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September 2002

Environmental Technology Verification Report

Lead in Dust Wipe Measurement Technology

KeyMaster Technologies X-Ray Fluorescence Instrument Pb-Test

Oak Ridge National Laboratory

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

ETV

EPA
U.S. Environmental Protection Agency

ornl
Oak Ridge National Laboratory

Verification Statement

TECHNOLOGY TYPE:	**X-RAY FLUORESCENCE**		
APPLICATION:	**MEASUREMENT OF LEAD IN DUST WIPES**		
TECHNOLOGY NAME:	**Pb-Test XRF Instrument**		
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification Program (ETV) to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations and stakeholder groups consisting of regulators, buyers, and vendor organizations, with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

Oak Ridge National Laboratory (ORNL) is one of the verification organizations operating under the Advanced Monitoring Systems (AMS) Center. AMS, which is administered by EPA's National Exposure Research Laboratory (NERL), is one of six technology areas under ETV. In this verification test, ORNL evaluated the performance of lead in dust wipe measurement technologies. This verification statement provides a summary of the test results for KeyMaster Technologies' Pb-Test x-ray fluorescence (XRF) instrument.

VERIFICATION TEST DESCRIPTION

This verification test was designed to evaluate technologies that detect and measure lead in dust wipes. The test was conducted at the Oak Ridge National Laboratory in Oak Ridge, TN, from January 7 through January 9, 2002. KeyMaster Technologies, a vendor of commercially-available, field portable x-ray fluorescence (XRF) instruments for lead detection and measurement, blindly analyzed 160 dust wipe samples containing known amounts of lead, ranging in concentration from ≤ 2 to 1,500 µg/wipe. The experimental design was particularly focused on important clearance standards, such as those identified in 40 CFR Part 745.227(e)(8)(viii) of 40 µg/ft^2 for floors, 250 µg/ft^2 for window sills, and 400 µg/ft^2 for window troughs. The samples included wipes newly-prepared and archived from the Environmental Lead Proficiency Analytical Testing Program (ELPAT). These samples were prepared from dust collected in households in North Carolina and Wisconsin. Also, newly-prepared samples were acquired from the University of Cincinnati (UC). The (UC) dust wipe samples were prepared from National Institute of Standards and Technology (NIST) Standard Reference Materials (SRMs). The results of the lead analyses generated by the technology were compared with results from analyses of similar samples by conventional laboratory methodology in a laboratory that was recognized as proficient by the National Lead Laboratory Accreditation Program (NLLAP) for dust testing. Details of the test, including a data summary and discussion of results, may be found in the report entitled *Environmental Technology Verification Report: Lead in Dust Wipe Detection Technology— KeyMaster Technologies, Pb-Test X-Ray Fluorescence Instrument,* EPA/600/R-02/058.

TECHNOLOGY DESCRIPTION

The Pb-Test is an energy dispersive x-ray fluorescence (EDXRF) spectrometer that uses a sealed, highly purified Cobalt-57 radioisotope source (<12 mCi) to excite a test sample's constituent elements. The Pb-Test utilizes the recently developed Cadmium Telluride (CdTe) Schottky diode detectors. The age of the detector at the time of testing was approximately 4 to 5 months. Each element produces x-rays at a unique set of energies, allowing one to non-destructively measure the elemental composition of a sample. These characteristic x-rays are continuously detected, identified, and quantified by the spectrometer during sample analysis. In other words, the energy of each x-ray identifies a particular element present in the sample and the rate at which the x-rays of a given energy are emitted allows the analyzer to determine the quantity of a particular element present in that sample. Signals from the detector are amplified, digitized, and then quantified via an integrated multichannel analyzer and data processor. Sample test results are displayed in total micrograms of lead per dust-wipe. KeyMaster did not provide a reporting limit for the instrument during the verification test.

VERIFICATION OF PERFORMANCE

The following performance characteristics of the Pb-Test XRF were observed:

Precision: Precision, based on the average percent relative standard deviation (RSD), was 18% for the ELPAT samples and 15% for the UC samples. A technology's performance is considered very precise if the average RSD is less than 10%, but acceptable as long as the average RSD is less than 20%.

Accuracy: Accuracy was assessed using the estimated concentrations of the ELPAT and UC samples. Acceptable bias falls in a range of average percent recovery values of 100% ± 25%. The average percent recovery values for the ELPAT and UC samples (excluding the "detectable blank" samples at concentrations < 2 µg/wipe that are described in more detail below) were 189% and 168%, respectively. If only those samples with concentrations between 200 and 1,500 µg/wipe are considered, the Pb-Test results were unbiased, with an average percent recovery value of 96% for ELPAT samples and 102% for the UC

samples. The Pb-Test results for samples at 800, and 1,500 µg/wipe were both negatively biased (78% and 72%, respectively), but there was not enough data to ascertain that the technology was negatively biased above 800 µg/wipe. For the NLLAP laboratory results, the average percent recovery values were 98% and 91%, respectively, for the ELPAT and UC samples. The NLLAP laboratory's negative bias for both the ELPAT and UC samples was statistically significant.

Comparability: A comparison of the average Pb-Test results and the average NLLAP-recognized laboratory results was performed for all samples (ELPAT and UC) for estimated concentrations above and below 200 µg/wipe. The correlation coefficient (r) for the $\leq$ 200 µg/wipe data set was 0.967 [slope (m) = 1.060, intercept = 66]. For the > 200 µg/wipe data, the r value was 0.989 [slope = 0.662, intercept = 121). The slopes for both data sets were statistically different from 1.00. The Pb-Test results above 200 µg/wipe indicate fair agreement with the NLLAP laboratory's results, since correlation coefficient values greater than 0.990 indicate good agreement with the laboratory data.

Detectable blanks: All twenty samples, prepared at concentrations < 2 µg/wipe, were reported as detections by the Pb-Test, with concentrations ranging from 46 to 137 µg/wipe.

False positive results: A false positive (fp) result is one in which the technology reports a result that is above the clearance level when the true (or estimated) concentration is actually below. For the UC samples, the Pb-Test reported 20 of a possible 38 fp results, while the NLLAP laboratory did not report any fp results. For the ELPAT samples, the Pb-Test reported 6 of a possible 12 fp results, while the NLLAP laboratory reported two.

False negative results: A false negative (fn) result is one in which the technology reports a result that is below the clearance level when the true (or estimated) concentration is actually above. For the UC samples, the Pb-Test reported 7 of a possible 22 fn results, while the NLLAP laboratory reported 23 of a possible 30 fn results. For the ELPAT samples, the Pb-Test reported 8 of a possible 28 fn results, while the NLLAP laboratory reported 7.

Completeness: Completeness is defined as the percentage of measurements that are judged to be usable (i.e., the result is not rejected). An acceptable completeness rate is 95% or greater. The Pb-Test instrument generated results for all 160 dust wipes samples for a completeness of 100%.

Sample Throughput: Sample throughput is a measure of the number of samples that can be processed and reported by a technology in a given period of time. With two analysts, the KeyMaster team accomplished a sample throughput rate of approximately eighty samples per 10-hour day. One operator prepared the samples, while the other performed the analyses. The vendor chose to run the samples on two instruments and report the average value. The instrument can be operated by a single trained analyst.

Overall Evaluation: The overall performance was characterized as having acceptable precision, biased high for concentrations below 200 µg/wipe, and unbiased for concentrations above 200 µg/wipe. The Pb-Test results above 200 µg/wipe were also found to be in fair linear agreement with the NLLAP laboratory's results. The verification team found that the Pb-Test was simple for the trained analyst to operate in the field, requiring less than one-half hour for initial setup. As with any technology selection, the user must determine if this technology is appropriate for the application and the project data quality objectives. Additionally, ORNL and ETV remind the reader that, while the ETV test provides valuable information in the form of a snapshot of performance, state, tribal, or federal requirements regarding the use of the technologies (such as NLLAP recognition for analysis of clearance samples where required) need to be followed. For more information on this and other verified technologies, visit the ETV web site at http://www.epa.gov/etv.

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Notice

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Acknowledgments

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Abbreviations and Acronyms

AIHA	American Industrial Hygiene Association
AMS	Advanced Monitoring Systems Center, ETV
ASTM	American Society for Testing and Materials
CDC	Centers for Disease Control and Prevention
CdTe	Cadmium Telluride
CFR	Code of Federal Regulations
CL	clearance level of 40, 250, and 400 μg/wipe
EDXRF	energy dispersive x-ray fluorescence
ELPAT	Environmental Lead Proficiency Analytical Testing program
EPA	U. S. Environmental Protection Agency
ETV	Environmental Technology Verification Program
ETVR	Environmental Technology Verification Report
fn	false negative result
fp	false positive result
ICP-AES	Inductively coupled plasma-atomic emission spectrometry
NERL	National Exposure Research Laboratory, U.S. EPA
NIOSH	National Institute for Occupational Safety and Health, CDC
NIST	National Institute of Standards & Technology
NLLAP	National Lead Laboratory Accreditation Program, U.S. EPA
OPPT	Office of Pollution Prevention and Toxics, U.S. EPA
ORNL	Oak Ridge National Laboratory
QA	quality assurance
QC	quality control
RSD	relative standard deviation
RTI	Research Triangle Institute
SD	standard deviation
SRM	Standard Reference Material
UC	University of Cincinnati
XRF	x-ray fluorescence instrument

Section 1 — Introduction

The U.S. Environmental Protection Agency (EPA) created the Environmental Technology Verification Program (ETV) to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations and stakeholder groups consisting of regulators, buyers, and vendor organizations, with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing verification test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

ETV is a voluntary program that seeks to provide objective performance information to all of the participants in the environmental marketplace and to assist them in making informed technology decisions. ETV does not rank technologies or compare their performance, label or list technologies as acceptable or unacceptable, seek to determine "best available technology," or approve or disapprove technologies. The program does not evaluate technologies at the bench or pilot scale and does not conduct or support research. Rather, it conducts and reports on testing designed to describe the performance of technologies under a range of environmental conditions and matrices.

The program now operates six centers covering a broad range of environmental areas. ETV began with a 5-year pilot phase (1995–2000) to test a wide range of partner and procedural alternatives in various technology areas, as well as the true market demand for and response to such a program. In these centers, EPA utilizes the expertise of partner "verification organizations" to design efficient processes for conducting performance tests of innovative technologies. These expert partners are both public and private organizations, including federal laboratories, states, industry consortia, and private sector entities. Verification organizations oversee and report verification activities based on testing and QA protocols developed with input from all major stakeholder/customer groups associated with the technology area. The verification described in this report was administered by the Advanced Monitoring Systems (AMS) Center, with Oak Ridge National Laboratory (ORNL) serving as the verification organization. (To learn more about ETV, visit ETV's Web site at http://www.epa.gov/etv.) The AMS Center is administered by EPA's National Exposure Research Laboratory (NERL).

The verification of a field analytical technology for measurement of lead in dust wipe samples is described in this report. The verification test was conducted in Oak Ridge, Tennessee, from January 7 through January 9, 2002. The performance of KeyMaster Technologies' Pb-Test x-ray fluorescence (XRF) instrument was determined. The technology was evaluated by comparing its results to estimated concentration values and with results obtained on similar samples using a recognized laboratory analytical method.

Section 2 — Technology Description

In this section, the vendor (with minimal editorial changes by ORNL) provides a description of the technology and the analytical procedure used during the verification testing activities.

General Technology Description

The Pb-Test (see Figure 1) is an energy dispersive x-ray fluorescence (EDXRF) spectrometer that uses a sealed, highly purified Cobalt-57 radioisotope source (<12 mCi, 4-5 months old at the time of the test) to excite a test sample's constituent elements. Each element produces x-rays at a unique set of energies, allowing the user to non-destructively measure the elemental composition of a sample. These characteristic x-rays are continuously detected, identified, and quantified by the spectrometer during sample analysis. In other words, the energy of each x-ray identifies a particular element present in the sample and the rate at which the x-rays of a given energy are emitted allows the analyzer to determine the quantity of a particular element present in that sample. The Pb-Test utilizes the recently developed Cadmium Telluride (CdTe) Schottky diode detectors. The use of Schottky contacts in CdTe detectors reduces the leakage current, permitting the use of a much higher bias voltage than in a standard detector. Since the charge transport properties of the CdTe detector are much higher, the net result is an improvement in the usable depth (sensitivity). Additionally, because hole tailing and electronic noise are reduced, not only is the sensitivity improved but resolution is much better. Signals from the detector are amplified, digitized, and then quantified via an integrated multichannel analyzer and data processor. Re-sourcing requirements are on the order of 15 to 24 months, depending on the user's needs. Sample test results are displayed in total micrograms of lead per dust-wipe.

Sample Preparation

For this test, the dust wipe samples had to be cut to 1/4 of the size of the original wipe. The wipes were cut such that the majority of the dust was included in the 1/4 area. The wipe was folded and placed in the sample holder which is the size of a small thimble (Figure 2). The wipe was pressed into the sample holder using a specially-designed tool that is provided with the instrument. The sample was then labeled and ready for analysis.

Figure 1. KeyMaster Technologies Pb-Test instrument.

Figure 2. Pb-Test sample holder.

Calibration

The instrument is factory calibrated. KeyMaster did not perform additional calibration checks during testing.

Sample Analysis

The Pb-Test should be turned on at least 10 minutes prior to taking the first measurement. **"Confirm"** precision was selected which indicated a 5 minute measurement. After placing the sample in the sample holder (Figure 2), the analysis started. When the measurement was completed, the Pb-Test automatically displayed the results in μg. For the verification test, two instruments were used, with one analyst analyzing all samples on both, and the average reading from the two instruments reported as the final result.

Section 3 — Verification Test Design

Objective

The purpose of this section is to describe the verification test design. It is a summary of the test plan (ORNL, 2001).

Testing Location and Conditions

The verification of field analytical technologies for lead in dust wipes was conducted at Oak Ridge National Laboratory, in Oak Ridge, TN. The test was conducted in an office. The temperature and relative humidity were monitored during field testing, but remained fairly constant. The average temperature and relative humidity over the three days of testing were 70 °F and 24%, respectively.

Drivers and Objectives for the Test

The purpose of this test was to evaluate the performance of field analytical technologies that are capable of analyzing dust wipe samples for lead contamination. This test provides information on the potential applicability of field technologies to EPA standards for dust clearance testing. The experimental design was designed around the three clearance standards of 40 $\mu g/ft^2$ for floors, 250 $\mu g/ft^2$ for window sills, and 400 $\mu g/ft^2$ for window troughs that are outlined in 40 CFR Part 745.227(e)(8)(viii) (CFR 2001).

The primary objectives of this verification were to evaluate the field analytical technologies in the following areas: (1) how well each performs relative to a conventional, fixed-site, analytical method for the analysis of dust wipe samples for lead; (2) how well each performs relative to results generated in previously rounds of ELPAT testing (described in the next section), and (3) the logistical and economic resources necessary to operate the technology. Secondary objectives for this verification were to evaluate the field analytical technology in terms of its reliability, ruggedness, cost, range of usefulness, sample throughput, data quality, and ease of use. Note that this verification test does not provide an assessment of the selection of locations for dust samples in a facility or an assessment of the way that dust samples are collected. The planning for this verification test follows the guidelines established in the data quality objectives process.

Summary of the Experimental Design

All of the samples analyzed in this verification test were prepared gravimetrically. At the time of the test, both of the wipes utilized in the test (PaceWipe™ and Aramsco LeadWipe™) were on the list of wipes recommended for lead testing by the American Society for Testing and Materials (ASTM, 1996). Initial consideration was given to conducting the test in a real-world situation, where the technologies would have been deployed in a housing unit that had been evacuated due to high levels of lead contamination. In addition to the safety concern of potentially subjecting participants to lead exposure, the spatial variability of adjacent samples would have been expected to be so great that it would be much larger than the anticipated variability of these types of technologies, thereby making it difficult to separate instrument/method variability and sampling variability. The availability of well-characterized samples derived from "real-world" environments made the use of proficiency testing samples (so-called "ELPAT" samples) and other prepared samples an attractive alternative.

ELPAT and Blank Sample Description

In 1992, the American Industrial Hygiene Association (AIHA) established the Environmental Lead Proficiency Analytical Testing (ELPAT) program. The ELPAT Program is a cooperative effort of the American Industrial Hygiene Association (AIHA), and researchers at the Centers for Disease Control and Prevention (CDC), National Institute for Occupational Safety and Health (NIOSH), and the EPA Office of Pollution Prevention and Toxics (OPPT). The ELPAT program is designed to assist laboratories in improving their analytical performance, and therefore, does not specify use of a particular analytical method. Participating laboratories are sent samples to analyze on a quarterly basis. The reported values must fall within a range of acceptable values in order for the laboratory to be deemed proficient for that quarter.

Research Triangle Institute (RTI) in Research Triangle Park, NC, is contracted to prepare and distribute the lead-containing paint, soil, and dust

wipe ELPAT samples. For the rounds of testing which have occurred since 1992, archived samples are available for purchase. Some of these samples were used in this verification test. Because the samples have already been tested by over one-hundred laboratories, a certified concentration value is supplied with each sample. This certified value represents a pooled measurement of all of the results submitted, with outliers excluded from the calculation.

The following description, taken from an internal RTI report, briefly outlines how the samples were prepared. RTI developed a repository of real-world housedust, collected from multiple homes in the Raleigh/Durham/Chapel Hill area, as well as from an intervention project in Wisconsin. After collection, the dust was sterilized by gamma irradiation, and sieved to 150 μm. A PaceWipe™ was prepared for receiving the dust by opening the foil pouch, removing the wet folded wipe and squeezing the excess moisture out by hand over a trash can. The wipe was then unfolded and briefly set on a Kimwipe™ to soak up excess moisture. The PaceWipe was then transferred to a flat plastic board to await the dust. After weighing a 0.1000 ± 0.0005 g portion of dust on weighing paper, the pre-weighed dust was gently tapped out onto the PaceWipe. The wipe was then folded and placed in a plastic vial, which was then capped. All vials containing the spiked wipes were stored in a cold room as a secondary means of retarding mold growth until shipment.

Before use in the ELPAT program, RTI performed a series of analyses to confirm that the samples were prepared within the quality guidelines established for the program. The data quality requirements for the ELPAT samples were: 1) the relative standard deviation of the samples analyzed by RTI must be 10% or less; 2) the measured concentrations must be within 20% of the target value that RTI was intending to prepare; and 3) analysis by an accredited laboratory must yield results within ± 20% of the RTI result. Ten samples were analyzed by RTI and nine samples were sent to the Wisconsin Occupational Health Laboratory for independent, confirmatory analysis. All ELPAT samples used in this test met the data quality requirements described above. The estimated concentration for an ELPAT sample used in this evaluation was the certified ("consensus") value (i.e., an analytically derived result).

RTI prepared the blank samples using the same preparation method as the ELPAT samples, but the concentration of lead was < 2 μg/wipe, well below the expected reporting limits of the participant technologies.

University of Cincinnati Sample Description

The ELPAT samples consisted of dust mounded in the center of a PaceWipe. The University of Cincinnati (UC) prepared "field QC samples" where the dust was sprinkled over the wipe, more similar to how a wipe would look when a dust wipe sample is collected in the field. The sample was prepared by weighing, so the concentrations can be estimated. In a typical scenario, UC sends these control samples to a laboratory along with actual field-collected samples as a quality check of the laboratory operations. Because the samples are visually indistinguishable from an actual field sample, are prepared on the same wipe, and are shipped in the same packaging, the laboratory blindly analyzes the control samples, which provides the user with an independent assessment of the quality of the laboratory's data.

A cluster of twenty UC samples prepared at the key clearance levels were added to the experimental design, primarily so that an abundance of data would exist near the clearance levels, in order to assess false positive and false negative error rates. The UC samples were prepared on Aramsco Lead Wipes™ (Lakeland, FL). The UC wipe samples were prepared using National Institute of Standards & Technology (NIST) Standard Reference Materials (SRMs). NIST SRM 2711 was used to prepare the 40 μg/wipe samples, and NIST SRM 2710 was used to prepare the 250 and 400 μg/wipe samples. Both SRM 2711 and SRM 2710 are Montana Soil containing trace concentrations of multiple elements, including lead. Some NIST SRM materials that are spiked on dust wipes are known to have low extraction recoveries when prepared by standard analytical methods (e.g., lead silicates cannot be extracted unless hydrofluoric acid is used) (Ashley et al., 1998). These particular SRMs are not known to contain lead silicates or to give lower lead recoveries. However, it is important to note the possibility of such when using NIST SRMs for lead dust wipe analysis, since similar SRMs (e.g., Buffalo river sediment from Wyoming) do show recoveries in the low 90% range (Ashley et al., 1998).

Because accurate and precise estimated concentrations for the UC samples were imperative, ORNL imposed the following data quality requirements for the UC-prepared wipe samples: 1) each estimated concentration had to be within a ± 10% interval of the target clearance level; 2) additional quality control (QC) samples (at least 5% of the total samples ordered) were to be prepared and analyzed by UC as a quality check prior to shipment of the samples; and 3) the relative standard deviation of the QC samples had to be $\leq$ 10%. It is important to note here the reason why the data quality requirements between the UC and ELPAT samples were different. The data quality requirements for the ELPAT samples (i.e., ± 20% of the target value) were established by the ELPAT program. Since archived samples were being used, those data quality requirements could not be changed.

As a quality check of the sample preparation process, UC prepared an additional 24 samples (5% of the total number ordered). UC extracted and analyzed the samples following internal procedures (nitric/hydrochloric acid extraction, followed by atomic absorption spectrometry - see EPA, 1996 for Method 3050B and Method 6010B) and provided those results to ORNL. For the 24 samples (eight at each of the three clearance levels), the average percent recovery (i.e., UC measured concentration/UC estimated concentration x 100%) was 97% (median value = 96%, standard deviation = 3%, range = 93% to 102%). Additionally, 42 randomly-selected samples (14 at each of the three clearance levels) were analyzed by the EPA Region 1 laboratory in North Chelmsford, MA, as an independent quality control check of the accuracy and precision of UC's sample preparation procedure (nitric acid digestion followed by ICP/AES analysis - EPA, 1996). The average percent recovery (EPA Region 1 reported concentration/UC estimated concentration x 100%) was 90% (median 89%, standard deviation = 2%), with a range of values from 86% to 93%. The average recovery determined from the EPA Region 1 analyses (90%) was lower than that which was determined by UC (102%), but both values were within the data quality requirement of 100 ± 10%. Based on these data, ORNL determined that the UC sample preparation process met the established data quality criteria and was deemed acceptable for use in the determination of false positive/false negative error rates.

Distribution and Number of Samples

A total of 160 samples were analyzed in the verification test. Figure 3 is a plot containing the distribution of the sample concentrations that were analyzed in this study. Twenty samples were prepared by the University of Cincinnati at +/- 10% of each of the three clearance levels (3 test levels x 20 samples = 60 samples total). Research Triangle Institute prepared 20 "blanks" at lead concentrations < 2 μg/wipe. These samples are noted as such in Figure 3. The remaining samples in Figure 3 are ELPAT samples. For most of the ELPAT samples, four samples were analyzed at each concentration level (16 test levels x 4 samples each = 64 samples total). There were two concentration levels (at 49 and 565 μg/wipe) where eight samples were analyzed. While the set of samples at each concentration level were prepared using homogeneous source materials and an identical preparation procedure, ELPAT samples cannot be considered true "replicates" because each sample was prepared individually. However, these samples represent four samples prepared similarly at a specified target concentration, with an estimated value calculated from more than 100 analyses of similarly prepared samples.

Sample Randomization

The samples were packaged in 20-mL plastic scintillation vials and labeled with a sample identifier. Each participant received the same suite of samples, but in a randomized order. The samples were distributed in batches of 16. Completion of chain-of-custody forms documented sample transfer.

Description of Performance Factors

In Section 5, technology performance is described in terms of precision, accuracy, completeness, and comparability, which are indicators of data quality (EPA, 1996). False positive and negative results, sample throughput, and ease of use are also described. Each of these performance characteristics is defined in this section.

Precision

Precision is the reproducibility of measurements under a given set of conditions. Standard deviations estimated at each concentration level can be used to establish the relationship between the uncertainty and the average lead concentration. Standard deviation (SD) and relative standard deviation (RSD) for replicate results are used to assess precision, using the following equation:

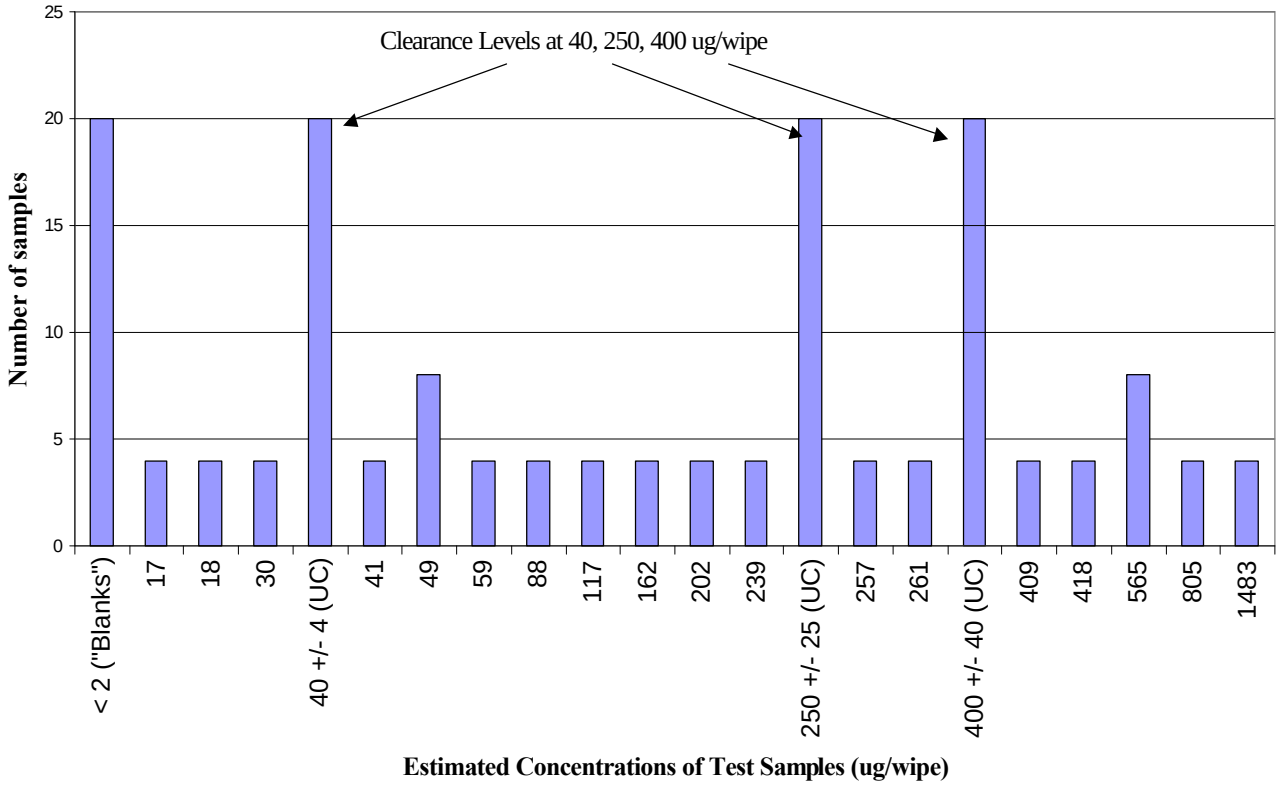

Figure 3. Distribution of concentration levels.

RSD = (SD/average concentration) × 100% . (Eq. 1)

The overall RSD is characterized by two summary values:

- mean — i.e., average;
- range — i.e., the highest and lowest RSD values that were reported.

The average RSD may not be the best representation of precision, but it is reported for convenient reference. An average RSD value less than 10% indicates that the measurements are very precise. RSDs greater than 20% should be viewed as indicators of larger variability and possibly non-normal distributions. The uncertainty in the analytical measurements will include influences from both the preparation (i.e., extraction) and measurement steps.

Accuracy

Accuracy is a measure of how close the measured lead concentrations are to estimated values of the true concentration. The estimated values for the ELPAT samples are the certificate values that are reported on the certificate of analysis sheet provided with the samples. The ELPAT certified values represent an average concentration determined by more than 100 accredited laboratories that participated in previous rounds of ELPAT testing. The UC estimated value is the concentration reported by UC for individual samples, calculated by the amount of NIST-traceable material loaded on the dust wipes. The accuracy and precision of the UC value was assessed by an independent laboratory analyzing randomly selected QC samples. An EPA laboratory in Region 1 analyzed 10% of the total number of samples prepared by UC at each of the three concentration levels and confirmed that the process used to prepare the samples met the pre-determined data quality objective of accuracy within a ± 10% interval of the estimated value.

Accuracy of the field technology measurements was statistically tested using t-tests or non-parametric tests at the 5% significance level. These statistical tests compared the average results with the overall estimated values using the precision of the sample

measurements. Bias was quantified by computing the percent recovery for four similar samples or a single sample using the equation:

percent recovery = [measured amount(s)/estimated value] × 100% (Eq. 2)

Accuracy was assessed using both the ELPAT and UC estimated concentrations. The comparison to the ELPAT value represents how close the technology reported results to the consensus value, which represents the amount of "recoverable" lead in the sample. Because the UC samples were prepared gravimetrically from samples of known lead content, the comparison to the UC samples represents how close the technology reported results to an absolute lead value. Comparison to the gravimetric values reveals any bias imposed by the tested sampling and analytical method.

The optimum percent recovery value is 100%. Percent recovery values greater than 125% indicate results that are biased high, and values less than 75% indicate results that are biased low. A small but statistically significant bias may be detectable for a field technology if precision is high (i.e., low standard deviation). The field technology can still have acceptable bias with an average percent recovery in the interval of 75% to 125%. Bias within the acceptable range can usually be corrected to 100% by modification of calibration methods.

Comparability

Comparability refers to how well the field technology and the conventional laboratory data agree. The difference between accuracy and comparability is that accuracy is judged relative to a known value, comparability is judged relative to the results of a laboratory procedure, which may or may not report the results accurately. Because true "replicates" were not available for use in this study, the averages from similar samples measured by the technology were compared with corresponding averages measured by the laboratory for all target concentration levels.

A correlation coefficient quantifies the linear relationship between two measurements (Draper and Smith, 1981). The correlation coefficient is denoted by the letter r; its value ranges from –1 to +1, where 0 indicates the absence of any linear relationship. The value r = –1 indicates a perfect negative linear relation (one measurement decreases as the second measurement increases); the value r = +1 indicates a perfect positive linear relation (one measurement increases as the second measurement increases). Correlation coefficients above 0.990 indicate good linear agreement. The slope of the linear regression line, denoted by the letter m, is related to r. Whereas r represents the linear association between the vendor and laboratory concentrations, m quantifies the amount of change in the vendor's measurements relative to the laboratory's measurements. A value of +1 for the slope indicates perfect agreement. Values greater than 1 indicate that the vendor results are generally higher than the laboratory, while values less than 1 indicate that the vendor results are usually lower than the laboratory.

Detectable Blanks

Twenty samples in the test were prepared at < 2 µg/wipe, below the anticipated reporting limits of both the field technologies and the laboratory. Any reported lead for these samples is considered a "detectable blank".

False Positive/Negative Results

A false positive (fp) result is one in which the technology detects lead in the sample above a clearance level when the sample actually contains lead below the clearance level (Keith et al., 1996). A false negative (fn) result is one in which the technology indicates that lead concentrations are less than the clearance level when the sample actually contains lead above the clearance level. For example, if the technology reports the sample concentration to be 35 µg/wipe, and the true concentration of the sample is 45 µg/wipe, the technology's result would be considered a fn at the 40 µg/wipe clearance level. Accordingly, if the technology reports the result as 45 µg/wipe and the true concentration is 35 µg/wipe, the technology's result would be a fp at the 40 µg/wipe clearance level.

A primary objective for this verification test was to assess the performance of the technology at each of the three clearance levels of 40, 250, and 400 µg/wipe, and estimate the probability of the field technology reporting a fp or fn result. For each clearance level, the probabilities of fn were estimated as curves that depend on a range of concentrations reported about the clearance level. These error probability curves were calculated from the results on the 60 UC samples at concentrations ± 10% of each clearance level. In order to generate

probability curves to model the likelihood of false negative results, it was assumed that the estimated concentration provided by UC was the true concentration. However, this evaluation did not include the gravimetric preparation uncertainty in the UC estimated concentration. This error is likely to be much smaller than other sources of measurement error (e.g., extraction efficiency and analytical).

The fp/fn evaluation also included a comparison to the ELPAT sample results. The "estimated" value for the UC and ELPAT samples are defined differently. The UC value is based on weight of the NIST-traceable material, while the ELPAT estimated value is the average analytical reported value from more than 100 accredited laboratories. The UC sample estimated lead content is determined gravimetrically, which should be closer to the "true" concentration than an analytical measurement that includes preparation and instrumental errors. In contrast, determining the technology's fp/fn error rates relative to the ELPAT estimated concentrations represents a comparison to typical laboratory values. One limitation of using the ELPAT sample is that concentrations covered a wider overall distribution of lead levels. Thus, the availability of sample concentrations that were tightly (i.e., +/- 10%) clustered about the clearance levels was limited. In order to perform a broader fp/fn analysis, the range of lead levels in the ELPAT samples that bracketed the pertinent clearance levels was extended to ± 25% of the target concentration.

Completeness

Completeness is defined as the percentage of measurements that are judged to be usable (i.e., the result is not rejected). An acceptable completeness is 95% or greater.

Sample Throughput

Sample throughput is a measure of the number of samples that can be processed and reported by a technology in a given period of time. Sample throughput is reported in Section 5 as number of samples per day per number of analysts.

Ease of Use

A significant decision factor in purchasing an instrument is how easy the technology is to use. Several factors are evaluated and reported on in Section 5:

- What is the required operator skill level (e.g., technician or advanced degree)?
- How many operators were used during the test?
- Could the technology be run by a single person?
- How much training would be required in order to run this technology?
- How much subjective decision-making is required?

Cost

An important factor in the consideration of whether to purchase a technology is cost. Costs involved with operating the technology and a typical laboratory analyses are estimated in Section 5. To account for the variability in cost data and assumptions, the economic analysis is presented as a list of cost elements and a range of costs for sample analysis. Several factors affect the cost of analysis. Where possible, these factors are addressed so that decision makers can independently complete a site-specific economic analysis to suit their needs.

Miscellaneous Factors

Any other information that might be useful to a person who is considering purchasing the technology is documented in Section 5 under "Observations". Examples of information that might be useful to a prospective purchaser are the amount of hazardous waste generated during the analyses, the ruggedness of the technology, the amount of electrical or battery power necessary to operate the technology, and aspects of the technology or method that make it user-friendly or user-unfriendly.

Section 4 — Laboratory Analyses

Background

EPA regulations (40 CFR Part 745.227(e)(8)(vii)) specify that residences and child occupied facilities built before 1978 that have undergone an abatement must pass clearance testing (CFR 2001). These EPA regulations also state in 40 CFR Part 745.227(f)(2) that dust samples for clearance must be analyzed by a laboratory recognized by EPA (CFR 2001). Many EPA-authorized state and tribal lead programs have the same or similar requirements. EPA's vehicle for recognizing laboratory proficiency is the National Lead Laboratory Accreditation Program (NLLAP). Although the NLLAP was initially designed to accredit fixed site laboratories, in August 1996 the NLLAP was modified so that mobile laboratory facilities and testing firms operating portable testing technologies could also apply for accreditation. Despite this modification, the NLLAP list of accredited laboratories has almost exclusively consisted of fixed site laboratories. One possible outcome of this ETV test is that more mobile laboratory facilities and testing firms operating portable testing technologies will apply for NLLAP accreditation. In order to assess whether the field portable technologies participating in this verification test produce results that are comparable to NLLAP-recognized data, an NLLAP-recognized laboratory was selected to analyze samples concurrently with the field testing.

NLLAP Laboratory Selection

NLLAP was established by the EPA Office of Pollution Prevention and Toxics under the legislative directive of Title X, the Lead-Based Paint Hazard Reduction Act of 1992. In order for laboratories to be recognized under the NLLAP, they must successfully participate in the ELPAT Program and undergo a systems audit. The acceptable range for the ELPAT test samples is based upon the reported values from participating laboratories. Acceptable results are within three standard deviations from the consensus value. A laboratory's performance is rated as proficient if either of the following criteria are met: (1) in the last two rounds, all samples are analyzed and the results are 100% acceptable; or (2) three-fourths (75%) or more of the accumulated results over four rounds are acceptable.

The NLLAP required systems audit must include an on-site evaluation by a private or public laboratory accreditation organization recognized by NLLAP. Some of the areas evaluated in the systems audit include laboratory personnel qualifications and training, analytical instrumentation, analytical methods, quality assurance procedures, and record keeping procedures.

The list of recognized laboratories is updated monthly. ORNL obtained the list of accredited laboratories in July 2001. The list consisted of approximately130 laboratories. Those laboratories which did not accept commercial samples and those located on the U.S. west coast were automatically eliminated as potential candidates. ORNL interviewed at random approximately ten laboratories and solicited information regarding cost, typical turnaround time, and data packaging. Based on these interviews and discussions with technical panel members who had personal experience with the potential laboratories, ORNL selected DataChem (Cincinnati, OH) as the fixed-site laboratory. As a final qualifying step, DataChem blindly analyzed 16 samples (8 ELPAT and 8 prepared by UC) in a pre-test study. As shown in Table 1 below, DataChem passed the pre-test by reporting concentrations that were within 25% of the estimated concentration for samples above the reporting limit.

Laboratory Method

The laboratory method used by DataChem was hot plate/nitric acid digestion, followed by inductively coupled plasma-atomic emission spectrometry (ICP-AES) analysis. The preparation and analytical procedures, as supplied by DataChem, can be found in the test plan (ORNL, 2001). To summarize the procedure, the wipe was digested in 2 mL of nitric acid, heated in a hotblock for 1 hour at 95 °C, diluted to 20 mL with distilled water, and analyzed by ICP-AES. DataChem's procedures are modifications of Methods 3050B and 6010B of EPA SW-846 Method Compendium for the preparation and analysis of metals in environmental matrices (EPA, 1996). Other specific references for the preparation and analysis of dust wipes are available from the American Society for Testing and Materials (ASTM, 1998).

Table 1. Summary of DataChem Pre-Test Results

Sample Type	DataChem Reported Conc (µg/wipe)	Estimated Conc (µg/wipe)	Percent Recovery	Analysis Order
ELPAT	<20	2.12	n/a	16
ELPAT	<20	2.12	n/a	12
ELPAT	41	41.3	99%	6
ELPAT	44	41.3	107%	3
ELPAT	190	201.6	94%	15
ELPAT	210	201.6	104%	9
ELPAT	440	408.7	108%	2
ELPAT	450	408.7	110%	13
UC	<20	10.3	n/a	4
UC	<20	5.9	n/a	1
UC	25	29.9	84%	14
UC	38	44	86%	10
UC	150	172.4	87%	11
UC	200	237.5	84%	7
UC	250	327.3	76%	5
UC	310	379	82%	8

Laboratory Performance

ORNL validated all of the laboratory data according to the procedure described in the verification test plan (ORNL, 2001). During the validation, the following aspects of the data were reviewed: completeness of the data package, correctness of the data, correlation between "replicate" sample results, and evaluation of QC sample results. Each of these categories is described in detail in the verification test plan. An evaluation of the performance of the laboratory results through statistical analysis of the data was performed and is summarized below. (See Section 3 for a detailed description of how the performance factors are defined and the calculations that are involved.)

In Table 2, DataChem's reported values are compared to the estimated values to determine percent recovery (i.e., accuracy of the DataChem results) for both the ELPAT and the UC samples. The results are also shown graphically in Figure 3. The average percent recovery for the ELPAT samples was 98%, while the average for the UC samples was 91%. Both Table 2 and Figure 4 indicate that the analytical results from the University of Cincinnati wipe samples were generally reported lower than the estimated value, while the results for the ELPAT samples were closer to the estimated value. The better agreement with the ELPAT samples is not unexpected, given that the ELPAT estimated concentrations represent analytical consensus values that include typical extraction inefficiencies and instrumental error. The negative bias observed with the UC and the ELPAT samples was statistically significant. The cause of the negative bias for the UC samples could be related to: 1) extraction inefficiencies (due to the use of NIST SRMs that contain lead that is unrecoverable with the extraction procedure which was used) and/or, 2) typical analytical variation due to preparation and measurement errors. Another indication of accuracy is the number of individual ELPAT results which were reported within the acceptance ranges that have been established for those samples. For the 72 ELPAT samples (> 20 µg/wipe), DataChem reported 71 (99%) within the acceptable ranges of values.

The precision assessment presented in Table 3 indicates that the analyses were very precise. The average RSD for the ELPAT samples was 7%, while the average RSD for the UC samples was 8%. The variability of the UC sample preparation process, provided for reference of the minimal achievable RSD for the UC samples, was 6%. A single estimate of the ELPAT variability was not determined, since the ELPAT samples were comprised of 20 different batches of samples. DataChem reported all 20 detectable blank samples correctly as < 20 µg/wipe. In addition, DataChem reported seven of the eight samples with estimated concentrations of either 16.9 µg/wipe or 17.6 µg/wipe as less than their reporting limit of 20 µg/wipe and only one was incorrectly reported as 30 µg/wipe.

Table 2. Summary of DataChem Percent Recovery Values by Sample Source

Statistic	ELPAT	UC
n [a]	72	60
average % recovery	98	91
standard deviation	9	3
minimum % recovery	81	86
maximum % recovery	143	102

[a] excludes estimated values <20 µg/wipe (n=28)

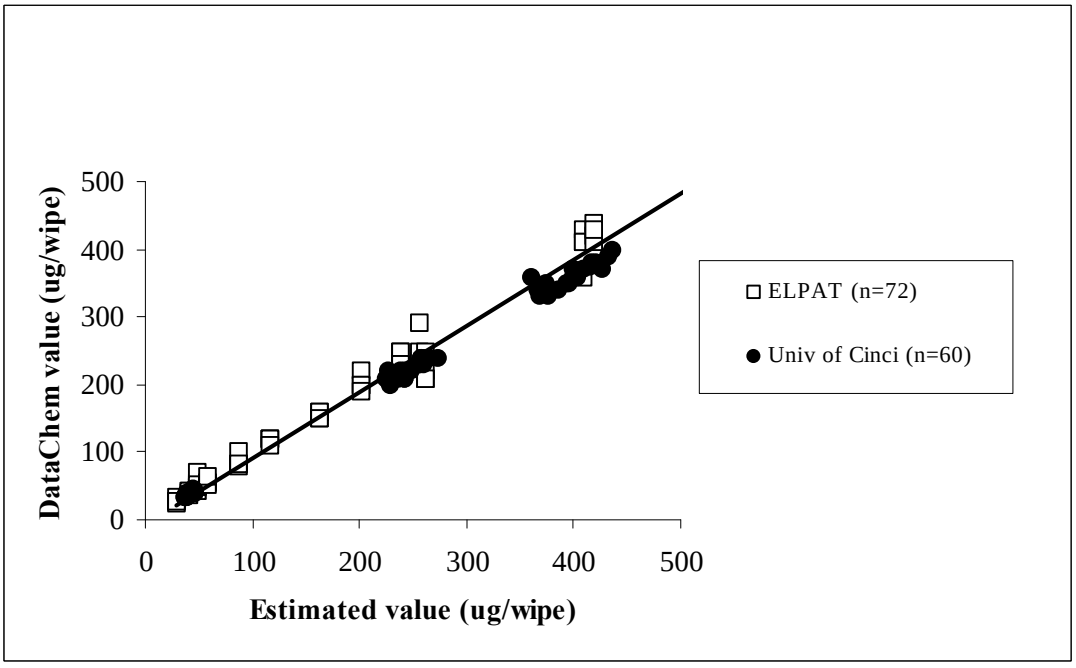

Figure 4. Plot of DataChem reported values versus estimated values, shown for concentrations less than 500 µg/wipe.

Table 3. Summary of DataChem Precision Estimates by Sample Source

Sample Source	n	average RSD	Min RSD	Max RSD
ELPAT	18 [a]	7	2	21
UC	3 [b]	8	6	9
UC preparation	3 [c]	6	6	7

[a] 4 replicates in each sample set
[b] 20 replicates in each sample set
[c] This value represents the variability in the sample preparation process.

An important evaluation parameter for the analysis of dust wipe samples is how the method performs at the clearance levels and the method's likelihood of reporting false positive (fp) and false negative (fn) results. Recall from the experimental design that 20 UC samples were prepared at ± 10% of each clearance level of 40, 250, and 400 µg/wipe, for a total of 60 UC samples. The ELPAT samples covered a wider range of concentrations. There was a total of 40 ELPAT samples that fell within a ±25% interval of the target values that could be used for the fp/fn assessment. The number of false negative and false positive results reported by DataChem relative to the UC and ELPAT estimated concentrations is summarized in Table 4. There are a specific number of possible fp and fn results. For example, if the estimated lead level on the wipe is less than the clearance level (CL), then it is not possible to produce a false negative result; only a false positive (i.e., > 40) result is possible. For the UC samples, in every case where the estimated concentration was less than the CL, DataChem reported a result for that was also less than the CL, indicating no fp results at any of the three CL. DataChem reported two fp results for the ELPAT samples out of a possible 12.

When the estimated concentration was above the clearance level, however, DataChem sometimes reported results as less than the clearance level. DataChem reported a higher rate of fn results for the UC samples than the ELPAT samples (23 of 30 vs 7 of 28 possible fn results, respectively). This finding is not surprising, since the results reported above indicated that DataChem's results were negatively biased, or reported lower than the estimated values for the UC samples. As stated in Section 3, it is important to note that in this evaluation, the estimated concentration of the UC samples is assumed to be the "true"concentration, and the uncertainty in gravimetric preparation for the UC estimated concentration is not considered in the evaluation.

Figures 5, 6, and 7 show models of the likelihood of DataChem reporting a false negative result at each of the clearance levels versus the true concentrations of the UC samples. (Note that only the UC samples must be used in generation of probability curves because these estimated values are a closer representation of the true lead concentration than the ELPAT estimated concentration. See Song et al., 2001.) These figures indicate that the likelihood of DataChem reporting false negative results for the UC samples at the exact clearance level is high, near 100% in all three cases. This means, for example, that if DataChem reported a value as exactly 250 µg/wipe, the probability that the true concentration is >250 is essentially 100%. Again, this is due to the negative bias that was observed in the measurement of the UC samples. The plots also demonstrate that, due to the relatively high level of precision of results reported by DataChem, the performance is very minimally impacted by performing replicate analyses, as the distribution of false negative probabilities is very similar whether 1 or 5 measurements (in Figures 5, 6, and 7, delineated as N = 1, N = 2, etc.) are performed. The interpretation of these curves for use in a "real-world" situation can be demonstrated by the following example. Suppose that a user decides that an acceptable level of risk for having false negative results is 5%. Using Figure 5, 5% FN probability (y = 0.05) corresponds to a "true" lead concentration of 46 µg/wipe (meaning if the true concentration of the sample is 46 µg/wipe, there is only a 5% chance/risk that DataChem will report the value as < 40 µg/wipe.)

By plotting DataChem's measured values versus the estimated concentrations, the equations of the linear regression lines can be calculated for each of the three CL. The slope, intercept, and correlation coefficient for the ELPAT and UC samples are presented in Table 5. The user might like to know at what reported value (and at what associated probability) will DataChem be likely to report a "clean" sample (i.e., there is a high probability that the true concentration is < CL). For example, for the UC samples, we know that a value reported by DataChem as 39 µg/wipe is biased low and will have a true concentration of > 40 (41.8 µg/wipe, using the linear regression equation in Table 5). A true concentration of 40 µg/wipe for a UC sample would correspond to a reported value rounded to the nearest whole number of 37 µg/wipe (see Table 5). For an ELPAT sample, a true concentration of 40 µg/wipe corresponds to a DataChem reported value of 40 µg/wipe, because the negative bias was not as large for the ELPAT samples. Estimates of the reported concentration at the 250 and 400 µg/wipe levels are reported in Table 5. In both cases, the reported concentrations for the ELPAT samples are higher (i.e., closer to the clearance level) than those of the UC samples.

The user is reminded that the data obtained during this verification test represent performance at one

point in time. The data produced by DataChem at some other time after the writing of this report may or may not be similar to what has been produced here. To understand a method's performance at critical clearance levels, it is recommended that the user perform their own assessment of the method's performance by including samples of known concentration (at or near the clearance levels) along with the analysis of "real-world" samples.

Table 4. False Positive/False Negative Results for DataChem Measurements of UC Samples

Evaluation Parameter	Sample Source	Number of Samples			Total
		40 µg/wipe	250 µg/wipe	400 µg/wipe	
fp: # samples where DataChem reported the result as > CL[a] of the # samples where the estimated concentration was < CL	UC	0 of 9	0 of 11	0 of 10	0 of 30
	ELPAT	0 of 4	2 of 8	0 of 0 [b]	2 of 12
fn: # samples where DataChem reported the result as < CL of the # samples where the estimated concentration was > CL	UC	5 of 11	9 of 9	9 of 10	23 of 30
	ELPAT	1 of 12	5 of 8	1 of 8	7 of 28

[a] CL = clearance level

[b] Because all eight ELPAT values were above 400 µg/wipe, no samples were available to assess fp results at this level.

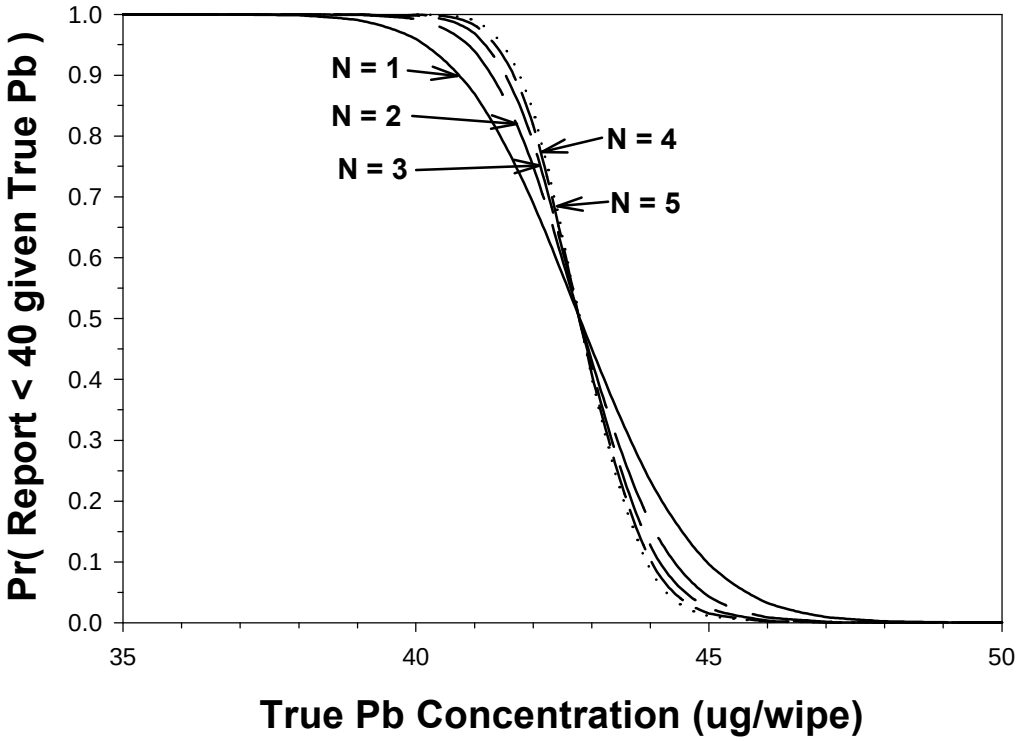

Figure 5. False negative probabilities for DataChem average concentrations at a target concentration level of 40 µg/wipe.

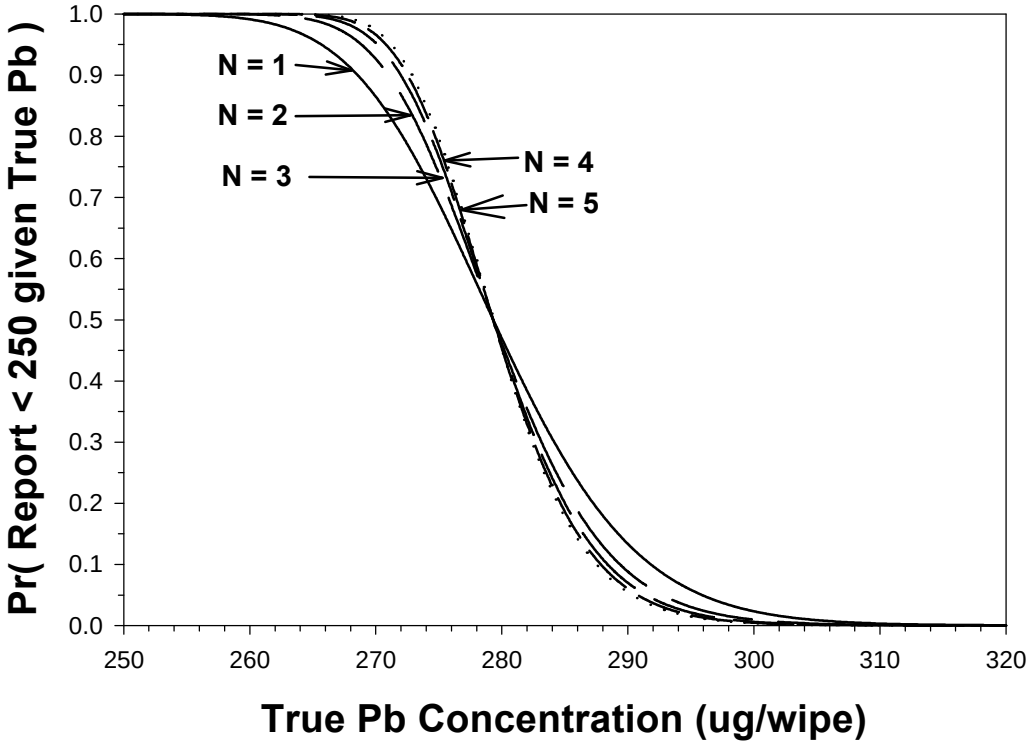

Figure 6. False negative probabilities for DataChem average concentrations at a target concentration level of 250 μg/wipe.

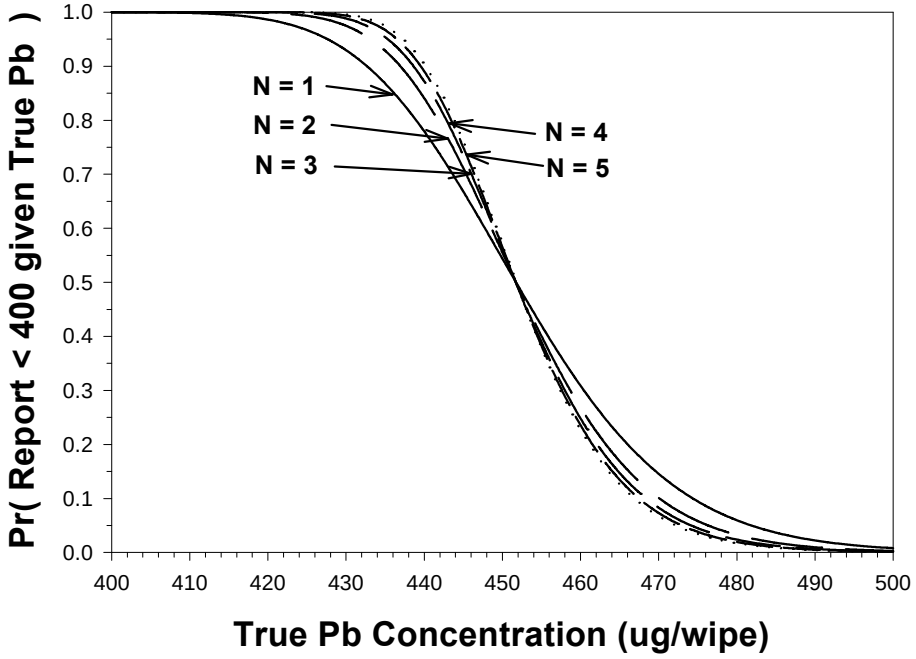

Figure 7. False negative probabilities for DataChem average concentrations at a target concentration level of 400 μg/wipe.

Table 5. Summary of the Linear Regression Constants and Recovery Data for DataChem's Measurements Versus the Estimated Concentrations at the Clearance Levels

Evaluation Parameter	40 µg/wipe		250 µg/wipe		400 µg/wipe	
	UC	ELPAT	UC	ELPAT	UC	ELPAT
n	20	16	20	16	20	8
slope	1.021	1.612	0.829	0.578	0.736	2.394
intercept	-3.673	-6.182	18.557	90.826	67.649	-575.771
correlation coefficient	0.884	0.840	0.879	0.549	0.861	0.492
average % recovery	93%	101%	90%	96%	91%	100%
SD of % recovery	4%	13%	3%	9%	3%	5%
Reported concentration at the CL	37 µg/wipe	40 µg/wipe	226 µg/wipe	234 µg/wipe	362 µg/wipe	382 µg/wipe

Section 5 — Technology Evaluation

Objective and Approach

The purpose of this section is to present a statistical evaluation of the Pb-Test XRF data and determine the technology's ability to measure lead in dust wipe samples. This section includes an evaluation of comparability through a one-to-one comparison with NLLAP-recognized laboratory data. Other aspects of the technology (such as accuracy, precision, cost, sample throughput, hazardous waste generation, and logistical operation) are also evaluated in this section. The Appendix contains the raw data provided by the vendor during the verification test that were used to assess the performance of the Pb-Test.

Precision

Precision is the reproducibility of measurements under a given set of conditions. Precision was determined by examining the results of blind analyses for replicate samples with estimated concentrations greater than 2 µg/wipe. For the ELPAT samples, precision was measured on each set of four samples from a particular round of archived samples. For the 20 sets of ELPAT samples, the Pb-Test's average RSD value was 18%, with a range from 7 to 54%, indicating that the Pb-Test's measurements were, on average, precise. For the UC samples, 20 samples were analyzed at three target concentration levels of 40, 250, and 400 µg/wipe. The average precision of the UC sample measurements by the Pb-Test was 15% RSD. The measurements above 200 µg/wipe (average RSD = 14%) were more precision than the results for the samples with concentrations below 200 µg/wipe (average RSD = 21%). With the expectation that UC was to prepare the samples as close to the target concentrations as possible, the allowable variability was 10% RSD. The actual variability of the UC preparation process was an average of 6% RSD.

Accuracy

Accuracy represents the closeness of the Pb-Test's measured concentrations to the estimated content of spiked samples. A plot of the Pb-Test percent recovery values versus the average estimated concentration for both UC and ELPAT samples is provided in Figure 8. A percent recovery value of 100% indicates that there is no difference between the Pb-Test result and the estimated value. Table 7 contains the summary of the percent recovery values for the ELPAT and UC samples, including an evaluation of concentrations above and below 200 µg/wipe. The Pb-Test results were biased high for concentrations below 200 µg/wipe (average % recovery = 282% for ELPAT samples and 300% for UC samples), with the amount of bias consistently decreasing as concentration increased (Figure 8). Above 200 µg/wipe, the Pb-Test results were unbiased (average % recovery = 96% for the ELPAT samples and 102% for the UC samples). The average % recovery values were not statistically different than 100%. The results at higher concentration levels (800 and 1,500 µg/wipe) indicated a negative bias (78% and 72%, respectively), but too few sample results existed at those concentrations to definitely say that the technology was biased low above 800 µg/wipe.

Table 6. Precision of the Pb-Test Instrument

Source	No. of sample sets	% RSD		
		avg	min	max
ELPAT	20 [a]	18	7	54
UC	3 [b]	15	10	19
> 200 µg/wipe	12	14	7	21
< 200 µg/wipe	11	21	7	54
UC prep [c]	3	6	4	7

[a] 4 replicates in each sample set
[b] 20 replicates in each sample set
[c] precision of UC sample preparation process

Another measure of accuracy is the number of results for the ELPAT samples that were reported within the individual acceptance ranges that have been established for those samples. Of the 80 ELPAT samples, the Pb-Test reported 34 of the results (43% of the total) within the acceptance ranges. If only the ELPAT samples above 200 µg/wipe are considered (40 samples), 32 samples (80%) are within the ELPAT acceptance limits.

Comparability

Comparability refers to how well the Pb-Test and the NLLAP-recognized laboratory data agreed. In this evaluation, the laboratory results are not presumed to be the "correct" answers. Rather, these results represent what a typical fixed laboratory would report for these types of samples. A direct comparison of the Pb-Test results and the laboratory results was performed for all ELPAT and UC samples. In Figures 9 and 10, the Pb-Test average concentration is plotted versus the DataChem average concentration in the range from 0 to 200 µg/wipe and 200 to 1500 µg/wipe, respectively. Note that, for this evaluation only, the ELPAT and UC samples are combined because there are only 3 UC data points. For concentrations less than 200 µg/wipe (Figure 9), the results agree in a linear fashion (m = 1.060, r = 0.967), but are biased high (intercept = 65.6). The average Pb-Test measurements were in fairly good agreement with the average laboratory results (Figure 10) for concentrations greater than 200 µg/wipe (r = 0.989), but the slope was statistically different than 1.00 (m = 0.662).

Table 7. Accuracy of Pb-Test Instrument

Statistic	ELPAT			UC		
	All	< 200 µg/wipe	> 200 µg/wipe	All	< 200 µg/wipe	> 200 µg/wipe
n [a]	80	40	40	60	20	40
average % recovery	189	282	96	168	300	102
standard deviation	154	173	20	102	64	18
minimum % recovery	60	65	60	78	203	78
maximum % recovery	753	753	141	485	485	145

[a] Excludes "detectable blank" samples at concentrations < 2 µg/wipe

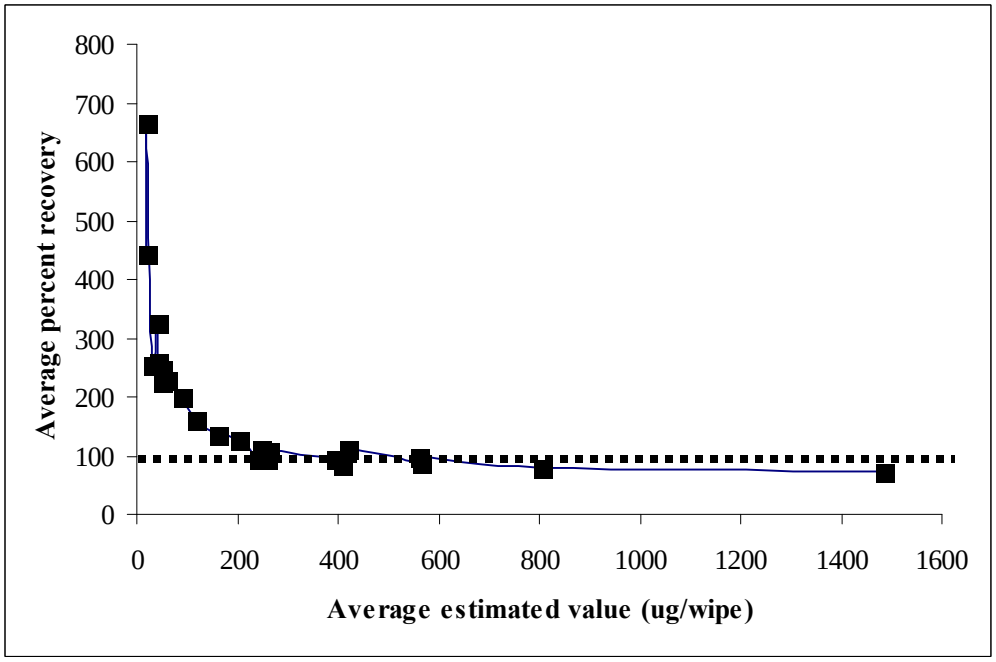

Figure 8. Plot of the Pb-Test's average percent recovery values (Pb-Test result/estimated value *x* 100%) versus the average estimated values for all concentrations and sample types (n=23). The dashed line represents 100% recovery – the value at which the Pb-Test result and the estimated value agree.

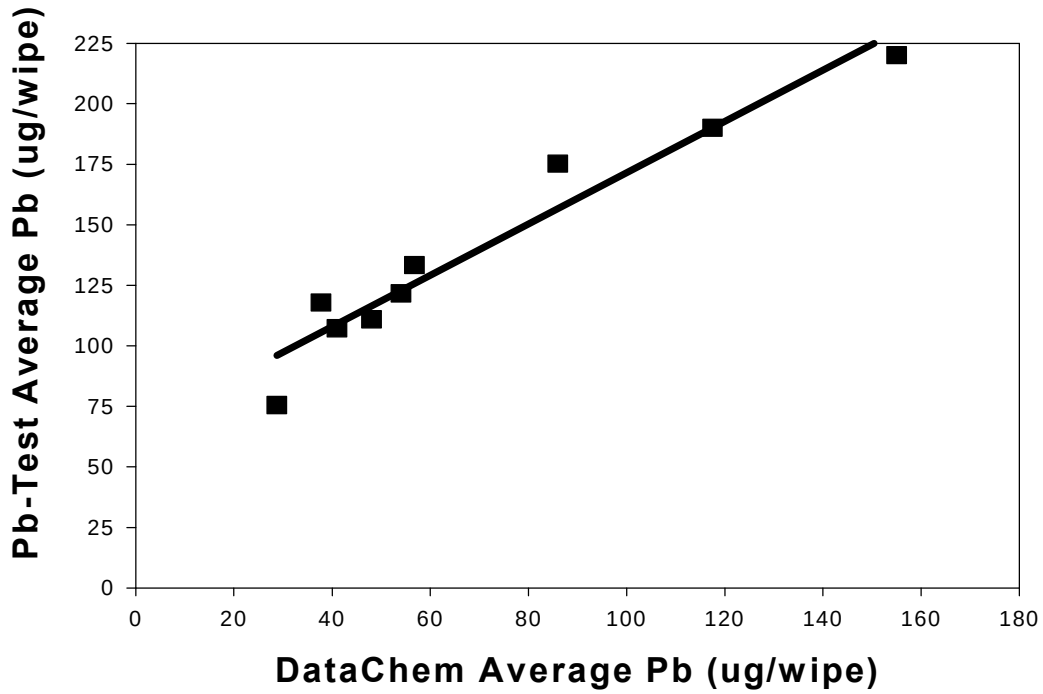

Figure 9. Plot of the Pb-Test average concentrations versus DataChem average concentrations for all UC and ELPAT samples with positive DataChem concentrations less than 200 µg/wipe (n=9). The equation of the linear regression line is y = 1.060x + 65.586, correlation coefficient r = 0.967.

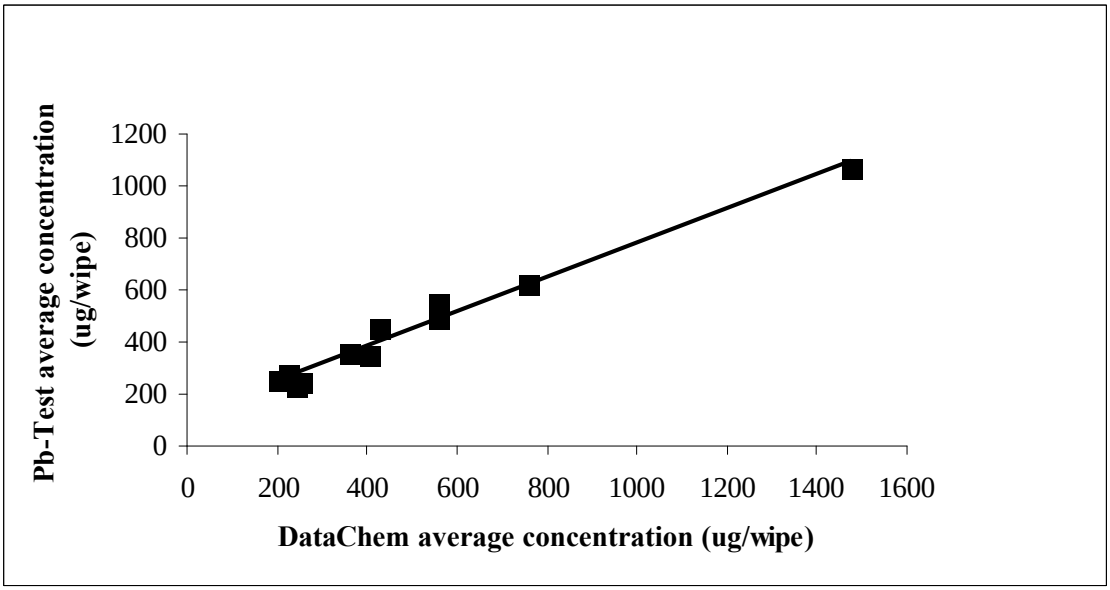

Figure 10. Plot of the Pb-Test average concentration versus the DataChem average concentration for all UC and ELPAT samples > 200 µg/wipe (n=12). The equation of the linear regression line is y = 0.662x + 121, r = 0.989.

Detectable Blanks

Of the samples that were prepared at < 2 μg/wipe, the Pb-Test reported all 20 samples as positive for lead, with concentrations ranging from 46 to 137 μg/wipe. KeyMaster did not provide a reporting limit for the instrument during the verification test.

False Positive/False Negative Results

Similar to the evaluation described and presented in Section 4 for DataChem, the number of false negative and false positive results reported by the Pb-Test relative to the estimated concentrations for both the ELPAT and UC samples are summarized in Table 8. In about half of the cases where the estimated concentration was less than the clearance level (CL), the Pb-Test reported a result that was greater than the CL (20 of 38 possible fp results for the UC samples, and 6 of 12 fp results for the ELPAT samples at the three CLs). When the estimated concentration was equal to or greater than the clearance level, the Pb-Test reported some as less than the CL, but most of the results as greater than the CL (7 of 22 possible fn results for UC samples and 8 of 28 fn results for ELPAT samples). About half of the fp results were at the 40 μg/wipe level, which is not surprising, based on the findings reported above that indicated that the Pb-Test results were positively biased, or reported more than the estimated values, for concentrations < 200 μg/wipe.

Table 9 presents the linear regression constants for Pb-Test measured concentrations versus estimated concentrations for the three CLs. The average recoveries indicate that the Pb-Test results were significantly positively biased at the 40 μg/wipe clearance level for both ELPAT and UC samples. The results were more accurate and precise at the 250 and 400 μg/wipe clearance levels.

For all UC samples, the slopes are not significantly different than zero at the 5% significance level. The non-significant slopes indicate that the false negative probabilities for the Pb-Test are constant (i.e., horizontal lines) over the concentration ranges examined. In Figures 11, 12 and 13, false negative probabilities at the three clearance levels are compared for DataChem and Pb-Test results. In these figures, the two-sided 90% confidence intervals (not shown for clarity) are used to express uncertainty on the false negative curves. In the three figures, the 90% confidence intervals for the two methods only overlap for parts of the true lead concentration ranges (greater than 43 μg/wipe for the 40 μg/wipe clearance level; from 257 μg/wipe to 334 μg/wipe for the 250 μg/wipe clearance level; and from 389 μg/wipe to 500 μg/wipe for the 400 μg/wipe clearance level). Both the constant probabilities for Pb-Test (i.e., horizontal lines) and the partial overlapping of the confidence intervals indicate that the Pb-Test false negative error rates are not comparable to DataChem's false negative error rates for all ranges of true lead concentrations in the three figures.

Once again, the reader is reminded that the fp/fn evaluation reported herein is based on the instrument's performance during this verification test. Results produced under different conditions and with different samples may or may not be similar. Regardless of analytical technique, there is some uncertainty in assessing false positive and false negative error rates around critical action levels due to "normal" levels of variability (Song et al., 2001). Analytical values falling near the level of interest should be interpreted with care for both fixed-laboratory and field-based analytical methods.

Table 8. False Positive/False Negative Error Rates for Pb-Test Measurements

Evaluation Parameter	Sample Source	Number of Samples			Total
		40 µg/wipe	250 µg/wipe	400 µg/wipe	
fp: # samples where Pb-Test reported the result as > CL[a] of the # samples where the estimated concentration was < CL	UC	11 of 11	6 of 11	3 of 16	20 of 38
	ELPAT	3 of 4	3 of 8	0 of 0 [b]	6 of 12
fn: # samples where Pb-Test reported the result as < CL of the # samples where the estimated concentration was > CL	UC	0 of 9	3 of 9	4 of 4	7 of 22
	ELPAT	0 of 12	3 of 8	5 of 8	8 of 28

[a] CL = clearance level

[b] Because all eight ELPAT values were above 400 µg/wipe, no samples were available to assess fp results at this level.

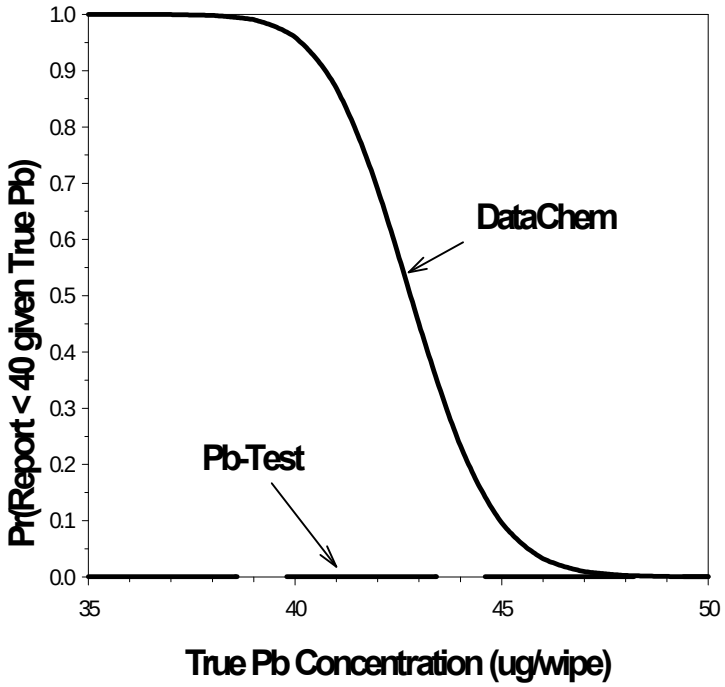

Figure 11. Comparison of the false negative probabilities for the Pb-Test and DataChem average concentrations at a target concentration of 40 µg/wipe.

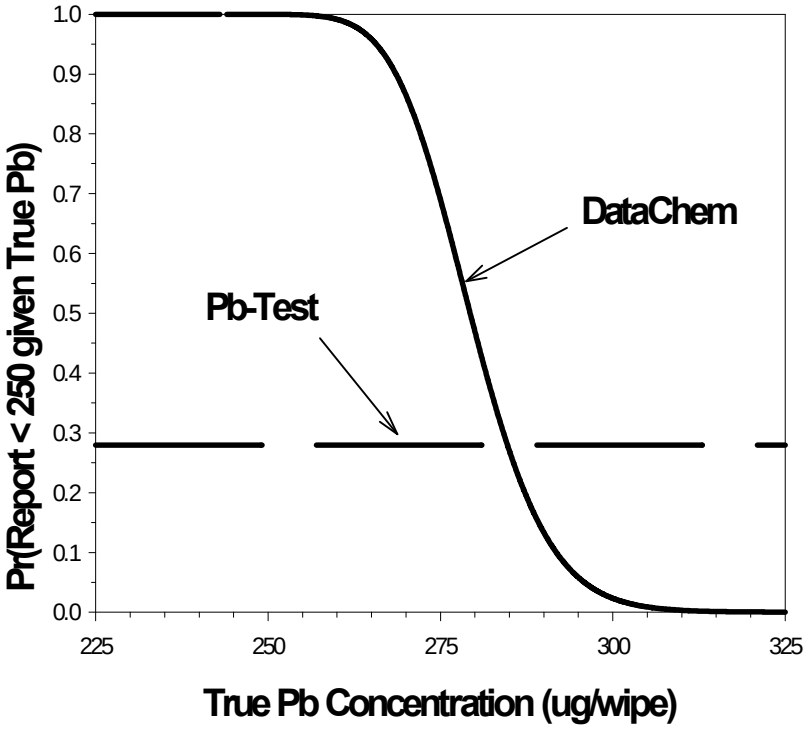

Figure 12. Comparison of the false negative probabilities for the Pb-Test and Data Chem average concentrations at a target concentration of 250 μg/wipe.

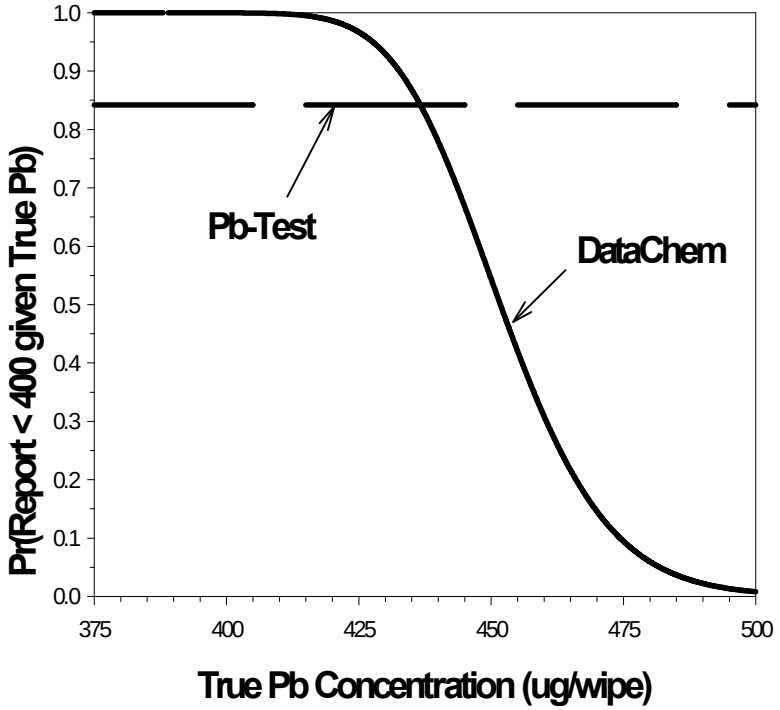

Figure 13. Comparison of the false negative probabilities for the Pb-Test and DataChem average concentrations at a target concentration of 400 μg/wipe.

Table 9. Summary of the Linear Regression and Recovery Data for the Pb-Test Response versus the Estimated Concentrations

Evaluation Parameter	40 µg/wipe		250 µg/wipe		400 µg/wipe	
	UC	ELPAT	UC	ELPAT	UC	ELPAT
n	20	16	20	16	20	8
slope	-0.490	2.090	-0.358	0.089	0.352	11.634
intercept	137.304	15.467	364.570	231.458	224.482	-4405.34
correlation coefficient	-0.064	0.564	-0.104	0.060	0.159	0.640
average % recovery	300%	247%	112%	107%	93%	98%
SD of % recovery	64%	73%	19%	19%	10%	21%
Reported concentration at the CL	118 µg/wipe	99 µg/wipe	275 µg/wipe	254 µg/wipe	365 µg/wipe	248 µg/wipe

Completeness

Completeness is defined as the percentage of measurements that are judged to be usable (i.e., the result was not rejected). Valid results were obtained by the technology for all 160 dust wipe samples. Therefore, completeness was 100%.

Sample Throughput

Sample throughput is representative of the estimated amount of time required to prepare and analyze the sample and perform the data analysis. Operating in the field, the two-person KeyMaster team accomplished a sample throughput rate of approximately eighty samples per 10-hour day for the 160 dust wipe analyses. One person did sample preparation and the other did sample analysis. Two instruments were used, with one analyst analyzing all samples on both, and the average reading from the two instruments reported as the final result.

Ease of Use

Two operators were used for the test because of the number of samples and the working conditions, but the technology can be operated by a single person. Users unfamiliar with the technology may need approximately one day of training to operate the instrument. No particular level of educational training is required for the operator. Both operators were company experts. All samples were analyzed on two instruments during the test, with the average result reported. This was done as a test of variability between instruments that KeyMaster elected to perform. A single instrument is intended to be used in typical applications.

Cost Assessment

The purpose of this economic analysis is to estimate the range of costs for analysis lead in dust wipe samples using the Pb-Test XRF and a typical laboratory method. The analysis was based on the results and experience gained from this verification test, costs provided by EDAX, KeyMaster's distributor, and representative costs provided by the laboratory to analyze the samples. To account for the variability in cost data and assumptions, the economic analysis is presented as a list of cost elements and a range of costs for sample analysis by the XRF instrument and by the laboratory. Costs were prepared at the time this report was written and are subject to change.

Several factors affected the cost of analysis. Where possible, these factors were addressed so that decision makers can complete a site-specific economic analysis to suit their needs. The following categories are considered in the estimate:

- sample shipment costs,
- labor costs, and
- equipment costs.

Each of these cost factors is defined and discussed and serves as the basis for the estimated cost ranges presented in Table 10. This analysis assumed that the individuals performing the analyses were fully trained to operate the technology. Costs for sample acquisition and pre-analytical sample preparation, tasks common to both methods, were not included in this assessment.

Table 10. Estimated analytical costs for lead dust wipe samples

Analysis method: Pb-Test XRF **Analyst/manufacturer:** KeyMaster Technologies **Sample throughput:** 80 samples/day		**Analysis method:** EPA SW846 6010b **NLLAP Laboratory:** DataChem **Actual turnaround:** 18 working days	
Cost category	**Cost ($)**	**Cost category**	**Cost ($)**
Sample shipment	0	**Sample shipment**	
		Labor	100–200
		Overnight shipping	50–100
Labor		**Labor**	
Rate	50–100/h per analyst	Rate	30 per sample
Equipment		**Equipment**	Included [a]
Mobilization/demobilization	0		
Instrument purchase price	15,130		
Instrument lease price	338 per month		
Reagents/supplies	0.70 per sample		
Re-sourcing 15-24 months	2,600		
Waste Disposal	0 [b]	**Waste Disposal**	Included

[a] "Included" indicates that the cost is included in the labor rate.

[b] There was no cost to dispose of hazardous waste from the verification test because KeyMaster kept the "used" wipes.

Pb-Test XRF Costs

The costs associated with using the instrument included labor and equipment costs. No sample shipment charges were associated with the cost of operating the instrument because the samples were analyzed on site.

Labor

Labor costs included on-site labor to perform the analyses. The cost of the on-site labor was estimated at a rate of $50–100/h, depending on the required expertise level of the analyst. This cost element included the labor involved during the entire analytical process, comprising sample preparation, sample management, analysis, and reporting. If the user would have to travel to the site, the cost of mobilization and demobilization, travel, and per diem expenses should also be considered. However, in a typical application where the Pb-Test might be used, the analysis would usually be carried out by a person located on site.

Equipment

Equipment costs included mobilization and demobilization, purchase of equipment, and the reagents and other consumable supplies necessary to complete the analysis.

- *Mobilization and demobilization*. This included the cost of shipping the equipment to the test site. For this verification test, the cost of shipping equipment and supplies was estimated at $150.

- *Instrument purchase*. The instrument can be purchased from EDAX for $15,130. The instrument comes standard with an 18-month factory warranty (excluding the source) to be free of manufacturer's defects, dust wipe analysis kit (100 wipes, 500 sample holders, calibration standard, sample compressor, and dust wipe block), off-line report generation software, two rechargeable batteries, charger, manuals, and carrying case. The instrument can be leased from EDAX for as low as $338 per month (with first and last month's payments in advance), but rates are dependent on customer's credit. With regards to training, the unit comes standard with a flowchart showing how to use the product as well as a detailed user manual. On-site training by EDAX is available at a fee.

- *Reagents and supplies*. Dust wipe holders are the only consumable item and can be purchased for $350 for a set of 500. Lynx dustwipes can be

purchased for $288 for100 wipes. Re-sourcing cost is about $2,600. KeyMaster recommends re-sourcing every 15 to 24 months, depending on the user's needs.

Laboratory Costs

Sample Shipment

The costs of shipping samples to the laboratory included overnight shipping charges as well as labor charges associated with the various organizations involved in the shipping process.

- *Labor*. This cost element included all of the tasks associated with shipping the samples to the NLLAP laboratory. Tasks included packing the shipping coolers, completing the chain-of-custody documentation, and completing the shipping forms. The estimate to complete this task ranged from 2 to 4 h, at $50 per hour.

- *Overnight shipping*. The overnight express shipping service cost was estimated to be $50 - 100 for two boxes of samples.

Labor, Equipment, and Waste Disposal

The labor quotes from commercial analytical laboratories that offered to perform the analyses for this verification test ranged from $20 to $30 per sample, with turnaround time estimates ranging from 7 to 14 days. Some laboratories can provide a 1-2 day turnaround, but the quick turnaround time was not necessary for this test. The quotes were dependent on many factors, including the perceived difficulty of the sample matrix, the current workload of the laboratory, data packaging, and the competitiveness of the market. This rate was a fully loaded analytical cost that included equipment, labor, waste disposal, and report preparation. The cost for DataChem to analyze samples for this verification test was $30 per sample, with a turnaround time of 18 working days.

Cost Assessment Summary

An overall cost estimate for use of the Pb-Test versus use of the NLLAP- laboratory was not made because of the extent of variation in the different cost factors, as outlined in Table 10. The overall costs for the application of any technology would be based on the number of samples requiring analysis, the sample type, and the site location and characteristics. Decision-making factors, such as turnaround time for results, must also be weighed against the cost estimate to determine the value of the field technology's providing immediate answers versus the laboratory's provision of reporting data within 18 days of receipt of samples.

Miscellaneous Factors

The following are general observations regarding the field operation and performance of the Pb-Test XRF instrument:

- KeyMaster Technologies is the manufacturer and developer of this instrument. EDAX is the distributor who markets and sells the technology.
- The instrument required no electrical power. The instrument worked continuously through at least 6 hours of each workday before the battery was changed.
- The KeyMaster analyst was ready for the first set of samples within 30 minutes of arriving on site.
- The KeyMaster analyst took one five-minute reading for each sample. The sample was analyzed on two separate instruments and the results were averaged to produce the final result. KeyMaster elected to analyze the samples on two instruments as a study of precision variation between instruments.
- This instrument can be used to detect and quantify multiple metals, although the instrument's performance for lead is the only metal that was verified in this test.
- Each wipe had to be cut to one-fourth of its original size, according to the KeyMaster method. This may have introduced some error in the measurements, as some dust might have been lost in this process, but no systematic errors were detected in the data that could be attributed to this practice. With the purchase of an instrument, KeyMaster/EDAX will provide the appropriately sized wipe with the instrument, so this step would be avoided.
- The instrument contains a radioactive source. The source was 4-5 months old at the time of the test. As the source decays, it may be necessary to increase the time of the measurement to obtain the same precision that was obtained with the source in this evaluation.
- Licensing requirements vary by state and EDAX offers contact information and guidance with instrument purchase or lease.
- This method did not generate any waste, other than the used dust wipe samples.
- It is recommended that KeyMaster/EDAX be

contacted with any specific questions (such as transportation issues) that a user might have.

Summary of Performance

A summary of performance is presented in Table 11. Note that performance is based on the specific protocols employed for this verification test. If different testing protocols are used, different performance results may be obtained.

The verification test found that the Pb-Test instrument was relatively simple for a trained analyst to operate in the field, requiring less than an one-half hour for initial setup. The sample throughput of the Pb-Test was eighty samples per day with two operators and two instruments.

The overall performance of the Pb-Test instrument for the analysis of lead in dust wipe samples was characterized as having acceptable precision, biased high for concentrations below 200 μg/wipe, but unbiased for concentrations greater than 200 μg/wipe.

ORNL and ETV remind the reader that, while the ETV test provides valuable information in the form of a snapshot of performance, state, tribal, or federal requirements regarding the use of the technologies (such as NLLAP recognition for analysis of clearance samples where required) need to be followed.

Table 11. Performance Summary for the Pb-Test Instrument

Feature/parameter		Performance summary			
		UC Samples		ELPAT Samples	
Precision : average RSD		15%		18%	
Accuracy: average % recovery		All samples: 168% > 200 µg/wipe only: 102%		All samples: 189% > 200 µg/wipe only: 96%	
Positive results on "detectable blank" samples (< 2 µg/wipe)		n/a		20 of 20 samples	
False positive results		DataChem Total: 0 of 30 0 at 40 µg/wipe 0 at 250 µg/wipe 0 at 400 µg/wipe	Pb-Test Total: 20 of 38 11 at 40 µg/wipe 6 at 250 µg/wipe 3 at 400 µg/wipe	DataChem 2 of 12 0 at 40 µg/wipe 2 at 250 µg/wipe 0 at 400 µg/wipe	Pb-Test Total: 6 of 12 3 at 40 µg/wipe 3 at 250 µg/wipe 0 at 400 µg/wipe
False negative results		DataChem 23 of 30 5 at 40 µg/wipe 9 at 250 µg/wipe 9 at 400 µg/wipe	Pb-Test Total: 7 of 22 0 at 40 µg/wipe 3 at 250 µg/wipe 4 at 400 µg/wipe	DataChem 7 of 28 1 at 40 µg/wipe 5 at 250 µg/wipe 1 at 400 µg/wipe	Pb-Test Total: 8 of 28 0 at 40 µg/wipe 3 at 250 µg/wipe 5 at 400 µg/wipe
Comparison with NLLAP-recognized laboratory results (excluding < 25 µg/wipe samples)	slope	≤ 200 µg/wipe samples only: 1.060 (standard error = 0.105) > 200 µg/wipe samples only: 0.662 (standard error = 0.031)			
	intercept	≤ 200 µg/wipe samples only: 66 (standard error = 8.416) > 200 µg/wipe samples only: 121 (standard error = 17.997)			
	correlation coefficient	≤ 200 µg/wipe samples only: 0.967 > 200 µg/wipe samples only: 0.989			
Overall evaluation		- Positive bias for concentrations ≤ 200 µg/wipe - Unbiased for concentrations > 200 µg/wipe - Acceptable Precision - Linear relationship to the NLLAP lab results for > 200 µg/wipe - Some fn results, but higher number of fp results			
Completeness		100% of 160 dust wipe samples			
Size and Weight		4" x 10" x 8"; 5.61 lbs			
Sample throughput (2 analysts and 2 instruments)		80 samples/10-hr day			
Power requirements		rechargeable Nickel-Cadmium battery			
Training requirements		on-site provided for a fee (contact EDAX)			
Cost		Purchase: $15,130 Lease: $338 per month (based on customer's credit) Reagents/Supplies: $0.70 per sample Annual re-sourcing: $2,600			
Waste generated		none			

Section 6 — References

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Appendix

KeyMaster's Pb-Test XRF Results Compared with Laboratory Results

Sample Analysis Order	Source	Rep	KeyMaster Pb-Test		DataChem	
			Result	Estimated	Result	Estimated
			µg/wipe	µg/wipe	µg/wipe	µg/wipe
6	ELPAT	1	136.87	1.3	<20	1.3
121	ELPAT	2	79.85	1.3	<20	1.3
110	ELPAT	3	53.55	1.3	<20	1.3
117	ELPAT	4	69.76	1.3	<20	1.3
128	ELPAT	1	69.46	1.3	<20	1.3
145	ELPAT	2	97.3	1.3	<20	1.3
32	ELPAT	3	60.11	1.3	<20	1.3
106	ELPAT	4	50.04	1.3	<20	1.3
113	ELPAT	1	45.62	1.3	<20	1.3
65	ELPAT	2	72.15	1.3	<20	1.3
126	ELPAT	3	45.51	1.3	<20	1.3
133	ELPAT	4	89.31	1.3	<20	1.3
53	ELPAT	1	46.79	1.3	<20	1.3
10	ELPAT	2	117.38	1.3	<20	1.3
157	ELPAT	3	94.23	1.3	<20	1.3
158	ELPAT	4	107.47	1.3	<20	1.3
30	ELPAT	1	72.36	1.3	<20	1.3
82	ELPAT	2	76.22	1.3	<20	1.3
67	ELPAT	3	98.68	1.3	<20	1.3
35	ELPAT	4	65.85	1.3	<20	1.3
62	ELPAT	1	117.99	16.9	<20	16.9
48	ELPAT	2	89.43	16.9	<20	16.9
154	ELPAT	3	127.25	16.9	<20	16.9
105	ELPAT	4	116.16	16.9	<20	16.9
49	ELPAT	1	109.83	17.6	30	17.6
9	ELPAT	2	22.05	17.6	<20	17.6
141	ELPAT	3	99.24	17.6	<20	17.6
120	ELPAT	4	81.91	17.6	<20	17.6
16	ELPAT	1	115.89	29.8	33	29.8
47	ELPAT	2	19.29	29.8	26	29.8
55	ELPAT	3	82.65	29.8	28	29.8
118	ELPAT	4	84.52	29.8	28	29.8

Sample Analysis Order	Source	Rep	KeyMaster Pb-Test		DataChem	
			Result	Estimated	Result	Estimated
			µg/wipe	µg/wipe	µg/wipe	µg/wipe
71	UC LAB	1	106.91	40.2	33	35.4
3	UC LAB	2	124.67	36.7	32	35.7
45	UC LAB	3	128.72	45.0	31	38.5
57	UC LAB	4	131.22	41.0	29	36.4
131	UC LAB	1	141.59	39.3	32	35.1
125	UC LAB	2	105.27	39.4	38	40.7
18	UC LAB	3	126.56	44.3	37	39.4
75	UC LAB	4	115.23	40.7	36	41.0
41	UC LAB	1	99.57	43.1	37	41.0
40	UC LAB	2	97.29	37.6	37	38.8
92	UC LAB	3	111.74	35.4	33	39.3
146	UC LAB	4	175.12	36.1	41	44.7
155	UC LAB	1	141.61	36.1	32	36.0
94	UC LAB	2	79.29	39.0	38	44.7
156	UC LAB	3	142.92	40.4	30	39.9
50	UC LAB	4	99.72	37.4	35	37.5
17	UC LAB	1	111.83	36.6	36	37.4
46	UC LAB	2	87.65	38.6	31	36.7
151	UC LAB	3	116.12	40.1	34	35.8
38	UC LAB	4	115.13	44.4	34	39.7
43	ELPAT	1	97.69	41.3	37	41.3
26	ELPAT	2	133.55	41.3	42	41.3
98	ELPAT	3	130.94	41.3	44	41.3
61	ELPAT	4	66.83	41.3	41	41.3
112	ELPAT	1	125.15	49.0	43	49.0
80	ELPAT	2	120.36	49.0	52	49.0
68	ELPAT	3	101.17	49.0	49	49.0
51	ELPAT	4	97.22	49.0	48	49.0
136	ELPAT	1	119.55	49.1	70	49.1
22	ELPAT	2	106.95	49.1	54	49.1
86	ELPAT	3	136.94	49.1	48	49.1
135	ELPAT	4	123.47	49.1	44	49.1
160	ELPAT	1	163.99	58.6	64	58.6
33	ELPAT	2	138.00	58.6	55	58.6
111	ELPAT	3	148.24	58.6	56	58.6
20	ELPAT	4	83.29	58.6	52	58.6

Sample Analysis Order	Source	Rep	KeyMaster Pb-Test		DataChem	
			Result	Estimated	Result	Estimated
			µg/wipe	µg/wipe	µg/wipe	µg/wipe
116	ELPAT	1	184.73	88.0	82	88.0
149	ELPAT	2	206.53	88.0	83	88.0
87	ELPAT	3	139.49	88.0	79	88.0
1	ELPAT	4	170.38	88.0	100	88.0
89	ELPAT	1	214.22	117.0	120	117.0
101	ELPAT	2	185.92	117.0	120	117.0
140	ELPAT	3	183.25	117.0	120	117.0
104	ELPAT	4	177.20	117.0	110	117.0
81	ELPAT	1	211.38	162.3	150	162.3
69	ELPAT	2	209.23	162.3	160	162.3
56	ELPAT	3	215.97	162.3	150	162.3
127	ELPAT	4	243.62	162.3	160	162.3
108	ELPAT	1	229.18	201.6	200	201.6
90	ELPAT	2	249.41	201.6	190	201.6
44	ELPAT	3	270.85	201.6	200	201.6
142	ELPAT	4	285.10	201.6	220	201.6
138	ELPAT	1	233.42	239.0	230	239.0
34	ELPAT	2	225.00	239.0	250	239.0
99	ELPAT	3	206.05	239.0	250	239.0
109	ELPAT	4	252.48	239.0	230	239.0
83	UC LAB	1	257.36	240.1	210	244.0
5	UC LAB	2	284.56	245.6	250	274.4
102	UC LAB	3	216.20	244.0	230	252.8
66	UC LAB	4	341.82	252.3	230	258.9
95	UC LAB	1	264.55	252.3	200	241.7
14	UC LAB	2	235.88	270.5	240	274.9
58	UC LAB	3	267.48	252.3	210	244.5
13	UC LAB	4	325.29	253.4	210	236.2
31	UC LAB	1	215.08	239.0	220	244.0
12	UC LAB	2	249.01	270.5	220	242.3
139	UC LAB	3	249.03	270.0	230	260.0
152	UC LAB	4	232.06	248.4	170	228.5
19	UC LAB	1	332.81	245.1	190	242.3
148	UC LAB	2	231.90	234.6	210	267.2
63	UC LAB	3	287.15	255.0	210	236.2
85	UC LAB	4	288.76	234.6	250	275.5
147	UC LAB	1	248.60	232.9	220	262.2
15	UC LAB	2	330.74	228.5	210	226.3
137	UC LAB	3	350.48	253.9	210	227.4
27	UC LAB	4	308.12	234.0	220	243.4

Sample Analysis Order	Source	Rep	KeyMaster Pb-Test		DataChem	
			Result	Estimated	Result	Estimated
			µg/wipe	µg/wipe	µg/wipe	µg/wipe
93	ELPAT	1	254.43	256.7	290	256.7
8	ELPAT	2	234.38	256.7	240	256.7
29	ELPAT	3	192.51	256.7	230	256.7
153	ELPAT	4	299.75	256.7	250	256.7
23	ELPAT	1	233.74	260.8	220	260.8
24	ELPAT	2	262.98	260.8	250	260.8
122	ELPAT	3	334.93	260.8	210	260.8
52	ELPAT	4	279.68	260.8	210	260.8
7	UC LAB	1	351.36	398.3	320	377.8
60	UC LAB	2	368.37	424.9	360	395.0
70	UC LAB	3	330.97	404.9	350	399.4
124	UC LAB	4	338.30	398.9	340	385.0
100	UC LAB	1	332.97	406.0	350	395.5
96	UC LAB	2	316.70	398.3	340	382.8
4	UC LAB	3	398.68	371.8	370	413.8
64	UC LAB	4	412.32	396.1	340	374.0
97	UC LAB	1	327.68	376.7	370	426.5
143	UC LAB	2	419.21	396.6	340	378.9
129	UC LAB	3	332.68	366.2	370	401.1
28	UC LAB	4	364.14	380.6	390	423.2
73	UC LAB	1	399.06	386.7	330	372.9
76	UC LAB	2	395.33	390.0	320	362.9
115	UC LAB	3	389.27	373.4	330	384.5
132	UC LAB	4	351.82	383.4	360	411.0
150	UC LAB	1	309.40	394.4	340	397.2
134	UC LAB	2	390.35	416.6	360	393.3
36	UC LAB	3	309.42	359.0	390	437.6
130	UC LAB	4	408.52	399.4	330	375.1
159	ELPAT	1	310.75	408.7	360	408.7
88	ELPAT	2	394.38	408.7	430	408.7
119	ELPAT	3	387.10	408.7	410	408.7
103	ELPAT	4	306.16	408.7	410	408.7
21	ELPAT	1	421.31	418.1	440	418.1
114	ELPAT	2	509.41	418.1	410	418.1
2	ELPAT	3	561.38	418.1	430	418.1
59	ELPAT	4	343.74	418.1	420	418.1

Sample Analysis Order	Source	Rep	KeyMaster Pb-Test		DataChem	
			Result	Estimated	Result	Estimated
			µg/wipe	µg/wipe	µg/wipe	µg/wipe
79	ELPAT	1	521.26	561.9	580	561.9
25	ELPAT	2	522.16	561.9	540	561.9
84	ELPAT	3	598.54	561.9	560	561.9
107	ELPAT	4	551.72	561.9	540	561.9
78	ELPAT	1	558.21	564.7	560	564.7
11	ELPAT	2	514.70	564.7	560	564.7
54	ELPAT	3	544.80	564.7	570	564.7
144	ELPAT	4	381.06	564.7	530	564.7
39	ELPAT	1	649.33	805.1	760	805.1
123	ELPAT	2	726.67	805.1	770	805.1
72	ELPAT	3	479.39	805.1	760	805.1
37	ELPAT	4	649.33	805.1	740	805.1
42	ELPAT	1	1155.83	1482.6	1500	1482.6
77	ELPAT	2	901.86	1482.6	1500	1482.6
91	ELPAT	3	1110.34	1482.6	1500	1482.6
74	ELPAT	4	1130.73	1482.6	1400	1482.6