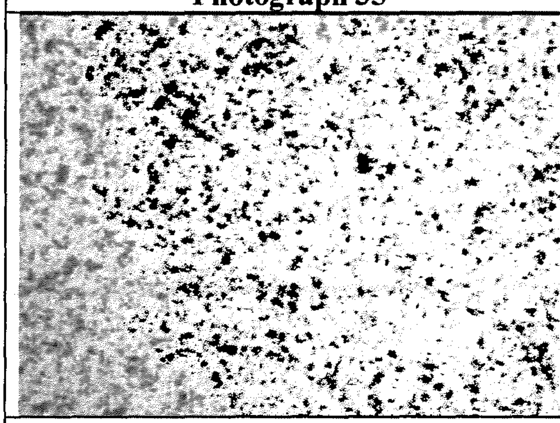
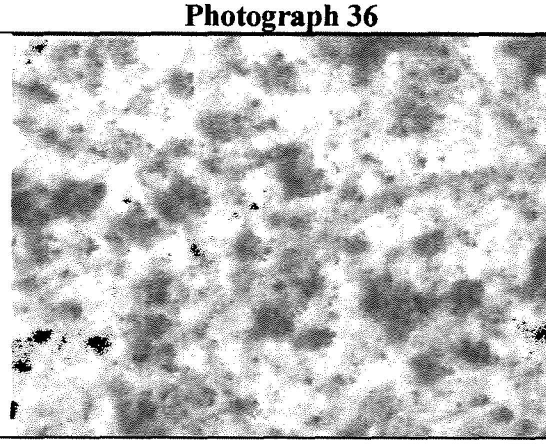
Photograph 23

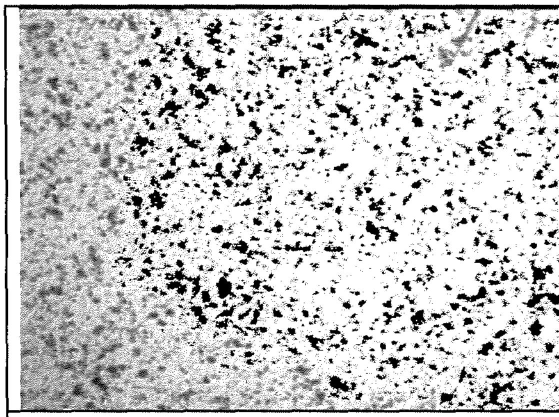
Fiberglass

	**Photograph 24** **Glass, Much of the glass used were larger fragments than this one.**
	**Photograph 25** **Zinc Powder, IOZ**
	**Photograph 26** **Stone Flour**

Photographs from Test 3

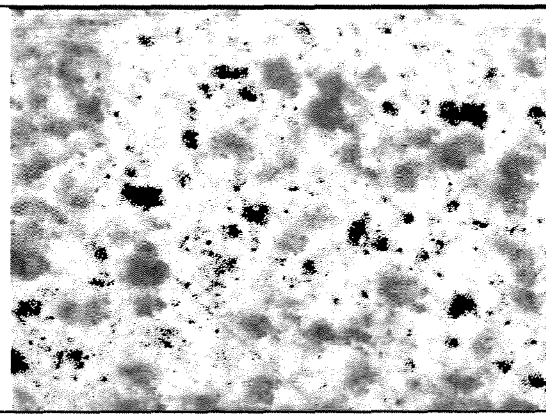
	
mm Scale, at 18X, each division is 1000 microns (1 mm) **Photograph 27**	**Graticle scale at approximately 110 X. Each division is 10 microns; the entire length is 1000 micron.** **Photograph 28**
	
3-1, at 18X **Photograph 29**	**3-1, at 110X** **Photograph 30**
	
3-2, at 18X **Photograph 31**	**3-2, at 110X** **Photograph 32**

	
3-3, at 18X **Photograph 33**	**3-3, at 110X** **Photograph 34**
	
3-4, at 18X **Photograph 35**	**3-4, at 110X** **Photograph 36**
	
3-5, at 18X **Photograph 37**	**3-5, at 110X** **Photograph 38**



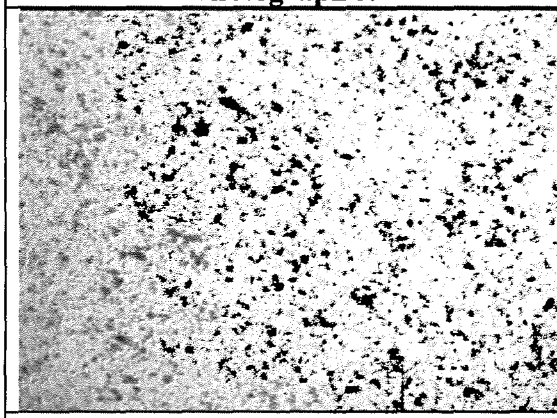
3-6, at 18X

Photograph 39



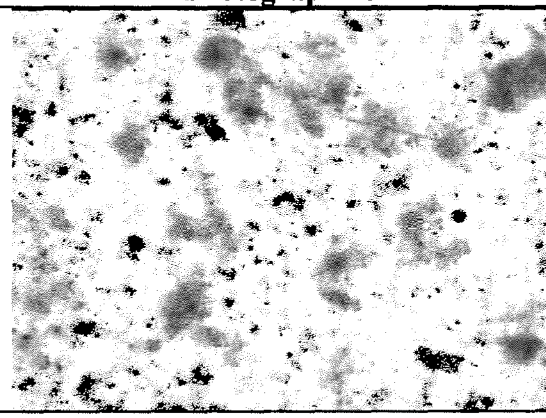
3-6, at 110X

Photograph 40



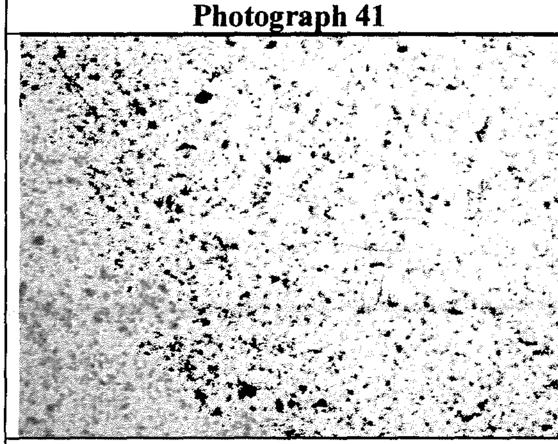
3-7, at 18X

Photograph 41



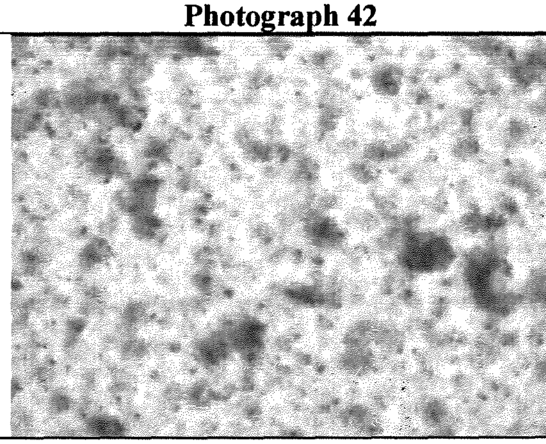
3-7, at 110X

Photograph 42



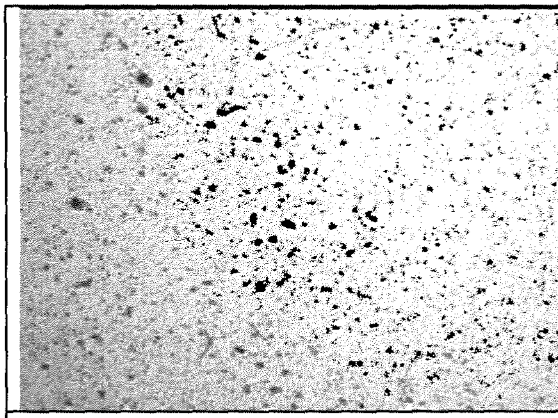
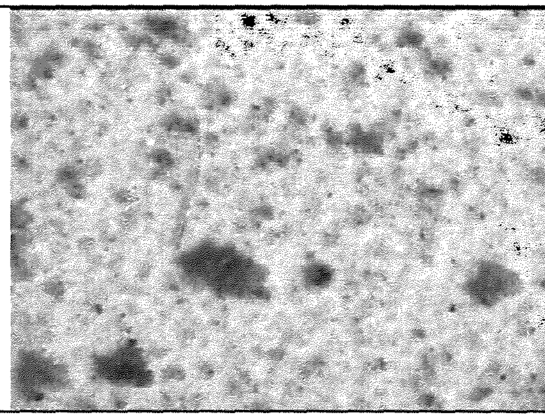
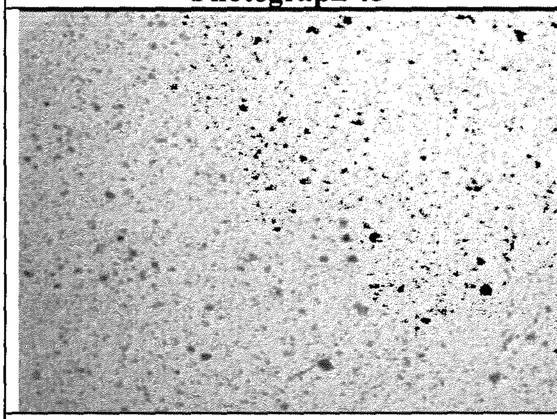
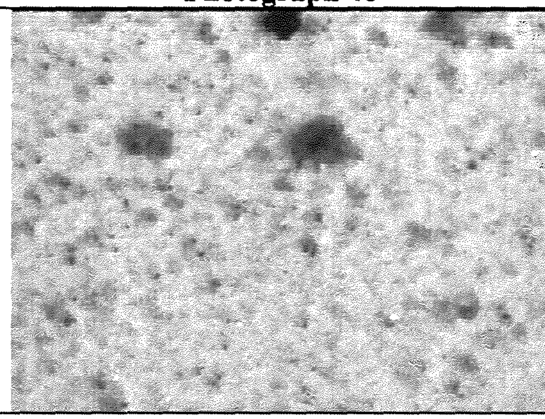
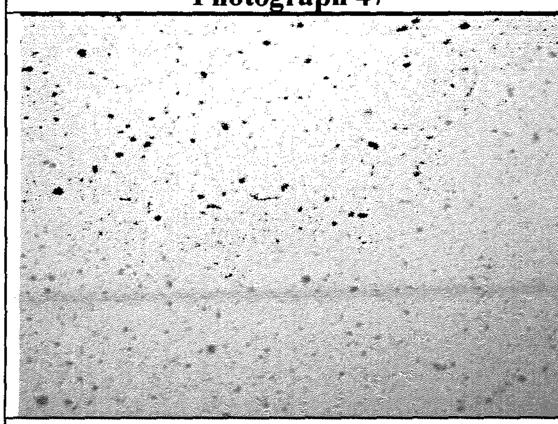
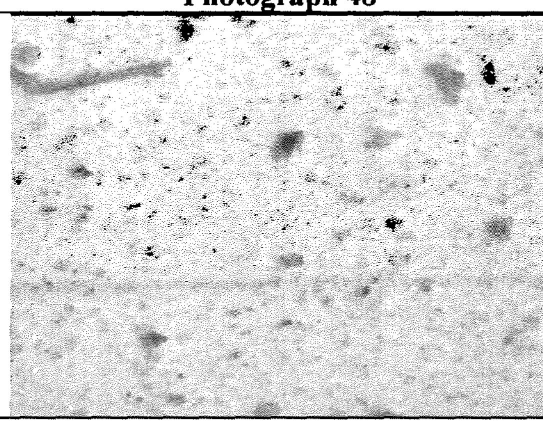
3-8, at 18X

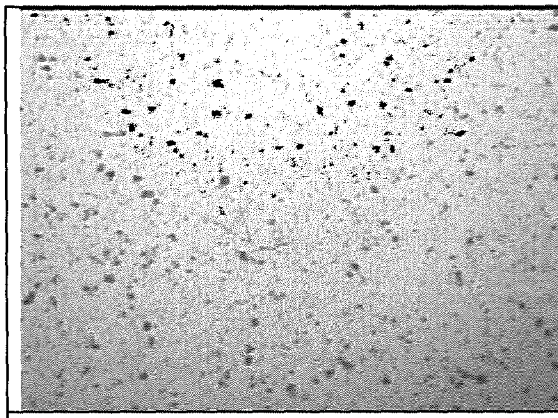
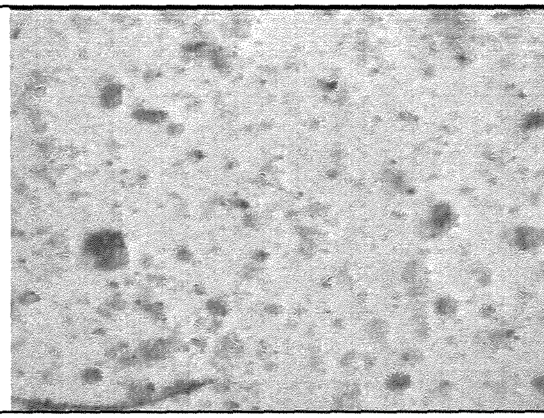
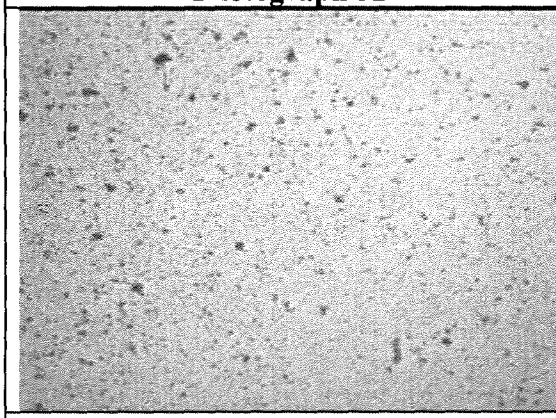
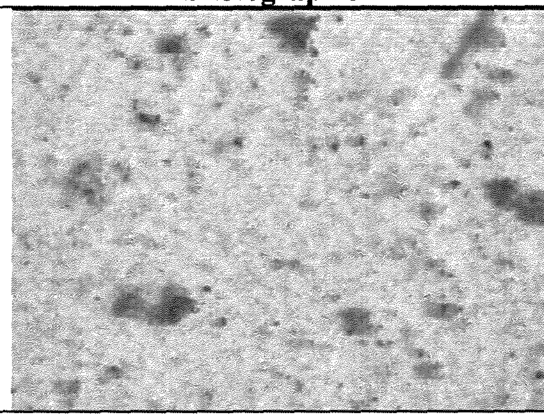
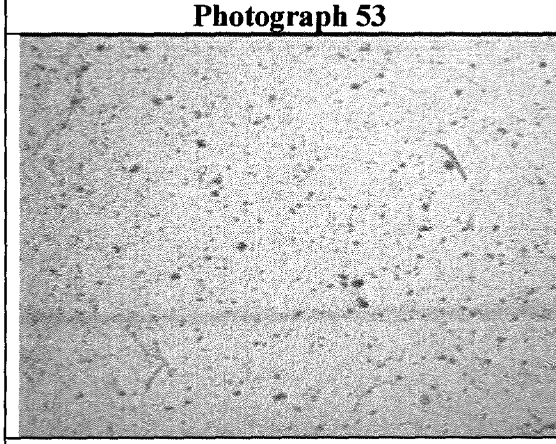
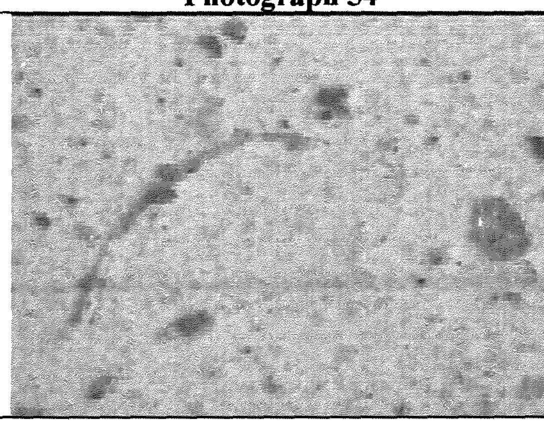
Photograph 43

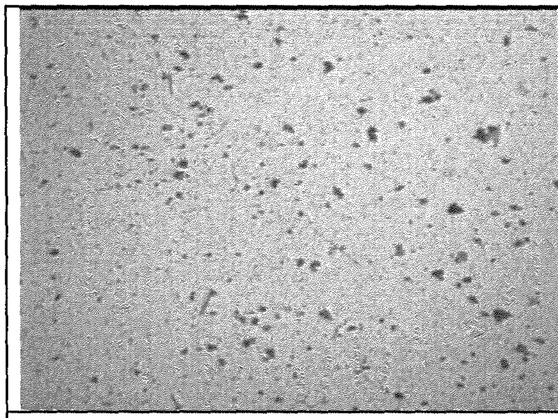
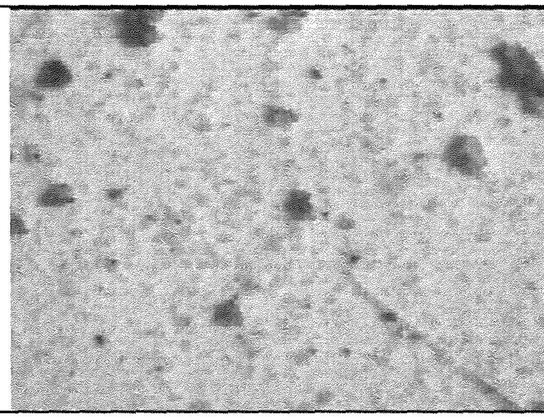
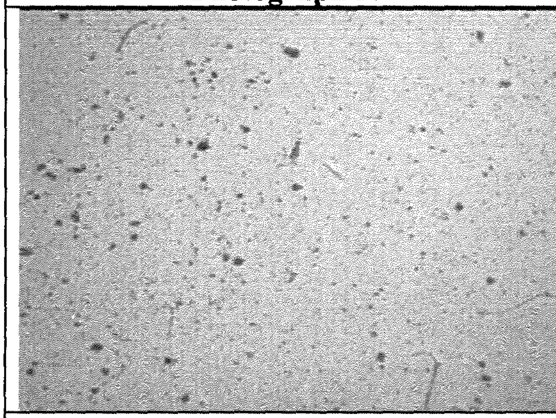
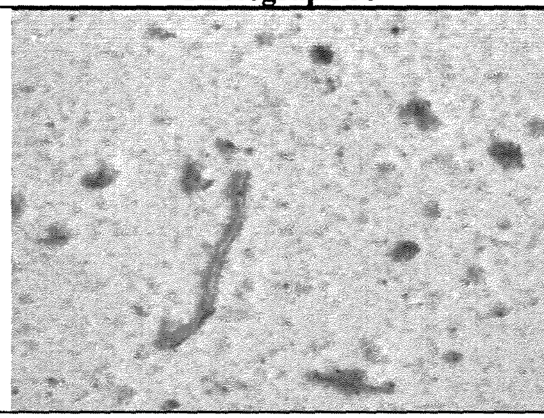
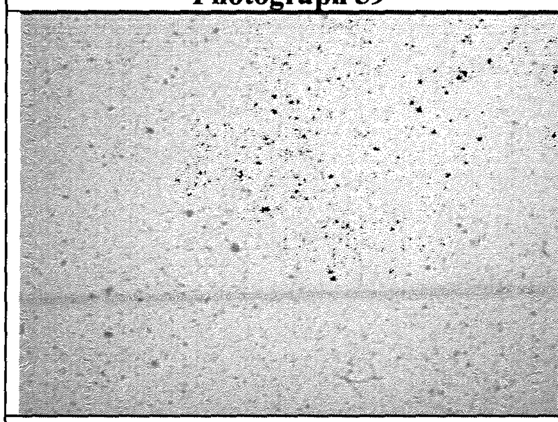
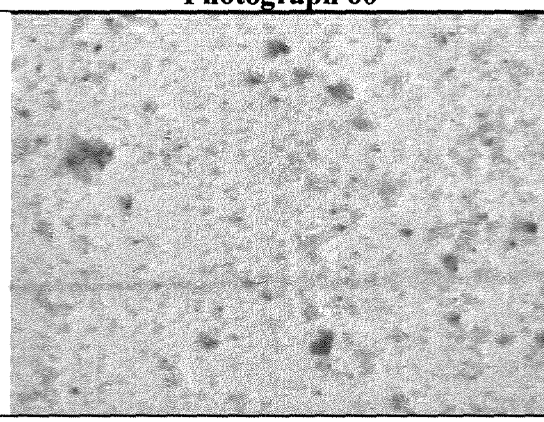


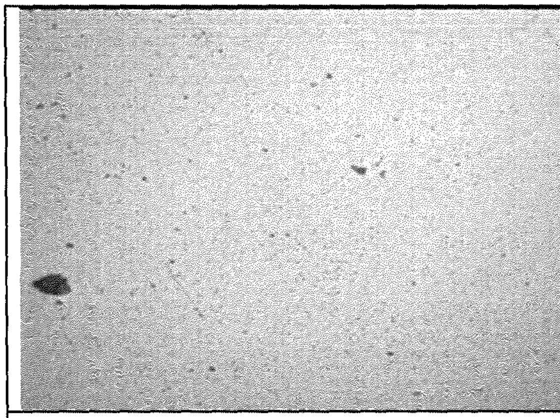
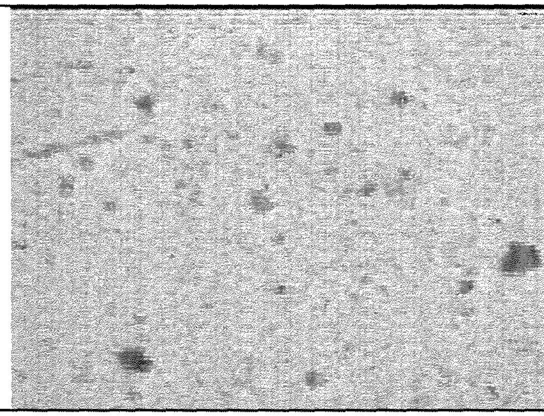
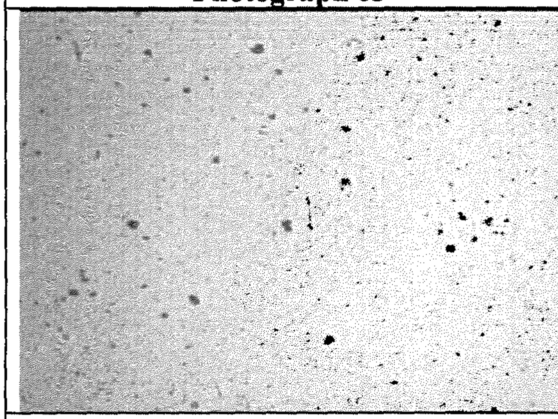
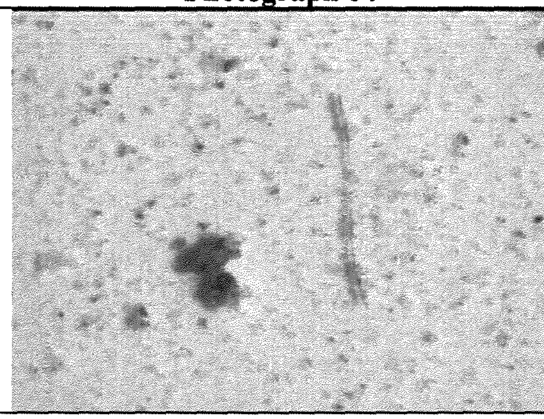
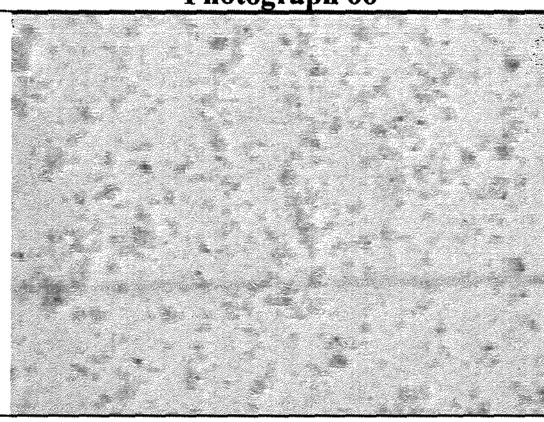
3-8, at 110X

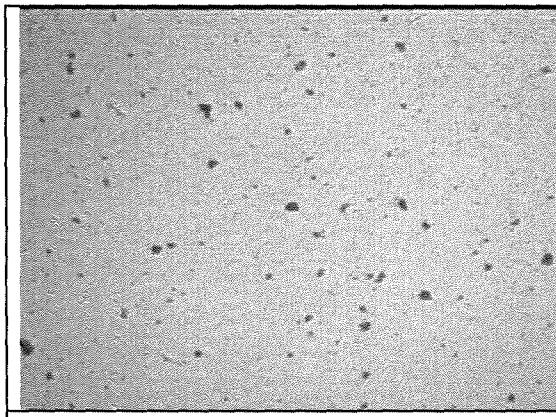
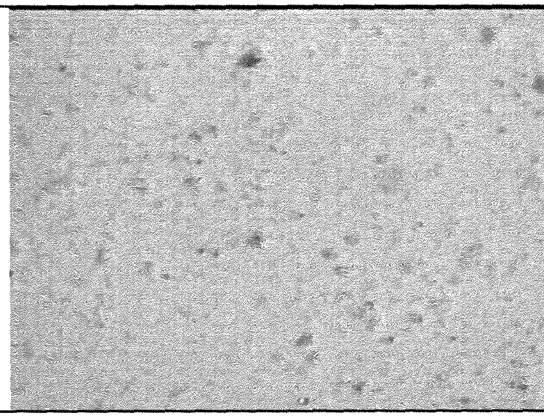
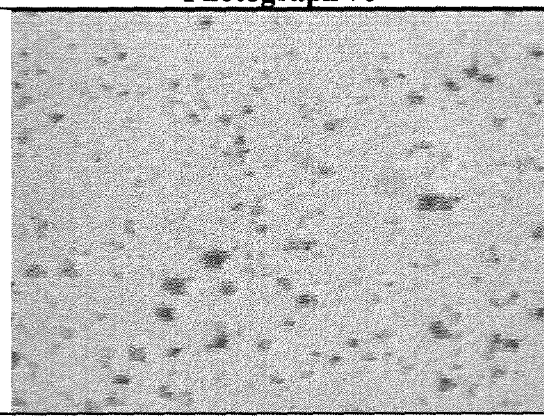
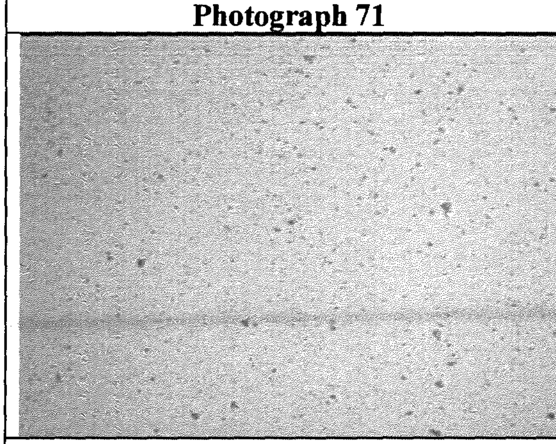
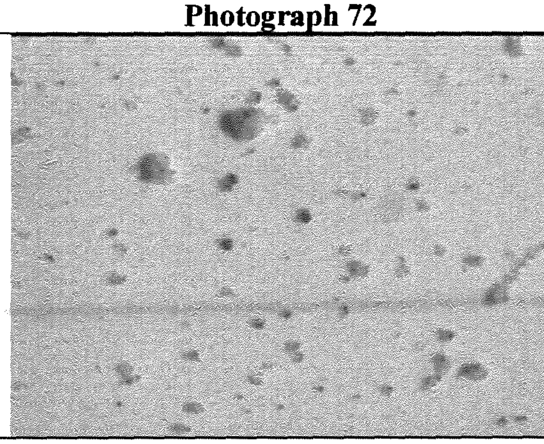
Photograph 44

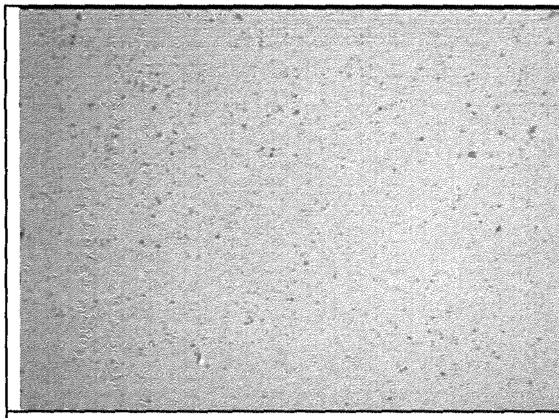
	
3-9, at 18X **Photograph 45**	**3-9, at 110X** **Photograph 46**
	
3-10, at 18X **Photograph 47**	**3-10, at 110X** **Photograph 48**
	
3-11, at 18X **Photograph 49**	**3-11, at 110X** **Photograph 50**

	
3-12, at 18X **Photograph 51**	**3-12, at 110X** **Photograph 52**
	
3-13, at 18X **Photograph 53**	**3-13, at 110X** **Photograph 54**
	
3-14, at 18X **Photograph 55**	**3-14, at 110X** **Photograph 56**

	
3-15, at 18X **Photograph 57**	**3-15, at 110X** **Photograph 58**
	
3-16, at 18X **Photograph 59**	**3-16, at 110X** **Photograph 60**
	
3-17, at 18X **Photograph 61**	**3-17, at 110X** **Photograph 62**

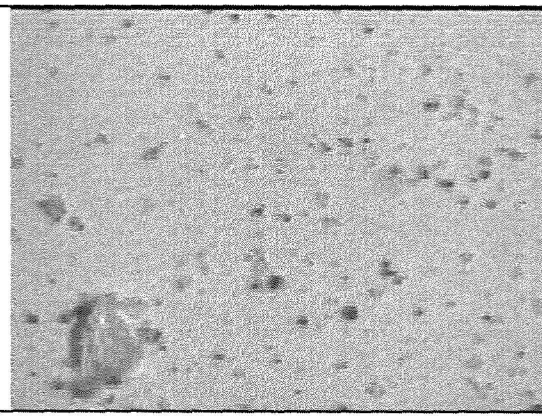
	
3-18, at 18X **Photograph 63**	**3-18, at 110X** **Photograph 64**
	
3-19, at 18X **Photograph 65**	**3-19, at 110X** **Photograph 66**
	
3-20, at 18X **Photograph 67**	**3-20, at 110X** **Photograph 68**

	
3-21, at 18X **Photograph 69**	**3-21, at 110X** **Photograph 70**
	
3-22, at 18X **Photograph 71**	**3-22, at 110X** **Photograph 72**
	
3-23, at 18X **Photograph 73**	**3-23, at 110X** **Photograph 74**



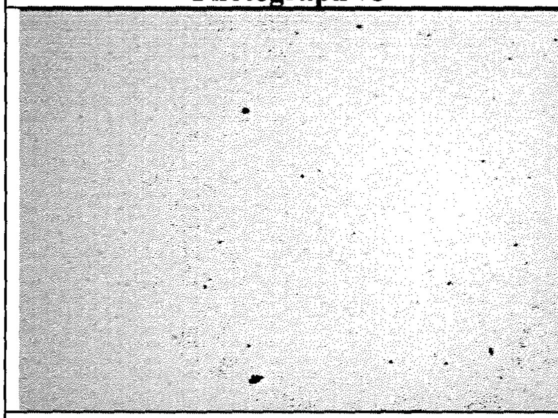
3-24, at 18X

Photograph 75



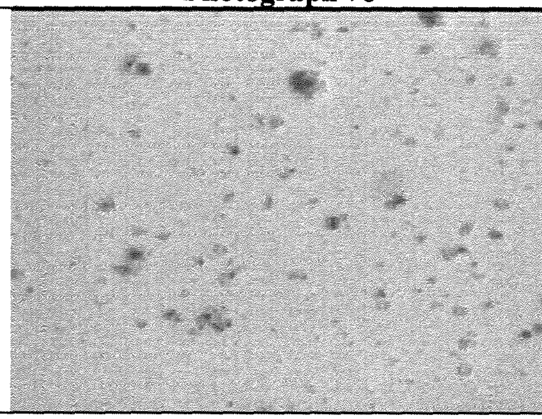
3-24, at 110X

Photograph 76



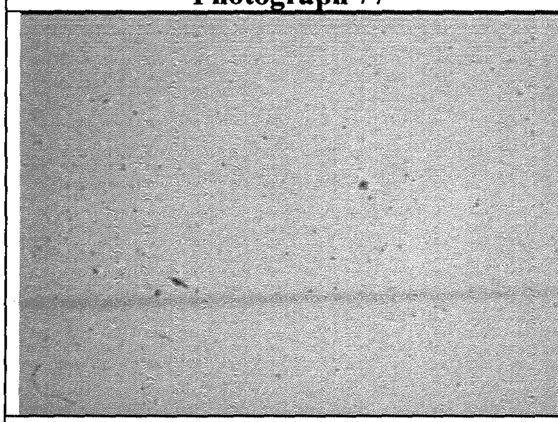
3-25, at 18X

Photograph 77



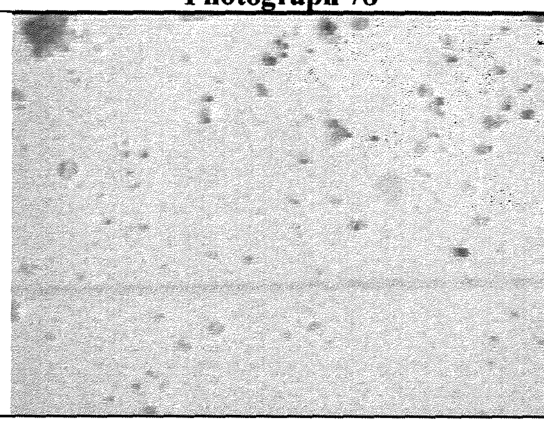
3-25, at 110X

Photograph 78



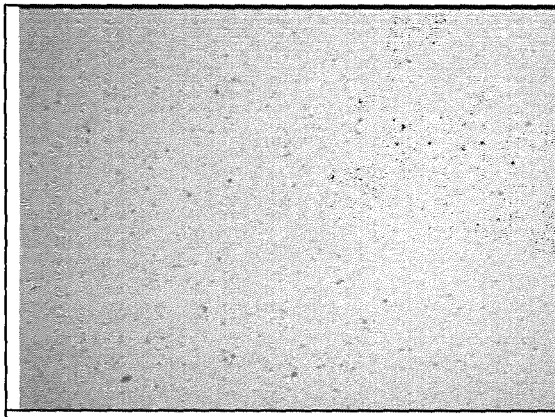
3-26, at 18X

Photograph 79



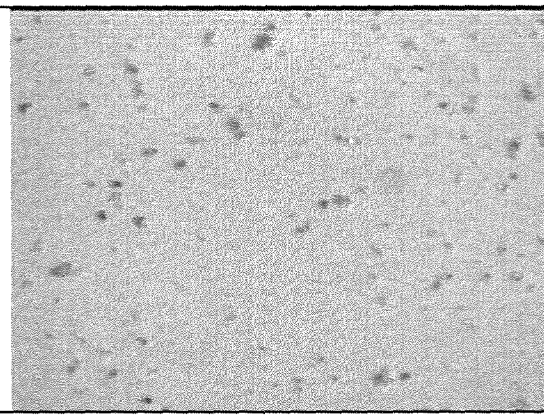
3-26, at 110X

Photograph 80



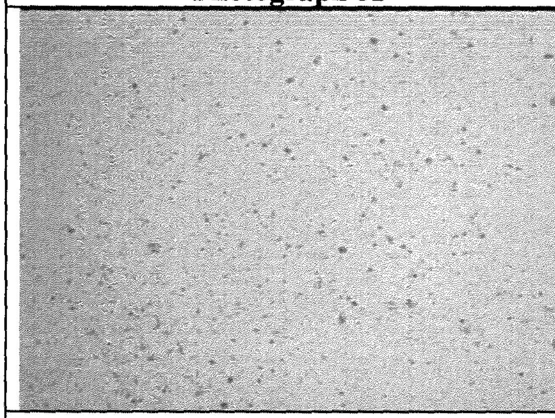
3-27., at 18X

Photograph 81



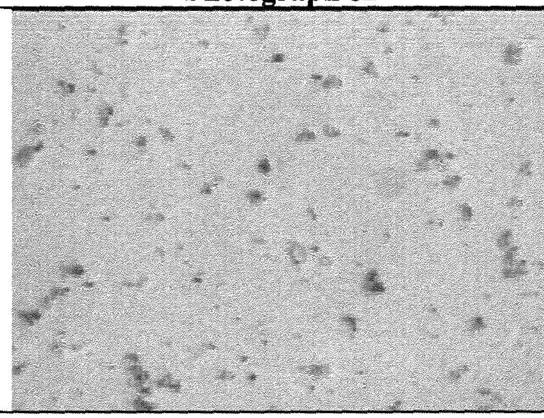
3-27, at 110X

Photograph 82



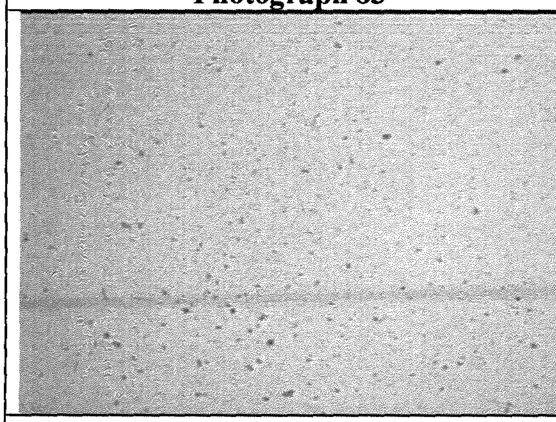
3-28, at 18X

Photograph 83



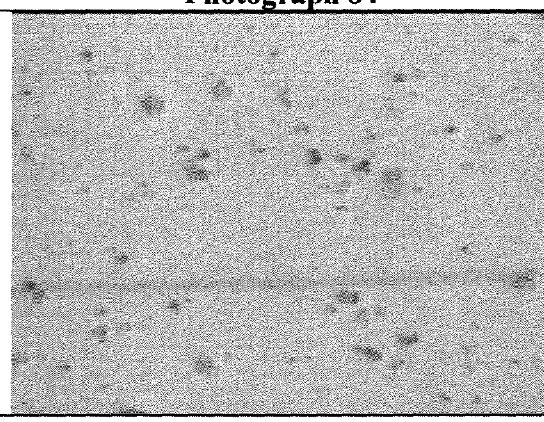
3-28, at 110X

Photograph 84



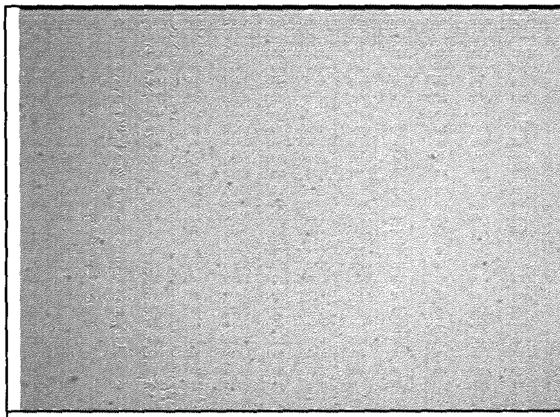
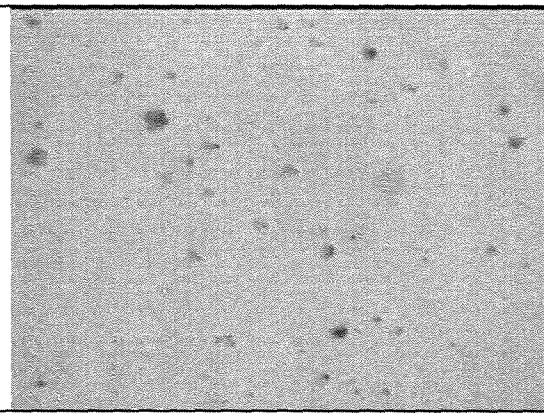
3-29, at 18X

Photograph 85



3-29, at 110X

Photograph 86

	
3-30, at 18X **Photograph 88**	**3-30, at 110X** **Photograph 89**