U.S Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Exposure Methods and Measurements Division
Air Quality Branch

STANDARD OPERATING PROCEDURE

SOP Title: Producing a Spatially Uniform Challenge Aerosol in a Large Wind Tunnel Using Commercially Available Polydisperse Size Standards

SOP ID: D-EMMD-AQB-029-SOP-01	Effective Date: November 13, 2015

SOP was Developed: ☐ In-house ☒ Extramural: Jacobs

SOP Discipline*: General Chemistry

Alternative Identification: SOP-J15-001.0

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Producing a Spatially Uniform Challenge Aerosol in a Large Wind Tunnel Using Commercially Available Polydisperse Size Standards
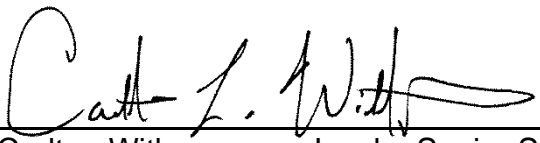
SOP-J15-001.0
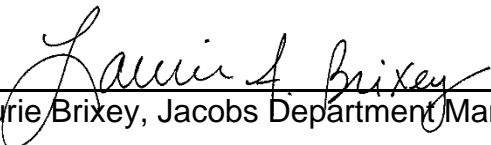**Revision of SOP-ZD-14-01(1)**

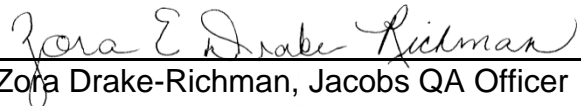**Contract EP-C-15-008**

November 2015

Prepared for

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1.0 Scope and Application

This standard operating procedure (SOP) describes the procedures necessary to generate an electrically charge neutralized, spatially uniform dispersion of commercially available particle size standards of known density. Procedures are given to determine spatial uniformity of the dispersion within the EPA Aerosol Test Facility (ATF) wind tunnel (in building B of EPA's Research Triangle Park, NC, campus) using a series of three isokinetic samplers, referred to as reference samplers.

2.0 Summary of Method

Particles are continuously aerosolized in the wind tunnel human exposure test section (HETS) where they are immediately entrained into the predominant flow of the wind tunnel. A series of fans are used to actively disperse the aerosolized particles as they are transported downstream. The aerosol is collected on an array of samplers within the sampler test section (STS), located downstream of the HETS. (See Figure 1 for a detailed schematic of the wind tunnel sections where the aerosol is generated, mixed, and then collected.) The aerosol generator is an assembly of components that aerosolize a continuous stream of particles with a net neutral charge into the HETS. The rate of generation is controlled by a volumetric bulk materials screw feeder. The materials dispensed by the feeder are introduced into a venturi vacuum pump, which aerosolizes the mixture using an ion-saturated air stream.

Specific aerosol generator set points were determined empirically to produce dispersion of either soda lime glass microspheres (glass beads) or Arizona Test Dust (ATD). For the purposes of this method, spatial aerosol uniformity has been validated up to 30 µm aerodynamic diameter using these two distinct particle types. The aerosol generation methods described in this SOP can be adapted to suit a number of particle materials or sizes. Procedures for validating the operational set points of the system to achieve a spatially uniform polydisperse aerosol are described in section 10.2.
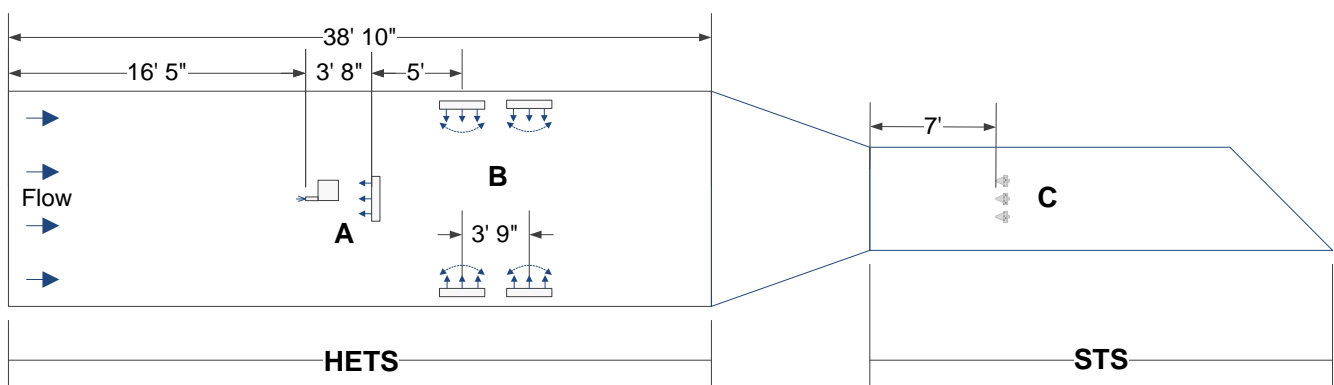

Figure 1. Wind tunnel with A) aerosol generation assembly and stationary fan, B) cross-flow mixing fans, and C) sampler positions within STS. Dimensions are in feet and inches.

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3.0   Definitions

ATD	Arizona Test Dust	mm	millimeter
ATF	Aerosol Test Facility	m/s	meters/second
DI H_2O	deionized water	µm	micrometer
ft	feet	PID	proportional, integral, derivative
HEPA	high-efficiency particulate air	psi	pounds per square inch
HETS	human exposure test section	s	second
in.	inches	STS	sampler test section
I/O	input/output	USB	universal serial bus
km/h	kilometers/hour	VCP	virtual communications port
min	minute	VDC	volts direct current
mL	milliliter		

4.0   Health and Safety Warnings

4.1   Methanol is used to rinse lab ware after washing to displace water and reduce drying time. It should only be handled in a negative-pressure exhaust hood by personnel wearing protective clothing.

4.2   Particle mixtures should be handled only within a well-ventilated environment, using the house point exhaust system to mitigate the risk of personal exposure.

5.0   Cautions

5.1   Care must be taken to reduce the risk of contaminating samples. Wash filter membranes and sampler components with deionized water (DI H_2O) prior to use to remove extraneous material. To avoid further contamination, cleaned items should be placed in a laminar flow hood with HEPA-filtered air.

5.2   It is good practice to operate the wind tunnel fan for a minimum of 30 min prior to startup. Maintaining a low velocity (1–2 km/h) within the STS will ensure the air is conditioned to reach temperature and humidity set points and to reduce background particle counts.

5.3   Consideration must be given to the order in which test preparation procedures are conducted inside the wind tunnel to avoid resuspension of particles from surfaces. All preparation activities required upstream of the STS should be conducted prior to deployment of the samplers to avoid contaminating the samples.

6.0   Personnel Qualifications

6.1   Personnel must have knowledge of laboratory safety practices.

6.2   Personnel should have sufficient background in aerosol science to perform the procedure without direct supervision.

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7.0 Equipment and Supplies

7.1 Equipment

Drying oven (Fisher Econotemp model 30F)

Balance (Ohaus Scout Pro model SP4001)

Aerosol generator assembly

Bulk materials feeder (Schenck AccuRate model 102 with ¼-in. hollow helix screw drive)

Stirrer and impact hammer assemblies (Rex Engineering models SP3103 and SP3104)

Ionizing nozzle with pulsed DC controller (Meech Static Eliminators Ltd. model 261-1/4 ion nozzle and 977CM)

Pressure regulator (Speedaire model 42K76)

Sonic nozzle (Vaccon venturi vacuum pump, P/N JS-90M-316SS)

Air compressor and ¼-in. tubing rated to 120 psi

30-in. pedestal fans (5) (AirMaster model UP30BN-S)

Thermal anemometer and connections (Dwyer model 471B)

Laptop with universal serial bus (USB) port, virtual communications port (VCP) driver (e.g., FTDI 2.08.30, which can be downloaded free at www.ftdichip.com/Drivers/VCP.htm), and terminal emulator to communicate via the serial command set provided with the anemometer (e.g., Microsoft HyperTerminal)

7.2 Materials

Polydisperse particle mixtures:

- Soda lime glass microspheres (P/N GL-0191-S, Mo-Sci Corporation)
- ISO 12103-1 Arizona Test Dust (Powder Technology, Inc.)

Methanol, 99%

Deionized water (DI H_2O)

Isoton II (Beckman Coulter, Inc., item no. 8546719)

Non-ionic dispersant Type IC (Beckman Coulter, Inc., item no. 6600705)

Glycerol, laboratory grade, 99.7% (VWR stock no. BDH1172-1LP)

7.3 Supplies

90-mm, 1.0-µm Whatman Nuclepore track-etch membranes (VWR stock no. 97058-236)

47-mm, 1.0-µm Whatman Nuclepore track-etch membranes (VWR stock no. 28158-410)

Drying tray for particle mixtures (VWR stock no. 62670-012)

Laboratory spatula (VWR stock no. 82027-532)

500-mL wide-mouth jar and lid with Teflon insert (VWR stock no. 15900-064)

1000-mL wide-mouth jar lid with Teflon insert (VWR stock no. 15900-072)

8.0 Instrument Calibration and Standardization

Samples used to validate aerosol uniformity will be analyzed with the Multisizer 4 particle counter. Refer to SOP-J15-003.0, "Determining Aerosol Size Distribution Using the Multisizer 4 Coulter Counter," for sample analysis instructions.

9.0 Sample Collection, Handling, and Preservation

This SOP outlines procedures specific to a three-point aerosol uniformity evaluation. To confirm the spatial uniformity of polydisperse aerosol within the wind tunnel, filter samples are collected in the STS according to SOP-J15-002.0, "Collection and Extraction of Challenge Aerosol for Subsequent Coulter Analysis," and analyzed using the Multisizer 4 SOP (SOP-J15-003.0).

10.0 Method

10.1 Bulk Particle Mixture Preparation

1. Transfer the bulk ATD particle mixture to a drying tray and use a spatula to distribute the material evenly.

2. Place the tray in a preheated drying oven until the bulk particle mixture is dry. Oven temperature and drying time used for a tray containing 2.5 kg of particle mixture is 300 °F for a minimum of 24 hours.

3. Separate the dried material into no more than 500-g portions and store in sealed wide-mouth glass jars. Use the balance to weigh the portions. Containers of dried materials can be stored at room temperature for use later. Label the jars with the name of the material, date the material was dried, date the material was transferred to the jar, and initials of who dried the material.

10.2 Wind Tunnel Preparation

1. Install the aerosol generation system assembly in the wind tunnel HETS as previously shown in Figure 1. The assembly should be positioned as shown in Figure 2 such that the dust feed nozzle (inset in Figure 2) is aligned parallel to the wind tunnel flow and disperses particle mixtures in the upstream direction.

2. Arrange the aerosol generation assembly from step 1 as shown in Figure 1. Center the outlet of the dust feed nozzle vertically and horizontally within the HETS and 16 ft 5 in. downstream of the HETS turbulence grid.

3. Install a 30-in. diameter pedestal fan 3 ft 8 in. downstream of the aerosol generation assembly, aligned with the dust feed nozzle and directed upstream as shown in Figure 3. This is referred to as the stationary aerosol generator fan.
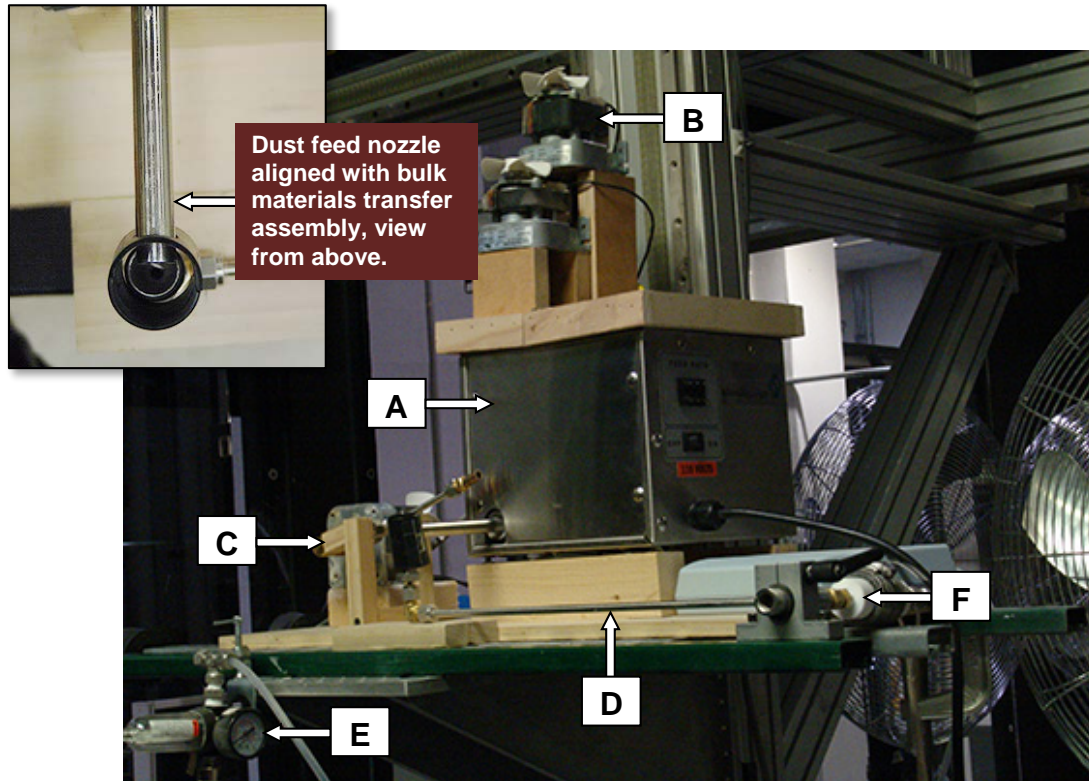
Figure 2. Aerosol generation system showing A) bulk materials feeder, B) stirrer assembly, C) impact hammer assembly, D) bulk materials transport assembly, E) pressure regulator, and F) sonic nozzle with ionizer.
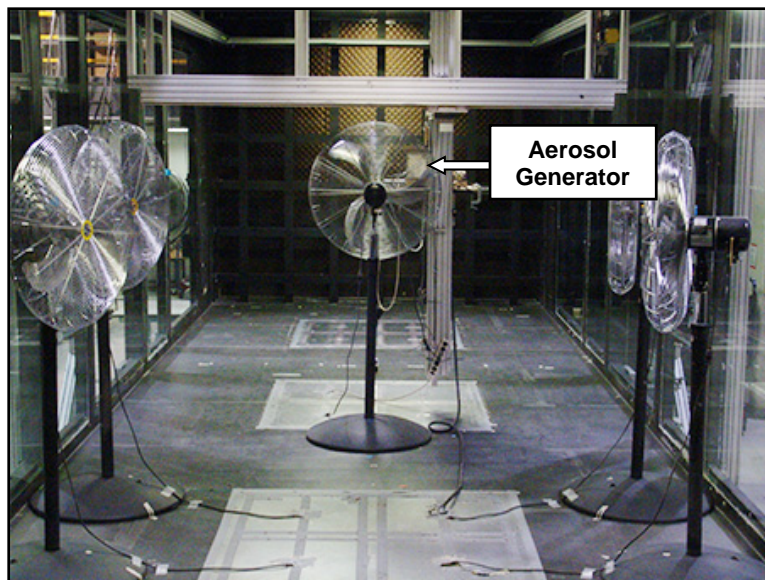

Figure 3. Upstream view of wind tunnel HETS with aerosol generator, mixing fans, and stationary fan, center.

4. Install two pairs of 30-in. cross-flow pedestal fans downstream of the aerosol generator fan (Figure 3). The first pair should be 5 ft downstream; the second should be 3 ft 9 in. from the first pair (Figure 1). Each fan should be 16 in. from the wall as measured from the rear of the fan cage. Pushing the base of each fan up against the wall should accomplish this. Each fan should be aligned so the mean flow is perpendicular to the flow of the wind tunnel. Per the fan manufacturer's operating manual, adjust the cam drive on the fan to oscillate at a 90° rotation. The rotations of the fans do not need to be synchronized with each other.

5. Transfer approximately a 500-g aliquot of the dried particle mixture to the bulk materials feeder on the aerosol generator assembly.

6. Refer to Table 1 for operational feed set points and fan speeds that are used to generate a spatially uniform particle mixture depending on whether glass beads or ATD is being used. Feed rates are nominal settings relative to the full scale of the feeder. Settings have been optimized to produce an aerosol concentration suited for a 90-min collection period.

Table 1. Operational Feed Set Points for Aerosol Generator and Mixing Fans

STS Wind Speed (km/h)	Mass Feed Rate (g/min)	Feed Set Point		Stationary Fan Speed	Oscillating Fan Speed
		Glass Beads	Arizona Test Dust		
2	1.4	140	100	Off	On/High
8	3.0	220	150	On/Medium	On/High
24	4.8	320	200	On/High	On/High

10.3 Wind Tunnel Fan Set Point

The wind tunnel fan is controlled via the Flow Control screen in the I/O software on the ATF control computer. To achieve a desired wind speed within the STS, the wind tunnel fan controls can be set to automatic (proportional, integral, derivative [PID]) or manual (DC voltage) adjustment. If automatic control is chosen, the fan speed will be adjusted according to measurements returned by the sonic anemometer at the rear of the STS. *Manual adjustment of fan speed is recommended.* In manual mode, fan speed is controlled by adjusting the output VDC.

The cumulative effects of the mixing fans and objects obstructing flow within the STS create turbulence resulting in unstable velocity measurements downstream. (The procedure for determining turbulence intensity can be found in section 10.4.) In automatic control mode, this instability produces large swings in the PID control of the wind tunnel fan to compensate for turbulence. To avoid these issues, wind speed is controlled manually and turbulence intensity is measured and recorded. The following steps are used to adjust the fan speed manually.

1. Install the thermal anemometer (Figure 4) in the STS, centered horizontally and vertically, at 7 ft downstream of the transition segment, the same location where the aerosol samples are collected.

Figure 4. Thermal anemometer.

2. Adjust the wind tunnel fan to the desired set point using the wind tunnel flow control screen.

3. Set the thermal anemometer to record velocity data at 1-s intervals for 8 min and start collection.

4. Once the reading has been completed, connect the USB adaptor from the anemometer probe to the laptop and save the .CSV file containing the wind velocity data collected in step 3 to the laptop.

5. Open the data file and view the wind velocity data. Calculate the average wind velocity (see section 12.2.1) from the first 7 min of data (420 data points).

6. Adjust the wind tunnel fan set point as necessary and record the wind speed. If the average wind velocity determined in step 5 does not reflect the desired wind velocity, adjust the voltage to the wind tunnel fan using the ATF computer and repeat steps 3 through 5 until the desired wind speed is reached.

10.4   Turbulence Intensity

Turbulence intensity describes the variations in wind speed across the STS. Using a single anemometer, an array of 21 wind velocity measurements are recorded within the STS. The array comprises three horizontal rows and seven vertical columns, with each point being 6 in. from another (Figure 5). From the velocity profile data, the turbulence intensity is determined by calculating the average of the relative standard deviations at each point.

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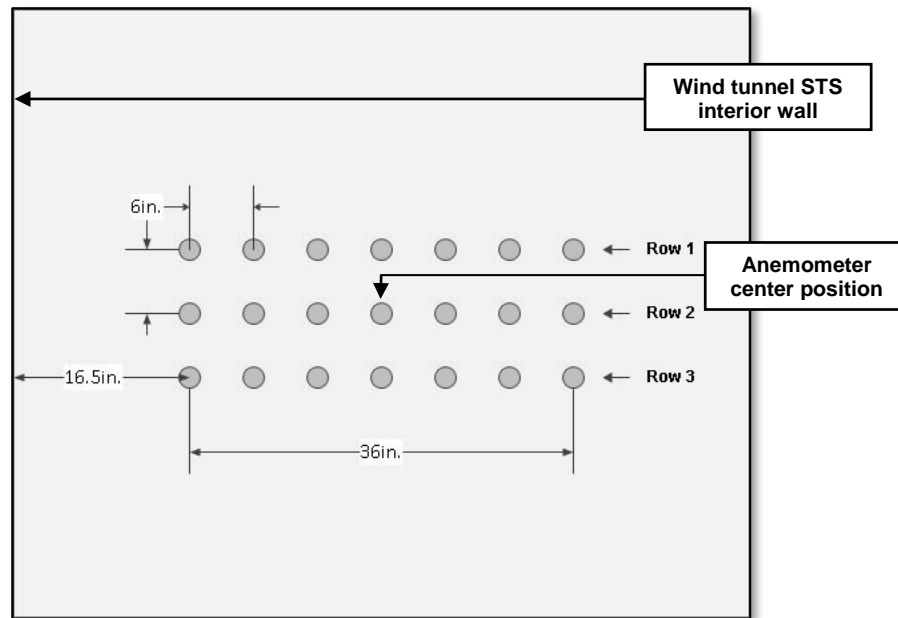
Figure 5. Anemometer position map within the STS (as viewed along the major axis of the wind tunnel) for 21-point wind tunnel velocity profile.

1. Adjust the wind tunnel fan output voltage to achieve the desired wind velocity at the center position of the array as depicted in Figure 5.

2. Collect velocity readings across the entire 21-point array for the velocity profile, resulting in 21 data files logged on the anemometer. This area represents the possible locations where candidate and reference samplers will be located. The reference samplers are typically located at the farthest points from the center within the 36-in. sampling area and are aligned centrally from the top and bottom of the STS.

3. Once the velocity profile has been completed, connect the anemometer hand-held device to the laptop and save the associated data files collected in step 2 for the velocity profile to the laptop.

4. Data are typically collected in approximately 8-min increments, with data points of 1 s collected. Copy the first 420 velocity readings (7 min of data) from each of the 21 points and paste them into a new Microsoft Excel workbook, separated into columns. Save the new file to the laptop as "Velocity Profile_*wind speed_date*.xlsx" for calculating the metrics needed to analyze the velocity profile data.

5. For each column of data, first calculate average wind velocity (see section 12.2.1) at 15-s intervals, which results in 28 average wind velocity readings at each position. Then using the 15-s average wind velocity data for each point, calculate the following metrics using the calculations defined in section 12:

    a. Average wind velocity, turbulence strength, and turbulence intensity (using n = 28).

    b. Average wind velocity across the array along with turbulence strength and turbulence intensity (using n = 21).

10.5 Aerosol Spatial Uniformity

Aerosol spatial uniformity is determined by comparing the aerosol concentration as measured by isokinetic samplers at three evenly spaced positions within the STS. For instructions on sample collection, refer to SOP-J15-002.0, "Collection and Extraction of Challenge Aerosol for Subsequent Coulter Analysis." For instructions on sample analysis, refer to SOP-J15-003.0, "Determining Aerosol Size Distribution Using the Multisizer 4 Coulter Counter." Once the samples have been collected and analyzed, review the data and compare the aerosol concentration collected at each sampler location. The aerosol concentration at each location should not deviate by more than 10% of the mean across the entire size range.

11.0 Troubleshooting

See the troubleshooting guides in the various operator manuals and the *Aerosol Test Facility Manual*, listed in section 15, for guidance on troubleshooting instruments and equipment.

12.0 Data Calculations

12.1 Terms Used in Calculations

$\bar{u}$ = average wind velocity (m/s)

u_i = wind velocity of individual reading (m/s)

u' = longitudinal velocity fluctuation (m/s)

u_{rms} = turbulent strength (dimensionless)

I = turbulence intensity (dimensionless)

12.2 Calculations

12.2.1 Average Wind Velocity

$$\bar{u} = \frac{1}{n} \sum_{i=1}^{n} u_i$$

where $n = 28$ for the number of 15-s average velocity readings at each of the 21 points in the array, and $n = 21$ for the number of average velocity readings in the velocity profile array.

12.2.2 Turbulence Strength

$$u_{rms} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (u'_i)^2}$$

where:

rms = root-mean square

$n = 28$ for the number of 15-s average velocity readings at each point

$n = 21$ for the number of average velocity readings in the velocity profile array

12.2.3 Turbulence Intensity

$$I = u_{rms} / \bar{u}$$

13.0 Quality Control and Quality Assurance

The aerosol concentration at each location should not deviate by more than 10% of the mean across the entire size range. If the deviation is greater than 10%, the aerosol is not spatially uniform and the entire process will need to be repeated after making adjustments to the system or its components.

14.0 Data and Records Management

The operator must maintain a laboratory notebook in which the experimental and sample details are recorded. Instrument records of use and maintenance are to be kept in the user's laboratory notebooks. Excel spreadsheets are used to record and calculate data. These files are maintained on the computer of the principal investigator, where they can be backed up during routine system backups by EPA.

15.0 References and Supporting Documentation

SOP-J15-002.0 (formerly draft SOP-ZD-14-02(1) prepared by Alion Science and Technology and RTI International), Collection and Extraction of Challenge Aerosol for Subsequent Coulter Analysis, August 2014. Research Triangle Park, NC: Jacobs Technology Inc.

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