

U.S. EPA
Technical Systems Audit
Supplementary Checklist for PM Continuous Monitors

1. On-site Technical Systems Audit of Thermo TEOM and TEOM-FDMS

Conducting the on-site audit of the Thermo TEOM or TEOM-FDMS involves evaluating several aspects of the set-up, operation, maintenance, and reporting of the monitor. For this audit checklist we have grouped the questions into four areas:

- a. Items to review at the monitor
- b. Items to review in the firmware and data logger
- c. Items to review at the inlet
- d. Maintenance and QC records to review.

This checklist can be applied to pre-FEM or FEM Thermo TEOM or TEOM-FDMS units. Pre-FEM Thermo TEOM and TEOM-FDMS monitors will be set up and operated nearly identical as FEMs, except that they may use a Sharp Cut Cyclone (SCC) rather than a Very Sharp Cut Cyclone (VSCC) and that an earlier version of firmware may be in use. There may be other engineering differences between a pre-FEM and FEM Thermo TEOM and TEOM-FDMS unit; however, these will likely be unnoticeable to the user or auditor. To the extent that any differences exist, it does not necessarily mean that the pre-FEM version is not being run appropriately.

Typical Thermo TEOM and TEOM-FDMS Set-ups:

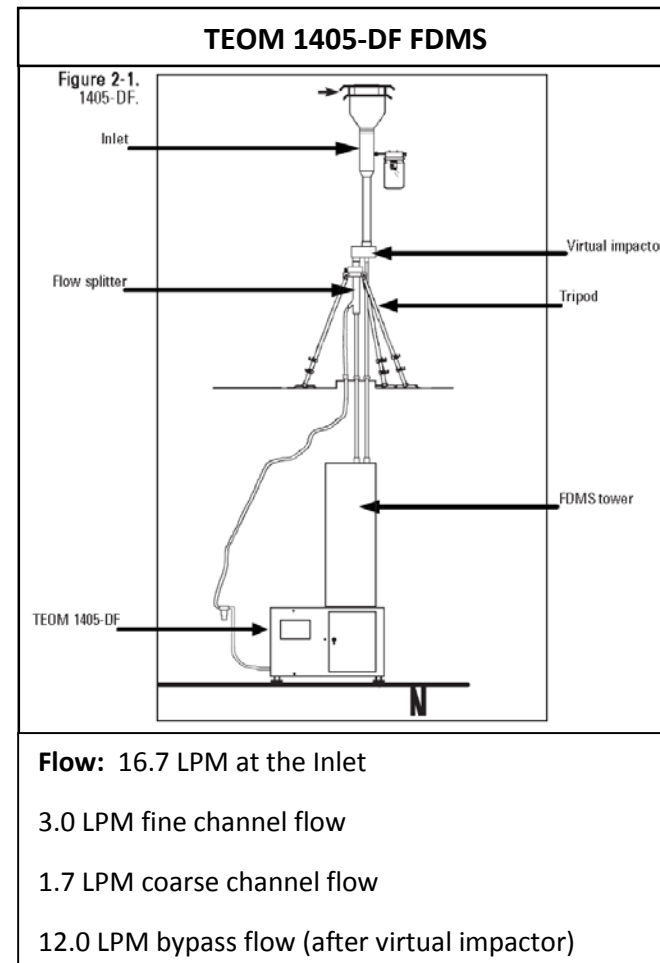
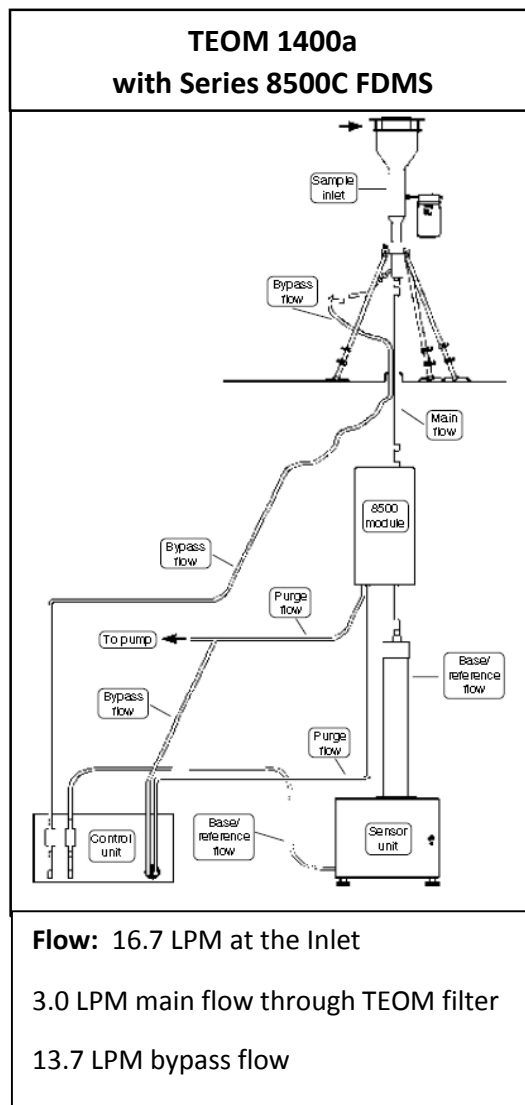
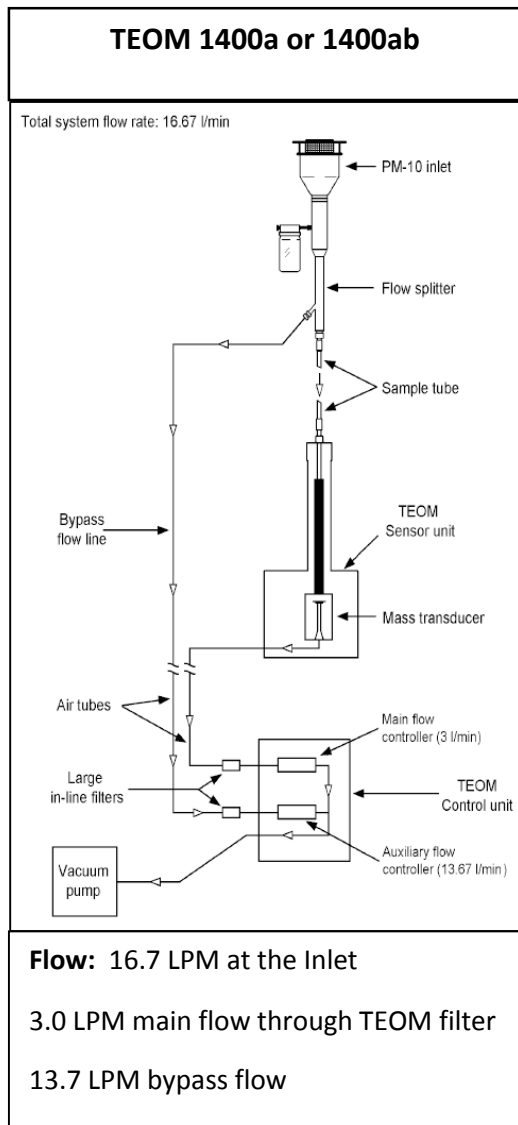







Table 1 - Summary of TEOM Makes and Models:

Model Number	Key Feature(s) of Monitor	Illustration	Firmware	PM _{2.5} Designation	PM ₁₀ Designation	PM _{10-2.5} Designation
TEOM 1400a or 1400ab	Original TEOM; electronics and measurement are in separate units.		Not identified as part of designation (latest is 3.019)	NA	EQPM-1090-079	NA
TEOM 1405	Updated version of TEOM (without FDMS); one unit for electronics and measurement					
TEOM 1400a with Series 8500C FDMS	Original TEOM with FDMS unit on top of monitor. Measurement and electronics are separate.		3.20 or later (latest is 3.5)	EQPM-0609-181	NA	NA
TEOM FDMS 1405 - F	Late model TEOM with one channel that is an all in one unit (electronics, monitor, and FDMS).		1.55 or later (latest is 1.71)		NA	NA
TEOM FDMS 1405 - DF	Late model TEOM that is an all in one unit set up with a virtual impactor. Two TEOM channels in one unit each measure PM allowing reporting of PM _{2.5} , PM ₁₀ , and PM _{10-2.5} .		1.50 or later (latest is 1.71)	EQPM-0609-182	EQPM-1013-208	EQPM-1013-207

Note: the last three numbers of the method designation is the method code used in AQS.

Summary of Flows on TEOM and TEOM-FDMS units (all units):

1. Air moves through the PM₁₀ inlet for initial aerosol separation of PM larger than PM₁₀.
2. If applicable, a second stage separator (i.e., a VSCC, SCC, or Virtual Impactor) is used to provide PM_{2.5} aerosol.
3. A flow splitter is used downstream of the separator(s) to lower the flow used in the TEOM measurement.
 - a. In PM_{2.5} TEOMs and TEOM FDMS units - Typically 13.67 LPM is used as the bypass flow and 3.0 LPM is used as the “Main” flow that is sent to the TEOM.
 - b. In the 1405-DF - Ambient air moves through the virtual impactor and is 15.0 LPM on the fine channel side and 1.67 LPM on the coarse channel side. A flow splitter is used on the fine channel side so that 3.0 LPM goes to the fine channel TEOM and 12.0 LPM is sent through the bypass line. On the coarse channel, the 1.67 LPM goes straight to the coarse channel TEOM.

Summary of Filter Dynamic Measurement System (FDMS) Operation, if applicable:

1. Sample air moves through the naphion dryer to lower the dew point.
2. Switching valve alternates the sample between Base and Reference Channels every 6 minutes.
 - Base Channel – sample air is sent to the TEOM filter for measurement of the base channel.
 - Reference Channel - A purge filter is used on the reference channel, which is cooled to 4 °C. This filtered air is then sent to the TEOM filter.
Note: This temperature may be set to 10 °C for hot/humid applications.
3. Use of the FDMS allows measurement of non-volatile (base measurement six minute measurement cycle) and semi-volatile (reference measurement six minute cycle where aerosol evaporates off the TEOM) PM to be measured using same approach as in the TEOM. TEOM FDMS units operate at 30 °C.

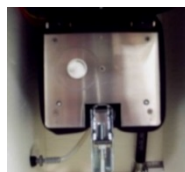
Summary of Tapered Element Oscillating Microbalance (TEOM) measurement:

1. Aerosol is collected on a Teflon filter which sits on top of a TEOM. The TEOM is hollow allowing air to move through the TEOM down to the flow system and pump.
2. Mass of the TEOM filter is continually weighed and calculated in real time.
3. Weighing principle used is similar to a laboratory microbalance
4. Mass detected by the TEOM is the result of the change in measurement of the frequency of oscillation that is directly coupled via a physical law.

$[Frequency = (Cal\ constant/mass)0.5]$



1400 and 8500C





1405-F



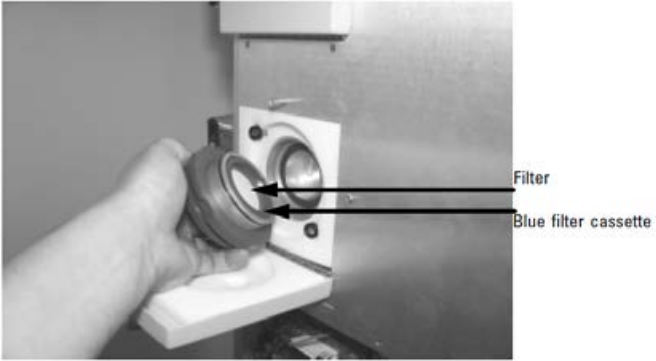



1405 - DF

Table 2 – Audit Questions for the Thermo TEOM and TEOM FDMS PM Continuous Monitors:

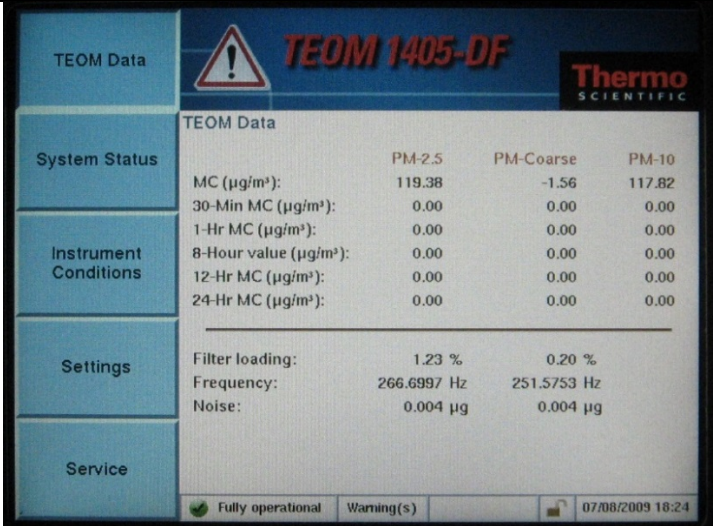
Question #	Item	Response	Comments
Items to review at the Monitor:			
1	Confirm the make and model of the PM continuous monitor.		
2	Does this make and model match what is identified in the annual network plan and reported to AQS?	<input type="checkbox"/> Yes <input type="checkbox"/> No	
3	If expected, is there an FEM sticker on the PM continuous Monitor?	<input type="checkbox"/> Yes <input type="checkbox"/> No	Automated Equivalent Methods: 1400 or 1405 for PM ₁₀ : EQPM-1090-079 1400a with Series 8500C or 1405 – F for PM _{2.5} : EQPM-0609-181 1405-DF: PM _{2.5} = EQPM-0609-182; PM ₁₀ = EQPM-1013-208; PM _{10-2.5} = EQPM-1013-207.
4	For instruments operated at 30 °C: Is the temperature of the shelter being adequately maintained to no more than 27°C? (TEOMs operated at 50 °C can tolerate less AC control (temps higher than 27 C will still work), but some cooling is still necessary to protect the electronics from high dew points)	<input type="checkbox"/> Yes <input type="checkbox"/> No	Note: The unit can only be heated (i.e., it cannot be cooled), so temperatures above 27 C may be more challenging to keep steady. For best results, locate the 1405-DF in an environment with relatively slow temperature fluctuations. Of particular concern on FDMS units—avoid a 12-min. air-conditioning (A/C) cycle.
5	Are there any concerns about the location of the monitor inside the shelter?	<input type="checkbox"/> Yes <input type="checkbox"/> No	This is largely professional judgement. Items of concern might include: substantial vibration where monitor is set-up; AC blowing directly on down tube; poor access to monitor; or direct sunlight on monitor.
6	Is the latest SOP and instrument manual for the PM continuous monitor available at the station? The instrument manual can be found at Thermo’s web site at: www.thermoscientific.com/aqilibrary . A username and password are required.	<input type="checkbox"/> Yes <input type="checkbox"/> No	1400a or 1400ab = Revision B, 06Sep2009 1405 = Revision A.000, 15Feb2008 1400a w/8500C = Revision C, 08Aug2008 1405 – F = Revision A.000, 22Sep2009 1405 – DF = Revision A.003, 16Sep2009
7	Is the SOP current? By whom was the SOP approved?	<input type="checkbox"/> Yes <input type="checkbox"/> No	Ask for SOP before the trip.



Question #	Item	Response	Comments
8	Are there any status warnings on the front display of the instrument?	<input type="checkbox"/> Yes <input type="checkbox"/> No Describe: _____	 Example of no status warning  Example of a status warning
9	What is the filter loading in % on the instrument?	PM _{2.5} : _____ PMc: _____	Ideally, the PM _{2.5} filter should be exchanged before it reaches 90% and always before filter loading reaches 100%. If heavy loading is expected or the operator may not be back to the site for a few days, it is recommended to exchange filters above 70% loading. The PMcoarse filter should be exchanged if at or above 25%. PMcoarse is only applicable to the 1405-DF.
10	What is the “Noise” reading on the front panel display of the instrument?	PM _{2.5} : _____ PMc: _____	Noise is the standard deviation of the change in frequency. The noise should be <0.100. High noise may be explained by a filter not being seated correctly on the TEOM, heavy loading on the filter, or a status condition causing instability and erratic readings. From a “best practice” standpoint it is very useful to graph the noise channel. Again, PMc is only applicable to the 1405-DF.
11	What is the sample pump vacuum pressure on the instrument?	Vacuum Pump pressure: _____	Unit will trigger status warning when pressure is ≥ 0.750 for a non-FDMS unit (TEOM only) and ≥ 0.400 for an FDMS unit. Note: For 1400 and 8500C units there is no internal tracking of this pressure; however, we recommend use of an external vacuum gauge.
12	Do the two inline filters at the back of the instrument appear relatively contamination free and working?		These filters prevent contamination from getting to the flow controllers. They should be replaced at least every 6 months, or as necessary.
13	Document the following key fields from the front of the monitor’s display. Note any issues such as a negative mass concentration, or flow or temperature different than expected.		<ol style="list-style-type: none"> 1. Last 1 - hour mass concentration: _____ 2. Last 24 hour mass concentration: _____ 3. Temperatures. These should be all the same; typically 50°C for a PM₁₀ or PM_{2.5} TEOM without an FDMS and 30°C for any configuration of PM_{2.5} or PM_{10-2.5} TEOM with an FDMS. Note: In some cases TEOMs without an FDMS are also run at 30°C, such as in the winter when high volatile aerosol may be expected. <ol style="list-style-type: none"> a. Case _____ °C


Question #	Item	Response	Comments
		b. Air _____°C c. CAP _____°C 4. Main Q: 3.00 is expected. _____ 5. Auxiliary Q: 13.67 is expected. _____	
14	If appropriate, have monitoring agency staff person open TEOM filter. Inspect area; are there any issues?	<input type="checkbox"/> Yes <input type="checkbox"/> No	
15	Are there spare TEOM filters equilibrating, but not in use in the filter area?	<input type="checkbox"/> Yes <input type="checkbox"/> No	 <p>The two filters on the top side of the picture on the left are the active TEOM filters for a 1405-DF; the two filters on the bottom are TEOM filters that are equilibrating and are therefore not in use yet. On an older TEOM unit, up to two spares may be placed next to the active filter, which is centered in the TEOM housing.</p>
16	Is one or more TEOM exchange tools available to change out TEOM filters?	<input type="checkbox"/> Yes <input type="checkbox"/> No	 <p>While a minimum of one filter exchange tool is expected; having two will allow using one to take off the exposed filter and one to seat the new TEOM filter. The two TEOM exchange tools should each be identified so that the new TEOM filters are only handled with the appropriate exchange tool.</p>
17	FDMS UNITS ONLY - If appropriate, have monitoring agency staff person open the FDMS unit purge filter(s) cassettes and inspect; are there any issues - PM _{2.5} FDMS units have one purge filter. - PM _{10-2.5} units have two purge filters.	<input type="checkbox"/> Yes <input type="checkbox"/> No	

Question #	Item	Response	Comments
			Cassettes should be blue thermo design with 47 mm Teflon filter loaded in it. Look for excessive dirt on filters or uneven loading on filters. Uneven loading may be a sign of pinholes or lack of consistent seal.
18	Approximately how far is the sampling pump placed away from the monitor? Is the pump isolated so as to minimize vibration to the monitor?	Distance: _____ <input type="checkbox"/> Yes <input type="checkbox"/> No	Distance between the monitor and pump will help to minimize vibration. Even placed a few feet away isolated on foam or rubber mat will help.
19	Confirm that the three pronged electrical plug is appropriately grounding the unit.	<input type="checkbox"/> Yes <input type="checkbox"/> No	One way to do this is to visually check the electrical box on the outside of the shelter and see that an earth ground is leading from it.
20	If necessary, have steps been taken to minimize condensation in the monitor?	<input type="checkbox"/> Yes <input type="checkbox"/> No	 <ul style="list-style-type: none"> - Insulate the sample tube extensions with pipe insulation (note: this is not required) - Install coalescing filter in bypass line in high humidity environments (also not required)
21	Describe any other issues with the monitor.		
22	Examine the Dryer Dew Point(s)	What are the readings?	<p>The 1405-DF has two dryers and therefore two readings; the 1405 and 8500C have one dryer. Dryer efficiency can be monitored by tracking the dew point temperature of the dryers. On a 1405-DF these are:</p> <ul style="list-style-type: none"> • TEOM A Dryer Dew Point • TEOM B Dryer Dew Point
Items to review in the Firmware and data logger:			
23	What version of software is identified on the monitor?		Compare to firmware in Table 2 above.

Question #	Item	Response	Comments																										
24	Is this version of software compliant with firmware requirements for the method identified in the “List of Reference and Equivalent Methods”?	<input type="checkbox"/> Yes <input type="checkbox"/> No	Note: It is not always necessary to upgrade to the latest firmware; check manufacturer’s web site for details.																										
25	How is the monitor connected to the data logger?	<input type="checkbox"/> RS-232 Cable <input type="checkbox"/> Analog cable <input type="checkbox"/> Other: please explain <input type="checkbox"/> Not connected to data logger	RS-232 is preferred. Explain rationale if another option is being used or if not connected. Note: Ethernet is available in the ‘ePort’ firmware works, but if users want to create own program the firmware is open source MYSQL.																										
26	<p>Data Storage Variables – Although only the FEM mass concentration variable is required to be sent to the data logger, the monitor can store from 8 to 20 PRC codes (depends on electronics and firmware) in the internal data storage of the monitor.</p> <p>The key question here is whether the agency is using the internal data storage to keep PRC codes? Such codes may be useful to validate data at a later date.</p>	<p>Older TEOM units store up to up to 8 PRC codes. Below are <u>recommended</u> PRC codes to store in the unit’s internal memory. Note: There are no specific requirements for which PRC codes must be logged other than the appropriate mass concentration.</p> <table border="1" data-bbox="894 735 1713 1040"> <thead> <tr> <th>PRC</th> <th>Description</th> <th>Units</th> </tr> </thead> <tbody> <tr> <td>008</td> <td>Mass Concentration (MC)</td> <td>µg/m³</td> </tr> <tr> <td>020</td> <td>FEM mass concentration (FEM MC)</td> <td>µg/m³</td> </tr> <tr> <td>104</td> <td>Reference Mass Concentration (Ref MC)</td> <td>µg/m³</td> </tr> <tr> <td>099</td> <td>Sample Dew Point</td> <td>°C</td> </tr> <tr> <td>114</td> <td>Ambient Dew Point</td> <td>°C</td> </tr> <tr> <td>035</td> <td>Filter Loading</td> <td>%</td> </tr> <tr> <td>013</td> <td>Noise</td> <td>Hz-Hz^a</td> </tr> <tr> <td>041</td> <td>Status Condition</td> <td>Code</td> </tr> </tbody> </table> <p>Late Model TEOM units store up to 20 PRC codes. Although these units can store up to 20 PRC codes, having both a PM_{2.5} and PM_c channel almost doubles the codes that are tracked. Additional PRC codes of interest to log may include ambient temperature, pressure, flow rates, and pump vacuum.</p>	PRC	Description	Units	008	Mass Concentration (MC)	µg/m ³	020	FEM mass concentration (FEM MC)	µg/m ³	104	Reference Mass Concentration (Ref MC)	µg/m ³	099	Sample Dew Point	°C	114	Ambient Dew Point	°C	035	Filter Loading	%	013	Noise	Hz-Hz ^a	041	Status Condition	Code
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Question #	Item	Response	Comments
27	Observe the last hour reported on the screen and compare this to data reported at the station data logger; are they the same?	<input type="checkbox"/> Yes <input type="checkbox"/> No	 <p>Typical 1405-DF front panel display.</p> <p>Note: The last hour reported may not be available for a couple minutes after the top of the hour; however, this data point represents the previous hour at the start of the hour. For example an updated value first posted at 10:02 am should represent the hour from 9 – 10 am. This hour would be stored as hour 09:00 in the data system.</p> <p>Non-FEM units may be run with minute data (or other averaging time) logged to the data logger rather than the hourly data. This is acceptable in cases where the monitor is not an FEM.</p>
28	Is the clock on the monitor set to run on local standard time (i.e., not day light savings time)?	<input type="checkbox"/> Yes <input type="checkbox"/> No	
28	Compare time on the monitor to time of data logger; is there any difference in time and if so how many minutes?	<input type="checkbox"/> Yes Min: _____ <input type="checkbox"/> No	Note: In some cases monitors are purposefully set to have an offset in the time reading. This is acceptable to ensure the latest reading is interpreted by the data system to represent the previous hour.
30	Verify firmware settings and note any discrepancies.	Flow control is set to “Actual Conditions” (unless a PM ₁₀ monitor, which would report data to STP).	

Question #	Item	Response	Comments
			Main flow is set to 3.00 on a PM _{2.5} channel. Note: In non-FEM cases a lower flow may be set (e.g., 2.00 LPM); this is allowed, but not typically expected. Temperature settings are set as expected: 50°C or 30°C.
31	Verify Sample Dew points are set to 4 degrees C.		In hot and or humid environments it may be permissible to have this set point at 10°C
32	Is the pump pressure monitored and working properly?	<input type="checkbox"/> Yes <input type="checkbox"/> No	Pump pressure <ul style="list-style-type: none"> • Maintain less than 0.3 atm for proper performance of dryer • Displayed on System screen in 1405-F/DF • 1405-F/DF TEOM monitors will show alarm if above 0.4 atm • Monitor using external vacuum gauge on 8500C
33	If applicable, describe any other issues in the firmware or data logger.	<input type="checkbox"/> Yes <input type="checkbox"/> No	
34	For 1400 and 8500C units, is there an external vacuum gauge attached to the pump used with the dryer?	<input type="checkbox"/> Yes <input type="checkbox"/> No	This should read roughly 20" of vacuum. Late model units incorporate sample vacuum in the design of the unit; therefore no external vacuum gauge is expected.
Activities to review at monitor's inlet:			
35	Is the PM ₁₀ inlet a "pie pan" design?	<input type="checkbox"/> Yes <input type="checkbox"/> No	 Note: All PM _{2.5} continuous monitors nominally operating at 16.7 lpm should use the pie-pan inlet design. Some PM ₁₀ continuous FEM monitors and older TEOMs (pre-FEM) may use the flat head inlet design.
36	Open the inside of the PM ₁₀ inlet. Describe the cleanliness of the inlet well.		Note: This should only be done with the sample pump temporarily shut off.
37	If expected, is the PM _{2.5} second stage separator an approved VSCC? 1405-DF units use a virtual impactor for PM _{2.5} separation.	<input type="checkbox"/> Yes <input type="checkbox"/> No	 Notes:

Question #	Item	Response	Comments
			1. VSCC's and SCC's look very similar in design. 2. Also, there are two designs of the VSCC; however, all PM _{2.5} continuous monitors should use the design above (i.e., VSCC-A). The VSCC-B design is used with BGI samplers.
38	Open the VSCC. Describe the cleanliness of the inside of the VSCC.		Note: This should only be done with the sample pump temporarily shut off.
39	Is there a gill screen or similar near the inlet that is also connected to the PM continuous monitor to provide an ambient temperature reading?	<input type="checkbox"/> Yes <input type="checkbox"/> No	 Note: Some older TEOMs used use a small PVC pipe as a shield for an ambient temperature sensor.
40	Do the Inlet and down tube appear perpendicular to the ground?	<input type="checkbox"/> Yes <input type="checkbox"/> No	Best judgement is fine.
41	Describe any other issues at the monitors' inlet.	<input type="checkbox"/> Yes <input type="checkbox"/> No	
Maintenance and QC Records to review:			
42	Does the agency use an audit sheet for regular maintenance and verifications? Or logbook?	<input type="checkbox"/> Yes <input type="checkbox"/> No	Review audit sheets and/or logbook while on site to ensure maintenance and verifications are performed at expected frequencies.
43	<u>Monthly and quarterly checks:</u> Is there a record documenting that the following checks are being performed at least monthly or quarterly, where identified?	<u>Yes</u> <u>No</u> <input type="checkbox"/> <input type="checkbox"/> Flow check <input type="checkbox"/> <input type="checkbox"/> Temperature check <input type="checkbox"/> <input type="checkbox"/> Barometric Pressure <input type="checkbox"/> <input type="checkbox"/> Leak check <input type="checkbox"/> <input type="checkbox"/> PM ₁₀ inlet is cleaned (at least quarterly) <input type="checkbox"/> <input type="checkbox"/> VSCC or virtual impactor is cleaned	
44	<u>12-month checks:</u> Is there a record documenting that the following checks are being performed at least every 12 months?	<u>Yes</u> <u>No</u> <input type="checkbox"/> <input type="checkbox"/> When was the last time the dryer was refurbished or changed out? (Note: These are to be changed out at least yearly; however, if the sample dew points cannot be maintained, the dryer may need to be changed out more often). <input type="checkbox"/> <input type="checkbox"/> Clean down tube <input type="checkbox"/> <input type="checkbox"/> Analog voltage audits, if applicable	

While on site, also perform the following:

1. Interview the operator and have routine procedures described.
2. Ask for documentation providing evidence that the flow standards being utilized by the operator and the agency's own auditor (these are required to be separate devices) are NIST traceable and within certification. The Agency office may need to be contacted for these.
3. Communicate any items that can be addressed in the field without compromising data quality.