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Thermo Scientific FDMS & Beta Attenuation Instrumentation – an overview and recommendations to maximize operational performance

2012 National Air Quality Conference

May 14-17, 2012

Denver CO

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We are the leading provider of analytical instruments, equipment, reagents and consumables, software and services for research, analysis, discovery and diagnostics

Company Snapshot

Size and Scale	▪ $11 billion in revenues ▪ 34,000 employees in 40 countries ▪ 350,000 customers ▪ 150 countries served
Unmatched Capabilities	▪ Complete portfolio ▪ World-class technologies ▪ Commercial and service strength
Leading Brands	▪ Two premier brands

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Fisher Scientific

What is “Air Quality Instruments”?

- Headquartered In Franklin, Massachusetts
- 450 Employees 450
- 3 Manufacturing Sites
- 100+ Air Monitoring Products
- Global Sales - 100+ Distributors; 30+ Countries
- Key People
  - TEOM – Jeffrey Ambs
  - Beta Attenuation – Kevin Goohs

The World Leader in Air Monitoring Instrumentation

Particulate Monitor Offering

- Manual PM Sampling
- Continuous PM Monitoring
- PM Chemical Speciation Monitoring
- Handheld/Survey PM Monitoring
- Stationary and Mobile Source Products
- Specialty Products

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Thermo Scientific PM2.5 FEM Monitors

- TEOM Monitors
  - TEOM 1405 F
  - TEOM 1405 DF
  - TEOM 1400/8500C FDMS
- Thermo 5014i Beta Monitor
- Thermo 5030 SHARP Monitor
- Thermo 5030i SHARP Monitor

  (Currently under test)

TEOM Monitors

- Theory of Operation
- Installation Requirements
- Operating Parameters
- Maintenance, Audits & Calibration
- System Updates
- Questions

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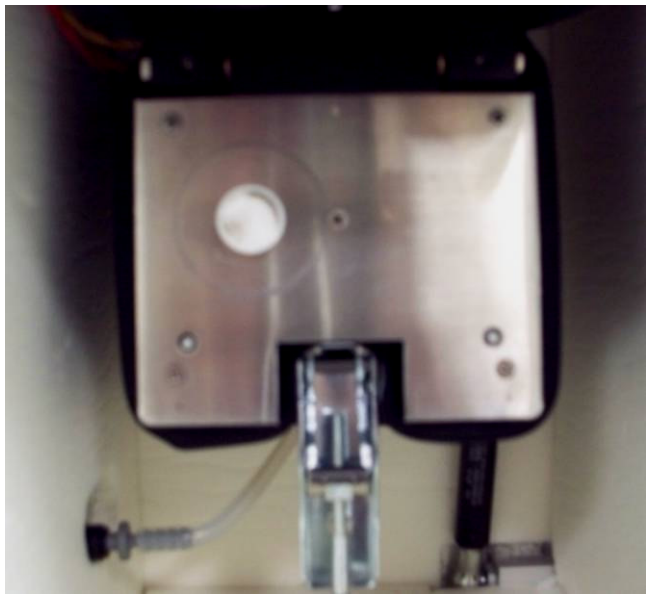
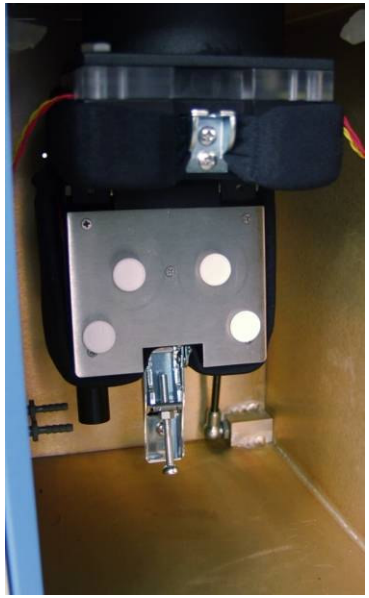
TEOM Monitor - Theory of Operation

- A true “gravimetric” instrument
- Ambient air flows through filters at a constant rate
- The filters are continuously weighed and the mass concentration is calculated in near real-time
  - Single PM for 1405-F and 8500C
  - 1405-DF measures PM2.5 and PMcoarse



1405F



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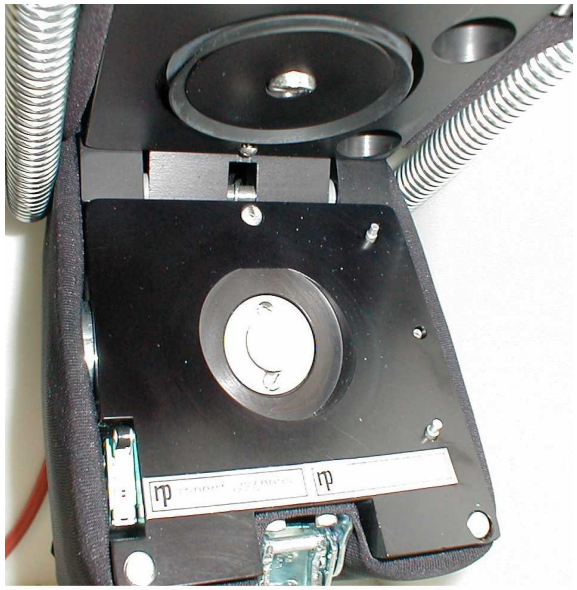

8500C

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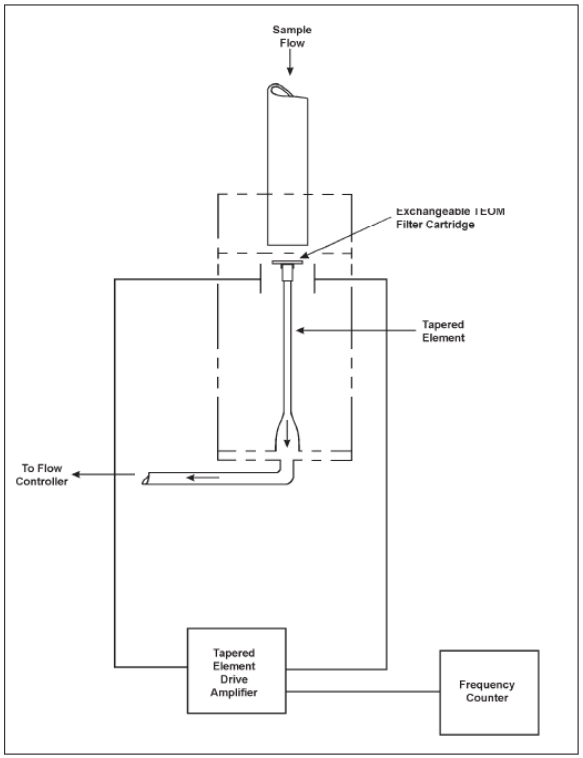
TEOM Monitor - Theory of Operation

- Weighing principle used is similar to a laboratory microbalance
- Mass detected by the sensor is the result of the change in measurement of the frequency of oscillation that is directly coupled via a physical law

$$Frequency = (\text{Cal constant}/\text{mass})^{0.5}$$



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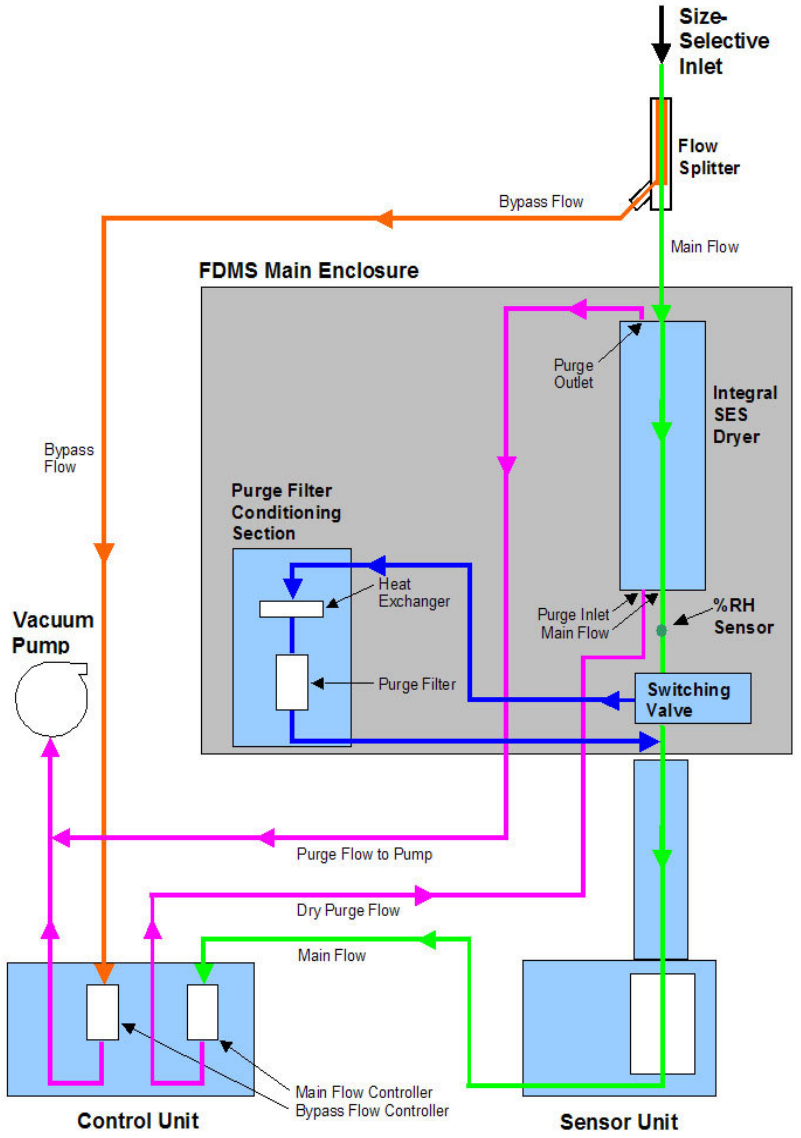
1405-F/DF and 8500C with Filter Dynamics Measurement System (FDMS)

- Switching valve alternates the sample between Base and Reference Channels every 6 minutes.
- The chiller filter is maintained at 4 ℃
- Provides measurement of non-volatile and semi-volatile PM concentrations



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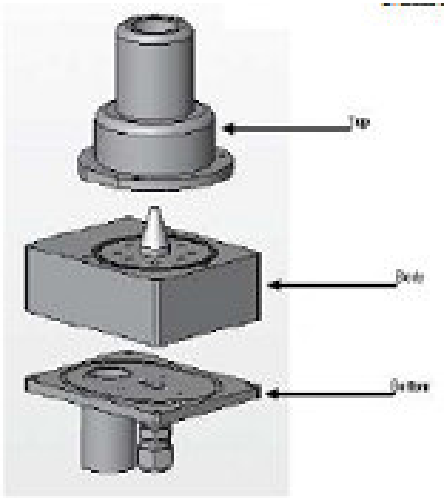
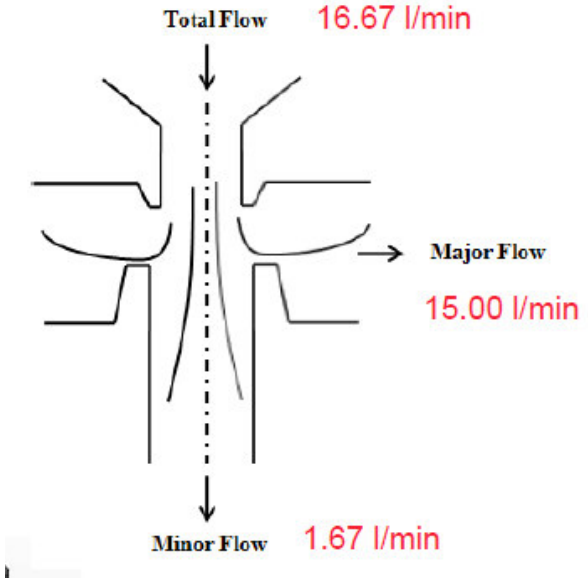
1405-DF TEOM

- Virtual Impactor Separates Fine and Coarse Fractions
- Dual Mass Transducers Provide Simultaneous PM2.5, PMcoarse, and PM10 Measurements
- FDMS Allows Monitor to Account for Semi-Volatile PM on Both Fine and Coarse Samples





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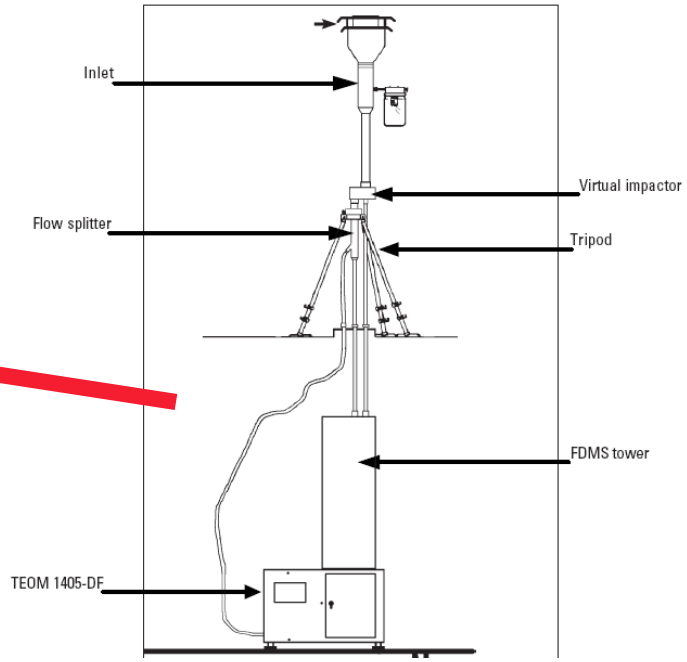
Installation Requirements

- Standard instrument siting requirements must be followed
  - Instructions are provided in operating manual
- Temperature controlled shelter, 8° ~ 25°C (46° ~ 77°F)
  - Avoid radical or fast temperature fluctuations
  - Protect from direct sunlight
- Provisions for sample lines and ambient temperature cable through the roof
  - 1405F and 8500C use a single sample line
  - 1405DF requires two sample lines
- Minimize sampler vibration
  - Remote mounting of sample pump
  - A/C vibrations
  - Other instrumentation

Installation Requirements

- Avoid close proximity to heating and air conditioning outlets
- Avoid condensation
  - Insulate the sample tube extensions with pipe insulation
  - Install coalescing filter in bypass line in high humidity environments



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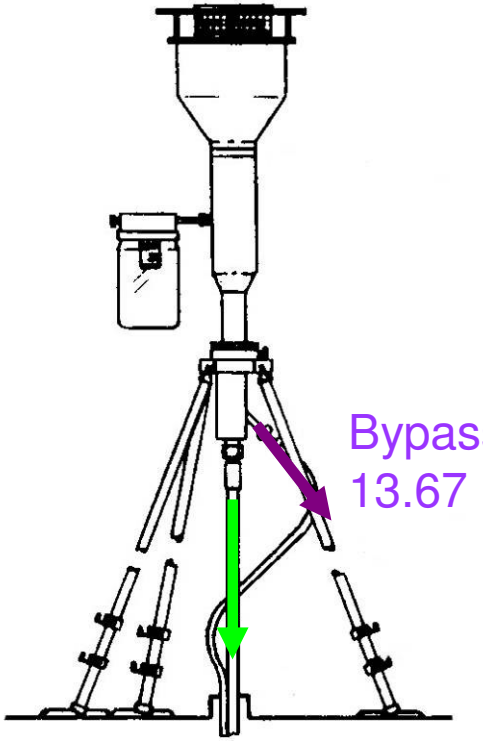
TEOM Flow Path: Inlet Section

16.7LPM

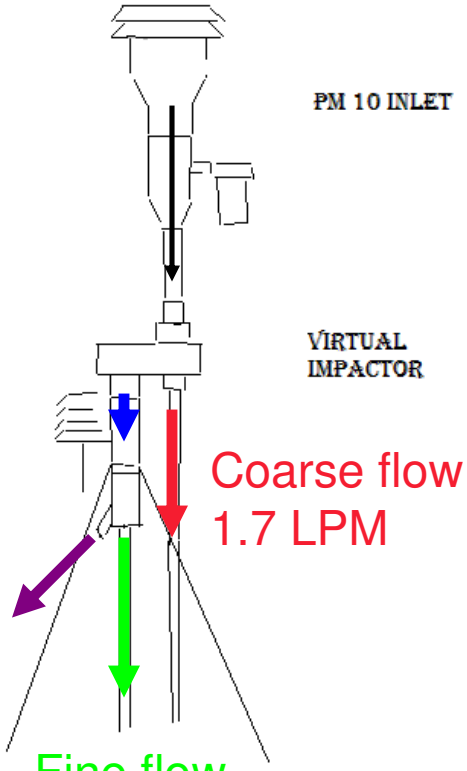


Bypass flow
13.67 LPM

Sample flow
3.0 LPM

1405-F and 8500C

16.7LPM



Coarse flow
1.7 LPM

Bypass flow
12.0 LPM

Fine flow
3.0 LPM

1405-DF

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Initial Set-up and Configuration Check

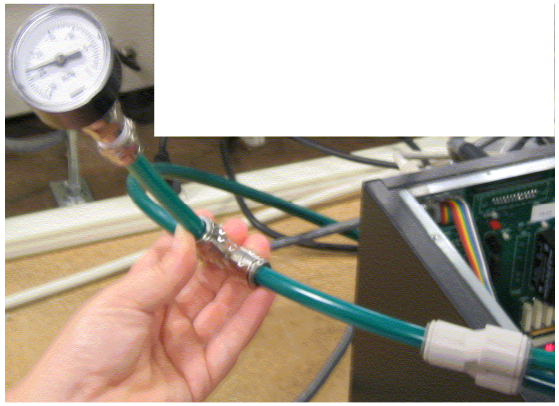
- Once the system hardware components are in place, the following steps will get the TEOM Monitor up and running:
  - Power on the instrument, vacuum pump, allow 1-hr warm-up
  - Review screen functions and screen displays (new users)
- Review/adjust the configuration parameters
  - Set Flow Control to Actual conditions
  - Review/adjust sample and bypass flow rates
  - Confirm K0 constant
  - Confirm Temperature settings
  - Confirm Mass Calculation Variables' settings (FEM Setting)
- Set the clock

Perform verifications/calibrations

- Leak check
- Ambient Temperature Calibration
- Barometric Pressure Calibration
- Flow calibration
- Load filters
  - Always install/change TEOM filters and chiller filters simultaneously
  - 1405-F and 8500C use a single TEOM and chiller filter
  - 1405-DF uses two TEOM filters and two chiller filters
- Select the Data Storage options desired

Operational Parameters

- Sample dewpoints
  - Must be less that 4°C to prevent condensation in chiller
  - Recommend that sample dewpoint be monitored and dryer refurbished if dewpoint is above -5°C
  - High dryer dewpoint can be an indicator of poor pump performance
  - High dryer dewpoint can be an indicator of a leak
- Dryer temperatures are relative indicator of shelter performance
- Pump pressure
  - Maintain less than 0.3 atm for proper performance of dryer
  - Displayed on System screen in 1405-F/DF
  - 1405-F/DF TEOM monitors will show alarm if above 0.4 atm
  - Monitor using external vacuum gauge on 8500C



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1405-F/DF TEOM Logging Parameters

- Recommended logging parameters

- FEM MC
- PM2.5 Base MC
- PM2.5 Ref MC
- PMc MC *
- PMc Base MC *
- PMc Ref MC *
- Ambient Temperature
- Ambient Humidity
- Ambient Pressure

- Vacuum Pump Pressure
- Status
- TEOM A Filter Loading
- TEOM A Dryer Temperature
- TEOM A Dryer Dew Point
- TEOM B Filter Loading *
- TEOM B Dryer Temperature *
- TEOM B Dryer Dew Point *

- Three additional available for user selection (20 total)

*** 1405-DF Only**

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8500C FDMS Logging Parameters

- Recommended logging parameters

- FEM MC
- Base MC
- Ref MC
- Dryer Temperature
- Dryer Dewpoint
- Status

- Two additional available for user selection (8 total)

- PRC 20 is FEM MC
- PRC 24 is FEM 1 Hour MC
- PRC 28 is FEM 24 Hour MC

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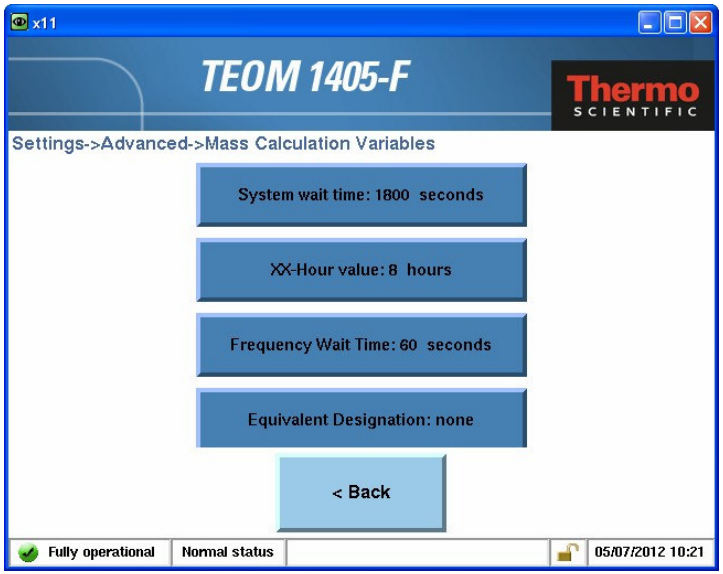
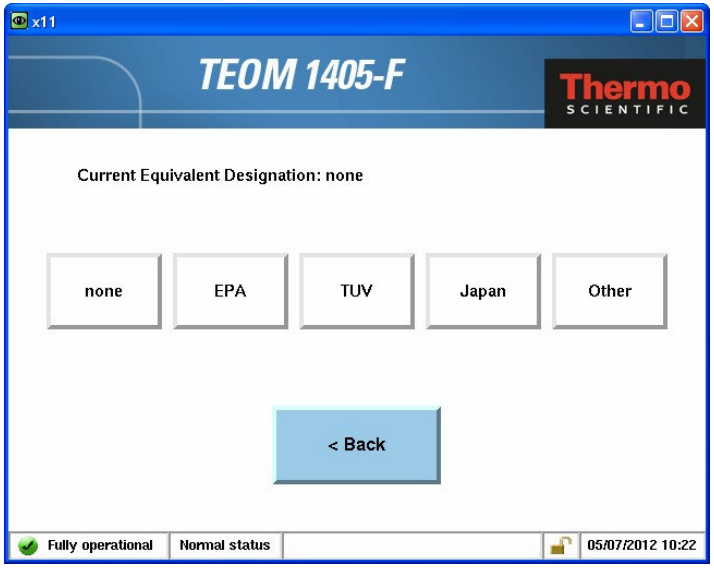
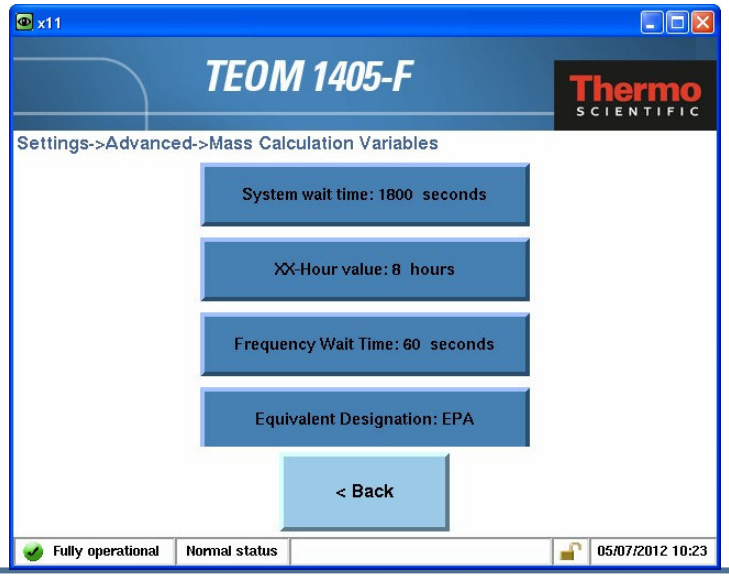
FEM vs non-FEM Mass Concentration Data

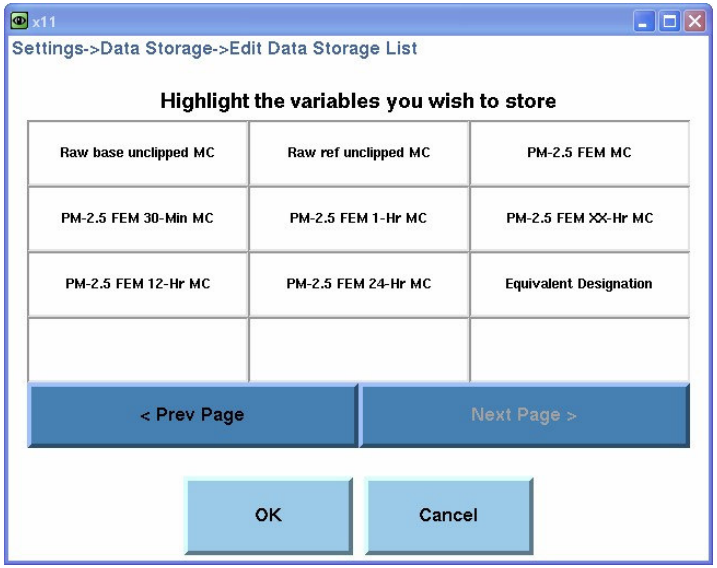
- With approval of FEM status, instituted additional MC value
- By default main screen displays non-FEM data
- Select US EPA FEM setting to display FEM MC values
- Select FEM Variables for data logging

1405-F/DF TEOM FEM Settings









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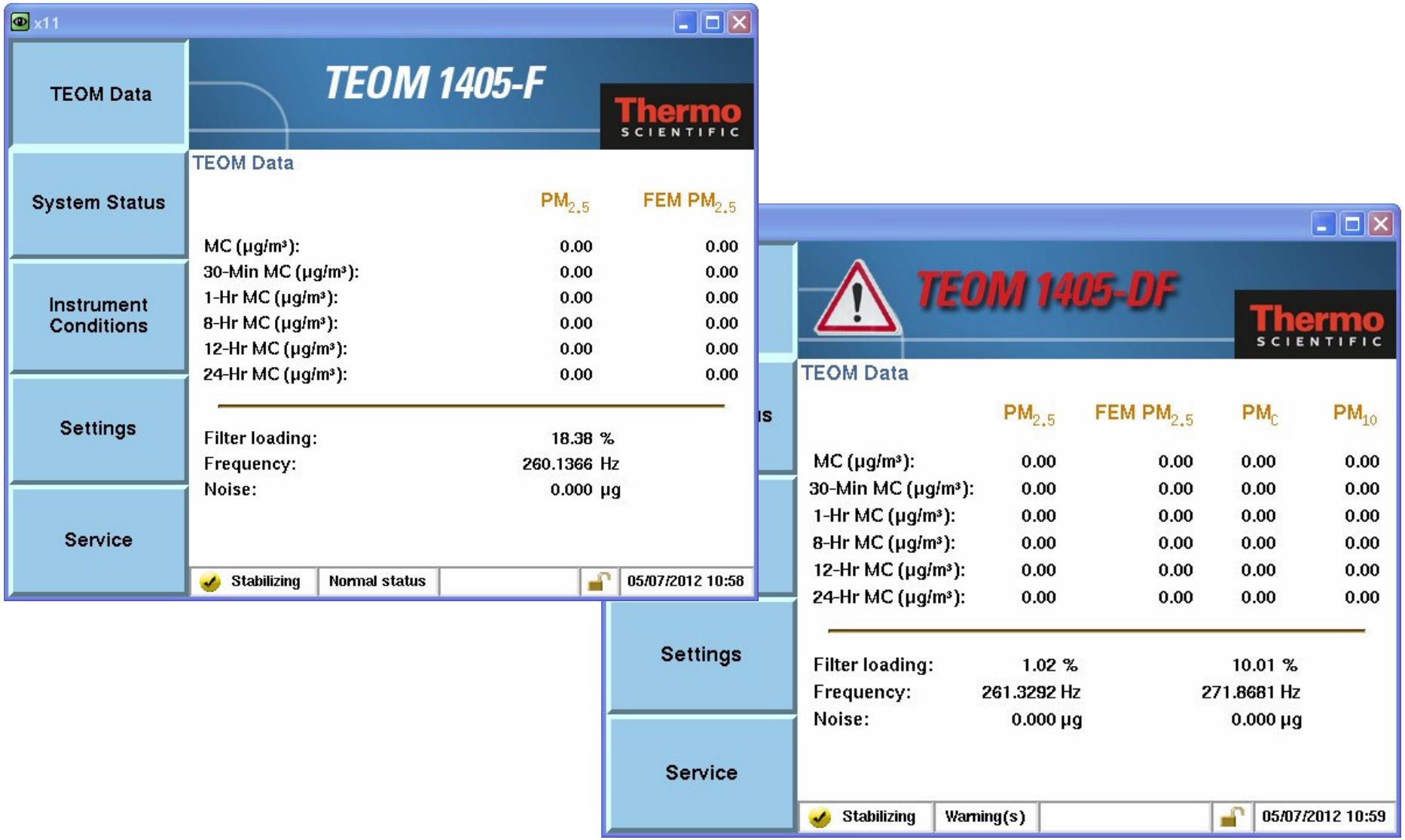
1405-F/DF TEOM FEM Main Screen with FEM Display



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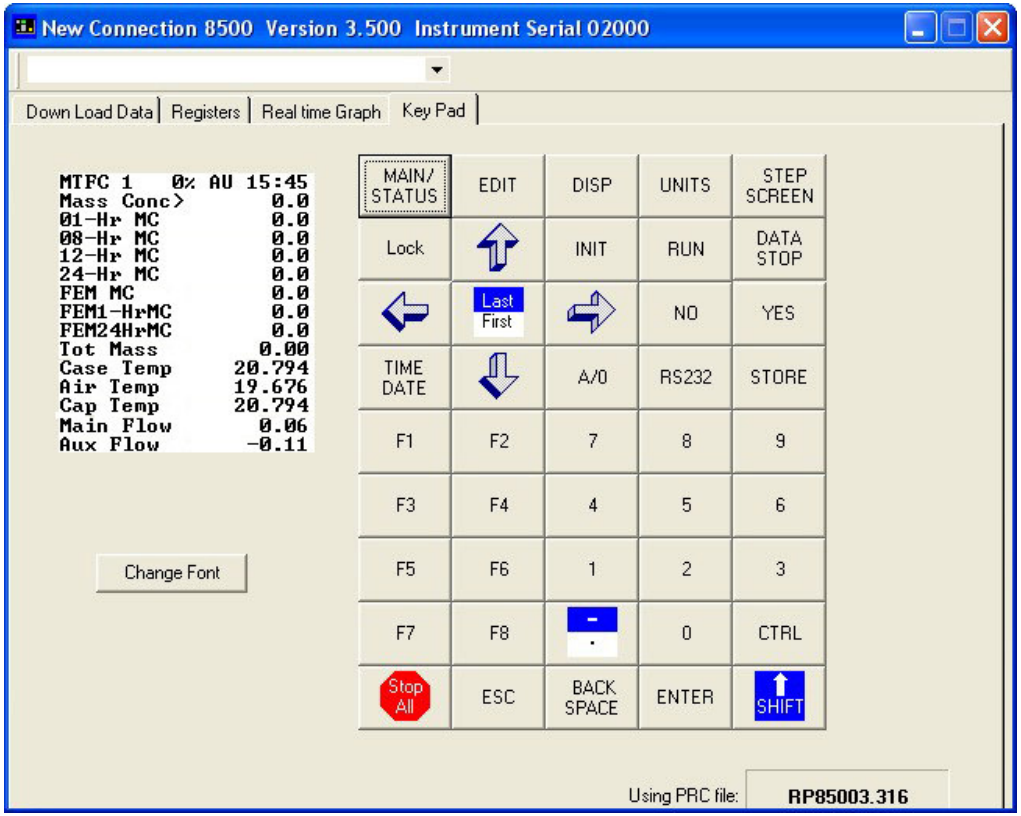
FDMS 8500C FEM Display and Logging

- FEM values are displayed on Main Screen
- Log FEM Values using PRC codes
  - PRC 20 is FEM MC
  - PRC 24 is FEM 1 Hour MC
  - PRC 28 is FEM 24 Hour MC



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Maintenance

- Recommended Maintenance Intervals:
  - **Replace TEOM filter**: Filter loading nears 75% or every 30 days
  - **Replace chilled filter**: When you exchange the TEOM filter
  - **Clean PM10 Inlet**: With every TEOM filter exchange
  - **Clean Virtual Impactor(1405-DF)**: With every TEOM filter exchange
  - **Clean VSCC (1405-F)**: With every TEOM filter exchange
  - **Replace In-Line filter**: Every 6 months
  - **Clean Coolers**: Once a year
  - **Clean Switching Valve**: Once a year
  - **Clean Air Inlet System**: Once a year
  - **Rebuild Vacuum Pump**: 12 to18 months
  - **Dryer Refurbishment**: Once a year

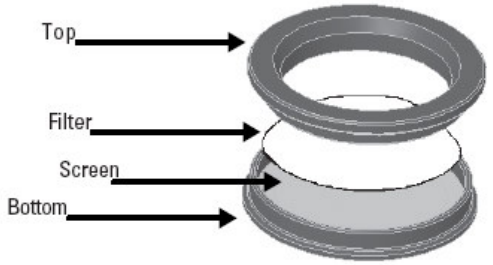
Filter Change Frequency

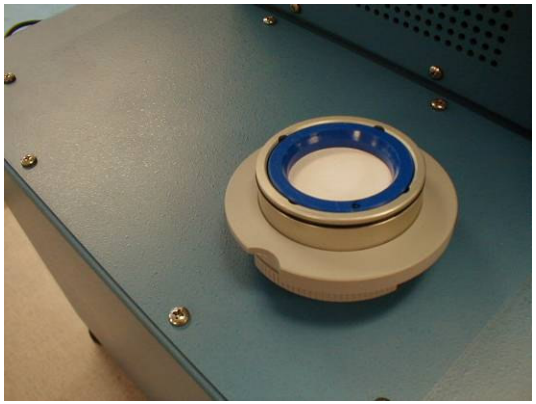
- TEOM Filter
  - Recommended that TEOM filter and chiller filter are replaced when filter loading reaches above 75%
  - In certain areas there may be instances where filter “history” may affect base and reference readings
  - Total MC values will be correct
  - Change more frequently in these conditions

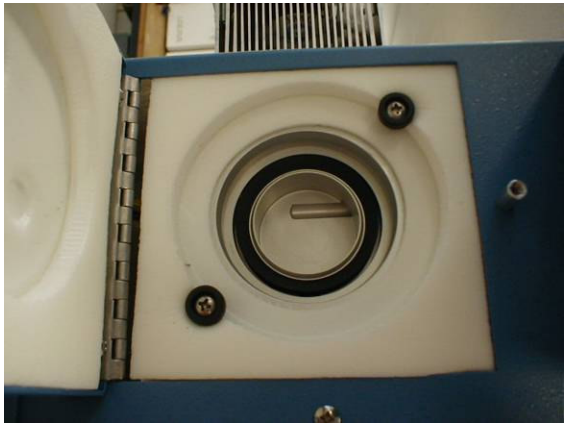
- TEOM Filter Notes
  - Use filter exchange tool to change filter
  - Install spare filters on equilibration posts in mass transducer
  - In the event of high noise, check and reseat TEOM filter

Filter Change Frequency

- Replacing Chiller Filter
  - Best practice is to open chiller ONLY with the switching valve in the Base position
  - Replace chiller filter at same time as TEOM filter







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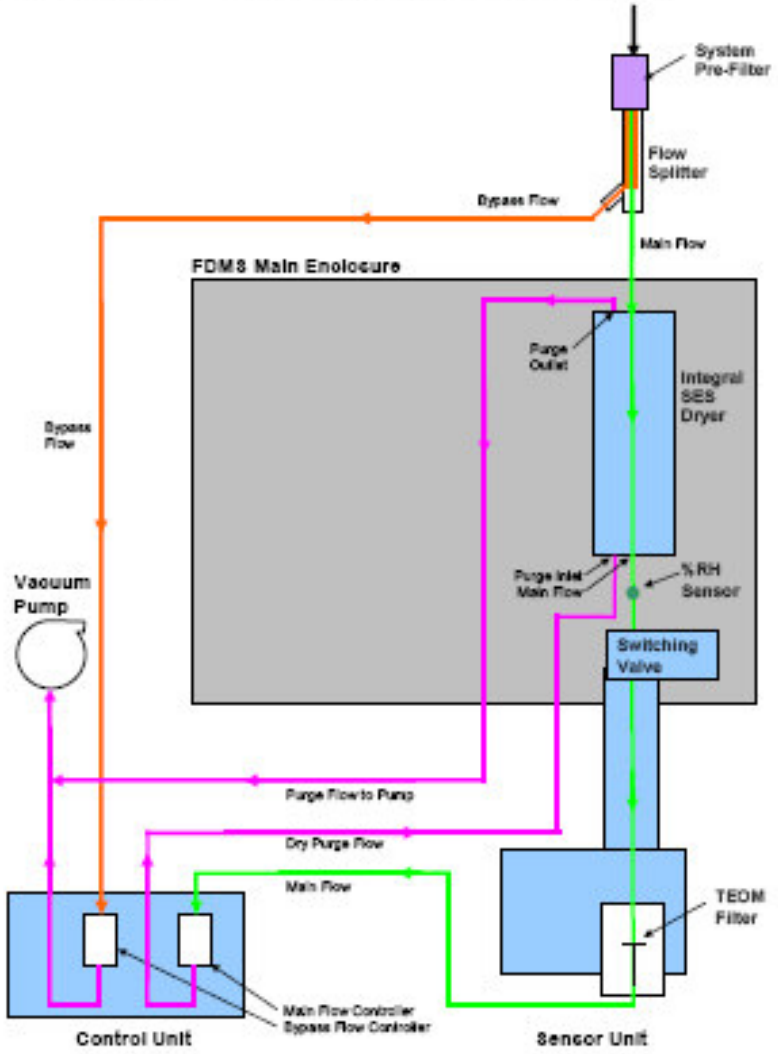
FDMS Dryer Refurbishment/Replacement

- If the sample dew point is positive or consistently reads near or within the 2 degrees of the chiller/conditioner set point
- Closely monitor when dewpoint rises above -5C
- Comparison of the sample dew point to the ambient dew point indicates that the sample dewpoint is not being controlled
- Dryers should be replaced annually
  - Higher particulate laden areas may need to replace dryer more frequently
- Baseline test can be used to confirm contamination
  - 24 hour sampling with Pre-filters installed

1405DF: Baseline Test

Pre-filter – sample or base mode



As filtered air passes through the dryer, the contaminant outgases from the Nafion and is transferred to the TEOM filter.

The contaminant adsorbs to the TEOM filter resulting in a positive base measurement

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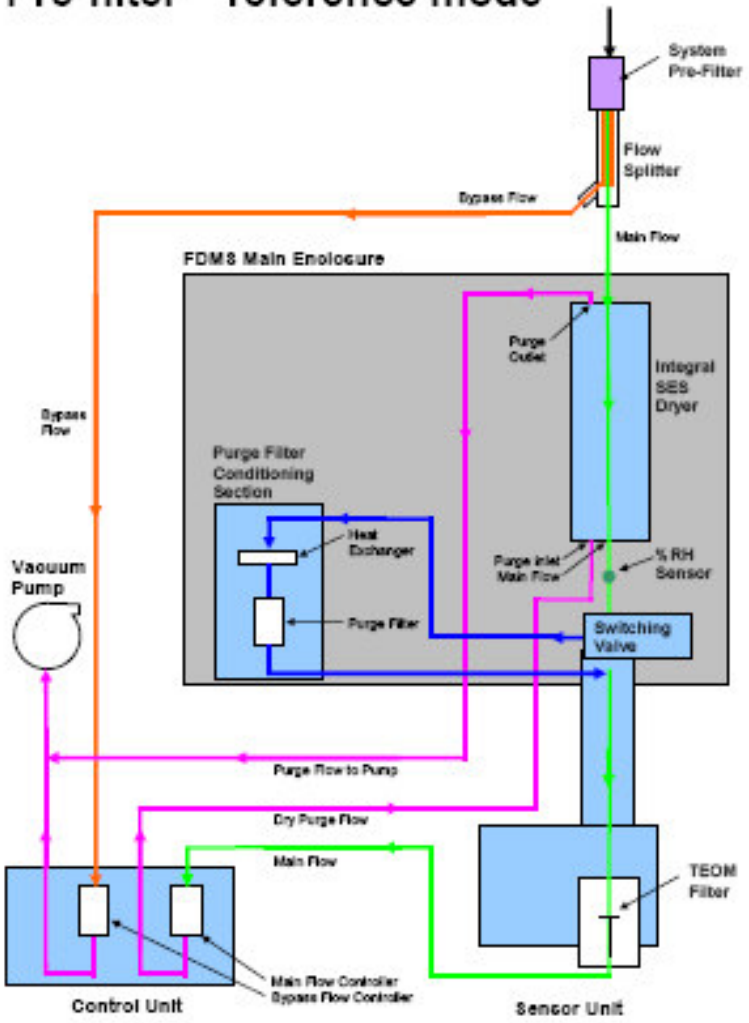
1405DF: Baseline Test

Pre-filter – reference mode



As filtered air passes through the dryer, the contaminant outgases from the Nafion and is transferred to the FDMS purge filter.

The gas leaving the purge filter does not contain the substance.

The contaminant-free gas allows the contaminant to desorb from the TEOM filter resulting in a negative reference measurement

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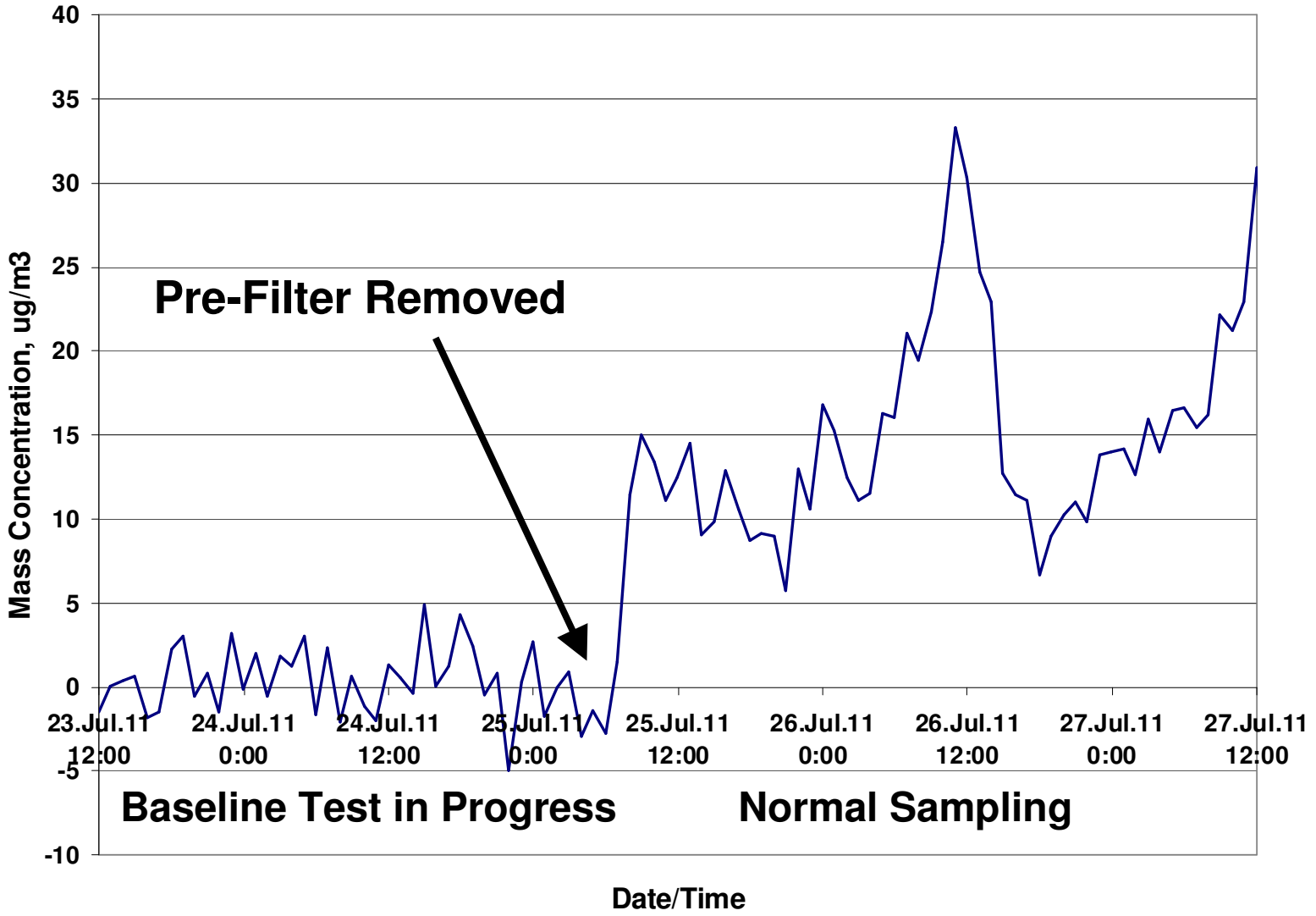
Baseline Test Example



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Annual Dryer Maintenance Data Sheet

- There are three(3) service options available:
  - New Dryer purchases offers convenience and quick delivery
    - Lead-time 2 days
  - Exchange Dryer program provides a low cost, high quality maintenance solution
    - Lead-time 2 to 5 days
    - Requires the return of their existing dryer
  - Depot Service option delivers a complete instrument service and dryer maintenance solution
    - Lead-time 2 weeks

- A Service Record Card will ship with:
  - All new and exchange dryer purchases
  - Depot serviced 1405 and 8500 instrument

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1405-DF: Audits & Calibration

- Recommended Interval of Frequency:
  - Ambient Temperature: Audit Monthly/ Calibration Yearly
  - Ambient Pressure: Audit Monthly/ Calibration Yearly
  - Flow (PM2.5, Coarse, Bypass): Audit Monthly/Calibration Yearly
  - Leak Check: Monthly
  - Analog Outputs: Once a Year
  - Mass Transducer: Audit Once a Year

Alternative Leak Check Procedure

- Used for small difficult to locate leaks
- Mimics normal operation
- Uses flow audit device and needle valve

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1405-DF: Error Codes

- Appendix A:

Table A-1. 1405-DF Status Codes

Code	Warning	Decimal	Reason for warning
0x40000000	%RH High Side A	1,073,741,824	>= 98%
0x20000000	Dryer A	536,870,912	> 2
0x10000000	Cooler A	268,435,456	> 0.5 C deviation
0x08000000	Exchange Filter A	134,217,728	> 90
0x04000000	Flow A	67,108,864	> 10% deviation
0x02000000	Heaters Side A	33,554,432	> 2% deviation
0x01000000	Mass Transducer A	16,777,216	frequency < 10 Hz
0x00400000	%RH High Side B	4,194,304	>= 98%
0x00200000	Dryer B	2,097,152	> 2
0x00100000	Cooler B	1,048,576	> 0.5 C deviation
0x00080000	Exchange Filter B	524,288	> 90
0x00040000	Flow B	262,144	> 10% deviation
0x00020000	Heaters Side B	131,072	> 2% deviation
0x00010000	Mass Transducer B	65,536	frequency < 10 Hz
0x00004000	User I/O Device	16,384	
0x00002000	FDMS Device	8,192	
0x00001000	Head 1	4,096	
0x00000800	Head 0	2,048	

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1405-DF: Error Codes

0x00000400	MFC 1 Device	1,024	
0x00000200	MFC 0 Device	512	
0x00000100	System Bus	256	
0x00000080	Vacuum Pressure	128	(Ambient - Vac) < 0.1 atm
0x00000040	Case or Cap Heater	64	> 2% deviation
0x00000020	FDMS Valve	32	
0x00000010	Bypass Flow	16	> 10% deviation
0x00000004	Database	4	Unable to log to the database
0x00000002	Enclosure Temp	2	temperature exceeds 60 C
0x00000001	Power Failure	1	

Multiple Errors Add in Hexadecimal

Appendix A explains how to decipher the codes

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System Updates

- FDMS switching valve is being updated to improve durability
- Software update fixes Top-of-the-Hour data logging
  - Version 1.56
- Ground strap to reduce touch screen lock-ups
- Chiller Condensation
  - Updated thermistor installation
  - Add insulation to dryer tubing to prevent condensation on tubing

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QUESTIONS??

Beta & SHARP Monitors

- Theory of Operation
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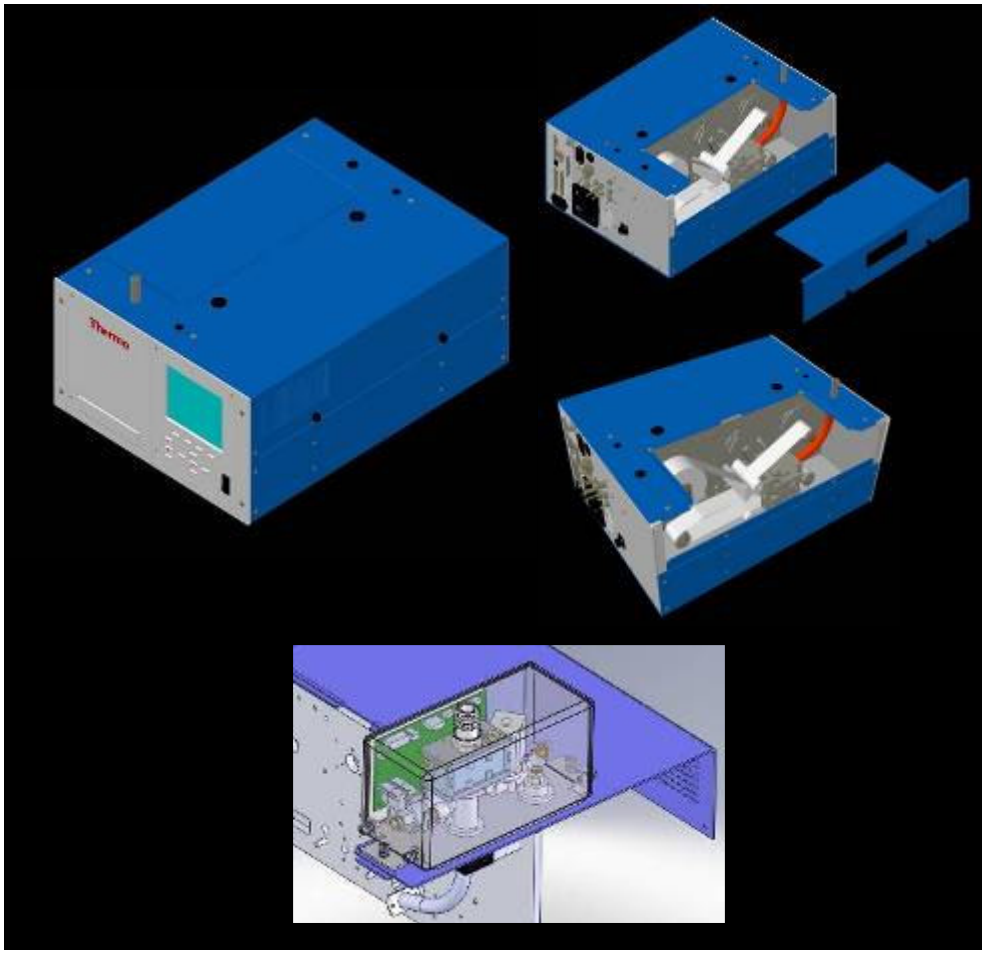
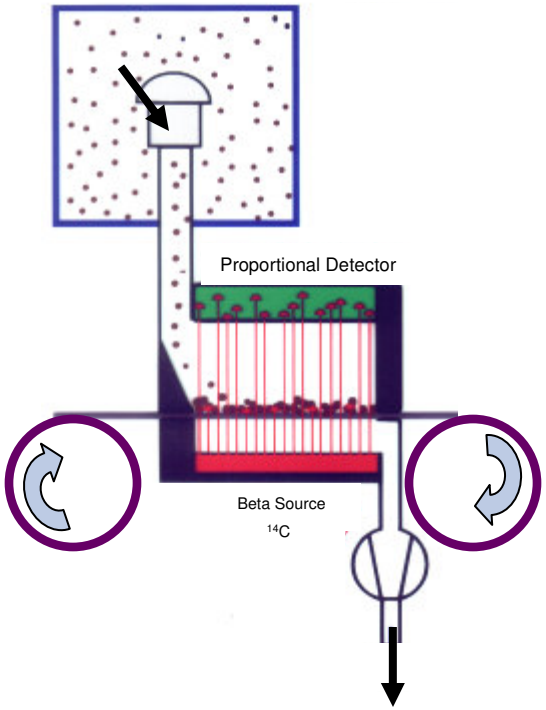


Theory of Operation

- The aerosol mass concentration C_β is obtained from beta attenuation by the application of the following relationship:

$$C_\beta = \frac{A}{\mu_m Q t}\left(\ln f_0 - \ln f_f\right)$$

- A = particle collection area
- μ_m = mass attenuation coefficient
- Q = sample volumetric flow rate
- t = sampling time
- f_0 = initial beta count (s^{-1})
- f_f = final beta count (s^{-1})



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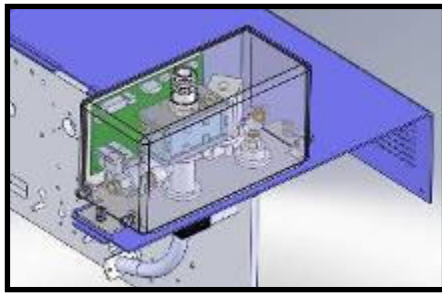
Theory of Operation

$$\mathbf{SHARP_n = R_n * (C_\beta avg / Ravg)_n}$$



R_n = Real-time Nephelometer

C_β avg = Avg. Beta concentration (20-480 min avg.)

R avg = Avg. Nephelometer concentration (20-480 min avg.)

Beta and Nephelometer average concentrations are integrated over identical periods (synchronized). The averaging period is optimized for concentration gradient and mass loading and frozen at boundary conditions.

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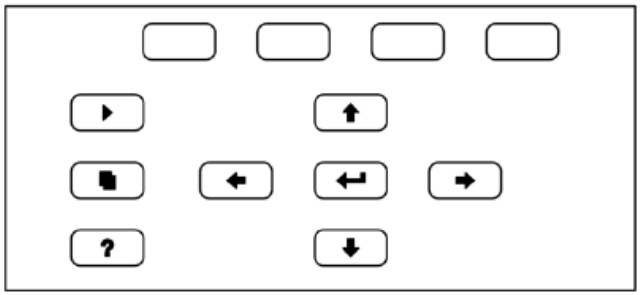
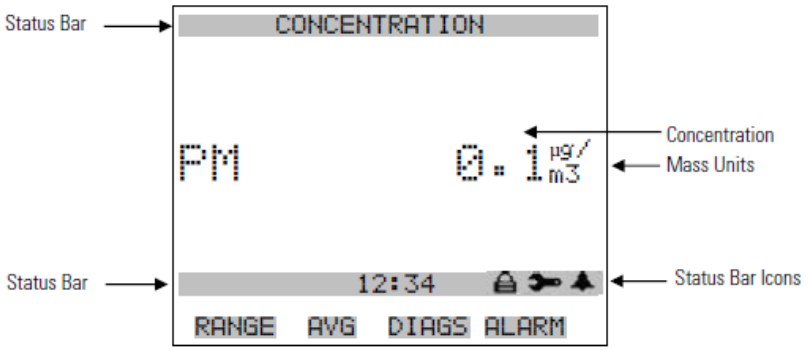
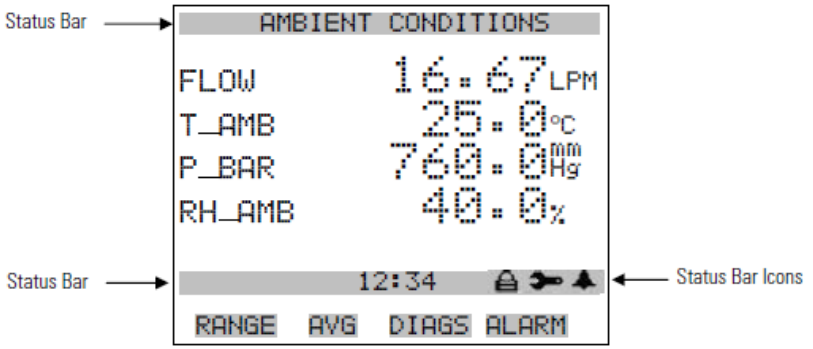
5014i / 5030i Display – *i*-series platform

The Pushbuttons allow the user to traverse the various screens/menus.







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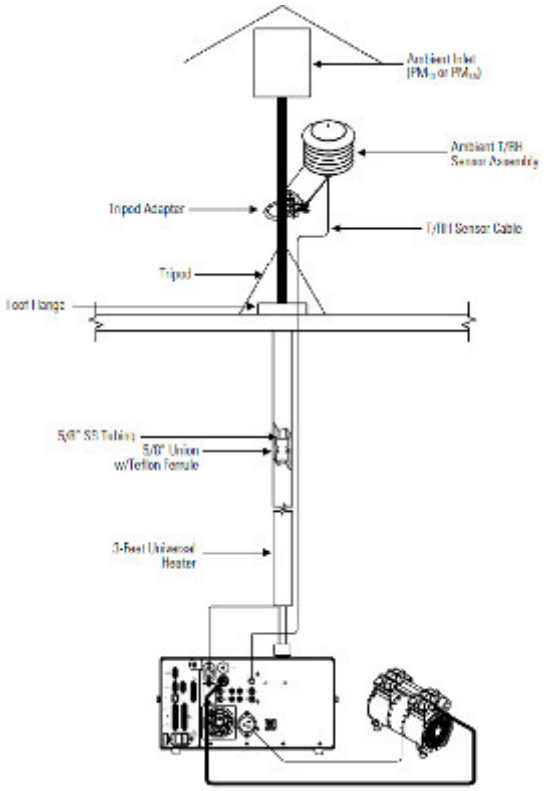
Installation Requirements

- Standard instrument siting requirements must be followed
  - Instructions are provided in operating manual
- Temperature controlled shelter, 4° ~ 50℃
  - Avoid radical or fast temperature fluctuations
  - Protect from direct sunlight
- Provisions for sample lines and ambient temperature and relative humidity cable through the roof
- Optimize sample tube installation
  - Assure leak tight fittings
  - Water proof roof flange
  - Insulate exposed sample tubing above and below heater

Installation Requirements

- Avoid close proximity to heating and air conditioning outlets
- Avoid condensation by insulating the sample tube extensions with pipe insulation
- Use designated AC Pump outlet on rear panel
- Assure use of proper fittings
- Assure water tight seals
- Conduct leak check on system



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Initial Set-up and Configuration Check

- Once the system hardware components are in place, the following steps will get the Beta and/or SHARP Monitor up and running:
  - Power on the Beta or SHARP Monitor and allow 1-hr warm-up within laboratory conditions
  - Conduct acceptance testing of monitor via diagnostics screens for expected electronic PCB voltages, temperatures, humidity, pressure and flow rate
  - Review/adjust the configuration parameters for heater control
    - Relative Humidity (set at 35%) – Required for FEM Operation
    - Fixed Temperature (minimum of 30 deg C, higher for humid environments)
  - Set Flow Control to Actual conditions
  - Verify integration time is set to 20 minutes - Required for FEM Operation
    - Adjust for more aggressive or quieter response for other tests
  - Confirm data logging and instrument clock settings

Perform verifications/calibrations

- Audit/Calibrate in following order:
  - Relative humidity
  - Pressures
  - Volumetric flow
- Conduct leak check using proper leak check adapter
- Confirm Mass Coefficient with foil cal kit
- Confirm proper filter tape operation via manual tape advance
- Confirm filter tape exchange rate (8 hour recommended for PM2.5)

Operational Parameters

- Flow Rate – 16.67 l/min
  - Should be within +/- 2% of reference device
- Leak Check
  - Should exhibit < 0.5 Lpm reduction with leak check adapter
  - Caution – leak check adapters are specific for this instrument. Do not use adapters from other products
- Mass Foil Calibration
  - Must be within +/- 2% of reference foil

Beta / SHARP Logging Parameters

- Recommended logging parameters

- Ambient Temperature
- Ambient Humidity
- Ambient Pressure
- Sample Temperature
- Sample Humidity
- Sample Pressure
- Volumetric Flow
- Orifice Delta-P
- Beta counts
- Beta Zero
- Alpha Counts

- Raw Mass
- Corrected Mass
- PM Concentration (Beta)
- SHARP Concentration*
- Nephelometer Concentration*
- LED Source current*
- LED Reference detector voltage*
- Status codes/flags
- 24 hour concentrations

- Two independent data files
  - 1-60 minute data logging

* SHARP only

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Maintenance

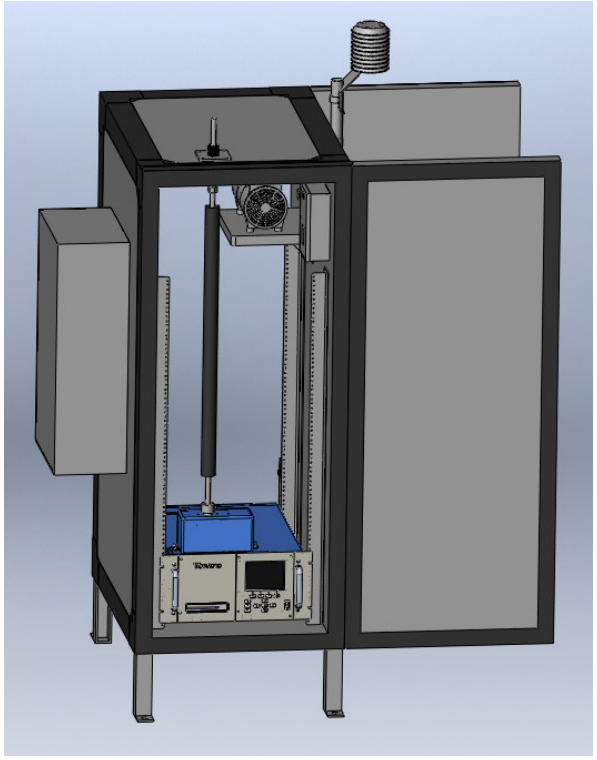
- Recommended Maintenance Intervals:
  - **Replace Filter Tape**: upon 10% remaining alarm
  - **Replace SHARP Zeroing filters**: Every 6 months
  - **Clean PM10 Inlet**: Monthly
  - **Clean Sharp-cut cyclone**: Monthly
  - **Clean Air Inlet System**: Once a year
  - **Rebuild Vacuum Pump**: 12 to18 months
  - **Clean Ambient Temp/RH Shield and assembly:** Annually

Beta & SHARP Monitor Audits & Calibration

- Recommended Interval of Frequency:
  - **Ambient Temperature:** Audit Monthly/ Calibration Yearly
  - **Ambient Pressure:** Audit Monthly/ Calibration Yearly
  - **Flow:** Audit Monthly/Calibration Yearly
  - **Leak Check:** Monthly
  - **Analog Outputs:** Once a Year
  - **Proportional Counter:** Audit Once a Year (mass foil kit)
  - **Nephelometer Zero:** Audit Quarterly / Automated Cal

System Updates

- Leak Check adapter available
- Software improvement for smoother heater PID control – improved stability
- Enclosure Release pending
  - Eliminates heater strip
  - Use of HVAC control only
  - Removes pump box and uses shelf



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QUESTIONS??

For more information please stop by our booth.