Standard Operating Procedure for the Continuous Measurement of Particulate Matter

Thermo Scientific TEOM 1400a
Ambient Particulate Monitor with 8500C FDMS
Federal Equivalent Method EQPM-0609-181 for $PM_{2.5}$

STI-910212-4083-SOP

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1. ABOUT THIS STANDARD OPERATING PROCEDURE

On June 17, 2009, the U.S. Environmental Protection Agency (EPA) designated the TEOM 1400a with Series 8500C FDMS [8500C FDMS], manufactured by Thermo Scientific, Inc., as a Federal Equivalent Method (FEM) for measuring concentrations of particles 2.5 microns in aerodynamic diameter and smaller ($PM_{2.5}$) in ambient air (see 74 FR 28696, EQPM-0609-181). The method employs conditioned filter sample collection and direct mass measurements with an inertial micro-balance (Tapered Element Oscillating Microbalance, or TEOM) in near real time. The Filter Dynamic Measurement System (FDMS) estimates, and adjusts for, the volatile component of the mass. Particle size separation is achieved by a cyclonic method.

This standard operating procedure (SOP) is based upon the Thermo Scientific, Inc., Series 8500 FDMS Filter Dynamics Measurement System Operating Manual (42-010874 Revision C, August 8, 2008) and Service Manual (TEOM Series 1400a service Manual [AB Serial Numbers] 42-003348, Revision B, April 2004). These manuals offer supplemental details not specifically covered in this SOP. An unpublished draft SOP developed by Thermo Scientific[1] provided some updated maintenance and operational protocols. Other SOPs, developed and submitted by users of TEOM samplers equipped with an FDMS, provided additional information particularly pertinent to routine, hands-on maintenance and operations. The cooperation of Thermo Scientific and the other contributors in development of this model SOP is gratefully acknowledged.

Sections 2 through 8 of this SOP offer synopses of some background topics. Hands-on users will find the most useful portions of the SOP to be **Section 9** "Installation Procedures" and **Section 10** "Quality Control and Maintenance Procedures." Installation usually occurs once (or perhaps infrequently under re-location) and includes receiving, acceptance testing, site and enclosure selection, and the actual putting in place of the system components, followed by system configuration, initial checks, and startup. Quality control (QC) and maintenance includes recurring QC procedures that ensure compliance with FEM criteria and regulatory standards, as well as periodic maintenance routines such as inlet cleaning and switching valve cleaning. Schedules of both must be maintained to ensure system health. **Table 10-1** lists the QC and maintenance protocols and gives cross references to SOP, Operating Manual, and Service Manual sections relevant to the procedures. Data validation and quality assurance procedures are covered in **Section 11**.

The SOP attempts to identify common pitfalls and emphasizes details of operating procedures that may help avoid operator missteps and frustration. These discussions are presented so that the rationale underlying the procedures is understood. Agencies may wish to exclude this level of detail from their SOPs. Since the SOP actually includes multiple operating procedures in one document, portions may be excerpted, edited, or eliminated as deemed appropriate. For example, since installation is often a one-time-only procedure, it may be judged as unnecessary in the SOP covering routine procedures.

[1] Ambs, J., McCabe, R., and Hiss, J. 2010. Standard Operating Procedure for the Continuous Measurement of Particulate Matter: Thermo Scientific TEOM 1400A with Series 8500C FDMS Ambient Particulate Matter Monitor. Version 10.

Some operating procedures in this SOP are modifications or addenda to the most recent version of the 8500C FDMS Operating Manual. These procedures, which have largely resulted from feedback from users through Thermo Technical Support, are currently being recommended by Thermo Scientific. Many of these have been covered in Thermo Scientific training classes and are available as Technical Documents through Thermo Scientific's Air Quality Instruments Online Library at www.thermoscientific.com/aqilibrary.

Users who already have a written SOP for the 8500C FDMS should consider reviewing these modifications for possible incorporation into their existing document. These modifications include

- New Program Register Code (PRC) variables for FEM reporting have been added, including mass concentration (MC), 1-hr MC, and 24-hr MC. Users who rely on the maximum eight parameter storage capability of the 8500C must carefully consider which variables to store (SOP Section 9.9.2).
- A modified full system leak check procedure (SOP Section 10.1.1).
- Leak checks and flow audits in both base and reference valve positions (SOP Sections 10.1.1 and 10.1.4).
- Dryer maintenance guidelines and a detailed dryer removal procedure (SOP Section 10.2.9).
- Detailed switching valve maintenance procedure (SOP Section 10.2.8).
- A new chiller cleaning procedure (SOP Section 10.2.10).
- A revised vacuum pump test procedure (SOP Section 10.1.7).
- A new zero test procedure (SOP Section 10.1.8).
- A recommendation to not install the flow audit filter, even though it is still included in the bill of materials for the 8500C FDMS (SOP Section 9.7, no. 17).

2. SCOPE AND APPLICABILITY

The purpose of this SOP is to provide a set of uniform protocols for installation, operation, maintenance, calibration, QC, and quality assurance (QA) of the TEOM 1400a Ambient Particulate Monitor with FDMS configured to meet EPA FEM EQPM-0609-181 for $PM_{2.5}$ mass. It is intended to be a "Model SOP" that incorporates best practices on the method, and its use is not required to meet the standards set forth under EQPM-0609-181. These best practices are being made available for incorporation by monitoring agencies, and for Regional offices to consider when approving an SOP. It is acknowledged that there will always be cases for which agencies' needs or guidance on writing SOPs is different from what is in the model.

To meet the FEM requirements for measurement of $PM_{2.5}$ mass as described in the Federal Register (74 FR 28696), the TEOM 1400a with FDMS must be

- Configured for sampling of fine ($PM_{2.5}$) particles using the U.S. EPA PM_{10} inlet specified in 40 CFR Part 50, Appendix L, Figs. L-2 thru L-19, followed by a BGI, Inc., Very Sharp Cut Cyclone (VSCC) particle size separator;
- Operated with a total volumetric flow rate of 16.67 lpm;
- Loaded with Series FDMS 8500 module operating software and an FDMS kit;
- Equipped with firmware version 3.20 or later (Version 3.50 and later have the FEM mass concentration Program Register Codes); and
- Operated in accordance with the Thermo Scientific TEOM 1400a Ambient Particulate Monitor with Series 8500C FDMS operating manual.

3. SUMMARY OF THE METHOD

The 8500C FDMS provides near-real-time measurement of $PM_{2.5}$ in ambient air, facilitating the measurement of both nonvolatile and volatile PM components. The overall system is composed of two main parts: the sampling system and the analysis and control system. The sampling system draws ambient air through a PM_{10} size selective inlet at 16.67 lpm, and then through a VSCC particle size separator that captures coarse particles between 2.5 and 10 microns in aerodynamic diameter. The $PM_{2.5}$ air stream is then split isokinetically into a reduced main (sample) flow rate of 3.0 lpm and a bypass flow of 13.67 lpm. The main air stream flows into the FDMS module, is routed through a Nafion dryer, and continues on to a switching valve, where it becomes either the base flow or the reference flow (described below). At any given time, the main flow is either the base flow or the reference flow. The analysis and control system of the 1400a includes a humidity sensor, flow controllers, data management hardware and software, and a sample collection filter that is attached to an inertial mass transducer, or microbalance (the TEOM), which is weighed continuously. The control system maintains the sample air stream at a constant volumetric flow rate, corrected for local temperature and barometric pressure. The tapered element oscillates at its natural frequency (like the tines of a tuning fork), determined by the physical characteristics of the tapered tube and the mass on its free end. Any mass added to the filter causes a proportional decrease in oscillation frequency, while loss of mass causes a proportional increase. An electronic control circuit senses the oscillation frequency and, through positive feedback, modifies energy input to the system to modulate any increase or decrease in frequency that is presumably due to changes in mass accumulation on the filter. A precision electronic counter measures the oscillation frequency using a 2-second sampling period. An automatic gain control circuit maintains the oscillation at a constant amplitude. **Figure 3-1** is a schematic representation of the 8500C FDMS from the roof-mounted air inlet through the sensing unit and control unit.

After the 16.7 lpm inlet flow is isokinetically split to attain the 3.0 lpm main flow and the 13.7 lpm bypass flow, the main flow, or sample stream, is passed through a diffusion dryer containing Nafion tubing specially designed to minimize particle loss. The dryer lowers the sample stream relative humidity (RH), minimizing the positive mass artifact associated with water sorption onto the collection filter, and making possible mass transducer operation at 5°C above the peak air monitoring station temperature (usually 30°C). An integrated humidity sensor, downstream of the dryer, measures the humidity of the sample stream to determine the drying efficiency. The dryers use recirculated air that has passed through the sample collection filter so that the dryer does not require any bottled air or a dedicated “zero” air system. **Figure 3-2** details the flow paths that exist in the 8500C FDMS.

When the sample air exits the dryer, it enters a switching valve that, every 6 minutes, alternately directs the air stream either to the sample collection filter (the base cycle) or to an alternate flow path (the reference cycle). The reference flow path includes a standard FRM-style 47-mm filter cassette with a TX-40 filter (Teflon-coated borosilicate) maintained at 4°C. The low temperature causes volatile PM components to condense on the filter, resulting in an air stream free of both non-volatile and volatile PM components. (The 47-mm filter itself can also be used for time-integrated chemical analysis.) This clean, reference air is routed to the mass collection filter. During this cycle, only the *changes* in the amounts of semi-volatile material previously collected on the sample filter are measured. This measurement is termed the “reference mass concentration” (Ref MC). The Ref MC provides an estimate of the volatile PM losses that occurred during the previous 6-minute sample cycle of ambient particle-laden air, and any loss of mass from the sample collection filter during the Ref MC cycle is quantified and added back to the PM concentration measured during the “base mass concentration” (Base MC) cycle, which measures the concentration of the ambient air sample. This sampling scheme of alternating Base MC and Ref MC cycles is what allows the 8500C FDMS to provide an estimate of $PM_{2.5}$ mass that includes both volatile and non-volatile components. Finally, a one-hour running average of the $PM_{2.5}$ mass concentration is updated every six minutes, calculated from the change in the filters’ sample mass (adjusted for volatile component losses) and the sampled air volume.

In summary, the Base MC is equal to the $PM_{2.5}$ concentration of the conditioned particle-laden sample stream (which is usually a positive number) and the Ref MC represents an estimate of the volatile portion of the total $PM_{2.5}$ concentration. The Ref MC will be a negative value if mass volatilizes from the filter. The final calculated mass concentration is equal to the Ref MC subtracted from the Base MC. Note that this means that the sampler is measuring particle-laden air for five 6-minute periods per hour (or half of the time) and filtered air for five alternating 6-minute sample periods each hour.

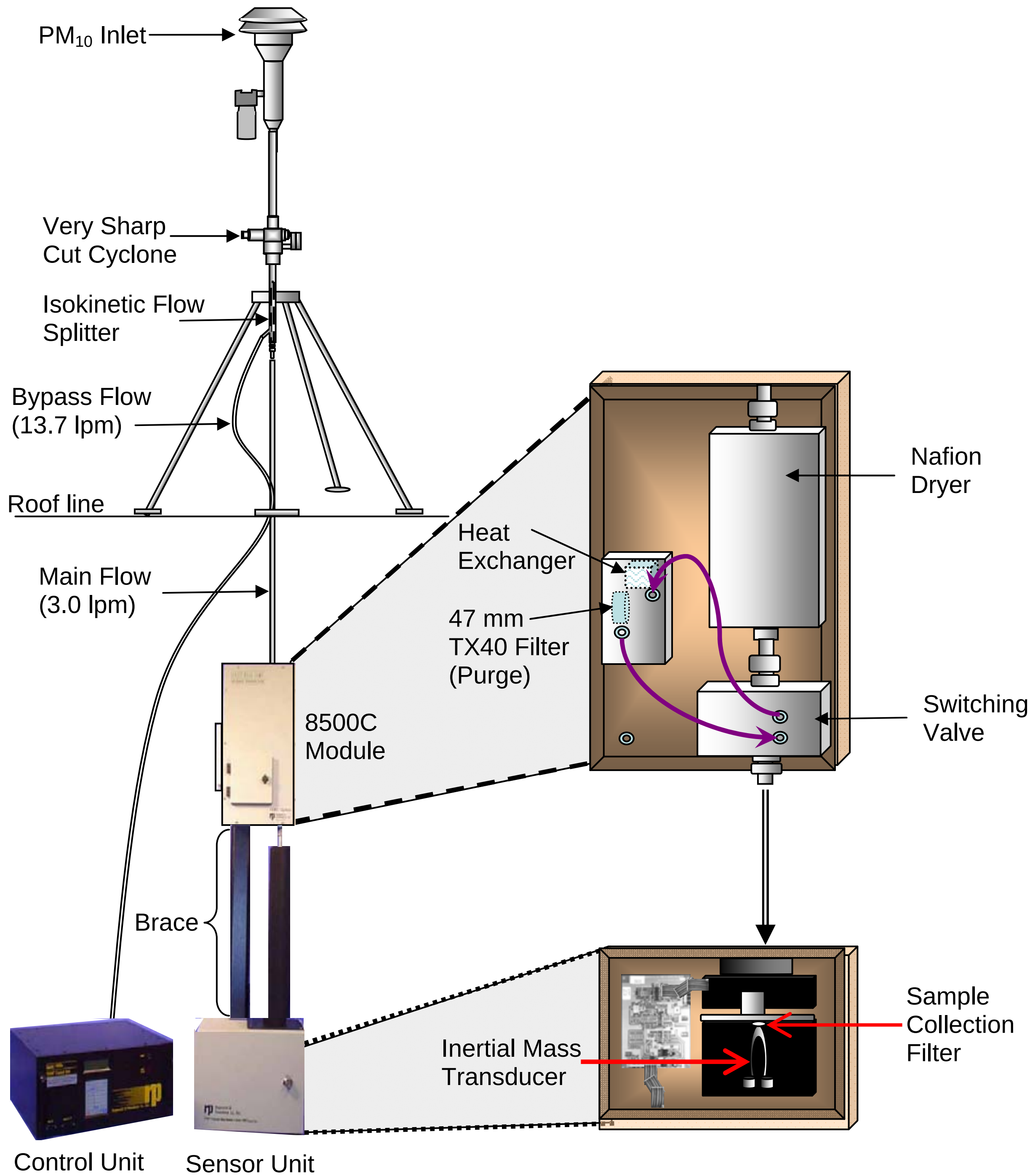

Figure 3-1. Schematic representation, including roof-mounted inlet hardware, of the TEOM 1400a with Series 8500C FDMS ambient $PM_{2.5}$ monitoring system.

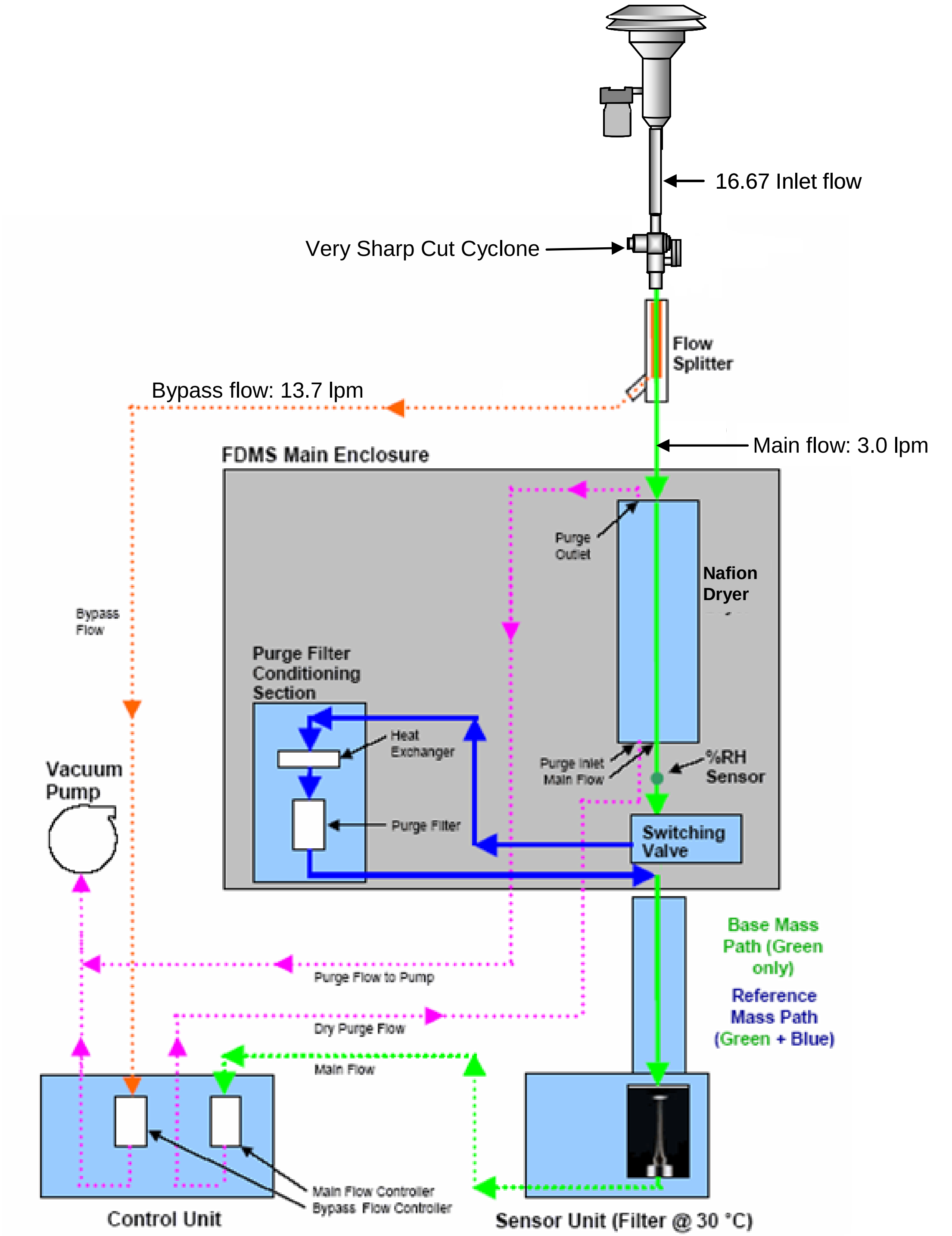

Figure 3-2. Schematic representation of the flow paths in the 8500C module, including the main flow (either base flow or reference flow), the bypass flow, and the purge flow. (Original schematic courtesy of Puget Sound Clean Air Agency.)

4. DEFINITIONS

Technical terms in this SOP are defined as they are introduced so that their meaning is made clear in context. This section explains some general terminology.

Two terms used throughout this SOP are “verification” and “validation”. These terms have similar, but distinctly different, meanings. *Verification* refers to the review of interim work steps to ensure they are acceptable and to determine whether the system is consistent, adheres to standards, uses reliable techniques, and performs the selected functions in the correct manner. Verification steps are performed during the process of data collection and include such things as checklists of basic functions and comparisons to standards. A leak check is an example of a verification procedure used with the 8500C FDMS. *Validation* involves determining whether the system complies with requirements, performs the functions for which it is intended, and meets the organization’s goals and user needs. It is a determination of correctness of the data and is usually performed only periodically (e.g., quarterly) or at the end of a project.

Similarly, the terms “quality control” (QC) and “quality assurance” (QA) are often used interchangeably, but in fact have important distinctions. QC refers to the operational techniques and activities used to fulfill the requirements for quality. QC is what the field technician practices when conducting maintenance and verification procedures on the 8500C FDMS. Routine QC procedures, such as flow checks, are referred to herein as QC checks or QC procedures. QA refers to the planned or systematic activities used to provide confidence that the requirements for quality are fulfilled. An independent audit is an example of a QA activity. QA protocols determine whether the QC procedures are adequate.

The term “audit” is often used in a generic way to mean check, inspect, examine, or assess, and many SOPs use the term to refer to QC procedures, such as flow checks or leak checks, that are carried out by field technicians during the course of normal operations and maintenance.

The term “calibration” refers to the act of adjusting an instrument after comparison with a standard. When referring to the instrument software, the term “calibration” is used to indicate a procedure that would alter instrument output. A “calibration check” involves only the checking of an instrument against a standard and involves no adjustment of the instrument.

5. HEALTH AND SAFETY WARNINGS

Safety precautions should be heeded during the setup and operation of the 8500C FDMS. General safety rules regarding electricity and power tools should be observed. High voltages may be present in all instrument enclosures. When accessing these enclosures, disconnect the power cord from the power source unless power is specifically required for the service procedure. Working at above-ground elevations and on ladders is frequently required, and precautions should be taken to avoid falls and personal injury.

6. INTERFERENCES

The 8500C FDMS has been designed to minimize potential interferences, but poor siting, inadequate electrical power, bad electrical grounding, poor control of the sample air RH in humid environments, oscillations in the temperature of the environmental enclosure, and significant vibrations are known sources of interference.

6.1 IMPROPER SITING

Interferences arising from improper siting can be avoided by exercising care during site selection and installation (Section 9.3). Particular attention should be paid to the design criteria for monitoring $PM_{2.5}$, including general monitoring requirements, spatial scales, and any special site requirements.

6.2 ELECTRICAL INTERFERENCE

Electrical connections should be thoroughly checked during installation, and the ground potential should be measured as part of the installation procedure. All sample tubing should be properly grounded to minimize the attraction of particulate matter to the tubing walls. Any buildup of static charges from an ungrounded tube can cause measurement errors. Measure the resistance between the inlet tubes and the chassis ground terminal on the power plug. The resistance should be a few ohms or less. The inlet air tube and 8500C FDMS are properly grounded, so direct electrically conductive connections to the sample inlet tubing will be adequately grounded. If plastic connections are used, additional grounding may be required.

6.3 RELATIVE HUMIDITY INTERFERENCE

Proper control of the RH in the sample stream is integral to proper sampler operation. RH issues should be addressed by carefully monitoring and maintaining shelter temperature and the dew point of the sample air stream to avoid introducing condensation into the sample train. Whenever the ambient dew point is significantly greater than the indoor shelter temperature (>5°C) the likelihood exists that condensation will occur in the sample train before entering the inlet of the 8500C FDMS or the water trap of the bypass flow. Under these circumstances, insulation of the sample tubes is required. If the temperature difference is extreme, it may be necessary to raise the shelter temperature to reduce the temperature difference.

6.4 TEMPERATURE INTERFERENCE

Care should be taken to maintain a *stable temperature* in the instrument shelter. Ideally, the temperature fluctuation should be less than 2°C in an hour. The temperature should also be maintained as close as possible to 5°C less than the operating temperature of the sample stream (which is generally 30°C). Best practices dictate the use of additional insulation, such as pipe insulation, on all exposed tubing. Air conditioning vents should be directed away from the instrument so that the air flow over the instrument is diffused.

6.5 VIBRATIONAL INTERFERENCE

Vibrations can affect any microbalance; therefore, care should be taken when placing the instrument in the shelter. Placing the instrument on an isolated bench may reduce excessive bench vibrations from other instruments. The 8500C FDMS pump, or any other pumps in the shelter, should be isolated from the instrument as far as is practicable. It may be useful to dampen pump vibrations by placing pumps on foam pads if such placement can be accomplished without creating a fire hazard. Also, consideration should be given to the roof mounting of the sample lines; if rigid connectors are used and the roof surface flexes during technician service activities, then excessive vibrations may be transferred to the transducer and cause erratic readings. A short flexible section of conductive rubber tubing (Thermo p/n 30-002274) can be used to mitigate the roof movement by allowing a 1- to 1.5-inch gap in the rigid tubing. Alternatively, an expanded and reinforced work surface can be added to the roof to minimize roof movement. The standard 3/8-inch tubing at a length of 5 meters is sufficient for avoiding influences from pump fluctuations. Tubing to the TEOM pump may need to be replaced with larger-diameter tubing or pipe to avoid an excessive pressure drop if longer line lengths are used.

7. PERSONNEL QUALIFICATIONS

While no special qualifications or training are necessary to operate the 8500C FDMS, a basic understanding of the principles governing ambient air sampling is assumed. The QA procedures detailed herein require an understanding of the 8500C FDMS flow system and proper operation of calibration reference devices.

EPA Quality Assurance Guidance Document 2.12 (U.S. Environmental Protection Agency, 1998) covers specifics of field personnel qualifications and provides the following general guidelines. All field operations personnel should be familiar with environmental field measurement techniques. Those who service the PM sampler in the field must be very conscientious and attentive to detail in order to report complete and high-quality $PM_{2.5}$ data. Persons qualified to perform $PM_{2.5}$ field operations should be able to

- Operate the $PM_{2.5}$ sampler;
- Calibrate, audit, and troubleshoot the $PM_{2.5}$ sampler; and
- Use common methods to determine temperature, pressure, and flow rate.

8. EQUIPMENT AND SUPPLIES

The 8500C FDMS Operating Manual contains a regular bill of materials for the standard system hardware provided by Thermo Scientific with each instrument purchased. Note that for FEM $PM_{2.5}$ monitoring, the VSCC must be specifically requested. Also, the flow audit filter is still a part of the regular bill of materials, but the current recommendation is to not install this system component (see SOP Section 9.7, no. 17).

Table 8-1 lists diagnostic and QC tools, consumables, basic cleaning supplies useful for monthly maintenance, and recommended spare parts. A complete listing of parts and part numbers is given in Appendix E of the 8500C FDMS Operating Manual. While it is not recommended that a complete inventory of spare parts be kept on hand for the 8500C FDMS, the items listed in Table 8-1 as “recommended spare parts” should be considered a minimum inventory. The recommended spare parts include seals for the switching valve, mass transducer, and chiller/conditioner assembly, and a pump rebuild kit. Additionally, having a spare dryer on hand will prevent prolonged downtime when the dryer is returned to Thermo for refurbishment. Thermo offers an annual dryer refurbishment service (p/n 75-010965) that includes cleaning and parts replacement. Thermo also offers an exchange program, at reduced prices, for certain components. Qualifying components include flow controllers, printed circuit boards (PCB), mass transducer assembly, switch valve assembly, and Nafion dryer assembly. Conductive rubber tube connectors (p/n 30-002274, not normally supplied) should be ordered and installed at the time of setup. These rubber tube connectors allow removal and servicing of 8500C FDMS components without disturbing the rooftop inlet hardware.

Table 8-1. Standard 8500C FDMS diagnostic tools and QC tools, consumables, and recommended spare parts.

Category	Components	Thermo Part Number	Use Schedule
Diagnostic tools	Flow calibrator(s)	NA	NA
	Temperature transfer standard	NA	NA
	Pressure transfer standard	NA	NA
	Digital multi-meter	NA	NA
	Mass calibration verification kit	59-008298	Yearly
	Hand tools (screwdrivers, wrenches, small sizes, etc.)	NA	NA
Consumables	TEOM filters	57-007225-0020	Every 30 days or as needed
	FDMS filters (47-mm Pallflex TX 40, box of 100)	10-002387-0100	Every 30 days or as needed
Recommended spare parts	Pump rebuild kit	Model-dependent	18 months
	Exit cylinder seal Rev A, filter exchange (for mass transducer)	22-002959	As needed
	Switching valve "V" seals for Rev C	22-010280	As needed
	Switching valve "V" seals for Rev B	22-008946	As needed
	V-Seal for chiller/conditioner	22-002680	As needed
	Valve cleaning brush (provided with instrument)	30-009091	As needed
Cleaning supplies	Ammonia-based cleaner	NA	Monthly
	Silicon grease	NA	Monthly
	Soap, alcohol or Freon solution	NA	Monthly
	Small soft-bristle brush	NA	Monthly
	Cotton swabs	NA	Monthly
	Paper towels, soft cloth	NA	Monthly
	Deionized (DI) water	NA	Monthly
	Hand cleaner	NA	Monthly

9. INSTALLATION PROCEDURES

This section of the SOP focuses on the installation of a new 8500C FDMS system purchased as a total package, including the 1400a control and sensor units and the 8500 module. Since the TEOM 1400a instruments existed before the FDMS module, add-on kits are available to convert the 1400a system to an 8500C system. Installing the add-on version involves some additional steps to accommodate the conversion, including the addition of a dual-flow hardware fitting and updating the 8500C FDMS firmware (FEM version) available from the Thermo Scientific website. Also, if the mass flow controllers in the system to be upgraded are of the original design, they will have to be upgraded as well. Explicit instructions for upgrading to an 8500C FDMS are given in the Series 8500 FDMS Filter Dynamics Measurement System Operating Manual (42-010874 Revision C, August 8, 2008) and are not covered here.

The 8500C FDMS Operating Manual provided by Thermo Scientific offers a comprehensive step-by-step procedure with many supporting pictures and should be the primary reference for installation. This SOP lists the main steps and highlights some tasks that may require extra care. Final users of this SOP may find it unnecessary to include these installation procedures if their SOPs focus on maintenance and operations only.

The major tasks associated with installation include

- Unpacking and inspecting the 8500C FDMS components (Section 9.1)
- Acceptance testing (Section 9.2)
- Site selection to meet the siting requirements of 40 CFR Part 58 (Section 9.3)
- Enclosure selection to provide the 8500C FDMS with an environment within its operating specifications (Section 9.4)
- A series of sequential steps to install the 8500C FDMS sampling system, sensing unit, and control unit (Section 9.7)
- A full system leak check (Section 10.1.1)
- Programming the monitor for sampling (Section 9.9)

Special precautions and tools needed for installation are described in Sections 9.5 and 9.6.

9.1 UNPACKING AND INSPECTION

A physical inspection of the 8500C FDMS system should be made upon receipt of the system from Thermo Scientific, Inc. Visible damage to the shipping container should be reported to the carrier. System components should be verified against the packing list, and any missing or damaged components should be reported immediately to Thermo Scientific.

9.2 ACCEPTANCE TESTING

The 8500C FDMS is factory tested and calibrated prior to shipment to the user. It is up to the user to decide which acceptance tests should be conducted. While testing procedures will vary by agency, it is generally advisable to set up the 8500C FDMS in a controlled environment, such as a laboratory or workshop, allowing key operational aspects of the instrument to be tested before deployment to a field site. Obviously, this requires a temporary setup of the instrument, so applicable portions of SOP Section 9.7 (Hardware Installation Steps) and of Section 2 of the 8500C FDMS Operating Manual should be consulted. (If acceptance tests are not conducted in the laboratory, then, at a minimum, the key operating parameters should be verified at the actual monitoring site before sampling begins.) The additional laboratory evaluation is helpful because it may identify instrument problems separately from problems that may be associated with instrument siting and field installation. Recommended acceptance testing procedures, more or less in order of importance, include the following:

- Full system leak check (SOP Section 10.1.1)
- Ambient temperature and pressure verification (SOP Sections 10.1.2 and 10.1.3)
- Verification of flow rate (SOP Section 10.1.4)
- Verification of mass transducer calibration (SOP Section 10.1.9)
- Vacuum pump test (SOP Section 10.1.7)
- 24-hour zero test to evaluate stability, bias, and noise (SOP Section 10.1.8)
- Collocated sampling with Federal Reference Method (FRM) samplers, when possible

Note that the recommendations are for verification tests, not necessarily for calibrations. These checks ensure accuracy and establish a starting point for future verifications. The 24-hour zero test provides estimates of baseline stability, bias, and noise. Collocated sampling will not always be possible, but if it can be accommodated, this test can provide additional confidence in the 8500C FDMS data.

Note that the 1400A Service Manual recommends that hardware calibrations be performed at installation and annually. Unless the verification procedures during acceptance testing and/or installation detect a problem, most users will not perform these calibrations at the time of installation. The calibration procedures are covered in the 1400A Service Manual as follows:

- **Analog board calibration** is required before the other hardware calibrations are performed. This procedure is covered in the 1400A Service Manual, Section 3.2.1.
- **Ambient temperature sensor calibration** is covered in the 1400A Service Manual, Section 3.2.3.
- **Ambient pressure sensor calibration** is covered in the 1400A Service Manual, Section 3.2.4.
- **Amplifier board calibration** is covered in the 1400A Service Manual, Section 3.2.2.

- **Flow controller calibration (hardware)** is covered in the 1400A Service Manual, Section 3.5.2.

9.3 SITE SELECTION

Site selection is important for ensuring the uniform collection of relevant (suitable to its intended purpose) and comparable ambient $PM_{2.5}$ data, and specific site criteria must be satisfied for the 8500C FDMS to meet the $PM_{2.5}$ FEM regulatory requirements. The design criteria for $PM_{2.5}$ monitoring sites, including general monitoring requirements, spatial scales, and special site requirements, are given in 40 CFR Part 58, App D, Section 4.7 (U.S. Environmental Protection Agency, 2008a).

Extensive details on all aspects of site criteria are given in 40 CFR Part 58, Appendix E (U.S. Environmental Protection Agency, 2006a). When siting an ambient $PM_{2.5}$ monitor such as the 8500C FDMS, the inlet height, inlet radius clearance, proximity to potential sources of particulate matter, and spacing from roadways and trees are of particular concern. **Table 9-1** lists the basic requirements applicable to each of these criteria.

Table 9-1. EPA $PM_{2.5}$ site selection specifications applicable to the 8500C FDMS include inlet height, inlet radius clearance, proximity to potential particulate matter sources, and distance from roadways.

Siting Parameter	Situation	Specification	Comments
Inlet height	General	2-15 m agl[a]	This height interval is considered the "breathing zone"
	On rooftop	2 m above roof surface	Matches inlet specifications for FRM samplers
	Collocated samplers	All inlets optimally at same sample height	Sample heights must meet general height specifications and be at least within 1 vertical meter of each other
	Inlet tube length	Maximum 16 ft (4.9 m)	If inlet is the highest point, then lightning rods are strongly recommended
Inlet radius clearance	General	Minimum 1 m radius clearance	Includes other sampler inlets or objects that may influence airflow
	Adjacent FEM or FRM	Minimum 1 m separation between inlets	
	Collocated	From 1 to 4 m between inlets	
	Near SSI Hi-Vol	Minimum 3 m between 8500C FDMS and Hi-Vol inlets	
	Near small obstructions	Minimum 2 m	Small obstructions include fences and walls
	Near large obstructions	Distance of 2x height of obstruction	Large obstructions: buildings, sound walls, billboards, etc.
	Overhanging trees	Minimum 20 m from tree drip line	
	Arc of unrestricted air flow	Unrestricted 270 degree arc	Prevailing direction of high concentrations must be in the arc
Nearby particulate sources	General	As far away as possible from blowers or vents	Note: filtered air can contaminate a sample as well as dirty air
Distance from roadways	Less than 3,000 VPD[b]	Minimum 5 m from nearest traffic lane	
	Elevated roadway (>25 m high)	Minimum 25 m away	
	Unpaved roads	As far away as possible	
	Other unpaved areas	As far away as possible	Unpaved sites with vegetative ground cover are acceptable

[a] Above ground level
[b] Vehicles per day

9.4 ENCLOSURE SELECTION

The 8500C FDMS may be housed in a walk-in shelter, a mobile trailer, or a specially made environmentally controlled mini-enclosure available from Thermo Scientific (see **Figure 9-1**). This mini-enclosure has two main compartments: p/n 34-010969-0120 houses the pump, sensor unit, control unit, and air conditioner, and p/n 59-010820-0120 houses the FDMS unit.

Whatever enclosure is selected, it must satisfy the 8500C FDMS operating temperature range requirement of 8-25°C. To achieve the best results, locate the 8500C FDMS in an environment with stable temperature. Avoid sampling locations with direct exposure to sunlight or near a heating or air-conditioning outlet.

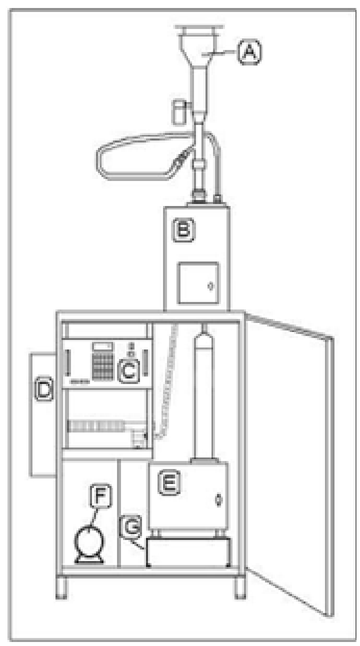

Figure 9-1. A picture and schematic of the environmentally controlled mini-enclosure available from Thermo Scientific. In the schematic drawing: (A) sample inlet, (B) FDMS enclosure, (C) control unit, (D) air conditioner, (E) sensor unit, (F) pump, and (G) spacer.

As noted in SOP Section 6 (Interferences), the enclosure temperature must be carefully regulated to prevent sampler malfunction and/or data bias. Ideally, the enclosure temperature should fluctuate less than 2°C in an hour. The enclosure temperature should also be maintained as close as possible to 5°C less than the operating temperature of the sample stream, which is generally 30°C.

In addition, the regulation of the shelter temperature should be based upon the dew point of the ambient air to keep condensation from overwhelming the trap and possibly damaging or affecting the operation of the sampler. As explained in SOP Section 6, whenever the ambient dew point is significantly greater (by more than 5°C) than the indoor shelter temperature, condensation may occur in the sample train before the sample enters the inlet of the 8500C FDMS or the water trap of the bypass flow. Under these circumstances, insulation of the sample tubes is required. If the temperature difference is extreme, it may be necessary to raise the shelter temperature to reduce the temperature difference.

Avoid areas subject to vibration. Since the tapered element microbalance is a harmonic oscillator, external vibrations can perturb the element itself or add uncertainty to the frequency measurements.

9.5 SPECIAL PRECAUTIONS REGARDING INSTALLATION OF THE 8500C FDMS

Some forethought prior to the installation of the system components can prevent subsequent problems; particular consideration should be given to the elements listed below.

- **Handle the sensor unit and control unit carefully,** and protect them from any falling debris when roof penetrations are made.
- **The 8500C FDMS is designed to be bench mounted.** Rack mounting is not practical.
- **Ensure proper inlet alignment and perpendicularity.** This placement is important to avoid transverse stress on the sample tube connectors, which can cause leaks. The sample line should proceed in a straight, vertical line from the PM_{10} inlet and VSCC to the inlet of the FDMS unit. The roof penetration for the sample lines should be 1.5 inches in diameter and should be located directly above the sample line inlet on the top of the instrument. The flexible bypass tubing and the signal cable for the temperature/humidity sensor can be routed thorough an existing side port, or a port can be drilled in the roof or wall of the shelter.
- **Consider the proper clearance** needed on the roof to accommodate the tripod that supports the air inlet in alignment with the instrument on the bench. The legs can be adjusted to different lengths (and angles) to best position the tripod.
- **Make certain the front door to the sampler has adequate clearance** to be fully opened for TEOM filter changes. The operator will generally have the best view for making TEOM filter changes if the instrument is placed at the front lip of the bench.
- **Provide adequate access to the back and side** of the instrument for maintenance, for repairs, and for changing the 47-mm TX40 filter in the chiller assembly.
- **Consider using the optional rubber coupler on the inlet**. A short section of flexible conductive rubber tube (p/n 30-002274) can be used as a junction in the sample tube between the top of the FDMS unit and the ceiling of the shelter. This tube has two functions: (1) it adds additional isolation between the mass transducer and the sample train and other roof components and helps minimize any vibrations, and (2) it makes it easier to break the sample line to facilitate dryer removal. Relying on the push-to-

connect (PTC) fitting to break the sample line requires accessing the roof and loosening fittings to pull the line up through the roof. If the flexible rubber tube is used, the gap in the rigid tubing should be only about 1 to 1.5 inches; a longer gap may cause the tubing to collapse or twist.

- **Provide proper grounding.** Poor electrical grounds in any particulate matter sampler can affect concentration values, and proper grounding of the inlet tube is needed to avoid static charge buildup that can lead to errors. The substantial inlet system has a potentially high capacitance, so adequate grounding needs to extend from the size separator inlets, through the sample inlet tubing, to the 8500C FDMS chassis, to earth ground. The instrument is designed so that a properly grounded electrical socket will generally be adequate, but it is best to measure the difference in the potential between the inlet tube and the 8500C FDMS chassis to confirm that the resistance is less than a few ohms.
- **Use a tubing cutter to cut the tubing to lengths.** Do not allow fragments to fall into the tubes; make sure all cuts are perpendicular to the tube.
- **Do not operate the instrument until the ambient temperature sensor is installed.** With no ambient temperature sensor, the mass flow controllers will attempt to control the sample flow as if the ambient temperature is absolute zero.
- **Route the tubing to avoid any HVAC system vents.** Reports of condensation problems have been linked to carelessly routed tubing, particularly for the bypass flow. Inadvertent heating of the sample inlet lines above the FDMS unit could volatilize some PM components before they are measured.
- **Provide roof support or harmonic isolation during maintenance.** Sampler maintenance will require operators to work on the roof, potentially causing the roof to flex, sample tubes to move, and the mass transducer to be disturbed. Methods to avoid this outcome include installation of a roof platform and/or installation of a section of conductive rubber tubing (p/n 30-002274) in the sample lines to absorb the shock of the roof movement. In addition, areas that receive snowfall should plan to avoid extreme temperature gradients or harmonic disturbance. Snow piled along the sample inlet may cause a steep temperature gradient in the sample flow path, preventing proper conditioning of the sample stream. It may be necessary to isolate the sample tube by using a roof flange such as a length of PVC pipe. Also, care should be taken during snow removal from the roof; the tubing may be damaged or the mass transducer disturbed if the inlet is hit by a shovel or other snow removal equipment.
- **Install the pump so that vibrations are dampened.** The pump may be placed on a piece of closed-cell foam to dampen vibration, but care must be taken not to create a fire hazard.
- **Uninterruptable Power Supply (UPS).** If a UPS is used, both the pump and the control unit should be plugged into the UPS to protect the mass flow controllers in the system. This is necessary because the control unit continuously monitors the flow rates and attempts to maintain the target flow rates by adjusting the valve in the flow controllers. If power is supplied to the control unit and not to the pump during a power failure, the controller will repeatedly send voltage to attempt to fully open the valve, possibly leading to valve failure.

- **Surge protection**. Some users may opt to install a power conditioning system in line, such as a "spike protector."
- **An important note about Swagelok fittings and how to tighten them**. There are some steps in the installation process that employ Swagelok fittings. The Operating Manual is careful to state to tighten these fittings 1-1/4 turn past finger tight when installing. This instruction is correct, but it *applies only to the initial installation* of the fitting. If the fitting is removed during maintenance and then re-installed, then the fitting should only be tightened 1/4 turn past finger tight. After the ferrule of the fitting has been set during the initial installation, any subsequent tightening beyond 1/4 turn past finger tight can ruin the seal and cause leaks.

9.6 TOOLS NEEDED FOR INSTALLATION

Table 9-2 lists the basic tools and supplies that are needed for installing the 8500C FDMS. Any given installation may require additional tools and supplies as dictated by the situation.

Table 9-2. Tools and supplies for installation of the 8500C FDMS.

Tools and Supplies	Remarks
Drill and drill bits	Half-inch, variable speed drill; a hole-saw to make the 1.5-inch (4 cm) roof penetration; additional drill bits if separate penetrations for bypass flow tubing and temperature sensor cable are desired. Depending on roof type, a drill bit extension may be needed.
Hand tools	Screwdriver set, socket set, nut drivers, plumb bob, tape measure, straight edge measure, metal file.
All-weather caulking	To waterproof the roof modifications and feet of the support tripod.
Firing strips	To secure sampler position on the bench.
Wood screws, lag screws	To secure tripod feet to roof and water trap to the wall.
Level	For checking the horizontal level of the 8500C FDMS and vertical level of the inlet.
Tubing cutters	To cut the stainless steel tubes and bypass tubing.
Universal Power Cord	To provide power to the instrument.
Digital multimeter	Calibrated, 3.5-digit; required for hardware calibration procedures.
Analog signal cable	2-conductor cable, if any of the three analog output channels are logged.
Pipe Insulation	To avoid condensation formation for samplers installed in humid areas.

9.7 8500C FDMS HARDWARE INSTALLATION STEPS

The Thermo Scientific 8500C FDMS Operating Manual provides detailed installation procedures, with helpful photos of an actual installation, and offers "Installation Considerations" (Operating Manual Section 2.1) on key features that must be heeded.

The left side of SOP Figure 3-1 depicts the 8500C FDMS system components as they would appear in a typical walk-in installation, with the tripod and inlets located on the roof and the sensor and control units placed on a bench or table. An alternative installation, pictured in Figure 9-1, places the 8500C FDMS in the Thermo Scientific environmentally controlled stand-alone outside enclosure. The installation procedures for this mini-enclosure are covered separately in Appendix K of the Operating Manual.

It is important to determine the location of the roof penetration and the position of the sensor unit before any structural modifications are made. Roof modifications for rooftops that are under warranty may need to be performed by a licensed contractor. Other special precautions are listed below. Once the installation is complete, a full system leak check must be conducted, the sample collection filters and the 47-mm purge filters must be installed, hardware calibrations should be performed, and the 8500C FDMS must be programmed to begin sampling.

For each of the installation steps outlined below, consult the Operating Manual for detailed instructions and illustrations for each step.

1. Install the control unit and sensor unit (Operating Manual Section 2.4).
2. Verify the voltage setting of the control unit. If the voltage setting is incorrect, then alternate fuses must be installed and an adjustment of the setting of the voltage setting switch will be required (Operating Manual Section 2.4.1).
3. Install the 8500C Module brace, attach the 8500C module enclosure, and install the insulation sleeve between the sensor unit and 8500C module (Operating Manual Section 2.4.2).
4. Assemble the main flow (Operating Manual Section 2.4.3.1) and bypass flow (Operating Manual Section 2.4.3.2) connections.
5. When cutting the 3/8-inch green tubing and assembling the flow connections, tubing lengths can be conserved if the Y PTC fitting that connects the bypass flow and the main flow to the pump is located at the back of the control unit and a single 3/8-inch line is used between this Y-connector and the pump. This arrangement also facilitates plumbing arrangements for the full system leak check (SOP Section 10.1.1).
6. Many flow connections use PTC fittings. To prevent air leaks, always fully engage the PTC fittings, pushing past the intermediate "stop" that occurs due to the O-ring.
7. When installing the large in-line filters, note that the arrows indicating flow direction on these filters point away from the direction of the actual flow. In this application, these filters are installed "backwards." This allows debris to accumulate on the exterior, visible section of the filter element, making it easy to assess whether the filter is dirty or not. Note: To prevent the water trap from filling with particulate

matter that is not visible, users may install the large in-line filter for the bypass tubing at the front end of the coil that leads to the coalescing filter in the water trap.

8. Assemble the 8500C module/control unit plumbing connections between the 8500C purge inlet and the main flow port of the dual flow fitting on the back of the control unit (the port with the dimple) and between the 8500C purge outlet and the Y-connector PTC fitting leading to the pump (Operating Manual Section 2.4.4).
9. Install the valve signal cable and the data interface cable between the 8500C module and the control unit (Operating Manual Section 2.4.5).
10. Position the sensor unit on the bench to match the port in the ceiling/rooftop. A plumb bob may be useful here. Install the electric- and air-connecting cable on the back of the sensor unit, being careful to not kink the cable (Operating Manual Section 2.4.6).
11. Install the sampling system (Operating Manual Section 2.5).
12. Assemble the flow splitter. Verify that the inner (sample) flow tube is properly positioned inside the body of the flow splitter. This dimension is essential to ensure isokinetic sampling (Operating Manual Section 2.5.1, especially Figure 2-106).
13. Assemble and install the tripod, insert the flow splitter, and adjust the legs of the tripod so that the open (upper) end of the flow splitter is 1.5 to 1.8 meters above the roof, is vertical (plumb), and is centered over the roof opening (Operating Manual Section 2.5.2). Once the tripod position is final, the feet of the tripod should be attached permanently to the roof with lag bolts or other suitable fasteners.
14. Assemble and install the sample tube. Using the supplied sample tube extensions and quick-connect fittings, complete the connections between the bottom of the sample tube of the flow splitter and the main inlet on the top of the 8500C module. If sample tubes need to be cut, remove any burrs or sharp edges (Operating Manual Section 2.5.3).
15. Thread the ambient temperature sensor cable from the roof, through the roof opening, and attach it to the “Ambient Temp” connection on the back of the control unit (Operating Manual Section 2.5.4).
16. Cut a length of the 3/8-inch nylon green tubing sufficient to reach between the bypass extension of the flow splitter and the control unit, and install it following the specific steps in Section 2.5.4 of the Operating Manual.
17. Note: It is not necessary to install the audit flow filter in the bypass line as described in Operating Manual Section 2.5.4. That flow adapter was carried over from the SES dryer and the original 8500 version A, which had a dryer on the bypass line. It was to protect the dryer on the bypass from clogging with particles when the bypass line, still with vacuum air flow, was removed from the flow splitter and placed on the ground or rooftop. It is not needed with the 8500C and, since it adds another potential leak source, the current recommendation is to not install it. (However, be careful to not throw the bypass line on the ground any time it is disconnected.)

18. Install the ambient temperature sensor mount, insert the ambient temperature sensor, and tighten the ambient temperature sensor holding nut (Operating Manual Section 2.5.4).
19. Weather seal the roof modifications.
20. Install the water condensation trap kit. Important: the condensation trap must be mounted lower than the control unit (Operating Manual Section 2.5.5). Be aware that the filter element will load from the inside and therefore may appear clean even when heavily loaded. To avoid this problem, the large in-line filter for the bypass line may be installed in front of the coil that leads to the water trap.
21. Install the in-line vacuum gauge (Operating Manual Section 2.5.5). This is an important component because it is used to monitor the condition of the pump. It can also be utilized in the full system leak check procedure. If this gauge is installed according to the Operating Manual procedure, then the plumbing modifications that are required to conduct the full system leak check (described in SOP Section 10.1.1) will be altered slightly. Those modifications call for the installation of a vacuum gauge, but two gauges are not required.
22. Install the PM_{10} and VSCC sampling inlets, ensuring that the entrance of the PM_{10} inlet is 1.8 to 2.1 meters above the roof (Operating Manual Section 2.5.6.1).
23. Perform a full system leak check. Note that the full system leak check protocol described in this SOP (see SOP Section 10.1.1) is different from the leak check described in the 8500C FDMS Operating Manual Section 3.5.
24. Install a filter on the mass transducer (SOP Section 9.8.2).
25. Install a 47-mm filter in the chiller compartment (SOP Section 9.8.3).
26. Program the monitor for sampling (SOP Section 9.9).

9.8 INSTALLING FILTERS

While the handling and exchange of TEOM sample filters and 47-mm FDMS filters is one of the most routine undertakings in operating the 8500C FDMS, careful attention to some special precautions and adherence to the sequential filter handling steps helps minimize potential problems, such as unwanted condensation in the chiller compartment or poor TEOM filter seating leading to unstable mass transducer frequencies.

With one exception, the 8500C FDMS should always be operated with a TEOM filter installed on the mass transducer and a 47-mm TX40 filter installed in the 8500C chiller. However, during the full system leak check procedure (SOP Section 10.1.1) the sample filter on the mass transducer should be removed. The large negative pressure during the leak check can damage the sample filter, and release of the system vacuum can dislodge particulate matter and potentially cause contamination problems.

The chiller filter should be changed every time the TEOM filter is changed, The TEOM filter should be changed every two to six weeks, depending on filter loading. The filter loading percentage value (TEOM Data screen) indicates the percentage of the TEOM filter's total capacity that has been used. Because this value is determined by the pressure drop of the main sample flow line, the instrument always shows a non-zero value even if no TEOM filter is mounted in the mass transducer. New TEOM filters generally exhibit filter loading percentages of 15% to 30% at a flow rate of 3 lpm and show lower percentages at lower flow rates. Because this value is an indication of a pressure drop, the loading does not progress in a linear fashion. To avoid data loss due to filter overloading, operators are cautioned to become familiar with the loading pattern typical of local conditions. The filter may require changing well below the indicated filter loading value of 100% to maintain the proper flow rate.

Some agencies collect the used 47-mm FDMS filters for post-sampling analysis. If so, special filter handling procedures, such as those used for FRM filters, must be implemented. The filters should be handled only with forceps or clean cotton gloves, and they may need to be pre-loaded into cassettes and transported with protective covers to ensure that the filters are not contaminated.

9.8.1 Special Precautions for Handling Filters

- Handling and exchanging TEOM sample filters:
  - Keep the door of the TEOM filter sensor housing open for as short a time as possible to minimize temperature changes in the system.
  - Do not touch the sample filter with anything except the filter exchange tool.
  - Ensure that the filter exchange tool is clean and free of any contamination that could be transferred to the TEOM filter.
  - Be careful not to lever or turn/twist the filter tool when removing or replacing a filter on the tapered element, as transverse stress can damage the element.
  - Always replace the filter with one of the filters on the storage pins on the sensor platform that have been equilibrated with conditions in the sensor block.
  - Always install a new filter from the box on the empty storage pin on the sensor platform so that it will be equilibrated when needed in the future.
  - Store the box with new filters inside the sensor housing.
  - Mass transducer filter seating errors have been common problems associated with TEOM use, and it is important that users ensure that the oscillating frequency is stable before leaving the unit unattended.
- Handling and exchanging FDMS 47-mm TX 40 filters:
  - Do not touch the FDMS filter with your fingers; use tweezers.
  - Prepare the 47-mm filter and filter cartridge *before* starting the procedure.
  - Wipe all condensation away from cold surfaces.
  - Only change the FDMS filter in *base mode*, never in reference mode.
  - Turn the FDMS power off during the filter change procedure and restore power when the procedure is complete.
  - Do not leave the cold filter compartment open any longer than necessary.

9.8.2 TEOM Filter Change Procedure

At the initial instrument setup, a TEOM filter, taken from a box of new filters, should be installed on the mass transducer according to the procedure below. At this time, two additional filters should be installed on the storage pins on the sensor platform. For future TEOM filter changes, one of these pre-conditioned filters should be used for filter changes, and a new filter from the box should be installed on the vacant storage pin.

Figure 9-2 shows a close-up view of the filter element being placed on the top of the tapered element (left), and schematically illustrates the loading steps, and unloading steps, of the sample filter on the tapered element (right). (Greater detail and additional pictures are provided in the 8500 FDMS Operating Manual Section 3.1.)

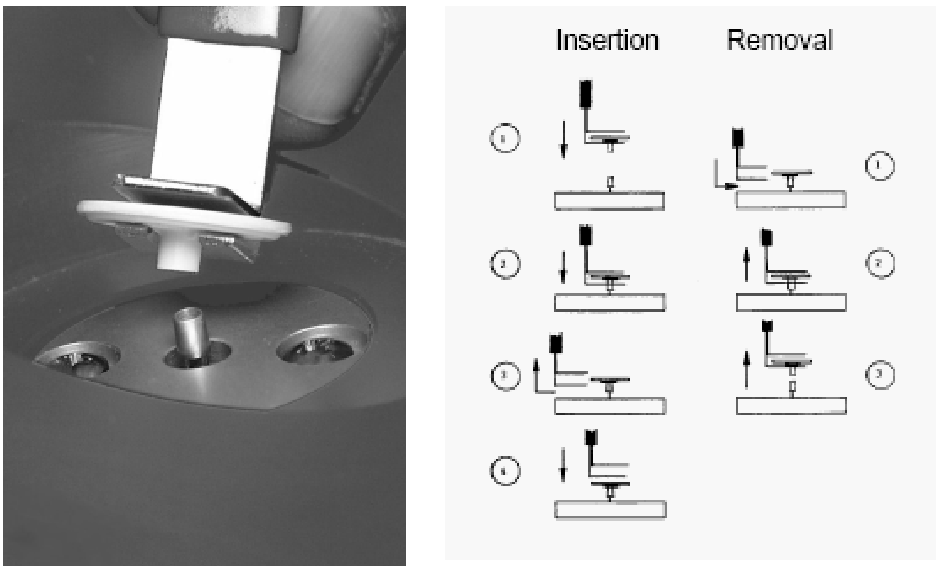

Figure 9-2. A close-up photograph of the filter element being placed on top of the tapered element (left), and steps in the filter insertion and removal process (right).

Follow these steps to change the TEOM filter:

1. Press the <DATA STOP> key on the control unit's keypad and verify that the unit is in DATA STOP mode, denoted by "S" in the mode display.
2. Open the sensor block by releasing the latch on the sensor unit outer door.
3. Use the clean filter exchange tool to carefully remove the used filter from the tapered element by pulling straight upward, being careful not to turn or twist the filter tool. Discard the used filter.
4. Pick up a new (conditioned) filter from the storage pins, lightly place it on the tip of the tapered element, and gently press down to initially seat the filter.

5. Retract the tool, sideways, without disturbing the filter. Place the bottom of the tool on top of the TEOM filter and push directly downward to secure the filter onto the tapered element. From one to three pounds of pressure is sufficient.

6. Close the sensor block housing and secure with the latch.

7. Press <F1> or <RUN>, and check that the mode changes from S to 1 and that the **RED** Status lamp on the front panel goes out after a few minutes. The mode will change through 2, 3, and then 4, indicating that the system is again in normal operation. This usually takes 5 to 10 minutes but can take up to 30 minutes depending on system status.

8. Check the vacuum gauge and note the value. Ideally, the vacuum should be better than -20 inches Hg (more negative). Acceptable performance is usually between -18 to -24 inches Hg. If the value is less than -18 inches Hg (less negative), the pump is in need of service or replacement.

9. Inspect the oscillating frequency change rate on the TEOM Data screen; the last two digits of the reading will fluctuate (due to noise) but the other digits should remain steady. Fluctuation observed in more than the last two digits may indicate that the TEOM filter is loose or defective. Reseat the filter and check the frequency again. If the frequency continues to show fluctuation in more than the last two digits, replace the filter again. This process may need to be repeated until the frequency stabilizes. Running the pump when the TEOM filter is installed will allow it to seat properly.

9.8.3 FDMS Filter Change Procedure

The FDMS filter change procedure involves first preparing the replacement filter cartridge and then actually changing the filter. Prepare the filter media and cartridge in a clean and dry area before starting the FDMS filter change procedure. Ensuring that the filter cartridge is prepared and ready to insert minimizes the amount of time the filter compartment must be left open, preventing condensation on the exposed cold surfaces.

Preparing the FDMS Filter Cartridge

1. Obtain a spare blue filter cartridge with stainless steel screen, a Pallflex 47-mm TX40 filter, a clean petri dish or poly bag, and a pair of filter tweezers.
2. Separate the two halves of the filter cartridge. (If the cartridge has a previously used filter installed, remove the spent filter and either store or discard, as required.)
3. Check that the steel screen and two cartridge halves are clean. If they are dirty, clean them. Check the screen and both halves of cartridge for damage, nicks, and chips. If damaged, discard the damaged components and replace with new components.
4. Take a new filter from the supply box using tweezers and place carefully into the lower half of the filter cartridge. **Never touch a new filter with your fingers.** The

dull textured side of the filter should face upward and the woven shiny side should face the stainless steel screen (see **Figure 9-3** below).

5. Fit the upper cartridge ring over the filter and press firmly down onto a clean dry surface to seal.
6. Put the cartridge into the polythene bag or Petri dish and seal it to prevent contamination or moisture from reaching the filter. Do not remove the filter until it is ready to be fit into the FDMS chiller compartment.

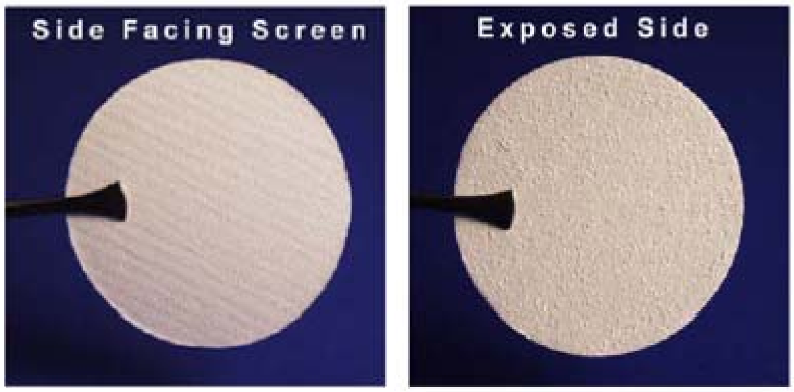

Figure 9-3. Photographs of the two sides of the Pallflex TX40 47 mm filter. The filter should be installed with the dull, textured side facing upward in the cassette (the exposed side), and the woven, shiny side toward the stainless steel screen.

Installing the Prepared FDMS Filter Cartridge

Figure 9-4 illustrates the stacking order of the filter cassette, the filter door, and the filter holder housing the blue filter cassette.

1. Press the <DATA STOP> key on the TEOM Control Unit keypad.
2. The 8500C FDMS *must be in BASE mode* before proceeding with the FDMS filter change. Press <14> and then <ENTER> on the keypad. This will display the current operating mode of the 8500C FDMS. If the unit is in REF mode, wait until the unit changes to BASE mode before proceeding.
3. Switch the power to the FDMS module **OFF** to lock the system in BASE mode. (The power can be switched off on the rear panel using the switch above the power cord.)
4. Open the access door on the left side of the FDMS module by releasing the thumbscrew, and then firmly grip and turn the grey seal counter-clockwise to release it.
5. Remove the blue filter cartridge and replace it with a new, prepared one. Place the cartridge into the holder with the foil back against the inner chamber and the filter facing upward.
6. Using a tissue, carefully wipe away any moisture that might be present in and around the filter chamber. Make sure no loose fibers or tissue are left behind.

7. Check the condition of the "V" seal. If it appears damaged, it should be replaced as soon as reasonably possible.
8. Replace the grey seal cap with the cartridge inside and turn to lock; then close the access door and secure with the thumbscrew.
9. Switch **ON** the FDMS power.

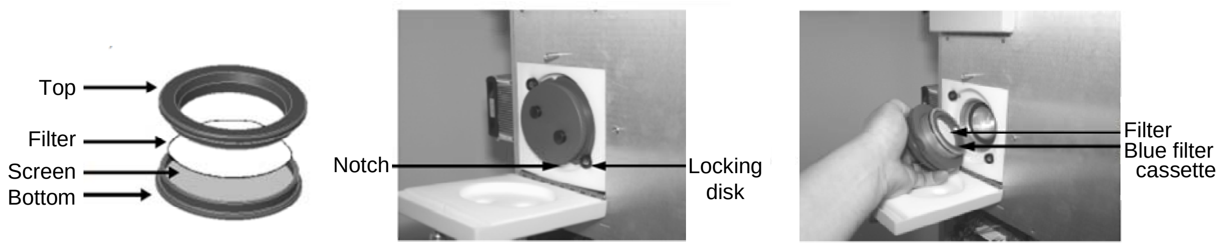

Figure 9-4. Illustration of the stacking order of the TX40 47-mm filter cassette (left); an open 47-mm filter door showing the filter holder (center); and the filter holder showing the cassette (right).

9.9 PROGRAMMING SETUP AND CONFIGURATION CHECK

Configuring the instrument requires that the user be able to navigate among screens and use the editing functions available on the keypad. A software overview is provided in Section 4 of the Operating Manual. Variables can only be edited when the unit is in the Setup mode, accessed by pressing the <DATA STOP> key.

Once the system hardware components are in place, a full system leak check has been conducted, and the filters have been installed, the programming and system configuration steps listed below will finalize the 8500C FDMS installation. Specific instructions for each step in the following list are given in Sections 9.9.1 through 9.9.3:

- Set the system clock.
- Review/adjust the configuration parameters.
  – Review/adjust the case, air, and cap temperature settings.
  – Review/adjust the main and bypass flow rates.
  – Set the monitor to sample and report data in actual (volumetric) conditions.
  – Confirm the unit serial number and calibration (K_0) constant.
  – Set up the data storage information.
- Configure the required communications parameters.
- Set up password protection, if appropriate, to protect from inadvertent configuration changes.
- Press <F1> or <RUN> to start data collection.

9.9.1 Set the System Clock

To set the system clock:

- Put the monitor in Setup by pressing the <DATA STOP> key.
- Press <Main/Status> and verify that the unit is in Setup Mode (the operating mode field on the Main Screen should display an "S").
- Press the <TIME/DATE> key on the keypad to display the Set Time screen.
- Press the <EDIT> key, use the arrow keys to position the cursor, and enter the current time and date in the appropriate fields.

9.9.2 Review and Adjust the Instrument Configuration Parameters

The default parameter settings in the instrument as received from Thermo Scientific must be verified, and adjusted if necessary.

Review and Adjust the Case, Air, and Cap Temperature Settings

- Display the Set Temps/Flows screen by pressing <STEP SCREEN> on the keypad and selecting "Set Temps/Flows" from the menu.
- The screen will display two numbers for each of the three temperature settings: the left hand column is the parameter setting, which can be adjusted when in Setup Mode, and the right hand column is the current reading (not adjustable). Verify that the left hand column reads "30.00" for each of the three temperature settings. Adjust if necessary.
- Remain in this screen to verify the flow settings (next step).

Review and Adjust the Main and Bypass Flow Rates

- While in the Set Temps/Flows screen, press the down arrow keys until "F-Main" and "F-Aux" appear on the left.
- Verify that "F-Main" is set to 3.00 and "F-Aux" is set to 13.67. Adjust if necessary.
- Remain in this screen to set the monitor for volumetric sampling (next step).

Set the Monitor to Sample and Report Data in Actual (Volumetric) Conditions

The 8500C FDMS must be set up for volumetric sampling and reporting to meet $PM_{2.5}$ FEM requirements.

- While in the Set Temps/Flows screen, press the down arrow keys until "T-A/S" and "P-A/S" appear on the left. These are the average and standard values for temperature and pressure.
- For volumetric sampling and reporting, both the average and standard temperature settings must be set to "99." Use the arrow keys to select the left and right columns for "T-A/S" and use the keypad to enter the value "99" for each.

- For volumetric sampling and reporting, both the average and standard pressure settings must be set to "9." Use the arrow keys to select the left and right columns for "P-A/S" and use the keypad to enter the value "9" for each.

Confirm the Unit Serial Number and Calibration (K_0) Constant

- Press <STEP Screen> to display the Menu screen and scroll and select "Set Hardware."
- Verify that the Calibration Constant and Serial Number on the screen match the instrument. These numbers are listed on the "Final Test Record" documents that are shipped from the factory.

Set up the Data Storage Information

The user must decide on the variables to be stored in the 8500C FDMS memory. The electronics platform in the 8500C FDMS limits data storage to eight variables per record. The interval at which the records are stored, which affects the total amount of data that can be stored internally, can be specified. Hourly storage is commonly used.

Agencies should review their data reporting requirements and data handling procedures and set up the data storage configuration in the 8500C FDMS in a way that best accommodates those requirements. Monitoring networks with more than one 8500C FDMS will want to assure that the data storage is configured identically among the units.

Software versions 3.5 and higher have new program register codes assigned to FEM mass concentrations. These are:

- PRC 20 is FEM mass concentration (MC).
- PRC 24 is FEM 1-hr MC, updated every hour.
- PRC 28 is FEM 24-hr MC, updated every hour.

Except for these FEM variables, Appendix B of the Operating Manual gives a listing of instrument PRC values. Note that *PRC values for the 8500C FDMS and the non-FDMS version of the TEOM 1400 are different.*

The existence of these new FEM PRC variables makes critical the choice of variables to store in the 8500C FDMS memory. Agencies that wish to monitor mass concentration variables as well as diagnostic variables should evaluate the possibility of using a data acquisition system (DAS) that is capable of employing the AK commands in the Operating Manual to request the values of as many PRCs as desired.

The corrected FEM concentrations and the uncorrected (raw) concentrations are all available via separate PRCs. However, the FEM correction is *not applied* to the Base- and Ref-MC values. Thus, these two values will add up to the uncorrected MC, and not to the FEM MC. The correction algorithm is applied to the MC only. If the user is limited to eight storage variables and wants to record all mass concentrations, some diagnostics will have to be sacrificed. **Table 9-3** suggests eight variables to store, along with their PRCs. Here, the 1-hr

MC and the Ref MC are logged, and the FEM MC is substituted in the Base MC slot. In this way the Base MC can be back-calculated. This approach supports storage of critical diagnostics.

Table 9-3. Suggested data storage variables to allow system health monitoring for the 8500C FDMS.

Suggested Data Storage Variables for the 8500C FDMS		
PRC	Description	Units
008	Mass concentration (MC)	$\mu g/m^3$
020	FEM mass concentration (FEM MC)	$\mu g/m^3$
104	Reference mass concentration (Ref MC)	$\mu g/m^3$
099	Sample dew point	°C
114	Ambient dew point	°C
035	Filter loading	%
013	Noise	Hz-Hz[a]
041	Status condition	code

[a]Standard deviation of the change in frequency

To set up data storage:

- Press <STORE> on the keypad to view the "View Storage" screen.
- From the "View Storage" screen, press the "Step Screen" key to display the "Set Storage" screen.
- Press the <EDIT> key (cursor changes to "?") and use the arrow keys to select the "Store Variable" fields 1-8.
- For each field, enter the PRC value for the desired variable by using the keypad or the arrow keys to increase/decrease the PRC. Using the <SHIFT> key changes values by 10 steps at a time, and the <CONTROL> key causes the PRC to change by 20 steps at a time.
- Select the interval field and enter the storage interval (in seconds).
- Select the "Stor Vars" field and enter the number of variables that are being stored. **WARNING**: All data are lost when the "Stor Vars" variable is changed.
- Press the <ENTER> key to accept the changes.

9.9.3 Configure the Required Communications Parameters

The final step in the setup of the 8500C FDMS is configuring the instrument's communication parameters to be compatible with the protocol(s) in use by the operating agency. Capturing the digital data via the RS-232 port is the recommended protocol, and most agencies have provisions for digital data logging. Capturing serial data is discussed below. The instrument also has available three analog outputs and two contact closure circuits that can be used to assist in monitoring the unit's operation. One user-configurable analog input is also available. Section 9 of the Operating Manual gives details on the data input and output capabilities. A brief summary of communication options is provided here, with references to the appropriate sections of the Operating Manual.

Analog Outputs (Operating Manual Section 9.2)

Three analog output channels are available, accessible via 15-pin connectors located on the front or back panel of the control unit (Operating Manual section 9.2.1). Each of the three channels is configurable for 1, 2, 5, or 10 VDC. (Hardware jumper settings may need to be changed, depending on the desired voltage outputs, see Operating Manual 9.2.2.) The user can assign the PRC value for the variable that is to be output, along with the minimum and maximum values that will be used to scale the output. Users should evaluate the input voltage restrictions of the data logger capturing the analog signals and set the parameters for the 8500C FDMS analog outputs accordingly.

Contact Closure Circuits (Operating Manual Section 9.3)

Two user-definable relay contacts are available, accessible via 15-pin connectors located on the front or back panel of the control unit (Operating Manual section 9.2.1). (The default settings are for status conditions and filter loading percentage.) The user enters the PRC to be tested, a comparison or logical operator, and a constant value against which the comparison is made. If the result of the comparison is "true," the monitor closes the circuit (makes contact); otherwise, the channel remains open.

Analog Inputs (Operating Manual Section 9.1)

While the 8500C FDMS has a total of eight analog inputs, seven of these are used by the instrument and cannot be configured by the user. One analog input (analog input "0"), located on the 15-pin analog I/O connector on the back of the unit, is user configurable. Details on how to set up this input are covered in Operating Manual Section 9.1. (Originally, in the 1400 TEOM, all eight analog inputs were available to log external signals, but the addition of the FDMS used all but one. This input option is infrequently used because most sites have an external data logging device and do not rely on the TEOM for capture and storage of external data signals.)

RS-232 Communications (Operating Manual Section 9.4)

Most agencies will utilize the RS-232 communications capabilities of the 8500C FDMS. There are several RS-232 modes available. The user should identify which of the RS-232 modes best fits their particular data downloading and reporting requirements. Web-based real-time data displays are becoming more common and are an excellent means by which to apply daily (or more frequent) data viewing and QC. For these users, the monitor may be configured for more frequent reporting or polling. The AK Protocol (and German Protocol) allows two-way communication, and, when used in combination with RPComm or TEOMCOMM software, allows users to control the instrument and obtain data remotely. Third-party data acquisition programs can also be programmed to communicate efficiently with the instrument using the AK Protocol commands. The RS-232 modes are summarized in **Table 9-4**. Once the appropriate mode has been selected, it is configured in the monitor via the “Set RS-232 Mode” screen, displayed by pressing <RS232> on the instrument’s keypad.

Table 9-4. Description of RS-232 modes.

RS-232 Mode	Description	Comments
None	Can use RPComm software to view/change instrument parameters and upload new software.	Instrument is shipped with RS-232 ports in RS-232 None mode.
Print On Line	In the Comm Print Settings screen the user specifies up to 6 variables (PRC Codes) to output, and also specifies the output interval (1800 seconds default).	Can download data to any serial device (not just a printer).
AK Protocol	User can retrieve current value of all variables, change system parameters, and download the data buffer. Setup in Com 2-Way Settings screen.	Allows two-way information exchange. Used in combination with RPComm and TEOMCOMM software. Can be used for modem communications.
German Protocol	German Ambient Network Protocol.	Allows request of 1, 2, or 3 predetermined system variables. Cannot select variables remotely.
Store to Print	Downloads all data records, from the storage pointer to the end of the storage buffer, to a serial printer.	Sends one record every two seconds. User sets the rate at which data records are stored, and specifies which variables will be downloaded. Continues output until RS-232 mode is changed.
Fast Store Out	Downloads all data records, from the storage pointer to the end of the storage buffer, to a PC or other serial data recording device.	User sets the rate at which data records are stored, and specifies which variables will be downloaded. Continues output until RS-232 mode is changed.

9.9.4 Set Up Password Protection

Three levels of keypad locking are available: unlock, low lock, and high lock. The unit is always shipped in unlock mode to allow access to all functions. Once the 8500C FDMS is configured and collecting data, the low lock mode is recommended for routine operations. This prevents inadvertent editing of any system variables, but allows viewing of all screens and changing of operating mode to facilitate maintenance procedures.

To put the unit in low lock mode:

- Press <LOCK> on the keypad.
- Enter the password (default is 100000).

- To return to unlock mode, repeat these steps.

To set the password:

- Press <STEP SCREEN> and scroll to “Set Passwords.”
- Press enter and move the cursor to the “Cur Lo Pass” line.
- Enter the current password.
- Scroll to “New Lo Pass” line, enter the new password, and press <ENTER>.

10. QUALITY CONTROL AND MAINTENANCE PROCEDURES

Once the 8500C FDMS is installed and configured, a regularly recurring protocol of quality control (QC) and maintenance procedures must be established to ensure that a continuous stream of high quality hourly $PM_{2.5}$ concentration data is obtained.

Quality control procedures, sometimes referred to as audits, typically occur on a monthly basis. While some maintenance procedures also occur monthly (e.g., cleaning of the size selective inlets), most occur every six months or annually. To illustrate how the components of these groups are related in time, **Table 10-1** lists the QC and maintenance procedures together, the frequency of recurrence recommended by Thermo Scientific, and the sections of this SOP that describe the sequential steps of each procedure. References to the appropriate sections of the 8500C FDMS Operating Manual and the 1400A Service manual are provided where applicable. Both QC and maintenance procedures are required to maintain system health and provide high quality data. In practice, it may be helpful to provide field technicians responsible for implementing the procedures with an actual calendar, or simple table, with the site-specific target dates for each protocol.

Each QC procedure is described in Section 10.1 of this SOP, and each maintenance procedure is described in Section 10.2.

10.1 QUALITY CONTROL PROCEDURES

The listed intervals at which these procedures should be conducted are those recommended by Thermo Scientific to ensure optimal data integrity. Some agencies conduct some of these procedures at a higher frequency than listed in the table to minimize the need to invalidate data because of a failure (e.g., filter overloading leading to a reduced sample flow rate) that may require that data be invalidated back to the last recorded acceptable value. This increased frequency is generally based on experience—if filter loading is exceeding the tolerance before the scheduled monthly visit, the logical solution is to perform the filter exchange more frequently (for example, bi-weekly) or to base the schedule on real-time monitoring of the filter loading. Since most QC procedures require that the sampling cycle be interrupted, the benefits of more frequent QC procedures need to be balanced against the loss of one or two hours of data.

Tolerance levels for verifications of flow, temperature, pressure, and leak checks must be specified so that field technicians understand when adjustments are needed and when they are not. It is important to consider that *frequent adjustments of instruments may not be necessary* and can lead to *more* data quality uncertainty. It is left to the site supervisor to decide on the recurrence schedule and the tolerance levels that best fit the circumstances.

Table 10-1. Thermo Scientific's recommended frequency of quality control and maintenance procedures, and relevant section references in this SOP, the 8500C FDMS Operating Manual (OM), and 1400A Service Manual (SM). Schedules may be altered for specific procedures (e.g., filter changes) depending on local conditions and experience.

Procedure Type	Item	Recommended Frequency				Location of Procedure		
		Install	Monthly	6 Mos.	Annual	SOP	OM	SM
Quality control	Full system[a] leak check	✓	✓			**10.1.1**	**3.5**	
	Ambient temp check	✓	✓			**10.1.2**	**12.2.4**	
	Ambient pressure check	✓	✓			**10.1.3**	**12.2.2**	
	Flow check	✓	✓			**10.1.4**	**12.2.3**	
	Change TEOM filter	✓	✓			**10.1.5**	**3.1**	
	Change FDMS filter	✓	✓			**10.1.6**	**3.2**	
	Vacuum pump test[a]	✓	✓			**10.1.7**		**3.1.5**
	Zero test	✓			✓	**10.1.8**		
	Mass transducer (K_0) check	✓			✓	**10.1.9**	**12.2.1**	**3.2.5**
Maintenance								
	Clean PM_{10} inlet	✓	✓			**10.2.1**	**App. G-1**	**3.1.1**
	Clean VSCC	✓	✓			**10.2.2**	**App. G-2**	**3.1.2**
	Exchange in-line filters	✓		✓		**10.2.3**	**12.1.1**	**3.1.3**
	Change water trap filter			✓		**10.2.4**		
	Test batteries	✓		✓		**10.2.5**		**3.1.4**
	Clean heated air inlet system	✓			✓	**10.2.6**	**12.1.2**	**3.1.6**
	Rebuild sump[b]				18 mos.	**10.2.7**		
	Switching valve cleaning and maintenance			✓		**10.2.8**	**12.1.3**	
	Dryer maintenance[c]				✓	**10.2.9**		
	Clean chiller				✓	**10.2.10**		

[a]The updates for these procedures in this SOP are recommended in place of those in either the Operating Manual or Service Manual

[b]Pump vacuum pressure must be maintained at greater than 65% of ambient pressure.

[c]Dryer maintenance means "replace the dryer." This frequency may be adjusted based on performance. See Section 10.2.9 for a discussion of dryer maintenance guidelines.

The QC procedures are presented in the order of their appearance in Table 10-1, and, in general, the monthly QC procedures should be conducted in this order. For example, it is important to do the ambient temperature and pressure verifications before the flow check since the flow controllers' adjustments of the flows are based upon these data inputs. Note that the Full System Leak Check procedure is different and more thorough than the regular leak check procedure described in the Operating Manual. The vacuum pump test described in the Service Manual also differs from the updated version described here. The zero test described here is not covered in either the Operating Manual or the service Manual.

In general, 40 CFR Part 58 App A (U.S. Environmental Protection Agency, 2008b) and 40 CFR Part 50 App L (U.S. Environmental Protection Agency, 2006b) requirements apply to all continuous $PM_{2.5}$ methods. The EPA Quality Assurance Handbook Volume II, Appendix D (U.S. Environmental Protection Agency, 2008c) provides some guidance regarding QC checks in the Continuous $PM_{2.5}$ Local Conditions Validation Template.

10.1.1 Full System Leak Check

The full system leak check described here is different from the leak check procedure described in the 8500C FDMS Operating Manual. By providing a more comprehensive check on the system, the full system leak check is designed to detect leaks that might go undetected under the normal leak check protocol. The protocol in the Operating Manual covers the sample path from the top of the flow splitter back to the flow sensors on each of the main and auxiliary flow paths. While this protocol is acceptable for the 1400A systems, the addition of the 8500C module requires that the purge path also remain leak free. This purge path starts from the outlet of the main flow controller and is routed back through the outer path of the dryer and then out to the vacuum source. A leak in this area as well as in any part of the system would cause issues in drying performance. A leak could introduce moisture in the path where the air should be dry in order for the sampler to function properly. Moister purge air would be less effective at drying the incoming sample air flow, driving the sample dew point upward. If left unattended, the sample dew point could approach or even exceed the chiller set point temperature and, when in the reference mode, induce more moisture because of condensation in the chiller. A leak in the purge path could also negatively impact the pump pressure through the outer path of the dryer and cause lower drying performance.

The full system leak check protocol requires an additional vacuum gauge, a manual valve, and a Tee fitting. When the valve is closed, it creates a closed loop isolated from the vacuum source. That loop should hold the vacuum if the system is leak free. Removal of the constant vacuum source will reveal any small imperfections (leaks).

Additional Parts Needed for the Full System Leak Check

To conduct the full system leak check, three additional plumbing parts are needed: a valve, a vacuum gauge, and a Tee fitting. The parts listed below and shown in **Figure 10-1**, available from McMaster-Carr, or equivalents may be used. Note: if a vacuum gauge has already been installed in the system, a second gauge is not needed, and the brass Tee noted below can be replaced with a 1/4-inch NPT male x female elbow (McMaster-Carr p/n 50785K43).

- Vacuum gauge; McMaster-Carr p/n 4002K14

- Brass elbow ball valve (lever), 1/4 inch; McMaster-Carr p/n 4847K11
- Tee, brass, 1/4-inch NPT male x female x female; McMaster-Carr p/n 50785K222

Figure 10-1. Photograph of the additional plumbing parts needed to conduct the full system leak check.

Modify the Pump Assembly

Modify the pump assembly as described in the steps below. Since the recommended interval for this full system leak check is once a month, agencies may wish to permanently install the additional plumbing parts to accommodate the leak check. Otherwise, the plumbing will need to be reconfigured for each leak check. Costs in 2010 for the parts totaled about $30.00. Agencies with multiple monitors will need to consider the tradeoff between extra monthly labor and multiple pump modification assemblies.

- Apply Teflon tape to the threads on the valve, gauge, and brass Tee (Figure 10-2, panels A, B).
- Remove the PTC fitting and the muffler from the pump (Figure 10-2, panels C, D).
- Assemble the fittings to the inlet of the pump (Figure 10-2, panels E, F):
  - Thread the valve into the pump inlet.
  - Attach the Tee to the valve.
  - Attach the gauge to the Tee.
  - Attach the PTC fitting to the Tee.
  - Replace the muffler.

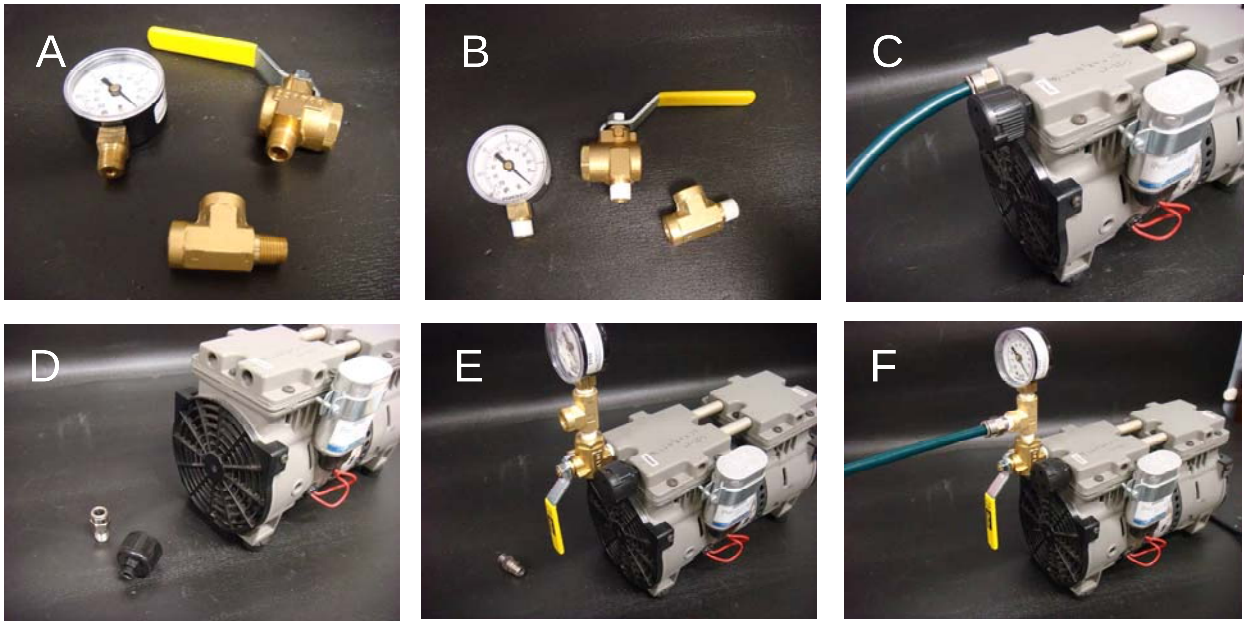

Figure 10-2. Illustration of the steps for assembling the full system leak check valve and vacuum gauge.

Conduct the Full System Leak Check

The main diagnostic for the full system leak check described here is different from that described in the Operating Manual. Here, pressure readings on a pressurized closed loop (vacuum), with the pump off, are used to judge the existence of leaks. The older leak check method relied on flow readings on a closed system with the pump running. In that case, care had to be taken to account for the non-linearity exhibited by the mass flow sensor at flow rates near zero, known as the non-linearity offset value or "NOV" (Operating Manual Section 3.5, bullet 11).

To ensure that all flow paths are checked, the full system leak check should be conducted twice, once when the switching valve is in the base cycle position, and once when the switching valve is in the reference cycle position. To determine the current valve position of the 8500C FDMS, on the control unit keyboard press <DATA STOP>, then "14," then <ENTER>. This will bring up a screen display that shows the current valve position.

- Verify that the pump is powered up and drawing air through the system.
- Remove the TEOM filter from the mass transducer.
- Remove the sample inlets from the flow splitter and install the flow audit adapter, in its open position, on the flow splitter.
- Close the valve on the flow audit adapter.
- Check the screen display and note if the FDMS switching valve is in the base cycle or reference cycle. Then switch the power to the FDMS module OFF to lock the system in its current mode. This step prevents the valve from switching in the middle of the leak

check. (The power switch is on the rear panel of the FDMS module, above the power cord.)

- Close the valve that was added between the leak check vacuum gauge and the pump. This produces a closed loop between the flow audit adapter on the flow splitter and the pump, and includes the main flow path of either the base or reference cycle.
- Turn the pump off. This does two things: it prevents any pump vibrations from affecting the stability of the needle on the vacuum gauge, and it prevents the pump from compensating for any small leak that may exist in the system.
- Observe the vacuum gauge for one full minute. The total system loss after one minute should be less than 1 inch Hg. A loss of greater than 1 inch Hg vacuum requires that the cause of the leak be determined and repaired.
- After a successful leak check, open the leak check valve (not the flow audit adapter valve) and restart the pump.
- Switch the power to the FDMS module back ON, and watch the control unit's screen display until it indicates that the switching valve is in the alternate position.
- Switch the power to the FDMS module OFF again to lock the valve into its new position.
- Close the valve between the vacuum gauge and the pump.
- Turn off the pump and observe the vacuum gauge for one full minute. The total system loss of this flow path after one minute should be less than 1 inch Hg. A loss of greater than 1 inch Hg vacuum requires that the cause of the leak be determined and repaired.
- Note: The criterion of "system pressure loss of less than one inch Hg in one minute" is based on recommendations from Thermo Scientific. In the case of data validation (SOP Section 11.2), the specifics regarding the tolerances allowed for the full system leak check procedure become important. Additional discussion of this point is included in SOP Section 11.2.

Troubleshooting Leaks

If a leak is detected, its origin must be tracked down and eliminated. The procedure to locate the leak should be carried out in a step-wise fashion, and the steps should be planned out to prevent damage to the dryer. Below are some tips, strategies (and warnings) for identifying leaks.

- If the leak check *fails under both the reference and base paths* and the test was conducted with the VSCC in place (i.e., only the PM_{10} inlet was removed), then remove the VSCC and install the flow audit adapter directly on the flow splitter and redo the leak check. If this fixes the leak, replace the O-rings in the VSCC.
- If the full system leak check *fails in the reference cycle but passes in the base cycle*, the leak must be located in the purge filter conditioning section of the flow path when the inner block of the switching valve slides to the reference position. The leak could be in the chiller itself, or the seal in the switching valve may have become rolled during the valve positioning. Eliminate the chiller by using one of the tubes from the front of the

switching valve. Disconnect one of the tubes from the port on the chiller and loop that tube to the other elbow fitting on the front of the valve. The unused tube should be disconnected at the valve and left disconnected. Perform the leak test in the reference position and the base position. If it passes in both positions, then the leak is in the chiller. If it fails on the reference only and passes on the base, then one of the seals in the valve is probably damaged or rolled. (See SOP Section 10.2.8 for valve disassembly.)

- If the full system leak check *fails in the base cycle but passes in the reference cycle*, then the leak is occurring in the switching valve when the inner block slides to the base position. (See SOP Section 10.2.8 for valve disassembly.)
- Other leak check failures will require that a shut-off valve be inserted at specific points in the flow paths to isolate discrete flow sections until the section with the leak is identified. For example, the auxiliary (bypass) flow can be removed from the equation by installing the valve close to the 8500C (beyond the Tee fitting that joins the purge outlet flow and the bypass flow to the pump), removing the bypass line from the flow splitter, and capping the flow splitter port with the Swagelok cap provided in the standard flow audit adapter package. Since the disconnected bypass line will still have air flow while the pump is running, it should either be capped or be set aside carefully to avoid having large debris drawn into the in-line bypass filter. If the leak test passes, then the leak is in auxiliary by-pass.
- The valve can be moved to a series of different positions to help narrow down the source of the leak, similarly to the step above. **CAUTION**: if the purge line shutoff is moved beyond the 8500C and closer to the back of the 1400A control unit vacuum Tee fitting, then the upper shutoff position (which in the routine leak check is the flow audit adapter valve on the top of the flow splitter) must be moved to a new position by installing a shut-off valve to remove the dryer from the path and prevent internal damage to the Nafion. There should never be air flow through the center of the dryer without air flow on the outside of the dryer during leak checks. However, the reverse flow configuration of vacuum pressure on the outside but not on the inside of the dryer is acceptable because the Nafion is supported, but note that this state should not continue for any extended period of time (hours). If the shutoff valve is moved beyond the 8500C module, then disconnect the switching valve from the dryer and cap the valve to remove the dryer from the path.

10.1.2 Ambient Temperature Verification

The verification of the ambient temperature sensor measurement should be made with a NIST-traceable external thermometer that is within its certification period. Some agencies may use a water bath for immersion of the reference thermometer and the 8500C FDMS ambient temperature probe. In that case, be careful not to immerse the probe's electrical connection and wire. Other agencies may make the comparison in ambient air. Tolerances may differ among agencies as well. The 8500C FDMS Operating Manual cites ± 2° C of the reference probe.

To verify the ambient temperature sensor measurement:

- Loosen the screws holding the ambient temperature probe, located just below the sample inlets, and slide the probe out of the holder. Alternatively, the reference probe may be inserted into the 8500C ambient temperature sensor holder and placed adjacent to the instrument's temperature sensor.
- Collocate the probe with the NIST-traceable certified thermometer (e.g., rubber band together) and allow the probes a few minutes to equilibrate.
- Display the "Set Temps/Flows" screen on the control unit by pressing "19" and then <ENTER> on the keypad.
- Scroll down until "Amb Temp" appears and the current ambient temperature is displayed on the right.
- Verify that the value in the "Amb Temp" field is within the agency's recommended tolerance. If it is out of tolerance, then an ambient temperature calibration procedure should be performed (1400A Service Manual, Section 3.2.3).
- Remain in the "Set Temps/Flows" screen to perform the ambient pressure verification.

10.1.3 Ambient Pressure Verification

The verification of the ambient pressure sensor measurement should be made with a NIST-traceable external pressure sensor that is within its certification period. Most agencies will use a tolerance of ±10 mm Hg.

To verify the ambient pressure sensor measurement:

- If the "Set Temps/Flows" screen is still being displayed, scroll to the "Amb Pres" field (just below the "Amb Temp" field), or display the "Set Temps/Flows" screen on the control unit by pressing "19" and then <ENTER> on the keypad.
- With the NIST-traceable reference sensor, determine the absolute ambient pressure in mm Hg (not corrected to sea level). If the current "Amb Pres" reading of the 8500C is outside the tolerance compared to the reference sensor, an ambient pressure calibration procedure must be performed (1400A Service Manual, Section 3.2.4).

10.1.4 Flow Rate Verification

A full system leak check, ambient temperature verification, and ambient pressure verification should be performed prior to verification of the flow rates. The total inlet flow rate is verified first; then the bypass flow is capped off and the main flow rate is verified. *The main flow should be verified in both the base and reference modes*. Check the certification date for the flow audit meter, which must be recertified annually. Any concentration data collected during this procedure is invalid.

To perform a flow-rate verification:

1. Disable data logging by pressing <DATA STOP> on the keypad.
2. Remove the sample inlets.
3. Install the flow audit adapter, with the valve in the open position, on the flow splitter.
4. On the Main screen, scroll until "Main Flow" and "Aux Flow" appear on the left and the current flows being measured by the monitor's flow controllers are shown on the right.
5. Confirm that these flows are within 2% of their set points. Flows outside the tolerance levels indicate that blockage or other problems may exist (for example, clogged in-line filters) and should be investigated.
6. Main flow: 3.0 ± 0.06 lpm (2.94 to 3.06 lpm)
7. Auxiliary flow: 13.67 ± 0.27 lpm (13.40 to 13.94 lpm)
8. Attach a certified flow transfer standard to the flow audit adapter and measure the total volumetric flow. A tolerance of ±5% from the reference standard is recommended here (40 CFR Part 58, App A, Table A-2), although flow rate tolerances may vary among agencies. To meet the 5% tolerance, the total volumetric flow should be between 15.8 and 17.5 lpm.
9. Verify the main flow rate. Disconnect the bypass flow line from the flow splitter and cap the exit of the flow splitter with a 3/8-inch Swagelok cap. (The bypass line will still have flow through it; set it aside carefully to avoid having large debris pulled through to the in-line filter.) To meet the 5% tolerance for the main flow rate, the total volumetric flow of the reference flow meter should be between 2.85 and 3.15 lpm.
    a. Press "14" (<1> then <4>) on the keypad and then <ENTER> and note which mode (base or reference) the sampler was in for that flow measurement.
    b. Manually switch the valve to the alternate position and recheck the main flow in the alternate main path.
    c. To change the valve position:
        i. Go to the Main Screen (mass concentration screen).
        ii. Press <DATA STOP>.
        iii. Press <F8>. If the instrument stops responding, exit the mass concentration screen and re-enter it.
    d. When the flow check of the alternate main flow path is complete, press "14" and <ENTER> and verify the valve position.
10. If the 8500C has passed the leak check, and the temperature and pressure verifications were within tolerance, but the flow checks were out of tolerance, then a flow control calibration should be performed. Either a software (Service Manual Section 3.5.1) or a hardware (Service Manual Section 3.5.2) calibration procedure may be used.

10.1.5 TEOM Filter Change

The recommended frequency for TEOM filter changes and the specific procedures are discussed in the Installation Section of this SOP. Special precautions are listed in Section 9.8.1, and stepwise procedures are given in Section 9.8.2.

10.1.6 FDMS Chiller Filter Change

The recommended frequency for FDMS filter changes and the specific procedures are discussed in the Installation Section of this SOP. Special precautions are listed in Section 9.8.1, and stepwise procedures are given in Section 9.8.3.

10.1.7 Vacuum Pump Test

System vacuum readings provide a log by which pump performance may be evaluated. For the dryer to provide sufficient drying capacity, system vacuum pressure must be at least 65% of ambient pressure. At a nominal atmospheric pressure of 29.92 inches Hg (1 atm), this is roughly 20 inches Hg vacuum. Instruments at high altitudes have lower operating pressures, so it is better to judge pump performance by the proportion of ambient pressure rather than by a constant value. If the instrument vacuum is not sufficient, rebuild the sample pump or replace it with a new pump.

It is highly recommended that the in-line vacuum gauge be installed during the initial instrument setup, as specified in SOP Section 9.7 and Operating Manual Section 2.5.5. This allows observation and recording of system vacuum pressure immediately following each full system leak check procedure.

If the system vacuum gauge is not installed, then the following procedure should be followed monthly to check the condition of the vacuum pump. The test requires a vacuum gauge capable of measuring 25 inches (650 mm) of Hg, a 3/8-inch PTC Tee fitting to install the gauge in-line, and short sections of the green 3/8-inch tubing.

To perform the vacuum test procedure:

1. Perform a full system leak check. (This makes the following steps redundant—if the full system leak check has been conducted, then the vacuum gauge is already in line.)
2. Connect the vacuum gauge to one port on the 3/8-inch PTC Tee fitting.
3. Insert a short section of the 3/8-inch green tubing into a second port on the 3/8-inch PTC Tee fitting.
4. Disconnect the 3/8-inch green tubing from the inlet to the sample pump.
5. Insert the 3/8-inch green tubing disconnected from the sample pump in Step 4 into the open port on the 3/8-inch PTC Tee fitting.
6. Insert the short section of 3/8-inch green tubing that was inserted into the 3/8-inch PTC Tee fitting in Step 2 into the sample inlet on the instrument sample pump.

7. Record the instrument pressure/vacuum. This value must be 20 inches Hg (510 mm) Hg vacuum or greater.

10.1.8 Zero Test

The intent of the zero test is to provide confidence that all components of the system are operating properly. The test should be conducted annually. This procedure offers one way to quantify system bias and noise to ensure they are within specification. Data from collocated reference measurements can also provide estimates of bias and noise and thereby reduce the frequency of zero tests. All maintenance should be performed to ensure proper instrument performance prior to performing a zero check.

To conduct a zero test:

1. Complete all maintenance, verification, and calibration procedures.
2. Install new TEOM and FDMS chiller filters.
3. Remove the sampling inlets.
4. Install a high-capacity filter on the inlet, taking care to position it to prevent rain or snow from entering the filter inlet.
5. Operate for a minimum of 24 hours to obtain the 8-hour bias data. Operate the instrument to determine the 8-hour mass concentration bias for three 8-hr periods. It may also be useful to calculate a running 8-hr average, beginning at hour 9 and running through the end of the test period.
6. The average offset for 8 hours should be within ±2 $\mu g/m^3$ of zero. If the offset is greater than ±2 $\mu g/m^3$, then the system is considered to have an unacceptable bias. Possible reasons for a failed zero test include
   a. System leaks
   b. Chiller contamination
   c. Dryer contamination
7. In addition to the bias evaluation, a short-term noise evaluation can be made by calculating the standard deviation from the mean to verify that this value is below ±5 $\mu g/m^3$.

10.1.9 Mass Transducer (K_0) Verification

Verification of the 8500C FDMS calibration constant should occur annually. The Thermo Scientific mass calibration verification kit (Thermo p/n 59-002107) contains a preweighed calibration filter, a filter exchange tool, desiccant for humidity protection of the calibration filter, and a humidity indicator. Refill kits are available (Thermo p/n 59-002019). The audit value of the calibration constant K_0 determined by this test should be ±2.5 % of the value currently entered in the 8500C FDMS configuration.

These cautions are advised:

- Use the provided filter exchange tool (with the red handle) only for handling the calibration filter and not for regular filter changes, and store it in a clean plastic bag. This helps prevent the transfer of contaminating mass to the calibration filter.
- Before the test begins, remove the sampling inlets and attach a zero filter. This prevents deposition of particulate mass directly on the calibration filter during the procedure.
- Tests resulting in the K_0 being more than 2.5% different from that currently entered in the instrument require action. Calling Thermo Scientific is advisable and may result in returning the unit. One possible cause of this error could be mass contamination on the calibration verification filter. Agencies with facilities that routinely measure FRM filters for mass (calibrated microbalance and humidity control) can have the mass of the calibration filter verified.
- When observing the frequency data for stable readings, observe only the first three decimal places, ignoring the last two (noise).

To perform the K_0 verification:

1. Press <DATA STOP> to halt data collection.
2. Install a zero filter on the sample inlet.
3. Remove the existing TEOM filter.
4. Press <STEP SCREEN> to display the Menu screen, scroll to "K_0 Confirmation," and press <ENTER> to display the "K_0" Confirmation" screen.
5. Press <EDIT> and scroll to the "Filt Wght" field.
6. Enter the weight of the preweighed calibration verification filter in the "Filt Wght" field.
7. Press "F1" or "RUN."
8. Wait for the oscillating frequency on the "K_0 Confirm" line to reach a maximum value and stabilize, observing the first three decimal places only.
9. When stable, press the <FIRST/LAST> key on the keypad to record the frequency "f0."
10. Install the calibration verification filter in the instrument and wait for the oscillating frequency to reach a new maximum value and stabilize.
11. When stable, press the <FIRST/LAST> key on the keypad to record the frequency "f1."
12. The instrument will compute and display the audit K_0 value on the "Audit K_0" line, and will also display the current K_0 value entered in the monitor and the percentage difference between the audit and currently entered K_0 values.
13. If mistakes occur while performing these steps, exit the K_0 confirmation screen and re-enter it. All values will be reset to zero.

10.2 MAINTENANCE PROCEDURES

Routine maintenance of the 8500C FDMS ensures system health and promotes high quality data. The frequency of the maintenance procedures described here can be modified according to local conditions and experience. Procrastination or delay can lead to instrument downtime and loss of data.

10.2.1 Cleaning the PM_{10} Inlet

The 8500C FDMS Operating Manual, Appendix G, provides detailed instructions, accompanied by photos, detailing all aspects of the inlet cleaning procedure; these are summarized below. Generally, the PM_{10} inlet should be thoroughly cleaned every one to three months. Local conditions and the experience of local agencies should dictate the interval.

Materials needed to clean the inlet:

- Soft-bristled paint brush
- Lint-free cloths
- Cotton swabs
- Water (or a mild solvent such as an ammonia-based cleaner)
- A #2 Phillips screwdriver to remove the top plates from the acceleration assembly of the inlet

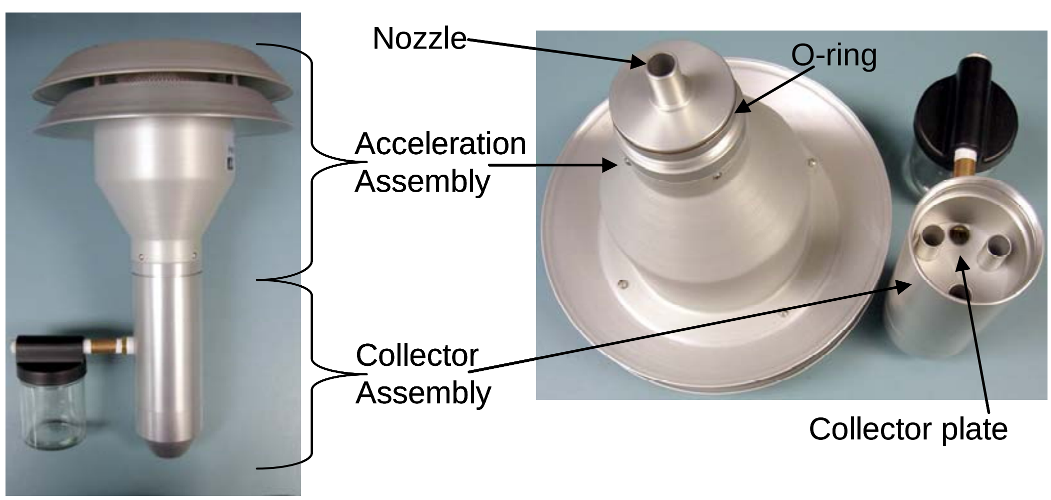

Figure 10-3. Photographs of the PM_{10} inlet and its two primary components, the Acceleration Assembly and the Collector Assembly.

Supplies that may be needed to clean the inlet include:

- Ammonia-based general-purpose cleaner

- Cotton swabs
- Small, soft-bristle brush
- Paper towels
- Distilled water
- Silicone-based grease for O-rings
- Small screwdriver
- Crescent wrench or open-end wrenches

To clean the inlet:

1. Remove the condensation jar and set it aside.
2. Unscrew the Collector Assembly (Figure 10-3, bottom portion of inlet) from the Acceleration Assembly (Figure 10-3, top portion of inlet) and set it aside.
3. Clean the Acceleration Assembly.
    a. Set the Acceleration Assembly upside down on its top plate and remove the four pan head screws on the bottom side. If the stand-offs turn, hold them in place with pliers.
    b. Lift the Acceleration Assembly off the top plate.
    c. Lift the lower plate up and carefully remove the insect screen.
    d. Clean all the inlet parts of the Acceleration Assembly inside and out (top plates, insect screen, and the Acceleration Assembly body). Depending on local conditions, parts may need to be wiped with brushes or a lint-free cloth, or blown out with compressed air. Alternatively, the parts may be washed with clean water, which is the best way to remove caked deposits that have accumulated in hard-to-reach places. Parts must be thoroughly dried before reassembly. Pay special attention to the acceleration nozzle at the base of the cone-shaped body; clean the inside of the nozzle by pushing a moistened piece of cloth through it.
    e. Inspect the large diameter O-ring at the base of the Acceleration Assembly. Replace if necessary. Apply a thin film of O-ring grease on the O-ring and a thin film on the aluminum threads of the Acceleration Assembly.
4. Clean the Collector Assembly (lower portion of inlet).
    a. Use a brush, lint-free cloth, and/or cotton swabs to clean the bottom collector plate, the collector assembly walls around the three vent tubes, and the weep hole in the collector plate. Water may be used if needed. Allow to dry.
    b. Clean inside the vent tubes by running a moistened cloth through them.
    c. Wipe out the area inside the bottom of the Collector Assembly where the two O-rings are located.
    d. Inspect the O-rings and replace if needed. Apply a thin film of O-ring grease on the O-rings.

5. Wipe out the condensation jar and the jar lid. Apply a thin film of grease to the seal inside the lid.
6. Reassemble the PM_{10} inlet, taking care to avoid cross-threading.

10.2.2 Cleaning the Very Sharp Cut Cyclone

The exact maintenance interval between cleanings of the VSCC depends on the particulate matter mass concentration and composition in the ambient air. Field and laboratory experience indicate a required cleaning interval of three to four weeks or more. Thermo Scientific suggests that the user clean the VSCC inlet more frequently until operational experience allows better determination of proper cleaning intervals based on your local conditions. **Figure 10-4** shows an exploded view of the VSCC assembly and the component parts, including the main body and chamber, the top cap, the transfer tube, and the emptying cup.

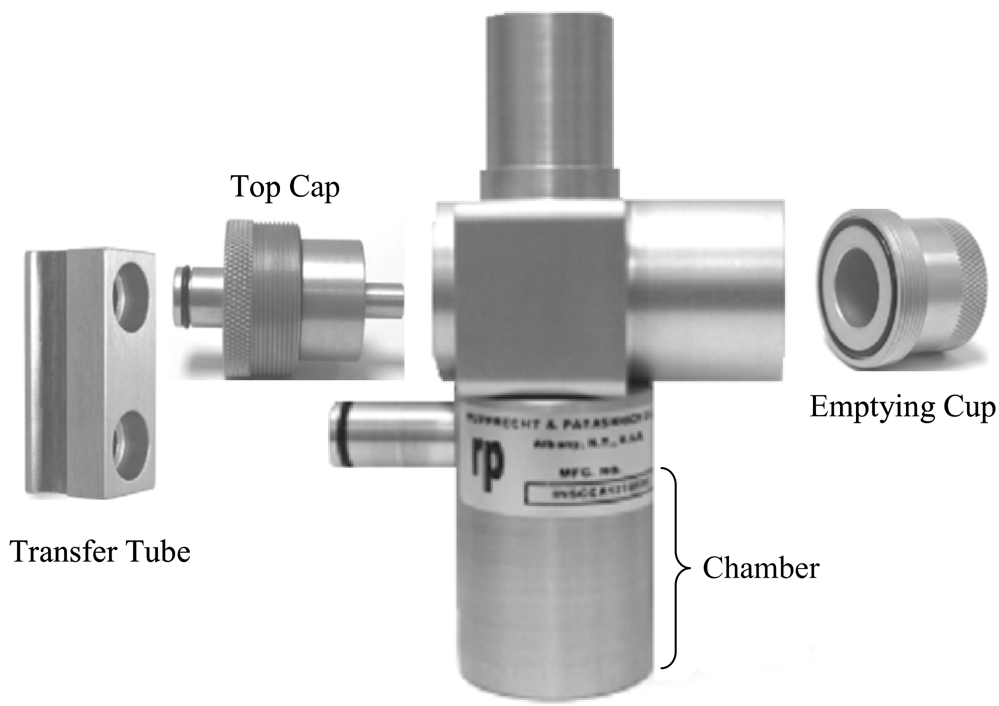

Figure 10-4. An exploded view of the Very Sharp Cut Cyclone, showing the four main components.

To clean the VSCC:

1. Remove the VSCC from the flow splitter.
2. Pull off the transfer tube. If this is too tight to remove by hand, pry it off with a rigid plastic lever.
3. Remove the top cap and the emptying cup.

4. Use a dampened “lint-free” wipe to remove visible deposits, especially in the cone inside the top cap and in the emptying cup.
5. Inspect all O-rings and replace if needed. Always lightly lubricate O-rings with silicone grease.

10.2.3 Changing the Large In-line Filters

The large in-line filters on the back of the control unit should be changed nominally every six months, or as necessary as determined by the user. Note that these filters are installed with the arrows on the filters pointing away from the control unit (against the flow). This arrangement allows the user to see the contamination as it is collected on the filter. If the water condensation trap is installed in the system, then the in-line filter of the bypass line will likely not have to be changed frequently because most of the particulate matter will be trapped by the filter element in the condensation trap. Similarly, particulate matter in the main flow is trapped by the TEOM filter.

10.2.4 Changing the Water Trap Filter

Unlike the in-line filters discussed in Section 10.2.3, the water trap filter cannot be positioned against the flow to allow the user to observe the buildup of material on the filter. The contaminants are collected on the inside and cannot be seen. Thus, it is important to maintain a regular schedule of filter changes until the needed frequency of filter replacement can be empirically determined. While SOP Table 10-1 suggests 6 months as the nominal frequency for filter changes, new installations should apply a three-month routine until the pattern of filter loading, which may well be seasonal, is determined.

10.2.5 Testing the CPU Coin Cell Battery

There is a coin cell battery (Thermo p/n 12-002049) on the CPU board that maintains the system clock and other configuration parameters when the unit is powered off. The battery should be tested every six months and should be replaced if the voltage is less than 2.75 VDC. The procedure given here and in the 1400 Service Manual is for Revision C and higher CPU boards. The CPU board serial number shows the revision. Contact Thermo for battery replacement procedures on CPU boards older than Revision C. Note: If the CPU battery is removed, the unit will lose the firmware because there is no capacitor holding the power level to retain the volatile memory. The user will be forced to reload the operating program. If the firmware version being reloaded is a major revision, the parameters such as serial number and K_0 would be overwritten on the EEPROM to a default value. Therefore, it is highly recommended to record all parameters and download any internal storage as a standard practice before replacing a CPU battery or uploading new operating firmware. After completing the update, ALWAYS verify these settings.

To check the CPU battery:

1. Wear an appropriate antistatic device.

2. Turn off the control unit power and remove the top panel.
3. Set the multimeter to DC volts. Place the positive probe on TP1 and the negative probe on TP2 (the + and – silver pads to the right of the battery holder when standing directly in front of the unit) and read the voltage. It should be 2.75 or higher.

To replace the CPU battery:

1. Wear an appropriate antistatic device.
2. Turn off the control unit power and remove the top panel.
3. Use needle-nose pliers to lift the clip holding the battery in place and pop the battery out of its housing with a small flat-blade screwdriver.
4. Insert the new battery by reversing the procedure in Step 3.

10.2.6 Cleaning the Heated Air Inlet System

It is recommended that the heated air inlet system be cleaned annually to remove the buildup of any particulate matter on its inner walls. A soft bristle brush (Thermo p/n 30-002227) and a cleaning solution such as soapy water, alcohol, or Freon solution are recommended for the cleaning process. A piece of plastic or other material is needed to protect the TEOM filter during the cleaning procedure. To minimize temperature changes in the system, keep the door of the sensor unit open only as long as necessary. The 8500C Operating Manual Section 12.1.2 has a series of pictures illustrating the steps in the cleaning process.

To clean the heated air inlet system:

1. Turn off the control unit and open the door of the sensor unit.
2. Remove the air thermistor from the cap of the TEOM mass transducer enclosure by pressing in on the metal locking clip and pulling out the thermistor probe.
3. Open the mass transducer door and place a plastic sheet or other protective material over the exposed part of the mass transducer.
4. Use the cleaning solution to clean all of the air inlet surfaces. The soft-bristle brush can be used to remove particulate matter from the insides of the walls of the air inlet.
5. Allow the surfaces to dry completely.
6. Remove the protective material from the exposed TEOM filter, and close and fasten the mass transducer into position.
7. Reinsert the air thermistor and close and latch the door to the sensor unit.
8. Power on the control unit.

10.2.7 Rebuilding the Vacuum Pump

The vacuum pump should be rebuilt when it can no longer maintain the system vacuum pressure, as determined by the pump test procedure in SOP Section 10.1.7, at at least 65% of the ambient pressure. Nominally, at standard atmospheric pressure of 29.92 inches Hg, this would be vacuum pressure of about 20 inches Hg. Higher elevations would have a lower threshold. There have been two pump models in the past delivered with the 1400A and 8500 systems. Because customers can convert older 1400A instruments, it is best to request a rebuild kit by pump model to ensure the correct kit is ordered and delivered. Follow the instructions that come with the vacuum pump rebuild kits.

10.2.8 Switching Valve Cleaning and Maintenance

It is important to verify which model valve is in the FDMS module. Original Revision C models have only one valve type, and the instructions given here are for that specific valve. Users with the original Revision B 8500 can update those units to a Revision C dryer and chiller through an upgrade offered by Thermo Scientific. However, because of limitations of the Revision B enclosure design, the Revision B valve cannot be updated to a Revision C valve. Users who upgrade to the Revision C dryer and chiller may inadvertently think that they have a Revision C switching valve when they indeed do not. This SOP addresses cleaning and maintenance of the Revision C valve only. Users with revision B valves should contact Thermo Scientific for specific instructions on cleaning and maintenance, because those procedures differ from Revision C procedures.

There are really two approaches to cleaning the switching valve. A relatively quick procedure may be used at frequent intervals, but a more complete cleaning, involving valve disassembly, should occur at least annually. The first approach, outlined in Operating Manual Section 12.1.3, involves disconnecting the outlet port on the bottom of the 8500C module and inserting a brush into the main flow outlet port to scrub the inside surface of the switching valve. The Operating Manual recommends doing this each time the sampling inlets are cleaned. This is a relatively quick procedure, and users must decide on the frequency with which to implement this maintenance task. When undertaking this procedure, be careful to not insert the brush so far that it goes through the valve and enters the dryer. Damage to the dryer could result.

The second approach to valve cleaning involves disassembling the valve to replace the seals and O-rings. This should be performed annually, at a minimum. Before disassembling the valve, be sure to have replacement V-seals (p/n 22-010280) and O-rings (p/n 22-000485-1012) on hand, as well as silicone grease for lubricating the seals.

The major steps are listed below, followed by step-by-step instructions:

1. Remove the dryer.
2. Remove the valve assembly.
3. Remove the face plate.
4. Remove the diverter block.
5. Remove the seals and inspect the Teflon tape.
6. Remove and replace the Teflon strips (if needed).
7. Clean the ports, housing plate, and diverter block.

8. Lubricate and install new V-seals and O-rings.
9. Reinsert the diverter block (if Teflon Strips were not replaced).
10. Reassemble the valve (if Teflon Strips were replaced).

1. Remove the Dryer

Providing adequate access for the removal and maintenance of the switching valve requires that the dryer first be removed. Refer to SOP Section 10.2.9 for specific instructions on how to remove the dryer assembly.

2. Remove the Valve Assembly from the 8500C Module

Note that in **Figure 10-5**, the 8500C module has been removed from the support stand and is shown lying on the module's right side. This is not required to remove the valve assembly.

To remove the valve:

1. Unplug the valve from the FDMS board (the red arrow in Figure 10-5, Panel A).
2. Remove the two screws from the bottom of the valve assembly (green circles in Figure 10-5, panel B). Support the valve and remove it from the enclosure, being careful not to let it drop or fall, as the fittings and switches could be damaged.

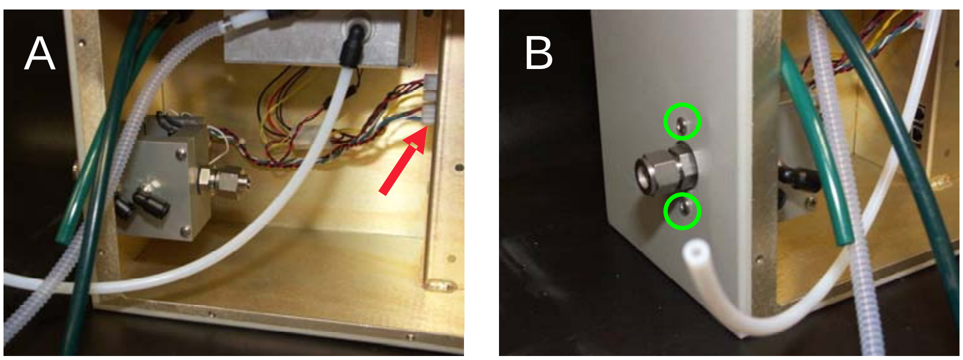

Figure 10-5. Photographs of the switching valve connections to the FDMS board (Panel A) and screws that hold the valve to the 8500C enclosure (panel B).

3. Remove the Face Plate

Before removing the face plate (**Figure 10-6**, panel B), ensure that the two screws holding the motor mount plate (Figure 10-6, Panel A) to the upper and lower housing plates are tight. While the assembly is being worked on, these two screws are the only support holding the position and spacing of the upper and lower plates of the valve. Then remove the four screws from the front face plate of the valve assembly (Figure 10-6, panel B). Be sure to note the orientation of the face plate to the top and bottom plates through the position of the ports. The port positions are illustrated in **Figure 10-7**.

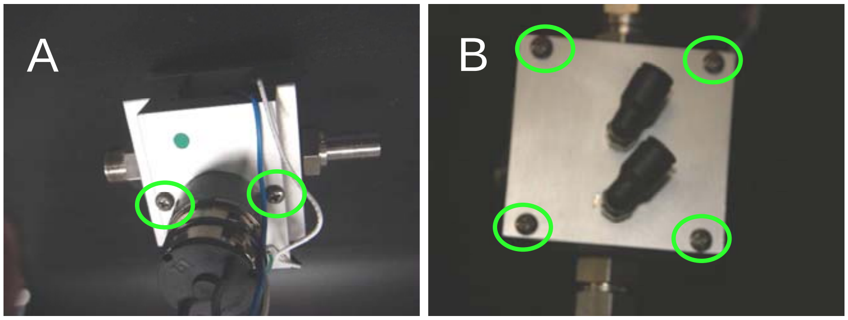

Figure 10-6. Photographs of the two screws that hold the motor mount plate to the upper and lower housing plates (Panel A) and the four screws holding the front face plate (Panel B).

4. Remove the Diverter Block

Note the orientation and the position of the diverter block. It must be replaced in the same orientation and position when the valve is reassembled. Slide the diverter block out from between the top plate and bottom plate (**Figure 10-7**). There is a brass bushing (shown in **Figure 10-8**, Panel A) on the motor cam pin behind the diverter block. This bushing may fall off when the diverter block is removed. Set the bushing aside for reassembly later.

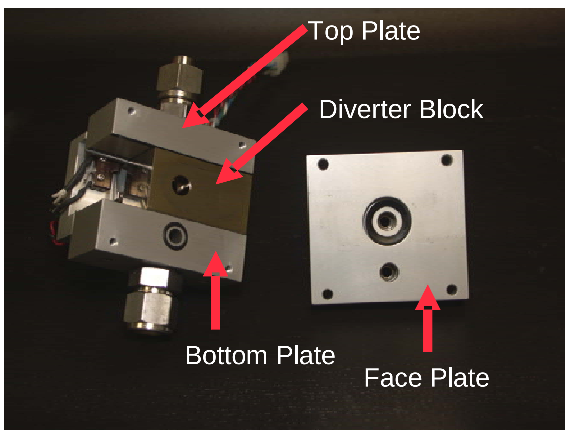

Figure 10-7. Photograph of the switching valve with the face plate removed, showing the positioning of the valve ports and the diverter block.

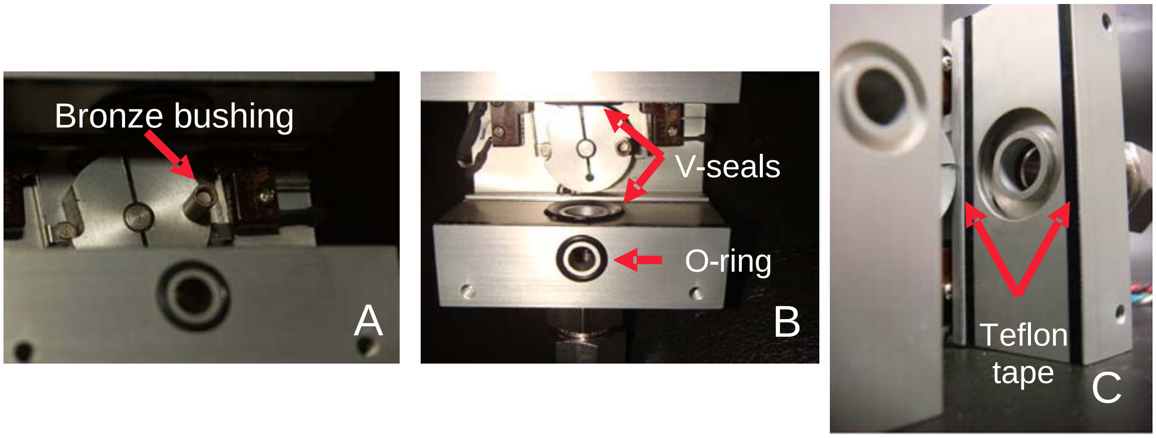

Figure 10-8. Photograph of the switching valve with the valve diverter block removed. The brass bushing on the motor cam pin is visible (Panel A), the V-seals and bottom plate O-ring are accessible (Panel B), and the Teflon tape (Panel C) can be inspected.

5. Remove the Seals and Inspect the Teflon Tape

Locate and remove the V-seals from the upper and lower valve housing plates (Figure 10-8, Panel B). Also remove the O-ring from the lower valve housing plate (Figure 10-8, Panel B) and from the interior side of the face plate (Figure 10-7).

Inspect the four strips of black Teflon tape, two on the upper valve housing plate and two on the lower plate (Figure 10-8, Panel C). If the tape exhibits evidence of wear, it should be removed and replaced. This requires further disassembly of the valve to remove the upper and lower valve housing plates.

6. Remove and Replace the Teflon Strips (if needed)

If the strips of Teflon tape need to be replaced, then the upper and lower valve housing plates must be removed to allow adequate access for removing and replacing the tape. To remove these plates, the two screws that hold the motor mount plate to the valve housing plates (see Figure 10-6) must be removed. Once the valve housing plates are removed, follow the steps below and refer to **Figure 10-9** to replace the Teflon tape. The Teflon tape material is available from Thermo Scientific (p/n 12-008934). Note: if the upper and lower housing plates are removed, the procedures in Step 9 below (Reinsert the diverter block) are not needed; rather, follow the procedures outlined in Step 10 below (Reassemble the valve).

To replace the Teflon strips:

1. Cut the Teflon tape into strips 3 inches long and 1/8 inch wide (Figure 10-9, Panel A).
2. Remove the old tape (Figure 10-9, Panel B).
3. Clean the area thoroughly with de-ionized (DI) water (Figure 10-9, Panel C). If glue residue remains on the metal, alcohol may be used to remove it, but do not use any

sharp object to scrape away the tape or glue residue. The anodized coating of the aluminum must be protected.

4. Peel the backing away from one of the tape strips (Figure 10-9, Panel D) and carefully press into place. Do not allow the tape to hang over the edge of the plate or into the V-seal area. A small amount of space should be visible on either side of the tape, as shown by the arrows in Figure 10-9, Panel E.
5. Repeat steps 1-4 for the other three pieces of Teflon tape.
6. The completed tape replacement should look straight and clean, as in Figure 10-9, Panel F. If there are irregularities in the tape, the procedure should be redone because the diverter block must be able to slide back and forth smoothly on the surface of the Teflon tape.

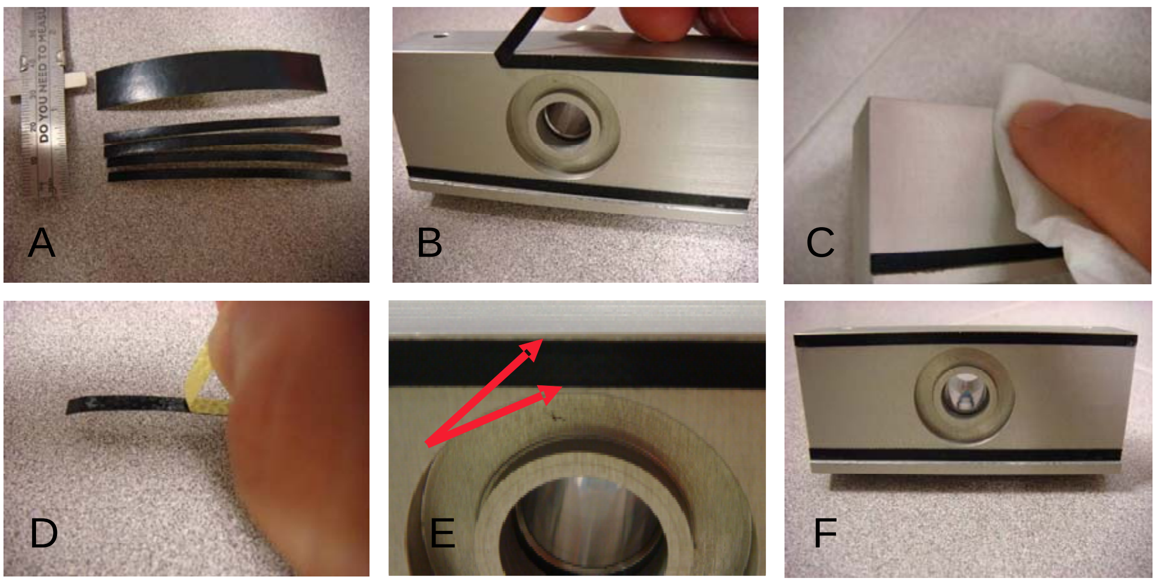

Figure 10-9. Illustrated steps for replacing the Teflon tape on the switching valve upper and lower housing plates.

7. Clean the Ports, Housing Plate, and Diverter Block

Before the V-seals and O-rings are replaced, the housing plates, the diverter block, and the ports in the switching valve need to be cleaned. Use a brush and DI water to clean the Swagelok fittings attached to the upper and lower housing plates (**Figure 10-10**, Panel A). Also clean the faces of the housing plates and the diverter block with DI water. Allow all pieces to dry thoroughly. Take extra care to not damage the polished surface of the diverter block (Figure 10-10, Panel B).

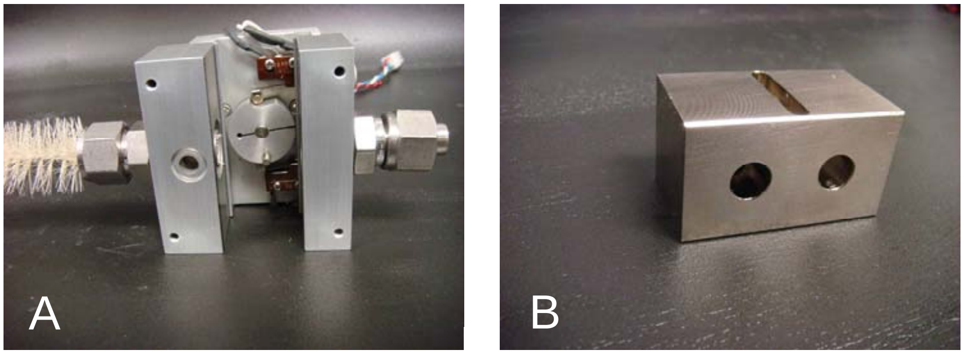

Figure 10-10. Photographs illustrating the use of a brush and DI water to clean the ports of the switching valve (Panel A). To protect the polished, anodized aluminum surface (Panel B), do not use any abrasive material when cleaning the diverter block with DI water.

8. Lubricate and Install New V-seals and O-rings

Use a small applicator (e.g., a cotton swab or finger) and apply a very thin film of silicone grease to each of the replacement V-seals and O-rings (**Figure 10-11**, Panels A and B). Press the V-seals and O-rings into place.

Figure 10-11. Photographs illustrating application of silicone grease to the V-seals and O-rings (Panels A, B) and repositioning of the brass bushing on the motor cam post (Panel C, arrow).

If the upper and lower housing plates are still attached to the motor mount plate (i.e., the procedure for replacing the Teflon tape was not needed), the brass bushing should be placed back on the motor cam post at this time (Figure 10-11, Panel C, arrow), and the special procedure outlined in Step 9 below should be followed to reinsert the diverter block. If the housing plates were removed so the Teflon strips could be replaced, then follow the procedure outlined under Step 10 below.

9. Reinsert the Diverter Block (if Teflon strips were not replaced)

If the upper and lower housing plates were not removed from the motor mount block that constitutes the back of the valve assembly, then special precautions must be taken when reinserting the diverter block. If the diverter block were to be simply slid back into position, there is a high likelihood that the edge of the V-seals would catch on the diverter block, fold over, and fail to seal properly (pictured in **Figure 10-12**, Panel A, arrow). To overcome this problem, cut a strip of heavy-weight paper about 6 inches (15 cm) long and 1/2 inch (1.2 cm) wide, and put a slight bend in the middle of the paper (Figure 10-12, Panel B). Fold the paper and place the ends over the V-seals, with the paper extending just past the end of the seals (Figure 10-12, Panel C).

Work the edges of the paper under the top and bottom edges of the diverter block while keeping the block just in front of the brass bushing on the motor cam post (**Figure 10-13**, Panel A). Slide the block forward, over the paper, so that the paper presses the V-seal down and allows the block to pass by without catching the leading edge of the seals (Figure 10-13, Panel B). Continue sliding the block over the paper until the slot on the back of the block is lined up with the motor pin and brass bushing. Push the block onto the bushing until the front of the block seats flush with the top and bottom plates (Figure 10-13, Panel C). When the block is fully in place, remove the guide paper. Align the front face plate with the assembly so that the open port at the bottom of the face plate lines up with the O-ring on the face of the lower housing plate, and tighten the four screws holding the face plate in place.

Figure 10-12. Photographs illustrating how reinsertion of the diverter block can cause the V-seals to fold (Panel A). A small section of heavy-weight paper (Panel B) may be used to help guide the diverter block over the seals (Panel C).

Figure 10-13. Photographs illustrating installation of the diverter block by working the folded paper under the top and bottom edges of the block (Panel A) so the paper prevents the seals from rolling as the block is reinserted (Panel B) and the block is properly aligned with the bushing on the cam pin. The block can then be pushed back so its front face is flush with the upper and lower housing plates (Panel C).

10. Reassemble the Valve (if the Teflon tape strips were replaced)

If the top and bottom housing plates were detached during the service procedure, they must be reassembled with particular attention to spacing and alignment so that the diverter block is free to move.

To align and assemble the valve:

1. Attach the front face plate to the bottom housing plate with the face plate screws (**Figure 10-14**, Panel A). The bottom housing plate is the one with the port with the O-ring. Orient the diverter block as shown.
2. Secure the upper housing plate to the front face plate, and place the assembly on its side, as shown in Figure 10-14, Panel B. The diverter plate should be held in place and should not move on its own.
3. Gently push on the top of the diverter block, as shown in Figure 10-14, Panel C. The block should slide easily and smoothly to the bottom.
4. Check the alignment of the diverter block by sliding it back and forth, as depicted in **Figure 10-15**, Panels A and B. It should slide smoothly and not "skip" across the V-seals. If the action is not smooth, loosen the face plate screws and adjust until smooth action is achieved, and then re-tighten the screws. Recheck the action after the screws are tight.

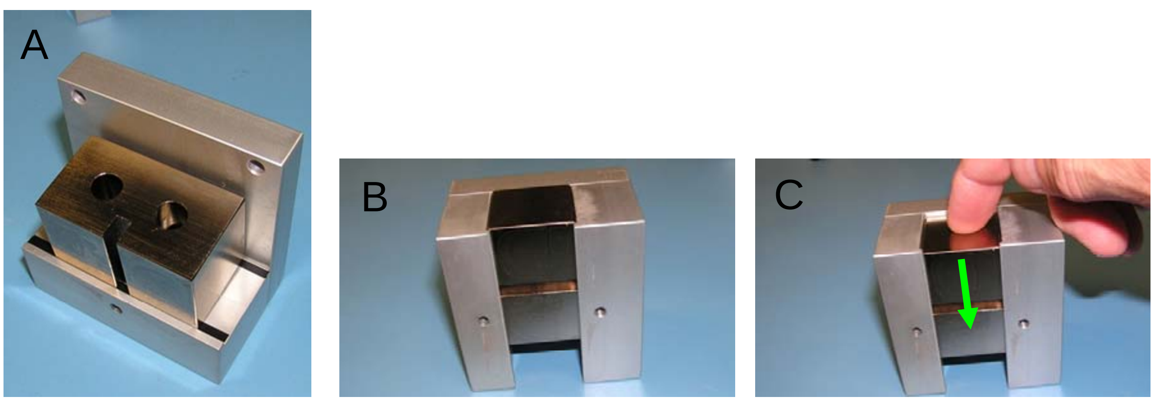

Figure 10-14. Photographs illustrating the proper orientation and alignment of the diverter block, which is essential to proper valve operation.

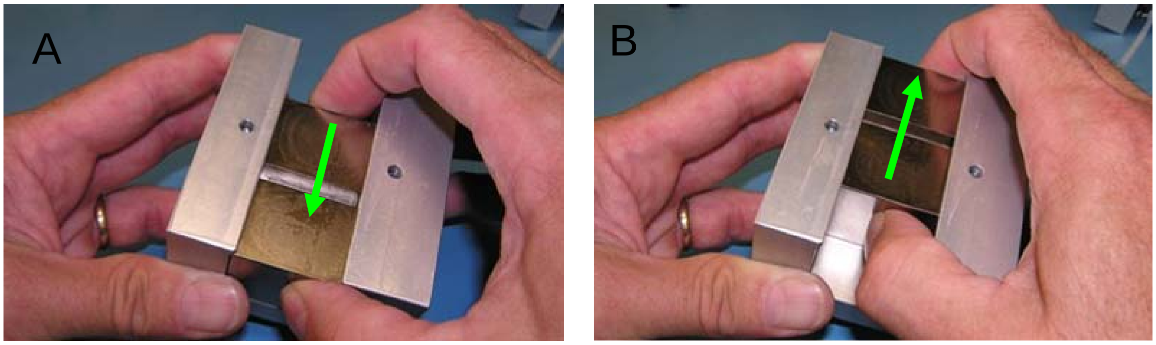

Figure 10-15. Photographs illustrating diverter block movement during valve reassembly. The diverter block should move freely between the upper and lower housing plates.

5. Before reassembling the valve, be sure that the brass bushing is in place on the motor cam (**Figure 10-16**, Panel A, arrow). Then position the diverter block so that the bushing sits in the diverter block slot when the two motor mount screws are lined up (Figure 10-16, Panel B). Attach and tighten the two motor mount plate screws.

6. Place the fully assembled valve (Figure 10-16, Panel C) back into the FDMS module enclosure, attach the two mounting screws through the bottom of the enclosure, and re-attach the wiring from the valve to the FDMS board.

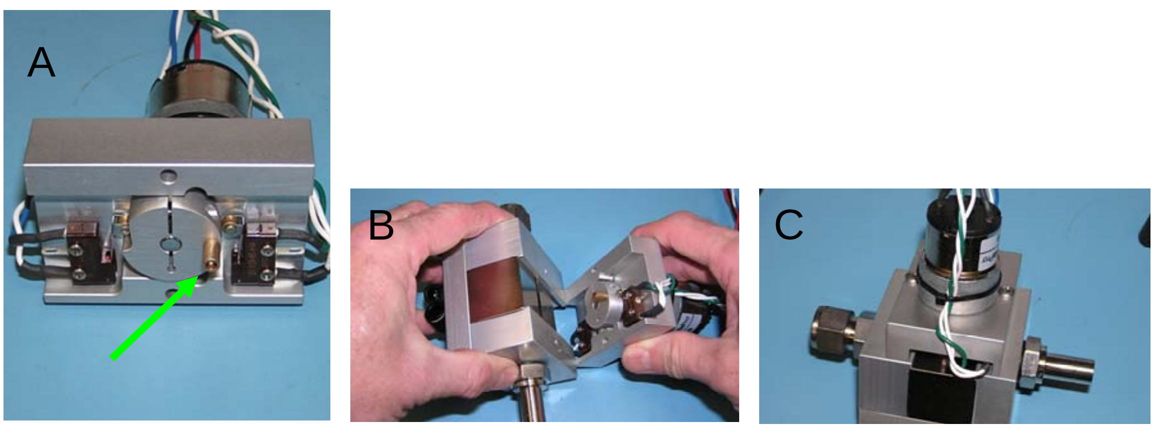

Figure 10-16. Photographs illustrating the reassembly of the switching valve. The brass bushing must be placed on the motor cam (Panel A) and the diverter block must be positioned so the bushing fits into the slot when the motor plate screws are lined up (Panel B). Once reassembled, the valve (Panel C) can be re-installed in the FDMS module enclosure.

10.2.9 Dryer Maintenance Guidelines and Dryer Removal Procedure

Proper dryer operation is essential for the 8500C FDMS to function correctly. Under most conditions, the dryer is capable of removing enough water vapor from the sample stream so that the factory default 4°C chiller temperature can be maintained without condensation forming in the chiller. Under very humid conditions (dew points higher than 25°C) the sample dew point should be closely monitored.

There are several indications that the dryer operation should be investigated:

- The sample dew point consistently reads within about 2° of the chiller/conditioner set point;
- Comparison of the sample dew point to the ambient dew point indicates that the sample dew point is not being controlled;
- The reference mass concentration remains below -5 μg/m^3 over a 24-hr baseline (zero test) period;
- The sample dew point shows large fluctuations; or
- The data collected from the 8500C FDMS diverges from the data collected from an FRM sampler.

Two potential dryer failure modes exist: (1) dryer efficiency decreases because the Nafion's ability to remove water from the sample stream is reduced with time in service, and (2) a contaminant residing in the dryer (in rare cases) causes a bias in the FDMS measurement.

Both pump vacuum and dryer efficiency can affect the instrument's ability to maintain a dew point below the chiller temperature. If the dryer and vacuum pump are performing properly and the sample dew point is close to or exceeds the chiller temperature of 4°C, the chiller temperature can be increased to 10°C to prevent condensation in the chiller. In areas where high humidity is common, dryer efficiency should be monitored, as dryers may need to be replaced more frequently than in areas of low ambient humidity.

Guidelines for monitoring the pump vacuum and dryer efficiency include:

- **Monitoring the pump vacuum.** Vacuum must be maintained at or above 65% of atmospheric pressure (20 inches of Hg, adjusted for elevation differences) to maintain adequate dryer efficiency.
- **Monitoring dryer efficiency.** The dryer efficiency can be estimated by monitoring the output dew point or the dryer status condition. If the sample dew point at the outlet of the dryer approaches the chiller temperature, a status condition will indicate insufficient drying.

In rare circumstances, the mass concentration measurement can be affected by dryer contamination. Over time, as the ambient air passes through the Nafion, some contamination from the particulate, and sometimes from gases, can collect and form a film on the Nafion. These contaminants may eventually off-gas and create false semi-volatile measurements that skew the actual readings. Suggested methods for ensuring that the dryer contamination is not affecting the mass concentration measurement follow:

- **Periodic zero tests** providing information on measurement offset and noise can be used to demonstrate FDMS data quality. In this regard, a good baseline measurement obtained during acceptance testing or upon installation can be invaluable. Periodic baseline evaluations (zero test; SOP Section 10.1.8) confirm that the monitor, including the dryer, is operating properly. These zero tests, combined with leak checks, flow checks, and calibration verifications, can be used to determine whether the dryer is affecting the mass concentration measurement.
- **Periodic comparisons to collocated reference measurements** ensure FDMS data quality. At sites where reference measurements are made, a periodic comparison can confirm the monitor, including the dryer, is operating properly. For the purposes of EPA PM sampling, "…the EPA will ensure that collocated sampling for estimating precision be implemented at 15 percent…of each method designation." (40 CFR Parts 53 and 58, Revisions to Ambient Air Monitoring Regulations.)
- **Chiller cleaning** (SOP Section 10.2.10) is part of the dryer decontamination process and should be conducted regularly.

Users should adopt one of two approaches for dryer maintenance: either replace the dryer on a routine basis, not to exceed the manufacturer's recommended interval of one year, or establish a set of maintenance practices that allow dryer performance to be tracked. This set of practices would include the establishment of a baseline zero test with periodic baseline evaluations. This practice is a useful diagnostic tool when a gradual increase in mass concentrations is observed. If the dryer is not working correctly, the 8500C FDMS may erroneously yield higher FEM $PM_{2.5}$ concentrations than the $PM_{2.5}$ data produced from a collocated FRM sampler. The dryer itself may not be the cause of the problem, so a full investigation is warranted. A dryer will not function correctly if the system vacuum is not maintained correctly due to a weak pump or a leak. The system vacuum pressure should be monitored and kept above 65% of ambient pressure. The system, including the dryer purge path, should be kept leak free.

If the dryer is determined to be compromised in performance and to require maintenance or repair, it must be removed and returned to Thermo Scientific. Thermo now has a dryer exchange program to accommodate users and minimize instrument downtime.

The major steps for dryer removal are listed below, followed with step-by-step instructions:

- Remove the front panel of the 8500C module.
- Disconnect tubing.
- Disconnect dryer fittings and remove the dryer.

Remove the Front Panel of the 8500C Module

To access the Nafion dryer, remove the ten screws on the front plate of the 8500C module (**Figure 10-17**, Panel A) to expose the 8500C components (Figure 10-17, Panel B).

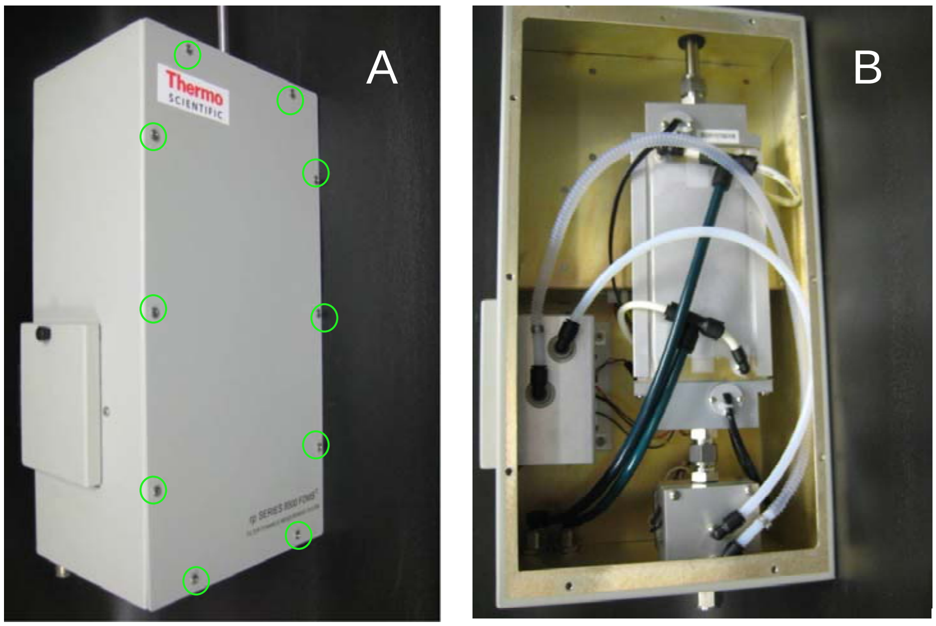

Figure 10-17. Photographs illustrating the front panel of the 8500C module and access to the dryer.

Disconnect Tubing

To facilitate dryer removal, some tubing must be disconnected. At the switching valve, remove the two Teflon lines that feed the chiller assembly (**Figure 10-18**, Panel A). Although this tubing is not connected to the dryer, disconnecting the tubing gets it out of the way. The dryer fittings are PTC fittings. To disconnect them, push inward on the locking ring (Figure 10-18, Panel B, red arrow) while pulling on the tube itself (Figure 10-18, Panel B, green arrows). Also remove the two green vacuum lines from the Tee fittings on the side of the dryer (Figure 10-18, Panels C, D).

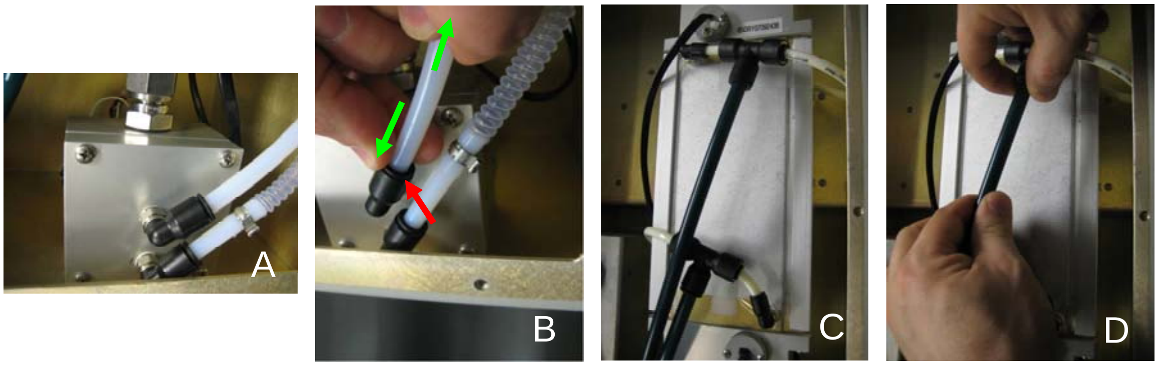

Figure 10-18. Photographs illustrating plumbing disconnections needed to facilitate dryer removal.

Disconnect the Dryer Swagelok Fittings and Remove the Dryer

Once the tubing is disconnected, the 8500C module should look like **Figure 10-19**, Panel A. Using open-end or adjustable wrenches, loosen the Swagelok fittings at the top of the dryer (Figure 10-19, Panel B). The inlet tube must be slid upward and away from the dryer (Panel C). If the flexible rubber coupling was installed on the inlet tube above the 8500C module, then removing this coupling will allow the inlet to be pulled away from the top of the dryer. If not, the connections securing the inlet tube on the rooftop will have to be loosened so that the inlet can be raised away from the body of the dryer.

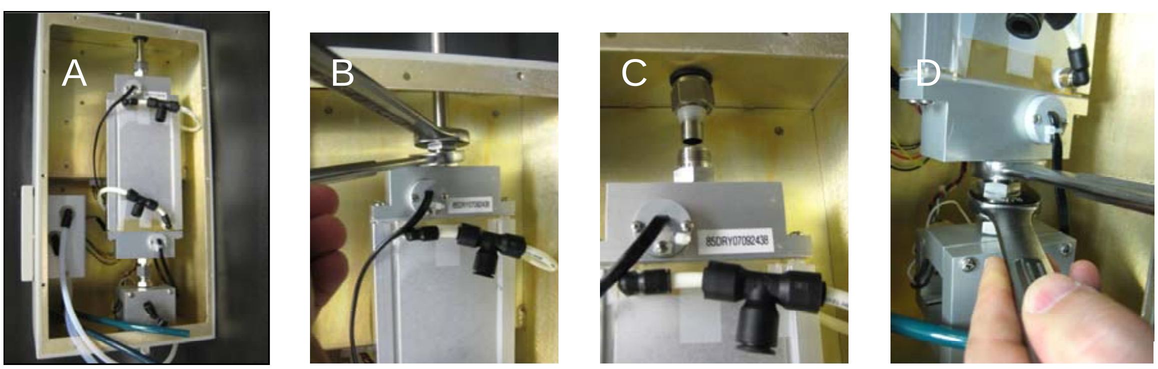

Figure 10-19. Photographs illustrating the Swagelok fittings at the top and bottom of the dryer that must be loosened so the inlet may be raised to allow dryer removal.

Next, loosen the bottom fitting (Figure 10-19, Panel D), and while supporting the dryer with one hand (**Figure 10-20**, Panel A), finish loosening the lower Swagelok nut. To make reassembly straightforward, label both of the dryer sensor cables as well as the jacks they are connected to (Figure 10-20, Panel B, arrows). Disconnect the two phone jack connectors and remove the dryer from the 8500C enclosure.

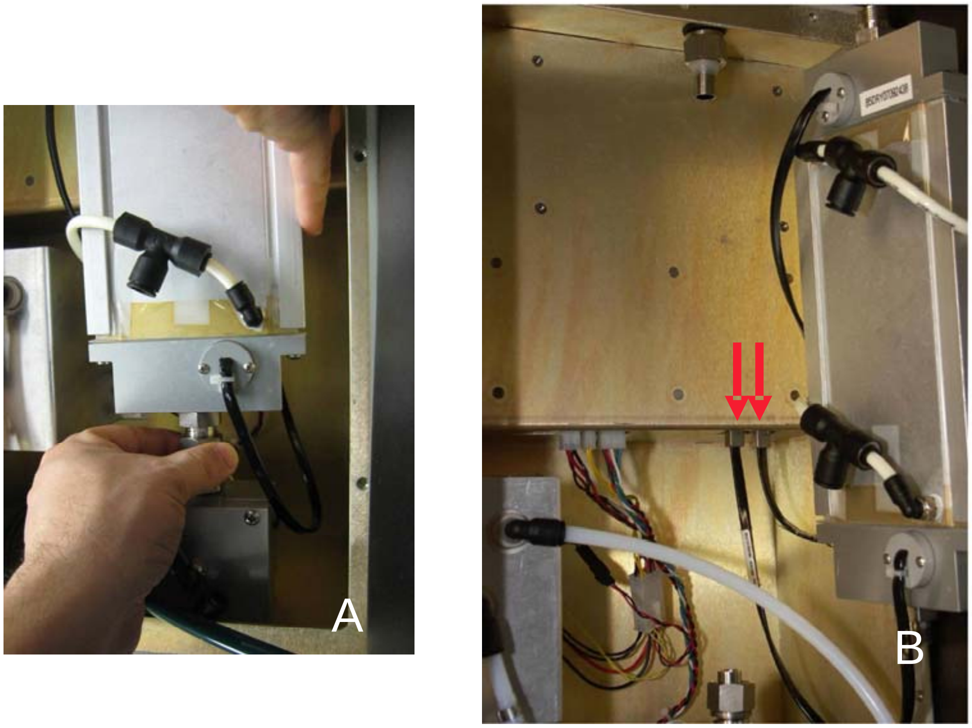

Figure 10-20. Photographs illustrating the final step in dryer removal. Support the dryer while the lower Swagelok nut is removed (Panel A); be sure to label the two sensor cables and their connecting jacks before removing them (Panel B, arrows).

10.2.10 Clean the Chiller

Thermo has released an updated method for cleaning the chiller in the 8500C. This method involves some simple plumbing reconfiguration to allow controlled flow through the chiller, and it requires heating the chiller compartment to 50°C for a specified time period (the chiller can act as a heater). The procedure requires an accessory package from Thermo that includes two needed fittings and a special RS232 cable (Chiller cleanout kit, p/n 59-011572). One of the fittings (orifice fitting) limits the flow to 1 lpm to allow uniform heating throughout the block. The procedure also requires version 4.0 of the 8500 Configuration Utility software that has an added control feature for setting the timer on the cleaning process.

Follow these steps to perform the chiller cleaning:

1. Press the <DATA STOP> key to halt data collection.
2. Remove the 47-mm cartridge and filter (**Figure 10-21**).

Figure 10-21. Photograph illustrating removal of the 47-mm cartridge and filter.

3. Wipe any visible residue off both the cartridge holder (the chiller cap) and the inside of the chiller compartment (**Figure 10-22**).

Figure 10-22. Example of a clean chiller cap. The chiller cap should be wiped clean of any residue at the beginning of the chiller cleaning process.

4. Replace the chiller cap (without the 47-mm filter holder) and close the chiller compartment door (**Figure 10-23**).

Figure 10-23. Illustration of the chiller cap replacement. For chiller cleaning, replace the chiller cap without the 47-mm filter holder.

5. Remove the front panel of the 8500C module to access the air lines and remove the connections (see **Figure 10-24**).
    a. The green 3/8-inch line going to the upper dryer connection is the vacuum supply. Disconnect this line from the Tee fitting by pushing against the fitting ring while pulling on the tube.
    b. Remove both of the Teflon tubes connected to the chiller.
6. Install the two adapters from the chiller cleanout kit (p/n 59-011572). The adapters allow controlled flow through the chiller during the heating (cleaning) process.
    a. Insert the orifice fitting (**Figure 10-25**) in the lower port of the chiller (**Figure 10-26**)
    b. Insert the adapter fitting (Figure 10-25) in the upper chiller port (Figure 10-26)
    c. Insert the vacuum line that was removed from the top of the dryer into the adapter fitting (Figure 10-26).

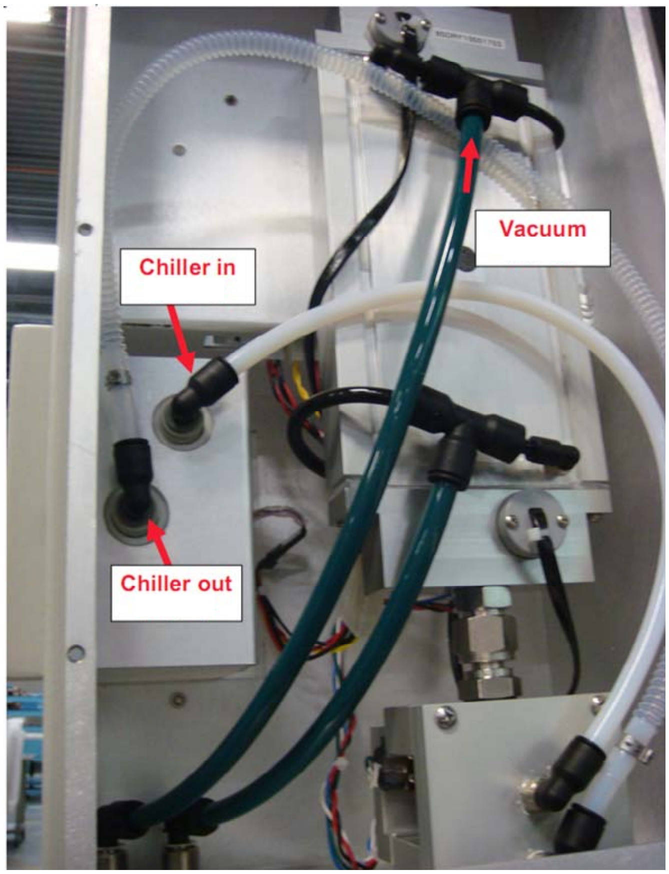

Figure 10-24. Plumbing changes needed for chiller cleaning. Disconnect the green tubing from the upper dryer fitting (the green vacuum line) and disconnect both Teflon tubes, one at the chiller in, and one at the chiller out.

Figure 10-25. Photograph of the two special fittings provided in the chiller cleanout kit (p/n 59-011572).

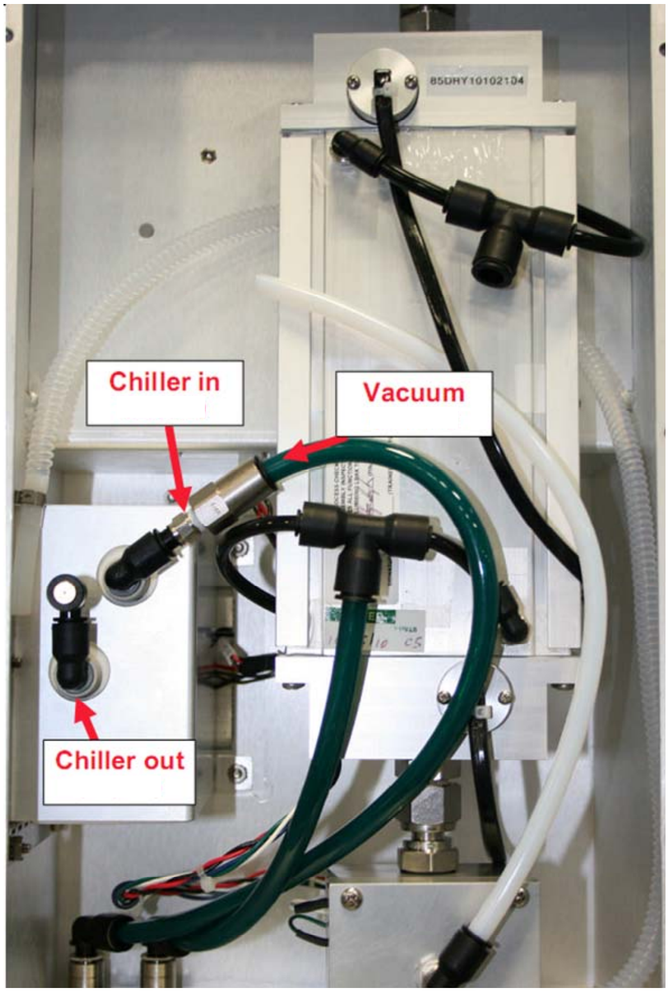

Figure 10-26. The completed plumbing reconfiguration for the chiller cleaning.

7. Start the 8500C Configuration Utility software and set up the required parameters.
    a. Using the special RS232 cable from the chiller cleanout kit, connect a computer to the 8500C via the RS232 connection on the back of the instrument (**Figure 10-27**).
    b. Start the "8500 Configuration Utility" program and click the button labeled "Advanced" at the top of the window (**Figure 10-28**).
    c. In the "Clean Mode" box (**Figure 10-29**, right panel, lower right) select the number of minutes (between 1 and 10) to remain at 50°C for cleaning. Five minutes is typical.

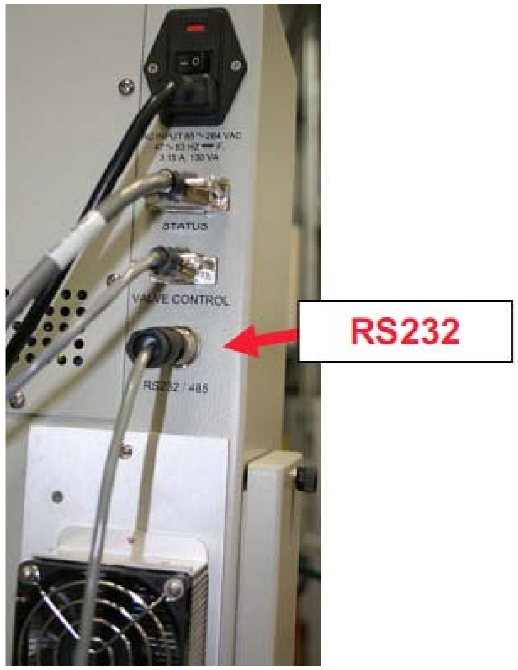

Figure 10-27. The RS232 connector of the 8500C. A special RS232 cable is provided with Chiller cleanout kit, p/n 59-011572.

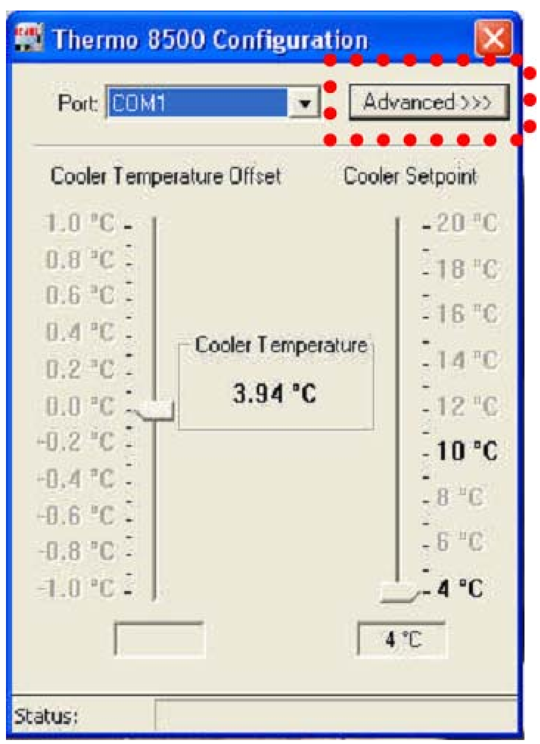

Figure 10-28. The left panel of the 8500 Configuration Utility initial window, illustrating the "Advanced" button.

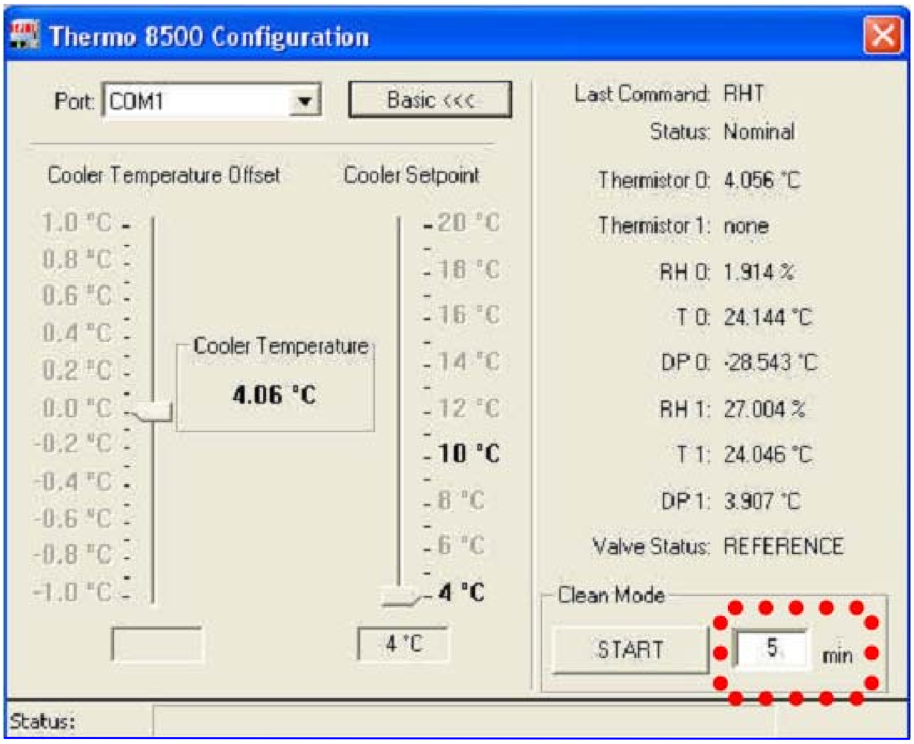

Figure 10-29. The features available under the "Advanced" button, including the Clean Mode option (lower right), where the length of the cleaning cycle is set.

8. Start the cleaning cycle.

   a. Press the <START> button.
   b. Check the status bar at the bottom of the window. It should read "In cleaning mode. Please wait…" (**Figure 10-30**).
   c. If the cycle needs to be aborted for any reason, press <STOP> in the Clean Mode box. If the cleaning cycle is stopped, the status bar should read "Cleaning cancelled. Press START to go back." (**Figure 10-31**, right panel.)
   d. After starting the clean cycle, the Cooler temperature will increase until it reaches 50°C.
   e. Once at temperature, the status mode will change to a countdown, indicating the time remaining at temperature (**Figure 10-32**).
   f. When time has expired, the status will indicate "Cleaning is done." (**Figure 10-33**) and the unit will revert to a chiller. Wait until the chiller returns to the set point (either 4°C or 10°C), and then reconnect the plumbing.

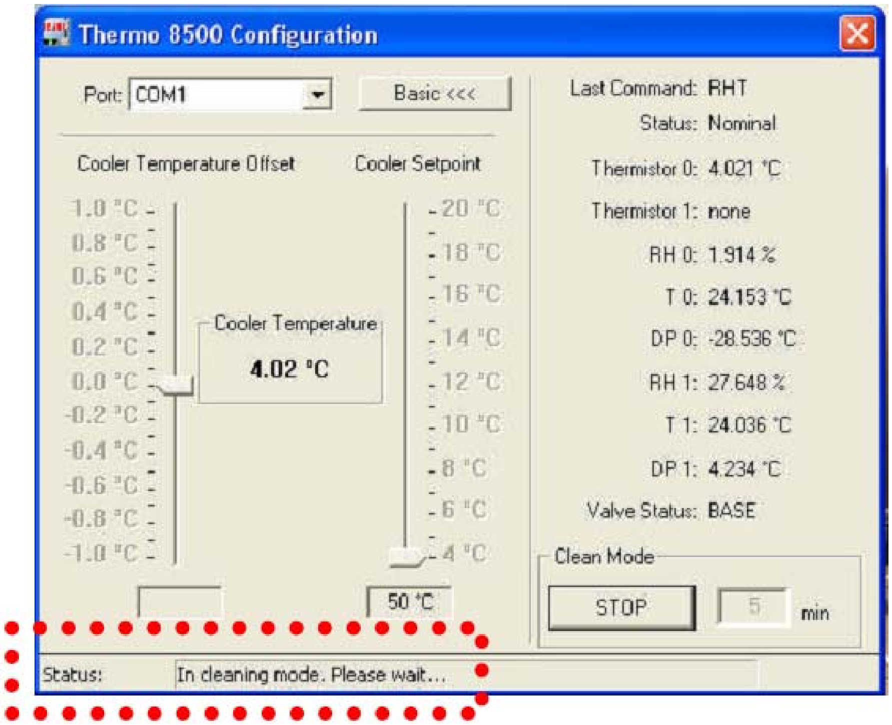

Figure 10-30. The Advanced Options screen showing the status bar message that appears during the chiller cleaning process.

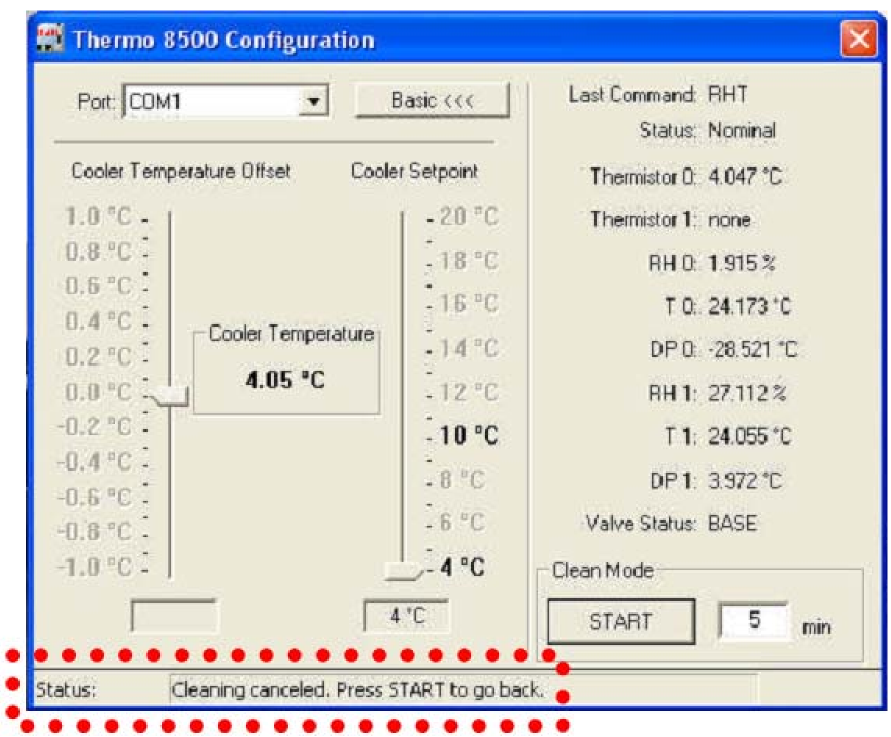

Figure 10-31. The Advanced Options screen showing the status bar message that appears if the chiller cleaning process is cancelled.

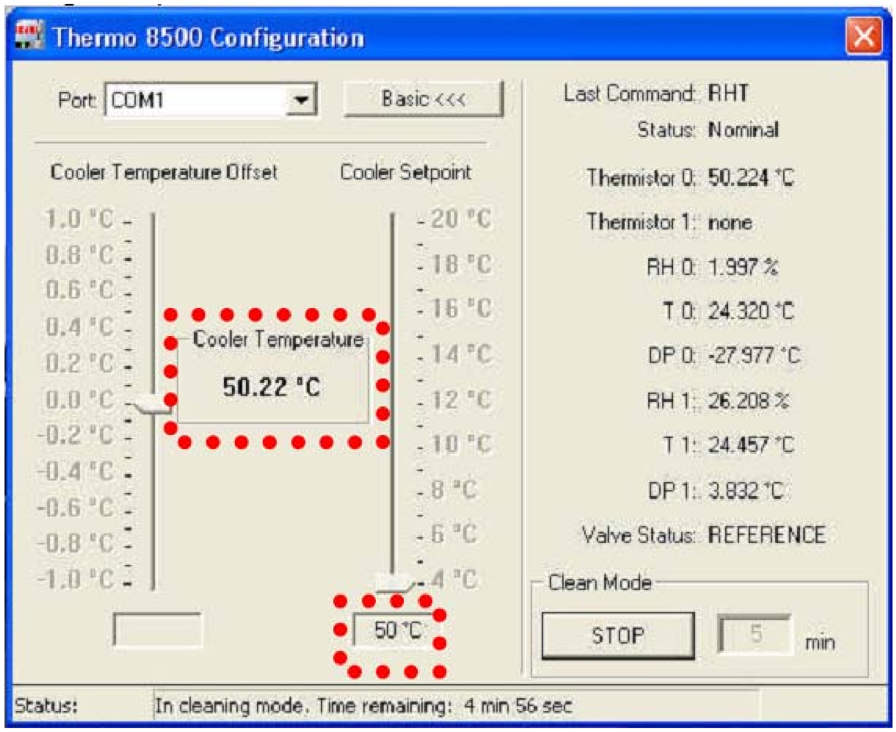

Figure 10-32. The Advanced Options screen, showing the cleaning mode status bar message that shows once the 50°C cleaning temperature is reached.

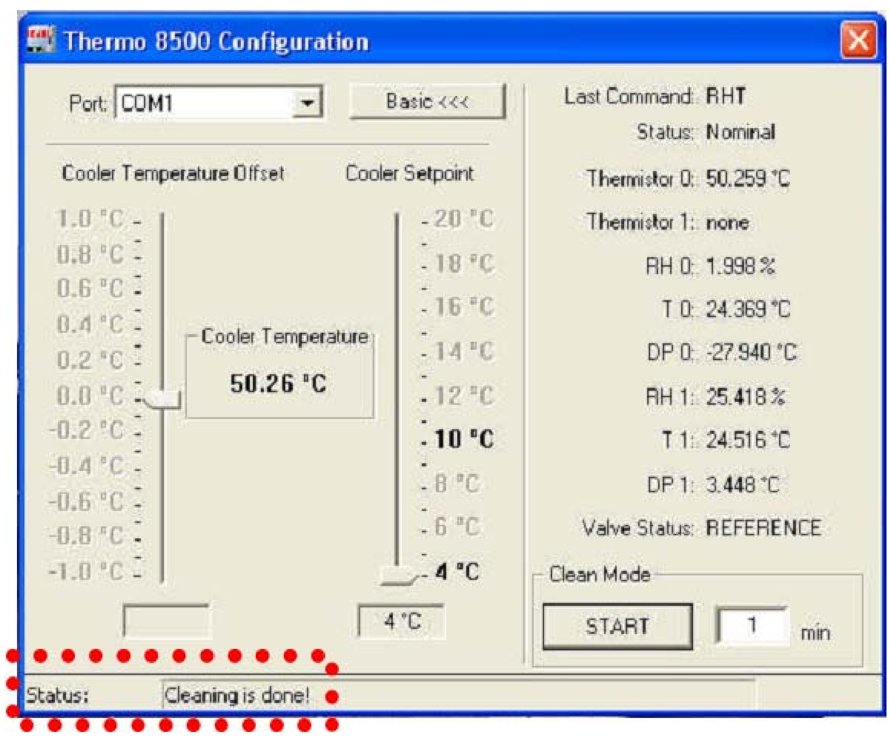

Figure 10-33. The Advanced Options screen, showing the cleaning mode status bar message that shows once the cleaning cycle is complete.

9. Reconnect the plumbing and close the FDMS module (refer to Figure 10-24 for the original plumbing configuration).
    a. Remove the two cleaner kit fittings from the chiller block.
    b. Replace the green vacuum line to the dryer.
    c. The longer Teflon tube connects from the bottom fitting on the chiller (chiller out) to the bottom fitting on the switching valve.
    d. The shorter Teflon tube connects between the top fitting on the chiller block and the top fitting on the switching valve.
    e. Replace the panel on the 8500C module.
    f. Wipe any visible residue off the filter cartridge holder (the chiller cap) and the inside of the chiller compartment.
    g. Replace the 47-mm filter holder, cleaned and with a new filter.

11. DATA VALIDATION AND QUALITY ASSURANCE

Generally speaking, 40 CFR Part 50, Appendix N ("Interpretation of the National Ambient Air Quality Standards for $PM_{2.5}$"), 40 CFR Part 50, Appendix L ("Reference Method for the Determination of Fine Particulate Matter as $PM_{2.5}$ in the Atmosphere"), 40 CFR Part 58, Appendix A ("Quality Assurance Requirements for SLAMS, SPMs and PSD Air Monitoring"), and EPA Quality Assurance Guidance Document 2.12 ("Monitoring $PM_{2.5}$ in Ambient Air Using Designated Reference or Class I Equivalent Methods") are all pertinent to data validation and QA protocols for FEM continuous $PM_{2.5}$ monitoring with the 8500C FDMS. These documents offer extensive details about procedures intended to assure that $PM_{2.5}$ data meet data quality objectives (DQO). In practice, these procedures are based on some basic principles that, if followed diligently, will foster high rates of data capture and minimize the need to invalidate data. These core principles include the field protocols intended to keep the 8500C FDMS operating in accordance with FEM designation EQPM-0609-181 and with the 8500C FDMS Operating Manual. The field protocols aid the post-processing data validation and QA protocols in judging whether collected data meet DQO criteria.

11.1 FIELD QUALITY CONTROL IMPACTS ON QUALITY ASSURANCE

The first line of defense against invalid data is the implementation of best practices in day-to-day operations affecting the data collection process:

- Understanding of the principle of operation of the equipment
- Acceptance testing of equipment
- Diligence in site selection followed by rigid installation procedures
- Scheduling and implementation of routine maintenance procedures (e.g., inlet cleaning)
- Scheduling and implementation of QC protocols (e.g., flow checks, leak checks, verification of instrument settings)
- Documentation/reporting of all field QC results and related field activities
- Daily review of real-time data
- Prompt troubleshooting of any observed operational problems

11.2 DATA VALIDATION

Four potential sources of information are directly related to validation of FEM $PM_{2.5}$ mass concentration data from the 8500C FDMS: (1) internally stored mass concentration and diagnostic data; (2) polled mass concentration and diagnostic data; (3) the site log information documenting local conditions and equipment operation; and (4) any standardized forms containing results from the routine maintenance and QC protocols.

11.2.1 Internally Stored 8500C FDMS Mass Concentration and Diagnostic Data

Data storage in the 8500C FDMS is limited to eight variables per record; the user must decide which mass concentration and diagnostic data to store. SOP Section 9.9.2 includes a recommendation that seeks to optimize usage of the available slots to record mass concentration data and critical diagnostic information. Also listed in Section 9.9.2 are the PRCs for the FEM mass concentrations. Appendix B of the Operating Manual lists all other PRC values. Some PRC codes listed there are defined only as "analog inputs." **Table 11-1** lists these PRC values and the associated variables. This information is provided for users employing the AK protocol with external data logging (See Section 11.2.2 below) who may wish to include these additional diagnostic variables.

Table 11-1. PRC values and assigned parameters for those PRC values listed in the Operating Manual only as "analog inputs."

PRC	Assigned Parameter
107	This is the only user-assigned input available
108	Voltage level from the 8500C module representing chiller status (98.xx is good/ 7X.xxx is bad)
109	Voltage level from 8500C representing valve positioning status (36.xx is good/ near 0 is bad)
110	Dryer temperature out
111	Dryer RH% out
112	Dryer temperature in
113	Dryer RH% in

Digital data from the 8500C FDMS should be used for data validation and ultimate submittal to regulatory agencies. This can be either the internally stored digital data, or externally acquired (data logger) digital data.

While the 8500C has three analog outputs available, it is recommended that these be used only to provide redundancy or to support specific QA protocols. Feeding analog signals for some variables to a strip chart recorder can be useful for tracking long-term changes in baseline values. For example, over time, as ambient air passes through the Nafion in the dryer, some contamination from particulate matter (and perhaps gases) can collect and form a film on the Nafion. These deposits may eventually off-gas and create false semi-volatile measurements that skew the actual readings. Tracking the Ref MC over a long period of time on a strip chart would allow observation of gradual increases that may lead one to suspect dryer contamination. The use of analog data would also require that the analog output board be periodically calibrated (Service Manual, Section 3.2.1).

11.2.2 Polled Data Sets

Most users will employ an external data logger to capture the mass concentration and diagnostic data from the 8500C FDMS. This is highly recommended, as it allows the capture and recording of more variables than can be stored internally in the 8500C. When an external data logger is used in combination with the AK Protocol, the user can query any of the PRC-coded variables. This scenario is becoming more common as agencies switch to the acquisition of real-time digital data that flows directly into a permanent database. Data acquired through an external DAS are extremely useful for real-time data applications such as forecasting or daily review of operational status. Ideally, mass concentration should be viewed on a daily basis. Agencies should establish nominal values for minimum and maximum mass concentration levels for Base MC, Ref MC, and FEM MC. These concentration levels would be used to flag situations that warrant additional investigation to ensure valid operational status of the 8500C FDMS. For example, 24-hr Ref MC concentrations of less than -5 $\mu g/m^3$ would suggest that dryer system performance should be investigated (dew points, vacuum pressure readings).

Polled data should be periodically verified against the data stored in the instrument. It is particularly important to verify the data logger-applied time stamps for accuracy.

11.2.3 Site Logs

Site logs maintained by the local operator allow the recording of qualitative information that may be useful during the data validation process. Digital site logs maintained in the DAS are becoming more common and make this information easily accessible. Information regarding the occurrence of unusual events (weather, traffic, HVAC malfunction, etc.) may explain spikes in data, or atypical or anomalous data. Most data loggers have the option of flagging data as invalid when routine maintenance procedures are performed on the equipment. This may not be automatic, and logs of maintenance visits can help track these events. The data analyst should have access to these site logs.

11.2.4 Routine Field QC Data

The purpose of periodic flow checks, leak checks, and other QC protocols is to provide quality assurance for the collected data; thus, it is essential that the information, both qualitative and quantitative, be transmitted to the data analyst responsible for the data validation process. This information transfer should be prescribed and not left to chance.

11.2.5 Data Validation Criteria

The EPA reference documents mentioned above were originally developed for 24-hr filter-based federal reference method sampling and have been adapted in this SOP to provide suggested guidelines for data validation criteria pertinent to continuous (hourly) $PM_{2.5}$ monitoring with the 8500C FDMS. The adaptations are modeled on the table, “Measurement Quality Objectives and Validation Templates,” in Appendix D of the QA Handbook, Volume II, Revision 1 (December, 2008). Two levels of adapted validation criteria are presented here: one level for criteria that are critical and must be met for validating data, and a second level that suggests the existence of potential problems that should be investigated.

The table from the QA Handbook has been modified to accommodate operational factors specific to the 8500C FDMS. In particular, the current recommendation for the full system leak check procedure relies on pressure changes in a closed loop system with the pump off. Thus, flow rates used previously as leak check validation criteria are not applicable with the full system leak check procedure recommended in this SOP. As with other validation criteria, it is left to individual agencies to adopt tolerance levels that are deemed appropriate. Whatever tolerances are used, accurate records must be maintained to assist the data analyst during data validation procedures.

Table 11-2 lists the critical criteria that *must* be met to ensure the quality of the data. Failure to meet any one of these criteria is cause for invalidation, unless there is compelling justification otherwise. One example of such justification would be known wildfires contributing to excessive filter loading. High filter loading can lead to flow perturbations, but these are nonetheless highly valuable data.

Table 11-2. Critical and operational data validation criteria for $PM_{2.5}$ continuous monitoring with the Thermo Scientific 8500C FDMS under FEM designation EQPM-0609-181.

Page 1 of 2

Criteria		Frequency	Tolerances	Reference
Critical Criteria: These criteria represent the most important sampling attribute data.				
Sampling period	Hourly	Hourly	75% minimum (45 minutes)	40 CFR Part 50 App L, Sec 3.3
	24-hr	Daily	75% minimum (1080 minutes)	40 CFR Part 50 App L, Sec 3.3
Flow	Average flow rate	Hourly	Inlet flow: ±5% of 16.67 lpm	40 CFR Part 50 App L, Sec 7.4; Method 2.12, Sec 10.2
			Main flow: 3.0 ± 0.2 lpm	8500C Operating manual, 42-010874 Revision C, August 8, 2008

Table 11-2. Critical and operational data validation criteria for $PM_{2.5}$ continuous monitoring with the Thermo Scientific 8500C FDMS under FEM designation EQPM-0609-181.

Criteria		Frequency	Tolerances	Reference
Verification	Single point flow (Reference std reading)	Monthly	±5% of design flow	40 CFR Part 50 App L, Sec 7.4; Method 2.12, Sec 10.2; 40 CFR Part 58, App A Table A-2
	Single point flow (instrument flow reading)	Monthly	±4% of reference std reading	40 CFR Part 50 App L, Sec 9.2.5; 40 CFR Part 58, App A Table A-2
	Full system leak check	Monthly	>1 inch Hg change in vacuum pressure in 1 minute, closed loop, pump off	SOP Section 10.1.1; Agency-specific tolerances
Sampler status	Significant malfunction codes	During occurrence	Codes 1, 2, 4, 8, 16, 32, 64, 128, 256	8500C Operating Manual, 42-010874 Revision C, August 8, 2008; SOP Section 11.2.5

The critical criteria for the 8500C FDMS include:

- Sampling period, including hourly and 24-hr data.
- Average hourly flow rate.
- Monthly flow rate verification.
- Monthly full system leak check (closed loop, pump off).
- Sampler status condition codes indicating the following sampler malfunctions, which are available via the AK protocol under PRC 041. When polled, status conditions are returned as a hexadecimal sum. When no status conditions exist, hex 0 is returned and status condition is "OK." (The current status condition appears in the upper left corner of the Main screen, and if the status is anything other than "OK," the Check Status light on the front of the control unit will illuminate.) **Table 11-3** summarizes the status conditions returned under PRC 041, along with implications for data validation. The term "conditional" refers to a weight-of-evidence approach to assessing data validity, where other operational or circumstantial factors are considered.

Table 11-3. Summary of status codes for the 8500C FDMS.

Status description	Hexadecimal	Status Code	Validation
Status OK	0	"OK"	Valid
Frequency signal failure	1	"M"	Conditional, the transducer is not providing a frequency signal
Temperature(s) outside of bounds	2	"T"	Conditional, ± 0.5 C°
Flow(s) outside of bounds	4	"F"	Invalid; main flow ± 0.1 lpm, bypass flow ± 0.4 lpm
Exchange filter	8	"X"	Conditional
Voltage low	16	"V"	Invalid; AC < 105 volts
Cooler status	32	"C"	Invalid; ± 1.0 C° from 4.0 °C
Valve position	64	"P"	Invalid; valve not positioned correctly
Drier status	128	"D"	Invalid; dew point downstream of 8500C > 2.0 °C
Inlet humidity high	256	"I"	Conditional; also triggered by "T" status since case temperature controls are disabled when there is no frequency output.

Table 11-4 lists criteria that indicate that there *might* be a problem with the quality of the data and further investigation may be warranted before making a determination about sample validity. An example of an item in this category would be failure to perform manufacturer-recommended maintenance. In addition, the sampler operation should be examined for overall reasonable operation. Data should not be invalidated without a documented reason, but subtle operational problems could result in less robust data. For instance, proper system vacuum and dryer operation are necessary for optimal operation and require detailed review to detect potential problems. Developing a full data validation protocol is left to the individual agency.

Table 11-4. Additional useful, but non-critical, data validation criteria for $PM_{2.5}$ continuous monitoring with the Thermo Scientific 8500C FDMS under FEM designation EQPM-0609-181.

Criteria		Frequency	Tolerances	Reference
Operational Criteria: These criteria represent tolerances when corrective action may be needed to reestablish optimal sampling attributes.				
Verification/ calibration	Full system leak check	Monthly	>0.5 inch Hg change in vacuum pressure in 1 minute, closed loop, pump off	SOP Section 10.1.1; Agency-specific tolerances
	Temperature verification	Monthly	±2°C	40 CFR Part 50 App L, Sec 9.3; Method 2.12, Sec 6.4; SOP Section 10.1.2
	Temperature calibration	Annually or on failed verification	±0.2°C	8500C Operating Manual, 42-010874 Revision C, August 8, 2008
	Barometric pressure verification	Monthly	±10 mm Hg	40 CFR Part 50 App L, Sec 9.3; Method 2.12, Sec 6.5; SOP Section 10.1.3
	Barometric pressure calibration	Annually or on failed verification	±10 mm Hg	8500C Operating manual, 42-010874 Revision C, August 8, 2008
	Flow calibration	Annually or on failed flow check	±2%	8500C Operating manual, 42-010874 Revision C, August 8, 2008
	Time verification	Monthly	1 min/month; ensure appropriate time stamp	40 CFR Part 50 App L, Sec 7.4
	Vacuum pump test	Monthly	>65% of ambient P (>20 in (510 mm) Hg vacuum pressure nominal)	SOP Section 10.1.7
	Zero test	Annually	±2 $\mu g/m^3$ of zero	SOP Section 10.1.8
	K_0 verification	Annually	±2.5 %	SOP Section 10.1.9
Cleaning	PM_{10} inlet and VSCC	Monthly	Cleaned	8500C Operating Manual, 42-010874 Revision C, August 8, 2008; SOP Section 10.2.1 & 10.2.2
	Heated air inlet system	Annually	Cleaned	SOP Section 10.2.6
	Switching valve	Annually	Cleaned	SOP Section 10.2.8
	Chiller	Annually	Cleaned	SOP Section 10.2.10
Other mfg recommended maintenance	Rebuild pump	18 months	Verified	SOP Section 10.2.7
	Replace dryer	12 months	Verified, monitor performance over time	SOP Section 10.2.9
	Change large in-line filter	As needed	Verified	SOP Section 10.2.3
	Change water trap	As needed	Verified	SOP Section 10.2.4

11.3 HANDLING NEGATIVE MASS DATA ARTIFACTS

Unlike criteria gaseous pollutants, airborne particulate matter (PM) can be heterogeneous. For example, it can consist of one or more elements (heavy metals such as lead and cadmium; carbon; minerals), inorganic compounds (salts), and semi-volatile components (organic carbon; secondary aerosols such as nitrates and sulfates; water). Particles can also exist in solid form, liquid form, or a mixture of both. PM is often hygroscopic, demonstrating an affinity for water at ambient RH of 75-80% or higher, but stubbornly retaining that bound water until experiencing RH of less than 30-35%. In general, fine particles (such as $PM_{2.5}$) are more volatile than coarse particles. It is this complexity that can lead to profound difficulty in the consistent quantification of PM air pollution. The challenge is to provide a measure of PM under well-defined thermodynamic conditions (temperature, pressure, filter face velocity, relative humidity).

Whether a continuous monitor such as the 8500C FDMS instrument or a gravimetric sampler is used, filter dynamics are always occurring. When particles are collected on a sample filter, their mass may be influenced by interaction with airborne gases (such as acid gases or water vapor), other particles in the sample air stream, or possibly the filter media. The thermodynamic conditions in the sample air stream and surrounding the sample filter influence the degree to which these ongoing reactions may occur. All of these processes define filter dynamics and may result in a positive or negative sampling artifact component of the PM mass concentration. The higher the time resolution of the PM measurement system, the better the PM mass concentration change resulting from filter dynamics can be observed. The 8500C FDMS facilitates quantifying these dynamics; however, the precision of hourly 8500C FDMS $PM_{2.5}$ data is about $\pm$ 2.5 $\mu g/m^3$. Therefore, it is reasonable to expect some small hourly negative values when the true mass concentration is very low (0 to 5 $\mu g/m^3$). This is not uncommon during rain events, for example. Overall, hourly mass concentration values should not routinely be lower than about –10 $\mu g/m^3$. As general guidance, small negative hourly values should be considered “clean” conditions and reported. When used to produce daily averages, all hourly values (both positive and negative) should be averaged using equal weighting. This is consistent with the physicochemical understanding of PM discussed above.

Although negative mass concentration numbers indicated by the 8500C FDMS monitor can be the result of the nature of particles described above, they can also be the result of an instrument fault. Thus, it is important to first rule out a malfunction of the monitor or instrumentation setup. Malfunctions may include system interruption from a temporary power failure, changing the 8500C FDMS filter without placing the instrument in "<DATA STOP> mode,” flow control or vacuum pump system fault, or failure of an electronics component (such as the frequency counter board). Generally, instrument faults will produce relatively large negative spiking in the mass concentration data. Erratic mass concentration data (many positive and negative spikes) can also be indicative of an instrument problem. It is advisable to also make use of site log notes to investigate further the possibility that the suspect data points were a result of a site visit for maintenance, audit, or other reasons.

11.4 DATA VALIDATION STEPS

Table 11-5 lists suggested sequential steps, their components, and specific procedures for validating continuous $PM_{2.5}$ mass data collected with the 8500C FDMS under FEM designation EQPM-0609-181.

Table 11-5. Data validation steps for 8500C FDMS FEM $PM_{2.5}$ data.

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Validation Step	Component	Procedure
Verify data source	Digital: direct download	The 8500C must be programmed with the 8 variables to be stored (see SOP Table 9-3 for recommendation). Direct data download is RS232 method dependent (SOP Section 9.9.3; Operating Manual Section 9.4).
	Digital: data logger	Use of AK two-way communication protocol commands is highly recommended to allow retrieval of as many desired PRC-queried diagnostic variables as the DAS can handle (Operating Manual Appendix C). Requires sending a separate command for each PRC. At minimum, query the variables listed in Table 9-3. Consult the Operating Manual, Appendix B, for a complete listing of PRCs and associated variables.
		Compare time stamp to internal data.
	Analog: data logger	Only three channels of analog data are available, so if used for mass concentration variables, no diagnostics available.
		Compare analog concentration to digital data (±1 μg).
		Compare time stamp to internal data.
Review 8500C FDMS data	Status codes	Determine each status code present (hexadecimal numbers) and whether significant fault occurred (SOP Section 11.2.5).
	Other logged variables	For reasonableness, baseline shifts.
Review field QC results	Flow checks	±4% of transfer standard lpm.
	Full system leak checks	>1 inch Hg loss over one minute, closed loop, pump off, invalidate back to last passing leak check, tolerance agency-specific.

Table 11-5. Data validation steps for 8500C FDMS FEM $PM_{2.5}$ data.

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Validation Step	Component	Procedure
Maintenance procedures	Inlet/VSCC cleaning	Verify
	Annual K_0 test	Verify
	Switching valve cleaning	Verify
	Dryer replacement	Verify annual replacement or document baseline drift
	Chiller cleaning	Verify
	Heated air inlet cleaning	Verify
	Sample pump rebuild	
Periodic component tests	Pump tests, in-line filter and water trap filter change, test CPU coin cell battery	Verify

12. REFERENCES

U.S. Environmental Protection Agency (1998) Quality assurance guidance document 2.12: Monitoring $PM_{2.5}$ in ambient air using designated reference or Class I equivalent methods. Prepared by the Human Exposure and Atmospheric Sciences Division, National Exposure Research Laboratory, Research Triangle Park, NC, November.

U.S. Environmental Protection Agency (2006a) Probe and monitoring path siting criteria for ambient air quality monitoring, 40 CFR Part 58, Appendix E.

U.S. Environmental Protection Agency (2006b) Reference method for the determination of fine particulate matter as $PM_{2.5}$ in the atmosphere, 40 CFR Part 50, Appendix L.

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U.S. Environmental Protection Agency (2008b) Quality assurance requirements for SLAMS, SPMs, and PSD air monitoring, 40 CFR Part 58, Appendix A.

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