Version II IMPROVE Sampler

Operating Procedures Manual for use in the

IMPROVE Monitoring Network

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Standard Operating Procedures
Technical Information Document TI 201A

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1. Introduction

1.1 IMPROVE Network

IMPROVE (Interagency Monitoring of Protected Visual Environments) is a cooperative program of the National Park Service, Forest Service, Bureau of Land Management, Fish and Wildlife Service, Environmental Protection Agency, and state agencies, whose primary purposes are the protection of visibility in Class I areas and characterization of regional haze.

The Version I IMPROVE sampler has been used in this network since 1988. Between 1996 and 1999 there were approximately 80 sites, 30 were under the direct control of the IMPROVE steering committee, and the remainder under the control of one of the cooperating agencies.

In 2000, the number of sites will increase to approximately 145, with 110 will be under the direct control of the IMPROVE steering committee. All of the 110 sites are in or near Class I visibility areas. These sites represent all 156 Class I areas, except Bering Sea NWR. The remaining sites are referred to as “Protocol” sites, and are under the control of one of the committee agencies, states, or tribes. The operation of the Protocol sites is identical to that of the IMPROVE sites. Almost all of the Protocol sites are in remote areas. The locations of planned sites for early year 2001 are shown in Figure 1 and listed in Table 1. In 2000, the sampling protocol shifted from twice a week to every third day. To accommodate both the increase in size and sampling frequency, a new version of the sampler was needed.

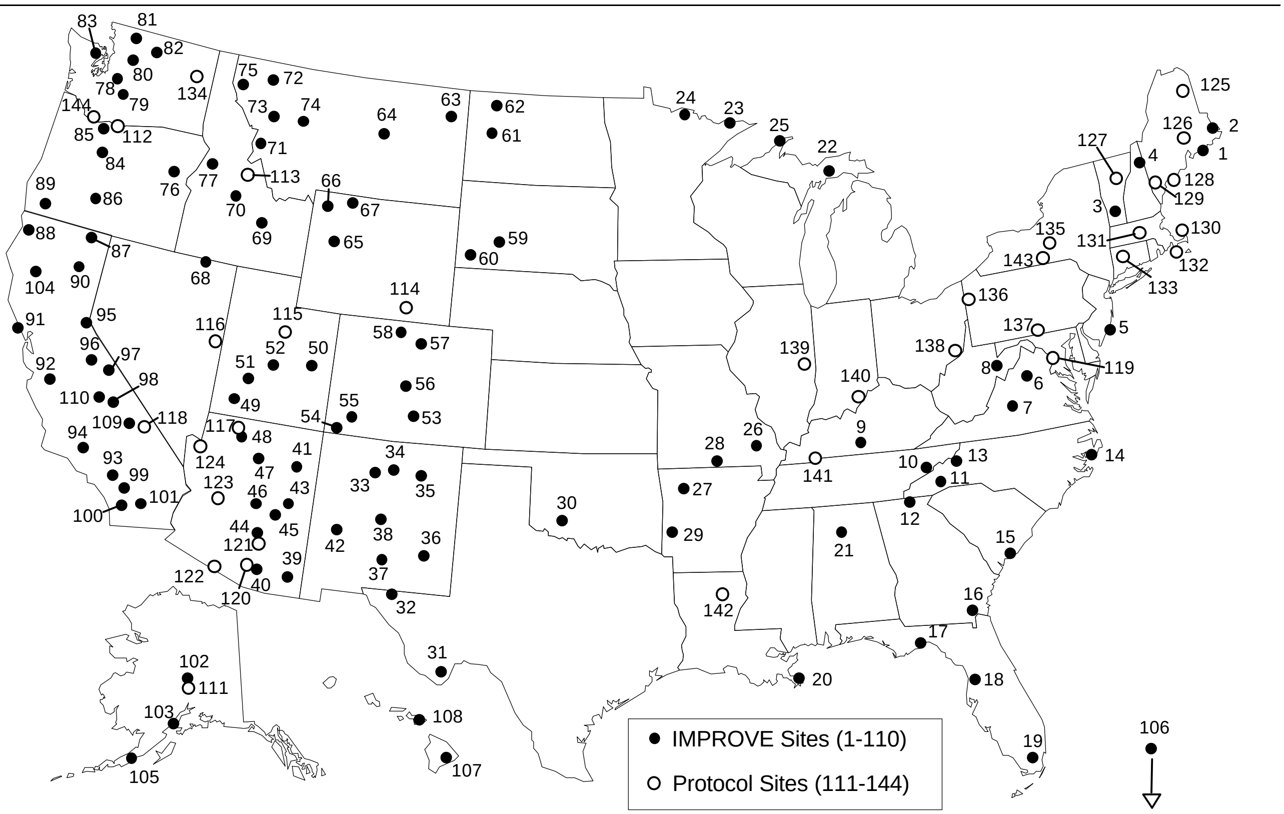

Figure 1. Aerosol sites in the IMPROVE Network in early 2001.

Table 1. IMPROVE and IMPROVE protocol sites in 2000.

n	*Represented Class I areas or Protocol Site*	*state*	*Agency*
1	Acadia	ME	IMPROVE
2	Moosehorn, Roosevelt Campobello	ME	IMPROVE
3	Lye Brook	VT	IMPROVE
4	Great Gulf, Presidential Range-Dry River	NH	IMPROVE
5	Brigantine	NJ	IMPROVE
6	Shenandoah	VA	IMPROVE
7	James River Face	VA	IMPROVE
8	Dolly Sods, Otter Creek	WV	IMPROVE
9	Mammoth Cave	KY	IMPROVE
10	Great Smoky Mtns, Joyce Kilmer-Slickrock	TN	IMPROVE
11	Shining Rock	NC	IMPROVE
12	Cohutta	GA	IMPROVE
13	Linville Gorge	NC	IMPROVE
14	Swanquarter	NC	IMPROVE
15	Cape Romain	SC	IMPROVE
16	Okefenokee, Wolf Island	GA	IMPROVE
17	Saint Marks	FL	IMPROVE
18	Chassahowitzka	FL	IMPROVE
19	Everglades	FL	IMPROVE
20	Breton	LA	IMPROVE
21	Sipsey	AL	IMPROVE
22	Seney	MI	IMPROVE
23	Boundary Waters	MN	IMPROVE
24	Voyageurs	MN	IMPROVE
25	Isle Royale	MI	IMPROVE
26	Mingo	MO	IMPROVE
27	Upper Buffalo	AR	IMPROVE
28	Hercules-Glades	MO	IMPROVE
29	Caney Creek	AR	IMPROVE
30	Wichita Mountain	OK	IMPROVE
31	Big Bend	TX	IMPROVE
32	Guadalupe Mountains, Carlsbad Caverns	TX	IMPROVE
33	Bandelier	NM	IMPROVE
34	San Pedro Parks	NM	IMPROVE
35	Wheeler Peak, Pecos	NM	IMPROVE
36	Salt Creek	NM	IMPROVE
37	White Mountain	NM	IMPROVE
38	Bosque del Apache	NM	IMPROVE
39	Chiricahua NM, Chiricahua W, Galiuro	AZ	IMPROVE
40	Saguaro	AZ	IMPROVE
41	Petrified Forest	AZ	IMPROVE
42	Gila	NM	IMPROVE
43	Mount Baldy	AZ	IMPROVE
44	Superstition	AZ	IMPROVE
45	Sierra Ancha	AZ	IMPROVE
46	Mazatzal, Pine Mountain	AZ	IMPROVE
47	Sycamore Canyon	AZ	IMPROVE
48	Grand Canyon (Hance site)	AZ	IMPROVE
49	Bryce Canyon	UT	IMPROVE
50	Canyonlands, Arches	UT	IMPROVE
51	Zion	UT	IMPROVE
52	Capitol Reef	UT	IMPROVE
53	Great Sand Dunes	CO	IMPROVE

n	*Represented Class I areas or Protocol Site*	*state*	*Agency*
54	Mesa Verde	CO	IMPROVE
55	Weminuche, La Garita, Black Canyon of Gunnison	CO	IMPROVE
56	Maroon Bells, West Elk, Eagles Nest, Flat Tops	CO	IMPROVE
57	Rocky Mountain	CO	IMPROVE
58	Mount Zirkel, Rawah	CO	IMPROVE
59	Badlands	SD	IMPROVE
60	Wind Cave	SD	IMPROVE
61	Theodore Roosevelt	ND	IMPROVE
62	Lostwood	ND	IMPROVE
63	Medicine Lake	MT	IMPROVE
64	UL Bend	MT	IMPROVE
65	Bridger, Fitzpatrick	WY	IMPROVE
66	Yellowstone, Grand Teton, Teton, Red Rock Lakes	WY	IMPROVE
67	North Absoraka, Washakie	WY	IMPROVE
68	Jarbidge	NV	IMPROVE
69	Craters of the Moon	ID	IMPROVE
70	Sawtooth	ID	IMPROVE
71	Anaconda-Pintler, Selway-Bitterroot	MT	IMPROVE
72	Glacier	MT	IMPROVE
73	Bob Marshall, Mission Mountains, Scapegoat	MT	IMPROVE
74	Gates of the Mountains	MT	IMPROVE
75	Cabinet Mountains	MT	IMPROVE
76	Eagle Cap, Strawberry Mountain	OR	IMPROVE
77	Hells Canyon	ID	IMPROVE
78	Mount Rainier	WA	IMPROVE
79	Goat Rock, Mt Adams	WA	IMPROVE
80	Alpine Lakes	WA	IMPROVE
81	North Cascades, Glacier Peak	WA	IMPROVE
82	Pasayten	WA	IMPROVE
83	Olympic	WA	IMPROVE
84	Three Sisters, Mount Jefferson, Mount Washington	OR	IMPROVE
85	Mount Hood	OR	IMPROVE
86	Crater Lake, Diamond Peak, Mountain Lakes, Gearhart Mountain	OR	IMPROVE
87	Lava Beds, South Warner	CA	IMPROVE
88	Redwood	CA	IMPROVE
89	Kalmiopsis	OR	IMPROVE
90	Lassen Volcanic, Caribou, Thousand Lakes	CA	IMPROVE
91	Point Reyes	CA	IMPROVE
92	Pinnacles, Ventana	CA	IMPROVE
93	San Gabriel, Cucamonga	CA	IMPROVE
94	San Rafael	CA	IMPROVE
95	Desolation, Mokelumne	CA	IMPROVE
96	Yosemite, Emigrant	CA	IMPROVE
97	Hoover	CA	IMPROVE
98	Sequoia, Kings Canyon	CA	IMPROVE
99	San Gorgonio, San Jacinto	CA	IMPROVE
100	Agua Tibia	CA	IMPROVE
101	Joshua Tree	CA	IMPROVE
102	Denali	AK	IMPROVE
103	Tuxedni	AK	IMPROVE
104	Marble Mountain, Yolla Bolly Middle Eel	CA	IMPROVE
105	Simeonof	AK	IMPROVE
106	Virgin Islands	VI	IMPROVE
107	Hawaii Volcanoes	HI	IMPROVE
n	*Represented Class I areas or Protocol Site*	*state*	*Agency*
108	Haleakala	HI	IMPROVE
109	Dome Land	CA	IMPROVE

110	Kaiser, Ansel Adams, John Muir	CA	IMPROVE
111	Trapper Creek-Denali	AK	NPS
112	Columbia River Gorge	WA	USFS
113	Salmon	ID	USFS
114	Brooklyn Lakes	WY	USFS
115	Lone Peak	UT	USFS
116	Great Basin	NV	NPS
117	Indian Gardens	AZ	NPS
118	Death Valley	CA	NPS
119	Washington DC	DC	NPS
120	Saguaro west	AZ	Arizona
121	Queen Valley	AZ	Arizona
122	Organ Pipe	AZ	Arizona
123	Hillside	AZ	Arizona
124	Meadview	AZ	Arizona
125	Presque Isle	ME	Micmac Tribe
126	Old Town	ME	Penobscot Tribe
127	Proctor Research	VT	Vermont
128	Casco Bay	ME	Maine
129	Bridgton	ME	Maine
130	Cape Cod	MA	Massachusetts
131	Quabbin Reservoir	MA	Massachusetts
132	Martha's Vineyard	MA	Wampanoags Tribe
133	Mohawk Mountain	CT	Connecticut
134	Spokane Reservation	WA	Spokane Tribe
135	Connecticut Hill	NY	EPA/CASTNet
136	M.K. Goddard	PA	EPA/CASTNet
137	Arendtsville	PA	EPA/CASTNet
138	Quaker City	OH	EPA/CASTNet
139	Bondville	IL	EPA/CASTNet
140	Livonia	IN	EPA/CASTNet
141	Cadiz	KY	EPA/CASTNet
142	Sikes	LA	EPA/CASTNet
143	Addison Pinnacle	NY	New York
145	Columbia Gorge	WA	USFS

1.2 Changes from Version I to Version II

The Version II sampler is not significantly different than the Version I sampler. Both consist of independent filter modules connected to a common controller module. Each filter module has independent air streams with separate sizing devices, critical orifice flow controllers, and pumps. Each module has solenoids for exposing up to four filters between changes. No change has been made in the sampling trains from the inlet to the filter. The same cyclones define the $PM_{2.5}$ cut point. Collocated tests show no differences in particulate concentrations. Other key components have not changed. Flow control continues to be obtained by a critical orifice between the filter and pump. In both versions, the flow rate for $PM_{2.5}$ particles is measured independently at two locations, ahead of the filter and between the filter and critical orifice.

The Version I sampler operated very reliably, with minimal downtime, but several factors led to the modifications. First, the change to a 1-day-in-3 protocol required replacement of the weekday-oriented clock. Microprocessor technology is much different in 1999 than in 1987, so we moved in this direction. Second, the samplers at existing sites were due for replacement, having been in the field for up to a decade. By shifting all samplers to Version II at this point, we could maintain a uniform network. Third, the cassettes we have used now for twenty years have been discontinued by the manufacturer. Having new cassettes made to our design opened up avenues for improving the way we handle filters in the laboratory and in the field.

The controller is the most significant change from Version I and II. Version I uses a programmable clock that is oriented to days of the week, while Version II uses a microprocessor. Other components of the sampler were modified to take advantage of the microprocessor.

- The dial flow rate gauges were replaced by transducers that can be read by the controller. All readings are displayed digitally on the controller screen.
- The mechanical elapsed timers were eliminated.

The shift to microprocessors and transducers changed the way we record the flow rates. The Version I sampler used flow rates measured at the time of sample change, both before and after sampling. The Version II microprocessor monitors the flow rate and temperature every minute and logs this information in magnetic memory. The data are downloaded onto a magnetic card transported with the cassettes. The operator still records the flow rates at the time of sample change for quality control, but this is now simplified and improved. In the Version I sampler, the operator had to read dials on flow rate gauges. In the Version II sampler, all information to be recorded on the logsheet is displayed digitally on the controller screen. The controller display follows the logsheets exactly. The operator is still expected to check the values recorded for reasonableness.

The second major change in the Version II sampler is in the filter cassettes. The new cassettes have the same dimensions of the old, but have a much superior design. The top and bottom of the new cassette are held together by O-rings instead of a screw fitting, which has eliminated leaks. Built-in stainless steel screens produce a more uniform particle distribution. The materials are the same as those used in the cassettes in the FRM sampler. The cassettes are currently available for 25mm filters with a 2.2 cm^2 collection area, 25mm filters with a 4 cm^2 collection area, and 37mm filters with a 6.4 cm^2 collection area. The cassettes can be stacked for a secondary filter. Collocated comparisons between the old and new cassettes show no differences in collection.

The installation of the cassettes in the sampler has also been improved. In the Version I sampler, the cassettes were loaded individually and attached to hoses from the solenoids. In the Version II sampler, the cassettes are installed in a cartridge in the central laboratory. Each cartridge holds four cassettes, with either ambient filters, field blanks, or no filter. The site operator exchanges the entire cartridge. Guide pins ensure that the cassettes are correctly oriented, eliminating the possibility that a given filter could run on the wrong date. The hoses between the cassettes and the solenoids have been replaced by a direct connection using a manifold that drops onto the cassettes. This eliminates leaks in the hoses and leaks around the cassettes from incorrect installation during sample changing.

Finally, many parts have been redesigned to make the sampler easier to maintain. The fiberglass enclosure has been replaced by steel enclosure of one-half the volume. Some components have been redesigned to allow any defective parts to be replaced quickly, minimizing down-time. For example, the electronics components for each filter module are enclosed in a removable box. If a component fails, a new box is expressed to the site and snapped in place.

1.3 Weekly Sample Changes

The filters are loaded into cassettes and cartridges at the central laboratory at Davis. All cassettes have caps to protect sample integrity. All the cartridges and the logsheet for a given change are enclosed in a resealable bag with the date of the sample change. Three bags will be shipped to and from the site in a “Blue Box” shipping container, labeled with all the sample changing dates.

The IMPROVE network will operate in the one-day-in-three protocol, with sample changing always on Tuesday. With this protocol, the arrangement of ambient filters will vary slightly for each week, with the pattern repeating every third week. Each Blue Box will have three bags, three logsheets, a one memory card and will be shipped every three weeks. The three types of cartridges are listed in Table 2. All cartridges will be labeled by the Tuesday sample-changing date.

Table 2: Types of cartridges for 1-day-in-3 sampling.

cartridge type	position 1	position 2	position 3	position 4
Type 1	Thursday	Sunday	unused	unused or field blank
Type 2	Wednesday	Saturday	Tuesday	unused or field blank
Type 3	Friday	Monday	empty hole	unused or field blank

For two of the three weeks, the sampler will be not be operating on the sample-changing day. For these sample changes, the operator records the final readings, replaces the old cartridges with new cartridges, and records the initial readings. The only difference is that there will be initial or final readings for the filter in position 3 on two of the three weeks. The logsheet and display will indicate when the values for position 3 are to be recorded.

The procedures are different every third week, when the sampler will be operating when the operator arrives. When the operator presses the buttons to start the sample change, the controller will suspend sampling, read the flow rates for all the filters and display the information to be recorded. For this change, the operator will have to transfer the cassette in position 3 from the old cartridge to the new. The key information for the operator is that the new cartridges will not have any cassette in position 3. The cassette in position 3 has a black O-ring attaching it and is the only one that can be removed without a special tool. After the cassette is transferred, the new cartridge in installed. After the initial readings are taken, the sampler will resume collection on the filters in position 3.

The field blanks in position 4 are completely transparent to the site operator and to the sampler controller. Flow rate measurements are not taken for field blanks. Selected sites will have secondary quartz filters for Module C. Two cartridges will stacked together in the sample handling laboratory and inserted by the site operator as a single unit. The module must be slightly modified to accommodate this. No special procedures are required for the site operator.

2. Description of Version II IMPROVE Sampler

2.1 Shelters

The sampler will be protected from direct sunlight by a shelter. The shelter will also protect the filters during sample-changing in rain or snow. This will vary from an outdoor stand with a sunshield to a fully enclosed but well-ventilated shelter. The shelters at IMPROVE sites will not be heated or air-conditioned. The length of the inlet stacks will be 1.83m at all sites.

The standard configuration is shown in Figure 2. Most sites will have four modules plus a controller. Selected sites will also have a quality assurance module. Each module will have its own pump requiring 3.3 amperes (A) at 120 volts (V).

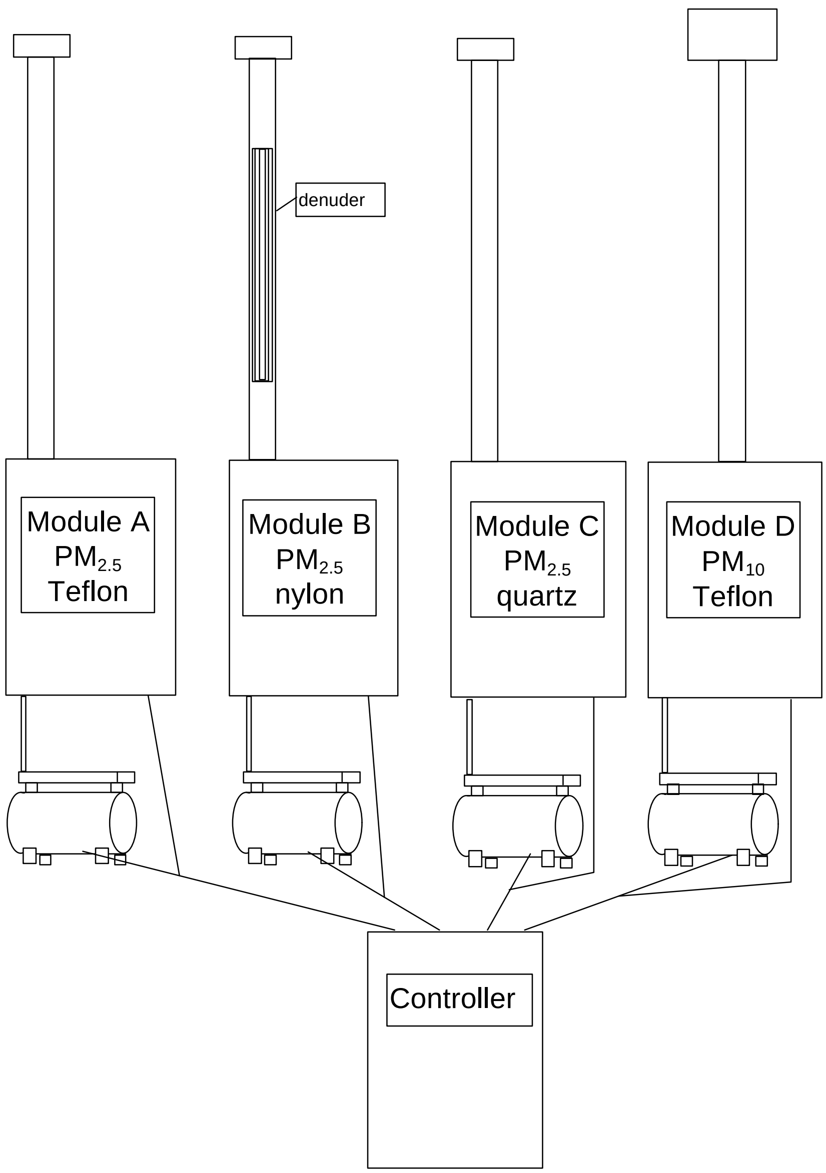

Figure 2. Typical sampler configuration.

2.2 $PM_{2.5}$ Filter Module

A Version II $PM_{2.5}$ module is shown in Figure 3.

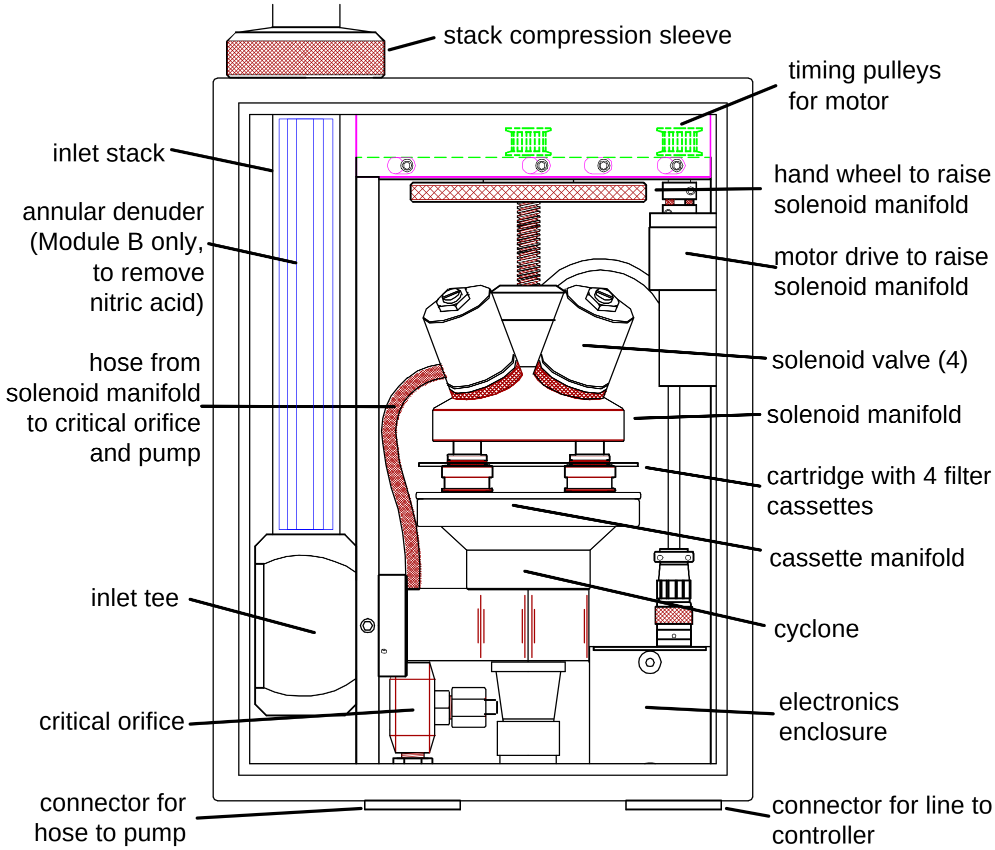

Figure 3. $PM_{2.5}$ module.

Inlet and Cyclone The ambient air enters through a screened inlet on top of the stack. This removes bugs, rain, and particles larger than 15 µm. The air stream then passes through a cyclone that removes particles larger than 2.5 µm. The cyclone has a 50 percent efficiency for 2.5 µm aerodynamic diameter particles at a flow rate of 22.8 L/min. A 5% decrease in flow rate, from 22.8 to 21.7 L/min, would increase the cut point from 2.5 to 2.9 µm.

Module B (nylon) has a carbonate-coated annular denuder to remove nitric acid. The denuder consists of four concentric 61-cm aluminum tubes. The calculated efficiency for removing HNO_3 is greater than 99.7%. The denuder is inserted in the inlet tube and held by O-rings.

The temperature of the air just before it reaches the cyclone is measured by a temperature probe in the base of one inlet stack. The temperature is measured every minute and the average recorded on the memory card every 15 minutes.

Critical Orifice Flow Control The flow rate at the cyclone is controlled by a critical orifice between the solenoids and the vacuum pump. Critical flow will be maintained as long as the vacuum behind the orifice is 53% of the atmospheric pressure or less. The primary reason for maintaining a constant volume flow rate of 22.8 L/min is to maintain a constant 2.5 µm cut point. There are two factors that cause the flow rate to vary from the nominal: the change in pressure drop across the filter and the change in ambient temperature. (The system is calibrated with a typical filter, so only the change from normal has an effect.) This is discussed in Appendix Section I.2. The diameter of the orifice can be adjusted by authorized technicians to give the desired nominal flow rate.

Flow Rate Measurement The flow rate is monitored by two pressure transducers. The flow rate ahead of the filter is determined from a transducer monitoring the pressure drop of air as it passes through the cyclone. The cyclone approximates a standard measuring orifice. The flow rate after the filter is determined from a transducer measuring the pressure relative to atmospheric just ahead of the critical orifice. This pressure drop is produced by the filter. Since the flow rate is determined before and after the filter, any leaks in the system can be identified at the time of filter installation. Both transducers are calibrated using a measuring orifice audit device that has been calibrated to a primary flow standard at the UC Davis laboratory. The controller will read and record both transducers every minute and record the averages every 15 minutes.

The flow rate equations for both transducers are expressed in parameterized form using parameters determined during the flow rate calibration at the site. There is also a pressure function based on the elevation of the site, F(elev), and a temperature function. The elevation factor is 1.00 for sites near sea level and increases to 1.20 at 10,000 feet, as listed in Table 3 on page 29. The temperature function varies from 0.95 at -9°C (17°F) to 1.05 at 50°C (122°F). The equation for the first transducer (across the cyclone) is:

$$Q_m = 10^a M^b F(elev) \sqrt{\frac{T+273}{293}},$$

where M is the "Mag" reading on the controller screen), F(elev) is the pressure function based on the elevation of the site, and a and b are calibration parameters normalized to 20°C and sea level.
The flow rate equation for the second transducer (before the critical orifice) is:

$$Q_v = \left(c - d * V\right) F(elev) \sqrt{\frac{T+273}{293}},$$

where V is the "Vac" reading on the controller screen, and c and d are calibration parameters.

Filter Cassettes and Cartridges The filter cassettes are manufactured specifically for the IMPROVE sampler. They are made of acetal homopolymer, with stainless steel screens. The two halves of the cassette are held together by an O-ring seal. A special tool is required to separate and assemble the two halves. This process is only done at the UC Davis central laboratory when the filters are unloaded and reloaded. The O-ring design has eliminated the leaks occasionally found with the threaded design of the old cassettes. The cassettes are always installed in cartridges, with four cassettes per cartridge. Most cassettes are held in the cartridges by a snap ring and cannot be removed easily. Some cassettes are to be moved from one cartridge and to a second cartridge in the field; these cassettes are held in by an O-ring and can be removed and inserted relatively easily. Each cartridge has a center hole and a small alignment hole. When the cartridge is placed on the cyclone manifold, alignment pins on the manifold prevent the cartridge from being rotated a quarter or half turn. For the $PM_{2.5}$ module, the labels and red/yellow/green dots on the cartridges will always be up.

All cassettes are labeled by site, module, and the date of sample collection. All cartridges are labeled by site, module, and the date of sample change.

2.3 PM_{10} Filter Module

A Version II PM_{10} module is shown in Figure 4. The particle size cut is determined by a standard commercial PM_{10} inlet.

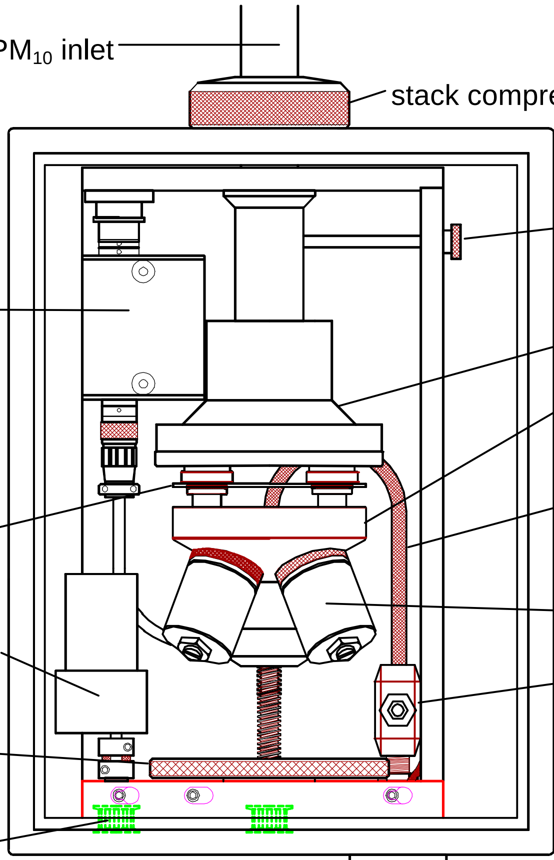

Figure 4. PM_{10} module.

Flow Rate Measurement The flow rate is monitored by a single pressure transducer between the filter and critical orifice. This transducer is calibrated using a measuring orifice audit device that has been calibrated to a spirometer at the UC Davis laboratory. The controller reads the transducer every minute and records the average every 15 minutes.

Filter Cassettes and Cartridges The same cassettes and cartridges are used in the PM_{10} module. The only difference is that they are inserted upside down compared to those for the $PM_{2.5}$. For the PM_{10} module (D), the labels and blue dot on the cartridge will be <u>down</u>.

3. Controller

3.1 General Description

The Version II controller consists of a TERN 16-bit controller, a Two Technologies terminal with LCD screen and a twenty button keypad, plus appropriate electric components. The controller is shown in Figure 5. The lower portion shows the connectors on the bottom of the module. The terminal can be removed from the controller to be closer to the sampler modules. This is useful during sampler calibration but not recommended during the weekly sample change. When left in the controller, the cord is contained in the storage pocket.

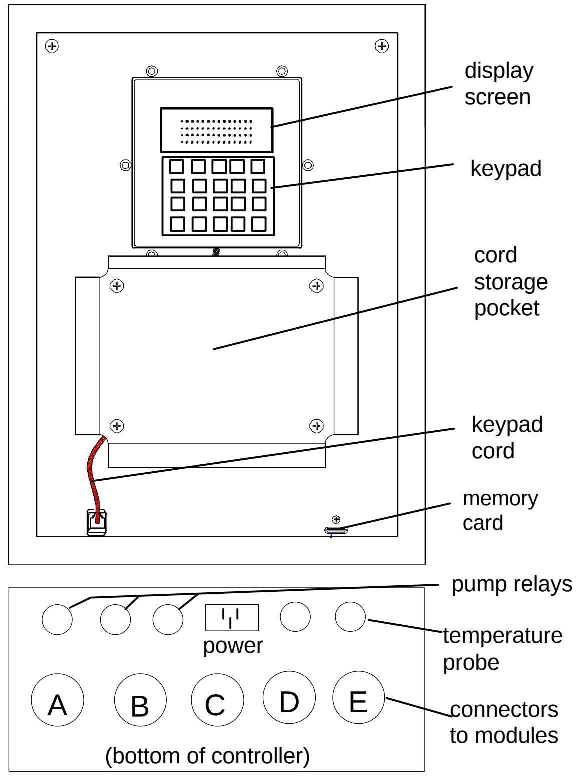

Figure 5. Controller module

The control programs are written in C/C++ on a computer and downloaded into the microprocessor.

Fifteen-minute averages of flow rate and temperature are downloaded into a removable ISSI Serial Flash Module (memory card) that is shipped between the site and the central laboratory with the filters. The memory card is 1 MB and will hold the information of about one year of sampling. This is normally changed every third week.

The controller can currently accommodate up to five filter modules.

The terminal is shown in greater detail in Figure 6. The LCD display has 4 lines of 20 characters. When the sampler is in the AUTO MODE, the LCD will display the current status of the sampler modules, as discussed in Section 3.2. All functions of the sampler are set up using menus and sub menus, as discussed in Section 3.3. The six keys to activate the menu are shown in the figure.

The **ENTER** key is generally used to jump to the next main step. The →**F4** or ←**F3** keys to move to the next or previous screens. In almost all cases, the screen will indicate the options.

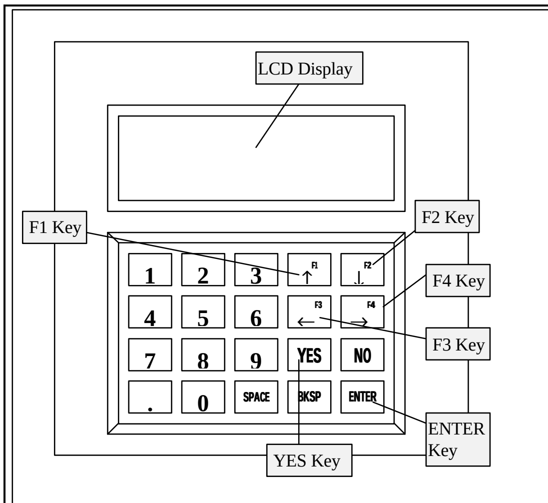

Figure 6. Controller terminal

The programmed controller is responsible for the following aspects of the sampler.

- Provide the site operator a status of current sampler operations.
- Provide the site operator an interface for recording initial and final measurements of the filters during sample change, using the LCD screen.
- Provide options for selecting sampling protocols and filter types. This is normally performed by the UC Davis technician at the time of installation.
- Set the date and time.
- Switch the filter solenoids and pump relays on and off.
- Measure and record the pressure transducers and temperature probe. A standard configuration has 7 transducers. Measurement is done once a minute and averages are recorded on the memory card every 15 minutes. The averages are also recorded whenever there is a power outage or the operator starts the sample change.
- Measure and record ambient temperature. This is on the same schedule as that of the pressure transducers.
- Download the measurements to a removable ISSI Serial Flash Module (memory card).

The controller program has two modes: an AUTO MODE and a MENU MODE. The program normally is in the AUTO MODE whether the sampler is on or off. During this AUTO MODE, there are several possible current status screens.

To move from the AUTO MODE to the MENU MODE, press the **ENTER** key. This will switch the display from a current status screen to a menu screen. The MENU MODE has a main menu and several sub-menus. After using a menu, make certain that the controller has returned to the AUTO MODE. After completing the standard filter change, the program will automatically return to the AUTO MODE. For other menus, press the **ENTER** key to return to the AUTO MODE.

3.2 Current Status Screens

When the sampler is in the AUTO MODE, it will show one of the three current status screens in Figure 7. In all current status screens, the top line shows the current date, time, and day of the week. The final digit indicates the sampling protocol: 1 for Wednesday/Saturday and 2 for one-day-in-three. For 5 seconds every minute, the bottom line of the screen will indicate that it is recording the flow rate and temperature sensors.

If samples are being collected, the controller will show screen 1. This screen will be showing on the sample changing day every third week. The temperature is expressed in volts from the probe and will be converted in the laboratory to the correct temperature.

If the sampler is off and if there are remaining sampling days, the controller will show screen 2. This screen should never be showing on the sample changing day.

If the sampler is off and if all the sampling periods are complete and the filters can be changed, the controller will show screen 3. This screen will be showing on two out of three sample changing days.

Screen 1. Sample collection is in process. The second line shows which filter is on and the voltage of the temperature probe. The bottom two lines show the elapsed time for all ambient filters.	**01/04/00 08:01 TUE 2** **Fil 3 ON, Temp= 98V** **Fil 1 |Fil 2 |Fil 3** **24hrs |24hrs	8hrs**
Screen 2. The sampler is off and is waiting for the next period. The last two lines indicate that everything is off.	**01/03/00 08:02 Mon 2** **A B C D** **OFF OFF OFF OFF**
Screen 3. All sampling with the current set of filters is completed. <u>The filters can now be changed</u>. Sampling will not resume unless the filters are changed.	**01/11/00 08:00 TUE 2** **SAMPLING** **COMPLETED**

Figure 7. Current status screens.

3.3 Main Menu

The MENU MODE can be accessed by pressing the **ENTER** key when the sampler is the AUTO MODE. When the **ENTER** button is pushed the main menu shown in Figure 8 will appear. If the program is “recording sensors” (5 seconds every minute), there will be a delay of up to 5 seconds.

```
F1=Filter Readings
F2=Change Date&Time
F3=Advanced Menu
ENTER=AUTO MODE
```

Figure 8. Main menu screen.

The screen indicates four options.

1. Pressing the ↑**F1** key will bring up the filter reading menu for the standard weekly filter change. Press this key to begin the sample changing procedures, as described in Section 4, Sample Changing Procedures.

2. Pressing the ↓**F2** key will bring up the menu to change the current date and time, as described in Section 3.4 Changing the Date and Time.

3. Pressing the ←**F3** key will bring up the advanced menu. The menu will allow the user to calibrate the flow rate and change the sampler protocols. This menu requires an access code. This menu is described in Section 6.2, Advanced Menu.

4. Pressing the **ENTER** key will return the sampler to AUTO MODE. The sampler must be in the AUTO MODE to collect samples. If the sampler is left in the MENU MODE without any input for longer than 15 minutes, the program should automatically revert to the AUTO MODE. However, to be safe, do not leave the sampler in the MENU MODE.

A fifth option allows you to check the version of the operating system. This information might be requested by UCD when trying to fix a software problem. Pressing the decimal point (.) will yield Figure 9. After five seconds, the program will automatically return to the main menu.

```
 UCD Sampler  nnnn
 Avgs every 15 min
Software Ver. 00.04
  July 2000 PHW
```

Figure 9. Program version screen.

3.4 Changing the Date and Time

From the AUTO MODE, press **ENTER** to reach the main menu. From the main menu, press the ↓**F2** key to enter the change time menu, shown in Figure 10. The item to be changed is underlined. By pressing the ←**F3** and →**F4** keys, you can move the underline left or right to the desired category (month, day, year, hour, minute). To increase or decrease the value of the category, use the ↑**F1** or ↓**F2** key. The day of the week will automatically change with the date.

```
12/01/00 08:00 SAT 3
F1&F2 adjusts values
F3&F4 to move cursor
Press ENTER to write
```

Figure 10. Change time screens.

When finished, press the **ENTER** key to record this information and return to the main menu.
Press the **ENTER** key a second time to return to the AUTO MODE.

4. Procedures for Sample Changing in the Field

4.1 Preparation and Summary

The operator will receive a “Blue Box’ shipping container from Davis every three weeks. Inside will be three resealable bags each containing the filters for one week and the corresponding logsheet. The bag will be labeled with the date that the filters are to be installed. The Blue Box will be labeled with all three dates. The Blue Box will also have a memory card in a pouch on the inside of the top cover. In each bag there will be cartridges, with four cassettes per cartridge. The cartridges will be color-coded for each module: A=red, B=yellow, C=green, D=blue.

Most sites will have two Blue Boxes, one being used at the site, and the other in transport or waiting at the site. The Blue Box should be received 10 days before the first sample-change day. At sites with possible delays in mail, there will be more than two Blue Boxes in the system. If the appropriate box is not present by the change date, the operator should contact the UCD laboratory (530-752-1123).

Before going to the site, the operator must check the dates on the Blue Box(es). If the first date on the new Blue Box is today’s date, the operator should bring both this Blue Box and the previous Blue Box. If

For all sample changes, the procedures are:

1. Initiate the changing sequence by pressing the **ENTER** and ↑**F1** keys.
2. Record the general data shown on the controller display, then press the **ENTER** key.
3. Record the Final Readings for each exposed filter, using the →**F4** key to move to the next filter. When finished check that all blanks in the log sheet are filled in and the numbers are reasonable. If okay, press the →**F4** key. To redo the readings, press the ←**F3** key.

4a. If this is not a sampling day. (Two out every three weeks. The sampler is not running when you got there.) Remove the cartridge of exposed cassettes from each module and replace it with a cartridge of clean cassettes. Do not remove any cassettes from their cartridges. When finished press the **ENTER** key.

4b. If this is a sampling day. (Every third week. The sampler is running when you got there.) The old cartridges will have a black O-ring in position 3 and the new cartridges have holes in position 3. Remove the old cartridge from the sampler. Move the cassette in position 3 of the old cartridge to the hole in the new cartridge. This cassette is held in with a black O-ring and is the only cassette that can be easily removed. Install the new cartridge. When finished check that all blanks on the right side of the log sheet are filled in and the numbers are reasonable. If okay, press the **ENTER** key.

5. If today’s bag is the first in a new blue box, remove the memory card from the controller and place it in the pouch of the old blue box. Remove the memory card from the new box and place in the controller. If there is no memory card in the new box, leave the old one in the controller.
6. Record the Initial Readings for each clean filter, using the →**F4** key to move to the next filter. When finished check that all blanks in the log sheet are filled in and the numbers are reasonable. If okay, press the →**F4** key. To redo the readings, press the ←**F3** key. The sampler will automatically return to the current status (operational) mode.

4.2 Initiating the Sample Changing Sequence

Begin sample changing by pressing the **ENTER** key (to go to the main menu) and the ↑**F1** key (to initiate the changing sequence).

The program asks whether to proceed with the readings. The terminal screen is shown in Figure 11. Press **YES** to proceed. (A **NO** response returns the program to the AUTO MODE. Use this if you accidentally pressed the ↑**F1** key.)

```
   Filter Reading
        PRESS
YES to Continue
 NO to Cancel
```

Figure 11. Continue screen 1.

In the sample-changing procedures, there are two types of screens. The first are temporary informational screens with the top line being "One moment please." These screens are to inform you that the controller is performing some task, such as turning on pumps or recording information on the memory card. No interaction is required. The remaining screens all require some response. In many cases, you will record a displayed value on the logsheet. For this type of screen, you will press the indicated key to proceed to the next screen. In the following figures, only those screens requiring an interaction are shown.

4.3 Exposed Filter Readings (Final Readings on the Logsheet)

There will be a series of informational screens with the upper lines showing "One moment please." These will indicate when the pumps are being turned on and when the readings are being recorded on the memory card. The program will automatically switch to the screens of Figure 12.

The displays for the final reading of the exposed filters requiring a response are shown in Figure 12.

Screen 1: Record on the logsheet the voltage of the temperature probe shown in this screen. (This will be converted to degrees in the laboratory.) When recorded, press the **ENTER** key to proceed.

Screen 2: Record on the final reading (right) side of the logsheet the information for each filter shown in this screen. The module designation (ABCDE) and the position number (FIL 2, FIL 2) are displayed. Record pressure readings (**Vac** & **Mag**) and the elapsed time in minutes (**ET**). When the information for the filter is recorded, press the →**F4** key to go to the next filter. To return to a previous display use the ←**F3** key. A standard sampler will have 8 or 12 filters.

```
Logsheet Entry
01/01/00 08:00 SAT 2
CurTemp  98V
Hit ENTER when ready
```

↓

```
Mod(A)
 Cass   Vac Mag  ET
(FIL 1)  12  32 1440
   F3-Bkwd  F4-Fwd
```

Figure 12. Exposed readings screens.

When all filters have been examined, , the screen shown in Figure 13 will appear. Check the logsheet for completeness. To retake the final readings press the ←**F3** key. If complete, proceed with the initial readings for the clean filters by pressing the **F4** key.

```
F3-GO BACK to take
   Exposed readings
F4-Replace EXPOSED
   filters w/ CLEAN
```

Figure 13. Continue screen 2.

4.4 Removing and installing cassettes

After the **F4** key is pressed, the screen shown in Figure 14 will appear.

Change the cartridges before pressing the **ENTER** key.

```
Remove EXPOSED
cassettes and
insert CLEAN ones.
Hit ENTER when done.
```

Figure 14. Exchange cassette screen.

To remove the cassettes, either activate the motor switch or use the hand wheel to raise the upper manifold. The cartridge will automatically separate from both manifolds.

There are two different procedures for changing filters, depending on whether the sampling day falls on Tuesday. The dates when the sampling date is on Tuesday are given in Table 5 of Appendix III. You will know this if the sampler was operating immediately before the sample change.

<u>If this is not a sampling day</u>. Remove the exposed cartridge for each module, put caps on all the cassettes, and place the exposed cartridge in the resealable bag with last week's date. Stack the cartridges to achieve the most compact shape, offsetting each one by 1/8 turn. Remove the appropriate cartridge from the bag with the current date. The cartridges will be color-coded: A=red, B=yellow, C=green, D=blue. Remove the caps and place them in the bag. Place the new cartridge in the lower manifold with the alignment pins through the holes in the cartridges. For the $PM_{2.5}$ modules (ABC), the stickers and the red, yellow, or green dot will be up. For the PM_{10} module (D), the stickers and the blue dot will be <u>down</u>. The alignment pins allow only one orientation. The cartridge will float on the pins. Lower the upper manifold using the motor switch or hand wheel.

<u>If this is a sampling day</u>. Remove the old cartridge from the sampler and get the new cartridge for the same module from the bag with the current date. This will have a hole in position 3. Move the cassette in position 3 from the old cartridge to the hole in the new cartridge. (The cassette in position 3 is held in by an O-ring and is the only cassette that can be easily removed.) Put caps on the three remaining cassettes in the exposed cartridge and place it in the resealable bag with last week's date. Remove the caps on the other three cassettes in the new cartridge and place them in the bag. Place the new cartridge in the lower manifold. The alignment pins will not allow it to be rotated. Lower the upper manifold using the motor switch or hand wheel.

> Care must be taken during this process of moving the cassette from the old to the new cartridge to protect the filter from contamination by rain or snow. If the roof does not adequately protect this process, you should remove all four of the exposed cartridges, move to a protected location, switch the position 3 cassettes from the old cartridges to the new and then return to the sampler to install the new cartridges.

Check that the caps are on all of the exposed cassettes. Arrange the four cartridges for the most compact shape by offsetting each one by 1/8 turn. Reseal the resealable bag when all cartridges are changed. If this is the last week of filters for the Blue Box, return it to Davis as soon as possible using the reversible mailing label.

If the bag of new cassettes is the first in the new box, the operator should replaced the memory card in the controller. Remove the memory card from the controller and place it in the pouch on the inside of the lid of the old box. Remove the memory card from the pouch in the new box and insert in the controller. If there is no memory card in the new box, leave the old memory card in the controller and make a note on the logsheet.

After all modules are changed, press **ENTER** to continue to the initial readings of clean cassettes.

4.5 Clean Filter Readings (Initial Readings on the Logsheet)

A series of temporary informational screens will appear (“One moment please.”) while the pumps are being turned on and the sensors are read. The display will automatically switch to the next screen.

If the filter was improperly installed, one of two error messages may appear on the screen. In both cases it will alternate between the message and what to do.

If the flow rate through the cyclone is much less than the nominal flow rate then the messages of Figure 15 will appear. There are two normal reasons for the condition. First, you may have failed to lower the cassette manifold. Second, you may have a missing cassette in the cartridge. Every third week, when the change day coincides with the sampling day, it is necessary to move the current filter from the old cartridge to the new. This message will occur if you forgot to transfer the cassette. In either case, correct the problem and press the ←**F3** key. If you have corrected the problem, it will proceed to Figure 17. If this does not work, and the installation appears to be correct, it is possible to override this check and proceed with the sample change. In this case, press the →**F4** key. The program proceed to Figure 17. Note that you will probably get the low flow message for all two or three filters in the cartridge.

```
      WARNING
LOW FLOW DETECTED
check Module (A) for
proper installation
```

```
Press:
F3-To re-check
   installed filters
F4-Ignore warning
```

Figure 15. Error, low flow through cyclone.

Note that this message will not appear for the PM_{10} D module because there is no cyclone. If the mistake was made for A, B, or C, check that D is properly installed.

If the cartridge was installed upside down, then the messages of Figure 16 will appear. Install the cartridge the correct direction shown on the diagram on the module door and press the ←**F3** key. If you have corrected the problem, it will proceed normally to Figure 17. If this does not work, and the installation appears to be correct, it is possible to override this check and proceed with the sample change. In this case, press the →**F4** key. The program proceed to Figure 17. Note that you will probably get the upside down message for all two or three filters in the cartridge.

```
WARNING: Cartridge
may be UPSIDE DOWN
check Module (A) for
proper installation
```

```
Press:
F3-To re-check
   installed filters
F4-Ignore warning
```

Figure 16. Error, cartridge upside down.

The displays for the initial reading of the clean filters requiring a response are shown in Figure 17. The information is to be recorded on the left side of the logsheet.

Record the pressure readings (**MxVac**, **Vac** & **Mag**) for each clean filter. There is a space for only one **MxVac** reading on the logsheet. The values for all filters in a given module will be the same. Therefore record this value only once for each module. When the information for the filter is recorded, press the →**F4** key to go to the next filter. To return to a previous display use the ←**F3** key. As with the exposed filter readings, cycle through each of the filters pressing the **F4** key.

```
Mod(A)
 Cass  MxVac Vac Mag
(FIL 1)  40   12  32
     F3-Bkwd  F4-Fwd
```

Figure 17. Clean filter readings screens.

When all filters have been examined, Figure 18 will appear. Check the left side of the logsheet for completeness. If not complete, or if it was necessary to redo the readings, press ←**F3**. If okay, press →**F4** to continue. This ends the recording of readings.

```
F3-GO BACK to take
   CLEAN filter
   readings
F4-FINISH
```

Figure 18. Continue screen 3.

The information for the clean filter will now be remeasured and the values recorded on the memory card. A series of temporary informational screens ("One moment please.") will indicate the status. The sampler will automatically exit from the MENU MODE and return to the AUTO MODE.

Every third week the sampler will resume sampling on Filter 3. The informational screens will say that the pumps are being started and the sensors are being recorded. The first current status screen of Figure 7 will automatically appear (Fil 3 ON).

For the other two weeks, the sampler remains off. The sensors will be read and the second current status screen of Figure 7 will automatically appear (everything OFF). In either case, you could make certain that a current status is showing on the screen before you leave.

4.6 Field Logsheets

Each shipping box will contain three resealable bags, each containing all the cartridges for the change, plus a logsheet. Two of the three logsheets will be exactly as shown in Figure 19. The third logsheet will not have any entries for position 3.

IMPROVE Network Field Log

Preweighed by:ABC
12/25/1999

INSTALL ON --> **ACAD1 01/18/2000**

CurTemp_____C

INITIAL READINGS | **FINAL READINGS**

Operator's Initials______ **Date:____/____/1999** **Time:________** | **Init____** **Date:____/____/1999** **Time:________**

SamDate	StrTim		MxVac	Cass	Vac	Mag	Vac	Mag	ET
**********	**********	**********	**********	**********	**********	**********	**********	**********	**********
01/19/2000	0000			1	__ __ __	__ __ __	__ __ __	__ __ __	__ __ __ __
		Mod A	__ __ __						
01/22/2000	0000			2	__ __ __	__ __ __	__ __ __	__ __ __	__ __ __ __
01/25/2000	0000			3	__ __ __	__ __ __	__ __ __	__ __ __	__ __ __ __
**********	**********	**********	**********	**********	**********	**********	**********	**********	**********
01/19/2000	0000			1	__ __ __	__ __ __	__ __ __	__ __ __	__ __ __ __
		Mod B	__ __ __						
01/22/2000	0000			2	__ __ __	__ __ __	__ __ __	__ __ __	__ __ __ __
01/25/2000	0000			3	__ __ __	__ __ __	__ __ __	__ __ __	__ __ __ __
**********	**********	**********	**********	**********	**********	**********	**********	**********	**********
01/19/2000	0000			1	__ __ __	__ __ __	__ __ __	__ __ __	__ __ __ __
		Mod C	__ __ __						
01/22/2000	0000			2	__ __ __	__ __ __	__ __ __	__ __ __	__ __ __ __
01/25/2000	0000			3	__ __ __	__ __ __	__ __ __	__ __ __	__ __ __ __
**********	**********	**********	**********	**********	**********	**********	**********	**********	**********
01/19/2000	0000			1	__ __ __		__ __ __		__ __ __ __
		Mod D	__ __ __						
01/22/2000	0000			2	__ __ __		__ __ __		__ __ __ __
01/25/2000	0000			3	__ __ __		__ __ __		__ __ __ __

Lab Use Only
TFF M11681
10.911
10.822
10.302

comments:

For Help Call (530) 752-1123

Figure 19. Three-filter field logsheet.

5. Troubleshooting Guide

If time and weather conditions permit, please try the steps listed below for common sampler problems before calling the UC Davis sample handing laboratory: Phone (530) 752-1123, FAX (530) 752-4107, e-mail fieldops@crocker.ucdavis.edu .

1) Missed change day.

   a) If there are remaining sampling days in the week:
   remove the exposed filters as would normally be done and put in the clean filters that were to have been installed on the last change day. Make a note on the logsheet.

   b) If the week is completely missed:
   remove the exposed filters as would normally be done but do not put in the filters for the missed change day. Keep these in the shipping box and send them back to Davis when both weeks in that box have passed. Install the appropriate filters for the current week. Make a note on the logsheet of the filters that were not installed.

2) The display is blank.

   a) Power may be out.

      i) Check main circuit breaker, cycle it off and on if you are unsure if it has blown.

      ii) Check power strip that sampler and pumps are plugged in to (this may be located inside the pump enclosure). There should be a switch on the power strip. If it is not lit, turn it off and then on again.

      iii) Check the power cord for the sampler. This black cord runs from the base of the control module to the power strip. If it is unplugged, reconnect it.

      iv) If you are still not sure if power is on:
      (a) Unplug one of the pumps from its outlet box.
      (b) Disconnect the silver vacuum hose connecter from the top of the pump.
      (c) Plug the pump cord directly into the power strip. It should start if there is power.
      (d) Reconnect the vacuum hose and plug the pump back into the duplex outlet box.

   b) Sometimes the display gets too cold. If this is a possible problem, remove the keypad by disconnecting the phone jack on the back and allow it to warm up.

3) The elapsed time reads zero.
Check the following to determine why sampling did not occur on the scheduled day. Indicate problem on logsheet. If you cannot determine cause of problem call UC Davis at 530-752-1123 as soon as possible.

   (a) Check that the date and time on the controller screen are correct. Adjust if necessary using menu option F2.

   (b) If possible, check whether there was a power outage for the entire day.

   (c) Look at the Module A filter—can any sample be seen? Even if clean, do not reuse the filter.

4) Pump will not start.

   i) Check that the pumps are all plugged in (the outlet box that the pump is plugged into may have a switch on it but this does not control the pump power).

   ii) Test the pump that is not starting by doing the following:

      (a) unplug one of the pumps from its outlet box.

      (b) Disconnect the silver vacuum hose connecter from the top of the pump.

      (c) Plug it the pump cord directly into the power strip. It should start if there is power.

      (d) Reconnect the vacuum hose and plug the pump back into the duplex outlet box.

   iii) Extreme cold may prevent pumps from starting. Remove pump to warm location (or come back when the weather is warmer) and test. If cold may be a problem:

      (a) Run pumps continuously by plugging into unswitched outlets (power strip or wall outlet).

      (b) Keep pumps warm by placing an automotive electric blanket or other heat source under the pumps.

5) The motor drive is not working.
You can raise and lower the cassette assembly using the hand wheel. Before this can be done, it is necessary to disengage the motor drive. The motor drive is shown in Figure 3 and Figure 4. For the $PM_{2.5}$ module, push down on the top of the drive while pulling the bottom toward yourself. Then swing the motor to the left to lock it in the disengaged position. The hand wheel may now be used to raise or lower the solenoid manifold. The procedure is the same for the PM_{10} module (D), except the motor is upside down compared to the $PM_{2.5}$ modules. Notify UC Davis by calling or making a note on the logsheet.

6) The temperature probes give incorrect readings.
Use an external thermometer and write the readings of both the internal probe and the external thermometer on the logsheet. Please note whether readings are in Farenheit or Centigrade.

6. Sampler Installation and Maintenance

6.1 Summary

Prior to the installation of the sampler, the site will be prepared by the local site operator for power and a shelter. The sampler will be shipped to the site.

Sampler installation will normally be done by a field technician from UC Davis. This consists of the following elements:
- Placing the controller and filter modules on a wall of the shelter and cutting a hole in the ceiling for the stacks.
- Connecting the cables between the controller, filter modules, and pumps and the vacuum hoses between the modules and the pumps.
- Using the advanced menu, selecting the sampling parameters.
- Using the advanced menu, calibrating the flow rates of the filter modules.
- Attaching the sample changing instructions, on the inside of the controller door.
- Training the site operators and jointly installing the initial set of filters.

Approximately six months after installation or annual maintenance, the site operator will be requested to check the flow rate calibration. Detailed instructions and the appropriate equipment will be sent from Davis. This check will be done more frequently if some problem is detected in the flow rate values.

Sampler maintenance will be done annual by a field technician from Davis. This will consist in the following elements:
- Calibrating the flow rates of the filter modules.
- Cleaning and refurbishing the sampler, include replacing parts where needed.
- Making scheduled modifications to the sampler and controller program.
- Calibrating the flow rates of the filter modules a second time.
- Discussing procedures with the site operator, and providing any necessary training for new site operators.

6.2 Advanced Menu

From the operational/current status mode, press **ENTER** to reach the main menu. From the main menu, press the ←**F3** key to enter the advanced menu. You will be asked to provide an authorization code. This will be provided to the site operators when needed. After the correct code is entered, the display of Figure 20 is shown.

```
F1=Calib  ENTER=Exit
F2=Site Config.
F3=Select Change Day
F4=Select Start Time
```

Figure 20. Advanced menu screen.

There are two menus for the IMPROVE network. The select change day and start time menus are used only for Special Studies.

• Perform flow rate calibration.	↑**F1** key	Section 6.3 Flow Rate Calibration
• Select sampling protocol.	↓**F2** key	Section 6.4 Site Configuration

6.3 Flow Rate Calibration

6.3.1 Calibration Equipment

The equipment needed for calibration are:

- a cartridge with four calibration cassettes for each filter type
- an audit device for the $PM_{2.5}$ and PM_{10} modules (Figure 21)
- a calculator
- calibration logsheets (Figure 22)

The audit device consists of a probe with a calibrated orifice and a magnehelic gauge. The probe is shortened for the PM_{10} module by removing the two extreme sections. The magnehelic has a magnetic backing; use this to attach the calibration magnehelic to the module door in the vertical position. Record the 'zero' reading on the logsheet. Insert the probe in the base of the $PM_{2.5}$ inlet or in the top of the PM_{10} inlet manifold , as shown in Figure 21.

The calibration cassette in position 1 contains a standard filter for the module. The other positions have different pressure drops to vary the flow rate through the module in the same way that a loaded filter would decrease the flow rate.

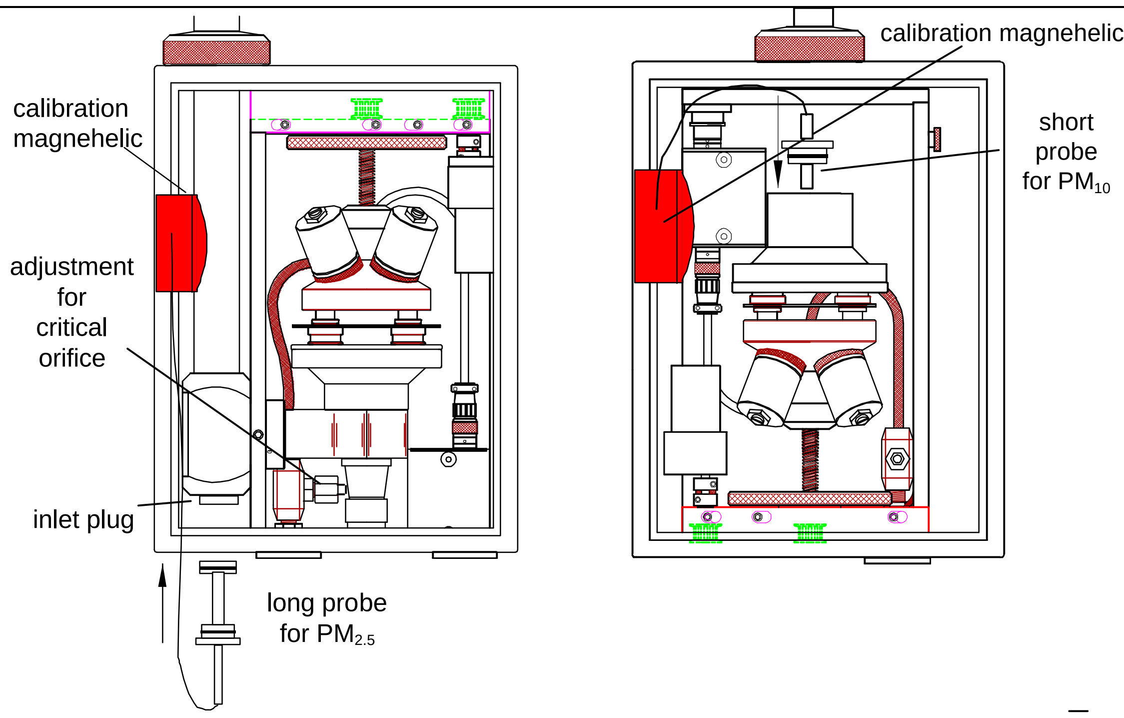

Figure 21. Insertion of calibration probe in $PM_{2.5}$ and PM_{10} modules.

Sampler Field Audit Form

Site Name: ______________________ Site Elevation Factor: ______________________
Audited by: ______________________ Date of Field Audit: ________/________/______
Audit Device Number: ______________ Audit Constants: a_o=__________ b_o=___________
Temperature: ___________________°C (reference only, not used)

Module Description: ____

Nominal Flow Rate

desired calibration magnehelic reading: $\Delta P_o = \left(\frac{23}{F(elev)} \frac{1}{10^{a_0}} \right)^{1/b_0}$ = ___________________

actual reading: ΔP_o = ________ flow rate at 20°C: $Q = F(elev) 10^{a_o} \left(\Delta P_o\right)^{b_o}$ = _____________

Four-Point Calibration

Calibration Cassette	Calibration Magnehelic ("H_2O)	Calibration Flow Rate (L/min)	System Vac Transducer	System Mag Transducer
# 1 nominal				
# 2				
# 3				
# 4				

flow rates relative to sea level and 20°C

System Mag $Q = 10^a M^b$ a=____________ b=_____________ r^2=_____________

System Vac $Q = c - d*V$ c=____________ d=_____________ r^2=_____________

Figure 22. Logsheet for nominal flow rate and four-point audit.

6.3.2 Calibration Controller Commands

From the operational/current status mode, press **ENTER** to reach the main menu. From the main menu, press the ←**F3** key to enter the advanced menu. From the advanced menu, press the ↓**F2** key to enter the calibration menu. Figure 23 shows the displays. Pressing the ←**F3** and →**F4** key will move backward or forward between filters. When the calibration is completed, press the **ENTER** key to return to the main menu and **ENTER** to return to the current status mode.

The controller will keep the solenoid for this filter open until the next solenoid is requested.

```
Starting pumps


Pump 1 Started
```

↓

```
Mod(A) ENTER to exit
Cass MxVac  Vac  Mag
(F1)  40.1 12.2 32.1
    F3-Bkwd  F4-Fwd
```

Figure 23. Flow calibration screens.

6.3.3 Adjusting the Nominal Flow Rate

<u>Warning</u>: Once sampling has begun, do not adjust the critical orifice until after you have made a full four-point calibration of the current settings.

The nominal flow rate is adjusted by varying the diameter of the critical orifice. This is done using the filter in the first position. After adjustment a full calibration must be done.

The appropriate nominal flow rate would be one that gave a flow rate of 22.8 L/min at the mean temperature of the network, which is approximately 15°C. The nominal flow rate will be set to give a flow rate of 23 L/min at 20°C. This corresponds to 22.8 L/min at 15°C. The desired reading on the on the calibration magnehelic should be:

$$M_o = \left(\frac{23}{F(elev)} \frac{1}{10^{a_0}} \right)^{1/b_0} ,$$

where a_o and b_o are the constants for the calibration magnehelic. Record the reading for the nominal flow rate on the logsheet shown in Figure 9. The elevation factors as a function of elevation are listed in Table 3. The elevations of the IMPROVE sites are listed in Appendix II.

Rotate the black knob on the critical orifice until the calibration magnehelic has the desired reading. Record the final measurements on the logsheet.

Table 3. Elevation factors as a function of elevation in meters.

meters	feet	F(elev)	P	meters	feet	F(elev)	P	meters	feet	F(elev)	P
0	0	1.000	29.90	1200	3,936	1.075	25.88	2400	7,872	1.158	22.32
50	164	1.003	29.72	1250	4,100	1.078	25.73	2450	8,036	1.161	22.18
100	328	1.006	29.55	1300	4,264	1.081	25.57	2500	8,200	1.165	22.04
150	492	1.009	29.37	1350	4,428	1.085	25.41	2550	8,364	1.168	21.90
200	656	1.012	29.20	1400	4,592	1.088	25.26	2600	8,528	1.172	21.76
250	820	1.015	29.02	1450	4,756	1.091	25.10	2650	8,692	1.176	21.63
300	984	1.018	28.85	1500	4,920	1.095	24.95	2700	8,856	1.180	21.49
350	1,148	1.021	28.68	1550	5,084	1.098	24.80	2750	9,020	1.183	21.35
400	1,312	1.024	28.51	1600	5,248	1.101	24.65	2800	9,184	1.187	21.22
450	1,476	1.027	28.34	1650	5,412	1.105	24.49	2850	9,348	1.191	21.09
500	1,640	1.030	28.17	1700	5,576	1.108	24.34	2900	9,512	1.195	20.95
550	1,804	1.033	28.00	1750	5,740	1.112	24.19	2950	9,676	1.198	20.82
600	1,968	1.036	27.83	1800	5,904	1.115	24.05	3000	9,840	1.202	20.69
650	2,132	1.040	27.67	1850	6,068	1.119	23.90	3050	10,004	1.206	20.56
700	2,296	1.043	27.50	1900	6,232	1.122	23.75	3100	10,168	1.210	20.43
750	2,460	1.046	27.34	1950	6,396	1.126	23.60	3150	10,332	1.214	20.30
800	2,624	1.049	27.17	2000	6,560	1.129	23.46	3200	10,496	1.218	20.17
850	2,788	1.052	27.01	2050	6,724	1.133	23.31	3250	10,660	1.221	20.04
900	2,952	1.055	26.84	2100	6,888	1.136	23.17	3300	10,824	1.225	19.91
950	3,116	1.059	26.68	2150	7,052	1.140	23.02	3350	10,988	1.229	19.79
1000	3,280	1.062	26.52	2200	7,216	1.143	22.88	3400	11,152	1.233	19.66
1050	3,444	1.065	26.36	2250	7,380	1.147	22.74	3450	11,316	1.237	19.53
1100	3,608	1.068	26.20	2300	7,544	1.150	22.60	3500	11,480	1.241	19.41
1150	3,772	1.072	26.04	2350	7,708	1.154	22.46	3550	11,644	1.245	19.28
1200	3,936	1.075	25.88	2400	7,872	1.158	22.32	3600	11,808	1.249	19.16

6.3.4 Four Point Calibration

1. Record on the calibration logsheet the calibration magnehelic readings and the system readings from the terminal display. Calculate the flow rates corrected to 20°C and sea level using the equation:

$$Q = 10^{a_o} \left(\Delta P_o\right)^{b_o} \quad ,$$

using the readings from the *Calibration Magnehelic ("H_2O)* column and the constants for the calibration magnehelic. Write these in the second column, *Calibration Flow Rate (L/min)*.

2. Repeat for the other three filters, using the YES button to shift between solenoids.
3. Perform a regression of the <u>log</u> of the calibration flow rate (y) as a function of the <u>log</u> of the sampler magnehelic reading (x). A reasonable fit yields a correlation coefficient (r^2) of 0.999. The constant a for the sampler magnehelic is the intercept, while the constant b is the slope. Record on logsheet.

4. Perform a regression of the calibration flow rate (y) as a function of the small gauge reading (x). Do not use logs. A reasonable fit yields a correlation coefficient (r^2) of 0.999. The constant c for the small gauge is the intercept, while the constant d is the slope.
5. If the calibration is unacceptable you will have to cycle through all the modules to get back to this module
6. When satisfied with the calibration, replace the calibration cassettes with the regular sampling cassettes.

6.4 Sampler Configuration

Every controller needs to be assigned a configuration. There are currently 2 protocols pre loaded in the processor for the IMPROVE network, Wed/Sat and 1-in-3. The current screen displays the protocol in the upper right corner, with 1=Wed/Sat and 2=1-in-3. (See Figure 7.)

To enter the configuration menu, press the **↓F2** key in the advanced menu. (From the current status mode, press **ENTER** to reach the main menu. From the main menu press the **←F3** key to enter the advanced menu.) Press the **ENTER** key to return to the main menu and **ENTER** a second time to return to the current status mode.

Sampler Code and Averaging Time

Each sampler will have a code equal to the last four digits of the UCD Inventory number on the tag inside Module A near the inlet stack. The first screen is shown in Figure 24. When a digit is entered it will appear on line 3. When four digits are entered a fourth line will say “Site Code Accepted”). If an incorrect digit is entered, you may erase it using the backspace key.

The second screen will then appear asking for the averaging time for the flow rate and temperature sensors. Enter 15 minutes. The numbers will appear on the fourth line.

```
Please enter 4 digit
 SITE CODE (eg 0001)


```

↓

```
Enter Data avg(mins)
  Then press enter
   Max: 1440 min

```

Figure 24. Sampler screens.

Protocol 2: IMPROVE: One day in Three Schedule

Selecting this program will set the sampler to sample every third day for 24 hours. The start time will always be 00:00 (midnight). The sampler will be changed every Tuesday. As shown in Figure 25, select the following options for the IMPROVE: One day in three protocol.

Select **IMPROVE**. Press **ENTER** to save and continue.

```
Select Study
*IMPROVE  SPECIAL
F3&F4 to change
Press ENTER to save
```

↓

Select **1/3**. Press the **ENTER** key to save and continue.

```
Select PROTOCOL
 W/S *1/3
F3&F4 to change
Press ENTER to save
```

↓

Select **Module Types**. Use the ←**F3** and →**F4** keys to move left or right, and the ↑**F1** and ↓**F2** keys to increase or decrease to letter designation (A, B, C, D, E, S, or nothing). Press the **ENTER** key to save and return to the advanced menu.

```
Select Module Types
MOD 1 2 3 4 5
    A B C D
```

Figure 25. Protocol 2 screens.

If any number was entered incorrectly, press the ↓**F2** key to rerun the site configuration program.

Press the **ENTER** key to return to the main menu and **ENTER** a second time to return to the current status mode.

Appendix I Flow Rate Equations

A-I.1 The Effect of Flow Rate on Cyclone Cut Point

The collection efficiency of the IMPROVE cyclone was characterized at the Health Sciences Instrumentation Facility at the University of California at Davis. The efficiency was measured as a function of particle size and flow rate using two separate methods: PSL and SPART. The PSL method uses microspheres of fluorescent polystyrene latex particles (PSL) produced by a Lovelace nebulizer and a vibrating stream generator and analyzed by electron micrographs. The SPART method uses a mixture of PSL particles produced by a Lovelace nebulizer and analyzed by a Single Particle Aerodynamic Relaxation Time (SPART) analyzer. The aerodynamic diameter for 50% collection, d_{50}, was determined for each flow rate. The relationship between diameter and flow rate is shown in Figure 26.

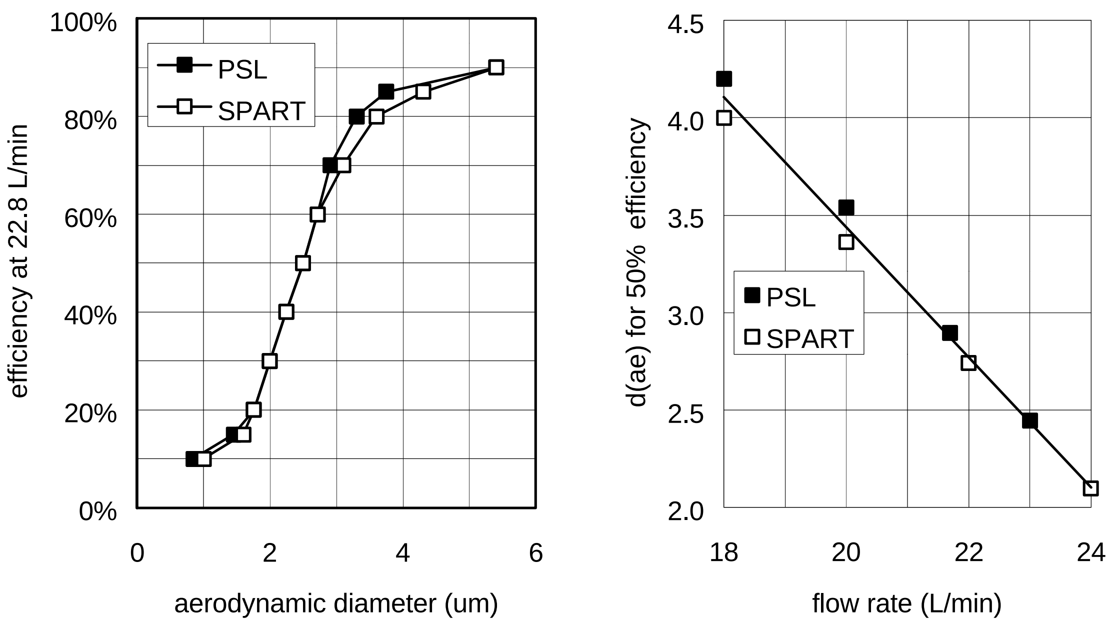

Figure 26. Cyclone collection efficiency.
The left plot shows the efficiency as a function of particle diameter at a flow rate of 22.8 L/min. The right plot shows the 50% cut point as a function of flow rate. The solid symbols are from PSL and the open symbols from SPART.

The best-fitting straight line in Figure 12 is based on measurements for both methods for flow rates between 18 and 24 L/min. The equation is:

$$d_{50} = 2.5 - 0.334 * (Q - 22.75) \qquad (1)$$

with a correlation coefficient of $r^2 = 0.991$. In order to maintain a constant cut point of 2.5 µm, it is necessary to maintain a constant volume flow rate of 22.8 L/min.

A-I.2 Flow Control by a Critical Orifice

The flow rate through each module of the IMPROVE sampler is maintained by a critical orifice, located between the filter and pump. The diameter is adjustable. As long as the pressure after the orifice is less than 52% of the pressure in front of the orifice, the air flow will be critical, that is, limited by the speed of sound and will not be affected by small changes in pump performance.

The volume flow rate is used in IMPROVE because the ambient concentration is important for visibility studies and the particle size cut varies with volume, not mass, flow rate. The volume flow rate increases as the pressure of the air decreases when the air passes through different stages. Since there is negligible pressure drop across the inlet, the volume flow rate does not change between the inlet and the cyclone. The pressure will decrease across the cyclone and filter. If this pressure drop is ΔP, then the inlet/cyclone flow rate is (1- ΔP) times the flow rate at the front of the critical orifice.

The flow rate through a critical orifice depends on the diameter of the orifice and the absolute temperature of the air at the front of the orifice. We will assume that this temperature is the same as the temperature at the cyclone measured by the probe. We have chosen to express all calibrations relative to 20°C. The equation for the inlet flow rate is

$$Q = Q_o * \left(1 - \frac{\Delta P}{P}\right) * \sqrt{\frac{T + 273}{293}} \ , \qquad (2)$$

where Q_0 is a constant and ΔP/P is the relative decrease in pressure across the filter. The pressure drop ΔP is produced either by the pressure drop of a clean filter or by filter loading. To remove the effect of the clean filter, each critical orifice is adjusted during calibration to give the desired flow rate with a typical clean filter appropriate for the module. The important pressure quantity is then the variation, δP, about the nominal pressure drop of the clean filter used in calibration, ΔP_{nom}:

$$\delta P = \Delta P - \Delta P_{nom} \qquad (3)$$

The δP associated with variations of clean filters can be negative or positive, and will affect all measurements for a sample period equally. The δP associated with filter loading will be positive and will increase over the sampling period.

The mean annual temperature for the network is about 15°C. In order to have the mean annual flow rate at 22.8 L/min, the critical orifices are adjusted to provide a flow rate of 23 L/min at 20°C with a typical filter in the cassette. The constant Q_0 in Equation 2 is then given by

$$Q_o = 23 * \left(1 - \frac{\Delta P_{nom}}{P}\right)^{-1} \ , \qquad (4)$$

Substituting Equation 4 into Equation 2, and assuming there is no variation in atmospheric pressure at the site, the flow rate is given by

$$Q = 23 * \left(1 - \frac{dP}{P - \Delta P_{nom}}\right) * \sqrt{\frac{T + 273}{293}} \ , \qquad (5)$$

Effect of Temperature and Pressure Drop on Cyclone Efficiency

Variations in temperature with site, month, and time of day affect the collection cut point but not the volume calculation. Table 4 shows the change in flow rate using the calibration procedures.

Table 4. Flow rate and 50% aerodynamic diameter *vs*. flow rate.

Table A1-1. Flow rate and 50% aerodynamic diameter *vs*. flow rate.

T (°C)	-20	-10	0	10	20	30	40	50
Q (L/min)	21.4	21.8	22.2	22.6	23.0	23.4	23.8	24.1
d_{50} (µm)	3.0	2.9	2.7	2.6	2.4	2.3	2.2	2.1

Because the flow rate is measured throughout the sampling period, variations in ΔP also affect the collection cut point but not than the volume calculation. For a typical western site, Canyonlands, the flow rate decreased 1% during the sampling period, which is much less than the precision of the measurements. For a heavily loaded eastern site, Shenandoah, the decrease was 3%.

A-I.3 Flow Rate through a Orifice Meter

An orifice meter consists of a restriction in the air path and a device to measure the pressure drop across the restriction. The audit devices and the cyclone are both used as orifice meters.

The flow rate through an orifice meter depends on the pressure drop across the restriction and the square root of the density of the air. Because the density is proportional to the pressure and absolute temperature, the flow rate can be written:

$$Q = Q_1 \left(dP\right)^b \sqrt{\frac{P_o}{P}} \sqrt{\frac{T+273}{293}} \qquad (6)$$

where Q_1, β, and P_O are constants. For laminar flow, β= 0.5. We express Equation 6 in parameterized form using the magnehelic reading, M, for the pressure drop:

$$Q = 10^a M^b \sqrt{\frac{P(\text{sea level})}{P(site)}} \sqrt{\frac{T+273}{293}} \;. \qquad (7)$$

We have arbitrarily defined all pressures relative to the standard pressure at sea level and all temperatures relative to 20°C. Thus, the parameters, a and b, are always calculated relative to 20°C and Davis. The value of b should be similar to that of β, around 0.5. The advantage in expressing the parameters relative to sea level is that all modules should have parameters with similar values independent of the site elevation.

Because of the difficulties in measuring the ambient pressure, we have chosen to use an average pressure based on the elevation of the site. The pressure-elevation function is discussed in Section A-I.4. We will write the pressure and temperature functions as F(elev) and f(T):

$$\text{F(elev)} = \sqrt{\frac{P(\text{sea level})}{P(site)}} \qquad \text{f(T)} = \sqrt{\frac{T+273}{293}} \;.$$

Thus, the flow rate Q in terms of the magnehelic transducer from Equation 7 is

$$Q = 10^a M^b F(elev)\; f(T) \qquad (8)$$

A-I.4 Pressure-Elevation Relationship

The ambient pressure enters into the equations for UCD audit devices and the system magnehelic as the square root of the pressure. Because of the difficulties of measuring the ambient pressure at each sample change, we have chosen to use an average pressure based on the elevation of the site. The actual pressure is used only in calibrating the audit devices at Davis.

Based on the 1954 tables of Treworth, the pressure at an elevation of Z meters is:

$$P = P(\text{sea level}) * \exp\left[-\left\{\frac{Z}{8437} + \left(\frac{Z}{26621}\right)^2\right\}\right], \tag{9}$$

It is convenient to define an elevation factor that is the square root of the pressure at sea level divided by the pressure at the site. This factor is expressed as

$$F(elev) = \sqrt{\frac{\text{P(sea level)}}{P(site)}} = \exp\left[\frac{Z}{16874} + \left(\frac{Z}{37648}\right)^2\right] \tag{10}$$

The values of nominal P and F(elev) as a function of elevation are given in Table 3 (page 29).

A-I.5 Calibration of Audit Devices

The reference flow rate is provided by a spirometer located in the sampler laboratory at UCD. The spirometer measurements are verified by a dry gas meter monitoring the exhaust to the calibration pump. Taking the logs of Equation 7A, the flow rate equation for the audit device is

$$\log(Q) = a_o + \log\sqrt{\left(\frac{29.92}{P}\right)\left(\frac{T+273}{293}\right)} + b_o * \log(M_o)\ . \tag{11}$$

The log of the meter reading, M_o, is regressed against the log of the flow rate for a set of four flow rates covering the normal range of the device. The constants relative to the nominal sea level pressure (29.92) and 20°C are calculated using

$$a_0 = \text{intercept} - \log\sqrt{\left(\frac{29.92}{P}\right)\left(\frac{T+273}{293}\right)} \qquad b_0 = slope\ . \tag{12}$$

A-I.6 Nominal Flow Rate Equation

In order to have a mean flow rate of 22.8 L/min at 15°C, the critical orifices are adjusted to provide a flow rate of 23 L/min at 20°C with a typical filter in the cassette. Using Equation 7b, the audit device flow rate at the site and 20°C is given by

$$Q_o = 10^{a_0}\, M_o^{\,b_0}\, F(\text{elev}) = 23.0\ \text{L/min} \tag{13}$$

The desired reading on the audit device is

$$M_o = \left(\frac{23}{F(elev)}\frac{1}{10^{a_0}}\right)^{1/b_0}\ . \tag{14}$$

A-I.7 Flow Rate Equation for the System Vacuum Gauge

The measurement by the vacuum transducer is based on the equation for the critical orifice, Equation 2:

$$Q = Q_o * \left(1 - \frac{\Delta P}{P}\right) *f(T) .$$

We can redefine the Q_0 constant to include the elevation factor:

$$Q = Q_3 * \left(1 - \frac{\Delta P}{P}\right) *f(T)\ F(elev) , \qquad (15)$$

where Q_3 is another constant. For a reading on the vacuum transducer of V, we can write this in terms of the positive parameters c and d as

$$Q = [c - d*V\ ]*f(T)\ F(elev). \qquad (16)$$

The parameters will be independent of temperature, but not independent of pressure. That is, they would change if the sampler were moved to a new location. The form of this equation was chosen to keep it parallel to that of the system orifice meter.

A-I.8 Calibration of the System Transducers

A four point calibration is made of the system orifice meter and the vacuum gauge at the site using an audit device to determine the flow rate at the inlet. The equations for the flow rate from the audit device (Q_o), the system orifice meter (Q_m), and the vacuum transducer (Q_v), all relative to sea level and 20°C are:

$$Q_o = 10^{a_0} M_o^{b_0} \qquad (17)$$

$$Q_m = 10^{a} M^{b} \qquad (18)$$

$$Q_v = c + d * V \qquad (19)$$

For each of the four points, Q_0 is calculated using Equation 17. For the system orifice meter, the log of Q_0 is regressed against the log of M: a is the intercept and b is the slope. For the vacuum transducer Q_0 is linearly regressed with V: c is the intercept and d is the slope.

Appendix II. Dates of Sample Collection for Every Third Day

The dates of sample collection for every third day are listed in Table 5.

Table 5. Dates of sample collection for every third day.
Dates where the sample collection is on a Tuesday are underlined.

2000			2001			2002			2003			2004		
1/1	5/3	9/3	1/1	5/1	9/1	1/2	5/2	9/2	1/3	5/3	9/3	1/1	5/3	9/3
1/4	5/6	9/6	1/4	5/4	9/4	1/5	5/5	9/5	1/6	5/6	9/6	1/4	5/6	9/6
1/7	5/9	9/9	1/7	5/7	9/7	1/8	5/8	9/8	1/9	5/9	9/9	1/7	5/9	9/9
1/10	5/12	9/12	1/10	5/10	9/10	1/11	5/11	9/11	1/12	5/12	9/12	1/10	5/12	9/12
1/13	5/15	9/15	1/13	5/13	9/13	1/14	5/14	9/14	1/15	5/15	9/15	1/13	5/15	9/15
1/16	5/18	9/18	1/16	5/16	9/16	1/17	5/17	9/17	1/18	5/18	9/18	1/16	5/18	9/18
1/19	5/21	9/21	1/19	5/19	9/19	1/20	5/20	9/20	1/21	5/21	9/21	1/19	5/21	9/21
1/22	5/24	9/24	1/22	5/22	9/22	1/23	5/23	9/23	1/24	5/24	9/24	1/22	5/24	9/24
1/25	5/27	9/27	1/25	5/25	9/25	1/26	5/26	9/26	1/27	5/27	9/27	1/25	5/27	9/27
1/28	5/30	9/30	1/28	5/28	9/28	1/29	5/29	9/29	1/30	5/30	9/30	1/28	5/30	9/30
1/31	6/2	10/3	1/31	5/31	10/1	2/1	6/1	10/2	2/2	6/2	10/3	1/31	6/2	10/3
2/3	6/5	10/6	2/3	6/3	10/4	2/4	6/4	10/5	2/5	6/5	10/6	2/3	6/5	10/6
2/6	6/8	10/9	2/6	6/6	10/7	2/7	6/7	10/8	2/8	6/8	10/9	2/6	6/8	10/9
2/9	6/11	10/12	2/9	6/9	10/10	2/10	6/10	10/11	2/11	6/11	10/12	2/9	6/11	10/12
2/12	6/14	10/15	2/12	6/12	10/13	2/13	6/13	10/14	2/14	6/14	10/15	2/12	6/14	10/15
2/15	6/17	10/18	2/15	6/15	10/16	2/16	6/16	10/17	2/17	6/17	10/18	2/15	6/17	10/18
2/18	6/20	10/21	2/18	6/18	10/19	2/19	6/19	10/20	2/20	6/20	10/21	2/18	6/20	10/21
2/21	6/23	10/24	2/21	6/21	10/22	2/22	6/22	10/23	2/23	6/23	10/24	2/21	6/23	10/24
2/24	6/26	10/27	2/24	6/24	10/25	2/25	6/25	10/26	2/26	6/26	10/27	2/24	6/26	10/27
2/27	6/29	10/30	2/27	6/27	10/28	2/28	6/28	10/29	3/1	6/29	10/30	2/27	6/29	10/30
3/1	7/2	11/2	3/2	6/30	10/31	3/3	7/1	11/1	3/4	7/2	11/2	3/1	7/2	11/2
3/4	7/5	11/5	3/5	7/3	11/3	3/6	7/4	11/4	3/7	7/5	11/5	3/4	7/5	11/5
3/7	7/8	11/8	3/8	7/6	11/6	3/9	7/7	11/7	3/10	7/8	11/8	3/7	7/8	11/8
3/10	7/11	11/11	3/11	7/9	11/9	3/12	7/10	11/10	3/13	7/11	11/11	3/10	7/11	11/11
3/13	7/14	11/14	3/14	7/12	11/12	3/15	7/13	11/13	3/16	7/14	11/14	3/13	7/14	11/14
3/16	7/17	11/17	3/17	7/15	11/15	3/18	7/16	11/16	3/19	7/17	11/17	3/16	7/17	11/17
3/19	7/20	11/20	3/20	7/18	11/18	3/21	7/19	11/19	3/22	7/20	11/20	3/19	7/20	11/20
3/22	7/23	11/23	3/23	7/21	11/21	3/24	7/22	11/22	3/25	7/23	11/23	3/22	7/23	11/23
3/25	7/26	11/26	3/26	7/24	11/24	3/27	7/25	11/25	3/28	7/26	11/26	3/25	7/26	11/26
3/28	7/29	11/29	3/29	7/27	11/27	3/30	7/28	11/28	3/31	7/29	11/29	3/28	7/29	11/29
3/31	8/1	12/2	4/1	7/30	11/30	4/2	7/31	12/1	4/3	8/1	12/2	3/31	8/1	12/2
4/3	8/4	12/5	4/4	8/2	12/3	4/5	8/3	12/4	4/6	8/4	12/5	4/3	8/4	12/5
4/6	8/7	12/8	4/7	8/5	12/6	4/8	8/6	12/7	4/9	8/7	12/8	4/6	8/7	12/8
4/9	8/10	12/11	4/10	8/8	12/9	4/11	8/9	12/10	4/12	8/10	12/11	4/9	8/10	12/11
4/12	8/13	12/14	4/13	8/11	12/12	4/14	8/12	12/13	4/15	8/13	12/14	4/12	8/13	12/14
4/15	8/16	12/17	4/16	8/14	12/15	4/17	8/15	12/16	4/18	8/16	12/17	4/15	8/16	12/17
4/18	8/19	12/20	4/19	8/17	12/18	4/20	8/18	12/19	4/21	8/19	12/20	4/18	8/19	12/20
4/21	8/22	12/23	4/22	8/20	12/21	4/23	8/21	12/22	4/24	8/22	12/23	4/21	8/22	12/23
4/24	8/25	12/26	4/25	8/23	12/24	4/26	8/24	12/25	4/27	8/25	12/26	4/24	8/25	12/26
4/27	8/28	12/29	4/28	8/26	12/27	4/29	8/27	12/28	4/30	8/28	12/29	4/27	8/28	12/29
4/30	8/31			8/29	12/30		8/30	12/31		8/31		4/30	8/31	