

# **Mercury Flue Gas Measurements: Understanding Draft EPA Method 324 and Validation Results**

**Paper # 106**

**Sheila H. Glesmann, Sharon Sjostrom, ADA-ES, Inc.**  
447 Larkspur Lane  
Severna Park, MD 21146

**Chuck Dene, EPRI**  
3412 Hillview Avenue  
Palo Alto, CA 94303

**Eric Prestbo, Frontier Geosciences, Inc.**  
414 Pontius Ave North  
Seattle, WA 98109

For Submittal to:  
EPRI-EPA-DOE-AW&MA Power Plant Air Pollutant Control “MEGA” Symposium, August 30-September 2, 2004, Washington, DC

## **ABSTRACT**

EPA’s new mercury measurement method has been included in the proposed NESHAP rule published in the January 30, 2004 Federal Register. The newly proposed test method, draft EPA Method 324, is based on the EPRI-developed Quick SEM™ test method, and employs a cartridge or sorbent trap with in-situ sample collection for total mercury measurement in low-dust flue gases. It has the flexibility to obtain measurements ranging from a few minutes to several days in duration. The method is non-isokinetic, uses no impingers, and does not require any chemical rinse of the sample train in the field. After sampling, the sorbent traps are sealed and analyzed in a laboratory by CVAFS. EPA has proposed the method as a reference method or for continuous compliance monitoring.

This paper will discuss the method in its current draft form, the development history of the sorbent trap test method for mercury, and report on results of field tests and the Method 301 Validation tests. Lessons learned from field application of the method, which has resulted in the validated version, will also be discussed. This will include data on field blanks, storage time, sample time, breakthrough, field duplicates (precision) and intercomparison with Ontario Hydro.

## **INTRODUCTION AND BACKGROUND**

Measuring mercury accurately and easily is key to the success of mercury control technologies and to the effectiveness of an emissions trading system. EPRI, ADA-ES, Inc. (ADA-ES), Frontier Geosciences, Inc. (Frontier) and other researchers have developed and applied a relatively simple method for mercury measurements on coal-fired flue gas, which EPA has now published as Draft Method 324 in their proposed Utility Mercury Reduction Rule (the Rule), published in the Federal Register on January 30, 2004.<sup>1</sup> Method 324 is called *Determination of Vapor Phase Flue Gas Mercury Emissions from Stationary Sources Using Dry Sorbent Trap Sampling*. The method is proposed in the Rule for application as either a reference method test or a continuous emissions monitoring method for mercury. The test method has been in use in various forms since the early 1990's, with extensive use in research applications and in field demonstrations of mercury and multi-pollutant control technologies.

EPA Draft Method 324 is a non-isokinetic test method that samples flue gas while minimizing particulate capture, and provides a measurement of total vapor-phase mercury emissions. Paired samples are collected in a batch mode using dry sorbent tubes, and sent for laboratory analysis using cold vapor atomic fluorescence spectrometry. The method can be used over periods of time ranging from 30 minutes to several days. The dry sorbent trap method can obtain detection limits an order of magnitude lower than the Ontario Hydro Method. It is a relatively simple method to operate, and since the sample times are variable, it can be used for longer-term evaluation of mercury emissions under various process conditions with minimal effort. A single technician can operate the test in the field, or it can be conducted in self-sustaining mode unmanned, with periodic changeout of the sample traps.

Validation testing for Method 324 was performed by ADA-ES and Frontier under contract to EPRI in 2003. The method was operated simultaneously with ASTM Method 6784-02 (Ontario Hydro), and standard Relative Accuracy and Method 301 calculations were applied to the data. These data, upon submittal to EPA, showed that the method was effective for mercury measurements in low-dust coal-fired applications.

This paper presents the history of method development and of relative accuracy and validation testing, a description of how the method is operated in the field and laboratory, and a description of various quality control tests that have been conducted.

## **SORBENT TRAP METHOD DEVELOPMENT HISTORY**

The applied field approach in use today stems from years of development of the sorbent trap method at many power plant sites since the early 1990's.<sup>2</sup> In 1996-99, for example, the sorbent traps were relied upon as the primary mercury measurement technique in a U.S. Department of Energy (DOE) program that demonstrated mercury and multi-pollutant control on western coals.<sup>3</sup> In the same time period we used the method to evaluate mercury removal across a pilot-scale baghouse on an eastern bituminous coal<sup>4</sup>. This work and programs at other sites were critical to the development of the test method and the validation of its results on a wide range of coals.

Intercomparison studies conducted by Frontier in 2000 and 2001 under DOE and EPA funding demonstrated that, in different configurations, the sorbent trap method was suitable for both total

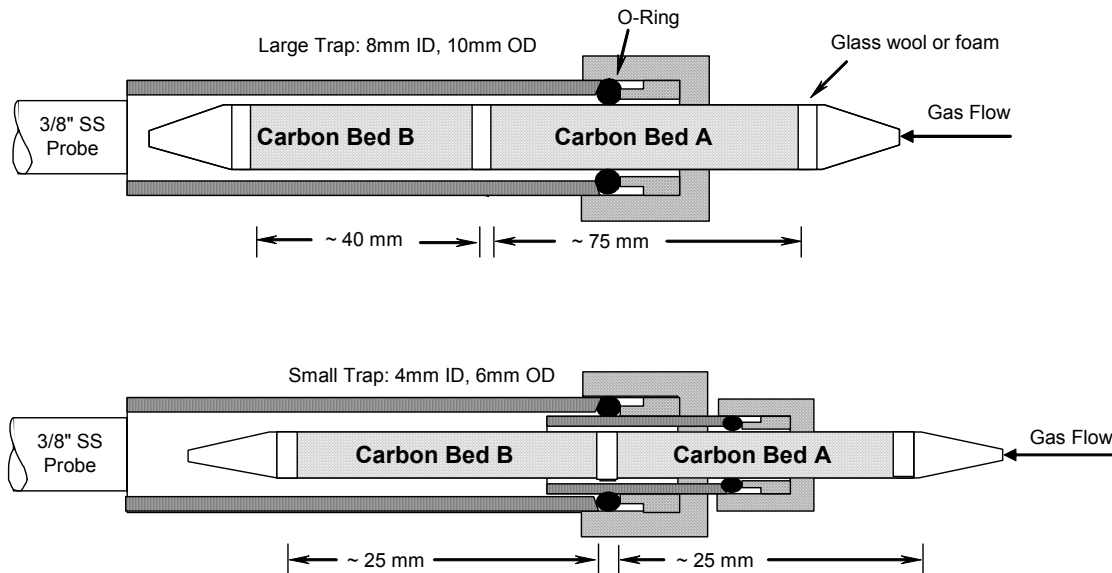
and speciated mercury measurements.<sup>5,6</sup> In general these tests were grab samples over periods ranging from 15 minutes to two hours in duration.

More recently the method has been adapted for longer-term (multi-day) sampling using a larger sorbent trap design. EPRI, ADA-ES and Frontier have applied the method in many applications over the past few years. EPRI's trade name for the method is QuickSEM™ (Quicksilver Emissions Monitor). In 2002 and 2003 development of the method as a field-friendly technique advanced significantly under EPRI funding. Fittings were improved to allow easier changeout of the sorbent traps, and components were made more robust for field application. Data logging was improved. Two trap sizes were developed by Frontier so that sampling periods could range from under an hour to a week and possibly as long as a month in duration.<sup>7</sup> The specifications of the two trap sizes are shown in Table 1 and Figure 1.

**Table 1.** Small and Large Trap Specifications. Two Sections Per Trap.

Trap Size	Internal Diameter (cm)	Total Bed Length (cm)	Nominal Mass of Trap Material (mg)	Nominal Flow Rate (L/sec)
Small	0.4	5.0	300	0.5
Large	0.8	11.5	2800	0.3

**Figure 1.** Diagram of Sorbent Traps and Connections with Probe.



NOT TO SCALE

The key QuickSEM™ development team in 2002 and 2003 included EPRI, ADA-ES, SparkWorks, and Frontier. Other project participants included RMB Consulting, APEX, Apogee Scientific, and MRI. Demonstration sites and additional support were provided by EPA, KCP&L, AEP, Southern Company/Alabama Power, SRP, CPSG and Dominion Energy/Virginia

Power. Ongoing development of the method is continuing by the authors and by EPRI Solutions, who also offers QuickSEM™ testing commercially.

Under EPRI sponsorship in 2002 and 2003, the method was used at several coal-fired units of various configurations<sup>8</sup>. The method is also continuing to be used by field test groups and researchers. Some utility companies are starting to use the method directly, owning the test equipment and deploying internal or contract test personnel to manage the sample turnaround. Some sites where the method was applied by the authors in 2002-2004 are described in Table 2. These sites varied in terms of coal type, unit configuration, and air pollution control devices. Test locations were downstream of the particulate control and all devices shown.

**Table 2.** Sample of Coal-Fired Application of the Sorbent Trap Method from 2002-Present.

Coal Type	HESP	SCR	Spray Dryer	ESP	Baghouse	Wet Scrubber	Total # Sites
Bituminous	x x	x x		5x	x COPHAC	x	8
Subbituminous		x	x  x	x 2x	p x p-COHPAC  x x		6
Lignite				x			1

p= pilot facility or slipstream pilot

## METHOD DESCRIPTION AS USED FOR VALIDATION TESTS

### Field Sampling

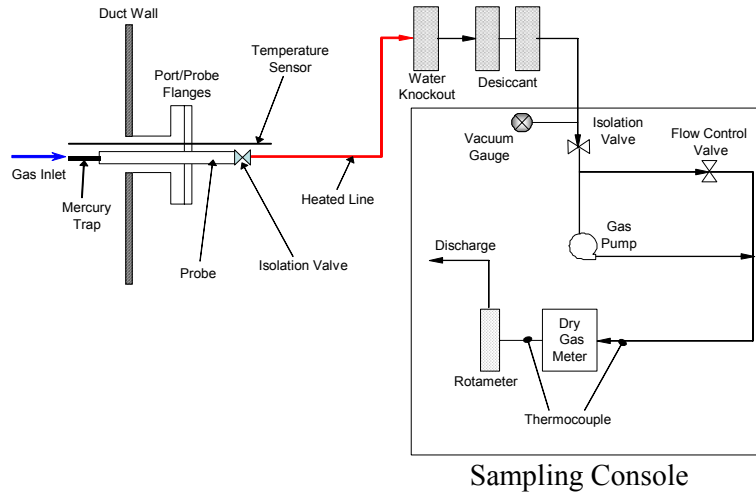
Known volumes of flue gas are extracted from a duct through a dry sorbent trap (containing a specially treated form of activated carbon) as a single-point sample, with a nominal flow rate of about 400 cc/min through each gas meter. The dry sorbent trap, which is in the flue gas stream during testing, is the entire mercury sample. The trap is recovered in the field and shipped to the laboratory for analysis.

Method 324 requires that paired samples be collected in the field. The analysis results of the paired sample trains are compared and are typically in agreement within 5-20% relative percent difference (RPD). In addition, each trap has two separate sorbent beds, and the rear or B bed is analyzed to evaluate whether any mercury breakthrough occurred. A field blank trap is analyzed to confirm overall sampling and analysis handling quality.

The sample train is fairly simple, as shown in Figure 2. It consists of a dry sorbent trap mounted directly on the end of a (usually heated) probe, sample lines to a moisture knockout, followed by a sampling console which contains a dry gas meter, a flow rate control device, temperature

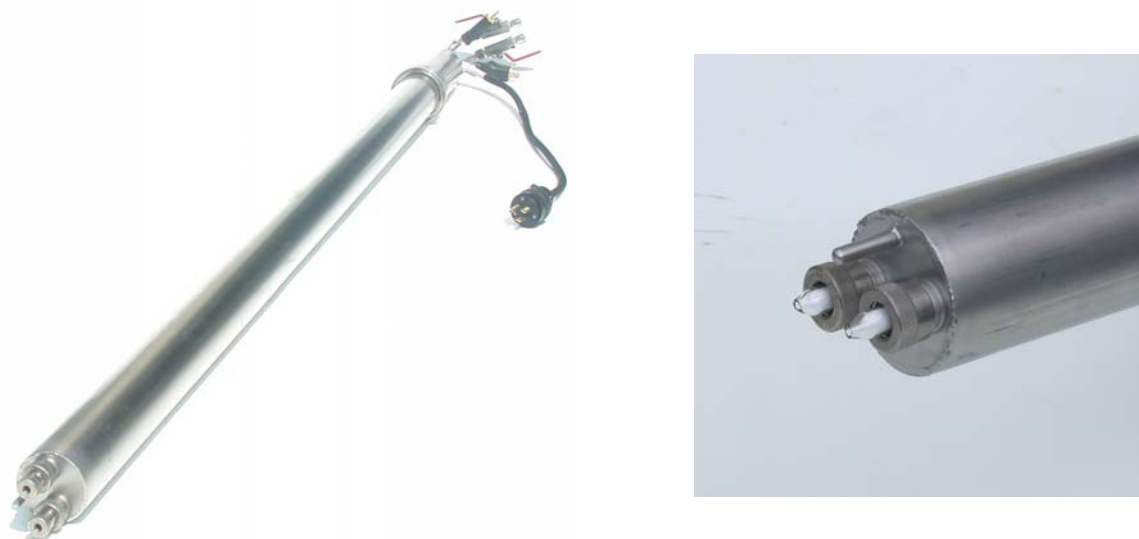
controllers, vacuum gauges, temperature indicators, and data logger. Stack temperature, sample probe temperature, flow meter gas temperature, and sampling volume are recorded on field sampling data sheets and a data logger for each sample run. Sample rate can be adjusted to be proportional to stack flow, as is currently required for longer-term sampling. Figure 3 shows a typical paired sampling probe for the method, as well as a closeup of sorbent traps installed in the probe.

**Figure 2.** Sample Train Configuration.



EPA Method 324 directly measures mercury concentration. Using stack gas flow rate and gaseous data from the plant's CEMS and coal Ultimate Analysis (or EPA Method 19 F-Factors if Ultimate Analysis is unavailable), results can be calculated and reported in lb/TBtu. Comparison tests between Ontario Hydro and Method 324 have shown that Method 324 is as accurate for total vapor-phase mercury, these results are presented in a later Section. Method 324 also compares favorably with reference methods for total mercury, in test locations that are downstream of a particulate collector. Sometimes the particulate-bound mercury reflected in an isokinetic sample is an artifact of the test method. This is avoided using Method 324 because particulate capture is minimized via low-flow sampling that is cross-current.

**Figure 3.** Typical Method 324 Paired Sampling Probe, and Closeup of Probe with Traps Installed. Photographs Provided by Apex Instruments.



## Laboratory

To date, the two key factors that have led to the success and reliability of the described method are the quality and design of the sorbent trap and the use of cold vapor atomic fluorescence spectroscopy (CVAFS) for mercury detection. The sorbent is made from washed charcoal and then chemically impregnated. The process to manufacture the traps is highly controlled, resulting in a nominal blank level of  $0.5 \pm 0.4$  ng of mercury per trap. The result is a sorbent trap, with a very low and consistent mercury blank and a high surface area that acts to chemisorb all gaseous mercury species. In contrast to physi-sorption, higher sampling temperatures actually enhance mercury capture when based on a chemisorption process. In addition, the chemisorption of the sample results in a very stable sample that requires no special handling, other than to protect it from contamination. The use of CVAFS for detection of mercury for environmental work has numerous advantages that have been discussed at length.<sup>9</sup> In short, the wide linear range, high selectivity and low detection limit provided by CVAFS results in a more robust, interference-free, sensitive, accurate, precise and cost-effective determination of mercury in comparison to other comparable detection methods. The application of CVAFS for mercury detection is a mature method, with several commercial options available, including automated systems.

In the laboratory, in a class-100 clean bench, the sorbent traps are broken open to quantitatively transfer the sorbent and packing material into trace clean digestion vials with Teflon lined lids. Clean techniques, as describe below, are use throughout the digestion and analysis procedure. As mentioned, for each sorbent trap there are two beds of charcoal, A and B, which are digested and analyzed separately. After the sorbent has been transferred to the vial, a 70:30 mixture of

HNO<sub>3</sub>/H<sub>2</sub>SO<sub>4</sub> acids is added to the vial such that the total acid volume will be at least 40% of the total volume. The vials are tightly capped and subjected to a hot (60 °C) leaching in the mixture of concentrated acids for 1.5 hours. The leachate is then diluted up to a precise volume with 5% (v/v) of a 0.7NBrCl solution on the day of analysis.

Although there are important details that are specific to the analysis of the described sorbent traps, the principle of analysis and instrument calibration is nearly identical to those described in EPA Method 1631. For analysis, a precise aliquot of digested sample is directly pipetted into an acidified, aqueous bubbler system, pre-purged of any residual mercury. Stannous chloride (SnCl<sub>2</sub>) is added to reduce the oxidized mercury in the sample aliquot to elemental mercury and the bubblers are immediately sealed. At the outlet of the bubbler is a soda-lime pre-trap, followed by a pre-blanked gold-coated quartz trap. The soda-lime is used to scrub acid gases and thus protect the gold-coated quartz traps, while quantitatively transferring the gaseous elemental mercury. The bubbler is then purged with UHP nitrogen (N<sub>2</sub>) for 20 minutes to drive the gaseous elemental out of the aqueous solution and onto the gold-coated quartz trap. The gold trap is removed from the bubbler, and transferred to the CVAFS analyzer analysis system, where it is heated, releasing the mercury onto a second, analytical gold-coated quartz trap, which in turn is heated directly into the CVAFS analyzer in an argon gas matrix. Mercury results are provided in units of ng/trap, or if provided to the laboratory with field data, in units of ug/Nm<sup>3</sup>.

## **Cleanliness**

Trace amounts of mercury are commonly found in dust, hair, saliva, clothing, water, soil, fly ash and other items that may come in contact with the sorbent traps. The success of the method requires that during preparation, transport, field handling, sampling, recovery and laboratory analysis of the sorbent traps, special attention must be paid to cleanliness procedures. This extends to the handling and storage of all the containers and reagents used in the analysis. This is necessary to avoid mercury contamination of the samples, which generally contain very small amounts of mercury. Although not directly applicable for sorbent traps, the principles described in EPA Method 1669 provide a framework for trace-clean environmental sampling.

The sorbent traps are designed and packaged to promote the ability to use clean techniques and avoid the introduction of foreign material. The ends of the sorbent traps are sealed at all times, except when making or breaking a connection, to avoid the introduction of foreign material, or the adsorption of mercury present in ambient air during trap transport and storage. The sorbent traps must also be stored in a low air mercury environment (<50 ng/m<sup>3</sup>). Trace clean techniques are especially important for short term sampling at facilities that have low mercury levels in the fluegas, either due to low coal concentrations or efficient mercury control applications. For example, the loading will be only 15 ng of mercury for a 1-hour sample at a flowrate of 0.5 liters per minute and a total fluegas mercury concentration of 0.5 µg/m<sup>3</sup>. Undiscovered contamination of the field blank or sample at such low loadings could have a significant impact on the reported results. So, clearly, low and constant blanks will be critical, as well as strict attention to cleanliness during all aspects of the measurement effort.

## **RECOMMENDED QC PROCEDURES**

The quality control specifications listed in Table 3 are designed to be performance-based measurements. For example, the requirement for paired trains is a key performance-based QC

measurement that evaluates the quality of the entire method, from sampling, trap quality, handling, digestion, and analysis to data calculations. The QC specifications and criteria in Table 3 have been routinely achieved using the above described sorbent trap and CVAFS detection.

**Table 3.** Expected Quality Control Procedures for Sorbent Trap, Sampling and Analysis.

QA/QC specification	Acceptance Criteria	Frequency
Reagent blank	<5 ng/digest and a standard deviation of 1.0 ng/digest. (n=3)	3 per analysis set of 20 sorbent traps
Sorbent Trap Blank	<5 ng/digest and a standard deviation of 1.0 ng/digest. (n=3)	Not required, but recommended for low sample trap loadings (<100 ng/digest) or if field blanks or the Trap Quality Indicator are above their acceptance criteria of 5 ng/digest
Sorbent trap field blank	<5 ng/trap or < 5% of average Hg collected on the traps.	1 per 10 field samples collected
B-Section Bed Analysis	<2% of A Section bed value or < 5 ng/digest	Every Sample
Paired train Results	Same as section 8.6.6 of PS-12A of 40 CFR Part 60, Appendix B	As required
Calibration Curve Correlation Coefficient (minimum of 5 points)	$r \geq 0.995$ , linear regression forced through zero	Beginning of analytical day, every 12 hours thereafter
Initial/Continuing Calibration Verification (ICV/CCV)	80-120% recovery	Following every calibration, 1 per 10 analytical cycles
Initial/Continuing Calibration Blank (ICB/ CCB)	Individual limit of < 0.25 ng/L (Instrument blanks are not blank corrected)	Following every calibration, 1 per 10 analytical cycles
Laboratory analytical and analytical spike duplicate (AS/ASD)	75-125% recovery with RPD $\leq 25$ 1 per analytical batch $\leq 20$ samples	1 per batch of 20 samples
Laboratory analytical duplicate (AD)	$\leq 20$ RPD/RSD	1 per batch of 20 samples

## VALIDATION TESTS

The Quick SEM™ method was run in paired trains in conjunction with paired Ontario Hydro test runs at a subbituminous coal site. Tests were run at the stack, with low mercury concentrations in the range of 1-3  $\mu\text{g}/\text{Nm}^3$ . Relative accuracy tests against duplicate trains of the Ontario Hydro method were conducted in June – July 2003. These tests were submitted to EPA for evaluation under Method 301 in October 2003, and EPA found that the results were acceptable to demonstrate the method was ready for draft publication as Method 324 in the Rule. The nine best runs of validation data that were submitted to EPA are shown in Table 4.

**Table 4.** QuickSEM™ Method 301 Calculation Results. Both Methods Used Paired Samples. All values are in  $\mu\text{g}/\text{Nm}^3$ .

<b>BEST 9 RUNS</b>					
Run ID	QSEM	OH	Avg QSEM	Avg OH	$d_m$
1	1.65	1.44	1.59	1.38	-0.21
	1.53	1.32			
2	3.17	3.39	2.91	3.39	0.47
	2.65	3.38			
3	1.84	2.27	2.15	2.32	0.17
	2.47	2.37			
4	1.95	1.83	1.82	2.11	0.28
	1.70	2.38			
5	1.51	1.53	1.35	1.40	0.05
	1.19	1.26			
8	1.67	1.56	1.56	1.40	-0.16
	1.44	1.24			
10	1.76	1.17	1.64	1.40	-0.24
	1.51	1.63			
11	1.90	1.51	1.72	1.42	-0.31
	1.55	1.32			
12	1.34	1.25	1.25	1.23	-0.03
	1.16	1.20			
<b>Sdev =</b>	0.517	0.703	0.499	0.708	0.263
<b>Variance =</b>	0.253	0.467		<b>n =</b>	9
<b>Average =</b>	1.78	1.78	1.78	1.78	0.003
<b>F - Test</b>	0.542	<b>Passed</b>			
				<b>SD =</b>	0.186
				<b>t - Test</b>	0.047
				<b>t<sub>n</sub> =</b>	1.397
				<b>CF =</b>	<b>No Bias</b>

Note: RA = 11.5% as calculated via 40 CFR Part 60, Appendix B, Performance Specification 2.

In November 2003 following the submittal of relative accuracy test results to EPA, the EPRI team of ADA-ES and Frontier drafted Method 324, submitting the final form to EPA in December.

One advantage of Method 324 is that it has very low detection limits and thus can quantify very low levels of mercury emissions. When performing relative accuracy comparisons even in low-mercury flue gas, the method responded well. The relative accuracy for Table 4 runs is 11.5%, which passes the <20% criteria. However, when very low measurement levels are reached EPA typically allows an alternative calculation using a percentage of the emissions standard. Since small differences become a large percentage of the reference method when low concentrations are the basis, the standard relative accuracy calculation as used for these becomes a more difficult criteria than the percent of standard comparison. In the Supplemental Notice of

Proposed Rule EPA has proposed an alternative criteria for mercury sorbent traps. If the average reference method test (Ontario Hydro in this case) results in flue gas mercury concentrations less than  $5.0 \mu\text{g}/\text{Nm}^3$ , the test results are acceptable if the difference between the mean value of the sorbent trap and the mean value of the reference method is less than  $1.0 \mu\text{g}/\text{Nm}^3$ . This less-stringent criteria is also easily passed by the validation data, with a mean of the absolute value of the differences between methods of  $0.21 \mu\text{g}/\text{Nm}^3$ .

## QUALITY CONTROL EVALUATIONS

### Precision

Precision between paired samples is an excellent quality control check with this test method because field problems such as broken or misplaced o-rings, meter box calibration problems, or other sample train leaks, are flagged by poorly matched pairs. In the case of a set of field testing conducted in 2003, paired trains showed poor comparability, with one sample train reporting consistently lower mercury values than the other. Meter box calibrations post-test showed that the calibration factor in one box was incorrect. This type of error is easily identified by paired samples. In the case of a calibration factor error, it can also be corrected for with proper data management.

EPA has proposed to use the higher value of the two paired samples for reporting purposes. Our team has suggested (during the Comment Period) an alternative of using the criteria of 20% RPD when comparing the paired samples, for acceptance of the average value as the reported emission concentration. When RPD exceeds 20%, the test data should be scrutinized for sampling or analytical discrepancies. In that case reporting the higher value is recommended, unless a correction can be made to the data based on calibrations.

**Table 5.** Results of Paired Sample Analyses.

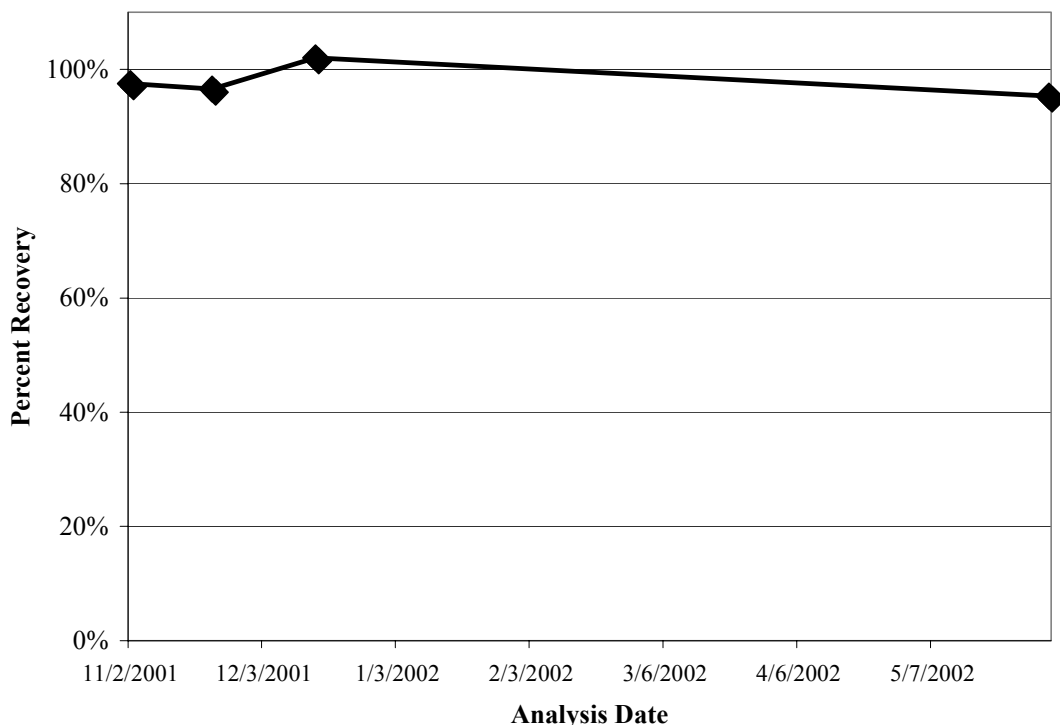
QA Measurement	Units	
Laboratory Analysis Precision, A-Trap	Mean of RPD and %RSD values	$4.8\% \pm 4.9\%(n=16)$
Paired Sample Trains Precision, Total Mercury	Mean and %RSD of the RPD for paired samples	$3.4\% \pm 3.2\%(n=4)$

### Storage time

The sorbent traps are currently made in sealed glass tubes, so they are very stable over months for storage prior to sampling. The traps are also protected after the ends have been broken open and post-sampling, because the sorbent traps are sealed tightly with endcaps and stored in clean air-tight plastic bags or plastic tubes. The chemi-sorption of the sampled mercury to the trap surface provides a very stable sample, which previous research has shown to retain the entire mercury signal for at least 3 months. After the sample has been properly digested, the sample is also very stable as shown in Figure 4. In this case, a 1000 ng spike of mercury was added to the digestion of a pre-analyzed sorbent trap that had been used to collect a flue gas sample. Over the course of 7 months, repeated analyses indicated that there was no observed loss of mercury in the

sample digest either through air, wall or readsorption to the carbon matrix (Figure 4). The acid-ratio-to-volume conditions required to avoid readsorption of mercury to the carbon matrix has been previously reported<sup>2</sup>.

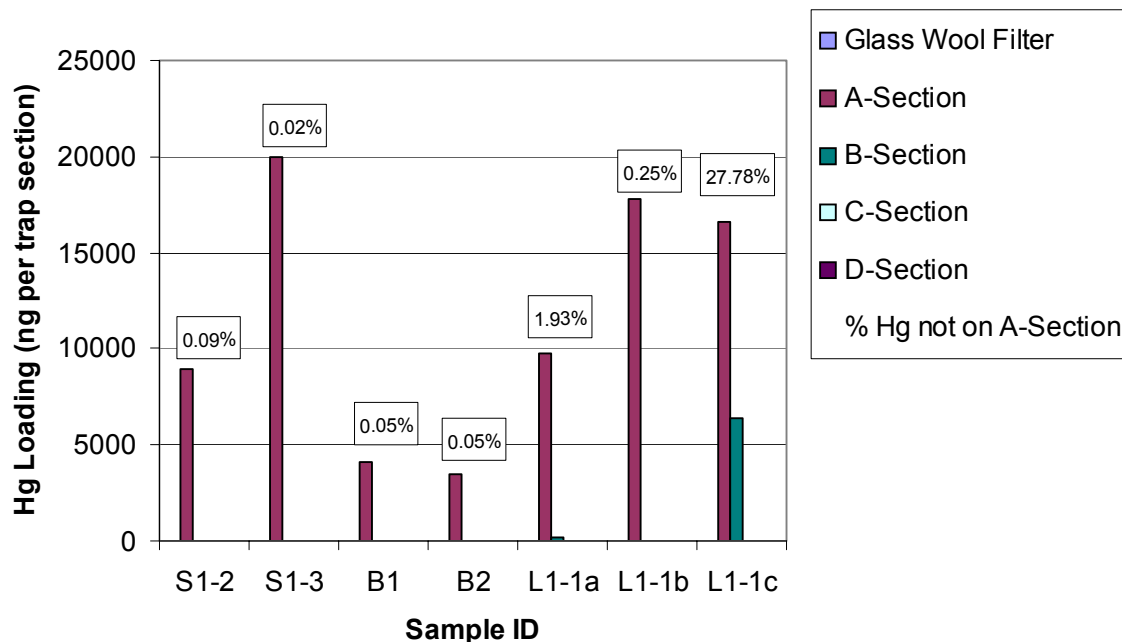
**Figure 4.** Results of Storage Time Study on a Sorbent Trap Used for Flue gas Mercury Measurement.



### Breakthrough

Initial trap design for the larger traps included a total of four bed sections. The beds were identified as A, B, C and D. Trap beds, as well as the glass wool plug on the front of the trap, were each analyzed for mercury individually. The percentage of Hg measured *not* on the front A section of the sorbent trap is shown in Figure 5. In several instances, we employed a 4-section trap to get better resolution on the potential for breakthrough. The C and D trap sections were nominally the same as blanks. Some of these samples were collected over 5 days. Following these types of analyses, the two-bed design was arrived at. Typically with the A and B bed sections in use, breakthrough onto the B bed is minimal, providing another quality control check on the sample handling and the blank level.

**Figure 5.** Breakthrough of mercury on the sorbent trap over extended sampling periods and high loading.



Note: Coal types are indicated by S=subbituminous, B=bituminous, L=lignite.

## METHOD 324 DISCUSSION

The test method was published by EPA as a performance-based method, meaning that if alternative techniques can yield results that are as accurate and precise as the techniques used to validate the method, those alternative procedures may be approved by the Administrator. The importance of validation tests for alternative analytical techniques cannot be overstated. The analytical techniques described herein, which are in use in QuickSEM™ sampling, have been proven in many different flue gas environments and over a wide range of mercury concentrations. The future of the method is very encouraging because of its low detection limits, ease of use, and excellent precision and accuracy. This has led it to be proposed by EPA as both a reference method and as a continuous compliance tool for mercury monitoring.

## CONCLUSIONS

Method 324 is preferred for mercury measurements because of its low detection limits, accuracy, simplicity, flexibility, stability, and ability to obtain short analytical turnaround times. Paired sampling generally shows very good precision. Comparison tests between Ontario Hydro and Method 324 have shown that Method 324 is as accurate for total vapor-phase mercury. Method 324 also compares favorably for total mercury, in test locations that are downstream of a particulate collector.

Applied to flue gas environments, the method has proven robust and accurate for both high and low mercury loadings. Effective field operation of EPA Method 324 has several key features:

- ✓ The method can be operated over periods of time from under an hour to multiple days, possibly weeks in duration.
- ✓ Cleanliness is critical to successful laboratory and field handling of the samples; for example laboratory cleanliness must be maintained to extremely stringent standards, similar to those procedures described in Method 1631.
- ✓ Field sampling must include accurate measurement of flue gas volume, avoidance of condensation in the sorbent trap, and clean sample handling.
- ✓ Trap quality control is key to maintaining consistently low blank levels.
- ✓ Condensation in the trap must be avoided during sampling.
- ✓ Current analytical procedures developed and maintained by Frontier are very effective at obtaining low detection limits in a broad range of coal-fired flue gases.
- ✓ The method is simpler to use in the field than comparable methods using wet chemistry, and provides good total vapor-phase mercury measurements in coal-fired flue gas environments.
- ✓ Method 324 has the potential to be used for process evaluation, mercury characterization, compliance testing, and continuous compliance demonstration.

## REFERENCES

1. Federal Register Volume 69, No. 20, p 4652 et. seq., January 30, 2004; and Supplemental Proposal...
2. Prestbo E.M. and Bloom N.S. (1995) "Mercury Speciation Adsorption (MESA) Method for Combustion Flue Gas: Methodology, Artifacts, Intercomparison and Atmospheric Implications," *Wat. Air Soil Pollut.*, 80:145
3. Haythornthwaite, S., S. Sjostrom, T. Ebner, J. Ruhl, R. Slye, J. Smith, T. Hunt, R. Chang, T. Brown, "Demonstration of Dry Carbon-Based Sorbent Injection for Mercury Control in Utility ESPs and Baghouses," EPRI-DOE-EPA Combined Utility Air Pollutant Control Symposium (MEGA Symposium), August 1997.
4. Waugh, E.G., B.K. Jensen, L.N. Lapatnick, F.X. Gibbons, S. Haythornthwaite, S. Sjostrom, J. Ruhl, R. Slye, R. Chang, "Mercury and Acid Gas Control in Utility Baghouses through Sorbent Injection – Pilot-Scale Demonstration," PowerGen, December 1997.
5. "Comparison of Sampling Methods to Determine Total and Speciated Mercury in Flue Gas," CRADA F00-038 Final Report, DOE/NETL-2001/1147, January 4, 2001.
6. Prestbo, E.M., et al, "Solid Sorbent Method: Results of a Performance Based Measurement System (PBMS) Validation Study," Report to the EPA Air Pollution Prevention and Control Division, National Risk Management Research Laboratory, Research Triangle Park, NC, 2001.
7. 2002 EPRI Report, "Measuring Mercury in a Coal-Fired Flue Gas," EPRI, Palo Alto, CA, 1004176.
8. 2003 EPRI Report for QSEM, "Status of Mercury Monitoring," EPRI, Palo Alto, CA, 1004843.
9. Mercury as a Global Pollutant, Water Air and Soil Pollution 80(1-4), 1995, Porcella, D.B., Huckabee, J.W. and Wheatley, B., eds. Kluwer Academic Publishers, Boston.

## **KEY WORDS**

Mercury

Measurement method

Method 324

Continuous mercury measurement

Sorbent trap

Quick SEM™