In-Depth Survey Report

Multiple Envelope Particle Expulsion Test of an Existing Advanced Facer Canceller System (AFCS) and an AFCS 200 Configuration

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Abstract

A multiple envelope particle test was conducted as a follow-up to the single envelope evaluation (Hammond et al. 2010) carried out by researchers from the National Institute for Occupational Safety and Health (NIOSH). The additional testing was requested by the United States Postal Service (USPS) to determine if a comparison of two mail processing machines might produce a different conclusion if tested using runs of multiple envelopes instead of using runs of single envelopes. For this additional experiment, researchers from NIOSH conducted an evaluation to compare particle expulsion using runs of 45 envelopes sent through USPS mail processing equipment—the Advanced Facer Canceller System (AFCS) and the AFCS 200 configuration. The AFCS 200 configuration was representative of a production design under the Biohazard Detection System (BDS) hood and in the BDS area. The AFCS 200 was developed to update the approximately 20 year old AFCS fleet of mail processing machines. The testing described in this report evaluated changes to the AFCS 200, such as belt speeds and pulley sizes, which might negatively impact the release of particles from mail pieces processed on the machine. The AFCS agitates and compresses mail pieces during initial mail processing operations to expel any biological hazards that could be contained in a mail piece. A BDS, located over initial hard pinch points on the AFCS, samples and analyzes the air for the presence of biohazards thereby preventing the delivery of a tainted letter to a target destination address.

To compare particle expulsion, an existing AFCS and AFCS 200 were tested side-by-side using multiple envelopes at Siemens Industry, Mobility USA, Infrastructure Logistics Postal Solutions in Arlington, TX. Each machine had a BDS hood ventilation system that captured expelled particles and allowed for sample collection from the exhaust stream of the BDS hose. Comparisons were based on particle count measurements taken from the sample hose of the BDS after 45 envelopes, one of which was loaded with dry polystyrene latex (PSL) spheres, were processed by each machine. A total of 240 runs of 45 envelopes (30 runs of 45 envelopes on each machine at BDS flow rates of 200 LPM and 90 runs of 45 envelopes on each machine at 400 LPM) were conducted. In every loaded run of 45 envelopes, the sixth envelope from the entrance to the BDS hood contained 10 mg of PSL spheres. Total particle counts from each loaded multiple envelope run were corrected by counts from a preceding run with 45 unloaded envelopes. The ratio of the geometric mean particle counts from the loaded multiple envelopes runs sent through the AFCS 200 to geometric mean particle counts from the loaded multiple envelope runs sent through the existing AFCS were 1.79 and 1.39 for BDS flow rates of 200 and 400 LPM, respectively. The lower 95% confidence limits for BDS flow rates of 200 and 400 LPM were 1.22 and 1.09, respectively. Based on the results of this testing, it can be stated, with 95% confidence, that the mean particle counts from the loaded multiple envelopes runs sent through the AFCS 200 were at least 9% higher than the mean particle count of loaded multiple envelopes runs sent through the existing AFCS. These findings are consistent with the single-envelope test findings [Hammond et al. 2010].

Introduction

The National Institute for Occupational Safety and Health (NIOSH) is located in the Centers for Disease Control and Prevention, 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. 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, biological, 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 develop, evaluate, and document the performance of control techniques in reducing potential health hazards in an industry or for a specific process.

The evaluation documented in this report is a follow-up to the single envelope particle evaluation summarized in report 279-25a [Hammond et al. 2010]. This additional report was initiated to summarize additional particle expulsion data collected at the end of the formal particle expulsion study that took place from February 16th to March 1, 2010 at Siemens Industry, Mobility USA, Infrastructure Logistics Postal Solutions in Arlington, TX. The additional data was collected at the request of the United States Postal Service (USPS) out of concern that the comparison of particle expulsion from two mail sorting machines might result in a different final conclusion if a single loaded envelope was processed among a group of multiple unloaded envelopes. To evaluate this, additional tests using a group of 45 envelopes per run were conducted on the existing Advanced Facer Canceller System (AFCS) and AFCS 200. The configuration of the mail sorting machines and test room were the same as described in report 279-25a [Hammond et al. 2010].

The purpose of this report and report 279-25a [Hammond et al. 2010] is to document an evaluation to determine whether a new generation of USPS mail processing machines will provide the same or better performance at preventing future biological attacks through the mail, when compared to the existing equipment. To compare particle expulsion, an existing AFCS and AFCS 200 were tested side-by-side at Siemens Industry, Mobility USA, Infrastructure Logistics Postal Solutions in Arlington, TX from February 16th to March 1, 2010. The AFCS 200 was representative of the production configuration under the Biohazard Detection System (BDS) hood and in the BDS area. Each machine had a BDS hood ventilation system that captured expelled particles and allowed for sample collection from the exhaust stream of the BDS hose. Comparisons were based on particle count measurements taken from the sample hose of the BDS after each run of 45 envelopes was processed by each machine.

The USPS AFCS 200 program has been developed to update the approximately twenty year old AFCS fleet. The AFCS 200 program deals with machine obsolescence, reduces maintenance, and integrates additional functionality of the AFCS fleet. The USPS has added several external systems to the AFCS in recent years including the BDS. The testing described here is to validate that changes to the AFCS 200 do not negatively impact particle expulsion.

Background

In 2001, researchers from NIOSH were requested to assist the USPS in the evaluation of particulate controls for various types of mail processing equipment. These controls have been installed to significantly reduce operator exposure to any potentially hazardous biological agents emitted from mail during normal mail processing and to detect these biological agents during initial mail processing operations thereby preventing their delivery to a target destination address. This effort is driven by the terrorist attacks in the fall of 2001 which used the mail as a delivery system for anthrax. Since 2001, NIOSH researchers have tested the effectiveness of the designed controls for the AFCS and other mail processing machinery at USPS Processing and Distribution Centers (P&DCs) in Ohio [Beamer et al. 2004], California [Hammond et al. 2009], Texas [Hammond et al. 2010], and the Washington, DC area [Topmiller et al. 2003; Beamer et al. 2005].

Description of Mail-Processing Equipment

The AFCS is an automated mail-processing system that culls, orients, cancels, scans, and sorts standard size (5 to 11.5 inches long by 3.5 to 6.125 inches high) mail pieces. When installed at USPS facilities, mail is delivered to the AFCS from another mail processing machine referred to as the 010 loose mail distribution system. The AFCS culls the mail to remove flats such as large envelopes, newsletters, magazines, and over-thick (greater than 0.25 in.) mail pieces. The mail is then properly oriented so it may be cancelled. Optical character recognition technology is used to read the addresses on the mail piece which is then sorted and distributed to numbered bins for further automated processing.

Hoods/enclosures were fitted around areas that have higher potential for agitating or compressing mail pieces. The agitation and compression of mail was the major cause of contaminant release from tainted mail pieces. The BDS was designed to draw air from an area of the AFCS that would most likely contain a biological contaminant emitted from an envelope due to agitation or compression. On the AFCS, this area is located just after the shingler at the singulator. As mail pieces move through the shingler, they are forced into an overlapping position, similar to roof shingles on a house. The mail stream continues to move toward the singulator. In this assembly, the mail stream is separated into individual pieces with a constant gap between the pieces. The mail pieces are tightly compressed and abruptly accelerated in a process that causes them to move as individual pieces.

The hood of the BDS is shaped like a tunnel and fits over the singulator area. The hood is approximately 4 inches wide by 5.5 inches high by 32 inches long. Air is drawn from the hood through a flexible duct into the detector which then analyzes the air for potential biological agents. If a hazard is detected, an alarm sounds and appropriate steps may be taken.

The existing AFCS and AFCS 200 BDS hood configurations were the same as the respective configurations tested by NIOSH researchers for hood capture efficiency using tracer gas at the Coppell, TX, P&DC [Hammond et al. 2010]. The BDS hood over the AFCS 200 included an upstream hood referred to as a pre-hood mounted over the shingler. The area downstream of the BDS hood on the AFCS 200 machine was entirely enclosed with removable lids. The Ventilation and Filtration System (VFS) was not installed and the diffuser was not activated during the test.

For this evaluation, an existing AFCS machine and an AFCS 200 machine were tested side-by-side at the Siemens Industry, Mobility USA, Infrastructure Logistics Postal Solutions in Arlington, TX. Instead of installing the entire mail processing machine, only the relevant modules of each machine were installed. The modules consisted of a flats extractor, shingler, singulator, and feeder for each mail processing machine. A test room was built around each machine separated by a weighing room and waste storage room. A schematic of the test room is shown in Figure 1.

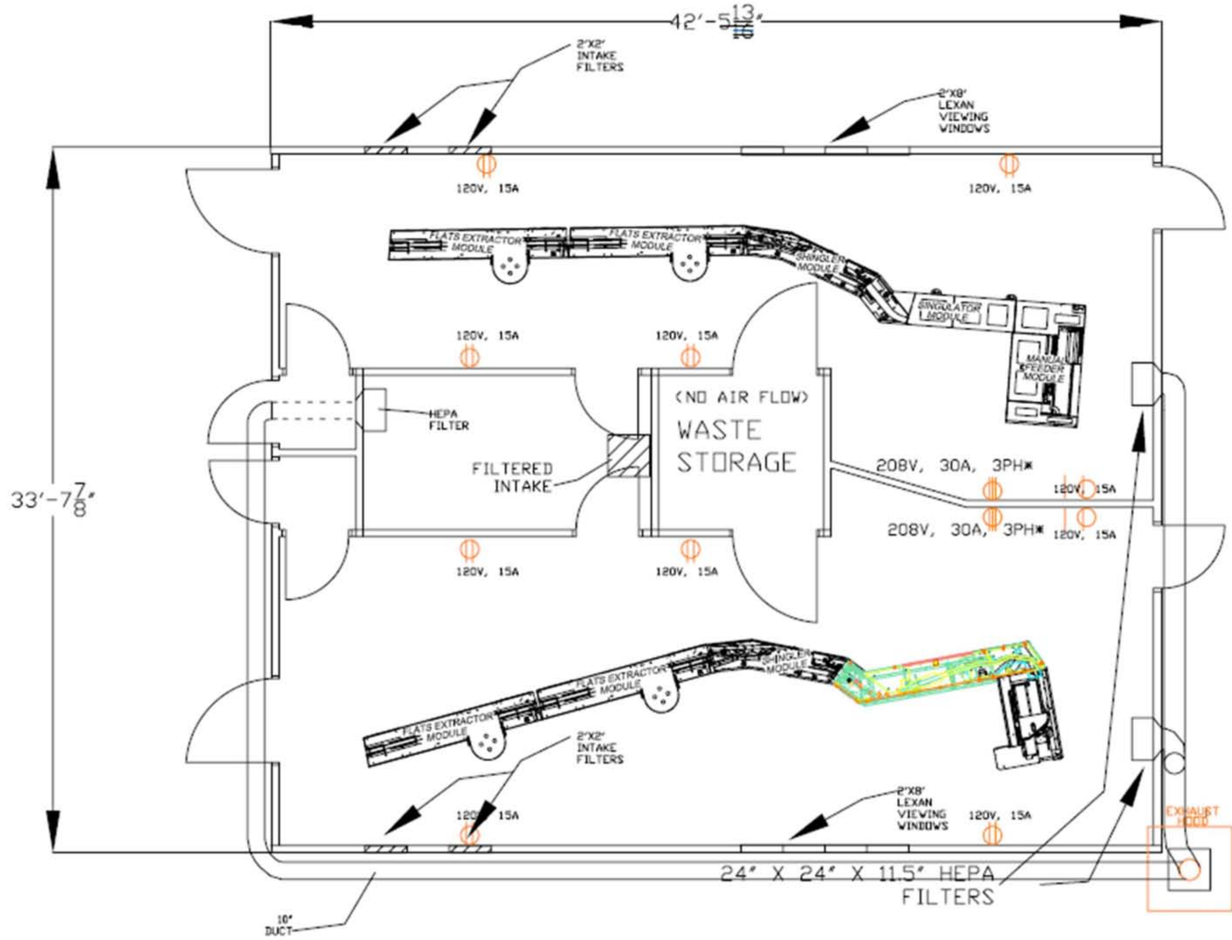

Figure 1: Test room

Experimental Design

The aim of the experiment was to compare the particle counts from the two machines at two BDS flow rates. The comparison was set up as a one-sided statistical test as follows:

- Null Hypothesis: AFCS 200 collects fewer particles than existing AFCS
- Alternative hypothesis: AFCS 200 collects at least as many particles as the existing AFCS

The reason to set up the hypotheses this way was that if the AFCS 200 was more efficient than the existing AFCS, then the null hypothesis should be rejected and it will be determined that the AFCS 200 collected at least as many particles as the existing AFCS. For each BDS flow rate, an experiment was set up so that there were enough replicates of each machine to reject with at least 90% probability the null hypothesis that the AFCS 200 particle count mean was less than the existing AFCS particle count mean, based on a t-test at the 95% confidence level. In addition, a 95% lower confidence limit for the ratio of new machine to old machine particle counts is presented for each of the BDS flow rates. Rejection of the null hypothesis is equivalent to obtaining lower confidence limits for the ratio (AFCS 200/existing AFCS) for each flow rate that exceeded a ratio of 1.

Methods

Test Aerosol

To quantitatively evaluate the release of particles from envelopes sent through mail processing equipment, a particle expulsion test method was developed and used. The test aerosol consisted of 2.5 µm dry PSL microspheres (Phosphorex Inc., Fall River, MA). Phosphorex, Inc. measured the particle size of the test aerosol on a Beckman-Coulter LS 13 320 Laser Diffraction Particle Size Analyzer and a Joel JSM-5610 Scanning Electron Microscope (SEM). Figure 2 shows the average particle size of 2.5 µm from the SEM picture. The particle size as measured by laser diffraction was consistent with the SEM picture with a mean of 2.5 µm and a standard deviation of 0.045 µm.

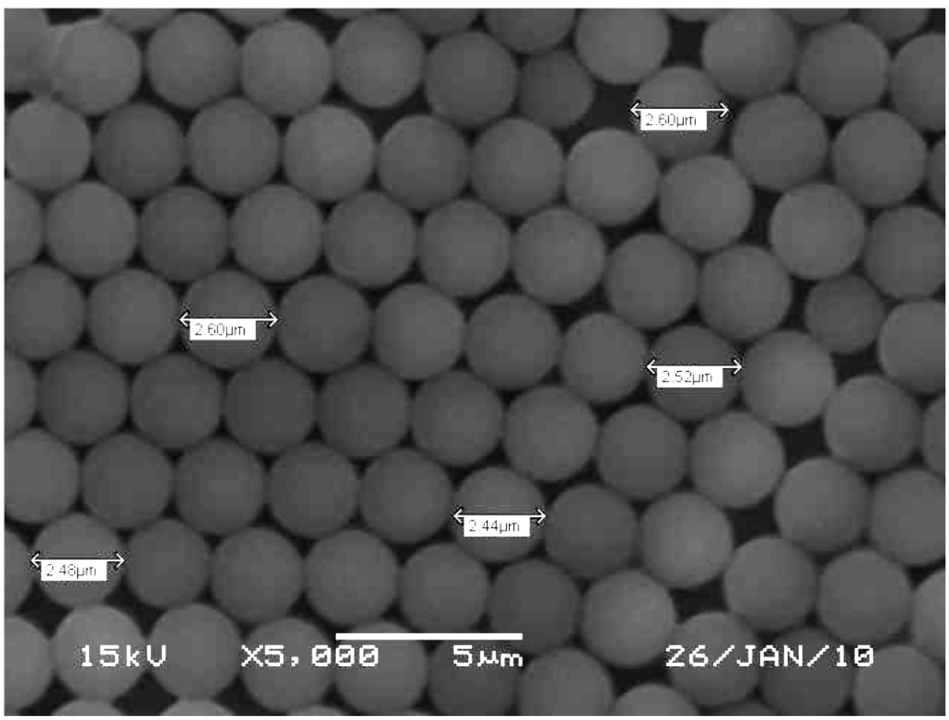

Figure 2: Image from the SEM of the dried microspheres.

Weighing Procedures

An analytical balance manufactured by A&D Company (model HR-120, A&D Company, Limited, Tokyo, Japan) was used to weigh the dry PSL spheres. The analytical balance was used with a marble table to eliminate vibration. Nitrile gloves were worn during all weighing procedures and tweezers were used during all handling of weighing dishes. PSL spheres were weighed using disposable anti-static polystyrene weighing dishes manufactured by Fisher Scientific (Cat No. 08-732-116, Thermo Fisher Scientific, Inc.). The weighing dishes remained in front of a static neutralizer (model # AD 1683, A&D Company, Limited, Tokyo, Japan) before and during weighing. An ionizing brush (model 1C200, NRD LLC, Grand Island, NY) was used to eliminate static and to remove dust from both sides of a weighing dish before an empty dish was weighed. An empty weighing dish was then placed on the scale and the doors of the weighing chamber were closed. After it reached a stabilized value, the scale was zeroed, establishing the tare weight of the dish. The weighing dish was removed from the scale and a small scoop was used to add 10 mg of 2.5 µm dry PSL spheres to the dish. The dish was reweighed to verify the mass of spheres. The dish was removed from the scale and the spheres were loaded into the front of two tri-folded 8.5” x 11” sheets of paper in an envelope (No. 10 Grip-Seal Security Envelopes, Columbian Envelopes) by turning the dish over above the letter and tapping on the back of the dish. The weighing dish was placed on the scale again and the stabilized value was subtracted from the previous weight to account for any spheres left in the dish. The weighing dish was then discarded. If the final weight was 10 mg ± 0.5 mg, the Grip-Seal envelope was sealed by peeling off the release strip and folding over the flap to form a seal then placing the envelope in a portable rack. If the final weight was outside of the 10 mg ± 0.5 mg range, the envelope was discarded and the procedures were repeated until 10 envelopes loaded with PSL spheres were prepared for a run on one machine. The set up for the weighing process is shown in Figure 3.

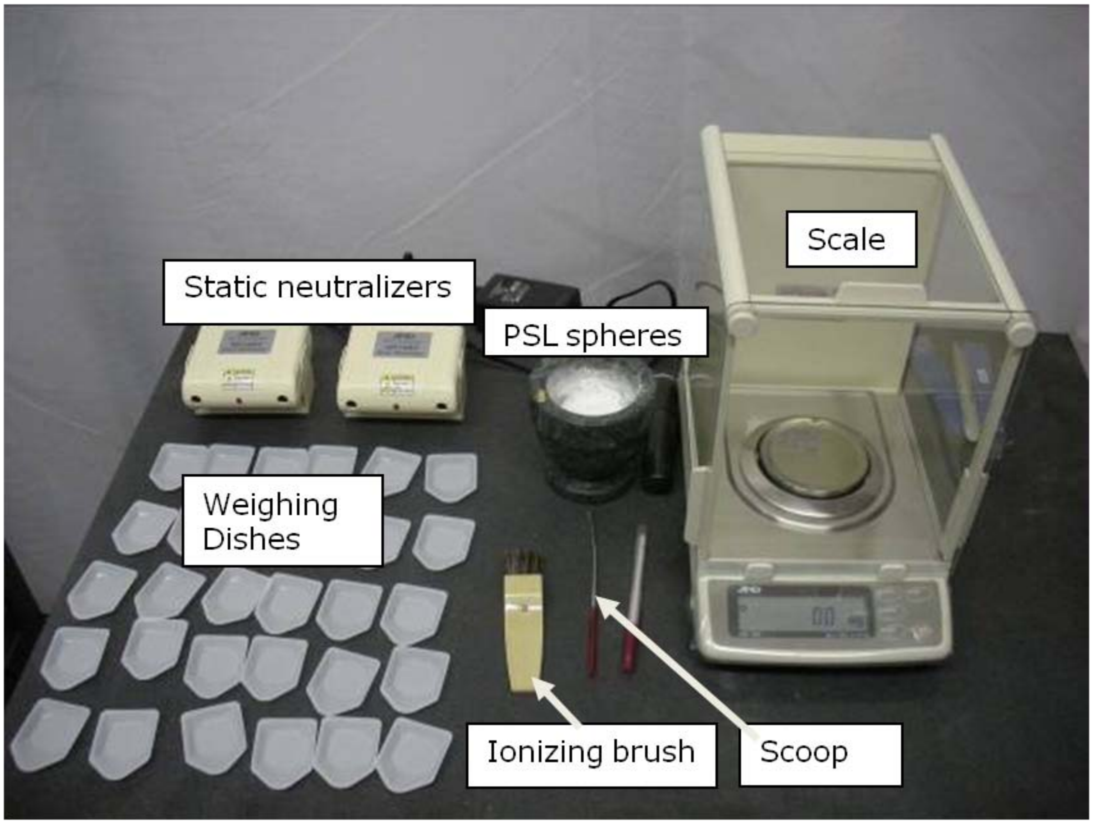

Figure 3: Set up for the weighing process

Test Apparatus and Equipment

Sampling was conducted directly from the BDS hose which was connected to the BDS hood over the singulator portion of the machine. Testing was conducted at both 200 LPM and 400 LPM flow rates through the BDS hose. The flow through the BDS hose was maintained by a BDS pump (Model 117417-05 Type H Windjammer, Ametek Inc.) and checked between every test run using a rotary meter (Model 11C175 ROOTS® Rotary Meter, Dresser Inc.). The inner diameter of the BDS hose was 30.7 mm. Calculations using the Reynolds number revealed turbulent flow through the BDS hose at both 200 LPM and 400 LPM flow rates. Three meters of flexible BDS hose length connected the BDS hood to a 1 m long 1-1/4 in inner diameter aluminum pipe. This provided more than 50 hose diameters of mixing in the BDS hose before the air entered the straight aluminum pipe. The aluminum pipe provided 25 additional upstream and 10 downstream diameters of smooth pipe at the point where an isokinetic sample was drawn. This allowed for a uniform velocity profile of the well mixed air at the point where the sample was drawn. The isokinetic sampling probe was inserted through a 90° 1-1/4 in inner diameter aluminum elbow. An isokinetic probe with an inner diameter at the inlet of 1.7 mm was used to sample from the aluminum pipe when the BDS flow was set to 400 LPM. An isokinetic probe with an inner diameter at the inlet of 2.4 mm was used when the BDS flow was set to 200 LPM. Drawings of the 1.7 mm and 2.4 mm isokinetic probes inserted through the 90° elbow are provided in Appendix A. The configuration of the sample line was the same on both machines. Since the two machines were tested as randomized pairs, it required moving back and forth between machines several times per day. All sampling equipment including the instrument and BDS hood were moved back and forth between machines to reduce the potential for bias based on differences in instrumentation or sampling equipment. The isokinetic sample probe from the aluminum pipe in line with the BDS hose is shown in Figure 5.

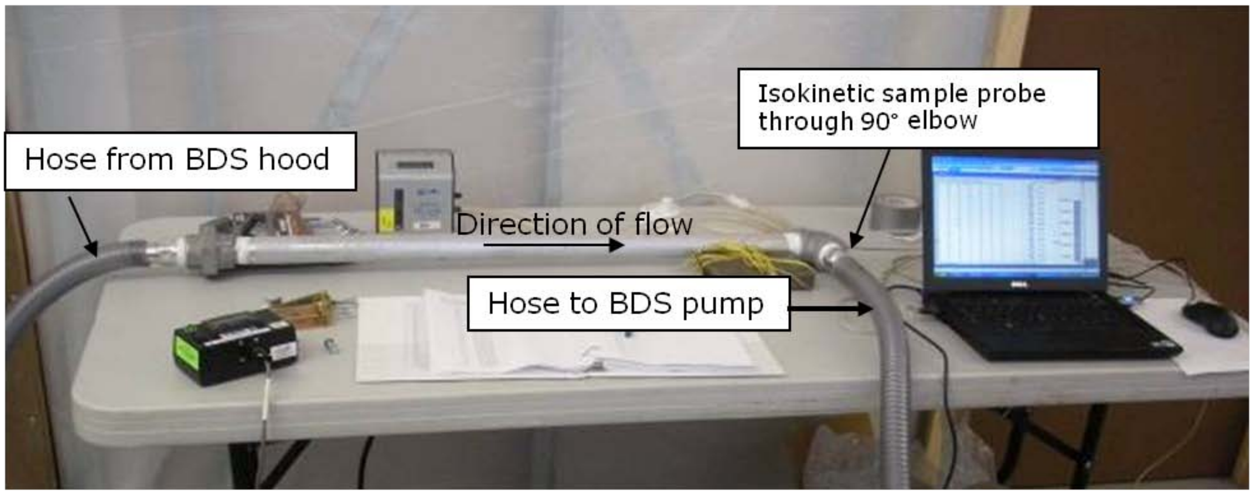

Figure 5: Sample location from the BDS hose

Particle counts from each machine were measured using a Grimm aerosol spectrometer (model 1.108SS, Grimm Aerosol Technik GmbH & Co. KG, Ainring, Germany). The Grimm aerosol spectrometer counts individual particles and sizes each particle, based upon the amount of light scattered, into one of fifteen particle size channels or bins between 0.3 and 20 µm. For this experiment, the Grimm was used in fast mode to log data at one second intervals in the 2-3 µm, 3-4 µm, 4-5 µm, 5-7.5 µm, 7.5-10 µm, 10-15 µm, and 15-20 µm size bins. The data collected in the 2-3 µm size bin were used for the 60 second sum of particle counts for both a loaded and unloaded envelope. The count range of the Grimm is from 1 to 2,000,000 particles per liter. The Grimm maintains a flow rate of 1.2 LPM using a built in volume controller that varies the RPM of a motor to maintain consistent flow through the instrument. The flow through the Grimm was checked in between every run for flow verification using a DryCal® DC-Lite dry flow meter (Model DCLT 12K Rev 1.08, DryCal®, Bios International Corporation).

Test Procedures

The existing AFCS and AFCS 200 machines were compared using runs of 45 envelopes stuffed with two tri-folded letters. In every loaded run of 45 envelopes, the sixth envelope from the entrance to the BDS hood contained 10 mg of PSL spheres. Each run of 45 envelopes containing a loaded envelope (one loaded envelope among 44 unloaded), was preceded by a run of 45 empty envelopes. The sum of the 60 second particle count in the 2-3 µm size bin from each unloaded multiple envelope run was subtracted from the sum of the 60 second particle count in the 2-3 µm size bin of the following loaded multiple envelope run. Loaded envelopes were filled in batches of 10 which were prepared immediately before a trial of test runs on a machine. The 10 loaded envelopes were staged in a rack in preparation for the 10 runs of 45 envelopes each. The 45 envelopes for each run were sent through the machine in a continuous stream with a time gap of 90 seconds following each 45 multiple unloaded envelope run and 120 seconds following each loaded multiple envelope run. This allowed for the decay of particle counts before the next run of 45 envelopes were sent through the singulator of the machine. Siemens Industry Field Service Specialists cleaned the machine after every 10 sets of 45 envelopes were processed. The cleaning procedures are provided in Appendix B. The two machines were tested as randomized pairs. All unloaded and loaded envelopes were used one time and then discarded.

Results

For a trial on a given machine, there were 10 alternating empty and loaded multiple envelope particle count totals. Each loaded multiple envelope particle count was corrected using the preceding empty multiple envelope particle count. Appendix C contains the particle count data in the 2-3 µm size bin for every unloaded and loaded multiple envelope run performed during the evaluation. The geometric mean was then calculated for each background corrected particle count. The particle count data were collected in three randomized blocks for the 200 LPM BDS flow rate and nine randomized blocks for the 400 LPM BDS flow rate randomly choosing which machine was evaluated first in each block. Table I provides the background-corrected geometric mean particle count and ratio (AFCS 200 / existing AFCS) by machine and BDS flow rate for each trial of 10 multiple envelope runs.

Table I: Geometric mean and ratios for each machine at 200 LPM and 400 LPM

	BDS Flow Rate Set to 200 LPM			BDS Flow Rate Set to 400 LPM		
Block	Existing AFCS Geometric Mean	AFCS 200 Geometric Mean	Ratio	Existing AFCS Geometric Mean	AFCS 200 Geometric Mean	Ratio
1	236549	556392	2.35	188269	162598	0.86
2	290861	533655	1.83	215576	330007	1.53
3	282774	377659	1.34	150537	188708	1.25
4				216220	206549	0.96
5				170848	205953	1.21
6				171296	280830	1.64
7				132778	259702	1.96
8				100459	239259	2.38
9				111713	152997	1.37
Geometric means	268957*	482222*	1.79	156895**	218815**	1.39

*These are the overall geometric mean particle counts for the 30 runs by machine at the 200 LPM flow rate.

** These are the overall geometric mean particle counts for the 90 runs by machine at the 400 LPM flow rate.

The data were collected in randomized blocks (AFCS 200, existing AFCS). Unlike the single envelope study [Hammond et al. 2010], for which the same number of blocks were used for both flow rates, the multi-envelope study was an add-on, and was only intended to determine if using multiple envelopes would produce a different conclusion than the previous single envelope experiment. Only three blocks were used when testing at 200 LPM, compared to nine blocks when testing at 400 LPM, because after three blocks a decision could be made for the 200 LPM flow rate data that the AFCS 200 counts exceeded those of the existing AFCS. Analyses were done separately for the two flow rates. Analysis of variance models were fitted to the natural log-transformed means of the ten background corrected measurements in each trial. The residuals from the fitted model were approximately normally distributed. In other words, the original scale data are approximately log-normally distributed. For each model, 95% confidence intervals for the ratio of AFCS 200 particle counts to existing AFCS counts are shown in Table II. Testing conducted at both 200 and 400 LPM flow rates give lower 95% confidence limits on the ratio (AFCS 200/existing AFCS) greater than 1; therefore, the statistical criterion (reject the hypothesis that the AFCS 200 is less than the existing AFCS) is satisfied for the test.

Table II: 95% confidence interval for the ratio AFCS 200 / Existing AFCS

Flow rate	95% confidence interval for the ratio AFCS 200 / Existing AFCS
200 LPM	(1.22, 2.64)
400 LPM	(1.09, 1.79)

Table III presents maximum and minimum measurements of temperature and humidity for each machine room during each block of testing at BDS flow rates of 200 LPM and 400 LPM. The maximum change in room temperature during testing of any 10 runs of 45 individual envelopes was 0.7 °F. The maximum change in room temperature within a block of testing was 1.4 °F. The maximum change in room humidity during any 10 runs of 45 individual envelopes was 1.3% relative humidity. The maximum change in room humidity within a block of testing was 4.3% relative humidity.

Table III: Temperature and humidity for each machine room by block

		BDS flow set to 200 LPM				BDS flow set to 400 LPM			
		Temperature (°F)		Humidity (% RH)		Temperature (°F)		Humidity (% RH)	
	Block	Max	Min	Max	Min	Max	Min	Max	Min
AFCS 200	1	72.5	72.5	17.9	17.5	73.2	73.2	19.2	18.7
Existing AFCS	1	73.8	73.2	16.9	16.5	73.2	73.2	18.6	18.2
AFCS 200	2	71.8	71.1	18.7	17.9	73.2	72.5	21.7	21.3
Existing AFCS	2	71.8	71.8	18.2	16.9	73.8	73.2	19.8	19.0
AFCS 200	3	71.8	71.1	19.6	19.2	72.5	72.5	27.7	27.2
Existing AFCS	3	72.5	72.5	18.2	17.8	73.2	73.2	26.0	25.1
AFCS 200	4					71.8	71.1	26.7	26.3
Existing AFCS	4					72.5	71.8	25.1	24.2
AFCS 200	5					72.5	72.5	26.3	25.8
Existing AFCS	5					73.2	72.5	24.2	23.8
AFCS 200	6					72.5	72.5	25.8	25.3
Existing AFCS	6					73.2	73.2	24.2	23.8
AFCS 200	7					72.5	71.8	24.4	24.4
Existing AFCS	7					72.5	71.8	22.9	22.4
AFCS 200	8					72.5	72.5	23.5	23.5
Existing AFCS	8					73.2	72.5	22.4	22.0
AFCS 200	9					72.5	72.5	23.5	23.1
Existing AFCS	9					73.2	72.5	27.4	26.5

Discussion

For the previous test described in report 279-25a [Hammond et. al, 2010], the influence of paper dust emitted in the 2-3 µm size bin was minimal compared to the particle count resulting from an envelope loaded with PSL spheres. During the multiple envelope test described in this report, the amount of paper dust emitted from 45 envelopes created a much higher background particle count of paper dust in the 2-3 µm size bin. This required increasing the mass of PSL spheres in the loaded envelope to get a noticeably higher particle count above the background paper dust emitted from 45 envelopes. During the multiple envelope testing, every loaded multiple envelope run released more particles than the preceding empty multiple envelope run. However, many of the signal to noise ratios were low. For the purposes of this testing, the signal to noise ratio was defined as the peak one second particle count from a loaded multiple envelope run divided by the peak one second particle count of the preceding unloaded multiple envelope run. The signal to noise ratio data were approximately log-normally distributed and the geometric mean and 95% confidence intervals by machine and flow rate are shown in Table IV.

Table IV: Geometric mean and 95% confidence limits for the ratio of the peak particle counts by machine and flow rate.

Experiment	Geometric mean	Upper 95% confidence limit	Lower 95% confidence limit
AFCS 200 at 200 LPM	7.5	9.9	5.5
Existing AFCS 200 LPM	12.0	15.0	10.1
AFCS 200 at 400 LPM	6.9	8.1	5.9
Existing AFCS 400 LPM	10.1	11.6	8.7

Higher signal to noise ratios could have been achieved a couple of different ways. One way would be to decrease the number of envelopes per run to reduce the background particle count generated from paper dust. Although adding more envelopes before and after the loaded envelope would have provided for a better simulation of a multiple envelope test, the signal to noise ratio decreases when adding more envelopes for the same mass loading of PSL spheres. A continuous stream of 45 envelopes were used for this test to allow for an approximately one second stream of envelopes to enter the hood immediately before the loaded envelope followed by a continuous four second stream of envelopes immediately after the loaded envelope. Four seconds was chosen based on previous single envelope particle count data which indicated that a high percentage of PSL spheres were captured in the first four seconds after an envelope passed through the singulator of the AFCS. Another way to improve the signal to noise ratio would be to increase the mass loading without increasing the number of envelopes. However, increasing the mass loading to achieve a high signal to noise ratio above the particle count generated from 45 envelopes would have caused the total particle counts to exceed the 2,000,000 particle per liter limit of the instrument. Operating above the instrument range increases the chances of coincidence error and instrument problems.

Instrument errors did not occur during any of the three blocks of testing at the 200 LPM flow rate for the multiple envelope tests. Instrument errors were encountered on approximately 10% of loaded multiple envelope runs of 45 envelopes on the AFCS 200 when testing at 400 LPM. When an instrument error was encountered, the data were discarded and a new set of 45 envelopes were used to repeat the portion of the run containing errors. The encountered instrument errors were likely due to operating near the maximum instrument limit of 2,000,000 particles per liter. According to the instrument manufacturer, the data are still very reliable up to 2,000,000 particles per liter, above which coincidence error becomes significant. Grimm Technologies recommended using one of their 10:1 or 100:1 diluters designed for the Grimm model 1.108SS when high particle counts are expected. Normally an experiment would be redesigned when instrument errors occur or when background particle counts create difficulties in testing. However, the sampling system and instrument configuration were set up for the previous single envelope experiment. This additional multiple envelope test was added after the last day of single envelope testing at the request of the USPS. The USPS requested that the data be shared since it was only intended to be used as a multiple envelope check to the single envelope data presented in report 279-25a [Hammond et. al, 2010].

Conclusions

For this testing, a total of 240 runs of 45 envelopes (30 runs of 45 envelopes on each machine at BDS flow rates of 200 LPM and 90 runs of 45 envelopes on each machine at 400 LPM) were conducted. In every loaded run of 45 envelopes the sixth envelope from the entrance to the BDS hood contained 10 mg of PSL spheres. Total particle counts from each loaded multiple envelope run were corrected by counts from a preceding run with 45 unloaded envelopes. The ratios of the geometric mean particle counts from the AFCS 200 to geometric mean particle counts of the existing AFCS were 1.79 and 1.39 for the 200 and 400 LPM BDS flow rates, respectively. The lower 95% confidence limits when testing at 200 and 400 LPM were 1.22 and 1.09, respectively. Based on the multiple envelope tests, it can be stated, with 95% confidence, that the mean AFCS 200 counts, in the size range evaluated, were at least 9% higher than the mean existing AFCS counts, for each BDS flow rate. These findings are consistent with the findings of the single envelope test [Hammond et al. 2010].

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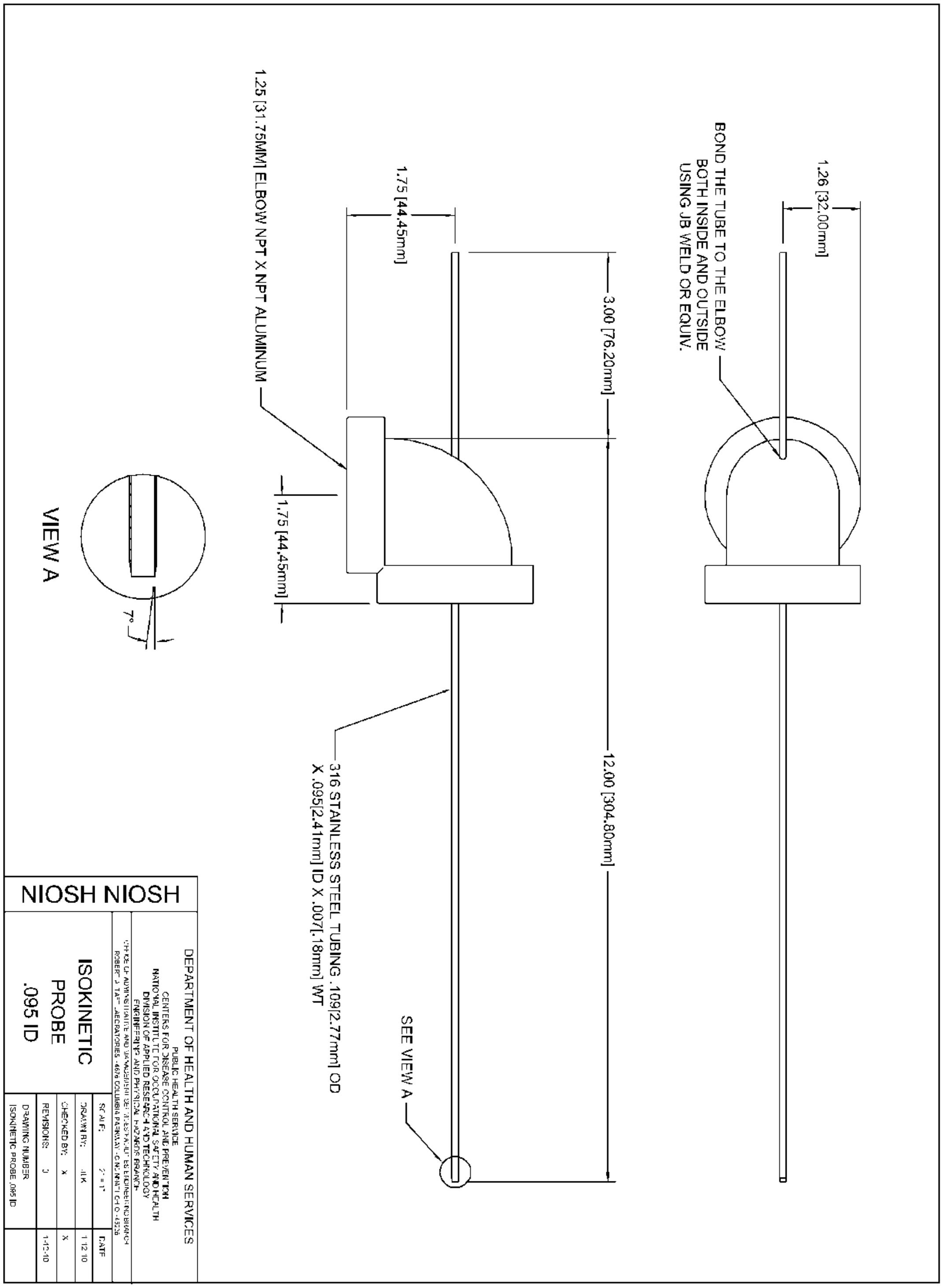
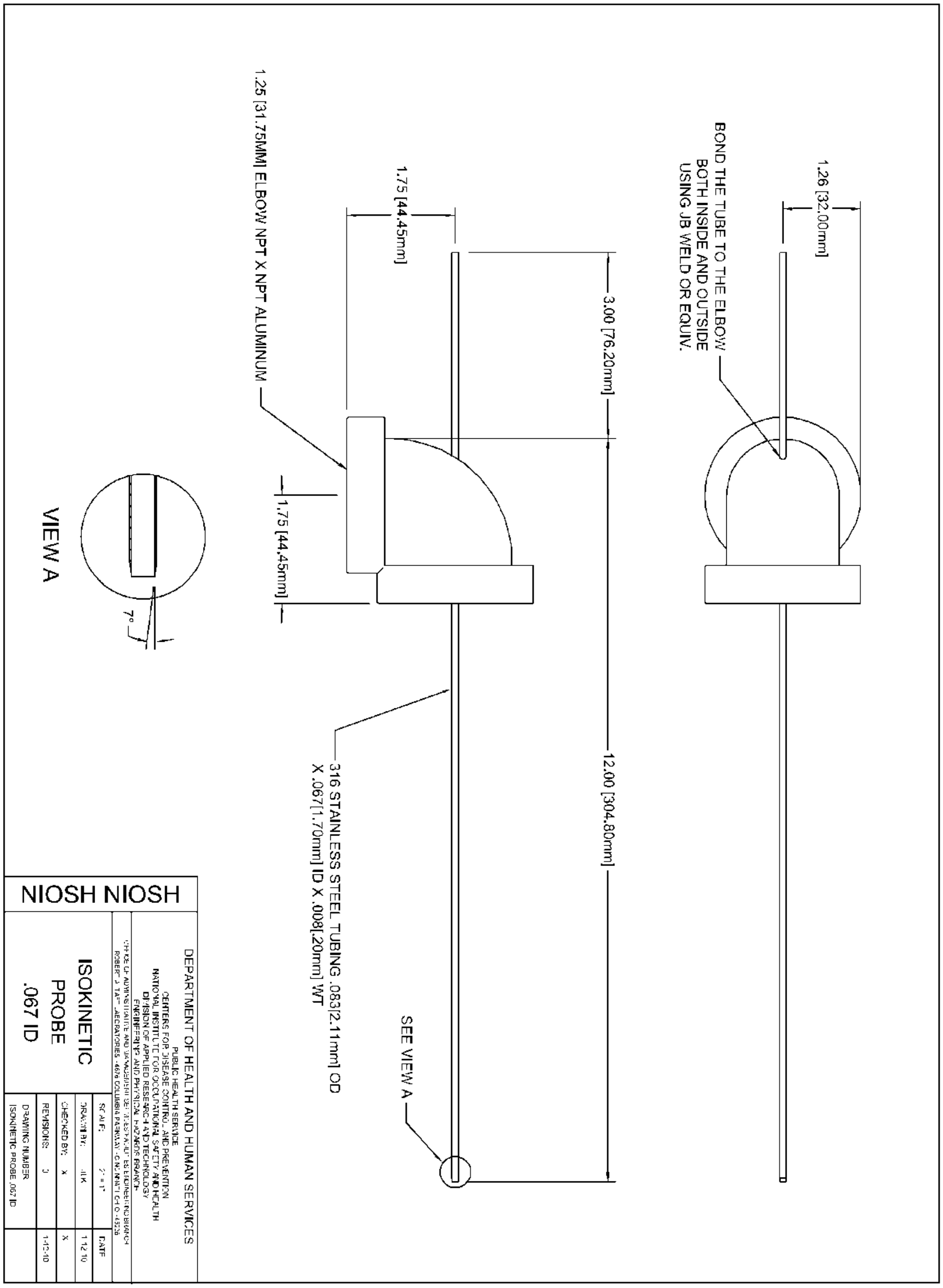
Appendix A

2.4 mm ID Isokinetic probe for testing at 200 LPM



1.7 mm ID Isokinetic probe for testing at 400 LPM



Appendix B

The following cleaning procedures were used after every 10 sets of 45 envelopes were processed on a machine.

1. All workers present in the test rooms wore safety glasses and half-mask respirators with P100 cartridges at all times including cleaning and testing.
2. To begin the cleaning procedures, Siemens Field Service Specialists adjusted the knob to rotate the BDS hood on its hinge to expose the inside of the BDS hood.
3. The inside of the BDS hood was cleaned using compressed air.
4. The BDS hood was removed to increase access to the singulator area of the machine.
5. The areas in and around the belts in the shingler and singulator portion of the machine were HEPA vacuumed to remove particles.
6. The areas in and around the belts of the shingler and singulator that were previously cleaned using a HEPA vacuum were also lightly sprayed with compressed air to further remove particles.
7. After cleaning, the BDS hood was attached and closed over the singulator portion of the machine.

Appendix C

Existing AFCS at 200 LPM

PSL loading	Block 1	Block 2	Block 3
45 empty envelopes	61490	66490	76050
10 mg	348050	227350	205470
45 empty envelopes	61520	68340	59040
10 mg	218510	310600	479440
45 empty envelopes	65050	58320	61340
10 mg	454910	717580	325300
45 empty envelopes	64780	55670	61140
10 mg	302290	391400	739490
45 empty envelopes	59690	51550	62000
10 mg	382800	173180	180670
45 empty envelopes	59230	59670	63700
10 mg	272810	430950	701570
45 empty envelopes	62940	55230	57680
10 mg	322930	301010	359700
45 empty envelopes	69020	51870	50530
10 mg	215960	602790	704500
45 empty envelopes	57440	62420	53280
10 mg	681880	186190	177920
45 empty envelopes	58380	82590	52980
10 mg	138370	746460	233040

Note: The 10 mg counts refer to the sum of the 60 second particle count in the 2-3 µm size bin from each of the 10 loaded multiple envelope runs. The 45 empty envelope particle counts refer to the sum of the 60 second particle count in the 2-3 µm size bin from each of the 10 unloaded multiple envelope run.

AFCS 200 at 200 LPM

PSL loading	Block 1	Block 2	Block 3
45 empty envelopes	216750	121970	132720
10 mg	526750	527580	394480
45 empty envelopes	189180	99120	105150
10 mg	773790	1056570	259870
45 empty envelopes	133830	110150	99650
10 mg	452040	672930	238190
45 empty envelopes	182010	149230	134370
10 mg	929070	350430	815570
45 empty envelopes	137320	102630	133250
10 mg	995240	479760	914740
45 empty envelopes	130900	114160	137430
10 mg	960720	882480	318120
45 empty envelopes	103300	103430	131290
10 mg	908860	1000170	736420
45 empty envelopes	116410	107990	137300
10 mg	668530	681430	501690
45 empty envelopes	119330	121930	125380
10 mg	768240	867120	766490
45 empty envelopes	101590	107470	134540
10 mg	422780	491140	908100

Note: The 10 mg counts refer to the sum of the 60 second particle count in the 2-3 µm size bin from each of the 10 loaded multiple envelope runs. The 45 empty envelope particle counts refer to the sum of the 60 second particle count in the 2-3 µm size bin from each of the 10 unloaded multiple envelope run.

Existing AFCS at 400 LPM

PSL loading	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9
45 empty envelopes	51430	49590	51180	68230	47030	62180	43170	21850	46070
10 mg	204190	321050	505540	196790	92860	166770	183900	125270	130290
45 empty envelopes	38260	51550	45010	52230	38800	44020	38620	18900	39400
10 mg	182650	221940	269500	141730	175290	287900	299500	283400	102290
45 empty envelopes	49120	47640	45720	46730	51630	50330	38010	19500	45320
10 mg	268070	225210	364850	572100	204490	127440	246850	92900	241430
45 empty envelopes	50830	49790	50780	49530	42720	48780	36660	20500	45020
10 mg	189720	286870	168440	312140	318520	608230	67270	90930	236240
45 empty envelopes	53440	48180	48840	46540	41560	47580	41120	21700	40060
10 mg	236630	330500	119860	260200	173210	195140	120010	134920	115420
45 empty envelopes	49680	49320	39370	47270	43770	49380	44020	21500	36060
10 mg	264120	202230	198830	191760	219380	468450	441050	94750	194880
45 empty envelopes	47070	52420	54130	40820	42010	44020	41830	21450	44730
10 mg	135570	200020	150480	411100	213820	116920	152450	45160	151090
45 empty envelopes	45570	50370	50430	48120	49620	45250	48480	21800	38260
10 mg	249600	333670	119010	410340	286250	181110	471170	78920	245780
45 empty envelopes	44080	52330	51630	45880	49280	49170	46070	23050	37210
10 mg	417060	470040	154260	307990	385350	236630	105340	612830	139230
45 empty envelopes	41270	42920	55350	47000	40870	40460	40770	22850	45570
10 mg	356550	190560	258530	176630	295230	212630	124370	134600	102120

Note: The 10 mg counts refer to the sum of the 60 second particle count in the 2-3 µm size bin from each of the 10 loaded multiple envelope runs. The 45 empty envelope particle counts refer to the sum of the 60 second particle count in the 2-3 µm size bin from each of the 10 unloaded multiple envelope run.

AFCS 200 at 400 LPM

PSL loading	Block 1	Block 2	Block 3	Block 4	Block 5	Block 6	Block 7	Block 8	Block 9
45 empty envelopes	101530	91770	74420	75700	83530	90330	73190	68950	83910
10 mg	267100	279320	194160	584700	387750	423580	160450	340590	202320
45 empty envelopes	94620	81030	64990	59830	72850	136480	75950	75800	83240
10 mg	350170	318360	99300	287040	169040	489410	264360	489290	153650
45 empty envelopes	85970	77510	83160	66830	66710	66490	62090	68390	78820
10 mg	457610	423560	245750	234010	479570	308990	277080	392500	195030
45 empty envelopes	75450	80550	77760	58790	78720	58080	71350	68350	69040
10 mg	313420	602520	276050	153190	233840	482010	450710	179770	242510
45 empty envelopes	102730	74920	66750	53570	76160	76190	57180	65220	59730
10 mg	138640	326100	328890	232500	478390	408070	365800	223990	316520
45 empty envelopes	91280	86240	64940	65240	71550	65150	63240	62090	70900
10 mg	331320	375210	446460	298890	271210	314830	417960	299170	207650
45 empty envelopes	104630	71610	62050	85630	59930	67440	73960	70390	68900
10 mg	328860	512080	513520	275980	451540	217160	368050	452780	333870
45 empty envelopes	99120	57430	62040	84850	57090	76540	64380	73440	81620
10 mg	142880	504160	466030	308970	172470	372760	350980	275400	177660
45 empty envelopes	73210	68840	67300	87080	55280	75950	61540	67290	76960
10 mg	216150	399140	264990	324290	170530	242760	321920	320370	211860
45 empty envelopes	67310	79490	60890	75920	52690	70140	56530	64780	60490
10 mg	352830	483390	180790	258950	227880	481760	489740	270780	407370

Note: The 10 mg counts refer to the sum of the 60 second particle count in the 2-3 µm size bin from each of the 10 loaded multiple envelope runs. The 45 empty envelope particle counts refer to the sum of the 60 second particle count in the 2-3 µm size bin from each of the 10 unloaded multiple envelope run.