PART THREE

Continuous Particulate Monitoring for $PM_{2.5}$ and PM_{10}

Chapter 7
Part Three - Continuous Particulate Monitoring for $PM_{2.5}$ and PM_{10}
Table of Contents

Page

1.0 Introduction **1**
1.1 Sampling Method Overview 1

2.0 Instrumentation **3**
2.1 Interferences 4
2.2 Instrument Description 4
2.2.1 Control Unit 4
2.2.2 PM10 Inlet or $PM_{2.5}$ Very Sharp Cut Cyclone 5
2.2.3 Sensor Unit 5
2.3 Ancillary Equipment 5

3.0 Site Selection **5**
3.1 Siting Requirements 5
3.2 Site Safety and Security 6

4.0 Monitor Installation, Calibration, and Operation **7**
4.1 Monitor Installation 7
4.2 Calibration of Components 8
4.2.1 Overview of Calibration Procedures 8
4.2.2 TEOM Calibration Procedure 10
4.2.3 SHARP Calibration Procedure 13
4.2.4 BAM Calibration Procedure 15
4.3 Monitor Operation 16

5.0 Data Acquisition **16**

6.0 Data Validation **16**

7.0 Performance Audit Procedures **18**
7.1 Flow-Rate Performance Audit Procedures 18
7.1.1 Audit Equipment 18
7.2 Overview of Audit Procedures 20
7.2.1 TEOM Audit Procedure 20
7.2.2 BAM Audit Procedure 21
7.2.3 SHARP Audit Procedure 22
7.3 Audit Data Reporting 24
7.4 Audit Frequency 24
7.5 Systems Audit 24

8.0 Precision and Accuracy Assessment **24**
8.1 Precision 24
8.2 Accuracy 24

9.0 Maintenance **25**
9.1 Recommended Maintenance and Frequency 25
9.2 As Needed Maintenance 25

10.0 Forms **25**
1 TEOM Calibration Form 26
2 TEOM® PM_{10} / $PM_{2.5}$ Audit Form 29
3 BAM Calibration Form 30
4 BAM Audit Form 33
5 SHARP Calibration Form 35
6 SHARP Audit Form 37

Figures

1 R&P TEOM 2
2 Met One BAM 3
3 Thermo Scientific SHARP 3

Tables

1 Standard Sampler Configuration 4
2 Example of Minimum Sampler Siting Criteria 6
3 Data Validation Criteria 17
4 Conversions 18
5 Recommended Maintenance & Frequencies 25

Photo

Inlet on Gary IITRI Roof 7

Part Three – Continuous Particulate Monitoring of $PM_{2.5}$ and PM_{10}

1.0 Introduction

Traditional particulate monitoring uses pre-weighted filters on which particles are collected over a 24-hour period. This sampling method is labor intensive requiring an operator to pick-up an exposed filter then install a new clean filter for each sample and at each sampling site. Exposed filters must then be transported back to a laboratory for conditioning, weighing, data calculation, and data entry. Samples are normally collected in a one every six day frequency (intermittent sampling).

The first continuous particulate monitors, installed in 1995, the PM_{10} TEOM® were installed at two sites in northern Indiana. This was followed roughly 10 years later with the introduction of Met One's BAM units and more recently Thermo Environmental's SHARP monitors.

The Thermo uses a Tapered Element Oscillating Microbalance (TEOM®) methodology to continuously measure particulate matter mass concentrations. Met One utilizes a Beta Attenuation Monitor (BAM), while the Thermo Synchronized Hybrid Ambient Real-Time Particulate Monitor (SHARP) combines nephelometric and radiometric measurements into one instrument. All three have received USEPA equivalency for $PM_{2.5}$ and PM_{10} monitoring

1.1 Sampling Method Overview

Ambient air is drawn into sampler through an air inlet followed by an exchangeable filter cartridge, or filter tape where the particulate mass collects. The inlet system is equipped with a sampling head which separates particles of either a 2.5 µm or 10 µm diameter ($PM_{2.5}$ or PM_{10}). The sampled air proceeds through the sensor unit; microbalance for the TEOM, beta attenuation for the BAM, and hybrid nephelometer/beta attenuation for the SHARP .

A TEOM makes use of a microbalance system. As the sample stream moves into the microbalance system, it is heated to the temperature specified by the control unit. This heating minimizes the deposition of water due to changes in ambient humidity. The control unit contains a flow controller, which regulates the sample stream through the monitor at flow rates between 0.5 and 6 liters per minute. A hollow tube is attached to a platform at its wide end (Tapered Element) and is vibrated at its natural frequency. As particulate matter gathers on the filter cartridge, the tube's natural frequency of oscillation decreases. The electronic microbalance system continually monitors this frequency.

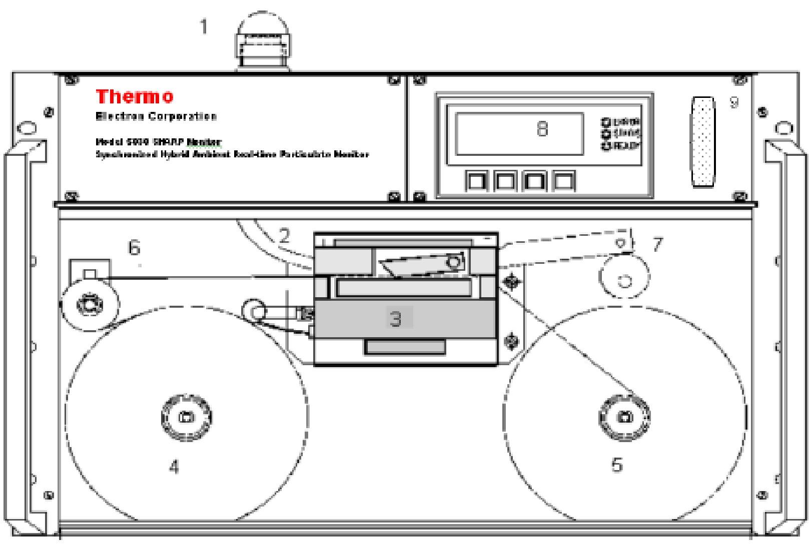
The BAM contains a small ^{14}C element which emits a constant source of high energy electrons. These beta particles are detected and counted by a sensitive scintillation detector. An external pump pulls a measured amount of dust-laden air through a filter tape. After the filter tape is loaded with ambient dust, it is automatically placed between the source and the detector thereby causing an attenuation of the beta particle signal. The degree of attenuation of the beta particle signal is used to determine the mass concentration of particulate matter on the filter tape, and hence the volumetric concentration of particulate matter in ambient air.

The SHARP incorporates a hybrid system utilizing two distinct measurement processes in one unit. The sample stream is first passed through the nephelometer where a sensor measures the light scattering cause by the particulate matter aerosol as it passes through an 880 nm illumination beam. Next the aerosol is deposited onto a filter tape. Here the instrument measures particulate concentrations by passing radiation through a known sample area to a detector, similar in principle to the BAM, referencing alpha (Rα) and beta (Rβ) counts to a reference.

Figure 1
TEOM
1400 (left) and 1405 (right)

Figure 2
Met One BAM

Figure 3
Thermo Scientific SHARP



2.0 Instrumentation

IDEM uses TEOMs, BAMs, and SHARPs for all continuous particulate data collection. Table 1 shows the standard configuration for each, as specified by the manufacturer.

Table 1
Standard Sampler Configuration

Parameter	TEOM	BAM	SHARP
Total Flow	16.7 liters per min (1 m^3/hr)	16.7 liters per min (1 m^3/hr)	16.7 liters per min (1 m^3/hr)
Sample Stream Temperature	50 °C	25 °C	25 °C
Particulate Matter Concentration Measurement Range	< 5 µg/m^3 to several µg/m^3	0 to 1,000 µg/m^3	0 to 1,000 µg/m3
Ambient Temperature Sensor	-25 ° to 105 °C	-30 ° to 55°C	-22 ° to 158 °C
Ambient Pressure Sensor	0.68 to 1.09 atmospheres (atm)	600 to 800 mmHg	600 to 800 mmHg

2.1. Interferences

These highly accurate and precise instruments can be affected by a variety of outside forces. These include, but are not limited to: vibrations, electrical interferences – such as blackouts, brown outs, power spikes, magnetic/electric fields, moisture, temperature, and improper siting.

The temperature of the TEOM's sample stream should be maintained within as narrow of a range as possible. Large temperature fluctuations (7 to 8 °F per minute) of the sample stream may cause measurement accuracy to decrease due to the inlet system's inability to adjust the temperature of the sample to that specified by the software before traveling to the microbalance system. Both the BAM and SHARP have built-in heater assemblies on the down tube, between the sample inlet and instrument, to help moderate both temperature and relative humidity.

Very high background radiation levels can possibly affect both the SHARP and BAM, as both utilize an internal radiation emitting source.

2.2. Instrument Description

The three real-time particulate monitors utilized by IDEM's monitoring network can be broken down into three parts; the control features, sensor, and inlet.

2.2.1 Control Unit

The control features houses the following:

- Mass flow controllers and the control electronics for operation
- The main electrical and air connections to the main power supply, the auxiliary control,

and the main vacuum pump/connections

- The main power switch, status light, and the keypad for operation

2.2.2 PM_{10} Inlet or $PM_{2.5}$ Very Sharp Cut Cyclone

A PM_{10} inlet is designed to allow only particulate matter ≤10 µm in diameter to remain suspended in the sample air stream as long as the flow rate of the system is maintained at 16.67 l/min. The inlet incorporates a rain and bug shield and is used on the BAM, SHARP, and TEOM. If the monitor is sampling $PM_{2.5}$, a very sharp cut cyclone (VSCC) is placed in-line directly below the PM_{10} inlet, and above the down tube. This cyclone further eliminates suspended particles, allowing only those ≤2.5 µm into the sampler. This combination of PM_{10} inlet and VSCC is identical to that used in intermittent sampling.

2.2.2 Sensor Unit

The sensor unit houses the mass transducer (TEOM), beta attenuation monitor (BAM/SHARP) and nephelometer (SHARP) sensing units and all included electronic circuit boards with the appropriate wiring for electricity and frequency signal output.

2.3. Ancillary Equipment

Listed below are several (but not inclusive) supplies required for operation of IDEM's monitoring network:

- Certified flow rate transfer standards (Bios, Chinook Streamline FTS kit, TriCal, or similar)
- Certified Barometer
- Certified thermometer
- Certified Relative Humidity Meter (SHARP)
- Certified Zero/Span Foil Kit (SHARP)
- Logbooks and database/laboratory and maintenance
- Manufacturer recommended spare parts

3.0 Site Selection

3.1. Siting Requirements

Basic siting criteria for the placement of ambient air samplers are documented in Table 2 in this section. This is not a complete listing of siting requirements; instead, an outline to be used by the operating agency to determine a sampler location. Complete siting criteria are presented in 40 CFR 58, Appendix E. All sampling locations must meet the guidelines set forth in 40 CFR Part 50 Appendix L, and Part 58 Appendix D as well as the siting guidelines outlined in Chapter 1, Section 4.0 of this manual.

As with any type of air monitoring study in which sample data are used to draw conclusions about a general population, the validity of the conclusions depends on the representativeness of the sample data. Therefore, the primary goal of a monitoring project is to select a site or sites where the collected particulate mass is representative of the monitored area.

Table 2
Example of Minimum Sampler Siting Criteria

Scale	Height Above Ground	Distance from supporting structure, meters		Other spacing criteria
		Vertical	Horizontal [a]	
Micro	2 to 7 meters	>2	>2	1. Should be >20 meters from trees.
Middle, Neighborhood, Urban, & Regional	2 to 15 meters	>2	>2	2. Distance from sampler to obstacle, such as buildings, must be twice the height that the obstacle protrudes above the sampler.
				3. Must have unrestricted airflow 270 degrees around the sampler inlet.
				4. No furnace or incineration flues should be nearby.[b]
				5. Spacing from roads varies with traffic (see (40 CFR 58, Appendix E).
				6. Sampler inlet is at least 2 m, but not greater than 4 m from any sampler having flow rates greater than 200 L/min, or 1 meter from samplers having flow rates less than 200 L/min. (See 40 CFR 58, Appendix E).

[a] When inlet is located on rooftop, this separation distance is in reference to walls, parapets, or penthouses located on the roof.

[b] Distance depends on the height of furnace or incineration flues, type of fuel or waste burned, and quality of fuel (sulfur, ash, or lead content). This is to avoid undue influences from minor pollutant sources. As a precautionary measure, the sampler should be placed at least 5 meters from the furnace or incinerator flue.

3.2. Site Safety and Security

Additional factors not specified in the Code of Federal Regulations (CFR) must be considered in determining where the monitor is deployed. These factors include accessibility under all weather conditions, availability of adequate electricity, and security of the monitoring personnel and equipment. The monitor must be situated where the operator can reach it safely despite adverse weather conditions. If the monitor (or part of the monitor i.e., sample inlet) is located on a rooftop, care should be taken that the operator's personal safety is not jeopardized by a slippery roof surface during inclement weather. Consideration also should be given to the fact that routine operation (i.e., calibration, maintenance, flow check, and audit) involves transporting supplies and equipment to and from the monitoring site.

To ensure that adequate power is available, consult the manufacturer's instruction manual for the sampler's minimum voltage and power requirements. Lack of stable power source can result in the loss of data because of power interruptions.

The security of the sampler itself depends mostly on its location. Rooftop sites with locked access and ground-level sites with fences are common. In all cases, the security of the operating personnel as well as the sampler should be considered.

Photo 1
Inlet on Gary IITRI Roof

4.0 Monitor Installation, Calibration, and Operation

4.1. Monitor Installation

All site selections and installations shall comply with siting criteria presented in 40 CFR 58, Appendix E. Installation should also adhere to section 3.2 Site Safety and Security in this document. The following is a general guideline for instrument installation. More detailed instructions should be referenced in their corresponding manuals.

Once a site has been selected and the instrument tested and found to be in working order:

1. Determine the exact location of the monitor and all included equipment, such as pumps. Care should be taken to allow room for both sample and electrical connections.

   - Both the BAM and SHARP instruments must be placed directly below the down tube
   - The TEOM unit itself does not need to be directly below the down tube, but its sensor unit does

2. Drill or use an existing opening in the structure's roof to allow for the instrument's down tube. In addition, mount the tripod or other down tube support structure, if needed, and the temperature/pressure sensor.

   - The TEOM also has a bypass flow line that is flexible and can be routed through the shelter's side or an existing port to alleviate the need for another hole in the roof

3. Inside the shelter, mount the instrument on a rack using the appropriate hardware, or place on a sturdy flat surface, such as a table or counter top.

   - Be sure to account for the down tube as mentioned above
   - If not rack mounting, be sure to properly secure the instrument to account for vibrations

4. Make all electrical, communication, and air connections. Be sure all packing material, shipping screws, and other similar materials have been removed prior to turning on.

5. Once installed, power on, allow instrument to warm up, and ensure that all functions are working properly.

4.2. Calibration of Components

4.2.1 Overview of Calibration Procedures

The following is a general guide to calibrating the continuous monitors used by IDEM. For more detailed instructions, refer to the specific monitor's user manual and the IDEM OAQ instrument specific SOP.

Useful Formulas for Calibration/Audit Procedures:

Reference Flow

$$Q_{Ref} = m * \left[\sqrt{\frac{\Delta P \ * \ T_{amb}}{P_{amb}}}\right] + b$$

Where:

Q_{Ref}	=	Reference flow (liters per minute)
m	=	FTS Slope
b	=	FTS Intercept
ΔP	=	Manometer reading ("H_2O)
T_{amb}	=	Reference ambient temperature (K)
P_{amb}	=	Reference ambient pressure (atm)

Temperature Conversion, Celsius to Kelvin

$$T_K = T_c + \ 273$$

Where:

T_K	=	Temperature in Kelvin
T_C	=	Temperature in Celsius

Barometric Pressure Conversion, mmHg to atm

$$P_{atm} = \frac{P_{mmhg}}{760}$$

Where:

P_{atm}	=	Pressure in atm
P_{mmhg}	=	Pressure in mmHg

Flow Conversion, True to Standard

$$Q_{std} = Q_{true}\left[\left(\frac{298}{T_{amb}}\right) * \left(\frac{P_{amb}}{760}\right)\right]$$

Q_{std}	=	Standard flow (liters per minute)
Q_{true}	=	True Flow (liters per minute)
T_{amb}	=	Reference ambient temperature (K)
P_{amb}	=	Reference ambient pressure (mmHg)

To calculate Reference/Observed Flow Difference

$$Diff = \left(\frac{Q_{Obs} - Q_{Ref}}{Q_{Ref}}\right) \times 100$$

Where:

Q_{Ref} = Reference flow (liters per minute)
Q_{Obs} = Observed flow (liters per minute)
Diff = Difference in percent

4.2.2 TEOM Calibration Procedure

Equipment required for calibration:

- Certified Thermometer/Temperature Probe
- Certified Barometer
- Certified Flow Transfer Standards (FTS, TriCal, deltaCal, or similar)
- Flow Audit Adapter (leak check device)
- Pre-weighed Calibration Filter
- Filter Exchange Tool
- Calibration Forms

A. Ambient Air Temperature and Pressure Verification:

1. Place a certified thermometer/temperature probe into the TEOM's ambient temperature sensor mount.
2. On the TEOM control panel, access the "Set Temps/Flows" screen. Arrow down until the Amb Temp and Amb Pres come into view.
3. Verify that the ambient temperature is within ±2 ˚C and the ambient pressure ± 10 mmHg of the transfer standards.
4. If either parameter falls outside the given range, an analog calibration is required. Refer to the TEOM service manual for more information on analog calibrations.
5. Ambient temperature and pressure verifications should be completed before a flow calibration/verification.

B. Leak Check:

1. Disable the corresponding channel in the LEADS system.
2. Use the up and down arrow keys on the TEOM to view the main and total flow values.
3. Remove the inlet from the down tube. If present, leave the very sharp cut cyclone in place.
4. Attach a flow audit device to the down tube or very sharp cyclone and close the device.

5. Record the flow values shown on the TEOM on the calibration form. Main flow should be < 0.15 lpm, while Total flow should be < 0.6 lpm. Return to the inlet and slowly open and remove the flow audit device. Replace the inlet on the down tube or VSCC.
6. If the values are higher than the allowable standard, a non-linearity offset value (NOV) may be established. This is done by:
7. Repeat the first 4 steps of the leak check procedure. Slowly open the flow audit device.
8. Unplug the pump from the power supply.
9. Wait several minutes to let the flow rates stabilize, then close the flow audit device.
10. Record the flow values. Take the original values and subtract the NOV.
11. Remove the flow audit device and replace the inlet.
12. Enable the corresponding channel in LEADS and leave an entry in electronic operator log.

C. Flow Verification/Calibration:

1. Disable the corresponding channel in the LEADS system.
2. Perform a leak check using a flow audit adapter.
3. Locate the flow audit adapter and ensure that the valve of the adapter is in its open position.
4. Remove the size-selective inlet from the flow splitter and replace it with the Flow Audit Adapter.
5. Make sure the Flow Audit Adaptor is in the open position.
6. When in the Main screen, scroll down to the "Main Flow" and "Aux Flow" lines. These values represent the actual volumetric flows as measured by the monitor's flow controllers.
7. Confirm that these flows are within ± 2% of their set points (3.0 l/min for the "Main Flow" and 13.67 l/min for the "Aux Flow"). Any greater deviation may indicate that the in-line filters are plugged or other blockages exist in the system.
8. Attach a reference flow meter to the top of the Flow Audit Adapter.
9. Read the total flow (approximately 16.67 l/min) on the reference flow meter. The total volumetric flow measured by the reference flow meter must be 16.67 ± 4% and ±5% of the design flow to be acceptable.
10. Disconnect the bypass flow line from the bypass extension on the bottom of the flow splitter located at the sample inlet.
11. Cap the exit of the flow splitter bypass extension with the 3/8-inch Swagelok cap.
12. Read the main flow (approximately 3.0 l/min) on the reference flow meter. The volumetric flow measured by the reference flow meter must be 3.0 ± 4% and ±5% of the design flow to be to be acceptable.

13. If the flow readings are within acceptable limits, remove the 3/8-inch Swagelok cap from the flow splitter bypass extension.
14. Install the bypass flow line onto the flow splitter bypass extension.
15. Perform a leak check.
16. Remove the flow audit adapter from the top of the flow splitter.
17. Install the sample inlet onto the flow splitter.
18. Install a new TEOM filter into the mass transducer.
19. Press <F1> or <Run>.
20. Enable the corresponding channel in LEADS and leave an entry in electronic operator log.

D. Mass Transducer Calibration Verification:

1. From any screen press 17<Enter> to access the K0 Confirmation screen. Confirm the Calibration Constant shown on the Set Hardware Screen is the same as that shown on the nameplate located on the left side of the mass transducer support cage.
2. Warm up the system with any filter cartridge that is not the calibration filter so that all the temperatures are at their normal operating conditions for at least one hour. The airflow through the system should be at its normal value, at or near 16.67 L/min combined main/auxiliary flows, during this period.
3. Disable the corresponding channel on the LEADS system. Enter the Setup Mode on the control unit by pressing the keypad "Data Stop". Turn off the air tube heater by setting the set point to 0 on the Set Temps/Flows Screen.
4. Unplug the vacuum pump so there is no flow through the instrument. This prevents particulate contamination of the calibration filter.
5. Scroll through the Menu Screen (using "Stop Screen" and the down arrow on the keypad of the control unit) and select the last item, "KO Confirmation".
6. When KO Confirmation is selected, the following screen will appear:

```
K0 Confirm       209.44188
>Filt Wght         0.07903
 287.53182       209.44186
 Audit K0             9683
```

7. Use the down arrow keypad to move to the "Filt Wght" Input the weight of the preweighed calibration filter, as recorded on the Kit data, on the line labeled “Filt Wght” by pressing the "Edit" keypad and then the value.
8. Open the mass transducer and remove the media filter from the tip of the tapered element using the filter exchange procedure. Close the mass transducer and sensor unit door. Operate the system without a filter and wait for the oscillating frequency shown in the

upper right-hand corner of the screen to reach a maximum value. Observe the frequency output next to "K0 confirm' on the first line of the K0 Confirmation screen. The frequency will increase, peak and then start to decrease in value. When the frequency peaks, press the 'First/Last" keypad (in the center of the arrow keys) to record this frequency value in the first slot of the third line of the screen. (Note: If you miss the peak you can open and close the transducer again and observe the frequency a second time to catch the peak value.)

9. Remove the filter tool and filter box containing the calibration filter

   Note: The calibration tool can be distinguished from a normal filter tool by its red handle. Do NOT use the calibration filter tool to remove or install any filters except for the calibration filter.)

10. Install the calibration verification filter with the filter exchange tool provided with the calibration kit, in the instrument. Note that the filter exchanges are normally performed with the pump on to help the filter become properly seated on the tapered element. Since the pump is not on, take special care to ensure that the filter is properly seated. Close the mass transducer and sensor unit door. Return the calibration tool immediately to the Kit and reseal the bag. Again watch the frequency output and the control unit's screen and when it peaks to reach a new maximum value.
11. Press the <First/Last> key again to record the frequency f1.
12. The instrument then automatically computes and displays the audit value of the calibration constant, K0 on the line entitled "Audit K0". An example of the final screen display is as follows:

K0 Confirm	209.44188
>Filt Wght	0.07903
287.53182	209.44186
Audit K0	9683
Actual K0	9627
% Diff	0.58

13. The K0 confirmation Screen also displays the current K0 value entered in the monitor and the percentage difference between the audit and currently entered value. The indicated difference should not be more than 2.5% from the original TEOM calibration constant.
14. Press F1 to leave the TEOM in "OK." Enable the corresponding channel in LEADS and leave an electronic operator log.

4.2.3 SHARP Calibration Procedure

Equipment required for calibration:

- Certified Thermometer/Temperature Probe
- Certified Barometer

- Certified Flow Transfer Standards (FTS, TriCal, deltaCal, or similar)
- Flow Audit Adapter (leak check device)
- Certified Relative Humidity Meter
- Certified Zero/Span Foil Kit
- HEPA Filter/Adapter
- Calibration Forms

Prior to beginning the SHARP calibration, ensure the instrument is operating properly. If the internal sample temperature sensor is to be calibrated, allow the instrument to operate at least one hour with the heating system turned OFF.

A. Temperature, Relative Humidity, and Barometric Pressure Sensor Calibration

1. Enter the Calibration Menu. Press “SET” to input the calibration menu code. Change the code to “4” using the “+” and “-” soft keys.
2. Press the “YES” key to perform a 1 point calibration of the barometric pressure, relative humidity, and all of the temperature sensors.
3. Obtain a reference ambient temperature by placing a certified temperature probe or thermometer near the SHARP ambient temperature sensor. Input the reference reading into the ambient (T1) temperature calibration screen using the “+” and “-” keys.
4. Repeat the process for T2 (Sample Temp), T3 (Orifice Temp), and T4 (Heater Temp). Reference temperature values can be obtained by measuring the shelter temperature. Allow an hour for T2, T3 and T4 to equilibrate with each other and the shelter temperature, with the heating system off, before taking a reading.
5. Perform a relative humidity calibration by placing the reference meter’s probe into the sample chamber and closing the door. Allow approximately one hour for equilibration. Input the reading into the relative humidity calibration screen.
6. Input the barometric pressure reading obtained from a certified barometer into the calibration screen.

B. Sample Flow Calibration

1. Before beginning a flow calibration, ensure that the pump is turned off. Remove the inlet and attach a certified flow transfer standard.
2. Turn the pump on through the calibration menu.
3. Press the CAL soft key to input the calibration coefficient using the “+” and “-” keys.
4. Adjust the indicated flow rate to match the certified transfer standard using the “+” and “-” keys. Allow at least 30 seconds between adjustments for flow equilibration.
5. Repeat the process until the indicated flow is ±2% of the certified transfer standard.

C. Mass Foil Calibration

1. Enter the “Foil Calibration” screen through the calibration menu and press the “YES” soft key.
2. Enter the span foil value, as noted on the span foil in the certified foil calibration kit, using the “+” and “-” soft keys. Once the correct value is displayed press “NEXT.”
3. After the beta attenuation chamber opens, cut the filter tape and pull out from the chamber. Insert the foil holder into the chamber. It should click into place. Once in place, press “NEXT.”
4. Once the chamber closes, insert the zero foil into the foil holder, press “NEXT.” The zeroing process should take ~200 seconds to complete.
5. With the zero complete, remove the foil and replace with the span foil. After pressing “NEXT” wait another 200 seconds for the span point to run.
6. A screen showing the old and new mass calibration factors will be displayed. Press “YES” to change the factors.
7. After the chamber opens again, remove the foil and foil holder. Replace the filter tape, ensuring proper placement through the chamber and across the rollers.
8. Perform a FC+Z (filter change and zero) by pressing the FC+Z soft key before returning the instrument to service.

D. Nephelometer Zero and Calibration

1. Install the HEPA filter on the inlet.
2. Enter the Nephelometer calibration screen through the calibration menu and press the “YES” soft key.
3. Allow the instrument several minutes to allow the nephelometer to stabilize. Press the “ZERO” soft key to begin the zeroing process. This is an automated process that should last less than two minutes.
4. Once the calibration is complete, exit the calibration menu, lock the keypad, and return the instrument to normal service. Enable the corresponding LEADS channel and leave an electronic operator log entry.

4.2.4 BAM Calibration Procedure

Equipment required for calibration:

- Certified Thermometer/Temperature Probe
- Certified Barometer
- Certified Flow Transfer Standards (FTS, TriCal, deltaCal, or similar)
- Calibration Forms

Before attempting a calibration ensure that the BAM has been powered on and allowed to warm up for at least an hour.

1. Disable the corresponding LEADS channel.
2. Obtain a reference ambient temperature reading by placing a certified temperature probe or thermometer near the BAM's ambient temperature sensor. Use a certified barometer to note the ambient barometric pressure.
3. On the BAM's control panel, enter the TEST> FLOW menu. Use the "NEXT" soft key to highlight the "AT" field. Input the reference temperature obtained in the previous step; repeat the process to input the barometric pressure in the "BP" field.
4. Remove the PM_{10} inlet and install the certified transfer standard. If the BAM is sampling $PM_{2.5}$, leave the very sharp cut cyclone in place. Return to the control panel and use the "NEXT" soft key to move to the first flow point of 15 l/min. The pump will start automatically; allow the BAM to equilibrate. Input the reference flow reading and press the "CAL" soft key to correct the BAM's reading.
5. Repeat the process for the other two calibration flow levels. The BAM will not change to match until all three points have been entered.
6. Replace the PM_{10} inlet on the down tube.
7. Exit the TEST>FLOW menu and leave the BAM in "Normal" mode.
8. Enable the corresponding LEADS channel and leave an electronic operator log.

4.3. Monitor Operation

Each monitor should be operated in accordance with the user's manual. In general, each should:

1. Be properly sited (refer to section 3 in this part).
2. Be connected to a reliable power source.
3. Have a valid calibration prior to collecting usable data.

5.0 Data Acquisition

Data is collected and stored using the Leading Environmental Analysis and Display System (LEADS) data logging system.

Disable data logger during maintenance, calibrations, and audits. This prevents erroneous results from being considered valid by LEADS.

6.0 Data Validation

Data validation criteria were developed from the instruments' operation manual recommendations and from staff's operational experience.

Table 3
Data Validation Criteria

Audit Limits and Actions (different instrument thresholds are noted)	
Flow Rate:	
Range Limit	Action
≤ ±4% ($PM_{2.5}$), ≤ ±7% (PM_{10}) of audit standard **AND** ≤ ±5% ($PM_{2.5}$) of design value (16.67 l/min)	Data Valid. Flow in-calibration.
> ±7% and ≤ ±10% (PM_{10}) of audit standard	Date Valid. Flow out-of-calibration
> ±4% ($PM_{2.5}$), > ±10% (PM_{10}) of audit standard **OR** > ±5% ($PM_{2.5}$) of design value (16.67 l/min)	Data Invalid. Invalid period determined by either last good flow audit, last calibration, last maintenance, or last flow-related diagnostic test.
Leak Check (TEOM)	
Limit	Action
Main Flow ≤ 0.15 l/min	Data Valid. Pass, no action.
Main Flow > 0.15 l/min	Data Invalid. Invalid period back to last good leak check.
Aux Flow ≤ 0.60 l/min	Data Valid. Pass, no action.
Aux Flow > 0.60 l/min	Data Invalid. Invalid period back to last good leak check.
Leak Check (BAM)	
Limit	Action
≤ 1.5 l/min	Data Valid. Pass, no action.
> 1.5 l/min	Data Invalid. Invalid period back to last good leak check.
Temperature & Barometric Pressure:	
≤ ±2 °C	Data Valid. Pass, no action
> ±2 °C	Data Valid. Recalibrate temperature sensor.
≤ ±10 mmHg	Data Valid. Pass, no action
> ±10 mmHg	Data Valid. Recalibrate barometric pressure sensor.

7.0 Performance Audit Procedures

The primary goal of an auditing program is to identify problems that may result in suspect or invalid data. Performance audits should be conducted under the following guidelines:

- Audits must be done without special preparation or adjustments made to the system
- The individual performing the audit must be someone other than the routine operator and must have a thorough knowledge of all instruments or processes being evaluated
- All aspects of the audit must be completely documented including the types of instruments and transfer standards, model and serial numbers, calibration information, etc.

Quality Assurance audits are conducted at least once per quarter.

Audits should start at the beginning of an hour or at least completed during the hour to minimize data loss.

7.1 Flow-Rate Performance Audit Procedures

7.1.1 Audit Equipment

- Chinook Engineering Streamline Flow Transfer Standards (FTS)
- Certified Digital Manometer
- Certified barometer
- Certified Temperature Probe(s) or Thermometer(s)
- Relative Humidity Meter (SHARP)
- Certified Zero/Span Foil Kit (SHARP)
- Temperature Sensor Dummy Wires (SHARP)

Audit Equations

Table 4
Conversions

mmHg to atmospheres (atm)	mmHg/760
atm to mmHg	atm* 760
°C to Kelvin (K)	°C + 273

True Flow Calculation

$$Q_{true} = \left[m * \sqrt{\frac{\Delta P * T_{amb}}{P_{amb}}} \right] + b$$

Where:

Q_{true}	=	True Flow rate, m^3/min
ΔP	=	Manometer pressure drop (in Hg)
P_{amb}	=	Ambient barometric pressure, mmHg
T_{amb}	=	Ambient Temperature K
m	=	FTS Slope
b	=	FTS Intercept

$$\% \, Difference = \left[\frac{(Q_{ob} - Q_{true})}{Q_{true}}\right] * 100$$

Where:

Q_{true}	=	True Flow rate, m^3/min
Q_{ob}	=	Observed (Sampler) Flow rate, m^3/min

If the sampler requires the conversion of actual/standard flow, use the following equation:

$$Q_{std} = Q_a(P_a/P_{std})(T_{std}/T_a)$$

$$Q_a = Q_{std}(P_{std}/P_a)(T_a/T_{std})$$

Where:

Q_{std}	=	standard volume flow rate, m^3/min
Q_a	=	actual volume flow rate, m^3/min
P_a	=	ambient barometric pressure, mmHg
P_{std}	=	standard barometric pressure, 760 mmHg
T_{std}	=	standard temperature, 298 K (25 ^oC + 273)
T_a	=	ambient temperature, K (^oC + 273)

Relative Humidity (SHARP) calculation

$$RH_{T2} = RH_{Ref} \times e^{-5161.8\left(\frac{1}{T_{Ref}} - \frac{1}{T_2}\right)}$$

Where:

RH_{T2}	=	SHARP Relative Humidity in %
RH_{Ref}	=	Reference Relative Humidity in %
T_{Ref}	=	Reference Ambient Temperature in K
T_2	=	SHARP Sample Temperature in K

Difference, in Percent calculation

$$Diff = \left(\frac{V_{Obs} - V_{Ref}}{V_{Ref}}\right) \times 100$$

Where:

V_{Ref} = Reference Value
V_{Obs} = Observed Value
Diff = Difference in percent

7.2 Overview of Audit Procedures

The following is only a general guide. For more detailed, sampler specific instructions, refer to the user's manual and instrument specific SOPs.

7.2.1 TEOM Audit Procedure

1. Place a certified temperature probe or thermometer near the TEOM's temperature sensor and allow to equilibrate.
2. Measure and record on the TEOM audit form the ambient temperature (°C) and ambient barometric pressure (mmHg). Allow sufficient time for the temperature probe to equilibrate to ambient conditions and ensure that the probe is not in direct sunlight or not in contact with any surfaces. The TEOM's ambient temperature should be within 2°C while the barometric pressure should be within 10 mmHg of the reference values collected.
3. On the control unit, note the observed ambient temperature and pressure. Record the TEOM status/mode, serial number, filter loading, date and time, as well as the last calibration date.
4. Disable the corresponding LEADS channel and press "F1" on the TEOM keypad to flag the data. Note the start time.
5. Access the sample inlet and remove the inlet by gently twisting and lifting. Place a certified flow transfer standard on the Very Sharp Cut Cyclone ($PM_{2.5}$) or down tube (PM_{10}). The use of a separate High (Total Flow) and low (Main Flow) flow FTS may be required. Allow the flow to equilibrate.
6. Record the pressure drop. Note the TEOM indicated flow. The total indicated flow should be within ±4% of the reference flow (±5% of design flow) if $PM_{2.5}$ and $\underline{+}$10% for PM_{10}.
7. Remove the green auxiliary line and plug the port.
8. Once more, allow the flow to equilibrate, record the pressure drop, and note the TEOM indicated flow. The TEOM indicated main flow should be ±4% of the reference flow (±5% of design flow) if $PM_{2.5}$ and $\underline{+}$10% for PM_{10}.
9. Reattach the green auxiliary line.
10. Remove the flow transfer standard and replace with a flow audit device for a leak check. Close the flow audit device.
11. Record the flow values for the main and total flows. The main flow value should be < 0.15 lpm, the total flow < 0.6 lpm.
12. Remove the flow audit device and replace the inlet.

13. Enable the corresponding LEADS channel and leave an electronic operator log entry.

7.2.2 BAM Audit Procedure

1. A BAM audit should be initiated while the unit is in COUNT/COUNTING mode.
2. Place a certified temperature probe or thermometer near the BAM's temperature sensor and allow to equilibrate. Ensure that the probe is not in direct sunlight or not in contact with any surfaces.
3. Measure and record on the BAM Audit Form the ambient temperature (°C) and ambient barometric pressure (mmHg). The BAM's ambient temperature should be within 2°C while the barometric pressure should be within 10 mmHg of the reference values collected.
4. On the control unit, note the observed ambient temperature and pressure. This can be accessed by hitting the "F1" Current key.
5. Hit the "EXIT" soft key and record the BAM status/mode, serial number, filter tape remaining, date and time, as well as the last calibration date.
6. Disable the corresponding LEADS channel.
7. On the BAM control unit, hit the "TEST" soft key to access the TEST menu. Use the left/right arrows to select "PUMP" and enter the PUMP screen.
8. The pump should be off before starting a flow audit.
9. Remove the inlet head and attach a certified flow transfer standard. If a VSCC is present, leave in line.
10. Return to the control unit and press the "PUMP ON" soft key. Note the BAM's indicated flow.
11. Collect a reference flow from the certified flow transfer standard. The BAM should be within ±4% of the reference flow (±5% of design flow).
12. Return to the control unit and press the "PUMP OFF" soft key.
13. Remove the certified transfer standard and attach a flow audit device to begin a leak check.
14. Return to the control unit and press the "PUMP ON" soft key. The indicated flow should be <1.5 lpm.
15. Press the "PUMP OFF" soft key. Slowly open and then remove the flow audit device. Replace the inlet.
16. Return to the control unit and hit the "EXIT" soft key twice to get back to the main menu. Select the "OPERATE" soft key to move to the Operate Mode screen. Ensure that the BAM OPERATE and STATUS commands are ON.
17. Press the "NORMAL" soft key to return the instrument to normal operation. It should now show the Normal display screen.
18. Enable the corresponding LEADS channel and leave an electronic operator log entry.

7.2.3 SHARP Audit Procedure

1. Check for any status/error lights and ensure that the instrument is in working order.
2. Measure and record on the Sharp Audit Form the ambient temperature (°C) and barometric pressure (mmHg). Allow sufficient time for the temperature probe to equilibrate to ambient conditions and ensure that the probe is not in direct sunlight or not in contact with any surfaces. The SHARP's ambient temperature should be within 2°Cof the reference value.
3. Disable the corresponding LEADS channel. Note the start time.
4. The SHARP ambient temperature (T_1) can be reached through the "Operation/Temperature Control System Menu." The ambient barometric pressure (P_3) is accessed through the "Service Menu" / "Hardware Diagnostics Menu."
5. Open the acrylic glass door and place the probe of a certified relative humidity meter and temperature probe inside. Close the door as tight as possible, taking care to not crimp the cords.
6. Allow the temperature and humidity to equilibrate for at least 20 minutes. Record the reference values.
7. The SHARP relative humidity (RH) and sample temperature (T_2) values can be found in the "Diagnostics Menu." The temperature and relative humidity should fall within 2°C of the reference.
8. Remove the RH meter and temperature probe.
9. Enter the "Calibration Menu" and unlock the keys. Use the calibration code to unlock the "Calibration Menu" and enter the "Air Flow Menu" to turn the pump off.
10. Exit the "Calibration Menu" and enter the "Service Menu." Under the "Hardware Diagnostics" submenu note the P_1 (orifice pressure) and P_2 (vacuum pressure) values, which should be close to zero. Disable the heater box in the "Operation Menu."
11. Remove the inlet from the down tube. If a VSCC is present, leave in place. Connect the HEPA filter to the down tube (or VSCC). The HEPA filter will filter out particulates while conducting the audit
12. Remove the temperature sensor wires from the rear of the control unit and replace with dummy wires. These dummy wires allow easier auditing of the Orifice (T_3), and Heater (T_4). Place a certified temperature probe or thermometer near the end of the wires.
13. Return to the "Calibration Menu" then "Air Flow Menu" to turn the pump on. Allow to equilibrate for at least five minutes.
14. Enter the "Nephelometer Menu." Record the Nephelometer concentration and analog values. If the value is negative or above 4 $\mu g/m^3$ contact the Ambient Monitoring Parameter Specialist to inform them of the results.
15. Exit and return to the "Calibration Menu" / "Air Flow Menu" and turn the pump off.
16. Remove the HEPA filter and attach a certified flow transfer standard to the down tube. Turn the pump on and allow flow to equilibrate for at least 5 minutes.

17. The SHARP indicated flow can be viewed in the “Calibration Menu” / “Air Flow Menu.”
18. Compare the SHARP indicated flow with the reference and record on the SHARP Audit Form. The values should be within 4% of the reference flow (5% of design flow).
19. Exit and return to the “Calibration Menu” / “Air Flow Menu” and turn the pump off. Remove the certified transfer standard and replace the HEPA filter. Turn the pump back on and allow to equilibrate for at least 30 minutes.
20. Audit the Orifice (T_3), and Heater (T_4) temperatures by comparing them to the shelter temperature using a certified temperature probe or thermometer. The SHARP values can be obtained in the “Service Menu” / “Hardware Diagnostics Menu.” Note on the SHARP Audit Form. Observed values should be ±2°C of the reference value.
21. Exit and return to the “Calibration Menu” / “Air Flow Menu” and turn the pump off.
22. Enter the “Foil Calibration Menu” screen to begin the mass detector audit.
23. Enter the span foil value, as noted on the span foil in the certified foil calibration kit, using the “+” and “-” soft keys. Once the correct value is displayed press “NEXT.”
24. After the beta attenuation chamber opens, cut the filter tape and pull out from the chamber. Insert the foil holder into the chamber. It should click into place. Once in place, press “NEXT.”
25. Once the chamber closes, insert the zero foil into the foil holder, press “NEXT.” The zeroing process should take ~200 seconds to complete.
26. With the zero complete, remove the foil and replace with the span foil. After pressing “NEXT” wait another 200 seconds for the span point to run.
27. A screen showing the old and new mass calibration factors will be displayed. Press “NO” to change the factors. This is only an Audit of the detector, so new values should not be entered. The old and new factors should be ± 5%. Record results on the SHARP Audit Form.
28. After the chamber opens again, remove the foil and foil holder. Replace the filter tape, ensuring proper placement through the chamber and across the rollers.
29. Ensure that a FC+Z (filter change and zero) is performed before returning the instrument to service.
30. Begin the Beta Attenuation Detector Audit. Enter the “Service Menu” / “Hardware Diagnostics Menu. / “Beta Attenuation Screen.” Press the “START” soft key.
31. Record the Rα (alpha counts) at 60 seconds. Press the “Rref” soft key and record the Rref and R_β at 60 seconds. Rref should be within 40-60% of R_β (beta counts).
32. Remove all audit equipment, reattach temperature sensors, and turn the temperature control system and heater on. Record the operational pump power in the “Display Menu.”
33. Lock the keys and return the instrument to operation. Note the end time and enable the corresponding LEADS channel and leave an entry in the electronic operator log.

7.3 Audit Data Reporting

Inform the site or network operator of the audit results as soon as possible after audit completion. A paper copy of the audit may be forwarded to the operator or personnel may view the audit in the database. If data is invalid, the auditor should promptly inform the operator verbally and in written form (memo or email).

7.4 Audit Frequency

The IDEM Office of Air Quality's Ambient monitoring section conducts verifications of all real-time particulate monitors in its network at least once each month to ensure minimal data loss. In addition, the Quality Assurance Section performs quarterly audits on all monitors. These audits include flow, temperature, and pressure tests, as well as a beta attenuation check in the SHARP.

7.5 Systems Audit

A system audit is review of the total monitoring process from site location, safety, and sampling to final analysis and data reporting and includes an on-site inspection. System audits are generally done at the initial set up of a network and on an annual or on an as needed basis thereafter. The specific guidelines and procedures for this type of audit are found in Chapter 15 of this manual, System Audit Criteria and Procedures for Evaluating Ambient Air Monitoring Networks.

8.0 Precision and Accuracy Assessment

8.1 Precision

Precision is the measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions. Precision is estimated by the use of a duplicate or collocated sampler at a selected monitoring location in a measurement network. One sampler is designated as the reporting sampler and one sampler is designated as the collocated sampler. The collocated sampler must be maintained, operated, calibrated, and audited in the same manner as the reporting sampler. Precision is calculated from the difference in the concentrations from the reporting and collocated samplers over a calendar quarter.

8.2 Accuracy

The accuracy of the network is measured by auditing the flow rate performance of the samplers in the network. The percentage difference between the audit flow rate and the sampler flow rate is used to determine accuracy. Two flows rates are audited on the TEOM® monitor: the main flow which is approximately 3 liters per minute and the total flow which is approximately 16 liters per minute. Only the total flow is used to estimate accuracy. Accuracy calculations are described in detail in 40 CFR Part 50, Appendix L, CFR Part 50, Appendix A.

The USEPA requires that 25 percent of the samplers within a reporting organization's network be audited for accuracy each quarter. To improve accuracy estimates, additional accuracy flow rate audits may be conducted each calendar quarter. IDEM-OAQ-QAS audits all continuous $PM_{2.5}$/PM_{10} samplers in its monitoring network at least once each quarter. This audit frequency provides additional accuracy flow rate data and also ensures minimal data loss due to "out-of-calibration" conditions.

9.0 Maintenance

Routine preventive maintenance helps prevent failures of the monitoring processes. The overall objective is to increase measurement reliability and prevent data loss. Follow the manufacturer's recommended guidelines for routine maintenance procedures.

Maintenance records must be kept for each sampler or instrument. These records should contain a history of the sampler, including all replacement parts, suppliers, costs, installation dates, etc.

9.1 Recommended Maintenance and Frequency

Table 5
Recommended Maintenance & Frequencies

Maintenance	Frequency
Clean PM_{10} or $PM_{2.5}$ inlet	Monthly
Large bypass in-line filter exchange	6 months
Battery test	6 months – change if necessary
Pump test	6 months (or pump power >95% in SHARP)
Clean air inlet system	1 year
Rebuild pump	18 months

9.2 As Needed Maintenance

- Exchange fuses
- Clock adjustment
- Resetting system
- System software download

10.0 Forms

*Continuous PM_{10} and $PM_{2.5}$ monitoring use the same calibration and audit forms.

Form 1
TEOM Calibration Form

TEOM 1400 AB Series Flow Controller Calibration

Site: ________________________________ Date:___/___/___ Initials: __________

Monitor: ______________________________________ Last Calibration: ___/___/___

Calibrator: _____________________________________ Last Calibration: ___/___/___

Average Temperature Setting: _____ °C Ambient Temperature: _______ °C

Average Pressure Setting: _______ atm. Ambient Pressure: _________ atm.

Main Flow: Main flow before adjustments: __________ LPM (should be 3.0 LPM)

Set main flow to 0.5 LPM = ______ LPM adjust R101 until flow meter = 0.5 LPM +/- 0.03 LPM
Adjusted to _______ LPM _______LPM _______LPM

Set Main flow to 4.5 LPM – Flow Meter = _______ LPM – adjusted R105 = ________LPM

Set Main flow back to 3.0 LPM – verify flow on flow meter: ___________ LPM

Bypass Flow: Bypass flow before adjustments: __________ LPM (should be 13.67 LPM)

Set bypass flow to 2.0 LPM = _________ LPM adjust R201 until flow meter = 2.0 =/- 0.2 LPM
Adjusted to: __________LPM ___________ LPM __________LPM

Set Bypass flow to 18.0 LPM – Flow Meter = _______ LPM – adjusted R205 = ________LPM

Set Bypass flow back to 13.67 LPM – verify flow on flow meter: ___________ LPM

Leak Check:

Main Flow = ________ Screen (0.15 LPM or below passes Leak check)
Did the System PASS or FAIL ?

Aux Flow = _________ Screen (0.60 LPM or below passes Leak check)
Did the System PASS or FAIL ?

Temperature Calibration: Thermometer = ___________ °C

Ambient Temp on Temp/Flow Screen = _________ °C Adjusted input 8 = _______°C

Pressure Calibration: + 10V test point = _______DVM Adjusted R304 = _______DVM

Barometer = _____ mmHg/_____atm TEOM screen = _____atm Adjusted R509 = _____ atm

Comments:____
____
____

TEOM Calibration Form (Continued)

TEOM 1400 AB Series Analog Calibration

Site:_______________________________ Date: ___/___/___ Initials: ___________________

Monitor: ____ Last Calibration:___/___/___

Analog Outputs:

Test Point 0 = _________ DVM 1 = _________ DMV 2 = _________ DMV

3 = _________ DMV 4 = _________ DMV 6 = _________ DMV

Analog Inputs:

Test Point 0 = _________ DMV TEOM Screen = _________ -> _________

1 = _________ DMV = _________ -> _________

2 = _________ DMV = _________ -> _________

3 = _________ DMV = _________ -> _________

4 = _________ DMV = _________ -> _________

5 = _________ DMV = _________ -> _________

6 = _________ DMV = _________ -> _________

7 = _________ DMV = _________ -> _________

8 = _________ DMV = _________ -> _________

9 = _________ DMV = _________ -> _________

10= _________ DMV = _________ -> _________

11= _________ DMV = _________ -> _________

12= _________ DMV = _________ -> _________

13= _________ DMV = _________ -> _________

14= _________ DMV = _________ -> _________

15= _________ DMV = _________ -> _________

TEOM Calibration Form (Continued)

TEOM 1400 AB Series Mass Transducer Calibration Verification

Site: ____________________ Date: ____________ Initials: _____________

TEOM Model / SN: ____

R & P Calibration Constant for the Unit: _____________________________________

Does Calibration Constant on the Set Hardware Screen match that shown on the nameplate located on the left side of the mass transducer support cage? _____ (Yes/No)

The following formula should be used to calculate the calibration constant (K):

$$K = \frac{M\ (\text{filter})}{1/f\ (1)\ (\text{Sq'd}) - 1/f\ (0)\ (\text{Sq'd})}$$

Where: M (filter) = filter mass (grams)
f (0) = frequency without filter (Hz)
f (1) = frequency with filter (Hz)

M (filter)	f (0)	f (1)
g.	g.	g.

R & P's Calibration Constant	Calculated Calibration Constant

% Difference: __________ %

***Must be within +/- 2.5%

Form 2
TEOM® PM_{10} / $PM_{2.5}$ Audit Form

Indiana Department of Environmental Management
Office of Air Quality
Quality Assurance Section
PM_{10}/$PM_{2.5}$ TEOM Audit

Site Information	
Site:	Audit Date:
AQS #: 18 -	Auditor:

Sampler Information			
Thermo FDMS TEOM Sampler Mode 1400A-8500 SN: ________________			
Screen Display on Arrival	Run Status:	Mode:	
	Filter Loading:	ST/ET:	
Sampler Calibration Date:		Last Audit/Verification Date:	
Sample Time		Sample Date	
Audit Correct Time		Correct Audit Date	
Comments			

Audit Devices Information					
Parameter	Audit Device/Model	Serial No.	Cert Date	Slope (m)	Intercept (b)
Temp	VWR Scientific Model 100A				
Baro Press	Digital Barometer AIR HB-1A				
Flow Rate	Chinook FTS - High				
	Chinook FTS - Low				

Difference = TEOM – QA	Audit Data		% Diff = (TEOM – QA) / QA * 100	
Parameter	TEOM	QA	Difference	Limit
Amb Temp (°C)				± 2 °C
Baro Press (atm)				
Baro Press (mmHg)				± 5 mmHg

FTS & Flow Data					
Parameter	TEOM	FTS (" H_2O)	QA	Difference	Limit
Main Flow (Lpm)					± 4 %
Total Flow (Lpm)					
Design Value Lpm)	16.67				± 5 %

Leak Check					
Main Flow		< 0.15 LPM	Aux Flow		< 0.60 LPM

COMMENTS

Useful Equations

$Q_{true} = \left[m * \sqrt{\frac{\Delta P * T_{amb}}{P_{amb}}} \right] + b$	*T_{amb} = Amb Temp(°C) + 273*	*P_{amb} = Baro Press (mmHg)/760*

Form 3:

BAM Calibration

Office of Air Quality – Air monitoring Branch

Date:______________ Site:_______________ Performed by:___________

Start Time:_________ End Time:__________ Last Cal:________________

Serial Number:_________ Asset Tag:__________

Audit Device Information:

FTS SN: ____________________ Certification Date:_________m:________b:_________

Thermometer SN: ____________ Certification Date: ___________

Barometer SN: _______________ Certification Date: ___________

Audit Data:

Display BP: _________ mmhg **Reference BP:** _________ mmhg Pass or Fail (+/- 10 mmhg)

Display Temp: _________ °C **Reference Temp**:_________ °C Pass or Fail (+/- 2 degrees)

Flow Audit:

Ambient Temp:_____°C + 273.15 = ______Kelvin BP:_____mmhg/760 = _______atm

BAM Display: ___________ LPM Observed Flow
Circle one: Standard or Actual? If in Standard LPM please convert to Actual LPM
Converted flow:_____________ LPM
Manometer Reading: ___________ inches of Water
Reference Flow: ___________ LPM
% Difference: ___________ Pass if % Difference < 3%
Leak Check: ___________ Pass if better than 1.5 LPM

Formulas and Conversions:

$$\text{Reference Flow} = m \times \sqrt{(\Delta P \times T_a)/BP} + b$$

$$\text{Actual Flow} = \text{Standard Flow} \times (760/298) \times (T_{REF}/P_{REF})$$

$$\% \text{ Difference} = \frac{\text{Observed Flow} - \text{True Flow}}{\text{True Flow}} \times 100$$

Pump Serial #:________________ Asset Tag:____________
Temp Probe Serial #:___________ Asset Tag:__________ Heater Asset Tag #:____________

Comments:____

Calibration Data:

Target	BAM	Reference	Inches of H_2O	Calibrated	% Difference
Ambient Temp			XXXXXXXXXX		XXXXXXXXXX
BP			XXXXXXXXXX		XXXXXXXXXX
Flow 1: 15.0					
Flow 2: 18.4					
Flow 3: 16.7					
Filter Temp			XXXXXXXXXXX		XXXXXXXXXXX
Filter RH			XXXXXXXXXXX		XXXXXXXXXXX

Slope _________ Intercept ________ Post Cal Flow = ________

Amb Temp________ K Barometric Pressure _______ atm Post cal Leak Check = ________

	BAM Output	Multimeter	Zeno Raw	Zeno Scaled
0.000				
0.100				
0.200				
0.300				
0.400				
0.500				
0.600				
0.700				
0.800				
0.900				
1.000				

Self Test Pass:___________ Intercept Adjustment Required:_______________

Reference Membrane Foil Span (ABS):OLD = ___________ NEW AVG= _________ % Diff = __________

ABS Test 1:________ 2:__________ 3:__________ 4:__________

Background Zero:OLD = ______________ Zeroed: Y or N NEW = ________________

Pump Changed or Rebuilt:_________ Down Tube Cleaned:________ Nozzle/Vane Cleaned:_______
Flow Controller Filter Changed:________Date/Time Adjustment:________Mode on Departure:_______

Form 4
BAM Audit Form

Indiana Department of Environmental Management
Office of Air Quality
Quality Assurance Section
Quarterly Beta Attenuation Monitor (BAM) Audit

Site Information	
Site:	Audit Date:
AQS #: 18 -	Auditor:

Sampler Information			
MET ONE BAM 1020 SN: ____________________			
Screen Display on Arrival	Mode/Run Status:	Audit Start:	
	Tape Remaining:	Audit Stop:	
Sampler Calibration Date:		Last Audit/Verification Date:	
Comments			

Audit Devices Information					
Parameter	Audit Device/Model	Serial No.	Cert Date	Slope (m)	Intercept (b)
Flow rate	Chinook FTS - White				
Temp	VWR Scientific Model 100A				
Baro Press	Digital Barometer AIR HB-1A				

Audit Data			Difference = BAM – QA	
Parameter	QA	BAM	Difference	Limit
Amb Temp (°C)				± 2 °C
Baro Press (mm Hg)				± 10 mmHg

Flow & Leak Check Data					
FTS (in. H_2O)		Amb. Temp (°K)		Baro. Press. (atm)	

QA act	Ta. °K	BP, mmHg	QA std
	298.1		
		760	

% Diff = (BAM – QA) / QA * 100

Parameter	QA_{std}	BAM_{std}	Difference	Limit
Total Flow (Lpm)				± 4 %
Leak Check (Lpm)				<1.0 Lpm

COMMENTS

Useful Equations

$Q_{true} = \left[m * \sqrt{\frac{\Delta P * T_{amb}}{P_{amb}}} \right] + b$	T_{amb} = Amb Temp(°C) + 273.1	P_{amb} = Baro Press (mmHg)/760

$$Q_{std} = Q_{act} \times \frac{P_{act}}{760\ mmHg} \times \frac{298}{T_{act}}$$

$$Q_{act} = Q_{std} \times \frac{T_{act} + 273.1}{298} \times \frac{760\ mmHg}{P_{act}}$$

Form 5
SHARP Calibration Form

SHARP Calibration Form

Site: ______________ Instrument Model No: ____________ Instrument Ser. No: ______________

Date: ______________ Time: ____________ FTS Ser No: ______________

I. Sensor Calibration

a. T_1 Current = _______ T_1 Reference = _______ T_1 Cal'd = _______
b. T_2 Current = _______ T_2 Reference = _______ T_2 Cal'd = _______
c. T_3 Current = _______ T_3 Reference = _______ T_3 Cal'd = _______
d. T_4 Current = _______ T_4 Reference = _______ T_4 Cal'd = _______
e. BP Current = ______ BP Reference = ______ BP Cal'd = ______

II. Flow Calibration

a. SHARP Indicated flow = __________ $^{L\,/\,hour}$ / 60 min = _________ $^{L}/_{min}$
b. Manometer Reading = _______ in H_2O Slope: ______Intercept:______
c. FTS Flow = _____________ $^{L}/_{min}$ X 60 min =___________ $^{L}/_{hour}$
d. Ref. T1 = ______________ Ref. BP = ________________
e. Calibrated SHARP flow = ________________

III. Instrument Zero

a. Nephelometer As Found As Left

Neph. Concentration = _________ $^{\mu g}/_{m}3$ = _________ $^{\mu g}/_{m}3$

Neph. Analog Value = _________ = _________

Zeroed? Circle Yes or NO (if yes, then fill out "As Left")

IV. Mass Foil Calibration

a. Current (Old) Amplification = _______
b. Audit (New) Amplification = _______
c. % Difference = 100 x [$^{(Old - New)}/_{New}$] = ____________%

V. Detector Zero (FC + Z)

I. Avg. R_α= __________ Is R_α<1.0? YES ____ NO_____
II. Avg. R_β = __________
III. Avg. R_{ref} = _________

Is R_{ref} between 40-60% of R_β? YES ____ NO_____

SHARP Calibration Form (Continued)

IV. RH Sensor Calibration

a. RH_{T2} = __________% at T_2 = __________ ° C = __________ K
Ref: Temp = __________ ° C = __________ K RH = __________%
RH_{T2} Converted = _______% RH Calibrated = ____________

RH Conversion Equation

$$RH_{T2} = RH_{Ref} * e^{-5161.8\left(\frac{1}{T_{Ref}} - \frac{1}{T_2}\right)}$$

*Temps need to be in Kelvin for conversion

IIV. Operational Pump Power = ________________%

IIIV. Other Pressure Sensors

a. P_1 @ zero = __________ hPa Span/Operational P_1 = ___________ hPa
P_2 @ zero = ___________ hPa Span/Operational P_2 = ___________ hPa

FC+Z Performed? YES or NO ________________________

VSCC and 1st Stage inlet cleaned/replaced? YES or NO ________________________

Date and Time match data logger? YES or NO ________________________

Keypad locked and channel reenabled in LEADS? YES or NO ________________________

Comments:____

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Form 6
SHARP Audit Form

SHARP Quarterly Data Form

Site: ______________ Instrument Model No: ____________ Instrument Ser. No: ______________
Date: ______________ Time: ____________ FTS Ser No: ______________

I. Temperature Sensors Audit Allowed Difference = ± 2° C
  a. Ambient Temp. = T_1 = _______ ° C
  Ref. Ambient Temp = _______ ° C Pass _______ Fail _______

II. RH Sensor Audit Allowed Difference = ± 3% RH
  a. RH_{T2} = __________% at T_2 = __________ ° C = __________ K
  Ref: Temp = __________ ° C = __________ K RH = __________%
  RH_{T2} Converted = _______% Pass _______ Fail _______

RH Conversion Equation

$$RH_{T2} = RH_{Ref} * e^{\wedge} \, {}^{-5161.8\,(1/T_{Ref} - 1/T_2)}$$

*Temps need to be in Kelvin for conversion

III. Pressure Sensors Allowed Diff = ±10 mmHg Pass _______ Fail _______
  a. P_1 @ zero = __________ hPa Span/Operational P_1 = ___________ hPa
  P_2 @ zero = ___________ hPa Span/Operational P_2 = ___________ hPa
  b. Amb. Pressure = P_3 = ____________ hPa = ____________ mmHg
  Ref. Amb. Pressure = ____________ mmHg Conversion: mmHg = hPa x 0.75

IV. Instrument Zero Allowed range = -0.5 to 4.0 $\mu g/m^3$ Pass _______ Fail______
  a. Nephelometer As Found As Left
  Neph. Concentration = __________ $\mu g/m^3$ = __________ $\mu g/m^3$
  Neph. Analog Value = __________ = __________
  Zeroed? Circle Yes or NO (if yes, then fill out "As Left")
  b. Detector [Perform immediately after FC+Z]
    i. Avg. R_α= __________ Is R_α<1.0? YES ____ NO_____
    ii. Avg. R_β = __________
    iii. Avg. R_{ref} = _________
    Is R_{ref} between 40-60% of R_β? YES ____ NO_____

V. Flow Rate Audit Allowed Difference = ±4% Pass_______ Fail_______
  a. SHARP Indicated flow = ___________ L / hour / 60 min = _______________ $^L/_{min}$
  b. Manometer Reading = __________ in H_2O Slope: _______ Intercept:_________
  c. FTS Audit Flow = _______________ $^L/_{min}$ X 60 min = _______________ $^L/_{hour}$
  d. % Difference = 100 x [$^{(SHARP - FTS)}/_{FTS}$] = _____________%

Sharp Audit Form (Continued)

VI. Operational Pump Power = ____________%

VII. Other Temp Sensors Audit   Allowed Range = ± 2° C

a. T_2 = ___________ ° C   Ref Temp. = ______ ° C   Pass______   Fail______

b. T_3 = ___________ ° C   Pass______   Fail______

c. T_4 = ___________ ° C   Pass______   Fail______

VIII. Mass Detector Audit   Allowed Difference = ± 5%   Pass______   Fail______

a. Current (Old) Amplification = _______

b. Audit (New) Amplification = _______

c. % Difference = 100 x [$^{(Old - New)}/_{New}$] = _____________%

FC+Z Performed?   YES or NO _______________________

VSCC and 1st Stage inlet cleaned/replaced?   YES or NO _______________________

Date and Time match data logger?   YES or NO _______________________

Keypad locked and channel reenabled in LEADS? YES or NO _______________________

Comments:____

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