



**Minnesota Pollution
Control Agency**

**STANDARD OPERATING PROCEDURE FOR THE CONTINUOUS
MEASUREMENT OF PARTICULATE MATTER**

**Met One BAM-1020 PM_{2.5} Federal Equivalent Method EQPM-0308-170 &
PM₁₀ Federal Equivalent Method EQPM-0798-122**

**REVISION 2
APRIL, 2015**

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1. ABOUT THIS STANDARD OPERATING PROCEDURE (SOP)

This standard operating procedure (SOP) for the Beta Attenuation Monitor Model 1020 (BAM-1020) is derived from the Met One Instruments, Inc. (Met One) BAM 1020 Particulate Monitor Operation Manual (Rev G) (Met One Instruments, 2008), and from SOPs submitted by BAM-1020 users from different regions of the United States with expertise in one or more areas involving setting up, operating, maintaining, quality assuring, validating, and/or reporting data for the BAM-1020 particulate matter (PM) monitor. It is meant to be used in conjunction with the BAM-1020 Manual (Rev G or later), which is a well-organized and user-friendly document that covers many details not specifically mentioned in this SOP. A copy of the BAM-1020 manual is provided with each instrument and should be kept at each monitoring site. Some of the diagrams and stepwise procedures in Revision G are reproduced in this SOP, and Met One Instruments' cooperation in development of this 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 in **Section 9** "Installation Procedures" and **Section 10** "Maintenance and Quality Control Procedures". Installation usually occurs once (or perhaps infrequently if instrument relocation is necessary) and includes receiving, site and enclosure selection, and the actual putting in place of the system components, followed by system configuration, initial checks, and startup. Maintenance and quality control (QC) includes periodic maintenance (e.g., filter tape changes, cleaning) and recurring QC procedures that ensure compliance with U.S. Environmental Protection Agency (EPA) Federal Equivalent Method (FEM) criteria and regulatory standards. Table 10-1 lists the QC protocols with cross-references to SOP sections describing the procedures.

Factors to consider when using external data loggers are discussed in **Section 12**, and data validation procedures are covered in **Section 13**.

Identification of common pitfalls and emphasis on operating procedure details that may help avoid operator missteps and frustration are the goals of this SOP. These discussions are presented so that the rationale underlying the procedures is clear. Checklists and forms referred to in the text are provided in the Appendices as examples that may be used in whole or in part.

2. SCOPE AND APPLICABILITY

The purpose of this SOP is to provide a set of uniform protocols for installation, operation, maintenance, calibration, and quality assurance (QA) of the Met One BAM-1020 configured to meet EPA FEM EQPM-0308-170 for PM_{2.5} mass and EPA FEM EQPM-0798-122 for PM₁₀.

This SOP cites the frequency of maintenance and the QA tolerances recommended by Met One as well as MPCA best practices. Where appropriate, manufacturer references are followed by discussions of the factors (risks) associated with using more frequent or less frequent QA procedures. References to EPA guidance documents related to these topics are also provided.

To meet the FEM requirements for measurement of PM_{2.5} mass as described in the EPA's [List of Designated Reference and Equivalent Methods](#), the BAM-1020 must be:

- operated for 24 1-hr average measurements;
- equipped with firmware revision 3.2.4 or later;
- operated with or without an inlet tube extension (BX-823);
- operated with or without external enclosures BX-902 or BX-903;
- operated in accordance with the BAM-1020 Particulate Monitor Operation Manual, revision F or later, and the Very Sharp Cut Cyclone (VSCC™) supplemental manual;
- equipped with a BX-596 ambient temperature and barometric pressure combination sensor;
- equipped with an internal BX-961 automatic flow controller operated in actual (volumetric) flow control mode;
- equipped with a standard BX-802 EPA PM₁₀ inlet head and a BGI VSCC™ (VSCC-A);
- equipped with a BX-827 (110V) or BX-830 (230V) Smart Inlet Heater with the heater RH regulation set point at 35% and the temperature control set to “off”;
- equipped with the 8470-1 revision D or later tape control transport assembly with close geometry beta source configuration;
- used with standard glass fiber filter tape;
- configured for a COUNT TIME parameter of 8 minutes and a SAMPLE TIME parameter of 42 minutes; and
- supplied with a BX-302 zero filter calibration kit. (This kit must be used to audit the BKGD (background) value upon unit deployment and periodically thereafter, as described in the BX-302 manual.)

To meet the FEM requirements for measurement of PM₁₀ as described in the EPA's [List of Designated Reference and Equivalent Methods](#), the BAM-1020 must be:

- operated for 24 1-hr average measurements;
- equipped with firmware revision 3.0 or later;
- operated with or without an inlet tube extension (BX-823);
- operated with or without external enclosures BX-902 or BX-903;
- operated in accordance with the BAM-1020 Particulate Monitor Operation Manual, revision F or later;
- equipped with a BX-596 ambient temperature and barometric pressure combination sensor;
- equipped with an internal BX-961 automatic flow controller operated in actual (volumetric) flow control mode;
- equipped with a standard BX-802 EPA PM₁₀ inlet head;
- equipped with a BX-827 (110V) or BX-830 (230V) Smart Inlet Heater with the heater RH regulation set point at 35% and the temperature control set to “off”;
- equipped with the 8470-1 revision D or later tape control transport assembly with close geometry beta source configuration;
- used with standard glass fiber filter tape;
- **Using newer BAM-1020 units and newer firmware for PM₁₀**
 - The PM_{2.5} FEM BAM-1020 configuration maintains the existing PM₁₀ designation. To use a PM_{2.5} FEM BAM-1020 for PM₁₀, simply remove the VSCC cyclone and set the CONC TYPE to STD. See Section 6.3 of BAM-1020 Particulate Monitor Operation Manual
 - The BKGD (background) zero correction for PM₁₀ BAM-1020 units may be determined in the field using the BX-302 zero filter kit if desired, although it is not a requirement.
 - It is no longer required that the BAM-1020 only be operated with a 50 minute sample time and 4 minute count times for PM₁₀ sampling. The 42 minute sample time and 8 minute count times used for the PM_{2.5} FEM configuration may be used for PM₁₀ sampling as well. See Section 6.2 of BAM-1020 Particulate Monitor Operation Manual.
 - PM₁₀ data is usually reported in EPA standard conditions. Newer BAM-1020 units (firmware 3.0 and later) have a CONC TYPE setting which must be set to STD, and a FLOW TYPE setting which should be set to ACTUAL for PM₁₀ sampling. This will cause the BAM to regulate the flow to actual conditions for a proper inlet cut-point, but store the concentration and flow volume based on

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standard conditions for reporting purposes. Older BAM-1020 units (firmware 2.58 and earlier) only had a FLOW TYPE setting, which must be set to STD for PM₁₀ monitoring. See Sections 5.2 and 6.3.

3. SUMMARY OF METHODS

The method for the BAM-1020 configured for PM_{2.5} FEM monitoring includes sampling of ambient air through a standard EPA PM₁₀ inlet head and a VSCC-A at a volumetric flow rate of 16.7 lpm. A Smart Heater attached to the inlet system, and controlled by relative humidity (RH) measured at the filter tape, minimizes positive artifact from water sorption in humid environments. Particles in the air stream are collected and measured on quartz fiber filter tape. PM_{2.5} concentrations and sampling attribute data are reported hourly. For PM₁₀ configuration is the same with the exception of the VSCC-A.

The BAM-1020 employs the principle of beta ray attenuation to measure particulate mass concentration in ambient air, and reports hourly mass concentrations in user-selectable units of mg/m³ or µg/m³. Particles are collected by pulling a measured volume of ambient air through glass fiber filter tape. A ¹⁴C element emits a constant source of high-energy electrons (beta particles) that pass through the clean filter tape before sample collection and again after the filter collects PM. The beta particles are attenuated as they collide with particles on the filter, and the beta particles are detected and counted by a sensitive scintillation detector. The attenuation through the clean filter is compared with that of the particle-laden filter. The decrease in signal detected by the BAM-1020 scintillation counter is inversely proportional to the mass loading on the filter tape, and, together with the known air volume, allows calculation of mass concentration. The spooled filter tape allows extended monitoring periods without operator intervention.

4. DEFINITIONS

Most technical terms in this SOP are defined as they are introduced so that their meaning is made clear in context.

A wide range of interpretation of the term “audit” exists. It is often used generically to mean check, inspect, examine, or assess, and many SOPs use the term audit to refer to quality control (QC) procedures, such as flow checks or leak checks, that are carried out by field technicians during the course of normal operations and maintenance. In this SOP, audit refers to the group of procedures that, taken together and conducted during a single site visit, verifies the status of all aspects of the BAM-1020. These procedures include flow audits, mechanical audits, and auditing of the setup and calibration values. If analog output is used, an analog voltage output audit would be included as well. An inclusive Audit Form is provided in Appendix C of this SOP. Routine QC procedures, such as flow checks, are referred to herein as QC checks or QC procedures. The word audit also connotes a degree of independence of the auditor, although audits can, and should, be undertaken periodically by regular staff to ensure that the BAM-1020 meets all requirements set forth under EQPM-0308-170, EQPM-0798-122, and in the Met One BAM-1020 Operation Manual, Rev G.

Two terms used throughout this SOP are “verification” and “validation”. These terms have similar, but distinct, 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 items as checklists and comparisons to standards. A leak check is an example of a verification procedure used with the BAM-1020. *Validation* involves determining whether the system complies with the requirements and performs 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 the project.

Similarly, the terms “quality control” and “quality assurance” are often used interchangeably, but in fact have important distinctions. Quality control 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 BAM-1020. Quality assurance (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.

The term “calibration” refers to the act of adjusting an instrument after comparison with a standard. A “calibration check” refers only to checking an instrument against a standard and involves no adjustment of the instrument.

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5. HEALTH AND SAFETY WARNINGS

Safety precautions should be heeded during the setup and operation of the BAM-1020. General safety rules regarding electricity and power tools should be observed. Working at above-ground elevations and on ladders is frequently required and precautions should be taken to avoid falls and personal injury. Users of the BAM-1020 need to be aware that it contains a radioactive component. The following paragraph is a direct quote from the BAM-1020 Operation Manual (Rev G):

“The Met One Instruments BAM-1020 contains a small ¹⁴C (Carbon 14) beta radiation-emitting source. The activity of the source is **60 μCi ±15μCi** (microcuries), which is below the “Exempt Concentration Limit” as defined in 10 CFR Section 30.70–Schedule A. The owner of a BAM-1020 is not required to obtain any license in the United States to own or operate the unit. The owner of a BAM-1020 may elect to return the entire unit to Met One Instruments for recycling of the ¹⁴C source when the unit has reached the end of its service life, although the owner is under no obligation to do so. Under no circumstances should anyone but factory technicians attempt to remove or access the beta source. The beta source has a half-life of about 5730 years, and should never need to be replaced. Neither the ¹⁴C source nor the beta particle detectors are serviceable in the field. Should these components require repair or replacement, the BAM-1020 must be returned to the factory for service and recalibration.”

6. INTERFERENCES

The BAM-1020 is a robust instrument that has minimal potential interferences. Poor siting, inadequate electrical grounding, and poor control of the RH of the sampled air in humid environments are known sources of interference. Interferences arising from improper siting can be avoided by exercising care during site selection (Section 9.3), and grounding and RH issues should be addressed during the setup process (Sections 9.5.1 and 9.5.10).

Contaminated or dirty quartz filter tape can also interfere with measurements. Proper storage and handling of the filter tape will minimize this interference (Section 9.6.3).

When used at high altitudes (greater than 4,000 feet, or atmospheric pressure less than 600 mm Hg), the BAM-1020 should be using the GAST pump, which is more efficient at low pressures than the Medo pump. The Medo pump is shipped by default, so if the GAST pump is desired, it must be specified. Earlier firmware had a “high altitude” bug that would indicate flow errors when there were none, but firmware versions 3.2.7 or later should be free of this bug. This firmware is available on Met One Instruments’ website for BAM-1020 users (http://metone.com/bam_user.php). Contact Met One for the required password.

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7. PERSONNEL QUALIFICATIONS

While no special qualifications or training are necessary to operate the BAM-1020, a basic understanding of the principles governing ambient air sampling is assumed. The QA procedures detailed herein require an understanding of the BAM-1020 flow system, calibration protocol, and recognition that out-of-the-ordinary protocols, such as the annual background zero test, must be followed to satisfy PM_{2.5} and PM₁₀ FEM requirements.

EPA Quality Assurance Guidance Document 2.12 (U.S. Environmental Protection Agency, 1998) covers the 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} and PM₁₀ data. Persons qualified to perform PM_{2.5} and PM₁₀ field operations should be able to

- operate the sampler;
- calibrate, audit, and troubleshoot the sampler; and
- use common methods to determine temperature, pressure, and flow rate.

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8. EQUIPMENT AND SUPPLIES

The equipment and supplies needed vary with the particular tasks associated with installing and operating the BAM-1020. A list of supplies is included with the operating procedure for each task:

- Installation – Section 9.5.2; Table 9-3
- Flow verification – Section 10.1.1
- Consumables and spare parts – Section 15; Table 15-1

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9. INSTALLATION PROCEDURES

The tasks associated with installation include unpacking and inspection of the BAM-1020 components, acceptance testing, site selection to meet 40 CFR Part 58 siting requirements, enclosure selection to provide the BAM-1020 with an environment within its operating specifications, a series of sequential steps to install the BAM-1020 main unit and its supporting peripheral hardware, and a series of instrument configuration procedures to ensure that the BAM-1020 meets FEM EQPM-0308-170 and EQPM-0798-122 requirements.

9.1 UNPACKING AND INSPECTION

A physical inspection of the BAM-1020 system should be made upon receipt of the system from Met One. Visible damage to the shipping container needs to be reported to the carrier. System components should be verified against the packing list and any missing or damaged components reported immediately to MetOne. The BAM-1020 is shipped with two white foam rings and a white plastic shim inside the front of the unit, which prevent the moving parts of the tape control assembly from being damaged in transit. Do not remove the foam rings until the BAM-1020 is ready to be installed. *These rings must be in place on the transport assembly anytime the unit is being transported in order to avoid damaging the tape control mechanism.* The special box and foam packing material that the BAM-1020 is shipped in should be stored, in the event the unit must be returned to the factory. Even if the box is discarded, *always save the foam rings.*

9.2 ACCEPTANCE TESTING

After the system components have been verified against the packing list, the system should be assembled on a bench and an acceptance test should be performed. This acceptance procedure, or bench test, should include a minimum battery of tests to ensure that the equipment is operational and meets manufacturer's specifications before it is moved to the field site. More rigorous tests, such as collocating the BAM-1020 with an FRM monitor for a period of time, can strengthen confidence in the data. Some agencies may mandate these tests as a required condition of acceptance.

Note that the 72-hr zero filter, or background, test is required at the time of field installation to meet the requirements of FEM EQPM-0308-170. It is important that this test be conducted at the field site to account for site-specific background noise. Agencies may opt to include the zero test as part of the bench test procedure to verify that the unit is working properly before being transported to a less stable environment in the field. From a practical standpoint, the farther away the actual field site is, the more thorough the bench testing should be.

Table 9-1 lists suggested acceptance testing protocols for the FEM BAM-1020 with references to the applicable sections of this SOP and of the BAM-1020 Operation Manual (Rev G).

Table 9-1. Suggested acceptance testing procedures for the FEM BAM-1020.

Test	Location	Comments	SOP Section	BAM-1020 Operation Manual (Rev G) Section
Power on and warm up	Bench	Verify that BX-596 temperature and pressure readings are realistic; also a good opportunity to check any auxiliary sensor signals	9.6.1	3.1
Self-test	Bench	Load tape and run self-test	9.6.3–9.6.4	3.4–3.5
Leak check	Bench	Should be < 1.0 lpm; preferably < 0.5 lpm	10.1.2	3.7
Zero test	Field	A field zero test is required by the FEM designation. A prior bench zero test may be desirable if the field site is remote.	9.6.10 (precautions listed)	7.7

9.3 SITE SELECTION

Site selection is important to ensure the uniform collection of compatible and comparable ambient PM_{2.5} and/or PM₁₀ data, and specific site criteria must be satisfied for the BAM-1020 to meet the PM_{2.5} and/or PM₁₀ FEM regulatory requirements. The design criteria for PM₁₀ are given in 40 CFR Part 58, App D, Section 4.6. The design criteria for PM_{2.5}, including general monitoring requirements, spatial scales, and special site requirements are given in 40 CFR Part 58, App D, Section 4.7.

Once general monitoring requirements are met, 40 CFR Part 58, Appendix E extensively details all aspects of site selection. The most important federal EPA site selection criteria applicable to ambient monitoring of PM_{2.5} and PM₁₀ with the BAM-1020 are inlet height, inlet radius clearance, proximity to potential sources of PM, and spacing from roadways. **Table 9-2** gives the basic limitations applicable to each of these criteria. Most monitors can be located so that they meet 40 CFR Part 58, Appendix E requirements, however, new sites can be located within limits of these requirements; sites may not meet all of these requirements and still produce useful data. Generally, establishing a monitoring site at any location is acceptable as long it can be demonstrated to be as representative of the monitoring area as it would be if all of the siting criteria were met. Besides the CFR, additional information is available in the BAM-1020 Operation Manual (Rev G, Section 2.3).

Table 9-2. EPA PM_{2.5} and PM₁₀ site selection specifications for the BAM-1020 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 m to 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
	Co-located 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 BAM or FRM	Minimum 1-m separation between inlets	
	Co-located	From 1 m to 4 m between inlets	2 m recommended
	Near SSI Hi-Vol	Minimum 3 m between BAM and Hi-Vol inlets	
	Near small obstructions	Minimum 2 m	Small obstructions: e.g., fences, walls
	Near large obstructions	Distance of 2x height of obstruction	Large obstructions: e.g., buildings, sound walls, billboards
	Overhanging trees	Minimum 20 m from tree drip line	
	Arc of unrestricted air flow	Unrestricted 270 degree arc	Prevailing direction of concentration must be in the arc
Nearby particulate sources	General	As far away as possible from blowers or vents	Note: both filtered air, as well as dirty air, can contaminate a sample
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 BAM-1020 may be housed in a walk-in shelter, a mobile trailer, or in specially made, environmentally controlled, mini-enclosures available from Met One (part number BX-902 or BX-903, diagrammed in the BAM-1020 Operation Manual Rev G, page 14). The enclosure must satisfy the BAM operating temperature range of 0-50°C and RH range of 0-90%, non-condensing. It is also important to minimize the temperature fluctuations that occur within any given hour. Temperature fluctuations of more than a few centigrade degrees within a single sampling hour can perturb concentration measurements on the order of several micrograms. Heating, ventilating, and air conditioning (HVAC) cycling commonly occurs multiple times per hour in small or poorly insulated enclosures, and this cycling potential should be taken into consideration during the enclosure selection process.

9.5 BAM INSTALLATION

The Met One BAM-1020 Operation Manual (Rev G, Chapter 2) covers all aspects of BAM installation procedures. This SOP identifies some special precautions (Section 9.5.1), provides a suggested list of tools required (Section 9.5.2), and describes the following installation tasks sequentially:

1. Determine the exact location for the BAM-1020, observing some special precautions listed in Section 9.5.1.
2. Perform roof modifications (penetrations) necessary to accommodate the air inlet (Section 9.5.3)
3. Install and seal the waterproof roof flange and lower the inlet pipe through the roof (Section 9.5.4)
4. Install the Smart Heater (Section 9.5.5)
5. Seat the inlet in the BAM, and tighten the roof flange coupling and BAM inlet set screws (Section 9.5.6)
6. Install support struts or otherwise stabilize the inlets and down-tube assembly (Section 9.5.7)
7. Install the BX-596 pressure and temperature sensor (Section 9.5.8)
8. Install the PM_{2.5} and PM₁₀ inlet separator heads (Section 9.5.9)
9. Check inlet tube grounding (Section 9.5.10)
10. Complete wiring and plumbing connections (Section 9.5.11)

Figure 9-1 is taken directly from the Met One BAM-1020 Operation Manual (Rev G) and depicts all the BAM-1020 components as they would in a typical walk-in installation. Not shown, but similarly diagrammed in the manual, is the installation of the BAM-1020 in the environmentally controlled mini-enclosure BX-902 or BX-903 (Rev G, page 14).

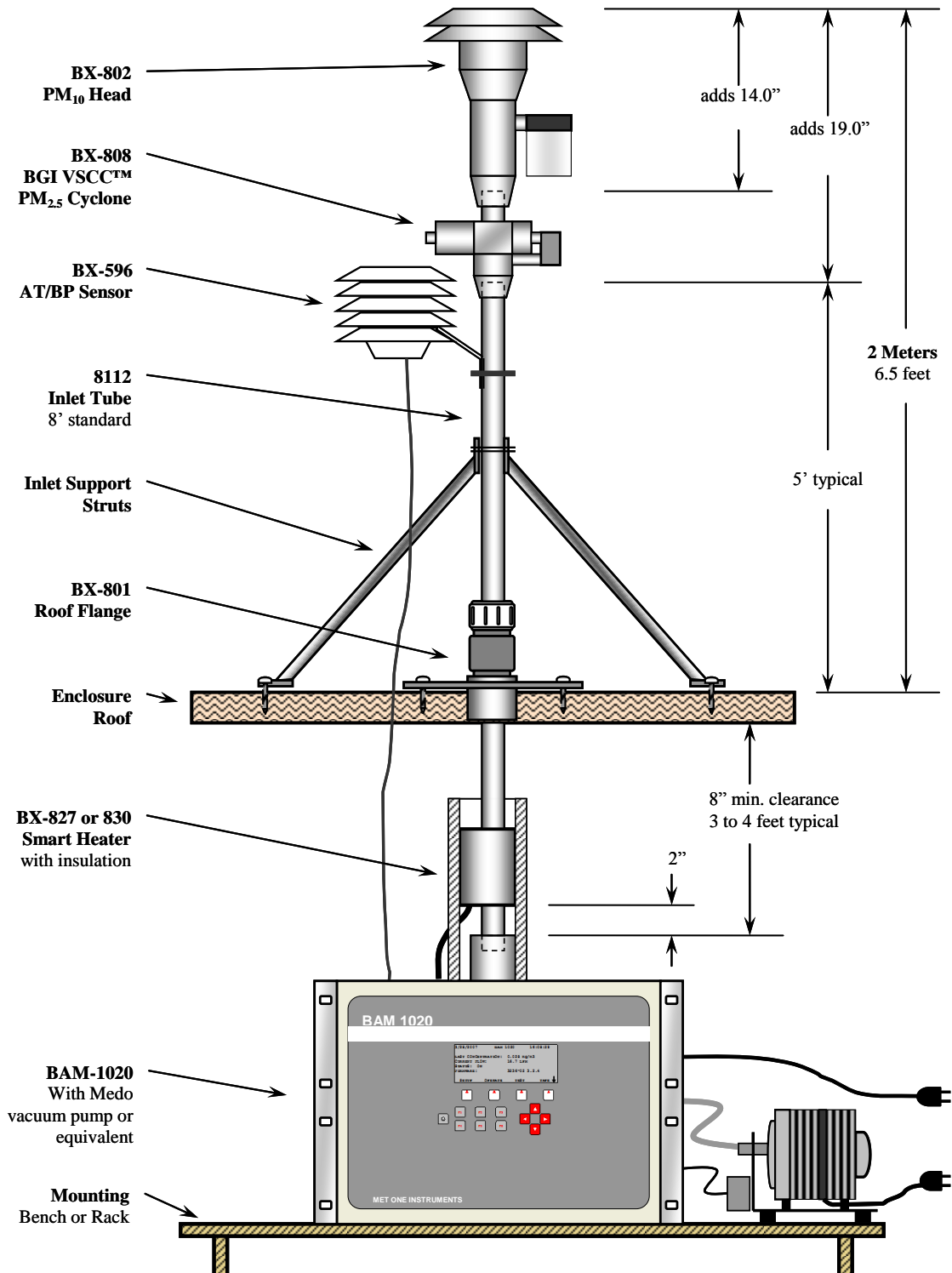
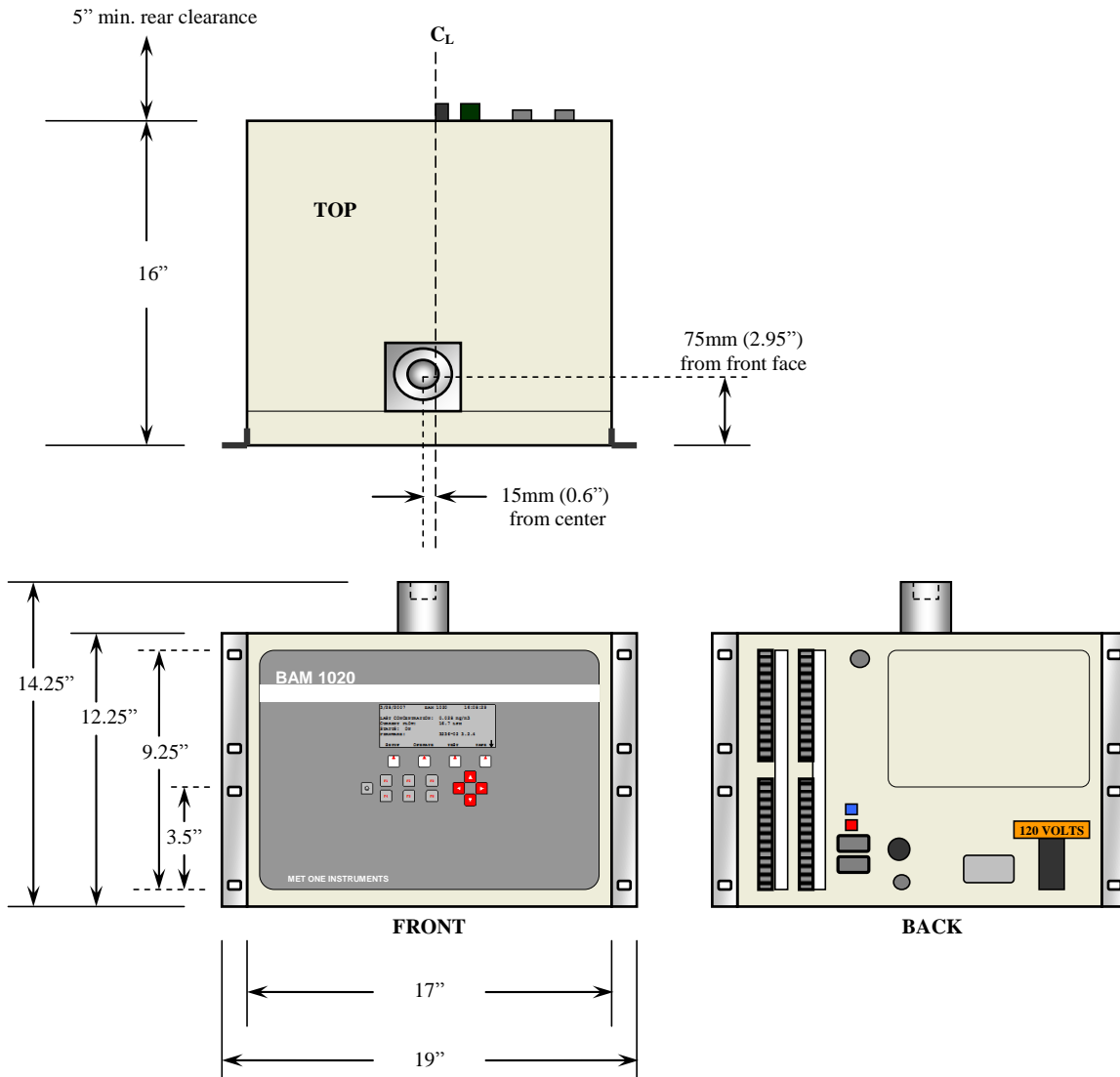


Figure 9-1. The basic installation configuration of the BAM-1020 in a walk-in shelter. Diagram courtesy of MetOne Instruments.

Figure 9-2 illustrates the mounting dimensions of the BAM-1020. This illustration is particularly useful when rack-mounting the instrument. Note that the inlet on the top of the BAM-1020 is slightly off-center from the center line of the instrument.



BAM-1020 mounting dimensions

Figure 9-2. Mounting dimensions of the BAM-1020. Diagram courtesy of Met One Instruments.

9.5.1 Special Precautions

Some planning prior to the installation of the system components can save a lot of frustration, and particular consideration should be given to the following elements. Note that, because of the inlet configuration, no other instrumentation can be installed above the BAM-1020.

- Take the time to optimize the location of the BAM-1020 in the shelter. Choose a location away from the main flow path of heated or cooled air from the HVAC system. The choice of location is important because the unit measures beta particles through a small gap of air around the filter tape at the beginning and the end of each hour. If the air temperature inside the enclosure has changed by more than about 2°C during this time, the concentration measurement can be affected on the order of several micrograms. MetOne recommends logging the air temperature inside the enclosure to monitor this effect. The exact temperature is not critical as long as it fluctuates as little as possible during any one hour.
- Decide whether to rack mount the unit or place it on a bench or table. The MetOne manual recommends rack mounting because it is more space-efficient and keeps the instrument level and in the proper position. To achieve proper alignment, the BAM-1020 must be level, and the inlet must be absolutely vertical. This alignment is important to avoid transverse stress on the inlet as it enters the top of the BAM-1020. Stress may interfere with nozzle movement or cause air leaks at the BAM inlet. A table or bench installation may facilitate meeting these conditions.
 - Bench or table installation allows the BAM to be shifted slightly if needed to ensure proper inlet tube alignment. Note that the inlet pipe should rotate freely in the BAM inlet when installed (before the roof flange seal and BAM inlet set screws are tightened, and the inlet support struts are secured). If the BAM inlet pipe does not turn freely when seated in the BAM inlet, adjust the position of the BAM and/or inlet pipe until it rotates freely.
 - Rack mounting requires very accurate measurements. If the BAM is to be rack mounted, there is little room for error in alignment of the roof penetration and the BAM inlet because the BAM cannot be moved to compensate for poor alignment. It may be best to install the BAM in the rack and use a plumb bob to mark the location of roof penetration.
 - Bench placement puts the unit at a level that makes removal of the cover and access to the interior more convenient.
 - Bench-mounted units should be fixed firmly after positioning. The bench, or table, should be immobile, and the BAM-1020 should be fastened to the bench. Once positioned, right angle brackets, attached to the table and to the BAM-1020 rack mounting rails, can be used to anchor the instrument.
- Provide clearance for the Smart Heater with insulation. A minimum of 12 inches between the top of the BAM-1020 and the ceiling is required to accommodate the full length of the cylindrical insulation provided with the Smart Heater. Available clearances in most

shelters are generally greater than 12 inches. The insulation can be cut if necessary to accommodate limited available space.

- Provide adequate access to the back of the instrument. Accessing the inside of the instrument, without having to remove it from a rack or removing the inlet, is more convenient for troubleshooting or repairs. Bench or table mounting is indicated to achieve this convenience.
- Provide proper grounding. Poor electrical grounds can affect background concentration values. While the BAM-1020 uses the standard safety ground line inside the power cord, an auxiliary ground to a grounding rod or a cold water pipe is recommended. Proper grounding of the inlet tube is also needed to avoid static charge buildup that can lead to errors. The inlet tube needs to be properly grounded to the BAM inlet (set screws on BAM inlet, see BAM-1020 Operation Manual, Rev G, page 12), the inlet grounded to the BAM chassis, and the BAM chassis to earth ground.
- Protect the down tube from snow accumulation. In areas where significant snow accumulation is anticipated, a 3-foot length of 4-inch PVC pipe can serve as a housing for the inlet tube on the rooftop. The pipe can protect the tube from bumps and scrapes during snow removal operations.

9.5.2 Tools Needed for Installation

Table 9-3 lists the basic tools and supplies needed to install the BAM-1020. Any given installation may require additional tools and supplies dictated by the situation.

Table 9-3. Tools and supplies for installation of the BAM-1020.

Tools and Supplies	Remarks
Drill, with hole saws and bits	Half-inch, variable speed drill preferred; hole saws: 1-3/8" (for inside shelter ceiling) and 2-1/4" or 2-1/2" (for exterior roof); 3/8" drill bit (to drill hole to accommodate cable from BX-596 pressure and temperature sensor)
Hand tools	Screwdriver set, socket set, nut drivers, plumb bob, tape measure
All weather caulking	To waterproof the roof flange and feet of support brackets
Lag screws	To secure roof flange and support brackets to roof
Signal cable	2-conductor cable for analog signals; 9-pin RS232 for digital
Rack mount screws, or right-angle brackets with screws	If the BAM is table- or bench-mounted, right angle brackets can be used to secure the BAM to the surface
Scotch tape or masking tape	For installation of filter tape
Level	To check the horizontal level of the BAM and vertical level of the inlet
Waterless hand cleaner	Useful after installation and before handling the filter tape

9.5.3 Prepare Roof Penetrations

The roof modifications described here are applicable to shelters with flat rooftops. Hardware supplied by MetOne includes a roof flange plate suitable for stations with a flat roof. Roof modifications for rooftops that are under warranty may need to be performed by a licensed contractor. Slanted rooftops will need special accommodation. Avoid roof rafters and any electrical wiring when setting up the roof penetration!

After the exact location of the roof penetration has been determined (ensuring accurate inlet perpendicularity with the BAM and adequate access to the instrument), the ceiling and roof holes may be drilled. If the BAM is in its final position (e.g., already rack-mounted), a plumb bob may be used to precisely mark the center point of the roof penetration. In this case the BAM must be protected from falling debris. First mark and drill the ceiling hole inside the shelter, then drill the larger hole from the outside through the roof to accommodate the supplied roof mounting flange.

The inlet tube is 1-5/16" in diameter, so the hole in the ceiling inside the shelter should be drilled with a 1-3/8" hole saw. During this process, the guide bit of the hole saw can also be used to mark the location of the *exterior* roof access hole by continuing to drill past the ceiling until the guide bit penetrates the outside roof; it may be useful to use a long guide drill bit in the hole saw. Be careful not to drill through the outside roof with the 1-3/8" hole saw.

Move to the rooftop and drill a 2-1/4" or 2-1/2" diameter hole in the exterior roof, using the guide hole marked earlier by the guide drill bit as center.

9.5.4 Install Waterproof Roof Flange and Insert the Inlet Pipe

The roof flange has a circular ridge on one side and threaded barrel on the other side. It is best if the threaded barrel of the flange assembly is installed downward, into the hole, assuming there is adequate room between the roof and the inside ceiling. Apply a generous amount of roof sealant (silicone or other suitable caulk) to the underside of the roof flange and place the flange in the hole. Secure the flange with four appropriately sized lag bolts, and caulk around the bolts to prevent leaks. Apply Teflon tape to the threads of the gray plastic watertight fitting, and screw it into the roof flange.

Remove the white cap and rubber seal from the flange assembly and temporarily set aside. This step facilitates installation of the inlet tube, as the rubber seal is a tight fit around the tube. Lower the inlet tube through the flange assembly in the roof and into the inlet receiver on the BAM-1020. Make sure the inlet tube is fully seated. Check that the inlet tube rotates freely. If it does not, there may be an inlet alignment problem that *needs to be corrected before proceeding*.

9.5.5 Install Smart Heater

Temporarily lift the inlet tube out of the BAM-1020 and slide the Smart Heater onto the inlet tube, with the heater cable positioned toward the bottom. Reinsert the inlet tube into the BAM-1020 and check that it is fully seated. Position the Smart Heater 2" above the BAM-1020 inlet

(see Figure 9-1) and tighten the two set screws that attach the heater to the inlet tube. Wrap the supplied 12" cylindrical insulation around the heater body, and peel back the adhesive cover strip to secure it in place. If the inlet tube is in the direct path of the air flow from the HVAC system, consider installing additional insulation on the exposed portions of the inlet tube.

9.5.6 Seal and Tighten the Inlet

Wet the inlet pipe rubber seal with water or alcohol and slide it down the pipe until it sits inside the gray plastic fitting that was previously screwed into the roof flange. This grommet is tight fitting, and wetting it will help slide it along the pipe. Be careful not to apply too much water or alcohol to avoid trickling down the tube into the inlet receiver on the top of the BAM-1020. When the grommet is in place, slide the white cap down the inlet and hand tighten it to the gray plastic fitting.

9.5.7 Attach Inlet Tube Stabilizing Supports

It is important to provide stabilizing support for the inlet tube on the rooftop to prevent the tube from flexing in the wind. The aluminum support struts supplied by Met One can be used for most flat-roof installations to stabilize the inlet tube. Some situations may require alternative means to achieve stabilization (for example, a camera tripod may be adapted, or PVC struts could be attached between the inlet tube and adjacent roof rails). The two supplied struts are typically fastened to the inlet tube with a supplied hose clamp, with the struts positioned about 90 degrees apart. The bottom ends of the struts are fastened to the roof with user-supplied lag bolts. The lag bolts should be caulked to prevent leaks. When installing the struts, be careful to maintain the plumb of the inlet tube, and do not tighten the struts in a position that applies transverse stress to the inlet.

9.5.8 Install the BX-596 Ambient Temperature (AT) and Barometric Pressure (BP) Sensor

The BX-596 AT and BP sensor provides the BAM-1020 with data necessary to maintain proper volumetric flow control and is required to meet FEM designation EQPM-0308-170 for PM_{2.5} mass. The sensor attaches directly to the inlet tube with a supplied U-bolt (see Figure 9-1). Position the sensor so that it does not interfere with support struts or the inlet separator heads. The BX-596 signal cable must be routed into the shelter and connected to the BAM. An existing entry port may be used, or a 3/8" hole may be added to the roof near the inlet tube to accommodate the cable. Caulk around the cable at this entry port to prevent leaks.

9.5.9 Install the PM_{2.5} and PM₁₀ Inlet Separator Heads

The PM_{2.5} BGI VSCC™ is required to meet FEM designation EQPM-0308-170 for PM_{2.5} mass. The VSCC™ is placed on the top of the inlet tube beneath the standard BX-802 EPA PM₁₀ inlet head.

9.5.10 Provide Inlet Tube Grounding

A solid station ground (earth ground) must be available for the BAM-1020 chassis ground, and care needs to be taken that the inlet tube is properly grounded to the BAM chassis ground. The inlet tube itself has large capacitance, and any buildup of static charges from an ungrounded inlet tube can cause errors in the BAM-1020 measurements. This ground is important, especially in areas with electromagnetic fields (e.g., near high voltage power lines or radio frequency antennas). Tightening the two 1/4-20 set screws located in the inlet receiver of the BAM secures the inlet tube and also creates a ground connection between the inlet tube and the chassis of the instrument. Met One recommends checking this ground by scraping away a small spot of the clear anodizing near the bottom of the inlet tube and measuring the resistance between that spot and the chassis ground terminals on the back of the BAM-1020: the resistance should be a few ohms or less.

Note that if the inlet tube utilizes an extension with a coupler between the sections, the rubber O-rings in the coupler isolate the two sections from each other. In that case, the two sections should be wired together with grounding clamps. Check the electrical resistance of the connection.

9.5.11 Complete Wiring and Plumbing

Wiring connections include the power cables to the BAM-1020 and to the pump (including a power supply, if used), a chassis ground wire, the BX-596 sensor wiring, the Smart Heater connection, analog output data connection or RS232 digital connection, and wiring between the data acquisition system (DAS) and any of the I/O or error relays provided on the back of the BAM-1020.

Provide power connections to the BAM-1020 and the pump. MetOne recommends that the BAM-1020 power cord be connected to an uninterruptable power supply (UPS; minimum 300W) because even a momentary power outage can cause the BAM to reset, causing loss of that hour's data. While the optimal configuration would include a UPS capable of supporting both the BAM-1020 and the pump, the amount of power needed would require a large UPS, and may be excessive from the standpoint of cost and need. There exists a concern that providing backup power to the BAM-1020, but not the pump, will cause deterioration of, or damage to, the mass flow controllers (MFCs), because the MFC will attempt to regulate the flow each second, even though there is no air flow through the unit. According to MetOne, the new MFCs being shipped with FEM versions of the BAM-1020 are more capable of handling pump failures than previous versions. Some agencies mandate that the BAM-1020 and the pump remain on the identical electrical circuit to avoid this issue. A site with frequent power failures or power fluctuations has a higher risk of MFC damage than sites with stable power and an adequate UPS backup system. The decision whether to employ a UPS is left to individual users.

Provide an auxiliary ground. While the BAM-1020 uses the standard safety ground line inside the power cord, an additional ground connection between the chassis ground terminal on the rear terminal strip and a grounding rod or cold water pipe is also recommended.

Connect the pump tubing and control signal cables. Place the pump in an accessible location and connect a sufficient length of the supplied tubing to the compression fittings on the pump and the rear of the BAM. Retain the leftover tubing for future use. Connect the two-wire signal cable supplied with the pump to the terminals on the back of the BAM marked “Pump Control”. The polarity of the wires does not matter, but the end of the cable with the square black ferrite filter goes toward the BAM-1020. Connect the other end of the cable to the two terminals of the pump control box mounted on the pump.

The pump muffler will eventually become clogged. To avoid this problem, remove the muffler and replace it with a 2 or 3 foot length of Tygon tubing to reduce pump noise and improve pump performance (less resistance).

Connect the cable from the BX-596 AT and BP sensor to the rear terminal strip of the BAM-1020 according to **Table 9-4**.

Table 9-4. Wiring connections between the BX-596 AT and BP sensor and the terminal strip on the rear of the BAM-1020.

Wire Color	Terminal Name
Yellow	Channel 6 SIG
Black/Shield	Channel 6 COM
Red	Channel 6 POWER
Green	Channel 6 ID
White	Channel 7 SIG

Connect the Smart Heater. Two versions of the Smart Heater exist for use with the FEM BAM-1020. Earlier versions of the Smart Heater simply plug directly into the back of the instrument, so the power for the heater comes internally from the BAM-1020. Newer versions have a relay module that plugs into the back of the BAM-1020 to which the cable from the Smart Heater is attached. The relay module then has a separate power cord that plugs into a 110V outlet.

Connect the data logger. If an external DAS is used, digital (RS232) connections should be used to log data whenever possible. Analog connections are provided on the rear of the BAM-1020 as well (terminals labeled VOLT OUT +/-). Signal processing of analog data requires additional attention to details involving time stamping and programmed range offsets in the instrument, as well as periodic voltage output verification tests. These and other data acquisition issues are discussed in **Section 11**.

9.6 INITIAL SETUP AND CONFIGURATION CHECK

When the system components are in place, use the following procedure to start up the BAM-1020.

1. Power on and allow 1-hr warm-up (Section 9.6.1)

2. Review and understand the keypad functions and screen displays needed for setup (Section 9.6.2)
3. Load a roll of filter tape (Section 9.6.3)
4. Perform a menu-driven Self-Test (Section 9.6.4)
5. Set the clock (Section 9.6.5)
6. Review configuration parameters (Section 9.6.6)
7. Perform a leak check and a flow calibration (Section 9.6.7)
8. Go to the Main Menu screen and wait for the BAM-1020 to auto start (Section 9.6.8)
9. View the “operate” menus during a regular sampling cycle (Section 9.6.9)
10. Conduct a 72-hr zero test (required for PM_{2.5} FEM EQPM-0308-170) (Section 9.6.10)

If the BAM-1020 will be connected to an external data logger, additional steps are required in the setup process. RS232 data communications are recommended whenever possible. BAM-1020 setup parameters and important issues that must be considered when connecting the instrument to an external DAS are covered in **Section 11**.

9.6.1 Power On and Warm Up

Verify that all wiring connections are attached appropriately: double check the BX-596 wiring, the chassis ground wire, the pump-control wiring, and the wiring for all sensors that are connected to the auxiliary inputs available on the back of the BAM-1020. Sensors that are not properly connected, or that are connected *after* the BAM-1020 is powered up, may not be recognized. While sensors connected after powering normally would only require cycling the power, troubleshooting can be frustrating if the user is not aware that the BAM-1020 may not recognize sensors connected after power is on.

Turn on the power switch (located on the back of the BAM-1020 above the power cord) and allow the unit to warm up for at least one hour. The Main Menu Screen will appear; because no filter tape has yet been loaded, the screen will flash “FILTER TAPE ERROR!” This one-hour warm-up period allows the vacuum tube in the beta detector to stabilize. Some additional setup tasks can be accomplished during this warm-up period. The first two or three hours of data following power-up should be discarded.

9.6.2 Keypad Functions and Screen Displays

The keypads and the screen display interface are used any time a technician interacts with the BAM-1020. There are many screen displays, but only a few are used during the setup process and routinely thereafter. The keypads are frequently referenced in this SOP and throughout the Met One BAM-1020 Operation Manual, so it is important to understand the functions of the different keypad groupings. There are four keypad groups: Soft Keys, Contrast Key, Function

Keys, and Arrow Keys. These keypads are depicted in **Figure 9-3**. This diagram is excerpted from the BAM-1020 Operation Manual and annotated.

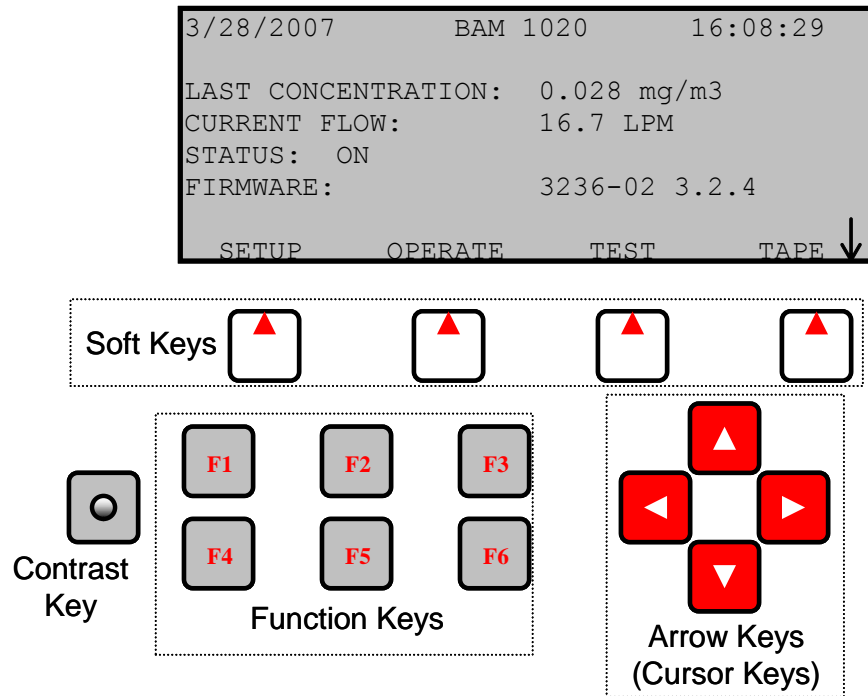


Figure 9-3. BAM-1020 keypad groupings and the Main Menu screen display.

9.6.2.1 Soft Keys

Each white Soft Key performs the function for the menu item that appears directly above it. The menu items change as the user cycles through the different options. These Soft Keys are widely used throughout the BAM-1020 operating system.

9.6.2.2 Arrow Keys

The red Arrow Keys (Cursor Keys) allow the user to navigate throughout the displayed screen, to select items, or to increase/decrease values.

9.6.2.3 Function Keys

The Function Keys open commonly accessed screens and are very useful for accessing data and information while the BAM-1020 is actively sampling because *they will not interrupt the sampling cycle*. Key F1 displays current (instantaneous) data; F2 displays latest average data; F3 displays errors, sorted by date; and F4 allows viewing of up to 12 days of stored concentration, flow volume, and external channel data. Key F5 is rarely used and Key F6 is not assigned a data function.

9.6.3 Loading Filter Tape

Figure 9-4 depicts the routing of the filter tape in the instrument. There are several things to be aware of during the tape-loading process:

- Ensure that, when the tape loading is complete, the pinch roller assembly is unlatched and lowered into place (a BAM-1020 self-test will catch this but the user must manually lower the pinch roller).
- Tighten the tape spool covers sufficiently; they can loosen during operation and cause a Tape Error and loss of data. Do not over-tightened to the point of damaging the spool threads.
- Always use an empty core tube on the take-up spool and never fasten the tape to the aluminum hub.

A roll of filter tape must be loaded into the BAM-1020 for sampling. One roll of tape should last more than 60 days under normal operation. It is important that several spare rolls of tape are available to avoid data interruptions. Save the used rolls of tape for post-sampling analysis. Used filter tape should never be “flipped over” or re-used! Doing so will result in measurement problems.

It is important to keep stray particles from contaminating the tape during the loading process. MetOne recommends wearing lint-free cotton gloves when handling the tape. At a minimum, hands should be clean before the tape is handled, and keeping some waterless hand cleaner on site is a good idea.

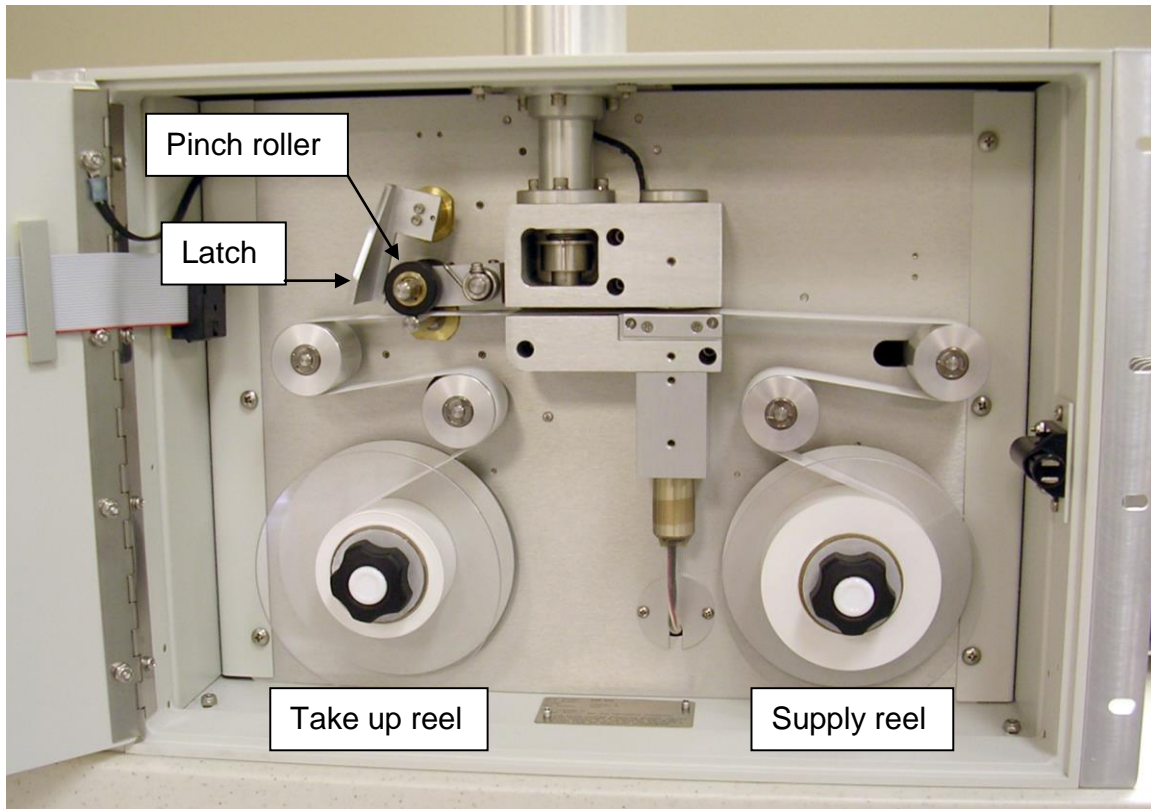


Figure 9-4. Filter tape routing in the BAM-1020.

Loading a roll of filter tape following these steps is a simple matter:

1. Turn the BAM-1020 on and enter the TAPE menu (Note: This menu is *not* the same as the TEST > TAPE menu). If the nozzle is not in the UP position, press the TENSION soft-key to raise the nozzle.
2. Lift the rubber pinch roller assembly (see Figure 9-4) and latch it in the UP position. Unscrew and remove the clear plastic spool covers.
3. An empty core tube **MUST** be installed on the left (take-up) reel hub to provide a surface for the used tape to spool-up on. Met One supplies a plastic core tube for use with the first roll of tape. After that, use the empty core tube left over from the last roll to spool-up the new roll. Never fasten the filter tape to the aluminum hub.
4. Load the new roll of filter tape onto the right (supply) reel, and route the tape through the transport assembly as shown in Figure 9-4. Attach the loose end of the filter tape to the empty core tube with cellophane tape or equivalent.
5. Rotate the tape roll by hand to remove excess slack; then install the clear plastic spool covers. The covers will clamp the rolls to the hubs to prevent slipping.
6. Align the filter tape so that it is centered on all of the rollers. Newer units have score marks on the rollers to aide in visually centering the tape.

7. Unlatch and lower the pinch roller assembly onto the tape. **The BAM will not function if the pinch rollers are latched up, and it does not automatically lower the roller assembly!**

9.6.4 Perform a Menu-Driven Self-Test

The self-test function should be run after each filter tape change. (Running this test is useful any time that troubleshooting is undertaken because it automatically tests most of the tape control and flow systems of the unit. Note that since the self-test checks the flow, the pump must be connected and ready to run!) Press the TAPE Soft Key and then press the SELF TEST soft-key to start the test. The test will take a few minutes, and the BAM-1020 will display the results of each tested item with an **OK** or a **FAIL** tag. If all the test items are **OK**, the self-test status screen will show “SELF TEST PASSED”, as shown in **Figure 9-5**. If any item fails, the self-test status screen will show “ERROR OCCURRED”. A description of all the parameters listed in the self-test screen is given in the BAM-1020 Operation Manual (Rev G, page 23).

```
02/08/1999      15:29:30
LATCH: OFF      TAPE BREAK: OK
CAPSTAN: OK     TAPE TENSION: OK
NOZZLE DN: OK  SHUTTLE: OK
NOZZLE UP: OK  REF EXTEND: OK
FLOW: OK       REF WITHDRAW: OK
Status: SELF TEST PASSED
TENSION SELF TEST EXIT
```

Figure 9-5. The self-test status screen following a test with no errors.

9.6.5 Set the BAM-1020 Clock

The clock setting can be accessed by pressing the SETUP Soft Key from the main screen, which will display a subset of menus, each containing specific information (**Figure 9-6**). Use the Arrow Keys to move to the desired menu, and press the SELECT Soft Key to display the information. Once set, most values in the SETUP menus will not have to be changed by the site operator. The SETUP values will not be lost if the unit is unplugged or powered down.

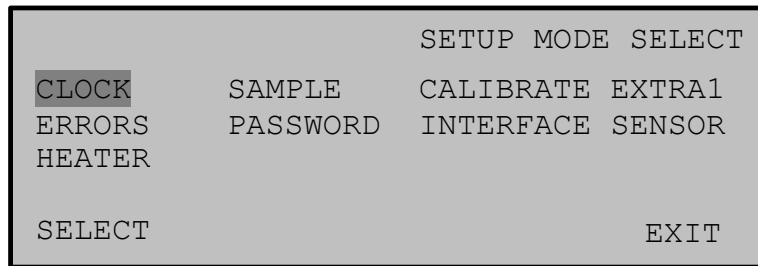


Figure 9-6. Pressing the SETUP Soft Key accesses the SETUP screen that contains a series of submenus with specific information.

BAM-1020 time is a 24-hr clock only. Use the arrow keys to select and increase/decrease the desired field, then press the SAVE soft-key. The BAM-1020 clock may drift as much as a minute or two per month. Met One recommends checking the clock monthly to ensure correct sample timing. **The BAM clock should be permanently set for Local Standard Time** and should never be reset to Daylight Savings Time. To express the hourly data on a different time basis (if needed), adjust by post-processing the time stamp.

9.6.6 Review System Configuration Parameters

In addition to the CLOCK screen, three screens must also be viewed to verify that the BAM-1020 is properly configured for FEM designation EQPM-0308-170 for sampling PM_{2.5} mass: the SAMPLE screen, the CALIBRATE screen, and the HEATER screen. Detailed descriptions of other SETUP menu screens are given in the BAM-1020 Operation Manual (Rev G, pages 39-51).

9.6.6.1 SAMPLE Settings Screen – Critical Information

Parameters governing the sampling protocol are accessed via the SETUP > SAMPLE screen (**Figure 9-7**). To meet FEM designation EQPM-0308-170 requirements, the BAM SAMPLE (the amount of time that the vacuum pump is on per cycle) and COUNT TIME (the amount of time the unit takes to perform the before-sampling I₀ and after-sampling I₃ counts) parameters must be set to 42 minutes and 8 minutes, respectively. Other fields can be adjusted by the user to be compatible with particular circumstances, but the default values suggested by Met One (shown in Figure 9-7) should be used as a starting point. Before changing any SAMPLE screen setup values, the effect(s) on instrument operation and data integrity should be fully understood. For example, meteorological data logged by the BAM-1020 at 5-minute resolution dramatically decreases the length of time data can be stored before being overwritten. The OFFSET parameter in particular is often misunderstood and has important ramifications for analog data acquisition (see **Section 11.3** for a discussion of this setting). A complete description of each SAMPLE screen parameter is given in the BAM-1020 Operation Manual (Rev G), along with acceptable ranges and limitations. The fields can be edited with the arrow keys and saved with the SAVE soft-key.

If multiple BAM-1020s are used in a network, entering a unique STATION # in the SETUP>SAMPLE screen is helpful. This identifier is included in each manual download and helps prevent confusion.

```
                                SETUP SAMPLE
RS232 9600 8N1      BAM SAMPLE 042 MIN
STATION # 01      MET SAMPLE 60 MIN
RANGE 1.000 mg   OFFSET -0.015 mg
CONC UNITS mg/m3 COUNT TIME 8 MIN
SAVE                                EXIT
```

Figure 9-7. This example SAMPLE screen reflects the correct BAM SAMPLE and COUNT TIME parameters to meet the requirements for FEM PM_{2.5} mass sampling.

9.6.6.2 CALIBRATE Screen – *Critical Information*

WARNING: Settings in the CALIBRATE screen are unit-specific calibration constants that cannot be changed without affecting the accuracy and proper operation of the unit.

Each BAM-1020 is calibrated at the factory and has unique calibration settings that are provided on an accompanying calibration certificate. A copy of this certificate, specific to the instrument's serial number, should be kept with the instrument at all times. The SETUP > CALIBRATE screen stores most of these factory-determined calibration parameters for the BAM-1020. Most of these settings will never be changed without specific information from Met One. It is good practice to periodically audit the BAM-1020 settings (Section 10.2.4 and Table 10.3) to verify that they have not been altered. The CALIBRATE screen is shown in **Figure 9-8**.

```
CALIBRATE SETUP
CONC TYPE: ACTUAL      FLOW RATE: 16.7
                        FLOW TYPE: ACTUAL
      Cv: 1.047          Qo: 0.000
      ABS: 0.822        μsw: 0.306
      K: 1.005          BKGD: -0.0030
STD TEMP: 25C          HEATER: AUTO
SAVE                  EXIT
```

Figure 9-8. The CALIBRATE SETUP screen stores the instrument-specific calibration constants, flow settings, and heater mode setting.

FEM designation EQPM-0308-170 requires that the FLOW RATE be set to 16.7 lpm, the CONC TYPE and FLOW TYPE both be set to ACTUAL, and the HEATER be set to AUTO. Actual flow (also referred to as volumetric flow) is controlled by, and reported at, ambient temperature and pressure conditions. The flow rate setting need never be changed in the SETUP > CALIBRATE screen. In earlier firmware, the flow rate setting was sometimes changed to test the pump and flow controller, but this function is now handled in the multi-point flow calibration procedure in FEM versions of the BAM-1020. Other FLOW TYPE settings (METERED and STANDARD) are described in the BAM-1020 Operation Manual (Rev G, page 31-32), but are not acceptable for FEM PM_{2.5} mass monitoring.

The unit-specific calibration constants (C_v , Q_0 , ABS, μ_{sw} , K) on the SETUP > CALIBRATE screen should agree with the values on the calibration certificate: compare the numbers on the screen with those on the certificate and verify that they are identical. *When the instrument is configured for FEM PM_{2.5} sampling, none of these settings are ever changed without specific advice from Met On.* Consult the BAM-1020 Operation Manual for a description of the calibration constants (Rev G, pages 43-44).

The BKGD (background) value is the factory-set zero correction (slope offset) for the BAM-1020 concentration. This value is determined by running the unit for at least 72 hours with a 0.2 micron zero filter on the inlet. The concentration values over this time are averaged, and the BKGD is the negative of this average. All stored and displayed data contain this correction. The BKGD value is typically between 0.000 and -0.005 mg/m³. *FEM designation EQPM-0308-170 requires that this zero test, or background test, be conducted when the BAM-1020 is installed and annually thereafter.* The instructions for conducting this test are presented in Section 9.6.10 and are also provided with the zero filter kit (BX-302) that Met One provides with the purchase of a PM_{2.5} FEM version of the BAM-1020. This BKGD value may need to be updated based on the results of the 72-hr zero test conducted at the time the BAM-1020 is installed. Note: The BKGD value is not to be confused with the OFFSET (range offset) value in the SETUP > SAMPLE menu. See the discussion in Section 11.4.

9.6.6.3 Review Smart Heater Control Settings in the HEATER Screen

When the HEATER mode in the CALIBRATE screen is set to AUTO (see Figure 9-8), the HEATER setup screen becomes available (**Figure 9-9**).

```
Heater Setup
  RH Control:   YES
  RH Setpoint:  35%
  Datalog RH:  YES (Chan 4)
  Delta-T Control: NO
  Delta-T Setpoint: 99 C
  Datalog Delta-T: NO (Chan 5)
  SAVE                               EXIT
```

Figure 9-9. The HEATER setup screen showing settings appropriate for FEM PM_{2.5} measurements.

The HEATER screen is accessed from the SETUP menu to verify or change the settings. For PM_{2.5} and PM₁₀ FEM monitoring, RH Control must be set to YES, RH Setpoint must be set to 35% (the equilibration RH for FRM filters), and Delta-T Control must be set to NO. The Smart Heater will be automatically turned on to full power whenever the humidity of the sample stream exceeds the RH Setpoint, helping to minimize positive artifact resulting from water sorption by the PM on the filter.

If no external sensors are connected to Channels 4 or 5, the filter tape RH can be logged on Channel 4 and Delta-T can be logged on Channel 5. Since Delta-T Control is set to NO, the Delta-T setpoint should be 99. Note that Delta-T can still be logged even though Delta-T control is disabled. Additional information on the Smart Heater settings is available in the BAM-1020 Operation Manual (Rev G, pages 50-51).

9.6.7 Perform a Self Test, an Initial Leak Check, and a Flow Calibration

Self tests, leak checks, flow verifications, and flow calibrations are QA protocols routinely performed QC protocols and are detailed in Section 10, “Maintenance and Operational Procedures”. Consult that section and follow the procedures outlined for a self test (9.6.4), a leak check (Section 10.1.2) and a flow calibration (Section 10.2.3).

9.6.8 Go to the Main Menu screen and Wait for the BAM-1020 to Auto-start

The installation and setup process is nearly complete. Exit to the Main Menu screen and verify that the “Status” line displays “ON” and that there are no errors. The unit will start the sampling cycle at the beginning of the next hour. The cycle begins with an 8-minute count (I_0) of beta particles through the clean tape, at which point the pump will turn on and run for 42 minutes. The cycle ends with another 8-minute count (I_3) through the particle laden spot. These three portions of the hourly cycle constitute 58 minutes, the remaining 2 minutes of the hour are used for tape transport and nozzle movement processes. A complete description of the BAM-1020 measurement cycle is given in the BAM-1020 Operation Manual (Rev G, pages 27-29). Understanding the measurement cycle is of great practical value to the user.

9.6.9 View the Operate Menus During a Regular Sampling Cycle

Once the BAM-1020 is set up and sampling, it should be allowed to run for several hours to confirm that everything is functioning correctly before the initial zero (BKGD) test is conducted, as required by EQPM-0308-170. This waiting time is opportune for the user (especially new users) to view the menus available during the sampling cycle. These menus are the FLOW STATISTICS screen, the OPERATE screen, and three other screens accessible via Soft Keys from the OPERATE screen: the NORMAL screen, the INSTANTANEOUS screen, and the

AVERAGE screen. These screens are described below. Viewing these screens will not interrupt the sampling cycle. *However, entering the SETUP or TEST menus during a sampling cycle will cause the cycle to abort.* The BAM-1020 will also stop itself if a non-correctable error is encountered, such as broken filter tape or failed air flow.

9.6.9.1 The FLOW STATISTICS Screen

All FEM approved BAM-1020 instruments are equipped with firmware version 3.2.4 or later. These firmware versions support a Main Menu Screen that has a small arrow at the bottom right corner (see Figure 9-3). Pressing the ARROW DOWN key while in the main menu screen will display the FLOW STATISTICS screen showing the current hour's statistics for sample time, flow, ambient temperature and barometric pressure (**Figure 9-10**).

```
03/28/2007  FLOW STATISTICS  16:26:30
SAMPLE START: 2007/03/28 16:08:30
      ELAPSED: 00:18:00
      FLOW RATE: 16.7 LPM
AVERAGE FLOW: 16.7 LPM
      FLOW CV: 0.2%
      VOLUME: 0.834m3
↓
EXIT
```

```
FLOW FLAG: OFF
      AT: 23.0
      MAX AT: 23.5
AVERAGE AT: 23.0
      MIN AT: 22.5
      BP: 760
      MAX BP: 765
AVERAGE BP: 760
      MIN BP: 755
```

Figure 9-10. The FLOW STATISTICS screen is entered by pressing the ARROW DOWN from the main menu.

Other screens available for viewing without interrupting the current sample cycle are accessed via the Soft Keys on the OPERATE screen. Exit the FLOW STATISTICS screen back to the main menu, and choose the OPERATE Soft Key. The OPERATE screen appears (**Figure 9-11**).

9.6.9.2 The OPERATE Screen

The DOWN arrow can be used to set the Operation Mode from ON to OFF. This action will stop the measurement cycle, but will not power-down the BAM-1020. The mode automatically resets to ON at the top of the hour.

```
11/15/2006   OPERATE MODE   14:13:07

      ↑ = ON
      ↓ = OFF
Operation Mode: ON
      Status: ON

NORMAL      INST      AVERAGE      EXIT
```

Figure 9-11. The OPERATE screen allows the user to power the BAM-1020 on or off and provides access to the NORMAL, INSTANTANEOUS, and AVERAGE screens.

The only ways to prevent the unit from automatically starting a cycle are to power off the unit, leave the unit in a TEST or SETUP menu, or leave the pinch rollers latched in the UP position.

The NORMAL screen (**Figure 9-12**), the INSTANTANEOUS screen (**Figure 9-13**), and the AVERAGE screen (not shown) are entered by pressing the Soft Key below the menu item on the OPERATE screen.

9.6.9.3 The NORMAL Screen

Since the NORMAL screen displays most of the important parameters of the sample progress in one place, it is useful to leave the BAM-1020 in the NORMAL screen whenever the unit is operating, instead of the Main Menu. The **LAST C** value indicates the last concentration record, updated at the end of the cycle. The **LAST m** value indicates the last measured value of the reference span membrane. The **LAST m** value should be very close or equal to the expected value (**ABS**) that is specific for each instrument. The other values are instantaneous measurements.

```
11/15/2006           Normal Mode           11:27:54

                                Flow(STD) : 16.7 LPM
                                Flow(ACTUAL) : 16.7 LPM
LAST C: 0.061 mg/m3           Press: 764 mmHg
LAST m: 0.806 mg/cm2         RH: 37 %
                                Heater: OFF
                                Delta-T: 4.2 C
STATUS: SAMPLING                                EXIT
```

Figure 9-12. The NORMAL screen displays most of the important parameters of the sample progress in one place.

9.6.9.4 The INSTANTANEOUS and AVERAGE Screens

The INST (Instantaneous) screen (Figure 9-13) displays the instantaneous data values of any optional sensors that may be connected to the BAM-1020 Channels 3 through 8. The AVERAGE screen (not shown) is similar to the INST, except the six external data logger channels are average values over the average period of the data logger (configurable, but usually 60 minutes). In both screens, the **Conc** (concentration) and **Qtot** (total flow volume) represent the most recent complete sampling period.

11/15/2006		CAL DATA FLAG: OFF		11:27:54	
	Eng Units		Eng Units		
1	Conc	0.010 mg	2	Qtot	.834 m3
3	WS	0.000	4	WD	0.000
5	BP	0.000	6	RH	0.000
7	SR	0.000	8	AT	0.000
		TOGGLE FLG VOLT/ENG		EXIT	

Figure 9-13. The INSTANTANEOUS screen is especially useful for monitoring optional sensors that may be connected to BAM-1020 Channels 3 through 8.

9.6.10 Conduct a 72-hr Field BKGD Zero Test

The BKGD value is a correction offset for beta-source fluctuations, mechanically induced bias, and site-specific interferences such as radio frequency or other electromagnetic perturbations that can cause bias in concentration measurements (see BAM-1020 Operation Manual, Rev G, Sections 6.3 and 7.7). This value is factory-calibrated for each unit under laboratory conditions, but BAM-1020 units set up to monitor PM_{2.5} under FEM EQPM-0308-170 must have this value field verified (and adjusted if necessary) when deployed in its normal operating environment, and periodically afterwards, using the BX-302 Zero Filter Calibration Kit (**Figure 9-14**). MetOne provides a separate manual for the zero test with each FEM BAM-1020. Note that the BAM-1020 “thinks” it is conducting normal sampling during the zero test, so it is important to record when the test is being performed because the instrument does not provide a flag or otherwise mark the data.



Figure 9-14. The BX-302 Zero Calibration Kit is required for the BKGD zero test.

Zero tests are performed periodically following installation. The frequency of recurrence is annually. Once the initial background is established, there should theoretically be no trend in the zero data, however, due to the extreme climate conditions of the area, an annual zero test ensures that there was no zero drift. A carefully established and stable zero suggests alternative strategies for periodic testing. For example, if the BKGD was set properly, conducting a 24-hr test, *without resetting the BKGD to zero*, should be within a microgram or two of zero. If it is not, the test could be continued. If the BKGD value is reset to zero at the beginning of the test (as described below), a 72-hr test is required.

This test is important because the BKGD correction is applied to each data point. The factors listed below should be taken into consideration any time a zero test is conducted.

- The required zero test (at the time of installation) should take place after the unit has been set up and operating for a day or so to ensure that the instrument is equilibrated and stable.
- Because the PM₁₀ inlet is removed during the zero test, precautions should be taken to avoid letting rain get into the zero filter. Attaching a piece of tubing to the filter in an arc, with the opening unobstructed and pointed downward with the aid of a zip tie, will mitigate this problem.
- The test should not be performed during a period of rapidly changing weather due to the associated changes in the density of the air mass, which can affect the count of beta particles as they pass through the air gap above the detector.

- A 72-hr test results in better statistics than does a 24- or 48-hr test. Do not shorten the length of the zero test when the BAM-1020 is installed.
- Use only digital data to calculate the BKGD value. Do not use external analog data logger values to calculate the BKGD.
- Temperature fluctuations should be minimized. All monitors show a floating response to temperature fluctuations; the BAM-1020 is no exception.
 - Fluctuations in ambient temperature are less important than the temperature inside the enclosure.
 - Data stability is acceptable with maximum fluctuations of $\pm 5^{\circ}\text{C}$.
 - ShelterOne shelters available from Met One are not cooled, only heated. These shelters need at least a fan for ventilation, which is now being provided with the shelter. Available Ekto shelters are considerably more expensive but provide climate control.
 - Controlling temperature fluctuations in small outdoor shelters is more difficult than it is in larger trailers or buildings, which are preferred for permanent installations.

The test involves running the BAM with a zero (0.2 micron) filter installed on the BGI VSCC™ (in place of the PM₁₀ inlet) for at least 72 hours. The new BKGD, calculated as an average of the hourly concentrations, is entered into the BAM in the CALIBRATE setup screen (see Figure 9-8) as a negative number. **Figure 9-15** shows a typical 72-hr time series trace of concentrations from a zero BKGD test.

Several specific steps are necessary for the BAM-1020 BKGD zero test:

1. Ensure that the BAM-1020 is properly warmed up.
2. Record the initial BKGD setting as listed in the CALIBRATE setup screen.
3. Set the BKGD value to 0.000.
4. Install the zero filter on the inlet.
5. Conduct a leak check (Section 10.1.2).
6. Calibrate the instrument (Section 10.2.3).
7. Ensure there are 72 consecutive valid hours of data.
8. Remove the first 4 hours of zero test values (run for 76 hours).
9. Ensure that no value exceeds $20 \mu\text{g}/\text{m}^3$
10. Ensure that there are no $-15 \mu\text{g}/\text{m}^3$ values. The default lower limit clamp (the minimum value that the BAM-1020 will report, regardless of what is measured) is $-15 \mu\text{g}/\text{m}^3$. The presence of this value in the results suggests that numbers more negative than $-15 \mu\text{g}/\text{m}^3$ may have been measured, but not reported. Thus, $-14 \mu\text{g}/\text{m}^3$ is the most negative value allowed for the zero test.

11. For the installation zero check, if the resulting average BKGD value is more than a microgram different from the previously programmed value, adjust it.

12. If the BAM-1020 reports any errors, rerun the test.

If the test fails the criteria above, take corrective action.

- Stabilize the temperature and rerun the test.
- Check that electrical grounding for the instrument is solid, including the down tube (see Section 9.5.10).

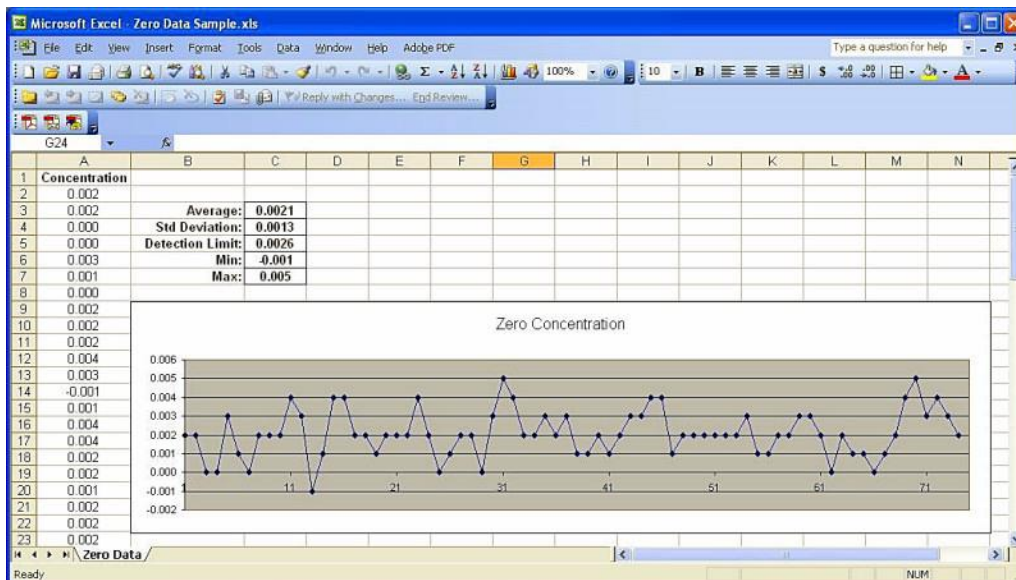


Figure 9-15. Typical BAM-102072-hr zero BKGD test results. This example is taken from the BAM-1020 Operation Manual (Rev G).

10. MAINTENANCE AND QUALITY CONTROL PROCEDURES

Once the FEM BAM-1020 is installed and configured, a regularly recurring protocol of maintenance and QC procedures must be established to ensure that a continuous stream of high quality hourly PM_{2.5} or PM₁₀ concentration data is obtained. **Table 10-1** lists the MetOne recommended maintenance and QC procedures, frequencies of recurrence, and the sections of this SOP that describe the sequential steps needed to perform each maintenance or QC procedure. 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.

The frequency at which these QC protocols are conducted is site- and agency-specific. Many agencies conduct some of these protocols (items with asterisk—*—in Table 10-1) more frequently (e.g., biweekly) than listed in the table to minimize the need to invalidate data because of a failed QC test (e.g., failed leak check), which requires that data be invalidated back to the most recently passed QC check. This increased frequency is generally based on experience—if monthly leak checks are failing because of debris buildup under the nozzle, the logical solution is to clean the nozzle bi-weekly. Since most QC protocols require that the sampling cycle be interrupted, more frequent QC procedures need to be balanced against the one two hours of data that are lost.

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. **Table 10-2** demonstrates specific action and critical tolerances for the QC checks.

It is important to consider that *frequent adjustments of instruments may not be necessary* and may lead to *more* data quality uncertainty. The site supervisor should decide on the recurrence schedule and the tolerance levels that best fit the circumstances.

Table 10-1. Met One-recommended maintenance and QC protocols, frequencies, and SOP section references. Items marked with an asterisk are performed at more frequent intervals by some agencies.

Maintenance or QC Item	Required Period	SOP Section(s)
Verify Flow Rate*	Biweekly	10.1.1
Conduct Leak Check*	Monthly	10.1.2
Clean the Nozzle and Vane*	Monthly	10.1.3
Clean the Capstan Shaft and Pinch Roller Tires*	Monthly	10.1.4
Clean the PM ₁₀ Inlet	Monthly	10.1.5
Clean the VSCC™	Monthly	10.1.6
Check the Error Log*	Monthly	10.1.7
Compare BAM-1020 Data to External Datalogger Data	Monthly	10.1.9
Replace Filter Tape	2 Months	10.2.1 (9.6.3)
Run SELF-TEST Function	2 Months	10.2.2 (9.6.4)
Verify Flow and Conduct Volumetric Flow Calibration P and T checks implied here	2 Months	10.2.3
Verify BAM-1020 Settings and Check Real-Time Clock	2 Months	10.2.4
Replace or Clean Pump Muffler (if used)	6 months	10.3.1
Test Filter Temperature and RH sensors	6 months	10.3.2
Test Smart Heater	6 months	10.3.3
Perform 72 hour BKGD (BX-302 zero filter) test	12 months	10.4.1
Clean Internal Debris Filter	12 Months	10.4.2
Check Membrane Span Foil	12 Months	10.4.3
Perform Beta Detector Count Rate and Dark Count Test	12 Months	10.4.4
Clean Inlet Tube	12 months	10.4.5
Test Analog DAC Output (if used)	12 Months	10.4.6
Independent audit	12 Months	10.4.7
Replace lithium coin cell battery on 3032 circuit board	12 Months	10.4.8
Rebuild Vacuum Pump*	24 months	10.5.1
Replace Nozzle O-ring (Special tools required)	24 months	10.5.2
Replace Pump Tubing	24 Months	10.5.3
Factory Recalibration. Not required except for units sent for major repairs.	—	

Table 10-2. “Quality Control Action and Critical Criteria for the Met One Instruments BAM-1020”

QC Check	Tolerance	Class	Procedure
Flow Rate 16.7 lpm	> ±4% (16.00-17.34)	Action	Troubleshoot Leak and/or Recalibrate Instrument Flow Rate.
Leak Check	>1.5 lpm		
Flow Rate 16.7 lpm	> ±6% (15.67-17.67)	Critical	Troubleshoot Leak and/or Recalibrate Instrument Flow Rate And Invalidate data back to last good Audit.
Leak Check	>3.0 lpm		
Temperature	± 2.5 °C	Action	Recalibrate Instrument.
Pressure	± 6 mm Hg		
Temperature	± 4.0 °C	Critical	Recalibrate Instrument And Invalidate data back to last good Audit.
Pressure	± 10mmHG		

10.1 MONTHLY MAINTENANCE AND QC

The monthly site visits and associated tasks are essential for maintaining optimal instrument performance. All data pertinent to the monthly maintenance and QC procedures should be documented in LIMS. Seven examples of QC forms are provided in Appendix A to be used as a guide in the field and to gather appropriate information that will ultimately be documented in LIMS. Electronic forms (e.g., MS Excel spreadsheets) are preferred by some users.

Order of events recommended for monthly QC:

1. Flow verification (as found)
2. Leak check (as found)
3. Nozzle and vane cleaning
4. Capstan shaft and pinch roller cleaning
5. PM₁₀ inlet and Very Sharp Cut Cyclone cleaning
6. Leak check (as left)
7. Flow verification (as left)
8. Error log check
9. Digital data download

10.1.1 Flow Verification

While the BAM-1020 can be set to any of three flow types—Metered, Standard, or Actual (Volumetric)—FEM designation EQPM-0308-170 for PM_{2.5} mass dictates that it be **configured for volumetric sampling**. Complete descriptions of the flow modes are given in the BAM-1020 Operation Manual (Rev G, pages 31-32).

The volumetric flow rate of 16.7 lpm should be verified at least on a monthly basis. Some users perform the flow verification while the BAM-1020 is in “normal” operating mode (i.e., while it is sampling) by removing the PM₁₀ inlet, attaching the flow reference standard to the inlet tube, and taking a flow reading. There are two potential problems with this approach: (1) the data are not flagged by the BAM-1020, and (2) there is the possibility of dislodging some debris within the inlet and having it fall through to the filter tape. Since the flow verification is generally followed by a leak check, requiring that the sample cycle be interrupted anyway, it is best to stop the cycle, enter the TEST>FLOW screen, choose the flow rate, and verify the flow.

10.1.1.1 Flow Rate Tolerances

The BAM-1020 is designed to operate with an airflow rate of 16.67 lpm. The particle separators require this flow rate in order to properly separate the correct sizes of particles from the air stream. These separators use the inertia of the particles as they flow through the inlet to sort out the ones above a certain size (cut point) so that they won't be measured by the instrument. If the airflow rate is not maintained within $\pm 5\%$ of the design value flow rate of 16.67 lpm, then particles of the wrong size may be allowed through or sorted out.

Flow rate tolerances differ between QC procedures implemented by the field operator and QA procedures implemented by an independent auditor, and the distinction is important (see Section 4). The Code of Federal Regulations (CFR) states that, for QA audit purposes, the FRM sampler flow display must be within 4% of the reference standard flow reading, and the reference standard reading must be within 5% of the design flow rate of 16.67 lpm. From the perspective of field-implemented QC protocols, the CFR-stated FRM flow criteria for a flow check is 4% from the expected 16.67 lpm (16.00-17.34 lpm). By applying these FRM standards to the FEM BAM-1020 field QC procedures, a flow rate within $\pm 4\%$ of the expected 16.67 is set as the tolerance for flow verifications.

10.1.1.2 Equipment Needed

Tools needed for flow rate verification include a NIST-traceable flow reference standard capable of volumetric flow measurements in the range of the BAM-1020 nominal flow rate of 16.7 lpm, which can be attached to the BAM-1020 inlet tube. The flow inlet adapter (MetOne BX-305) may be needed to make this connection, depending on the flow reference standard that is used.

10.1.1.3 Perform “As Found” Flow Rate Verification

It is recommended that the *timing* of the flow verification relative to the sample cycle be taken into consideration. It is best to interrupt the cycle just after the top of the hour when the I₃ count

finishes and the BAM writes the recent hour's data to memory. This timing provides a full hour to perform the flow verification and the other monthly maintenance and QC procedures before the next sample cycle begins.

The following steps enable “as found” flow rate verification:

1. Allow the flow reference standard to equilibrate with ambient conditions. This step can take up to 30 minutes, depending on where the flow standard was stored (e.g., inside a hot vehicle).
2. From the Main menu, press the TEST Soft Key and stop the sample cycle.
3. Select the TEST > FLOW menu to access the MULTIPOINT FLOW CALIBRATE screen (see Figure 10-7). (Note: do not use the TEST > PUMP menu selection to verify the volumetric flow rate because that flow rate is given in standard conditions, not volumetric.)
4. Press the NEXT Soft Key until “FLOW 3” is highlighted. The pump will be running and the flow controller will be regulating the flow to 16.7 lpm volumetric.
5. Remove the PM₁₀ inlet (for PM_{2.5} samplers leave the VSCC™ attached to the inlet down tube).
6. Attach the reference flow standard to the inlet tube and allow the reading to stabilize.
7. Record the “as found” volumetric flow rate from the flow reference standard.
8. Record the flow rate from the CALIBRATE screen shown under the BAM column for FLOW 3.
9. If the “as found” flow reference standard reading is more than 4% different from 16.67 lpm (± 0.67 lpm, or outside the range 16.0 to 17.34 lpm), a flow calibration should be performed.
10. Continue with other maintenance and QC procedures and, when complete, replace the PM₁₀ inlet and when applicable the VSCC™, and place the BAM into OPERATE mode.

10.1.2 Conduct a Leak Check

The “as found” leak check should be performed *after* the “as found” flow verification.

- From the Main menu, press the TEST Soft Key and stop the sample cycle.
- Remove the PM₁₀ inlet from the inlet tube (for PM_{2.5} samplers leave the VSCC™ attached to the inlet down tube). Install a BX-305 or BX-302 leak test valve (or equivalent valve for auditing FRM samplers) onto the inlet tube. Turn the valve to the OFF position to prevent any air from entering the inlet tube.
- In the TEST > TAPE menu, advance the tape to a fresh, unused spot.

- In the TEST > PUMP menu, turn on the pump. The flow rate should drop below **1.0 lpm**. If the leak flow value is 1.0 lpm or greater, the nozzle and vane need cleaning, or there may be another small leak in the system.
- Resolve the leak and perform the check again. A properly functioning BAM with a clean nozzle and vane will usually have a leak value of about **0.5 lpm** or less using this method.
- Turn the pump off, remove the leak test valve, and re-install the inlet heads.

Most air leaks in the BAM-1020 system occur at the nozzle where it contacts the filter tape. **The BAM-1020 has no way of automatically detecting a leak at this interface**, because the airflow sensor is located downstream of the filter tape. There will normally be a very small amount of leakage at the tape, but an excessive leak lets an unknown amount of air enter the system through the leak instead of the inlet. This will cause the concentration to be incorrect because, even though the flow controller may be maintaining the flow rate at 16.7 lpm, the portion of the flow coming through the leak is not from the outside ambient air, and it has not passed through the separator inlet. A significant leak at the nozzle will also cause the air flow at the inlet to be outside the $\pm 4\%$ tolerance of the 16.7 lpm nominal flow rate. **Allowing a leak to persist may invalidate an unknown amount of data!**

Leak checks are performed bi-weekly or at least monthly and whenever the filter tape is changed. A significant “as found” leak (nominally greater than 1.5 lpm) will require that data be invalidated all the way back to the last known good leak test (see “Leak Check Tolerances” below). The nozzle and vane cleaning require the removal of the filter tape from the nozzle interface, so a follow-up, or “as left”, leak check should be performed—even if the “as found” leak check was within tolerance.

Whatever interval is used, it is probably best to include the nozzle and vane cleaning on the same schedule, requiring an “as found leak test”, then a nozzle and vane cleaning, followed by an “as left” leak test.

10.1.2.1 Leak Check Tolerances

In July 2003, MetOne lowered the tolerance for the leak check from 1.5 lpm to 1.0 lpm. The typical recommended threshold for invalidating data is the existence of an “as-found” leak value (before cleaning nozzle and vane) of 1.5 lpm or higher. One way to view the leak check is to consider anything under 0.5 lpm to be “good”, with readings between 0.5 and 1.0 lpm indicating potential problems, such as the beginning of debris problems at the nozzle/tape interface. Readings between 1.0 and 1.5 lpm may not cause data to be invalidated, but should certainly prompt investigation and perhaps corrective action.

10.1.2.2 Leak Isolation

Since most leaks occur at the nozzle/tape interface, regular cleaning will normally prevent or correct this problem. However, there are many other places in the air sample train from inlet to

pump where leaks are possible. If nozzle and vane cleaning fail to cure a leak, then a second cleaning is recommended—perhaps something was missed the first time.

A leak that persists must be tracked down. MetOne now offers a soft rubber sheet with a ¼ inch hole in it (PN 7440), which is highly recommended as a tool to have on hand. **Figure 10-1** is a flow chart depicting the sequential steps to take when tracking down a leak.

10.1.3 Clean the Nozzle and Vane

Regularly cleaning the BAM-1020 nozzle may be the single most important factor in preventing failed leak checks and optimizing data accuracy. Monthly cleaning (and at every filter tape change) has generally proven adequate for this procedure, but more frequent cleaning may be necessary in some environments. High leak values normally indicate a build-up of filter material at or near the nozzle/filter paper interface, compromising the interface “seal”, allowing air to be drawn in around the nozzle perimeter. Left uncorrected, the accuracy of the measurements can be affected and, in some situations, negative concentration values and/or low correlation with reference equipment may result. When the nozzle is lowered, the downward pressure on these pieces of filter material can punch a hole in the tape (**Figure 10-2**, right panel). A puncture in the tape allows the beta particles to pass through without attenuation. This defect may reduce the post-sample count, and, in situations of low ambient PM_{2.5} or PM₁₀ concentrations, may cause this count to be larger than the pre-sample count, resulting in a negative concentration.

Theoretically, nozzle and vane cleaning would be performed only when the tape is changed, and the BAM-1020 should operate hole-punch-free the entire time between tape change periods. Hole-punching that occurs between tape change periods indicates that a problem exists and needs to be corrected, especially if the hole-punching reoccurs regularly.

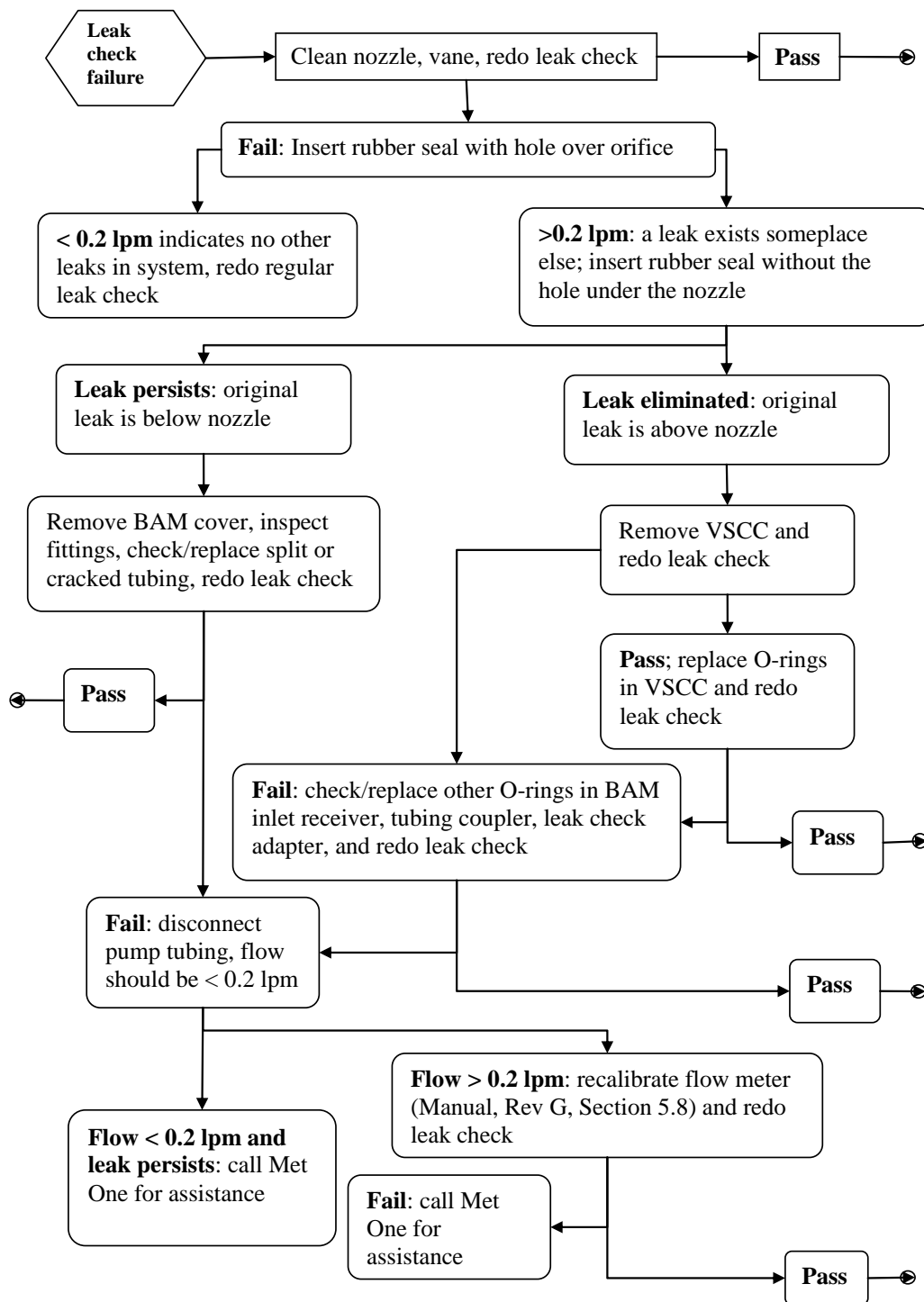


Figure 10-1. A decision tree/flow diagram for identifying leaks in the BAM-1020.

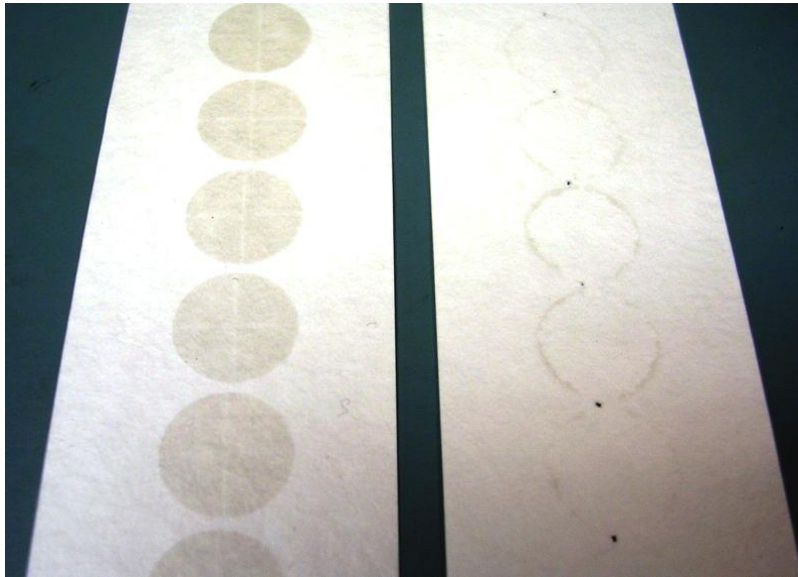


Figure 10-2. Filter tape from a BAM-1020 with a clean nozzle and vane (left) and from a poorly maintained unit (right), where debris accumulation under the nozzle has punched a hole in the tape and caused the nozzle to leak, creating the halo effect. (Photo courtesy of MetOne.)

Nozzle and Vane Cleaning Procedure

The following steps are needed to clean the nozzle and vane. Refer to the photos in **Figure 10-3**.

1. Raise the nozzle in the TEST > PUMP menu. Remove the filter tape (if installed) from the nozzle area. It is not necessary to completely remove the tape from the spools.
2. With the nozzle up, use a small flashlight to inspect the cross-hair vane.
3. Clean the vane with a cotton-tipped applicator and isopropyl alcohol. Hardened deposits may have to be carefully scraped off with the wooden end of the applicator or a dental pick or similar tool.
4. Lower the nozzle in the TEST > PUMP menu. Lift the nozzle with your finger and insert another cotton swab with alcohol between the nozzle and the vane. Let the nozzle press down onto the swab with its spring pressure (Figure 10-3, left panel).
5. Use your fingers to rotate the nozzle while keeping the swab in place. A few rotations should clean the nozzle lip.
6. Repeat the nozzle cleaning until the swabs come out clean.
7. Inspect the nozzle lip and vane for any burrs which may cause leaks or tape damage.

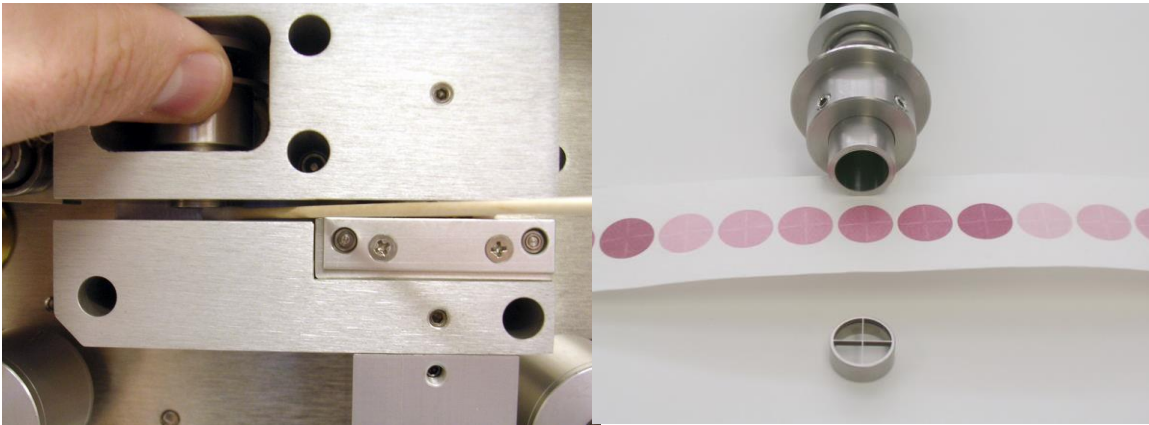


Figure 10-3. A cotton-tipped applicator and isopropyl alcohol are used to clean the BAM-1020 nozzle and vane (left panel). A view of the nozzle, sampled filter tape, and filter tape support vane are shown in the right panel.

10.1.4 Clean the Capstan Shaft and Pinch Roller Tires

Figure 9-4 shows the location of the pinch rollers. The capstan shaft is the stainless steel shaft that the rubber pinch roller rests on. Use a cotton tipped swab moistened with isopropyl alcohol to wipe down the pinch roller tires and the capstan shaft. This action is easiest to do when the pinch roller is latched in the UP position.

10.1.5 Clean the PM₁₀ Inlet

The PM₁₀ inlet needs to be disassembled and cleaned monthly. Instruments in environments with high ambient PM₁₀ concentrations or in areas prone to fugitive dust emissions may require more frequent cleaning of PM₁₀ inlets than those in cleaner environments. MetOne currently recommends that the particle trap (or collector plate) located in the top part of the Collector Assembly (**Figure 10-4**) be cleaned monthly, and that the acceleration chambers be cleaned quarterly. MetOne offers a BAM Inlet Cleaning Kit specifically for this purpose (PN BX-344), which includes a pull-rope, tube brush, microfiber rags, cleaning brushes, o-ring grease, and cotton applicators. Generic equivalents of these items may be used (soft bristled paint brushes, pipe cleaners, “lint free” cloths etc.). A #2 Phillips screwdriver is needed to remove the top plates from the acceleration assembly of the PM₁₀ inlet. Hands should be clean for this procedure.

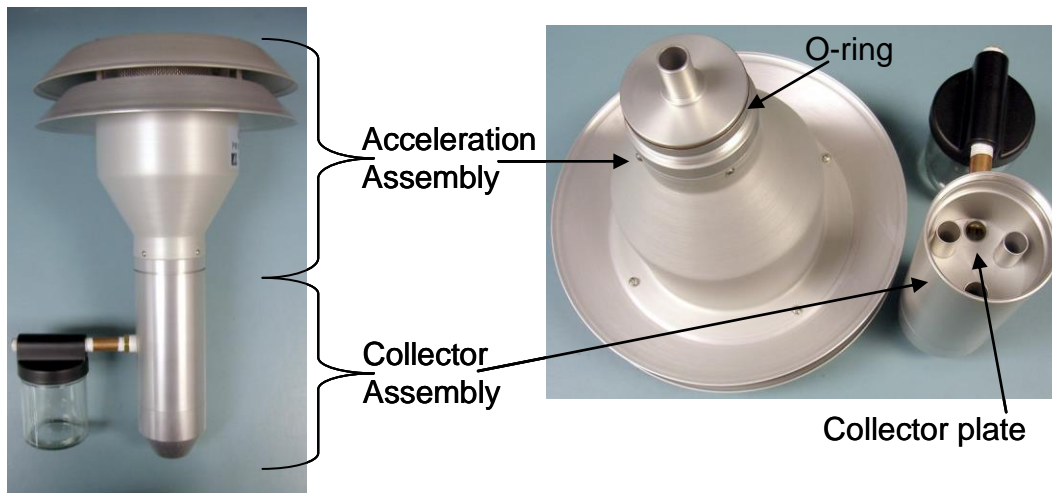


Figure 10-4. The PM₁₀ inlet has two primary components, the Acceleration Assembly and the Collector Assembly.

10.1.5.1 Clean the Collector Assembly (Monthly)

1. Remove the condensation jar and set it aside.
2. Unscrew the Collector Assembly (Figure 10-4, bottom portion of inlet) from Acceleration Assembly (Figure 10-4, top portion of inlet).
3. Use a brush, lint free cloth and/or cotton swabs to clean the bottom collector plate and the collector assembly walls around the three vent tubes, and the weep hole in the collector plate. Water can be used if needed. Allow to dry.
4. Clean inside the vent tubes by running a moistened cloth through them.
5. At the bottom of the Collector Assembly, wipe out the inside area where the two O-rings are situated.
6. Inspect the O-rings and replace if needed. Apply a thin film of O-ring grease on the O-rings.
7. Wipe out the condensation jar and the jar lid. Apply a thin film of grease to the cork seal inside the lid. Clean hands here too, before reassembling (e.g., using wet wipes).

10.1.5.2 Clean the Acceleration Assembly (Quarterly):

1. 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.
2. Lift the Acceleration assembly off the top plate. Lift the lower plate up and carefully remove the insect screen.
3. Clean all the inlet parts of the Acceleration Assembly inside and out (top plates, insect screen, and the Accelerator Assembly body). Parts may only need to be wiped with

brushes or a lint-free cloth, or blown out with compressed air. Alternatively the parts may actually be “washed” in clean water; this is the only good way to remove any caked deposits that may have accumulated in hard-to-reach places. Parts must be thoroughly dried before re-assembly. 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. Inspect the large diameter O-ring at the base of the Accelerator Assembly.

4. Replace the O-ring if necessary, or apply a thin film of O-ring grease on the O-ring and a thin film on the aluminum threads of the acceleration assembly.
5. To avoid contamination of other items, clean hands with a wet wipe or similar material to clean off O-ring grease.
6. Reassemble the PM₁₀ inlet.

10.1.6 Clean the VSCC™

The BGI VSCC™ (**Figure 10-5**) is an essential component of the inlet system for PM_{2.5} monitoring. It needs to be diligently maintained or it will corrode. The VSCC™ should be cleaned every 30 days (i.e., treat the inlet as one would for an FRM). A spare O-ring kit (BGI Inc., PN VSCC™2A) should be kept on hand. Disassemble and clean the VSCC™ following these steps:

1. Remove the VSCC™ from its installed position in the instrument.
2. Pull off the side transfer tube. If it is too tight to remove by hand, pry it off with a rigid plastic lever. Care should be taken to not damage the two O-ring seals.
3. Unscrew the top cap and the grit pot.
4. Use alcohol wipes, or if unavailable, a dampened cloth, to remove all visible deposits. These deposits are most likely to be found at the bottom of the cone (located beneath the grit pot) and inside the grit pot.
5. Inspect all O-rings for shape and integrity. If at all suspect, replace. Lubricate all O-rings with light grease. It is important to well lubricate the transfer tube to avoid difficult disassembly.
6. Clean hands with alcohol wipe or similar media.
7. Assemble in reverse order and reinstall.

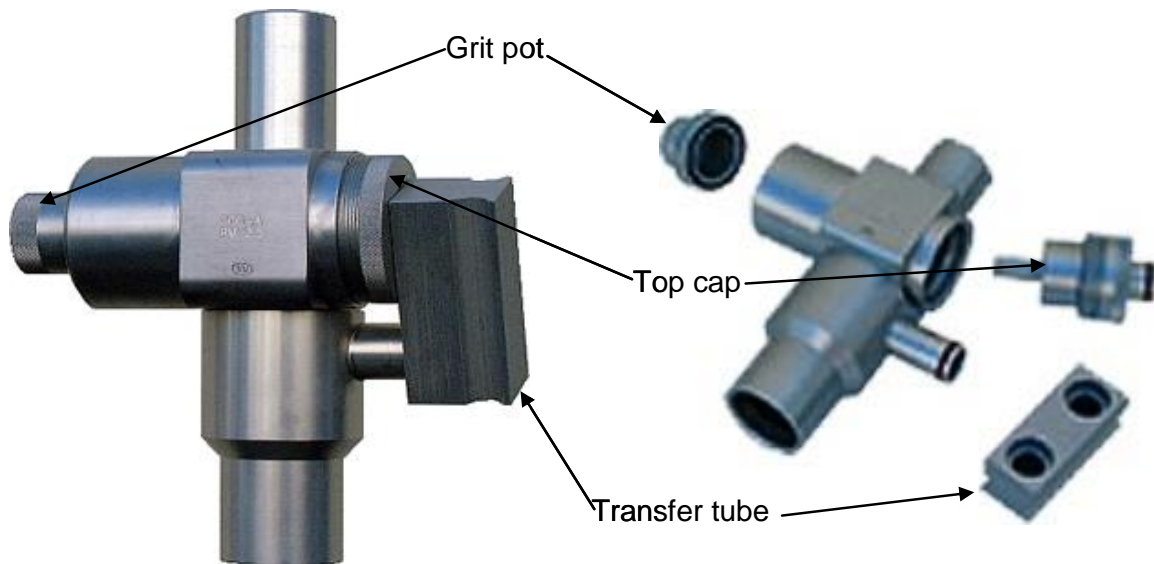


Figure 10-5. The VSCC™ particle separator.

10.1.7 Check the Error Log

There are two methods to check the BAM-1020 error log. The F3 function key (Error Recall) will return up to 100 errors logged during the most recent 12 days, sorted by date. The F3 key can be used without interrupting a sample cycle. These methods are handy for QC checks during regular maintenance. If analog data are being recorded and the BAM-1020 is set up to report errors with the analog output signal (with errors causing full scale voltage output), it is important to check the error log as part of the monthly routine. Some errors will cause the voltage output to go to full scale, but there is nothing wrong with the concentration data. These data would have to be retrieved digitally from the BAM-1020 memory. One example of this voltage error would be a failure of an external reset of the BAM-1020 clock by an external relay. The concentration data are valid, but because of the failure of the clock synchronization protocol, the time stamp associated with the analog data may be in error.

A listing of error flags more than 12 days old requires that the digital data be downloaded and reviewed (Section 10.1.8).

10.1.8 Download the Digital Data Log

It is very important to download the digital data log from the BAM-1020 soon after the installation is complete to confirm that any externally logged data are accurate. It should be part of the regular monthly maintenance schedule in situations where there is no external data acquisition system in place. The amount of internal memory in the BAM-1020 is limited to 4,369 records (182 days at 1 record per hour, but only 15 days if 5-minute meteorological data are being stored). Any catastrophic failure (e.g., fire) may cause loss of all stored data.

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Complete descriptions of the methods for digital data retrieval are given in the BAM-1020 Operation Manual (Rev G, pages 70-79). The most common way, described here, is to retrieve the data with a desktop or laptop computer through the BAM-1020 2-way RS232 serial port, using the HyperTerminal® communications program, or a similar terminal program. A female-to-female 9-pin RS232 cable is required, and modern laptops may need a USB-to-RS232 serial adapter (e.g., Belkin F5U109), or an optional PCMCIA card that has a serial port (e.g., Quatech SSP-100).

Follow these steps to download the BAM-1020 data via HyperTerminal®:

1. Connect one end of the 9-pin cable to the COM port connector on the BAM-1020 (the upper RS232 connector on the back of the unit), and the other to the computer.
2. Ensure that the BAM-1020 user interface is in the main top-level menu or the OPERATE menu. The serial port is disabled in all other menus.
3. Open HyperTerminal® and set the communication properties (File>Properties>Connect To Tab>Configure Button):
 - a. Bits per second: 9600
 - b. Data bits: 8
 - c. Parity: None
 - d. Stop bits: 1
 - e. Flow Control: None
4. The data should be saved to a file; so from the HyperTerminal® Transfer Menu, choose Capture Text, select a location for the file, and click the “Start” button. When the download begins, HyperTerminal® will automatically store the data to the text file.
5. Hit the return (ENTER) key three times and an asterisk (*) will appear on the screen, signifying that the BAM-1020 is ready to communicate.
6. Once communication is established, press the “h” key to view the BAM-1020 System Menu (**Figure 10-6**). You can now send any of the characters in the menu (0-9) to retrieve the designated files. The menu options are described in the BAM-1020 Operation Manual (Rev G, pages 72-78).

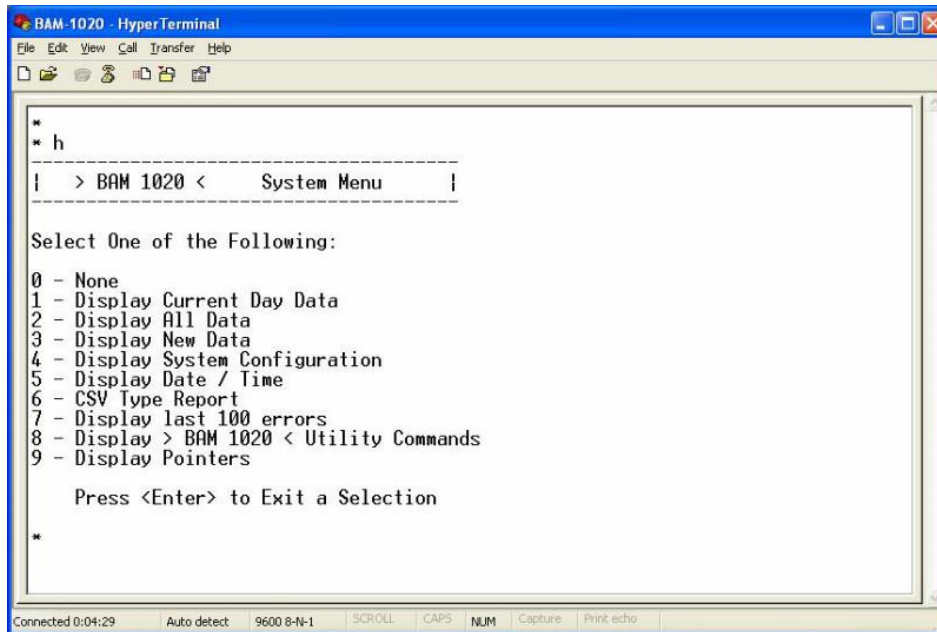


Figure 10-6. Once communication has been established with the BAM-1020, pressing the “h” key will display the System Menu, allowing the choice of several types of files to be downloaded.

7. The recommended data retrieval method is File Type 6, the “CSV Type Report”. This file type can be opened in Excel or other spreadsheet programs. When “CSV Type Report” is requested, the BAM-1020 responds with a second menu:
 - * 6
 - CSV Type Reports

 - 2 - Display All Data
 - 3 - Display New Data
 - 4 - Display Last Data

 - 5 - Display All Flow Stats
 - 6 - Display New Flow Stats

 - 7 - Display All 5-Min Flow
 - 8 - Display New 5-Min Flow
8. File options 5-8 are only available in BAM-1020 units configured for FEM PM_{2.5} sampling. They are described in the BAM-1020 Operation Manual (Rev G, page 77).

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```
High Flow Alarm, 20
Low Flow Alarm, 10
  Heat Mode, AUTO
  Heat OFF, 20
  RH Ctrl, YES
  RH SetPt, 35
  RH Log, YES
  DT Ctrl, NO
  DT SetPt, 99
  DT Log, NO
  BAM Sample, 42
  MET Sample, 60
  Cycle Mode, STANDARD
Fault Polarity, NORM
Reset Polarity, NORM
Maintenance, OFF
EUMILRNFPDCT
000000000000
  AP, 000150
  Baud Rate, 9600
Printer Report, 2
  e3, 00.000
  e4, 15.000

Channel,      1,      2,      3,      4,      5,      6,
Sensor ID,    255,    255,    255,    255,    255,    255,
Channel ID,   255,    255,    255,    255,    255,    255,
Name,         XXXXX,   XXXXX,   XXXXX,   XXXXX,   XXXXX,   XXXXX,
Units,        XXX,     XXX,     XXX,     XXX,     XXX,     XXX,
Prec,         0,      0,      0,      0,      0,      0,
FS Volts,     1.000,   1.000,   1.000,   1.000,   1.000,   1.000,
Mult,         1.000,   1.000,   1.000,   1.000,   1.000,   1.000,
Offset,       0.000,   0.000,   0.000,   0.000,   0.000,   0.000,
Vect/Scalar,  S,       S,       S,       S,       S,       S,
Inv Slope,    N,       N,       N,       N,       N,       N,
```

10.1.9 Compare Internal BAM-1020 Data to External Data Logger Data

In most applications, an external DAS is used to collect the hourly data from the BAM-1020. When using an external DAS, a fundamental QC protocol is a monthly comparison of the internally stored data (assumed to be the “most correct”) with the data stored by the DAS. This comparison is particularly important after a new installation so that any errors associated with the acquisition process can be identified and corrected to avoid continued propagation of the error. Digitally acquired data are less susceptible (although not immune) to acquisition errors than analog, which has some special requirements; **digital methods are recommended whenever possible**. Recommendations for digital or analog interfacing between the BAM-1020 with an external DAS are covered in Section 11.

The comparison of the BAM-1020 internal data with DAS data should focus on timestamps and the concentration data:

- Digitally acquired concentration data in the DAS should agree exactly with the concentration data stored internally in the BAM-1020. If it does not, a time-stamping problem may exist. Compare a specific record in the DAS with the previous and following records (based on the time stamp) downloaded directly from the BAM-1020. If one of these records matches, a one-hour offset needs to be corrected in the data acquisition protocol or in post-processing. See Section 11.2 for a discussion of the possible causes of and solutions for mismatched time stamps in digital data.
- Concentration data collected by the DAS from the *analog* output of the BAM-1020 should agree with the internal BAM-1020 digital data within $1 \mu\text{g}/\text{m}^3$ ($0.001 \text{ mg}/\text{m}^3$). Discrepancies of a few $\mu\text{g}/\text{m}^3$ may be attributable to faulty digital-to-analog-converter (DAC) electronics, or simply sloppy wiring between the BAM-1020 terminal strip and the DAS analog inputs. An Analog Output Test using the BAM-1020 DAC Test Menu should be conducted (BAM-1020 Operation Manual, Rev G, page 60).
- A consistent offset of $15 \mu\text{g}/\text{m}^3$ suggests that the DAS has not been properly programmed to account for the $0.015 \text{ mg}/\text{m}^3$ OFFSET in the SAMPLE Settings screen that is the default OFFSET value for the FEM BAM-1020 (Figure 9-7). See Section 11.3 for a discussion of the BAM OFFSET parameter and analog DA.
- Inconsistencies between analog and digital data of more than a few $\mu\text{g}/\text{m}^3$ can occur if the DAS uses an averaging function, and the clocks of the BAM-1020 and the DAS are not perfectly synchronized. This inconsistency can result in hourly concentration values from adjacent hours being averaged together, making the resulting concentration difficult to match with digital data. Use of the EARLY operating mode can overcome this problem. See SOP Section 11.4 and the BAM-1020 Operation Manual (Rev G, page 65).
- The scenarios described above regarding analog data can be additionally confounded if there is a time stamping problem with the analog data, so be sure to factor that into troubleshooting of discrepancies between downloaded digital data and analog data.

10.2 TWO-MONTH MAINTENANCE AND QC

Two-month maintenance and QC procedures include

- replacing filter tape (Sections 9.6.3, 10.2.1);
- conducting self-tests (Section 10.2.2);
- conducting pressure, temperature, and flow check and possibly calibrations (Section 10.2.3); and
- verifying BAM-1020 settings and checking the clock (Section 10.2.4).

10.2.1 Replace Filter Tape

Refer to Section 9.6.3 or to the BAM-1020 Operation Manual (Rev G, page 21) for instructions on changing the filter tape.

10.2.2 Run Self-Test Function

Refer to Section 9.6.4 or to the BAM-1020 Operation Manual (Rev G, page 21) for instructions on performing the self test. This test must be conducted each time the filter tape is changed and at any other time that the sampling cycle is interrupted.

10.2.3 Verify Flow, Temperature, Pressure, and Calibrate If Needed

A flow calibration is nominally recommended every two months. However, if verifications establish that the instrument is operating well within the specified tolerances (see example Table 10-2), there is no “requirement” that the instrument be recalibrated.

All BAM-1020 instruments configured for FEM PM_{2.5} monitoring must use volumetric (also known as “actual”) flow control, and thus must have the ambient pressure and temperature sensor (BX-596) as part of the system hardware. The FLOW Type must be set to ACTUAL in the SETUP > Calibrate menu, making the MULTIPOINT FLOW CALIBRATION screen available (**Figure 10-7**). The screen is accessed through the Soft Keys via SETUP > TEST > FLOW. When the screen is accessed the BAM-1020 nozzle will automatically lower.

MULTIPOINT FLOW CALIBRATION				
	TARGET	BAM	STD	
	AT:	23.8	23.8	C
	BP:	760	760	mmHg
<CAL>	FLOW 1:	15.0	15.0	LPM
	FLOW 2:	18.3	18.3	LPM
	FLOW 3:	16.7	16.7	LPM
CAL	NEXT	DEFAULT	EXIT	

Figure 10-7. The MULTIPOINT FLOW CALIBRATION screen.

Referring to the MULTIPOINT FLOW CALIBRATION screen in Figure 10-7, the “BAM” column is indicates the BAM-1020 measurements for each parameter, and the “STD” column is indicates where the correct values from the reference standard are to be entered. The <CAL> symbol will appear next to the parameter selected for calibration.

The AT and BP calibrations must occur prior to the flow calibrations since the flow control depends on those parameters. Be sure that the reference standard temperature sensor is adequately equilibrated with ambient conditions. If it has been inside a hot vehicle or stored in an air-conditioned shelter and the ambient temperature is significantly different, it may take some time for sensor to equilibrate, depending on the amount of thermal mass physically surrounding the sensor.

To conduct the calibrations,

1. Measure the ambient temperature with the reference standard positioned near the BX-596 ambient temperature probe. If a hand-held temperature probe is used, place the probe in the radiation shield, or on back side of the BX-596 to screen it from direct sun light. Whatever style of reference temperature standard is used, it should be screened from direct sunlight. Allow the reference standard to stabilize and enter the value from the reference standard into the STD field using the arrow keys. Press the CAL hot key to correct the BAM reading. The BAM and STD temperature values should now be the same.
2. Press the NEXT hot key to move the <CAL> indicator to the BP field, and repeat the same steps for barometric pressure.
3. After the temperature and pressure readings are correct, remove the PM₁₀ inlet and the VSCC™ from the inlet tube and install the reference flow meter onto the inlet. Press the NEXT hot key to move the <CAL> indicator to the first flow point of 15.0 lpm. The pump will turn on automatically. Allow the unit to regulate the flow until the BAM reading stabilizes at the target flow rate. Enter the flow value from your standard into the STD field using the arrow keys. Press the CAL hot key to correct the BAM reading. **NOTE:** The BAM reading will not change to match the STD until after you have entered all three calibration points.
4. Press the NEXT hot key to move the <CAL> indicator to the second flow point of 18.3 lpm and repeat the process.
5. Press the NEXT hot key to move the <CAL> indicator to the third flow point of 16.7 lpm and repeat the process. Enter the flow value and press <CAL>. When all of the calibrations are complete, the BAM-1020 flow readings should match the traceable flow standard reading at 16.7 lpm, +/- 0.1 lpm.
6. Exit the calibration menu.
7. Perform a regular flow verification after the calibration is complete.

The DEFAULT Soft Key will reset the user calibration from the selected parameter and replace it with a factory setting. If any of the FLOW parameters are selected, the DEFAULT key will reset the calibrations of *all three* flow points. This feature can be used to start over with a calibration if difficulty is encountered.

10.2.4 Verify the BAM-1020 Settings

The BAM-1020 settings should be verified every few months. Assuming that the setup parameters were input correctly and checked at installation, it is easy to forgo periodic verification of the BAM-1020 settings because the settings are rarely intentionally altered. However, it is not uncommon to access infrequently used screens and, once in those screens, it is easy to change numbers. Routine verification of BAM-1020 settings is good standard operating procedure.

Table 10-3 lists the settings that should be checked every two months. The screens where the setup parameters are stored are given as well. The “Expected/Default” column contains the values (constants) of the setup parameters as required for FEM PM_{2.5} sampling under EQPM-0308-170. Some setup parameters are user assigned or instrument specific. A copy of this table is provided in Appendix B as a form with provisions for recording date, BAM-1020 serial number, technician name, etc. By following the monthly, bi-monthly, semi-annual and annual QC routines, all the audit parameters on this form will have been verified during the year, many at multiple times. The instrument specific calibration values are listed on the Calibration Certificate provided with each BAM-1020.

Table 10-3. Verification of the BAM-1020 setup parameters requires accessing 8 separate SETUP screens. (See Appendix B for a version of this table as a form.)

BAM-1020 FEM PM _{2.5} Setup and Calibration Values				
Screen	Parameter	Expected/Default	As Found Value	Adjusted Value
SETUP > CLOCK	Clock Time/Date	Local Std Time		
SETUP > SAMPLE	RS232	9600, 8, N, 1		
	BAM SAMPLE	42 min		
	STATION #	User assigned		
	MET SAMPLE	User assigned		
	RANGE	1.000 mg		
	OFFSET	-0.015 mg		
	CONC UNITS	mg OR µg		
	COUNT TIME	8 min		
SETUP > CALIBRATE	FLOW RATE	16.7 lpm		
	CONC TYPE	Actual		
	FLOW TYPE	Actual		
	Cv	Instrument specific		
	Qo	Instrument specific		
	ABS	Instrument specific		
	µ sw	Instrument specific		
	K Factor	Instrument specific		
	BKGD	Instrument specific		
	STD TEMP	25 C		
HEATER	AUTO			
SETUP > EXTRA1	e1	-0.015 mg		
SETUP > ERRORS	Errors	User assigned		
	AP	150		
	FRI	10		
	FRh	20		
SETUP > PASSWORD	Password	F1 F2 F3 F4		
SETUP > INTERFACE	Cycle Mode	User assigned		
SETUP > HEATER	RH Control	YES		
	RH Setpoint	35%		
	Datalog RH	YES (Chan 4)		
	Delta-T Control	NO		
	Delta-T Setpoint	99		
	Datalog Delta-T	Yes (Chan 5)		

10.3 SIX-MONTH MAINTENANCE AND QC

A few maintenance items occur only every six months:

- Service the pump muffler
- Test the filter RH sensor
- Test the filter temperature sensor
- Test the Smart Heater

10.3.1 Replace or Clean the Pump Muffler

The gray plastic pump mufflers clog after several months. Replace the muffler every six months, or, as a temporary fix, drill a hole in the end of it. The brass mufflers can often be cleaned with a solvent. One way to avoid pump muffler maintenance is to replace the pump muffler with a 30-inch length of Tygon tubing. This tubing will not clog, reduces the pump noise as well as the mufflers, and improves pump performance.

10.3.2 Test the Filter Temperature and RH Sensors

To test the filter temperature sensor,

1. From the Main menu, select TEST and then FILTER-T. This screen is used to calibrate the filter temperature sensor located in the air stream beneath the filter tape. When this screen is entered, the BAM will automatically raise the nozzle and turn the pump on. This action allows the filter temperature sensor to equilibrate with ambient room air without the heating effects of the Smart Heater.
2. Allow the pump to run for at least 5 minutes to allow the sensor to equilibrate. During this same period, allow the reference standard temperature sensor to equilibrate with the room temperature.
3. Press the RESET hot key to clear out any past calibration values.
4. Enter the ambient room temperature from the reference standard into the REFERENCE field and press the CALIBRATE hot key. The BAM reading should change to match within +/- 1 deg C.
5. The RESET hot key can be used to revert to default calibrations and start over if difficulty is encountered.

To test the filter RH sensor,

1. From the Main menu, select TEST and then RH. This screen, which functions exactly like the FILTER-T screen, is used to calibrate the filter RH sensor located in the air stream beneath the filter tape.
2. Allow the pump to run for at least 5 minutes to allow the sensor to equilibrate.
3. Press the RESET hot key to clear out any past calibration values.

4. Enter the ambient room relative humidity from the reference standard into the REFERENCE field and press the CALIBRATE hot key. The BAM reading should change to match within +/- **4% RH**.
5. The RESET hot key can be used to revert to default calibrations and start over if difficulty is encountered.

10.3.3 Test the Smart Heater

1. From the Main menu, select TEST and then HEATER. This screen is used to force the Smart Heater ON or OFF for testing purposes. The heater takes several minutes to heat up or cool down noticeably.
2. If the heater is on (warm to the touch), force it off to allow it to cool for several minutes. Turn it back on and verify that it warms up.
3. If the heater is cool to the touch when it is initially checked, force the heater on and verify that it warms after several minutes.
4. The heater automatically turns back off upon exit from the screen.

10.4 TWELVE-MONTH MAINTENANCE AND QC

There are a number of procedures and tests that should be performed once a year. While most of these annual routines are based on recommendations from Met One, **the 72-hr BKGD or zero-filter test is *required*** by EQPM-0308-170 at the time the BAM-1020 is installed at the monitoring site, and “periodically” thereafter.

10.4.1 Perform 72-hr BKGD (BX-302 Zero Filter) Test

Instructions for completing this test are given in Section 9.6.10, BAM Installation . This test is important and is required at the time of installation. The frequency at which the test occurs, however, should be based on the factors discussed in Section 9.5.

10.4.2 Clean or Replace the Internal Debris Filter

An internal debris filter is located in the flow path of the BAM-1020 (see diagram in BAM-1020 Operation Manual, Rev G, page 30). This filter should be cleaned or replaced annually. The filter element can only be replaced (MetOne PN 580292).

10.4.3 Check the Membrane Span Foil

The membrane span foil is made of cellophane material that provides a span reference for the BAM-1020. The typical calibrated value of the membrane is around 800 µg, but this value is specific to each instrument (also known as the ABS value). The BAM-1020 performs a span

check each hour by extending the reference membrane so that it is positioned between the beta source and the scintillation counter. A complete description of this span check process is given in the BAM-1020 Operation Manual (Rev G) on page 28. The value of this measurement is displayed on the NORMAL screen as the “LAST m”. The LAST m value should be very close or equal to the ABS value given on the Calibration certificate. Values in excess of $\pm 5\%$ are flagged as errors (a “D” error for “Deviant Membrane Density”; also known as “Cal error”). If the D error bit is set to ON in the SETUP > ERROR screen, the analog voltage output will also go to full scale.

To check the membrane span foil,

1. from the Main menu, choose TEST > CALIBRATE, bringing up the CALIBRATION MODE screen for the reference membrane;
2. press the START Soft Key to begin the 8-minute test;
3. when complete, record the Calibration mass;
4. repeat the test two more times (total three tests);
5. Calculate the average mass; and
6. compare this value with the ABS value in the SETUP >>CALIBRATE screen.

If the calculated average mass is higher than the ABS value for a particular instrument, this may indicate that there is a buildup of material on the membrane; either dirt, or water marks, or some other marking. An average lower than the ABS value could indicate that the high voltage to the Beta Detector tube is low, the count circuit is malfunctioning, or there is a hole or tear in the cellophane material. Inspect the reference membrane for signs of damage; if there is damage, call the MetOne Service department.

10.4.4 Perform Beta Detector Count Rate and Dark Count Test

The TEST > COUNT screen allows the user to check the function of the beta detector and beta source separate from the rest of the mechanical or flow operations. Each count test will take 4 minutes, and will show the number of beta particles counted as they accumulate. The final count value will stay on the display after the counting is finished, and up to six count tests can be displayed on the screen at once. Count tests are usually performed with a clean section of filter tape between the source and detector, as in normal operation. The test also allows the membrane to be extended between the source and detector as well, if desired.

Press the GO Soft Key to start the 4-minute count test. The counting will immediately begin. After four minutes the counting will stop and wait for the operator to initiate another cycle or EXIT. The resulting COUNT value is the total number of beta particles counted during the four-minute test. This count will increment rapidly during the test. Typical 4-minute count values are between 600,000 and 1,000,000 counts through clean filter tape. The count total will be lower if the span membrane is extended. If the count total is less than 500,000, the beta detector is possibly wearing out.

10.4.5 Clean Inlet Tube

Annual cleaning of the inlet tube is recommended in the BAM-1020 Operation Manual (Rev G), but the site administrator should determine what frequency is most appropriate.

Proper cleaning of the inlet tube requires that the tube be lifted out of the inlet at the top of the BAM-1020. Note: take care to protect the inlet of the BAM-1020 receiver from any debris.

To clean the inlet tube,

1. loosen the set screws in the BAM-1020 inlet receiver;
2. loosen the white cap on the roof mounting flange;
3. loosen the clamp securing the support struts to the inlet tube;
4. drop a rope down the tube, and at the bottom end, tie on a clean cloth that can be pulled up through the tube to clean the walls;
5. repeat until clean.

10.4.6 Test the Analog DAC Output

If analog data are being recorded, the DAC operation should be verified. This includes verification at the terminal strip of the BAM-1020 and at the input terminals of the data logger. Multiple voltage levels should be checked.

The SETUP > TEST > DAC screen is used to test the function of the analog concentration output voltage and the DAC electronics. Use the up/down arrow keys to set the voltage anywhere from **0.000 to 1.000 volts** in 0.100 increments. Measure the VOLT OUT +/- terminals on the back of the BAM-1020 with a high-quality voltmeter and verify that the actual voltage matches the BAM-1020 display value within ± 0.001 volts at each point. If the analog output does not match the value on the TEST > DAC screen, contact the MetOne Service department for instructions. Attach the voltmeter to the input of the data logger and repeat the test to verify that the correct voltages get to the data logger inputs. If the voltages at the data logger inputs do not match those measured at the terminal strip of the BAM-1020, check the integrity of the wiring between the BAM-1020 and the data logger. The DAC output cannot go negative.

10.4.7 Replace Lithium Coin Cell Battery on 3032 Circuit Board

The lithium coin cell battery location on the BAM-1020 3032 circuit board should be replaced bi-annually. This battery provides the power to maintain the BAM-1020 clock and the stored configuration settings and sample data when the instrument is powered down. When changing the battery, the operator needs to pay careful attention to the electrical system as the battery must be changed with the AC power on, otherwise the date/time, data log, and error log will be lost.

10.5 TWENTY-FOUR-MONTH MAINTENANCE

The 24-month maintenance items may need to be performed more frequently, depending on circumstances.

10.5.1 Rebuild the Vacuum Pump

The vacuum pump should be rebuilt every two years. The Medo 925A pump that ships with the BAM-1020 has the advantage of a very easy rebuild, which consists of removing four head bolts, sliding out the old piston and inserting a new one. Pump rebuild kits are available from MetOne (PN 680839). Gast pump rebuild kits come with separate instructions.

10.5.2 Replace the Nozzle O-rings

Replacement of the nozzle O-rings requires special tools. MetOne can provide these along with specific instructions accompanied by pictures to accommodate this process. No special skill are required, just attention to detail.

10.5.3 Replace the Pump Tubing

The pump tubing can crack and cause leaks that are difficult to detect. Replace the tubing between the pump and the back of the BAM-1020 at least every two years.

11. QA AUDITS

The MPCA Environmental Data Quality Unit must perform QA audits and process evaluations to determine the accuracy of the PM monitoring systems and, the data it produces. The primary goal of the Environmental Data Quality Unit QA Team is to identify system errors that may result in suspect or invalid data. This assessment of the accuracy and efficiency of the PM measurement systems is achieved by conducting performance audits as outlined in the CFR 40 Part 58, Appendix A, and the U.S EPA Quality Assurance Handbook for Air Pollution Measurement Systems as described under the following guidelines:

- Without special preparation or adjustment of the system to be audited.
- By an individual with a thorough knowledge of the instrument or process being evaluated, but not the routine operator.
- With accurate, calibrated, NIST-traceable transfer standards that are completely independent of those used for routine calibration and QC flow-checks.
- With complete documentation of audit information for submission to the operating agency. The audit information includes, but is not limited to, types of instruments and audit transfer standards, instrument model and serial numbers, transfer-standard traceability, calibration information, and collected audit data.

Appendix C contains a BAM-1020 Quality Assurance Audit Form which covers flow parameters, mechanical condition, and a review of setup and calibration values. A full audit, conducted twice a year by an independent reviewer, will provide added assurance that the BAM-1020 is being maintained and operated according to best practices. The audit procedures described here are pulled directly from the BAM-1020 Particulate Monitor Operation Manual, BAM-1020-9800 Rev G. The requirements for these audits and evaluations are summarized in Table 11-1.

Table 11-1. BAM-1020 setup audit criteria. (See Appendix C for a version of this table as a form.)

BAM-1020 Audit Criteria		
Parameter	Frequency	Acceptance Criteria
Ambient Temperature C	2/year	±2°C
Barometric Pressure mmHg	2/year	±10 mmHg
PM _{2.5} Flow Verification	2/year	±4% of 16.7 lpm
PM ₁₀ Flow Verification	2/year	±7% of 16.7 lpm
Leak rate	2/year	<1.5 lpm

11.1 FLOW TRANSFER STANDARD (FTS)

Flow rate audits can be performed with either a BGI triCal or the Chinook Streamline Flow Transfer Standard.

11.1.1 BGI triCal

The triCal measures volumetric flow rates by utilizing a pressure transducer to assess the pressure drop by air being drawn through a venturi. As the flow rate through the venturi increases, the pressure drop increases as the square root. Measurements are made at nearly the true operating conditions of the sampler, due to most of the pressure drop being fully recovered in the expansion section of the venturi. The triCal is furnished with 3 auto-ranging venturies, which cover a 0.1 – 30.0 lpm range. Barometric pressure and temperature are monitored and displayed on a continuous basis, when the triCal is on. The triCal is returned to BGI Inc. on a 2 yearly basis for re-certification.

11.1.2 Chinook Streamline Flow Transfer Standard (FTS)

The Streamline FTS, manufactured by Chinook Engineering, is an orifice type flow meter used to perform flow rate audits as well as temperature and barometric pressure audits. The actual flow rate (Qa) through the Streamline FTS is a function of the pressure drop through the device (ΔP), the ambient air temperature (T_{amb}), and the ambient pressure (P_{amb}). Each Streamline FTS has a unique pair of calibration constants, m and b, which are derived from a NIST traceable certification. The Streamline FTS is returned to Chinook Engineering on a 2 yearly basis for re-certification.

11.2 BAM-1020 SAMPLER AUDIT PROCEDURES

If the BGI triCal will be used for this audit, it should be removed from its carrying case and allowed to adapt to site conditions for approximately 10 minutes before turning it on. Switch the triCal using the off/on switch, located on the right side.

The screen will display the following message: **Please insert Venturi 1-2-3.**

Select venturi 1 (6-30 lpm range). With the venturi held vertically, plain end downwards (“O” rings up) insert the venturi into the hole in the top of the triCal. **The triCal will display the version, its serial number and the range of the venturi inserted.** Then a triCal will perform a self-calibration. When finished, **the battery life %, BP, Tfil, Tamb, and Q: Under range** will be displayed.

Select a tubing cap for the tubing needed to attach the triCal to the Flow Audit Adapter (FAA) and place it onto the venturi. Attach one end of the tubing to the cap. Insert the temperature cable to the 3-prong opening, located on the right side of the triCal. When, inserted, the Tfil temperature will be displayed on the triCal’s LED. Place triCal in a safe location until use.

If using a Chinook Streamline Pro, place external temperature audit probe near BAM temperature probe and let stabilize for approximately 10 minutes. Place flow adapter directly on VSCC/SCC connected to inlet.

- A. Remove PM₁₀ inlet from sampler and place it in a safe location.. If monitoring for PM_{2.5} leave VSCC/SCC connected to inlet.
- B. Record audit results on Audit Sheet referenced in Appendix C
- C. Ensure ambient particulate levels at PM_{2.5} sites are <49 µg/m³ (<112 µg/m³ for PM10 monitors) before disabling the BAM channel. If particulate levels are >49 µg/m³, (>112 µg/m³ for PM10 monitors), do not place channel in *Maintenance*. **Do not perform any audits if the channel is not disabled.**
- D. Disable the BAM channel following by going to **TEST SCREEN**.

11.2.1 Clock Time Audit

- A. Compare the BAM sampler's date and time to a reference clock. The sampler date and time can be taken from the **Normal Mode Screen**. Record both the Sampler and Audit date and time onto the Audit Sheet, the time should be within ±3 mins.

11.2.2 Barometric Pressure Audit

The auditor has the option of either using the triCal or Chinook or equivalent. All instruments are NIST traceable.

- A. Press the **TEST** key. Using the right arrow key, move the cursor over to the word "**FLOW**" and press **SELECT**. A screen with "Enter Password" will be displayed. Enter the assigned password.
- B. Record the BAM and reference barometric pressure value onto the Audit Sheet.
- C. If the BAM's barometric pressure differs from the audit barometric pressure by more than 10 mm Hg, notify the Head of Field Operations/Monitoring. The triCal or Chinook should be returned to the QA Lab for comparison against another certified NIST standard. If it is found to be within spec, the BAM's ambient pressure sensor will need to be re-calibrated.
- D. Remain in the *Audit Screen* for the following procedure.

11.2.3 Ambient Temperature Audit

The auditor has the option of either using the triCal or Chinook or equivalent. All instruments are NIST traceable.

- A. Record the BAM and reference ambient temperature value onto the Audit Sheet.
- B. If using the triCal or Chinook, insert the temperature probe into the ambient temperature shield housing the PM_{2.5}'s ambient temperature probe. Allow the temperature reading to stabilize before recording it on the Audit Sheet.
- C. Document on the Audit Sheet whether the ambient temperature was within ±2°C and whether the Audit passed or failed.
- G. If the BAM's temperature differs from the audit temperature by more than ±2°C, notify the Head of Field Operations/Monitoring. The audit device used should be returned to the QA Lab for comparison against another NIST standard. If it is found to be within spec, the BAM's ambient temperature probe will need to be re-calibrated.

11.2.4 Leak Check

- A. Remove the PM₁₀ head from the BAM inlet system. Attach a flow audit adapter, with the valve closed, to the end of the inlet.
- B. In the **Main Menu**, press **TEST**. In the **TEST** menu, select **TAPE** to advance the tape one window.
- C. From the **Main Menu**, press **TEST**. In the **TEST** menu, select **PUMP** and turn on the pump.
- D. Record the indicated flow rate onto the Audit Sheet. The flow rate should be <1.0 lpm. The reason there is a 1.0 lpm allowance is due to the nozzle filter paper interface. Under these test conditions, the pressure differential across this interface is 21”Hg. This is an order of magnitude greater than the BAM-1020 will encounter during sampling. If the flow is <1.0 lpm, there will not be a leak during normal operation.
- E. Slowly open the flow audit adapter valve. Remove the flow audit adapter from the end of the inlet. Replace the PM10 head onto the inlet.
- F. Performing a leak check will generate an error code, due to insufficient flow through the inlet. A “**SELF TEST**”, which will be performed after the flow rate audit, is required to reset the sampler.

11.2.5 Flow Rate Audit

- A. In the **Main Menu**, press **TEST**. In the **TEST** menu, select **TAPE** and advance the tape one window.
- B. Press the **TEST** key. Using the right arrow key, move the cursor over to the word ‘**FLOW**’ and press the **Select** key.
- C. Press the “**PUMP ON**” key and allow the pump to run for several minutes. The cursor will automatically move to the ‘**VOLUMETRIC FLOWRATE**’ row under the column labeled ‘**REFERENCE**’. The value in the “**VOLUMETRIC FLOWRATE**’ row under the ‘**BAM**’ column, must read 16.7.
- D. Record the BAM and the reference Vol. Flow Rate onto the Audit Sheet.

11.2.6 Self-Test

- A. The BAM-1020 has a built in self-test function. That checks both the current operational status and resets any error code that may exist.
- B. Return to the **Main Menu**. Press **TAPE** and then press **SELF TEST**. The sampler will automatically go through a series of internal checks. The test takes approximately 4 minutes.
- C. The results of these checks will be sequentially displayed. If the check passed, the word **SELF TEST PASS** will be displayed. If the check failed, the word **FAIL** will be displayed.
- D. Upon completion of the “**SELF TEST**”, press **EXIT** to return to the **Operations-Normal Menu**.

12. USING AN EXTERNAL DATA ACQUISITION SYSTEM (DAS)

An external DAS or data logger can be used to collect data from the BAM-1020. Using an external DAS allows efficient integration of data from multiple monitors and facilitates timely reporting of data. Collection of real-time data supports forecasting of pollution episodes, and is invaluable for maintaining high data capture rates for remote monitors where daily monitoring of the data can alert the data user to operational problems. The BAM-1020 supports both analog and digital data output; however, **digital data acquisition is recommended**. The following sections provide information on the MPCA monitoring network external data logging capabilities for the BAM-1020.

12.1 DIGITAL POLLING CONSIDERATIONS FOR THE BAM-1020

Digital data acquisition is recommended whenever possible because it eliminates the potential for errors that are traceable to analog data acquisition protocols. These errors include (1) incorrect concentrations from using data logger averaging functions when the logger and BAM are not perfectly time synced; (2) inaccurate BAM output voltage levels received by the logger due to a faulty DAC or poor wiring connections; (3) improper use of the BAM-1020 OFFSET parameter or failure to compensate for this in the logger program; and (4) improper time stamping of hourly analog data-related BAM EARLY Mode or STANDARD Mode operation. There are two cycle modes for the BAM-1020—the STANDARD mode and the EARLY mode. The cycle mode has important implications both in the analog data stream and on the internally stored hourly data. The timing cycle within a given sample hour differs between these modes. This cycle is described in detail in the BAM-1020 Operation Manual (Rev G, pages 65-66), and needs to be understood for the external data logger to be set up appropriately.

12.1.1 Mechanical Interrupts

The most important consideration when collecting digital data is to remember that the BAM-1020 only calculates concentration data once an hour; during other parts of the hour (especially near the beginning and end of each hour), the BAM is often moving tape transport parts and making mechanical adjustments which **prevent the unit from responding to digital data requests** due to a busy processor. This is especially important if large amounts of data are to be downloaded at once, since it can take more than 10 minutes to download the entire data log. If the download overlaps a mechanical motion by the BAM, the data can be delayed by several seconds in the middle, or even interrupted entirely. Small digital files (such as the last hourly record only) can be downloaded very quickly, and may be accomplished at almost any time during the hour as long as the timing is carefully controlled. **It is highly recommended that the BAM clock be regularly synchronized by the external data logger to prevent timing problems due to clock drift.** Digital clock resets are implemented differently in BAM-1020 EARLY mode and STANDARD mode. These clock resets are described in the BAM-1020 Operation Manual (Rev G, page 66).

If a data logger is programmed to digitally request data from the BAM-1020 continuously throughout the hour (such as every minute), there will almost certainly be a number of requests each hour that will be ignored by the BAM due to mechanical interrupts.

12.1.2 BAM-1020 Digital Data Format

External digital data loggers should be programmed to request the latest hourly BAM data record in .CSV (comma separated values) format, just as with a computer through the serial port as outlined in Section 10.1.8. The data logger program must select and store the desired parameters from the BAM-1020 data array, and ignore the others.

BAM data records are always the same length, order, format, and content. Each hourly digital data record includes date, time, concentration (CONC), sampled air volume (Qtot), 6 auxiliary sensor channels, and 12 alarm status bits (described in Section 10.1.8 and also in the BAM-1020 Operation Manual, Rev G, page 76). The auxiliary data fields are present whether they are used or not, so they may contain “dummy” data. The BAM-1020 stores all data parameters and alarms in memory each hour.

The PM_{2.5} FEM version of the BAM-1020 offers the option of flow statistics associated with each hour’s sample (**Table 12-1** and BAM-1020 Operation Manual, Rev G, page 77). These statistics must be requested by a data logger command issued separately from that requesting the normally downloaded data (CONC, Qtot, etc). In relational databases, these additional flow statistics data would be matched to concentration data by querying on time stamp. The flow statistics will be most helpful during the data validation process (Section 12).

Table 12-1. FEM BAM-1020 PM_{2.5} monitor flow statistics for each hour’s data.

Field	Description
Start	Start time of BAM sample period.
Elapsed	Elapsed BAM sample time.
Flow	Average flow rate for the BAM sample period.
CV	Flow rate coefficient of variance for the BAM sample period.
Volume	Sample volume for the BAM sample period.
Flag	Flow regulation out of range warning flag.
AT	Average ambient temperature for the BAM sample period.
AT Min	Minimum ambient temperature for the BAM sample period.
AT Max	Maximum ambient temperature for the BAM sample period.
BP	Average ambient pressure for the BAM sample period.
AT Min	Minimum ambient pressure for the BAM sample period.
AT Max	Maximum ambient pressure for the BAM sample period.

The OFFSET parameter needs no special treatment in digital data logging, since the digitally stored data have not been modified for output (analog data are modified by the OFFSET

parameter for output, see Section 11.3). While digital data acquisition is recommended whenever possible, the acquisition is not immune to errors and requires particular attention to time stamping, so data should be compared with internal BAM-1020 data for verification of time stamps. Concentration and air volume (Q_{tot}) data should agree exactly.

12.2 TIME STAMPING

Proper time stamping is an issue affecting both analog and digital data acquisition scenarios, and extra care should be taken that the appropriate time stamp is assigned to each hourly record. Internal BAM-1020 time stamps are assigned differently in the STANDARD and EARLY operating modes (SETUP > INTERFACE screen), and understanding how they are assigned is essential when comparing the directly downloaded BAM-1020 data with data logger acquired data.

Internal BAM-1020 time stamps:

- In STANDARD operating mode, internal time stamps represent the end of the sampled hour, so a time stamp of 09:00 represents the sample collected from 08:00-09:00.
- In EARLY operating mode, internal time stamps represent the beginning of the sampled hour, so a time stamp of 09:00 represents the sample collected from 09:00-10:00.
- Internal time stamps default to 00:00 to 23:00 for both operating modes. This default makes sense for the EARLY mode, but is less intuitive for the STANDARD mode. In many date/time systems, the 00:00 hour could easily be assigned an incorrect date during processing, since it is difficult to envision the 11:00 p.m.-to-midnight sample labeled as 00:00. (Firmware versions 3.2.5 or later have an option of 01:00 to 24:00.)

Most external data loggers will assign a time stamp to each data record, overriding the BAM-1020 time stamp, so that a single time stamp will represent all the parameters gathered by the DAS, including other monitors at the station.

Data logger assigned time stamps:

- In STANDARD operating mode, the BAM-1020 concentration voltage is available for polling for the entire hour following the measurement cycle. Analog voltage or digital data may be polled anytime within the hour with the understanding that the data represent the previous hour's sample. Data logger assigned time stamps will have to be corrected to reflect the correct sample period.
- In EARLY operating mode, the BAM-1020 concentration output voltage is available only from the last 5 minutes (minutes 55-60) of the hour just sampled. In this way, the data logger will assign a time stamp within the current hour. For the balance of the hour, the output voltage is 0.920 volts. Since timing is critical, an hourly synchronization of the BAM-1020 clock with the DAS clock is required (BAM-1020 Operation Manual, Rev G, pages 65-66). While digital data can be acquired from BAM-1020 internal storage anytime during the hour, the logger assigned time stamp may or may not agree with the

BAM-1020 assigned time stamp depending on whether the data was queried inside the 5-minute window, or outside the 5-minute window. EARLY operating mode is usually used for time-synchronized analog DA.

- Polling protocols differ among data loggers. Optimally, the logger should query the BAM-1020 analog or digital data only once per hour because the BAM-1020 only provides one data record per hour. With synchronized clocks, and knowing the time of the scan and the operating mode of the BAM-1020, the time stamp can be appropriately assigned, or corrected after the polling is complete. Many loggers use averaging functions to poll the BAM-1020. Besides requiring close scrutiny of the time stamp, an averaging approach can pose some particular data hazards (see Section 11.4.1).

12.3 THE OFFSET PARAMETER

The OFFSET parameter is a frequently misunderstood setting in the BAM-1020 SETUP > SAMPLE screen. It should not be confused with the BKGD value found in the SETUP > CALIBRATION screen, which is the zero correction factor applied to each hourly measurement. Similarly, the OFFSET parameter should not be confused with the “e1” parameter found in the SETUP > EXTRA1 screen which is the “lower concentration limit clamp”, which is the lowest concentration value that the BAM-1020 will report, regardless of what is measured.

OFFSET is used to set the lower end of the BAM-1020 measurement range, and could more accurately be called a “range offset”. The default value for OFFSET for PM_{2.5} FEM monitoring is -0.015 mg. This value causes the entire range of the BAM-1020 to shift down so that it reports from -0.015 to 0.985 mg, instead of from 0 to 1.000 mg (assuming the RANGE is set to 1.000 mg). This shift allows the unit to measure slightly negative concentration numbers near zero, which is helpful to differentiate between normal noise and a failure such as punctured filter tape. In digital DA, the OFFSET parameter poses no special problems since the data are acquired directly from the BAM-1020 memory. However, analog data requires correction for the OFFSET.

12.4 ANALOG DATA LOGGER INTERFACING WITH THE BAM-1020

Historically, analog data have been the primary means of logging BAM-1020 data, but this method is limited to reporting only PM_{2.5} concentration (CONC), along with full scale voltage signals (concentration) to indicate error conditions for some internal BAM-1020 errors. (Some errors can also be signaled by the relay outputs; see BAM-1020 Operation Manual, Rev G, pages 66-68.) Analog data need special considerations that must be understood to avoid errors in reported concentrations, and the BAM-1020 EARLY operating mode is strongly recommended for analog data acquisition protocols.

The analog output type is selectable between isolated voltage (0-1 or 0-10 volt DC) and isolated current (4-20 or 0-16 mA). The one-volt range is by far the most common. The rear panel dipswitches are used to select the output (**Table 12-2**).

The full-scale value of the output voltage corresponds to the full-scale measurement of the BAM-1020, determined by the RANGE and OFFSET setting (Figure 9-7). It is most important to verify that the data logger is compensating for the OFFSET parameter. The analog output should be tested and verified.

Table 12-2. BAM-1020 rear panel dip switch positions for selection of analog output options.

SWITCH	ON	OFF
SW1	0-10 VDC	0-1 VDC
SW2	4-20 mA	0-16 mA
SW3	Not Used	Not Used
SW4	Not Used	Not Used

12.4.1 Importance of Clock Synchronization in Analog Data Acquisition

One reason for recommending digital data acquisition is that analog data acquisition can lead to erroneous data if clock synchronization between the BAM-1020 and the data logger is not precise and a data logger averaging function is used to process the analog data. When the BAM is in STANDARD cycle mode, it outputs an hourly concentration at the top of the hour that represents the hour just sampled. The analog output holds the voltage representing this concentration for the entire hour, until the next hour's sampling is complete and the analog output voltage is updated to a new value. It is easy to see that if the clocks between the logger and the BAM are different, and multiple scans are taken and fed into an average, the average hourly concentration calculated by the data logger could contain values from different hours. This discrepancy can be very difficult to track down during post-processing QC.

12.4.2 Correcting the OFFSET in Analog Data Acquisition

The analog output voltage from a BAM-1020 programmed with a negative offset will still range from 0 to 1 VDC (or 0 to 10 VDC, selectable) because the BAM-1020 voltage output cannot go negative. With an OFFSET of -0.015 mg, the output voltage of 0 to 1.000 volt equals -0.015 to 0.985 mg, instead of 0.000 to 1.000 mg. The BAM-1020 will *add* the number of millivolts equivalent to the absolute value of the negative offset to the analog output. This scaling must be taken into account by the voltage slope and intercept in the external data logger.

For example, in the case of an offset of -0.015 mg, the configuration of the data logger must use a slope of 1000 and an intercept of -15. When the data logger receives the analog signal from the BAM, it multiplies the voltage by 1000 and adds the intercept. If the BAM measures a concentration of 0.025 mg/m³, it sends a voltage of 0.040 V (0.025 V + 0.015 V offset) to the analog output. When the data logger receives this signal, it performs the multiplication to yield 40 µg/m³, and then adds the intercept (-15) to yield the correct concentration of 25 µg/m³. In the same way, a measured concentration of -0.015 mg/m³ will be scaled to 0.000 V on the analog

out, and application of the multiplier and intercept in the data logger will yield a concentration of $-15 \mu\text{g}/\text{m}^3$.

Changing the offset setting will affect past data already stored to memory. Always download any old data before changing settings and clear the memory. Firmware version 3.2.4 or later (required for $\text{PM}_{2.5}$ FEM monitoring) will display a prompt to clear (i.e., download and clear) the memory before changing this setting.

12.4.3 Error Relays

In addition to the analog output, input and output relay connections are provided on the rear panel of the BAM-1020 to allow the unit to be used with an external data logger. The function of each input and output is described in the BAM-1020 Operation Manual (Rev G, pages 67-68). Using these relays in analog DA systems can provide more complete operating information than can be obtained from just the analog output signal alone.

13. DATA VALIDATION AND QUALITY ASSURANCE

Generally speaking, pertinent to data validation and QA protocols for FEM continuous PM_{2.5} and PM₁₀ monitoring with the BAM-1020 are the following documents: (1) 40 CFR Part 50 Appendix N (“Interpretation of the National Ambient Air Quality Standards for PM_{2.5}”), (2) 40 CFR Part 50 Appendix L (“Reference Method for the Determination of Fine Particulate Matter as PM_{2.5} in the Atmosphere”), (3) 40 CFR Part 58 Appendix A (“Quality Assurance Requirements for SLAMS, SPMs and PSD Air Monitoring”), (4) EPA Quality Assurance Guidance Document 2.12 (“Monitoring PM_{2.5} in Ambient Air Using Designated Reference or Class I Equivalent Methods”), (5) 40 CFR 50 Appendix J, and (6) QA Handbook Appendix D Continuous PM₁₀ Conditions Validation Template. These documents offer extensive details about procedures intended to ensure that PM_{2.5} and PM₁₀ 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 QC protocols intended to keep the BAM-1020 operating in accordance with FEM designations EQPM-0308-170 and EQPM-0798-122, and with the BAM-1020 User’s Operation Manual (Rev G or later). The field protocols aid the post-processing data validation and QA protocols, during which collected data are judged under DQO criteria.

13.1 FIELD QUALITY CONTROL IMPACTS QUALITY ASSURANCE

The first line of defense against invalid data is the implementation of best practices in day-to-day QC 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, instrument settings)
- Documentation/reporting of all field QC results and related field activities
- Daily review of real-time data via agency central data system
- Prompt troubleshooting of any observed operational problems

13.2 DATA VALIDATION

Data validation is part of data Quality Assurance (QA). Two primary sources of information are directly related to validation of FEM PM_{2.5} and PM₁₀ data from the BAM-1020. One is the sampling attribute data generated and stored by the BAM-1020 itself (Q_{tot} and associated flow

statistics and error codes), and the other is the site log information containing results from the periodic QC protocols.

13.2.1 BAM-1020 Generated Sampling Attribute Data

The FEM BAM-1020 internal data files, or content-equivalent digitally acquired files, should be the source files used for data validation and ultimate submittal to regulatory agencies. Analog data must be reconciled against the internal digital data in any case, so it behooves the data analyst to begin with the original digital data. Externally acquired (data logger) digital data proven to be a true replicate of the internally stored data could be used, with special attention to ensure that data logger-applied time stamps are accurate. This scenario is becoming more common as agencies switch to real-time digital data acquisition that flows directly into a permanent database. Flow statistics, now available from FEM BAM-1020 instruments, should be downloaded and utilized for QA and data validation. This step requires a separate data query to the BAM-1020 as these statistics are not part of the normal data record.

13.2.2 Field QC Generated Sampling Attribute Data

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—not left to chance. It may take the form of negative reporting, that is, only those field QC procedures that result in a “fail” condition need be reported, saving the data analyst from poring over data that the field technician has already documented as acceptable, or “passing”. One method of implementing a negative reporting structure would be to keep a separate log of failed QC tests, containing information such as technician name, date, QC test performed, result, corrective action, retest result, etc., that would be periodically passed to the data analyst. Note, however, that some QC protocols are not “pass/fail”, but only need verification that they were carried out (e.g., inlet cleaning).

13.2.3 Data Validation Criteria

The EPA documents noted in Section 12 were originally developed for 24-hr filter-based Reference Method sampling, and have been adapted in **Table 13-1** to provide guidelines for data validation criteria pertinent to continuous (hourly) PM_{2.5} and PM₁₀ monitoring with the BAM-1020. The table is modeled on a table in Appendix D, “Measurement Quality Objectives and Validation Templates”, of the QA Handbook, Volume II, Revision 1 (December, 2008).

The top panel of Table 13-1 lists the 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 an otherwise compelling justification. One example of such justification would be known wildfires contributing to excessive filter loading. High filter loading can lead to flow perturbations, but these data are nonetheless highly valuable. These criteria include the 42-minute sampling period for hourly data (and extended to 24-hr data), hourly flow rate and flow rate variability (available

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from internally stored BAM-1020 flow statistics), and the monthly flow check and leak check. Note that the leak check failure is set at 1.5 lpm. The bottom panel in the table lists criteria that indicate there *might* be a problem with the quality of the data and further investigation may be warranted before making a determination about sample validity. Example criteria in this category would be failure to perform manufacturer recommended inlet cleaning or less than optimal leak check results.

Table 13-1. Critical and operational data validation criteria for the Met One BAM-1020 under FEM designation EQPM-0308-170 and EQPM-0798-122.

Criteria		Frequency	Tolerances	Reference
Critical Criteria: These criteria represent the most important sampling attribute data				
Sampling period	Hourly	Hourly	42 minutes	BAM-1020 Manual, Rev G
	24-hr	Daily	1008 minutes	40 CFR Part 50 App L, Sec 3.3
Flow statistics (in BAM-1020 file memory)	Average Flow Rate	Hourly	±5% of 16.67 lpm	40 CFR Part 50 App L, Sec 7.4; Method 2.12, Sec 10.2
	Flow Rate Variability	Hourly	Coefficient of variation 2% or less	40 CFR Part 50 App L, Sec 7.4.3.2
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
	Single point flow (BAM-1020 Flow Reading)	Biweekly	±4% of Reference Std Reading	40 CFR Part 50 App L, Sec 9.2.5
	Leak Check	Monthly	<1.5 lpm	BAM-1020 Manual Rev G
Operational Criteria: These criteria represent tolerances when corrective action may be needed to reestablish optimal sampling attributes				
Verification /Calibration	Leak Check	Monthly	>1.0 lpm	BAM-1020 Manual Rev G
	Reference membrane	Hourly	±5% of ABS (“D” error)	BAM-1020 Manual, Rev G
	BX-596 Temp Verification	2 Months	±2°C	40 CFR Part 50 App L, Sec 9.3; Method 2.12, Sec 6.4
	BX-596 Temp Calibration	2 Months	±0.2°C	BAM-1020 Manual, Rev G
	BX-596 Barometric Pressure Verification	2 Months	±10 mm Hg	40 CFR Part 50 App L, Sec 9.3; Method 2.12, Sec 6.5
	BX-596 Barometric Pressure Calibration	2 Months	±1 mm Hg	BAM-1020 Manual, Rev G
	3-Point Flow Calibration	2 Months or on Failed Flow Check	±0.1 lpm	BAM-1020 Manual, Rev G
	Filter RH Calibration	6 Months	±4% RH	BAM-1020 Manual, Rev G
	Filter Temp Calibration	6 Months	±1°C	BAM-1020 Manual, Rev G
Cleaning	PM ₁₀ Inlet and VSCC™	Monthly	Cleaned	BAM-1020 Manual, Rev G; Method 2.12, Sec 9.3
	Nozzle, vane, pinch roller, capstan	Monthly	Cleaned	BAM-1020 Manual, Rev G
Other Mfg Recommended Maintenance	Clean pump muffler; test Smart heater	6 Months	Verified	BAM-1020 Manual, Rev G
	Zero filter test, Clean internal	12 Months	Verified	BAM-1020 Manual,

	filter; Beta detector test; check span foil; clean inlet tube			Rev G
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13.2.4 Data Validation Steps

Table 13-2 lists suggested sequential steps, their components, and specific procedures for validation of continuous PM_{2.5} mass data collected with the BAM-1020 under FEM designation EQPM-0308-170. EPA Quality Assurance Guidance Document 2.12 provides good guidance.

Table 13-2. Data validation steps for BAM-1020 FEM PM_{2.5} and PM₁₀ data.

Validation Step	Component	Procedure
Verify Data Source	Digital: Direct Download	Download csv format file
		Download flow statistics (optional, useful)
	Digital: Data Logger	Collect Conc, Q _{tot} , Error codes, Flow statistics
		Compare time stamp to internal data
	Analog: Data Logger	Compare concentration to internal data ($\pm 1 \mu\text{g}$) Compare time stamp to internal data
Review BAM-1020 Attribute Data	Full scale concentration, Analog data	Sort records for full scale data (0.985 mg); look for errors causing FS output but digital CONC data are valid (e.g., errors P, R, N, E), if found, retrieve digital data.
	Full scale concentration, Digital data	Usually maintenance (M) or power fail (L) errors: invalidate
	Q _{tot}	A good validation indicator. If Q _{tot} varies, suggests a problem with temperature or pressure probe, or pump. Recommend rigid tolerance for Q _{tot} ($0.700 \pm 0.003 \text{ m}^3$)
	Error flags	Review specific errors and invalidate accordingly
Review BAM-1020 Flow Statistics (useful, but really only the Q _{tot} is needed to judge sample volume)	Elapsed time	42 minutes
	Average flow	$\pm 5\%$ of 16.67 lpm
	Coefficient of variation	< 2%
	Sample volume	Recommend rigid tolerance for Q _{tot} ($0.700 \pm 0.003 \text{ m}^3$)
	Temperature and Pressure Stats	Average, Max, Min for reasonableness
Review Field QC (Operator log sheets)	Flow checks	$\pm 4\%$ of 16.67 lpm
	Leak checks	> 1.5 lpm, invalidate back to last passing leak check (agency-specific value)
	Calibration	At least annually, or on failed verification
Maintenance procedures	Inlet cleaning	Verify inlets cleaned (30 days for VSCC™), agency-specific intervals.

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	Periodic zero test	Verify and evaluate
Periodic component tests	Test: Filter T and RH, Smart Heater, Beta Count Rate, Analog DAC	Verify (Operator log sheets)

14. DIAGNOSTICS AND TROUBLESHOOTING

The MetOne BAM-1020 Operation Manual provides a troubleshooting table (Rev G, pages 53-56) containing information on some of the more common BAM-1020 problems which may be encountered, and some steps to identify and remedy the problems.

15. CONSUMABLES AND SPARE PARTS TO HAVE ON HAND

The items in **Table 15-1** are suggested to be kept available, especially at remote sites that are visited infrequently.

Table 15-1. List of suggested consumables and spare parts to have on hand.

Consumable or Part	Usage
Filter tape roll	60 days/roll
Cotton-Tipped Applicators	Nozzle, vane, inlet cleaning
Isopropyl alcohol	Nozzle, vane, inlet cleaning
Pump rebuild kit	
In-line filter element	
O-rings, Nozzle	
O-rings, Inlet receiver (2 required)	
Fuse, 3.15A, 250V, 5x20mm (2 Required)	
O-Rings, VSCC™, set of 6	
O-Rings, PM ₁₀ Head, set of 3	
Low lint wet wipes	Nozzle, vane, inlet cleaning
Hand cleaner	Tape loading, inlet cleaning

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16. REFERENCES

1. MetOne Instruments, Inc., (2008) BAM 1020 particulate monitor operation manual. Prepared by Met One Instruments, Inc., Grants Pass, OR, BAM-1020-9800 Rev G.
2. 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.
3. STI-905505.05-3645-SOP, August, 2011.

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APPENDIX A

MINNESOTA POLLUTION CONTROL AGENCY FEM-BAM FLOW CHECK FORM

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**Minnesota Pollution Control Agency
Air Analysis and Monitoring Unit
FEM-BAM Flow check Form**

Site # _____ BAM # : _____ CHNK # _____ Date _____ Operator _____
m = _____ Clean VSCC Clean Inlet Head Clean nozzle Self-Test OK REF OK
Yes No Yes No Yes No Yes No Yes No Yes No
Qtot = _____ m3 RH _____ % Heater OFF ON Warm to touch: YES NO
BAM c = _____ ug ESC c = _____ ug Filter tape pressure: _____ mmHg Delta-T: _____ C
BAM CLK: _____ ESC: _____ Last error: _____

	As Found	Chinook	As Left
Ambient temp	_____	_____	_____ C
BP	_____	_____	_____ mmHg
Flow Check:	15.0 _____	_____	_____ Lpm
(16.33- 17.0 Lpm)	18.4 _____	_____	_____
	16.7 _____	_____	_____
Leak check (<1.0 Lpm)	_____ Lpm		
Comments:	_____		

Site # _____ BAM # : _____ CHNK # _____ Date _____ Operator _____
m = _____ Clean VSCC Clean Inlet Head Clean nozzle Self-Test OK REF OK
Yes No Yes No Yes No Yes No Yes No Yes No
Qtot = _____ m3 RH _____ % Heater OFF ON Warm to touch: YES NO
BAM c = _____ ug ESC c = _____ ug Filter tape pressure: _____ mmHg Delta-T: _____ C
BAM CLK: _____ ESC: _____ Last error: _____

	As Found	Chinook	As Left
Ambient temp	_____	_____	_____ C
BP	_____	_____	_____ mmHg
Flow Check:	15.0 _____	_____	_____ Lpm
(16.33- 17.0 Lpm)	18.4 _____	_____	_____
	16.7 _____	_____	_____
Leak check (<1.0 Lpm)	_____ Lpm		
Comments:	_____		

APPENDIX B

SETUP AND CALIBRATION VALUES CHECK FORM

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BAM-1020 FEM PM _{2.5} Setup and Calibration Values Check Form				
BAM-1020 serial Number:				
Technician:				
Date:				
Site:				
Screen	Parameter	Expected/Default	As Found Value	Adjusted Value
SETUP > CLOCK	Clock Time/Date			
SETUP > SAMPLE	RS232	9600,8,N,1		
	BAM SAMPLE	42 min		
	STATION #			
	MET SAMPLE			
	RANGE	1.000 mg		
	OFFSET	-0.015 mg		
	CONC UNITS	mg / µg		
	COUNT TIME	8 min		
SETUP > CALIBRATE	FLOW RATE	16.7 lpm		
	CONC TYPE	Actual		
	FLOW TYPE	Actual		
	Cv			
	Qo			
	ABS			
	µ sw			
	K Factor			
	BKGD			
	STD TEMP	25 C		
	HEATER	AUTO		
SETUP > EXTRA1	e1	-0.015 mg		
SETUP > ERRORS	Errors			
	AP	150		
	FRI	10		
	FRh	20		
SETUP > PASSWORD	Password			
SETUP > INTERFACE	Cycle Mode			
SETUP > HEATER	RH Control	YES		
	RH Setpoint	35%		
	Datalog RH	YES (Chan 4)		
	Delta-T Control	NO		
	Delta-T Setpoint	99		
	Datalog Delta-T	Yes (Chan 5)		

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APPENDIX C

BAM 1020 QUALITY ASSURANCE AUDIT FORM

 <p>Minnesota Pollution Control Agency 520 Lafayette Road North St. Paul, MN 55155-4194</p>	<p>EAO/Quality Assurance and Performance Management Unit</p>																														
BAM 1020 QUALITY ASSURANCE AUDIT FORM																															
Site No. _____ Location _____ Date _____ Auditor _____ Start Time _____ End Time _____ Monitor Model No. <u>Bam 1020</u> Serial No. _____ Operator _____																															
STANDARDS:																															
Flow Rate Audit Device Mfg _____	Serial No. _____ Cert. Date: _____																														
Temperature Audit Device Mfg _____	Serial No. _____ Cert. Date: _____																														
Pressure Audit Device Mfg _____	Serial No. _____ Cert. Date: _____																														
OPERATIONAL PARAMETERS:																															
	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 15%;">BAM</th> <th style="width: 15%;">Ref. Std</th> <th style="width: 30%;">DO FIRST:</th> <th style="width: 15%;">BAM</th> <th style="width: 25%;">Logger</th> </tr> </thead> <tbody> <tr> <td>Ambient Temperature C:</td> <td></td> <td>Last c value:</td> <td></td> <td></td> </tr> <tr> <td>Barometric Pressure mmHg:</td> <td></td> <td>Last m: Value:</td> <td></td> <td style="text-align: center;">NA</td> </tr> <tr> <td>Flowrate lpm Actual Volumetric:</td> <td></td> <td>RH %:</td> <td></td> <td style="text-align: center;">NA</td> </tr> <tr> <td>(Use 16.7 Lpm range)</td> <td></td> <td>Inlet Heater on?Y/N</td> <td></td> <td style="text-align: center;">Warm/Hot?</td> </tr> <tr> <td>Leak rate (lpm):</td> <td style="text-align: center;">NA</td> <td>Time Sync (CST):</td> <td></td> <td></td> </tr> </tbody> </table>	BAM	Ref. Std	DO FIRST:	BAM	Logger	Ambient Temperature C:		Last c value:			Barometric Pressure mmHg:		Last m: Value:		NA	Flowrate lpm Actual Volumetric:		RH %:		NA	(Use 16.7 Lpm range)		Inlet Heater on?Y/N		Warm/Hot?	Leak rate (lpm):	NA	Time Sync (CST):		
BAM	Ref. Std	DO FIRST:	BAM	Logger																											
Ambient Temperature C:		Last c value:																													
Barometric Pressure mmHg:		Last m: Value:		NA																											
Flowrate lpm Actual Volumetric:		RH %:		NA																											
(Use 16.7 Lpm range)		Inlet Heater on?Y/N		Warm/Hot?																											
Leak rate (lpm):	NA	Time Sync (CST):																													
MECHANICAL PARAMETERS:																															
(y/n)	(y/n)																														
Pump muffler unclogged:	PM10 trap cleaned:																														
Sample nozzle clean:	PM10 drip jar empty:																														
Tape support vane clean :	PM10 bug screen clean:																														
Capstan shaft clean :	PM2.5 trap cleaned:																														
Rubber pinch rollers clean:	Inlet tube seal OK:																														
Chassis ground wire installed :	Inlet tube aligned OK:																														
ERROR LOG (last six):																															
1) _____	4) _____	SelfTest:																													
2) _____	5) _____	(circle one) pass fail																													
3) _____	6) _____	Last 72 hour ZERO result:																													
		Date: _____																													
COMMENT FIELD:		Last QC checks by operators:																													
REV: 09RID																															