IN-DEPTH SURVEY REPORT. EVALUATION OF VENTILATION/FILTRATION SYSTEM FOR THE 010 CULLING SYSTEM

at

United States Postal Service
Cleveland Processing and Distribution Center
Cleveland, Ohio

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ABSTRACT

Researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of the Ventilation/Filtration System (VFS) developed for the United States Postal Service (USPS) mail processing equipment – the 010 Culling System. The VFS was developed and installed by a private contractor hired by the USPS to reduce the potential for employee exposure to harmful substances that could be contained in mail pieces processed by the equipment. This effort is in response to the 2001 terrorist attacks that used the mail as a delivery system for anthrax. NIOSH was asked to assist the USPS in evaluating controls for this and other mail processing equipment.

Evaluations were based on a variety of tests including tracer gas (TG) experiments, air velocity measurements and smoke release observations to evaluate contaminant capture efficiency, as well as simultaneous particle count experiments upstream and downstream of the VFS filtration to evaluate system filtration efficiency. The experiments showed that the system met or exceeded minimum contaminant capture velocities (100 feet per minute), except at the Waterfall areas. Lower capture velocities at the Waterfall areas, however, were mitigated by the fact that these areas are largely enclosed, tracer gas capture at these areas met acceptance criteria and, smoke release observations indicated good contaminant capture. It should also be noted that "dirty filter" testing showed that capture velocities were relatively unchanged at several key locations when the air handling units operated at lower capacities (in order to simulate loaded/"dirty" filters). Additionally, contaminant filtration capabilities met or exceeded the 99.7% filtration efficiency requirement at Air Handling Units 2 and 3. Moreover, test results at Air Handling Unit 1 showed that the filtration efficiency was at least 99.97% after vendor modifications were made to the system.

Based on the results as discussed in this report, the following comments summarize the effectiveness of the Ventilation and Filtration System.

Capture Capabilities

- Overall, testing showed that contaminant capture capabilities met or exceeded USPS requirements.
- The high volumes of air being entrained into the VFS exhaust at the flats extractors and at the conveyor immediately leading to the AFCS occasionally resulted in partial clogging of the VFS exhaust air intakes.
- This condition did not necessarily lead to inadequate performance of the VFS, however VFS performance would be optimized if an engineering solution were developed to prevent the blockage of VFS exhaust intakes.
- The vendor of the VFS is aware of this situation and is enhancing the system to eliminate such blockage.
- "Dirty filter" testing, in which capture velocity measurements were made at several locations at reduced VFS air flows in order to simulate loaded/dirty filters, showed that capture velocities were relatively unchanged under these conditions.

- Lower capture velocities at the Waterfall areas were mitigated by the fact that
  - these areas are largely enclosed,
  - tracer gas capture at these areas met acceptance criteria and,
  - smoke release observations indicated good contaminant capture

Filtration Capabilities

- The modifications made to 010 VFS Unit # 1 prior to meeting the 99 97% efficiency requirement should be made a permanent change to the manufacturing process of that unit The vendor has acknowledged this situation and has made the necessary enhancements
- Tests conducted with AAF HEPA filters and Donaldson HEPA filters in 010 VFS Unit # 1 show filters are interchangeable
- Extreme care should be taken when performing any maintenance on any VFS, particularly any operation that could disturb the seal of the filters inside the VFS housing
- Real-time total system integrity testing is the only reliable test method for evaluating total system filtration performance
- It is recommended that the USPS should implement a system to routinely test the system filtration efficiency of all units As was demonstrated in this research, small leaks and perforations in the filter media can easily breach system integrity

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is located in the Centers for Disease Control and Prevention (CDC), within the Department of Health and Human Services NIOSH was established in 1970 by the Occupational Safety and Health Act at the same time that the Occupational Safety and Health Administration (OSHA) was established in the Department of Labor (DOL) The OSHAct legislation mandated NIOSH to conduct research and education programs separate from the standard-setting and enforcement functions conducted by OSHA. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards

The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology (DART) has been given the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness Since 1976, EPHB (and its forerunner, the Engineering Control and Technology Branch) has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique The objective of each of these studies has been to evaluate and document control techniques and to determine the effectiveness of the control techniques in reducing potential health hazards in an industry or for a specific process

Researchers from NIOSH were requested to assist the USPS in the evaluation of contaminant controls for various mail processing equipment These new controls are being installed to significantly reduce operator exposure to any potentially hazardous contaminants emitted from mail pieces during normal mail processing This effort is driven by the 2001 terrorist attacks which used the mail as a delivery system for anthrax NIOSH researchers have subsequently made several trips to Washington, DC area postal facilities to observe mail-processing equipment in operation and to study the effectiveness of the newly designed controls

The control evaluated in this report is a first article ventilation/filtration system (VFS) for the 010 Culling System. This control was designed and installed by a USPS contractor to significantly reduce the potential for operator exposure to bacterial contaminants that could be contained in mail pieces processed by this equipment This system was evaluated at the Cleveland, Ohio Processing and Distribution Center (P&DC) during a field survey that took place March 11-14 and 25-28, 2003

DESCRIPTION OF EQUIPMENT

The USPS 010 Culling System is comprised of 2 conveyor systems that size the collection mail brought to the P&DC into letters, flats (magazine size), and parcels The first system is called the Dual Pass Rough Cull (DPRC) and the second is the Loose Mail Distribution System (LMDS) The hampers of raw mail are loaded into the DPRC. Flats and parcels are separated from the letter mail and sent to the appropriate areas of the facility for processing The output of the LMDS sends letter mail to the next stage in its processing which is the cancellation equipment

At the time of evaluation, the VFS for the 010 Culling System consisted of 3 separate air-handling/filtration units that provided exhaust for various locations of possible contaminant release Air-handling Unit # 1 processed about 8,000 cubic feet per minute (cfm) Air-Handling Units # 2 and 3 processed about 18,000 cfm. Each of these air-handling units was fitted with three stages of filtration composed of a pre-filter, a MERV 14 filter and a High Efficiency Particulate Air (HEPA) filter Furthermore, several areas of potential contaminant release were enclosed or partially enclosed by the manufacturer so that the VFS could more effectively protect the worker from exposure

METHODS

TRACER GAS

Apparatus

To quantitatively evaluate the capture efficiency of the ventilation system, a tracer gas method was used The gas, CP sulfur hexafluoride (SF_6), was released at a constant rate at points in and near the sorter to determine the capture efficiency of the VFS at these release points The gas was supplied through a mass flow controller (Model 1359C-10000SV, MKS Baratron® & Control Products, Six Shattuck Road, Andover, Massachusetts, 01810) set to produce about 4 parts per million (ppm) in the exhaust outlet of the system. The exhaust from the ventilation system was filtered and then returned to the workroom near the ceiling The concentration of the SF_6 was measured in the exhaust duct, just upstream of the filters In order to sample this air stream uniformly, the exhaust air was drawn through a 1/4 in diameter copper tube having six 3/32 in diameter holes spread uniformly across the duct diameter, inserted into and perpendicular to the exhaust duct After exiting the copper tube, the air was first filtered (HEPA Capsule Filter, Model # 12127, Gelman Sciences, Incorporated, Ann Arbor, Michigan, 48106) to remove dust, and then pulled through a MIRAN® 203 Specific Vapor Analyzer (Thermo Environmental Instruments, 8 West Forge Parkway, Franklin, MA 02038), using an AirCon® high volume air sampler (Gilian Instrument Corporation, W Caldwell, New Jersey) set for approximately 30 liters per minute, and using Tygon® tubing throughout the sampling system. After exiting the pump, the sampled air was released into the workroom. The analogue output signal from the MIRAN® was routed to a PCMCIA 12-bit analog card (Quatech Model # DAQP-12, Akron, OH) which allowed data storage and display at one-second intervals in real-time on a portable computer

Procedures

For these measurements, the output signal from the MIRAN® was recorded at 1 second intervals Each measurement of capture efficiency was recorded for a 2 to 4 minute interval The MIRAN® concentration corresponding to 100% capture was measured by releasing the SF_6 directly into a duct supplying the exhaust intake in that part of the system. This measurement was made immediately before and after the rest of the capture efficiency measurements as well as between a number of the efficiency measurements, to detect and correct for drift in the 100% level All of the tracer gas measurements were made with the ventilation system blower turned on A list of the sampling sites is given in Table 1

SMOKE RELEASE

Apparatus

A smoke machine (Mini Fogger, Model F-800, Chauvet USA, 3000 North 29th Court, Hollywood, Florida, 33020) was used to visualize air movement in and around these systems

Procedures

By releasing smoke at points in and around the sorter with the VFS operating, the path of the smoke, and thus any airborne material released at that point, could be determined If the smoke was captured quickly and directly by the VFS, it was a good indication of acceptable control design and performance If the smoke was slow to be captured when released at a certain point, or took a circuitous route to the air intake for the exhaust, the VFS design was considered marginal at that point A list of the sampling sites is given in Table 2

CAPTURE VELOCITY

Apparatus

An anemometer was used to measure air speeds at exhaust openings on the LMDS and DPRC (Velocicalc® Plus Anemometer, Model 8388, TSI Incorporated, P O Box 64394, St Paul, Minnesota, 55164)

Procedures

To measure the velocities achieved by the control at critical points, the anemometer was held perpendicular to the flow direction at those points Velocities were recorded at the hamper dumper and at exhaust openings around the system. To check capture velocities at the furthest point from the air intake, the anemometer was held at the edge of the equipment where a worker would be positioned A list of the sampling sites is given in Table 3

"DIRTY FILTER TESTING"

It was advantageous to the USPS to also make some limited testing simulating "dirty" filters This testing was borne out of concern that fully loaded filter media would have a performance limiting effect on the capture efficiency of the VFS "Dirty Filter" simulation was accomplished by restricting the airflow of the VFS The pressure alarm, which activates when filter media needs to be replaced, was activated Under these conditions, air velocity measurements were made at a representative sampling of locations (see Table 5 for specific locations) The procedure for making these measurements mirrors that of all other air velocity measurements in this report

FILTRATION EFFICIENCY

Apparatus

Testing of the VFS was intended to determine whether the filtration efficiency of the overall filter bank housing met critical performance criteria Specifically, the entire VFS had to provide 99 97% efficiency or better against particles in the size range of 0 3 μm to 3 0 μm during normal operation The testing method employed two GRIMM Model 1 108 Portable Dust Monitors (GRIMM Technologies, Ainring, Germany) These optical particle counters

(OPCs) were each equipped with a GRIMM Model 1.152 Isokinetic Sampling Probe that sampled parallel to the air stream at a rate of 1.2 L/min. The OPCs measure concentration of particles per unit volume by means of light-scattering technology where a semiconductor-laser serves as the light-source. The OPCs determine particle size based upon the amount of light scattered by individual particles which enter the detector volume. The scattered signal is collected at approximately 90 degrees by a mirror and transferred to a recipient-diode. The signal passes to a multi-channel size classifier and finally to a pulse height analyzer that classifies the signal in channels according to size and then logs the sampling results on a data storage card. Particles in 15 different size channels are counted as follows: 0.30-0.40 µm, 0.40-0.50 µm, 0.50-0.65 µm, 0.65-0.80 µm, 0.80-1.0 µm, 1.0-1.6 µm, 1.6-2.0 µm, 2.0-3.0 µm, 3.0-4.0 µm, 4.0-5.0 µm, 5.0-7.5 µm, 7.5-10 µm, 10-15 µm, 15-20 µm, and >20 µm. The instrument operates from 4-45°C with a particle concentration range of 1-2,000,000 particle counts per liter. The sensitivity is 1 particle per liter and the instruments reproducibility is quoted as ±2 percent.[1]

Procedures

Prior to use, the GRIMM optical particle counters were selected as a matched pair. Since two OPC instruments were employed, several identical units were tested in the laboratory and the two units that produced the most comparable results were selected as a pair for testing. This comparison was necessary even with all the instruments having been calibrated together in order to avoid bias in results stemming from instrument-to-instrument variability.

To conduct the testing of the filtration component of the VFS, the access panels to the knockdown screen chamber and the motor chamber of the VFS were removed or opened (see Figure 1 for a schematic of filtration system). Then, one GRIMM Portable Dust Monitor was placed upstream of the filters to measure particle concentration data with an isokinetic sampling probe at the center of the filter bank. The probe was placed facing the air stream and as close to the main intake-duct as possible. The second GRIMM Portable Dust Monitor was placed downstream of the HEPA filters to measure particle count data with an isokinetic sampling probe at the center of the filter bank. Here the probe was positioned facing the HEPA filters as close to the fan inlet as possible. By ensuring that the GRIMMs' probes were placed in front of the fan, no aerosol generated by the motor would be able to bias the measured downstream particle concentration. In this way only particles that penetrated the system by 1) filter penetration, 2) leakage around the filters, and/or 3) leakage in the filter housing itself would be considered registered by the particle counters. Once the OPCs were in place, they were turned on and data collection began. The access panels on the VFS housing were replaced taking care to make certain no leakage through the panel seals could take place.

The ambient particles or dust that entered the VFS at the air inlet were used as the challenge. This arrangement was appropriate for the USPS P&DC environment where mechanical agitation of letters produced consistently high levels of background particulate. The OPCs recorded data every minute on a data storage card. The matched OPCs were operated under

[1] GRIMM Technologies, Inc. GRIMM Dust Monitor Series 1.100 Operator's Manual (2003)

normal operating conditions for a time interval of at least 45 minutes, of which the first 15 minutes of data were ignored in order to allow time for the units to stabilize At the end of the testing period, the data for both OPCs were downloaded to a portable computer and placed in a spread sheet for analysis

The OPCs used in this investigation measure aerosol particle concentration in 15 different particle size ranges from 0 30-0 40 μm to >20 μm, but only particle sizes of ≤3 μm were evaluated in this study since the acceptance criteria called for a minimum filter efficiency of 99 97% at the 95% confidence level for particle size ranges from 0 3μm to 3 0μm. Further, since ambient aerosol was the challenge agent, the only statistically valid size ranges were those that were ≤3 μm These were the only size ranges that contained sufficient data (i e , the particle counts were high enough) for statistically significant calculations

Therefore, for particle sizes up to 3 μm, the overall filtration efficiency of the VFS for each particle size was then calculated

$$\% \text{ Efficiency} = \left[1 - \left(\frac{C_D}{C_U}\right)\right] \times 100$$

where C_D is the downstream aerosol particle concentration and C_U the upstream aerosol particle concentration This efficiency calculation was performed on each minute of data for each individual particle size Then, an overall average efficiency and the associated 95 percent confidence interval for each particle size range was calculated

RESULTS

Tracer gas

The mass flow controller was set to produce a 4 ppm concentration of SF_6 in the ventilation system exhaust when 100% of the gas was being captured The relative concentration in the exhaust as a result of tracer dosing at any point, which is equivalent to the capture efficiency at that point, is given in Table 1 Point estimates for measured capture efficiencies were at least 98% at all locations tested

Smoke

All smoke release observations made when the VFS exhaust inlets were clear indicate that the VFS clears generated smoke quickly and effectively However, the VFS exhaust inlets were partially covered with mail at times at the flats extractors and LL-conveyors that deposit mail to the Advanced Facer Canceller System. The end result is that capture efficiency could have been even better improved if all exhaust inlets could be kept free of mail

Air Velocity

Contaminant capture velocities met or exceeded USPS requirement of 100 feet per minute (fpm), except at the waterfall areas (see Table 3) However, smoke release observations and tracer gas experimentation, which offer a more direct indication of contaminant capture efficiency, indicated that the VFS capture velocities at waterfall areas are sufficient to protect USPS workers in a manner consistent with other areas under VFS control

Filtration Efficiency

Total system filtration efficiency met or exceeded USPS requirement of 99 97 percent for 010 VFS Units # 2 and # 3 during first test 010 VFS Unit # 1 did not meet USPS requirement of 99 97 percent during initial testing, but did exceed requirement after system modifications were made by manufacturer Tests conducted with AAF HEPA filters and Donaldson HEPA filters in 010 VFS Unit # 1 show filters are interchangeable Please refer to tables 5-9 for details of filtration efficiency testing

"Dirty Filter" Testing

"Dirty filter" testing, in which capture velocity measurements were made at several locations at reduced VFS air flows in order to simulate loaded/dirty filters, showed that capture velocities were relatively unchanged at several locations Lower capture velocities at the Waterfall areas were mitigated by the fact that these areas are largely enclosed, tracer gas capture at these areas met acceptance criteria, and smoke release observations indicated good contaminant capture

DISCUSSION

As was conveyed in the Results section of this report, testing showed that contaminant capture capabilities met or exceeded USPS requirements, with a few exceptions First, VFS exhaust slots at the flats extractors and at the conveyor immediately leading to the AFCS were occasionally found to be partially blocked At the time of the survey, it was believed that this condition was caused by high volumes of air being entrained into the VFS that would draw and hold mail over the slots It should be noted, however, that the capture capability of the VFS still met USPS requirements at these locations, in large part due to the high volumes of air being moved into the system. The vendor and USPS Engineering were made aware of this problem and are looking into possible solutions in order to optimize VFS performance Second, results indicate that capture velocities at the waterfall areas did not meet the minimum USPS requirement of 100 fpm. However, this circumstance is mitigated by the fact that these areas are largely enclosed and that tracer gas experimentation and smoke release observations indicate adequate capture efficiency In point of fact, smoke release observations and tracer gas experimentation tend to provide a more direct indication of system capture performance

At the request of the USPS, limited testing was completed with somewhat reduced airflows throughout the VFS system. This was done to simulate conditions resulting from a fully loaded or "dirty" filter Although the system was designed to provide optimal protection to workers, even with loaded filters, USPS Engineering was interested in testing this "worst case" scenario Locations were chosen for "dirty filter" testing because they experienced relatively low capture velocities in testing with unrestricted airflow Results indicate that the restricted airflow during this testing did not significantly influence VFS performance

The filtration component of the VFS met minimum requirements of 99 97% filtration efficiency at all locations after minor adjustments were made to Unit 1 Obviously, these changes should be made permanent and introduced to all subsequent production models Most importantly, investigation of possible air leaks in Unit 1 showed that small leaks and perforations in the filter media can easily breach system integrity Therefore, the USPS should be vigilant in systematically testing these systems and performing adequate preventative maintenance

CONCLUSIONS

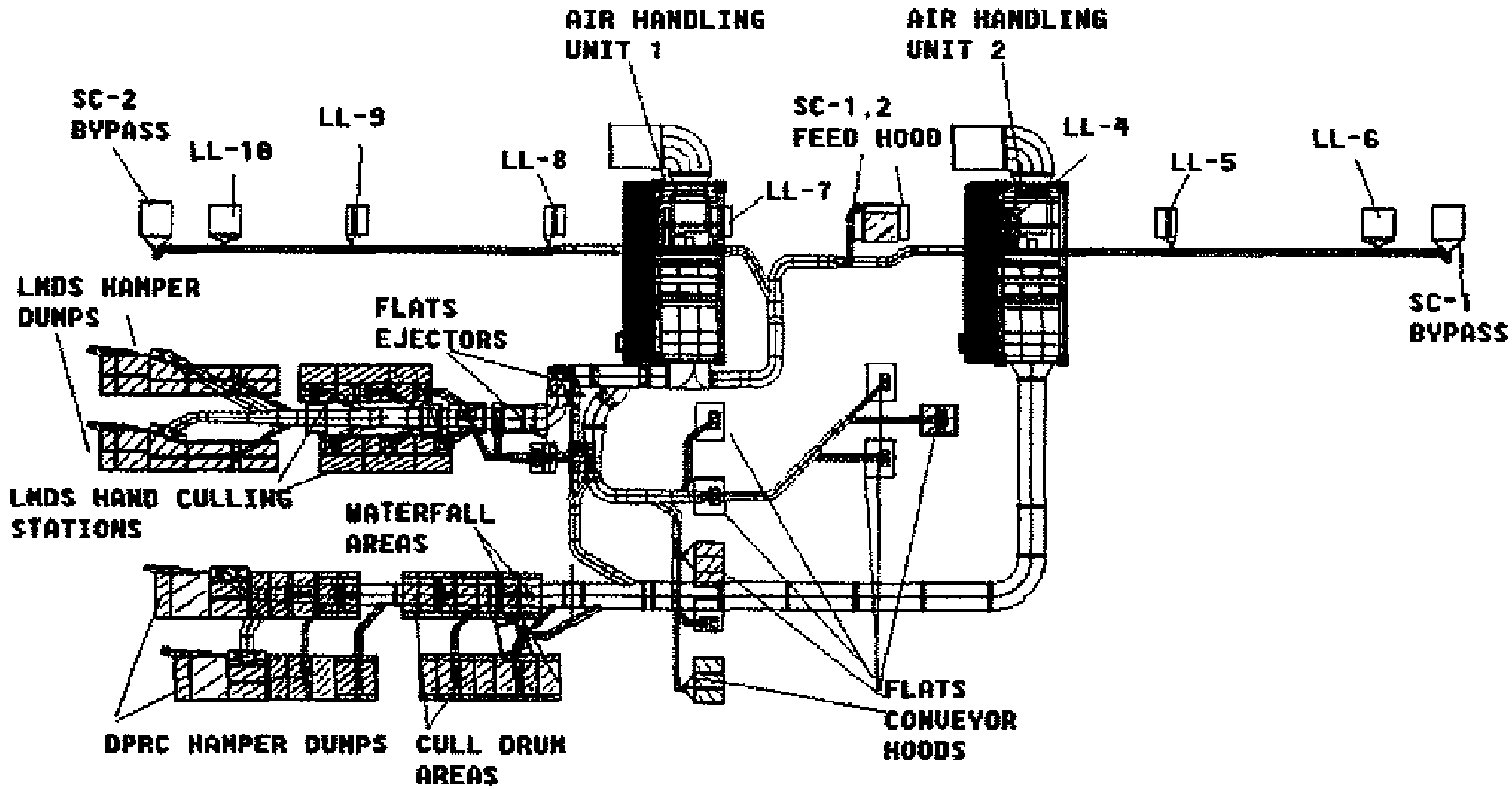
Based on the previous results, the following comments summarize the effectiveness of the Ventilation and Filtration System.

Capture Capabilities

- Overall, testing showed that contaminant capture capabilities met or exceeded USPS requirements
- The high volumes of air being entrained into the VFS exhaust at the flats extractors and at the conveyor immediately leading to the AFCS sometimes resulted in partial clogging of the VFS exhaust air intakes
- This condition did not necessarily lead to inadequate performance of the VFS, however VFS performance would be optimized if an engineering solution were developed to prevent the blockage of VFS exhaust intakes
- The vendor of the VFS is aware of this situation and is enhancing the system to eliminate such blockage
- "Dirty filter" testing, in which capture velocity measurements were made at several locations at reduced VFS air flows in order to simulate loaded/dirty filters, showed that capture velocities were relatively unchanged at several locations
- Lower capture velocities at the Waterfall areas were mitigated by the fact that
    - these areas are largely enclosed,
    - tracer gas capture at these areas met acceptance criteria and,
    - smoke release observations indicated good contaminant capture

Filtration Capabilities

- The modifications made to 010 VFS Unit # 1 prior to meeting the 99 97% efficiency requirement should be made a permanent change to the manufacturing process of that unit The vendor has acknowledged this situation and has made the necessary enhancements
- Tests conducted with AAF HEPA filters and Donaldson HEPA filters in 010 VFS Unit # 1 show filters are interchangeable
- Extreme care should be taken when performing any maintenance on any VFS, particularly any operation that could disturb the seal of the filters inside the VFS housing
- Real-time total system integrity testing is the only reliable test method for evaluating total system filtration performance
- It is recommended that the USPS should implement a system to routinely test the system filtration efficiency of all units As was demonstrated in this research, small leaks and perforations in the filter media can easily breach system integrity



OVERVIEW OF 010 LOOSE MAIL CULLING SYSTEM

Table 1 Positions for Tracer Gas Release and Measured Efficiencies

Description of Measurement Location	Efficiency
LEFT-HAND LMDS HAND CULLING STATION A (CLOSEST TO HAMPER DUMP)	>98%
LEFT-HAND LMDS HAND CULLING STATION B	98%
LEFT-HAND LMDS HAND CULLING STATION C	>98%
LEFT-HAND LMDS HAMPER DUMP	>98%
RIGHT-HAND LMDS HAND CULLING STATION A (CLOSEST TO HAMPER DUMP)	98%
RIGHT-HAND LMDS HAND CULLING STATION B	>98%
RIGHT-HAND LMDS HAND CULLING STATION C	98%
RIGHT-HAND LMDS HAMPER DUMP	98%
LEFT-HAND DPRC HAMPER DUMP	>98%
RIGHT-HAND DPRC HAMPER DUMP	>98%
LEFT-HAND DPRC WATERFALL AREA (BOTTOM OF LETTER DROP)	>98%
RIGHT-HAND DPRC WATERFALL AREA (BOTTOM OF LETTER DROP)	>98%
SC-2 BYPASS AT BOTTOM OF CART	98%
SC-1 BYPASS AT BOTTOM OF CART	98%
UNDERNEATH FLATS EXTRACTOR # 1	>98%
UNDERNEATH FLATS EXTRACTOR # 2	>98%
UNDER LH DPRC CULL DRUM	98%
UNDER RH DPRC CULL DRUM	>98%

Table 2 Positions for Smoke Release Observations and Comments

AREA OF RELEASE	COMMENTS
FACING CONTROLS	RAPID CAPTURE OF SMOKE
HAMPER DUMP IN	RAPID CAPTURE OF SMOKE
HAND CULL A IN	RAPID CAPTURE OF SMOKE
HAND CULL B IN	RAPID CAPTURE OF SMOKE
HAND CULL C IN	RAPID CAPTURE OF SMOKE
FACING CONTROLS	RAPID CAPTURE OF SMOKE
HAMPER DUMP OUT	RAPID CAPTURE OF SMOKE
HAND CULL A OUT	RAPID CAPTURE OF SMOKE
HAND CULL C OUT	RAPID CAPTURE OF SMOKE
FACING CONTROLS	RAPID CAPTURE OF SMOKE
HAMPER DUMP IN	RAPID CAPTURE OF SMOKE
HAND CULL A IN	RAPID CAPTURE OF SMOKE
HAND CULL B IN	RAPID CAPTURE OF SMOKE
HAND CULL C IN	RAPID CAPTURE OF SMOKE
FACING CONTROLS	RAPID CAPTURE OF SMOKE
HAMPER DUMP OUT	RAPID CAPTURE OF SMOKE
HAND CULL A OUT	RAPID CAPTURE OF SMOKE
LL 12	RAPID CAPTURE OF SMOKE
LL 13	RAPID CAPTURE OF SMOKE
LL 14	RAPID CAPTURE OF SMOKE
BYPASS RIGHT	RAPID CAPTURE OF SMOKE
HAMPER DUMP OUT	RAPID CAPTURE OF SMOKE
UPDRAFT HOOD OUT	RAPID CAPTURE OF SMOKE
METERING CONVEYOR OUT	RAPID CAPTURE OF SMOKE
CULL DRUM OUT	RAPID CAPTURE OF SMOKE
WATERFALL OUT	RAPID CAPTURE OF SMOKE
LL 12	RAPID CAPTURE OF SMOKE
LL 13	RAPID CAPTURE OF SMOKE
LL 14	RAPID CAPTURE OF SMOKE
BYPASS RIGHT	RAPID CAPTURE OF SMOKE
HAMPER DUMP OUT	RAPID CAPTURE OF SMOKE
UPDRAFT HOOD OUT	RAPID CAPTURE OF SMOKE
METERING CONVEYOR OUT	RAPID CAPTURE OF SMOKE
CULL DRUM OUT	RAPID CAPTURE OF SMOKE
METERING CONVEYOR IN	RAPID CAPTURE OF SMOKE
CULL DRUM IN	RAPID CAPTURE OF SMOKE
WATERFALL IN	RAPID CAPTURE OF SMOKE
FLATS EXTRACTOR IN	RAPID CAPTURE OF SMOKE
LETTER DISCHARGE IN	RAPID CAPTURE OF SMOKE

Table 3 Positions for Air Velocity Measurements and Recorded Values

AREA	AVERAGE CONTAMINANT CAPTURE VELOCITY (VALUES OF TRIALS IN FEET PER MINUTE)
LEFT-HAND 010 HAND CULLING STATION A (AT FACE OF PLASTIC CURTAIN AT VARIOUS LOCATIONS)	133
LEFT-HAND 010 HAND CULLING STATION B (AT FACE OF PLASTIC CURTAIN AT VARIOUS LOCATIONS)	144
LEFT-HAND 010 HAND CULLING STATION C (AT FACE OF PLASTIC CURTAIN AT VARIOUS LOCATIONS)	151
RIGHT-HAND 010 HAND CULLING STATION A (AT FACE OF PLASTIC CURTAIN AT VARIOUS LOCATIONS)	164
RIGHT-HAND 010 HAND CULLING STATION B (AT FACE OF PLASTIC CURTAIN AT VARIOUS LOCATIONS)	139
RIGHT-HAND 010 HAND CULLING STATION C (AT FACE OF PLASTIC CURTAIN AT VARIOUS LOCATIONS)	142
LEFT-HAND DPRC HAMPER DUMP (AT FACE OF PLASTIC CURTAIN AT VARIOUS LOCATIONS)	232
RIGHT-HAND DPRC HAMPER DUMP (AT FACE OF PLASTIC CURTAIN AT VARIOUS LOCATIONS)	210
LEFT-HAND 010 HAMPER DUMP (AT FACE OF PLASTIC CURTAIN AT VARIOUS LOCATIONS)	126
RIGHT-HAND 010 HAMPER DUMP (AT FACE OF PLASTIC CURTAIN AT VARIOUS LOCATIONS)	157
WATERFALL 1	*63*
WATERFALL 2	*58*
FLATS EXTRACTOR 1	100
FLATS EXTRACTOR 2	144

Table 4 Air Velocities for "Dirty Filter" Testing

	Trial 1	Trial 2	Trial 3	Average
LEFT-HAND DPRC WATERFALL AREA (BOTTOM OF LETTER DROP)	61	52	63	**59**
RIGHT-HAND DPRC WATERFALL AREA (BOTTOM OF LETTER DROP)	62	71	57	**63**
Flats Extractor 1	141	150	141	**144**
Flats Extractor 2	102	101	99	**101**

Table 5 010 VFS Unit 1 with <u>AAF HEPA Filters</u> Installed, Thursday, March 13, 2003

Particle Size Range	Measured
0 3-0 4μm	**99 714%** (99 679 99 749)
0 4-0 5μm	**99 669%** (99 603 99 734)
0 5-0 65μm	**99 107%** (98 921 99 294)
0 65-0 8μm	**97 941%** (97 491 98 391)
0 8-1 0μm	**97 456%** (96 795-98 118)
1 0-1 6μm	**96 342%** (95 165-97 520)
1 6-2 0μm	**96 156%** (94 705 97 607)
2 0-3 0μm	**99 026%** (98 473 99 579)

Table 6 010 VFS Unit 1 with AAF HEPA Filters Installed, Monday, March 24, 2003

Particle Size Range	Measured
0 3-0 4μm	99 989% (99 986 99 992)
0 4-0 5μm	99 991% (99 987 99 996)
0 5-0 65μm	99 995% (99 987 100 00)
0 65-0 8μm	>99 999%
0 8-1 0μm	>99 999%
1 0-1 6μm	>99 999%
1 6-2 0μm	>99 999%
2 0-3 0μm	>99 999%

Table 7 010 VFS Unit 1 with Donaldson HEPA Filters Installed, Friday, March 28, 2003

Particle Size Range	Measured
0 3-0 4μm	99 991% (99 988 99 995)
0 4-0 5μm	99 989% (99 981 99 997)
0 5-0 65μm	>99 999%
0 65-0 8μm	>99 999%
0 8-1 0μm	>99 999%
1 0-1 6μm	>99 999%
1 6-2 0μm	>99 999%
2 0-3 0μm	>99 999%

Table 8 010 VFS Unit 2 with AAF HEPA Filters Installed, Tuesday, March 11, 2003

Particle Size Range	Measured
0 3-0 4μm	**99 998%** (99 997 99 999)
0 4-0 5μm	**99 996%** (99 992 100 00)
0 5-0 65μm	**99 996%** (99 989 100 00)
0 65-0 8μm	**>99 999%**
0 8-1 0μm	**>99 999%**
1 0-1 6μm	**>99 999%**
1 6-2 0μm	**>99 999%**
2 0-3 0μm	**>99 999%**

Table 9 010 VFS Unit 3 with <u>AAF HEPA Filters</u> Installed, Tuesday, March 11, 2003

Particle Size Range	Measured
0 3-0 4μm	99 990% (99 986 99 993)
0 4-0 5μm	99 991% (99 984-99 997)
0 5-0 65μm	99 986% (99 970 100 00)
0 65-0 8μm	>99 999%
0 8-1 0μm	>99 999%
1 0-1 6μm	>99 999%
1 6-2 0μm	>99 999%
2 0-3 0μm	>99 999%