ABSTRACT

JEFFREY JOHNSON. Determination of Respirable Mass Concentration Using a High Volume Air Sampler and a Sedimentation Method for Fractionation.
(Under the direction of PARKER REIST)

A preliminary study of a new method for determining respirable mass concentration is described. This method uses a high volume air sampler and subsequent fractionation of the collected mass using a particle sedimentation technique. Side-by-side comparisons of this method with cyclones were made in the field and in the laboratory. There was good agreement among the samplers in the laboratory, but poor agreement in the field. The effect of wind on the samplers' capture efficiencies is the primary hypothesized source of error among the field results.

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INTRODUCTION

A method for determining respirable mass concentration using a high volume air sampler has been developed. This method provides a quick, simple, and inexpensive means for determining respirable concentration using the standard high volume air sampler. A particular advantage of this method is that it does not require a bulky, as well as expensive, size selective inlet, and it may be adapted to other size selection classifications. A thoracic or inhalable mass concentration can be determined using this method. This method may be used to asses respirable concentrations retrospectively, by analyzing previously collected filters.

There are several alternative methods for determining respirable mass concentrations. These often require expensive equipment and a skilled operator. For example an impactor is expensive, and difficulties can arise in obtaining reliable results. An additional method would be to use a personal size selective sampler, a cyclone. In fact, the accuracy of the developed method will be assessed using a cyclone. Also, at this time a respirable size selective inlet does not exist for a high volume air sampler.

The method for determining respirable mass concentration will require a high volume air sample, and a subsequent fractionation of the collected particles. The fractionation method will be the liquid sedimentation technique using the Andreasen sedimentation pipette. A slight modification of this technique will be implemented to enhance representation of results.

This technique was used in a study concerning silica exposures while sandblasting.[1] That study was focused on the actual exposures, rather than the method of determining respirable mass concentration. So a quantitative comparison of the high volume sampler method (HV method) to the cyclones was not performed. But the results seem to indicate a general trend of agreement. That preliminary study formed the basis of the quantitative evaluation of the HV method reported here. The HV method evaluation was performed in the field, as well as in the laboratory.

BACKGROUND

Respirable particulate material is defined by the American Conference of Governmental Industrial Hygienists (ACGIH) as an aerosol with a median aerodynamic diameter of 4.0 micrometers.[2] This aerosol is capable of depositing in the gas-exchange region of the lung. Some materials exhibit toxicity only when deposited in the gas exchange region, therefore accurate quantification of this material is very important.

The proposed sampling method is an alternative to the typical methods of respirable mass sampling. With any new method, accuracy and precision must be determined before any confidences can be expressed. To determine the accuracy and precision of this method, experimental results must be compared to results from an accepted and trusted method. The selection of the most trusted and accepted method for determining respirable mass concentration was a very important decision in this study. The selected method should be preferred by experts now and into the future, providing longevity to the results. The method should accurately and reliably quantify respirable mass concentration.

The most commonly used, and presumably trusted, method in the occupational setting employs a device called a cyclone. A cyclone is a size-selective sampler that will remove particles that are larger than those of interest. This allows the particles of interest to pass through the device and collect on a filter for quantification. In theory, a cyclone can be designed to exclusively permit all particles below one size range to be collected. This instrument can have the sole purpose of providing respirable mass concentration. This specialization provides the best method for producing consistent respirable mass concentration. Therefore, a cyclone of some size, design, and composition should provide the study with the most accurate and reliable standard.

A cyclone's particle size-selective range can vary depending on its size, design, and construction material. The size of a cyclone refers to its internal diameter. This internal chamber is where most of the size selecting takes place. Generally, smaller

cyclones cut at smaller particle diameters. The size cyclone recommended by the ACGIH is a 10 mm cyclone.

The internal design of the cyclone, is quite important. Air and particles entering the cyclone must pass through the inner chamber to accelerate larger particles to the interior walls, where they can be collected. A potentially severe problem occurs when particles are allowed to bypass the inner chamber and go straight through the cyclone. Without the circular acceleration the larger particles will not be removed, instead they will be collected on the filter and incorrectly assumed to be respirable. Moreover, larger particles contribute much more mass per particle than smaller particles. A few large particles incorrectly assigned as respirable, can drastically and incorrectly increase the collected mass. Therefore the cyclone chosen must have an engineered barrier, preventing large particle bypass.

The material from which a cyclone is made is a variable that has received considerable attention, due to the highly suspected influence of electrostatic charge. The issue of charging effects has lead to two general types of construction materials, conducting or semiconducting (metal) and nonconducting (nylon). Several studies have been carried out that compare nylon and metal cyclones. A common problem with these studies is that they used the horizontal elutriator, which emulates the British Medical Research Council (BMRC) curve, as the frame of reference. With this frame of reference, conclusions concerning the ACGIH definition of respirable are difficult to derive. Nevertheless, trends and relative differences are revealed.

Sass-Kortsak *et al.* compared the 10 mm nylon to a 9 mm aluminum cyclone with the horizontal elutriator as the standard for comparison.[3] The test aerosols were silica and wood dusts. The silica was a commercially available dust sieved with a 325 mesh. The wood dust was manufactured by placing a beltsander on a piece of mahogany wood. A blender was used as the aerosol generator. The effect of aerosol type and relative humidity was also evaluated.

That study found that in all cases the nylon cyclone undersampled, while the metal cyclone oversampled. The metal cyclone always reported a higher respirable dust concentration than the nylon cyclone. The study also found that when sampling wood dust, differing relative humidities did not seem to change the sampling results. But when silica dust was used a trend emerged. As the relative humidity went up, the nylon cyclone passed a higher concentration of silica particles. This trend was not found in the metal cyclone. The reason for this discrepancy probably involves electrostatic charging effects, which are more apparent in low humidity environments. The apparent difference between wood and silica dust, according to the authors, is due to humidity in the wood reducing electrostatic effects.

The Sass-Kortsak study showed that the metal cyclone consistently oversampled, while the nylon cyclone consistently undersampled. But, this conclusion can not be reached when the ACGIH criterion is the relevant standard. This study used a horizontal elutriator which size-selects according to the BMRC criteria. What can be concluded is that the metal cyclone consistently reported a higher concentration than the nylon cyclone. Without a relevant ACGIH relevant standard, determining which is "correct" is very difficult.[3]

Verma *et al.* conducted a hard rock mining field study comparing the 10 mm nylon cyclone to the SIMPEDS and BCIRA metal cyclones.[4] Again, the reference sampler was the horizontal elutriator which performs according to the BMRC criteria. In this study the nylon cyclone reported a lower respirable concentration compared to the metal cyclones, but the difference was not statistically significant. Sampling was conducted in mines with high humidities. Given the information in the Sass-Kortsak *et al.* study concerning humidity, we would expect the nylon cyclone to report relatively higher concentrations, due solely to humidity effects. So, the statistically nonsignificant difference is probably correct, given this humid environment.[4] Another concern is the comparison of a sampler designed to conform to the ACGIH criteria, being compared to

the BMRC criteria, namely the horizontal elutriator. The ACGIH and BMRC criteria are slightly different. The criteria have differing median cut points, 4 μm for the ACGIH and 5 μm for the BMRC. Also, the BMRC definition has a smaller particle size range, ~0 to 7.1 μm, than the ACGIH definition, ~0 to 10 μm.[5] An inescapable error occurs when respirable dust concentrations, from samplers conforming to different criteria, are compared.

Knight *et al.* also compared the 10 mm nylon cyclone to the BCIRA metal cyclone, and other size-selective samplers.[6] Again the reference sampler was a horizontal elutriator. This study found that the nylon cyclones undersampled and the metal cyclones oversampled, with the BMRC criteria as the standard. These size-selective samplers were compared in the laboratory, as well as in the field. The laboratory aerosols were composed of 125 μm sieved coal (50% respirable) and commercially available silica sand (65% respirable). The field sampling was conducted in a hard rock mining environment. The sampling results were very similar for the two environments. The authors mention charge build up as contributing to the nylon cyclone's under sampling. The authors went so far as to state "It would appear prudent to build cyclones and filter holders from metal or semi-conductors rather than insulators to minimize such effects." Finally the authors said the metal BCIRA is better for hard rock mining sampling than the nylon cyclone. One must keep in mind the BCIRA cyclone is designed to perform to the BMRC's criteria. So, its performance should match the BMRC's criteria better than a sampler designed to meet the ACGIH's criteria. The authors did go on to say that the nylon cyclone is "adequate" for sampling in these environments.[6]

The overwhelming issue with nylon cyclones seems to be electrostatic charging altering its efficiency. Several other articles indicate that charging effects significantly alter the performance.[7,8,9] Briant *et al.* compared a cyclone constructed of graphite with a nylon coating, to a normal nylon cyclone.[8] The graphite filled cyclone was not found

to be influenced by electrostatic effects. The authors of these articles recommend that cyclones be constructed of electrically conducting materials.

It seems that conducting or semiconducting cyclones outperform their nylon counterparts. Yet, the problem with making this decision is that these studies did not evaluate the performance of the size-selective samplers, using the ACGIH criteria. All related studies use the BMRC criteria as the basis of comparison. The problem may have resulted from how the criteria were developed. The BMRC criterion is based on the performance of the horizontal elutriator, while the ACGIH criteria resulted from the Atomic Energy Commission's (AEC) medical studies of particle deposition in the lung. The size selective sampler that best emulates the BMRC criterion is the sampler which is based on the BMRC criterion. The ACGIH definition it is not that simple. It is based on the cumulative probability function of a standardized normal variable, or a mathematical relationship. The difficulties arise when we try to design a machine that will perform to this criterion, instead of making the criteria "perform" to the machine, as with the BMRC. A possible interpretation of this is that no one really knows which sampler best emulates the ACGIH criteria; therefore the ACGIH criterion is not used by investigators as the basis of comparison for sampler evaluation.

Given the recommendations of the previously mentioned studies a cyclone constructed of conducting material seems to be a prudent choice. There is an unverifiable suspicion of over sampling, which if so, provides a more conservative estimate of exposure. Using the metal cyclone errs on the side of safety for the employee. There is substantial evidence that the nylon cyclone is subject to electrostatic charge, and can report a concentration less than actual. This concern is eliminated with a cyclone constructed of a conducting material. The cyclone used in this study was constructed of conducting materials, for the aforementioned reasons.

Although the ACGIH specified cyclone as of this writing is a 10-mm nylon cyclone, the evidence suggests that a conducting cyclone will perform better by

eliminating electrostatic influences. Moreover the 10-mm nylon cyclone is designed to cut at 3.5 micrometers, instead of the recently adopted criteria where 4 micrometers is suggested as the 50% cut. The cyclone used in this study will need to perform according to the new criteria. This is an additional reason for not using the ACGIH specified 10-mm nylon cyclone.

Finally, the results of the previously mentioned studies aid in the sampler selection process. Yet care must be taken when direct comparisons of the studies are performed, due to the use of different aerosols. Different aerosols will produce different results, depending on their size distributions. For the this study the relative differences between samplers were the major concern. Thus a rigid quantitative assessment is not needed.

The chosen standard for comparison in this study is the 10-mm steel cyclone produced by BGI. The specific model number is the BGI-4. The dimensions of the cyclone produce a cut at 4.0 micrometers, consistent with the new ACGIH criteria. The BGI-4 has an inner barrier to prevent or minimize particle bypass. Its steel construction minimizes effects due to electrostatic charging. This cyclone is not specified by the ACGIH now, but given its advantages, may be specified in the future. This cyclone seems the prudent choice for providing longevity to the results of this study.

METHOD DESCRIPTION AND THEORY

The proposed method consists of a high volume air sample, with a subsequent particle size analysis using a liquid sedimentation technique. A high volume air sampler is equipped with a standard 8x10 inch glass fiber filter, and allowed to run until a layer of particles accumulates. Once this "cake" has formed the sample is ready for analysis. The formation of the cake is an absolute necessity for several reasons. Cake formation insures that there is enough removable material for analysis. Without sufficient material the sedimentation technique will lose considerable accuracy, or make analysis impossible.

Furthermore, cake formation ensures that the material removed for analysis is representative of the aerosol's size distribution. Although the glass fiber filter may have an efficiency close to one with initial use, all particles captured can not be removed for analysis at this point. The smaller particles tend to embed deep within the filter making removal difficult. Analysis without these particles would produce an altered distribution. So, as the pores in the filter become filled, the cake forms. The smaller particles will embed in the cake, as opposed to the filter itself. Thus, when the cake is removed for analysis, it contains the smaller particles of concern.

After sample collection, the particles are removed from the filter by scraping the cake with a dull edge. When scraping the particles from the filter, care must be taken not to remove filter material. This material contributes mass that can be mistakenly quantified as aerosolized particles. Preventing this invariably results in material remaining in the filter. Yet, this is not a concern as long as a sufficient cake has formed.

The removed particles are then placed into a sedimentation pipette for fractionation. The fractionation method was developed by Reist and Creed.[10] This method is based on particle settling velocity in a medium, water for this study. The settling velocity is determined by Stokes' law. Particles of different diameters will reach different terminal settling velocities, thus falling different distances within the medium in

a given time. The differences in distance fallen separate the particles. The particles with larger diameters will fall faster and thus farther from a given point than the smaller diameter particles. This relationship is represented by the following formula:

$$d = \sqrt{\frac{18\mu y}{(\rho_p - \rho_m)gtC_c}} \qquad (1)$$

d = particle diameter (cm) Stokes' diameter
μ = viscosity of medium (g cm^{-1} sec^{-1})
y = distance particle has fallen (cm)
ρ_p = density of particle (g cm^{-3})
ρ_m = density of medium (g cm^{-3})
g = acceleration of due to gravity (cm sec^{-2})
t = time (sec)
C_c = slip correction factor, 1 for the size range of concern

The diameter provided by equation (1) is the Stokes' Diameter.[11] The Stokes' diameter is the "diameter of a sphere of the same density as the particle in question having the same settling velocity as that particle."[11] For the purpose of this study we need an aerodynamic diameter, as opposed to a Stokes' diameter. The aerodynamic diameter is the "diameter of a unit density sphere (density = 1 g/cm^3) having the same aerodynamic properties as the particle in question."[11] This states that as long as the terminal settling velocities of two particles are the same, regardless of physical size and/or shape, they will have identical aerodynamic diameters.[11] To convert the Stokes' diameter to an aerodynamic diameter, the Stoke's diameter is multiplied by the square root of the particle's density. This transformation is necessary when comparing the sedimentation technique's results to the cyclone's results, because the cyclone's performance is based on aerodynamic diameter.

The particles of primary interest in the analysis were composed of quartz, thus the a density of 2.65 g/cm^3 was used in equation (1). The use of one density to describe all particles in the sample results in an error. Reist and Creed, developers of the sedimentation method, determined that this error would be less than 10 % as long as the

true particle densities were 2.0 g/cm^3 or greater. The use of a 2.65 g/cm^3 value for density will result in significant error with particles having a density lower than 2.0 g/cm^3.

Given the particle size information, determined by equation (1), the percentage of particles at any desired size can be determined. This is accomplished using a sedimentation pipette, filled with water and the material of concern. The sedimentation pipette consists of a cylinder and a pipette with a 3-way stopcock that can be fixed at a given height inside the cylinder. After addition of water and material, the system is shaken to ensure complete mixing. At time intervals, determined by equation (1) 10 ml aliquots are removed and placed into preweighed drying pans. Once dry, the mass remaining on the pans is used to produce the particle size distribution. The analysis will produce a plot of particle size versus percent less than that size. An example is provided in Fig. 1. The percentage of particles at any desired size and smaller can be found from this plot. The reader is advised to consult the original study by Reist and Creed, for additional details.

A slight modification of the Reist and Creed method was needed for this study. They state, "The weight of each sample is expressed as a percentage of the first sample drawn to give the percentage of the suspended particulates having particle sizes equal to or smaller than that given by equation (1)."[10] This states that all fractions are based on the first aliquot that is drawn. This procedure seemed to produce an error between the HV and cyclone method for determining respirable mass concentration.

The alternative method uses the mass obtained from a theoretical 10 ml aliquot of the initial concentration, as the frame of reference. The initial concentration refers to the mass of material in the total volume of water. This frame of reference is needed, as opposed to the first drawn aliquot, because these samples contain very large grains. These large grains, when analyzed with the sedimentation technique, fall quickly and have no chance of being drawn up in the first aliquot. The Reist and Creed

computational method assumes that the first aliquot contains the relative mass contribution of all particles in the suspension. This is valid when these large grains are not present. Yet when they are present, their contribution is not recognized. This makes the respirable fraction increase, because the denominator in the ratio, respirable aliquots to first aliquot, is lower. This phenomenon results in a significant error in the fractionation process. Additionally, these large grains contribute considerable mass to the Total Suspended Particulate (TSP) concentration, from which the respirable concentration is derived. Large grains will boost the TSP and subsequently the respirable concentration. So, the contribution of the large grains is recognized in the TSP concentration, but not in the fractionation process. The alternative method solves this problem by accounting for the large grains in the fractionation process.

The respirable concentration from the HV method is found by first determining the respirable mass collected on the filter. This is accomplished by determining the fractions of total mass on the filter between successive values of diameter in the ACGIH respirable mass definition. These fractions of total mass between successive values must be used, as opposed to the values themselves, due to the format of the sedimentation method. The results are presented as previously stated, as diameter versus percent less than that diameter. The values themselves cannot be used because the method does not indicate the percentage of particles at any one distinct size. The method indicates the percentage of particles of a given size and smaller. A range of particle sizes must be used. The particle size range is then set to be the fraction between successive values in the ACGIH definition. Table 1 provides a sample of respirable mass determination, using this method.

These fractions, column D, are then multiplied by the total mass collected on the filter to provide the mass of particles between successive values, column E. The midpoints of the percentages indicated for each size from the respirable definition, column G, are then multiplied by the corresponding mass for that size, column E to

produce the respirable mass for each size range, column H. Since these masses are for sizes between successive values of the respirable definition, the midpoints of the percentages indicated for each size are used. The masses in column H are summed to provide the respirable mass.

FIELD PROCEDURE

The BGI-4 cyclone and the high volume sampler were run side by side in the field. The sampling runs were conducted at the construction site of a hazardous waste landfill. This construction site was located in Richland, Washington on the Department of Energy's Hanford site. Richland's desert climate and sandy soil produce significant dust storms when strong winds occur. This, as well as the construction traffic, generated sufficient dust for the study.

The cyclone was originally equipped with cellulose nitrate filters with a nominal pore size of 0.8 μm. These filters were found to be highly hygroscopic, and provided erratic weights. In subsequent runs, Polyvinyl Chloride (PVC) filters with a nominal pore size of 5 μm replaced the cellulose nitrate filters and produced stable and reliable filter weights. The filters were desiccated before and after sample collection and weighed on a Mettler M3 balance with a resolution of 0.001 mg. With the filter and filter pad in place the cyclone's flow rate, 2.2 lpm for the BGI-4, was calibrated using a Sho-Rate ERC 803 rotameter. The rotameter was calibrated with Gillian Gilibrator having a 20 cc to 6 lpm range. The pump used was an AC powered Allegro Industries A-100 vacuum pump. The pump was originally equipped with a SKC 2-inlet adjustable flow manifold. This manifold was used so two cyclones could be run simultaneously. The pump was later equipped with a SKC 4-inlet adjustable flow manifold, for 2 cyclones and 2 total dust measurements. This air sampling train was not flow correcting. But, post sampling calibration did not show a significant drop in flow rate for the loaded filters. The total dust measurements were to be compared to the high volume TSP. The pump and cyclones were placed in a well-vented housing. The purpose of the housing was to provide protection for the pump and to slow air speeds down in the event of dust storms. It was not presumed that the cyclone with a flow rate of 2.2 lpm would be able to capture particles in a 30 mph wind storm. The housing was supposed to slow the moving air sufficiently for representative sampling. The effects of the housing were

assessed by placing one cyclone inside and one outside the housing. The samplers were run until a cake had formed on the high volume air sampler filter.

The high volume sampler, model number 2310, is a product of General Metal Works Incorporated, a subsidiary of Andersen Samplers. The sampler is equipped with an anemometer flow controller and an Engler timer. The 8x10 glass fiber filter, produced by Grasbey was desiccated in an 185° Celsius oven before and after sampling. The desiccated filter was weighed on a Mettler AE 163 balance with a resolution of 0.0001g. After post weighing the loaded filter, it was gently scraped with a dull edge, to remove the particles for sedimentation analysis. The material removed from the filter and used in the analysis was weighed, on the Mettler AE 163 balance. The material was then transferred to the sedimentation pipette along with a known quantity of water. The initial concentration is calculated from the ratio of material to quantity of water. The solution is shaken for five minutes. In the meantime, metal pans used for holding and drying the aliquots, are numbered and preweighed. The metal pans are weighed on the Mettler AE 163 balance with a resolution of 0.0001g. At predetermined time intervals, 10 ml aliquots are taken using the pipette, and placed in the metal pans. The pans and their contents are dried, in the previously mentioned oven, and reweighed. The net weights of the pans are used for determination of the distribution. As discussed earlier, the fraction at each size range is determined by the ratio of the corresponding pan net weight to the mass in the theoretical 10 ml aliquot of the initial concentration. These fractions produce the percentage of particles smaller than the coinciding diameter.

A log-probability plot of diameter versus percentage of particles smaller than that diameter is performed. This plot is usually linear and a line of best fit can be determined. From this line, the fractions used in the previously mentioned respirable mass determination, are found. The percent error between the two respirable concentrations, with the cyclone as the standard, is determined for each run.

In the later runs, five measurements were made during each run: the high volume TSP concentration, 2 total dust measurements using a closed face, 3 piece - 37 mm cassettes with a 2.2 lpm flow rate, and 2 respirable dust measurements using the cyclone operated at 2.2 lpm. An attempt was made to orient the cassette perpendicular to the ground, yet the inlet sometimes shifted during sampling. A 37 mm cassette and cyclone were paired and located on the outside of the housing while the other pair remained on the inside. This was the typical sampling train for later runs. Earlier runs did not include the 37 mm cassette total dust measurements.

Ten distinct sampling runs were made at the construction site. The sampling train was altered as different questions were asked and problems arose. The sampling configuration originated with one high volume sampler and two cyclones positioned inside the housing. Four runs were made with this configuration. The error between the high volume technique and cyclone was quite erratic. The source of error was sought, and the cyclone housing was a possible influence that could be controlled. The next run had one cyclone inside the housing and one outside the housing. With significant error still unexplained, 37 mm cassettes were employed to measure total dust. The sampling train for the remaining five runs consisted of a high volume sampler and one cyclone and one 37 mm cassette outside the housing, with an identical pair inside the housing.

LAB PROCEDURE

The need for sampling runs conducted in a controlled environment was found necessary after completion of the field runs. The field results seemed erratic necessitating sampling where variables such as wind, aerosol size and composition, humidity, and aerosol concentration could be controlled. The laboratory trials were conducted in a 10' by 10' by 8.5' chamber, where temperature and humidity were held relatively constant. Air currents in the chamber were generated by the exhaust system's pull of air into the chamber, as well as, the aerosol ejector's air trajectory. These variables were held constant for all sampling runs in the chamber.

The aerosol size and composition were altered to investigate a possible influence upon the HV method. Twelve different aerosols were used, ten of which originated from agricultural soil. The other two aerosols used in this study were fine and coarse Arizona Road Dust (ARD). The ten agricultural-soil aerosols were produced from five separate bulk soil samples. Each bulk sample was sieved at 1.0 mm and 53 μm to produce two distinct aerosols per soil, making ten total aerosols. The 1 mm and 53 μm sieve points were chosen based on the experience of the field trials. Extremely large grains, approximately 1 mm were found on the field samples taken in the desert climate of Richland, Washington. These large grains along with high winds were believed to cause the erratic results seen in the data, due to the different sampling efficiencies.

Yet it is theorized that large grains would not affect the respirable concentration of the HV method. The mass contribution of the large particles would lower the respirable fraction by increasing the total mass on the filter. But the lowering of the respirable fraction would be offset by an increased total mass, resulting in approximately the same respirable concentration. Aerosols with these sieve points were used to determine if large grains alone were responsible, although theory suggest no possible influence. Ideally this portion of the procedure would have been conducted in a wind

tunnel to test the influence of wind as well as large grains. This laboratory setting would have been more representative of field conditions, but was not possible.

Agricultural soils were chosen so that respirable quartz content could be investigated in a concurrent study. The bulk samples were taken from five agricultural sites in Johnston County, North Carolina. Each aerosol was sized by the sedimentation method to determine respirable fraction and mean aerodynamic diameter. Table 2 provides a list of the aerosols used in this study, with the corresponding respirable fraction and mean aerodynamic diameter.

The setup for the fifty total runs conducted in the chamber consisted of a high volume air sample, 2 respirable mass samples, and two total dust samples. The high volume air sampler was placed inside a General Metal Works housing, with the cyclones and 37 mm cassettes affixed to the housing by a series of rods and clamps. The cyclones and 37 mm cassettes were approximately 2 feet from the housing inlet, and were not enclosed by a separate housing.

The original sampling train for the respirable and total dust samplers employed a Gast air pump with a series of Ys, clamps, and rotameters, providing 4 sample lines where flow could be regulated individually. This sampling train was found to be unreliable in maintaining a predetermined flow rate. The high filter loadings induced a sufficient pressure drop, so that flow rate was altered. Ten of the fifty runs were made with this sampling train. To eliminate this problem flow correcting personal sampling pumps were employed for the respirable and total dust measurements. The ten runs conducted with the original setup were repeated with the flow correcting pumps. Table 2 also lists the number of values for each configuration and aerosol. The chamber and all sampling equipment were cleaned between runs, where different aerosols were used. This eliminated the possibility of contamination.

The aerosol was produced with a rotary feed ejector. This machine operates by filling a groove, in a horizontally rotating wheel, with the bulk aerosol. The rotating

filled groove delivers a fixed quantity of material at a constant rate to the ejector. The material is aspirated from the groove using a compressed air ejector. The ejection rate is controlled by varying the speed of the turning wheel. A diagram of the laboratory setup is provided in Fig. 2.

Each run was conducted with a constant aerosol feed rate. The run continued until the pressure drop across the high volume sampler denoted sufficient loading for analysis. The method requires at least 2-3 grams of material be deposited on the filter, to have sufficient material to analyze with the sedimentation technique. Loadings below this will not provide reliable aliquot weights when the sedimentation analysis is performed. The filter loadings for the laboratory and field portion of the study were equivalent, both being based upon the collection of a sufficient mass. The sedimentation analysis for each run was conducted the same as described in the field procedure.

DATA ANALYSIS

The respirable method data, in Appendix A, was analyzed by two different procedures. To test for statistically significant differences among the methods, the two-way ANOVA was employed. This test also examined the possible interaction between HV method and aerosol, and HV method and concentration. To conduct this analysis the concentration values had to be standardized so that a possible aerosol effect could be observed. Without this procedure concentration and aerosol effects would be indistinguishable. The respirable concentration values were standardized by dividing the respirable concentration by HV TSP concentration for that specific run. This results in a respirable fraction value for each method, which theoretically should be identical. The respirable fraction for this study is defined as the respirable mass in an aerosol divided by all suspended mass in that aerosol. The high volume sampler is assumed to collect all suspended particles in a given aerosol, and therefore provides a sound basis for the respirable fraction.

For each test the null hypothesis is: At the 95% confidence level there is not a statistically significant difference between the methods. Notationally, is as follows:

$$H_0: \mu_{\text{HV respirable. fraction}} = \mu_{\text{Cyclone respirable. fraction}}$$

$$H_A: \mu_{\text{HV respirable. fraction}} \neq \mu_{\text{Cyclone respirable. fraction}}$$

$$\alpha = 0.05$$

In the results a P value greater than 0.05 indicates there is not a statistically significant difference while a P value less than 0.05 indicates there is a statistically significant difference between the means.

The interaction terms are used to indicate a change in the method as other variables change. This was used to decide if aerosol composition alters the method

results. A significant P value for the interaction of respirable method and aerosol would indicate that the HV method results are changing with respect to aerosol composition.

Before the previously described procedures were performed all data points where the respirable concentration exceeded 30 mg/M^3 were removed. Respirable concentrations above 30 mg/M^3 are very rare and do not represent "real world" conditions. However these points remained in the data set when concentration effects on the HV method were evaluated. The data were grouped by HV TSP concentration into the following categories: ambient concentration (less than 1 mg/M^3), 23 - 59.99 mg/M^3, 60 - 99.99 mg/M^3, and 100 + mg/M^3. The category ranges were chosen arbitrarily. A significant P value for the interaction of respirable method and concentration would indicate a change in method results as concentration changes.

The other procedure used in the analysis was calculating the mean and standard deviation of the absolute values of percent error. The absolute percent error calculation for the respirable method data is as follows:

$$\text{Percent Error} = \frac{|\text{Hi Vol Respirable concentration - Cyclone Concentration}|}{\text{Cyclone Concentration}} \text{ X } 100$$

The absolute value must be used in the numerator so that when calculating the mean, positive and negative values do not cancel out. If positive and negative values were allowed to cancel out the reported error would be lower than actual. Also, the cyclone is the standard for comparison, thus it is used as the "correct" value in the equation. This procedure is used to show the magnitude of the relative differences between the methods.

The agreement between HV TSP concentration and a 37 mm cassette concentration was also evaluated, as a secondary focus. The data for the comparison of these two TSP methods are given in Appendix B. These data were analyzed by a slightly different procedure than the respirable method data. All values where an error occurred

in the procedure were deleted. These errors occurred much more frequently with the TSP method than the respirable method. Most of these errors were associated with material loss due to high loadings, which is not likely to occur with respirable samples. The TSP method data was not analyzed with the ANOVA procedure. The reason for this was the TSP data could not be standardized by dividing by the high volume sampler concentration, as was appropriate with the respirable results. This was not appropriate because the HV TSP "fraction" would always be 1. A HV TSP value of 1, for all measurements would provide a falsely low variance in the ANOVA analysis. The falsely low variance would cause the ANOVA analysis to reveal false differences in the data. For this reason, mean and standard deviation of percent error was used solely to evaluate the performance of the samplers. The absolute percent error calculation used an equation similar to the respirable method procedure. The absolute percent error calculation for the TSP method data is as follows:

$$\text{Percent Error} = \frac{\left|\text{HV TSP concentration - 37 mm Cass. TSP Concentration}\right|}{\text{HV TSP concentration}} \text{ X } 100$$

The HV TSP concentration was arbitrarily chosen as the standard for comparison.

The effect of soil type and concentration can not be evaluated by the significance of an interaction term. This must be done by subjective comparison of the percent errors for each group.

RESPIRABLE METHOD RESULTS AND DISCUSSION

The data were grouped according to Aerosol Group given in Table 2, for the procedures in the data analysis. Specific values for each procedure were generated for the data as a whole, and each aerosol group. These analyses produced the respirable and TSP method results provided in Tables 3 and 4.

The respirable method results, when all aerosols tested are considered together, suggest the methods do not have a statistically significant difference. This is indicated by the 0.0619 P value for HV method versus cyclone method. The corresponding average percent error of 34.78 %, with a standard deviation of 79.08 seems to contradict the ANOVA results. The statistically nonsignificant difference may be due to the large variability in the data set, as indicated by the large standard deviation. Excess variability reduces the ability to discern significant differences in the data. Thus the difference between methods is statistically nonsignificant, but the percent error indicates a sizable difference in the methods. The interaction term, Respirable method by aerosol type is highly significant (P value of 0.0001) implying the results of the method are significantly changing as the aerosol composition changes.

Given this significant interaction term the aerosols had to be separated into the previously mentioned aerosol groups to identify the specific aerosol or aerosols that were producing the overall significant difference. The results from the agricultural soils produced no significant difference, with a P value of 0.0802. The average percent error of 16.9 %, agreed with this finding. The variability was considerably lower, with a standard deviation of 13.77. The interaction term for this test was significant (P value 0.0226) suggesting a difference in methods as the soils varied. The P value for the overall test of soils was suspiciously close to the 0.05 value, which, taken together with the significant interaction term, seems to suggest an aerosol effect among the soils.

An alternative coding of soils was used to investigate this significant interaction term. The soils were coded according to how they sieved, 1.0 mm and 53 μm. This

would reveal a difference in method concerning very large particles, because the 1.0 mm soils would have very large grains, while the 53 μm soils would not. This interaction term was not significant (P value of 0.6074), indicating large grains were, statistically, not influencing the methods. This result confirmed the theorized lack of influence regarding large particles. Yet, the combined effect of wind and large particles which could have produced the erratic field results, remains concealed.

Fig. 3, the plot of the soils data, shows the fairly tight agreement with the methods. There seems to be a general trend towards the HV method providing a higher value as noted by more points above the perfect equality line. But, generally there seems to be good agreement. Also, the 1.0 mm and 53 μm soils seem to be giving consistent results, as indicated by equal proportions of data points for both groups around the equality line. This validates the nonsignificant interaction term found when the data was coded by sieved size.

Arizona Road Dust was the next aerosol group to be evaluated. All ARD runs were used in this evaluation, including the initial runs without the flow compensating pumps. The ANOVA results reveal a highly significant difference among methods with a P value of 0.0001. With this small of a P value one would expect a large average percent error, yet this was not the case. The average percent error was 17.94 % with a standard deviation of 10.47. The average suggests a decent agreement, yet statistically there seems to be a vast difference. In this statistical test the "vastness" of the difference is determined by the variability in the results. This data set has less variability, indicated by the lower standard deviation so that smaller differences will be recognized. The recognized statistical difference does exist, yet this difference has little significance considering the low average percent error. The nonsignificant interaction term for ARD implies statistically consistent results with both the coarse and fine ARD.

Fig. 4 displays this data, showing most data points centralized around the equality line. There is a tendency for the cyclone to report a higher concentration than the HV

technique. This is evident in the majority of points lying below the equality line. Care must be taken when the spread of points around the equality line for the ARD and soils data is compared to the field data. The axes are condensed in the ARD and soils plots for the larger concentration range. Condensing the axes makes the scatter appear to be less than if the axes were expanded.

The field results, coded as the ambient aerosol, provided respirable results inconsistent with the laboratory results. The values were so inconsistent that any effects due to the previously mentioned housing were no longer significant. The P value for the comparison of the methods was 0.1496 implying no significant difference. Yet the average percent error was 120.3 % with a standard deviation of 168.8. These values are inconsistent with the ANOVA results of a nonsignificant difference. The ANOVA results, as previously stated, are based on the variability in the data. The large amount of variability hides any real differences in the methods, causing the ANOVA analysis to report no significant difference. The large variability in this data is evident in the range of percent errors, -65.87% to 538.6%. Yet, 10 of the 18 values were within $\pm$ 27%. The plot of these data, Fig. 5, displays this information. The large variability is evident in the scatter of the points. The points with the greatest distance from the equality line are almost all favoring the HV method. This seems to show that, in this field sampling environment, when the methods diverge the HV method reports a higher respirable concentration than the cyclone.

A general trend appears when the direction of error for each aerosol group is examined. In the ambient and soils aerosols where the method respirable fraction was 0.01 to 0.15, the HV method concentration is higher, yet in the ARD aerosol groups where the respirable fraction is 0.19 to 0.43 the cyclone concentration is higher. A comparison of Fig. 3, 4, and 5 shows this trend. There appears to be a respirable fraction influence in the method, however its effect does not seem to alter the results significantly, as shown in the previous analysis.

Finally the effect of aerosol concentration was assessed using the procedure previously described. The interaction of respirable method and aerosol concentration provided a P value of 0.6026, suggesting a nonsignificant change in the method as the concentration changed. Except for the ambient concentrations, the percent error for each concentration grouping is around 20%, a respectable result. There does seem to be a trend in the data of average error increasing as the concentration increases. A similar trend is seen with the variability. The concentrations used in this analysis are very high and not applicable to the typical sampling situation. Also, this analysis is flawed in that each aerosol group is not represented in each concentration group. The ambient group (up to 1 mg/M^3) is composed of the field samples exclusively. Table 5, shows the aerosol representation for each concentration grouping. This data can only allude to a possible increase in error between methods, as concentration increases.

Overall the respirable method results possess good agreement in the laboratory portion of the study, but poor agreement in the field portion. The field results not only have poor agreement but also a large amount of variability. The source of this large variability and poor agreement that is present in the field data but not in the laboratory data must result from a variable that is controlled in the laboratory data, but not in the field. These include wind, aerosol size and composition, humidity, and aerosol concentration.

Also, significant sampling errors occurred in some of the field runs, which were solved when the laboratory portion of the study began. These errors included an improperly seated high volume sampler inlet, the use of cellulose nitrate filters for the cyclones, and the use of a non-flow-correcting pump for the cyclones. The leaking high volume sampler allowed suspended mass to bypass the filter, and made the accuracy of the volume of air sampled questionable. This error occurred in 6 of 9 sampling runs, which include the outliers, noted in Fig. 5. The cellulose nitrate filters were highly hygroscopic and produced erratic cyclone filter weights. This error occurred on 6 of 10

sampling runs, including the outliers. The non-flow-correcting pumps produced a significant error on one run where a large decrease in flow occurred. But, in the other nine runs the post calibration of the cyclones indicated no significant change in flow. Constant flow is important for cyclones, in order to maintain proper particle selecting performance.

These errors certainly contribute to the variability in the field data, but are not solely responsible for the discrepancy in the results. If these errors were the culprit, then the percent error would have been large for all of the first 6 runs, and small for the last 3 (9 total usable runs). Two of the first six runs had small percent errors, and 1 of the last 3 had large errors. This inconsistency lead to the conclusion that these errors are not the sole culprit for the discrepancy in the field data. It is the author's opinion that the ultimate source of the poor field results, is due to the wind and differing capture efficiencies, yet the sampling errors definitely contributed.

This field environment was subject to winds around 35 mph on occasion. The capture efficiency of a cyclone pulling 2.2 lpm and a high volume sampler pulling around 1200 lpm will not be the same in this environment. The high volume sampler is more likely to capture a representative size distribution than the cyclone. The cyclone was not designed for air with a considerable velocity and is less likely to collect particles, they will simply blow past the inlet. With low wind velocities such as in the sampling chamber, particle inertia is low, so inlet capture efficiency is less of a concern.

An additional source of variability could have resulted from different aerosol concentrations at the inlets. The samplers were placed in a construction site where heavy equipment was being operated. These pieces of equipment generated dust plumes as they traveled past the samplers. If the plumes reached one sampler and not the other an error will result. I did not observe this occurring, and over the 4 to 5 day sampling period any bias should even out. Yet it is a possible source of the discrepancy, although it is not very likely. A sampling position where individual plumes did not travel past the

samplers would have been more favorable. But due to limited time to conduct the study, the author chose to sample in the position with the highest available concentration. This was needed to load the filters as quickly as possible so that a maximum number of samples could be collected before the conclusion of the field study. In this location the filter would load in approximately 3 to 10 days, whereas a position without a point source would have taken considerably longer.

For example, an identical sampling train was set up near a coal-powered power plant in North Carolina. After running the equipment for 3 weeks there was still not enough material to analyze. So a TSP concentration of at least a few hundred $\mu g/M^3$ is needed to attempt this technique. There needs to be at least 1.5 grams of material to analyze and one can assume about 75% removal efficiency, so that the filter needs at least 2 grams of collected material before the method can be attempted. This is not feasible in some sampling environments.

An additional point concerning the respirable method results is the relationship between suspended particulate respirable fraction and bulk sample respirable fraction. To reiterate, the respirable fraction is the ratio of respirable sized particles to total particles in the sample. In the suspended particulate case, total particles has been defined, for this study, as everything capable of being collected by the high volume sampler regardless of size. For bulk samples it is the total mass of particles. For soil samples this becomes considerably more complicated, due to the presence of pebbles that contribute considerably to the total particulate mass. The inclusion of grains or pebbles that will never become airborne is illogical, which leads to the question of what is the upper bound of particle size for a soil sample. The size chosen will affect the respirable fraction. A larger size will reduce the fraction, while a smaller size will raise it. The author chose 1.0 mm as an upper bound due to a believed influence by these particles in the method, and 53 µm which is in the broad size range of concern for health effects.

The bulk respirable fraction for the 53μm soil is approximately double that of the 1.0 mm soil, as shown in Table 2.

In all cases, as expected, the suspended respirable fraction is more than the bulk respirable fraction. This is due primarily to gravitational settling. The large particles settle out quickly, while the respirable particles remain suspended. Thus there is a range for the respirable fraction of a bulk sample, depending on which analysis is used. The minimum fraction will be provided in the bulk sample sedimentation results. This value is the least conservative regarding potential adverse health effects.

The maximum value for the respirable fraction of a bulk sample is not easy to determine. To determine the maximum respirable fraction the bulk sample would be suspended and, then after a given time period, measurements taken. The difficulties arise in deciding how long to wait before the measurements are taken. As time increases the respirable fraction increases, due to large particle sedimentation. The maximum fraction will be found when all nonrespirable material has settled out, yielding 100 % respirable. So the maximum respirable fraction is 100% for any bulk sample, yet this is of little practical use.

A compromise could be provided by continuously suspending bulk sample, and simultaneously sampling the air for the duration of the suspending process. Particles too large to remain suspended for a sufficient time to be collected by the high volume sampler will be removed. If the particles are so large that they are removed in this process, they will never enter the human airways. An advantage of this method is that it simulates the continual aerosol production and settling typically found. This method is more conservative regarding health effects, than the bulk sample measurements. It is also a useful and reasonable approach when compared to the maximum fraction procedure.

There does not seem to be a single value for respirable fraction. The respirable fraction is continually changing with time and environmental conditions. The measured

respirable fraction depends on: the bulk sample conditions (wet and/or compacted sample), presence of nonsuspendable grains, how it is produced (complete or partial suspension referring to particle sizes), and how long after terminating aerosol production the respirable fraction is measured.

Additionally, the use of a bulk respirable fraction, TSP concentration, and a coefficient representing the aerosolization process, to predict respirable concentration is suggested. A reliable method using these factors would allow rapid screening of the potential for respirable material exposure among a population. This proposed screening method approximates respirable concentration using the product of the bulk respirable fraction, a TSP concentration, and an aerosolization coefficient. The aerosolization coefficient is the most difficult to describe. Yet before beginning an exhaustive pursuit of this aerosolization coefficient, the correlation between the product of the bulk respirable fraction and TSP concentration, and respirable concentration should be evaluated. If no correlation exists the screening method will not be useful.

This procedure was performed and the results are given in Table 6. With all the data considered together the R^2 value was 0.81 which is a decent agreement. Yet, when the individual aerosol groups are evaluated separately the results differ. The Arizona Road Dust group had the strongest correlation among the aerosols groups with an R^2 value of 0.68. A plot of HV soil method versus cyclone concentration is included in Fig. 6. The soils, which is how this screening method would be used, had a weak R^2 value of 0.23. A plot of these values is given in Fig. 7. The field results were uncorrelated, with an R^2 value of 0.08. Fig. 8 displays these results. The weak correlation among the soils suggests the screening method would not be useful.

TSP METHOD RESULTS AND DISCUSSION

The TSP method results are given in Table 4. The data were grouped in a manner similar to the respirable method analysis, with the only exception being the exclusion of data points where errors occurred in the procedure. When all the TSP data were grouped together the average percent error was 22.41%, with a standard deviation of 17.84. This is a decent overall agreement, yet there is considerable variability among the aerosol groups. The soils aerosol group had a 26.16% average percent error, with a standard deviation of 13.57. While the ARD aerosol group provided a good agreement with a 11.63% average and 9.98 standard deviation. By far the worst results came from the field sampling where the average percent error was 60.26% and standard deviation of 20.59. The TSP field results are based on 6 values resulting from 3 runs, so caution must be used in the interpretation. Figures 9, 10, and 11 provide a graphical presentation of the results. The general trend of the high volume sampler reporting a higher concentration is evident in the scatter of the points above the equality line.

A concentration effect on the TSP method is not obvious in the data. There may be a general trend of increasing error with concentration as noted in the jump from 13.49% for the lowest concentration range, to 26.01% and 21.08% for the higher ranges. The variability has a gradual but seemingly insignificant increase.

These results seem to suggest that each sampler has a different cut size, for the TSP concentration which is likely to be the primary source of the discrepancy in the laboratory portion of the data. If the size selection of the inlet was the same, the reported concentrations would be almost identical. So, when the majority of the suspended particles are below the cut sizes of both samplers the reported concentrations will be very close. This may explain why the ARD provided the best results. The ARD has the smallest mean aerodynamic diameter, among all tested aerosols, thus the highest fraction of particles below the cut sizes of both samplers. Moreover, as the mean aerodynamic diameter increases the error between the methods should increase. This may be evident

in the increase in error associated with the soils aerosol group. The larger particles are more likely to collect on the high volume sampler than the 37 mm cassette, due to its higher flowrate and the relative paucity of larger particles in the sample.

The large discrepancy in the field results is likely to be due to the wind effect, as noted in the respirable results. The capture efficiency of the samplers in a high wind environment will be quite different due to the greater inertia associated with large particles. Also, large particles that were captured by the 37 mm cassette operated at 2.2 lpm would not adhere to the filter. These particles, which contribute significant mass, were subject to falling off the filter. This error was minimized but not eliminated by exercising extreme care when handling the filter.

CONCLUSION

The HV respirable method has good agreement with the cyclone in the laboratory, under controlled conditions but with field measurements they diverge. The deviation may be due to the different capture efficiencies of the samplers under windy field conditions. Which sampler had the most representative capture efficiency in these conditions remains unknown. Without this information it is difficult to determine if the HV method reports a valid respirable concentration. In the absence of these field influences the HV method does seem to provide a reasonable estimate of respirable concentration. Aerosol composition and size distribution did not seem to alter the results, but increasing concentration is suspected to increase the associated error. Further study is needed to substantiate this.

The TSP method results also provided poor results in the field, while providing mediocre results in the laboratory. The effect of wind on capture efficiency is believed to be responsible for the majority of the divergence in the field data. The main influence among these samplers in the laboratory and the field is the mean aerodynamic diameter of the aerosol. As the mean aerodynamic diameter increased the methods diverged. This relationship was evident in the laboratory data. The study suggests that knowledge of the aerosol size distribution is necessary if results from each method are to be compared.

The results of this study confirm a commonly held notion that although a procedure works in the controlled environment of the lab, it quite often will not work in the uncontrolled field environment. The challenge is to discern which variables are present in the field that are creating the discrepancy. As previously mentioned, wind is highly suspected as the culprit of the dissimilar lab and field results in this study. With the benefit of hindsight, a respirable standard other than the cyclone would have been used in the field portion of this study. In this uncontrolled environment samplers with similar flowrates and similar capture efficiencies might have produced similar results. A PM_{10} sampler might have been a more desirable standard. The PM_{10} sampler has a

size-selective inlet and a flowrate similar to the high volume air sampler. This is not a respirable standard but, the HV method is easily modified to produce this size-selective concentration.

The appropriate value for respirable fraction remains a difficult issue. The difficulties originate in the varying nature of the respirable fraction. The continuous suspension and sampling procedure previously described may be an adequate compromise. This method provides a more conservative estimate of potential respirable material exposure, than analyzing the bulk material.

REFERENCES

1. Reist, P.C. and Brantley C.D.: Abrasive Blasting With Quartz Sand: Factors Affecting The Potential For Incidental Exposure To Respirable Silica. Master's Thesis, University of North Carolina at Chapel Hill Department of Environmental Sciences and Engineering.

2. American Conference of Governmental Industrial Hygienist (ACGIH): *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.* Cincinnati, OH: ACGIH, 1993.

3. A. Sass-Kortsak, C. O'Brien, P. Bozek, and J. Purdham: Comparison of the 10-mm Nylon Cyclone, Horizontal Elutriator, and Aluminum Cyclone for Silica and Wood Dust Measurements. Appl. Occup. Environ. Hyg. 8(1):31-36 (1993).

4. D. Verma, A. Sebestyen, J. Julian, and D. Muir: Field Comparison of Respirable Dust Samplers. Ann. Occup. Hyg. 36(1):23-34 (1992).

5. Lippmann, M.: *Size-Selective Hazard Sampling,* pp. H-10 to H-12, in Air Sampling Instruments, 6th Ed.. P.J. Lioy and M.H. Lioy, eds., ACGIH. Cincinnati, OH (1983).

6. G. Knight and E. Moore: Comparison of Respirable Dust Samplers for Use in Hard Rock Mines. Am. Ind. Hyg. Assoc. J. 48(4):354-363 (1987).

7. W. Pickett, Jr. and E. Sansone: The Effect of Varying Inlet Geometry on the Collection Characteristics of a 10-Millimeter Nylon Cyclone. Am. Ind. Hyg. Assoc. J. 34:421-428 (1973).

8. J. Briant and O. Moss: The influence of Electrostatic Charge on the Performance of 10-mm Nylon Cyclones. Am. Ind. Hyg. Assoc. J. 45(7):440-445 (1984).

9. B. Almich and G. Carson: Some Effects on 10-mm Nylon Cyclone Performance. Am. Ind. Hyg. Assoc. J. 35:603-612 (1974).

10. Reist, P.C. and Creed D.: Use of a Sedimentation Method for Determining Respirable Mass Fraction in a Bulk Sample. Am. Ind. Hyg. Assoc. J. 55(7):619-625 (1994).

11. Reist, P.C.: *Aerosol Science and Technology.* New York: McGraw-Hill, 1993. p. 6, 70.

Table 1

Respirable Mass Determination

A Particle Diameter	B Fraction from Plot	C Particle Diameter Range	D * Fraction of Total Mass	E * Mass in Range mg	F Respirable Definition Fraction	G Midpoint of Respirable Fraction	H Respirable mass mg
10	0.5789	n/a	n/a	n/a	0.01	n/a	0.00
8	0.514	10 to 8	0.0649	239.74	0.05	0.03	7.19
7	0.4741	8 to 7	0.0399	147.30	0.09	0.07	10.31
6	0.4301	7 to 6	0.044	162.44	0.17	0.13	21.12
5	0.3769	6 to 5	0.0532	196.61	0.3	0.235	46.20
4	0.3169	5 to 4	0.06	221.74	0.5	0.4	88.69
3	0.2461	4 to 3	0.0709	261.88	0.74	0.62	162.37
2	0.162	3 to 2	0.084	310.44	0.91	0.825	256.11
1	0.067	2 to 1	0.0951	351.33	0.97	0.94	330.25
< 1.0	0.067	< 1.0	0.067	247.39	1	1	247.39
					Total Respirable Mass =		1169.63

* Total Mass on Filter = 3695 mg

Table 2

Sample Configuration

Test Location	Test	Aerosol Group	Specific Aerosol	Bulk Sample Characteristics: Respirable Fraction	Bulk Sample Characteristics: Geometric Mean um	Corresponding values Used in Analysis: HV Values	Cyclone Values	37 mm Values
Field	HV Resp. vs Cyclone	Ambient	Ambient	~0.01	86.5	9	18	n/a
Lab	HV Resp. vs Cyclone	ARD	Coarse	0.061	60.1	10	20	n/a
Lab	HV Resp. vs Cyclone	ARD	Fine	0.140	24.3	12	24	n/a
Lab	HV Resp. vs Cyclone	Soils	1.0 mm hb1mma	0.017		3	6	n/a
Lab	HV Resp. vs Cyclone	Soils	53 um hb53uma	0.021	39.7	3	6	n/a
Lab	HV Resp. vs Cyclone	Soils	1.0 mm jdi951ma	0.012		2	4	n/a
Lab	HV Resp. vs Cyclone	Soils	53 um jdi9553a	0.023	33.1	3	6	n/a
Lab	HV Resp. vs Cyclone	Soils	1.0 mm dnfr951a	0.012		3	6	n/a
Lab	HV Resp. vs Cyclone	Soils	53 um dfr9553a	0.025	44.8	3	6	n/a
Lab	HV Resp. vs Cyclone	Soils	1.0 mm rdbd951a	0.014	686.3	2	4	n/a
Lab	HV Resp. vs Cyclone	Soils	53 um rdd9553a	0.022	43.5	3	6	n/a
Lab	HV Resp. vs Cyclone	Soils	1.0 mm jd3011mm	0.014		3	6	n/a
Lab	HV Resp. vs Cyclone	Soils	53 um jd30153a	0.039	28.2	3	6	n/a
Field	HV TSP vs 37 mm	Ambient	Ambient	~0.01	86.5	3	n/a	6
Lab	HV TSP vs 37 mm	ARD	Coarse	0.061	60.1	9	n/a	16
Lab	HV TSP vs 37 mm	ARD	Fine	0.140	24.3	10	n/a	20
Lab	HV TSP vs 37 mm	Soils	1.0 mm hb1mma	0.017		3	n/a	6
Lab	HV TSP vs 37 mm	Soils	53 um hb53uma	0.021	39.7	3	n/a	6
Lab	HV TSP vs 37 mm	Soils	1.0 mm jdi951ma	0.012		2	n/a	2
Lab	HV TSP vs 37 mm	Soils	53 um jdi9553a	0.023	33.1	3	n/a	6
Lab	HV TSP vs 37 mm	Soils	1.0 mm dnfr951a	0.012		3	n/a	6
Lab	HV TSP vs 37 mm	Soils	53 um dfr9553a	0.025	44.8	3	n/a	3
Lab	HV TSP vs 37 mm	Soils	1.0 mm rdbd951a	0.014	686.3	2	n/a	3
Lab	HV TSP vs 37 mm	Soils	53 um rdd9553a	0.022	43.5	1	n/a	1
Lab	HV TSP vs 37 mm	Soils	1.0 mm jd3011mm	0.014		3	n/a	5
Lab	HV TSP vs 37 mm	Soils	53 um jd30153a	0.039	28.2	3	n/a	5

Table 3

Respirable Method Results

Test	Aerosol Groups	P value	Average % Error	% Error SD
HV resp. vs. Cyclone	All data	0.0619	34.78	79.08
Interaction Of Resp. Method and aerosol	All data	0.0001	n/a	n/a
HV resp. vs. Cyclone	Soils only	0.0802	16.9	13.77
Interaction Of Resp. Method and aerosol	Soils only	0.0226	n/a	n/a
Interaction Of Resp. Method and aerosol	Soils only 1.0 mm vs. 53um	0.6074	n/a	n/a
HV resp. vs. Cyclone	ARD only	0.0001	17.94	10.47
Interaction Of Resp. Method and aerosol	ARD only	0.3060	n/a	n/a
HV resp. vs. Cyclone	Ambient only	0.1496	120.3	168.8
Interaction Of	All data	0.6026	n/a	n/a
Resp. Method and Conc.	Ambient conc.	n/a	120.3	168.8
	23 - 59 mg/M^3	n/a	16.45	10.16
	60 - 99 mg/M^3	n/a	19.13	19.13
	100+ mg/M^3	n/a	21.25	21.25

Table 4

TSP Method Results

Test	Aerosol Groups	Average % Error	% Error SD
HV TSP vs. 37 mm	All data	22.41	17.84
HV TSP vs. 37 mm	Soils only	26.16	13.57
HV TSP vs. 37 mm	ARD only	11.63	9.98
HV TSP vs. 37 mm	Ambient only	60.26	20.59
Interaction Of	All data	n/a	n/a
TSP Method and Conc.	Ambient conc.	60.26	20.59
	23 - 59 mg/M^3	13.49	11.1
	60 - 99 mg/M^3	26.01	12.71
	100+ mg/M^3	21.08	16.47

Table 5

Respirable Method Concentration Configuration

TSP Concentration Group mg/M^3	# of Values in Group Ambient	ARD	Soils
Ambient (up to 1 mg/M^3)	27	0	0
23 to 59.99	0	36	24
60 to 99.99	0	12	39
100+	0	18	21

TSP Method Concentration Configuration

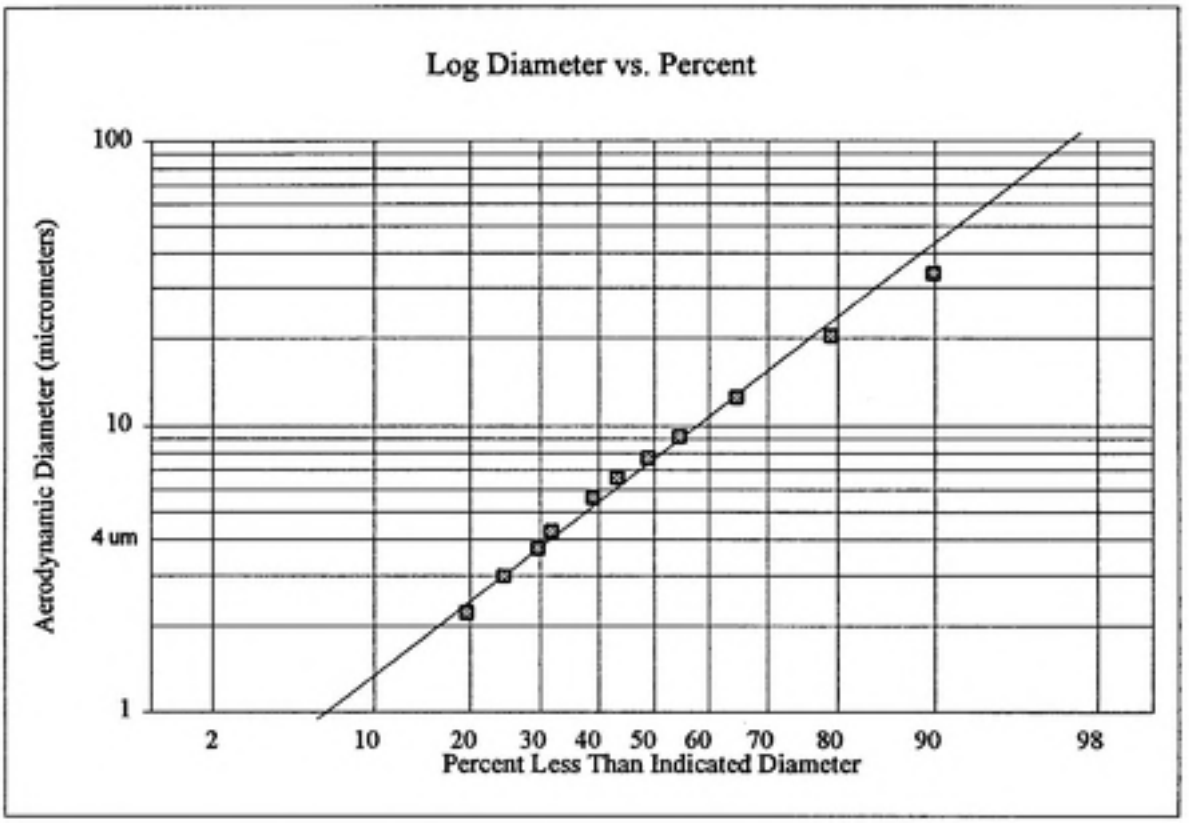
TSP Concentration Group mg/M^3	# of Values in Group Ambient	ARD	Soils
Ambient (up to 1 mg/M^3)	9	0	0
23 to 59.99	0	27	21
60 to 99.99	0	12	32
100+	0	16	16

Table 6

HV Soil Method Results

Test	Aerosol Groups	R^2
HV resp. vs. Cyclone	All data	0.81
HV resp. vs. Cyclone	Soils only	0.23
HV resp. vs. Cyclone	ARD only	0.68
HV resp. vs. Cyclone	Ambient only	0.08

Figure 1



Example of a Typical HV Method Size Distribution

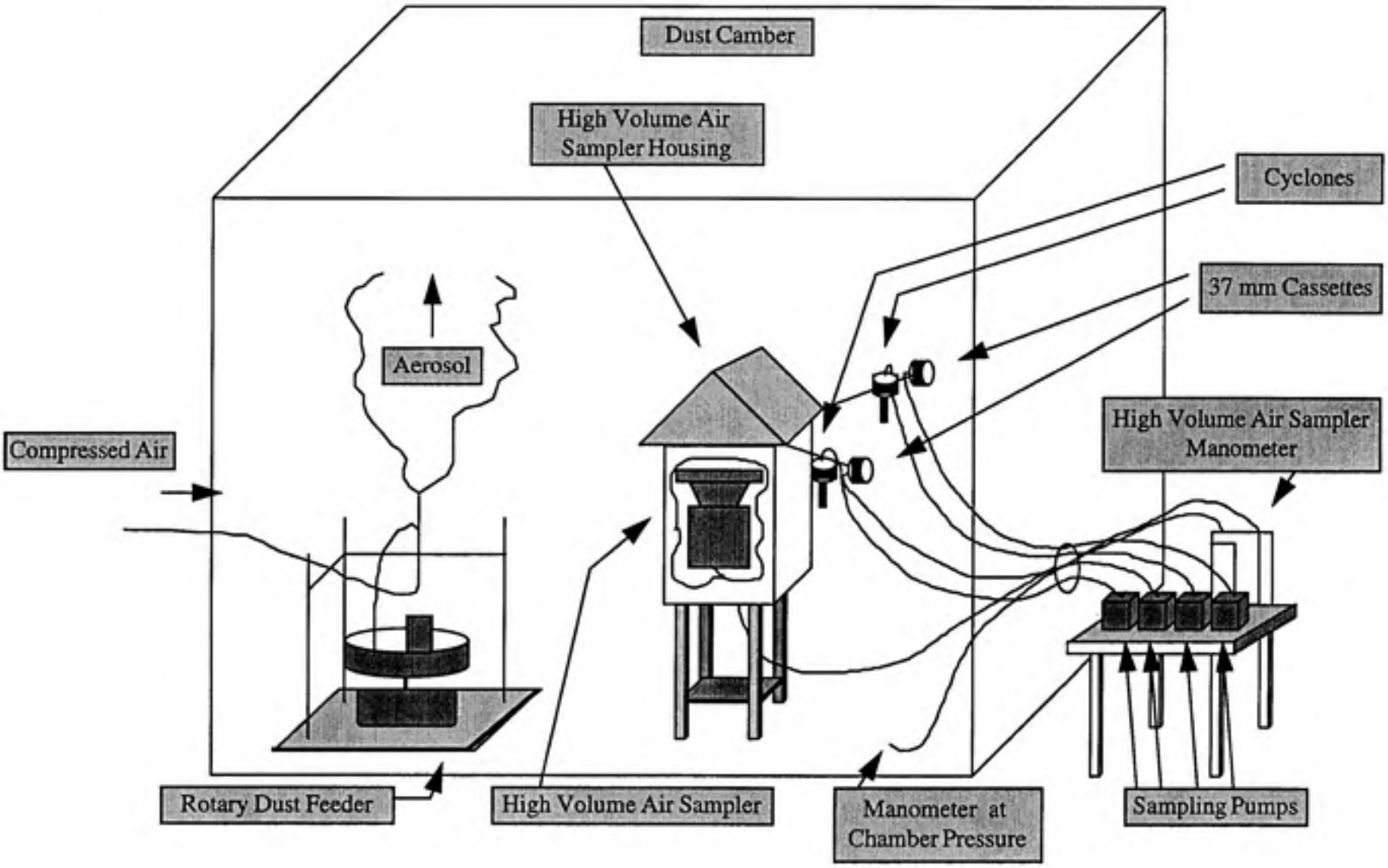


Figure 2. Diagram of Expiremental Set-up

Figure 3

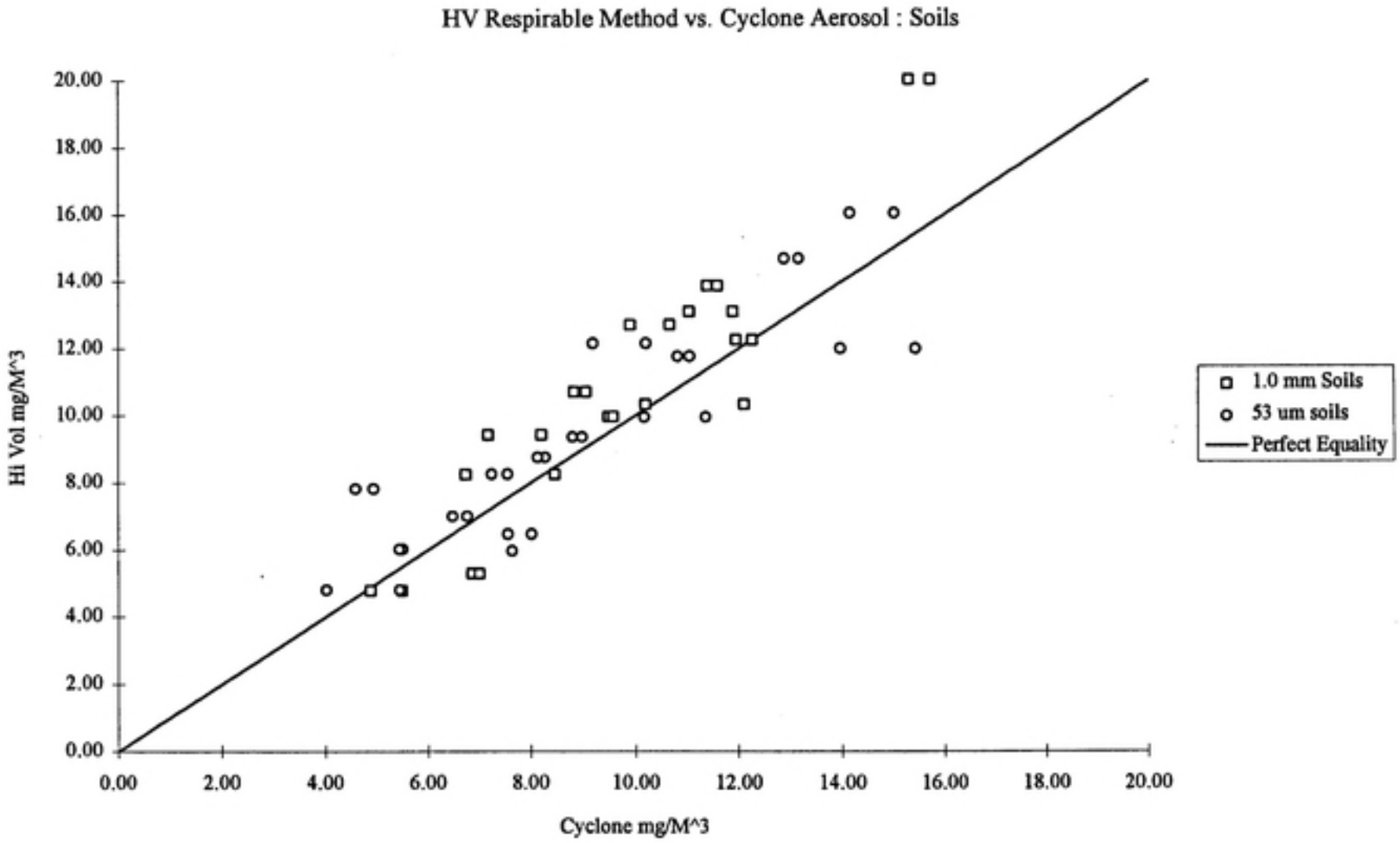

HV Respirable Method vs. Cyclone Aerosol : Soils
Hi Vol mg/M^3
Cyclone mg/M^3
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
1.0 mm Soils
53 um soils
Perfect Equality

Figure 4

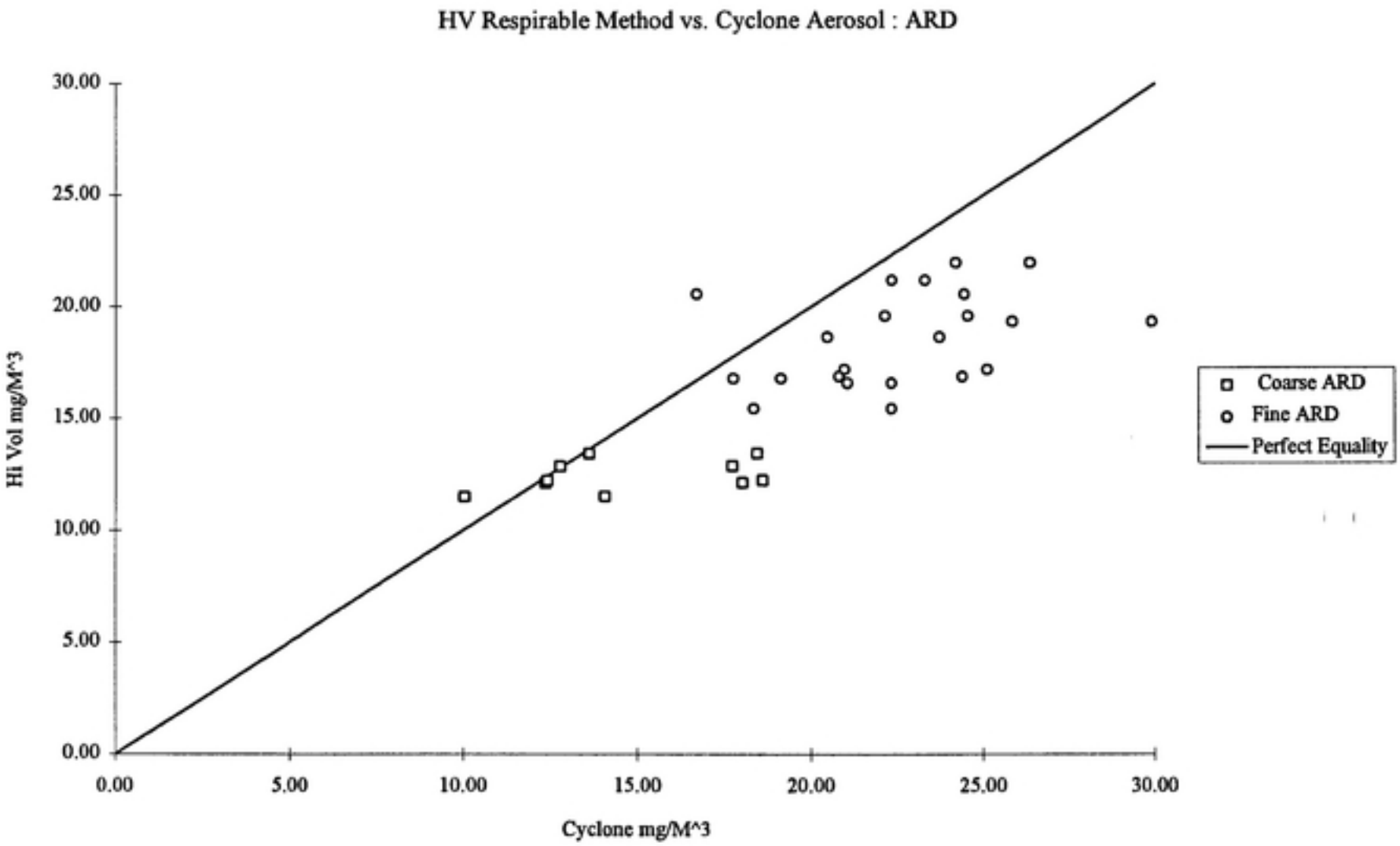

HV Respirable Method vs. Cyclone Aerosol : ARD
Hi Vol mg/M^3
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Cyclone mg/M^3
Coarse ARD
Fine ARD
Perfect Equality

Figure 5

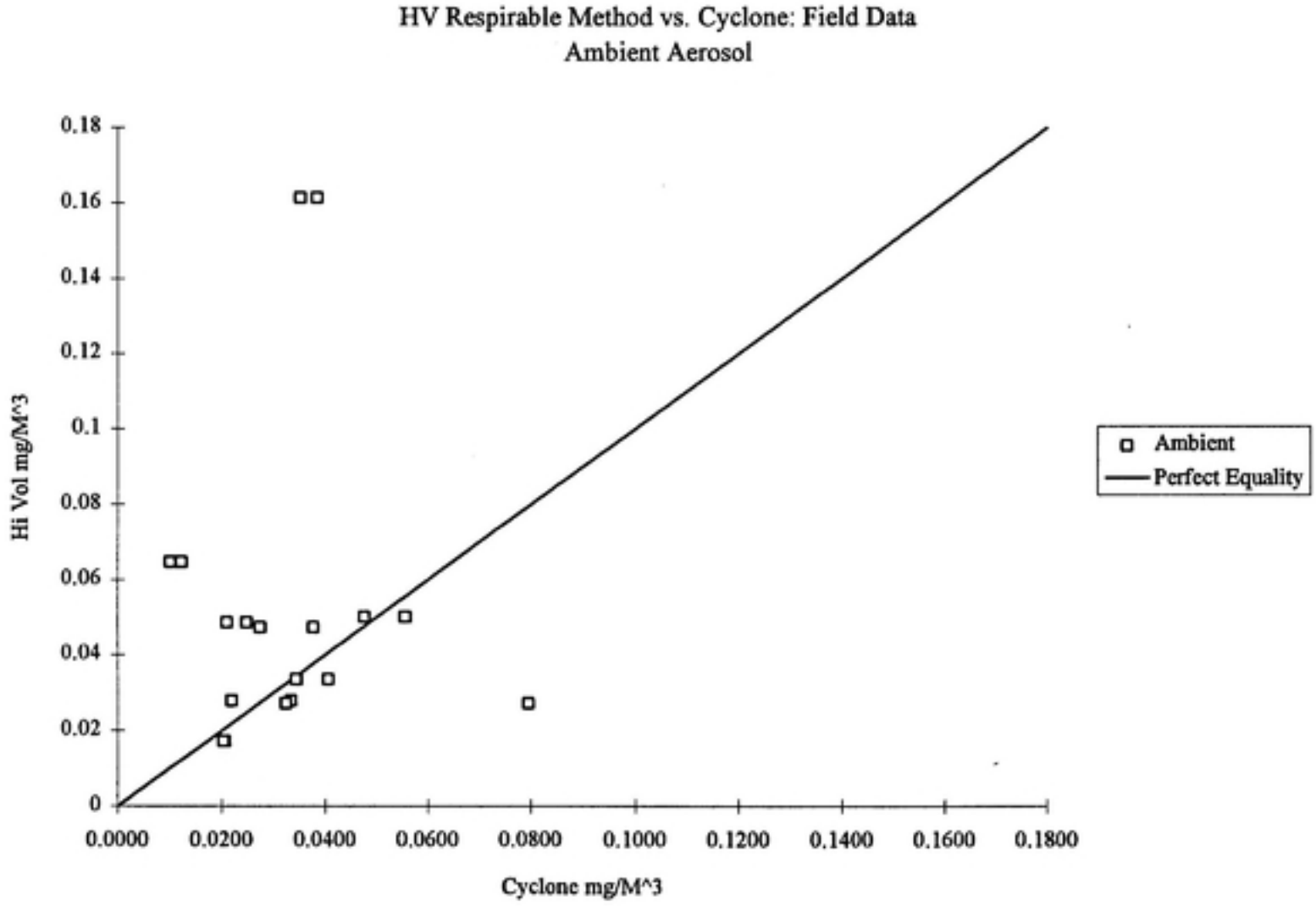

HV Respirable Method vs. Cyclone: Field Data
Ambient Aerosol
Hi Vol mg/M^3
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.0000
0.0200
0.0400
0.0600
0.0800
0.1000
0.1200
0.1400
0.1600
0.1800
Cyclone mg/M^3
Ambient
Perfect Equality

Figure 6

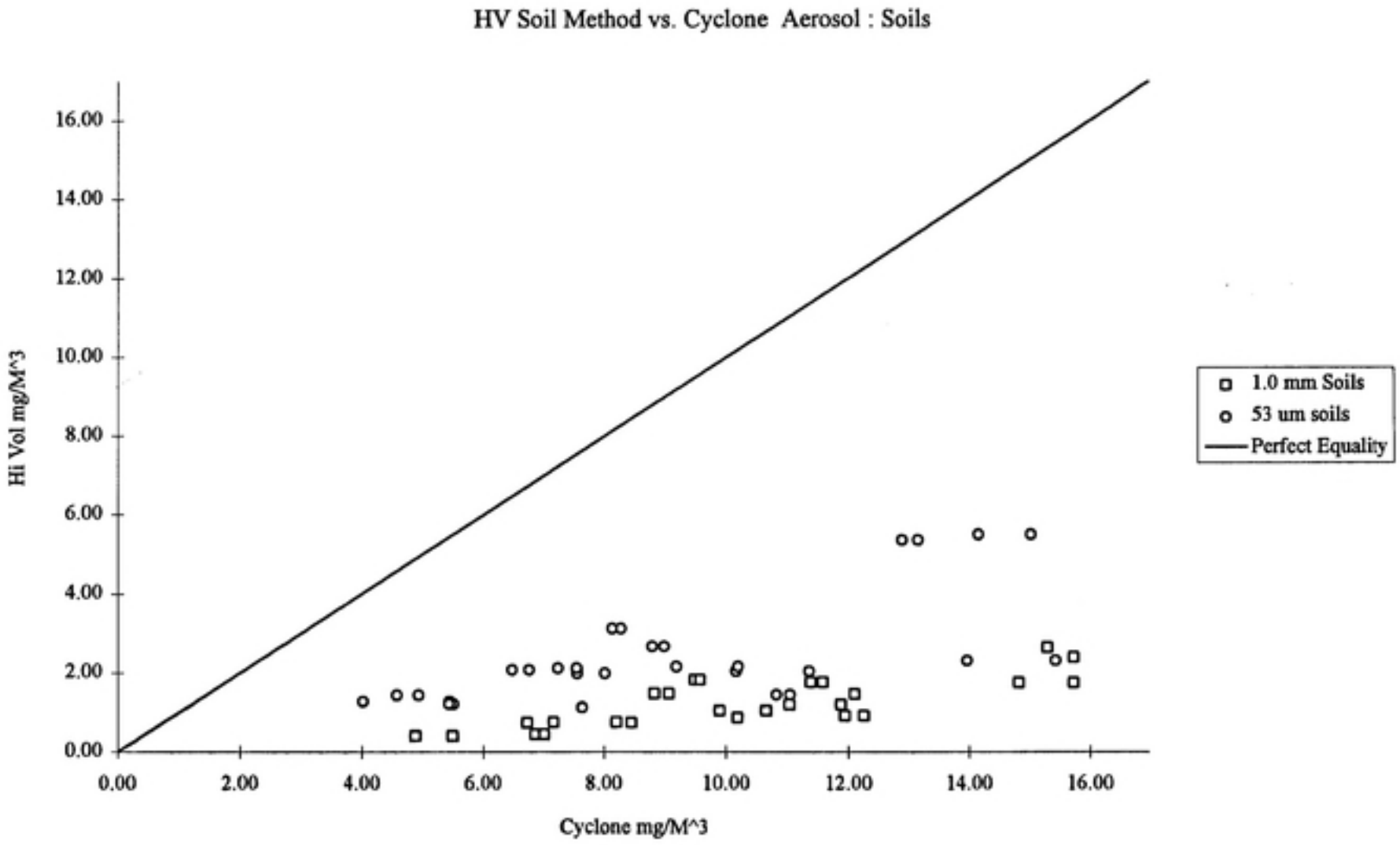

HV Soil Method vs. Cyclone Aerosol : Soils
Hi Vol mg/M^3
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
Cyclone mg/M^3
1.0 mm Soils
53 um soils
Perfect Equality

Figure 7

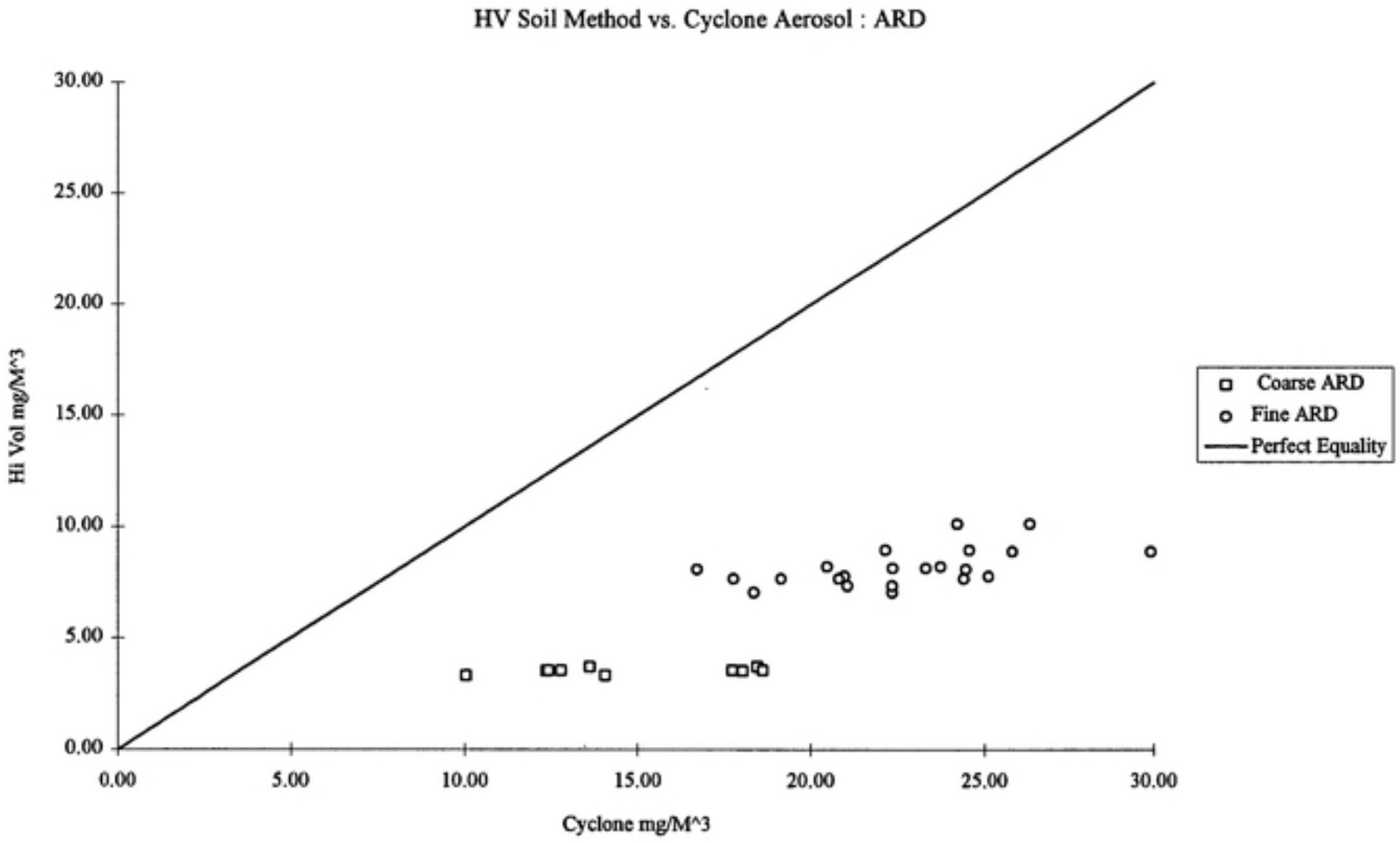

HV Soil Method vs. Cyclone Aerosol : ARD
Hi Vol mg/M^3
Cyclone mg/M^3
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Coarse ARD
Fine ARD
Perfect Equality

Figure 8

HV Soil Method vs.Cyclone: Field Data
Ambient Aerosol

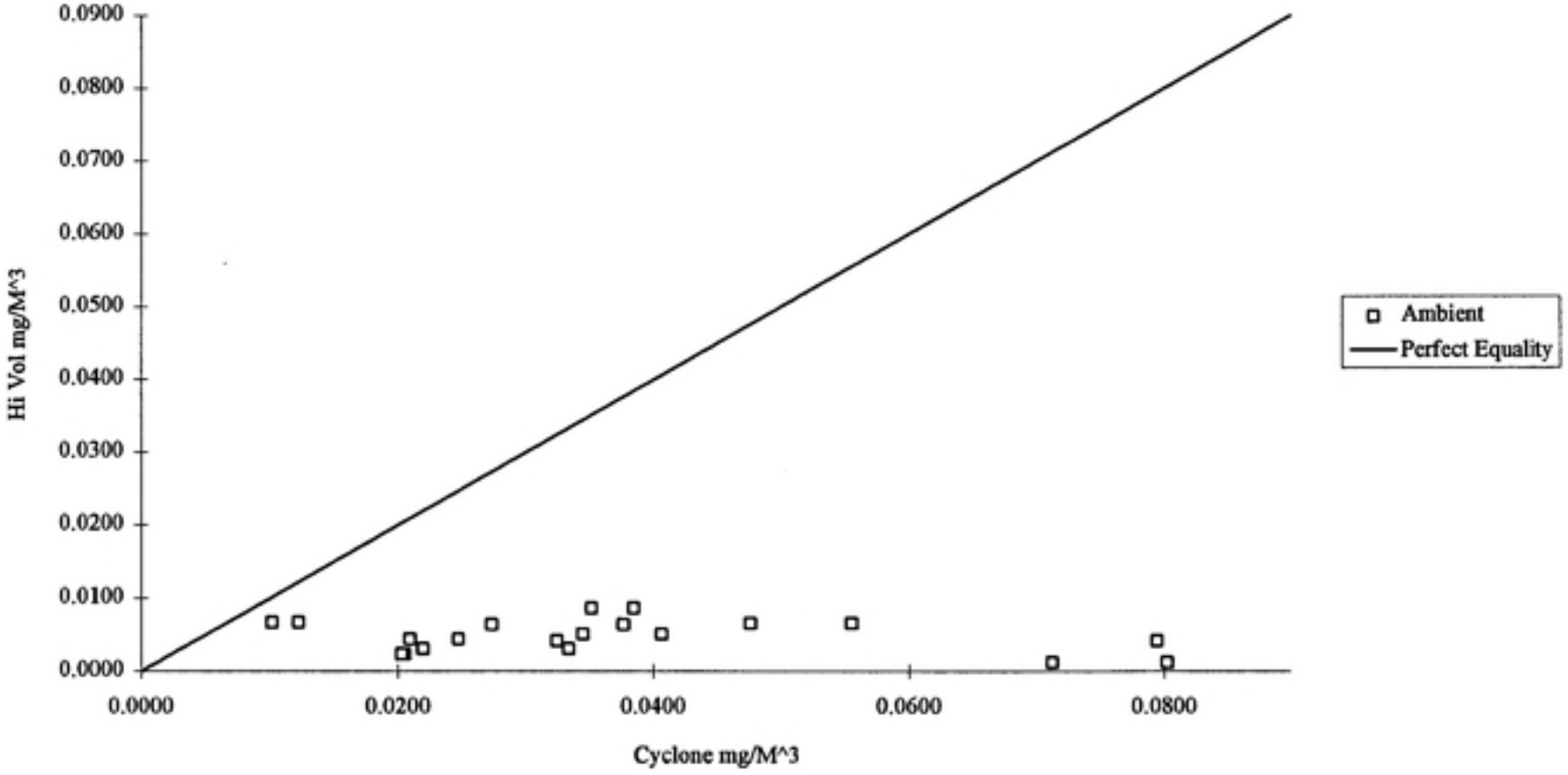


Figure 9

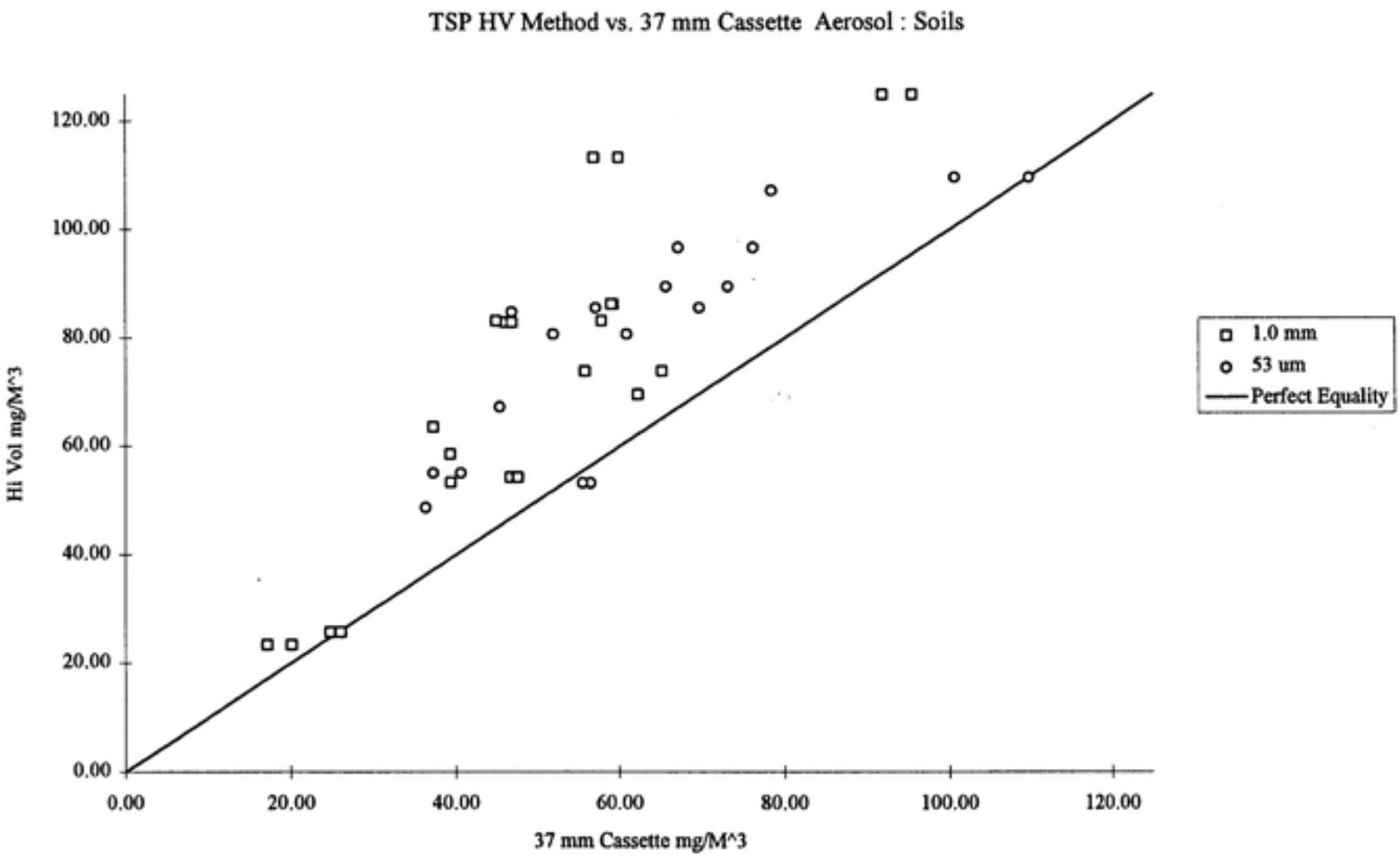

TSP HV Method vs. 37 mm Cassette Aerosol : Soils
Hi Vol mg/M^3
37 mm Cassette mg/M^3
0.00
20.00
40.00
60.00
80.00
100.00
120.00
1.0 mm
53 um
Perfect Equality

Figure 10

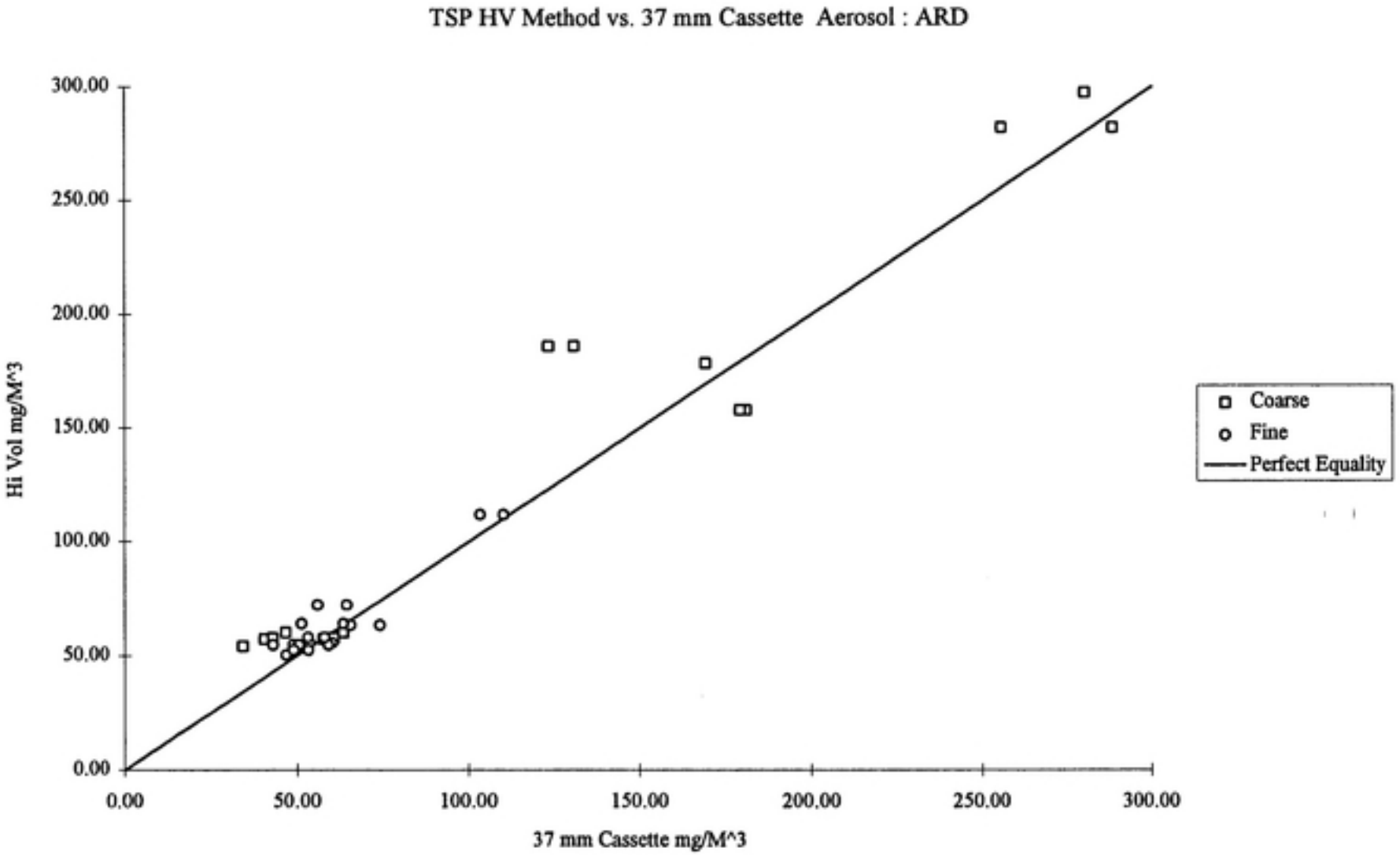
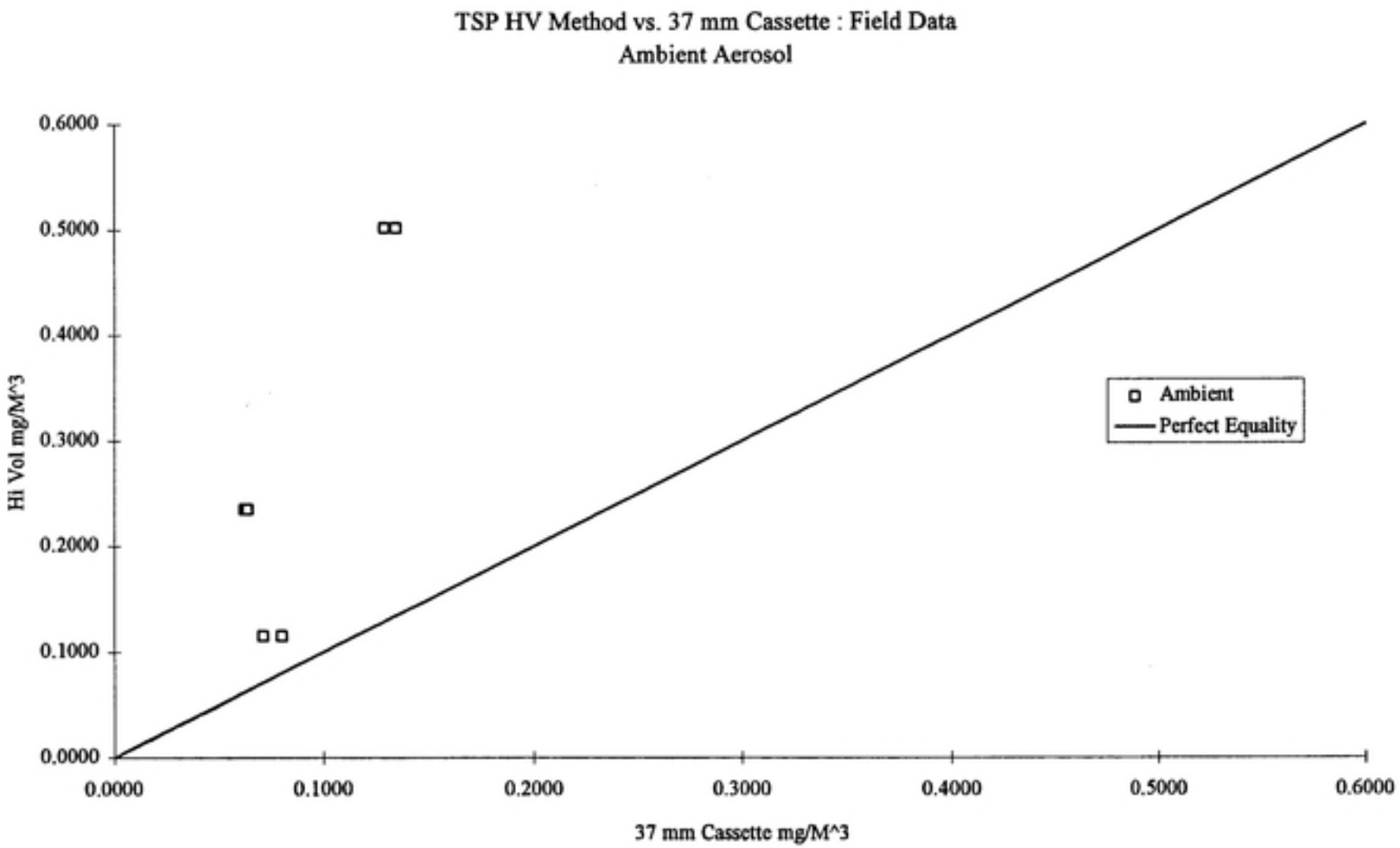

TSP HV Method vs. 37 mm Cassette Aerosol : ARD
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Hi Vol mg/M^3
0.00
50.00
100.00
150.00
200.00
250.00
300.00
37 mm Cassette mg/M^3
Coarse
Fine
Perfect Equality

Figure 11


TSP HV Method vs. 37 mm Cassette : Field Data
Ambient Aerosol
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
Hi Vol mg/M^3
0.0000
0.1000
0.2000
0.3000
0.4000
0.5000
0.6000
37 mm Cassette mg/M^3
Ambient
Perfect Equality

Appendix A

Respirable Method Raw Data

Sample Number	Aerosol Type	Bulk Respirable Fraction	Resp. Concentration mg/M^3	Respirable Method	Respirable Fraction	% Error
HV-1A	AMBIENT	~0.01	0.0278	HV	0.0928	
HV-1A	AMBIENT	~0.01	0.0333	CYC	0.1111	-16.52
HV-1A	AMBIENT	~0.01	0.0219	CYC	0.0731	26.94
HV-2A	AMBIENT	~0.01	0.0472	HV	0.0739	
HV-2A	AMBIENT	~0.01	0.0273	CYC	0.0427	72.89
HV-2A	AMBIENT	~0.01	0.0376	CYC	0.0588	25.53
HV-3A	AMBIENT	~0.01	0.0645	HV	0.0965	
HV-3A	AMBIENT	~0.01	0.0101	CYC	0.0151	538.61
HV-3A	AMBIENT	~0.01	0.0122	CYC	0.0183	428.69
HV-4A	AMBIENT	~0.01	0.1613	HV	0.1867	
HV-4A	AMBIENT	~0.01	0.0384	CYC	0.0444	320.05
HV-4A	AMBIENT	~0.01	0.0351	CYC	0.0406	359.54
HV-5A	AMBIENT	~0.01	0.0500	HV	0.0770	
HV-5A	AMBIENT	~0.01	0.0555	CYC	0.0855	-9.91
HV-5A	AMBIENT	~0.01	0.0476	CYC	0.0733	5.04
HV-6MA	AMBIENT	~0.01	0.0485	HV	0.1115	
HV-6MA	AMBIENT	~0.01	0.0209	CYC	0.0481	132.06
HV-6MA	AMBIENT	~0.01	0.0247	CYC	0.0568	96.36
HV-7A	AMBIENT	~0.01	0.0271	HV	0.0657	
HV-7A	AMBIENT	~0.01	0.0324	CYC	0.0785	-16.36
HV-7A	AMBIENT	~0.01	0.0794	CYC	0.1924	-65.87
HV-8A	AMBIENT	~0.01	0.0335	HV	0.0668	
HV-8A	AMBIENT	~0.01	0.0406	CYC	0.0810	-17.49
HV-8A	AMBIENT	~0.01	0.0344	CYC	0.0686	-2.62
HV-10A	AMBIENT	~0.01	0.0172	HV	0.0733	
HV-10A	AMBIENT	~0.01	0.0205	CYC	0.0874	-16.10
HV-10A	AMBIENT	~0.01	0.0203	CYC	0.0866	-15.27
HVUNC-1A	CRSEARD	0.0613	41.39	HV	0.2229	
HVUNC-1A	CRSEARD	0.0613	40.31	CYC	0.2171	2.68
HVUNC-1A	CRSEARD	0.0613	41.14	CYC	0.2215	0.61
HVUNC-2A	CRSEARD	0.0613	36.36	HV	0.2042	
HVUNC-2A	CRSEARD	0.0613	45.40	CYC	0.2549	-19.91
HVUNC-2A	CRSEARD	0.0613	53.36	CYC	0.2996	-31.86
HVUNC-3A	CRSEARD	0.0613	66.30	HV	0.2232	
HVUNC-3A	CRSEARD	0.0613	84.09	CYC	0.2830	-21.16
HVUNC-3A	CRSEARD	0.0613	86.67	CYC	0.2917	-23.50
HVUNC-4A	CRSEARD	0.0613	59.36	HV	0.2106	
HVUNC-4A	CRSEARD	0.0613	84.73	CYC	0.3006	-29.94
HVUNC-4A	CRSEARD	0.0613	90.80	CYC	0.3221	-34.63
HVUNC-5A	CRSEARD	0.0613	34.88	HV	0.2215	
HVUNC-5A	CRSEARD	0.0613	52.90	CYC	0.3359	-34.06

HVUNC-5A	CRSEARD	0.0613	53.23	CYC	0.3380	-34.47
HVUNC-6A	FINEARD	0.1401	34.68	HV	0.3108	
HVUNC-6A	FINEARD	0.1401	38.10	CYC	0.3414	-8.98
HVUNC-6A	FINEARD	0.1401	42.23	CYC	0.3784	-17.88
HVUNC-7A	FINEARD	0.1401	19.34	HV	0.3055	
HVUNC-7A	FINEARD	0.1401	25.82	CYC	0.4079	-25.10
HVUNC-7A	FINEARD	0.1401	29.90	CYC	0.4724	-35.32
HVUNC-8A	FINEARD	0.1401	17.18	HV	0.3101	
HVUNC-8A	FINEARD	0.1401	20.96	CYC	0.3783	-18.03
HVUNC-8A	FINEARD	0.1401	25.11	CYC	0.4532	-31.58
HVUNC-9A	FINEARD	0.1401	16.87	HV	0.3090	
HVUNC-9A	FINEARD	0.1401	20.80	CYC	0.3810	-18.89
HVUNC-9A	FINEARD	0.1401	24.39	CYC	0.4467	-30.83
HVUNC-10A	FINEARD	0.1401	15.42	HV	0.3072	
HVUNC-10A	FINEARD	0.1401	18.34	CYC	0.3653	-15.92
HVUNC-10A	FINEARD	0.1401	22.32	CYC	0.4446	-30.91
HVUNC-12A	FINEARD	0.1401	19.57	HV	0.3067	
HVUNC-12A	FINEARD	0.1401	22.13	CYC	0.3469	-11.57
HVUNC-12A	FINEARD	0.1401	24.54	CYC	0.3846	-20.25
HVUNC-13A	FINEARD	0.1401	18.62	HV	0.3188	
HVUNC-13A	FINEARD	0.1401	20.47	CYC	0.3505	-9.04
HVUNC-13A	FINEARD	0.1401	23.72	CYC	0.4062	-21.50
HVUNC-14A	FINEARD	0.1401	16.77	HV	0.3071	
HVUNC-14A	FINEARD	0.1401	17.77	CYC	0.3255	-5.63
HVUNC-14A	FINEARD	0.1401	19.13	CYC	0.3504	-12.34
HVUNC-15A	FINEARD	0.1401	16.56	HV	0.3166	
HVUNC-15A	FINEARD	0.1401	21.04	CYC	0.4023	-21.29
HVUNC-15A	FINEARD	0.1401	22.32	CYC	0.4268	-25.81
HVUNC-16A	FINEARD	0.1401	20.56	HV	0.3569	
HVUNC-16A	FINEARD	0.1401	16.71	CYC	0.2901	23.04
HVUNC-16A	FINEARD	0.1401	24.44	CYC	0.4243	-15.88
HVUNC-17A	FINEARD	0.1401	21.18	HV	0.3658	
HVUNC-17A	FINEARD	0.1401	22.33	CYC	0.3857	-5.15
HVUNC-17A	FINEARD	0.1401	23.29	CYC	0.4022	-9.06
HVUNC-19A	FINEARD	0.1401	21.97	HV	0.3043	
HVUNC-19A	FINEARD	0.1401	24.19	CYC	0.3350	-9.18
HVUNC-19A	FINEARD	0.1401	26.33	CYC	0.3647	-16.56
HVUNC-20A	CRSEARD	0.0613	12.83	HV	0.2235	
HVUNC-20A	CRSEARD	0.0613	12.78	CYC	0.2226	0.39
HVUNC-20A	CRSEARD	0.0613	17.74	CYC	0.3091	-27.68
HVUNC-21A	CRSEARD	0.0613	12.09	HV	0.2117	
HVUNC-21A	CRSEARD	0.0613	12.36	CYC	0.2165	-2.18
HVUNC-21A	CRSEARD	0.0613	18.02	CYC	0.3156	-32.91
HVUNC-22A	CRSEARD	0.0613	13.40	HV	0.2233	
HVUNC-22A	CRSEARD	0.0613	13.62	CYC	0.2270	-1.62
HVUNC-22A	CRSEARD	0.0613	18.44	CYC	0.3073	-27.33
HVUNC-23A	CRSEARD	0.0613	12.21	HV	0.2127	
HVUNC-23A	CRSEARD	0.0613	12.43	CYC	0.2166	-1.77

HVUNC-23A	CRSEARD	0.0613	18.60	CYC	0.3240	-34.35
HVUNC-24A	CRSEARD	0.0613	11.48	HV	0.2130	
HVUNC-24A	CRSEARD	0.0613	10.03	CYC	0.1861	14.46
HVUNC-24A	CRSEARD	0.0613	14.07	CYC	0.2610	-18.41
HVUNC-25A	HB1MMA	0.0168	4.78	HV	0.2052	
HVUNC-25A	HB1MMA	0.0168	4.88	CYC	0.2094	-2.05
HVUNC-25A	HB1MMA	0.0168	5.49	CYC	0.2356	-12.93
HVUNC-26A	HB1MMA	0.0168	5.29	HV	0.2066	
HVUNC-26A	HB1MMA	0.0168	6.85	CYC	0.2676	-22.77
HVUNC-26A	HB1MMA	0.0168	7.00	CYC	0.2734	-24.43
HVUNC-27A	HB1MMA	0.0168	12.25	HV	0.2260	
HVUNC-27A	HB1MMA	0.0168	11.94	CYC	0.2203	2.60
HVUNC-27A	HB1MMA	0.0168	12.25	CYC	0.2260	0.00
HVUNC-28A	HB53UMA	0.0211	9.94	HV	0.1029	
HVUNC-28A	HB53UMA	0.0211	10.16	CYC	0.1052	-2.17
HVUNC-28A	HB53UMA	0.0211	11.35	CYC	0.1175	-12.42
HVUNC-29A	HB53UMA	0.0211	5.96	HV	0.1120	
HVUNC-29A	HB53UMA	0.0211	7.63	CYC	0.1434	-21.89
HVUNC-29A	HB53UMA	0.0211	7.63	CYC	0.1434	-21.89
HVUNC-30A	HB53UMA	0.0211	11.99	HV	0.1095	
HVUNC-30A	HB53UMA	0.0211	13.96	CYC	0.1275	-14.11
HVUNC-30A	HB53UMA	0.0211	15.43	CYC	0.1409	-22.29
HVUNC-31A	JDI951MA	0.0124	8.24	HV	0.1409	
HVUNC-31A	JDI951MA	0.0124	6.72	CYC	0.1149	22.62
HVUNC-31A	JDI951MA	0.0124	8.45	CYC	0.1444	-2.49
HVUNC-32A	JDI951MA	0.0124	10.31	HV	0.1486	
HVUNC-32A	JDI951MA	0.0124	10.18	CYC	0.1467	1.28
HVUNC-32A	JDI951MA	0.0124	12.10	CYC	0.1744	-14.79
HVUNC-33A	JDI9553A	0.0232	6.46	HV	0.0756	
HVUNC-33A	JDI9553A	0.0232	7.55	CYC	0.0883	-14.44
HVUNC-33A	JDI9553A	0.0232	8.01	CYC	0.0937	-19.35
HVUNC-34A	JDI9553A	0.0232	6.99	HV	0.0782	
HVUNC-34A	JDI9553A	0.0232	6.47	CYC	0.0724	8.04
HVUNC-34A	JDI9553A	0.0232	6.75	CYC	0.0755	3.56
HVUNC-35A	JDI9553A	0.0232	4.80	HV	0.0873	
HVUNC-35A	JDI9553A	0.0232	4.02	CYC	0.0731	19.40
HVUNC-35A	JDI9553A	0.0232	5.44	CYC	0.0989	-11.76
HVUNC-36A	DNFR951A	0.0123	9.95	HV	0.1156	
HVUNC-36A	DNFR951A	0.0123	9.48	CYC	0.1101	4.96
HVUNC-36A	DNFR951A	0.0123	9.57	CYC	0.1111	3.97
HVUNC-37A	DNFR951A	0.0123	13.85	HV	0.1667	
HVUNC-37A	DNFR951A	0.0123	11.38	CYC	0.1369	21.70
HVUNC-37A	DNFR951A	0.0123	11.58	CYC	0.1394	19.60
HVUNC-38A	DNFR951A	0.0123	20.01	HV	0.1768	
HVUNC-38A	DNFR951A	0.0123	15.30	CYC	0.1352	30.78
HVUNC-38A	DNFR951A	0.0123	15.72	CYC	0.1389	27.29
HVUNC-39A	DFR9553A	0.0249	6.01	HV	0.1237	
HVUNC-39A	DFR9553A	0.0249	5.43	CYC	0.1117	10.68

HVUNC-39A	DFR9553A	0.0249	5.50	CYC	0.1132	9.27
HVUNC-40A	DFR9553A	0.0249	8.26	HV	0.0975	
HVUNC-40A	DFR9553A	0.0249	7.23	CYC	0.0854	14.25
HVUNC-40A	DFR9553A	0.0249	7.54	CYC	0.0890	9.55
HVUNC-41A	DFR9553A	0.0249	9.35	HV	0.0873	
HVUNC-41A	DFR9553A	0.0249	8.79	CYC	0.0821	6.37
HVUNC-41A	DFR9553A	0.0249	8.98	CYC	0.0838	4.12
HVUNC-42A	RDD9553A	0.0215	11.76	HV	0.1750	
HVUNC-42A	RDD9553A	0.0215	10.81	CYC	0.1609	8.79
HVUNC-42A	RDD9553A	0.0215	11.04	CYC	0.1643	6.52
HVUNC-43A	RDBD951A	0.0144	10.69	HV	0.1683	
HVUNC-43A	RDBD951A	0.0144	8.82	CYC	0.1389	21.20
HVUNC-43A	RDBD951A	0.0144	9.05	CYC	0.1425	18.12
HVUNC-44A	RDBD951A	0.0144	13.09	HV	0.1581	
HVUNC-44A	RDBD951A	0.0144	11.03	CYC	0.1332	18.68
HVUNC-44A	RDBD951A	0.0144	11.88	CYC	0.1435	10.19
HVUNC-45A	RDD9553A	0.0215	7.81	HV	0.1171	
HVUNC-45A	RDD9553A	0.0215	4.58	CYC	0.0687	70.52
HVUNC-45A	RDD9553A	0.0215	4.93	CYC	0.0739	58.42
HVUNC-46A	RDD9553A	0.0215	12.16	HV	0.1215	
HVUNC-46A	RDD9553A	0.0215	9.18	CYC	0.0917	32.46
HVUNC-46A	RDD9553A	0.0215	10.19	CYC	0.1018	19.33
HVUNC-47A	JD3011MM	0.014	12.69	HV	0.1720	
HVUNC-47A	JD3011MM	0.014	9.89	CYC	0.1340	28.31
HVUNC-47A	JD3011MM	0.014	10.65	CYC	0.1443	19.15
HVUNC-48A	JD3011MM	0.014	9.41	HV	0.1765	
HVUNC-48A	JD3011MM	0.014	7.16	CYC	0.1343	31.42
HVUNC-48A	JD3011MM	0.014	8.20	CYC	0.1538	14.76
HVUNC-49A	JD3011MM	0.014	22.13	HV	0.1775	
HVUNC-49A	JD3011MM	0.014	14.82	CYC	0.1188	49.33
HVUNC-49A	JD3011MM	0.014	15.72	CYC	0.1261	40.78
HVUNC-50A	JD30153A	0.0386	8.75	HV	0.1086	
HVUNC-50A	JD30153A	0.0386	8.13	CYC	0.1009	7.63
HVUNC-50A	JD30153A	0.0386	8.27	CYC	0.1026	5.80
HVUNC-51A	JD30153A	0.0386	16.04	HV	0.1128	
HVUNC-51A	JD30153A	0.0386	14.15	CYC	0.0995	13.36
HVUNC-51A	JD30153A	0.0386	15.02	CYC	0.1056	6.79
HVUNC-52A	JD30153A	0.0386	14.69	HV	0.1061	
HVUNC-52A	JD30153A	0.0386	12.88	CYC	0.0930	14.05
HVUNC-52A	JD30153A	0.0386	13.15	CYC	0.0949	11.71

Appendix B

TSP Method Raw Data

Sample Number	Aerosol Type	Bulk Respirable Fraction	Total Dust Concentration mg/M^3	TSP Method	% Error	
HV-6MA	AMBIENT	~0.01	0.4349	HV		ERROR
HV-6MA	AMBIENT	~0.01	0.0239	37MM	-94.504484	ERROR
HV-6MA	AMBIENT	~0.01	0.0247	37MM	-94.320533	ERROR
HV-7A	AMBIENT	~0.01	0.4126	HV		ERROR
HV-7A	AMBIENT	~0.01	0.1188	37MM	-71.20698	ERROR
HV-7A	AMBIENT	~0.01	0.1644	37MM	-60.155114	ERROR
HV-8A	AMBIENT	~0.01	0.5012	HV		
HV-8A	AMBIENT	~0.01	0.1286	37MM	-74.34158	
HV-8A	AMBIENT	~0.01	0.1340	37MM	-73.264166	
HV-9A	AMBIENT	~0.01	0.1145	HV		
HV-9A	AMBIENT	~0.01	0.0712	37MM	-37.816594	
HV-9A	AMBIENT	~0.01	0.0802	37MM	-29.956332	
HV-10A	AMBIENT	~0.01	0.2345	HV		
HV-10A	AMBIENT	~0.01	0.0624	37MM	-73.390192	
HV-10A	AMBIENT	~0.01	0.0638	37MM	-72.793177	
HVUNC-1A	CRSEARD	~0.01	185.70	HV		
HVUNC-1A	CRSEARD	~0.01	130.37	37MM	-29.795369	
HVUNC-1A	CRSEARD	~0.01	122.89	37MM	-33.823371	
HVUNC-2A	CRSEARD	~0.01	178.10	HV		
HVUNC-2A	CRSEARD	~0.01	169.19	37MM	-5.0028074	
HVUNC-2A	CRSEARD	~0.01	94.92	37MM	-46.704099	ERROR
HVUNC-3A	CRSEARD	~0.01	297.10	HV		
HVUNC-3A	CRSEARD	~0.01	262.24	37MM	-11.733423	ERROR
HVUNC-3A	CRSEARD	~0.01	279.91	37MM	-5.7859307	
HVUNC-4A	CRSEARD	~0.01	281.90	HV		
HVUNC-4A	CRSEARD	~0.01	255.44	37MM	-9.3863072	
HVUNC-4A	CRSEARD	~0.01	288.17	37MM	2.22419298	
HVUNC-5A	CRSEARD	0.0613	157.50	HV		
HVUNC-5A	CRSEARD	0.0613	180.82	37MM	14.8063492	
HVUNC-5A	CRSEARD	0.0613	179.15	37MM	13.7460317	
HVUNC-6A	FINEARD	0.0613	111.60	HV		
HVUNC-6A	FINEARD	0.0613	103.14	37MM	-7.5806452	
HVUNC-6A	FINEARD	0.0613	109.96	37MM	-1.4695341	
HVUNC-7A	FINEARD	0.0613	63.30	HV		
HVUNC-7A	FINEARD	0.0613	65.40	37MM	3.31753555	
HVUNC-7A	FINEARD	0.0613	73.83	37MM	16.6350711	
HVUNC-8A	FINEARD	0.0613	55.40	HV		
HVUNC-8A	FINEARD	0.0613	53.61	37MM	-3.2310469	
HVUNC-8A	FINEARD	0.0613	60.09	37MM	8.46570397	
HVUNC-9A	FINEARD	0.0613	54.60	HV		
HVUNC-9A	FINEARD	0.0613	48.89	37MM	-10.457875	

HVUNC-9A	FINEARD	0.0613	59.04	37MM	8.13186813	
HVUNC-10A	FINEARD	0.1401	50.20	HV		
HVUNC-10A	FINEARD	0.1401	47.07	37MM	-6.2350598	
HVUNC-10A	FINEARD	0.1401	46.85	37MM	-6.6733068	
HVUNC-12A	FINEARD	0.1401	63.80	HV		
HVUNC-12A	FINEARD	0.1401	51.25	37MM	-19.670846	
HVUNC-12A	FINEARD	0.1401	63.29	37MM	-0.799373	
HVUNC-13A	FINEARD	0.1401	58.40	HV		ERROR
HVUNC-13A	FINEARD	0.1401	67.33	37MM	15.2910959	ERROR
HVUNC-13A	FINEARD	0.1401	58.89	37MM	0.8390411	ERROR
HVUNC-14A	FINEARD	0.1401	54.60	HV		
HVUNC-14A	FINEARD	0.1401	42.96	37MM	-21.318681	
HVUNC-14A	FINEARD	0.1401	50.51	37MM	-7.4908425	
HVUNC-15A	FINEARD	0.1401	52.30	HV		
HVUNC-15A	FINEARD	0.1401	49.00	37MM	-6.3097514	
HVUNC-15A	FINEARD	0.1401	53.25	37MM	1.81644359	
HVUNC-16A	FINEARD	0.1401	57.60	HV		ERROR
HVUNC-16A	FINEARD	0.1401	52.66	37MM	-8.5763889	ERROR
HVUNC-16A	FINEARD	0.1401	57.19	37MM	-0.7118056	ERROR
HVUNC-17A	FINEARD	0.1401	57.90	HV		
HVUNC-17A	FINEARD	0.1401	53.11	37MM	-8.2728843	
HVUNC-17A	FINEARD	0.1401	57.91	37MM	0.01727116	
HVUNC-19A	FINEARD	0.1401	72.20	HV		
HVUNC-19A	FINEARD	0.1401	56.00	37MM	-22.437673	
HVUNC-19A	FINEARD	0.1401	64.35	37MM	-10.872576	
HVUNC-20A	CRSEARD	0.1401	57.40	HV		ERROR
HVUNC-20A	CRSEARD	0.1401	37.77	37MM	-34.198606	ERROR
HVUNC-20A	CRSEARD	0.1401	60.36	37MM	5.15679443	ERROR
HVUNC-21A	CRSEARD	0.1401	57.10	HV		
HVUNC-21A	CRSEARD	0.1401	40.54	37MM	-29.001751	
HVUNC-21A	CRSEARD	0.1401	57.54	37MM	0.77057793	
HVUNC-22A	CRSEARD	0.1401	60.00	HV		
HVUNC-22A	CRSEARD	0.1401	46.67	37MM	-22.216667	
HVUNC-22A	CRSEARD	0.1401	63.25	37MM	5.41666667	
HVUNC-23A	CRSEARD	0.1401	57.40	HV		
HVUNC-23A	CRSEARD	0.1401	42.78	37MM	-25.470383	
HVUNC-23A	CRSEARD	0.1401	60.45	37MM	5.31358885	
HVUNC-24A	CRSEARD	0.0613	53.90	HV		
HVUNC-24A	CRSEARD	0.0613	34.21	37MM	-36.530612	
HVUNC-24A	CRSEARD	0.0613	49.55	37MM	-8.0705009	
HVUNC-25A	HB1MMA	0.0613	23.30	HV		
HVUNC-25A	HB1MMA	0.0613	17.17	37MM	-26.309013	
HVUNC-25A	HB1MMA	0.0613	20.09	37MM	-13.776824	
HVUNC-26A	HB1MMA	0.0613	25.60	HV		
HVUNC-26A	HB1MMA	0.0613	24.70	37MM	-3.515625	
HVUNC-26A	HB1MMA	0.0613	25.94	37MM	1.328125	
HVUNC-27A	HB1MMA	0.0613	54.20	HV		
HVUNC-27A	HB1MMA	0.0613	46.64	37MM	-13.948339	

HVUNC-27A	HB1MMA	0.0613	47.50	37MM	-12.361624
HVUNC-28A	HB53UMA	0.0613	96.60	HV	
HVUNC-28A	HB53UMA	0.0613	67.04	37MM	-30.600414
HVUNC-28A	HB53UMA	0.0613	76.11	37MM	-21.21118
HVUNC-29A	HB53UMA	0.0168	53.20	HV	
HVUNC-29A	HB53UMA	0.0168	56.32	37MM	5.86466165
HVUNC-29A	HB53UMA	0.0168	55.45	37MM	4.22932331
HVUNC-30A	HB53UMA	0.0168	109.50	HV	
HVUNC-30A	HB53UMA	0.0168	100.51	37MM	-8.2100457
HVUNC-30A	HB53UMA	0.0168	109.62	37MM	0.10958904
HVUNC-31A	JDI951MA	0.0168	58.50	HV	
HVUNC-31A	JDI951MA	0.0168	39.22	37MM	-32.957265
HVUNC-31A	JDI951MA	0.0168	26.39	37MM	-54.888889 ERROR
HVUNC-32A	JDI951MA	0.0211	69.40	HV	
HVUNC-32A	JDI951MA	0.0211	62.11	37MM	-10.504323
HVUNC-32A	JDI951MA	0.0211	43.56	37MM	-37.233429 ERROR
HVUNC-33A	JDI9553A	0.0211	85.50	HV	
HVUNC-33A	JDI9553A	0.0211	69.59	37MM	-18.608187
HVUNC-33A	JDI9553A	0.0211	56.93	37MM	-33.415205
HVUNC-34A	JDI9553A	0.0211	89.40	HV	
HVUNC-34A	JDI9553A	0.0211	73.05	37MM	-18.288591
HVUNC-34A	JDI9553A	0.0211	65.54	37MM	-26.689038
HVUNC-35A	JDI9553A	0.0124	55.00	HV	
HVUNC-35A	JDI9553A	0.0124	37.19	37MM	-32.381818
HVUNC-35A	JDI9553A	0.0124	40.51	37MM	-26.345455
HVUNC-36A	DNFR951A	0.0124	86.10	HV	
HVUNC-36A	DNFR951A	0.0124	59.12	37MM	-31.335656
HVUNC-36A	DNFR951A	0.0124	58.91	37MM	-31.579559
HVUNC-37A	DNFR951A	0.0232	83.10	HV	
HVUNC-37A	DNFR951A	0.0232	57.67	37MM	-30.601685
HVUNC-37A	DNFR951A	0.0232	44.85	37MM	-46.028881
HVUNC-38A	DNFR951A	0.0232	113.20	HV	
HVUNC-38A	DNFR951A	0.0232	59.75	37MM	-47.217314
HVUNC-38A	DNFR951A	0.0232	56.73	37MM	-49.885159
HVUNC-39A	DFR9553A	0.0232	48.60	HV	
HVUNC-39A	DFR9553A	0.0232	36.26	37MM	-25.390947
HVUNC-39A	DFR9553A	0.0232	22.45	37MM	-53.806584 ERROR
HVUNC-40A	DFR9553A	0.0123	84.70	HV	
HVUNC-40A	DFR9553A	0.0123	63.27	37MM	-25.301063 ERROR
HVUNC-40A	DFR9553A	0.0123	46.77	37MM	-44.781582
HVUNC-41A	DFR9553A	0.0123	107.10	HV	
HVUNC-41A	DFR9553A	0.0123	51.05	37MM	-52.334267 ERROR
HVUNC-41A	DFR9553A	0.0123	78.33	37MM	-26.862745
HVUNC-42A	RDD9553A	0.0123	67.20	HV	
HVUNC-42A	RDD9553A	0.0123	45.27	37MM	-32.633929
HVUNC-42A	RDD9553A	0.0123	37.08	37MM	-44.821429 ERROR
HVUNC-43A	RDBD951A	0.0249	63.50	HV	
HVUNC-43A	RDBD951A	0.0249	30.89	37MM	-51.354331 ERROR

HVUNC-43A	RDBD951A	0.0249	37.20	37MM	-41.417323	
HVUNC-44A	RDBD951A	0.0249	82.80	HV		
HVUNC-44A	RDBD951A	0.0249	46.00	37MM	-44.444444	
HVUNC-44A	RDBD951A	0.0249	46.75	37MM	-43.538647	
HVUNC-45A	RDD9553A	0.0249	66.70	HV		ERROR
HVUNC-45A	RDD9553A	0.0249	28.07	37MM	-57.916042	ERROR
HVUNC-45A	RDD9553A	0.0249	ERROR	37MM	#VALUE!	ERROR
HVUNC-46A	RDD9553A	0.0215	100.10	HV		ERROR
HVUNC-46A	RDD9553A	0.0215	52.80	37MM	-47.252747	ERROR
HVUNC-46A	RDD9553A	0.0215	60.95	37MM	-39.110889	ERROR
HVUNC-47A	JD3011MM	0.0144	73.80	HV		
HVUNC-47A	JD3011MM	0.0144	65.07	37MM	-11.829268	
HVUNC-47A	JD3011MM	0.0144	55.67	37MM	-24.566396	
HVUNC-48A	JD3011MM	0.0144	53.30	HV		
HVUNC-48A	JD3011MM	0.0144	29.92	37MM	-43.864916	ERROR
HVUNC-48A	JD3011MM	0.0144	39.28	37MM	-26.30394	
HVUNC-49A	JD3011MM	0.0215	124.70	HV		
HVUNC-49A	JD3011MM	0.0215	95.41	37MM	-23.488372	
HVUNC-49A	JD3011MM	0.0215	91.82	37MM	-26.367281	
HVUNC-50A	JD30153A	0.0215	80.60	HV		
HVUNC-50A	JD30153A	0.0215	60.79	37MM	-24.578164	
HVUNC-50A	JD30153A	0.0215	51.79	37MM	-35.744417	
HVUNC-51A	JD30153A	0.014	142.20	HV		
HVUNC-51A	JD30153A	0.014	103.01	37MM	-27.559775	ERROR
HVUNC-51A	JD30153A	0.014	101.80	37MM	-28.410689	
HVUNC-52A	JD30153A	0.014	138.50	TSP		
HVUNC-52A	JD30153A	0.014	81.21	37MM	-41.364621	
HVUNC-52A	JD30153A	0.014	74.73	37MM	-46.043321	

ERROR indicates point was discarded due to error