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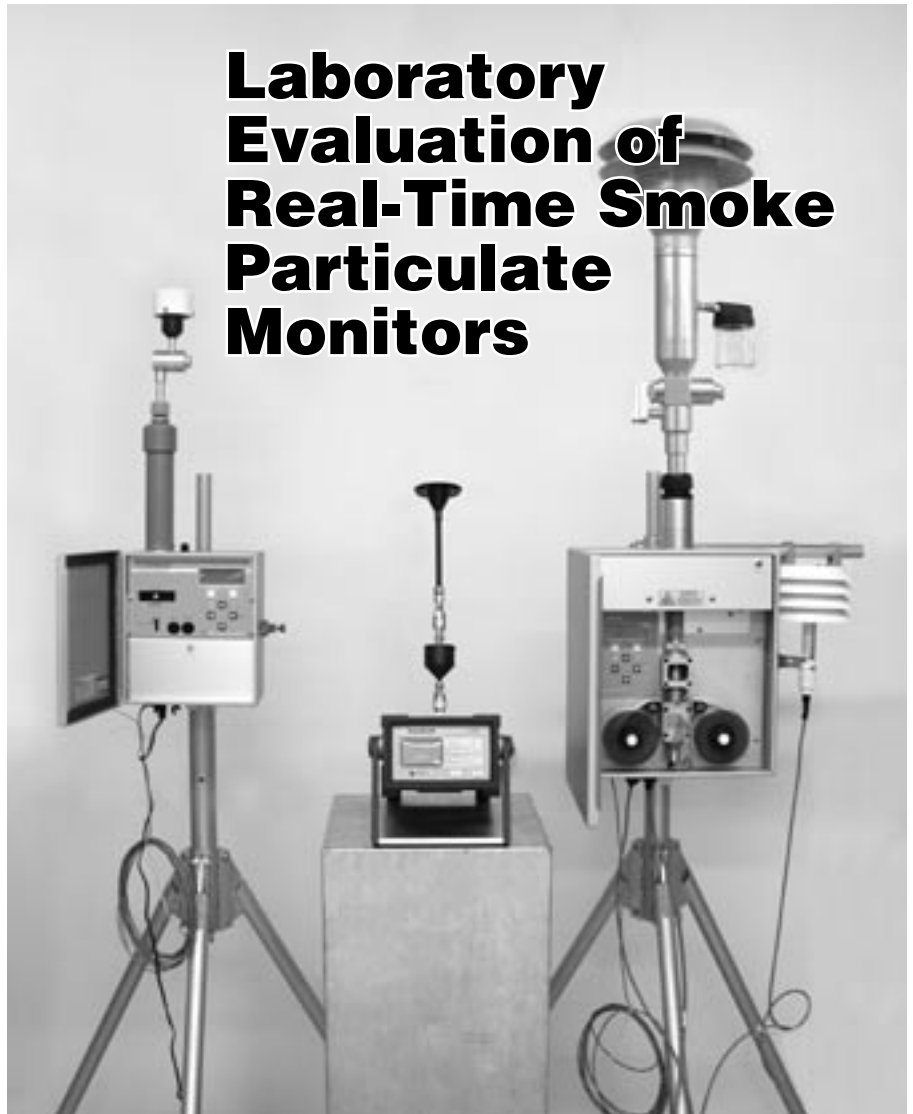
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Laboratory Evaluation of Real-Time Smoke Particulate Monitors



Laboratory Evaluation of Real-Time Smoke Particulate Monitors



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Technology and Development Program
Missoula, MT**

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Acknowledgments

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Introduction

Monitoring smoke particulate concentrations from prescribed burns and wildland fires is becoming increasingly important. Because prescribed burns are more prevalent, the impact of their smoke on communities is more significant. In addition, the number and intensity of wildland fires are increasing, especially in the West, causing Federal, State, county, and local officials to issue more frequent and more detailed smoke advisories and health warnings.

Determining smoke particulate concentrations in real time is key in assisting air quality officials. Many real-time particulate concentration monitors use optical (light-scattering) measurements to estimate particulate concentrations. Other monitors use attenuation devices or other means to estimate concentrations. Several years ago, the U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center (MTDC) was asked to evaluate commercial real-time particulate concentration monitors. The evaluation included studies that placed real-time samplers beside an approved Federal Reference Method (FRM) gravimetric sampler in a laboratory and in a field setting. The goals of these tests were to determine the accuracy of the monitors when measuring smoke particulate, to determine correction algorithms to adjust values from the instruments for more accurate results, and to assess such things as ease of use, reliability, and portability.

Laboratory tests were conducted in the Rocky Mountain Research Station's Fire Sciences Laboratory (FSL) in Missoula, MT. The real-time and FRM samplers were on a platform 55 feet above the floor of the laboratory's burn chamber. Smoke was generated by burning small piles of pine needles near the floor. Fans mixed the smoke in the chamber.

Two reports, *Laboratory Evaluation of Two Optical Instruments for Real-Time Particulate Monitoring* (9925–2806–MTDC), and *Evaluation of Optical Instruments for Real-Time Continuous Monitoring of Smoke Particulates* (0025–2860–MTDC) detail the results of those tests (figure 1).

Field tests of the real-time instruments were conducted to determine whether the laboratory results could be replicated in the field. Again, the instruments were placed beside the FRM monitor to allow comparative results. In 1998 and 1999, the instruments were set up downwind of prescribed burns around western

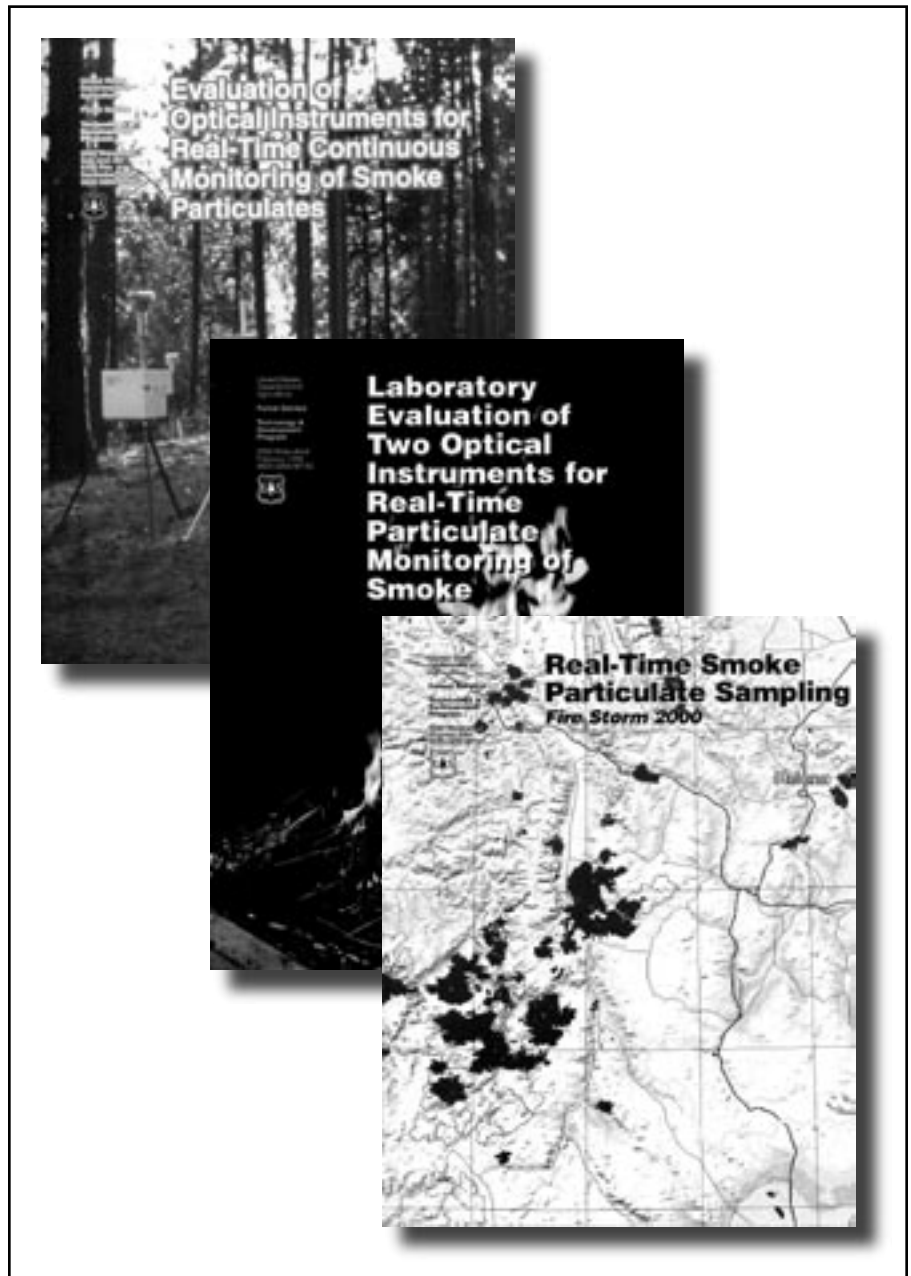


Figure 1—Three reports (9925–2806–MTDC, 0025–2860–MTDC, and 0125–2832–MTDC) detail the evaluations of several real-time smoke particulate monitors in laboratory and field environments.

Introduction

Montana. Results from these tests are detailed in *Evaluation of Optical Instruments for Real-Time Continuous Monitoring of Smoke Particulates*. In

the summer of 2000, the western part of Montana experienced huge wildland fires that filled the valleys with smoke for nearly the entire month of August. We placed instruments in Missoula and

Hamilton, MT, during that time. Results from these field tests are described in *Real-Time Smoke Particulate Sampling, Fire Storm 2000* (0125-2832-MTDC).

Laboratory Tests of Real-Time Particulate Samplers

Since 2000, several new or improved real-time particulate samplers have become commercially available. MTDC was asked to conduct laboratory tests to compare the new samplers with the FRM sampler to determine the accuracy of the new instruments when estimating smoke particulate concentrations. As in the previous laboratory tests, we set up the instruments side by side on the elevated platform at the Fire Sciences Laboratory's smoke chamber platform and burned pine needles to generate smoke particulate. Filters used in the FRM gravimetric instrument were weighed by the Montana Department of Environmental Quality.

Real-Time Instruments

Three new or improved real-time instruments were tested. Two were new instruments developed by MetOne Instruments, Inc. The other was an improved version of an instrument we had tested previously, the MIE DataRAM4. MetOne Instruments manufactures the BAM 1020, an EPA-approved equivalent method PM_{10} real-time particulate sampler that uses beta attenuation to estimate particulate concentrations. The instrument can be configured with a $PM_{2.5}$ cutoff device to estimate $PM_{2.5}$ concentrations. The instrument was not developed as, nor was it intended to be, a portable device. MetOne developed the portable E-BAM (figures 2 and 3), a smaller version of the BAM 1020, which uses the same technology to estimate mass concentrations. MetOne also developed a new instrument called the E-Sampler for estimating real-time concentrations. The E-Sampler uses light-scattering principles to estimate mass concentrations. The MIE DataRAM4 is similar to the DataRAM 2000, which we tested previously, but the DataRAM4 includes a second optical wavelength to increase accuracy.



Figure 2—MetOne Instruments' E-BAM monitor is a portable real-time beta-attenuation $PM_{2.5}$ and PM_{10} particulate monitor.



Figure 3—The E-BAM monitor with its environmental door open. The instrument collects particulate on a filter tape that automatically advances when the tape is full.

E-BAM—MetOne Instruments' E-BAM (the E stands for environmentally protected) monitor uses a three-part process to estimate mass concentrations. First, beta particles from a naturally occurring radioactive isotope are emitted through a filter tape and counted. Second, sampled air is passed through the filter paper and particles are deposited. Finally, beta particles are again passed through the paper and recounted. The second count will be lower than the first, because beta particles will have been absorbed by the deposited particulate. Calculations can determine the mass of the deposited particulate. The mass is divided by the amount of sampled air to calculate the concentration in mass per unit volume. When the filter paper reaches a predetermined concentration, the paper will automatically advance and begin a new collection.

The E-BAM monitor is a portable instrument that can operate in hostile environments without the need for an additional enclosure. It can operate using line (110 volts AC), battery, or solar power. It can be configured with EPA-approved PM_{10} and $PM_{2.5}$ cutoff devices to remove particulate larger than PM_{10} or $PM_{2.5}$, respectively. It uses pressure and ambient temperature sensors to measure airflow accurately. The E-BAM monitor can be mounted on a tripod and configured to accept a variety of ambient monitoring sensors like windspeed and direction, relative humidity, and temperature. A six-channel data logger stores all the information. The range of measured concentration is 0 to 100 milligrams per cubic meter. The data logger can be programmed to report as often as every minute. Data can be downloaded using an RS-232 serial port. A laptop computer or a modem can be configured to transmit the data using telephone lines, cell phone connections, or satellite telemetry.

The E-BAM measures 16 inches high by $13\frac{1}{2}$ inches wide by 8 inches deep. It weighs about 28 pounds without the

PM_{10} and $PM_{2.5}$ inlets. The inlets weigh an additional 7.5 pounds and add 30 inches to the height when they are installed. A power supply to operate the instrument off 110-volt AC line power weighs 14 pounds.

More information can be found at MetOne Instruments' Web site at <http://www.metone.com> or by calling 541-471-7111.

MetOne Instruments' E-Sampler—The MetOne Instruments E-Sampler (figure 4) uses light-scattering principles to estimate mass concentrations

of airborne particulate. An internal visible laser diode is focused and directed through the sample air. When particulate-laden sample air intersects the laser beam, a portion of the light is scattered. The scattered light is collected at a near forward angle and focused on a photodiode that converts the light to an electrical signal. The signal strength is proportional to the amount of scattered light. An algorithm converts the electrical signal to mass concentration.

The E-Sampler is a small, lightweight instrument housed in an environmentally

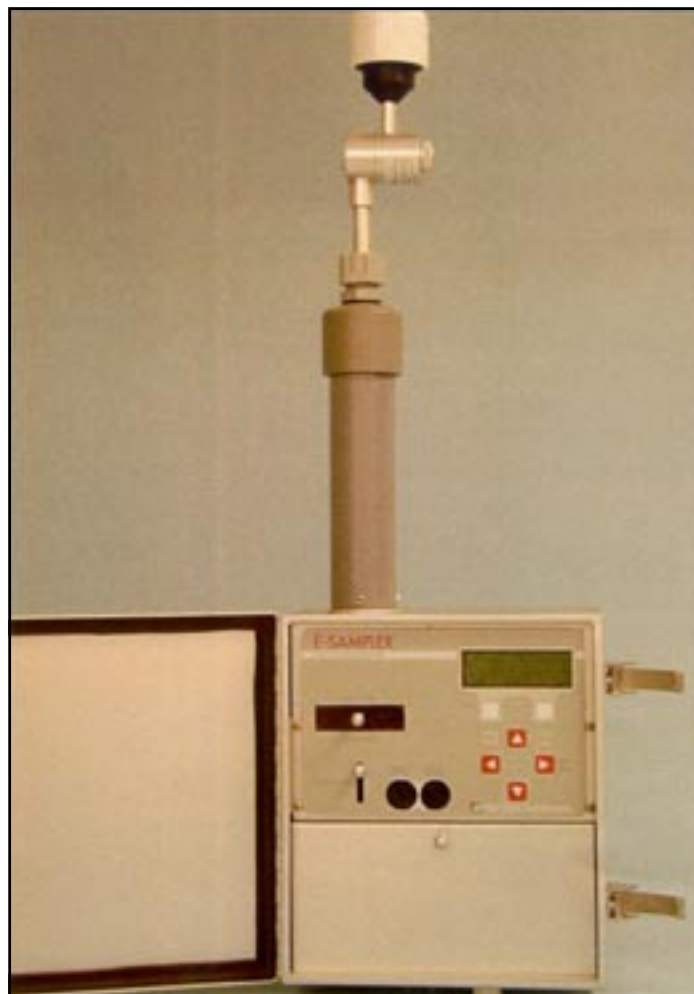


Figure 4—MetOne Instruments' E-Sampler uses light-scattering principles to estimate particulate concentrations.

protected enclosure. It can estimate particulate concentrations up to 100 milligrams per cubic meter. It can be configured for total suspended particulate (TSP), PM_{10} , $PM_{2.5}$, and PM_{1} , using a cutoff device. The E-Sampler can be mounted on a tripod and operated using line, solar, or battery power. A six-channel data logger accommodates other meteorological sensors such as windspeed and direction, relative humidity, and ambient temperature. The sampler also has an inlet heater that can be programmed to operate when the inlet airflow's relative humidity reaches a particular level. Humidity can cause the instrument to overestimate particulate concentrations. The heater removes moisture from the air before it is sampled.

The E-Sampler is considered a dual technology instrument. Besides the real-time optical scattering measurement, the E-Sampler also incorporates a gravimetric filter system using the same 47-millimeter filters as the FRM sampler. The results from the gravimetric device can be used to improve the accuracy of the real-time estimations.

The E-Sampler is compact, 10 inches wide by 12 inches high by 5 inches deep. It weighs 13 pounds with the $PM_{2.5}$ inlet, heater, and power supply.

More information can be found by visiting MetOne Instruments' Web site at: <http://www.metone.com> or by calling 541-471-7111.

MIE DataRAM4—The MIE DataRAM4 (figure 5) is an upgraded version of the DataRAM 2000, which we tested from 1998 to 2000. The DataRAM4 uses light-scattering principles to estimate mass concentrations. However, the DataRAM4 has dual light sources at different wavelengths (600 and 880 nanometers). In theory, this dual wavelength allows the DataRAM4 to better estimate mass concentrations based on an algorithm from the scattering signals from each light source. The algorithm uses the mean particle diameter size computed from



Figure 5—The Thermo-Electron MIE DataRAM4 (shown with satellite telemetry system) is a dual-wavelength, light-scattering device that estimates particulate concentrations.

the light scattering to correct the mass concentrations.

Some of the new features of the DataRAM4 include internal temperature and relative humidity sensors, the ability to autocorrect concentrations when measuring air at high relative humidities, and the ability to measure mean particle diameter size. It can measure particulate concentrations up to 400 milligrams per cubic meter and has a built-in data logger to store up to 50,000 data points. Like the E-Sampler, the DataRAM4 has a built-in gravimetric filter system for custom calibrations, although it uses a 37-millimeter membrane filter that is smaller than the 47-millimeter filter used in the FRM sampler.

The DataRAM4 monitor is 5.3 inches high by 7.3 inches wide by 13.6 inches long and weighs 11.7 pounds.

More information on the MIE DataRAM4 can be found at: <http://www.thermo.com> or by calling 1-800-241-6898.

Test Goals and Methods

Several goals were established before starting the tests. One goal was to determine the accuracy of each instrument compared to the FRM sampler. Also, because we had four E-BAM monitors to test, we wanted to determine the approximate precision of each instrument to the others. Another goal was to determine the effect of enabling the particle-size correction feature on the two DataRAM4 monitors. We ran tests with the size correction feature enabled on each instrument, disabled on each instrument, and enabled on one and disabled on the other. This test protocol will allow us to determine a correction algorithm for the DataRAM4 with the size correction feature enabled.

The tests were conducted in the Fire Sciences Laboratory's large (131,000 cubic foot) combustion chamber. The

Laboratory Tests of Real-Time Particulate Samplers

instruments were placed on a smoke-sampling platform 55 feet above the chamber floor (figures 6 and 7). The experiments were conducted at ambient conditions (65 to 80 degrees Fahrenheit at about 30 percent relative humidity). The tests sampled smoke from small burning beds of white pine needles near the chamber floor. Fans mixed the smoke in the chamber. The instruments were close to each other to ensure that the same smoky air was sampled.

The instruments used for the tests included four E-BAM monitors, two DataRAM4 monitors, one E-Sampler, and an FRM sampler (BGI PQ-200). The instruments were configured with their respective $PM_{2.5}$ cutoff device. All the instruments were calibrated before the tests. All the real-time instruments were set for an average time of 1 minute and were run continuously throughout the tests. Before testing each day, a self test was conducted on the E-BAM monitors. The E-Sampler and DataRAM monitors were calibrated to zero.

The FRM sampler was programmed to run for different lengths of time, depending on the current smoke particulate concentrations. The goal was to collect at least 100 micrograms of mass on the gravimetric filters for accurate filter weights. The FRM sampler draws about 1 cubic meter of air per hour. So if the particulate concentration in the chamber was about 100 micrograms per cubic meter of air, the FRM sampler was programmed to run for at least 1 hour. After the filters were weighed by the Montana Department of Environmental Quality, their weight was divided by the total volume of air drawn through the filter for the particular time period to obtain the average mass concentration. That value was compared to the average mass concentration estimated by the real-time instruments during the same period.



Figure 6—The E-BAM monitor was tested in the Rocky Mountain Fire Sciences Laboratory's smoke chamber.



Figure 7—The BGI PQ-200 Federal Reference Method sampler (left) with MetOne Instruments' E-Sampler (middle) and the two DataRAM4 monitors (right).

Results and Discussion

A total of 30 tests were conducted. The average particulate concentrations ranged from 30 to 1,288 micrograms per cubic meter as determined by the FRM sampler. Most of the data is evenly distributed between 30 and 800 micrograms per cubic meter. The 1,288 micrograms per cubic meter test was not included in these results because it would have influenced best-fit-line equations and correlation coefficients. Statistical results were based on least squares-linear regression equations and correlation factors. Table 1 displays the results for all the instruments. Figures 8 to 14 show the results for each instrument when compared to the FRM sampler. Each figure shows the appropriate data points, the slope equation, and the correlation coefficient for the best-fit line. A line representing a one-to-one relationship is also shown.

E-BAM—Three of the E-BAM monitors operated during all the tests. The fourth arrived late and was run for only 12

tests. Figures 8, 9, 10, and 11 show the results for each E-BAM sampler when compared to the FRM sampler results. On average, the E-BAM samplers overestimated the mass concentration by 13.5 percent with the highest (serial number 4334) overestimating

the concentration by 21 percent and the lowest (serial number 1675) overestimating the concentration by 9 percent. Correlation coefficients for all the E-BAM samplers were very high, all over 0.9939.

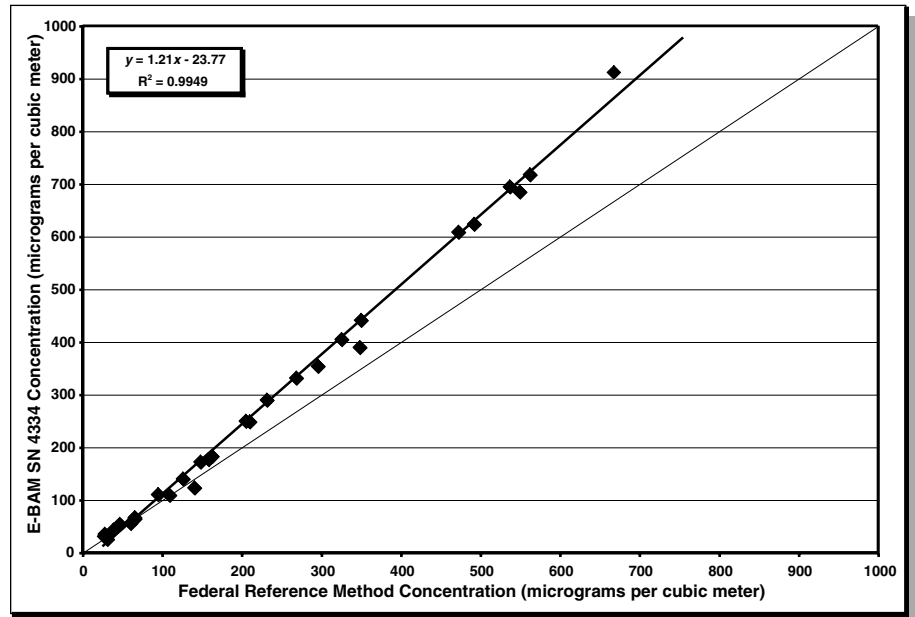


Figure 8—Results for the E-BAM (serial number 4334) and the BGI PQ-200 Federal Reference Method sampler.

Table 1—Linear regression results for real-time instruments compared to the BGI PQ-200 Federal Reference Method sampler.

Real-time particulate samplers	Regression slope	Intercept (micrograms per cubic meter)	Correlation coefficient
E-BAM (serial number 4334)	1.21	-23.77	0.9949
E-BAM (serial number 5321)	1.14	-24.15	0.9939
E-BAM (serial number 5324)	1.10	-11.49	0.9946
E-BAM (serial number 1675)	1.09	-13.80	0.9981
E-Sampler	1.13	3.41	0.9628
DataRAM (serial number D034, size correction enabled)	2.87	22.54	0.9912
DataRAM (serial number D172, size correction enabled)	2.57	51.49	0.9712

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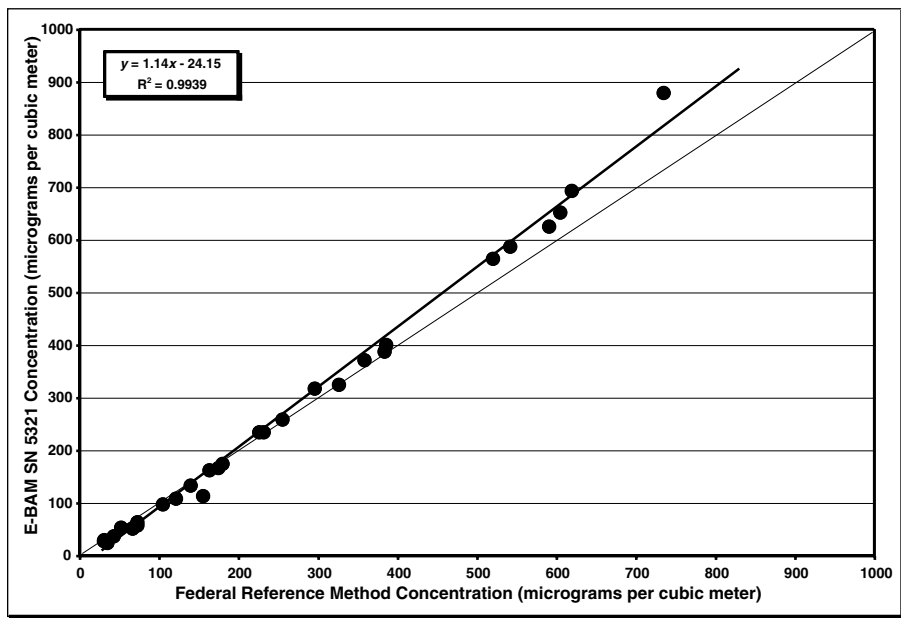


Figure 9—Results for the E-BAM (serial number 5321) and the BGI PQ-200 Federal Reference Method sampler.

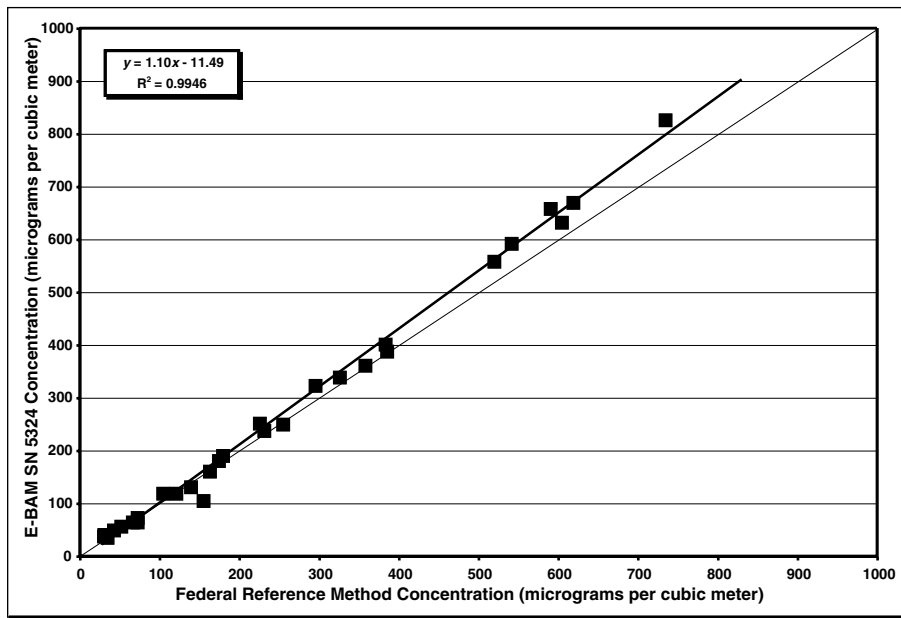


Figure 10—Results for the E-BAM (serial number 5324) and the BGI PQ-200 Federal Reference Method sampler.

E-Sampler—Results of the E-Sampler are shown in figure 12. The E-Sampler overestimated the mass concentration of smoke by 13 percent when compared to the FRM sampler. The correlation coefficient was 0.9628.

DataRAM4—The DataRAM monitors were operated with the particle size correction feature enabled or disabled. Figure 13 represents the results of the two DataRAM monitors with the size correction feature enabled. DataRAM serial number D172 overestimated the smoke mass concentration by 157 percent (2.57 times) compared to the FRM sampler. DataRAM serial number D034 overestimated concentration by 187 percent (2.87 times). Both had high correlation coefficients of 0.9712 or higher. The percent of difference between the two instruments' estimations averaged 11.7 percent.

The DataRAM results with the size correction feature disabled showed that both instruments overestimated the mass concentration results compared to the FRM sampler (figure 14). DataRAM serial number D034 overestimated concentration by 92 percent (1.92 times), while DataRAM serial number D172 overestimated concentration by 187 percent (2.87 times). Again, correlation coefficients were high, 0.9266 or higher.

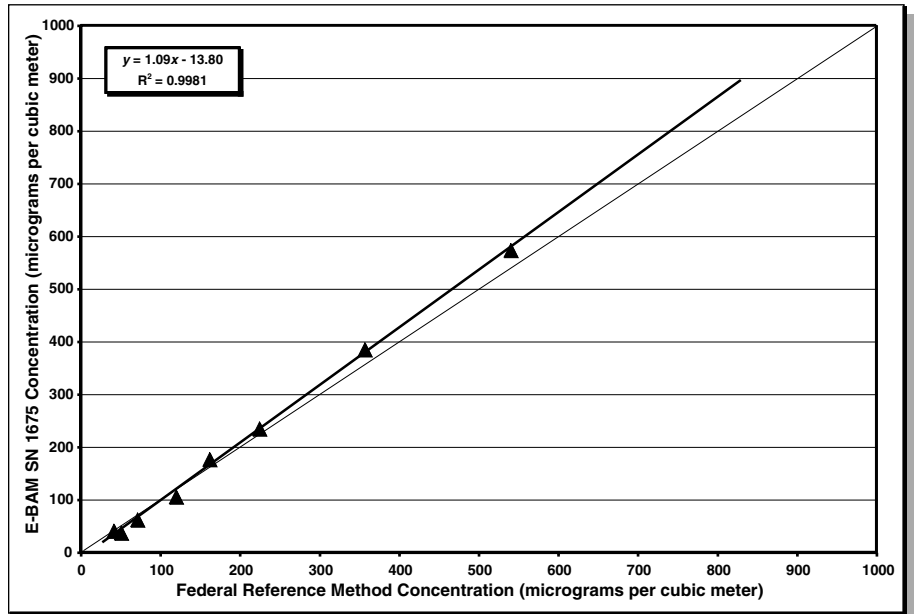


Figure 11—Results for the E-BAM (serial number 1675) and the BGI PQ-200 Federal Reference Method sampler.

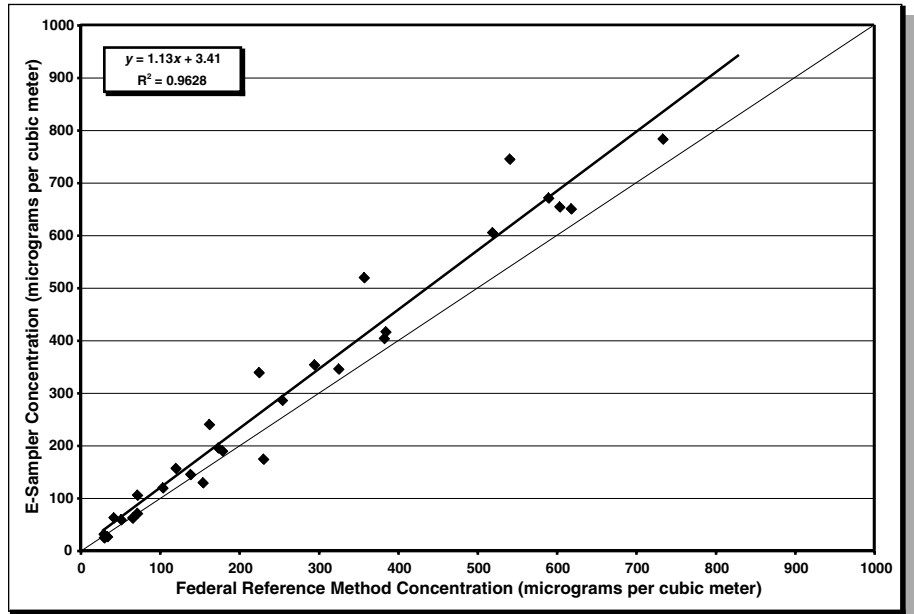


Figure 12—Results for the E-Sampler and the BGI PQ-200 Federal Reference Method sampler.

Laboratory Tests of Real-Time Particulate Samplers

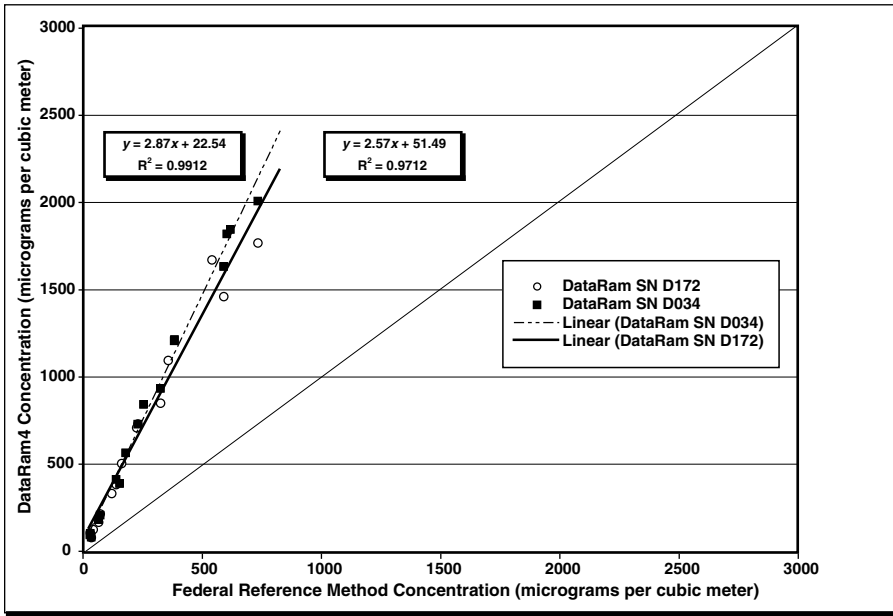


Figure 13—Results for the two DataRAM4 monitors with the size correction feature enabled and for the BGI PQ-200 Federal Reference Method sampler.

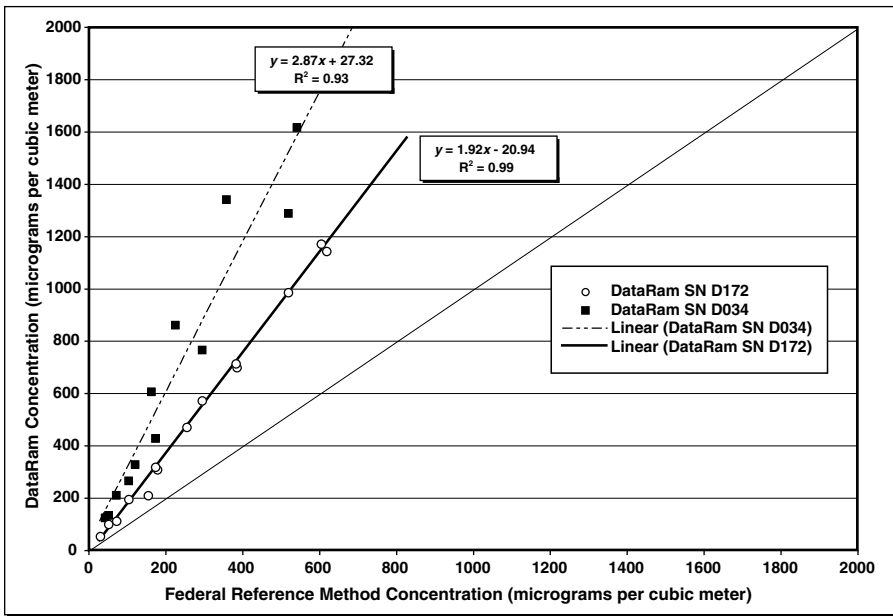


Figure 14—Results of the two DataRAM4 monitors with the size correction feature disabled and for the BGI PQ-200 Federal Reference Method sampler.

Conclusions

The MetOne Instruments' E-BAM sampler appears to be an accurate instrument when measuring smoke particulate. On average, the samplers tend to overestimate smoke particulate concentrations by 13.5 percent when compared to the FRM sampler. Correcting the reported values from the instruments by this amount will provide even better results. Results between instruments were relatively close, with a difference of 12 percent between the highest and lowest estimated values.

The E-Sampler also was fairly accurate when estimating smoke particulate concentrations. It overestimated mass concentrations by 13 percent over a wide range of concentrations. We only had one instrument to test, so we were unable to compare different E-Samplers to each other.

The DataRAM4 monitor overestimated the mass concentrations by a significant amount, although this was not unexpected based on the results of previous tests. There was a large

disparity (49 percent) in the two instruments when estimating the mass concentrations with the particle size correction feature disabled. However, when this feature was enabled, the two instruments' estimations were much closer to one another (within 11 percent). They overestimated the mass concentration of smoke by an average of 172 percent (2.72 times). Anyone using a DataRAM4 should enable the size correction feature, and when measuring smoke particulate, multiply the concentration by 0.37 (1/2.72).

Conclusions

Notes:

Notes:

About the Author...

Andy Trent is a project engineer at MTDC. He received his bachelor's degree in mechanical engineering from Montana State University in 1989. Before coming to MTDC in 1996, he worked as a civilian engineer for the U.S. Department of the Navy. Andy works on projects in the nurseries and reforestation, forest health protection, and watershed, soil, and air programs.

Library Card

Trent, Andy. 2003. Laboratory evaluation of new real-time smoke particulate monitors. Tech. Rep. 0325-2834-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 14 p.

Describes the results of tests of new instruments that can be used to measure the particulate concentrations from forest fire smoke in real time. These instruments use the optical properties of light passed through air samples or other properties of sampled air to estimate particulate levels in real time. The new instruments included two samplers by MetOne Instruments, Inc., the E-BAM and the E-Sampler, and one by MIE, an improved version of the DataRAM4 monitor. All the instruments being tested were mounted side-by-side alongside a Federal Reference Method gravimetric sampler that was the standard all machines were judged against. Gravimetric samplers capture particulate that can be weighed to determine particulate concentration. Smoke was generated by burning beds of white pine needles in the burn chamber of the USDA Forest Service, Rocky Mountain Research Station's Fire Sciences Laboratory in Missoula. The E-BAM samplers overestimated smoke particulate by 13 percent compared to the Federal Reference Method sampler, but the four E-BAM samplers' results were within 12 percent of each other. The E-Samplers' results were similar to each other. The new MIE DataRAM4 monitor has a particulate-size correction feature that should be enabled for the most accurate results. The DataRAM4 monitor overestimated particulate concentrations by 172 percent, but the results of the two machines tested were within 11 percent of each other. Earlier studies (*Laboratory Evaluation of Two Optical Instruments for Real-Time Particulate Monitoring*, 9925-2806-MTDC, and *Evaluation of Optical Instruments for Real-Time Continuous Monitoring of Smoke Particulates*, 0025-2860-MTDC) tested older instruments in the laboratory. Results of field tests of older instruments are reported in *Real-Time Smoke Particulate Sampling, Fire Storm 2000* (0125-2832-MTDC).

Keywords: aethalometers, air quality, gravimetric samplers, nephelometers, real time, samplers, smoke management, wood smoke

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