FACILITATING HWC MACT COMPLIANCE, EVALUATING PM CEMSs DOWNSTREAM OF HEPA FILTERS

John A. Etheridge, R. ArunKumar, Larry E. Pearson, John C. Luthe, Christopher B. Winstead, Olin P. Norton, Walter R. Okhuysen, Donna M. Rogers, and Charles A. Waggoner.

ABSTRACT

The US Environmental Protection Agency (EPA) and the US Department of Energy (DOE) signed a Memorandum of Understanding (MOU) to coordinate research efforts to the maximum extent possible for issues associated with treatment and disposal of mixed wastes. A DOE study intended to investigate problems associated with selection of particulate matter (PM) continuous emission monitoring systems (CEMSs) was one of the first projects selected by the MOU Core Management Team for inclusion in this DOE-EPA venture. The project was chosen because implementation of the Hazardous Waste Combustor (HWC) MACT PM CEMS requirement will be most problematic for those mixed waste incinerators that employ HEPA filters in their off-gas treatment system. A Technical Working Group (TWG) was formed to help provide direction for the research effort and is populated by personnel from state and federal EPA, DOE headquarters, DOE focus areas, and the Diagnostic Instrumentation and Analysis Laboratory (DIAL). Work outlined in this paper is being conducted at the DIAL facilities on the campus of Mississippi State University.

The EPA has consistently indicated its intention to implement the PM CEMS requirement of the HWC MACT as soon as effective monitoring technologies exist. The extremely low concentrations of predominantly sub-micrometer PM downstream of HEPA filters represents a substantially different set of measurement obstacles when compared to non-HEPA filtered emissions. Minimum detection limits must be orders of magnitude lower and methods of calibration (with respect to mass emission rate) become more difficult to develop and defend.

Mixed waste HWCs represent a small fraction of the universe of facilities subject to the MACT and EPA faces the dilemma of deciding if it is the part of the population of facilities to use when determining whether or not effective PM CEMS exist in the marketplace. Additionally, calibration and operational precision requirements called for in Performance Specification 112 (PS 11) are far more difficult to achieve downstream of a HEPA filter. Measuring the low mass emission rates encountered downstream of a HEPA filter using a gravimetric technique is well beyond the capabilities of EPA's Reference Method 5I. In order

to be ultimately successful, these studies need to address both the regulatory and technical issues that are associated with the determination of mass emission rates of PM downstream of HEPA filters. This study will provide preliminary data for development of regulatory requirements under the HWC MACT rubric.

Project Objectives

The objectives of this study are: (1) determine the capability of current PM CEMSs to measure/monitor mass emission rates downstream of HEPA filters under conditions equivalent to those encountered in DOE mixed waste treatment processes, (2) determine if data generated by such measurements can be used to effectively monitor the operational status of HEPA filters, (3) determine how changes in the source term (chemical and/or physical nature of the PM) affect instrumental accuracy or precision, and (4) correlate all measurements to results that are obtained with the standard EPA extractive method 5I. It should be pointed out that while numerous measurements will be made to evaluate HEPA filter performance, the focus of this study is directed at monitoring PM downstream of filters and not evaluating filter performance.

An initial set of performance requirements for viable PM CEMSs has been put forth by EPA in their Performance Specification 11. A recent update of this standard was published in the Federal Register on 12/12/01. A central part of this effort will be concerned with evaluating the performance of commercial PM CEMSs in a HEPA filtered air stream relative to requirements contained in PS 11. Three problem areas are immediately obvious when considering this work: (1) detections limits of current PM CEMSs appear deficient, (2) anticipated levels are significantly below detection limits of RM 5I, and (3) gravimetric determination of expected mass emission rates is probably not feasible within the required sampling time.

Figure 1 provides a correlation between the challenge level of PM upstream of a HEPA filter, PM concentration downstream of the filter, filter lifetime, and PM CEMS detection limits. Commercially available PM CEMS can be segregated into three general design categories: (1) optical (light scattering), (2) beta attenuation, and (3) triboelectric. The detection limit identified in Figure 1 is the most sensitive of the published values for currently available units.

Figure 1 reveals several interesting points: (1) current PM CEMS units are unlikely to be able to detect the PM levels that will be encountered in systems where HEPA filters will last for more that 30 days, (2) some units may be able to detect the levels of PM upstream of the filter, and (3) the 23 mg/m^3 design limit for HEPA filters is well below the 34 mg/m^3 MACT limit.

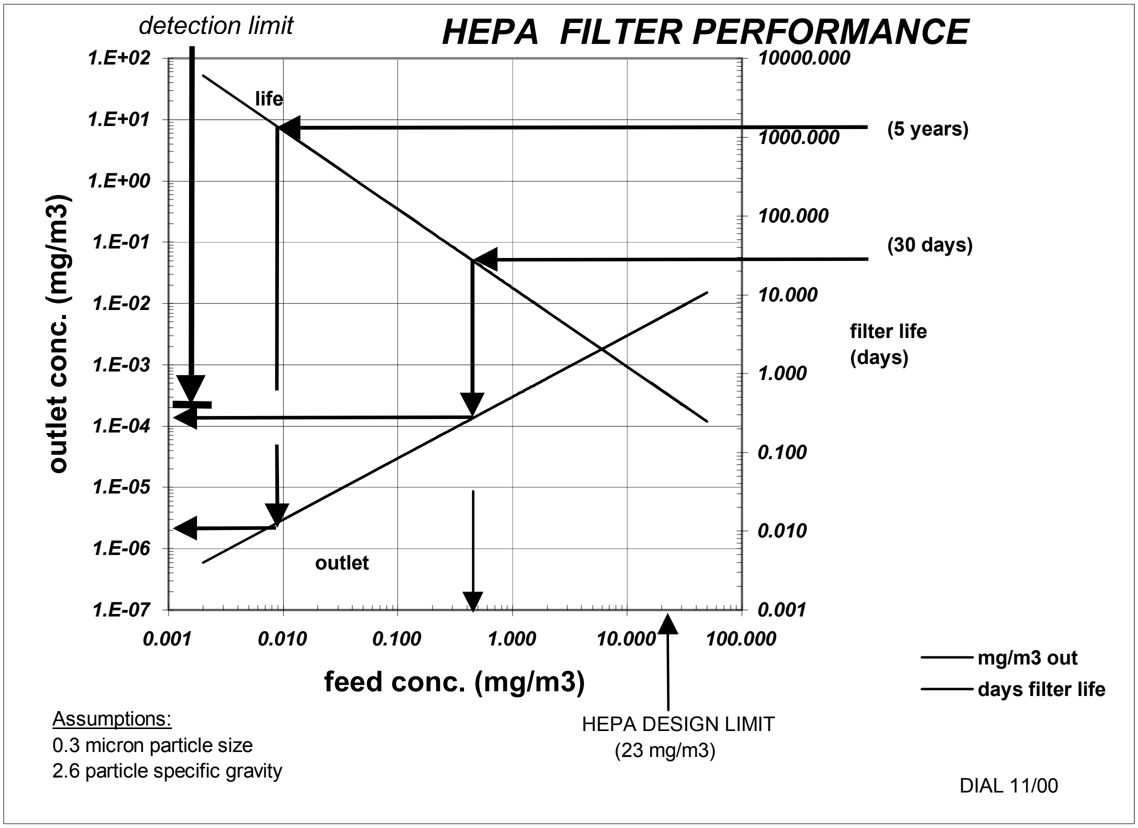

Fig. 1. Correlation of PM Levels Up and Downstream of HEPA Filters

One of the more difficult requirements of PS 11 involves gravimetric calibration of the PM CEMS, presumably RM 5I. For HEPA filtered gas streams, method 5I will not be able to provide data in a reasonable sampling time as shown in Table I. The minimum sample catch for a method 5I measurement is 3 mg and the target mass is 10 mg. Table I gives sampling times required for collection of 3mg 5I samples at a sampling rate of 0.75 cfm as a function of mass loading rates in the air stream being interrogated. It is clear from these data that 5I sampling times will be excessive, even if the upstream PM concentration exceeds the maximum design loading rate of 23 mg/m^3.

Table I. Reference Method 5I Sampling Times

Upstream Concentration (mg/m3)	Sampling Time (min)	Downstream Concentration (mg/m3)	Sampling Time (days)
30	4.7	0.009	11
10	14	0.003	33
5	28	0.0015	65
1	141	0.0003	326

Evaluation of Commercial PM CEMSs

A variety of commercially available CEMSs will be evaluated with regard to their performance downstream of a HEPA filter. Commercial optical technologies used for PM monitoring in gas streams measure number densities while emission guidelines are most frequently associated with mass based limits (as is the case with the HWC MACT). Conversion of data from number density based measurements to mass units requires knowledge of the reflective/refractive nature of the particles, particle density, and the PSD of the population being interrogated. Conversion of measurement data to mass units requires assumptions in each of the areas listed above and these assumptions may not be valid over time as the HEPA ages or loads with particulate matter or as the particle composition and/or size distribution changes. In non-HEPA installations, these variables are taken into account by an on-site calibration using method 5I under the guidelines of Performance Specification 11 (PS 11).

However, as noted in Table I, method 5I will not be useful for measurements downstream of a HEPA filter. Optical measurements to estimate mass are complicated by the small size of the particles under consideration. The most penetrating particle size for HEPA filters is close to 100 nanometers and this sized particle will dominate the downstream particle size distribution. Light scattering units tend to loose sensitivity rapidly as particle diameters drop below 0.5 micrometers, the scattering cross-section begins to drop as a function of the diameter to the 6^{th} power. Thus for the ultra-fine PM that would be encountered, the sensitivity of scattering-based systems must be determined.

An option available to resolve the above complications will be to use EPA Reference Method 5I to verify the performance of a more advanced benchmark instrument, such as an electrical low pressure impactor (ELPI) at concentrations higher than those expected downstream of a HEPA filter. The ELPI can be used for both electronic and gravimetric PM determinations. Once verification of the electrical measurement capability is carried out with respect to gravimetric measurement of the ELPI impactor stages and method 5I, electrical measurements will be used for PM measurements at the very low post-HEPA loadings. An additional technology that can be employed to estimate mass emission rates is a differential mobility analyzer-condensation particle counter (DMA-CPC). These methodologies will not be strictly compliant with EPA's PS 11 for PM CEMS, but will provide guidance with regard to developing an alternative calibration method to PS 11.

Benchmark PM Measurements

It was stated in the previous section that PS 11 calls for gravimetric calibration of PM CEMS and that Reference Method 5I is not capable of measuring the mass loading rate downstream of a HEPA filter. In the absence of a gravimetric measurement technique, a set of benchmark measurement techniques capable of measuring both the number density and particle size distribution (PSD) of PM downstream of a HEPA filter is essential for success of this project. Technologies selected to serve as benchmark measurement methods for this study are the ELPI and DMA-CPC. A commercial DMA-CPC is marketed by TSI and is referred to as a scanning mobility particle sizing system (SMPS). Two versions of this unit have been acquired, the difference being the sensitivity and counting range of the CPC units.

Figures 2 and 3 provide a depiction of the effective ranges of particle sizes and number densities for the ELPI and both versions of the SMPS. Use of the two different units allows for comparison aerodynamic and mobility PSDs. Additionally, the units are complimentary with regard to range of sizes that can be measured, the ELPI has an effective particle size range of 0.1 to 10 micrometers and the SMPS from 0.01 to 1 micrometers.

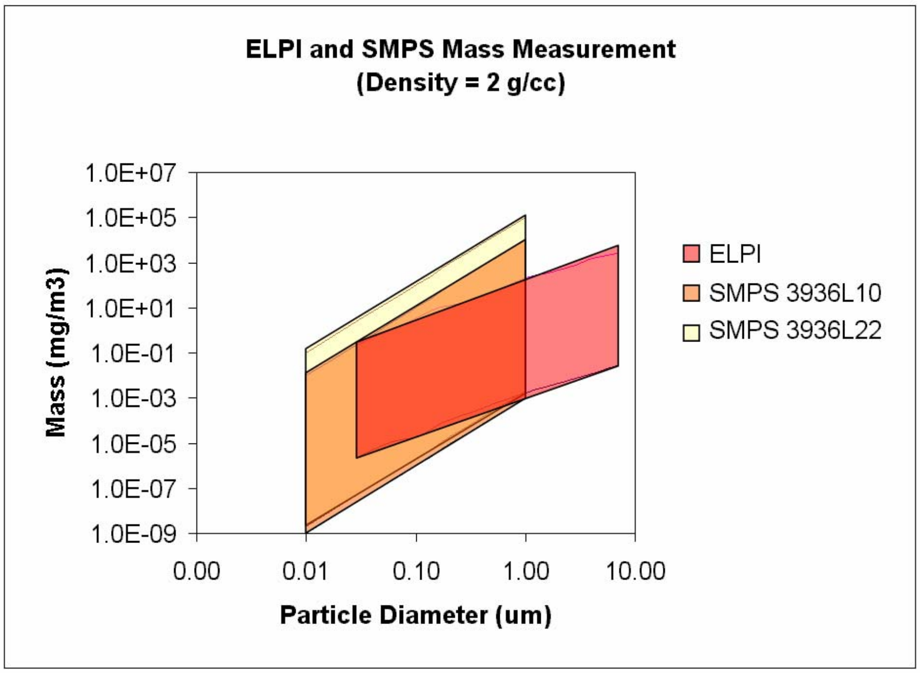

Fig. 2. ELPI and SMPS mass measurement

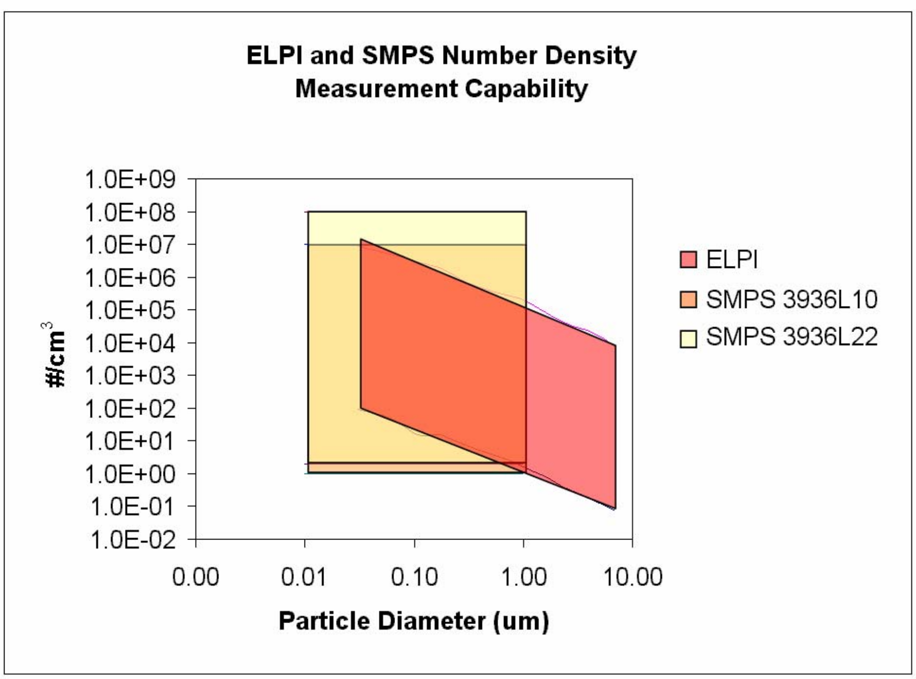

Fig. 3. ELPI and SMPS Number Density Measurement Capability

Establishment of Test Stand Performance Capabilities

It is essential that the test conditions employed in these HEPA filter testing activities be comparable to those encountered by HEPA filters in functioning DOE facilities. Engineering activities intended to ensure that test stand(s) are able to establish and maintain targeted test conditions require a set of targets to serve as design criteria. Additionally, numerous considerations must be taken into account with regard to location of access ports for sampling, injection of PM challenge agents, and test stand decontamination between tests. Finally, it is necessary to take into account accuracy and precision requirements for sensors to ensure that the data collected are appropriate. Therefore, sensor performance requirements, data collection rates, and data management requirements must also be established.

Applicability of the HWC MACT to a facility that employs HEPA filters in treatment of flue gases has direct bearing on test conditions for this work. There are numerous off-gas parameters that vary among the DOE processes utilizing HEPA filters as a pollution control device. However, HEPA filters are typically the last unit in the off-gas treatment system and the conditions they experience are bounded by their design criteria. The conditions that need to be specified during conduction of the testing being considered here include:

1. Media Velocity
2. Temperature
3. Relative Humidity
4. Static Pressure of the Duct
5. PM PSD, Loading Rate, and Chemical Composition
6. Concentration of Corrosive Gases (usually low)

The first four of these parameters have significant bearing on the design of the test stand to be used in this work. A preliminary review of the operating conditions experienced by HEPA filters in several DOE facilities subject to the HWC MACT has been conducted. Results of this research can be found in Table II and will be used in development of an initial set of Test Stand Operational Ranges.

Table II. Test Stand Operational Ranges

Parameter	Range	Units
Volumetric Flow	20 to 150	% design capacity of filter
Media Velocity *	3 to 10	Feet per minute
Temperature	Ambient to 250	Degrees F
Relative Humidity	50 to 95	% relative humidity
Static Pressure	-10 to +28	Inches of water column
Background PM Level	0 **	

*media velocity = volumetric flow / filter area.
** Below Detection Levels for all measurement techniques employed

EPA has also contracted with EERGC to provide project support by developing a more complete set of conditions based on engineering calculations and a thorough review of permit and operating conditions of DOE facilities subject to the HWC MACT. The EERGC data provide a much more comprehensive look at the operating conditions of DOE facilities which use HEPA filters in their off-gas systems. The Test Stand Performance Requirements have been reviewed in light of this expanded set of information and adjusted accordingly.

Matrices of Testing Activities

In May 1999 the Defense Nuclear Issued Technical Report 23 entitled "HEPA Filters Used in the Department of Energy's Hazardous Facilities" which describes observations and concerns related to the effects of several challenge agents and conditions seen by HEPA filters in some installations. Many of the issues of concern remain unresolved. The aim of this report was to spur activities which will help eliminate what is called "confusing guidance" concerning the performance characteristics of HEPA filters, and to improve the quality of assumptions used to support safety analysis of installed HEPA filters. The tests described in this section are aimed at supporting this goal.

Based on the DNSFB Tech 23 Report, the DOE 2000-2 Initiative, the EERGC Report, and information from members of the HEPA NTWG, a set of parameters of interest was chosen for this testing series. The challenge agents and conditions of interest are: Fire/temperature, wetting, filter strength, leaks, and aging. Source terms of interest are: PM concentration, temperature, relative humidity, media velocity, particle size distribution, and filter differential pressure.

Two categories of testing will be undertaken in this work. A Failure Mode sequence of tests will be conducted to determine the potential of using a PM CEMS to monitor the operational status of a HEPA filter. A second series of tests will be conducted to evaluate the effects of changes in the source term on downstream measurements made by the PM CEMS. The test matrix contained in Table III identifies the failure modes that will be addressed by this test sequence along with the parameters of interest for each failure mode. This matrix indicates that there are a several parameters that come into play with each failure mode. There is also a significant amount of "coupling" between the parameters as they relate to each of the failure modes. To complete this test sequence while considering each of the parameters that can affect the failure mode as an independent variable would be a monumental task. Use of statistical experimental design will limit the number of test runs while still producing results that describe these failure modes in sufficient detail and accuracy to be technically acceptable.

Table III. Failure Mode Testing Variable Matrix

Failure mode	Conc	Temp	R.H. %	Media Veocity	PSD	Filter DP	Monitor	Misc.
Pin holes, Tears	Ref	Ref	Ref	Ref	Ref	Measured	Benchmark	Hole size
Seal leaks	Ref	Ref	Ref	Ref	Ref	Measured	Benchmark	Leak Config.
Temp. Excursion	Ref	100 degF over spec	Ref	Ref	Ref	Measured	Benchmark	Time at temp
Moisture	Ref	Ref	90%	Ref	Ref	Measured	Benchmark	Time at R.H.
Aging	Ref	Ref	Ref	Ref	Ref	Measured	Benchmark	Time since manuf.

Ref denotes parameters to be operated at a standard reference value,

The test matrix found in Table IV reflects the source terms to be addressed by the second test sequence along with the parameters of interest for each source term. The matrix identifies the parameters that will be used to define a particular test case. A statistical experimental design will also be employed for this second phase of testing activities

Table IV. Source Term Testing Variable Matrix

Source Term	PM Conc.	Temp.	R.H. %	Media Velocity	PSD	Filter DP	Monitor	Misc.
PSD	Ref	Ref	Ref	Ref	X	Measured	Benchmark	
H2O-soluble PM	Ref	Ref	90% R.H.	Ref	Ref	Measured	Benchmark	Time at humidity
Smoke	Ref	Ref	Ref	Ref	Ref	Measured	Benchmark	Smoke Duration
Heat	Ref	X	Ref	Ref	Ref	Measured	Benchmark	
PM loading	high	Ref	Ref	Ref	Ref	Measured	Benchmark	Time at challenge

X denotes parameters to be varied,
Ref denotes parameters to be operated at a standard reference value,

Statistical Experimental Design

The large number of factors (parameters) to be included in the experimental design make it impractical to independently examine the effects of each parameter. With such a large number of factors, a full factorial or even a fractional-factorial experimental design would involve many test runs, each of which requiring hours or days of activity.

Therefore a statistical design will be employed in involving investigation of the influence of only one, or at most two factors. Within this design it is recognized that effects due to interactions among factors will not be discernable. This series of experiments is best seen as a preliminary screening experiment, intended to identify the most important factors for further research.

Variability arising from filter loading and therefore filtering efficiency will be minimized by using new filters for those experiments sensitive to this phenomena. It is recognized that variability of individual HEPA filters may be another source of experimental error. This will be minimized by using only AG-1 filters and employing a blocking where runs made with a given HEPA filter will constitute a block.

The change of filter properties with time within a block, will be dealt with by: (1) using replication, with the individual test runs occurring in different sequence within a block and (2) by measuring the pressure drop across the filter, which is a surrogate for filter loading, and treating this parameter as a covariate.

To quantify the differences between filters (blocks), a particular set of factor values (Concentration level 1, PSD level 1, etc.) has been designated as a baseline condition. One test run under these baseline conditions will be made with each new filter when it is first placed into service. This test run will serve as a control for the differences between individual filters.

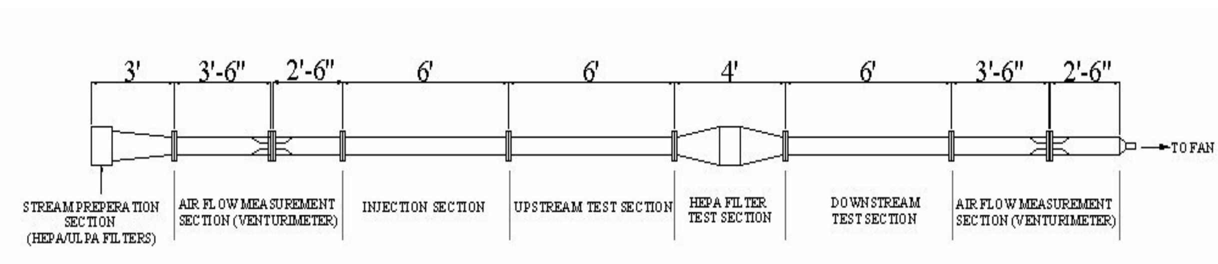

Fig. 4. Schematic of the Test facility

Test Stand Design

In order to provide a facility that would be a suitably flexible system for undertaking the testing activities outlined in this project, DIAL is in the process of designing and constructing a test stand. The salient features are shown in the schematic in Figure 2.

The inlet filtration section consists of a series of pre-filters, HEPA and ULPA (1'x1') filters, to remove ambient particles providing a very clean process stream on which to perform testing. This is followed by a 6" diameter flow measurement section that can house either a venturi meter or an orifice plate for making flow measurements. Dual sets of pressure measurement devices will be utilized in order to ensure flow accuracy. A venturi meter is the device of choice due to the lower unrecoverable pressure drop. To prevent the infiltration of ambient air particulates the flanges used to mate test sections will be ConFlat flanges with OFHC copper gaskets, which necessitates the use of stainless steel tubing as opposed to pipe. In addition, to minimize wall effects from interior surfaces, each of the sections will be electro-polished.

The injection section is where the challenge agents (DOP, particulate, smoke, steam, etc.) will be introduced. Sufficient mixing lengths are provided in this section to ensure a uniform flow into the measurement section. Gas temperature, pressure and humidity measurements will be performed at the inlet of the upstream measurement section. This section will also be equipped with a sufficient number of ports to allow for extractive sampling (method 5I, ELPI,etc.), velocity (Pitot Tube), as well as ports that provide optical access to the gas stream so that a variety of instrumentation can be utilized in conducting the testing.

The HEPA filter housing will be designed to house a standard 1'x1'x6" HEPA filter. This filter housing will be constructed by a manufacturer of HEPA filters and will conform as close as possible to the requirements set down in AG-1. Velocity measurements will be conducted to ensure that the distribution of velocities across the face of the filter are within 20% of the average. In addition, standard DOP testing will be performed to ensure that there is no leakage/bypass around the filter.

The HEPA unit is followed by a downstream measurement section, equipped with the same variety of ports as the upstream measurement section. A venturi flow measurement section is then utilized to ensure that there has been no leakage of ambient air into the test section. Temperature, pressure and humidity measurements will also be performed at the inlet to this section.

As outlined elsewhere, the primary facility design criteria for testing the 1'x1'x6" HEPA filter is at a flow rate of 250 cfm with tests to be performed between 20% (50 cfm) and 150% (375 cfm) of the nominal flow rate. The nominal flow rate is 25% of a standard 2'x2'x6" HEPA filter rated for flow at 100 scfm. Our calculations show that the maximum pressure drop (with 5 in. wc across each of the filter units and flow meters) that can be expected for the range of design flow rates is about 28" wc at 375 scfm. Allowing for a factor of safety we estimate that all the air required can be drawn through the test facility using a 7.5 Hp vortex regenerative blower.

A central requirement of the testing activities that will be conducted is the rigorous control of the testing environment, particularly the test stand. This translates to being able to sense and control critical operational parameters (using a variety of instruments) of the test stands for the purposes of stability and repeatability of test conditions. DIAL maintains a M&TE Calibration program that outlines individual calibration procedures and records to be maintained. The test stand will have an array of sensors and measurement devices used for data collection, control, and for monitoring of test stand operation. In addition to these Category I sensors and instruments, having NIST traceable calibration, other Category II instruments, which do not require NIST traceable certification will be used for evaluation and verification of operation/maintenance. Control of the primary test facility operating parameters will be through a state of the art LON works networked system, already available at DIAL. Space and power for providing an inlet air-heater are available at the DIAL test facility if additional air heating is necessary.

Of particular importance in this program is the ability to make a variety of flow measurements. Determination of the volumetric flow rate and/or flow velocity of flue gases is of critical importance to accurate PM sampling and reporting of PM concentrations. A variety of flow rates and duct sizes may be encountered during the course of testing activities, necessitating the use of an array of flow measuring techniques. A list of the sensors available to make these flow measurements along with their minimum required accuracy is presented in Table V.

Table V. Flow Sensors

Velocity/Flow Technique	Accuracy
Pitot tube	5% of FS**
Venturi meter	5% of FS
Orifice plate meter	5% of FS
Mass Flow meter	5% of FS
LDV (laser doppler velocimeter)	5% of reading

** Full Scale

It is essential that the test conditions and equipment employed in our activities be comparable to those encountered by HEPA filters in functioning DOE facilities. Our engineering activities intend to ensure that test stand(s) be able to establish and maintain targeted test conditions as well as follow standard industry practice and design criteria. Among these standards, criteria, and industry practices that we will consider include ASME AG-1; AS ME AG-N509; ASME N510; Institute of Environmental Sciences (IES) RP-CC001.3; IES RP-CC007.1; IES RP-CC013; IES-RP-CC021.1 etc.

Test Stand Performance Verification

An obvious set of activities that must be completed is the simple verification of a test stand's capability to meet and hold the targeted ranges of performance for which it was designed. However, many of the aspects of the testing that will be conducted under this test plan will require a knowledge of properties such as wall deposition rate of PM, characterization of flow patterns as a function of duct velocity, and the establishment of equivalent sampling locations per RM 5I.

The first set of tests will be conducted to ensure that the flow rates and velocities are within the design specifications and that the flows can be measured with sufficient accuracy and precision. Flow patterns will also be evaluated to ensure that a turbulent, non-cyclonic flow pattern is established. Initial tests will be conducted using filtered ambient air without altering either the temperature or humidity. Air flow measurements will include use of venturi/orifice plate flow meters, Pitot tubes, and Laser Doppler Velocimetry (LDV). The flow measurements will be analyzed for accuracy, precision and stability, as well as being cross-checked between the different techniques. Any ambient infiltration into the test stand will be made obvious by differences between the upstream and downstream flow measurements.

EPA Reference Method 5I, EPLI and SMPS measurements of background PM levels will be initiated once the flow testing has begun. The first sequence of tests to evaluate background PM levels will serve multiple purposes by facilitating development of procedures for startup, shutdown, and test stand decontamination. These testing activities will provide the needed data to evaluate and fine tune operating procedures to reduce background PM concentrations to the lowest possible levels. The final sequence of characterization testing will evaluate the accuracy with which targeted PM concentrations can be achieved using the range of particle generators and feeders.

Wall losses and non-uniform flow patterns are only two of the many possible causes of variations in particulate concentration. There are additional precautions that must be taken to ensure that two locations are equivalent in terms of particulate concentrations. EPA Method 1 (for stack diameter > 12 inches) and Method 1A (for 4″ < d stack < 12″) specify the criteria that must be considered in determining the suitability of a sampling location. Most of these involve the distance required downstream and upstream of a flow disturbance.

When an alternate method is to be compared to the reference method it is necessary to experimentally verify that the sampling locations are indeed equivalent. One method involves the use of repetitive "side by side" sampling wherein two identical samplers are located at theoretically equivalent traverse locations and multiple sets of samples are obtained. The measurements are then statistically analyzed. It may also be necessary to correct for increases in flow velocity due to flow obstruction by the sample nozzle and/or probe.

On some occasions "side by side" sampling is not possible due to conflicting access requirements. For these situations sampling locations are positioned along the flow path such that adequate distance is given for the flow to redevelop and mix. For such cascaded locations it may be necessary to adjust or correct for the reduction in flow velocity caused by the removal of material from the flow.

Wall losses of PM are important because they constitute a loss of PM between the point it is injected and where the filter is located or where the PM concentration is measured. This is a potential source of systematic error. Before conducting the Benchmark HEPA filter efficiency tests, the rate of loss of PM due to wall deposition must be quantified. Wall losses are due to factors that include wall impaction, and other forces such as thermophoresis or electrophoresis. Gravitational settling is also recognized as being a possible source of systematic error.

Experimentally, particle loss can be evaluated by injecting known amounts of particles and then measuring the particle loading at different distances downstream. Additionally, particles of various dimensions that have been coated with fluorescent dyes can be injected into the test stand followed by inspection of the inner surfaces of the duct with a UV light source. Regions and patterns of deposition will be determined and used as qualitative information in modeling activities. In the event that measurable quantities of PM are deposited, these particles can be reclaimed for gravimetric analysis and determination of PSD. Theoretically, simplified numerical models of particle transport in a turbulent flow will be used to predict particle trajectories.

Benchmark Measurements of HEPA Filtering Efficiency

Many of the issues that will be addressed as a part of this study can be traced back to changes in the filtering efficiency of a HEPA filter as it either ages or becomes loaded with PM. The precision of making HEPA efficiency measurements needs to be demonstrated before variability between individual filters can be investigated.

The traditional method of evaluating HEPA filter performance involves challenging the filter using DOP or a similar liquid aerosol. This technique requires an input level of DOP several orders of magnitude higher than PM levels a HEPA would normally experience. An evaluation of the extent to which the high exposures to DOP affects filter performance will be made in order to facilitate reuse of HEPA filters acquired for this study. The extent to which DOP evaporation can interfere with evaluation of filtering efficiency will also be investigated. Finally, data will be collected to compare measured filtering efficiencies using equivalent concentrations of solid PM and liquid aerosol (DOP or equivalent) challenge agents near the maximum loading level of 23 mg/m3.

Benchmark Solid PM Calibration Testing will be conducted using a particle feeder or aerosol generator capable of producing solid salt particles as the challenge agent. Measurements will be made both up and downstream of the filter using an ELPI and an SMPS in order to approximate both the mass concentration and PSD of the entrained PM. This experimental design allows the test to be carried out at or near the PM loading range normally seen by a HEPA filter. Comparison of up and downstream concentrations will provide the filtering efficiency.

Benchmark DOP Calibration Filter Testing segment of this project will be conducted using ATI equipment like that employed by the various DOE Filter Test Facilities that have been located across the complex. The DOP loading will be conducted at an aerosol concentrations of 100 micrograms /liter, the level normally used for in-situ filter testing. Although this level of loading is significantly higher than the recommended input level to a HEPA, it is required in order to obtain reliable measurements downstream of the filter. Measurements will also be made at the 20 to 40 micrograms/liter level for comparison purposes.

Special decontamination procedures will be developed to ensure that all traces of DOP are removed from the system after each test. Standard operating procedures that are developed in conjunction with the decontamination procedure will include conduction of selected wall loss measurements using solid PM challenge agents to verify that Benchmark performance levels have been reestablished.

Calibration of PM Generators

A variety of PM generators will be employed in the course of this study. Testing will require challenging HEPA filters with mono-disperse and poly-disperse aerosols, both solids and liquids. Testing will also require the capability of producing various PM challenge concentrations with a differing of particle size distributions.

A set of calibrated techniques must be devised that is capable of measuring PM concentrations both up- and downstream of a HEPA filter. This translates to concentrations that range from the HWC MACT (34 mg/m^3) or the accepted maximum loading rate for HEPA filters (23 mg/m^3) for PM levels upstream of a filter to PM concentrations that would be four orders of magnitude less than these values for the anticipated concentrations downstream of the filter.

HEPA filtering efficiency is defined as the demonstrated ability to remove at least 99.97% of entrained PM that is 0.3 micrometers or larger in diameter. One aspect of this testing activity will be evaluation of the PSD of PM both up and downstream of the filter. Clearly, the anticipated upper and lower ranges of PM PSD will be markedly different in these regions and will likely involve correlation of measurements that have been made using two distinctly different technologies. Correlation of measurement data between different measurement technologies needs to be conducted using both liquid and solid aerosols and for a range of PSDs.

The physical and chemical nature of the PM used in testing will also be varied. The chemical nature and PSD of PM used as challenge agents for this testing needs to be matched as well as possible with those properties of PM encountered in DOE Facilities subject to the HWC MACT. This most frequently consists of solid material; however, the behavior of liquid aerosols will also be investigated.

It is also important to recognize that the concentration ranges of different types of PM will need to be accurately established in order to facilitate the calibration of instruments and conduction of testing activities. This means that a variety of characterized and calibrated PM generators and particle feeders will be required to complete this work. A table of the potential PM injectors that could be used for seeding the stream is shown below.

Table VI. Particle Generator Performance Ranges

Particle Generator	Type	Size Range (Mean Diameter) (um)	Particle Concentration
TSI 3450	Monodisperse	1-200	$<10^4$ cc
TSI 3080	Monodisperse	0.002-1.0	$<10^5$ cc
TSI 3475	Monodisperse	0.1-8	$>10^6$ cc
TSI 3480	Monodisperse	0.002 - 0.1	$<10^7$ cc
TSI 3433	Powder	0.5 - 50	0.3 to 50 mg/m^3
TSI 3400	Powder	0.5 - 40	10 to 100 mg/m^3
TSI 3076	Poly. atomizer	0.01 - 2 (0.3 um)	$>10^7$ cc (count mean)
TSI 3079	Poly. atomizer	0.01 - 2 (0.3 um)	$>10^8$ cc (count mean)
TSI 9302A	Poly. atomizer	0.01 - 2 (0.3 um)	$>10^7$ cc count mean)
TSI 9306A	Poly. atomizer	0.01 - 2 (0.3 um)	$>10^4$ cc (count mean)

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