EXHIBIT I

ENERGY RESEARCH CENTER

LEHIGH UNIVERSITY

Bethlehem, PA

ARMSTRONG PROJECT

EVALUATION AND COMPARISON OF U.S. AND EU REFERENCE METHODS FOR MEASUREMENT OF MERCURY, HEAVY METALS, $PM_{2.5}$ AND PM_{10} EMISSIONS FROM FOSSIL-FIRED POWER PLANTS

FINAL REPORT

Prepared for:

Allegheny Energy Corporation
CONECTIV Energy
Constellation Power Source Generation
Dominion Resources Services, Inc.
Detroit Edison Company
Electric Power Research Institute
FirstEnergy Corporation
Oklahoma Gas and Electric Company
Ontario Power Generation, LLC
PPL Generation, LLC
Southern Company Services, Inc.
U.S. Environmental Protection Agency
and
The Italian Ministry of Economic Development
The Institute for Environment and Sustainability
of the Joint Research Centre

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February 2007

07-400-02-03

Armstrong Test Team

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EXECUTIVE SUMMARY

With mercury regulations pending and control technologies in the full-scale demonstration stage, measurement of mercury (Hg) in combustion flue gas is of critical importance. The ability to accurately and reliably measure mercury is fundamental to demonstrating compliance when regulations are promulgated and, in the meantime, to ensuring adequate quantification of mercury removal during the demonstration and commercialization of the various mercury control technologies.

The important issue facing electric utility industry is a short compliance timeline: by January 1, 2009, certified continuous mercury monitors (CMM) need to be installed. Following certification, a certified CMM should collect 12 months of mercury emissions data. Reporting of data for compliance monitoring would start on January 1, 2010. This gives two years for CMM installation and certification, and three years until mandatory reporting for emissions compliance, Figure E-1.

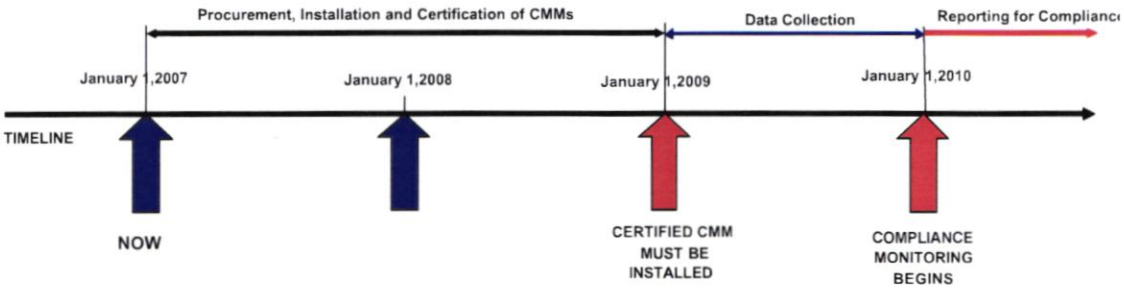

Figure E-1: Mercury Compliance Timeline

Collecting a representative flue gas sample for Hg analysis from coal combustion flue gas produces many challenges. The complexity of flue gas chemistry, relatively high temperatures, reactivity of mercury species, and particulate loading must be addressed to ensure that the flue gas sample that reaches the mercury-measuring device is representative of the gas stream within the duct or stack. In addition to measuring total mercury accurately, the identification and quantification of species of mercury is also very important. Mercury emissions from anthropogenic sources occur in three forms: solid particulate-associated mercury $Hg^{(p)}$; gaseous divalent mercury, Hg^{2+}; and gaseous elemental mercury, Hg^{0}.

Continuous monitoring of mercury emissions will be needed for all stationary sources where annual Hg emissions exceed 29 pounds of Hg. The Ontario Hydro wet

chemistry method (OHM) and dry sorbent trap methods provide good results for total and speciated mercury measurements. However, these methods are not designed to provide the real-time data often necessary for environmental compliance.

Hg CEMs are similar to other combustion system CEMs in that a sample is extracted from the gas stream, conditioned, and sent to a remote analyzer for detection. However, as stated earlier, mercury is present in three different forms (Hg^p, Hg^{2+}, and Hg^0), which greatly complicates the measurement process. As they are currently configured and utilized, Hg CEMs possess several challenges to long-term, low-maintenance continuous operation for flue gas mercury monitoring. The two main challenges include the areas of sample collection and flue gas conditioning. Collecting a representative flue gas sample for mercury analysis from coal combustion flue gas is not an easy task.

With the support from the U.S. EPA, EPRI, U.S. electrical utility companies, and the Italian Ministry of Economic Development, The Institute for Environment and Sustainability of the Joint Research Centre, and with great help from Allegheny Energy, the ERC organized a field test where the commercially available Hg CEMs and sorbent trap methods were field-tested at Allegheny Energy's Armstrong Generating Station and compared to the reference method.

The main project objectives included:

- Testing of mercury CEMs under field conditions and comparison against the reference method (OHM).
- Testing of the Appendix K sorbent trap methods under field conditions and comparison against the reference method (OHM).
- Field-testing of the EPA Instrumental Reference Method (IRM) for mercury.
- Comparison of the reference methods and test equipment for Hg measurement developed in the U.S. and EU.
- Comparison of the reference methods for heavy metals, $PM_{2.5}$, and PM_{10} measurement developed in the U.S. and EU.

The sorbent trap testing was conducted in parallel to the OHM tests. The start and end times for the OHM and sorbent trap tests were coordinated to allow direct comparison of the results. The Hg CEM and sorbent trap method results were

compared to the mercury concentrations measured by OHM. Collected OHM samples were analyzed on-site.

A total of 72 OHM tests were performed. In addition, 36 samples were obtained by the EU reference Method. The total number of sorbent trap tests, performed by all test teams, was 186. Based on the number of the performed tests, the Armstrong field test represents one of the most comprehensive field test efforts in the mercury measurement area conducted in the U.S.

Also, as part of the Armstrong project, the U.S. EPA, in association with Arcadis, performed a first field test of the new Instrumental Reference Method (IRM).

Field testing was performed in July 2006 by a joint U.S. and EU team at the Allegheny Energy Armstrong Generating Station, located northeast of Pittsburgh, Pennsylvania. For the first part of the test, the plant was firing bituminous coals with high and varying mercury content from local mines. For the second part of the test, a low-Hg coal from Virginia was fired.

This report is divided into two parts. Project objectives, technical approach, test site, test equipment and methods, and Hg CEMs are described in Part 1 of the report. Test results are presented in Part 2.

A comparison of the gas-phase mercury concentration measured by the Hg CEMs and OHM shows a very good agreement between the mercury concentrations measured by both methods, Figure E-2. Also, the inter-comparison between different Hg CEMs is very good, especially for the low-Hg coal.

A comparison of the total mercury Hg^T measured by the sorbent trap methods and OHM, presented in Figure E-3, also shows a very good agreement of results obtained by both methods.

The average bias error B in the gas-phase Hg concentration measured at Armstrong by the Hg CEMs and OHM ranges from -4.2 to + 10.5 percent. The bias error for the high-Hg coal is in the -3.1 to 10.5 percent range, while for the low-Hg coal the value of B is in the -10.4 to 4.6 percent range. The values of bias error for Hg CEMs tested at Armstrong are presented in Figure E-4.

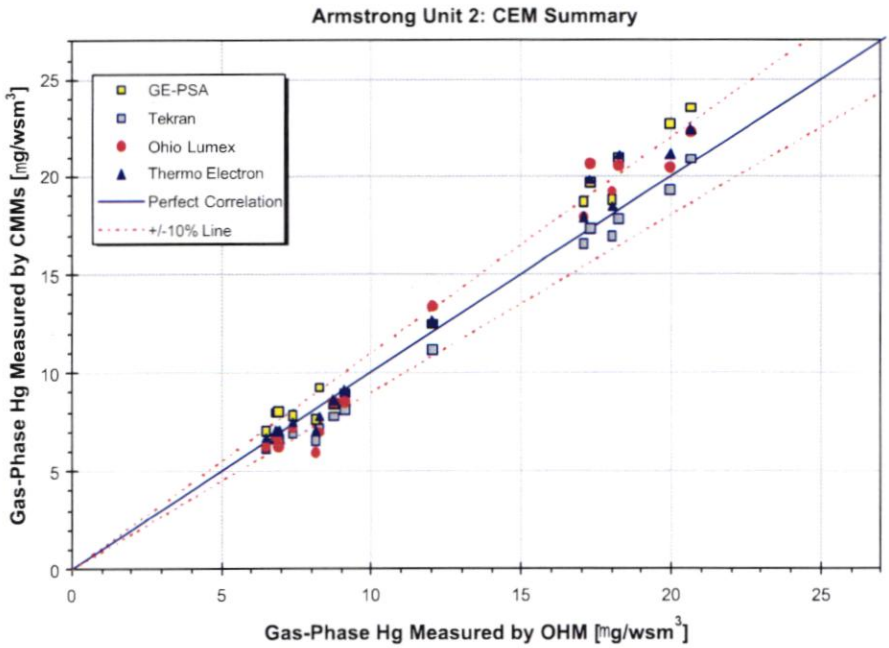

Figure E-2: Comparison of Gas-Phase Hg Concentration Measured By Hg CEMs and OHM

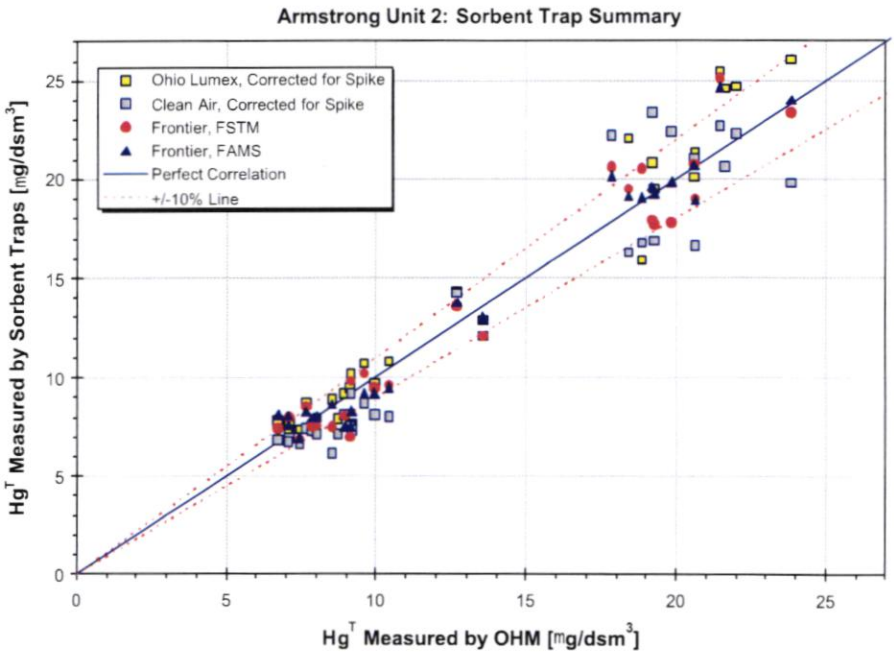

Figure E-3: Comparison of Hg^T Concentration Measured By Sorbent Traps and OHM

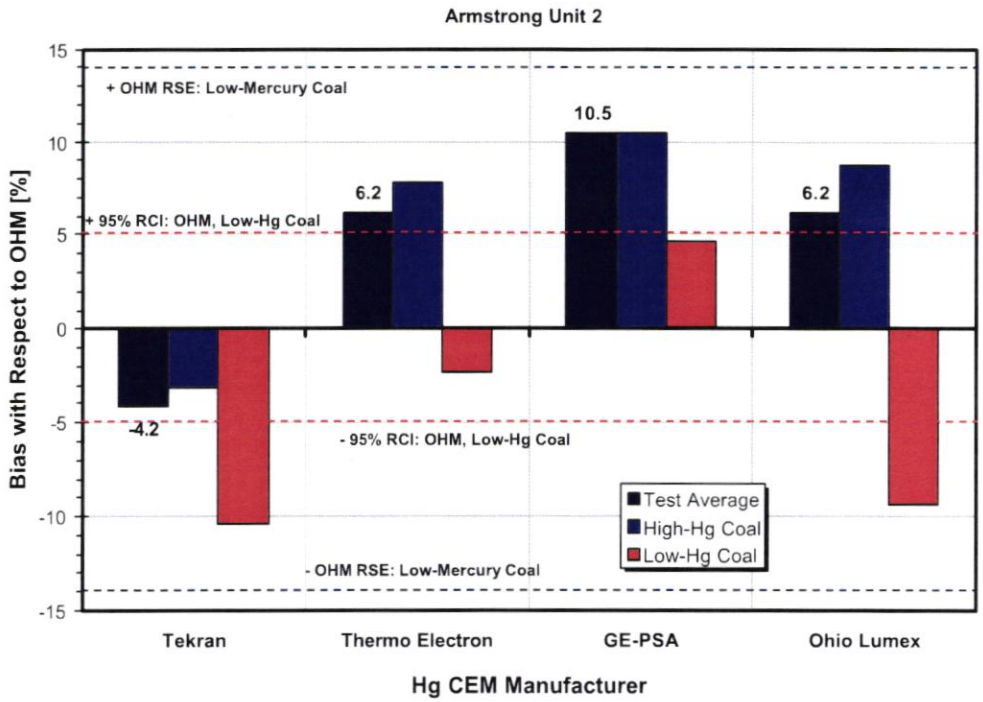

Figure E-4: Hg CEM Bias Error With Respect To OHM

The results of a statistical analysis involving comparison of the interval estimates show that the bias between the OHM, GE-PSA CMM and Ohio Lumex Hg CEM results for the high-Hg coals fired at Armstrong is statistically significant. For the low-Hg coals, the analysis shows that the bias between the OHM, Tekran CMM and Ohio Lumex CEM is statistically significant.

The average bias error in Hg^T concentration, measured by the sorbent trap methods and OHM, ranges from –4.7 to 11.3 percent. The bias error for the high-Hg coal is within the -1 to 13.3 percent range, while for the low-Hg coal B is within the -12 to 7.9 percent range. The values of bias error, for sorbent trap methods tested at Armstrong, are presented in Figure E-5.

For the sorbent trap results obtained by the Ohio Lumex – Apex Instruments test team, not correcting the results for spike resulted in an increase in the bias error; for the CleanAir Engineering - CONSOL results, the bias error for the uncorrected results decreased. The lowest bias error was achieved by the Frontier Geosciences' FSTM and FAMS methods.

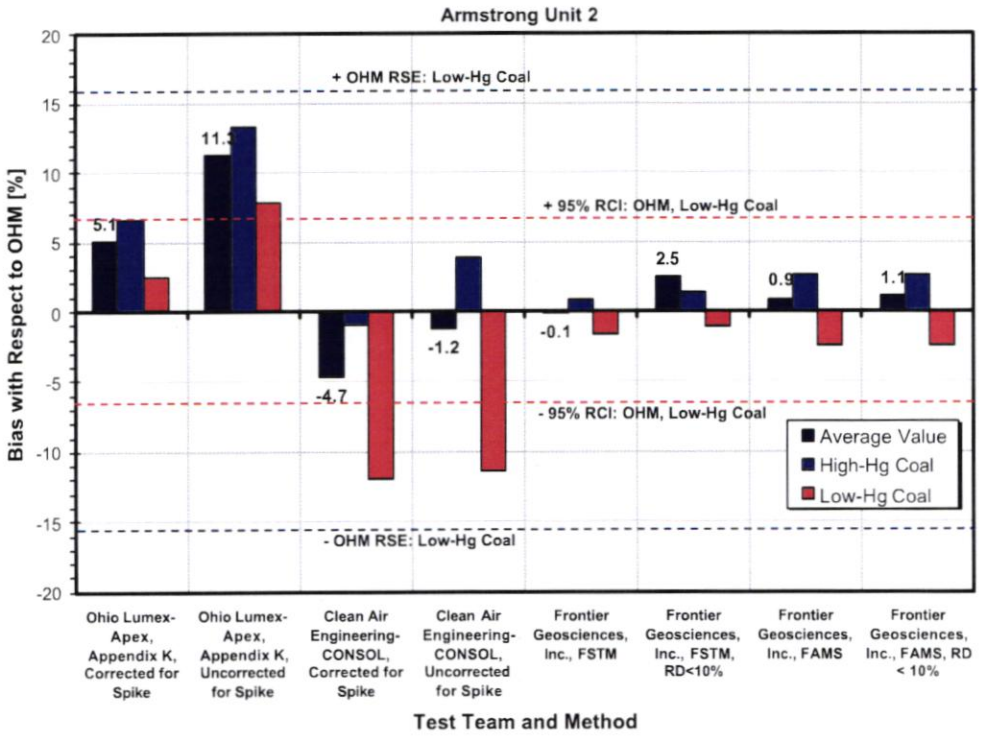

Figure E-5: Sorbent Trap Bias Error With Respect To OHM

The results of a statistical analysis involving comparison of the interval estimates show that the bias between the OHM uncorrected Ohio Lumex and Clean Air Engineering results for the high-Hg coals fired at Armstrong is statistically significant. For the low-Hg coal fired at Armstrong, the bias between the OHM and uncorrected Ohio Lumex results is statistically significant.

The precision of the corrected and uncorrected for spike Appendix K method results was used to determine the effect of spike correction. The results show that spike correction has a very small and inconsistent effect on the precision of the Appendix K results obtained at Armstrong.

A comparison of the Hg^T concentration values measured by EN-13211 and OHM shows a very good correlation between the two EU and U.S. Reference Methods for Hg^T measurement. In summary, EN-13211 performed very well and, on average, produced almost identical values compared to OHM. This means that Hg emission rates measured by the Reference Methods in the USA and European Union are, from the practical point of view, identical and Global trading (if it ever becomes a reality), would be fair and unbiased, as far as measurement accuracy is concerned.

The results from the Armstrong field test show there is a good agreement between the Reference Method (OHM), Hg CEMs, and sorbent trap method results. The maximum bias, calculated for the Armstrong data, is in the 10 percent range. Also, the precision of the OHM results obtained at Armstrong was comparable to the results obtained at other sites.

Based on the obtained results and experience with the test equipment and Hg monitors, recommendations are provided for the dry stacks concerning the automation of the OHM, application of the sorbent trap methods, Instrumental Reference Method hardware, and methods for Hg stratification measurement.

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EXECUTIVE SUMMARY

1. INTRODUCTION

As the U.S. and world population grows, energy use increases. Increased energy usage requires an increase in electric power generation, which constitutes one of the major components of the total energy needs. Increased power generation from fossil-fired power plants also results in increased emissions of pollutants, such as NO_x, SO_x, Hg, heavy metals and particulate matter (PM).

Pollution emissions are regulated by Government rules and regulations, which typically require continuous measurement of emissions and periodic calibration of the continuous emission monitoring system (CEMs) using approved reference methods. Instrumentation, techniques, and reference methods for the measurement of NO_x and SO_x emissions are mature technologies, with well established procedures, accuracy and reliability.

Of the 189 substances designated hazardous air pollutants by the U.S. Environmental Protection Agency (EPA), mercury (Hg) has attracted significant attention in the world due to its increased levels in the environment and well-documented food chain transport and bio-accumulation. As a consequence, on March 15, 2005, the EPA issued the Clean Air Mercury Rules (CAMR), which mandate national Hg reductions from coal-fired power plants through a "Cap and Trade" Program of 23 percent in 2010 (Phase I, based SO_2 and NO_x co-benefit controls) and 69 percent by 2018 (Phase II). As a consequence of these Hg regulations, research and development of cost-effective techniques for measurement and control of mercury emissions from coal-fired boilers has become an urgent issue for the power generation industry.

However, instrumentation, techniques, and reference methods for the measurement of heavy metals and PMs are still in the development or field testing stages. The only reference method currently approved in the U.S. for Hg is ASTM D6784-02, Standard Test Method for Elemental, Oxidized Particle-bound, and Total Mercury in Flue Gas Generated from Coal-Fired Stationary Sources (also known as the Ontario Hydro Method).

The Ontario Hydro Method (OHM) is a wet chemistry method developed for measuring total and elemental mercury at power plant stack operating conditions. Although very accurate, the OHM is time-consuming, man-power intensive and expensive. Typically, three good OHM readings can be obtained per day by a well trained and experienced test crew, assuming no equipment problems, such as leakage or sample contamination, and no tests need to be repeated. Since the EPA regulations require nine good repeat tests at full-load per RATA, mercury RATAs could be very time-consuming and expensive.

The other important issue, facing the electric utility industry, is a short compliance timeline: by January 1, 2009, certified continuous mercury monitors (CMM) need to be installed. Following certification, a certified CMM should collect 12 months of mercury emissions data. Reporting of data for compliance monitoring would start on January 1, 2010. This gives two years for CMM installation and certification, and three years until mandatory reporting for emissions compliance, Figure 1-1.

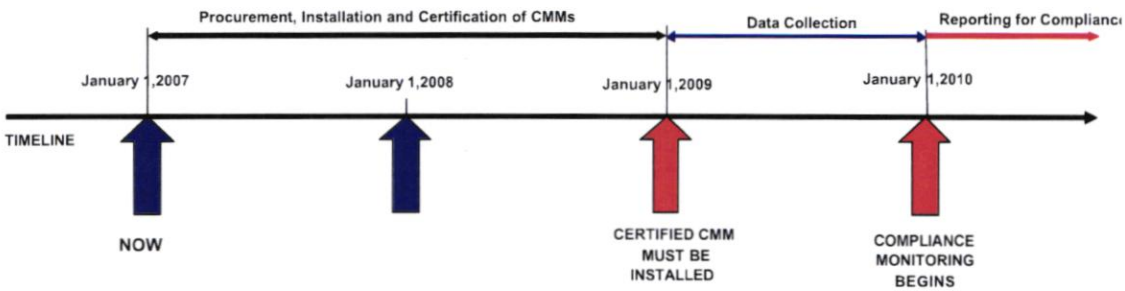

Figure 1-1: Mercury Compliance Timeline

Mercury emissions from U.S. power plants are presented in Figure 1-2. Under the Clean Air Mercury Rule (CAMR), mercury reduction of 21 percent would be required in Phase I by 2010. This would reduce annual mercury emissions by 10 tons. A 69 percent mercury reduction would be required in Phase II by 2018. This would result in an annual mercury emissions reduction of 38 tons.

Some states are pushing mercury compliance deadlines forward, reducing the time available for emission compliance, and also requiring larger mercury reductions than Federal regulations.

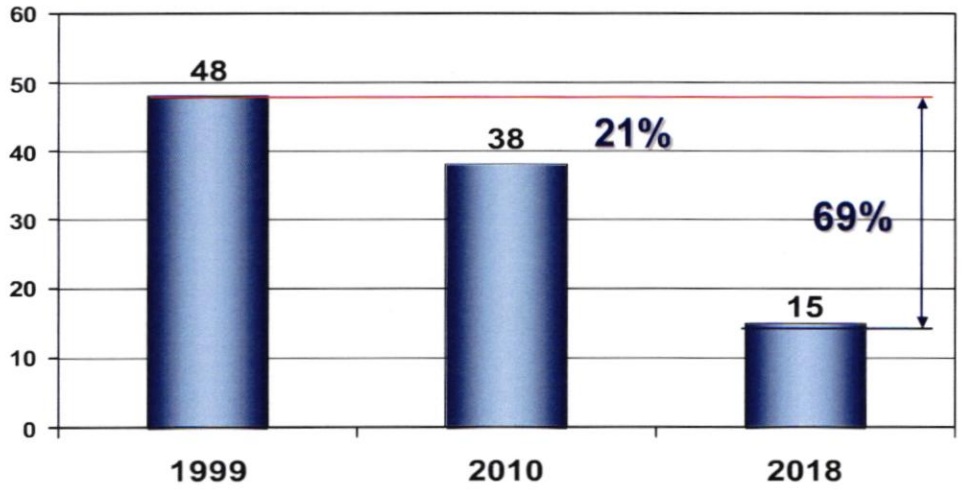

Figure 1-2: Mercury Emissions from U.S. Power Plants under Clean Air Mercury Rule (CAMR), In Tons per Year

Given a short time-line for mercury emissions compliance, commercial availability of CMMs in terms of accuracy, repeatability, and reliability is of extreme interest to the electric utility industry. Also, there is a serious concern as to whether or not enough trained test personnel will be available to perform mercury RATA tests. There is an urgent need for quicker, less man-power intensive and less expensive reference methods for Hg measurement.

With the support from the U.S. EPA, EPRI, U.S. Electrical Utility Companies, and the European Commission, the Lehigh University Energy Research Center (ERC) with great help from Allegheny Energy, organized a field test in which three continuous and two semi-continuous CMMs, currently commercially available in the U.S., were installed and field-tested at Allegheny Energy's Armstrong Generating Station. The continuous mercury CEMs were provided by Thermo Electron, Tekran, and PS Analytical. The semi-continuous mercury CEMs were provided by Ohio Lumex and Horiba.

The CMM results were compared to the mercury concentrations measured by the Reference Methods (RM) for mercury, developed in the United States (U.S.) and European Union (EU). The Ontario Hydro method (OHM) was used as a "gold" reference or standard for all measurements. On-site analysis of collected OHM samples was performed by Western Kentucky University (WKU), using their mobile test laboratory.

In addition, mercury emissions were also measured by the Sorbent Trap Method (Appendix K). Sorbent tubes and test equipment were provided by three manufacturers: Frontier GeoSciences, CleanAir & CONSOL, and Ohio Lumex & Apex.

Measurement of heavy metals and PMs was also performed by using RMs, developed in the U.S. and the European Union (EU). Comparison of the results was performed.

Field testing was performed in July 2006 by a joint US. and EU team at the Allegheny Energy Armstrong Generating Station, located northeast of Pittsburgh, Pennsylvania. The plant is firing bituminous coals with varying mercury content.

Also, as part of the Armstrong project, the U.S. EPA in association with Arcadis performed a first field test of the new Instrumental Reference Method (IRM). IRM results are presented in the Appendix. The CMMs provided by Tekran, Thermo Electron, GE & PS Analytical, and Ohio Lumex were used for the IRM tests.

2. PROJECT OBJECTIVES

The main objectives of the Armstrong project were the following:

- Test continuous and semi-continuous CMMs under field conditions and compare readings against the reference method (OHM) to determine CMM accuracy and repeatability.
- Test Appendix K (Part 75) Sorbent Trap (ST) method under field conditions and compare results against the reference method (OHM). The results of this comparison provided evidence as to whether or not the ST method could be considered as a potential reference method for mercury.
- Compare mercury concentrations measured by the CMMs and ST. The results provided information on the potential bias between CMMs and STs.
- Field-test EPA Instrumental Reference Method (IRM) for mercury. The IRM is designed as an alternative to OHM with the intent to provide an additional RM for mercury RATAs.
- Compare reference methods for Hg developed by the European Union (EU) and the United States (U.S.).