10-29-2014

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Scholar Commons Citation

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Characterization of the Airborne Particulates Generated by a Spray Polyurethane Foam Insulation Kit

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Public Health
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College of Public Health
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Date of Approval:
October 29, 2014

Keywords: isocyanates; particle size; particle size-selective sampling; 4,4'-diphenylmethane diisocyanate; cascade impactor

Dedication

In loving memory of DeAnne Auclair. You will always be remembered and continue to be an inspiration.

Acknowledgments

This research and the education that supported it was made possible through the hard work of the staff and faculty of University of South Florida (USF), College of Public Health (COPH) and the Sunshine Education and Research Center (ERC). The National Institute of Occupational Safety Health’s funding of ERCs across the nation allowed me and students alike to obtain a master’s level education and conduct research that works to improve public health. For this I am sincerely appreciative.

I would also like to specifically express my deepest appreciation to the faculty of the Department of Environmental and Occupational Health and my thesis committee. My committee’s support and guidance throughout the research process provided me the opportunity to draw together the education I received at the COPH and apply it. The research simply would not have possible without their efforts. Thank you for everything.

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Abstract

Spray Polyurethane Foam insulation (SPF) kits are currently being marketed and sold to do-it-yourselfers to meet various insulating needs. Like commercial SPF systems, the primary health concern with SPF kits is user overexposure to the isocyanates during product application. The potential health risk associated with SPF applications is driven by several factors including (but not limited to): the toxicity of isocyanates; the potentially high exposure intensity; the quantity of isocyanates used in the process; the enclosed nature of the environment in which the product could be applied; the potentially high exposure duration/frequency; and the limited availability of control measures to reduce agent intensity (e.g., personal protective equipment, dilution ventilation). To better understand the potential hazards associated with the use of SPF kits, the current study was designed to provide an initial characterization of user exposure to airborne particulate during the application process. Specifically, the study would aim to answer the following:

- What is the particle size distribution of the aerosol a SPF kit user is exposed to during application?
- What is the airborne particle mass concentration a SPF kit user is exposed to during application?

To answer these questions, a single commercially available SPF kit was selected for use and a mock residential environment was constructed to support repeated applications of SPF. Size-selective and total dust air sampling were conducted during the applications to determine the particle size distribution and mass concentration of aerosols generated by the selected kit.

The particle size distributions developed from the size selective sampling results showed the presence of airborne particulate capable of penetration to the gas exchange regions of the respiratory tract. The average mass median diameter and geometric standard deviation of the particle size distributions were 4.6 µm and 2.7 respectively. The total dust sampling results showed mean airborne concentrations of 10.40 mg/m^3. Based on the sampling results the study, personal air monitoring is needed to assess the degree of user exposure to methylene diphenyl diisocyanate (MDI) and to provide information for the selection of exposure control methods.

Introduction

Spray Polyurethane Foam Insulation Background

Proposed Benefits

Spray Polyurethane Foam insulation (SPF) is developed by several manufactures and is currently being marketed as a superior substitute for traditional cavity fill products such as fiberglass batts/rolls, fiberglass loose fill, and cellulose (Honeywell, n.d.). Proponents of SPF propose several benefits to its use including: sustainment of material properties; improved indoor air quality; low waste stream contributions; and energy savings for producers, installers, and users (http://www.sprayfoam.org/). These benefits can make SPF particularly attractive to commercial and residential project teams seeking Leadership in Energy and Environmental Design (LEED) Certification. Projects using spray foam insulation can gain points in several LEED credit categories such as Indoor Environmental Quality, Energy and Atmosphere, and Materials and Resources (Honeywell, n.d.-b). These same benefits also make SPF attractive to do-it-yourselfers and small contractors doing home improvement projects.

Properties

The properties of SPF also allow its use in a wide range of commercial and residential applications. SPF can be used to seal/insulate wall cavities, attic spaces, hot tubs/bath tubs, floor spaces, and block or brick wall (Commercial Thermal Solutions, n.d.). In commercial settings, it can function as a sealant/insulator for roofing systems, walls, tanks and vessels, piping, HVAC ductwork, and cold storage units (Commercial Thermal Solutions, n.d.; SPFA, n.d.). The manufacturers of SPF propose many more applications than those listed here but it can reasonably be assumed that the list of applications will continue to grow as consumer needs evolve and manufacturers of SPF adapt to meet consumer needs with product solutions.

Products

There are a variety of SPF products on the market sold by several manufactures. The products are commonly categorized by the characteristics or properties of the SPF. Characteristics can include: cell structure (i.e., open cell, closed cell), rise or cure time (i.e., fast rise, slow rise), density, fire rating, and the number of chemical components used to develop the insulation (e.g., one-component, two-component). These characteristics, by design, make a particular SPF product a better fit for certain applications than others. For example, one component foams are designed for sealing cracks, seams and smaller cracks where two component foams are designed for application over larger surface areas or for filling large voids and gaps (SPFA, n.d.).

Application Systems

SPF products can also be differentiated by the systems used to apply the product. For example, SPF can be applied by professional contractors using commercial SPF rigs/systems or it can be applied using disposable SPF kits commonly referred to as do-it-yourself kits. The SPF kits are sold in common sizes based on theoretical yield in board feet (e.g., 100 bd. ft., 200 bd. ft., 600 bd. ft.). Commercial SPF systems use bulk chemical materials and the amount of insulation coverage is scalable to the specific project/job. Commercial SPF systems are generally used for large residential work or commercial jobs whereas SPF kits are typically used for jobs smaller in scale or do-it-yourself projects.

Chemical Components

Common to both commercial two component SPF systems and two component SPF kits are the basic elements of each system and their functions. Both systems use an isocyanate component and a polyhydroxy alcohol (polyol) component to develop the SPF (Lesage, Stanley, Karoly, & Lichtenberg, 2007). The isocyanate component, commonly referred to as Part A or the ISO side, is comprised of polymeric methylene diphenyl diisocyanate (pMDI) with methylene diphenyl diisocyanate (MDI) constituents (specifically 4,4'-diphenylmethane diisocyanate having the a CAS # of 101-68-8). The polyol component (e.g., Part B; Polyol side) generally consists of a polyol, as the main component, plus a mix of catalysts and additives (Lesage et al., 2007). Each component, Part A and Part B, is handled and stored in separate containers. During installation, the components are delivered to a handheld spray gun via separate flexible lines. When the spray gun is operated the components are blended and casted onto the surface of a structure. The reaction begins when the components are mixed and finishes within minutes of application. A blowing agent, either chemical or physical in nature, is also present in the one or both of the components. The blowing agent functions to develop the cellular structure of the SPF which plays a large role in the insulating properties (e.g., R-Value) of the end product (Connecticut Department of Public Health, 2010).

Public Health Significance

Several chemical constituents of SPF have associated Occupational Exposure Limits (OELs) however the primary agents of concern with SPF are the isocyanates. SPF associated health risk is driven by several factors including (but not limited to): the toxicity of isocyanates; the potentially high exposure intensity; the quantity of isocyanates used in the process (i.e., mix ratios for Part A and Part B are 1:1); the enclosed nature of the environment in which the product is applied; the potentially high exposure duration/frequency; and the available control measures to reduce agent intensity (e.g., personal protective equipment, dilution ventilation). The potential health risk is supported by several studies where researchers reported isocyanate exposures in excess of applicable OELs (Bilan, Haflidson, & McVittie, 1989; Crespo & Galan, 1999; Lesage et al., 2007) and the presence of aerosols (Lesage et al., 2007).

At the time of this study, all investigations into worker exposure had focused on the exposures of professional SPF contractors using commercial SPF systems (Bilan et al., 1989; Crespo & Galan, 1999; Lesage et al., 2007). No studies were discovered during literature review that evaluated exposures associated with the use of SPF kits. Given the similarities between commercial SPF systems and SPF kits, the accessibility of SPF kits by the general public, the visibility of these systems on the internet (e.g., social media, manufacturer websites), and the potential for use by untrained and unprotected users, there is a need for exposure characterization so the health risks associated with these systems can be better understood. SPF kits may pose a significant health risk to users if not properly employed, and due to the volume of potential users, may have the ability to substantially impact public health.

Purpose of the Study

The purpose of this study was to provide an initial characterization the airborne particulate exposure a SPF kit user would experience during SPF application. This characterization would provide information useful in the assessment of health risk and towards this end, would also work to support method selection for those evaluating airborne isocyanate exposures associated with SPF kits. The study would also serve as a foundation for future research.

To accomplish these goals, the study was designed to answer the following questions:

1. What is the particle size distribution of the aerosol a SPF kit user is exposed to during application?
2. What is the airborne particle mass concentration a SPF kit user is exposed to during application?

Study Limitations

A single SPF kit dispensing closed cell, fast rise, fire resistant (Class 1/A rating) SPF was used for the duration of the study. Although care was taken during the product selection process to ensure the chemical components of the kit and the properties of the SPF (i.e., density, cure time, R-value) were similar to other manufactures (to facilitate the generalizability of the study), there are differences in the mechanical components of systems from different manufacturers such as the mixing nozzles and the spray guns which could have an impact on the concentration and particle size distribution of the aerosols generated. Several manufactures also offer different nozzles for the same spray gun to adjust the dimensions of the spray profile for varying SPF applications; this could also affect the aerosol generated. For example, a fan type nozzle is generally used to cover large surface areas in an even coat whereas a cone type nozzle offers a circular spray profile that can be used to fill relatively smaller gaps and cavities (Dow, n.d.-b). A low pressure fan type nozzle was used for the duration of this study.

Literature Review

Health Effects of Isocyanates

Isocyanates are a family of highly reactive, low molecular weight chemicals known to be hazardous to human health (NIOSH, n.d.-a; OSHA, n.d.). They are potent sensitizing agents which are irritating to the respiratory tract, gastrointestinal tract, mucus membranes, eyes and skin (NIOSH, n.d.-a; Streicher et al., 2000). The most common disease/illness associated with overexposure to isocyanates is asthma resulting from sensitization (Streicher et al., 2000). Signs and symptoms of isocyanate induced asthma are indicative of acute obstructive respiratory diseases and include coughing, wheezing, shortness of breath, tightness in the chest, and nocturnal awakening (NIOSH, 2004; Streicher et al., 2000). Isocyanate induced asthma has been recognized as a major contributor to occupational asthma in the United States as a whole and has caused death in workers (NIOSH, 1996, 2007). This is of particular significance since occupational asthma has been reported as being the most frequently diagnosed occupational respiratory disorder in the U.S (NIOSH, 2007).

Less prevalent adverse health outcomes associated with isocyanate exposures are hypersensitivity pneumonitis (HP) and contact dermatitis (Streicher et al., 2000). The initial symptoms of isocyanate induced HP are flu-like in nature and include shortness of breath, nonproductive cough, fever, chills, sweats, malaise, and nausea (NIOSH, 2004). Continued exposure to isocyanate after the initial onset of HP can lead to more severe health effects such as an irreversible decrease in pulmonary function and diffuse interstitial fibrosis (NIOSH, 2004). Contact dermatitis from dermal exposure to isocyanates may present as a rash, itching, hives, and/or swelling of the extremities (NIOSH, 2004). Contact dermatitis can be either the irritant or allergic form making control of dermal exposures important since a relatively minute amount of isocyantate may be capable of eliciting an adverse health effect (Streicher et al., 2000).

Exposure Limits of SPF Isocyanates

The isocyanate component (i.e., Part A, ISO side) of SPF is composed of polymeric isocyanate (pMDI) and the monomeric isocyanate (MDI). The American Conference of Governmental Industrial Hygienists (ACGIH), the National Institute of Occupational Safety and Health (NIOSH), and the Occupational Safety and Health Administration (OSHA) all have established OELs for MDI (i.e., 4,4'-diphenylmethane diisocyanate, CAS number 101-68-8) but do not have OELs for polymeric isocyanates (e.g., pMDI). This has the potential to be problematic when assessing exposures associated with SPF since studies have shown that polymeric isocyanates are capable of producing negative health effects similar to monomeric isocyanates (Bello et al., 2004; Streicher et al., 2000). A possible solution available to those determining the acceptability of exposures to pMDI is the use of non-specific standards which measure total isocyanate groups (as NCO) (Bello et al., 2004). Such non-specific standards are currently in use by European health and safety organizations such as the United Kingdom’s Health and Safety Executive (UK HSE) (Bello et al., 2004; Streicher et al., 2000).

Occupational Exposure Limits for MDI set by OSHA, NIOSH, and the ACGIH are provided in Table 1 below (ACGIH, 2011). The non-specific OELs for total isocyante groups (NCO) established by UK HSE are also included for comparison (Bello et al., 2004). These OELs are extremely low when the entire body of OELs is considered and are an indication of the toxicity of these chemical agents. They also indicate of the level of sensitivity and accuracy required of the methods and measurement systems used to evaluate exposure levels.

Table 1. Occupational Exposure Limits for SPF Isocyanates

Organization	Chemical Species	CAS	Occupational Exposure Limit *Type*	 *Concentration (mg/m^3)*	 *Concentration (ppm)*
OSHA	MDI	101-68-8	PEL-C	0.20	0.020
ACGIH	MDI	101-68-8	TLV-TWA (8 hr)	0.05	0.005
NIOSH	MDI	101-68-8	REL-TWA (10 hr)	0.05	0.005
NIOSH	MDI	101-68-8	REL-C (10 min)	0.20	0.020
UK-HSE	total NCO	-	WEL-TWA (8 hr)	0.02	-
UK-HSE	total NCO	-	WEL-C (10 min)	0.07	-

Notes:

TLV - Threshold Limit Value	TWA - Time Weighted Average
PEL - Permissible Exposure Limit	STEL - Sort Term Exposure Limit
REL - Recommended Exposure Limit	C - Ceiling

Isocyanate Air Sampling and Analytical Method Considerations

The evaluation of airborne isocyanates is highly complex. So much so that an entire section of Chapter K of the NIOSH Manual of Analytical Methods (NMAM) was dedicated to the issues associated with the sampling and analysis of isocyanates. The reader is directed to an article by Streicher et al. (2000), which is a revision to NMAM Chapter K, for a thorough discussion of the issues associated with isocyanate air sampling and analytical methods. What follows is a brief summary of this article with a focus on the considerations that apply to SPF exposure assessment.

The challenges of isocyanate sampling and analysis stem from the chemical and physical properties of the family of chemical agents. Isocyanates are highly unstable, reacting not only with the polyol component of product, in the case of SPF, but also with water/water vapor (Streicher et al., 2000). This makes both sampling duration and humidity factors for consideration when performing air sampling because isocyanates can continue to react after aspiration by a sampling device. Consequently, derivitization to stabilize and improve quantitative analysis of sampled isocyanates is a necessary step in all air sampling methods (Streicher et al., 2000).

Isocyanate exposure assessment can be further complicated by the presence of multiple isocyanate species in the same volume of air sampled. Air samples can contain unreacted isocyanates (i.e., polymeric isocyanates [pMDI] and monomeric isocyanates [MDI]) as well as intermediates due to partial reactions of the isocyanate and polyol components (Streicher et al., 2000). This can impact decisions of exposure acceptability depending on the standard selected for exposure assessment (see previous section). For example, if an analytical method was selected to measure monomeric MDI concentrations for comparison against the respective OEL there is a possibility that other isocyanate species in the sample would be present but not quantified.

Isocyanates can also exist as vapors or as aerosols of varying particle size (Streicher et al., 2000). The physical state/form is generally dependent on the vapor pressure of the isocyanate species, ambient temperature, as well as the mechanical and chemical processes at work. When considering exposures to SPF, users have the potential to be simultaneously exposed to both isocyanate vapors and aerosols containing unreacted isocyanates (Lesage et al., 2007). This complicates the selection of sampling devices when assessing SPF exposures and stresses importance of the evaluator understanding the capabilities and limitations of the sampling devices and media used. Related and of equal importance is knowledge of the characteristics (i.e., particle size distribution) of the aerosols to be sampled.

Streicher et al. (2000) reviewed the various sampling devices and methods used to collect and derivatize airborne isocyanates. Of particular relevance to this study was the capability of the sampling devices to collect and stabilize isocyanate aerosols. It has been shown that impingers allow significant penetration of aerosols less than 2 µm in diameter (i.e., AED) but efficiently collect vapors and particles greater than 2 µm (Streicher et al., 2000). Closed and open face 37 mm filters are known to efficiently collect particles up to 20 µm including those less that 2 µm. When specifically considering the collection of isocyanates, reagent coated glass fiber filters (GFFs) have been found to prevent passage of both isocyanate vapors and aerosols of varying size. Both impingers and filters are expected to undersample, relative to the human inhalation efficiency, when used in environments with relatively high wind speeds (those not typically encountered indoors) and when sampling large particles (e.g., > 20 µm) (Streicher et al., 2000). Considerable wall losses have also been recognized when sampling large particles with impingers and filters (Streicher et al., 2000).

In addition to the efficiency in which isocyanates are collected, the efficiency they are derivatized must also be assessed when selecting methods and sampling devices. Aerosols generated during the application of isocyanate products (i.e., SPF) will typically contain a mixture of isocyanate and polyol (Streicher et al., 2000). For efficient derivatization, the isocyanate and the polyol must be separated/dispersed and the reagent must be accessible to the isocyanate groups. If this is not accomplished, the isocyanate and polyol within the aerosol droplets will be lost to reaction. Impingers are expected to be more efficient at the derivatization of isocyanate particles than reagent coated GFFs because the droplets are submerged in a solvent which serves to both dissolve/separate product components (i.e., Polyol; ISO) and provide a vehicle for the reagent to come into contact with exposed isocyanate groups. Aerosols collected by GFFs have been shown to have minimal contact with filter fibers in micrographs (Streicher et al., 2000). This has the potential to reduce the reagent contact isocyanate groups and in turn reduce derivatization efficiency. The addition of a small amount non-volatile solvent to GFFs and field extraction of GFFs post sampling are two practices used to address this issue and improve derivatization efficiency (Lesage et al., 2007; Streicher et al., 2000). Field extraction is addressed in in NIOSH Method 5525 of the NMAM.

Previous Studies of SPF Exposures

The number of published studies evaluating exposures to SPF (with MDI-based isocyanates) is limited but they provide a useful foundation of information for exposure assessments in the field and further research on the topic. A timeline depicting the studies discovered during the literature review for the present study are shown below. The literature search/review process used for the study is also shown in Appendix A.

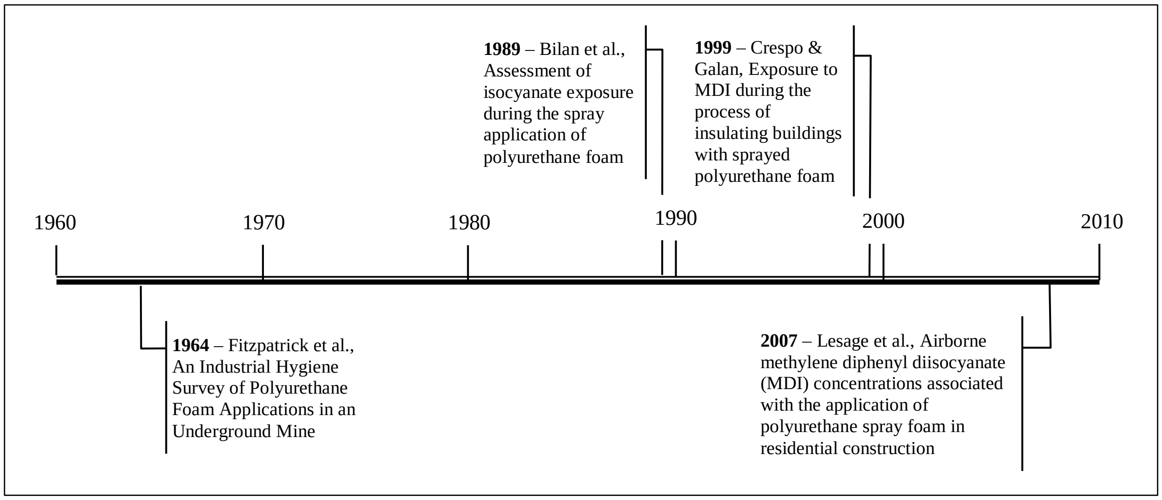


Figure 1. Timeline of reviewed spray polyurethane foam insulation studies.

The SPF studies reviewed generally focused on exposures during various construction oriented applications with exception of the work of Fitzpatrick et al. (1964) which evaluated exposures in an underground mine. This study was not reviewed in detail due to the disparities in environmental conditions between underground mine applications and above ground construction applications (Bilan et al., 1989). Also, the designs of SPF systems have changed since this early study which further limits it’s applicability to more current SPF operations (Bilan et al., 1989).

Bilan et al. (1989) evaluated MDI exposures at eight jobsites during various SPF applications including: roofs, barns, a walk-in cooler, a Quonset hut, and horse stalls. Both personal and area samples were taken indoors and outdoors with the area samples taken at various distances from the spray operations. The results of the area air monitoring supported the establishment of a “working zone” around the spray operations within which there was an increased potential for overexposure. This approach for area sampling was later followed Lesage et al. (2007). Personal air monitoring results ranged from 0.008 ppm – 0.129 ppm for SPF sprayers and 0.001 ppm – 0.018 ppm for workers assisting SPF sprayers with applications (hereafter referred to as SPF helpers). The personal air monitoring results showed that SPF sprayer exposure to MDI exceeded the OSHA PEL-C in 4 out of 5 indoor evaluations and 2 out of 3 outdoor evaluations.

As might be expected, environmental conditions and the tasks of the SPF workers were found to have an impact on exposure intensities during the study. Indoor exposures were indirectly related the surface area of the applied SPF and size of space insulated. For example, MDI exposures experienced in a small enclosure where 750 sq. ft. of SPF was applied were greater (approx. 2 orders of magnitude) than exposures in a large walk-in cooler where 3375 sq. ft. of SPF was applied. SPF sprayer exposures outdoors were lower than sprayer exposures indoors and ranged from 0.003 ppm – 0.050 ppm. In contrast to SPF sprayer exposures, the air monitoring results of the SPF helpers showed that exposures levels were greater outdoors than those experienced indoors. The researchers attributed the results of the SPF helpers to differences in work practices between indoor and outdoor SPF operations. That is, outdoor operations evaluated during the study were all roofing jobs and required the helpers to be in closer proximity to spraying operations and at times hold a windscreen to ensure proper application. This rationale for greater SPF helper exposures outdoors is plausible given the results of the area sampling and support for a “working zone” around spray operations.

Crespo and Galan (1999) evaluated personal exposures to MDI during the application of SPF in a large office building, terrace houses, and flats. The scope of the study included a total of 17 construction sites (1 large office building; 2 groups of terrace houses; 14 blocks of flats) with 13 indoor applications evaluated and 5 outdoor applications (i.e., 2 facades, 3 roofs) evaluated. In contrast to Bilan et al. (1989) who performed sampling only during the actual spraying of SPF, Crespo and Galan (1999) conducted personal sampling during the entire SPF spraying process. This approach included the time the crews repositioned and cleaned SPF equipment and was thought by the researchers to result in exposure levels representative of the most common work conditions. SPF sprayer and SPF helper mean weighted exposures (sampling time only) ranged from 0.017 mg/m^3 – 0.400 mg/m^3 and 0.004 mg/m^3 – 0.308 mg/m^3 respectively. SPF helper exposures to MDI were lower than those experienced by SPF sprayers and when considering environmental conditions, exposures of both the sprayers and the helpers were greater indoors than outdoors. The effect environmental conditions (i.e., indoors vs outdoors) had on the exposures experienced by the helpers in this study opposes those presented by Bilan et al. (1989) but emphasizes the relationship between the tasks/practices of the helpers and their exposure levels to MDI. That is, the more proximate helper tasks and practices bring them to active spraying operations, and the longer they remain within the “working zone”, the higher their risk of overexposure to MDI.

Like and Bilan et al. (1989) and Crespo and Galan (1999), Lesage et al. (2007) conducted personal air monitoring to evaluate exposures to MDI. The study also went beyond these evaluations to assess several related exposures experienced by workers applying SPF. Specifically, Lesage et al. (2007) designed their study to answer the following questions:

Table 2. Lesage et al. (2007) Research Questions

#	Question
1	What are the airborne concentrations of MDI and HCFC-141b and potential exposures to the spray foam applicator and assistant during foam application?
2	How quickly do the airborne MDI concentrations decline after foam application ceases?
3	How does the airborne MDI concentration vary with distance away from the application?
4	Is there any off-gassing of MDI after the foam has fully cured?
5	What is the particle size distribution of the spray foam aerosol; specifically what percentage is respirable?
6	How do the various sampling methods for MDI (filter and impinger) compare?

To answer these questions, Lesage et al. (2007) evaluated exposures during the application of SPF in 5 single-family houses in the US (2 homes) and Canada (3 homes). SPF was sprayed on the basement walls of the Canadian homes (2 inches deep) and both the exterior and basement walls of the US homes (1 inch deep). The windows and doors of all the houses were installed prior to SPF installation to help ensure similar environmental conditions across the different sites and between sampling surveys. In contrast to the studies of Crespo and Galan (1999) and Bilan et al. (1989), there were no outdoor applications evaluated as part of the study and the study did not focus on the exposures of the SPF helpers. Additionally, a one-component SPF containing MDI not used previous studies was used to fill cavities around the windows. The reader is directed to Lesage et al. (2007) for the additional details on the one component SPF as it will not be discussed further here due to the limited applicability to the present study.

A combination of personal and area monitoring were conducted to assess/characterize exposures to SPF and answer the research questions posed in Table 3 above. Personal air sampling was conducted to evaluate exposures to MDI monomer, MDI oligomer, and the physical blowing agent HCFC-141b. Area sampling was performed to: evaluate the concentration of MDI (oligomer and monomer) and HCFC-141b as a function of the distance from spraying operations; the concentration of MDI (oligomer and monomer) as a function of time following application; the particle size distribution of the SPF aerosols; and the presence of MDI on foam surfaces following application. The researchers also used both filter and impinger sampling methods (see Table 3) for the collection of SPF to allow comparison of the results given similar exposure conditions.

Personal air monitoring results showed exposures both above and below established OELs. Sprayer personal air monitoring results for MDI monomer were above the OSHA PEL (PEL-C 0.02 mg/m^3) in nine of the thirteen samples taken and ranged from 0.07 mg/m^3 to 2.05 mg/m^3. The results of sprayer personal air monitoring for MDI oligomers ranged from 0.01 mg/m^3 to 0.89 mg/m^3 and were lower than MDI monomer results for each of the corresponding sampling events. Although there is no US regulatory OEL (i.e., OSHA PEL) established for HCFC-141b, personal monitoring results for HCFC-141b (i.e., sprayer) ranged from 171 mg/m^3 to 4300 mg/m^3 and were reported to be below the American Industrial Hygiene Association (AIHA) Workplace Environmental Exposure Limit (WEEL) of 500 ppm (WEEL – TWA [8hr]). The sampling times for HCFC-141b ranged from 12-51 min and it is assumed that the researchers considered the non-application/sampling times of the exposure profile to be zero when calculating the HCFC-141b TWA.

Area monitoring conducted at various distances from spray operations showed a decrease in mean MDI (monomer and oligomer) concentration levels as the distance from spraying operations increased (i.e., indirect relationship). These results are in general agreement with those of Bilan et al. (1989) and offer support for the "working zone" concept, however, the results were highly disperse (see Table 3 below) making the determination of a safe distance from these data problematic without further study. Additionally, there were concentrations of MDI above the MDI PEL-C measured at each distance interval (Lesage et al., 2007, p. 154). Area monitoring for HCFC-141b, unlike MDI, showed no relationship between concentration and distance. These results are not unexpected given the physical state of the agent and, as indicated by the researchers, the rather small size and irregular shape of space in which the samples were taken (Lesage et al., 2007).

Area sampling conducted as a function of time (i.e., 15 min, 30 min , 45 min , 60 min , 75 min, 90 min, next day) found measureable concentrations of MDI at 15 minutes (3 of the 5 surveys) and 45 minutes (1 survey) (Lesage et al., 2007, p. 151) following application. The concentrations of MDI (monomer) measured ranged from 0.003 mg/m^3 to 0.019 mg/m^3 and were are all below the OSHA PEL-C. All other samples results were below the limit of quantification (LOQ), including those taken the next day, but the researchers stressed the importance of product formulations and application conditions when considering the data for operational and administrative guidelines. Similar concerns related to safe re-entry following SPF installation have also been communicated by the Environmental Protection Agency (EPA, 2013).

Table 3. Summary of Lesage et al. Sampling Results at Various Distances

Statistic	1-3 meters		3-6 meters		6-12 meters	
	MDI Monomer	*MDI Oligomer*	*MDI Monomer*	*MDI Oligomer*	*MDI Monomer*	*MDI Oligomer*
Sample Size (*n*)	13	13	13	12	11	9
Mean ($\bar{x}$), *mg/m*^{3}	0.603	0.285	0.344	0.182	0.166	0.122
Median (*M*), *mg/m*^{3}	0.300	0.157	0.217	0.145	0.079	0.085
SD (s), *mg/m*^{3}	0.495	0.283	0.355	0.201	0.238	0.153
Range, *mg/m*^{3}	1.403	0.810	1.115	0.676	0.798	0.490

When sample collection methodologies were compared, both area and personal monitoring results using impinger collection methods were greater than those using filter based collection methods. A student's t test showed a significant difference between the data obtained using the impinger and that obtained using each of the filter methods (Lesage et al., 2007). The researchers suggested the significant difference in results was related to the highly reactive nature of the SPF and the particle size distribution of the aerosols. That is, the airborne particles were large enough to be efficiently collected by an impinger (> 2 µm) and impinger methods are more effective than filter methods at derivitizing/stabilizing captured SPF aerosols (see Isocyanate Air Sampling and Analytical Method Considerations above).

Similar to the impinger + filter method described in NMAM Method 5525, the researchers used backup filters in series behind the impingers during Survey 2 personal and area sampling events. The backup filters functioned to collect fine particles having the potential to pass through the impingers (particles < 2 µm) and consisted of glass fiber filters coated with 1-(2-methoxy phenyl) piperazine (MOPIP). The absence of measureable results of MDI on the filters indicated that the impingers effectively collected the SPF aerosol and resulted in the researches to discontinue use of impinger + filter methods in subsequent surveys. The lack of measureable results on backup filters was also suggested to support the rationale for the significant difference between filter and impinger based methods. That is, no results indicates particles were large enough to be collected by impinger; particles are more efficiently derivitized by impingers; and more efficient derivitization results in greater measurements.

Marple Personal Cascade Impactors were used to perform the area size-selective sampling for the study (Lesage et al., 2007). The 8-stage impactors were located in the center of the rooms during SPF application and were operated at a flow rate of 2L/min for a total 6 sampling events spread across 3 surveys (i.e., Survey 3 – 2 samples; Survey 4 – 1 sample; Survey 5 – 3 samples). It is assumed that the impactors were placed atop tripods at a height ranging from 1.5 - 2 meters as was described for the other area samplers used in the study. The researchers used precut polycarbonate filters for the first seven stages of the impactors and a polyvinyl chloride (PVC) filter for the last stage of the impactors. Gravimetic analysis was performed on the filters to determine the mass distribution of the airborne SPF particles and the mass concentrations per stage were calculated using sampling flow rates. The particle size distributions were presented in histogram format and showed a relatively low proportion of the particulate mass sampled to be < 2 um in diameter. The mean respirable fraction for the distributions was reported to be 20% with a standard deviation of 4.3% (Lesage et al., 2007, p. 153). The reader is directed to Rubow, Marple, Olin, and McCawley (1987) for further information on the impactors used in the study including (but not limited to): instrument operation, design characteristics, cut-off points of the stages, particle loss, and collection efficiencies.

To evaluate workers potential exposures to isocyantes via the dermal route, surface monitoring was performed using surface wipes (i.e., SWYPES). The surfaces of the SPF were tested immediately following application then the same locations were tested again 15 minutes later. All 20 surfaces evaluated showed positive results for isocyanates immediately following application but the results were negative at 15 minutes post application. These results indicate the SPF components were properly proportioned during the surveys monitored and are not surprising given the cure rates of common SPF products (Dow, n.d.-a; Technologies, n.d.).

It should be noted that the particle size selective sampling was conducted during surveys 3, 4, and 5 so it would appear that the researchers did not have the distribution data available to them prior to making the determination to discontinue use of the backup filters. Since the distribution data was as support the rationale for the significant difference between filter and impinger methods it can be assumed that having the data prior to sampling would have been useful in determining sample collection methodology and in doing so supports the need for studies that provide particle size distribution data.

Table 3 below summarizes the key characteristics of the studies discussed above for comparison purposes:

Table 4. Characteristics of Previous SPF Exposure Assessment Studies

Study/Article	Application Characteristics	Agent(s) Evaluated	Exposure Routes Evaluated	Sample Type	Analytical Methods Referenced in Article
Bilan et al. (1989)	Eight applications evaluated: – 5 indoor applications sampled (*2 barns, 1 walk-in cooler, 1 Quonset hut, and horse stalls*) – 3 outdoor sampling events sampled *(3 roofs*)	MDI (monomer)	inhalation	personal air monitoring (helper and sprayer); area air monitoring	Modified Marcali Method (Ontario Ministry of Labour, Regulation 455/83)
Crespo and Galan (1999)	Eighteen applications evaluated: – 13 indoor applications sampled (*large office building, 2 groups of terrace houses, 14 blocks of flats*) – 5 outdoor sampling events sampled (*2 facades and 3 roofs*)	MDI (monomer)	inhalation	personal air monitoring (helper and sprayer)	Method MTA/MA-034/95 (NIOSH-Spain)
Lesage et al. (2007)	Five applications evaluated: – 5 indoor applications sampled (*5 single family homes)*	MDI (monomer); MDI (oligomer); unpolymerized isocyantes; HCFC-141b; SPF aerosols	inhalation; skin/dermal	personal air monitoring (sprayer/applicator); area air monitoring; surface monitoring; particle size-selective area monitoring	NIOSH 5521 (impinger and filter), modified NIOSH 5521 (filter treated with co-solvent MOPIP), ISO-CHEK method, gravimetric analysis, surface wipe method (SWYPES); IRSST MAM Methods 345-1, 237-2, 238-1

Definitions:
NIOSH – National Institute for Occupational Safety and Health
IRSST - Institut de recherche Robert-Sauvé en santé et en sécurité du travail
MAM – Manual of Analytical Methods
MOPIP - 1-(2-methoxy phenyl) piperazine
MDI - methylene diphenyl diisocyanate

Methods and Materials

Size-selective and total dust air sampling were conducted to determine the particle size distribution and concentration of aerosols generated by an SPF Kit. To allow for generalizability and control of the study, a mock residential construction environment was fabricated to perform the surveys within. The basic process flow used for the study is depicted in Figure 2 below and the detailed procedure developed to support and execute the study can be found in Appendix B.

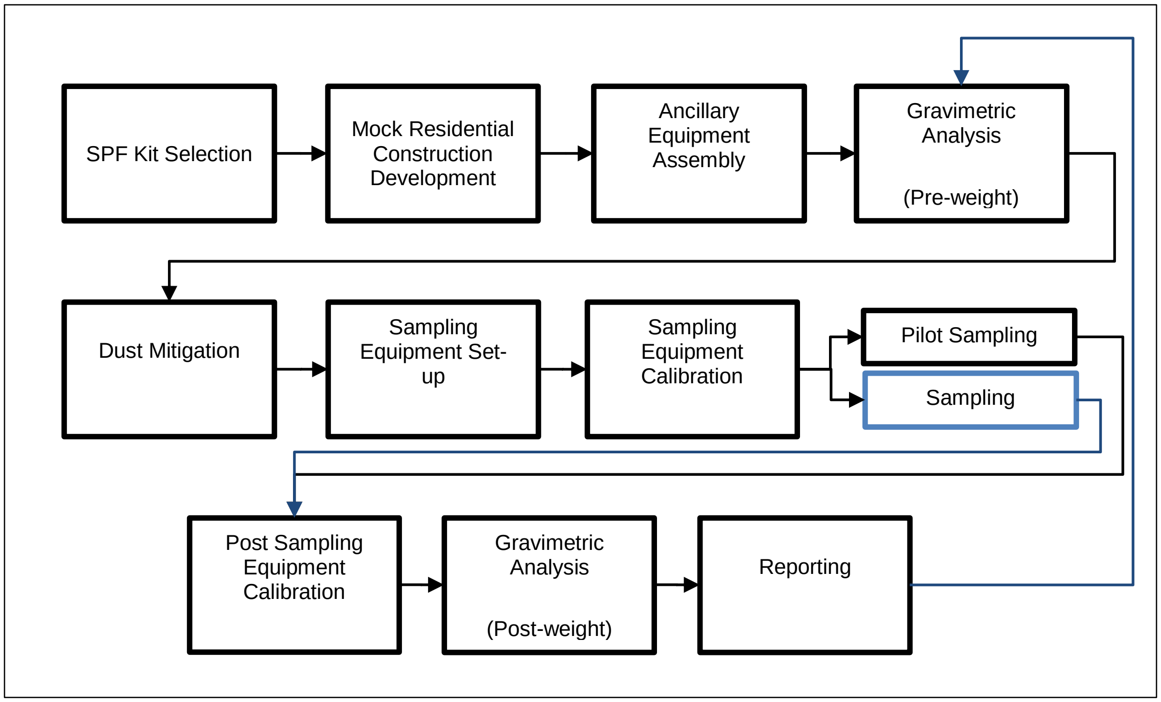


Figure 2. Study process flow diagram

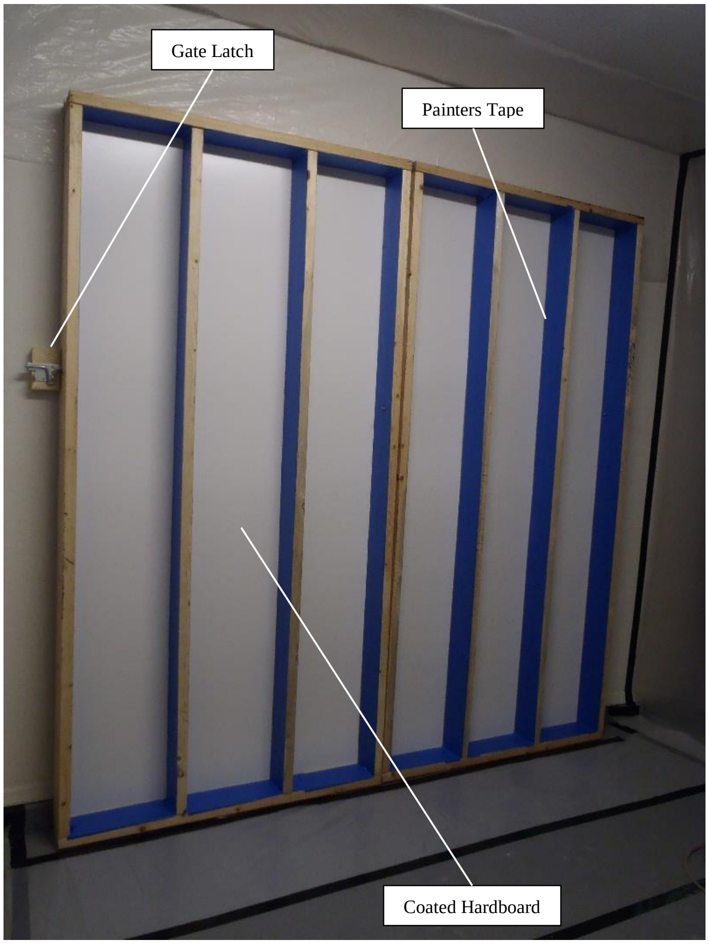
SPF Kit Selection

The SPF Kit selection process consisted of a review of several manufacturers' websites, instructional videos, and technical literature to include Material Safety Data Sheets (MSDS). The goal of the review was to select a kit that had commonalities with other kits on the market, was visible and accessible to a large population of potential buyers, had technical literature and instructional materials that would support the execution of the study, and was of sufficient quantity to support several surveys. The Dow Froth Pak 620 (hereafter referred to as the SPF Kit) was ultimately selected for use and the interested reader is directed to the company's website for product technical information (Dow, n.d.-a).

Mock Residential Construction

A mock residential environment was constructed in a finished one car garage with painted walls and floor. The construction consisted of building two mock wall sections for repeated application of SPF and the fabrication of a suitable enclosure in which the application and sampling would take place. Each wall section was 4 feet wide by 8 feet tall and was framed with 2″ x 6″ boards, 16 inch on center, for a total of 4 vertical studs and two horizontal plates per wall section (see Figure 3 below). A 4′ x 8′ sheet of coated 1/8″ white hardboard was attached to each frame and the wall sections were positioned beside one another against the wall of the garage. The entire application area of the two wall sections measured 8 feet wide by 8 feet tall (64 ft^2). The coated hardboard was selected for use in lieu of plywood or particle board to reduce dust and the potential for sample contamination by non-SPF particulates. Once positioned, gate latches affixed to the garage wall were slid into drilled holes on the outermost studs of each wall section (see Figure 3) securing the sections firmly in place. The seams of the wall sections where the studs mated with the white hardboard were taped with blue painters tape to aid in clean-up and removal of SPF between applications/surveys (See Figure 3). New sheets of white hardboard and new painters tape were used for each survey. The frames were also cleaned of any SPF prior to each survey.

To enclose the application space and isolate it from the remainder of the garage footprint, two large pieces of plastic sheeting were cut to size then attached to the ceilings and garage walls (see Figure 3). The seams were sealed with duct tape and a flap was cut in the plastic sheeting to allow passage of persons and equipment (see Figure 3). The sheeting was also used above and below the mock wall to facilitate clean-up due to gun drips/overspray and to protect the finished surfaces of the garage.



a.) Mock Wall Sections Prepared for Foam Application

b.) Plastic Enclosure w/Seams Sealed

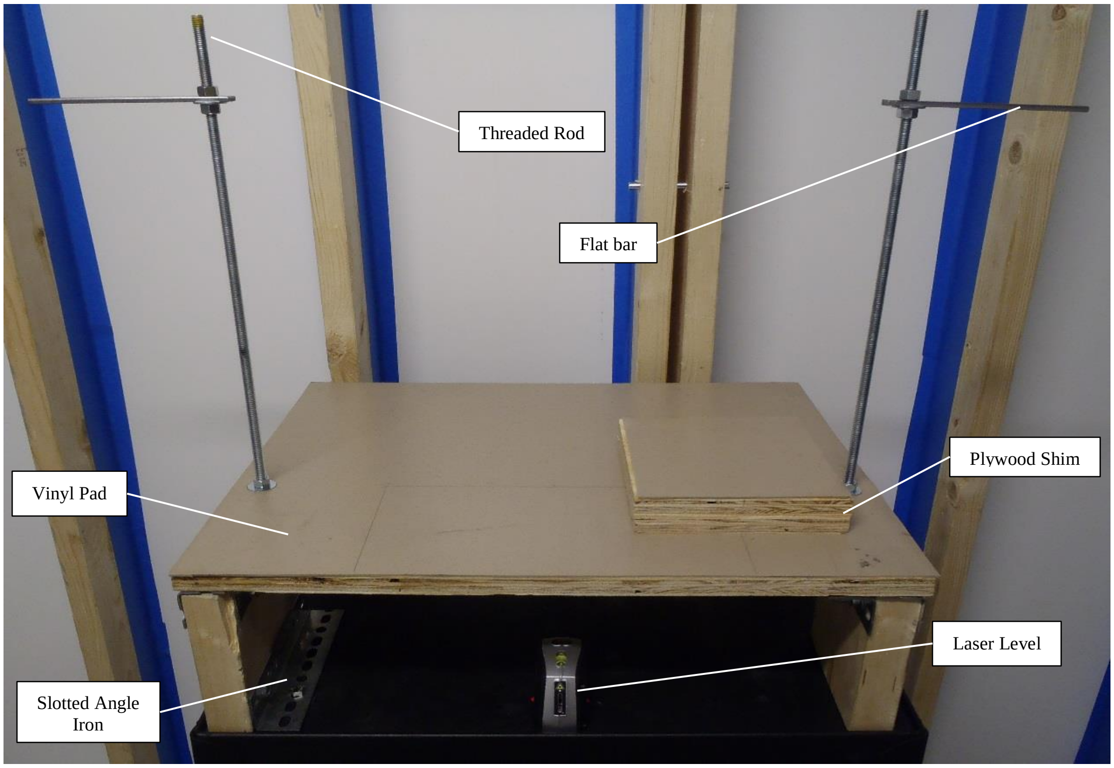
c.) Enclosure Entrance Flap

Figure 3. Mock wall sections and enclosure. a.) Completed wall sections secured in place with painters tape installed. b.) Plastic sheeting installed and sealed. c.) Flap type entrance into enclosure.

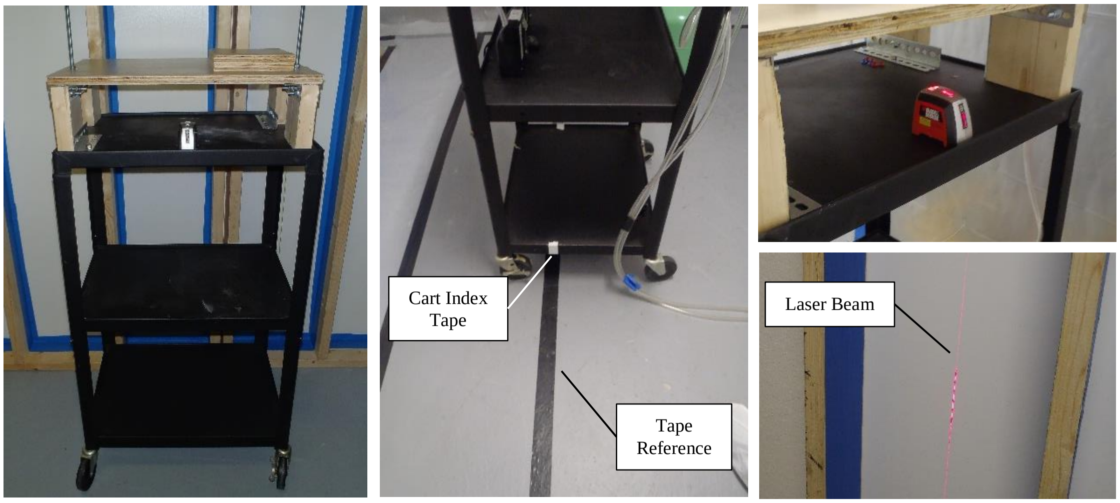
Ancillary Equipment Assembly

A three shelf lab cart was modified to support the placement and transport of the sampling equipment during the surveys. To bring the sampling devices to breathing zone level, a stand was build out of 2″ x 6″ boards, ¾″ plywood, slotted angle iron, and various attaching hardware (e.g., bolts, washers). All components of the stand were cut to size, assembled, then the stand was mounted to the top of the cart (see Figure 4). Plywood shims were used to raise the size-selective sampler inlets (i.e., cascade impactors) to level (see Figure 4). To ensure the sampling devices remained in place during the surveys/sampling events, a sheet of foam vinyl padding was adhered to the top of the stand with spray adhesive. Holes were drilled in the plywood surface and threaded rods were inserted to serve as stand-offs for sampling devices. Nuts and washers were used to secure the rods to the stand and to hold two pieces of flat bar (one per rod) in place. The flat bar was used to hang the personal samplers from and maintain them level with the size-selective samplers (see Figure 3).

To maintain consistent cart positioning during the surveys, a laser leveling device was mounted on the top metal shelf of the cart and a line of duct tape was installed on the floor parallel to the mock wall sections. The laser level emitted a vertical beam which was centered between the wall cavities during each spraying sequence and the tape line on the floor was aligned with an index tape on the cart (see Figure 4). Through the use of both physical references, the samplers were maintained at approximately 1.3 meters from the wall during each survey. The distance used was an approximation of a user's positioning during application ((i.e., distance from wall = 50th percentile arm reach distance [acromial process to functional pinch, male] + gun w/nozzle length + recommended spraying distance from operators manual) (Wickens, Gordon, & Liu, 2004).



a.) Stand components



b.) Stand mounted on lab

c.) Reference tape aligned w/cart index

d.) Laser illuminating cavity

Figure 4. Laboratory cart modified w/stand. a.) Stand with components described. b.) Stand shown mounted on top of lab cart. c.) Lab cart shown aligned with tape reference on the floor. d.) Laser level powered on casting vertical beam on the center of the wall cavity

Gravimetric Analysis

Gravametric analysis was used to determine the particle size distribution and concentration of the aerosols generated by the SPF Kit. Using an analytical balance (i.e., Mettler Model AE163), the pre-sampling and post-sampling weights of the each sampling media were obtained. The pre-sampling weight was subtracted from the post weight yielding the total mass collected on the filter during the respective sampling event. Once corrections for blanks/controls and ambient particulate concentrations were made, the corrected mass was available for calculations of total dust concentration and particle mass distribution.

To obtain both pre-sample measurements, the sampling media used for each survey (i.e., 81 mm pre-cut glass fiber substrates for the Andersen Cascade Impactors; 37 mm polyvinyl chloride (PVC) filters for 37mm cartridges) were removed from their packaging and carefully placed in Petri dishes using tweezers and filter handling tools. The Petri dishes were organized on a lab surface (i.e., cart/counter) and the filters/substrates were left to equilibrate overnight in a weigh room. The following day the ambient conditions were recorded and the filters were removed from their Petri dishes then weighed twice on the analytical balance (detailed weighing method can be found in Appendix B). Once weighed, the substrates were placed back in their respective Petri dishes, labeled, and the dishes closed for transport to the survey site. The 37 mm filters were placed on filter pads in 37mm cassettes which were then assembled, labeled, and sealed for transport with the Petri dishes. Post-sample weighings were conducted using the same general measurement process however the second measurement served only as a quality control check (see Appendix B).

a.) Analytical Balances in Weigh Room

b.) Analytical Balance Display w/Perti Dish

c.) Glass Fiber Substrates and 37 mm Filter Equilibrating in Weigh Room

Figure 5. Analytical balances and filters/substrates in weigh room. a.) Analytical balance used for Surveys 1-3 shown in the middle – Mettler Model 163. b.) Display of balance shown under load. c.) 81mm glass fiber substrates for cascade impactors and 37 mm filters for total dust.

The operator’s manuals for the size selective sampler and analytical balance, Bisesi (2003), and NIOSH Method 0500 were all used to guide the execution of the gravimetric analysis (NIOSH, n.d.-b; Tisch Environmental, 1999; Toledo, 2001). The same weigh room and analytical balance were used for all the surveys with the exception of the pilot survey where it was determined that the initial analytical balance (i.e., Mettler Model 240) lacked the sensitivity needed for the study. Efforts were also made to complete measurements under similar conditions (e.g., same time of day, same ambient conditions) to maintain consistency across measurements and reduce errors related to humidity.

Dust Mitigation

Dust mitigation activities were conducted prior to each survey to reduce the likelihood of non-SPF airborne particulates being collected during the sampling events. First, the entire mock wall and floor of the enclosed space were first vacuumed with a wet/dry HEPA vacuum. This would reduce the potential for settled non-SPF particulates to be entrained in the SPF aerosol during application. Then a HEPA air purifier was operated in the enclosure for approximately one hour to reduce the airborne particulates in the space. The HEPA vacuum and air purifier are pictured in Figure 6 below.

a.) Rigid 14 gal Wet/Dry Vac with HEPA filtration

b.) Honeywell True HEPA Allergen Remover

Figure 6. Photograph of wet dry/vac and air purifier used for dust mitigation. Photographs of equipment taken at later date not at survey site.

Sampling Equipment Set-up

Size Selective Sampling

Two high volume air sampling pumps were placed outside the enclosure to provide the necessary 28.3 L/min volumetric airflow needed for operation of the size selective samplers (i.e., Andersen Cascade Impactors). Flexible air sampling tubing (1/4″ inner diameter) was ran from the inlet valve of each pump to the lab cart where the size-selective samplers would be staged during the surveys. The tubing was bound together with tape periodically down the length of tubing and to a vertical leg of the cart to allow for easier management of the tubing during the surveys. Care was taken to ensure there was adequate slack in the tubing to allow the cart to easily traverse the mock wall without impacting the security of the samplers. Two additional segments of flexible tubing were connected to the outlets of the high volume pumps and ran outside the garage. Placement of the high volume samplers outside the enclosure and running the exhaust to the outside would reduce the potential for airborne particulates (i.e., oil mist) generated by the high volume pumps to be collected during the surveys.

Two Andersen Cascade Impactors were used to perform the size-selective sampling for the study. An instruction manual for the impactor providing guidance for assembly, sampling, analysis, and data interpretation was used for the operation of the device (Tisch Environmental, 1999). One impactor was fitted and operated with a pre-seperator and the other was operated with the standard inlet cone. Set-up of the impactors began with disassembly, cleaning, and inspection of the impactor components in a laboratory environment then transporting them to the field site (i.e., garage). At the field site the impactors were placed on wax paper and carefully disassembled with the stages and stainless steel plates laid out in sequential order. The corresponding subtrates in their Petri dishes were then matched with their respective stage based on the perti dish labeling (see Figures 6 and 7). Each stage was then assembled beginning with the last stage (base) of the impactor with the corresponding subtrates placed on each stainless steel plate. Computer duster was used to reduce the likelihood of dust contamination during assembly by gently blowing off the surfaces of the stages and stainless steel plates prior placement of the substrates.

Once assembled, the impactors were carefully transported into the enclosure and placed atop the lab cart stand in their designated location. A leak check was performed on each impactor to ensure the stages had properly sealed with one another. If the leak check failed the stages were gently adjusted and the leak check repeated until the vacuum on the system was maintained. After a successful leak check, a 37mm filter cassette assembly was connected in series with each impactor and their corresponding high volume pump using flexible tubing. The 37mm PVC (5 µm) filter housed in the filter cassette would serve as the final stage of the impactor and the mass collected would be used in the determining particle size distribution of the SPF aerosol. Labeling of the flexible tubing running from each pump as well as labeling of the equipment would ensure the same pump was used to operate the same impactor throughout each survey conducted. The sampling train having the impactor with the standard inlet cone was identified as Size Selective Sampling Train (1); the impactor with the pre-separator was identified as Size Selective Sampling (2); Sample and equipment data for each survey can be found in Appendix C.

Figure 7. Andersen Cascade Impactor disassembled – SSS1. Stages of the cascade impactor are shown laid out across the top; stainless steel plates are shown in the middle; 81 mm glass fiber subtrates are shown in Petri dishes on the bottom. The pre-separator is shown in the upper right hand corner of the photograph.

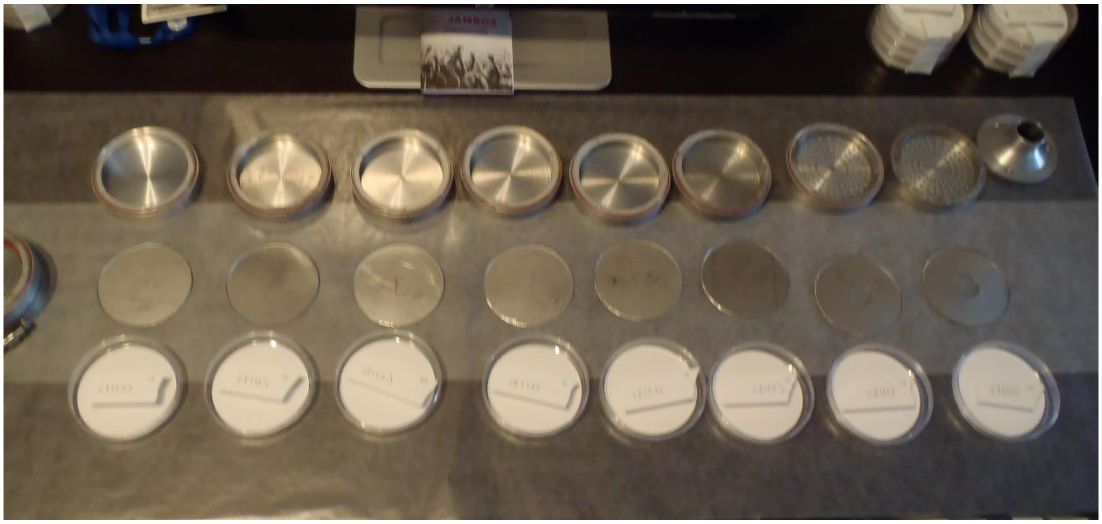


Figure 8. Andersen Cascade Impactor disassembled – SSS2. Stages of the cascade impactor are shown laid out across the top; stainless steel plates are shown in the middle; 81 mm glass fiber subtrates are shown in Petri dishes on the bottom. The standard inlet cone is shown in the upper right hand corner of the photograph.

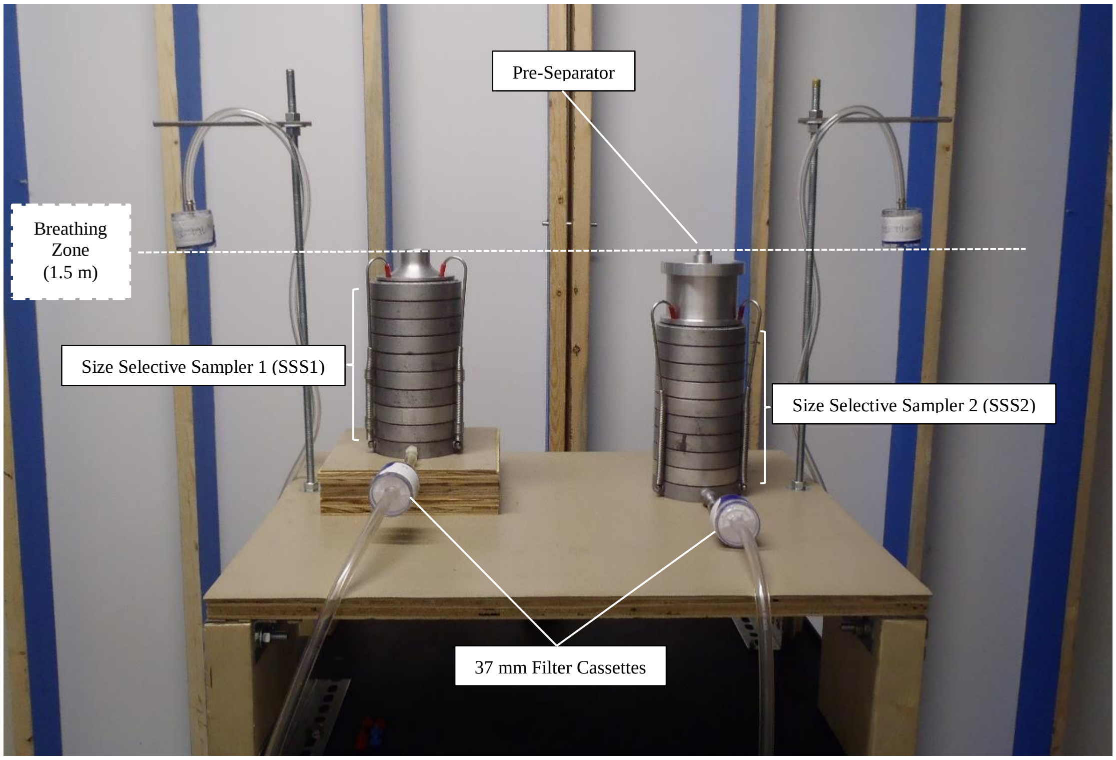


Figure 9. Andersen Cascade Impactors set-up for sampling.

Total Dust Sampling

Two personal air sampling pumps were used for all total dust sampling events conducted for the study. The pumps were labeled and placed on the middle shelf of the cart allowing them to travel with the sampling devices during the surveys. Flexible air sampling tubing (1/4 inner diameter) was used to connect the pumps to their corresponding 37mm filter cassettes for each survey. The tubing was coiled around the threaded rods and hung over the flat bar stand-offs allowing positioning of the 37 mm filter cassettes at breathing zone level (see Figure 9). NIOSH method 0500 was used to support all total dust sampling activities.

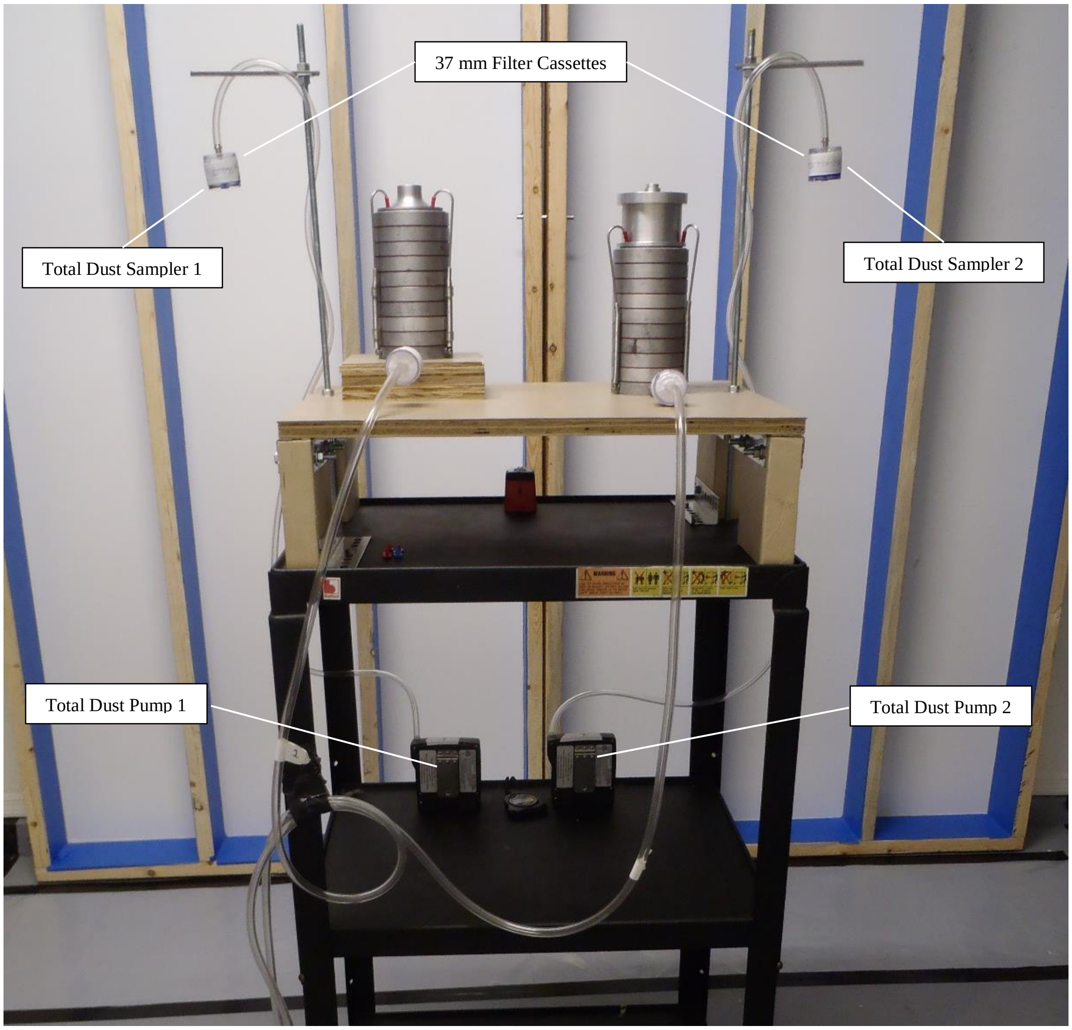


Figure 10. Total dust pumps and samplers staged for survey.

Sampling Equipment Calibration

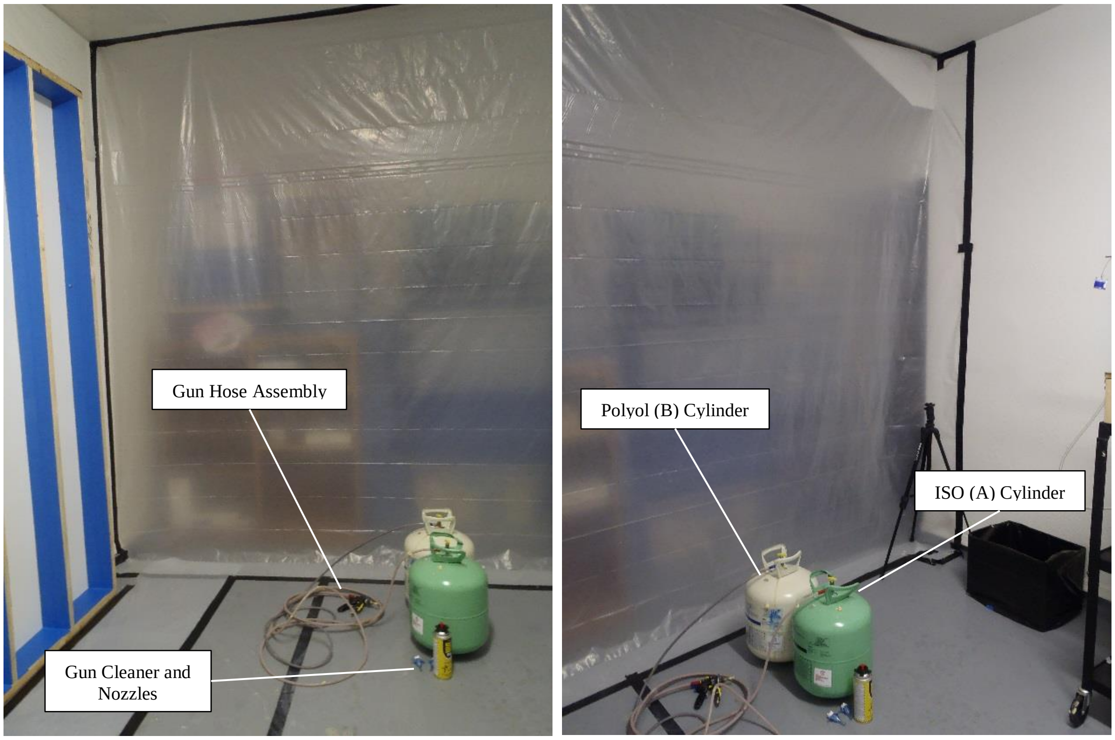
The sampling pumps were calibrated using a primary standard prior to and after all sampling events. Pre-sample calibration began with powering on the pump to be calibrated allowing it to warm up for approximately 5 minutes. The pump was then powered down and the calibrator connected using flexible tubing. For the impactors, drilled rubber stoppers with stems installed were inserted into the inlets of the pre-seperator/cone to allow connection. For the total dust sampling trains, a representative 37 mm filter cassette was used in place of the filter cassette assemblies to be used for survey. The pumps were then powered back on and the volumetric flow rate adjusted to the desired rate using the user interface (personal sampling pumps) and the installed inlet valves (high volume pumps). The size-selective sampling trains were calibrated to 28.3 L/min and the total dust sampling trains were calibrated to 2.0 L/min. A total of 10 volumetric flow rate measurements were taken for each calibration event. The average of the measurements would be used for the final pre-sampling calibration value. Once calibration was complete, the pumps were powered down, all calibration equipment was removed, and the sampling trains were returned to their sampling configurations.

Post sampling calibration was performed in the same manner as pre-sampling calibration with the exception that the measurements were completed outside the enclosure to reduce the potential for contamination during the calibration process. There was also no need for the pump warm up since they were at running temperature from the sampling event. The average of the pre-sample and post sample calibrations would be used for all calculations of volumetric flow rates for the sampling events. Please see Appendix D for all calibration data.

SPF Application

The application of SPF consisted of SPF kit assembly and the “insulating” of the mock walls for each survey conducted. The SPF kit was packaged in three separate boxes; one for the ISO (A) Cylinder, one for the Polyol (B) Cylinder, and one containing the 15 ft gun hose assembly, spray nozzles (4 fan nozzles; 8 cone nozles), operating instructions, a petroleum jelly packet, and a wrench (see Figure 10). The kit was assembled and used using the operating instructions with the Dow instructional videos offering additional detailed guidance (Dow, n.d.-b). Once assembled, the SPF Kit was placed within the enclosure in a location that would not interfere with the cart or require movement of the cylinders during the surveys (see Figure 11).

Figure 11. Dow Froth-Pak 620 Kit. Image obtained from Best Materials website (http://www.bestmaterials.com/detail.aspx?ID=16367).



a.) SPF Kit - View 1

a.) SPF Kit - View 2

Figure 12. Assembled SPF kit staged for application. a.) Photograph shows gun cleaner and extra nozzles by the cylinders. The gun hose assembly is shown in front of the cylinders. b.) The green ISO (A) Cylinder and the beige Polyol (B) cylinder are shown beside one another

Prior to beginning SPF application, the gun components were cleaned and prepped to ensure proper operation during each survey. A gun cleaning product was first used to clean the surface where the nozzles attached to the gun hose assembly. The cleaner removed any SPF/chemical components remaining from prior surveys and allowed for a clean surface for the application of petroleum jelly included in the kit. The jelly, which was applied liberally to the mating surface of the gun, functioned to prevent any leaking SPF chemicals from sticking to the surface of the gun during operation. Following gun prep, two low pressure fan tips were placed beside the SPF cylinders (see Figure 11); one for installation in the gun hose assembly for application and the other served as a back-up if during the survey the nozzle became plugged. The low pressure fan tip nozzles were selected for use with the study due to their immediate availability in the kit and their designed use for coating large surfaces such as wall cavities. The gun cleaner was also placed nearby the cylinders in the event there was an issue with the gun and SPF needed to be quickly cleared/cleaned. Additionally, the components of the SPF kit were also physically inspected to ensure the integrity of the system prior to operation.

To begin use, the valves of the ISO (A) Cylinder and Polyol (B) Cylinder were fully opened allowing each chemical component to flow to the spray gun. Flow was observable through the clear flexible lines of the gun hose assembly. With no nozzle installed, the gun hose assembly was purged into a waste receptacle by actuating the trigger of the gun. The purging process allowed for verification of component flow from each tank, the expelling of any air trapped in the lines, and the introduction of fresh product into the flexible lines. When purging was complete (and all deficiencies corrected), the gun was cleaned (if needed) and additional petroleum jelly was applied to the inside face of the gun (gun-nozzle mating surface). A nozzle was then installed in the spray gun and system was ready for application. Personal protective equipment was inspected and donned prior to the discharge of any SPF.

Application began in the left most cavity of the mock wall and proceeded to the right with each cavity being insulated fully prior to moving to the next cavity in the sequence. Once at the end of the mock wall (far right) the wall cavities were filled in the reverse order and the process repeated until the survey was complete. The spray gun was held approximately the same distance (≈1 ft) from the wall for each survey and the same application technique was used for all surveys with the exception of the pilot survey. During the pilot survey foam was applied to each survey until there was a full coating of insulation in the cavity. Application was only paused to move to the next cavity and reposition the sampling cart. Based on the pilot survey, the application technique was adapted to optimize sampling time, survey count, and SPF product utilization.

The adapted technique for Surveys 1, 2, and 3 was used to control the amount of surface to be insulted per application period as well as the time between application periods. During each application period, one half of each cavity was coated with SPF. The time between applications was then maintained at 15 seconds. Once the time between applications had passed, the other half of the cavity was filled and the cart was repositioned in front of the next cavity to be filled during the next 15 second period. A clock display was used to facilitate time tracking between applications (see Figure 12). The sequence in which the cavities were filled was the same for all surveys. For each survey, the SPF kit was operated as soon as possible after turning on the sampling pumps and the application of SPF stopped just prior to shutting down the sampling pumps. The thickness of the applied SPF ranged from approximately 0.5” to 4” (see Figure 13) and the SPF was completely removed from the mock walls between applications. The SPF was cleared from the walls through the removal and replacement of SPF coated hardboard/painters tape and the cleaning of the wall frames. Razor scrapers were used to clean the wall frames to reduce the introduction of particulates into the environment.

b.) SPF Coated Wall Cavity

a.) SPF Coated Mock Wall

c.) Clock Display

d.) Hardboard with SPF – Mock Wall Rebuild

Figure 13. SPF application. a.) Mock wall sections insulated w/SPF. b.) Close-up of SPF filled cavity. c.) Time display used for surveys. d. SPF adhered to hardboard during mock wall rebuild.

Sampling

Total Dust – Ambient

Sampling for total dust was performed in the enclosure prior to beginning the application of SPF but after all dust mitigation measures were completed. These ambient samples would serve to quantify any airborne particulates not related to the application of SPF and would be used to correct the mass collected on the filters/substrates during surveys. The duration of the ambient sampling events were approximately 15 min (see Appendix C) for each survey and two personal sampling trains were operated. The sampling trains were calibrated before and after each sampling event.

Total Dust

Once the ambient sampling and set-up of the SPF Kit were complete, the two personal sampling pumps for the total dust sampling trains were simultaneously powered on via the user interfaces on the pumps. Immediately following activation of the sampling trains, a stopwatch nearby the pumps was turned on keep time for the sampling event. The SPF application process then commenced and the two sampling trains traveled on the cart from cavity to cavity as each was coated with SPF. When the sampling time neared 15 minutes (Survey 3 sampling time was approx. 24 minutes to run out the SPF cylinders) the application of SPF was stopped and the two personal sampling pumps powered down completing the sampling event. The times of the sampling event were recorded and post sampling calibration was completed outside of the enclosure. Following post sampling calibration the samplers were disconnected from the sampling trains, plugged, and stored for shipment back to the laboratory for gravimetric analysis.

Size Selective Sampling

The size selective sampling for the each survey began and ended at approximately the same time as the total dust sampling. To activate the size selective sampling trains, the pumps were powered on remotely via a switch on a power strip placed within the enclosure. A stopwatch placed nearby the switch was used to track time for the sampling event. Like the total dust samplers (37 mm filter cassettes), the Andersen Cascade Impactors traveled on the cart as it was positioned in front of each cavity during SPF application. Unlike the total dust sampling trains, the high volume pumps remained fixed outside the enclosure during the surveys. Caution was taken when moving the cart so as to not disturb the integrity of the impactors or flexible tubing connections. At approximately 15 minutes (Survey 3 sampling time was approx. 24 minutes to run out the SPF cylinders) from the start of the sampling event, the pumps were powered down and the stopwatch stopped. Like stated above, the post calibration of the size-selective sampling trains was performed outside of the enclosure. Following post calibration the impactors were disconnected from the sampling trains and carefully moved to a desk were they would be disassembled. As each stage was disassembled the substrate was removed from the stainless steel plate and stored in its respective Petri dish. Once all substrates were stored in Petri dishes they were carefully packed for transport back the laboratory for gravimetric analysis.

Sampling Summary

The sampling information for each survey can be found in Appendix C. Each sampling event was videotaped to aid in quality control review. The positioning of the total dust samplers (37 mm filter cassettes) and size-selective samplers (Andersen Cascade Impactors) were maintained over the course of the surveys through the use of the reference tape and laser alignment device. The consistent cart positioning over the course of the each survey would help to ensure consistent results across surveys as would the methodical application of SPF. Care was taken during each survey not to disturb the integrity of the size selective samplers as the instruments are delicate and abrupt movements could have an impact on the placement of the plates/substrates within and affect measurements. The samplers (37 mm filter cassettes and Andersen Cascade Impactors) remained for the most part clean (e.g., very few visible specks on exterior of surfaces) throughout the surveys and although particulates could be seen in the air, visibility was always maintained. It should be noted however, that there was an odor in the vicinity hours after application and re-entry into the enclosure was never conducted unprotected until the day after once naturally ventilated.

Results

The following tables and figures summarize the results for Surveys 1, 2, and 3. The supporting data for the tables/figures can be found in Appendices E, F, and G. These appendices and the results below are grouped by process to aid in review and ease comparison across the surveys. Since the Pilot Survey was used primarily to refine methods and materials, it was not included in the following results summary. The results of the Pilot Survey as well as the supporting data/information are captured entirely in Appendix H.

Total Dust Sampling

The results of the total dust samplings for Surveys 1, 2, and 3, are summarized in Table 5 below. Ambient - Total Dust sampling results and Total Dust sampling results are grouped by survey and by sampling train. Ambient – Total Dust sampling results are identified in the table as “Ambient” and sampling trains are identified as “1” or “2”. Total dust samplings are identified as “Total Dust” and the sampling trains are identified in the same manner as the Ambient- Total Dust. As shown in the table, there were no blank/controls taken in Survey 1 but there were blanks/controls taken in Surveys 2 and 3. The formulae used for blank corrections are shown in the notes section of the table as are all the other formulas used for the calculation of the concentrations presented.

Table 5. Total Dust (Particulates Not Otherwise Specified) Sampling Summary

Survey	Sample Description	Filter Mass, Pre-Sample (mg)	Filter Mass, Post Sample (mg)	Mass Collected (mg)	Average Blank Mass (mg)	Mass Collected, Blank Corrected (mg)	Sample Flow Rate (L/min)	Sample Duration (min)	Sample Volume (m^3)	[3]Concentration (mg/m^3)
[1]**Survey 1**	Ambient 1	15.175	15.190	0.015	–	–	1.964	15.05	0.03	0.51
	Ambient 2	15.770	15.790	0.020	–	–	1.989	15.05	0.03	0.67
	Total Dust 1	15.005	15.390	0.385	–	–	2.004	16.10	0.03	11.35
	Total Dust 2	14.840	15.230	0.390	–	–	2.024	16.10	0.03	11.38
[2]**Survey 2**	Ambient 1	13.355	13.360	0.005	0.010	-0.005	1.951	15.03	0.03	ND
	Total Dust 1	12.750	13.020	0.270	0.010	0.260	1.963	15.17	0.03	8.74
	Total Dust 2	13.025	13.230	0.205	0.010	0.195	1.973	15.17	0.03	6.52
Survey 3	Ambient 1	14.060	14.070	0.010	-0.005	0.015	1.965	15.07	0.03	0.51
	Ambient 2	13.095	13.100	0.005	-0.005	0.010	1.989	15.07	0.03	0.33
	Total Dust 1	14.590	15.180	0.590	-0.005	0.595	1.985	24.40	0.05	11.86
	Total Dust 2	13.015	13.640	0.625	-0.005	0.630	1.994	24.40	0.05	12.53

Formulas:

Mass Collected (mg) = [Filter Mass, Post Sample (mg)] - [Filter Mass, Pre-Sample (mg)]

Mass Collected - Blank Corrected (mg) = [Mass Collected (mg)] - [Average Blank Mass (mg)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration - Ambient (mg/m^3) = [Mass Collected-Blank Corrected (mg)] / [Sample Volume (m^3)]

Concentration - Total Dust (mg/m^3) = ([Mass Collected-Blank Corrected (mg)] / [Sample Volume (m^3)]) - [Average Concentration-Ambient (mg/m^3)]

Sample Flow Rate = ([Pre Cal Flow Rate (L/min)] + [Post Cal Flow Rate (L/min)]) / 2

Notes:

[1] No controls/blanks taken for Test 2

[2] Ambient 2 filter was contaminated during post weighing; sample excluded from summary.

[3] Concentrations ≤ 0 were considered Non-Detect (ND)

Size Selective Sampling

Particle Size Distribution

The results of the size-selective sampling for Surveys 1, 2, and 3 are summarized in the Tables 6, 7, and 8 below. The stages of the Andersen Cascade Impactor and the associated particle size ranges are shown to the left in each table and are arranged from smallest particle size range to largest. The results for each size-selective sampling train (i.e., SSS1, SSS2) are shown side by side for each survey and the formulae used for calculation of the results are shown below each table. The basic procedures described by Hinds (1999, pp. 95-97) and Ramachandran (2005, pp. 113-127) were used to guide the development of the tables as well as graphs depicting the particle size distribution data.

Figures 14-18 present the size-selective sampling results in various graphical formats to allow for visualization and comparison of the results. Figure 14 shows the cumulative particle size distributions for each survey plotted on a logarithmic scale to allow for comparison between size-selective sampling trains (i.e., SSS1 and SSS2) as well as visualization of the particle size distribution shape and size over the course of the study. In Figures 15 and 16, the cumulative particle size data for Surveys 1, 2, and 3 were averaged then plotted for each sampling train. The data range for each mean calculation are represented by the max and min bars shown for each plot. Figures 17 and 18 show the mean mass percent for each particle size interval in bar graph format. Like Figures 15 and 16, the mean calculations were grouped by size-selective sampling train the range of the data for each mean calculation are represented by max/min bars. The tables containing the data presented in Figures 15-18 can be found in Appendix G (Tables 19A-22A).

Table 6. Cumulative Particle Size Distributions - Survey 1

Survey	**Stage**	**Particle Size Range (µm)**	**Size Selective Sampling Train 1**				**Size Selective Sampling Train 2**			
			Mass Collected (g)	*Mass Percent (%)*	*Cumulative Mass (g)*	*Cumulative Mass Percent (%)*	*Mass Collected (g)*	*Mass Percent (%)*	*Cumulative Mass (g)*	*Cumulative Mass Percent (%)*
Survey 1	Filter	0 - 0.4	0.00007	1.07	0.00007	1.07	0.00001	0.29	0.00001	0.29
	7	0.4 - 0.7	0.00009	1.30	0.00016	2.38	0.00008	1.43	0.00009	1.72
	6	0.7 - 1.1	0.00028	4.37	0.00044	6.75	0.00037	6.98	0.00046	8.70
	5	1.1 - 2.1	0.00073	11.13	0.00117	17.88	0.00081	15.58	0.00127	24.28
	4	2.1 - 3.3	0.00094	14.50	0.00211	32.39	0.00079	15.11	0.00206	39.39
	3	3.3 - 4.7	0.00105	16.12	0.00316	48.50	0.00100	19.02	0.00306	58.41
	2	4.7 - 5.8	0.00062	9.59	0.00378	58.10	0.00064	12.14	0.00369	70.55
	1	5.8-9.0	0.00131	20.03	0.00509	78.13	0.00097	18.45	0.00466	89.01
	0	> 9.0	0.00142	21.87	0.00651	100.00	0.00058	10.99	0.00523	100.00
	Total		**0.00651**				**0.00523**			

Formulas:

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cumulative Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cumulative Mass Percent (%) = ([Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]) / [Total Mass Collected (g)] *100

Notes:

Pre-separator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

Table 7. Cumulative Particle Size Distributions - Survey 2

Survey	**Stage**	**Particle Size Range (µm)**	**Size Selective Sampling Train 1**				**Size Selective Sampling Train 2**			
			Mass Collected (g)	*Mass Percent (%)*	*Cumulative Mass (g)*	*Cumulative Mass Percent (%)*	*Mass Collected (g)*	*Mass Percent (%)*	*Cumulative Mass (g)*	*Cumulative Mass Percent (%)*
Survey 2	Filter	0 - 0.4	0.00005	1.32	0.00005	1.32	0.00006	1.86	0.00006	1.86
	7	0.4 - 0.7	0.00014	3.70	0.00019	5.02	0.00018	5.75	0.00024	7.61
	6	0.7 - 1.1	0.00025	6.61	0.00044	11.62	0.00024	7.45	0.00049	15.06
	5	1.1 - 2.1	0.00046	12.29	0.00091	23.91	0.00052	16.15	0.00100	31.21
	4	2.1 - 3.3	0.00051	13.47	0.00142	37.38	0.00050	15.37	0.00150	46.58
	3	3.3 - 4.7	0.00063	16.64	0.00205	54.03	0.00055	17.24	0.00205	63.82
	2	4.7 - 5.8	0.00032	8.32	0.00236	62.35	0.00041	12.58	0.00246	76.40
	1	5.8-9.0	0.00070	18.36	0.00306	80.71	0.00045	14.13	0.00292	90.53
	0	> 9.0	0.00073	19.29	0.00379	100.00	0.00031	9.47	0.00322	100.00
	Total		**0.00379**				**0.00322**			

Formulas:

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cumulative Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cumulative Mass Percent (%) = ([Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]) / [Total Mass Collected (g)] *100

Notes:

Pre-separator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

Table 8. Cumulative Particle Size Distributions - Survey 3

Survey	**Stage**	**Particle Size Range (µm)**	**Size Selective Sampling Train 1**				**Size Selective Sampling Train 2**			
			Mass Collected (g)	*Mass Percent (%)*	*Cumulative Mass (g)*	*Cumulative Mass Percent (%)*	*Mass Collected (g)*	*Mass Percent (%)*	*Cumulative Mass (g)*	*Cumulative Mass Percent (%)*
Survey 3	Filter	0 - 0.4	0.00001	0.16	0.00001	0.16	0.00004	0.50	0.00004	0.50
	7	0.4 - 0.7	0.00009	1.01	0.00011	1.17	0.00014	1.69	0.00018	2.19
	6	0.7 - 1.1	0.00032	3.34	0.00042	4.50	0.00034	4.26	0.00052	6.45
	5	1.1 - 2.1	0.00095	10.02	0.00137	14.52	0.00108	13.60	0.00160	20.05
	4	2.1 - 3.3	0.00133	14.04	0.00270	28.56	0.00130	16.29	0.00290	36.34
	3	3.3 - 4.7	0.00172	18.18	0.00441	46.74	0.00157	19.67	0.00447	56.02
	2	4.7 - 5.8	0.00091	9.70	0.00533	56.44	0.00125	15.60	0.00571	71.62
	1	5.8-9.0	0.00201	21.30	0.00734	77.74	0.00153	19.24	0.00725	90.85
	0	> 9.0	0.00210	22.26	0.00944	100.00	0.00073	9.15	0.00798	100.00
	Total		**0.00944**				**0.00798**			

Formulas:

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cumulative Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cumulative Mass Percent (%) = ([Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]) / [Total Mass Collected (g)] *100

Notes:

Pre-separator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

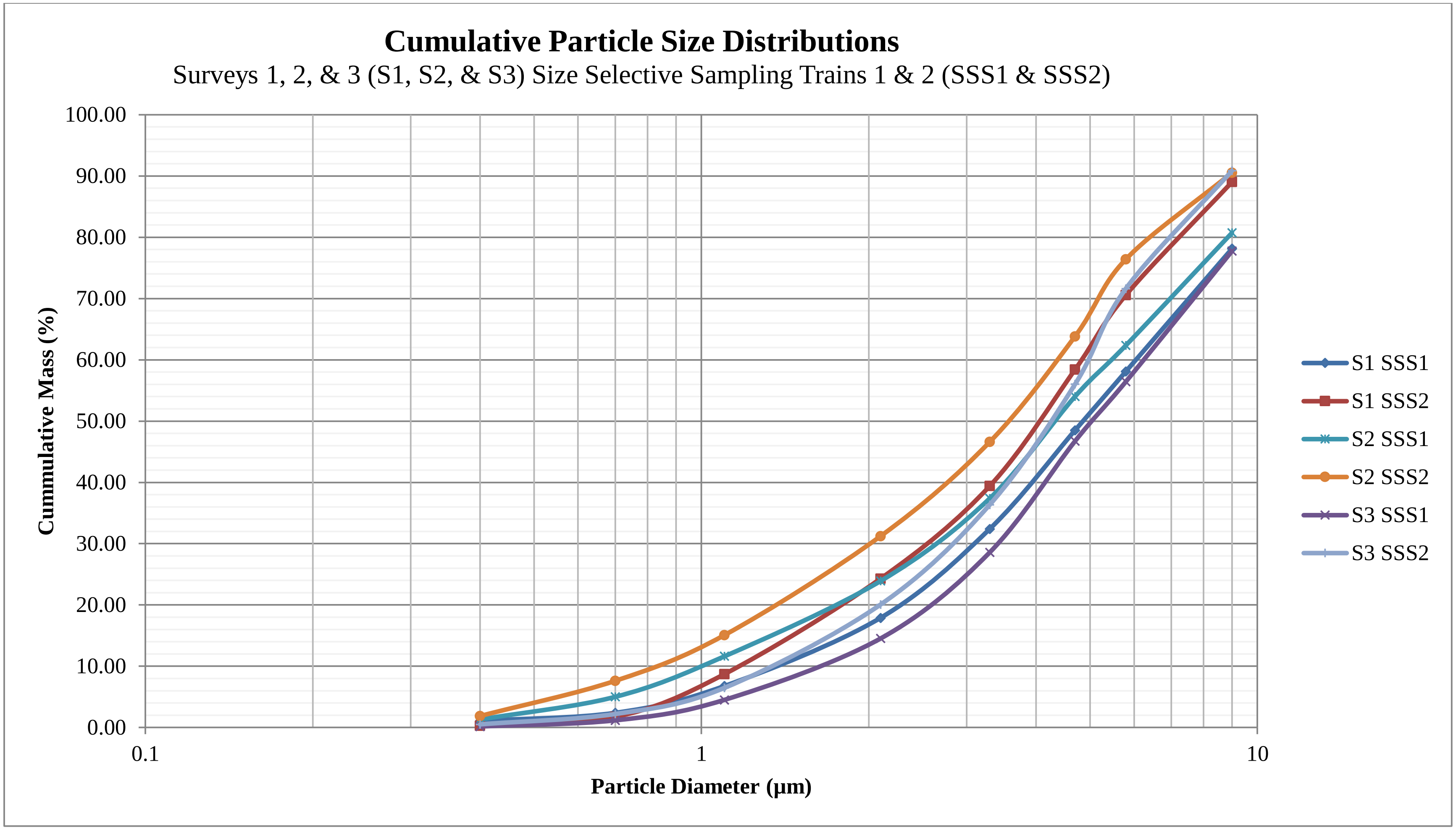


Figure 14. Surveys 1, 2, and 3 cumulative particle size distributions. The legend identifies each distribution by survey number (e.g., S1) and sampling train (e.g., SSS1).

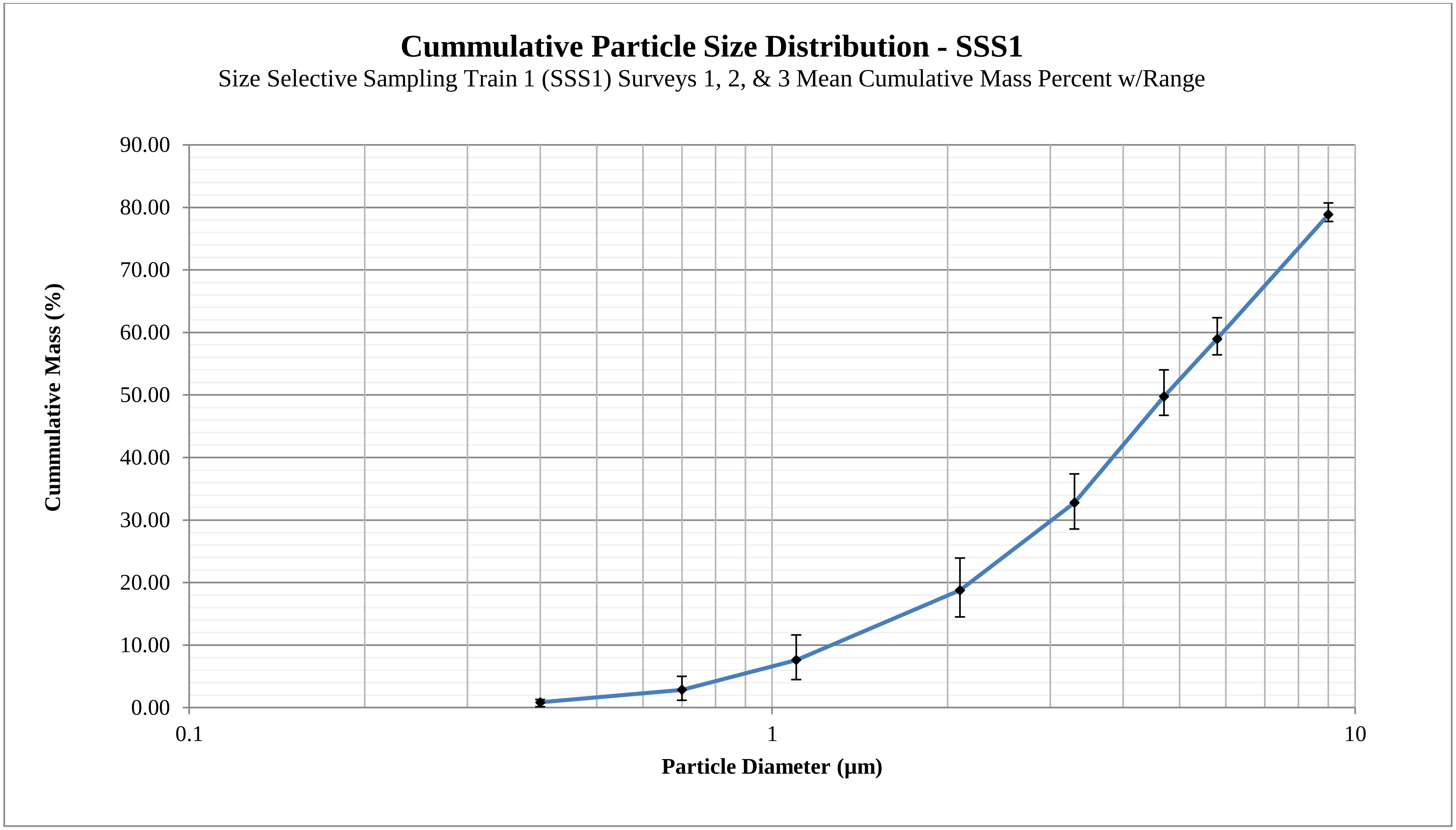


Figure 15. Mean cumulative particle size distribution – SSS1. The average particle size distribution of Surveys 1, 2, and 3 for size selective sampling train 1 is shown with max/min bars.

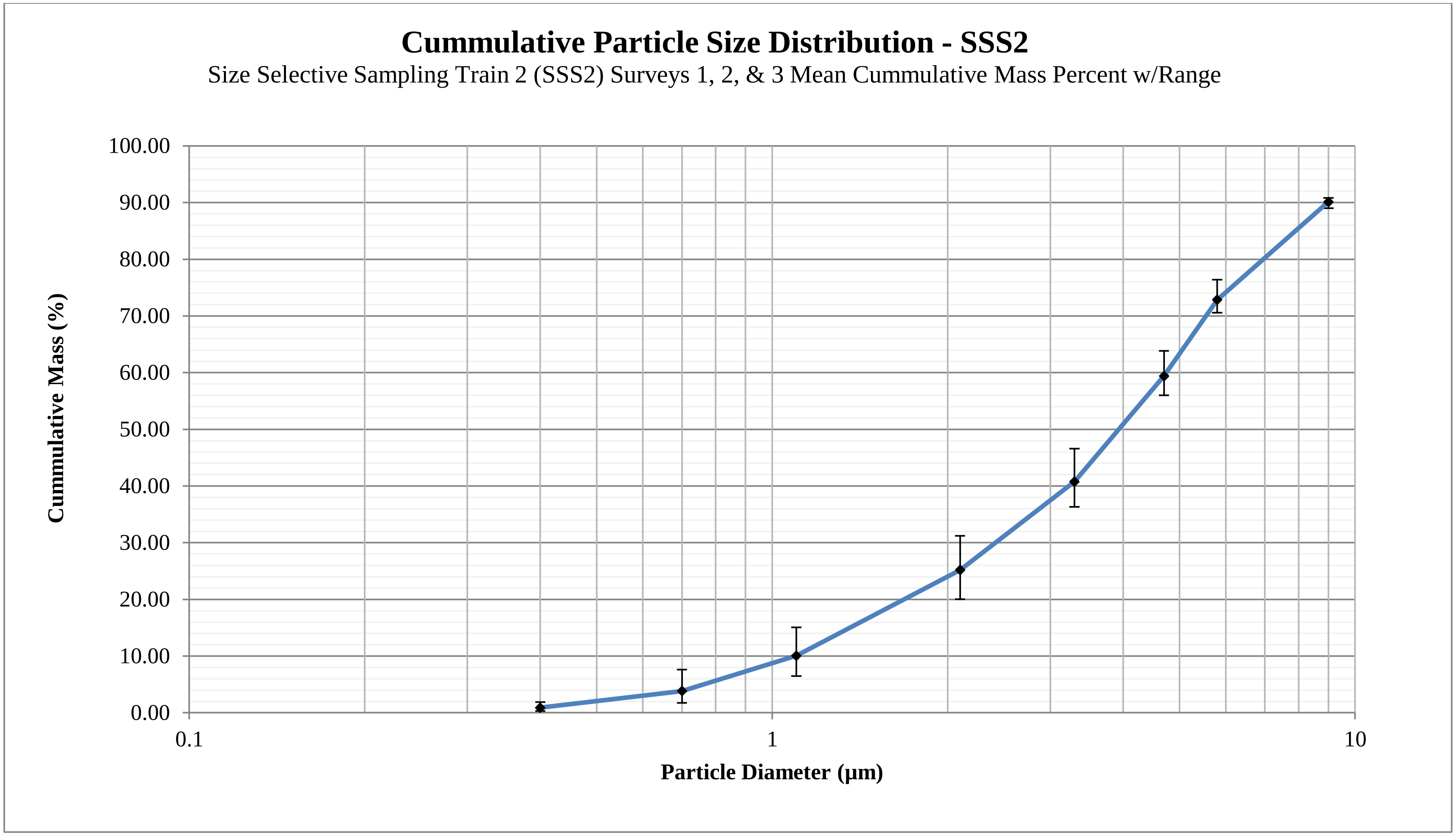


Figure 16. Mean cumulative particle size distribution – SSS2. The average particle size distribution of Surveys 1, 2, and 3 for size selective sampling train 2 is shown with max/min bars.

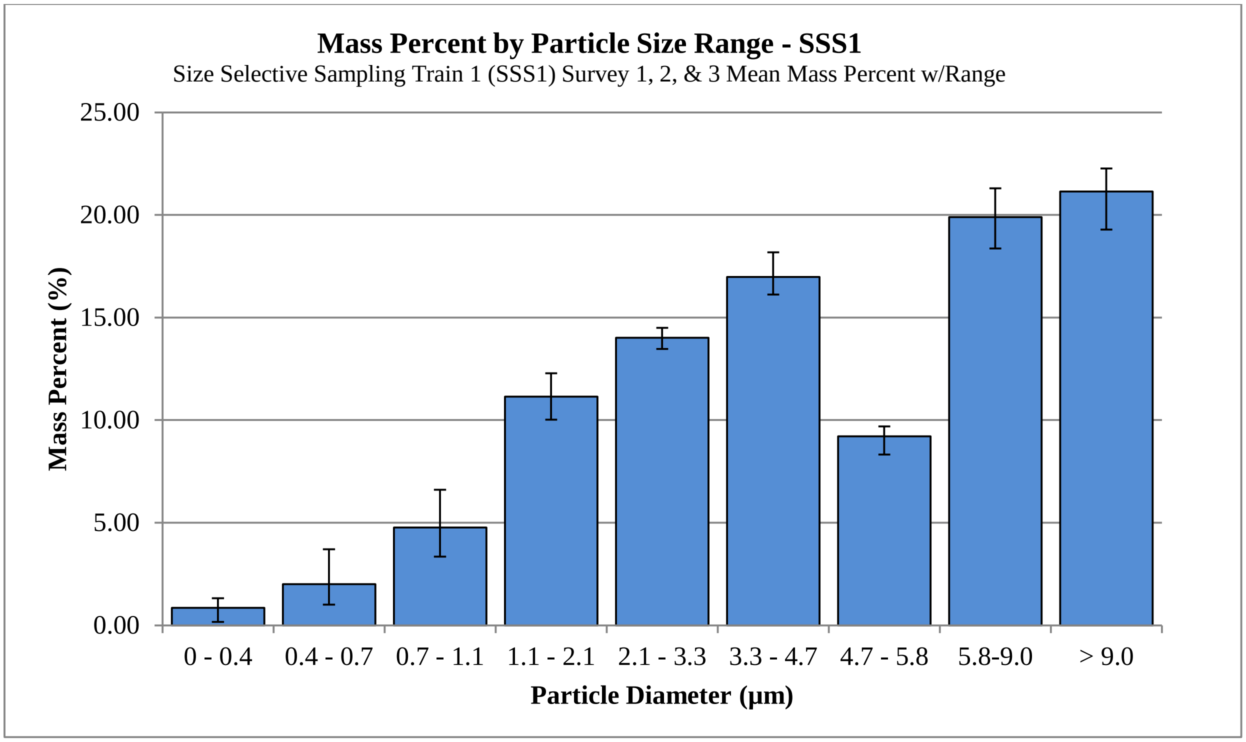


Figure 17. Mean mass percent by particle size range – SSS1. The average mass percent (Surveys 1, 2 and 3) for each size range collected by size selective sampling train 2 is shown with max/min bars.

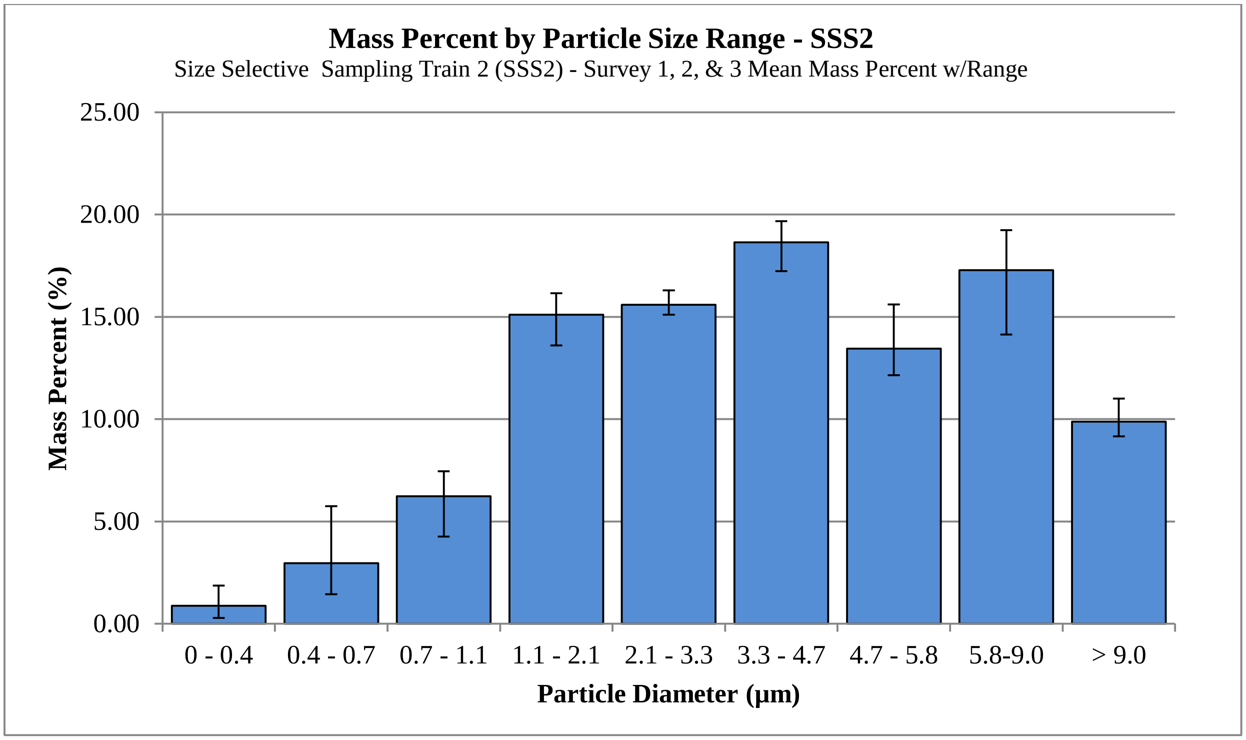


Figure 18. Mean mass percent by particle size range – SSS2. The average mass percent (Surveys 1, 2 and 3) for each size range collected by size selective sampling train 2 is shown with max/min bars.

The mean cumulative particle size distribution data shown above (i.e., Figures 15 and 16) are presented in log-probability plot format below in Figures 19 and 20. The basic procedures described by Hinds (1999, pp. 94-97) were used to guide development of the log-probability plots and the software program DPlot was used for construction and presentation (Hydesoft Computing, 2014). Figure 19 shows mean cumulative particle size distributions for both size-selective sampling trains and Figure 20 shows the SSS1 plot with a line of best fit. Using the Figure 20 plot, a graphical analysis was performed to characterize the mean particle size distribution using the method described by Hinds (1999); Table 9 presents these results.

Graphical analysis of the log-probability plot (i.e., Figure 20) was limited to SSS1 due to the differences in cascade impactor configurations during the study. That is, the SSS1 cascade impactor was operated with a standard inlet cone and the SSS2 cascade impactor was operated with a pre-separator installed. This difference in configuration, although useful for understanding the distribution of particles greater than 9 µm, resulted in difference in the mass collected by the following stage for each size selective sampling train. Consequently, this resulted in a difference in mass percent distribution between the trains and prevented the inclusion of all particle size data for mean calculations. Additionally, the use of the pre-separator also resulted in the collection of mass in the pre-separator itself which was not recoverable/measureable. For this reason, the log-probability graphical analysis was only performed on SSS1 results.

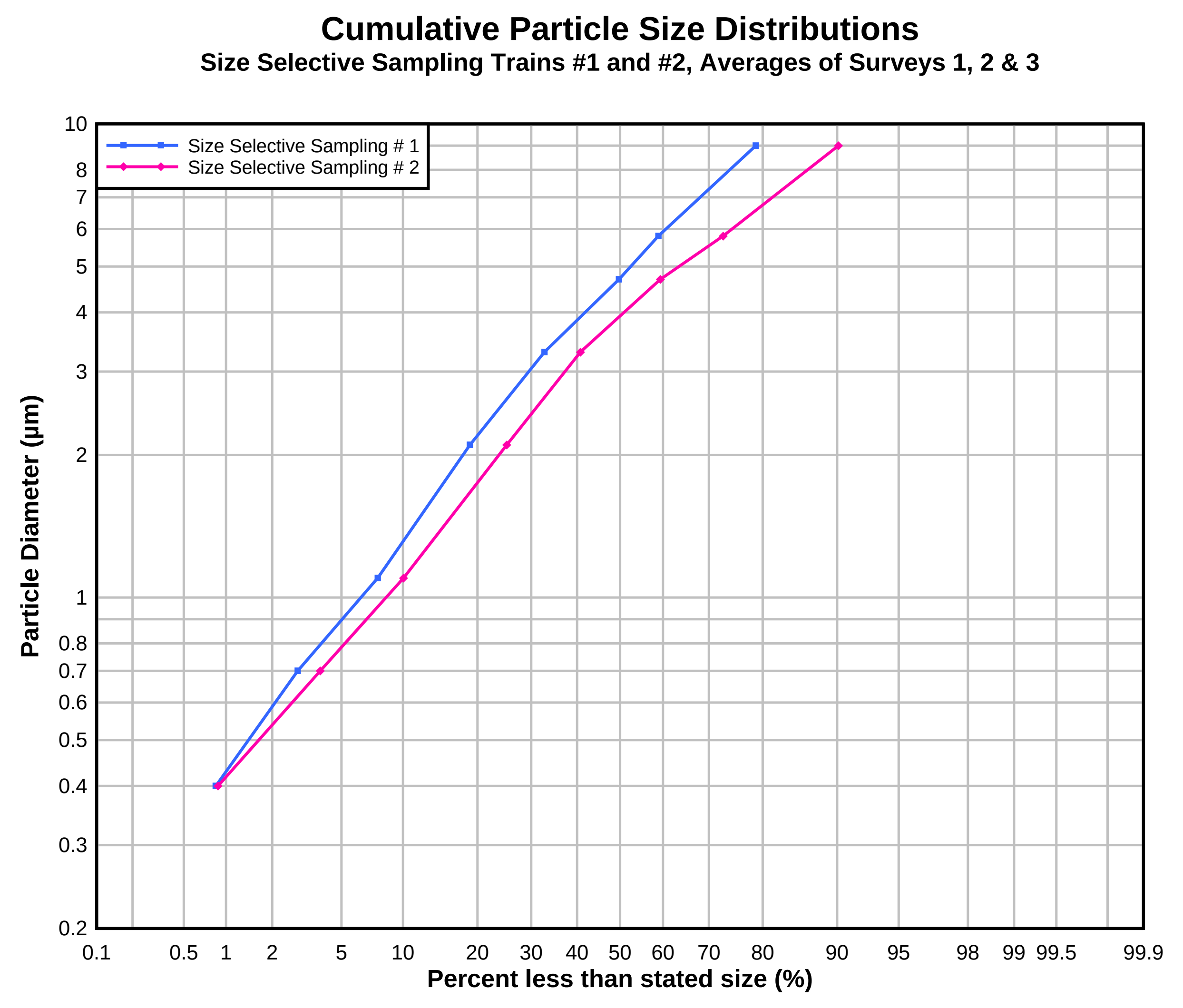


Figure 19. Cumulative particle size distributions – SSS1 & SSS2. The mean of the particle size distributions collected by size selective sampling trains 1 and 2 are shown plotted on a log-probability graph.

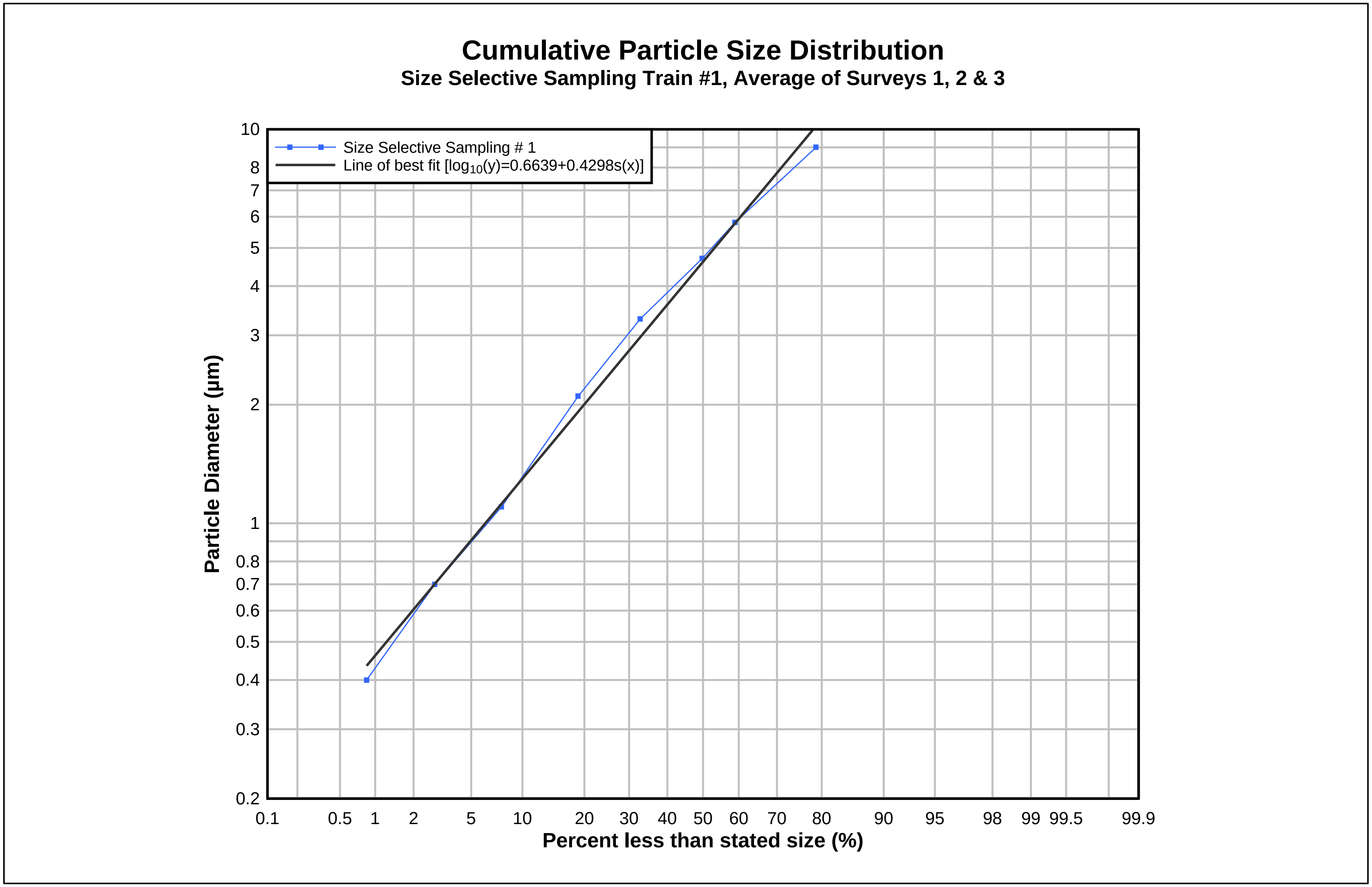


Figure 20. Cumulative particle size distribution – SSS1. The mean of the particle size distribution collected by size-selective sampling train 1 is shown with a line of best fit.

Table 9. Particle Size Distribution Analysis, Log-Probability Plot

Statistic	Unit	Value
16th percentile particle size ($d_{16\%}$)	µm	1.7
50th percentile particle size ($d_{50\%}$)	µm	4.6
Mass Median Diameter (MMD)	µm	4.6
[1]Geometric Standard Deviation (GSD)	–	2.7

Formulas:

$MMD = d_{50\%}$

$GSD = d_{50\%} / d_{16\%}$

Notes:

[1] GSD has no units

Mass Concentration by Particle Size Range

Tables 10-15 show the size-selective sampling results for the study by sampling train/survey with corresponding sampling information (i.e., flow rate, duration, volume). Using the sampling data and the mass collected per stage the cumulative mass concentration and mass concentration by particle size range were calculated. These concentrations are presented in the last two columns of Tables 10-15 and the formulae used for their calculation are in the shown below each table. The mean cumulative concentrations and concentrations by particle size range for each sampling train are shown in Figures 21 and 22. These 4 axis figures present the cut-points for the Andersen Cascade impactor, the particle size ranges for each stage, the cumulative concentration, and the concentrations per particle size range.

Table 10. Concentration by Particle Size Range & Cumulative Concentration – Survey 1, SSS1

Survey	Stage	Particle Size Range (µm)	Mass Collected (g)	Average Blank Mass (g)	Mass Collected, Blank Corrected (g)	Cumulative Mass (g)	Sample Flow Rate (L/min)	Sample Duration (min)	Sample Volume (m^3)	Concentration (mg/m^3)	Cumulative Concentration (mg/m^3)
Survey 1	Filter	0 - 0.4	0.00007	–	–	0.00007	28.324	15.75	0.45	0.16	0.16
	7	0.4 - 0.7	0.00009	–	–	0.00016	28.324	15.75	0.45	0.19	0.35
	6	0.7 - 1.1	0.00028	–	–	0.00044	28.324	15.75	0.45	0.64	0.99
	5	1.1 - 2.1	0.00073	–	–	0.00117	28.324	15.75	0.45	1.63	2.61
	4	2.1 - 3.3	0.00094	–	–	0.00211	28.324	15.75	0.45	2.12	4.73
	3	3.3 - 4.7	0.00105	–	–	0.00316	28.324	15.75	0.45	2.35	7.08
	2	4.7 - 5.8	0.00062	–	–	0.00378	28.324	15.75	0.45	1.40	8.48
	1	5.8-9.0	0.00131	–	–	0.00509	28.324	15.75	0.45	2.93	11.41
	0	> 9.0	0.00142	–	–	0.00651	28.324	15.75	0.45	3.19	14.60
	Total		**0.00651**								

Formulas:

Mass Collected (g) = [Filter Mass, Post Sample (g)] – [Filter Mass, Pre-Sample (g)]

Cumulative Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected Particle Size Ranges < n (g)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration = [Mass Collected (mg)] / [Sample Volume (m^3)] × [1000 mg / 1 g]

Cumulative Concentration (mg/m^3) = [Cumulative Mass (g)] / [Sample Volume (m^3)]

Notes:

No controls/blanks taken for Survey 1

Table 11. Concentration by Particle Size Range & Cumulative Concentration – Survey 2, SSS1

Survey	Stage	Particle Size Range (µm)	Mass Collected (g)	Average Blank Mass (g)	Mass Collected, Blank Corrected (g)	Cumulative Mass (g)	Sample Flow Rate (L/min)	Sample Duration (min)	Sample Volume (m3)	Concentration (mg/m3)	Cumulative Concentration (mg/m3)
Survey 2	Filter	0 - 0.4	0.00005	0.000010	0.00004	0.00004	28.277	15.03	0.43	0.09	0.09
	7	0.4 - 0.7	0.00014	0.000014	0.00013	0.00017	28.277	15.03	0.43	0.30	0.39
	6	0.7 - 1.1	0.00025	0.000014	0.00024	0.00040	28.277	15.03	0.43	0.56	0.95
	5	1.1 - 2.1	0.00046	0.000014	0.00045	0.00085	28.277	15.03	0.43	1.06	2.01
	4	2.1 - 3.3	0.00051	0.000014	0.00050	0.00135	28.277	15.03	0.43	1.17	3.18
	3	3.3 - 4.7	0.00063	0.000014	0.00062	0.00197	28.277	15.03	0.43	1.45	4.63
	2	4.7 - 5.8	0.00032	0.000014	0.00030	0.00227	28.277	15.03	0.43	0.71	5.33
	1	5.8-9.0	0.00070	0.000014	0.00068	0.00295	28.277	15.03	0.43	1.60	6.94
	0	> 9.0	0.00073	0.000014	0.00072	0.00366	28.277	15.03	0.43	1.68	8.62
	Total		**0.00379**		**0.00366**						

Formulas:

Mass Collected (g) = [Filter Mass, Post Sample (g)] – [Filter Mass, Pre-Sample (g)]

Mass Collected, Blank Corrected (mg) = [Mass Collected (mg)] – [Average Blank Mass (mg)]

Cumulative Mass (g) = [Mass Collected, Blank Corrected Particle Size Range$_n$ (g)] + [Mass Collected, Blank Corrected Particle Size Ranges < n (g)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration (mg/m^3) = [Mass Collected, Blank Corrected (mg)] / [Sample Volume (m^3)] × [1000 mg / 1 g]

Cumulative Concentration (mg/m^3) = [Cumulative Mass (g)] / [Sample Volume (m^3)]

Table 12. Concentration by Particle Size Range & Cumulative Concentration – Survey 3, SSS1

Survey	**Stage**	**Particle Size Range (µm)**	**Mass Collected (g)**	**Average Blank Mass (g)**	**Mass Collected, Blank Corrected (g)**	**Cumulative Mass (g)**	**Sample Flow Rate (L/min)**	**Sample Duration (min)**	**Sample Volume (m^3)**	**Concentration (mg/m^3)**	**Cumulative Concentration (mg/m^3)**
Survey 3	Filter	0 - 0.4	0.00001	-0.000005	0.00002	0.00002	28.291	24.35	0.69	0.03	0.03
	7	0.4 - 0.7	0.00009	-0.000032	0.00013	0.00015	28.291	24.35	0.69	0.19	0.21
	6	0.7 - 1.1	0.00032	-0.000032	0.00035	0.00049	28.291	24.35	0.69	0.50	0.72
	5	1.1 - 2.1	0.00095	-0.000032	0.00098	0.00147	28.291	24.35	0.69	1.42	2.14
	4	2.1 - 3.3	0.00133	-0.000032	0.00136	0.00283	28.291	24.35	0.69	1.97	4.11
	3	3.3 - 4.7	0.00172	-0.000032	0.00175	0.00458	28.291	24.35	0.69	2.54	6.64
	2	4.7 - 5.8	0.00091	-0.000032	0.00095	0.00553	28.291	24.35	0.69	1.38	8.02
	1	5.8-9.0	0.00201	-0.000032	0.00204	0.00757	28.291	24.35	0.69	2.96	10.99
	0	> 9.0	0.00210	-0.000032	0.00213	0.00970	28.291	24.35	0.69	3.10	14.08
	Total		**0.00944**		**0.00970**						

Formulas:

Mass Collected (g) = [Filter Mass, Post Sample (g)] – [Filter Mass, Pre-Sample (g)]

Mass Collected, Blank Corrected (mg) = [Mass Collected (mg)] – [Average Blank Mass (mg)]

Cumulative Mass (g) = [Mass Collected, Blank Corrected Particle Size Range$_n$ (g)] + [Mass Collected, Blank Corrected Particle Size Ranges < n (g)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration (mg/m^3) = [Mass Collected, Blank Corrected (mg)] / [Sample Volume (m^3)] × [1000 mg / 1 g]

Cumulative Concentration (mg/m^3) = [Cumulative Mass (g)] / [Sample Volume (m^3)]

Table 13. Concentration by Particle Size Range & Cumulative Concentration – Survey 1, SSS2

Survey	Stage	Particle Size Range (µm)	Mass Collected (g)	Average Blank Mass (g)	Mass Collected, Blank Corrected (g)	Cumulative Mass (g)	Sample Flow Rate (L/min)	Sample Duration (min)	Sample Volume (m^3)	Concentration (mg/m^3)	Cumulative Concentration (mg/m^3)
Survey 1	Filter	0 - 0.4	0.00001	–	–	0.00001	28.365	15.75	0.45	0.03	0.03
	7	0.4 - 0.7	0.00008	–	–	0.00009	28.365	15.75	0.45	0.17	0.20
	6	0.7 - 1.1	0.00037	–	–	0.00046	28.365	15.75	0.45	0.82	1.02
	5	1.1 - 2.1	0.00081	–	–	0.00127	28.365	15.75	0.45	1.82	2.84
	4	2.1 - 3.3	0.00079	–	–	0.00206	28.365	15.75	0.45	1.77	4.61
	3	3.3 - 4.7	0.00100	–	–	0.00306	28.365	15.75	0.45	2.23	6.84
	2	4.7 - 5.8	0.00064	–	–	0.00369	28.365	15.75	0.45	1.42	8.26
	1	5.8-9.0	0.00097	–	–	0.00466	28.365	15.75	0.45	2.16	10.42
	0	> 9.0	0.00058	–	–	0.00523	28.365	15.75	0.45	1.29	11.71
	Total		**0.00523**								

Formulas:

Mass Collected (g) = [Filter Mass, Post Sample (g)] – [Filter Mass, Pre-Sample (g)]

Cumulative Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected Particle Size Ranges < n (g)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration = [Mass Collected (mg)] / [Sample Volume (m^3)] × [1000 mg / 1 g]

Cumulative Concentration (mg/m^3) = [Cumulative Mass (g)] / [Sample Volume (m^3)]

Notes:

No controls/blanks taken for Survey 1

Table 14. Concentration by Particle Size Range & Cumulative Concentration – Survey 2, SSS2

Survey	Stage	Particle Size Range (µm)	Mass Collected (g)	Average Blank Mass (g)	Mass Collected, Blank Corrected (g)	Cumulative Mass (g)	Sample Flow Rate (L/min)	Sample Duration (min)	Sample Volume (m^3)	Concentration (mg/m^3)	Cumulative Concentration (mg/m^3)
Survey 2	Filter	0 - 0.4	0.00006	0.000010	0.00005	0.00005	28.218	15.03	0.42	0.12	0.12
	7	0.4 - 0.7	0.00018	0.000014	0.00017	0.00022	28.218	15.03	0.42	0.40	0.52
	6	0.7 - 1.1	0.00024	0.000014	0.00023	0.00045	28.218	15.03	0.42	0.53	1.05
	5	1.1 - 2.1	0.00052	0.000014	0.00051	0.00095	28.218	15.03	0.42	1.19	2.25
	4	2.1 - 3.3	0.00050	0.000014	0.00048	0.00143	28.218	15.03	0.42	1.13	3.38
	3	3.3 - 4.7	0.00055	0.000014	0.00054	0.00198	28.218	15.03	0.42	1.28	4.66
	2	4.7 - 5.8	0.00041	0.000014	0.00039	0.00237	28.218	15.03	0.42	0.92	5.58
	1	5.8-9.0	0.00045	0.000014	0.00044	0.00281	28.218	15.03	0.42	1.04	6.62
	0	> 9.0	0.00031	0.000014	0.00029	0.00310	28.218	15.03	0.42	0.69	7.31
	Total		**0.00322**		**0.00310**						

Formulas:

Mass Collected (g) = [Filter Mass, Post Sample (g)] – [Filter Mass, Pre-Sample (g)]

Mass Collected, Blank Corrected (mg) = [Mass Collected (mg)] – [Average Blank Mass (mg)]

Cumulative Mass (g) = [Mass Collected, Blank Corrected Particle Size Range$_n$ (g)] + [Mass Collected, Blank Corrected Particle Size Ranges < n (g)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration (mg/m^3) = [Mass Collected, Blank Corrected (mg)] / [Sample Volume (m^3)] × [1000 mg / 1 g]

Cumulative Concentration (mg/m^3) = [Cumulative Mass (g)] / [Sample Volume (m^3)]

Table 15. Concentration by Particle Size Range & Cumulative Concentration – Survey 3, SSS2

Survey	Stage	Particle Size Range (µm)	Mass Collected (g)	Average Blank Mass (g)	Mass Collected, Blank Corrected (g)	Cumulative Mass (g)	Sample Flow Rate (L/min)	Sample Duration (min)	Sample Volume (m^3)	Concentration (mg/m^3)	Cumulative Concentration (mg/m^3)
Survey 3	Filter	0 - 0.4	0.00004	-0.000005	0.00004	0.00004	28.780	24.35	0.70	0.06	0.06
	7	0.4 - 0.7	0.00014	-0.000032	0.00017	0.00021	28.780	24.35	0.70	0.24	0.30
	6	0.7 - 1.1	0.00034	-0.000032	0.00037	0.00058	28.780	24.35	0.70	0.53	0.83
	5	1.1 - 2.1	0.00108	-0.000032	0.00112	0.00170	28.780	24.35	0.70	1.59	2.43
	4	2.1 - 3.3	0.00130	-0.000032	0.00133	0.00303	28.780	24.35	0.70	1.90	4.33
	3	3.3 - 4.7	0.00157	-0.000032	0.00160	0.00464	28.780	24.35	0.70	2.29	6.62
	2	4.7 - 5.8	0.00125	-0.000032	0.00128	0.00591	28.780	24.35	0.70	1.82	8.44
	1	5.8-9.0	0.00153	-0.000032	0.00157	0.00748	28.780	24.35	0.70	2.24	10.68
	0	> 9.0	0.00073	-0.000032	0.00076	0.00824	28.780	24.35	0.70	1.09	11.77
	Total		**0.00798**		**0.00824**						

Formulas:

Mass Collected (g) = [Filter Mass, Post Sample (g)] – [Filter Mass, Pre-Sample (g)]

Mass Collected, Blank Corrected (mg) = [Mass Collected (mg)] – [Average Blank Mass (mg)]

Cumulative Mass (g) = [Mass Collected, Blank Corrected Particle Size Range$_n$ (g)] + [Mass Collected, Blank Corrected Particle Size Ranges < n (g)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration (mg/m^3) = [Mass Collected, Blank Corrected (mg)] / [Sample Volume (m^3)] × [1000 mg / 1 g]

Cumulative Concentration (mg/m^3) = [Cumulative Mass (g)] / [Sample Volume (m^3)]

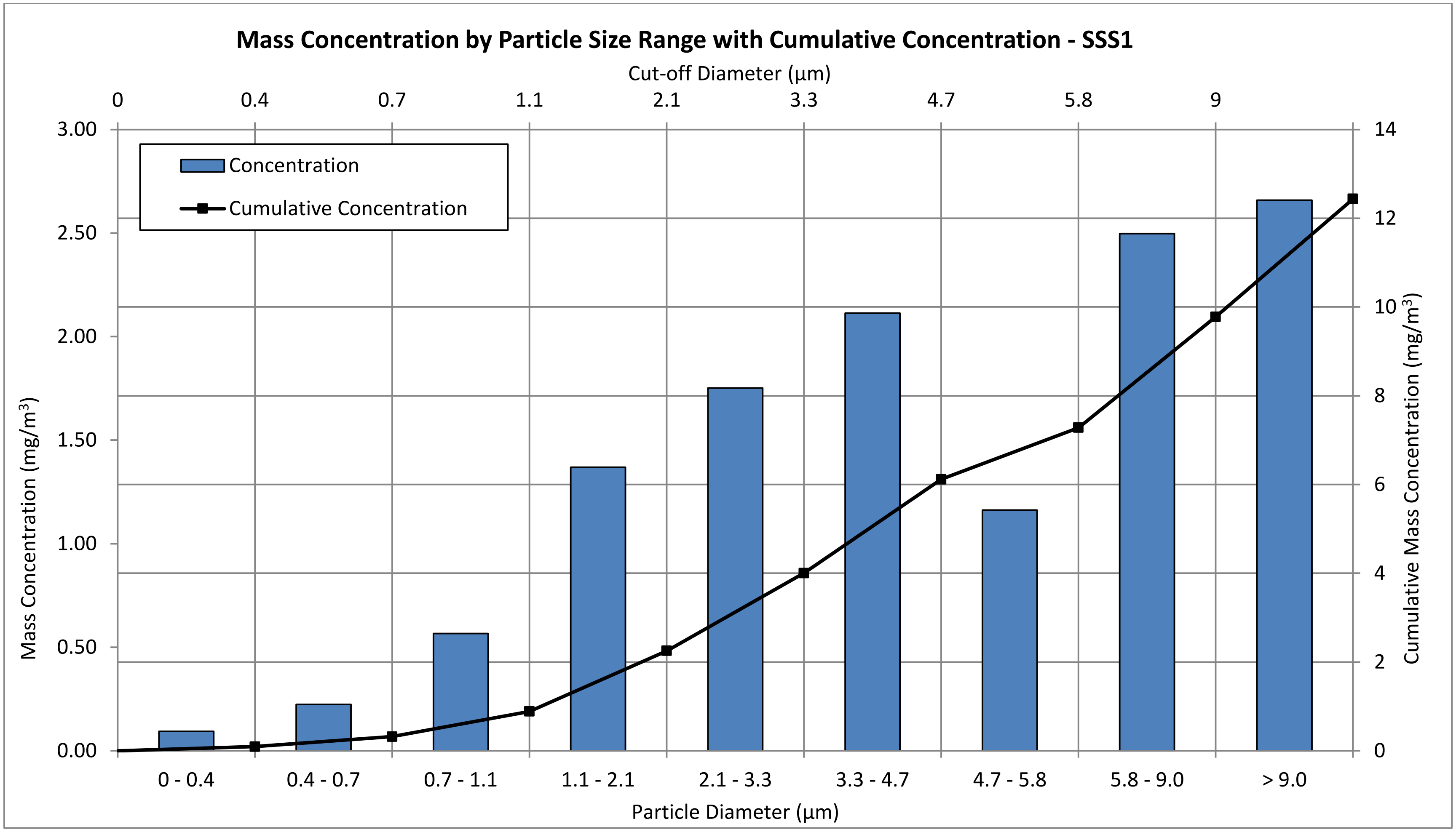


Figure 21. Mean mass concentration by particle size range with cumulative concentration overlay – SSS1.

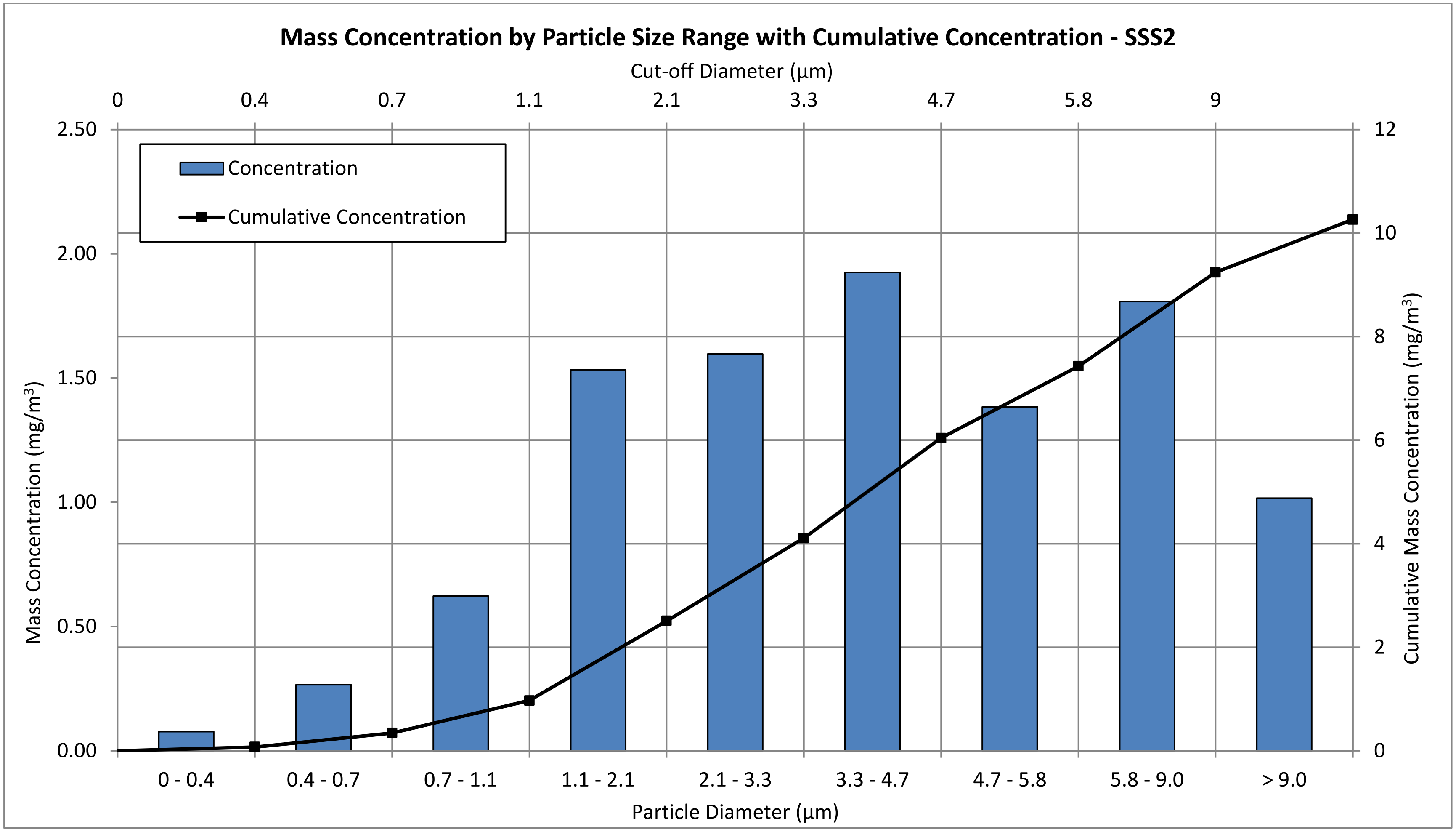


Figure 22. Mean mass concentration per particle size range with cumulative concentration overlay – SSS2.

Discussion

Study Considerations

The air sampling surveys performed during the study worked to provide an initial characterization of the airborne particulates a user may experience during SPF application. A variety of graphical representations and tables of the air sampling results were developed to analyze and communicate the particle size distributions and the mass concentrations of the aerosols generated by the kit. Being that much the service life of the kit was included in the sampling events presented, the results also provided information on exposures as the kit progressed through its life-cycle. Due to the scope of the study however, there were limitations that require emphasis prior to further discussion. The results presented do not include those data collected during the Pilot Study (see Appendix H) since these sampling events were used to refine the sampling process and equipment to be used for the remainder of the study. As stated prior, there are several manufacturers of SPF kits and each spray gun can generally be used with different nozzles, all of which could result in different aerosol characteristics. Lastly, the capacity of the kit and design of the study allowed for only 3 sampling events which limited the application of statistical analyses across surveys.

Aerosol Characteristics

The cumulative particle size distributions for each survey are plotted in Figure 14. As shown in the figure, the particle size distributions were visually similar shape however a distinction/grouping can be seen between the survey results of SSS1 and SSS2. This apparent difference is likely an artifact of the differences in impactor configuration between the two sampling trains as discussed earlier. That is, due to the cut-point differences between the standard inlet cone installed on SSS1 and the pre-separator on SSS2, the mass collected by the first stage differed by design which in turn had an impact on the mass percentages presented. To quantitatively compare the results between each sampling train as well as the results of each sampling train over the course of the study, percent difference calculations and student's t tests were performed. These comparative analyses are captured in Appendix I.

Percent difference calculations within sampling trains and are shown in Table 29A. The mean percent differences for SSS1 and SSS2, inclusive of all surveys, were calculated to be 32% and 33% respectively. These means were calculated using the average percent difference for each survey presented in Table 29A. As can be seen in the table, there were relatively significant percent differences associated with both the Filter and Stage 7 of each survey ranging up to 157%. Since the percent difference data sets were skewed, medians were also calculated for each survey comparison to offer another measure of central tendency (see Table 29A). The median values ranged from 10% to 21% and support the similarities in particle size distribution shape seen in Figure 14 when comparisons are made within size selective sampling trains.

Percent difference calculations between sampling train results are shown in Table 30A. The focus of the comparisons was to quantify the differences between the results of the size selective sampling trains and in doing so gain information on the impacts the configuration differences in cascade impactors had on the particle size distributions. To assess impacts, the percent differences between the stages of each size selective sampling train were calculated for each survey. These percent difference values were then grouped based on similarity of the impactor components and averaged for comparison. One group included the Stage 1 through the Filter and the other group included Stage 0 which captured the difference in configuration (i.e., standard inlet vs. pre-seperator). The mean percent difference for Stage 1 – Filter was 24.65% and was 87.98% for Stage 0. Since the Stage – Filter data set had a few relatively high values the medians was also calculated. The median percent difference for Stage 1 – Filter and Stage 0 were 15.83% and 85.00% respectively. The Stage 0 median and mean percent differences were respectively 5.3 and 3.5 times greater than those calculated for Stages 1 – Filter. Both the median and mean comparisons support the assumption that the configurations of the impactors had an impact on the particle size distribution presented.

Given the results of the percent difference comparisons an independent sample *t*-test was performed to compare the mass collected by the size selective sampling over the course of the study. The *t*-test was computed using the Microsoft excel data analysis package at an alpha level of .05 and is presented in Table 32A. The *t*-test did not find a significant difference between the mass collected by SSS1 (M = 0.00104, SD = 0.00133) and SSS2 (M = 0.00086, SD = 0.00106), t (56) = 0.56209, p = 0.57630. Although a significant difference was not found, due to the difference in impactor configuration, the results of the percent comparisons, and knowledge that there was likely aerosol mass unaccounted for the pre-separator, it was decided to only use the results of SSS1 for log-probability analysis.

As discussed in the results section, the log-probability graphical procedure described by Hinds (1999) was used to generate the log-probability plot shown in Figure 20. The plot was used to determine the mass median diameter (MMD) and geometric standard deviation (GSD) of the mean particle size distribution developed from SSS1 size selective sampling results. The MMD and GSD together function to define a particle size distribution and for mean particle size distribution associated with SSS1 they were found to be 4.6 µm (MMD) and 2.7 (GSD) (Hinds, 1999). Although the MMD and GSD characterized the particle size distribution they did not offer information on the mass or concentration of the aerosol generated by the kit.

To characterize the aerosol from a mass concentration perspective, total dust sampling was performed and concentrations per particle size range were calculated from the size selective sampling results. The total dust results for the study ranged from 6.52 mg/m^3 to 12.53 mg/m3 with the maximum concentrations sampled during Survey 3 and minimum results measured during Survey 2. The mean total dust concentration (i.e., mean of Total Dust 1 and 2) decreased by 33% from Survey 1 to 2 with both sampling times approximately 15 minutes in length. Mean mass concentrations increased by 37% from Survey 2 to 3 with an increase in sampling time from 15 minutes to 24 minutes for Survey 3. The increase in concentration suggests concentration level is related to application time in that concentrations decreased from Survey 1 to Survey 2 with approximately equal sampling times. However, under the design of the current study a relationship could not be established. The mean cumulative mass concentrations of the size selective sampling surveys were in general agreement with total dust mass concentrations with percent differences of 15% for Survey 1, 4% for Survey 2, and 6% for Survey 3 (see Table 33A).

Significance of Results – Human Health Risk

The total dust and size selective sampling conducted provided a quantitative evaluation of the mass concentration and size distribution of the airborne particulates generated by the SPF Kit. What the study did not provide information on was the chemical composition of the aerosol collected so the level of isocyanate exposure associated with the surveys was unknown. Although the degree of isocyante exposure was not evaluated as part of the study, information useful in the exposure assessment process was nonetheless gained. The particle size distributions generated from the size selective sampling results showed that the SPF kit generated airborne particulates capable of deposition within all three regions (i.e., head airways region, tracheobronchial region, gas exchange region) of the human respiratory tract (Hinds, 1999). This is of significance because there are isocyanate-induced illnesses associated with multiple regions of the respiratory system (see Health Effects section). For example, the most common disease associated with isocyanate inhalation exposure is occupational asthma and the aerosols generated by the kit had the potential to deposit within the tracheobronchial region where the target organs associated with asthma reside (Streicher et al., 2000; Vincent, 1999). Isocyanate exposure can also result in rhinitis which is associated with nasal structures in the head airways region (NIOSH, 2007). In general, if the SPF particles reaching the tissues of the respiratory tract are not fully cured, there is a potential for isocyanate contact and the elicitation of negative health effects associated with isocyanate exposure.

Method Selection

As discussed earlier in this manuscript, size selective sampling provides needed particle size information for the selection of analytical methods. This particle size information allows those evaluating exposures to MDI/pMDI to account for the limitations of sample collection devices thus ensuring accurate results. The particle size distributions measured in Surveys 1, 2, and 3 all show the presence of aerosols both larger than and smaller than 2 µm. This of importance since impingers are recommend for the sampling of SPF aerosols but their collection efficiency has been shown to degrade when sampling particles smaller than 2 µm (Streicher et al., 2000). To ensure the efficient collection of MDI/pMDI vapors, SPF aerosols > 2 µm, as well as SPF aerosols < 2 µm, the impinger + filter method described in NMAM Method 5525 is recommended for the evaluation of exposures associated with the use of these SPF Kits.

Recommendations and Improvements

To better understand the health risks to users of SPF Kits more research in the area is needed. Firstly, personal air monitoring to evaluate user exposures to MDI/pMDI is needed to determine the degree of exposure and acceptability when compared to respective OELs. Since these kits are produced by several manufacturers and are of differing design, these exposure assessments should include kits from the various manufacturers. As a component of these exposure assessments, size selective sampling to determine the particle size distribution of the aerosols generated should also be conducted for the same purposes it they were conducted for the present study. However, the sampling environment should be considered when selecting a suitable size-selective sampling device. For example, a Marple personal cascade impactor might be a good choice in a field environment due to its size, versatility as both an area and personal sampler, as well as its successful use by Lesage et al. (2007) for the sampling SPF aerosols (Rubow et al., 1987). The interested reader is directed to ACGIH (2001, pp. 93-134) for size selective sampling information and device selection.

Secondly, although the mock residential environment used in this study had the benefits of being semi-controlled, personal monitoring should also be conducted during real life applications following accepted comprehensive exposure assessment approaches (Bullock & Ignacio, 2006). These exposure assessments would allow for a real world evaluation of the exposures as well as comparisons to be made to previous studies which evaluated exposures associated with commercial SPF application systems (Bilan et al., 1989; Crespo & Galan, 1999; Lesage et al., 2007). The development of associations between environmental factors and MDI exposure level could be studied much like previous studies did. For example, many of the assessments performed by Lesage et al. (2007) would be applicable to the use of SPF Kits and instrumental for development of a useful exposure profile. Recommend SPF Kit assessments would include:

a. Evaluation of MDI airborne concentrations as a function of time to provide information as to the degree of hazard during and after SPF application. Exposure information could aid in the selection of control methods, determination of safe re-entry times, and whether or not there is MDI off- gassing associated with the applied product.

b. Evaluation of MDI airborne concentrations as a function of distance to determine if there is a “working zone” in which exposures outside of which would be acceptable when compared to OELs.

c. Dermal and surface sampling to assess the degree of dermal hazards present during and after the use of the SPF Kits.

Conclusion

The isocyanates used in SPF Kits are harmful to human health and due to their low vapor pressure, are expected to mainly be present in the air in the liquid/aerosol state (IRSST, 2013). The SPF Kit selected for the study was found to generate aerosols capable of penetration and deposition within the regions of the human respiratory tract where various isocyante-induced illnesses can develop. Although the mass concentration of isocyante was not evaluated as part of the study, the mass concentration of aerosol collected during the air sampling events (mean 10.40 mg/m^3) could be considered substantial given the relatively low OELs associated with isocyantes (i.e., MDI PEL-C is 0.20 mg/m^3) and volume of isocyanate used in the process. Further study is needed to quantify the levels of isocyanate exposures experienced by users of SPF Kits and based on the size selective sampling conducted during the study, the impinger + filter method described in Method 5525 of the NMAM is recommended for use.

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Appendices

Appendix A. Literature Review Process

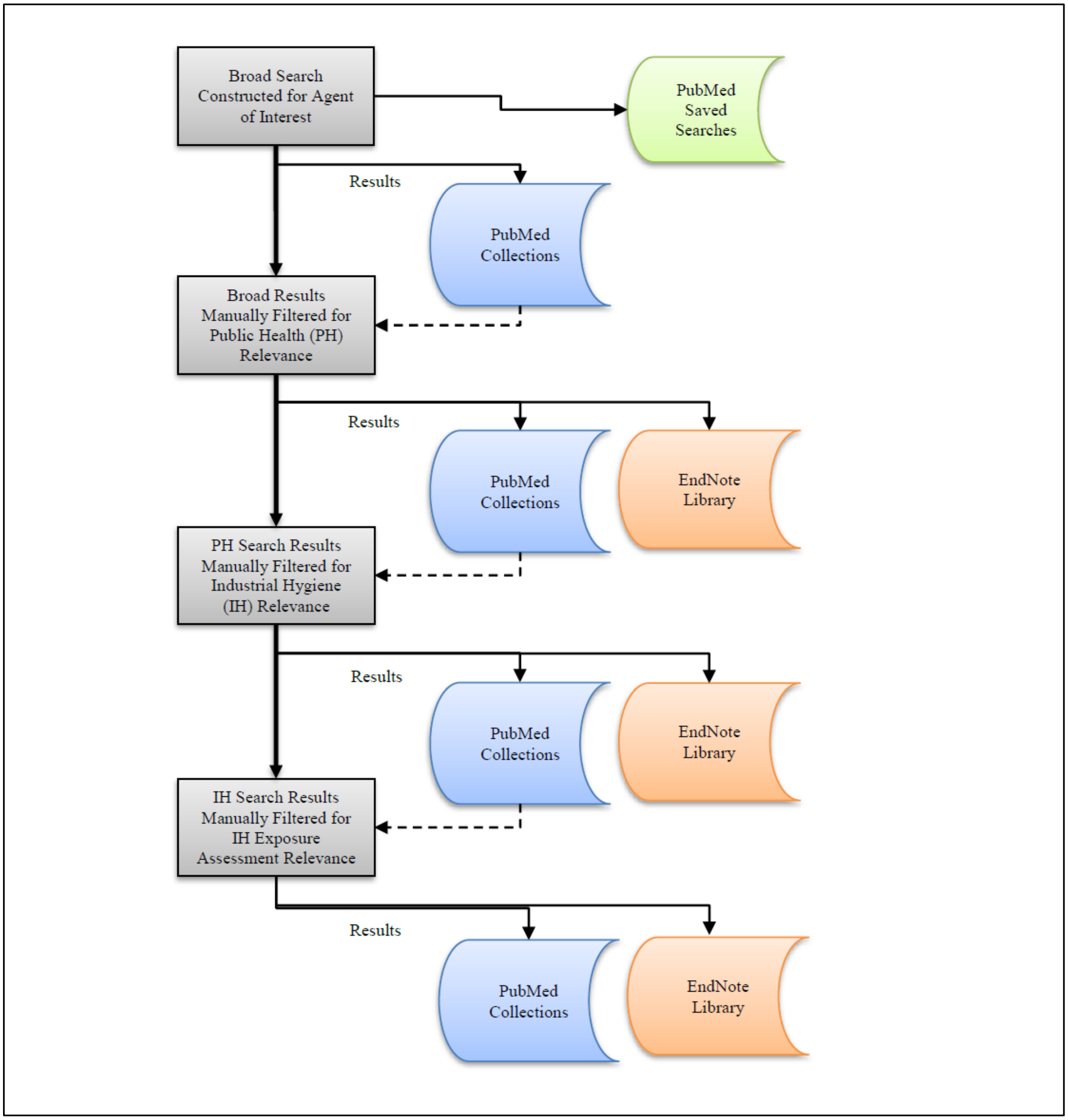


Figure 1A. Research article search and filtration process.

Appendix B. Thesis Project Methodology

Thesis Project Methodology

USF COLLEGE OF
PUBLIC HEALTH

Thesis Project Methodology
Loren Foster
U1682085

Appendix B. Thesis Project Methodology (Continued)

Table of Contents

Appendix B. Thesis Project Methodology (Continued)

PURPOSE

The purpose of this document is to communicate the methodology proposed for the project. This will facilitate the identification of equipment needs and allow for methodology refinement through committee review. The final methodology used will ultimately be reflected in this document and summarized in the final thesis manuscript.

METHODOLOGY

The figure below illustrates the general process to be used for the project and provides the framework for the step-by-step methodology that follows.

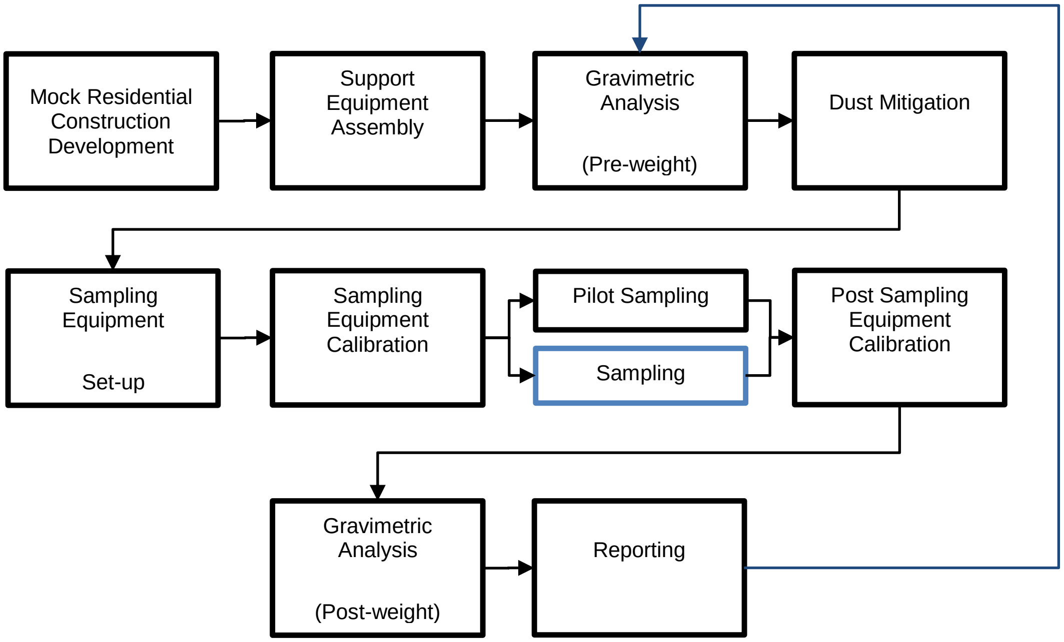


Figure 1. Methodology Process Flow Diagram

Mock Residential Construction Development

Step-by-step method:

1) Construct a mock 8 ft. x 8 ft. residential wall for insulation application (see Appendix A)
   a) Purchase 2 in. x 6 in. boards (10) 8 ft in length
   b) Purchase coated 4 ft. x 8 ft. wall boards (2) for application surface (low dust surfacing)
   c) Cut bottom plates (2) and top plates (2) for wall frames at 4 feet lengths
   d) Mark plates at 16 inch intervals to allow for construction of wall frame with boards 16 inch on center
   e) Cut vertical wall frames boards (8) at 7 ft. 9 in. in length
   f) Assemble 4 ft. x 8 ft. wall frames (2)
   g) Attach coated wall board to each wall frame
   h) Apply painters tape to seams/frame allowing for easy cleanup following application of insulation

Appendix B. Thesis Project Methodology (Continued)

2) Secure wall frames to existing wall surface (see Appendix A)
    a) Stand wall fames on end and position them side by side against wall
    b) Attach standoffs to existing structure
    c) Attach gate latches to standoffs
    d) Drill hole in wall frames to allow for latch entry
    e) Slide latches into drilled holes securing mock walls in place

3) Install plastic sheeting to isolate/contain insulating process and protect existing residence. Process is aligned with that proposed by the EPA for control of SPF (http://www.epa.gov/dfe/pubs/projects/spf/spray_polyurethane_foam.html)
    a) Cut plastic sheeting to size and affix to existing structure with staples
    b) Prior to insulation application, tape seams to mitigate the risk of insulation escaping enclosure

Support Equipment Assembly

Step-by-step method:

1) Assemble a cart for support of sampling equipment
    a) Acquire two level cart with casters from COPH
    b) Measure dimensions of cart for the construction of a stand to be placed on the cart
    c) Build a stand to a height that places Andersen Impactor nozzles in breathing zone (1.5 m from ground)
    d) Attach standoffs/lab stands to the stand to hold the total dust samplers in breathing zone (1.5 m from ground);
    e) Ensure standoff alignment with planned placement of impactors

Gravimetric Analysis – Pre-weight

Step-by-step method:

1) Place 37mm PVC Filters (total dust) and 81 mm glass substrates (Andersen Cascade Impactors) in the aerosols laboratory to equilibrate overnight

2) Weigh each substrate using the analytical balance
    a) Zero the analytic balance with the sash in the closed position
    b) Open sash and using forceps, transport the substrate near the antistatic radiation source
    c) Place filter on balance
    d) Close sash and record weight (W_{1a})
    e) Repeat measurement (W_{1b}); if within ±0.00005 mg from W_{1a} record measurement; if difference is greater repeat measurement until W_{1a} and W_{1b} are within ±0.00005 mg
    f) Repeat for each substrate
    g) Place all substrates in Petri dishes
    h) Seal and label all Petri dishes

3) Weigh each filter using the analytical balance (refer to NIOSH method 0500)
    a) Zero the analytic balance with the sash in the closed position
    b) Open sash and using forceps, transport the substrate near the antistatic radiation source
    c) Place filter on balance

   d) Close sash and record weight (W_{1a})
   e) Repeat measurement (W_{1b}); if within ±0.00005 mg from W_{1a} record measurement; if difference is greater repeat measurement until W_{1a} and W_{1b} are within ±0.00005 mg
   f) Repeat for each substrate
   g) Place all substrates in Petri dishes
   h) Seal and label all Petri dishes

Dust Mitigation

1) Seal all seams of enclosure with painters tape
2) Vacuum all surfaces with HEPA vacuum
3) Turn on HEPA residential air purifier inside enclosure and run for approx. 1 hr

Sampling Equipment Set-up

Step-by-step method:

1) Assemble size selective sampling train
   a) Place high volume vane pumps (2) outside of plastic enclosure
   b) Assemble cascade impactors (2)
      i) Follow procedures outlined in Andersen Cascade Impactor Manual
   c) Position cascade impactors (2) on stand/cart
      i) Align cascade impactors horizontally and ensure adequate spacing between each; mark location
   d) Connect the pumps and impactors with ¼ inner diameter flexible tubing

2) Assemble total dust sampling train
   a) Place personal sampling pumps (2) on lower shelf of the cart
   b) Connect the personal sampling pumps and 37mm filter calibration filter cassette assemblies (4) with ¼ inner diameter flexible tubing (the cassettes will not be used for the sampling)
   c) Attach the filter cassettes/tubing to the standoffs so the inlets are in the breathing zone and aligned with the cascade impactors (see Figure 2 below)

3) Stage cart for sampling
   a) Distance from wall = (50th percentile arm reach distance [i.e., acromial process to functional pinch, male]) + (gun w/nozzle length) + (spraying distance)
   b) Tape reference line parallel with wall and on cart so distance from wall is maintained throughout sampling
   c) Mount laser pointer at middle of cart to provide reference on wall during sampling process
   d) Align cart so laser pointer splits the first cavity to be filled with SPF

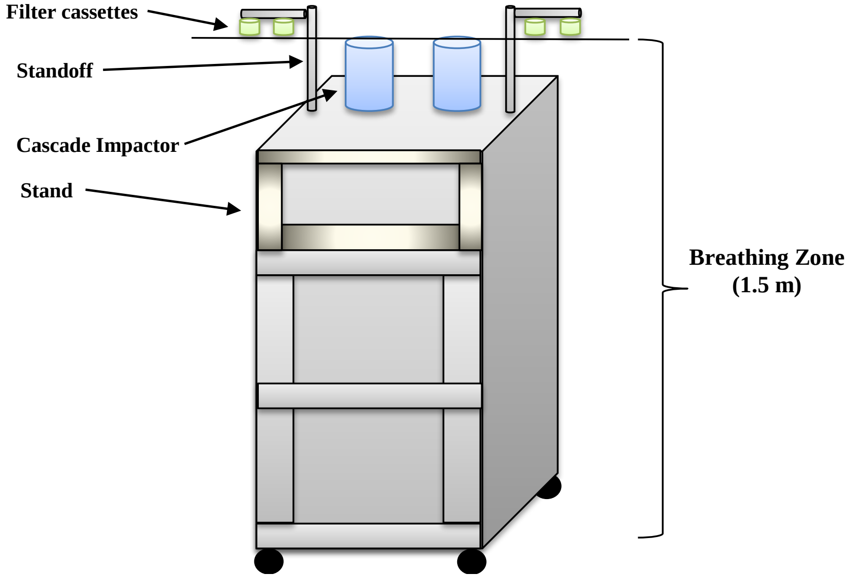
Figure 2. Depiction of Stand on Cart with Impactors and Total Dust Samplers Set-up

Sampling Equipment Calibration

Step-by-step method:

1) Calibrate the high volume pumps using a primary standard

Appendix B. Thesis Project Methodology (Continued)



   a) Turn on pumps and allow to warm up/stabilize for approximately 5 min
      i) Temporarily disconnect tubing from pumps during warm up
   b) Reconnect tubing to pump and install calibration tubing assembly into the inlet of a cascade impactor
   c) Connect calibrator to the calibration tubing assembly
   d) Adjust flow control valve until flow rate is 28.3 L/min
   e) Record a series (10) of flow rate measurements using calibrator
   f) Calculate average flow rate; ensure average is within acceptable limits (5%) of desired flow rate
   g) Power down pump
   h) Repeat process for additional cascade impactor
   i) Remove calibration tubing assembly and mass flow meter; store equipment

2) Calibrate personal sampling pumps using primary standard
   a) Turn on pumps and allow to warm up/stabilize for approximately 5 min
   b) Connect calibration filter cassette and Dry Cal with ¼ in inner diameter flexible tubing
   c) Reconnect tubing to pump and adjust flow to 2.0 L/min
   d) Record a series (10) of flow rate measurements using calibrator
   e) Calculate average flow rate; ensure average is within acceptable limits (5%) of desired flow rate
   f) Power down pump
   g) Repeat for additional total dust samplers
   h) Remove calibration tubing, calibration filter cassettes (2), and Dry Cal; store equipment

Pilot Sampling

Step-by-step method:

1) Set up and begin recording with video camera
2) Place SPF Part A and Part B cylinders on scale and record weights
3) Take ambient relative humidity, temperature, and pressure measurements

4) Start total dust sampling – Ambient
    a) Power on personal sampling pumps (2) and allow to warm up/stabilize for approx. 5 min
    b) Remove plugs from pre weighed filter cassettes, power down personal sampling pumps (2), and connect to tubing completing the total dust (Ambient) sampling train
    c) Power on personal sampling pumps (2) beginning total dust sampling; record start time
    d) Sample for 10 min

5) Stop total dust sampling – Ambient
    a) Power down personal sampling pumps (2); record time
    b) Remove pre weighed filter cassettes and insert plugs to avoid contamination
    c) Store and label pre weighed filter cassettes

6) Don PPE – partial protection
    a) Tyvek suit
    b) Boot covers
    c) Chemical protective gloves
    d) Goggles

7) Prepare the SPF Kit for application of spray foam
    a) Follow the instructions provided by the manufacturer
    b) Use instructional videos provided on the manufacturer website
    c) Follow best practices provided on Spray Polyurethane Foam Alliance website
    d) Use a fan spray nozzle (4lbs/min)

8) Power on sampling pumps (2 high volume pumps, 2 personal pumps) and allow to warm up for approx. 5 min (if needed)

9) Prepare size selective sampling train
    a) Temporarily power down high volume pumps (2) and connect tubing to the assembled cascade impactors (with pre-weighed glass fiber substrates) completing the size selective sampling train

10) Prepare total dust sampling train - In Process
    a) Temporarily power down pumps (2) and connect tubing to the pre weighed filter cassettes completing the total dust (In process) sampling trains

11) Don PPE – full protection
    a) Don respirator – perform leak check

12) Start size selective sampling <u>and</u> total dust sampling – In Process
    a) Power on personal sampling pumps (2) beginning total dust sampling; record start time
    b) Power on high volume pumps (2) beginning size selective sampling; record start time

13) Apply spray foam insulation to the mock wall

  a) Don PPE – full protection
  b) Begin application of SPF to the first cavity of mock wall; fill to an even coat approximately 2 in. in depth; follow manufacturer's instructions
  c) Ensure gun sweep rate is consistent so as to have the application time per cavity approx. equal and the total time for the entire wall 10 min
  d) Once the first cavity is filled reposition body and cart to the next cavity; ensure cart alignment with laser pointer and reference tape
  e) Begin applying SPF to the second cavity in the same manner as the first
  f) Repeat application method for all cavities of the 8 ft. x 8 ft. mock wall

14) Stop application of SPF; leave spray nozzle in place
15) Stop size selective sampling <u>and</u> total dust sampling – In Process
    a) Power down pumps after 10 min; record time; ensure simultaneous stops of pumps (4)
    b) Remove pre weighed filter cassettes and insert plugs to prevent contamination
    c) Install calibration filter cassettes on total dust sampling trains for post calibration
    d) Power on personal pumps and high volume pumps (to remain stabilized/warm for post calibration) – if needed

16) Perform post sampling calibration for total dust and size selective sampling trains (see section Post Sampling Calibration)

17) Disassemble cascade impactors and place glass substrates in Petri dishes; store and label
    a) Follow instructions in Andersen Cascade Impactor Manual

Sampling

Step-by-step method:

1) Set up and begin recording with video camera
2) Place SPF Part A and Part B cylinders on scale and record weights
3) Take ambient relative humidity, temperature, and pressure measurements
4) Start total dust sampling – Ambient
    a) Power on personal sampling pumps (2) and allow to warm up/stabilize for approx. 5 min
    b) Remove plugs from pre weighed filter cassettes, power down personal sampling pumps (2), and connect to tubing completing the total dust (Ambient) sampling train
    c) Power on personal sampling pumps (2) beginning total dust sampling; record start time
    d) Sample for 15 min

5) Stop total dust sampling – Ambient
    a) Power down personal sampling pumps (2); record time
    b) Remove pre weighed filter cassettes and insert plugs to avoid contamination
    c) Store and label pre weighed filter cassettes

6) Don PPE – partial protection
    a) Tyvek suit
    b) Boot covers
    c) Chemical protective gloves

Appendix B. Thesis Project Methodology (Continued)

    d) Goggles
7) Prepare the SPF Kit for application of spray foam
    a) Follow the instructions provided by the manufacturer
    b) Use instructional videos provided on the manufacturer website
    c) Follow best practices provided on Spray Polyurethane Foam Alliance website
    d) Use a fan spray gun tip (4lbs/min)

8) Power on sampling pumps (2 high volume pumps, 2 personal pumps) and allow to warm up for approx. 5 min

9) Prepare size selective sampling train
    a) Temporarily power down high volume pumps (2) and connect tubing to the assembled cascade impactors (with pre-weighed glass fiber substrates) completing the size selective sampling train

10) Prepare total dust sampling train - In Process
    a) Temporarily power down pumps (2) and connect tubing to the pre weighed filter cassettes completing the total dust (In process) sampling trains

11) Don PPE – full protection
    a) Don respirator – perform leak check

12) Start size selective sampling <u>and</u> total dust sampling – In Process
    a) Power on personal sampling pumps (2) beginning total dust sampling; record start time
    b) Power on high volume pumps (2) beginning size selective sampling; record start time

13) Apply spray foam insulation to the mock wall
    a) Don PPE – full protection
    b) Begin application of SPF to the first cavity of mock wall; fill to an even coat approximately 1 in. in depth; follow manufacturer's instructions
    c) Ensure gun sweep rate is consistent so as to have the application time per cavity approximately equal and the total time for the entire wall
        i) Total time for the entire wall will be based on the pilot sampling
    d) Once the first cavity is filled reposition body and cart to the next cavity; ensure cart alignment with laser pointer and reference tape
    e) Begin applying SPF to the second cavity in the same manner as the first
    f) Repeat application method for all cavities of the 8 ft. x 8 ft. mock wall

14) Stop application of SPF; leave spray nozzle in place
15) Stop size selective sampling <u>and</u> total dust sampling – In Process
    a) Power down pumps at time determined by pilot sampling; record time; ensure simultaneous stops of pumps (4)
    b) Remove pre weighed filter cassettes and insert plugs to prevent contamination
    c) Install calibration filter cassettes on total dust sampling trains for post calibration

  d) Power on personal pumps and high volume pumps (to remain stabilized/warm for post calibration)

16) Disassemble cascade impactors and place glass substrates in Petri dishes; store and label
  a) Follow instructions in Andersen Cascade Impactor Manual

17) Store and label all pre weighed filter cassettes

Post Sampling Equipment Calibration

1) Calibrate the high volume pumps using primary standard
  a) Ensure pumps are warmed up/stable (have ran for approximately 5 min)
  b) Connect cascade impactor with tubing to the filter cassette installed post sampling
  c) Install calibration tubing assembly into the inlet of a cascade impactor
  d) Attach calibrator to the calibration tubing assembly
  e) Record a series (10) of flow rate measurements using mass flow meter
  f) Calculate average flow rate; ensure average is within acceptable limits (5%) of pre sampling calibration flow rate
  g) Power down pump
  h) Repeat process for additional cascade impactor
  i) Remove calibration tubing assembly and calibrator; store equipment

2) Calibrate personal sampling pumps using primary standard
  a) Ensure pumps are warmed up/stable (have ran for approximately 5 min)
  b) Connect calibration filter cassette and calibrator with tubing
  c) Record a series (10) of flow rate measurements using Dry Cal
  d) Calculate average flow rate; ensure average is within acceptable limits (5%) of pre sampling calibration flow rate
  e) Power down pump
  f) Repeat for additional total dust samplers
  g) Remove calibration tubing , calibration filter cassettes (2), and Dry Cal; store equipment

Gravimetric Analysis – Post-weight

Step-by-step method:

1) Place 37mm PVC Filters (total dust) and 81 mm glass substrates (Andersen Cascade Impactors) in the weigh room to equilibrate overnight
  a) Remove plugs from filter cassettes and open Petri dishes
  b) Put up signage to alert lab users of ongoing project

2) Weigh each substrate using the analytical balance
  a) Zero the analytic balance with the sash in the closed position
  b) Open sash and using forceps, transport the substrate w/sample near the antistatic radiation source
  c) Place substrate on balance
  d) Close sash and record weight (W_{2a})
  e)

   f) Repeat measurement (W_{2b}); if within ± 0.00005 g of W_{2a} measurement is acceptable; if W_{2b} is not within ± 0.00005 g measurement is repeated
   g) Repeat for each substrate
   h) Place all substrates back in Petri dishes
   i) Calculate sample weights

3) Weigh each filter using the analytical balance (refer to NIOSH method 0500)
   a) Carefully disassemble 3 piece filter cassettes
   b) Zero the analytic balance with the sash in the closed position
   c) Open sash and using forceps transport the filter w/sample near the antistatic radiation source
   d) Place filter on balance
   e) Close sash and record weight (W_{2a})
   f) Repeat measurement (W_{2b}); if within ± 0.00005 g of W_{2a} measurement is acceptable; if W_{2b} is not within ± 0.00005 g measurement is repeated
   g) Repeat for each filter
   h) Place all filters in Petri dishes
   i) Calculate sample weights

Reporting

Step-by-step method:

1) Provide pilot sampling results to the committee in tabular and graphical formats for review
   a) Review will determine the adjustments necessary for the follow on sampling events
2) Provide follow on sampling results in the manner that they will be presented in the final thesis manuscript for review
   a) Adapt data presentation based on feedback from the committee
3) Provide final draft of thesis manuscript to committee for review prior to the thesis defense
4) Develop PowerPoint slides for thesis defense which include the data presentation used in the final thesis manuscript
5) Conduct thesis defense

Appendix B. Thesis Project Methodology (Continued)

CONCLUDING REMARKS

Following committee review, the student will request a meeting to discuss/finalize the methods for the pilot sampling. No samplings will take place prior to this meeting.

Appendix C. Field Sampling and Equipment Information

Table 1A. Survey 1 Field Sampling Information

Survey 1 Field Sampling Information					
Sample Description	Sample ID	Pump	Pump ID	Collection Device/Media	Duration (min)
Ambient 1	A1	Buck Basic 5	1	37 mm 3 piece cassette with PVC filter	15.05
Ambient 2	A2	Buck Basic 5	2	37 mm 3 piece cassette with PVC filter	15.05
Ambient 1B	A1B	Buck Basic 5	1	37 mm 3 piece cassette with PVC filter	15.02
Ambient 2B	A2B	Buck Basic 5	2	37 mm 3 piece cassette with PVC filter	15.02
Total Dust 1	TD1	Buck Basic 5	1	37 mm 3 piece cassette with PVC filter	16.10
Total Dust 2	TD2	Buck Basic 5	2	37 mm 3 piece cassette with PVC filter	16.10
Size Selective 1 (Filter)	CI(37)1	Gast Hi Vol 1/4 HP	1	37 mm 3 piece cassette with PVC filter	15.75
Size Selective 2 (Filter)	CI(37)2	Gast Hi Vol 1/3 HP	2	37 mm 3 piece cassette with PVC filter	15.75
Size Selective 1	CI1 (0-7)	Gast Hi Vol 1/4 HP	1	Andersen cascade impactor w/glass fiber substrates	15.75
Size Selective 2	CI2 (0-7)	Gast Hi Vol 1/3 HP	2	Andersen cascade impactor w/glass fiber substrates	15.75

Notes

Issues with pump start up on A1 and A2; Resolved issue and began time from fix. Took another ambient sample (A1B and A2B) as backup.

Stop watch used for all durations.

Appendix C. Field Sampling and Equipment Information (Continued)

Table 2A. Survey 2 Field Sampling Information

Survey 2 Field Sampling Information					
Sample Description	Sample ID	Pump	Pump ID	Collection Device/Media	Duration (min)
Ambient 1	A1	Buck Basic 5	1	37 mm 3 piece cassette with PVC filter	15.03
Ambient 2	A2	Buck Basic 5	2	37 mm 3 piece cassette with PVC filter	15.03
Total Dust 1	TD1	Buck Basic 5	1	37 mm 3 piece cassette with PVC filter	15.17
Total Dust 2	TD2	Buck Basic 5	2	37 mm 3 piece cassette with PVC filter	15.17
Size Selective 1 (Filter)	CI(37)1	Gast Hi Vol 1/4 HP	1	37 mm 3 piece cassette with PVC filter	15.03
Size Selective 2 (Filter)	CI(37)2	Gast Hi Vol 1/3 HP	2	37 mm 3 piece cassette with PVC filter	15.03
Size Selective 1	CI1 (0-7)	Gast Hi Vol 1/4 HP	1	Andersen cascade impactor w/glass fiber substrates	15.03
Size Selective 2	CI2 (0-7)	Gast Hi Vol 1/3 HP	2	Andersen cascade impactor w/glass fiber substrates	15.03

Notes

Stop watch used for all durations

Appendix C. Field Sampling and Equipment Information (Continued)

Table 3A. Survey 3 Field Sampling Information

Survey 3 Field Sampling Information					
Sample Description	Sample ID	Pump	Pump ID	Collection Device/Media	Duration (min)
Ambient 1	A1	Buck Basic 5	1	37 mm 3 piece cassette with PVC filter	15.07
Ambient 2	A2	Buck Basic 5	2	37 mm 3 piece cassette with PVC filter	15.07
Total Dust 1	TD1	Buck Basic 5	1	37 mm 3 piece cassette with PVC filter	24.40
Total Dust 2	TD2	Buck Basic 5	2	37 mm 3 piece cassette with PVC filter	24.40
Size Selective 1 (Filter)	CI(37)1	Gast Hi Vol 1/4 HP	1	37 mm 3 piece cassette with PVC filter	24.35
Size Selective 2 (Filter)	CI(37)2	Gast Hi Vol 1/3 HP	2	37 mm 3 piece cassette with PVC filter	24.35
Size Selective 1	CI1 (0-7)	Gast Hi Vol 1/4 HP	1	Andersen cascade impactor w/glass fiber substrates	24.35
Size Selective 2	CI2 (0-7)	Gast Hi Vol 1/3 HP	2	Andersen cascade impactor w/glass fiber substrates	24.35

Notes

Stop watches used for all durations

Appendix D. Calibration Data

Table 4A. Survey 1 Air Sampling Pump Calibration

Survey 1 Air Sampling Pump Calibration														
	Volumetrric Flow Rate (L/min)													
	Ambient 1		Ambient 2		Total Dust 1		Total Dust 2		Size Selective 1			Size Selective 2		
Measurement	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Post Cal	Pre Cal	Post Cal	Post Cal
Q_1	1.981	1.953	1.968	2.035	1.988	1.963	1.972	2.017	28.324	28.309	28.333	28.284	28.407	28.353
Q_2	1.947	1.903	1.986	1.964	2.024	1.952	1.975	2.069	28.324	28.358	28.309	28.309	28.491	28.383
Q_3	1.997	1.921	2.008	1.970	1.964	2.037	1.990	2.067	28.324	28.284	28.333	28.333	28.275	28.250
Q_4	1.991	1.940	2.039	1.968	2.054	2.001	2.054	2.043	28.348	28.309	28.309	28.309	28.466	28.442
Q_5	1.924	1.984	1.960	2.014	2.049	2.028	2.056	2.039	28.324	28.309	28.358	28.353	28.491	28.177
Q_6	1.996	1.952	2.009	2.019	2.021	1.936	2.038	2.000	28.348	28.315	28.309	28.333	28.491	28.383
Q_7	1.902	2.023	1.954	1.967	2.040	1.918	2.051	1.984	28.324	28.315	28.333	28.284	28.466	28.442
Q_8	2.006	1.981	2.052	1.987	2.038	2.011	2.033	1.988	28.324	28.309	28.333	28.333	28.359	28.442
Q_9	1.934	1.919	1.959	1.964	2.073	2.020	2.020	1.985	28.324	28.309	28.333	28.358	28.442	28.491
Q_{10}	1.971	1.988	1.972	1.993	2.008	1.947	2.025	2.059	28.324	28.313	28.333	28.333	28.432	28.466
Q_{avg}	1.971	1.957	1.990	1.988	2.026	1.981	2.021	2.026	28.328	▨	28.321	28.322	▨	28.407

Ambient Conditions - Pre Cal
Air Temperature: 25.3 °C
Air Pressure: 1017 mb
Relative Humidity: 59.6 %
Dew Point: 16.8 °C

Ambient Conditions - Post Cal
Air Temperature: 24.8 °C
Air Pressure: 1018 mb
Relative Humidity: 64.5 %
Dew Point: 17.8 °C

Intruments
Defender 510 Primary Gas Flow Calibrator
DryCal Primary Gas Flow Meter, DC Lite

Notes
Date - 17Nov12: Time 2.39 (Pre Cal), Time 6:36 (Post Cal)
Measurements taken at field experiment site.
Initial post calibration measurement was abnormally high (approx 28.6 L/min) for Size Selective 1. Reseated calibration tubing and allowed pumps to warm; resulting measurements were near pre calibration mesurements and are recorded above. Suspect pumps cooled during calibration of other sampling trains.

Appendix D. Calibration Data (Continued)

Table 5A. Survey 2 Air Sampling Pump Calibration

Survey 2 Air Sampling Pump Calibration													
	Volumetric Flow Rate (L/min)												
	Ambient 1		Ambient 2		Total Dust 1		Total Dust 2		Size Selective 1		Size Selective 2		
Measurement	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Post Cal
Q_1	1.992	1.894	1.980	1.951	2.007	1.990	1.956	1.952	28.284	28.284	28.324	28.104	28.204
Q_2	1.894	1.896	1.957	1.946	2.003	1.969	1.955	1.959	28.235	28.235	28.302	28.153	28.104
Q_3	1.918	1.996	1.997	1.975	1.925	1.932	1.949	1.949	28.284	28.309	28.275	28.131	28.282
Q_4	1.984	1.911	1.960	1.993	2.000	1.921	2.028	1.948	28.260	28.309	28.299	28.153	28.129
Q_5	1.942	1.912	2.069	1.947	1.956	1.989	1.945	1.951	28.284	28.260	28.275	28.107	28.058
Q_6	1.986	2.017	2.029	1.960	2.012	1.904	2.030	2.006	28.284	28.260	28.299	28.104	28.152
Q_7	1.999	1.918	1.973	1.961	1.941	1.940	1.983	1.954	28.333	28.260	28.325	28.131	28.129
Q_8	1.935	1.951	2.015	2.028	1.923	1.943	1.973	1.960	28.260	28.250	28.324	28.131	28.104
Q_9	1.921	2.018	1.993	1.984	2.008	1.942	1.964	2.006	28.309	28.275	28.325	28.129	28.083
Q_{10}	2.002	1.923	2.050	1.976	1.945	1.972	2.024	1.956	28.309	28.250	28.324	28.107	28.083
Q_{avg}	1.957	1.944	1.996	1.972	1.972	1.953	1.981	1.964	28.284	28.269	28.307	▨	28.129

Ambient Conditions - Pre Cal	**Ambient Conditions - Post Cal**
Air Temperature: 25.3°C	Air Temperature: 25.4°C
Air Pressure: 1016 mb	Air Pressure: 1016mb
Relative Humidity: 57.0%	Relative Humidity: 56.9%
Dew Point: 16.3°C	Dew Point: 16.9°C

Intruments

Fisher Scientific hygro/temp/dew point/pressure pen

Defender 510 Primary Gas Flow Calibrator

DryCal Primary Gas Flow Meter, DC Lite

Notes

Date - 17Nov12: Time 2.39 (Pre Cal), Time 6:36 (Post Cal).

Measurements taken at field experiment site.

Post cal conditions measured approx 1 hr after completion of sampling; area was not ventilated or adjusted.

Appendix D. Calibration Data (Continued)

Table 6A. Survey 3 Air Sampling Pump Calibration

Survey 3 Air Sampling Pump Calibration												
	Volumetrric Flow Rate (L/min)											
	Ambient 1		Ambient 2		Total Dust 1		Total Dust 2		Size Selective 1		Size Selective 2	
Measurement	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal
Q_1	1.954	1.998	1.989	2.011	1.992	1.988	1.980	1.948	28.348	28.284	28.260	29.591
Q_2	1.994	1.978	2.017	1.994	1.912	1.906	2.039	1.975	28.324	28.260	28.284	28.564
Q_3	1.987	1.988	1.963	1.963	1.987	2.004	1.952	2.017	28.275	28.260	28.260	28.618
Q_4	1.926	1.969	1.958	2.040	1.997	1.981	1.960	1.961	28.319	28.260	28.260	29.618
Q_5	2.002	1.991	1.959	2.034	1.912	2.015	2.053	1.993	28.319	28.235	28.235	29.564
Q_6	1.966	1.980	1.972	1.970	1.911	2.005	1.987	2.029	28.324	28.333	28.284	29.591
Q_7	1.964	1.941	1.967	1.971	2.000	2.025	2.026	2.052	28.250	28.289	28.284	29.618
Q_8	1.910	2.004	2.017	1.979	1.924	2.079	1.991	2.032	28.275	28.309	28.235	29.618
Q_9	1.999	1.915	1.980	1.983	2.002	2.091	2.007	1.952	28.299	28.333	28.275	28.591
Q_{10}	1.914	1.919	2.044	1.954	1.952	2.013	1.978	1.951	28.299	28.358	28.260	29.591
Q_{avg}	1.962	1.968	1.987	1.990	1.959	2.011	1.997	1.991	28.291	28.291	28.263	29.296

Ambient Conditions - Pre Cal	Ambient Conditions - Post Cal
Air Temperature: 24.4 °C	Air Temperature: 26.4 °C
Air Pressure: 1013 mb	Air Pressure: 1014 mb
Relative Humidity: 61 %	Relative Humidity: 64 %
Dew Point: 16.2 °C	Dew Point: 18.4 °C

Intruments

Fisher Scientific hygro/temp/dew point/pressure pen
Defender 510 Primary Gas Flow Calibrator
DryCal Primary Gas Flow Meter, DC Lite

Notes

Date - 18Dec12: Time 3:26 (Pre Cal), Time 5:49 (Post Cal)
Measurements taken at field experiment site

Appendix E. Gravimetric Analysis

Table 7A. Survey 1 Gravimetric Analysis Data

Survey 1 Gravimetric Analysis Data

Sample ID	Pre-Sampling Media Wt (g)			Post Sampling Media Wt (g)	Sample Weight (g)
	W_1	W_2	W_{avg}		
A1	0.01518	0.01517	0.01518	0.01519	0.00001
A2	0.01575	0.01579	0.01577	0.01579	0.00002
TD1	0.01501	0.01500	0.01501	0.01539	0.00038
TD2	0.01484	0.01484	0.01484	0.01523	0.00039
CI(37)1	0.01349	0.01349	0.01349	0.01356	0.00007
CI(37)2	0.01379	0.01378	0.01379	0.01380	0.00001
CI1(0)	0.31049	0.31052	0.31051	0.31193	0.00142
CI1(1)	0.30712	0.30713	0.30713	0.30843	0.00131
CI1(2)	0.33873	0.33872	0.33873	0.33935	0.00062
CI1(3)	0.34164	0.34164	0.34164	0.34269	0.00105
CI1(4)	0.34138	0.34139	0.34139	0.34233	0.00094
CI1(5)	0.33927	0.33928	0.33928	0.34000	0.00073
CI1(6)	0.34039	0.34040	0.34040	0.34068	0.00028
CI1(7)	0.33788	0.33785	0.33787	0.33795	0.00009
CI2(0)	0.30820	0.30821	0.30821	0.30878	0.00058
CI2(1)	0.30844	0.30845	0.30845	0.30941	0.00097
CI2(2)	0.33632	0.33629	0.33631	0.33694	0.00064
CI2(3)	0.33472	0.33471	0.33472	0.33571	0.00100
CI2(4)	0.33098	0.33098	0.33098	0.33177	0.00079
CI2(5)	0.34109	0.34110	0.34110	0.34191	0.00081
CI2(6)	0.33903	0.33902	0.33903	0.33939	0.00037
CI2(7)	0.33563	0.33566	0.33565	0.33572	0.00008
A1B	0.01600	0.01601	0.01601	0.01599	-0.00001
A2B	0.01387	0.01389	0.01388	0.01384	-0.00004

Pre Weight Ambient Conditions
Air Temperature: 22.2 °C
Air Pressure: 1023 mb
Relative Humidity: 54.2 %
Dew Point: 12.7 °C

Post Weight Ambient Conditions - Day 1
Air Temperature: 23.3 °C
Air Pressure: 1017 mb
Relative Humidity: 53.1 %
Dew Point: 13.2 °C

Post Weight Ambient Conditions - Day 2
Air Temperature: 22.8 °C
Air Pressure: 1017 mb
Relative Humidity: 53.5 %
Dew Point: 13.2 °C

Appendix E. Gravimetric Analysis (Continued)

Table 8A. Survey 2 Gravimetric Analysis Data

Survey 2 Gravimetric Analysis Data

Sample ID	Pre-Sampling Media Wt (g)			Post Sampling Media Wt (g)	QC Post Wt (g)	Sample Weight (g)
	W_1	W_2	W_{avg}			
A1	0.01335	0.01336	0.01336	0.01336	0.01335	0.00000
A2	0.01293	0.01291	0.01292			
TD1	0.01274	0.01276	0.01275	0.01302	0.01300	0.00027
TD2	0.01303	0.01302	0.01303	0.01323	0.01323	0.00021
CI(37)1	0.01396	0.01398	0.01397	0.01402	0.01402	0.00005
CI(37)2	0.01332	0.01334	0.01333	0.01339	0.01340	0.00006
CI1(0)	0.31134	0.31134	0.31134	0.31207	0.31206	0.00073
CI1(1)	0.30985	0.30982	0.30984	0.31053	0.31054	0.00070
CI1(2)	0.33398	0.33395	0.33397	0.33428	0.33427	0.00032
CI1(3)	0.33443	0.33439	0.33441	0.33504	0.33504	0.00063
CI1(4)	0.33919	0.33917	0.33918	0.33969	0.33969	0.00051
CI1(5)	0.33857	0.33854	0.33856	0.33902	0.33902	0.00046
CI1(6)	0.34054	0.34052	0.34053	0.34078	0.34078	0.00025
CI1(7)	0.33725	0.33723	0.33724	0.33738	0.33736	0.00014
CI2(0)	0.31137	0.31136	0.31137	0.31167	0.31169	0.00031
CI2(1)	0.31044	0.31043	0.31044	0.31089	0.31092	0.00045
CI2(2)	0.33540	0.33541	0.33541	0.33581	0.33582	0.00041
CI2(3)	0.33753	0.33754	0.33754	0.33809	0.33809	0.00055
CI2(4)	0.33517	0.33518	0.33518	0.33567	0.33568	0.00050
CI2(5)	0.33256	0.33258	0.33257	0.33309	0.33308	0.00052
CI2(6)	0.33922	0.33918	0.33920	0.33944	0.33945	0.00024
CI2(7)	0.33993	0.33992	0.33993	0.34011	0.34006	0.00018
CICon1	0.31057	0.31056	0.31057	0.31056	0.31052	0.00000
CICon2	0.31163	0.31161	0.31162	0.31164	0.31161	0.00002
CICon3	0.34059	0.34058	0.34059	0.34059	0.34062	0.00000
CICon4	0.33574	0.33575	0.33575	0.33578	0.33576	0.00004
(37)Con1	0.01339	0.01339	0.01339	0.01338	0.01338	-0.00001
(37)Con1	0.01337	0.01339	0.01338	0.01341	0.01346	0.00003

Pre Weight Ambient Conditions
Air Temperature: 23.1 °C
Air Pressure: 1023 mb
Relative Humidity: 55.7 %
Dew Point: 14.0 °C

Post Weight Ambient Conditions - Day 1
Air Temperature: 23.2 °C
Air Pressure: 1012 mb
Relative Humidity: 54.9 %
Dew Point: 13.5 °C

Notes
A2 filter dropped during post weight and contaminated; A2 will not be used for total dust calculation
Controls/Field balnks were used in this test; "Con" in ID indicates control/field blank

Table 9A. Survey 3 Gravimetric Analysis Data

Survey 3 Gravimetric Analysis Data

Sample ID	Pre-Sampling Media Wt (g)			Post Sampling Media Wt (g)	QC Post Wt (g)	Sample Weight (g)
	W_1	W_2	W_{avg}			
A1	0.01407	0.01405	0.01406	0.01407	0.01405	0.00001
A2	0.01311	0.01308	0.01310	0.01310	0.01306	0.00001
TD1	0.01460	0.01458	0.01459	0.01518	0.01515	0.00059
TD2	0.01302	0.01301	0.01302	0.01364	0.01365	0.00062
CI(37)1	0.01294	0.01293	0.01294	0.01295	0.01297	0.00001
CI(37)2	0.01429	0.01429	0.01429	0.01433	0.01432	0.00004
CI1(0)	0.26148	0.26146	0.26147	0.26357	0.26356	0.00210
CI1(1)	0.25860	0.25860	0.25860	0.26061	0.26057	0.00201
CI1(2)	0.27939	0.27940	0.27940	0.28031	0.28029	0.00091
CI1(3)	0.27943	0.27944	0.27944	0.28115	0.28116	0.00172
CI1(4)	0.27756	0.27757	0.27757	0.27889	0.27887	0.00133
CI1(5)	0.27793	0.27792	0.27793	0.27887	0.27885	0.00095
CI1(6)	0.27719	0.27720	0.27720	0.27751	0.27750	0.00032
CI1(7)	0.27759	0.27760	0.27760	0.27769	0.27769	0.00009
CI2(0)	0.26218	0.26216	0.26217	0.26290	0.26289	0.00073
CI2(1)	0.26120	0.26121	0.26121	0.26274	0.26273	0.00153
CI2(2)	0.27732	0.27735	0.27734	0.27858	0.27859	0.00125
CI2(3)	0.27683	0.27683	0.27683	0.27840	0.27841	0.00157
CI2(4)	0.27463	0.27461	0.27462	0.27592	0.27592	0.00130
CI2(5)	0.27593	0.27594	0.27594	0.27702	0.27702	0.00108
CI2(6)	0.27728	0.27728	0.27728	0.27762	0.27762	0.00034
CI2(7)	0.27574	0.27573	0.27574	0.27587	0.27584	0.00014
CICon1	0.26066	0.26066	0.26066	0.26060	0.26062	-0.00006
CICon2	0.26189	0.26190	0.26190	0.26187	0.26182	-0.00002
CICon3	0.27791	0.27791	0.27791	0.27789	0.27787	-0.00002
CICon4	0.27495	0.27494	0.27495	0.27492	0.27490	-0.00002
(37)Con1	0.01301	0.01301	0.01301	0.01301	0.01300	0.00000
(37)Con2	0.01385	0.01385	0.01385	0.01384	0.01384	-0.00001

Pre Weight Ambient Conditions

Air Temperature: 23.2 °C
Air Pressure: 1016 mb
Relative Humidity: 56.6 %
Dew Point: 14.2 °C

Post Weight Ambient Conditions

Air Temperature: 22.6 °C
Air Pressure: 1019 mb
Relative Humidity: 30.1 %
Dew Point: 4.0 °C

Notes

Controls/Field balnks were used in this test; "Con" in ID indicates control/field blank

Appendix F. Total Dust Sampling Results

Table 10A. Survey 1 Sampling Particulates Not Otherwise Specified (Total Dust)

Survey 1 Sampling Particulates Not Otherwise Specified (Total Dust)

Sample Description	Filter Mass, Pre-Sample (mg)	Filter Mass, Post Sample (mg)	Mass Collected (mg)	Sample Flow Rate (L/min)	Sample Duration (min)	Sample Volume (m^3)	Concentration (mg/m^3)
Ambient 1	15.175	15.190	0.015	1.964	15.05	0.03	0.51
Ambient 2	15.770	15.790	0.020	1.989	15.05	0.03	0.67
Total Dust 1	15.005	15.390	0.385	2.004	16.10	0.03	11.35
Total Dust 2	14.840	15.230	0.390	2.024	16.10	0.03	11.38

Formulas

Mass Collected (mg) = [Filter Mass, Post Sample (mg)] - [Filter Mass, Pre-Sample (mg)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration - Ambient (mg/m^3) = [Mass Collected (mg)] / [Sample Volume (m^3)]

Concentration - Total Dust (mg/m^3) = ([Mass Collected (mg)] / [Sample Volume (m^3)]) - [Mean Ambient Concentration (mg)]

Calibration

Instrument: DryCal Primary Flow Meter, DC Lite

Sample Flow Rate = ([Pre Cal Flow Rate (L/min)] + [Post Cal Flow Rate (L/min)]) / 2

Appendix F. Total Dust Sampling Results (Continued)

Table 11A. Survey 2 Sampling Particulates Not Otherwise Specified (Total Dust)

Survey 2 Sampling Particulates Not Otherwise Specified (Total Dust)									
Sample Description	Filter Mass, Pre-Sample (mg)	Filter Mass, Post Sample (mg)	Mass Collected (mg)	Mean Blank Mass (mg)	Mass Collected, Blank Corrected (mg)	Sample Flow Rate (L/min)	Sample Duration (min)	Sample Volume (m^3)	[1]Concentration (mg/m^3)
Ambient 1	13.355	13.360	0.005	0.010	-0.005	1.951	15.03	0.03	ND
Total Dust 1	12.750	13.020	0.270	0.010	0.260	1.963	15.17	0.03	8.74
Total Dust 2	13.025	13.230	0.205	0.010	0.195	1.973	15.17	0.03	6.52

Formulas

Mass Collected (mg) = [Filter Mass, Post Sample (mg)] - [Filter Mass, Pre-Sample (mg)]

Mass Collected - Blank Corrected (mg) = [Mass Collected (mg)] - [Average Blank Mass (mg)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration - Ambient (mg/m^3) = [Mass Collected-Blank Corrected (mg)] / [Sample Volume (m^3)

Concentration - Total Dust (mg/m^3) = ([Mass Collected-Blank Corrected (mg)] / [Sample Volume (m^3)]) - [Mean Ambient Concentration (mg/m^3)

Calibration

Instrument: DryCal Primary Flow Meter, DC Lite

Sample Flow Rate = ([Pre Cal Flow Rate (L/min)] + [Post Cal Flow Rate (L/min)]) / 2

Notes

[1] Concentrations ≤ 0 were considered Non-Detect (ND)

Appendix F. Total Dust Sampling Results (Continued)

Table 12A. Survey 3 Sampling Particulates Not Otherwise Specified (Total Dust)

Survey 3 Sampling Particulates Not Otherwise Specified (Total Dust)									
Sample Description	Filter Mass, Pre-Sample (mg)	Filter Mass, Post Sample (mg)	Mass Collected (mg)	Mean Blank Mass (mg)	Mass Collected, Blank Corrected (mg)	Sample Flow Rate (L/min)	Sample Duration (min)	Sample Volume (m^3)	Concentration (mg/m^3)
Ambient 1	14.060	14.070	0.010	-0.005	0.015	1.965	15.07	0.03	0.51
Ambient 2	13.095	13.100	0.005	-0.005	0.010	1.989	15.07	0.03	0.33
Total Dust 1	14.590	15.180	0.590	-0.005	0.595	1.985	24.40	0.05	11.86
Total Dust 2	13.015	13.640	0.625	-0.005	0.630	1.994	24.40	0.05	12.53

Formulas

Mass Collected (mg) = [Filter Mass, Post Sample (mg)] - [Filter Mass, Pre-Sample (mg)]

Mass Collected - Blank Corrected (mg) = [Mass Collected (mg)] - [Average Blank Mass (mg)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration - Ambient (mg/m^3) = [Mass Collected-Blank Corrected (mg)] / [Sample Volume (m^3)

Concentration - Total Dust (mg/m^3) = ([Mass Collected-Blank Corrected (mg)] / [Sample Volume (m^3)]) - [Mean Ambient Concentration (mg/m^3)]

Calibration

Instrument: DryCal Primary Flow Meter, DC Lite

Sample Flow Rate = ([Pre Cal Flow Rate (L/min)] + [Post Cal Flow Rate (L/min)]) / 2

Appendix G. Size Selective Sampling Results

Table 13A. Survey 1 Particle Size Distribution Data - Size Selective Sampling 1 (SSS1)

Survey 1 Particle Size Distribution Data - Size Selective Sampling 1 (SSS1)							
Stage	Particle Size Range (µm)	Stage Mass, Pre-Sample (g)	Stage Mass, Post-Sample (g)	Mass Collected (g)	Mass Percent (%)	Cumulative Mass (g)	Cummulative Mass Percent (%)
Filter	0 - 0.4	0.01349	0.01356	0.00007	1.07	0.00007	1.07
7	0.4 - 0.7	0.33787	0.33795	0.00009	1.30	0.00016	2.38
6	0.7 - 1.1	0.34040	0.34068	0.00028	4.37	0.00044	6.75
5	1.1 - 2.1	0.33928	0.34000	0.00073	11.13	0.00117	17.88
4	2.1 - 3.3	0.34139	0.34233	0.00094	14.50	0.00211	32.39
3	3.3 - 4.7	0.34164	0.34269	0.00105	16.12	0.00316	48.50
2	4.7 - 5.8	0.33873	0.33935	0.00062	9.59	0.00378	58.10
1	5.8-9.0	0.30713	0.30843	0.00131	20.03	0.00509	78.13
0	> 9.0	0.31051	0.31193	0.00142	21.87	0.00651	100.00
Total				0.00651			

Formulas

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cummalitive Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cummalitive Mass Percent (%) = ([Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n])/[Total Mass Collected (g)] *100

Notes

Pre-seperator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

Appendix G. Size Selective Sampling Results (Continued)

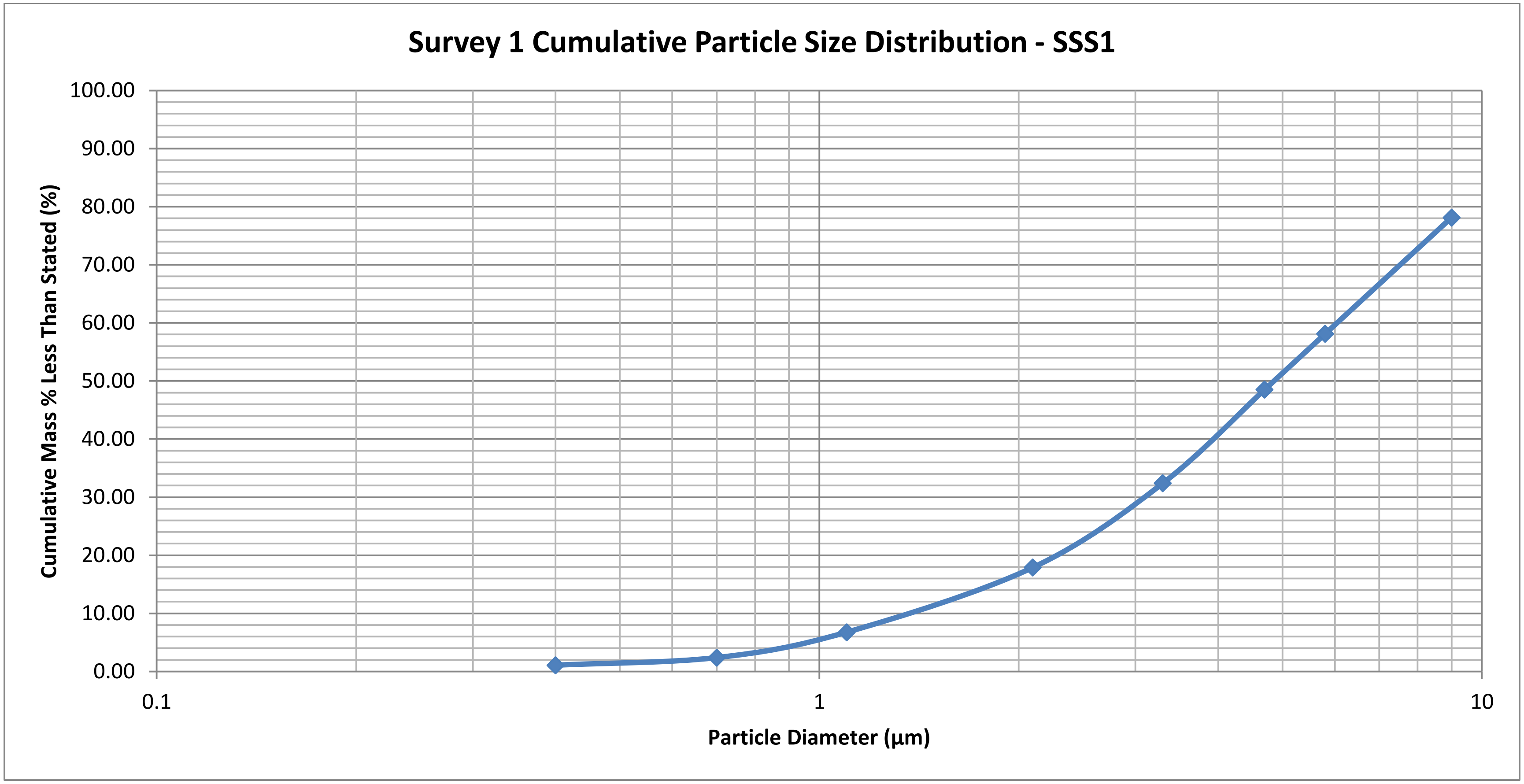


Figure 2A. Survey 1 Cumulative Particle Size Distribution – SSS1.

Appendix G. Size Selective Sampling Results (Continued)

Table 14A. Survey 1 Particle Size Distribution Data - Size Selective Sampling 2 (SSS2)

Survey 1 Particle Size Distribution Data - Size Selective Sampling 2 (SSS2)							
Stage	Particle Size Range (µm)	Stage Mass, Pre-Sample (g)	Stage Mass, Post-Sample (g)	Mass Collected (g)	Mass Percent (%)	Cumulative Mass (g)	Cummulative Mass Percent (%)
Filter	0 - 0.4	0.01379	0.01380	0.00001	0.29	0.00001	0.29
7	0.4 - 0.7	0.33565	0.33572	0.00008	1.43	0.00009	1.72
6	0.7 - 1.1	0.33903	0.33939	0.00037	6.98	0.00046	8.70
5	1.1 - 2.1	0.34110	0.34191	0.00081	15.58	0.00127	24.28
4	2.1 - 3.3	0.33098	0.33177	0.00079	15.11	0.00206	39.39
3	3.3 - 4.7	0.33472	0.33571	0.00100	19.02	0.00306	58.41
2	4.7 - 5.8	0.33631	0.33694	0.00064	12.14	0.00369	70.55
1	5.8-9.0	0.30845	0.30941	0.00097	18.45	0.00466	89.01
0	> 9.0	0.30821	0.30878	0.00058	10.99	0.00523	100.00
Total				0.00523			

Formulas

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cummalitive Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cummalitive Mass Percent (%) = ([Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n])/[Total Mass Collected (g)] *100

Notes

Pre-seperator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

Appendix G. Size Selective Sampling Results (Continued)

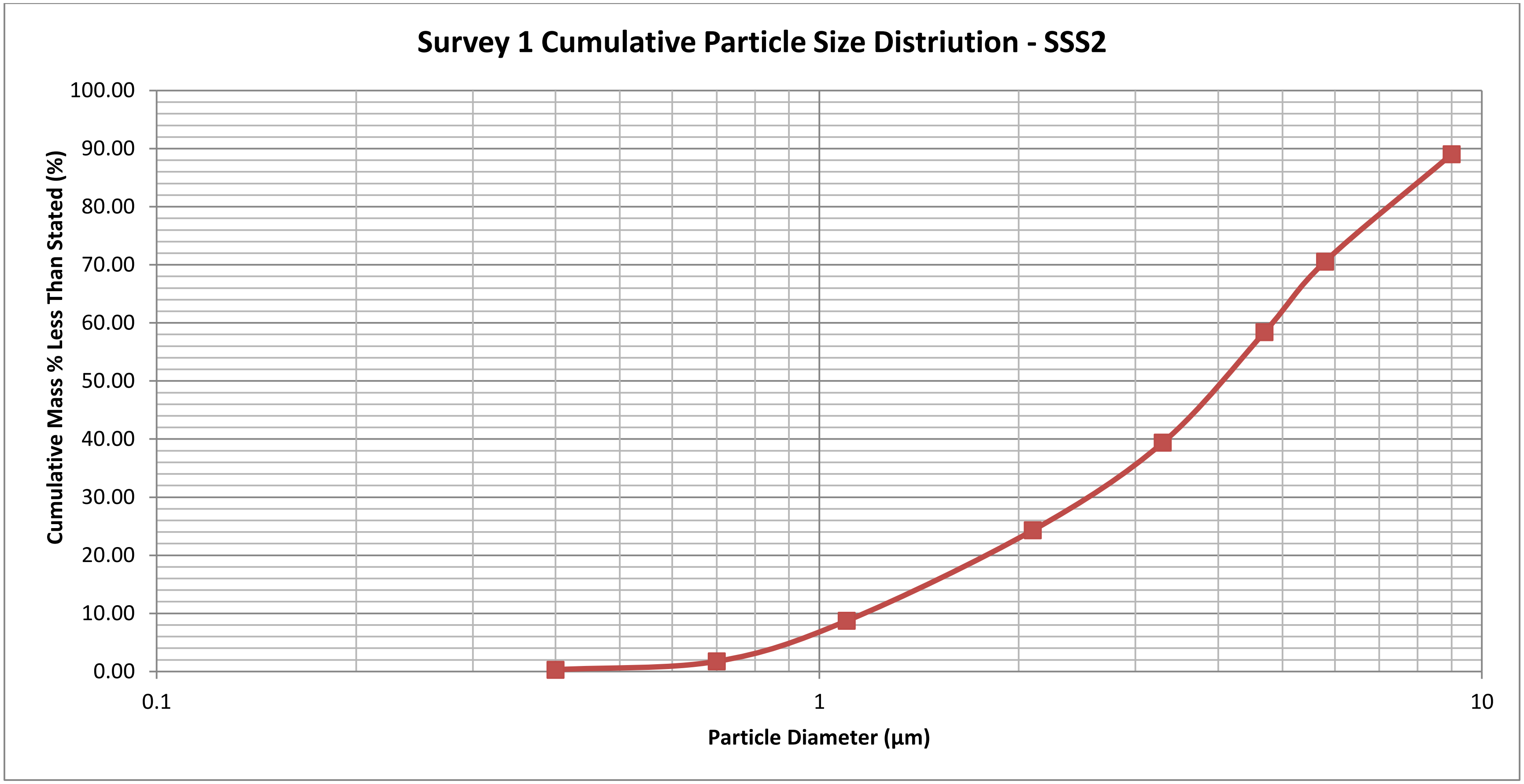


Figure 3A. Survey 1 Cumulative Particle Size Distribution – SSS2

Appendix G. Size Selective Sampling Results (Continued)

Table 15A. Survey 2 Particle Size Distribution Data - Size Selective Sampling 1 (SSS1)

Survey 2 Particle Size Distribution Data - Size Selective Sampling 1 (SSS1)							
Stage	Particle Size Range (µm)	Stage Mass, Pre-Sample (g)	Stage Mass, Post-Sample (g)	Mass Collected (g)	Mass Percent (%)	Cumulative Mass (g)	Cummulative Mass Percent (%)
Filter	0 - 0.4	0.01397	0.01402	0.00005	1.32	0.00005	1.32
7	0.4 - 0.7	0.33724	0.33738	0.00014	3.70	0.00019	5.02
6	0.7 - 1.1	0.34053	0.34078	0.00025	6.61	0.00044	11.62
5	1.1 - 2.1	0.33856	0.33902	0.00046	12.29	0.00091	23.91
4	2.1 - 3.3	0.33918	0.33969	0.00051	13.47	0.00142	37.38
3	3.3 - 4.7	0.33441	0.33504	0.00063	16.64	0.00205	54.03
2	4.7 - 5.8	0.33397	0.33428	0.00032	8.32	0.00236	62.35
1	5.8-9.0	0.30984	0.31053	0.00070	18.36	0.00306	80.71
0	> 9.0	0.31134	0.31207	0.00073	19.29	0.00379	100.00
Total				0.00379			

Formulas

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cummalitive Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cummalitive Mass Percent (%) = ([Mass Collected Particle Size Range (g)] + [Mass Collected (g) Particle Size Ranges < n])/[Total Mass Collected (g)] *100

Notes

Pre-seperator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

Appendix G. Size Selective Sampling Results (Continued)

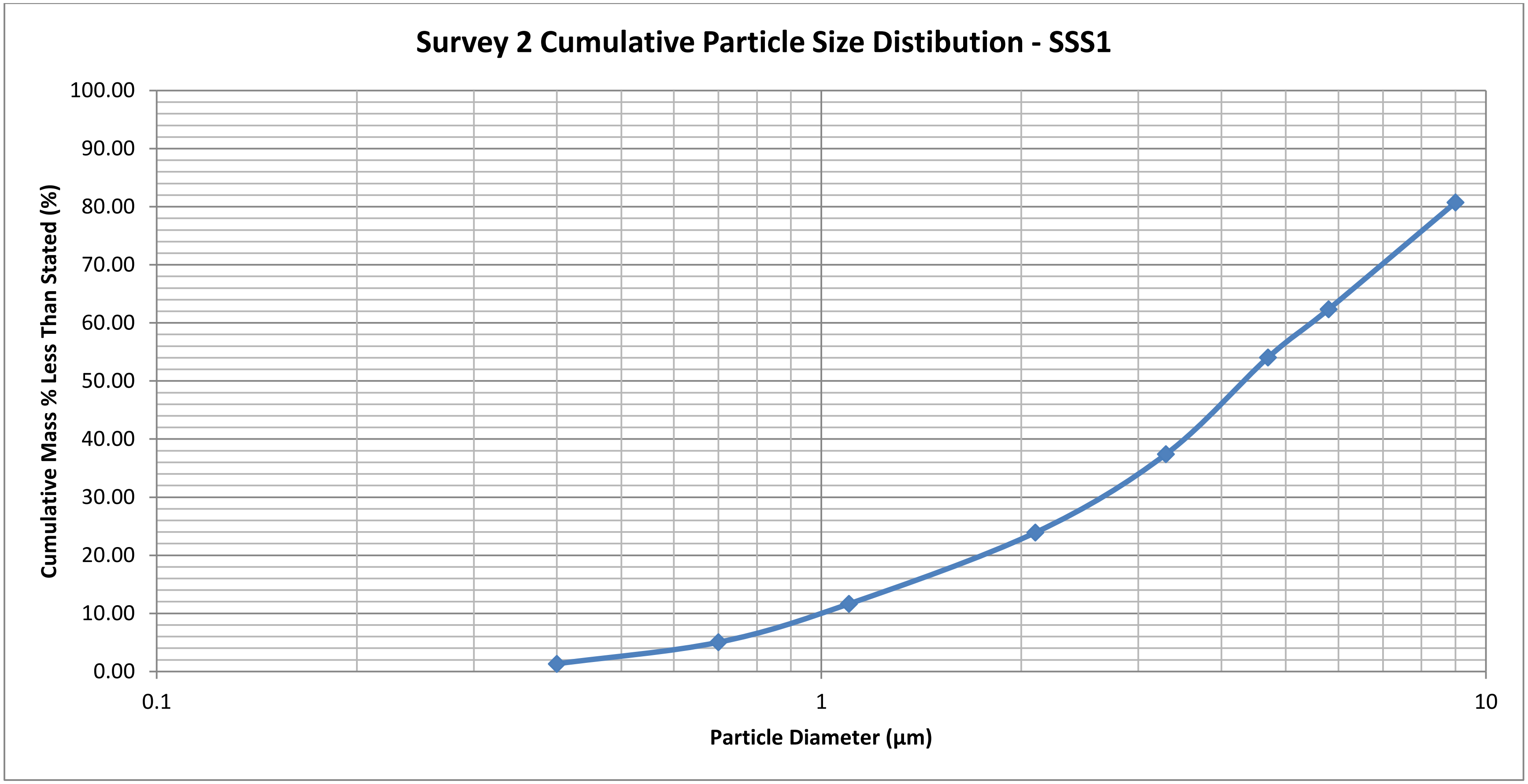


Figure 4A. Survey 2 Cumulative Particle Size Distribution – SSS1

Appendix G. Size Selective Sampling Results (Continued)

Table 16A. Survey 2 Particle Size Distribution Data - Size Selective Sampling 2

Survey 2 Particle Size Distribution Data - Size Selective Sampling 2

Stage	Particle Size Range (µm)	Stage Mass, Pre-Sample (g)	Stage Mass, Post-Sample (g)	Mass Collected (g)	Mass Percent (%)	Cumulative Mass (g)	Cummulative Mass Percent (%)
Filter	0 - 0.4	0.01333	0.01339	0.00006	1.86	0.00006	1.86
7	0.4 - 0.7	0.33993	0.34011	0.00018	5.75	0.00024	7.61
6	0.7 - 1.1	0.33920	0.33944	0.00024	7.45	0.00049	15.06
5	1.1 - 2.1	0.33257	0.33309	0.00052	16.15	0.00100	31.21
4	2.1 - 3.3	0.33518	0.33567	0.00050	15.37	0.00150	46.58
3	3.3 - 4.7	0.33754	0.33809	0.00055	17.24	0.00205	63.82
2	4.7 - 5.8	0.33541	0.33581	0.00041	12.58	0.00246	76.40
1	5.8-9.0	0.31044	0.31089	0.00045	14.13	0.00292	90.53
0	> 9.0	0.31137	0.31167	0.00031	9.47	0.00322	100.00
Total				0.00322			

Formulas

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cummalitive Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cummalitive Mass Percent (%) = ([Mass Collected Particle Size Range (g)] + [Mass Collected (g) Particle Size Ranges < n])/[Total Mass Collected (g)] *100

Notes

Pre-seperator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

Appendix G. Size Selective Sampling Results (Continued)

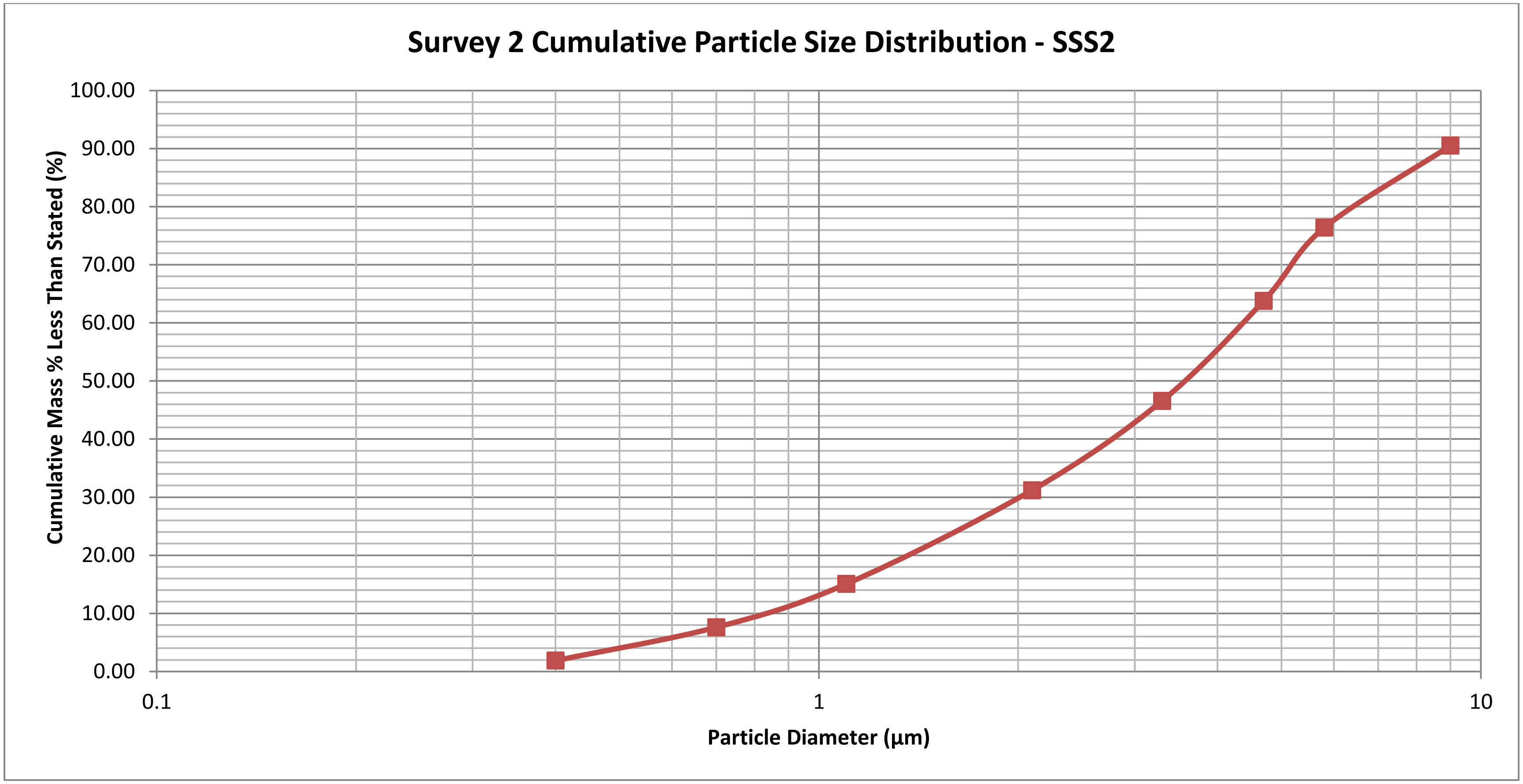


Figure 5A. Survey 2 Cumulative Particle Size Distribution – SSS2

Appendix G. Size Selective Sampling Results (Continued)

Table 17A. Survey 3 Particle Size Distribution Data - Size Selective Sampling 1 (SSS1)

Survey 3 Particle Size Distribution Data - Size Selective Sampling 1 (SSS1)

Stage	Particle Size Range (µm)	Stage Mass, Pre-Sample (g)	Stage Mass, Post-Sample (g)	Mass Collected (g)	Mass Percent (%)	Cumulative Mass (g)	Cummulative Mass Percent (%)
Filter	0 - 0.4	0.01294	0.01295	0.00001	0.16	0.00001	0.16
7	0.4 - 0.7	0.27760	0.27769	0.00009	1.01	0.00011	1.17
6	0.7 - 1.1	0.27720	0.27751	0.00032	3.34	0.00042	4.50
5	1.1 - 2.1	0.27793	0.27887	0.00095	10.02	0.00137	14.52
4	2.1 - 3.3	0.27757	0.27889	0.00133	14.04	0.00270	28.56
3	3.3 - 4.7	0.27944	0.28115	0.00172	18.18	0.00441	46.74
2	4.7 - 5.8	0.27940	0.28031	0.00091	9.70	0.00533	56.44
1	5.8-9.0	0.25860	0.26061	0.00201	21.30	0.00734	77.74
0	> 9.0	0.26147	0.26357	0.00210	22.26	0.00944	100.00
Total				0.00944			

Formulas

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cummalitive Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cummalitive Mass Percent (%) = ([Mass Collected Particle Size Range (g)] + [Mass Collected (g) Particle Size Ranges < n])/[Total Mass Collected (g)] *100

Notes

Pre-seperator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

Appendix G. Size Selective Sampling Results (Continued)

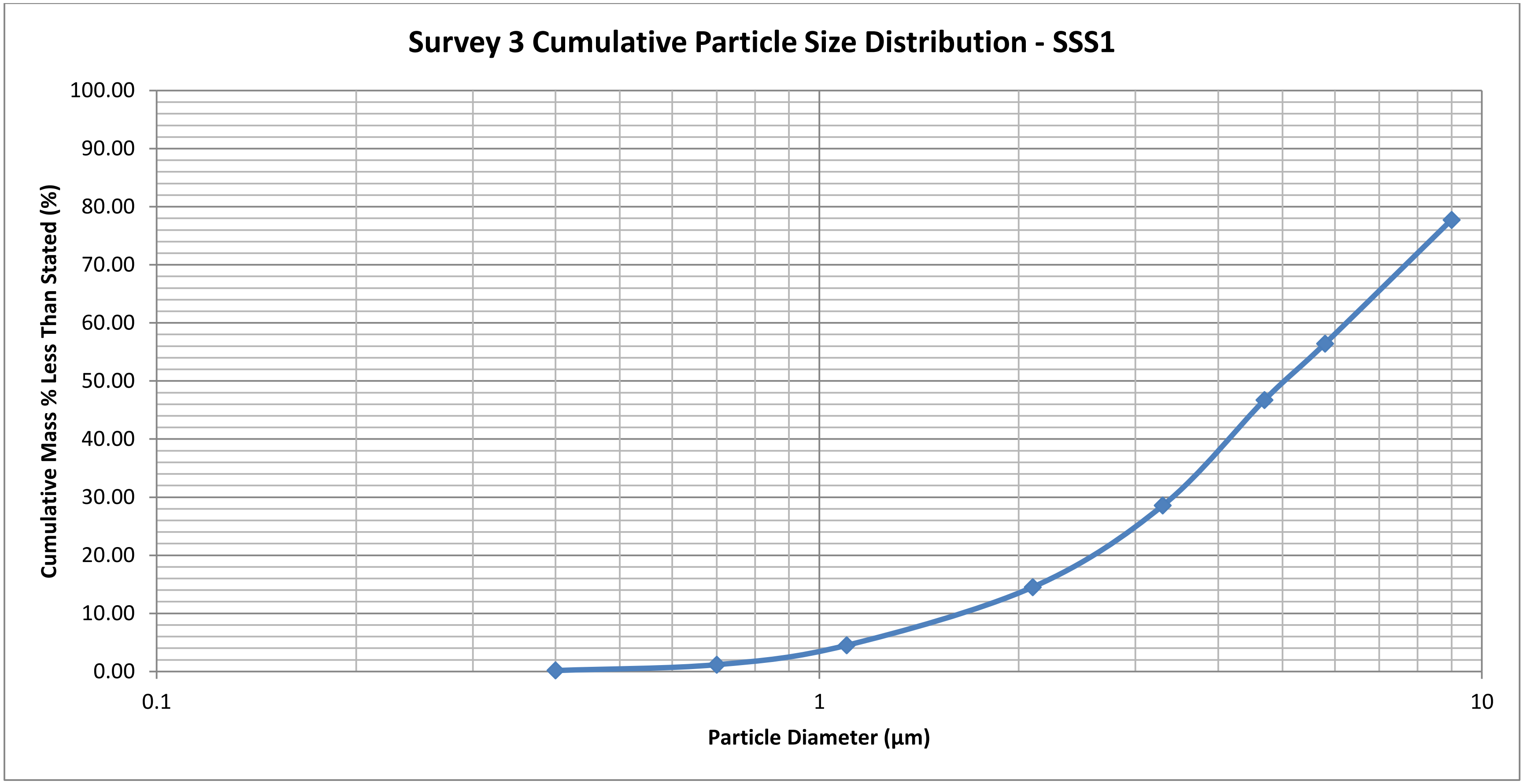


Figure 6A. Survey 3 Cumulative Particle size Distribution – SSS1

Appendix G. Size Selective Sampling Results (Continued)

Table 18A. Survey 3 Particle Size Distribution Data - Size Selective Sampling 2 (SSS2)

Survey 3 Particle Size Distribution Data - Size Selective Sampling 2 (SSS2)							
Stage	Particle Size Range (µm)	Stage Mass, Pre-Sample (g)	Stage Mass, Post-Sample (g)	Mass Collected (g)	Mass Percent (%)	Cumulative Mass (g)	Cummulative Mass Percent (%)
Filter	0 - 0.4	0.01429	0.01433	0.00004	0.50	0.00004	0.50
7	0.4 - 0.7	0.27574	0.27587	0.00014	1.69	0.00018	2.19
6	0.7 - 1.1	0.27728	0.27762	0.00034	4.26	0.00052	6.45
5	1.1 - 2.1	0.27594	0.27702	0.00108	13.60	0.00160	20.05
4	2.1 - 3.3	0.27462	0.27592	0.00130	16.29	0.00290	36.34
3	3.3 - 4.7	0.27683	0.27840	0.00157	19.67	0.00447	56.02
2	4.7 - 5.8	0.27734	0.27858	0.00125	15.60	0.00571	71.62
1	5.8-9.0	0.26121	0.26274	0.00153	19.24	0.00725	90.85
0	> 9.0	0.26217	0.26290	0.00073	9.15	0.00798	100.00
Total				0.00798			

Formulas

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cummalitive Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cummalitive Mass Percent (%) = ([Mass Collected Particle Size Range (g)] + [Mass Collected (g) Particle Size Ranges < n])/[Total Mass Collected (g)] *100

Notes

Pre-seperator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

Appendix G. Size Selective Sampling Results (Continued)

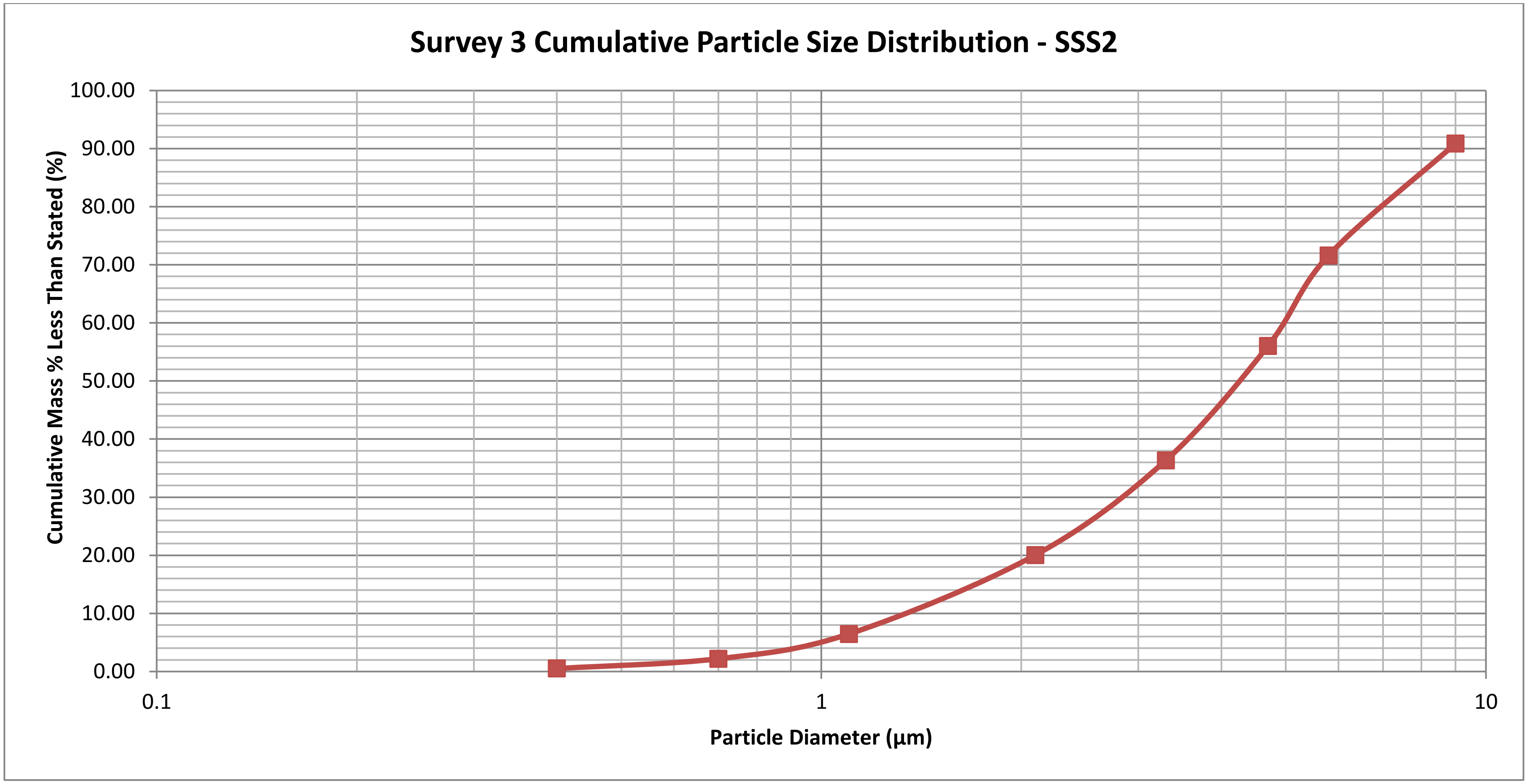


Figure 7A. Survey 3 Cumulative Particle Size Distribution – SSS2

Appendix G. Size Selective Sampling Results (Continued)

Table 19A. Mean Cumulative Mass Percent w/Range - SSS1

Mean Cumulative Mass Percent w/Range - SSS1			
Upper Limit of Particle Size Range (µm)	Mean Cum Mass Percent (%)	Max Range Bar (%)	Min Range Bar (%)
0.4	0.85	0.47	0.69
0.7	2.85	2.16	1.69
1.1	7.63	4.00	3.12
2.1	18.77	5.14	4.25
3.3	32.78	4.61	4.21
4.7	49.76	4.27	3.02
5.8	58.96	3.39	2.52
9	78.86	1.85	1.12
—	100.00	0.00	0.00

Formulas

Mean Cumulative Mass Percent (%) = [Sum Survey 1, 2, & 3 Particle Size Range Cumulative Mass Percent$_n$ (%)] / [Survey Count]

Appendix G. Size Selective Sampling Results (Continued)

Table 20A. Mean Cumulative Mass Percent w/Range - SSS2

Mean Cumulative Mass Percent w/Range - SSS2			
Upper Limit of Particle Size Range (µm)	Avg Cum Mass Percent (%)	Max Range Bar (%)	Min Range Bar (%)
0.4	0.88	0.98	0.60
0.7	3.84	3.77	2.12
1.1	10.07	4.99	3.62
2.1	25.18	6.03	5.13
3.3	40.77	5.81	4.43
4.7	59.42	4.40	3.40
5.8	72.86	3.54	2.30
9	90.13	0.72	1.12
—	100.00	0.00	0.00

Formulas

Mean Cumulative Mass Percent (%) = [Sum Survey 1, 2, & 3 Particle Size Range Cumulative Mass Percent$_n$ (%)] / [Survey Count]

Appendix G. Size Selective Sampling Results (Continued)

Table 21A. Mean Mass Percent by Particle Size Range - SSS1

Mean Mass Percent by Particle Size Range - SSS1				
Stage	Particle Size (µm)	Avg Mass Percent (%)	Max Range Bar (%)	Min Range Bar (%)
Filter	0 - 0.4	0.85	0.47	0.69
7	0.4 - 0.7	2.00	1.70	1.00
6	0.7 - 1.1	4.77	1.83	1.43
5	1.1 - 2.1	11.14	1.14	1.13
4	2.1 - 3.3	14.01	0.50	0.53
3	3.3 - 4.7	16.98	1.20	0.86
2	4.7 - 5.8	9.20	0.49	0.88
1	5.8-9.0	19.90	1.40	1.54
0	> 9.0	21.14	1.12	1.85

Formulas

Mean Mass Percent (%) = [Sum Survey 1, 2, & 3 Particle Size Range Mass Percent$_n$ (%)] / [Survey Count]

Appendix G. Size Selective Sampling Results (Continued)

Table 22A. Mean Mass Percent by Particle Size Range - SSS2

Mean Mass Percent by Particle Size Range - SSS2				
Stage	Particle Size (µm)	Avg Mass Percent (%)	Max Range Bar (%)	Min Range Bar (%)
Filter	0 - 0.4	0.88	0.98	0.60
7	0.4 - 0.7	2.96	2.79	1.52
6	0.7 - 1.1	6.23	1.22	1.97
5	1.1 - 2.1	15.11	1.04	1.51
4	2.1 - 3.3	15.59	0.70	0.48
3	3.3 - 4.7	18.65	1.03	1.41
2	4.7 - 5.8	13.44	2.16	1.30
1	5.8-9.0	17.27	1.96	3.14
0	> 9.0	9.87	1.12	0.72

Formulas

Mean Mass Percent (%) = [Sum Survey 1, 2, & 3 Particle Size Range Mass Percent$_n$ (%)] / [Survey Count]

Appendix H. Pilot Sampling Data

Table 23A. Pilot Survey Air Sampling Pump Calibration

Pilot Survey Air Sampling Pump Calibration												
Measurement	Volumetric Flow Rate (L/min)											
	Ambient 1		Ambient 2		Total Dust 1		Total Dust 2		Size Selective 1		Size Selective 2	
	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal	Pre Cal	Post Cal
Q_1	2.023	2.007	2.003	2.004	2.020	2.000	2.053	1.990	28.299	27.330	28.324	27.912
Q_2	2.001	2.010	1.961	1.988	2.017	1.993	2.017	2.042	28.324	27.440	28.324	27.960
Q_3	2.013	2.007	1.962	2.002	2.014	1.974	1.971	2.003	28.250	27.420	28.324	27.960
Q_4	2.015	2.007	2.042	2.023	2.002	1.997	2.050	1.967	28.299	27.472	28.324	27.912
Q_5	2.015	2.010	2.043	2.062	2.000	2.068	1.968	2.002	28.324	27.466	28.407	27.912
Q_6	2.014	1.994	1.959	2.016	2.019	2.015	2.022	1.992	28.299	27.466	28.324	27.888
Q_7	2.024	2.008	1.957	2.041	2.018	2.044	2.025	1.990	28.324	27.466	28.249	27.888
Q_8	2.012	2.007	2.031	2.034	2.002	2.046	2.055	1.979	28.299	27.568	28.348	27.912
Q_9	2.023	1.993	1.996	1.978	2.006	2.035	2.062	1.969	28.324	27.559	28.324	27.936
Q_{10}	2.013	2.007	2.010	1.972	2.007	2.062	1.970	1.999	28.275	27.536	28.324	28.007
Q_{avg}	2.015	2.005	1.994	2.006	2.011	2.017	2.019	1.995	28.301	27.466	28.332	27.929

Ambient Conditions

Air Temperature: 25.5 °C

Air Pressure: 1013 mb

Relative Humidity: 52%

Intruments

Defender 510 Primary Gas Flow Calibrator

DryCal Primary Gas Flow Meter, DC Lite

Notes

Date - 02Nov12: Time - 1542.

Measurements at field experiment site.

Appendix H. Pilot Sampling Data (Continued)

Table 24A. Pilot Survey Field Sampling Information

Pilot Survey Field Sampling Information					
Sample Description	Sample ID	Pump	Pump ID	Collection Device/Media	Duration (min)
Ambient 1	A1	Buck Basic 5	1	37 mm 3 piece cassette with PVC filter	10.00
Ambient 2	A2	Buck Basic 5	2	37 mm 3 piece cassette with PVC filter	10.00
Total Dust 1	TD1	Buck Basic 5	1	37 mm 3 piece cassette with PVC filter	10.17
Total Dust 2	TD2	Buck Basic 5	2	37 mm 3 piece cassette with PVC filter	10.17
Size Selective 1 (Filter)	CI(37)1	Gast Hi Vol 1/4 HP	1	37 mm 3 piece cassette with PVC filter	10.15
Size Selective 2 (Filter)	CI(37)2	Gast Hi Vol 1/3 HP	2	37 mm 3 piece cassette with PVC filter	10.15
Size Selective 1	CI1 (0-7)	Gast Hi Vol 1/4 HP	1	Andersen cascade impactor w/glass fiber substrates	10.15
Size Selective 2	CI2 (0-7)	Gast Hi Vol 1/3 HP	2	Andersen cascade impactor w/glass fiber substrates	10.15

Ambient Conditions

Air Temperature: 25.5 °C

Air Pressure: 1013 mb

Relative Humidity: 52%

Notes

Cascade impactor subtrates CI1(0) and CI1(1) were damaged during assembly and replaced with CI2(0b) and CI2(1b).

Stop watch used for all durations except Ambient 1 and Ambient 2.

Appendix H. Pilot Sampling Data (Continued)

Table 25A. Pilot Survey Gravimetric Analysis Data

Pilot Survey Gravimetric Analysis Data					
	Pre-Sampling Media Wt (g)			Post Sampling Media Wt (g)	
Sample ID	W_1	W_2	W_{avg}		Sample Weight (g)
A1	0.0138	0.0138	0.0138	0.0138	0.0000
A2	0.0141	0.0139	0.0140	0.0139	-0.0001
TD1	0.0125	0.0125	0.0125	0.0129	0.0004
TD2	0.0134	0.0134	0.0134	0.0135	0.0001
CI(37)1	0.0139	0.0138	0.0139	0.0138	0.0000
CI(37)2	0.0126	0.0126	0.0126	0.0125	-0.0001
CI2(0b)	0.3101	0.3101	0.3101	0.3117	0.0016
CI2(1b)	0.3094	0.3093	0.3094	0.3108	0.0015
CI1(2)	0.3433	0.3433	0.3433	0.3436	0.0003
CI1(3)	0.3397	0.3397	0.3397	0.3407	0.0010
CI1(4)	0.3370	0.3367	0.3369	0.3392	0.0024
CI1(5)	0.3418	0.3417	0.3418	0.3442	0.0025
CI1(6)	0.3372	0.3374	0.3373	0.3437	0.0064
CI1(7)	0.3408	0.3409	0.3409	0.3428	0.0020
CI2(0)	0.3117	0.3116	0.3117	0.3124	0.0008
CI2(1)	0.3124	0.3126	0.3125	0.3135	0.0010
CI2(2)	0.3359	0.3357	0.3358	0.3368	0.0010
CI2(3)	0.3391	0.3392	0.3392	0.3400	0.0009
CI2(4)	0.3387	0.3386	0.3387	0.3378	-0.0009
CI2(5)	0.3434	0.3435	0.3435	0.3422	-0.0013
CI2(6)	0.3432	0.3433	0.3433	0.3376	-0.0056
CI2(7)	0.3427	0.3427	0.3427	0.3409	-0.0018

Pre Weight Ambient Conditions

Air Temperature: 22 °C

Air Pressure: 1008 mb

Relative Humidity: 61%

Post Weight Ambient Conditions

Air Temperature: 21 °C

Air Pressure: 1012 mb

Relative Humidity: 62%

Appendix H. Pilot Sampling Data (Continued)

Table 26A. Pilot Survey Sampling Particulates Not Otherwise Specified (Total Dust)

Pilot Survey Sampling Particulates Not Otherwise Specified (Total Dust)							
Sample Description	Filter Mass, Pre-Sample (mg)	Filter Mass, Post Sample (mg)	Mass Collected (mg)	Sample Flow Rate (L/min)	Sample Duration (min)	Sample Volume (m^3)	[1]Concentration (mg/m^3)
Ambient 1	13.800	13.800	0.000	2.010	10.00	0.02	ND
Ambient 2	14.000	13.900	-0.100	2.000	10.00	0.02	ND
Total Dust 1	12.500	12.900	0.400	2.014	10.17	0.02	19.54
Total Dust 2	13.400	13.500	0.100	2.007	10.17	0.02	4.90

Formulas

Mass Collected (mg) = [Filter Mass, Post Sample (mg)] - [Filter Mass, Pre-Sample (mg)]

Sample Volume (m^3) = [Sample Flow Rate (L/min)] × [Sample Duration (min)] × [1 m^3/1000 L]

Concentration - Ambient (mg/m^3) = [Mass Collected (mg)] / [Sample Volume (m^3)]

Concentration - Total Dust (mg/m^3) = ([Mass Collected (mg)] / [Sample Volume (m^3)]) - [Mean Ambient Concentration (mg)]

Calibration

Instrument: DryCal Primary Flow Meter, DC Lite

Sample Flow Rate = ([Pre Cal Flow Rate (L/min)] + [Post Cal Flow Rate (L/min)]) / 2

Notes

[1] Concentrations ≤ 0 were considered Non-Detect (ND)

Table 27A. Pilot Survey Particle Size Distribution Data - Size Selective Sampling 1 (SSS1)

Pilot Survey Particle Size Distribution Data - Size Selective Sampling 1 (SSS1)							
Stage	Particle Size Range (µm)	Stage Mass, Pre-Sample (g)	Stage Mass, Post-Sample (g)	Mass Collected (g)	Mass Percent (%)	Cumulative Mass (g)	Cummulative Mass Percent (%)
Filter	0 - 0.4	0.0139	0.0139	0.0000	0.28	0.0000	0.28
7	0.4 - 0.7	0.3409	0.3428	0.0020	11.11	0.0020	11.40
6	0.7 - 1.1	0.3373	0.3437	0.0064	36.47	0.0084	47.86
5	1.1 - 2.1	0.3418	0.3442	0.0025	13.96	0.0109	61.82
4	2.1 - 3.3	0.3369	0.3392	0.0024	13.39	0.0132	75.21
3	3.3 - 4.7	0.3397	0.3407	0.0010	5.70	0.0142	80.91
2	4.7 - 5.8	0.3433	0.3436	0.0003	1.71	0.0145	82.62
1	5.8-9.0	0.3094	0.3108	0.0015	8.26	0.0160	90.88
0	> 9.0	0.3101	0.3117	0.0016	9.12	0.0176	100.00
Total				0.0176			

Formulas

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cummalitive Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cummalitive Mass Percent (%) = ([Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n])/[Total Mass Collected (g)] *100

Notes

Pre-seperator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

Appendix H. Pilot Sampling Data (Continued)

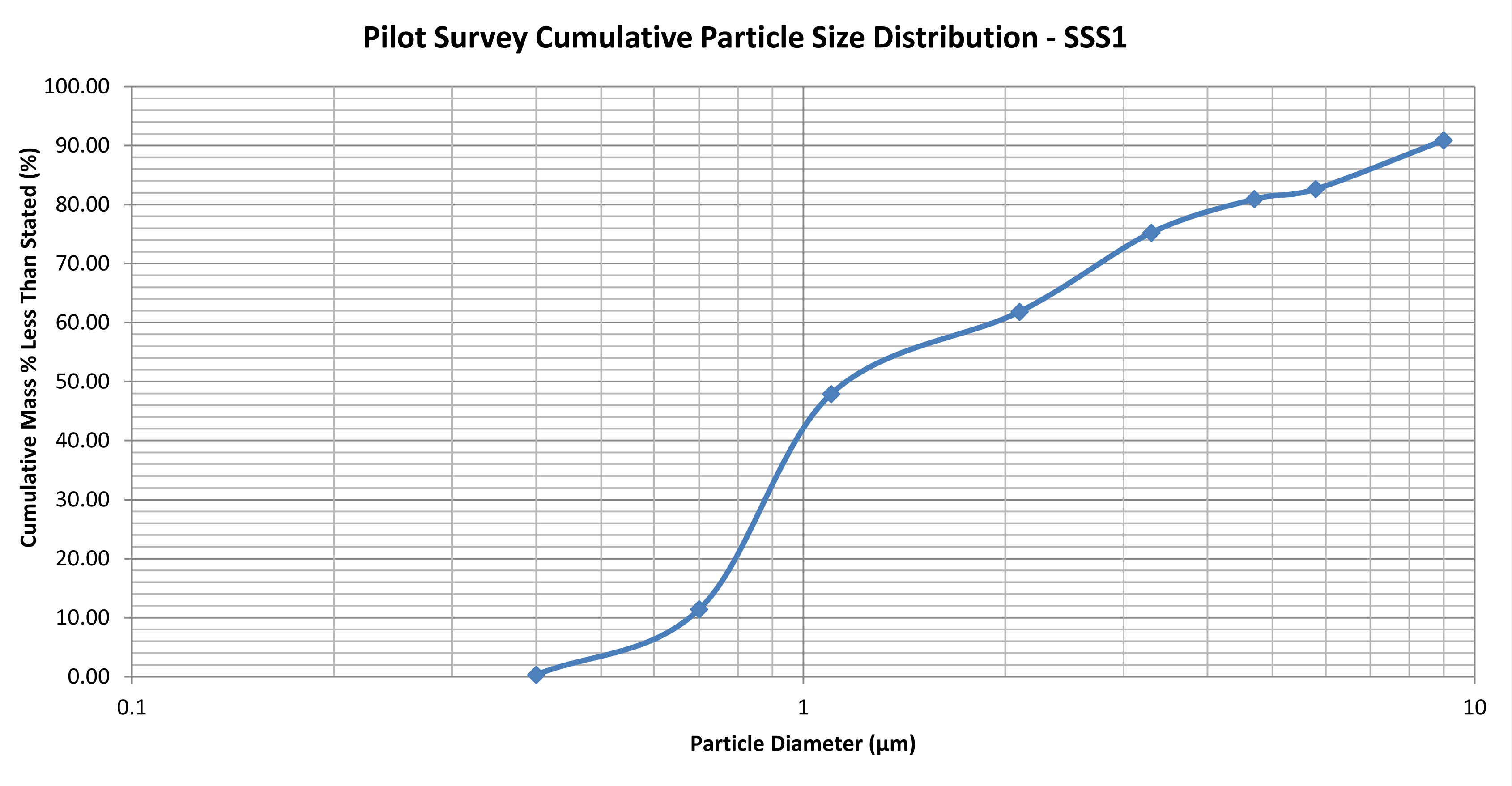


Figure 8A. Pilot Survey Cumulative Particle Size Distribution – SSS1

Appendix H. Pilot Sampling Data (Continued)

Table 28A. Pilot Survey Particle Size Distribution Data - Size Selective Sampling 2 (SSS2)

Pilot Survey Particle Size Distribution Data - Size Selective Sampling 2 (SSS2)

Stage	Particle Size Range (µm)	Stage Mass, Pre-Sample (g)	Stage Mass, Post-Sample (g)	Mass Collected (g)	Mass Percent (%)	Cumulative Mass (g)	Cumulative Mass Percent (%)
Filter	0 - 0.4	0.0126	0.0125	0.0000	0.00	0.0000	0.00
7	0.4 - 0.7	0.3427	0.3409	0.0000	0.00	0.0000	0.00
6	0.7 - 1.1	0.3433	0.3376	0.0000	0.00	0.0000	0.00
5	1.1 - 2.1	0.3435	0.3422	0.0000	0.00	0.0000	0.00
4	2.1 - 3.3	0.3387	0.3378	0.0000	0.00	0.0000	0.00
3	3.3 - 4.7	0.3392	0.3400	0.0009	23.61	0.0009	23.61
2	4.7 - 5.8	0.3358	0.3368	0.0010	27.78	0.0019	51.39
1	5.8-9.0	0.3125	0.3135	0.0010	27.78	0.0029	79.17
0	> 9.0	0.3117	0.3124	0.0008	20.83	0.0036	100.00
Total				0.0036			

Formulas

Mass Collected (g) = [Filter Mass, Post Sample (g)] - [Filter Mass, Pre-Sample (g)]

Mass Percent (%) = [Mass Collected (g)]/[Total Mass Collected (g)] *100

Cumulative Mass (g) = [Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n]

Cumulative Mass Percent (%) = ([Mass Collected Particle Size Range$_n$ (g)] + [Mass Collected (g) Particle Size Ranges < n])/[Total Mass Collected (g)] *100

Notes

Pre-seperator used on cascade impactor for size selective sampling train 2; cutpoint 10 µm @ 28.3 L/min

Appendix H. Pilot Sampling Data (Continued)

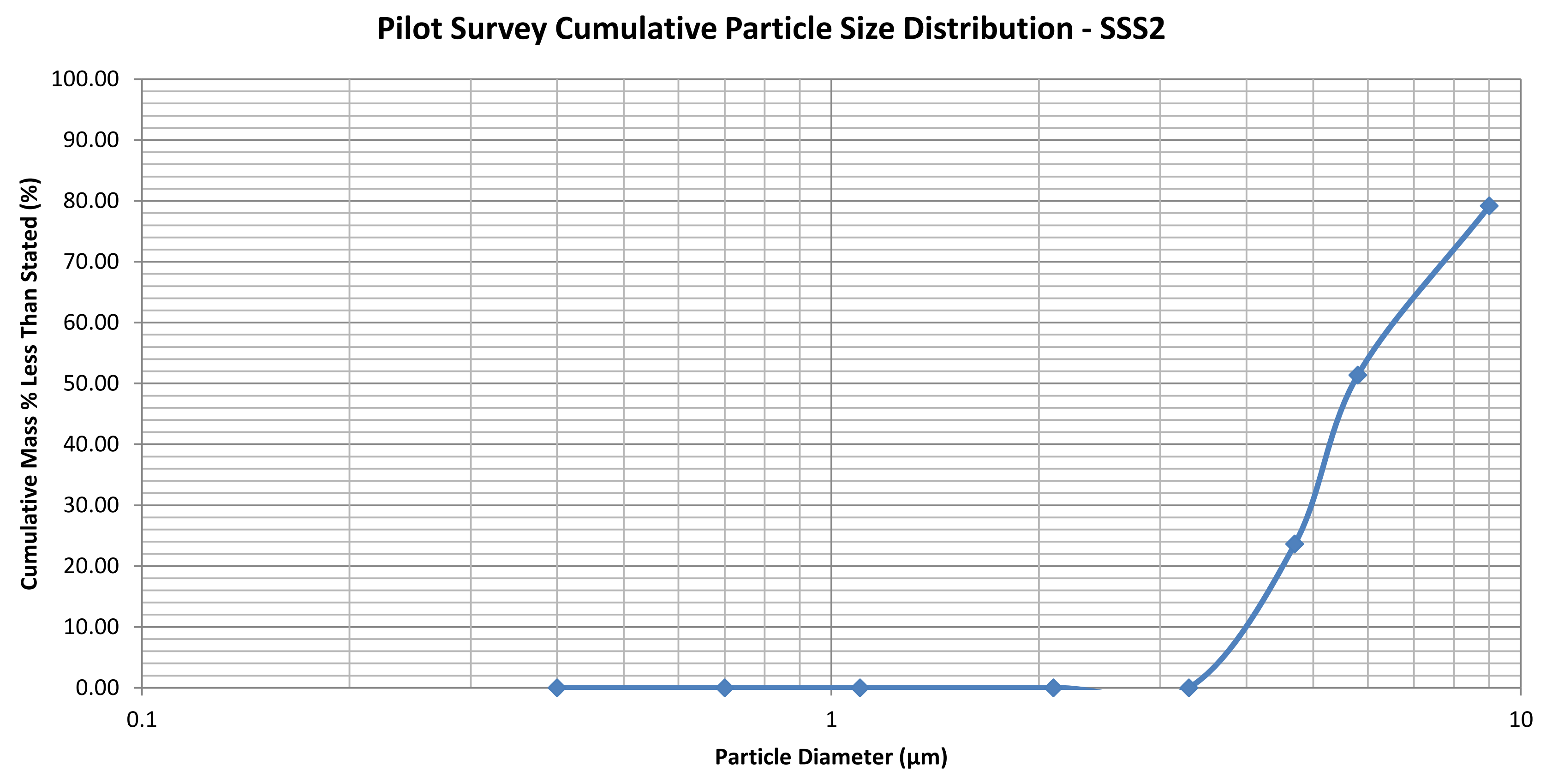


Figure 9A. Pilot Survey Cumulative Particle Size Distribution – SSS2

Appendix I. Comparative Analyses

Table 29A. Particle Size Distribution Comparison within Sampling Train Results

Particle Size Distribution Comparison Within Sampling Train Results								
Size Selective Sampling Train	**Stage**	**Particle Size Range (µm)**	**Mass Percent by Stage (%)**			**Percent Difference (%)**		
			Survey 1 Mass Percent	Survey 2 Mass Percent	Survey 3 Mass Percent	Percent Diff. Surveys 1 & 2	Percent Diff. Surveys 1 & 3	Percent Diff. Surveys 2 & 3
1	Filter	0 - 0.4	1.07	1.32	0.16	20.59	148.44	157.03
	7	0.4 - 0.7	1.30	3.70	1.01	95.70	25.77	114.41
	6	0.7 - 1.1	4.37	6.61	3.34	40.63	26.86	65.70
	5	1.1 - 2.1	11.13	12.29	10.02	9.88	10.52	20.35
	4	2.1 - 3.3	14.50	13.47	14.04	7.37	3.23	4.14
	3	3.3 - 4.7	16.12	16.64	18.18	3.22	12.02	8.80
	2	4.7 - 5.8	9.59	8.32	9.70	14.19	1.09	15.27
	1	5.8-9.0	20.03	18.36	21.30	8.69	6.16	14.83
	0	> 9.0	21.87	19.29	22.26	12.57	1.74	14.30
	Avg					**23.65**	**26.20**	**46.09**
	Median					**12.57**	**10.52**	**15.27**
2	Filter	0 - 0.4	0.29	1.86	0.50	146.64	54.42	115.21
	7	0.4 - 0.7	1.43	5.75	1.69	120.10	16.49	109.01
	6	0.7 - 1.1	6.98	7.45	4.26	6.57	48.37	54.51
	5	1.1 - 2.1	15.58	16.15	13.60	3.57	13.62	17.16
	4	2.1 - 3.3	15.11	15.37	16.29	1.76	7.55	5.80
	3	3.3 - 4.7	19.02	17.24	19.67	9.87	3.36	13.21
	2	4.7 - 5.8	12.14	12.58	15.60	3.53	24.94	21.46
	1	5.8-9.0	18.45	14.13	19.24	26.52	4.16	30.60
	0	> 9.0	10.99	9.47	9.15	14.88	18.33	3.48
	Avg					**37.05**	**21.25**	**41.16**
	Median					**9.87**	**16.49**	**21.46**

Formulas:

Percent Difference: (|[Mass Percent Survey$_a$] - [Mass Percent Survey$_b$]|) / (([Mass Percent Survey$_a$] + [Mass Percent Survey$_b$]) / 2)

Appendix I. Comparative Analyses (Continued)

Table 30A. Particle Size Distribution Comparison between Sampling Trains

Particle Size Distribution Comparison Between Sampling Trains										
Stage	**Particle Size Range (µm)**	**Survey 1**			**Survey 2**			**Survey 3**		
		Mass SSS1 (g)	Mass SSS2 (g)	Percent Difference	Mass SSS1 (g)	Mass SSS2 (g)	Percent Difference	Mass SSS1 (g)	Mass SSS2 (g)	Percent Difference
Filter	0 - 0.4	0.00007	0.00001	129.41	0.00005	0.00006	18.18	0.00001	0.00004	90.91
7	0.4 - 0.7	0.00009	0.00008	12.50	0.00014	0.00018	27.69	0.00009	0.00014	34.78
6	0.7 - 1.1	0.00028	0.00037	24.62	0.00025	0.00024	4.08	0.00032	0.00034	7.63
5	1.1 - 2.1	0.00073	0.00081	11.69	0.00046	0.00052	11.17	0.00095	0.00108	13.79
4	2.1 - 3.3	0.00094	0.00079	17.87	0.00051	0.00050	2.99	0.00133	0.00130	1.90
3	3.3 - 4.7	0.00105	0.00100	5.38	0.00063	0.00055	12.66	0.00172	0.00157	8.83
2	4.7 - 5.8	0.00062	0.00064	1.59	0.00032	0.00041	25.00	0.00091	0.00125	30.56
1	5.8-9.0	0.00131	0.00097	29.96	0.00070	0.00045	41.74	0.00201	0.00153	26.80
0	> 9.0	0.00142	0.00058	85.00	0.00073	0.00031	82.13	0.00210	0.00073	96.82

Mean Percent Difference Between SSS1 and SS2, All Surveys - Stages 1, 2, 3.....Filter = **24.65**

[1]*Mean Percent Difference Between SSS1 and SS2, All Surveys - Stages 1, 2, 3.....Filter =* **16.88**

Median Percent Difference Between SSS1 and SS2, All Surveys - Stages 1, 2, 3.....Filter = **15.83**

Mean Percent Difference Between SSS1 and SS2, All Surveys - Stage 0 = **87.98**

Median Percent Difference Between SSS1 and SS2, All Surveys - Stage 0 = **85.00**

Notes:

[1] Grubbs Test conducted on data set and two outliers removed, 129.41% and 90.91%

Appendix I. Comparative Analyses (Continued)

Table 31A. Grubbs Test for Outliers – Percent Difference Stage 1 – Filter

Grubbs Test for Outliers - Percent Difference, Stage 1 - Filter			
Data Raw	Data Sort$_a$	Data Sort$_b$	Data Sort$_c$
129.41	1.59		
12.50	1.90	1.59	
24.62	2.99	1.90	1.59
11.69	4.08	2.99	1.90
17.87	5.38	4.08	2.99
5.38	7.63	5.38	4.08
1.59	8.83	7.63	5.38
29.96	11.17	8.83	7.63
18.18	11.69	11.17	8.83
27.69	12.50	11.69	11.17
4.08	12.66	12.50	11.69
11.17	13.79	12.66	12.50
2.99	17.87	13.79	12.66
12.66	18.18	17.87	13.79
25.00	24.62	18.18	17.87
41.74	25.00	24.62	18.18
90.91	26.80	25.00	24.62
34.78	27.69	26.80	25.00
7.63	29.96	27.69	26.80
13.79	30.56	29.96	27.69
1.90	34.78	30.56	29.96
8.83	41.74	34.78	30.56
30.56	90.91	41.74	34.78
26.80	129.41	90.91	41.74
Std Dev	**29.14497**	**19.17115**	**11.637212**
Mean	**25**	**20**	**17**
max X_i	**129**	**91**	**42**
G	**3.59434**	**3.6935142**	**2.1360391**
Crit Value	**2.8217**	**2.8217**	**2.8217**
Reject T?	**yes**	**yes**	**no**

Appendix I. Comparative Analyses (Continued)

Table 32A. Independent Samples t-Test of Size Selective Sampling Results

Independent Samples t-Test of Size Selective Sampling Results		
	SSS1 Mass (g)	*SSS2 Mass (g)*
Mean	0.001036	0.000858
Variance	1.77E-06	1.13E-06
Observations	29	29
Pooled Variance	1.45E-06	
Hypothesized Mean Difference	0	
df	56	
t Stat	0.562087	
P(T<=t) one-tail	0.28815	
t Critical one-tail	1.672522	
P(T<=t) two-tail	0.5763	
t Critical two-tail	2.003241	

Appendix I. Comparative Analyses (Continued)

Table 33A. Total Dust – Size Selective Sampling Concentration Comparison

Concentration Comparison - Total Dust vs. Size Selective Sampling			
Survey	SSS Conc. Mean SSS 1 &2 (mg/m^3)	TD Conc. Mean TD 1 &2 (mg/m^3)	Percent Difference (%)
1	13.16	11.37	14.60
2	7.96	7.63	4.34
3	12.92	12.20	5.78
Avg	**11.35**	**10.40**	**8.24**

<u>Formulas:</u>

Percent Difference: (|[SSS Conc Survey$_a$] - [TD Conc Survey$_a$]|) / (([SSS Conc Survey$_a$] + [TD Conc Survey$_a$]) / 2)