Exelon Generation

4300 Winfield Road
Warrenville, IL 60555
630 657 2000 Office

RS-15-283
October 30, 2015

10 CFR 50.54(f)

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

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

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

References:

(1) Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004

(2) SECY-12-0093: R. W. Borchardt, U.S. Nuclear Regulatory Commission, to The Commissioners, U.S. Nuclear Regulatory Commission, "Closure Options for Generic Safety Issue - 191, Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," dated July 9, 2012

(3) 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

(4) 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

Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on Pressurized-Water Reactor (PWR) Sump Performance," concluded that debris could clog the containment sump strainers in pressurized water reactors (PWRs), leading to the loss of net positive suction head for the emergency core cooling system and containment spray system pumps. The Nuclear Regulatory Commission (NRC) subsequently issued Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004, (Reference 1) requesting that licensees address the issues raised by GSI-191. GL 2004-02 was focused on demonstrating compliance with 10 CFR 50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors."

Since the issuance of GL 2004-02, the industry, through extensive testing has made significant strides in understanding the effects of post-LOCA debris generation, debris transport, sump screen effectiveness, and most recently, in-vessel effects of the debris that bypasses the sump screens. Large scope modifications have been implemented to increase the surface area of the sump strainers and reduce the debris quantities that reach the sump strainers.

On July 9, 2012, the NRC staff issued SECY-12-0093, "Closure Options for Generic Safety Issue - 191, Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," (Reference 2). SECY-12-0093 presents three options to the Commission; each considered a viable path for resolving GSI-191.

The options are:

- Option 1: Compliance with 10 CFR 50.46 based on approved models;
- Option 2: Mitigative measures and alternate methods approach; and
- Option 3: Different regulatory treatment for suction strainer and in-vessel effects.

Based on their low fiber status, Braidwood Station, Units 1 and 2; and Byron Station, Units 1 and 2, have chosen Option 1. The associated resolution plan was communicated to the NRC in Reference 4. Reference 4 stated that the only remaining open issue related to the resolution of GSI-191 is in-vessel downstream effects. In-vessel downstream effects refers to post-accident debris in the recirculated water in containment accumulating at the bottom of the fuel assemblies, having potential to reduce cooling flow to the core and degrading long term core cooling.

As documented in Reference 4, to address in-vessel downstream effects, Braidwood Station and Byron Station will use the acceptance criteria of 15 grams/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. This document sets acceptance criteria for debris loading to ensure long term core cooling is maintained. Note that the actual debris load for both Braidwood Station and Byron Station is 2.6 grams/fuel assembly as noted in Attachment 1, page A1.

The required actions to complete the resolution plan specified in Reference 4 are to document the quantity of fibrous debris that reaches the sump strainers; and document compliance with the limitations and conditions specified in the NRC Safety Evaluation (Reference 3) associated with WCAP-16793-NP Revision 2.

In Reference 4, EGC committed to document the final resolution of the in-vessel downstream effects for all four Braidwood Station and Byron Station units upon startup of Braidwood Station, Unit 2, Cycle 19 in the fall of 2015. In a September 28, 2015 teleconference between J. Wiebe (NRC) and J. A. Bauer (EGC), it was agreed that the subject information would be submitted to the NRC on or before November 2, 2015. This documentation is provided in Attachment 1 to this letter.

In summary, it should be noted that:

1. There have been no changes to the information previously presented in Reference 4.
2. No additional physical modifications were required for any of the four units.
3. All limitations and conditions specified in Reference 3 have been met as documented in Attachment 1.

In addition, Reference 3, Section 5.0, "Conclusions," notes that WCAP-16793-NP Revision 2 "does not evaluate the potential for debris in the core to change flow patterns or otherwise inhibit the mixing of boric acid that could result in earlier boric acid precipitation. Ongoing PWROG efforts are addressing boric acid precipitation in a separate program." EGC has documented this issue in the Corrective Action Program and is monitoring the industry resolution of this concern which is being addressed by the PWR Owners Group (PWROG), Project Authorization PA-ASC-1188 R2, "Post-LOCA Boric Acid Precipitation Evaluation Model Requirements, Assessment of Experimental Database and Recommendations for Closure."

If you have any questions or require additional information, 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 30th day of October 2015.

Respectfully,

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

Attachment: Braidwood Station and Byron Station, Design Analysis 2014-04466, Revision 0, 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 0
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] 14, Attachment D, page D28

Analysis No.: [1] 2014-04466 **Revision:** [2] 0 Major ☒ Minor ☐

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

EC/ECR No.: [4] 403499(Braidwood), 403564(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]

Original Issue

	Print Name	Sign Name	Date
Preparer: [20]	E. DeCristofaro	See Sargent & Lundy Document	12/5/2014

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

	Print Name	Sign Name	Date
Reviewer: [22]	M. Ross, H. Kopke	See Sargent & Lundy Document	12/5/2014

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

	Print Name	Sign Name	Date
(For External Analyses Only) **External Approver:** [24]	R.Peterson	See Sargent & Lundy Document	7/14/2015
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]	G. Wilhelmsen	George Wilhelmsen	10/21/2015

Exelon Owner Review Record

Design Analysis: 2014-04466 Revision 0

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	10-15-2015
Kevin Dhaese (Byron)	Kevin Dhaese	10.15.15

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.:	7-14-15
PREPARER:	Eric R. DeCristofaro	DATE:	12/5/2014
REVIEWER:	Matthew M. Ross	DATE:	12/5/2014
REVIEWER:	Helmut R. Kopke (Client Comment Incorporation)	DATE:	12/5/2014
APPROVER:	Robert J. Peterson	DATE:	7-14-15

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:	

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

	Page
Cover Page	1
Table of Contents	2
1.0 Background and Purpose	3
2.0 References	4
3.0 Limitations and Conditions to the use of WCAP-16793-NP, Rev. 2	6
4.0 Impact of WCAP-16793-NP, Revision 2, on LOCADM Analysis	14
5.0 Conclusions	14

	# of Pages
Attachment A: Grams of Fiber Per Fuel Assembly	1
Attachment B: Available Driving Head	3
Attachment C: Maximum Flow Rate Per Fuel Assembly	1
Attachment D: Exelon Power Labs Report (Ref. 2.19)	28

1.0 BACKGROUND AND PURPOSE

The current Byron/Braidwood in-vessel effects analysis is documented in Westinghouse Calculation Note CN-SEE-I-07-38, Revision 1, "LOCADM Analysis," dated July 14, 2010. This calculation is based on Revision 1 of WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," dated April 2009. The calculation presented the results of the LOCADM analysis (maximum deposition thickness and fuel cladding temperature). 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. Revision 2 to WCAP-16793-NP has been issued along with an associated NRC Safety Evaluation since the issuance of the current in-vessel effects analysis (CN-SEE-I-07-38, Rev. 1).

The purpose of this calculation is to assess the impact of WCAP-16793-NP, Revision 2, and its associated NRC Safety Evaluation on the Byron and Braidwood GSI-191 in-vessel effects analysis. Specifically, this calculation will addresses the fourteen limitations and conditions presented in Section 4.0 of the NRC Safety Evaluation Report (SER) for WCAP-16793-NP, Revision 2, that 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 grams of fiber per fuel assembly.
- **Attachment B** calculates the available driving head.
- **Attachment C** calculates the maximum flow rate 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 (Including Minor Rev. 5A), "SI/RHR/CS/CV System Hydraulic Analysis in Support of GSI-191."

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. 1 (Including Minor Rev. 1A), "LOCADM Analysis for Byron/Braidwood Units 1 and 2."

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	< 613°F	< 800°F
Maximum Total Deposition Thickness	< 17 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 613°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 show that the maximum fuel cladding temperature does not exceed 800 °F and that the total debris deposition on the fuel rods is less than 50 mils.

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 show that the maximum fuel cladding temperature does not exceed 800 °F and that the total debris deposition on the fuel rods is less than 50 mils.

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 [Refs. 2.14 and 2.20]. The fiber only bypass testing [Ref. 2.14] used a fiber debris load which bounded both the hot-leg and cold-leg breaks. The fiber calculated to bypass the strainers and reach the fuel assembly is 2.6 grams per fuel assembly (See Attachment A). This quantity was determined by performing strainer bypass testing using the plant strainer design, plant-specific debris loads, and plant-specific flow velocities [Refs. 2.14 and 2.20]. 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 methodology is consistent with CCI's standard methodology which was found to be substantially consistent with NEI's recommended fiber preparation procedure [Ref. 2.21].

The results of the 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.

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" methodology is not used.

4.0 IMPACT OF WCAP-16793-NP, REVISION 2, ON LOCADM ANALYSIS

The impact of WCAP-16793-NP, Revision 2, and its associated NRC Safety Evaluation on the Byron and Braidwood GSI-191 in-vessel effects analysis (Calculation Note Number CN-SEE-I-07-38, Ref. 2.22) was assessed by reviewing the changes marked by revision bars in Revision 2 of WCAP-16793-NP. The revision levels of the input documents to the LOCADM analysis (OG-07-419, OG-07-534, and OG-08-64) in Revision 2 of WCAP-16793-NP are the same as those in Revision 1 and no additional guidance was added. In addition, the guidance relating to the existing in-vessel effects analysis remained unchanged. Therefore, no changes to the LOCADM analysis are required due to the change from Revision 1 to Revision 2 of WCAP-16793-NP.

5.0 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. In addition, no changes to the LOCADM analysis are required due to the change from Revision 1 to Revision 2 of WCAP-16793-NP.

ATTACHMENT A: GRAMS OF FIBER PER FUEL ASSEMBLY

From Table 4-1 in Calculation Note Number CN-SEE-I-07-38 [Ref. 2.22] the total mass of fiber that bypasses the strainer is 1.125 pounds. Per Table 4.1-1 of the Byron/Braidwood UFSAR there are 193 fuel assemblies per unit [Ref. 2.9].

Table A.1: Computation of Fiber Bypass Per Fuel Assembly

Debris	Bypass Amount (lb_m)	Bypass Amount (grams)[a]	Number of Fuel Assemblies	Bypass Fiber Debris Amount per Fuel Assembly (grams)
Fiber	1.125	510.3	193	2.6

(a) The conversion to grams is 453.6 grams per pound.

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)
$Z_{core\text{-}in}$ = 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.

Exelon PowerLabs®

Exelon PowerLabs®, LLC.
Technical Services West
36400 S. Essex Road
Wilmington, IL 60481-9500

www.exelonpowerlabs.com
815-458-7640
815-458-7851 fax

To: **B. Davenport**
Mechanical/Structural Engineering
Cantera

From: **William Treasurer**
(815)458-7654
william.treasurer@ExelonCorp.com

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 8th (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:** Measure the mass per volume of debris in the downstream water samples passing through the strainer.

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		Time	Number	Solids
		mg/L				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		Time	Number	Solids
		mg/L				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.

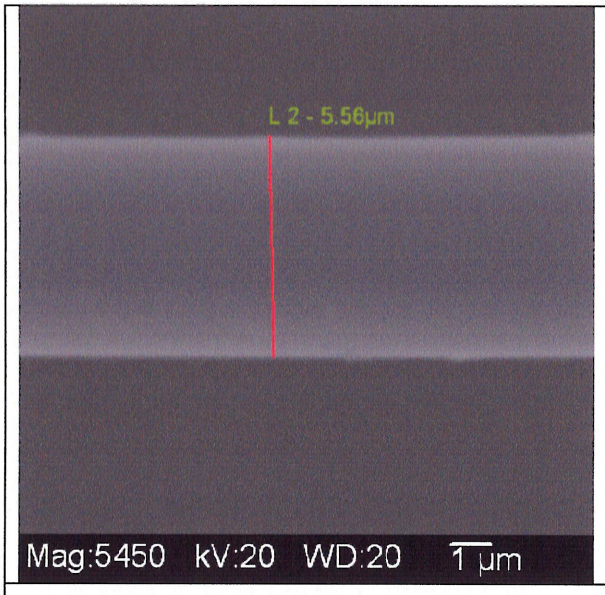
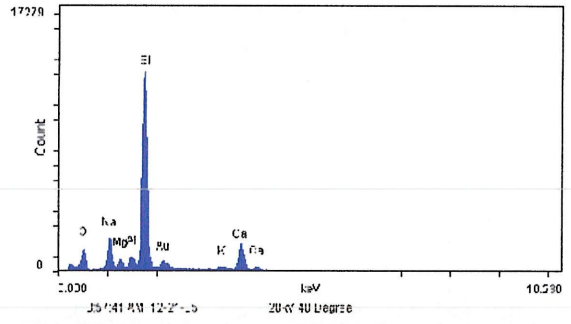
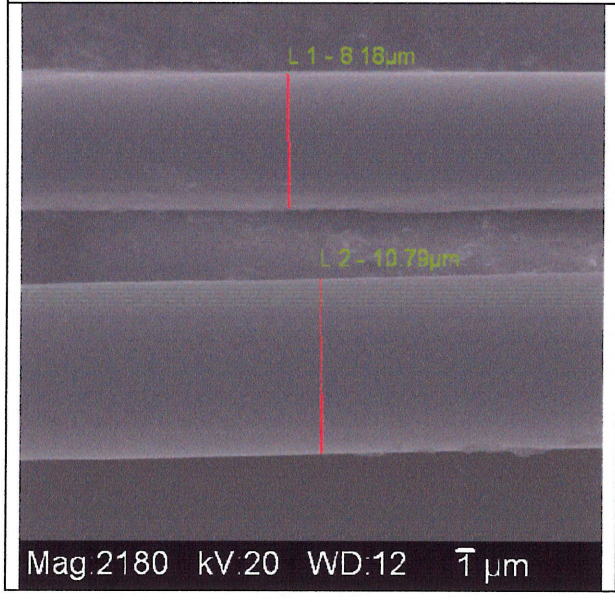
Technician(s): W. Treasurer

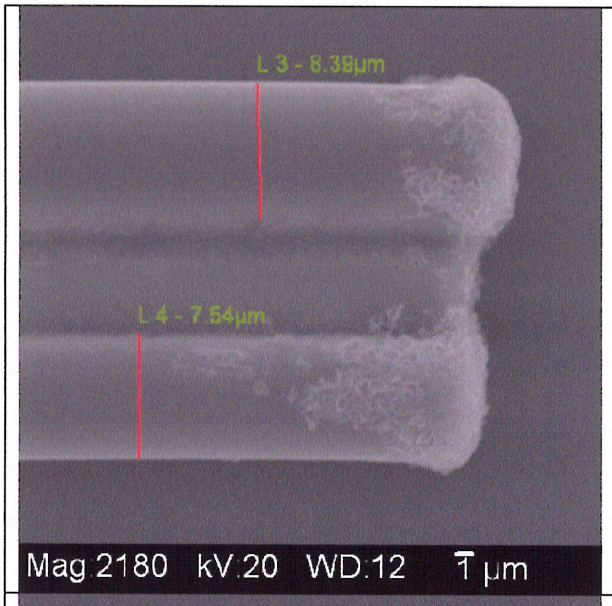
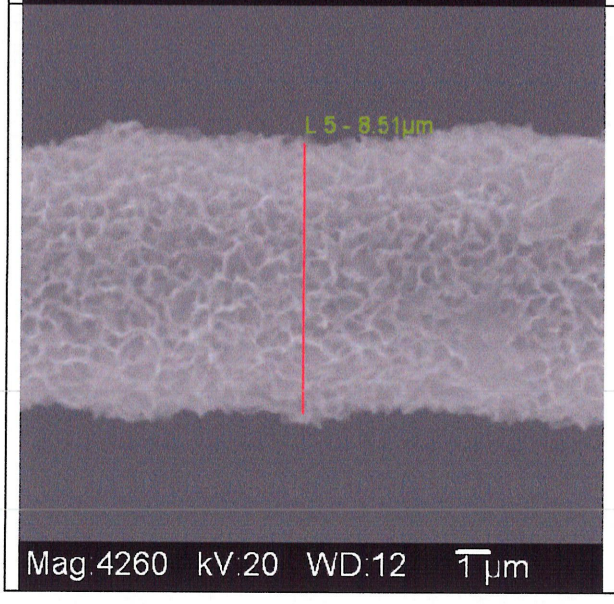
Prepared by: _____(signed original in file)_

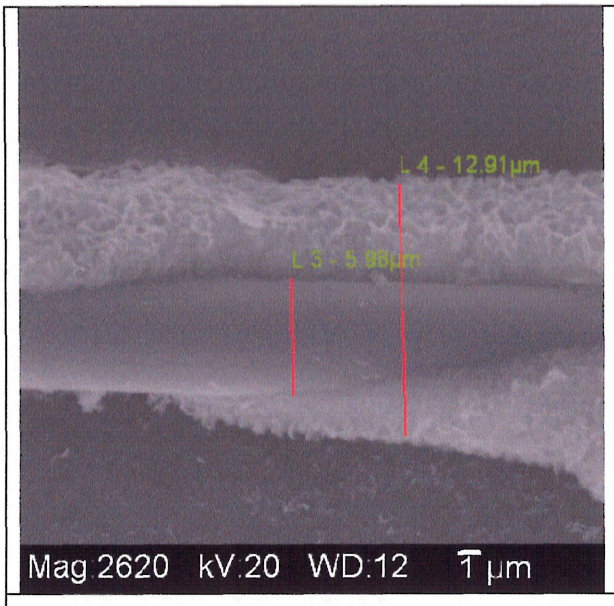
Approved by: _____(signed original in file)_
Title xx/xx/2005

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

Fiber Diameter Characterization

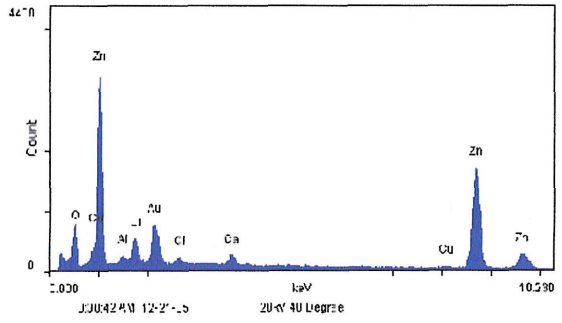
	**Photograph 1** **Fiberglass Feedstock used in Test 6. The diameters varied from 5 to almost 10 microns. No zinc deposition was seen. The length to width ratio was in excess of 10:1.**
	**Spectrum 1** **Typical EDXA spectrum of fiberglass; it is primarily silicon with lesser amounts of sodium, calcium, 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**



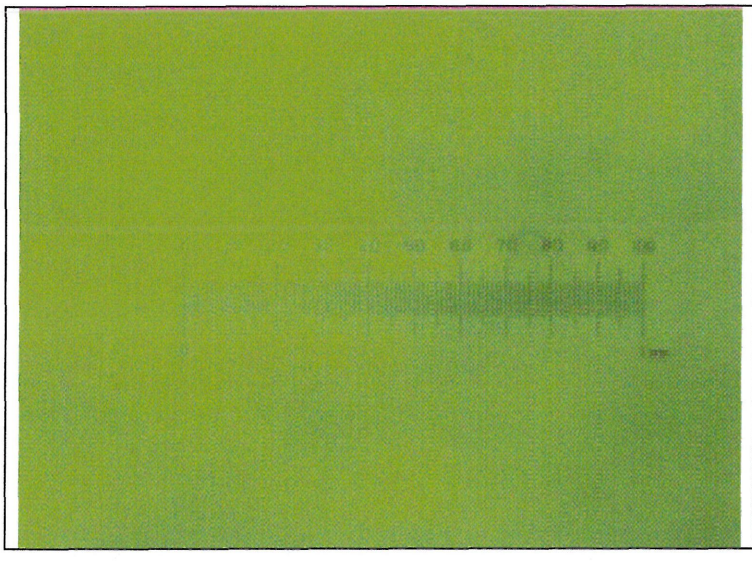
Photograph 5

Coated fiber showing fiberglass core and zinc coating



Spectrum 2

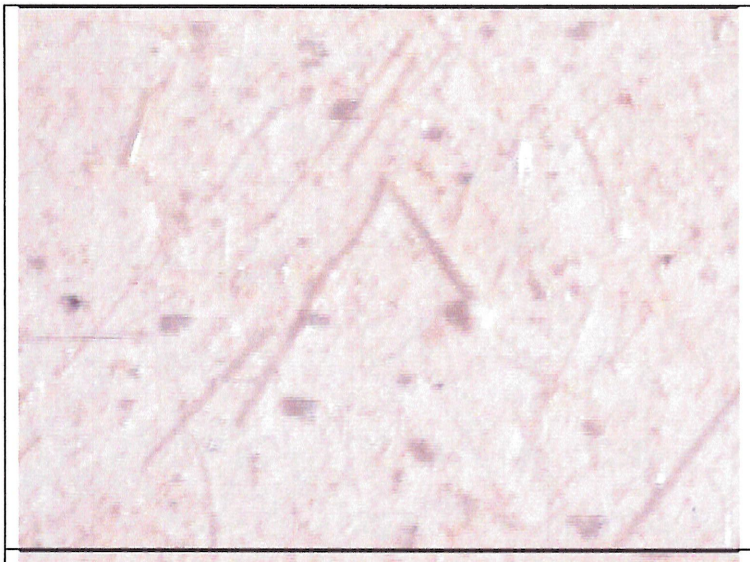
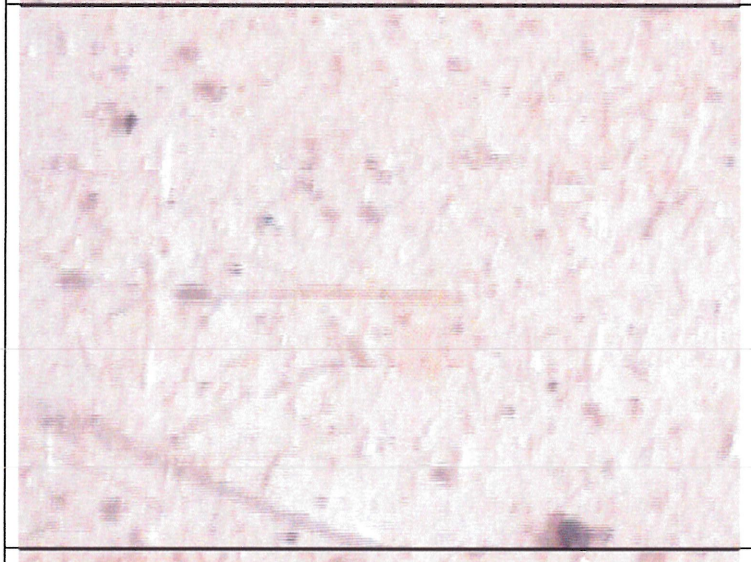
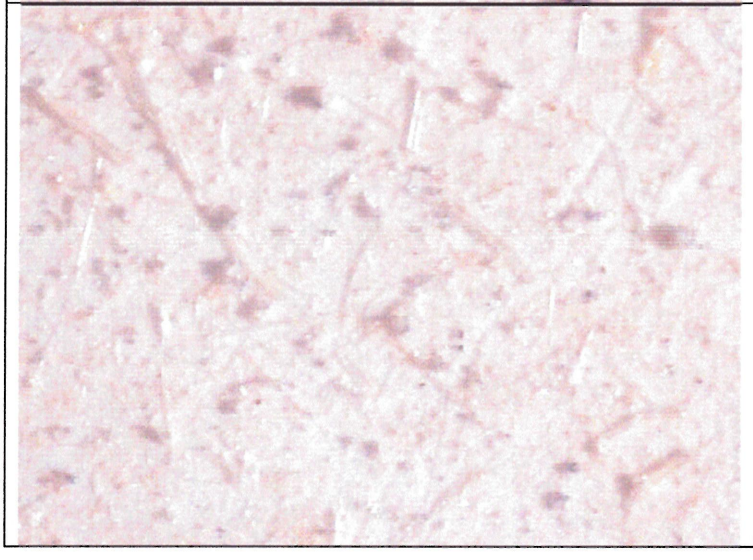
EDXA of the zinc coating on the fiber

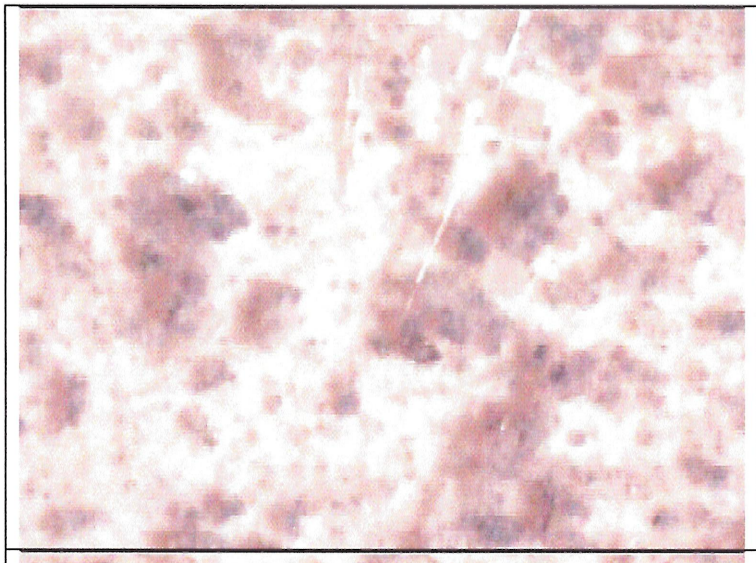
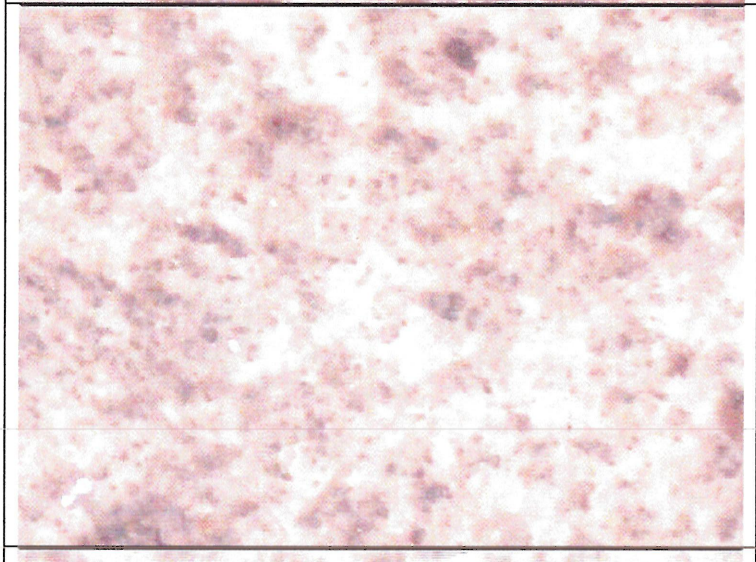
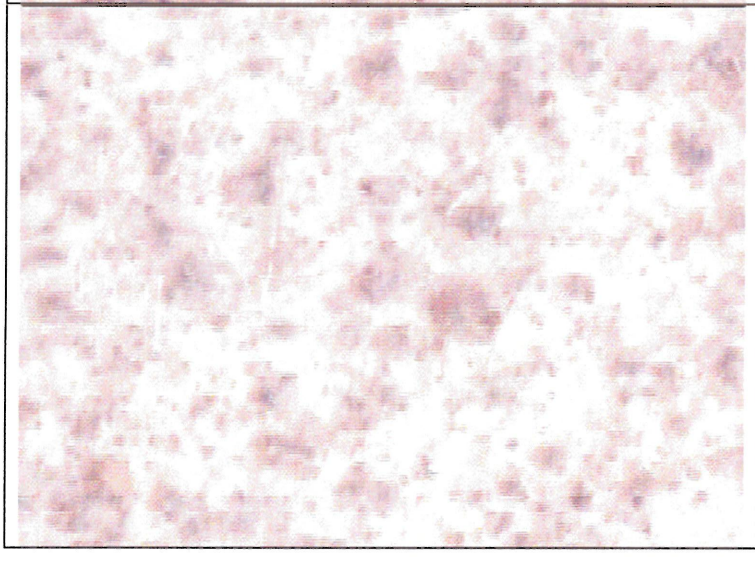


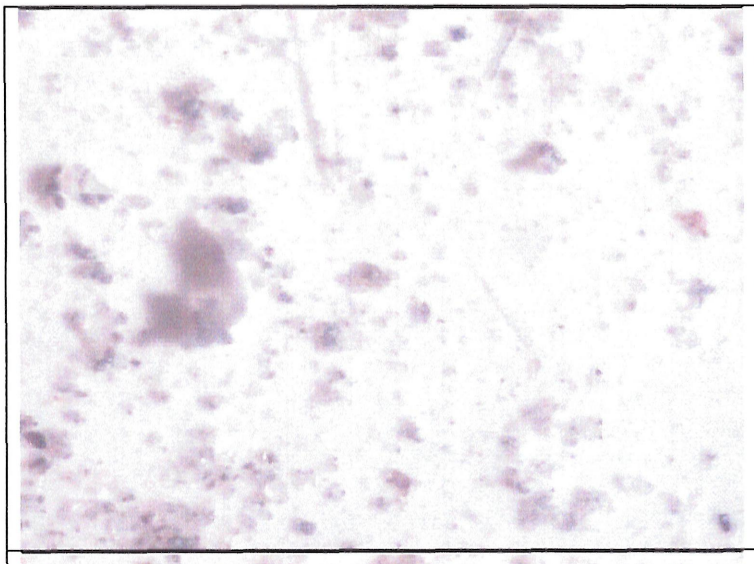
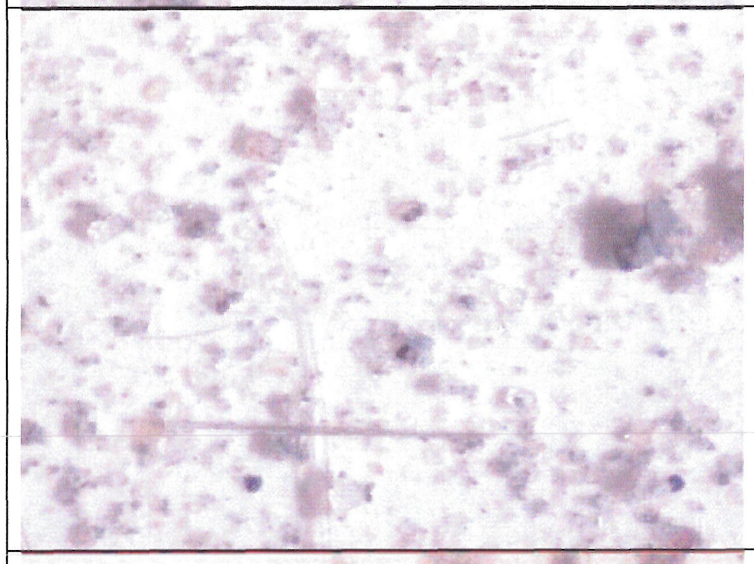
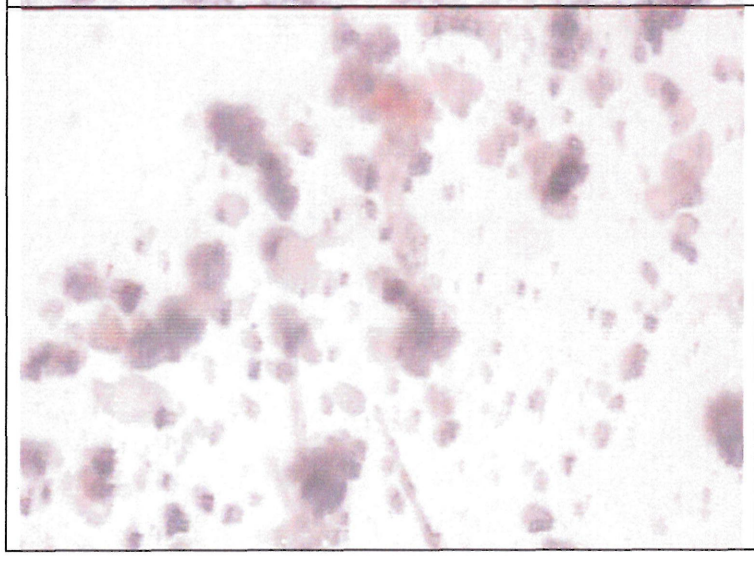
Photograph 6

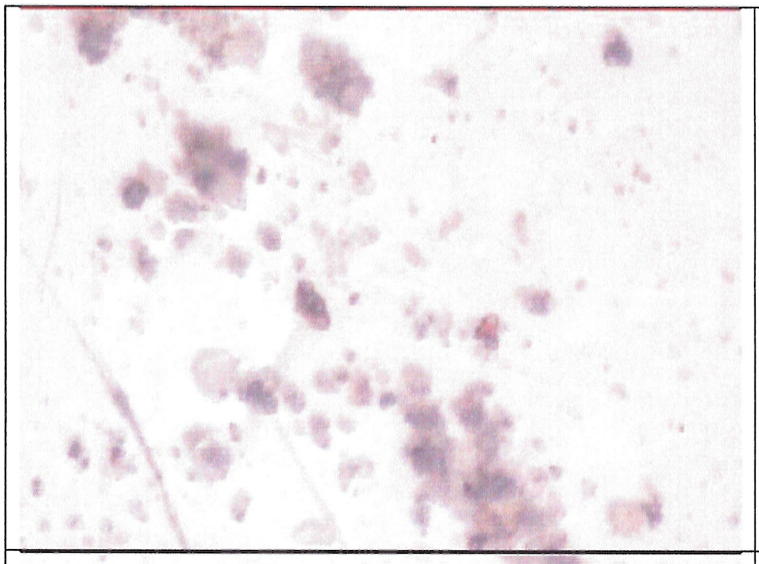
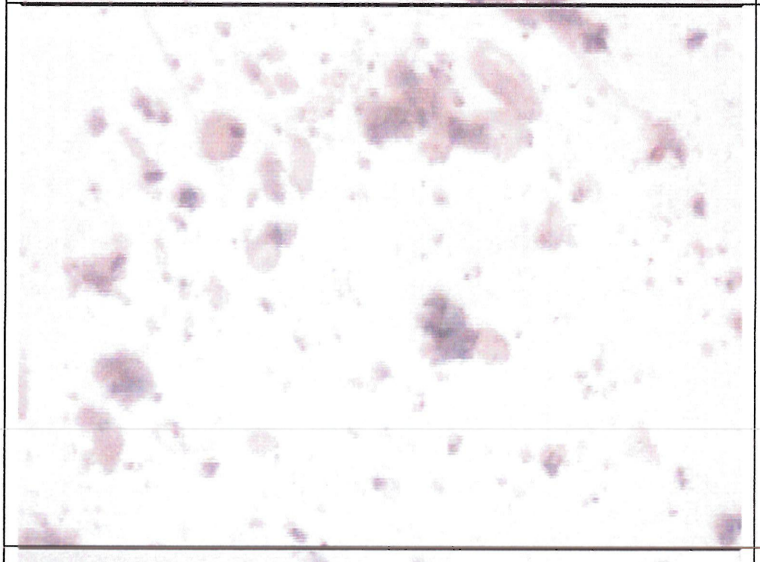
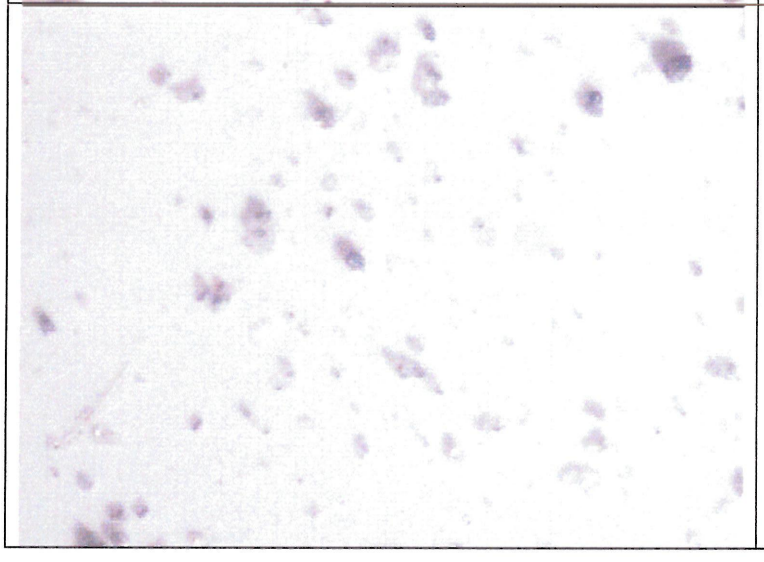
This is a photograph of a graticle scale at approximately 110 X. Each division is 10 microns; the entire length is 1000 micron.

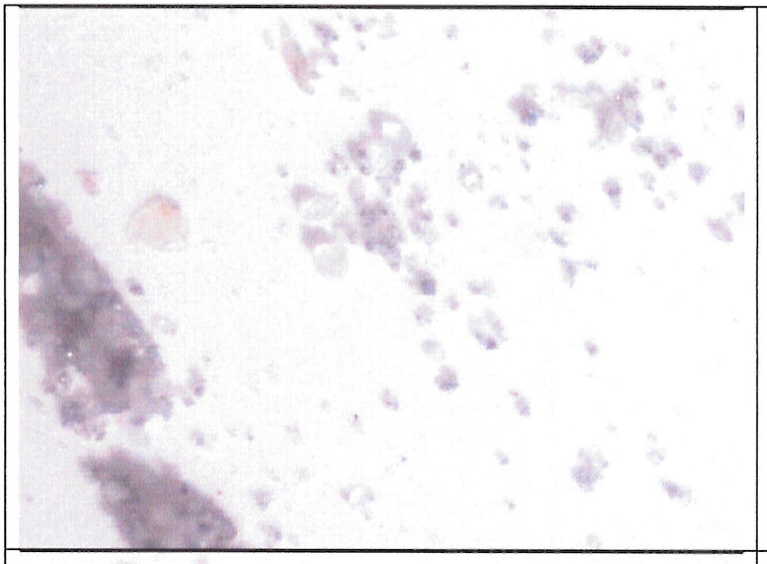
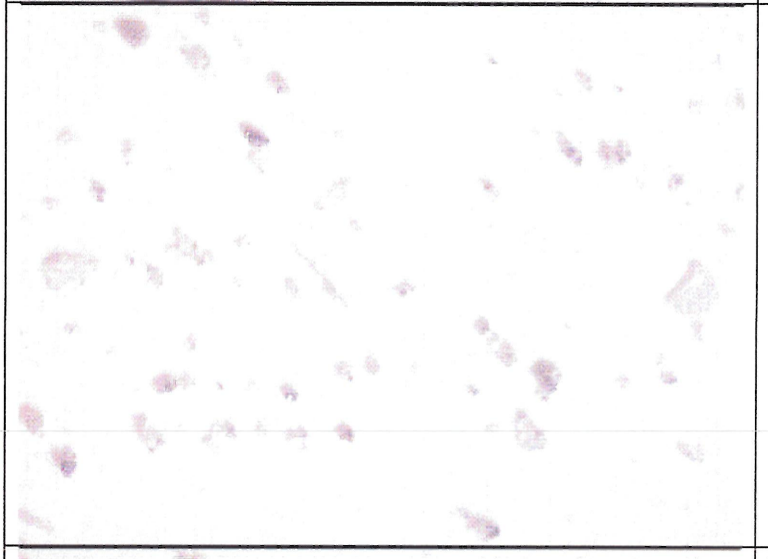
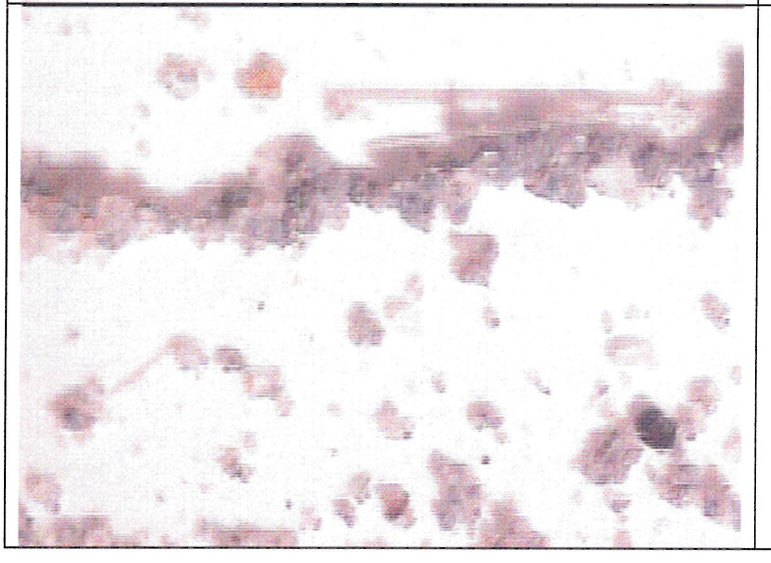
Photographs of the Filters at 110X

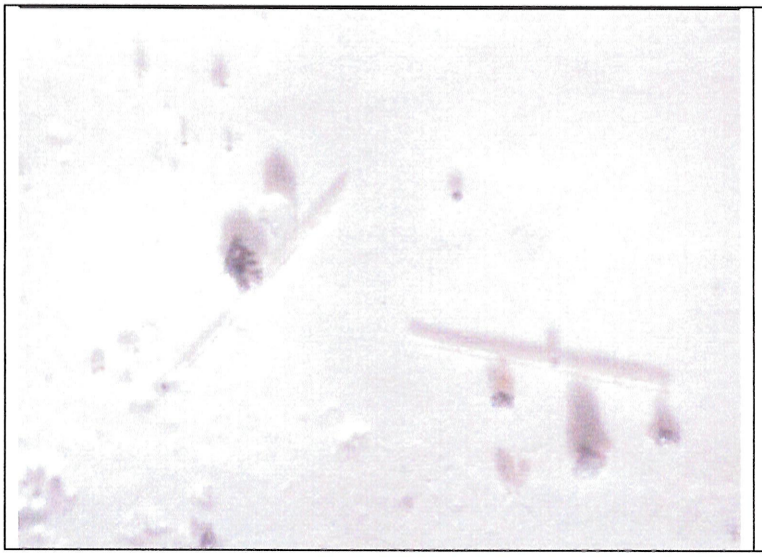
	**Photograph 7** **Filter 6-1, View 1**
	**Photograph 8** **Filter 6-1, View 2**
	**Photograph 9** **Filter 6-1, View 3**

	**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**

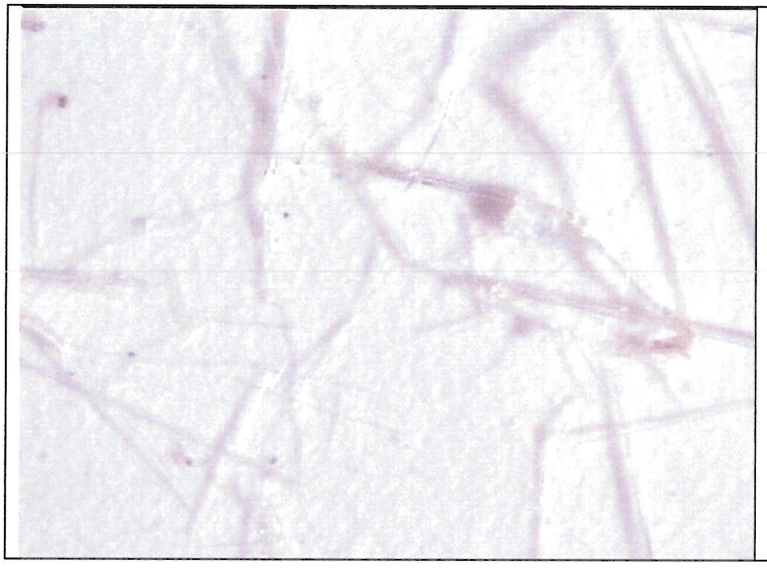
	**Photograph 16** **Filter 6-5, View 2**
	**Photograph 17** **Filter 6-5, View 3**
	**Photograph 18** **Filter 6-8, View 1**

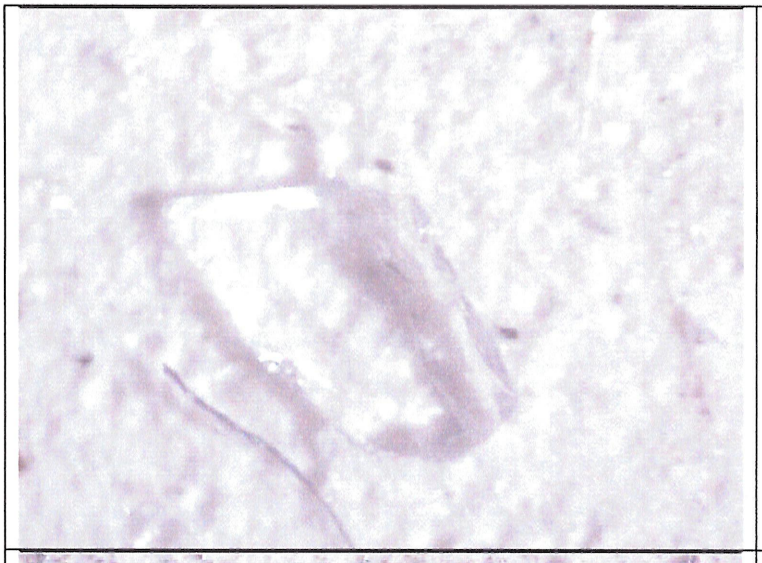
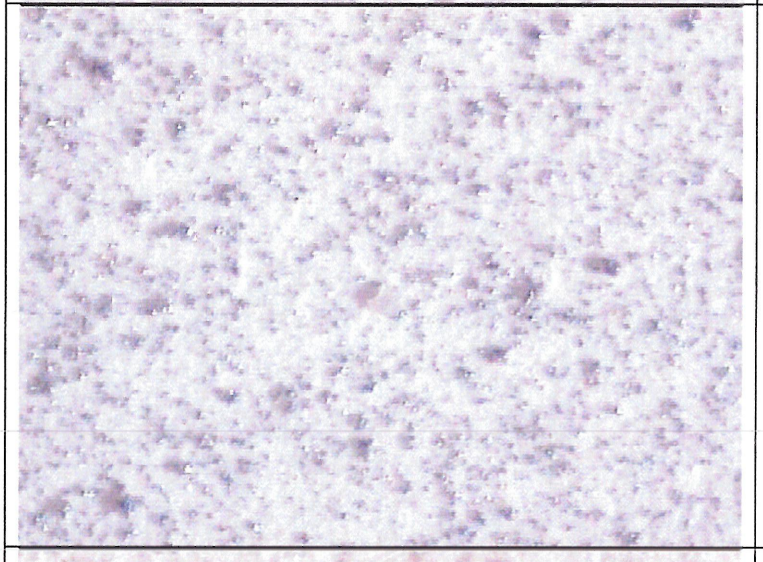
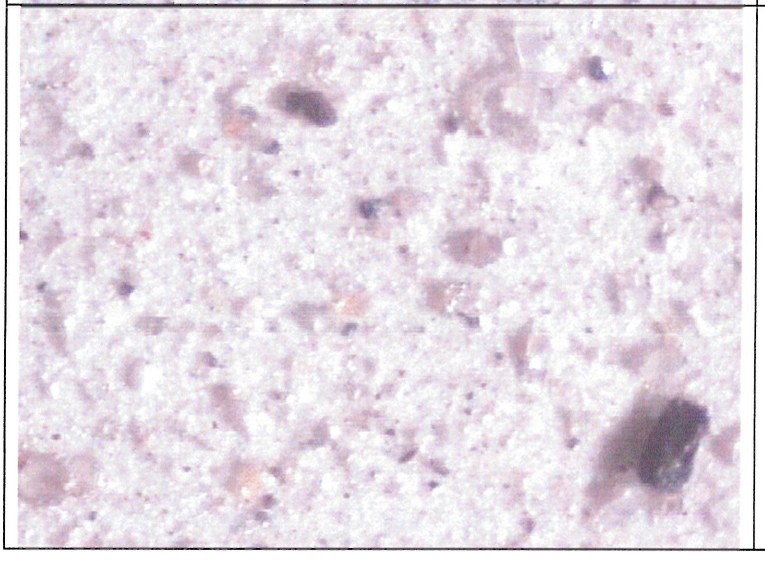
	**Photograph 19** **Filter 6-8, View 2**
	**Photograph 20** **Filter 6-11, View 1**
	**Photograph 21** **Filter 6-11, View 2**

	**Photograph 22** **Filter 6-14, View 1**

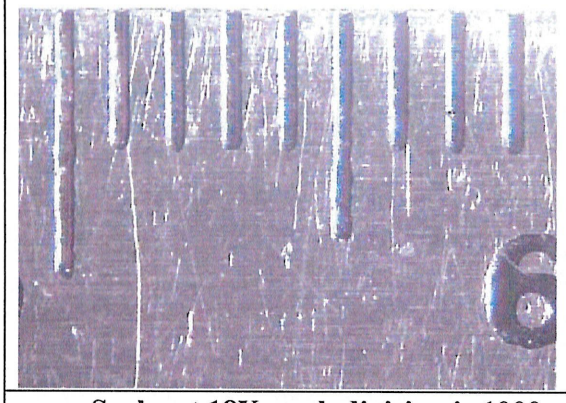
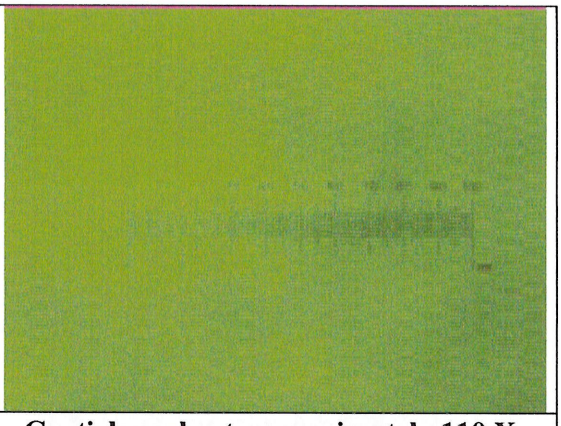
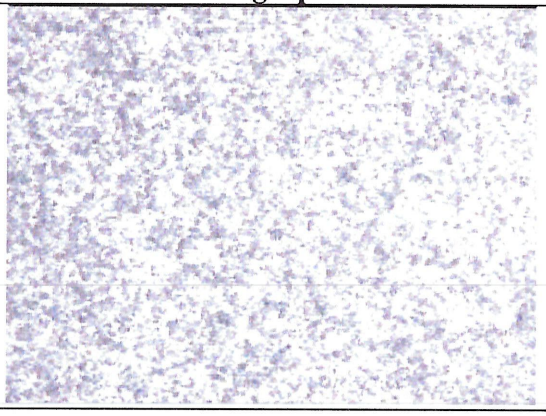
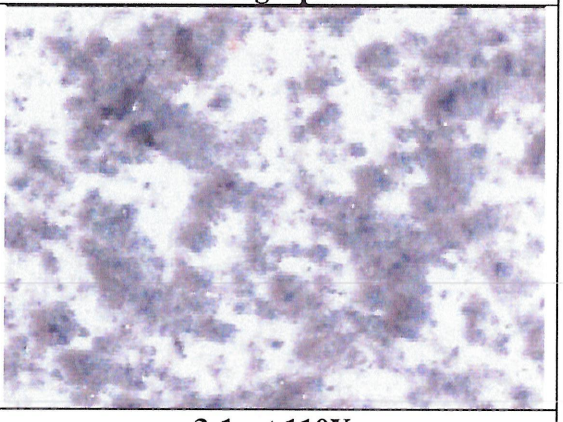
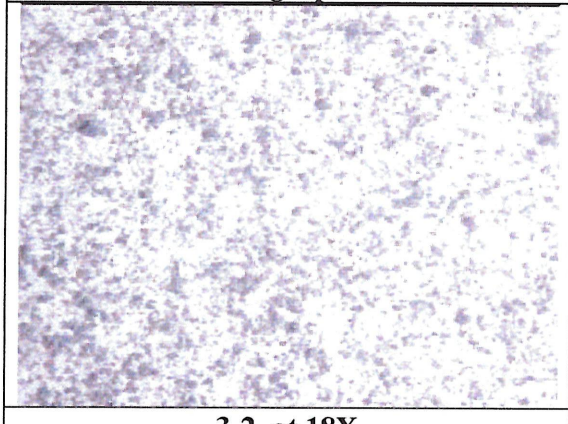
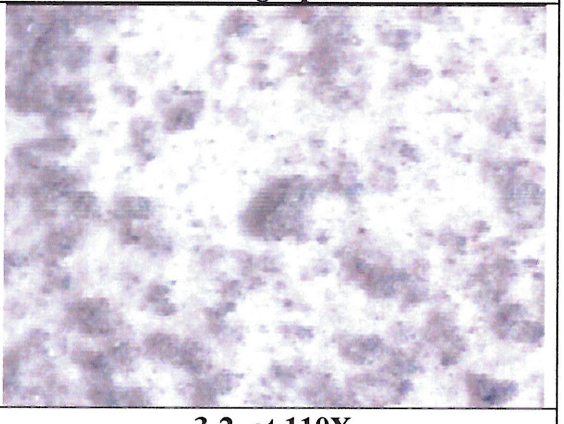
Photographs of the Feed Stock Materials at 110X

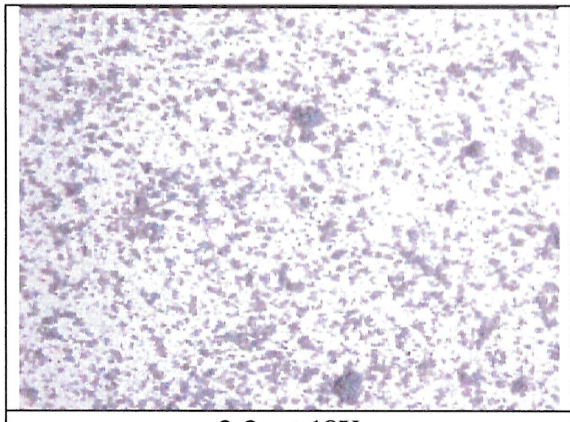
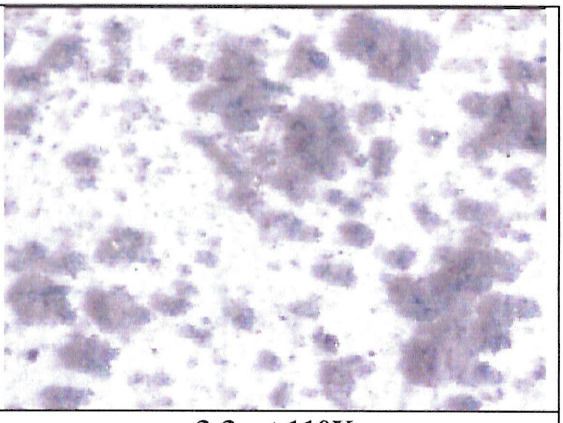
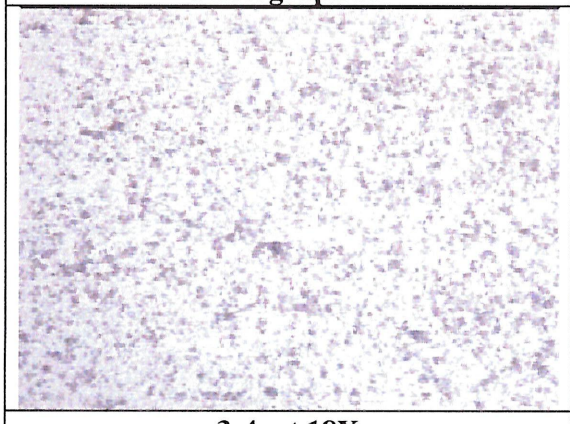
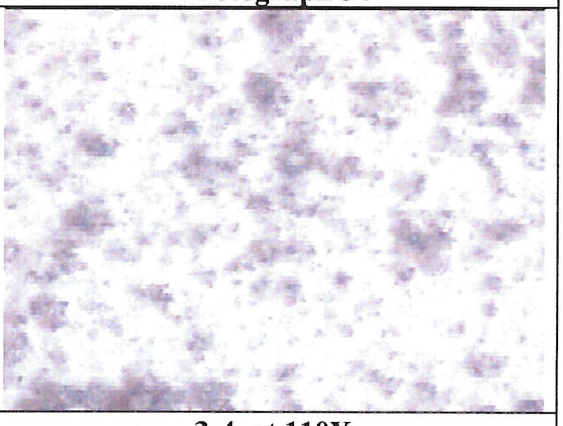
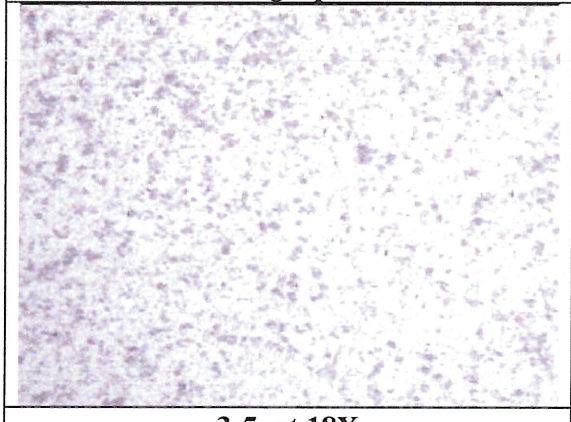
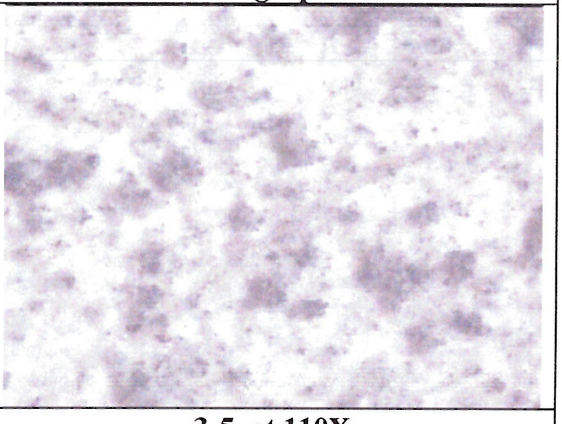
The following are photographs of the materials used for Test 3 taken with the stereomicroscope at 110X.

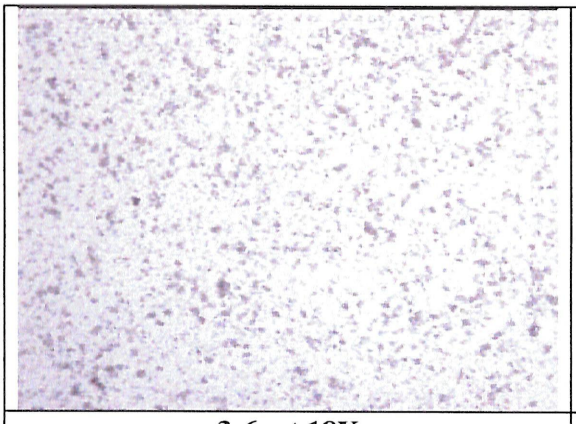
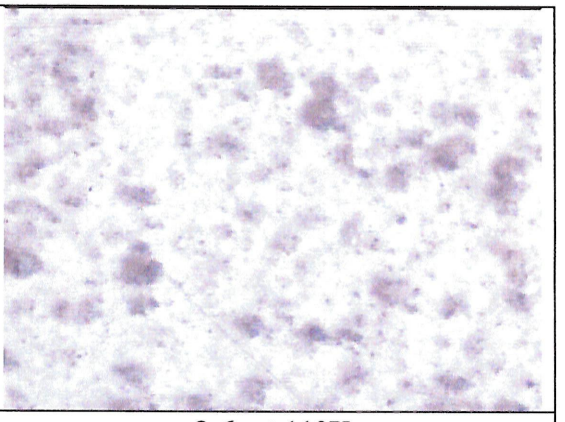
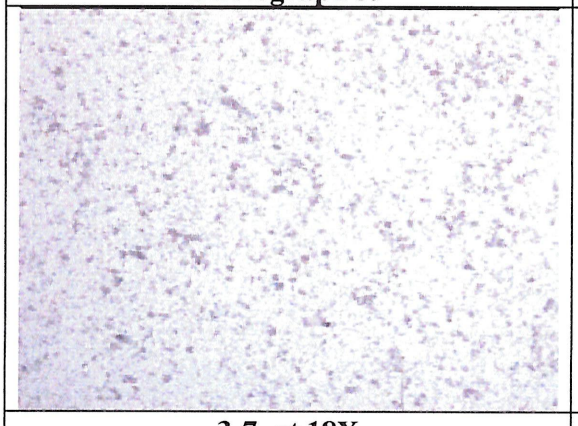
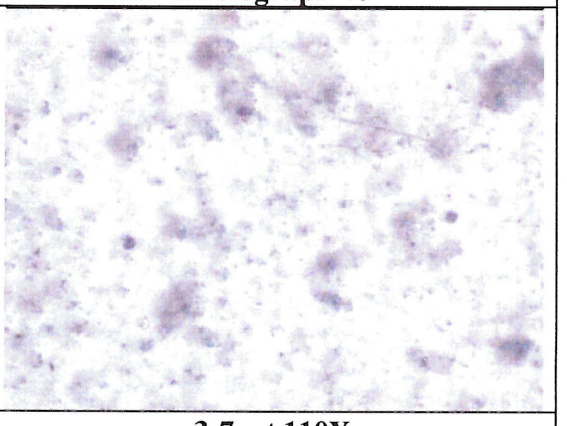
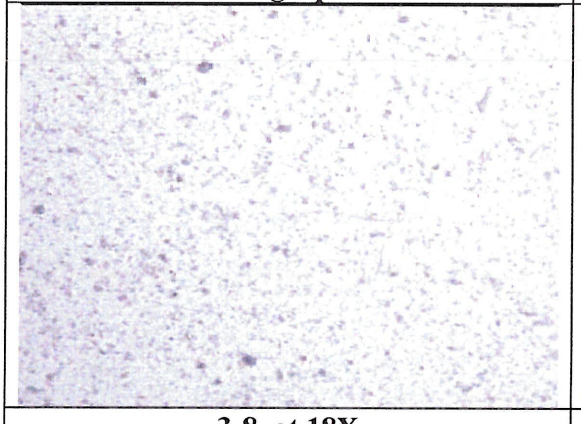
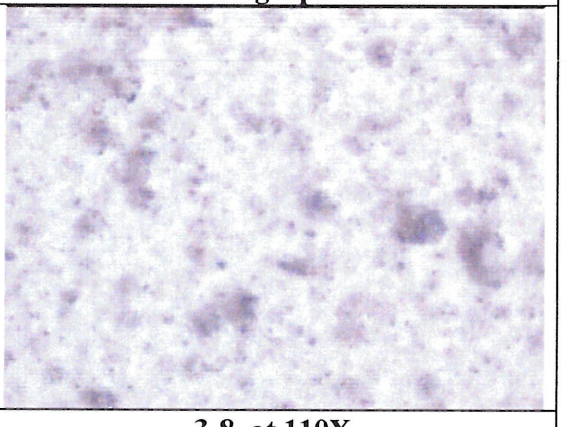
	**Photograph 23** **Fiberglass**

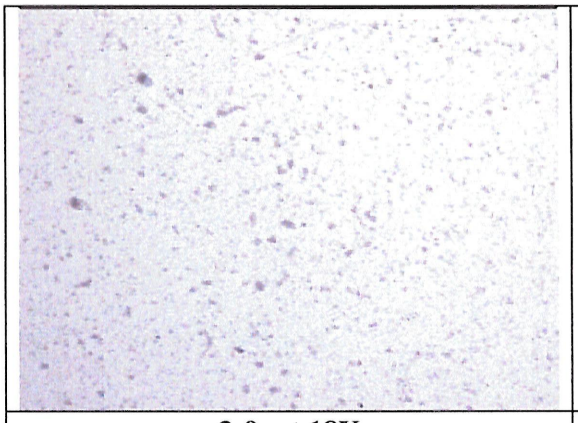
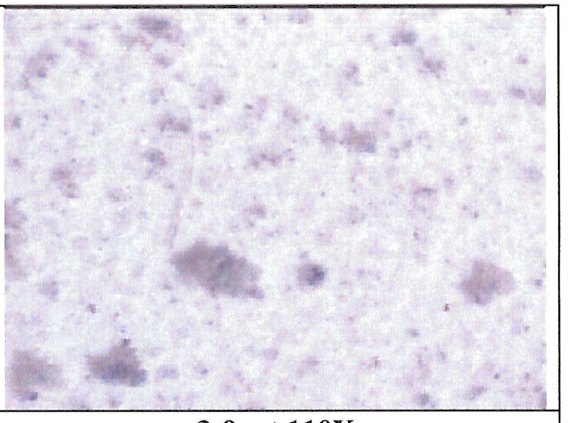
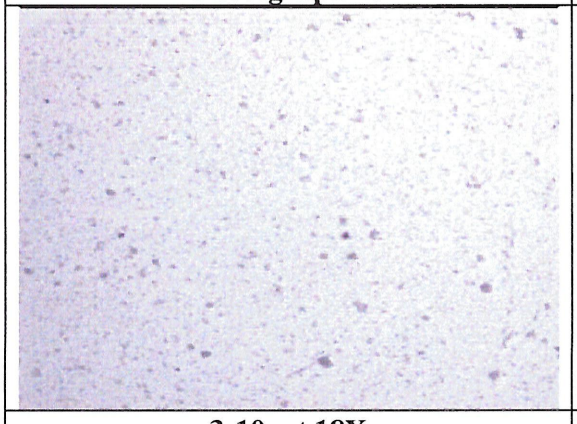
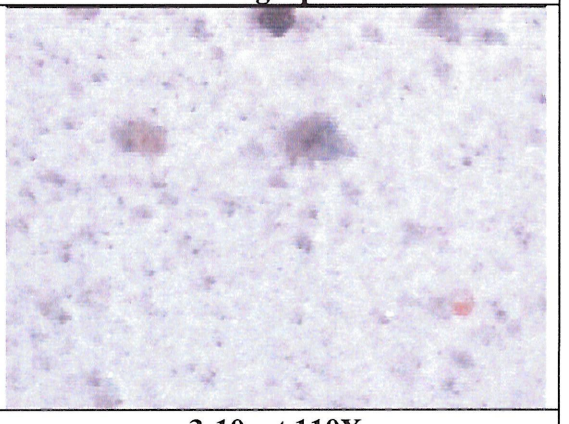
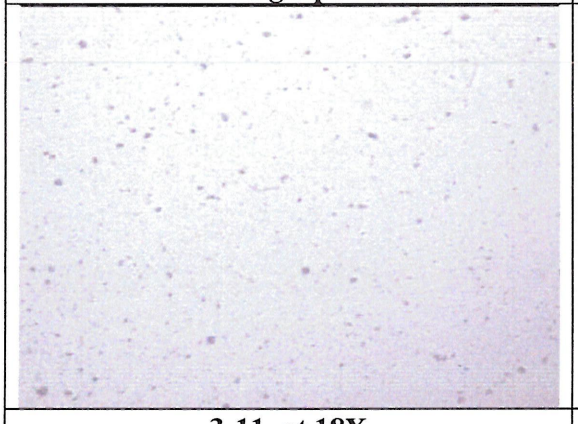
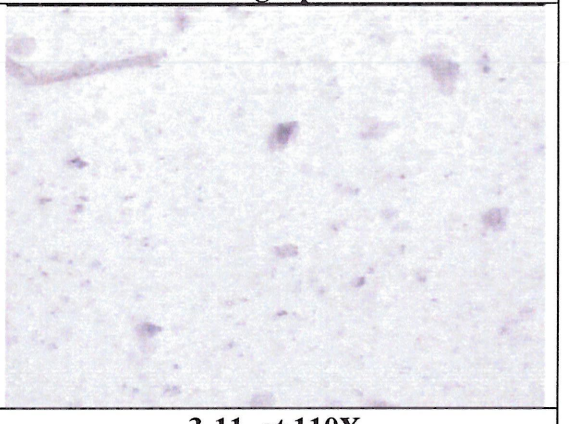
	**Photograph 24** **Glass, Much of the glass used were larger fragments than this one.**
	**Photograph 25** **Zinc Powder, IOZ**
	**Photograph 26** **Stone Flour**

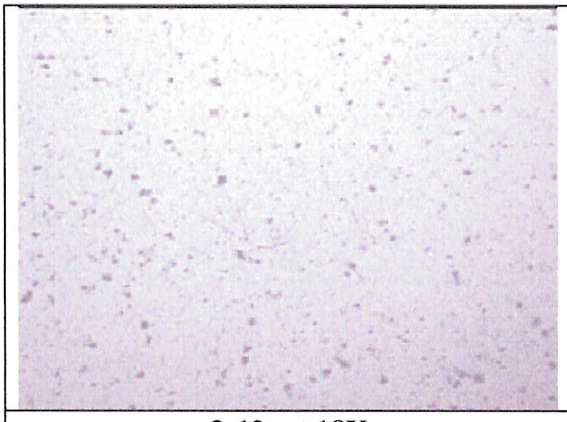
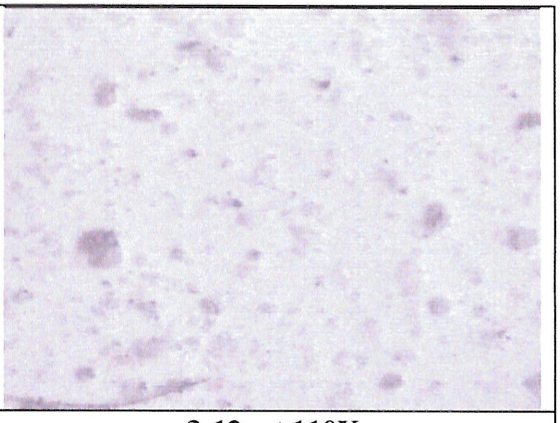
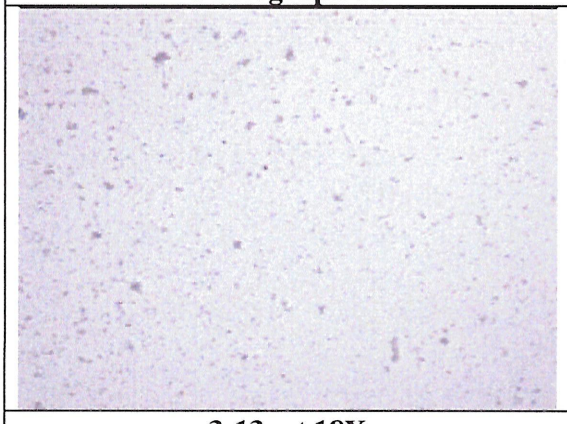
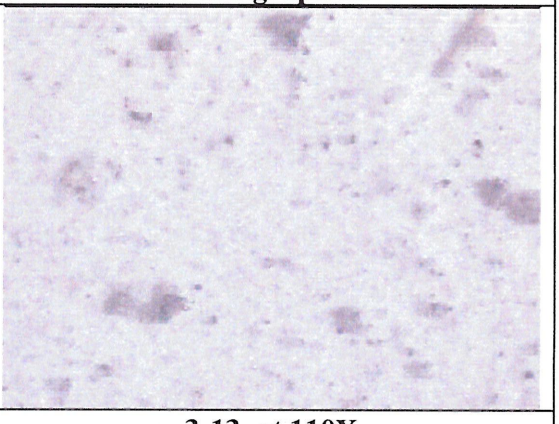
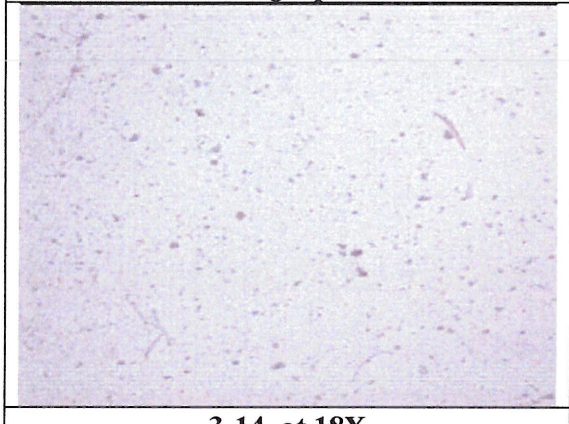
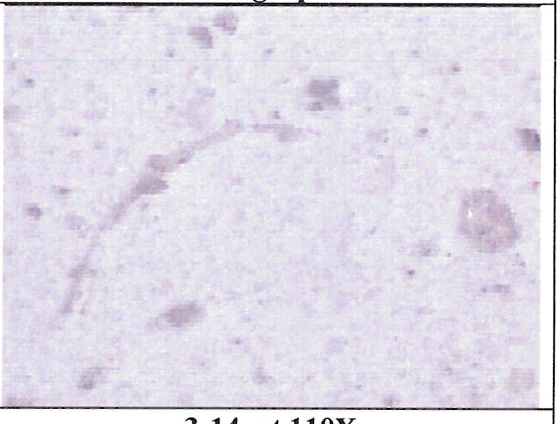
Photographs from Test 3

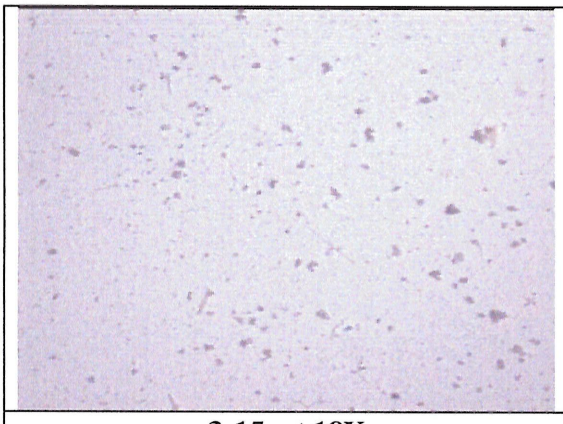
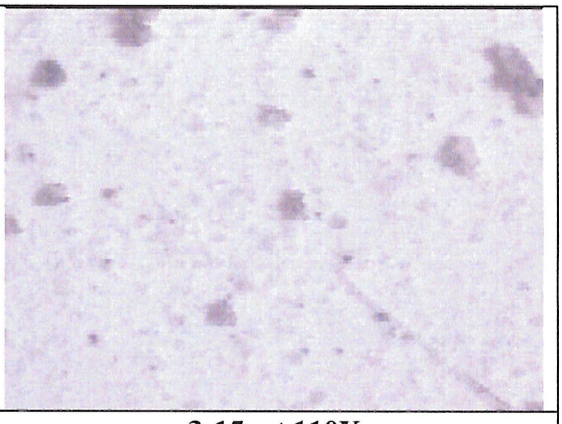
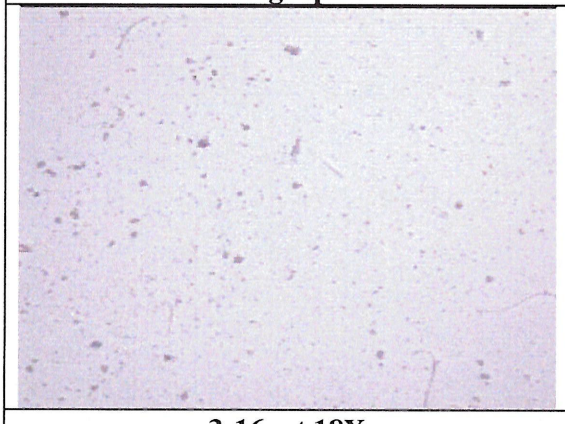
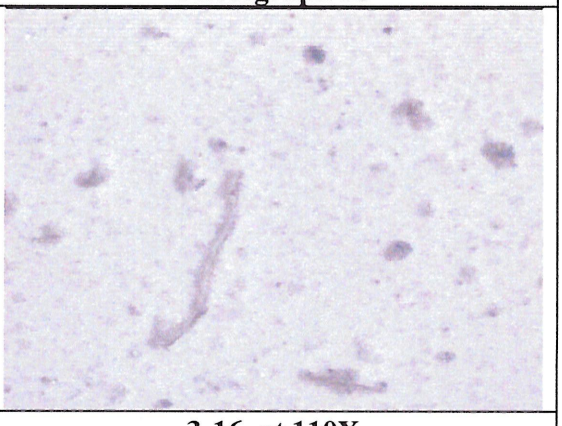
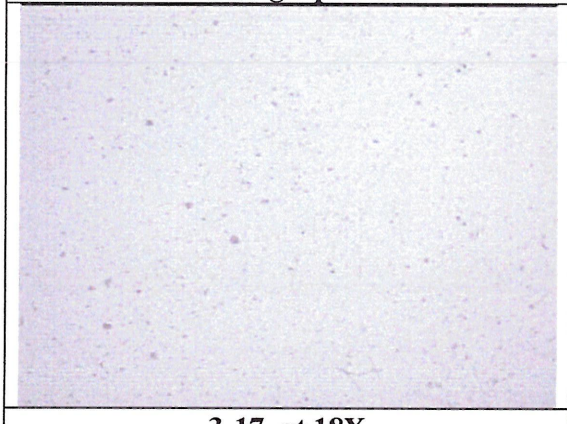
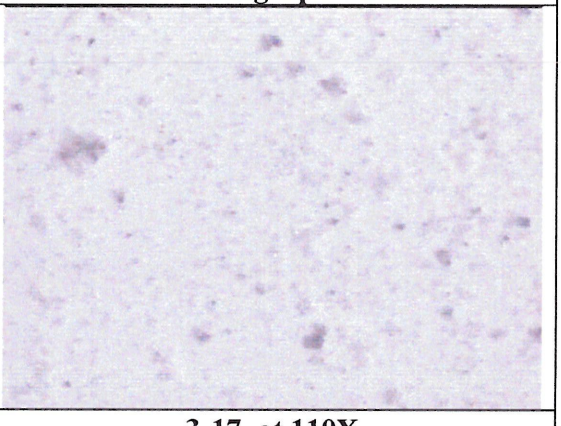
	
mm Scale, at 18X, each division is 1000 microns (1 mm) **Photograph 27**	**Graticle scale at approximately 110 X. Each division is 10 microns; the entire length is 1000 micron.** **Photograph 28**
	
3-1, at 18X **Photograph 29**	**3-1, at 110X** **Photograph 30**
	
3-2, at 18X **Photograph 31**	**3-2,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

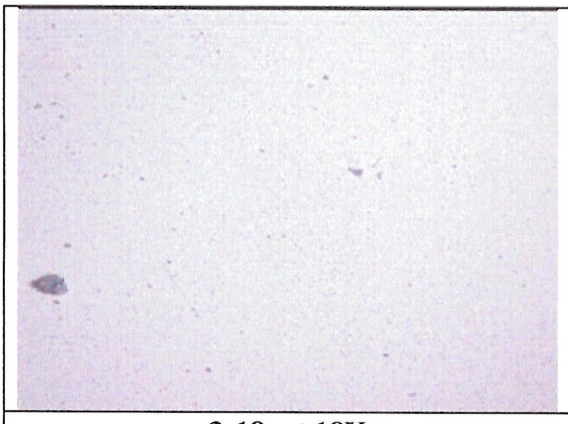
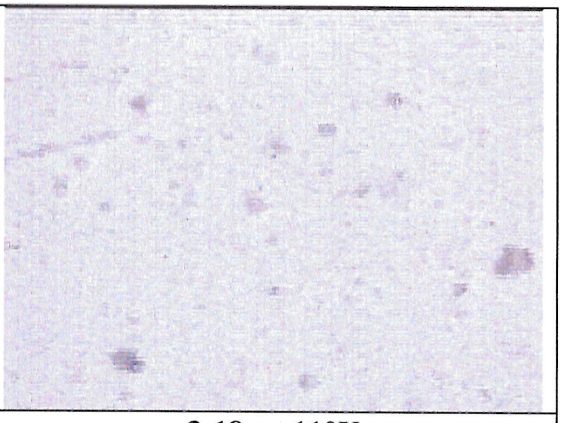
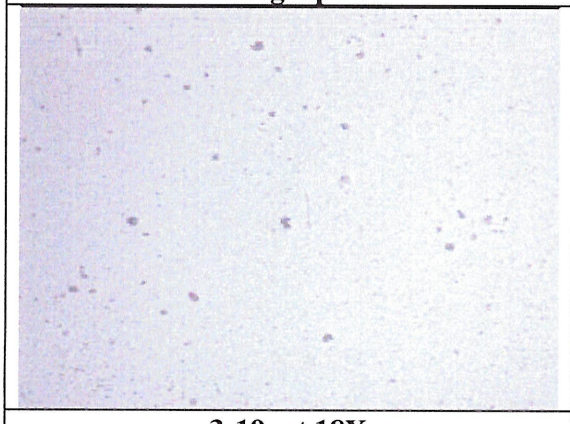
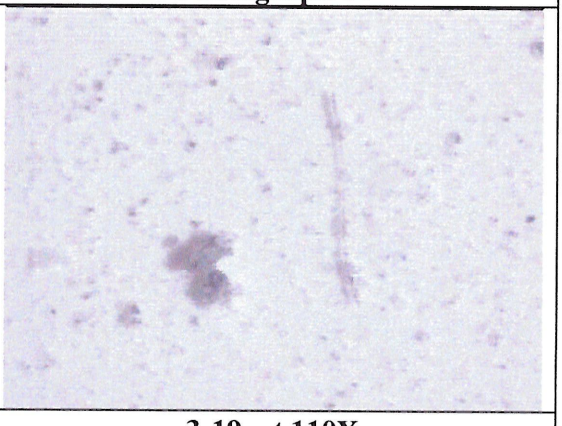
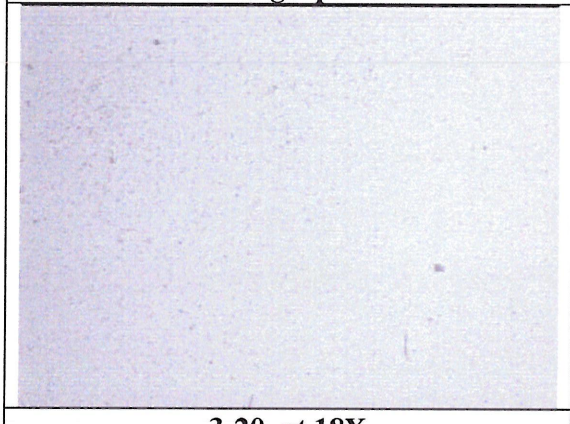
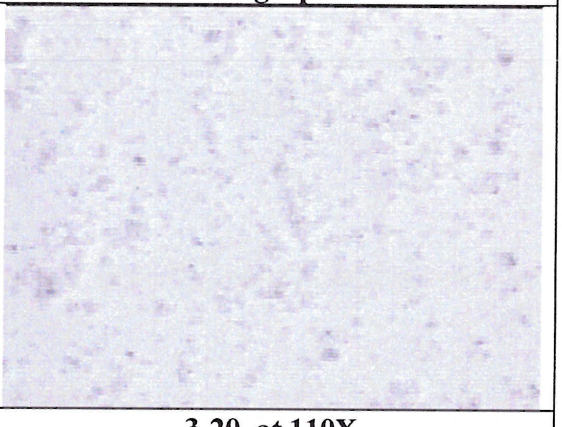
	
3-3, at 18X **Photograph 33**	**3-3, at 110X** **Photograph 34**
	
3-4, at 18X **Photograph 35**	**3-4, at 110X** **Photograph 36**
	
3-5, at 18X **Photograph 37**	**3-5, at 110X** **Photograph 38**

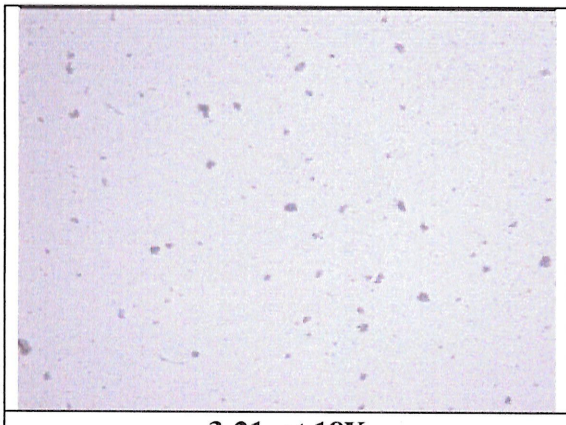
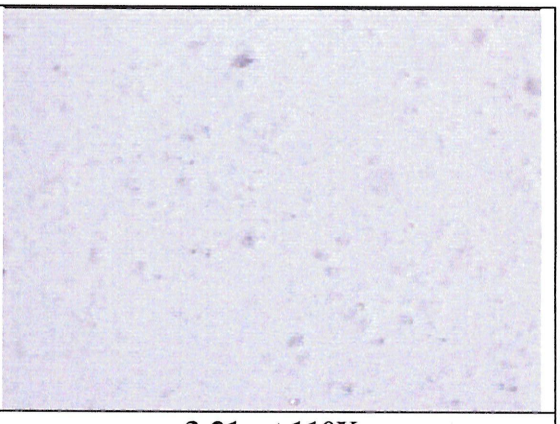
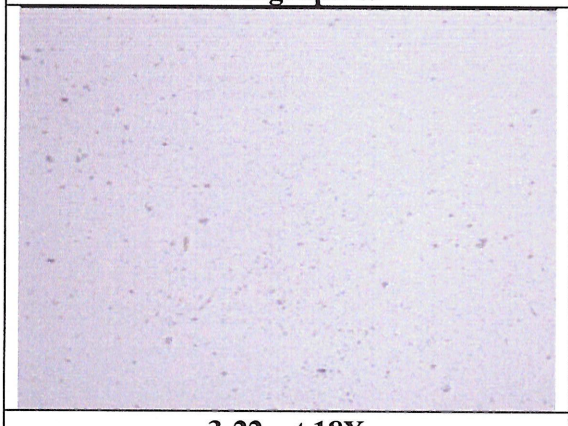
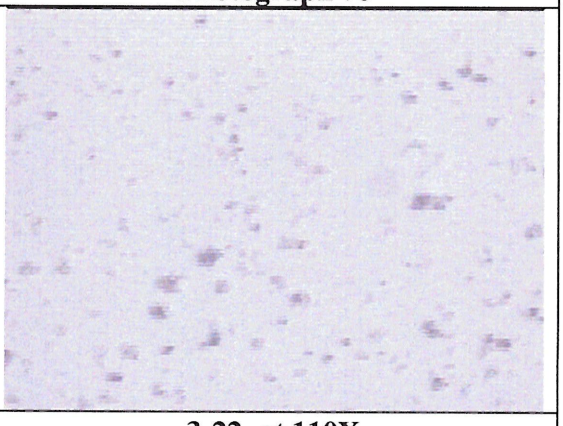
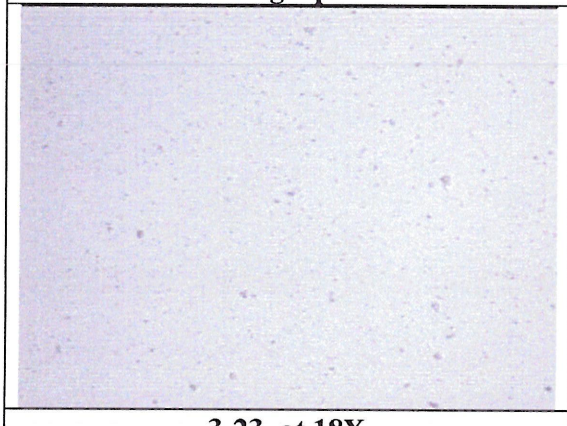
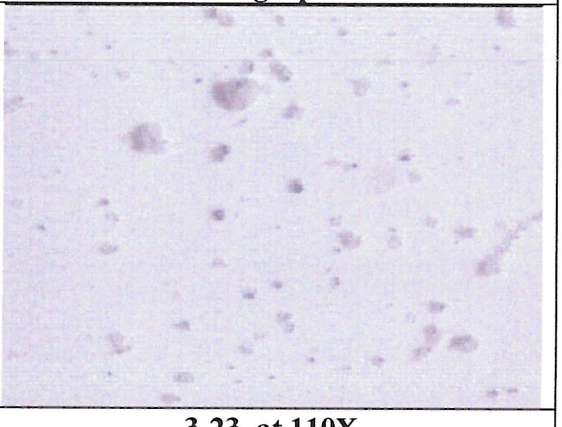
	
3-6, at 18X **Photograph 39**	**3-6, at 110X** **Photograph 40**
	
3-7, at 18X **Photograph 41**	**3-7, at 110X** **Photograph 42**
	
3-8, at 18X **Photograph 43**	**3-8, at 110X** **Photograph 44**

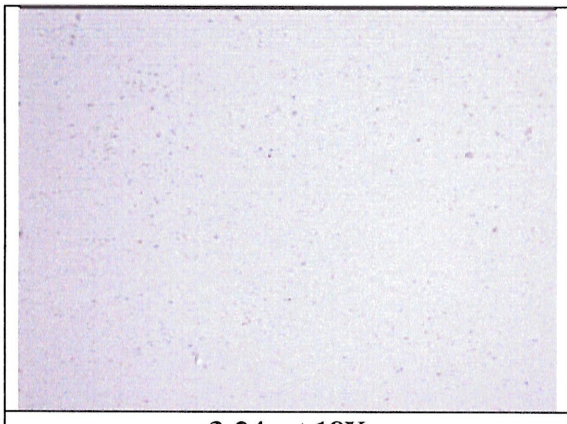
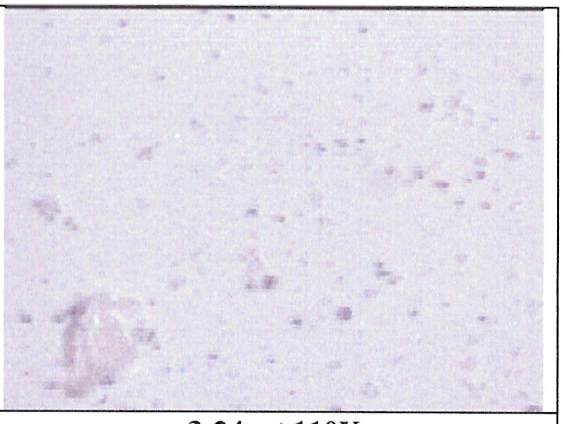
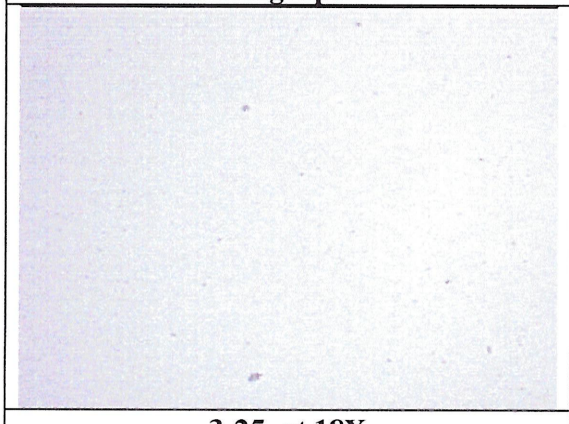
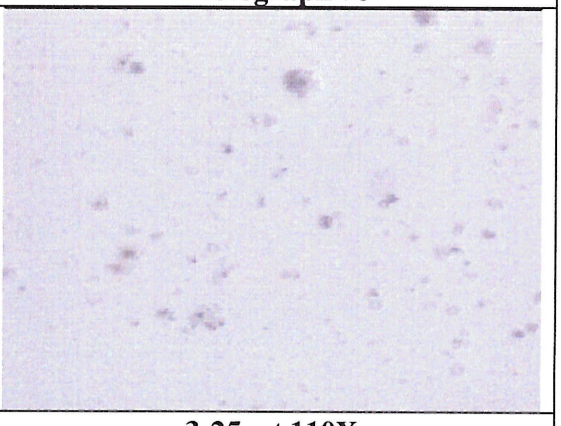
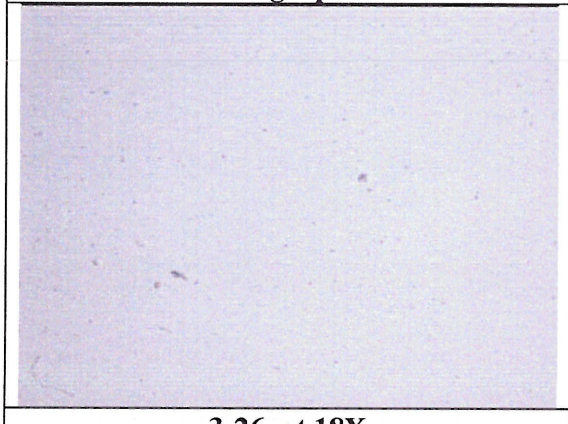
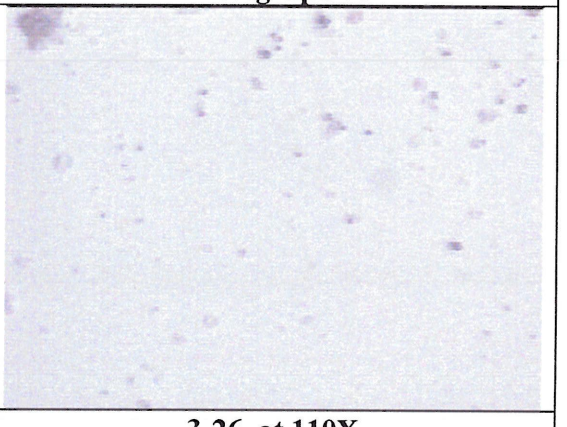
	
3-9, at 18X **Photograph 45**	**3-9, at 110X** **Photograph 46**
	
3-10, at 18X **Photograph 47**	**3-10, at 110X** **Photograph 48**
	
3-11, at 18X **Photograph 49**	**3-11, at 110X** **Photograph 50**

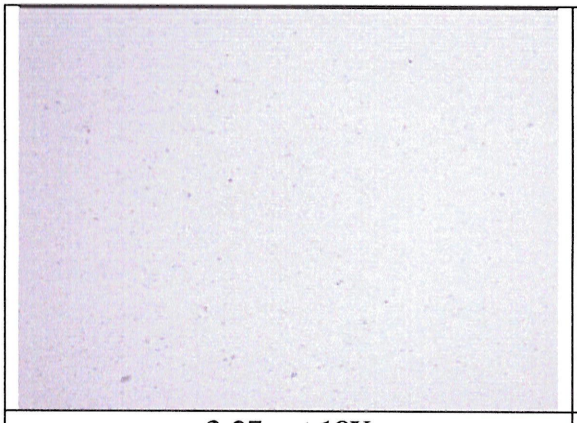
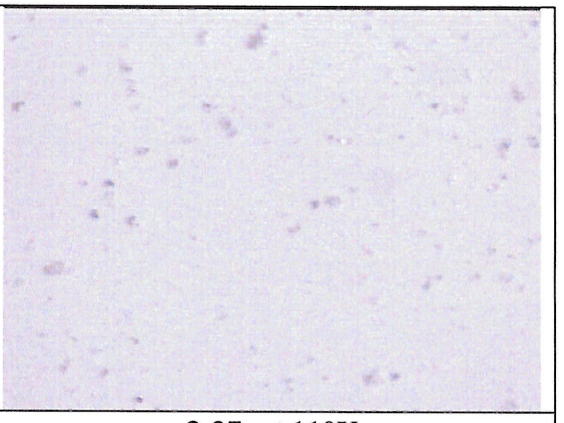
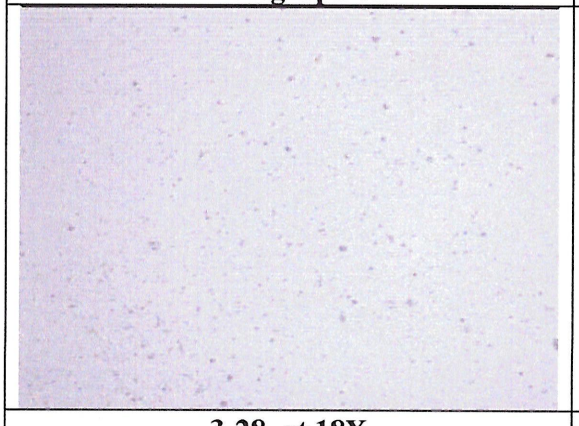
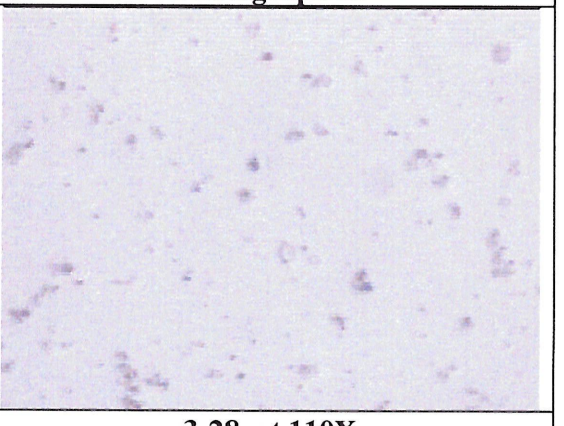
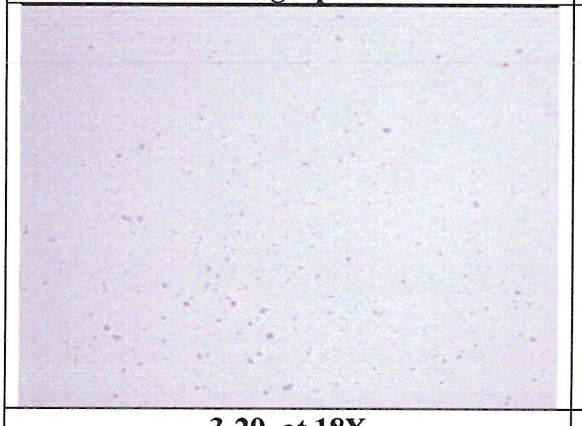
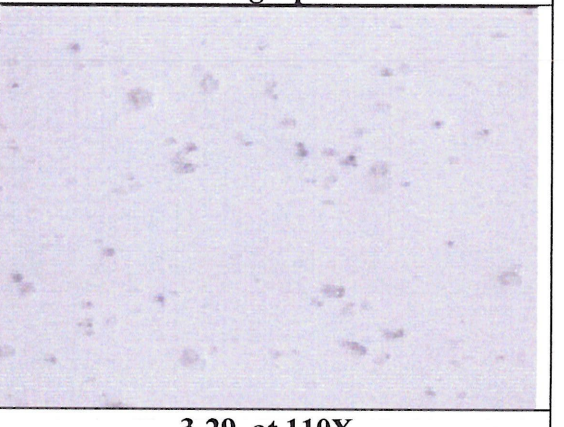
	
3-12, at 18X **Photograph 51**	**3-12, at 110X** **Photograph 52**
	
3-13, at 18X **Photograph 53**	**3-13, at 110X** **Photograph 54**
	
3-14, at 18X **Photograph 55**	**3-14, at 110X** **Photograph 56**

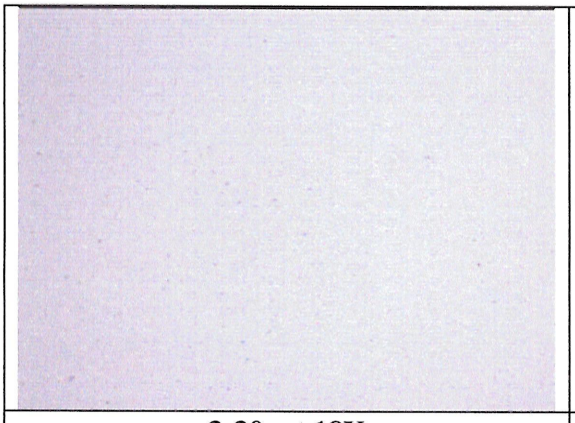
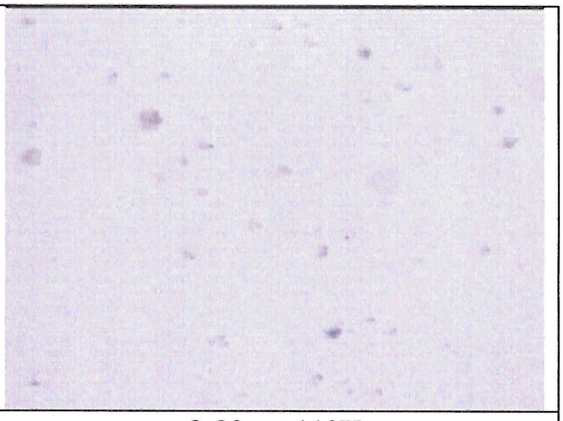
	
3-15, at 18X **Photograph 57**	**3-15, at 110X** **Photograph 58**
	
3-16, at 18X **Photograph 59**	**3-16, at 110X** **Photograph 60**
	
3-17, at 18X **Photograph 61**	**3-17, at 110X** **Photograph 62**

	
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**