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METHODOLOGY FOR XRF PERFORMANCE CHARACTERISTIC SHEETS

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CONTRIBUTING ORGANIZATIONS

The methodology described in this report is part of a task funded by the U.S. Environmental Protection Agency and the U.S. Department of Housing and Urban Development. The task was managed by the U.S. Environmental Protection Agency. The task was conducted collaboratively by three organizations under contract to the Environmental Protection Agency: Battelle Memorial Institute, Midwest Research Institute, and QuanTech. Each organization's responsibilities are listed below.

Battelle Memorial Institute

Battelle Memorial Institute (Battelle) was responsible for oversight of archive sample maintenance and archive testing.

Midwest Research Institute

Midwest Research Institute (MRI) was responsible for the operations manual, sample maintenance, collection of paint samples, laboratory analysis, and supervision of testing.

QuanTech

QuanTech (formerly David C. Cox & Associates) was responsible for testing design, data management, development of statistical methods, and the writing of this report and the *XRF Performance Characteristic Sheets*.

U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA) co-funded the task, managed the task, reviewed task documents, and managed the peer review of this report. The EPA Project Leader was John Schwemberger. The EPA Work Assignment Managers were Sam Brown, John Scalera and John Schwemberger. The EPA Project Officers were Sam Brown, Jill Hacker, Phil Robinson, and Sineta Wooten.

U.S. Department of Housing and Development

The Department of Housing and Urban Development (HUD) co-funded the task, and was responsible for reviews of the *XRF Performance Characteristic Sheets* and for contacts with the manufacturers of lead-based paint testing technologies. The key HUD staff member was Bill Wisner.

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EXECUTIVE SUMMARY

The methodology described in this report was developed as part of a task funded by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD) to collect information needed for the development of federal guidance on testing paint for lead. The methodology was specifically used to develop testing guidance that is supplemental information to be used in conjunction with Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* ("HUD Guidelines").

Information collected from an EPA/HUD field study conducted in 1993 provided background for Chapter 7 of the HUD Guidelines. This field study came about due to the passage of Title X (Section 1017 of the Residential Lead-Based Paint Hazard Reduction Act of 1992), which mandated that the federal government establish guidelines for lead-based paint hazard evaluation and reduction. From the field study came detailed information EPA and HUD needed in order to provide up-to-date field testing guidance for portable X-ray fluorescence (XRF) instruments. The results from the field study are reported in two documents. A summary report, entitled *A Field Test of Lead-Based Paint Testing Technologies: Summary Report* (EPA 747-R-95-002a), contains an overview of the results from the field study. This report is available from the National Lead Information Center (1-800-424-LEAD). The other report is a technical report entitled *A Field Test of Lead-Based Paint Testing Technologies: Technical Report* (EPA 747-R-95-002b) which presents results from the field study in detail. This report can be obtained by calling the National Technical Information Service (NTIS) at 703-487-4650 and ordering the report by its NTIS reference number, PB96-125026.

A primary conclusion of the EPA/HUD field study is that testing by K-shell XRF instruments, with laboratory confirmation of inconclusive XRF results, and with substrate correction in cases where this is effective in reducing bias, is a viable way to test for lead-based paint. This approach can produce satisfactory results for classifying the paint on architectural components using the federal threshold of 1.0 mg/cm^2. These findings were incorporated into Chapter 7 of the HUD Guidelines.

Since it was anticipated that there would be ongoing improvements in the performance of XRF instrumentation as the demand for testing for lead-based paint increased, Chapter 7 was written to defer to easily updated documents for providing testing guidance for specific instruments. The documents are called *XRF Performance Characteristic Sheets* (PCSs). PCSs are XRF instrument model specific documents intended to provide up-to-date testing guidance and performance information. This information includes the specification of conclusive and inconclusive XRF results. Each *XRF Performance Characteristic Sheet* (PCS) also states whether or not substrate correction is recommended, and, if necessary, provides supplemental guidance on field

substrate correction procedures. The PCSs also provide calibration check values to be used in conjunction with one of the NIST Standard Reference Material paint films and a procedure for evaluating XRF testing.

This report documents the methodology used to develop and produce the XRF Performance Characteristic Sheets.

1. INTRODUCTION

1.1 Background

This report documents the methodology used for developing the XRF Performance Characteristic Sheets (PCSs) produced jointly by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD). This document is to supersede previous draft versions of this document. On several occasions a different draft version was released to coincide with the release of a new PCS. No further testing or PCS development is planned under an EPA contract.

To date, eight XRF Performance Characteristic Sheets have been released by EPA and HUD and are reproduced in appendix D of this document. The PCSs are supplemental to the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* ("HUD Guidelines") mandated by Section 1017 of the Residential Lead-Based Paint Hazard Reduction Act of 1992. The HUD Guidelines provide comprehensive information on how to evaluate and respond to lead-based paint hazards in residential housing. In particular, Chapter 7 of the HUD Guidelines describes how to conduct a lead-based paint inspection. The XRF Performance Characteristic Sheets contain instrument-specific information needed to conduct a lead-based paint inspection as delineated by Chapter 7.

The data for the development of the XRF Performance Characteristic Sheets come from two sources. The first source is the EPA/HUD field study, which was conducted in 1993 to obtain the data and information necessary to develop federal guidance on lead-based paint testing. The results of the field study are published in two reports. A summary report, entitled *A Field Test of Lead-Based Paint Testing Technologies: Summary Report* (EPA 747-R-95-002a), contains an overview of the results from the field study. A technical report, entitled *A Field Test of Lead-Based Paint Testing Technologies: Technical Report* (EPA 747-R-95-002b), contains details of the study procedures and results. (The summary report is available from the National Lead Information Center by calling 1-800-424-LEAD and requesting the report by its title and EPA report number, EPA 747-R-95-002a. The technical report is available from the National Technical Information Center (NTIS) by calling 703-487-4650 and ordering the report by its NTIS reference number, PB96-125026. The HUD Guidelines are available from HUD USER by calling 1-800-245-2691 or, in the Washington D.C. area, 301-251-5154.

The second source of data for the XRF Performance Characteristic Sheets is XRF testing using an archive of samples collected during and after the EPA/HUD field study. During the field study, samples of painted housing components were removed from the houses and testing locations, repairs were made to the houses, and the samples themselves were packaged and shipped to a laboratory facility. Some

additional reference samples were acquired from EPA's Office of Research and Development, and added to the archive sample materials.

The archive materials were originally intended for quality assurance and data verification subsequent to the EPA/HUD field study and for testing a few new XRF instruments or chemical test kits that might become commercially available after the study was completed. However, at the request of HUD, the archive samples became the basis for an interim testing program for new XRF instruments while the National Institute of Standards and Technology (NIST) proceeded with the development of a protocol for laboratory testing of new XRF instruments. Accordingly, only non-destructive technologies for testing lead in paint were evaluated by the archive testing, so as to preserve the samples. Portable XRF instruments were the only technology that meet the requirement of non-destructiveness.

In most cases, the data used for developing the XRF Performance Characteristic Sheets came from either the EPA/HUD field study or from archive testing; in one case, data were available from both the field study and archive testing. The source of the data for the XRF Performance Characteristic Sheet (PCS) development is indicated on each PCS.

In the EPA/HUD field study, 1,290 test locations were marked on architectural components with an indelible-ink-inscribed standardized template in three different cities: ten single-family houses in Denver, Colorado, four units of a multifamily housing development in Louisville, Kentucky, and eight units of a multifamily housing development in Philadelphia, Pennsylvania. About ten percent of the 1,290 test locations were selected for collection for the archive facility. Building materials that contained the targeted test locations were collected and later assembled into the EPA/HUD archive facility.

At the EPA/HUD archive facility, the samples are attached to eight by four foot plywood sheets. The plywood sheets were arranged in a rectangular configuration approximately 32 feet long by 20 feet wide and 8 feet high, at least four feet within the exterior walls, and at least four feet from adjacent objects. All materials used to attach the samples to the plywood sheets were kept as far as possible from positions lying directly behind XRF test areas. To minimize interference with XRF testing, plywood was removed from the back side of the sample locations except for a few samples. These exceptions include all brick and concrete samples which were first placed in a wood box before attaching them to the plywood sheet. Furthermore, for those samples that needed additional support from behind, such as drywall, Styrofoam was placed into the hole from where the plywood had been removed. Unique numbers were assigned to each sample for identification purposes. The lead levels for each sample were determined from laboratory analysis. XRF instruments tested for lead in paint at the designated areas on each sample.

PCS information was derived from analyzing the XRF testing results and corresponding lead levels from data collected during the EPA/HUD field study or from the archive facility testing. The PCSs provide inconclusive range values and threshold values; state whether or not substrate correction is recommended; and, if necessary, provide supplemental guidance on field substrate correction procedures. Inconclusive ranges and thresholds are defined and illustrated in section 5.4. Substrate correction is discussed in section 5.3. The values reported for the inconclusive ranges and thresholds were derived from either bias-corrected XRF results or from uncorrected results, depending on whether correcting for substrate bias is recommended. Bias and precision estimates shown in the PCSs, however, were derived from uncorrected results.

Much of the information reported on a PCS consists of estimates obtained by fitting a model to XRF instrument testing data. The model, which was originally developed for the EPA/HUD field study, describes the statistical properties of XRF measurements as a function of the lead level. From the model, it is possible to estimate the bias and precision of an XRF instrument at pre-specified lead levels; determine whether or not a benefit from substrate correction is demonstrated; and, derive inconclusive ranges and thresholds for the classification of XRF measurements relative to the 1.0 mg/cm^2 federal standard. For example, with an inconclusive range of 0.8 to 1.3, an XRF result less than or equal to 0.8 indicates a lead level below the federal standard. An XRF result greater than or equal to 1.3 indicates a lead level greater than or equal to the federal standard. An XRF result strictly between 0.8 and 1.3 is regarded as inconclusive, and referred to laboratory testing for a final resolution. Inconclusive ranges and thresholds are described more fully in section 5.4 of this document.

The remaining sections of this document provide greater detail about XRF Performance Characteristic Sheets and their development. Section 2 explains compliance with Quality Assurance Project Plan Objectives. Section 3 explains archive policy issues related to testing the archive samples and PCS development. Section 4 provides descriptions of samples from both the EPA/HUD field study and the archive. Section 5 provides details of the statistical methodology used to derive the numerical information reported on a PCS. The model used for this purpose is presented, and details concerning its application to XRF measurements obtained from both the field study and archive testing are discussed. Appendix A provides information about XRF testing. Appendix B discusses the statistical treatment of XRF measurements taken with variable reading times. Appendix C lists errors and corrections in previously released XRF Performance Characteristic Sheets. Appendix D provides all of the eight XRF Performance Characteristic Sheets released to date, with all corrections made, and related empirical results corresponding to each PCS. Appendix E is an example of a sample PCS that is shorter than the current version.

The XRF Performance Characteristic Sheets (PCS) for the Princeton Gamma-Tech XK-3, the Scitec MAP-3, and the Warrington Microlead I Revision 4 were

developed from data collected during the EPA/HUD field study. A PCS for the TN Technologies Pb Analyzer was developed from the field study and from two separate testing events at the archive facility. PCSs for the Niton XL-309, the Radiation Monitoring Device LPA-1, the Advanced Detectors (formerly Xsirius) LeadStar, and the Scitec MAP 4 were developed from archive testing data. Archive testing has been conducted with the Princeton Gamma-Tech XK-3 and the Warrington Microlead I Revision 4, but the testing took place after the release of the first edition of the PCS for those two instruments. Results of archive testing for the XK-3 and the Microlead I Revision 4 have not been included in the development of the PCS for those two instruments.

1.2 Peer Review

This report was reviewed independently by five members of a peer review panel. Peer review comments which are important for interpreting the report are discussed below.

A reviewer commented on the distribution of lead levels in the archive samples and choice of the pivotal values 0.5 mg/cm^2 and 2.0 mg/cm^2 for determining inconclusive ranges and thresholds. These pivotal values were chosen because they produced inconclusive ranges and thresholds that were most similar to those obtained under a direct and more complicated derivation, which involves integrating against a lognormal density.

Another comment was related to the equal weighting of results from the EPA/HUD field study and archive testing. In making the comment, however, the reviewer noted that combining results of the field study and archive study by weighting by sample size would cause the field study to dominate the archive testing. Upon consideration of the comment, equal weighting of the archive testing and the field study results was deemed appropriate.

One reviewer pointed out that the report indicated that in certain cases uncorrected XRF results as high as 3.0 mg/cm^2 could be false positives (that is, the true lead level could in fact be less than 1.0 mg/cm^2 as measured by laboratory analysis). The XRF Performance Characteristic Sheets have always used 4.0 mg/cm^2 as the cut-off for substrate correction. Section 5.3.2, **Measurement Range Subject to Substrate Correction**, discusses this issue.

Another reviewer commented on a perceived lack of “real world” testing, and raised a number of concerns, such as effects of electrical wiring, piping, fasteners, grease, dirt, contact papers, irregular surfaces, and electromagnetic fields and the decision to test instruments with radioactive sources no older than six months. The archive was constructed almost exclusively with “real world” painted components from houses and dwelling units built before 1978. Numerous different textures, surfaces,

paint layerings, and substrate combinations are present in the archive. Although it has been beyond the scope of archive testing to test the effects of wiring, piping, fasteners, and electromagnetic fields, federal guidance has tended to recommend avoiding testing where and when there are obvious potential interferences. The decision to use sources no more than six months old has been done for two reasons: 1) to test instruments under the most similar conditions possible and 2) to perform instrument testing as quickly as possible. Testing with an older source can make use of a PCS by increasing the reading time as necessary, according to the age and half-life of the source. Whether older sources raise performance issues, aside from requiring longer reading times, has not been explored.

There were many comments regarding the clarity of the presentation, especially technical issues. Revisions for clarity were made in most of those sections indicated by the reviewers. However, some sections were unavoidably technical and detailed. One reviewer commented that the XRF Performance Characteristic Sheets were too detailed and confusing, and commented favorably on the proposed shortened version of a PCS provided in one of the appendices of this report. The proposed shorter form will not be pursued by EPA at this time. The shorter form or a similar form may be pursued in the future.

There were review comments on editorial mistakes in the XRF Performance Characteristic Sheets and on simple calculation errors in some of the empirical results tables associated with the XRF Performance Characteristic Sheets. Corrections were made where necessary. Other corrections to the PCSs, based on internal review, were also made. Appendix C contains a summary of the corrections to the PCSs. Appendix D contains all the XRF Performance Characteristic Sheets released to the public as of August 31, 1997, with all corrections made.

2. COMPLIANCE WITH QUALITY ASSURANCE PROJECT PLAN OBJECTIVES

The development of Performance Characteristic Sheets follows from objectives laid out in an addendum to "Quality Assurance Project Plan for Comparative Field Study of Methodologies Used to Detect Lead in Paint" dated December 14, 1994. These objectives are listed and discussed below:

The first and primary objective was to provide a limited evaluation of new XRF instruments that were not in the full study and to report the results to HUD.

The archive facility was designed to meet this objective. Archive testing is the basis for the development of PCSs for instruments that were not tested in the full (EPA/HUD field) study. For instruments that were tested in the full study, PCSs have been developed using the study data, possibly in combination with archive testing data.

The addendum listed eight "study objectives" that further elaborated the goals of the first objective:

(1) *Estimate the bias of the new XRF instruments at 0 and 1.0 milligrams per square centimeter to within plus or minus 0.2 with 95% confidence, overall, and to within plus or minus 0.4 with 95% confidence on wood, metal, and plaster.*

Tables in appendix D of this document report estimated standard errors for the bias at the 0.0 and 1.0 mg/cm^2 lead levels, for each XRF instrument that has a PCS. These standard errors, reported by substrate, seldom exceed 0.1. A 95% confidence interval is formed by adding and subtracting 2 times the standard error from the bias estimate, which suggests that objective (1) is achieved on a substrate-specific basis. The standard error of a pooled estimate, consisting of a weighted average of substrate-specific estimates, would satisfy the plus or minus 0.2 criterion for those instruments that have a PCS.

(2) *Estimate the precision of the new XRF instruments at 0 and 1.0 milligrams per square centimeter to within plus or minus 3 times what was in the full study (with 95% confidence), overall and on wood, metal, and plaster.*

Estimates from the full EPA/HUD field study are based on a sample size of about 1,200. Estimates for new XRF instruments are based on archive tests, each of which contributes a sample size of about 150. The sample size ratio, based on a single archive test, is approximately 8, and the square root of this ratio is less than 3. In addition, precision estimates for newer XRF instruments have been found to be lower than for instruments tested in the field study. These factors suggest that objective (2) is met by the PCS development process.

(3) *Develop an operating characteristic curve over all substrates and on wood, metal, and plaster for each new XRF. Estimate the threshold probability and 50% point with precision no more than three times the standard errors of similar parameter estimates in the full study.*

The PCS development process does not make use of the information that an operating characteristic curve would provide, including the threshold probability and 50-percent point. Operating characteristic curves and quantities derived from them are therefore not estimated.

(4) *Estimate the inconclusive region for each XRF using order statistics, overall and on wood, metal, and plaster. Compute misclassification rates and inconclusive rates overall and for wood, metal, and plaster substrates.*

The estimation of inconclusive regions is central to the PCS development process. These regions consist of inconclusive ranges and thresholds that are derived from a model that is fit to testing data. Misclassification and inconclusive rates are reported in appendix D of this document.

A model-based approach is used instead of order statistics, because sample sizes are usually too small to obtain stable estimates using the latter approach. A model-based approach overcomes this difficulty by imposing reasonable assumptions on the data. Estimated percentiles are obtained as simple functions of the estimated model parameters. Calculation of inconclusive ranges and thresholds is fully explained in section 5.4 of this document.

(5) *Estimate the bias and precision of each new XRF on the NIST SRMs and develop control limits for usage of these instruments in the field.*

Control readings are made in the archive testing of an XRF instrument, using the NIST Standard Reference Material paint films (SRMs). The NIST SRMs and their role in archive testing are more fully discussed in section 4.4 of this document. Readings made on red NIST SRMs, which have a lead level of 1.02 mg/cm^2, over wood control blocks are used to estimate bias and precision. These bias and precision estimates are then used to derive the calibration check bounds that appear on a PCS, as described in section 5.5 of this document.

(6) *Estimate time for a nominal reading using the standard operating protocol for each new instrument.*

For instruments that have a variable-time reading mode, a statistical summary of reading times is given on the PCSs. As explained in appendix E, this information is provided to give a more complete accounting of the precision of XRF measurements taken with variable reading times. In fixed-time reading mode, the situation is simpler: actual reading times are longer than nominal reading times by a factor that depends on the age and type of radioisotope used by the instrument. The reading time does not raise precision issues for an instrument in fixed-time reading mode, and for this reason information about the actual versus nominal reading time is not provided on the PCSs for these instruments.

(7) *Determine the influence of paint thickness on XRF measurements.*

This objective was not addressed by the PCS development process, because paint thickness is not a controllable factor in nondestructive lead testing. Variation in XRF measurements that is due to paint thickness is treated as a part of the total variation attributed to an instrument.

(8) *Assess the performance of auxiliary indicators of XRF performance, such as the "absorption index" of the Niton XL.*

The auxiliary indicators referred to are typically specific to a given instrument. To include an assessment of the performance of each of these indicators would require the PCSs to depart from a standardized format. For this reason the PCSs are not designed to address every data feature of an XRF instrument, but only those most directly related to performance issues that are common to all XRF instruments. The PCS development process retains the flexibility to include new instrument features, as it has done, for instance, with variable-time reading modes, which have been adopted by a number of instruments.

The second objective was to deal with spatial variability in the paint samples. This was done by taking a second sample for ICP analysis so as to better characterize the lead in the paint in the XRF test area, by using this second sample to validate interpolation models, and by taking XRF readings at additional locations on the archived material to determine the impact of additional areas on XRF measurements.

A second set of ICP measurements was taken on each of the archive samples, and XRF measurements are taken on as many as three separate locations per sample in archive testing. These additional measurements have not been used to date in the PCS development process. The main obstacle to their usage is the need for further research into how the additional data can be used to effect an improvement in

estimation. This is discussed in section 5.2 of the present document for the case of laboratory duplicate ICP measurements.

The addendum listed three "study objectives" that further elaborated the goals of the second objective:

(1) *Estimate the lead in paint in the primary XRF testing area using an average of samples near the primary XRF testing area.*

The average of multiple ICP measurements is not currently used as an estimate of the true lead level in the PCS development process, because it is not clear that the average constitutes an improvement over the use of a single measurement. This point is further explained in response to (2) below.

(2) *Investigate interpolation models for spatial variation in paint using paint chip samples at varying distances.*

Further investigation of the spatial variation in lead levels across a sample was suggested by the results of the EPA/HUD field study. The method used to account for this variation will play a key role in determining how multiple ICP measurements can be combined to obtain an improved estimate of the lead level. The development of a model for this purpose was investigated, but is not complete at this time, and remains an area for possible future research.

(3) *Characterize differences between XRF testing at one area versus XRF testing at three areas on a sample.*

Variation in XRF measurements across an archive sample has been noted. Some of this variation may be attributed to spatial variation in lead levels, as discussed above. Other sources of variation are attributable to the XRF instrument. The characterization of these sources of variation remains an area for future research.

The third and last objective was to determine if the order of substrate materials has an effect on XRF readings.

In the archive testing of an XRF instrument, the samples are tested in a randomized order. As a result, consecutive readings usually involve a change in substrate materials. The issue of whether these substrate changes introduce effects was investigated with the TN Technologies Pb Analyzer, which was the first XRF instrument tested at the archive facility. A preliminary set of measurements was taken

on the archive samples ordered by substrate. No significant differences were found between the two sets of measurements. This issue is discussed in section 4.5 of the present document.

3. ARCHIVE FACILITY TESTING AND REPORTING

This chapter describes in general terms the testing of the archive samples and the release of the resulting XRF Performance Characteristic Sheets. Testing and publication practices are described, as are recommendations for improvements in the future.

3.1 Initial Testing of New Instruments

Underlying the XRF Performance Characteristic Sheets is the concept of responding to changes in technology. The PCSs are regarded as documentation that can be supplemented, replaced, or updated as new XRF instruments enter the market.

As stated above, testing with the archive samples has been restricted to non-destructive technologies, and at this time portable XRF instruments are the only paint testing technology that meets the requirement of being non-destructive for archive testing purposes. Archive testing policy has placed the first priority on testing new instruments from manufacturers who have not had an XRF Performance Characteristic Sheet published in the past. The second priority has been on testing instruments that can be ascertained to be different from past and current instruments by a review of product literature and operations manuals. Changes to instruments that are cosmetic in nature or otherwise do not affect the readings of lead in paint have not called for archive testing to date. However, some instruments that were extensively tested in the EPA/HUD field study were tested at the archive at the request of the National Institute of Standards and Technology (NIST). Data from these instruments was collected following protocols that allow the data to be used for PCS development.

3.2 Testing Practices

After an instrument has been designated for testing, a protocol for archive testing is developed, based on the operations manual for the instrument and the data requirements for producing a PCS. The protocol indicates which operation modes of the instrument will be used, if there is more than one mode.

Operation of the XRF instruments during archive testing has been carried out either by Dr. Mary McKnight of NIST or by operators from independent testing companies under subcontract to an EPA contractor. Testing has been supervised and monitored by staff from organizations under contract to EPA. Operators from testing companies have been required to obtain training with the instrument they operate prior to archive testing. Instruments with sources no more than six months old are preferred, and most of the archive testing has been done with such instruments. Two rounds of

testing, with different machines[1] of the instrument type, are preferred in order to obtain information about variation across machines at minimal cost. In practice, for a variety of reasons, PCSs have been released with only one round of testing, or with more than two rounds of testing. All rounds of testing that are available at the time of PCS development are used.

Instruments operated by Dr. McKnight have been owned by NIST or, in one case, loaned to NIST. Instruments operated by the personnel from testing companies may be owned or leased by the companies. For subcontractor testing, manufacturers have been asked by archive facility staff to furnish the names of three or more testing companies that might bid on the testing subcontract. It is plausible that the manufacturers loan new machines to the subcontractors for use in archive testing, as would be expected for a new model or version of the instrument.

An instrument may fail to pass a calibration check, experience battery failure, or may for other reasons be precluded from further use during testing. When such cases have arisen, the instrument in question has been replaced by a back-up machine so that testing may be completed on all archive samples. For subcontractor testing, it has become a standard policy to require that a back-up machine be available on-site. If an instrument fails during testing, all readings since the last successful quality control (QC) check are repeated. Quality control procedures are discussed in section 4.4.

3.3 Analysis of Data and Release of the XRF Performance Characteristic Sheets

After completion of testing, the test data are analyzed to meet the reporting requirements in the XRF Performance Characteristic Sheets. The key elements for the PCS are the determination of the inconclusive range or threshold for each substrate, the determination of substrates for which substrate correction is recommended, and the determination of the tolerance values for calibration checks specified by Chapter 7 of the HUD Guidelines. Estimates of bias and precision of the instrument are also published as part of the PCS. Each Sheet is reviewed, and after resolution of comments, the Sheet is made available to the public through the National Lead Information Center. Copies of the Sheets can be requested by calling 1-800-434-LEAD and requesting the XRF Performance Characteristic Sheets.

Although it is not stated on the PCS, testing with a PCS that is current at the time of testing is considered by EPA and HUD to be valid testing, regardless of any

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[1]It is necessary to distinguish a *type* of instrument (model, make, version, etc.) from a physical *unit*. The term “instrument” is used to refer to either where doing so is not ambiguous. Otherwise, the term “instrument” is used to refer to a type, and the term “machine” is used to refer to a physical unit.

subsequent changes in PCS methodology or in XRF instrumentation. However, it is expected that a tester will always make sure that he or she is using a current PCS at the time when conducting a lead-based paint inspection.

3.4 Future Improvements

Based on experiences with testing, a number of areas of archive facility testing and PCS development are subject to change. The PCSs themselves could be simplified in the future (an example of a simplified PCS is in appendix E). Because of the increased availability of XRF modes that have a variable instead of a fixed time, an analysis approach for variable time modes has been developed. (This approach is described in appendix B). The issue of making recommendations for substrate correction based on archive samples is one that requires additional research.

4. SAMPLE DESCRIPTIONS AND SAMPLING PROTOCOL SUMMARY

4.1 Sample Descriptions

4.1.1 EPA/HUD Field Study Sample Descriptions

For the EPA/HUD field study, primary among considerations for the selection of housing units was the selection of units with a wide distribution of surface types and the selection of units that were likely to represent those that are currently being routinely tested for lead-based paint. Therefore, both multifamily housing units and single-family housing units were included in the field study to generate results that represent both these types of housing.

With the cooperation of the public housing authority and following site inspections by study team members, test locations in the EPA/HUD field study were selected in housing units in three different cities. In Louisville, Kentucky, test locations were selected in four units in a multifamily housing development, two units each inside two buildings of the development. In Denver, Colorado, test locations were selected in ten single-family homes and in Philadelphia, Pennsylvania, eight units in a multifamily housing development were selected inside two buildings of the development.

Within the housing units chosen for the study, test locations were selected and marked. A test location was an area on a painted building component where measurements for lead-based paint were taken. Examples of building components included walls, baseboards, doors, and window frames. The material underlying the test locations was classified as being one of the following six substrates: brick, concrete, metal, drywall, plaster, or wood.

A breakdown of the selected test locations for each city in the EPA/HUD field study follows. In Louisville, a total of 25 test locations per housing unit were selected for testing for a total of 100 locations. A total of 75 test locations per house were selected in Denver and 55 locations per housing unit were selected in Philadelphia. Thus, a total of 1,290 test locations were selected for the EPA/HUD field study. Table 4-1 provides an additional breakdown of test locations for each of the six substrates.

Table 4-1. Number of Test Locations Per Substrate by Dwelling in the EPA/HUD Field Study.

CITY	DWELLING	YEAR BUILT	NUMBER OF TEST LOCATIONS PER SUBSTRATE					
			Brick	Concrete	Drywall	Metal	Plaster	Wood
Louisville	1	1937	0	4	4	17	9	16
	2	1937	0	4	7	11	11	17
Denver	1	1943	20	4	4	4	15	28
	2	1948	0	1	0	10	20	44
	3	1952	0	2	8	2	22	41
	4	1905	0	15	25	3	10	22
	5	1949	3	0	20	6	0	46
	6	1948	0	6	18	8	0	43
	7	1952	0	10	16	12	0	37
	8	1890	21	15	1	6	13	19
	9	1949	21	1	0	9	21	23
	10	1947	16	44	13	2	0	0
Philadelphia	1	1942	2	15	2	16	11	9
	2	1942	2	15	2	12	12	12
	3	1942	0	15	2	16	13	9
	4	1942	0	15	2	19	13	6
	5	1942	2	15	0	16	18	4
	6	1942	2	15	0	16	18	4
	7	1942	2	15	0	16	18	4
	8	1942	2	15	0	16	18	4

4.1.2 Archive Sample Descriptions

The EPA/HUD archive facility is a collection of 158 samples that has been assembled as a mechanism for testing and evaluating XRF instruments. Each archive sample consists of a substantial piece of painted substrate that has been kept intact as much as possible, and displaying the testing template, if applicable.

Ten percent of the 1,290 test locations in the EPA/HUD field study were targeted for archiving. Given the likelihood of breakage, slightly more than ten percent were selected for removal in order to collect at least the targeted number of samples. The selection of test locations were made by a field statistician under constraints such as ease of removal and transport, willingness of the public housing authority to allow the

removal, and lead levels in the paint as measured by prior XRF testing data[2]. None of the selected samples were marked as archive samples until all testing was completed.

Archive sample selections were made using a randomized stratification sampling scheme; the stratification was based on lead levels provided by XRF measurements. Of the selected test locations, (approximately) one-fourth of them were selected from test locations with measured lead levels less than 0.5 mg/cm^2 lead, another one-fourth of them were selected from test locations with measured lead levels equal to and greater than 3.0 mg/cm^2 lead, and the remaining one-half of the test locations were selected from test locations with measured lead levels equal to and greater than 0.5 mg/cm^2 lead but less than 3.0 mg/cm^2 lead. The removal of wood, metal, drywall, and plaster test materials was relatively straightforward. (However, several of the drywall and plaster samples were very fragile and became unusable due to breakage during removal or shipping). Brick and, especially, concrete test materials were much more difficult to remove.

After the samples were removed from the houses and testing locations, the samples themselves were packaged and shipped to a site that became the archive facility. Next, the samples were mounted onto four by eight foot plywood sheets. The plywood sheets were arranged in a rectangular configuration approximately 32 feet long by 20 feet wide and 8 feet high, at least four feet within the exterior walls, and at least four feet from adjacent objects. All materials used to attach the samples to the plywood sheets were kept as far as possible from positions lying directly behind XRF test areas. To minimize interference with XRF testing, plywood was removed from the back side of the sample locations except for a few samples. These exceptions include all brick and concrete samples, which were first placed in a wood box before attaching them to the plywood sheets. Furthermore, for those samples that needed additional support from behind, such as drywall, Styrofoam was placed into the hole resulting from the removal of the plywood. Unique numbers were assigned to each sample for identification purposes. The lead levels for each sample were determined from laboratory analysis. XRF instruments tested the designated area on each sample for lead.

The total number of test samples from the EPA/HUD field study that actually became mounted in the archive facility was 132 samples. From all four units in Louisville, a total of 13 field study test samples were collected and mounted at the archive facility. From nine houses in Denver, 76 field samples were collected and mounted and from three units in Philadelphia, 43 field samples were collected and mounted.

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[2]Selections were made in the field, after XRF testing had been done but before paint samples were analyzed by the laboratory. Thus, at the time, the best available source of lead level measurements were provided by XRF instruments.

Twenty-six additional samples were mounted and became archive samples. During the EPA/HUD field study in Louisville, building components were retrieved from construction site waste areas; nine of them became archive samples. Thirteen samples were added simply by marking test areas on the back sides of 13 already-mounted archive samples. The last additions were four wood samples that were donated to the archive facility from another lead-based paint research project funded by EPA's Office of Research and Development. Thus, the archive facility includes a total of 158 archive samples. Table 4-2 provides a summary of the origin, date, and the number of archive samples per substrate type by dwelling.

4.2 Component Makeup

Samples from the EPA/HUD field study and samples in the archive facility were categorized into the building components from which they were made. These components, for example, in a bedroom, could be the ceiling, floor, walls, a door, its casing, the window sash, or casings. Table 4-3 displays number and overall percent of samples in the field study samples for each type of component. Table 4-4 provides the same information for the archive samples.

4.3 Distribution of Lead Levels

In the EPA/HUD field study, paint samples were collected at 1,290 sampling locations in the three cities. There were 100 locations in two multifamily buildings in Louisville, 750 in ten single-family houses in Denver, and 440 in eight multifamily units in Philadelphia. Each sample was analyzed using a modified NIOSH 7082 method[3] applied to a 0.5 gram subsample of the sample (if it weighed more than 0.5 gram), taken after homogenization of the sample. Table 4-5 presents summary statistics in mg/cm^2 lead by substrate, aggregated across cities from the 1,290 test locations in the field study and from the 158 test locations in the EPA/HUD archive facility. Comparisons of the medians to the arithmetic means shown in Table 4-5 indicates that the lead level distribution is skewed toward high levels in most cases.

[3]The NIOSH Method 7082 is designed to prepare and analyze air filter samples for analysis of many inorganic elements, including lead. Modifications were needed to make it applicable to processing paint samples. Details are provided in the technical report to the EPA/HUD field study.

Table 4-2. The Originating City and Construction Date (if known) of Archive Samples Categorized by Dwelling and Substrate Type

ORIGIN	DWELLING[a]	YEAR BUILT	NUMBER OF TEST LOCATIONS PER SUBSTRATE					
			Brick	Concrete	Drywall	Metal	Plaster	Wood
Louisville	1	1937	0	0	0	1	1	6
	2	1937	0	0	0	2	2	1
	unknown[b]	1937	0	0	1	5	3	0
Denver	2	1948	0	0	0	5	1	9
	3	1952	0	0	3	0	1	9
	4	1905	0	1	0	1	0	3
	5	1949	0	0	0	2	0	2
	6	1948	0	0	2	1	0	7
	7	1952	0	0	2	1	0	7
	8	1890	3	0	1	2	4	3
	9	1949	0	0	0	1	1	2
	10	1947	0	1	5	0	0	0
Philadelphia	5	1942	0	0	0	6	8	5
	6	1942	0	0	0	6	7	1
	8	1942	0	0	0	5	10	4
Backside	n/a	n/a	0	0	0	0	7	6
Donated	unknown[c]	unknown[c]	0	0	0	0	0	4

[a]The dwelling numbering scheme is described in the technical report to the field study.
[b]Building components were retrieved from the construction site waste areas within the multifamily development where the EPA/HUD field study was being conducted. Even though the exact unit from which these samples were taken is not known, it is reasonable to assume that all units in the housing development were constructed at the same time.
[c]Samples donated from another lead-based paint research project funded by EPA's Office of Research and Development.

Table 4-3. The Number and Overall Percent of Samples in the EPA/HUD Field Study for Each Type of Component.

COMPONENT	NO. OF SAMPLES	OVERALL PERCENT	COMPONENT	NO. OF SAMPLES	OVERALL PERCENT
Ext. door frame	58	4.5	Gutter	16	1.2
Door frame	9	0.7	Downspout	13	1.0
Exterior door	7	0.5	Door jamb	30	2.3
Interior door	9	0.7	Door casing	5	0.4
Ext. window sill	2	0.2	Door	84	6.5
Int. window sill	3	0.2	Window sill	34	2.6
Window casing	27	2.1	Window sash	9	0.7
Bar top	2	0.2	Facia	12	0.9
Threshold	5	0.4	Shutter	2	0.2
Shelf	47	3.6	Header	17	1.3
Closet wall	8	0.6	Drawer	2	0.2
Shelf support	19	1.5	Cabinet	24	1.9
Wall trim	13	1.0	Closet door	5	0.4
Wall	513	39.8	Closet shelf	3	0.2
Support column	47	3.6	Foundation	20	1.6
Ceiling beam	54	4.2	Mail box or slot	3	0.2
Ceiling hatch door	3	0.2	Heating register	1	0.1
Floor baseboard	43	3.3	Pipe	8	0.6
Elec. box cover	9	0.7	Plumbing access	7	0.5
Duct	34	2.6	Rafter support	2	0.2
Stair riser	17	1.3	Rafter	6	0.5
Stair stringer	2	0.2	Floor	13	1.0
Coat rack support	1	0.1	Roof flashing	2	0.2
Medicine cabinet	4	0.3	Closet baseboard	14	1.1
Side of bar	1	0.1	Awning	6	0.5
Railing cap	7	0.5	Unknown	8	0.6

Table 4-4. The Number and Overall Percent of Samples in the EPA/HUD Archive Facility for Each Type of Component.

COMPONENT	NO. OF SAMPLES	OVERALL PERCENT
Door frame	3	1.9
Door: exterior	1	0.6
Door: interior	3	1.9
Threshold	1	0.6
Shelf	11	7.0
Closet wall	1	0.6
Shelf support	5	3.2
Wall trim	5	3.2
Wall	50	31.6
Ceiling hatch door	1	0.6
Floor baseboard	16	10.1
Electrical box cover	2	1.3
Duct	2	1.3
Medicine cabinet	3	1.9
Gutter	4	2.5
Downspout	5	3.2
Door jamb	1	0.6
Door casing	1	0.6
Door	16	10.1
Cabinet	6	3.8
Closet shelf	1	0.6
Mail box or slot	2	1.3
Pipe	1	0.6
Closet baseboard	5	3.2
Awning	3	1.9
Unknown	9	5.7

4.4 Control Blocks and Quality Control Procedures

Control blocks were developed to permit the investigation of quality control (QC) procedures and for calibration check development. Control blocks were constructed from various building materials representing the commonly encountered substrates. XRF measurements were taken on the control blocks while covered with known levels of lead-in-paint films enclosed in plastic. The plastic film is a Standard Reference Material (SRM 2579) available from the U.S. National Institute of Standards and Technology (NIST) and referred to as NIST SRM films. XRF measurements were also taken on control blocks that were not covered with the NIST SRM films.

Control blocks were constructed of six different types of materials: brick, concrete (with aggregate), drywall, metal, plaster, and wood (pine). The brick control block was a "standard" baked clay brick. The other five control blocks measured approximately four by four inches on the surface and varied in thickness, depending on their composition.

For each XRF testing day, all control block measurements made by a specific XRF operator were always performed on the same set of control blocks at a fixed location and the blocks were always placed on twelve inches of Styrofoam support. These restrictions were made to assure that differences observed in control block data would be free from influence from physical differences (including control block differences) and to eliminate any effects from underlying materials.

Three types of control block measurements were taken: 1) beginning of test day, 2) periodically during the day, and 3) at the end of the test day. For information on control block testing for specific XRF instruments and locations, refer to the testing protocols described in appendix A.

4.5 Order of Testing

For the EPA/HUD field study, XRF testing was performed in a specific testing order with respect to substrate type. All like substrates in a unit were grouped together for testing before moving to the next substrate. An analysis of the data collected for the field study gave indication that the grouped-substrate ordering did not affect the accuracy of XRF measurement data. (A detailed description of the ordering and analysis is provided in the technical report to the field study). XRF measurements of archive samples taken in grouped-substrate order were compared to XRF measurements of archive samples taken in random order. Similarly, results showed that the ordering did not affect XRF measurements. These results are given below. Therefore, for PCS development, archive samples were tested in a random order, irrespective of substrate, to better match the ordering that would typically occur in a lead-based paint inspection.

4.5.1 Archive Sample Ordering

In January 1995, the Pb Analyzer XRF was used for two rounds of archive testing. For the first round of testing, the archive samples were tested using a grouped-substrate ordering. For the second round, the archive samples were tested in random order. A comparison of the two types of ordering was made by comparing the XRF measurements taken during each round. Estimates of bias and precision, for non-substrate corrected (uncorrected) XRF results, at four levels of lead in paint: 0.0, 0.5, 1.0, and 2.0 mg/cm^2 were computed using a regression model for each round of testing. (The issue of substrate correction is discussed in section 5.3). Table 4-6 provides the bias estimates and Table 4-7 provides the precision estimates for each round of testing. Comparisons of the values in these tables indicates that the order of testing has little effect on these estimates.

Table 4-5. Summary Statistics of Laboratory Modified NIOSH 70821 ICP Analyses Results Reported in mg/cm^2 Lead Units Categorized by Substrate For Samples From the EPA/HUD Field Study and Samples In the EPA/HUD Archive Facility.

STUDY	SUBSTRATE	SAMPLE SIZE	MINIMUM	25TH PERCENTILE	MEDIAN	ARITHMETIC MEAN	75TH PERCENTILE	MAXIMUM	STANDARD DEVIATION
Archive	Brick[a]	3	0.0035	-	10.72	9.41	-	17.50	8.82
	Concrete[a]	2	0.0009	-	0.05	0.05	-	0.10	0.07
	Drywall	14	0.0002	0.0014	0.04	0.20	0.25	0.90	0.31
	Metal	38	0.0032	0.1340	0.32	0.85	1.56	3.97	1.03
	Plaster	38	0.0024	0.1602	0.31	1.72	0.75	16.07	3.83
	Wood	63	0.0003	0.0821	0.46	2.69	2.22	30.11	5.89
Field	Brick	93	0.0001	0.003	0.19	3.38	0.65	34.09	7.13
	Concrete	226	0.0005	0.02	0.19	0.74	0.43	15.98	1.98
	Drywall	124	0.0001	0.002	0.02	0.09	0.08	0.90	0.17
	Metal	217	0.0002	0.10	0.34	0.79	0.90	6.50	1.14
	Plaster	242	0.0003	0.10	0.23	1.02	0.42	37.29	3.47
	Wood	388	0.0001	0.04	0.17	1.54	1.36	30.11	3.68

[a]The 25th and 75th percentiles were not reported for these cases due to small sample sizes.

Table 4-6. Bias Comparison Calculated Based on Measurements Taken by the Pb Analyzer in Grouped-Substrate Order and in Random Order.

LEAD LEVEL (mg/cm^2)	BIAS (mg/cm^2)	
	Grouped-Substrate Order	Random Order
0.0	0.00	0.03
0.5	0.19	0.21
1.0	0.37	0.38
2.0	0.75	0.73

Table 4-7. Precision Comparison Calculated Based on Measurements Taken by the Pb Analyzer in Grouped-Substrate Order and in Random Order.

LEAD LEVEL (mg/cm^2)	PRECISION* (mg/cm^2)	
	Grouped-Substrate Order	Random Order
0.0	0.11	0.12
0.5	0.37	0.35
1.0	0.52	0.47
2.0	0.72	0.66

*Precision at 1 standard deviation

The nonparametric sign test was used to test XRF measurements for differences in results from the two rounds of testing. The XRF measurements from the first round of testing were paired with XRF measurements from the same sample in the second round of testing. A total of 153 measurement pairs were used in the sign test. In 75 pairs, the measurements taken in random order were greater than measurements taken in grouped-substrate order, in 68 pairs the measurements taken in grouped-substrate order were greater, and in 10 pairs the measurements were equal. This result is consistent, at the 5 percent level, with the null hypothesis that there is no effect attributable to the order in which the measurements were taken.

4.6 Testing Protocols

Testing protocols for each XRF instrument under evaluation were developed from manufacturer-supplied documents such as the manufacturers' instrument operating manuals. Efforts were made to perform XRF testing in a manner consistent with manufacturer guidance subject to the restriction that no destructive testing is permitted. Sampling locations were tested using extensive before, during, and after

quality control checks on NIST SRM films placed over control blocks of representative substrates. Testing at each sampling location included XRF measurements on one or more painted surfaces plus XRF measurements on a bare substrate area both with and without being covered by the 1.02 mg/cm^2 lead NIST SRM film. Appendix A provides additional information about the XRF instrument testing protocols.

4.7 EPA/HUD Field Study Data vs. Archive Facility Data

XRF Performance Characteristic Sheets were developed using data collected either from the EPA/HUD field study or from testing archive samples. It should be noted that the archive samples are not a subset of those in the field study, but a smaller set that largely overlaps the field study samples as well. A comparison of the field study data to the archive facility data can be made by comparing the performance of the Pb Analyzer in the field study with its performance in archive testing. Results from the Pb Analyzer were selected for this comparison since the instrument used to test the archives was the same physical instrument used to test a majority of the test locations in the field study. Furthermore, the same individual operated the Pb Analyzer for all of the testing on archives and field samples.

The data collected from the EPA/HUD field study (and reported in *A Field Test of Lead-Based Paint Testing Technologies: Technical Report*, EPA 747-R-95-002b, May 1995) are designated below as "FIELD". The data collected from the archive testing is designated below as "ARCHIVE".

Comparisons of the information presented on PCSs are the basis for making comparisons of the performance of the Pb Analyzer. Results from each of the following are examined and discussed below: 1) substrate correction recommendations, 2) calibration checks, 3) inconclusive ranges and thresholds, 4) bias, 5) precision, and 6) empirical results. In general, these results do not indicate better performance on the archive samples. However, some differences were observed and are stated below.

1) Substrate correction recommendation: There is no need of, or benefit from, substrate correction as indicated by the results from both the archive testing and the field study.

2) Calibration checks: Calibration checks, computed from results of the field study and archive testing, are presented in Table 4-8. A calibration check consists of an interval bounded at the lower end by a “minus value” and at the upper end by a “plus value.” The minus and plus values, which are estimated from measurements taken on red NIST SRM films (1.02 mg/cm^2 lead level) placed over wood control blocks, are used to determine if an XRF machine is operating within acceptable calibration parameters, as explained in section 5.5. It is seen in Table 4-8 that the widths of the two intervals are the same, but the interval from the field study is more nearly centered about zero.

Table 4-8. Calibration Check Comparison Computed from Measurements Taken by the Pb Analyzer.

TYPE	CALIBRATION CHECK (mg/cm^2)	
	Field	Archive
Minus value	-0.3	-0.2
Plus value	+0.4	+0.5

3) Bias: The bias of the field study measurements and the archive testing measurements are provided below in Table 4-9. These bias figures are estimates derived from fitting a model to the data, as explained in section 5.1. A comparison of the biases from the two sources shows that in all but one case, the absolute value of the bias estimates for the field measurements were less than those for the archive measurements. On the archive, Pb Analyzer measurements exhibited very little bias at lead levels near 0.0 mg/cm^2, but the bias was positive and became progressively larger as the lead level increased. Therefore, some differences in bias can be observed when comparing Pb Analyzer measurements on field study samples to archive samples. It is important to note, however, that other instruments have demonstrated both high and low bias on the archive samples. The XL demonstrated low bias on the archive samples. The LPA-1, on one occasion, demonstrated low bias and on another occasion, demonstrated high bias on the archive samples. These biases may be observed in the PCSs provided in appendix D. Thus, there is a lack of evidence to conclude that the bias with the archive samples differs from the field study samples bias.

4) Precision: The precision of the field study measurements and the archive testing measurements are provided in Table 4-10. These precision figures are estimates derived from fitting the same model to the data that gave the bias estimates presented in Table 4-9. As occurred for the bias comparison, in all but one case the precision estimates of the field measurements were less than or equal to those for the archive measurements for the Pb Analyzer. However, other XRF instruments have measured field and archive samples with varying degrees of precision as shown in the PCSs in appendix D. Therefore, there is a lack of evidence to conclude that the precision of measurement of archive samples differs from that of the field study.

Table 4-9. Bias Comparison for Measurements Taken by the Pb Analyzer.

LEAD LEVEL (mg/cm^2)	SUBSTRATE	BIAS (mg/cm^2)	
		Field	Archive
0.0	Brick	0.0	0.0
	Concrete	0.0	0.0
	Drywall	0.0	0.0
	Metal	1.0	0.0
	Plaster	0.0	0.0
	Wood	0.0	0.0
0.5	Brick	0.0	0.2
	Concrete	0.0	0.2
	Drywall	0.1	0.2
	Metal	0.0	0.2
	Plaster	0.0	0.2
	Wood	0.0	0.2
1.0	Brick	0.0	0.4
	Concrete	0.0	0.4
	Drywall	0.2	0.4
	Metal	0.0	0.4
	Plaster	-0.1	0.4
	Wood	0.3	0.4
2.0	Brick	0.0	0.7
	Concrete	0.0	0.7
	Drywall	0.4	0.7
	Metal	0.0	0.7
	Plaster	-0.3	0.7
	Wood	0.6	0.7

5) Inconclusive ranges and thresholds: The inconclusive ranges and thresholds computed from results of the field study and the archive testing are provided in Table 4-11. Section 5 provides details on how these values were computed. Comparison of the results from the two sources shows differences in thresholds and inconclusive ranges. Thresholds are present for brick, concrete, and plaster substrates for the field results whereas no thresholds are shown for any of the substrates for the archive results. For the other three substrates, the inconclusive ranges are all wider for the archive results. However, the thresholds and inconclusive ranges determined from EPA/HUD filed study data are included within the inconclusive ranges determined from archive data.

Table 4-10. Precision Comparison for Measurements Taken by the Pb Analyzer.

LEAD LEVEL (mg/cm^2)	SUBSTRATE	PRECISION* (mg/cm^2)	
		Field	Archive
0.0	Brick	0.1	0.1
	Concrete	0.1	0.1
	Drywall	0.1	0.1
	Metal	0.2	0.1
	Plaster	0.1	0.1
	Wood	0.1	0.1
0.5	Brick	0.3	0.3
	Concrete	0.3	0.3
	Drywall	0.2	0.3
	Metal	0.3	0.3
	Plaster	0.2	0.3
	Wood	0.3	0.3
1.0	Brick	0.4	0.5
	Concrete	0.4	0.5
	Drywall	0.3	0.5
	Metal	0.4	0.5
	Plaster	0.2	0.5
	Wood	0.5	0.5
2.0	Brick	0.5	0.7
	Concrete	0.5	0.7
	Drywall	0.4	0.7
	Metal	0.5	0.7
	Plaster	0.3	0.7
	Wood	0.6	0.7

*Precision at 1 standard deviation

6) Empirical results: The overall misclassification (error) rates and inconclusive rates that resulted from applying the Table 4-11 inconclusive ranges and thresholds to the test data are given in Table 4-12. Two of the three rates are lowest for the field study: the false positive rate and the inconclusive rate.

Table 4-11. Inconclusive Ranges and Threshold Comparison for Measurements Taken by the Pb Analyzer.

DATA SOURCE	SUBSTRATE	THRESHOLD (mg/cm^2)	INCONCLUSIVE RANGE (mg/cm^2)
EPA/HUD field study	Brick	1.0	None
	Concrete	1.0	None
	Drywall	None	0.9 to 1.2
	Metal	None	0.9 to 1.1
	Plaster	0.9	None
	Wood	None	0.9 to 1.3
Archive Testing	Brick	None	0.9 to 1.4
	Concrete	None	0.9 to 1.4
	Drywall	None	0.9 to 1.4
	Metal	None	0.9 to 1.4
	Plaster	None	0.9 to 1.4
	Wood	None	0.9 to 1.4

Table 4-12. Overall Misclassification and Inconclusive Rates Comparison for Measurements Taken by the Pb Analyzer.

DESCRIPTION	FALSE POSITIVE	FALSE NEGATIVE	INCONCLUSIVE
Field study results	20/717 (2.8%)	12/220 (5.5%)	21/1190 = 1.8%
Archive testing results	7/113 (6.2%)	1/41 (2.4%)	7/154 = 4.6%

4.8 EPA/HUD Field Study Data vs. National Survey Data

In 1990, a HUD-sponsored national survey of lead-based paint in housing ("National Survey") was conducted and has been reported in *Report on the National Survey of Lead-Based Paint in Housing, Base Report*, EPA 747-R-95-003, April, 1995; *Report on the National Survey of Lead-Based Paint in Housing, Appendix I: Design and Methodology*, EPA 747-R-95-004, April, 1995; and *Report on the National Survey of Lead-Based Paint in Housing, Appendix II: Analysis*, EPA 747-R-95-005, April, 1995. These reports are available from the National Lead Information Center (1-800-424-LEAD). The National Survey was carefully designed to give representative samples of the private and public housing stocks in the U.S. It is therefore of interest to determine the extent to which the lead levels represented in the EPA/HUD field study agree with those from the National Survey.

Summary statistics for XRF measured lead levels reported for the National Survey were compared to results found in the EPA/HUD field study. This comparison

found that the reported lead levels for the two studies appear to be similar. It should be noted that the comparison was limited in scope due to the fact that the two studies had different objectives. Some of the similarities and differences between the two studies as well as a brief description of the comparison and results are described below.

XRF measurements reported by the MAP-3 XRF instruments in Denver and Philadelphia for the EPA/HUD field study were used to compare to the MAP-3 XRF instrument results reported for the National Survey. The measurements taken from the field study are averages of three *screen* mode values whereas the measurements taken in the National Survey were single *test* mode readings. The results reported for Denver were compared to the National Survey results for private housing. Similarly, the results reported for Philadelphia for the field study were compared to the National Survey public housing results. This was done since all housing tested in Denver were single-family homes and the housing tested in Philadelphia were part of a multifamily housing development.

Prior to comparing the MAP-3 measurements taken from the two studies, it was necessary to account for the censoring of the readings taken for the National Survey. The instruments used for the National Survey never reported a reading less than zero (that is, negative readings were never reported), even though readings less than zero were otherwise possible. Thus, all negative readings reported for the EPA/HUD field study were set equal to zero before summary statistics were computed.

Tables 4-13 and 4-14 below provide summary statistics for censored results for readings taken by the two MAP-3 “field classifications” in the EPA/HUD field study. A field classification represents a set of 1,190 readings taken at all of the sample locations in Denver and Philadelphia. The fact that there were two field classifications for the MAP-3 means that there are two complete sets of readings for this instrument on a common set of samples. One MAP-3 machine made all readings in the first field classification (Field Study I); two different MAP-3 machines were used in the second field classification (Field Study II). Results for the two field classifications are shown in Tables 4-13 and 4-14. Also provided in these tables are National Survey results, as reported in Appendix II of the above mentioned publication. A comparison of the summary statistics reveals similar results, particularly when comparing means and medians. However, some differences may be observed when comparing the statistics for the common areas. The lead levels of the common areas in the National Survey are more varied and have higher means and medians.

Table 4-13. Percentile and Mean for XRF Measurements for Public Housing Units by Sample Location (mg/cm^2).

STATISTIC	INTERIOR			COMMON AREAS		
	Field Study I	Field Study II	National Survey	Field Study I	Field Study II	National Survey
Minimum	0.00	0.00	0.00	0.00	0.00	0.00
1 %	0.00	0.00	0.00	0.00	0.00	0.00
5 %	0.00	0.00	0.00	0.00	0.00	0.00
10 %	0.00	0.00	0.00	0.00	0.00	0.00
25 %	0.00	0.00	0.05	0.00	0.00	0.06
Median	0.27	0.14	0.21	0.00	0.00	0.31
75 %	0.86	0.84	0.68	0.30	0.32	1.08
90 %	2.23	2.11	1.74	2.56	2.71	2.42
95 %	3.56	3.25	2.64	4.50	4.60	4.58
99 %	5.23	5.00	4.78	6.66	7.36	23.28
Maximum	6.64	6.54	12.76	6.66	7.36	23.96
Mean	0.72	0.66	0.58	0.62	0.65	1.17
Std. Dev.	1.15	1.10	2.81	1.43	1.51	7.90
No. of Samples	385	385	1,731	55	55	553

Table 4-14. Percentile and Mean for XRF Measurements for Private Housing Units by Sample Location (mg/cm^2).

STATISTIC	INTERIOR			EXTERIOR		
	Field Study I	Field Study II	National Survey	Field Study I	Field Study II	National Survey
Minimum	0.00	0.00	0.00	0.00	0.00	0.00
1 %	0.00	0.00	0.00	0.00	0.00	0.00
5 %	0.00	0.00	0.00	0.00	0.00	0.00
10 %	0.00	0.00	0.00	0.00	0.00	0.00
25 %	0.00	0.00	0.03	0.00	0.00	0.05
Median	0.05	0.03	0.19	0.35	0.36	0.42
75 %	0.39	0.38	0.60	2.53	2.56	1.85
90 %	1.18	1.08	1.66	6.35	5.90	5.81
95 %	3.61	3.70	4.49	12.83	9.68	9.30
99 %	18.58	18.79	10.18	22.05	22.95	27.71
Maximum	26.73	25.59	21.82	28.03	29.94	53.81
Mean	0.90	0.87	0.81	2.28	2.14	2.07
Std. Dev.	3.24	3.08	1.95	4.44	4.24	4.64
No. of Samples	447	447	4,273	303	303	1,047

5. PCS DEVELOPMENT AND STATISTICAL METHODOLOGY

Numerical entities on a PCS related to XRF instrument performance are estimates obtained from field testing data. This section describes the statistical methodology used in PCS-related estimation. The estimates obtained by applying the methodology described in this section are given in appendix D. Empirical classification results based on these estimates are also given in appendix D.

Some of the material in this chapter is unavoidably technical, in particular sections 5.1.1, 5.1.6, 5.1.7, and 5.6.1. Readers who do not have a background in statistics, or are not interested in mathematical details, can skip over these sections with little loss of comprehension of the remaining material.

5.1 Bias and Precision Estimation

The PCS reports estimates of bias and precision, for uncorrected XRF results, at four levels of lead in paint: 0.0, 0.5, 1.0, and 2.0 mg/cm^2. If substrate correction is recommended on some or all substrates, estimates of bias and precision of the corrected measurements at the 0.5 mg/cm^2 and 2.0 mg/cm^2 lead levels are also required to calculate an inconclusive range or threshold, although the estimates do not appear in the PCS but are shown in appendix D. Since estimation is based on XRF results obtained on field samples, two fundamental issues have to be addressed in order to estimate bias and precision at the four indicated lead levels:

- The lead levels of field samples, in the archive as in the EPA/HUD field study, are distributed towards lower values, with diminishing concentration of samples near any fixed lead level as the lead level increases;

- Lead levels are themselves estimated by laboratory analysis of paint samples using ICP-AES ("ICP"), which accounts for some of the apparent imprecision of XRF results.

These two factors make it impossible to directly observe the bias and precision of XRF results under field conditions, or at pre-specified lead levels. Estimation of these quantities is performed using the model introduced in the EPA/HUD field study.

5.1.1 The XRF Measurement Model

The XRF measurement model is a mathematical expression that relates XRF results to the true level of lead in paint, accounting for the fact that the lead level is estimated by ICP. The form of the model used in PCS development is defined by the following two equations:

(1) $XRF = a + b\cdot (Pb) + \varepsilon + \tau\cdot (Pb)^{1/2}$
$log(ICP) = log(Pb) + \delta.$

In this model, *XRF* and *ICP* are observable quantities representing the XRF measurement and the ICP-measured lead level respectively. The true lead level, represented by *Pb*, is not observable. The terms ε, τ and δ are independent, normal random variables each having mean 0, and variances given by $Var(\varepsilon) = c$, $Var(\tau) = d$, and $Var(\delta) = \sigma_\delta^2$. The model parameters *(a,b,c,d)* describe the linkage of an XRF measurement to the true lead level:

- The expression $a + b\cdot(Pb)$ defines a linear regression relationship between the mean XRF measurement and the true lead level. The intercept *a* represents the mean XRF measurement when the lead level is 0.0 mg/cm^2. The slope *b* measures the change in the mean XRF measurement per unit change in the true lead level.

- The expression $\varepsilon + \tau\cdot(Pb)^{1/2}$ is the residual (error) term in the linear regression. This residual has mean zero, and variance given by the expression $c + d\cdot(Pb)$. In other words, the residual variance is not constant with respect to the lead level, but increases linearly with it. When the lead level is 0.0 mg/cm^2 the residual variance is equal to *c*. Parameter *d* measures the change in variance per unit change in the true lead level.

Under the model, the bias (*B*) and precision (*SD*) at a fixed lead level $Pb = p$ can be expressed as follows:

(2) $B(p) = a + (b-1)\cdot p$
$SD(p) = [c + d\cdot p]^{1/2}$

The quantities *B(p)* and *SD(p)* are conceptual, representing true, innate characteristics of an XRF instrument that can only be inferred from data obtained with the instrument. This is done by using the data to obtain estimates of the model parameters *(a,b,c,d)*. Bias and precision estimates can then be obtained at any lead level *p* by substitution, using the above formulas for *B(p)* and *SD(p)*. In PCS development, estimates for *B* and *SD* at the lead levels p = 0.0, 0.5, 1.0 and 2.0 (mg/cm^2) are reported.

The term σ_δ^2 is the variance of the error caused by using *log(ICP)* as a substitute for *log(Pb)*. A value for this term must be obtained externally, as it was in the EPA/HUD

field study. Based on an analysis of laboratory duplicate ICP measurements from the field study, it was found that $\sigma_\delta = .3$ for Denver samples and $\sigma_\delta = .2$ for Philadelphia and Louisville samples were reasonable values to use in PCS-related work.

The model represented by (1) differs slightly from the model developed in the EPA/HUD field study. The model used in the field study has the following form:

(3) $$XRF = a + b\cdot (Pb) + \varepsilon + \tau\cdot Pb$$
$$log(ICP) = log(Pb) + \delta,$$

which leads to the following expressions for the bias and precision:

(4) $$B_0(p) = a + (b-1)\cdot p$$
$$SD_0(p) = [c + d\cdot p^2]^{1/2}.$$

The only difference between the two forms of the XRF measurement model represented by (1) and (3) is the manner in which the precision is expressed. In (2), $SD(p)$ increases at a rate approximately proportional to the square root of p. In (4), $SD_0(p)$ increases at a rate approximately proportional to the lead level p itself. As a result, $SD_0(p)$ can be substantially larger than $SD(p)$ for high lead levels. It was found that the precision estimates provided by $SD_0(p)$ and $SD(p)$ were similar for lead levels up to 1.0 mg/cm^2, and that both closely agreed with nonparametric estimates within this lead range. At the 2.0 mg/cm^2 lead level, $SD_0(p)$ usually gave higher estimates than $SD(p)$. The decision to use $SD(p)$ instead of $SD_0(p)$ in PCS development was motivated by the fact that the estimates provided by $SD(p)$ at the 2.0 mg/cm^2 lead level agreed more closely with nonparametric estimates[4] than the estimates provided by $SD_0(p)$.

Parameter estimates in the XRF measurement model are obtained using maximum likelihood. It is assumed that the true distribution of lead levels is lognormal, and that σ_δ is known. For Denver samples and EPA's Office of Research and Development samples, $\sigma_\delta = 0.3$, and for Philadelphia and Louisville samples, $\sigma_\delta = 0.2$, are used in PCS-related estimation. The joint density of XRF measurement ("XRF") and ICP is then approximated using numerical integration at every (XRF, ICP) data pair. The maximum likelihood estimate (MLE) is obtained by maximizing the product of the densities using a Newton-Raphson algorithm. An estimated covariance matrix of the MLE is obtained upon convergence of the algorithm using asymptotic theory, which

[4]The nonparametric procedure used is based on fitting monotone (also referred to as "isotonic") regressions, as described in the technical report to the EPA/HUD field study.

gives standard errors of the parameter estimates and of related quantities. The constraints $c,d \geq 0$ are imposed in order to ensure feasible solutions. These details are further elaborated in the technical report to the EPA/HUD field study.

5.1.2 Data Used in Model Estimation

Only XRF results for which the representative ICP-measured lead level is less than 4.0 mg/cm^2 are used in estimating the XRF measurement model parameters. XRF results on brick and concrete samples in the archive are excluded from model estimation. Treatment of brick and concrete results in archive testing is discussed in section 5.1.3. The designation of a representative ICP measurement for a sample is discussed in section 5.2. The 4.0 mg/cm^2 upper limit is imposed because characteristics of instrument performance relevant to PCS development and addressed with the model involve lead levels of 2.0 mg/cm^2 or less. And, because a number of XRF instruments do not read above a certain value, restricting the range of lead levels makes it less likely that truncated XRF measurements would complicate a model-based analysis. The 4.0 mg/cm^2 upper limit is the same as that adopted for substrate correction when needed, as explained in section 5.3.2.

XRF results identified as outliers are also excluded from analyses. Outliers, based on the derivation of nonparametric standardized residuals as defined in the EPA/HUD field study technical report, are also excluded from model estimation. An outlier is indicated if the nonparametric standardized residual exceeds 3.3 in absolute value. This criterion typically results in the designation of no more than one measurement (out of more than 150) as an outlier.

Measurements made on one of the archive samples are excluded from model estimation because of concern regarding the accuracy of the representative ICP measurement. This sample has a wood substrate, and an ICP measurement less than 0.1 mg/cm^2. With restriction of the data to ICP less than or equal to 4.0 mg/cm^2, exclusion of brick and concrete archive samples, and exclusion of the mentioned wood sample, there are 139 measurements per archive test available for model fitting: 14 drywall, 38 metal, 34 plaster, and 53 wood.

5.1.3 Estimation Using XRF Instrument Testing Data

The evaluation of XRF instruments in the EPA/HUD field study differed from archive testing in several important respects. The field study was conducted at more than 1,000 sample locations, in contrast to the approximately 150 samples available for

testing in the archive. In most cases, several machines of the same instrument type were typically used in the field study, with different operators[5]. For example, 5 different Microlead I machines were used by four different operators in the field study. Machines and/or operators were changed according to conditions that prevailed during the progress of the field study. In contrast, a single archive test of an XRF instrument normally consists of one machine used by one operator. If multiple rounds of archive testing are conducted with an XRF instrument, possibly with different machines and/or operators, each set of XRF results is obtained on common samples. Two rounds of testing are desired for PCS development so as to capture information on XRF inter-machine variability at minimum cost.

This section describes how model estimates are obtained with a single machine of an XRF instrument type, either in the EPA/HUD field study or in the archive. An explanation of the methods used to combine results obtained with multiple machines of a given XRF instrument type is provided in section 5.1.4.

Model estimates based on the EPA/HUD field study data were obtained by substrate, with several qualifications related to brick. For the Microlead I, model estimates for brick were not obtained, because the model did not adequately describe the features of this instrument on brick substrates. The estimates reported are averages and standard deviations obtained for individual machines, which were then pooled. Only XRF results for samples with ICP measurements less than 1.0 mg/cm^2 were used in this analysis, because it was found that Microlead I measurements were essentially unaffected by the lead level within this range, thereby justifying the use of simple summary statistics. The sparseness of lead levels between 1.0 mg/cm^2 and 4.0 mg/cm^2 made it difficult to infer whether this condition persisted for lead levels in the wider range. For the MAP-3, brick and concrete data were combined, because the model did not give stable estimates for brick alone under the ICP less than or equal to 4.0 mg/cm^2 range restriction.

Fitting XRF measurement models separately by substrate cannot give reliable bias and precision estimates based on archive testing data, due to the small sample sizes by substrate indicated in section 5.1.2. Consequently, it is necessary to pool data across all substrates for the purpose of estimation. In order to recognize substrate differences, three indicator (dummy) variables are used for drywall, metal and plaster substrates within the scope of a single model. To illustrate, if a sample has a plaster

[5]Again, the distinction between “instrument” and “machine” is emphasized: “instrument” refers to a particular make or brand, “machine” to a specific physical unit of a particular make or brand.

substrate, the indicator variables for drywall and metal are set to 0, and the indicator variable for plaster is set to equal to 1. If a sample has a wood substrate, all three indicator variables are set to 0. As explained in section 5.1.2, brick and concrete sample measurements are not used in model estimation. The use of indicator variables allows separate, substrate-specific bias estimates to be obtained. The estimates are based on a common slope parameter (*b*) and on common variation parameters (*c* and *d*). Thus, the difference in bias estimates at two different lead levels is the same for all substrates. Similarly, the precision estimates are the same for all substrates.

The indicator variable model has 7 parameters (*a,b,D,M,P,c,d*), with *D*, *M* and *P* denoting coefficients for the drywall, metal, and plaster substrate indicator variables, respectively. Bias estimates for wood are obtained by setting the three indicator variables to zero. The following demonstrates how bias and precision estimates are obtained, by substrate, at lead level p (mg/cm^2):

SUBSTRATE	BIAS	PRECISION
Drywall	$a + (b-1)\cdot p + D$	$[c + d\cdot p]^{1/2}$
Metal	$a + (b-1)\cdot p + M$	$[c + d\cdot p]^{1/2}$
Plaster	$a + (b-1)\cdot p + P$	$[c + d\cdot p]^{1/2}$
Wood	$a + (b-1)\cdot p$	$[c + d\cdot p]^{1/2}$

Separate substrate estimates are given only if the indicator variable model has a significant (5% level) likelihood ratio test (LRT) with respect to the model having no indicator variables. The LRT statistic has an approximate chi-square distribution with three degrees of freedom. If the LRT statistic is less than 7.8, which is the 5% critical value, it is concluded that no significant differences between the 4 substrates are found, and the same bias is reported for each of the substrates.

Estimation for brick and concrete substrates requires a different approach, since the archive contains only 3 brick and 2 concrete samples. Applying the 4.0 mg/cm^2 cutoff to these substrates would eliminate 2 of the 3 brick samples. Increasing the cutoff to 15 mg/cm^2 adds back one brick sample, which provides some, albeit limited, information on how XRF instruments perform at a high lead level.

The following methodology is used to obtain combined estimates for brick and concrete substrates. The statistic $T = Y_w - a - b\cdot X_w$ is computed using the 2 brick and 2 concrete measurements on samples with ICP less than or equal to 15 mg/cm^2, where Y_w is the weighted average XRF result; X_w is the weighed average ICP measurement; and *a* and *b* are model parameters based on drywall, metal, plaster and wood samples. The weights are reciprocals of $[c + d\cdot x_i]^{½}$, where x_i is one of the four ICP measurements, and *c* and *d* are model parameters. An adjustment to the bias

estimates for brick and concrete is made only if the absolute value of *T* exceeds two times its estimated standard error. If this condition is satisfied, estimates of the form $a + (b-1)\cdot p + T$ are reported for the bias on brick and concrete. If this condition is not satisfied, the estimates for brick and concrete are the same as those reported for wood.

5.1.4 Combining XRF Results from Different Testing Scenarios

An important finding of the EPA/HUD field study is that variation in performance between different machines of an XRF instrument type can be substantial. Archive testing continues to validate this observation. Intermachine variation is recognized in the methods used to combine XRF results from different testing scenarios. This section explains how the results of XRF instrument testing are combined using different machines in the field study; using different archive tests (typically with different machines); and, combining field study and archive testing data. The distinction between machines and instruments is again emphasized; the beginning of section 5.1.3 explains the distinction and its differing implications for field study and archive testing.

PCSs were developed from EPA/HUD field study, or archive data, or both. PCSs for the Princeton Gamma-Tech XK-3, the Scitec MAP-3, and the Warrington Microlead I Revision 4 were developed from data collected during the EPA/HUD field study. A PCS for the TN Technologies Pb Analyzer was developed from the field study and from two separate testing events at the archive facility. PCSs for the Niton XL-309, the Radiation Monitoring Device LPA-1, the Advanced Detectors LeadStar, and the Scitec MAP 4 were developed from archive testing data. Table 5-1 reports the number of machines that were used in the EPA/HUD field study, upon which testing data in PCS development is based and shows where the testing was done. The LeadStar PCS guidance distinguishes between instruments with software versions earlier than version 4.1 and those with software version 4.1 through version 4.3. Thus, on Table 5-1, there is a separate entry for each software version. Similarly, the LPA-1 PCS provides guidance for two categories of instruments. Guidance is provided for instruments purchased before June 26, 1995 and have not been serviced since June 26, 1995 and also for instruments sold or serviced after June 26, 1995. So there is a separate entry for each LPA-1 instrument category for the LPA-1 on Table 5-1.

Table 5-1. Number of XRF Machines Used for PCS Development by Origin of Data for Each XRF Instrument.

XRF INSTRUMENT MODEL[a]	ORIGIN OF DATA

	EPA/HUD FIELD STUDY	ARCHIVE FACILITY
XK-3	3	0
MAP-3	4	0
MAP 4	0	2
Microlead I	5	0
Pb Analyzer	2	2
XL	0	1
LPA-1[b]	0	2
LPA-1[c]	0	1
LeadStar[d]	0	2
LeadStar[e]	0	2

[a]PCS guidance applies to all versions of each model except as noted below.
[b] Used for developing PCS guidance for LPA-1 instruments purchased before 6/26/95 and had not been serviced since 6/26/95.
[c] Used for developing PCS guidance for LPA-1 instruments sold or serviced after June 26, 1995.
[d] Used for developing PCS guidance for LeadStar instruments with software versions earlier than version 4.1.
[e] Used for developing PCS guidance for LeadStar instruments with software versions 4.1 to version 4.3.

Three of the four K-shell instruments tested in the EPA/HUD field study (MAP-3, Microlead I and XK-3) exhibited significant differences between machines. For these instruments, model parameters were estimated separately for each machine, and the results pooled by averaging with weights based on sample sizes. Pooling results, instead of data, avoided inflating the estimated SDs of the instrument due to intermachine differences. It also avoided the problem of mixing repeated measurements taken at the same sample locations, which applies to all of the K-shell instruments except the Pb Analyzer. The use of unequal weights in pooling reflects the circumstances by which different machines came into use during the course of the field study. Variation in sample sizes, sample lead levels, and possibly other factors that could affect the reliability of estimates obtained for individual machines, motivated the decision not to weight estimates equally.

Sample sizes by machine for a given instrument varied by substrate, and in some cases were too small for accurate model estimation. Estimates for an individual machine were obtained provided that there were at least 25 observations available. For the Microlead I, two machines exhibited problems on certain substrates. For one machine, data were used only in obtaining pooled estimates for brick. For the other one, data were used only in obtaining pooled estimates for brick and drywall.

If the PCS is based on separate archive tests made with the same type of instrument, the estimated model parameters are averaged to produce bias and precision estimates. Precision estimates are not inflated due to intermachine or other differences that may have existed between tests. Ranges are reported along with the bias and precision estimates if data from more than one archive test are used. The model form with the least aggregation across substrates (see section 5.1.3) is used as the basis for pooling. For example, if the first archive test produces a model parameter estimate indicating significant substrate differences, but the second archive test of the same XRF instrument does not, the same model with indicator variables for drywall, metal and plaster is estimated with both sets of data separately before pooling. The unweighted average used in pooling assigns equal importance to each archive test that was conducted.

If the PCS is based on a combination of EPA/HUD field study and archive testing, pooling is conducted in two stages: (1) weighted averaging of estimated model parameters obtained by machine in the field study, as described above in this section; (2) unweighted averaging of the field study estimate obtained in (1) with the estimated model parameters obtained for each archive test. The second stage treats the field study evaluation of the XRF instrument, with different machines, essentially the same as one archive test, despite the larger sample size of the field study. This is done to prevent the field study evaluation from dominating the archive testing evaluation in PCS development.

5.1.5 Standard Error Estimates

An approximate covariance matrix of estimated model parameters, based on non-repeated measurements with a single machine, is obtained using standard maximum likelihood theory. For bias and precision estimates derived from the model parameters, standard error (SE) estimates are obtained from the estimated covariance matrix. When model estimates are pooled using repeated measurements at common sample locations, which occurs after multiple rounds of archive testing, conservative SE estimates are obtained using the triangle inequality, which states that the SE for the average of two estimates is less than or equal to the average of the SEs.

5.1.6 Relation to Previous Work

The XRF measurement model represented by (1) is an example of a nonlinear, heteroscedastic measurement error model. Fuller (1987) is a standard reference for measurement error models, and it describes the use of maximum likelihood estimation for these models. Provided that the explanatory variable (in the present case, the true lead levels of the tested samples) can be regarded as randomly selected from a population and regularity conditions are met, maximum likelihood estimates are asymptotically normal and efficient. The use of numerical integration to approximate the likelihood function is recognized as a necessity when the required probability densities cannot be obtained in closed form.

5.2 Laboratory Measurement of Lead Levels

In the EPA/HUD field study, a primary paint sample was defined for each sample location (field sample). A laboratory ICP measurement based on the primary paint sample[6] constituted the representative lead-level measurement for the field sample. This ICP measurement was, in most cases, the only one taken. It serves as the "best" estimate of the lead level in PCS development that is based on the field study data.

By contrast, all archive samples have one primary and at least one additional ICP measurement. An archive sample that was also in the EPA/HUD field study inherits the ICP measurement taken on the primary paint sample in the field study as its primary ICP measurement. Primary ICP measurements for archive samples that were not in the field study are based on paint samples collected according to protocols similar to those used in the field study. The paint sample collection protocols are described in detail in the technical report to the EPA/HUD field study. A second set of paint samples was collected from each archive sample after the archive was assembled. Secondary ICP measurements are based on these additional paint samples.

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[6]A modified NIOSH Method 7082 was used to prepare the paint samples. The NIOSH Method 7082 is designed to prepare and analyze air filter samples for analysis of many inorganic elements, including lead. Modifications were needed to make it applicable to processing paint samples. Details are provided in the technical report to the EPA/HUD field study.

Secondary ICP measurements were made so that, when combined with the primary ICP measurements, improved estimates of the lead levels of paint at XRF testing locations may be obtained. The manner in which this combination should be made is, at the time this document is published, an unresolved issue that may be addressed in the future. At the present time, the primary ICP measurements are used as representative lead-level measurements for the archive samples, as they were in the field study evaluation.

5.3 Substrate Correction

Substrate correction is recommended for an XRF instrument if data suggest that it can reduce bias to a significant degree. Substrate correction is performed by subtracting from the XRF results a correction value determined separately in each house for single-family housing or in each development for multifamily housing, for each substrate recommended for correction. To obtain the correction value, three measurements are taken at each of two areas of the substrate type in question, with red NIST SRM film (1.02 mg/cm^2 lead level) placed over the areas that had been scraped clean of their paint covering. The correction value is the average of the six readings minus 1.02 mg/cm^2. Substrate correction may be recommended on all, some, or no substrates.

5.3.1 Criteria for Recommending Substrate Correction

For PCSs based on EPA/HUD field study data, substrate correction is recommended in accordance with the study conclusions on the effectiveness of red NIST SRM average correction as described in the technical report to the field study. For PCSs based on archive testing data, a recommendation for substrate correction is based on the criteria given below.

1. Is the estimated bias significantly different from zero and at least 0.1 mg/cm^2 in absolute value at the 0.0 mg/cm^2 and 1.0 mg/cm^2 lead levels?

2. Is the correction value, when computed from archive testing results[7], significantly different from zero?

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[7]A correction value, based on archive testing results, is the average of all XRF measurements taken on the red NIST SRM covering the bare substrate areas of the same substrate type, minus 1.02.

3. Does correction of XRF results on substrates meeting the first two conditions result in a decrease in the magnitude of the estimated bias of at least 0.1 mg/cm^2?

Substrate correction is recommended if significant bias is detected on a substrate and if evidence suggests that substrate correction can reduce the bias to a significant extent. If substrate correction is not recommended, it is possible that significant bias was detected, but that correction was not found to be an effective remedy. Recommendations regarding substrate correction should not be used to draw inferences about the bias of an XRF instrument.

If the PCS is based on repeated archive tests with the same type of instrument, substrate correction is recommended on those substrates for which the above criteria are met in at least one of the tests. For example, if the need for substrate correction was indicated on metal and wood in the first round of archive testing of instrument XYZ, and on metal and plaster in the second round of archive testing, the PCS for instrument XYZ based on the combination of the two tests will recommend substrate correction on metal, plaster and wood. The PCS for the Pb Analyzer, which does not recommend using substrate correction, was the only PCS developed using both EPA/HUD field study and archive testing data. Thus, substrate correction methodology was not developed for PCSs derived from both EPA/HUD field study and archive testing data.

5.3.2 Measurement Range Subject to Substrate Correction

A recommendation of substrate correction applies only to XRF results less than 4.0 mg/cm^2. This is because XRF results of 4.0 mg/cm^2 or greater do reliably indicate the presence of lead without the use of substrate correction across a wide range of instruments. Table 5-2 presents results from the EPA/HUD field study that support this finding. For each of the four K-shell XRF instruments evaluated in the field study, fewer than 5% of XRF readings greater than or equal to 4.0 mg/cm^2 were obtained on samples with ICP-measured lead levels less than 1.0 mg/cm^2. It is noteworthy that a reduction of the cutoff value to 3.0 mg/cm^2 would substantially increase the rate of false positive results especially for the Microlead I and XK-3 instruments, both of which were found to benefit from substrate correction. The 95% confidence intervals presented in Table 5-2 demonstrate that the false positive rates for the Microlead I and XK-3 are significantly greater than 5% with a 3.0 mg/cm^2 cutoff value, and that none of the instruments considered had false positive rates that are significantly greater than 5% with a 4.0 mg/cm^2 cutoff value. Thus, the use of 4.0 mg/cm^2 as a cutoff value for substrate correction can be expected to produce an acceptably small percentage of

false positive results due to uncorrected readings, with a minimal amount of unnecessary correction.

An alternative approach would be to treat the substrate correction cutoff value as an instrument-specific parameter to be estimated from the testing data. The advantage to this approach is that instruments with cutoff values lower than 4.0 mg/cm^2 would require substrate correction less frequently than if a single 4.0 mg/cm^2 cutoff value were used for all instruments. The estimated cutoff value for an instrument would, however, reflect the testing characteristics of only a small number of machines. And, the sparseness of higher lead levels in the archive may make accurate estimation of the cutoff value difficult. Whether or not the balance of arguments favors the use of instrument-specific cutoff values for substrate correction is a topic that merits exploration in future PCS development activity.

Table 5-2. Frequencies and Percentages With 95% Confidence Intervals of **False Positive Results**[*] for XRF Readings Obtained When the Uncorrected XRF Reading is Greater Than or Equal to 2.0 mg/cm^2, 3.0 mg/cm^2, or 4.0 mg/cm^2, Based on the EPA/HUD Field Study Data.

INSTRUMENT	MEASURE	UNCORRECTED XRF READINGS Greater Than or Equal to		
		2.0	3.0	4.0
Pb Analyzer	Frequency	2 / 156	0 / 106	0 / 76
	Percentage	1.3%	0.0%	0.0%
	95% Conf. Int.[‡]	0.2, 4.6	0.0, 3.4	0.0, 4.7
MAP-3	Frequency	21 / 343	5 / 240	1 / 161
	Percentage	6.1%	2.1%	0.6%
	95% Conf. Int.	3.9, 9.4	0.7, 4.8	0.0, 3.4
Microlead I	Frequency	75 / 446	24 / 298	9 / 214
	Percentage	16.8%	8.1%	4.2%
	95% Conf. Int.	13.5, 20.7	5.3, 11.2	1.9, 8.1
XK-3	Frequency	261 / 657	38 / 336	7 / 214
	Percentage	39.7%	11.3%	3.3%
	95% Conf. Int.	36.0, 43.6	8.2, 15.3	1.3, 6.9
All Instruments Combined	Frequency	359 / 1602	67 / 980	17 / 665
	Percentage	22.4%	6.8%	2.6%
	95% Conf. Int.	20.4, 24.6	5.3, 8.4	1.5, 4.1

[*]A false positive result refers to an XRF reading of 1.0 mg/cm^2 or greater when the ICP-measured lead level is less than 1.0 mg/cm^2.
[‡]Upper and lower bounds for a 95% confidence interval for the percentage.

5.4 Inconclusive Ranges and Thresholds

The purpose of an inconclusive range or threshold is to give a rule by which an XRF result, corrected for substrate bias as needed, can classify the lead level of a painted surface relative to the 1.0 mg/cm^2 federal standard for lead in paint. Negative, positive, and inconclusive classifications are the possible outcomes when using an inconclusive range. A positive classification is an inference that the lead level is greater

than or equal to the 1.0 mg/cm^2 federal standard, and a negative classification is an inference that the lead level is less than the 1.0 mg/cm^2 federal standard. An inconclusive classification means that the XRF result cannot reliably distinguish between positive and negative classifications, and that laboratory confirmation is required to resolve the ambiguity. Negative and positive classifications are the only possible outcomes when using a threshold; there is no inconclusive classification. The procedures for classifying XRF results when using an inconclusive range or a threshold are described in section 5.4.1.

Inconclusive ranges and thresholds are derived for an XRF instrument by substrate. Inconclusive ranges and thresholds are designed to achieve, approximately:

- A five percent (5%) rate of false positive results, over a representative range of lead levels below the 1.0 mg/cm^2 federal standard;

- A five percent (5%) rate of false negative results, over a representative range of lead levels at or above the 1.0 mg/cm^2 federal standard;

- A minimal rate of inconclusive results.

If substrate correction is recommended, the inconclusive range or threshold reported is applicable to substrate corrected XRF results only. Bias and precision values, which are based on uncorrected XRF results, may not appear to be consistent with the inconclusive range or threshold reported if substrate correction is recommended. Section 5.4.6 presents examples of how inconclusive ranges and thresholds are calculated.

5.4.1 Classification Using Inconclusive Ranges and Thresholds

An inconclusive range is expressed as a lower (x_L) and an upper (x_U) number. With an inconclusive range, an XRF result is classified as:

- **Negative**, if it is less than or equal to x_L;

- **Positive**, if it is greater than or equal to x_U;

- **Inconclusive**, if it is greater than x_L and it is less than x_U.

For example, with an inconclusive range of 0.6 to 1.1 (mg/cm^2), an XRF result of 0.6 is classified as negative. If substrate correction is recommended for the XRF instrument on a substrate being tested, the correction must be performed before making reference to an inconclusive range.

A threshold is expressed as a single number (x_T). With a threshold, an XRF result is classified as:

- **Negative**, if it is less than x_T;
- **Positive**, if it is greater than or equal to x_T.

For example, with a threshold of 0.6 an XRF result of 0.6 mg/cm^2 is classified as positive. There is no inconclusive classification with a threshold. If substrate correction is recommended for the XRF instrument on a substrate being tested, the XRF result must be substrate corrected, as indicated, before reference to a threshold is made.

5.4.2 Data Used in Inconclusive Range and Threshold Derivation

Inconclusive ranges and thresholds are estimated for an XRF instrument using the same testing data from which bias and precision estimates are derived. Data are pooled across machines and/or substrates according to the conventions outlined in sections 5.1.3 and 5.1.4 for bias and precision estimation. Since the variation in XRF measurements for particular machines has been found to be substantially greater than the variation across machines for the instruments tested to date, adjustments for intermachine variation have not been made. The reported inconclusive ranges or thresholds based on pooled results should provide adequate leeway for differences between machines of the same instrument type, if the machines are similar to those tested. In future testing, direct consideration of intermachine variation in the computation of inconclusive ranges and thresholds may be necessary, depending on the magnitude of intermachine variation relative to within-machine variation.

5.4.3 Model-Based Derivation of Inconclusive Ranges and Thresholds

Archive and/or EPA/HUD field study testing data are used to obtain estimates of the parameters of the model described in section 5.1. The model, with its estimated parameters, gives an approximate description of the probabilistic behavior of XRF measurements as a function of the lead level. Specifically, XRF measurements for a

single machine and at a fixed lead level $Pb = p$, are assumed to follow a normal distribution, with bias $B(p)$ and precision (standard deviation) $SD(p)$, using the terminology of section 5.1.1. These properties guide the construction of inconclusive ranges and thresholds, according to the procedure explained in sections 5.4.5 through 5.4.9 below.

In principle, the upper and lower endpoints of an inconclusive range can be estimated without a model. To estimate the lower endpoint, XRF results for samples with ICP-measured lead levels greater than or equal to 1.0 mg/cm^2 are examined. The fifth percentile of these results constitutes an estimate of the lower endpoint. Similarly, the 95th percentile of XRF results for samples with ICP less than 1.0 mg/cm^2 constitutes an estimate of the upper endpoint. Although easy to derive, these nonparametric estimates are highly variable, except in very large samples. The lower endpoint of an inconclusive range based on a single archive test would in essence be determined by the second smallest XRF result for these samples. Two unusually low XRF results would be sufficient to create a wide inconclusive range. A model-based approach avoids this difficulty by adopting reasonable assumptions about the probabilistic nature of XRF measurements, based on results of the EPA/HUD field study. Another factor in favor of a model-based approach is that the model takes into account error in ICP-measured lead levels, which is not possible in the nonparametric approach.

5.4.4 Number of Decimal Places Reported

Inconclusive ranges and thresholds are reported to one decimal place, by rounding to the nearest tenth. Calculations used to derive these quantities are performed on a computer using its full arithmetic accuracy. The use of rounded quantities in calculations, such as bias and precision estimates reported on a PCS, may produce slightly different results.

5.4.5 Criteria for Inconclusive Range and Threshold Derivation

The three objectives stated at the beginning of section 5.4 guide the derivation of inconclusive ranges and thresholds. These objectives, which are to achieve a 5% rate of false positives, a 5% rate of false negatives, and a minimal rate of inconclusive classifications, are somewhat vague, because it was established in section 5.1 that the performance characteristics of an XRF instrument depend on the lead level of paint being tested. It is therefore necessary to express these objectives in terms of criteria that are achievable in specific terms.

The following six criteria are used to guide the derivation of inconclusive ranges and thresholds that meet the objectives stated at the beginning of section 5.4:

1. The probability of a false negative classification cannot be greater than five percent (5%) when the true lead level is 2.0 mg/cm^2 or greater.

2. The probability of a false positive classification cannot be greater than five percent (5%) when the true lead level is 0.5 mg/cm^2 or smaller.

3. An XRF result of 1.0 mg/cm^2 or greater cannot be classified as negative.

4. An XRF result of 0.0 mg/cm^2 or less can only be classified as negative.

5. An XRF result that is greater than or equal to its expected value at the 1.0 mg/cm^2 lead level cannot be classified as negative.

6. An XRF result that is less than its expected value at the 1.0 mg/cm^2 lead level cannot be classified as positive.

The lead levels 2.0 mg/cm^2 and 0.5 mg/cm^2 appearing in Criteria 1 and 2 are called pivotal values. It is explained in section 5.4.6 below why, by obtaining 5% false negative and 5% false positive classification rates at these pivotal lead levels, it is possible to achieve, approximately, the same objectives over a range of lead levels similar to that found in the EPA/HUD field study.

Criterion 3 mandates, for an inconclusive range, that the lower endpoint, designated x_L , be 0.9 or smaller, since larger values could lead to XRF results equal to 1.0 being classified as negative. For the same reason, thresholds, designated x_T , must be 1.0 or smaller. Criterion 4 mandates that x_L cannot be negative, and that x_T cannot be zero or less. Criteria 5 and 6 together state that if a threshold is obtained, it must coincide with the expected value of an XRF result at the 1.0 mg/cm^2 lead level. The criteria are not symmetric with respect to the treatment of XRF results above and below the 1.0 mg/cm^2 federal standard. For instance, an XRF result of 1.1 classified as a negative is not feasible, but an XRF result of 0.9 classified as a positive is feasible.

5.4.6 Use of 0.5 mg/cm^2 and 2.0 mg/cm^2 as Pivotal Values

Criteria 1 and 2 in section 5.4.5 refer to the 0.5 mg/cm^2 and 2.0 mg/cm^2 lead levels. These two pivotal values are used to represent lead levels below and above the 1.0 mg/cm^2 federal standard for the purpose of calculating inconclusive ranges and

thresholds. Relative to the distribution of lead levels of the 1,290 EPA/HUD field study samples, 0.5 mg/cm^2 is slightly larger than the median of lead levels below the federal standard, and 2.0 mg/cm^2 is slightly smaller than the median of lead levels above the federal standard. This property is desirable for remaining within the five percent false positive and five percent false negative rate targets across samples having variable lead levels.

Use of the pivotal values 0.5 mg/cm^2 and 2.0 mg/cm^2 was found to produce inconclusive ranges and thresholds similar to those obtained with a more direct, and more complicated, procedure that does not require the use of pivots. The procedure in reference uses the model introduced in section 5.1 to compute the integrated estimated probability of a false negative across a range of lead levels greater than or equal to 1.0 mg/cm^2, and the integrated estimated probability of a false positive across a range of lead levels below 1.0 mg/cm^2. The integrated estimated probabilities are calculated using lognormal distributions, by substrate, for lead levels similar to the observed distribution of measured lead levels[8] in the EPA/HUD field study. The integrated estimated probabilities are given by the following expressions:

$$FN(x_L) = \frac{\int_1^{\infty} Prob(XRF \le x_L \mid Pb = p) f(p) dp}{\int_1^{\infty} f(p) dp}$$

$$FP(x_U) = \frac{\int_0^{1} Prob(XRF \ge x_U \mid Pb = p) f(p) dp}{\int_0^{1} f(p) dp}$$

The probabilities inside the integrals are approximated by normal distributions using parameter estimates obtained from the XRF measurement model. The lognormal density is given by *f(p)*. The upper (x_U) and lower (x_L) bounds of the inconclusive range are set so that both FP(x_U) and FN(x_L) are equal to 5%, using a line-search procedure. Inconclusive ranges and thresholds for instruments tested in the EPA/HUD field study obtained with the direct procedure were compared to inconclusive ranges and thresholds calculated using a variety of pivotal values. The choice of 0.5 mg/cm^2 and

[8]Measured lead levels from the EPA/HUD field study were found to be comparable in distribution to a national survey of lead-based paint in housing conducted in 1990 (see section 4.8).

2.0 mg/cm^2 as pivotal values gave the best approximation to the direct procedure for the range of instruments that were tested.

5.4.7 Properties of Inconclusive Ranges and Thresholds

Section 5.4.5 lists criteria which inconclusive ranges and thresholds must satisfy. The inconclusive range or threshold obtained for an instrument reflects the objectives that motivated its derivation, and the constraints under which it was derived. Interpretation of an inconclusive range or threshold in light of other performance characteristics of the XRF instrument, such as bias and precision estimates, should take this factor into account. For example, an XRF instrument that gives unbiased results at all lead levels does not necessarily have an inconclusive range that is symmetrical with respect to the 1.0 mg/cm^2 federal standard. Additionally, positive and negative bias at the 1.0 mg/cm^2 lead level do not affect the process of obtaining an inconclusive range or threshold in the same manner. The following is a review of some of the properties of inconclusive ranges and thresholds to aid in their interpretation:

Asymmetrical inconclusive ranges. There are two reasons why an inconclusive range may appear off-centered with respect to the bias exhibited at the 1.0 mg/cm^2 lead level: (1) the pivotal values 0.5 mg/cm^2 and 2.0 mg/cm^2 are not centered about 1.0 mg/cm^2, and (2) most XRF instruments have precision (SD) estimates that increase with the lead level. The choice of the indicated pivotal values, which is explained in section 5.4.6, reflects the skewed distribution of lead levels found in the EPA/HUD field study, which in turn is a reasonable reflection of lead levels likely to be encountered in practical lead-based paint testing. Inconclusive ranges and thresholds are designed to be the smallest feasible solutions that give approximately 5% false positive and 5% false negative classifications under practical testing conditions. The imposition of a symmetry requirement would lead to wider inconclusive ranges; thresholds replaced with inconclusive ranges; and, ultimately, a greater proportion of inconclusive classifications.

Disparate treatment of bias. Criterion 3 mandates that an XRF result that is 1.0 or greater cannot be classified as negative, regardless of the bias. To illustrate how this affects the derivation of an inconclusive range or threshold, what would have been a threshold of 1.3 is converted into an inconclusive range of 0.9 to 1.3. This is necessary to avoid classifying an XRF result of 1.2, for example, as negative. Bias of the opposite kind, however, is not treated in the same manner: a threshold of 0.7, for example, does not violate Criterion 3. As a result, an XRF instruments that has high precision but systematic, positive bias may report an inconclusive range on its PCS, while a different instrument with inferior precision and systematic, negative bias of the same magnitude

may report a threshold. This discussion underscores the invalidity of using an inconclusive range or threshold as a stand-alone measure of the accuracy or precision of an XRF instrument.

Meaning of the 5% targets. The 5% targets for false positive and false negative classifications are across ranges of lead levels less than 1.0 mg/cm^2 and greater than or equal to 1.0 mg/cm^2, respectively. The probability of a false positive classification at a fixed lead level slightly below 1.0 mg/cm^2 will be greater than 5%, as will the probability of a false negative classification at a fixed lead level slightly above 1.0 mg/cm^2.

5.4.8 Calculation of Inconclusive Ranges and Thresholds

The process leading to the calculation of inconclusive ranges and thresholds is central to PCS development:

1. XRF testing data are obtained for a particular instrument, from the EPA/HUD field study and/or the archive.

2. Testing data are used to estimate parameters of the model described in section 5.1. Results from several tests are combined in the manner described in section 5.1.4.

3. Bias and precision estimates are obtained, using the estimated model parameters, at the following lead levels: 0.5, 1.0 and 2.0 mg/cm^2. (Bias and precision estimates were also obtained at 0.0 mg/cm^2 lead, but, these estimates were not used to develop PCS inconclusive ranges or thresholds.)

4. Bias and precision estimates obtained in step 3 are used to derive an inconclusive range or threshold that conforms to the six criteria outlined in section 5.4.5.

The calculation of inconclusive ranges and thresholds is illustrated in this section with three examples. In each example the estimated model parameters, which are given, are assumed to have been obtained using maximum likelihood estimation.

Example 1: Archive testing of an XRF instrument results in the following estimated model parameters, following the procedure outlined in section 5.1.3:

$a = 0.15, b = 1.08, c = 0.12, d = 0.05$.

Substrate correction is assumed not to have been recommended on any substrate. The same bias and precision estimates are reported for all substrates on the PCS, and a common inconclusive range or threshold is also reported. The expected value (*EV*) of an XRF result at lead level *p* is estimated by $EV(p) = 0.15 + 1.08 \cdot p$, and the SD is estimated by $SD(p) = [0.12 + 0.05 \cdot p]^{1/2}$. The following table gives values for the three lead levels used in the derivation of inconclusive ranges and thresholds.

p	*EV(p)*	*SD(p)*
0.5	0.69	0.38
1.0	1.23	0.41
2.0	2.31	0.47

The first step is to use estimates from the table to derive a Lower Interval at the 0.5 mg/cm^2 lead level, and an Upper Interval at the 2.0 mg/cm^2 lead level:

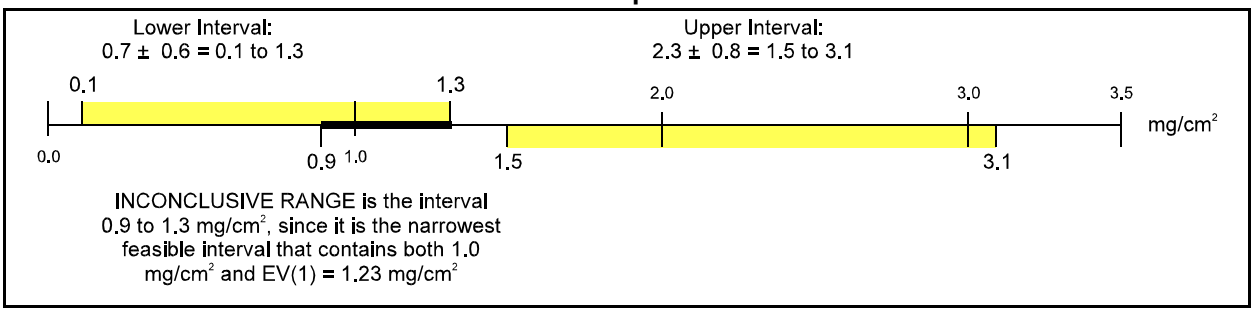
Lower Interval = $EV(0.5) \pm 1.645 \cdot SD(0.5)$
= $0.69 \pm 1.645 \cdot (0.38)$
= 0.1 to 1.3

Upper Interval = $EV(2.0) \pm 1.645 \cdot SD(2.0)$
= $2.31 \pm 1.645 \cdot (0.47)$
= 1.5 to 3.1

The Lower Interval is chosen so that there is a five percent (approximate) probability of obtaining an XRF result greater than 1.3 if the lead level is 0.5 mg/cm^2. Similarly, the Upper Interval is chosen so that there is about a five percent probability of obtaining an XRF result less than 1.5 if the lead level is 2.0 mg/cm^2. In order to meet criteria 1 and 2, any interval with x_L less than or equal to 1.5 and x_U greater than or equal to 1.3 would work. Threshold values x_T set anywhere between 1.3 and 1.5 would also work.

The second, and final, step is to modify the inconclusive range or threshold as needed to satisfy criteria 3 through 6. Since $EV(1.0) = 1.23$ is not between 1.3 and 1.5, a threshold solution is not feasible (criterion 5), making 1.2 to 1.3 the narrowest possible inconclusive range. Since the lower endpoint cannot be 1.0 or greater (criterion 3), the narrowest possible inconclusive range is 0.9 to 1.3, which reflects rounding to one decimal place. The process of determining this inconclusive range is depicted graphically below.

Example 1



Example 2: An XRF instrument is tested twice on the archive. On both occasions, the procedure outlined in section 5.1.4 points to the use of a model with indicator variables for drywall, metal and plaster. Since the same sample size applies to both tests, pooling takes the form of averaging the model parameters. The following are the estimated model parameters for the two tests.

Parameter	Test 1	Test 2	Pooled
a (wood)	-0.116	-0.052	-0.084
b	1.126	0.965	1.046
D (drywall)	0.098	0.149	0.124
M (metal)	-0.302	-0.186	-0.244
P (plaster)	0.004	0.014	0.009
c	0.066	0.048	0.057
d	0.104	0.112	0.108

Suppose that the criteria for substrate correction outlined in section 5.3.1 are met for metal in Test 1, but not in Test 2. As explained in section 5.3.1, metal is recommended for substrate correction using the pooled results, because it is recommended at least once. Suppose that the pooled correction factor for metal, based on averaging correction factors for Tests 1 and 2, is -0.28. Brick and concrete results are assumed to be reported using parameters (*a,b,c,d*) of the pooled model, as explained in section 5.1.4, which therefore coincide with results for wood.

The following illustrates the derivation of the inconclusive range or threshold for metal. With substrate correction, the expected value for an XRF result at lead level *p* is estimated by

$$EV(p) = a + M + b \cdot p - \{\text{metal correction}\}$$
$$= -0.048 + 1.046 \cdot p$$

The SD is estimated by $SD(p) = [0.057 + 0.108 \cdot p]^{1/2}$, the same for all substrates. The following table gives values for the three lead levels used in the derivation.

p	*EV(p)*	*SD(p)*
0.5	0.48	0.33
1.0	1.00	0.41
2.0	2.04	0.52

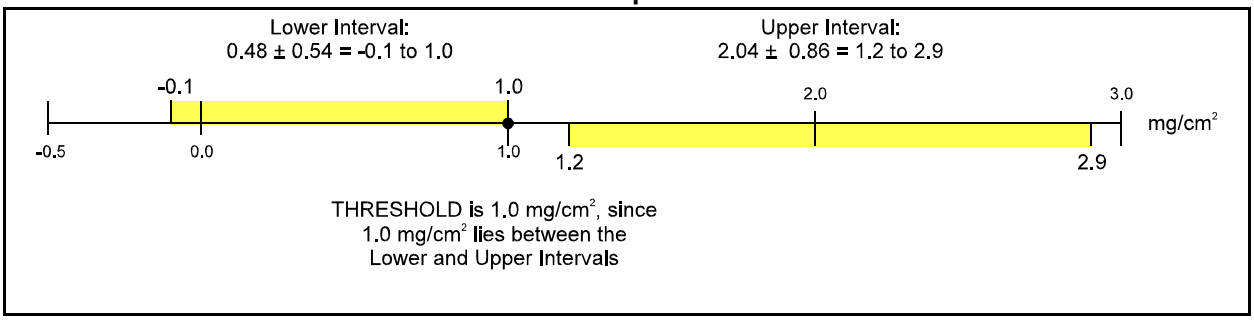
As in Example 1, the first step is to obtain a Lower Interval and an Upper Interval, as shown below.

Lower Interval = $EV(0.5) \pm 1.645 \cdot SD(0.5)$
= $0.48 \pm 1.645 \cdot (0.33)$
= -0.1 to 1.0

Upper Interval = $EV(2.0) \pm 1.645 \cdot SD(2.0)$
= $2.04 \pm 1.645 \cdot (0.52)$
= 1.2 to 2.9

Since the two intervals do not overlap, a threshold x_T chosen between 1.0 and 1.2 meets criteria 1 and 2, but only 1.0 is also feasible under criterion 3. Since the expected value at 1.0 mg/cm^2 is 1.00, a threshold solution x_T = 1.0 is reported for substrate corrected metal on the PCS. The process of determining this threshold solution is depicted graphically below.

Example 2



Example 3: Data from archive testing of an XRF instrument yield the following estimated model parameters:

$a = 0.1, b = 0.8, c = 0.1, d = 0.2$.

These estimates apply to all substrates, and substrate correction is not recommended. The following table gives values for the three lead levels needed in the derivation of an inconclusive range or threshold.

p	*EV(p)*	*SD(p)*
0.5	0.50	0.45
1.0	0.90	0.55
2.0	1.70	0.71

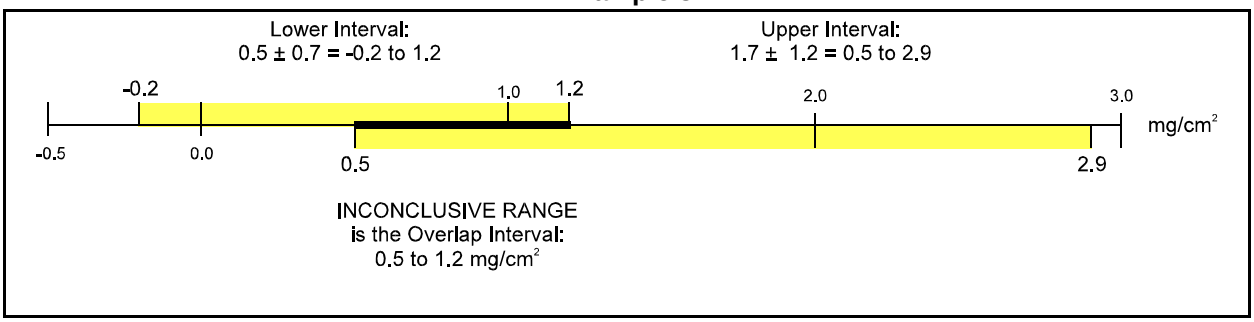
From these values the following Lower and Upper Intervals are obtained:

Lower Interval = $EV(0.5) \pm 1.645 \cdot SD(0.5)$
= $0.50 \pm 1.645 \cdot (0.45)$
= -0.2 to 1.2

Upper Interval = $EV(2.0) \pm 1.645 \cdot SD(2.0)$
= $1.70 \pm 1.645 \cdot (0.71)$
= 0.5 to 2.9

Unlike the first two examples, the Lower and Upper Intervals overlap in the range 0.5 to 1.2. Because this overlap interval contains both 1.0 and *EV(1.0) = 0.90*, it is not necessary to widen it further in order to satisfy the 6 criteria for inconclusive ranges given in section 5.4.5. The inconclusive range for this example is therefore 0.5 to 1.2, as illustrated below.

Example 3



5.4.9 Classification Performance of Inconclusive Ranges and Thresholds

Inconclusive ranges and thresholds are derived from model estimates. The observed (empirical) rates of false positive and false negative classifications based on testing data, and reported in appendix D, are subject to variation from the five percent targets that are set for these rates. Small sample sizes, especially from archive testing,

should be taken into account when comparing the empirical rates to the targeted five percent rate. For instance, there are 45 archive samples with ICP-measured lead levels greater than 1.0 mg/cm^2. If only three false negative results are observed, the empirical false negative rate is 6.7 percent. With four false negative classifications the rate becomes 8.9 percent, seemingly in violation of the five percent target. In fact, four out of 45 false negative results is an outcome compatible (at the 95 percent confidence level) with a true false negative rate of five percent.

The inconclusive ranges and thresholds reported on a PCS are estimates obtained from data on one, or perhaps several, machines of an XRF instrument type. They are designed for machines similar to those that were tested. The extent to which the machine or machines that were tested are representative of a larger population of machines cannot be formally determined. Consequently, a different machine of the same instrument type may have false positive or false negative rates that are higher than the five percent targets. The use of substrate correction where indicated was found to significantly reduce variation between machines, and should broaden the applicability of the inconclusive rates and thresholds reported on a PCS beyond the machines that were tested.

5.5 XRF Calibration Check Methodology

The XRF calibration check reported on a PCS is performed using the average of three consecutive XRF results obtained on red NIST SRM film placed over a wood control block, minus the 1.02 mg/cm^2 lead level of red NIST SRM film. Failure of the calibration check occurs if this quantity is less than the "minus value" or greater than the "plus value" reported in the PCS. In the event of failure, the PCS recommends that the manufacturer's instructions be followed to bring the machine into control. The minus and plus values are derived so that there is approximately a 1 in 200 (one-half of one percent) chance of failing a properly calibrated instrument.

The minus and plus values are estimates derived from testing one or more machines of an XRF instrument type on red NIST SRM film placed over wood control blocks. For each machine that was tested, bias and variance estimates are obtained from averages of three successive wood control readings. If more than one machine was tested, the separate machine estimates are combined to give pooled bias and within-machines variance estimates. These combined estimates are used to calculate the minus and plus values for the XRF calibration check. In two-way analysis of variance (ANOVA) terminology, the pooled bias is the grand mean; the within-machines variance is a weighted average of the separate machine variance estimates. The within-machines variance does not reflect variation between machines. If only one machine was tested, the bias and variance estimates for that machine are used.

If B represents the bias estimate and SD the square root of the variance estimate, the minus and plus values are computed as follows:

$$\text{minus value} = B - t_{k,.0025} \cdot SD$$
$$\text{plus value} = B + t_{k,.0025} \cdot SD,$$

where k is the number of degrees of freedom (total sample size minus the number of machines tested), and $t_{k,.0025}$ is the upper .0025 probability cutoff for a Student's t distribution with k degrees of freedom. For k greater than 30, $t_{k,.0025}$ is approximately equal to 3. For k equal to 10, $t_{k,.0025}$ is approximately equal to 4. Instruments tested in the EPA/HUD field study had greater than 30 triplicate wood control readings. In archive testing, fewer triplicate wood control readings are made, with 10 or 11 such triplicate readings being typical.

5.6 XRF Re-evaluation Test Methodology

Chapter 7 of the HUD Guidelines, as implemented in XRF Performance Characteristic Sheets, provides a method to be used for evaluating XRF testing by means of a re-test of selected components followed by comparison of the original and re-test results. Although the details differ in single- and multifamily units, the basic idea is to re-test ten randomly selected testing combinations (defined as locations on painted surfaces) and then compare the average of the ten re-tests to the original average. If the difference of the two averages exceeds a calculated tolerance, a potential problem is indicated and an additional ten re-tests are performed at random. If the second re-test is also out of tolerance, a failure of the re-test is declared. This creates a prima facie case for deficiencies in the inspection, ranging from sloppy procedures to outright fraud, and indicates the need for a more thorough examination of the testing that has been performed. The re-test procedure is calibrated to result in spurious failures in approximately 1% of inspections. That is, the re-test procedure will indicate the need for further examination of the testing in about 1 out of 100 cases where there is actually no problem, and the re-test failure is merely a random event.

This section describes the statistical methodology underlying the re-test method, for both single-family and multifamily applications. Examples are presented to illustrate the calculations needed for the re-test. Finally, an error in some of the previously published versions of the re-test method is discussed, and its impact illustrated through an example.

5.6.1 Re-Testing in Multifamily Housing

In multifamily housing, an XRF result has been defined as a single reading taken on a testing combination, defined as a location on the painted surface of a building

component such as a wall, door or baseboard. To implement the re-test in a multifamily development, select two units at random from those already tested in the development. Then select 5 testing combinations in each unit which are known to have been previously tested, although the exact location of the test will usually be unavailable. For example, the re-tester will generally know only that a wall in a certain room was tested. He will usually not know the exact tested spot on the wall, and may not even know which wall in the room was previously selected. The re-test selection procedure gives a total of ten testing combinations to be re-tested. Where possible, the re-testing should be done using the same instrument and inspector as the original test, that is, the re-testing should be carried out while the original inspection team is still on-site and available.

Let $X_{i,1}$, I = 1,...,10, denote the original XRF result on the i^{th} testing combination selected for the re-test. Similarly, let $X_{i,2}$ denote the re-test result on the i^{th} combination. Assuming that both the original and the re-test are honest measurements, $X_{i,1}$ and $X_{i,2}$ have the same distribution, which can be represented by the sum of a normal and a lognormal random variable having mean μ_i and variance σ^2. Here, μ_i represents the true average lead level, in mg/cm^2, on the testing combination. For example, μ_i might represent the average lead level on the walls in a room. The variance σ^2 represents the combined effect of (normal) XRF measurement error and (lognormal) spatial variation in the true lead level across the testing combination. Thus,

$$\sigma^2 = \sigma_1^2 + \sigma_2^2,$$

where σ_1^2 represents XRF measurement error and σ_2^2 represents spatial variation in true lead across the testing combination. The technical report to the EPA/HUD field study sheds light on the possible magnitude of σ_1^2 and σ_2^2. Table 2-3 of the technical report indicates a range of standard deviations for single K-shell XRF readings of from 0.03 mg/cm^2 to 0.72 mg/cm^2, depending on the instrument, substrate and lead level. In the interests of simplicity of the re-test method, a value σ_1 = 0.4 mg/cm^2 (that is, σ_1^2 = 0.16) was selected from this range as a reasonably representative value.

The technical report demonstrated that the magnitude of spatial variation in lead levels across a testing combination was proportional to the true lead level. That is, there was greater absolute variation in lead levels across more highly leaded components. This leads to the equation

$$\sigma_2^2 = C^2 \cdot \mu_i^2,$$

where "C" is a constant factor. Table 4-21 of the technical report to the field study, which shows the results of analysis conducted on a logarithmic scale, indicates a value C = 0.27 based on field duplicate samples taken a distance 9 inches apart in multifamily

dwellings in Philadelphia. The EPA/HUD field study sheds no light on spatial variation between samples taken greater distances apart. However, such variation is likely to be greater than that reported in the field study. To allow for this fact, a value C = 0.6 was chosen to represent spatial variation in lead levels across an entire testing combination. This leads to the following statistical model for re-testing data:

$$X_{i,1} \sim NLN(\mu,\sigma_1^2+C^2\cdot \mu_i^2) = NLN(\mu,0.16+0.36\mu_i^2),$$

and

$$X_{i,2} \sim NLN(\mu,\sigma_1^2+C^2\cdot \mu_i^2) = NLN(\mu,0.16+0.36\mu_i^2),$$

where μ is the true (unknown) average lead level on the testing combination, and NLN refers to the fact that the underlying distribution is that of the sum of a normal and a lognormal random variable.

Let $XBAR_1$ and $XBAR_2$ denote the average of the ten original XRF results and the ten re-test XRF results, respectively. That is,

$$XBAR_k = (X_{1,k} + ... + X_{10,k}) \div 10, \; k = 1,2.$$

Then, assuming statistical independence of the original and re-test XRF measurements, it follows that, approximately,

$$XBAR_1 - XBAR_2 \sim N(0,0.032+0.0072(\mu_1^2 + ... + \mu_{10}^2)),$$

where again μ_i is the true but unknown average lead level in mg/cm^2 on the ith testing combination, I = 1,...,10. Observe that the underlying distribution is now *normal*, instead of the normal-lognormal combination used for the individual XRF results. A remark on the use of a normal approximation for $XBAR_1 - XBAR_2$ can be found at the end of this section. The best available estimate of μ_i is the average

$$M_i = (X_{i,1} + X_{i,2}) \div 2.$$

This leads to the approximate equation

$$XBAR_1 - XBAR_2 \sim N(0,0.032+0.0072\cdot (M_1^2 + ... + M_{10}^2)).$$

The approximate tolerance value for the re-test is then defined as

$$*XBAR_1 - XBAR_2* > 1.645\cdot (0.032+0.0072\cdot (M_1^2 + ... + M_{10}^2))^{½}.$$

Assuming no true difference between the original and re-test results, the probability of exceeding the critical value is approximately 10%, from the standard normal theory. Thus, the probability of spurious failure of two re-tests is 10%· 10% = 1%.

The statement that $XBAR_1$ - $XBAR_2$ approximately follows a normal distribution, in spite of the fact that its averaged constituents do not, is a consequence of the Central Limit Theorem. To illustrate the effectiveness of the approximation, 10,000 values of $XBAR_1$ - $XBAR_2$ were randomly simulated on a computer, based on $X_{i,1}$ and $X_{i,2}$ generated as NLN(μ,0.16+0.36μ^2) for μ = 1, and i ranging from 1 to 10. The following table gives various percentiles of the distribution obtained from the 10,000 simulated values (actual) and from the normal approximation (theory):

Percentile	Theory	Actual
5th	-0.53	-0.54
25th	-0.22	-0.22
50th	0.00	0.00
75th	0.22	0.22
95th	0.53	0.53

It is clear that the normal approximation agrees closely with the actual distribution of $XBAR_1$ - $XBAR_2$, and that its use in testing the difference between the original and re-test results is justified.

5.6.2 Re-Testing in Single-Family Housing

In single-family housing, an XRF result has been defined as the average of three readings taken at randomly selected locations on a testing combination. This is because spatial variation in lead levels across housing components was found, in the above-referenced EPA/HUD field study, to be larger in single-family housing than in multifamily housing. The re-test procedure is similar. Select ten testing combinations at random in the single-family dwelling and re-test them with the same instrument and operator. Apply the same tolerance calculation that was used in the multifamily case, except that three-reading averages are used as the XRF results in all cases instead of single readings.

The statistical properties of the re-test are similar to those for the multifamily case, despite the difference between single and triple readings. There are two reasons for this. First, the EPA/HUD field study found that XRF measurement variability was generally very similar whether a single reading or the average of three readings was used to define the XRF result. Thus, the XRF measurement component of variability is similar in the multifamily and single-family re-tests. With regard to the spatial variation in lead levels across a testing combination, Table 4-21 of the technical report shows a standard deviation of 0.47 on a logarithmic scale for single-family housing in Denver as compared to a standard deviation of 0.27 for multifamily housing in Philadelphia. Thus, the standard deviation for spatial variation (on the measurement scale) is estimated as $0.47 \cdot \mu$ for single-family housing as compared to $0.27 \cdot \mu$ for multifamily housing. Thus, the standard deviation for the average of three readings in single family dwellings is estimated as $0.47 \cdot \mu \div \sqrt{3} = 0.27 \cdot \mu$, which is the same as the standard deviation for a single reading in the multifamily case. Thus, the spatial variability for the average of three readings in the single-family case is estimated to be the same as the spatial variability for a single reading in the multifamily case. The bottom line is that the statistical properties of a single reading in the multifamily case are similar to those of the average of three readings at randomly selected locations in the single-family case. Hence, the same re-test formulas apply to the single-family and multifamily cases, bearing in mind the different definitions of XRF result.

5.6.3 Examples of Re-Test Calculations

Example 1: Suppose the following original and re-test results were obtained (mg/cm^2):

Original: 1.2, 2.1, 3.0, 1.5, 1.6, 4.5, 2.0, 0.2, 0.1, 0.0.

Re-Test: 1.6, 1.8, 2.5, 1.9, 1.3, 3.7, 3.2, 0.0, 0.7, 0.5.

The average of the ten original XRF results is $XBAR_1 = 1.62$, while the average of the re-tests is $XBAR_2 = 1.72$. Thus, $*XBAR_1 - XBAR_2* = 0.1$. The critical value is computed as follows. First, the averages (M_i, i =1,...10) of the original and re-test results by testing combination are computed to be:

1.4, 1.95, 2.75, 1.7, 1.45, 4.1, 2.6, 0.1, 0.4, and 0.25.

Next, the sum of the squared averages is computed to be:

$$M_1^2 + ... + M_{10}^2 = 1.4^2 + ... + 0.25^2 = 42.12.$$

Thus, the critical value is

$$1.645 \cdot (0.032 + 0.0072 \cdot 42.12)^{1/2} = 0.95.$$

Therefore, since 0.1 < 0.95, the re-test is passed in this case.

Example 2: Suppose the following original and re-test results were obtained (mg/cm^2):

Original: 1.2, 2.1, 3.0, 1.5, 1.6, 4.5, 2.0, 0.2, 0.1, 0.0.

Re-Test: 4.0, 1.8, 2.5, 1.9, 1.3, 3.7, 3.2, 4.0, 0.7, 5.0.

Clearly, several of the re-test results differ markedly from the original results in this case. The difference of the averages is $*XBAR_1 - XBAR_2*$ = 1.19. In this case, the critical value is 1.10, so the re-test fails, necessitating a second re-test. For a second re-test, another, different set of ten randomly selected testing combinations is selected. Suppose the following second original and second re-test results were obtained (mg/cm^2):

2^{nd} Original: 0.9, 1.2, 1.1, 1.5, 2.4, 0.1, 2.2, 0.1, 0.1, 0.2.

2^{nd} Re-Test: 2.6, 2.7, 3.2, 3.8, 5.2, 1.3, 3.1, 4.0, 1.7, 1.4.

The average of the second ten original XRF results is $XBAR_1$ = 0.98, while the average of the second re-tests is $XBAR_2$ = 3.16. Thus, $*XBAR_1 - XBAR_2*$ = 2.18. The critical value is computed by first finding the averages of the second original and second re-test results by testing combination. Next, the sum of the squared averages is computed. The critical value was computed to be 0.99. As with the first re-test, several of the second re-test results differ markedly from the second original results. In this case, the critical value is 0.99, so the second re-test fails since the 2.18 > 0.99. Whenever both re-tests fail, the inspection should be considered deficient.

5.6.4 Error in Re-Test Formula

The re-test formula is presented in words in the 1995 HUD Guidelines and in some of the previously published XRF Performance Characteristic Sheets is incorrect. The wording has been corrected on all of the XRF Performance Characteristic Sheets in Appendix D. The following wording (that appeared in some cases):

"Compute the square of each of the ten original and ten retest XRF results. Add these squares of XRF results together. Call this quantity C."

is incorrect, and should be replaced by the following:

"**Compute the average of the original and re-test result for each of the ten testing combinations. Square the average for each testing combination. Add the ten squared averages together. Call this quantity C.**"

The net effect of the erroneous wording is to make it more difficult for a re-test to fail. This reduces the frequency of spurious failures, but also makes it more difficult to detect instances of fraud or other problems. As an example, consider the test/re-test results in Example 2 of section 5.6.3. The use of the erroneous formula has the effect in this example of increasing the critical value from 1.10 to 1.68, which would mean that the re-test would pass instead of failing. The wording will be corrected in subsequent versions of the XRF Performance Characteristic Sheets.

5.7 XRF Results That Do Not Consist of Fixed Reading Time Measurements

In the EPA/HUD field study, XRF instruments were evaluated relative to a fixed, nominal 15-second reading time, or, in one case, a fixed, nominal 60-second reading time. The XRF measurement model (section 5.1.1) was developed for XRF results obtained with fixed reading times. Subsequent to the completion of the field study, several XRF instruments emerged that do not report a fixed reading time measurement as its outcome. In some cases, a random reading time is used, which may be determined in various ways, such as (1) reading until the machine determines that a target precision level (for example, 0.2 mg/cm^2) has been reached, or (2) reading until the machine determines that sufficient information is available to distinguish the lead level from being above or below a certain target value, such as the 1.0 mg/cm^2 federal standard. In at least one other case, several nominally-fixed reading time K- and L-shell readings are processed together in an algorithm to determine whether the lead level is as above or below a target value.

An approach for analyzing variable time XRF measurements is described in appendix B. Two PCSs with variable time modes are the LeadStar and MAP 4 PCSs. These PCSs start on pages D-3 and D-60, respectively, in appendix D.

6.0 REFERENCES

1. U.S. Environmental Protection Agency (1997), *Archive Operations and Protocols*, EPA Report Number 747-R-97-004.

2. Siegmund, D., (1985), *Sequential Analysis*, Springer-Verlag: New York.

3. Strömberg, U, (1991), *Computational Statistics and Data Analysis* (11) 205-219.

4. Title X--Residential Lead-Based Paint Hazard Reduction Act of 1992, Public Law 102-550.

5. U.S. Environmental Protection Agency (1995), *A Field Test of Lead-Based Paint Testing Technologies: Technical Report*, EPA Report No. 747-R-95-002b.

6. U.S. Environmental Protection Agency (1995), *Report on the National Survey of Lead-Based Paint in Housing, Appendix II: Analysis*, EPA Report No. 747-R-95-005.

APPENDICES

APPENDIX A: XRF INSTRUMENT OPERATING PROTOCOLS

A.1 Introduction

PCS development applied XRF instrument results from testing samples from either the EPA/HUD field study or the archive facility. Testing protocols used by XRF instruments in the EPA/HUD field study can be found in the appendices of the report entitled *A Field Test of Lead-Based Paint Testing Technologies: Technical Report* (EPA 747-R-95-002b). This report can be ordered from the National Technical Information Service (NTIS) at 703-487-4650 (NTIS reference number, PB96-125026). A detailed description of the XRF testing methodologies used in the EPA/HUD field study, some of which also apply to testing the archive samples, is provided in Chapter 3 of the technical report. A familiarity with these methodologies may be beneficial to the reader. Provided in this appendix are descriptions of the testing protocols used by XRF instruments to test the archive samples. The document entitled *Archive Operations and Protocols* (EPA 747-R-97-004) provides detailed descriptions of the testing protocols.

A.2 Brief Description of Testing Areas

As many as four specific test areas are found on each archive sample and are referred to as X1, X2, X3, and BARE. The protocols in this appendix refer to these specific test areas. A brief description of each follows.

X1 is the primary painted test area on the sample.

X2 and **X3** are the secondary and tertiary painted test areas. Test data taken from the X2 and X3 test areas were not used during PCS development.

BARE is the test area from which all paint had been removed.

All archive samples have at least the X1 and BARE test areas. The archive samples with the greatest surface area generally also have the X2 and X3 test areas. Detailed descriptions of X1 and BARE may be found in Chapter 3 of the technical report to the EPA/HUD field study referenced above.

A.3 Summary of Testing Protocols

All of the XRF testing protocols used for testing the archive samples have common features. This commonality allows for describing these protocols using a general flow chart. Figure A-1 is a general flow chart that provides a description of the common protocol features for all XRF instruments that tested the archive samples.

APPENDIX A: XRF INSTRUMENT OPERATING PROTOCOLS

Since each XRF instrument has its own unique operating characteristics, the XRF testing protocols vary from the common protocol features to account for these unique operating characteristics. Table A-1 describes the different operating modes and number of readings used to perform quality control procedures, and Table A-2 provides the same information for readings taken on archive samples.

The operating mode shown in Table A-2 for the XL requires some additional explanation since the mode indicated in this table is not specifically identified in the manufacturer user manual. Collection of a longer measurement with this XRF, according to the May 5, 1994 version of the XL user manual, is based on the manufacturer's manual and additional information supplied by the manufacturer.

APPENDIX A: XRF INSTRUMENT OPERATING PROTOCOLS

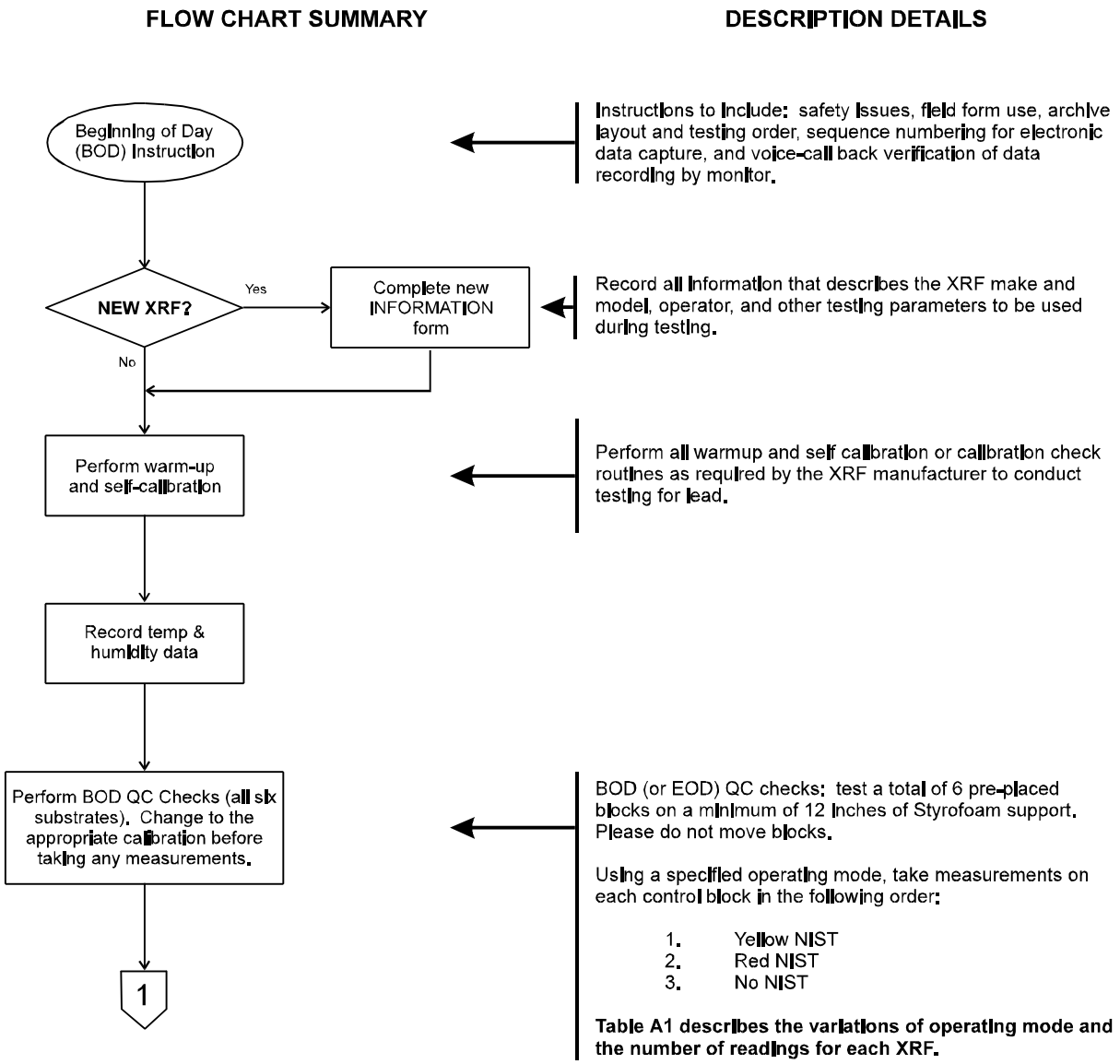


Figure A-1. General flow chart for XRF testing of archive samples.

APPENDIX A: XRF INSTRUMENT OPERATING PROTOCOLS

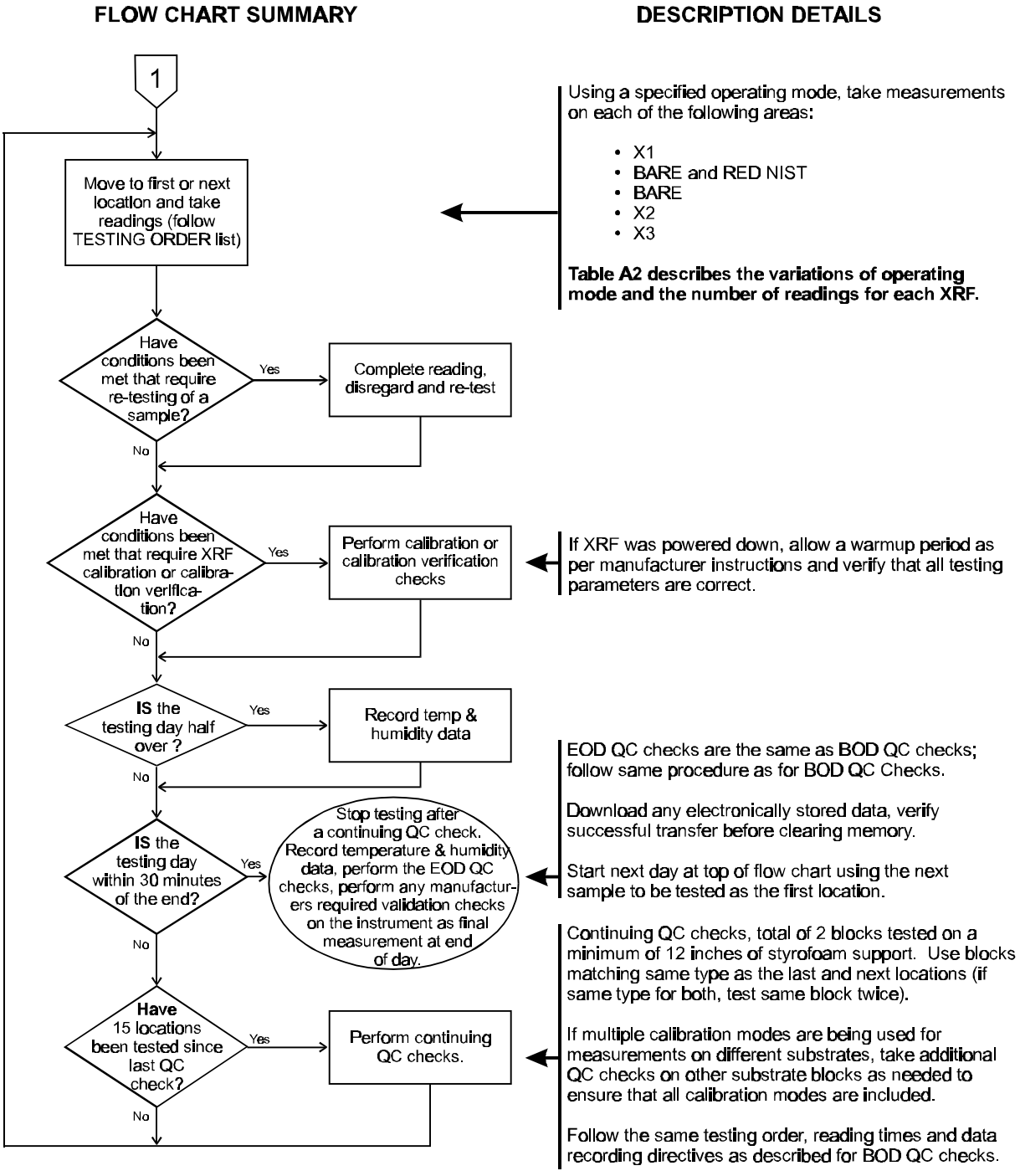


Figure A-1 (Continued). General flow chart for XRF testing of archive samples.

APPENDIX A: XRF INSTRUMENT OPERATING PROTOCOLS

Table A-1. Variations in the Beginning and End of Day Quality Control Samples Used for XRF Testing of Archive Samples.

XRF MODEL	TESTING DATES	OPERATOR[a]	OPERATING MODE	NOMINAL READING TIME (SEC)	NO. OF READINGS COLLECTED[b]		
					Y	R	B
Pb Analyzer	01/18-20/95	PTF	Real time	15	1	3	1
	09/14-15/95	NIST	Real time	15	1	1-3	1
LPA-1	03/12-14/95	NIST	Standard	20	1	1	1
	06/13-26/95	NIST	Standard	20	0	3	3
	07/17-19/95	PTF	Standard	30	1	1-3	1
	09/11-12/95	NIST	Standard	30	1	1-3	1
XL	03/15-17/95	NIST	Standard	20	1	1	1
	06/13-26/95	NIST	Standard	20	0	3	3
LeadStar I	06/06-08/95	NIST	Standard	15	1	1-3	1
	08/14-16/95	PTF	Standard	15	1	1-3	1
	08/17-19/96	PTF	Standard	15	1	1-3	1
	09/04-06/96	PTF	Standard	15	1	1-3	1
Microlead I revision 4	09/13-14/95	NIST	Standard	15	1	1-3	1
MAP 4	02/05-07/96	NIST	Test	variable	1	1-3	1
	02/19-21/96	PTF	Test	variable	1	1-3	1
XK-3	02/08/96	NIST	Standard	15	1	1-3	1

[a]PTF is an abbreviation for private testing firm, NIST is an abbreviation for National Institute of Standards and Technology.
[b]Readings on each control block: Y = Yellow NIST film SRM 2579 covering the control block.
R = Red NIST film SRM 2579 covering the control block.
B = Bare, not covered with any paint films.

APPENDIX A: XRF INSTRUMENT OPERATING PROTOCOLS

Table A-2. Variations in Measurements at Test Areas of Archive Samples.

XRF MODEL	TESTING DATES	OPERATOR[a]	NO. OF SAMPLES[b]	OPERATING MODE	NOMINAL READING TIME (SEC)	NO. OF READINGS[c]				
						X1	R	B	X2	X3
Pb Analyzer	01/18-20/95	PTF	154[d]	Real Time	15	3	3	1	1	1
	09/14-15/95	NIST	158	Real Time	15	1	1	1	0	0
LPA-1	03/12-14/95	NIST	154	Quick	variable	1	1	1	0	0
				Standard	20	1	1	1	1	1
	06/13-26/95[e]	NIST	4[f]	Quick	variable	1	1	1	1	1
				Standard	20	1	1	1	1	1
	07/17-19/95	PTF	158	Quick	variable	1	1	1	1	1
				Standard	30	1	1	1	1	1
	09/11-12/95	NIST	158	Quick	variable	1	1	1	1	1
				Standard	30	1	1	1	1	1
XL	03/15-17/95	NIST	154	variable[g]	variable	1	1	1	1	1
	06/13-26/95[e]	NIST	4[f]	variable[g]	variable	1	1	1	1	1
LeadStar I	06/06-08/95	NIST	158	Standard	15	1	1	1	1	1
				Brief	variable	1	0	0	0	0
	08/14-16/95	PTF	158	Standard	15	1	1	1	1	1
				Brief	variable	1	0	0	0	0
	08/27-29/96	PTF	158	Standard	15	1	1	1	1	1
				Brief	variable	1	0	0	0	0
	09/04-06/96	PTF	158	Standard	15	1	1	1	1	1
				Brief	variable	1	0	0	0	0
Microlead I	09/13-14/95	NIST	158	Standard	15	1	1	1	0	0
MAP 4	02/05-07/96	NIST	158	Standard[h,i]	variable	1	1	1	1	1
				Unlimited[i]	variable	1	0	0	0	0
	02/19-21/96	PTF	158	Standard[h,i]	variable	1	1	1	1	1
				Unlimited[i]	variable	1	0	0	0	0
XK-3	02/08/96	NIST	158	Standard	15	1	1	1	0	0

[a]PTF is an abbreviation for private testing firm, NIST is an abbreviation for National Institute of Standards and Technology.
[b]Four additional plaster samples from Denver were added to the Archives in June 1995 for a total number of 158.
[c]Readings at sample areas: X1 = Primary XRF test area, R = Red NIST film SRM 2579 covering the bare area, B = Bare area, not covered with any paint films, X2 = Secondary XRF test area, and X3 = Tertiary XRF test area.
[d]154 samples were tested twice, see section 4.5 of this document.
[e]Testing on these dates was performed to capture wood control block readings as well for PCS development.
[f]The four additional plaster samples under note b above were tested.
[g]The testing mode varied depending on previous results as described under “How to Classify Readings” on the XL PCS. Refer to the Archive Operations and Protocols report for additional information.
[h]For X1 areas, mode of testing was performed using both "Screen" and "Test" followed by "Confirm" mode if the "Test" mode could not classify the result as either positive or negative. For R, B, X2, and X3 sample areas, only "Test" mode was used.
[i]A different internal calibration was used for non-aluminum metal substrates than for all other substrates.

APPENDIX B: METHODOLOGICAL ISSUES IN THE ANALYSIS OF XRF MEASUREMENTS WITH VARIABLE READING TIMES

B.1 Introduction

The statistical methodology that has been adopted for analyzing XRF measurements in the development of Performance Characteristic Sheets (PCSs) is based on fixed reading times. This designation was motivated by the EPA/HUD field study, in which fixed 15-second measurements were used to evaluate the performance of XRF instruments. Subsequent to the field study, however, several XRF instruments have emerged that give variable reading time measurements. Instead of reading until a fixed amount of time has elapsed, such instruments read until the conditions of a stopping rule are met. The stopping rules are of two types: (1) to continue reading until a fixed level of precision (SD) is achieved; (2) to continue reading until the machine can reliably classify the lead level as above or below a certain target, such as the 1.0 mg/cm^2 federal standard. In addition, the operator may terminate the reading if a maximum time allotment has been exhausted.

The purpose of this appendix is to describe methodological issues that arise in the analysis of variable reading time XRF measurements, and to describe analyses related to other features of these instruments that are appropriate for inclusion in a PCS. The following terminology will be used to refer to the variable reading time measurement modalities considered in this appendix:

- **Precision mode**, in which reading continues until the instrument determines that a target precision level has been achieved;

- **Unlimited mode**, in which reading continues until the instrument determines that the lead level can be classified as above or below a target value;

- **Sequential mode**, in which a sequence of precision mode measurements is made, with progressively higher levels of precision, until the lead level can be classified as above or below a target value.

These modes may, for a particular XRF instrument, be subdivided further. For example, one instrument designates separate precision modes corresponding to precision levels of 0.4 mg/cm^2, 0.2 mg/cm^2, and 0.1 mg/cm^2. An XRF instrument typically adopts its own nomenclature for its measurement modalities, which may not agree in all details with the terminology adopted in this appendix. Because sequential mode is essentially a discretized version of unlimited mode, it is not treated separately in this appendix.

APPENDIX B: METHODOLOGICAL ISSUES IN THE ANALYSIS OF XRF MEASUREMENTS WITH VARIABLE READING TIMES

In archive testing, measurements may be taken in all or only a subset of the available precision modes at each sample. It is anticipated, however, that measurements in at least one of the precision modes would be obtained on every sample. If available, an unlimited mode measurement would be obtained on every sample, as would ancillary information reported by the machine, including the reading time. Because the reading time is an important element of performance, it would be collected manually if the instrument does not provide this information directly, or if it does not do so reliably.

B.2 Variable Reading Time Measurements

In precision mode, the machine continues to read until it determines that a specified precision level has been reached. It is assumed that precision refers to the standard deviation (SD), or to some fixed multiple of the SD. Ostensibly, the resulting measurements have a constant precision that does not depend on the lead level, in contrast to the observed performance of most XRF instruments that use fixed reading times. In actuality, however, increasing the time of readings made by a machine at a fixed location can only diminish instrumental variation, leaving non-instrumental variation essentially untouched. Non-instrumental variation, due to characteristics of painted building components other than the lead level that may affect the performance of an XRF instrument, was found to be a substantial factor in the EPA/HUD field study. This finding was confirmed with one of the XRF instruments tested at the archive in its precision modes, for which evidence of heteroscedasticity remained on all substrates except metal.

Unlimited mode also uses a variable reading time, but the stopping rule is designed to detect whether or not the lead level is above an action level. With a 1.0 mg/cm^2 action level, for instance, the instrument continues to test the painted surface until the resulting measurement is outside of the range $1.0 \pm p$, where p is a "precision bound" that diminishes with time. Measurements that are well above or below the action level are likely to require shorter reading times than those that are close to the action level.

B.3 A Model for Variable Reading Time Measurements

For fixed reading times, the XRF measurement model described in section 5.1.1 states that XRF measurements are normally distributed, with mean and variance related in a simple way to the lead level. A fixed reading time model does not

necessarily provide an accurate description of XRF measurements obtained with variable reading times, because the reading times may contain information about the lead level. Readings made in real time, which depend on counts received by the instrument, may be related to a Poisson process. Since the number of counts is typically large, the increment in counts over a short time interval is approximately normally distributed. This observation is the basis of a conceptual framework that is applicable to variable reading time measurements.

Let $Y(t)$ denote the XRF reading obtained on a given sample at time t. Although it is likely that the instrument processes data in fixed time increments, it will be convenient to regard t as a continuous time parameter. Suppose that a fixed, one-second reading $Y(1)$ is distributed as normal with mean μ and variance ^{2}. If the reading process is unbiased, μ is the level of lead in the paint sample being tested. Let $W(t)$ denote a normal diffusion process with parameters $(\mu,$. Another way of stating this is that, if t_1 and t_2 are reading times with t_1 less than t_2, then the difference $W(t_2) - W(t_1)$ is distributed as normal with mean $(t_2 - t_1)\mu$, and variance $(t_2 - t_1)$ ^{2}. Define $W(0) = 0$. Accordingly,

$$Y(t) \qquad \frac{W(t)}{t}$$

constitutes a model for the XRF readings obtained in real time.

This model is consistent with the treatment of fixed reading times that was described in chapter 5, because $Y(t)$ is a normal random variable with mean μ and variance $^2/t$ if t is a fixed reading time. In other words, longer reading times diminish the variance by the familiar rule for independent sampling. As noted above, this model only accounts for instrumental variation, which is the only kind of precision that an XRF instrument can discern, and therefore use, in deciding when to stop reading. The reading times required for both precision and unlimited mode measurements are random, because they depend on data that the instrument has received up to that point in time.

B.3.1 Precision Mode Readings

In precision mode, testing continues until the estimated precision reaches its target value. If the precision is estimated using a sample standard deviation, which is a reasonable assumption, then the stopping rule is independent of the value of $W(t)$ or

Y(t) at any time *t*. It then follows that the resulting XRF measurement remains an unbiased estimate of μ. If reading times for the precision modes do not fluctuate greatly, the resulting XRF measurements are approximately normally distributed, and the XRF measurement model presented in section 5.1.1 may continue to be used. Bias and precision estimates, and inconclusive ranges/thresholds, can be derived in the same manner as in the fixed reading time case.

If the performance of an XRF instrument is affected by recognizable substrate attributes, it is appropriate to group its testing data accordingly for model estimation and other PCS development purposes. This applies in particular to instruments that have special substrate calibration settings, and those for which reading times depend on the density of the substrate, or on other substrate-related features.

B.3.2 Unlimited Mode Readings

The situation is different for unlimited mode readings, because the stopping rule depends on the value of the measurement process. Using a 1.0 mg/cm^2 action level for illustration, it is plausible that the stopping rule is similar to the following: keep reading until the null hypothesis that $\mu = 1$ is rejected in a two-tailed test. The stopping time is the smallest value of *t* such that the following inequality is satisfied:

$$Y(t) \quad 1 \qquad c\frac{s(t)}{\sqrt{t}}$$

where *s(t)* is an estimate of the standard deviation of a one-second reading, based on information available at time *t*. As *t* becomes larger, *s(t)* is approximately the same as

.

The resulting XRF measurement has several noteworthy properties:

- it is a biased estimate of μ;
- it has a standard deviation that is smallest when the true lead level is equal to the action level, and it increases as the lead level either increases or decreases away from the action level;
- it is not normally distributed, especially for lead levels that are close to the action level.

These properties suggest that the XRF measurement model is not an appropriate device for describing unlimited mode readings. In particular, the meaning of bias in this context is difficult to formulate in a useful way, because it is designed to improve the classification of painted surfaces relative to the action level.

A proper understanding of the statistical properties of unlimited mode measurements resides in their diffusion process foundation. That this aspect is also embedded in a regression problem, which in turn is embedded in an ICP measurement error problem, makes PCS development of unlimited mode measurements a challenging task that requires a sustained effort. As more instruments adopt this modality of measurement, it will be worthwhile to make a concerted effort in this direction.

B.4 Nonparametric Inconclusive Ranges for Unlimited Mode Readings

An inconclusive range is derived from estimates of the 95th percentile of XRF readings at the 0.5 mg/cm^2 lead level, and the 5th percentile of XRF readings at the 2.0 mg/cm^2 lead level. When the underlying distribution is normal, these estimates are quickly obtained from the XRF measurement model. When the underlying distributions are unknown and suspected to be nonnormal, this approach does not work. Nonparametric estimates of the 5th and 95th percentiles, as functions of the lead level, can be derived under an assumption that these percentiles are increasing functions of the lead level. These are called isotonic (or monotonic) estimates, and are derived in a manner similar to monotone regression. The assumption needed to justify the use of this procedure is valid for unlimited mode measurements modeled in the manner described above.

The archive data used to derive the nonparametric percentile estimates are those for which the laboratory-measured (ICP) lead level is less than 4.0 mg/cm^2, and excluding any outliers that are designated in precision mode analyses. All substrates are grouped together, because sample sizes are too small to give separate estimates for each substrate type. This is a drawback to the approach, along with the inability to account for ICP measurement error. The nonparametric estimates are step functions, because they are based on grouping data in a way that the sample 5th and 95th percentiles are nondecreasing in the laboratory-measured lead level. Linear interpolation is used to obtain estimates at the 0.5 mg/cm^2 and 2.0 mg/cm^2 lead levels. If several archive tests were made, estimates are obtained for each test separately, and pooled by averaging.

Pooling is illustrated below with hypothetical numbers:

5th percentile: at 2.0 mg/cm^2 — first = 0.82, second = 1.54, pooled = 1.18

95th percentile: at 0.5 mg/cm^2 — first = 0.92, second = 1.26, pooled = 1.09

Inconclusive range: initial threshold of 1.09, rounded to 1.1, which is converted to an interval that covers the 1.0 action level: $x_L = 0.9$, $x_U = 1.1$

B.5 Substrate Correction

The method for determining the need for substrate correction, and for applying substrate correction where recommended, is the same for precision mode measurements as it is for fixed reading time measurements. This is because precision mode measurements exhibit bias in the same manner as fixed reading time measurements, as explained in section E.3.1. Thus, the methodology described in section 5.3 remains applicable to this mode of variable reading time measurement.

Substrate correction recommendations do not apply to unlimited mode measurements. The development of a methodology for substrate correction that is applicable to unlimited mode readings remains an unresolved issue. Substrate correction that is recommended for precision mode measurements should not be used with unlimited mode measurements.

APPENDIX C: XRF PERFORMANCE CHARACTERISTIC SHEETS ERRATA

C.1 Introduction

A few errors have been identified in previously released XRF Performance Characteristic Sheets (PCSs). The errors and corrections are described in this appendix. The PCSs that are reproduced and provided in appendix D of this document have been corrected of any known errors.

C.2 Errors Appearing in the "Instructions for Evaluating XRF Testing" Section

Some of the PCSs were released with errors in the "Instructions for Evaluating XRF Testing" section of the PCS. The following wording was incorrect:

> "Compute the square of each of the ten original and ten retest XRF results. Add these squares of XRF results together. Call this quantity C."

This wording was replaced with the following:

> "Compute the average of the original and re-test result for each of the ten testing combinations. Square the average for each testing combination. Add the ten squared averages together. Call this quantity C."

The net effect of the erroneous wording was to make it more difficult for a re-test to fail. This reduces the frequency of spurious failures, but also makes it more difficult to detect instances of fraud or other problems. As an example, consider the test/re-test effect in example 2 of section 5.6.3. The use of the erroneous formula has the effect in this example of increasing the critical value from 1.10 to 1.68, which would mean that the re-test would pass instead of failing.

C.3 Errors Appearing in the MAP-3 PCS and Corrections

Errors were found for reported estimates for 60-second readings in the MAP-3 PCS. At 0.0 mg/cm^2, the bias for plaster was incorrectly reported as -0.8. The correct value is -0.9. At 0.5 mg/cm^2, the bias for plaster was incorrectly reported as -0.6. The correct value is -0.7. At 2.0 mg/cm^2, the bias for metal was incorrectly reported as 0.9. The correct value is 0.8. At 1.0 mg/cm^2, the precision for wood was incorrectly reported as 0.4. The correct value is 0.5. At 2.0 mg/cm^2, the precision for wood was incorrectly reported as 0.4. The correct value is 0.6. At 2.0 mg/cm^2, the precision for metal was incorrectly reported as 0.5. The correct value is 0.6.

APPENDIX C (continued): XRF PERFORMANCE CHARACTERISTIC SHEETS ERRATA

C.4 Errors Appearing in the LeadStar and MAP 4 PCSs and Corrections

The source strengths were incorrectly reported in the MAP 4 PCS. The strength of the source installed in July 1994 was incorrectly reported as 9.4 mCi. The correct value is 10.1 mCi. The strength of the source installed in September 1994 was incorrectly reported as 10.6 mCi. The correct value is 11.5 mCi.

Grammatical errors were found in the LeadStar and MAP 4 PCS. The changes involved spelling corrections and additional wording for clarification and improved flow. The LeadStar and MAP 4 PCSs in appendix D have been corrected for these errors.

C.5 Errors Appearing in the LPA-1 PCS and Corrections

Two errors were found in the LPA-1 PCS. On page 9 of 12, at 0.0 mg/cm^2, the bias for metal was incorrectly reported as -0.4. The correct value is -0.5. On page 10 of 12, at 2.0 mg/cm^2, the lower bound of the bias range for metal was incorrectly reported as -0.8. The correct value is -0.7.

C.6 Errors Appearing in the Microlead I PCS and Corrections

Four estimates were omitted from page 5 of 5 in the Microlead I PCS. At 0.5 mg/cm^2, the bias for brick was omitted. The correct value is 0.4. At 2.0 mg/cm^2, the bias for brick was omitted. The correct value is 0.7. At 0.5 mg/cm^2, the precision for brick was omitted. The correct value is 0.5. At 2.0 mg/cm^2, the precision for brick was omitted. The correct value is 0.5.

C.7 Error Appearing in the Title of the PCSs and Correction

PCSs were incorrectly titled with the plural word “Characteristics”. The correct title uses a singular “Characteristic”. Thus, the correct title for all Edition 1 versions is “XRF Performance Characteristic Sheet”.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

D.1 Introduction

The XRF Performance Characteristic Sheets (PCSs) that have been released as of August 31, 1997, with all corrections made as necessary, are provided in this appendix. See Appendix C for a summary of the corrections to the PCSs.

Following each PCS are associated results such as inconclusive ranges and thresholds for cases where substrate correction is recommended but not performed, bias and precision estimates, the standard errors of these estimates, and classification results based on empirical data. In general, following each PCS will be the following tables: tables for XRF inconclusive ranges and thresholds for cases where substrate correction is recommended but not performed, tables of bias and their standard errors, tables of precision and their standard errors, and tables of classification rates.

An important note about the tables presenting results for cases where substrate correction is recommended but not performed follows. **IT SHOULD BE EMPHASIZED THAT THESE RESULTS ARE PRESENTED FOR ILLUSTRATIVE PURPOSES ONLY, AND SHOULD NOT BE USED AS SUBSTITUTES FOR PERFORMING SUBSTRATE CORRECTION.** If substrate correction is recommended, testing of the XRF instrument has shown a reduction in bias through the use of substrate correction. Moreover, substrate correction tends to diminish the variation between machines, which in turn broadens the applicability of inconclusive ranges and thresholds for substrate corrected readings beyond the machines that were tested. A similar property does not hold for inconclusive ranges and thresholds developed with non-corrected readings when a benefit from performing substrate correction was observed.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

D.2 XRF Performance Characteristic Sheet for the Advanced Detectors LeadStar and Related Results

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Advanced Detectors; LeadStar

EFFECTIVE DATE: October 7, 1996 **EDITION NO.**: 1

MANUFACTURER AND MODEL:

Make:	*Advanced Detectors, Inc.*
Model:	*LeadStar*
Source:	Co^{57}
Note:	This sheet supersedes all previous sheets for the XRF instrument of the make, model, and source shown above.

EVALUATION DATA SOURCE AND DATE:

This sheet is supplemental information to be used in conjunction with Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* ("HUD Guidelines"). Performance parameters shown on this sheet are calculated from the EPA/HUD evaluation using archived building components. Testing was conducted on approximately 150 test locations. All of the test locations were tested twice in 1995, in June and in August. Two instruments (both installed with software version 4.05) were used in the June 1995 testing and one instrument (with software version 4.08) was used in the August 1995 testing. All three instruments had a June 1995 source at 15 mCi initial strength. The same test locations were tested twice again in 1996, in August and in September. One instrument (with software version 4.30) was used in the August 1996 testing, with a July 1996 source at 15 mCi initial strength. One instrument (also with software version 4.30) was used in the September 1996 testing, with an August 1996 source at 15 mCi initial strength. Each instrument had a distinct serial number.

FIELD OPERATION GUIDANCE

OPERATING PARAMETERS:

Performance parameters shown in this sheet are applicable only when operating the instrument under the same conditions as the evaluation testing and using the procedures described in Chapter 7 of the HUD Guidelines. Operating parameters include:

- Manufacturer-recommended warm-up and quality control procedures
- Use the Multifamily Decision Flowchart for determining the presence of lead on a component type in multifamily housing
- Take readings on three locations per component for single-family housing and one location per component for multifamily housing
- Calibration checks are taken using the red (1.02 mg/cm^2) NIST Standard Reference Material (SRM No. 2579) paint film
- Readings for determining the substrate correction values are taken on bare substrate covered with red (1.02 mg/cm^2) NIST SRM paint film
- Lead-based paint is defined as paint with lead equal to or in excess of 1.0 mg/cm^2.

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Figure D-1. XRF Performance Characteristic Sheet for the Advanced Detectors LeadStar.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Advanced Detectors; LeadStar

XRF CALIBRATION CHECK:

Chapter 7 of the HUD Guidelines recommends using a calibration check procedure to determine the operating condition of the XRF instrument. For this instrument, calibration check readings should be taken in *Fixed Mode*. If the observed calibration check average minus 1.02 mg/cm^2 is greater than the positive (plus) calibration check tolerance value, or less than the negative (minus) calibration check tolerance value, then the instructions provided by the manufacturer should be followed in order to bring the instrument back into control before any more XRF testing is done. This calibration check is estimated to produce an incorrect result (that is, a finding that the instrument is out of calibration) very infrequently - once out of every 200 times this procedure is followed.

Use the following calibration check tolerance values for *Fixed Mode* readings for those instruments with software versions 4.1 to 4.30. (This guidance may be used for software versions higher than 4.30 if the higher software version incorporates the same signal processing and data treatment algorithms that are in software version 4.30).

minus value =	-0.2 mg/cm^2
plus value =	+0.0 mg/cm^2

Use the following calibration check tolerance values for *Fixed Mode* readings for those instruments with software versions earlier than version 4.1.

minus value =	-0.2 mg/cm^2
plus value =	+0.1 mg/cm^2

(Operators may choose to use limits in the manufacturer's operations manual for this calibration check. The rate of an incorrect result if the limits in the manufacturer's operations manual are followed may be different from the rate of an incorrect result stated here.)

FOR XRF RESULTS BELOW 4.0 mg/cm^2, SUBSTRATE CORRECTION RECOMMENDED FOR:

For those instruments with software versions 4.1 to 4.30. (This guidance may be used for software versions higher than 4.30 if the higher software version incorporates the same signal processing and data treatment algorithms that are in software version 4.30).

none

For those instruments with software versions earlier than version 4.1

Metal

SUBSTRATE CORRECTION NOT RECOMMENDED FOR:

For those instruments with software versions 4.1 to 4.30.

Brick, Concrete, Drywall, Metal, Plaster, and Wood

For those instruments with software versions earlier than version 4.1.

Brick, Concrete, Drywall, Plaster, and Wood

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Figure D-1 continued. XRF Performance Characteristic Sheet for the Advanced Detectors LeadStar.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Advanced Detectors; LeadStar

SUBSTRATE CORRECTION VALUE COMPUTATION:

Chapter 7 of the HUD Guidelines provides guidance on correcting XRF results for substrate bias. Supplemental guidance for using the red (1.02 mg/cm^2) NIST SRM paint film for substrate correction is provided below.

XRF results are corrected for substrate bias by subtracting from each XRF result a correction value determined separately in each house for single-family housing or in each development for multifamily housing, for each substrate. The correction value is an average of XRF readings taken over red NIST SRM (1.02 mg/cm^2) paint films at test locations that had been scraped clean of their paint covering. Compute the correction values as follows:

- Using the same XRF instrument, take three readings on a bare substrate area covered with the red NIST SRM (1.02 mg/cm^2) paint film. Repeat this procedure by taking three more readings on a second bare substrate area of the same substrate covered with the red NIST SRM (1.02 mg/cm^2) paint film.

- Compute the correction value for each substrate type by computing the average of all six readings as shown below.

  For each substrate type recommended for substrate correction:

$$\textit{Correction Value} = \frac{1^{st} + 2^{nd} + 3^{rd} + 4^{th} + 5^{th} + 6^{th}\ \textit{Reading}}{6} - 1.02 mg/cm^2$$

INCONCLUSIVE RANGE OR THRESHOLD:

XRF results are classified using either the threshold or the inconclusive range. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. For computing the XRF result, use all digits that are reported by the instrument. For the threshold, results are classified as positive if they are greater than or equal to the threshold, and negative if they are less than the threshold. There is no inconclusive classification when using the threshold. For the inconclusive range, results are classified as positive if they are greater than or equal to the upper limit of the inconclusive range, and negative if they are less than or equal to the lower limit of the inconclusive range. Thresholds and inconclusive ranges reported here were determined for comparing results to the 1.0 mg/cm^2 standard. For a listing of laboratories recommended by the EPA National Lead Laboratory Accreditation Program (NLLAP) for the analysis of samples to resolve an inconclusive XRF result or additional confirmational analysis, call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

For those instruments with software versions 4.1 to 4.30. (This guidance may be used for software versions higher than 4.30 if the higher software version incorporates the same signal processing and data treatment algorithms that are in software version 4.30).

Figure D-1 continued. XRF Performance Characteristic Sheet for the Advanced Detectors LeadStar.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Advanced Detectors; LeadStar

15-SECOND FIXED MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)	INCONCLUSIVE RANGE (mg/cm^2)
Results not corrected for substrate bias	Brick	None	0.9 to 1.1
	Concrete	None	0.9 to 1.1
	Drywall	None	0.9 to 1.1
	Metal	None	0.9 to 1.2
	Plaster	1.0	None
	Wood	None	0.9 to 1.1

BRIEF MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD in mg/cm^2
Results not corrected for substrate bias	Brick	1.0
	Concrete	1.0
	Drywall	1.0
	Metal	1.0
	Plaster	1.0
	Wood	1.0

For those instruments with software versions earlier than version 4.1.

15-SECOND FIXED MODE READING DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE in mg/cm^2
Results corrected for substrate bias for readings on metal substrates only	Brick	0.9 to 1.3
	Concrete	0.9 to 1.3
	Drywall	0.9 to 1.1
	Metal	0.9 to 1.1
	Plaster	0.9 to 1.1
	Wood	0.9 to 1.1

INSTRUCTIONS FOR EVALUATING XRF TESTING:

Chapter 7 of the HUD Guidelines recommends several options for evaluating XRF testing. Among those options is the following procedure which may be used after XRF testing has been completed. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. If a multifamily housing development is being retested, randomly select two units from within the development from which the ten testing combinations should be randomly selected.

Randomly select ten testing combinations for retesting from each house or from the two selected units.

Conduct XRF retesting at the ten testing combinations selected for retesting.

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Figure D-1 continued. XRF Performance Characteristic Sheet for the Advanced Detectors LeadStar.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Advanced Detectors; LeadStar

Determine if the XRF testing in the units or house passed or failed the test by applying the steps below.

Compute the Retest Tolerance Limit by the following steps:

Determine XRF results for the original and retest XRF readings. Do not correct the original or retest results for substrate bias. In single-family housing a result is defined as the average of three readings. In multifamily housing, a result is a single reading. Therefore, there will be ten original and ten retest XRF results for each house or for the two selected units.

Compute the average of the original and re-test result for each of the ten testing combinations.

Square the average for each testing combination.

Add the ten squared averages together. Call this quantity C.

Multiply the number C by 0.0072. Call this quantity D.

Add the number 0.032 to D. Call this quantity E.

Take the square root of E. Call this quantity F.

Multiply F by 1.645. The result is the Retest Tolerance Limit.

Compute the overall average of all ten retest XRF results over all ten testing combination selected for retesting.

Take the difference of the overall average of the ten original XRF results and the overall average of the ten retest XRF results. If the difference is negative, drop the negative sign.

If the difference of the overall averages is less than the Retest Tolerance Limit, the inspection has passed the retest. If the difference of the overall averages equals or exceeds the Retest Tolerance Limit, this procedure should be repeated with ten new testing combinations. If the difference of the overall averages is equal to or greater than the Retest Tolerance Limit a second time, then the inspection should be considered deficient.

Use of this procedure is estimated to produce a spurious result approximately 1% of the time. That is, results of this procedure will call for further examination when no examination is warranted in approximately 1 out of 100 dwelling units tested.

TESTING TIMES:

For *Fixed Mode*, the LeadStar instrument tests for a set length of time before a result is obtained and displayed. For *Brief Mode*, the LeadStar instrument tests until a reading is obtained relative to an operator set *Action Level*. The following table provides a summary of testing times for readings taken in *Brief Mode* with an *Action Level* set to 1.0 mg/cm^2. All times have been scaled relative to an initial source strength of 15 mCi. Note that source strength and factors such as substrate may affect testing times.

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Figure D-1 continued. XRF Performance Characteristic Sheet for the Advanced Detectors LeadStar.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Advanced Detectors; LeadStar

Results from testing in August 1996 and September 1996

BRIEF MODE TESTING TIMES* (Seconds)						
SUBSTRATE	ALL DATA			MEDIAN FOR LABORATORY-MEASURED LEAD LEVELS (mg/cm^2)		
	25th Percentile	Median	75th Percentile	Pb < 0.25	0.25	1.0
Wood Drywall	7	7	8	7	8	7
Metal	7	7	8	7	8	7
Brick Concrete Plaster	8	8	9	8	8	8

*Testing times are based on readings obtained relative to a 1.0 mg/cm^2 *Action Level*.

BIAS AND PRECISION:

Do not use these bias and precision data to correct for substrate bias. These bias and precision data were computed without substrate correction from samples with reported laboratory results less than 4.0 mg/cm^2 lead. There were 15 test locations taken in *Fixed Mode* with a laboratory reported result equal to or greater than 4.0 mg/cm^2 lead. The fifteen test locations were each tested four times in *Fixed Mode*, once under software version 4.05, once under software version 4.08, and twice under software version 4.30. Of the 15 test locations tested under software version 4.05, one case resulted in an XRF reading less than 1.0 mg/cm^2. Of the 45 test locations tested under software versions 4.08 and 4.30, there were no instances in which an XRF reading was less than 1.0 mg/cm^2. Each of the fifteen test locations was tested in *Brief Mode* twice, both under software version 4.30. Out of the 30 *Brief Mode* testing cases, there were no instances in which an XRF reading was less than 1.0 mg/cm^2. The following data are for illustrative purposes only. Actual bias must be determined on-site. Inconclusive ranges provided above already account for bias and precision. Units are in mg/cm^2.

Figure D-1 continued. XRF Performance Characteristic Sheet for the Advanced Detectors LeadStar.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Advanced Detectors; LeadStar

For those instruments with software versions 4.1 to 4.30.

FIXED MODE READINGS MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	PRECISION* (mg/cm^2)
0.0 mg/cm^2	Brick	0.0	0.1
	Concrete	0.0	0.1
	Drywall	0.0	0.1
	Metal	0.1	0.1
	Plaster	-0.1	0.1
	Wood	0.0	0.1
0.5 mg/cm^2	Brick	0.1	0.2
	Concrete	0.1	0.2
	Drywall	0.0	0.2
	Metal	0.1	0.2
	Plaster	0.0	0.2
	Wood	0.1	0.2
1.0 mg/cm^2	Brick	0.1	0.3
	Concrete	0.1	0.3
	Drywall	0.1	0.3
	Metal	0.2	0.3
	Plaster	0.0	0.3
	Wood	0.1	0.3
2.0 mg/cm^2	Brick	0.2	0.4
	Concrete	0.2	0.4
	Drywall	0.2	0.4
	Metal	0.3	0.4
	Plaster	0.1	0.4
	Wood	0.2	0.4

*Precision at 1 standard deviation

Figure D-1 continued. XRF Performance Characteristic Sheet for the Advanced Detectors LeadStar.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Advanced Detectors; LeadStar

For those instruments with software versions earlier than version 4.1.

FIXED MODE READINGS MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	PRECISION* (mg/cm^2)
0.0 mg/cm^2	Brick	0.1	0.1
	Concrete	0.1	0.1
	Drywall	0.0	0.1
	Metal	0.1	0.1
	Plaster	0.0	0.1
	Wood	0.0	0.1
0.5 mg/cm^2	Brick	0.2	0.2
	Concrete	0.2	0.2
	Drywall	0.1	0.2
	Metal	0.2	0.2
	Plaster	0.1	0.2
	Wood	0.1	0.2
1.0 mg/cm^2	Brick	0.3	0.3
	Concrete	0.3	0.3
	Drywall	0.1	0.3
	Metal	0.2	0.3
	Plaster	0.1	0.3
	Wood	0.1	0.3
2.0 mg/cm^2	Brick	0.4	0.5
	Concrete	0.4	0.5
	Drywall	0.3	0.5
	Metal	0.4	0.5
	Plaster	0.3	0.5
	Wood	0.3	0.5

*Precision at 1 standard deviation

A document titled *Methodology for XRF Performance Characteristic Sheets* provides an explanation of the statistical methodology used to construct the data in the sheets, and provides empirical results from using the recommended inconclusive ranges or thresholds for specific XRF instruments. For a copy of this document call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

This XRF Performance Characteristic Sheet is a joint product of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD). The issuance of this sheet does not constitute rulemaking. The information provided here is intended solely as guidance to be used in conjunction with Chapter 7 of the *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. EPA and HUD reserve the right to revise this guidance. Please address questions and comments on this sheet to: Director, Office of Lead-Based Paint Abatement and Poisoning Prevention, U.S. Department of Housing and Urban Development, Room B-133, 451 Seventh St, S.W., Washington, DC 20410.

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Figure D-1 continued. XRF Performance Characteristic Sheet for the Advanced Detectors LeadStar.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-1. Bias Estimates, and Their Standard Errors, of Advanced Detectors LeadStar 15-Second Fixed Mode Readings For Those Instruments With Software Versions 4.1 to 4.30.

15-SECOND FIXED MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR
0.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.0 0.0 0.0 0.1 -0.1 0.0	0.02 0.02 0.02 0.02 0.02 0.02
0.5 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.1 0.1 0.0 0.1 0.0 0.1	0.03 0.03 0.03 0.03 0.03 0.03
1.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.1 0.1 0.1 0.2 0.0 0.1	0.05 0.05 0.05 0.05 0.05 0.05
2.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.2 0.2 0.2 0.3 0.1 0.2	0.09 0.09 0.09 0.09 0.09 0.09

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-2. Precision Estimates, and Their Standard Errors, of Advanced Detectors LeadStar 15-Second Fixed Mode Readings For Those Instruments With Software Versions 4.1 to 4.30.

15-SECOND FIXED MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION (mg/cm^2)	STANDARD ERROR
0.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.1 0.1 0.1 0.1 0.1 0.1	0.01 0.01 0.01 0.01 0.01 0.01
0.5 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.2 0.2 0.2 0.2 0.2 0.2	0.02 0.02 0.02 0.02 0.02 0.02
1.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.3 0.3 0.3 0.3 0.3 0.3	0.03 0.03 0.03 0.03 0.03 0.03
2.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.4 0.4 0.4 0.4 0.4 0.4	0.05 0.05 0.05 0.05 0.05 0.05

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-3. Inconclusive Range For Advanced Detectors LeadStar 15-Second Fixed Mode Readings For Results Where Substrate Correction Is Not Performed, But Substrate Correction is Recommended For Those Instruments With Software Versions Earlier Than Version 4.1.

15-SECOND FIXED MODE READING DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)
Readings not corrected for substrate bias	Metal	0.9 to 1.2

Table D-4. Bias Estimates, and Their Standard Errors, of Advanced Detectors LeadStar 15-Second Fixed Mode Readings For Those Instruments With Software Versions Earlier Than Version 4.1.

15-SECOND FIXED MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR
0.0 mg/cm^2	No	Brick	0.1	0.06
		Concrete	0.1	0.06
		Drywall	0.0	0.02
		Metal	0.1	0.03
		Plaster	0.0	0.02
		Wood	0.0	0.02
	Yes	Metal	-0.1	0.04
0.5 mg/cm^2	No	Brick	0.2	0.06
		Concrete	0.2	0.06
		Drywall	0.1	0.03
		Metal	0.2	0.03
		Plaster	0.1	0.03
		Wood	0.1	0.03
	Yes	Metal	0.0	0.04
1.0 mg/cm^2	No	Brick	0.3	0.07
		Concrete	0.3	0.07
		Drywall	0.1	0.05
		Metal	0.2	0.06
		Plaster	0.1	0.05
		Wood	0.1	0.05
	Yes	Metal	0.1	0.06
2.0 mg/cm^2	No	Brick	0.4	0.11
		Concrete	0.4	0.11
		Drywall	0.3	0.11
		Metal	0.4	0.11
		Plaster	0.3	0.11
		Wood	0.3	0.11
	Yes	Metal	0.2	0.11

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-5. Precision Estimates, and Their Standard Errors, of Advanced Detectors LeadStar 15-Second Fixed Mode Readings For Those Instruments With Software Versions Earlier Than Version 4.1.

15-SECOND FIXED MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION (mg/cm^2)	STANDARD ERROR
0.0 mg/cm^2	No	Brick	0.1	0.01
		Concrete	0.1	0.01
		Drywall	0.1	0.01
		Metal	0.1	0.01
		Plaster	0.1	0.01
		Wood	0.1	0.01
	Yes	Metal	0.1	0.02
0.5 mg/cm^2	No	Brick	0.2	0.03
		Concrete	0.2	0.03
		Drywall	0.2	0.03
		Metal	0.2	0.03
		Plaster	0.2	0.03
		Wood	0.2	0.03
	Yes	Metal	0.3	0.03
1.0 mg/cm^2	No	Brick	0.3	0.04
		Concrete	0.3	0.04
		Drywall	0.3	0.04
		Metal	0.3	0.04
		Plaster	0.3	0.04
		Wood	0.3	0.04
	Yes	Metal	0.4	0.05
2.0 mg/cm^2	No	Brick	0.5	0.05
		Concrete	0.5	0.05
		Drywall	0.5	0.05
		Metal	0.5	0.05
		Plaster	0.5	0.05
		Wood	0.5	0.05
	Yes	Metal	0.5	0.07

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-6. Classification Results For Advanced Detectors LeadStar Brief Mode (Uncorrected), Classified Using Threshold Values Reported in the XRF Performance Characteristic Sheet For Instruments With Software Versions 4.1 to 4.30.

SUBSTRATE	THRESHOLD	FALSE POSITIVE RATE	FALSE NEGATIVE RATE
Brick	1.0	0.0% (0/2)	0.0% (0/4)
Concrete	1.0	0.0% (0/4)	(0/0)
Drywall	1.0	0.0% (0/28)	(0/0)
Metal	1.0	5.6% (3/54)	0.0% (0/22)
Plaster	1.0	3.4% (2/58)	0.0% (0/18)
Wood	1.0	7.5% (6/80)	6.5% (3/46)
TOTAL		4.9% (11/226)	3.3% (3/90)

Table D-7. Classification Results For Advanced Detectors LeadStar 15-Second Fixed Mode Readings (Uncorrected), Classified Using Inconclusive Ranges or Threshold Values Reported in the XRF Performance Characteristic Sheet For Instruments With Software Versions 4.1 to 4.30.

SUBSTRATE	INCONCLUSIVE RANGE OR THRESHOLD	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.9 to 1.1	0.0% (0/2)	0.0% (0/4)	0.0% (0/6)
Concrete	0.9 to 1.1	0.0% (0/4)	(0/0)	0.0% (0/4)
Drywall	0.9 to 1.1	0.0% (0/28)	(0/0)	0.0% (0/28)
Metal	0.9 to 1.2	3.7% (2/54)	0.0% (0/22)	9.2% (7/76)
Plaster	1.0	3.4% (2/58)	0.0% (0/18)	0.0% (0/76)
Wood	0.9 to 1.1	6.3% (5/80)	0.0% (0/46)	4.0% (5/126)
TOTAL		4.0% (9/226)	0.0% (0/90)	3.8% (12/316)

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-8. Classification Results For Advanced Detectors LeadStar 15-Second Fixed Mode Readings (Metal Substrates Corrected and Uncorrected), Classified Using Inconclusive Ranges Reported in the XRF Performance Characteristic Sheet For Instruments With Software Versions Earlier Than Version 4.1.

SUBSTRATE	INCONCLUSIVE RANGE	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.9 to 1.3	0.0% (0/2)	0.0% (0/4)	0.0% (0/6)
Concrete	0.9 to 1.3	0.0% (0/4)	(0/0)	0.0% (0/4)
Drywall	0.9 to 1.1	0.0% (0/28)	(0/0)	0.0% (0/28)
Metal	0.9 to 1.1	0.0% (0/54)	0.0% (0/22)	3.9% (3/76)
Plaster	0.9 to 1.1	3.4% (2/58)	5.6% (1/18)	0.0% (0/76)
Wood	0.9 to 1.1	7.7% (6/78)	0.0% (0/46)	5.6% (7/126)
Metal (Uncorrected)	0.9 to 1.2	0.0% (0/54)	0.0% (0/22)	10.5% (8/76)
TOTAL*		3.5% (8/226)	1.1% (1/90)	3.2% (10/316)

*Total results are for values reported in PCS.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

D.3 XRF Performance Characteristic Sheet for the Radiation Monitoring Device LPA-1 and Related Results

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

EFFECTIVE DATE: November 27, 1995 **EDITION NO.**: 1

MANUFACTURER AND MODEL:

Make: *Radiation Monitoring Devices*
Model: *LPA-1*
Source: Co^{57}
Note: This sheet supersedes all previous sheets for the XRF instrument of the make, model, and source shown above.

EVALUATION DATA SOURCE AND DATE:

This sheet is supplemental information to be used in conjunction with Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* ("HUD Guidelines"). Performance parameters shown on this sheet are calculated from the EPA/HUD evaluation using archived building components. Testing was conducted on approximately 150 test locations. All of the test locations were tested three times, once in March 1995, once in July 1995, and once in September 1995 using three distinct instruments. The instrument that performed testing in March had a new source installed in January 1995 with 12 mCi initial strength. The instrument that performed testing in July had a new source installed in June 1995 with 12 mCi initial strength. The instrument that performed testing in September had a new source installed in February 1995 with 12 mCi initial strength. LPA-1 instruments that were purchased before June 26, 1995 and have not been serviced since June 26, 1995 have a different version of firmware than those instruments sold or serviced after June 26, 1995. Therefore, this sheet distinguishes between instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995 from those instruments serviced or sold after this date.

FIELD OPERATION GUIDANCE

OPERATING PARAMETERS:

Performance parameters shown in this sheet are applicable only when operating the instrument under the same conditions as the evaluation testing and using the procedures described in Chapter 7 of the HUD Guidelines. Operating parameters include:

- Manufacturer-recommended warm-up and quality control procedures
- Use the Multifamily Decision Flowchart for determining the presence of lead on a component type in multifamily housing
- Quick mode, nominal 20-second standard mode, or nominal 30-second standard mode readings on three locations per component for single-family housing and one location per component for multifamily housing
- The nominal reading time for standard mode readings must be adjusted to account for source decay
- Calibration checks are taken using nominal 30-second standard mode readings and the red (1.02 mg/cm^2) NIST Standard Reference Material (SRM No. 2579) paint film

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Figure D-2. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

- Readings for determining the substrate correction values are taken on bare substrate covered with red (1.02 mg/cm^2) NIST SRM paint film
- Lead-based paint is defined as paint with lead equal to or in excess of 1.0 mg/cm^2.

XRF CALIBRATION CHECK:

Chapter 7 of the HUD Guidelines recommends using a calibration check procedure to determine the operating condition of the XRF instrument. For this instrument, calibration check readings should be taken with nominal 30-second standard mode readings regardless of the date of purchase or servicing. If the observed calibration check average minus 1.02 mg/cm^2 is greater than the positive (plus) calibration check tolerance value, or less than the negative (minus) calibration check tolerance value, then the instructions provided by the manufacturer should be followed in order to bring the instrument back into control before any more XRF testing is done. This calibration check is estimated to produce an incorrect result (that is, a finding that the instrument is out of calibration) very infrequently - once out of every 200 times this procedure is followed.

For those instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995 use the following calibration check tolerance values:

minus value = -0.3 mg/cm^2
plus value = +0.1 mg/cm^2

For those instruments sold or serviced after June 26, 1995 use the following calibration check tolerance values:

minus value = -0.3 mg/cm^2
plus value = +0.3 mg/cm^2

XRF RESULTS BELOW 4.0 mg/cm^2, SUBSTRATE CORRECTION RECOMMENDED FOR:

For those instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995:

- Metal and wood using quick mode or either 20-second or 30-second standard mode readings

For those instruments sold or serviced after June 26, 1995:

- Metal using 30-second standard mode readings
- None using quick mode readings

SUBSTRATE CORRECTION NOT RECOMMENDED FOR:

For those instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995:

- Brick, Concrete, Drywall, and Plaster using quick mode or either 20-second or 30-second standard mode readings

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Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

For those instruments sold or serviced after June 26, 1995:

- Brick, Concrete, Drywall, Plaster, and Wood using 30-second standard mode readings
- Brick, Concrete, Drywall, Metal, Plaster, and Wood using quick mode readings

SUBSTRATE CORRECTION VALUE COMPUTATION:

Chapter 7 of the HUD Guidelines provides guidance on correcting XRF results for substrate bias. Supplemental guidance for using the red (1.02 mg/cm^2) NIST SRM paint film for substrate correction is provided below.

XRF results are corrected for substrate bias by subtracting from each XRF result a correction value determined separately in each house for single-family housing or in each development for multifamily housing, for each substrate. The correction value is an average of XRF readings taken over red NIST SRM (1.02 mg/cm^2) paint films at test locations that had been scraped clean of their paint covering. Compute the correction values as follows:

- Using the same XRF instrument, take three readings on a bare substrate area covered with the red NIST SRM (1.02 mg/cm^2) paint film. Repeat this procedure by taking three more readings on a second bare substrate area of the same substrate.
- Compute the correction value for each substrate type by computing the average of all six readings as shown below.

For each substrate type:

- Repeat this procedure for each substrate tested in the house or housing development as needed.

$$\left.\begin{array}{c}\textit{Correction}\\ \textit{Value}\end{array}\right\} \quad \frac{1^{st} \quad 2^{nd} \quad 3^{rd} \quad 4^{th} \quad 5^{th} \quad 6^{th} \ \textit{Reading}}{6} \quad 1.02 mg/cm^2$$

CLASSIFICATION OF RESULTS USING THRESHOLD VALUES:

XRF results are classified using either the threshold or the inconclusive range. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. For computing the XRF result, use all digits that are reported by the instrument. For the threshold, results are classified as positive if they are greater than or equal to the threshold, and negative if they are less than the threshold. There is no inconclusive classification when using the threshold. For the inconclusive range, results are classified as positive if they are greater than or equal to the upper limit of the inconclusive range, and negative if they are less than or equal to the lower limit of the inconclusive range. Thresholds and inconclusive ranges were determined for comparing results to the 1.0 mg/cm^2 standard. For a listing of laboratories recommended by the EPA National Lead Laboratory Accreditation Program (NLLAP) for the analysis of samples to resolve an inconclusive XRF result or additional confirmational analysis, call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

For those instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995:

30-SECOND STANDARD MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)
Results corrected for substrate bias on metal and wood substrates only	Brick Concrete Drywall Metal Plaster Wood	0.8 0.8 0.7 0.8 0.8 0.9

For those instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995:

20-SECOND STANDARD MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)
Results corrected for substrate bias on metal and wood substrates only	Brick Concrete Drywall Metal Plaster Wood	0.7 0.7 0.7 0.9 0.8 0.8

For those instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995:

QUICK MODE READING DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)
Results corrected for substrate bias on metal and wood substrates only	Brick Concrete Drywall Metal Plaster Wood	0.7 - 0.8 0.7 - 0.8 0.6 - 0.8 0.9 - 1.0 0.7 - 0.8 0.7 - 0.8

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Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

For those instruments sold or serviced after June 26, 1995:

30-SECOND STANDARD MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)
Results corrected for substrate bias on metal substrate only	Brick Concrete Drywall Metal Plaster Wood	1.0 1.0 1.0 0.9 1.0 1.0

For those instruments sold or serviced after June 26, 1995:

QUICK MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)	INCONCLUSIVE RANGE (mg/cm^2)
Readings not corrected for substrate bias on any substrate	Brick Concrete Drywall Metal Plaster Wood	1.0 1.0 1.0 None None 1.0	None None None 0.9 to 1.3 0.9 to 1.0 None

INSTRUCTIONS FOR EVALUATING XRF TESTING:

Chapter 7 of the HUD Guidelines recommends several options for evaluating XRF testing. Among those options is the following procedure which may be used after XRF testing has been completed. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. If a multifamily housing development is being

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Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

retested, randomly select two units from within the development from which the ten testing combinations should be randomly selected.

Randomly select ten testing combinations for retesting from each house or from the two selected units.

Conduct XRF retesting at the ten testing combinations selected for retesting.

Determine if the XRF testing in the units or house passed or failed the test by applying the steps below.

Compute the Retest Tolerance Limit by the following steps:

Determine XRF results for the original and retest XRF readings. Do not correct the original or retest results for substrate bias. In single-family housing a result is defined as the average of three readings. In multifamily housing, a result is a single reading. Therefore, there will be ten original and ten retest XRF results for each house or for the two selected units.

Compute the average of the original and re-test result for each of the ten testing combinations.

Square the average for each testing combination.

Add the ten squared averages together. Call this quantity C.

Multiply the number C by 0.0072. Call this quantity D.

Add the number 0.032 to D. Call this quantity E.

Take the square root of E. Call this quantity F.

Multiply F by 1.645. The result is the Retest Tolerance Limit.

Compute the overall average of all ten retest XRF results over all ten testing combination selected for retesting.

Take the difference of the overall average of the ten original XRF results and the overall average of the ten retest XRF results. If the difference is negative, drop the negative sign.

If the difference of the overall averages is less than the Retest Tolerance Limit, the inspection has passed the retest. If the difference of the overall averages equals or exceeds the Retest Tolerance Limit, this procedure should be repeated with ten new testing combinations. If the difference of the overall averages is equal to or greater than the Retest Tolerance Limit a second time, then the inspection should be considered deficient.

Use of this procedure is estimated to produce a spurious result approximately 1% of the time. That is, results of this procedure will call for further examination when no examination is warranted in approximately 1 out of 100 dwelling units tested.

Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

BIAS AND PRECISION:

Do not use these bias and precision data to correct for substrate bias. These bias and precision data were computed without substrate correction from samples with reported laboratory results less than 4.0 mg/cm^2 lead. The data which were used to determine the bias and precision estimates given in the three tables above have the following properties. During the March testing, there were 11 test locations with a laboratory reported result equal to or greater than 4.0 mg/cm^2 lead. Of these, one 20-second standard mode reading was less than 1.0 mg/cm^2 and none of the quick mode readings were less than 1.0 mg/cm^2. During the July testing, there were 15 test locations with a laboratory reported result equal to or greater than 4.0 mg/cm^2 lead. Of these, one 30-second standard mode reading was less than 1.0 mg/cm^2 and none of the quick mode readings were less than 1.0 mg/cm^2. During the September testing, there were 15 test locations with a laboratory reported result equal to or greater than 4.0 mg/cm^2 lead. Of these, two 20-second and one 30-second standard mode readings were less than 1.0 mg/cm^2, and one quick mode reading was less than 1.0 mg/cm^2. The two instruments that tested in March and September are representative of instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995 and the instrument that tested in July is representative of instruments sold or serviced after June 26, 1995. These data are for illustrative purposes only. Actual bias must be determined on the site. Inconclusive ranges provided above already account for bias and precision. Bias and precision ranges are provided to show the variability that was found between machines of the same model. Units are in mg/cm^2.

Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

For those instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995:

20-SECOND READING MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	BIAS RANGE* (mg/cm^2)	PRECISION† (mg/cm^2)	PRECISION RANGE* (mg/cm^2)
0.0 mg/cm^2	Brick	-0.2	(-0.1,-0.2)	0.2	(0.1, 0.2)
	Concrete	-0.2	(-0.1,-0.2)	0.2	(0.1, 0.2)
	Drywall	-0.2	(-0.2,-0.3)	0.2	(0.1, 0.2)
	Metal	-0.4	(-0.4,-0.5)	0.2	(0.1, 0.2)
	Plaster	-0.1	(-0.1,-0.1)	0.2	(0.1, 0.2)
	Wood	-0.2	(-0.1,-0.2)	0.2	(0.1, 0.2)
0.5 mg/cm^2	Brick	-0.2	(-0.2,-0.3)	0.3	(0.2, 0.3)
	Concrete	-0.2	(-0.2,-0.3)	0.3	(0.2, 0.3)
	Drywall	-0.3	(-0.2,-0.3)	0.3	(0.2, 0.3)
	Metal	-0.5	(-0.4,-0.6)	0.3	(0.2, 0.3)
	Plaster	-0.2	(-0.2,-0.2)	0.3	(0.2, 0.3)
	Wood	-0.2	(-0.2,-0.3)	0.3	(0.2, 0.3)
1.0 mg/cm^2	Brick	-0.3	(-0.2,-0.4)	0.3	(0.3, 0.4)
	Concrete	-0.3	(-0.2,-0.4)	0.3	(0.3, 0.4)
	Drywall	-0.3	(-0.3,-0.4)	0.3	(0.3, 0.4)
	Metal	-0.6	(-0.5,-0.6)	0.3	(0.3, 0.4)
	Plaster	-0.2	(-0.2,-0.2)	0.3	(0.3, 0.4)
	Wood	-0.3	(-0.2,-0.4)	0.3	(0.3, 0.4)
2.0 mg/cm^2	Brick	-0.4	(-0.3,-0.5)	0.5	(0.4, 0.5)
	Concrete	-0.4	(-0.3,-0.5)	0.5	(0.4, 0.5)
	Drywall	-0.5	(-0.4,-0.5)	0.5	(0.4, 0.5)
	Metal	-0.7	(-0.6,-0.7)	0.5	(0.4, 0.5)
	Plaster	-0.3	(-0.3,-0.4)	0.5	(0.4, 0.5)
	Wood	-0.4	(-0.3,-0.5)	0.5	(0.4, 0.5)

*Ranges are provided to show the variability between machines of the same model.
†Precision at 1 standard deviation.

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Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

For those instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995:

30-SECOND READING MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	PRECISION* (mg/cm^2)
0.0 mg/cm^2	Brick	-0.1	0.1
	Concrete	-0.1	0.1
	Drywall	-0.2	0.1
	Metal	-0.5	0.1
	Plaster	-0.1	0.1
	Wood	-0.1	0.1
0.5 mg/cm^2	Brick	-0.2	0.2
	Concrete	-0.2	0.2
	Drywall	-0.3	0.2
	Metal	-0.5	0.2
	Plaster	-0.1	0.2
	Wood	-0.2	0.2
1.0 mg/cm^2	Brick	-0.2	0.3
	Concrete	-0.2	0.3
	Drywall	-0.3	0.3
	Metal	-0.6	0.3
	Plaster	-0.2	0.3
	Wood	-0.2	0.3
2.0 mg/cm^2	Brick	-0.4	0.4
	Concrete	-0.4	0.4
	Drywall	-0.5	0.4
	Metal	-0.7	0.4
	Plaster	-0.3	0.4
	Wood	-0.4	0.4

*Precision at 1 standard deviation.

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Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

For those instruments sold prior to June 26, 1995 and have not been serviced since June 26, 1995:

QUICK MODE MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	BIAS RANGE (mg/cm^2)	PRECISION* (mg/cm^2)	PRECISION RANGE (mg/cm^2)
0.0 mg/cm^2	Brick	-0.2	(-0.2,-0.3)	0.3	(0.3, 0.3)
	Concrete	-0.2	(-0.2,-0.3)	0.3	(0.3, 0.3)
	Drywall	-0.3	(-0.2,-0.3)	0.3	(0.3, 0.3)
	Metal	-0.6	(-0.6,-0.7)	0.3	(0.3, 0.3)
	Plaster	-0.2	(-0.2,-0.2)	0.3	(0.3, 0.3)
	Wood	-0.2	(-0.2,-0.3)	0.3	(0.3, 0.3)
0.5 mg/cm^2	Brick	-0.3	(-0.2,-0.3)	0.4	(0.3, 0.4)
	Concrete	-0.3	(-0.2,-0.3)	0.4	(0.3, 0.4)
	Drywall	-0.3	(-0.3,-0.4)	0.4	(0.3, 0.4)
	Metal	-0.7	(-0.6,-0.8)	0.4	(0.3, 0.4)
	Plaster	-0.2	(-0.2,-0.2)	0.4	(0.3, 0.4)
	Wood	-0.3	(-0.2,-0.3)	0.4	(0.3, 0.4)
1.0 mg/cm^2	Brick	-0.3	(-0.3,-0.4)	0.4	(0.4, 0.5)
	Concrete	-0.3	(-0.3,-0.4)	0.4	(0.4, 0.5)
	Drywall	-0.4	(-0.3,-0.4)	0.4	(0.4, 0.5)
	Metal	-0.7	(-0.7,-0.8)	0.4	(0.4, 0.5)
	Plaster	-0.3	(-0.3,-0.3)	0.4	(0.4, 0.5)
	Wood	-0.3	(-0.3,-0.4)	0.4	(0.4, 0.5)
2.0 mg/cm^2	Brick	-0.4	(-0.4,-0.5)	0.5	(0.4, 0.6)
	Concrete	-0.4	(-0.4,-0.5)	0.5	(0.4, 0.6)
	Drywall	-0.5	(-0.4,-0.6)	0.5	(0.4, 0.6)
	Metal	-0.8	(-0.7,-1.0)	0.5	(0.4, 0.6)
	Plaster	-0.4	(-0.4,-0.4)	0.5	(0.4, 0.6)
	Wood	-0.4	(-0.4,-0.5)	0.5	(0.4, 0.6)

Ranges are provided to show the variability between machines of the same model.
*Precision at 1 standard deviation.

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Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

For those instruments sold or serviced after June 26, 1995:

30-SECOND STANDARD MODE READING MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	PRECISION* (mg/cm^2)
0.0 mg/cm^2	Brick	0.0	0.1
	Concrete	0.0	0.1
	Drywall	0.1	0.1
	Metal	0.3	0.1
	Plaster	0.1	0.1
	Wood	0.0	0.1
0.5 mg/cm^2	Brick	0.0	0.2
	Concrete	0.0	0.2
	Drywall	0.0	0.2
	Metal	0.2	0.2
	Plaster	0.0	0.2
	Wood	0.0	0.2
1.0 mg/cm^2	Brick	0.0	0.3
	Concrete	0.0	0.3
	Drywall	0.0	0.3
	Metal	0.2	0.3
	Plaster	0.0	0.3
	Wood	0.0	0.3
2.0 mg/cm^2	Brick	-0.1	0.4
	Concrete	-0.1	0.4
	Drywall	-0.1	0.4
	Metal	0.1	0.4
	Plaster	-0.1	0.4
	Wood	-0.1	0.4

*Precision at 1 standard deviation.

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Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Radiation Monitoring Devices; LPA-1

For those instruments sold or serviced after June 26, 1995:

QUICK MODE READING MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	PRECISION* (mg/cm^2)
0.0 mg/cm^2	Brick	0.0	0.2
	Concrete	0.0	0.2
	Drywall	0.1	0.2
	Metal	0.2	0.2
	Plaster	0.0	0.2
	Wood	0.0	0.2
0.5 mg/cm^2	Brick	0.0	0.3
	Concrete	0.0	0.3
	Drywall	0.0	0.3
	Metal	0.2	0.3
	Plaster	0.0	0.3
	Wood	0.0	0.3
1.0 mg/cm^2	Brick	0.0	0.4
	Concrete	0.0	0.4
	Drywall	0.0	0.4
	Metal	0.1	0.4
	Plaster	-0.1	0.4
	Wood	0.0	0.4
2.0 mg/cm^2	Brick	-0.1	0.5
	Concrete	-0.1	0.5
	Drywall	-0.1	0.5
	Metal	0.1	0.5
	Plaster	-0.1	0.5
	Wood	-0.1	0.5

*Precision at 1 standard deviation.

A document titled *Methodology for XRF Performance Characteristic Sheets* provides an explanation of the statistical methodology used to construct the data in the sheets and provides empirical results from using the recommended inconclusive ranges or thresholds for specific XRF instruments. For a copy of this document call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

This XRF Performance Characteristic Sheet is a joint product of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD). The issuance of this sheet does not constitute rulemaking. The information provided here is intended solely as guidance to be used in conjunction with Chapter 7 of the *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. EPA and HUD reserve the right to revise this guidance. Please address questions and comments on this sheet to: Director, Office of Lead-Based Paint Abatement and Poisoning Prevention, U.S. Department of Housing and Urban Development, Room B-133, 451 Seventh St, S.W., Washington, DC 20410.

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Figure D-2 continued. XRF Performance Characteristic Sheet for the Radiation Monitoring Devices LPA-1.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-9. Threshold Results For Radiation Monitoring Device LPA-1 30-Second Standard Mode Readings For Results Where Substrate Correction Is Not Performed, But Substrate Correction Is Recommended For Instruments For Those Instruments Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995.

30-SECOND STANDARD MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)
Readings not corrected for substrate bias on any substrate	Metal Wood	0.4 0.8

Table D-10. Threshold Results For Radiation Monitoring Device LPA-1 20-Second Standard Mode Readings For Results Where Substrate Correction Is Not Performed, But Substrate Correction Is Recommended For Instruments For Those Instruments Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995.

20-SECOND STANDARD MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)
Readings not corrected for substrate bias on any substrate	Metal Wood	0.4 0.7

Table D-11. Inconclusive Range Results For Radiation Monitoring Device LPA-1 Quick Mode Readings For Results Where Substrate Correction Is Not Performed, But Substrate Correction Is Recommended For Instruments For Those Instruments Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995.

QUICK MODE READING DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)
Readings not corrected for substrate bias on any substrate	Metal Wood	0.3 to 0.4 0.7 to 0.8

Table D-12. Threshold Results For Radiation Monitoring Device LPA-1 30-Second Standard Mode Readings For Results Where Substrate Correction Is Not Performed, But Substrate Correction Is Recommended For Instruments For Those Instruments Sold or Serviced After June 26, 1995.

30-SECOND STANDARD MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)
Readings not corrected for substrate bias on any substrate	Metal	0.9 to 1.2

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-13. Bias Estimates, and Their Standard Errors, of Radiation Monitoring Device LPA-1 20-Second Standard Mode Readings For Those Instruments Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995.

20-SECOND STANDARD MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR FOR BIAS
0.0 mg/cm^2	No	Brick	-0.2	0.03
		Concrete	-0.2	0.03
		Drywall	-0.2	0.05
		Metal	-0.4	0.04
		Plaster	-0.1	0.04
		Wood	-0.2	0.03
	Yes	Metal	0.0	0.03
		Wood	0.0	0.03
0.5 mg/cm^2	No	Brick	-0.2	0.04
		Concrete	-0.2	0.04
		Drywall	-0.3	0.06
		Metal	-0.5	0.04
		Plaster	-0.2	0.04
		Wood	-0.2	0.04
	Yes	Metal	-0.2	0.04
		Wood	-0.1	0.04
1.0 mg/cm^2	No	Brick	-0.3	0.05
		Concrete	-0.3	0.05
		Drywall	-0.3	0.07
		Metal	-0.6	0.06
		Plaster	-0.2	0.06
		Wood	-0.3	0.05
	Yes	Metal	-0.4	0.05
		Wood	-0.2	0.05
2.0 mg/cm^2	No	Brick	-0.4	0.10
		Concrete	-0.4	0.10
		Drywall	-0.5	0.12
		Metal	-0.7	0.10
		Plaster	-0.3	0.10
		Wood	-0.4	0.10
	Yes	Metal	-0.8	0.10
		Wood	-0.3	0.10

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-14. Bias Estimates, and Their Standard Errors, of Radiation Monitoring Device LPA-1 30-Second Standard Mode Readings For Those Instruments Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995.

30-SECOND STANDARD MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR FOR BIAS
0.0 mg/cm^2	No	Brick	-0.1	0.03
		Concrete	-0.1	0.03
		Drywall	-0.2	0.04
		Metal	-0.5	0.03
		Plaster	-0.1	0.03
		Wood	-0.1	0.03
	Yes	Metal	0.0	0.05
		Wood	0.0	0.03
0.5 mg/cm^2	No	Brick	-0.2	0.03
		Concrete	-0.2	0.03
		Drywall	-0.3	0.04
		Metal	-0.5	0.03
		Plaster	-0.1	0.03
		Wood	-0.2	0.03
	Yes	Metal	-0.1	0.05
		Wood	0.0	0.03
1.0 mg/cm^2	No	Brick	-0.2	0.05
		Concrete	-0.2	0.05
		Drywall	-0.3	0.06
		Metal	-0.6	0.05
		Plaster	-0.2	0.05
		Wood	-0.2	0.05
	Yes	Metal	-0.2	0.06
		Wood	-0.1	0.05
2.0 mg/cm^2	No	Brick	-0.4	0.09
		Concrete	-0.4	0.09
		Drywall	-0.5	0.10
		Metal	-0.7	0.10
		Plaster	-0.3	0.09
		Wood	-0.4	0.09
	Yes	Metal	-0.3	0.10
		Wood	-0.2	0.09

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-15. Bias Estimates, and Their Standard Errors, of Radiation Monitoring Device LPA-1 Quick Mode Readings For Those Instruments Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995.

QUICK MODE MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR FOR BIAS
0.0 mg/cm^2	No	Brick	-0.2	0.05
		Concrete	-0.2	0.05
		Drywall	-0.3	0.08
		Metal	-0.6	0.06
		Plaster	-0.2	0.06
		Wood	-0.2	0.05
	Yes	Metal	0.0	0.06
		Wood	-0.1	0.05
0.5 mg/cm^2	No	Brick	-0.3	0.05
		Concrete	-0.3	0.05
		Drywall	-0.3	0.09
		Metal	-0.7	0.06
		Plaster	-0.2	0.06
		Wood	-0.3	0.05
	Yes	Metal	0.0	0.06
		Wood	-0.2	0.05
1.0 mg/cm^2	No	Brick	-0.3	0.07
		Concrete	-0.3	0.07
		Drywall	-0.4	0.10
		Metal	-0.7	0.07
		Plaster	-0.3	0.07
		Wood	-0.3	0.07
	Yes	Metal	-0.1	0.07
		Wood	-0.3	0.07
2.0 mg/cm^2	No	Brick	-0.4	0.12
		Concrete	-0.4	0.12
		Drywall	-0.5	0.14
		Metal	-0.8	0.12
		Plaster	-0.4	0.12
		Wood	-0.4	0.12
	Yes	Metal	-0.2	0.12
		Wood	-0.4	0.12

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-16. Bias Estimates, and Their Standard Errors, of Radiation Monitoring Device LPA-1 30-Second Standard Mode Readings For Those Instruments Sold or Serviced after June 26, 1995.

30-SECOND STANDARD MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR FOR BIAS
0.0 mg/cm^2	No	Brick	0.0	0.03
		Concrete	0.0	0.03
		Drywall	0.1	0.04
		Metal	0.3	0.03
		Plaster	0.1	0.03
		Wood	0.0	0.03
	Yes	Metal	0.0	0.03
0.5 mg/cm^2	No	Brick	0.0	0.03
		Concrete	0.0	0.03
		Drywall	0.0	0.05
		Metal	0.2	0.03
		Plaster	0.0	0.03
		Wood	0.0	0.03
	Yes	Metal	-0.1	0.03
1.0 mg/cm^2	No	Brick	0.0	0.05
		Concrete	0.0	0.05
		Drywall	0.0	0.06
		Metal	0.2	0.05
		Plaster	0.0	0.05
		Wood	0.0	0.05
	Yes	Metal	-0.1	0.05
2.0 mg/cm^2	No	Brick	-0.1	0.09
		Concrete	-0.1	0.09
		Drywall	-0.1	0.10
		Metal	0.1	0.09
		Plaster	-0.1	0.09
		Wood	-0.1	0.09
	Yes	Metal	-0.2	0.09

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-17. Bias Estimates, and Their Standard Errors, of Radiation Monitoring Device LPA-1 Quick Mode Readings For Those Instruments Sold or Serviced after June 26, 1995.

QUICK MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR FOR BIAS
0.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.0 0.0 0.1 0.2 0.0 0.0	0.04 0.04 0.06 0.05 0.05 0.04
0.5 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.0 0.0 0.0 0.2 0.0 0.0	0.04 0.04 0.07 0.05 0.05 0.04
1.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.0 0.0 0.0 0.1 -0.1 0.0	0.06 0.06 0.08 0.07 0.07 0.06
2.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	-0.1 -0.1 -0.1 0.1 -0.1 -0.1	0.12 0.12 0.13 0.11 0.12 0.12

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-18. Precision Estimates, and Their Standard Errors, of Radiation Monitoring Device LPA-1 20-Second Standard Mode Readings For Those Instruments Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995.

20-SECOND STANDARD MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	Brick	0.2	0.02
		Concrete	0.2	0.02
		Drywall	0.2	0.02
		Metal	0.2	0.02
		Plaster	0.2	0.02
		Wood	0.2	0.02
	Yes	Metal	0.2	0.02
		Wood	0.2	0.02
0.5 mg/cm^2	No	Brick	0.3	0.03
		Concrete	0.3	0.03
		Drywall	0.3	0.03
		Metal	0.3	0.03
		Plaster	0.3	0.03
		Wood	0.3	0.03
	Yes	Metal	0.3	0.02
		Wood	0.3	0.03
1.0 mg/cm^2	No	Brick	0.3	0.04
		Concrete	0.3	0.04
		Drywall	0.3	0.04
		Metal	0.3	0.04
		Plaster	0.3	0.04
		Wood	0.3	0.04
	Yes	Metal	0.4	0.04
		Wood	0.3	0.04
2.0 mg/cm^2	No	Brick	0.5	0.07
		Concrete	0.5	0.07
		Drywall	0.5	0.07
		Metal	0.5	0.07
		Plaster	0.5	0.07
		Wood	0.5	0.07
	Yes	Metal	0.5	0.07
		Wood	0.5	0.07

*Precision at 1 standard deviation.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-19. Precision Estimates, and Their Standard Errors, of Radiation Monitoring Device LPA-1 30-Second Standard Mode Readings For Those Instruments Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995.

30-SECOND STANDARD MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	Brick	0.1	0.01
		Concrete	0.1	0.01
		Drywall	0.1	0.01
		Metal	0.1	0.01
		Plaster	0.1	0.01
		Wood	0.1	0.01
	Yes	Metal	0.1	0.02
		Wood	0.1	0.01
0.5 mg/cm^2	No	Brick	0.2	0.02
		Concrete	0.2	0.02
		Drywall	0.2	0.02
		Metal	0.2	0.02
		Plaster	0.2	0.02
		Wood	0.2	0.02
	Yes	Metal	0.2	0.02
		Wood	0.2	0.02
1.0 mg/cm^2	No	Brick	0.3	0.04
		Concrete	0.3	0.04
		Drywall	0.3	0.04
		Metal	0.3	0.04
		Plaster	0.3	0.04
		Wood	0.3	0.04
	Yes	Metal	0.3	0.04
		Wood	0.3	0.03
2.0 mg/cm^2	No	Brick	0.4	0.05
		Concrete	0.4	0.05
		Drywall	0.4	0.05
		Metal	0.4	0.05
		Plaster	0.4	0.05
		Wood	0.4	0.05
	Yes	Metal	0.4	0.05
		Wood	0.4	0.05

*Precision at 1 standard deviation.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-20. Precision Estimates, and Their Standard Errors, of Radiation Monitoring Device LPA-1 Quick Mode Readings For Those Instruments Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995.

QUICK MODE MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	Brick	0.3	0.03
		Concrete	0.3	0.03
		Drywall	0.3	0.03
		Metal	0.3	0.03
		Plaster	0.3	0.03
		Wood	0.3	0.03
	Yes	Metal	0.3	0.03
		Wood	0.3	0.03
0.5 mg/cm^2	No	Brick	0.4	0.03
		Concrete	0.4	0.03
		Drywall	0.4	0.03
		Metal	0.4	0.03
		Plaster	0.4	0.03
		Wood	0.4	0.03
	Yes	Metal	0.4	0.03
		Wood	0.4	0.03
1.0 mg/cm^2	No	Brick	0.4	0.05
		Concrete	0.4	0.05
		Drywall	0.4	0.05
		Metal	0.4	0.05
		Plaster	0.4	0.05
		Wood	0.4	0.05
	Yes	Metal	0.5	0.05
		Wood	0.4	0.05
2.0 mg/cm^2	No	Brick	0.5	0.09
		Concrete	0.5	0.09
		Drywall	0.5	0.09
		Metal	0.5	0.09
		Plaster	0.5	0.09
		Wood	0.5	0.09
	Yes	Metal	0.6	0.09
		Wood	0.5	0.09

*Precision at 1 standard deviation.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-21. Precision Estimates, and Their Standard Errors of Radiation Monitoring Device LPA-1 30-Second Standard Mode Readings For Those Instruments Sold or Serviced After June 26, 1995.

30-SECOND STANDARD MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	Brick	0.1	0.01
		Concrete	0.1	0.01
		Drywall	0.1	0.01
		Metal	0.1	0.01
		Plaster	0.1	0.01
		Wood	0.1	0.01
	Yes	Metal	0.2	0.01
0.5 mg/cm^2	No	Brick	0.2	0.02
		Concrete	0.2	0.02
		Drywall	0.2	0.02
		Metal	0.2	0.02
		Plaster	0.2	0.02
		Wood	0.2	0.02
	Yes	Metal	0.2	0.02
1.0 mg/cm^2	No	Brick	0.3	0.04
		Concrete	0.3	0.04
		Drywall	0.3	0.04
		Metal	0.3	0.04
		Plaster	0.3	0.04
		Wood	0.3	0.04
	Yes	Metal	0.3	0.03
2.0 mg/cm^2	No	Brick	0.4	0.05
		Concrete	0.4	0.05
		Drywall	0.4	0.05
		Metal	0.4	0.05
		Plaster	0.4	0.05
		Wood	0.4	0.05
	Yes	Metal	0.4	0.05

*Precision at 1 standard deviation.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-22. Precision Estimates, and Their Standard Errors, of Radiation Monitoring Device LPA-1 Quick Mode Readings For Those Instruments Sold or Serviced After June 26, 1995.

QUICK MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.2 0.2 0.2 0.2 0.2 0.2	0.02 0.02 0.02 0.02 0.02 0.02
0.5 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.3 0.3 0.3 0.3 0.3 0.3	0.03 0.03 0.03 0.03 0.03 0.03
1.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.4 0.4 0.4 0.4 0.4 0.4	0.05 0.05 0.05 0.05 0.05 0.05
2.0 mg/cm^2	No	Brick Concrete Drywall Metal Plaster Wood	0.5 0.5 0.5 0.5 0.5 0.5	0.07 0.07 0.07 0.07 0.07 0.07

*Precision at 1 standard deviation.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-23. Classification Results For Radiation Monitoring Device LPA-1 30-Second Readings (Metal Substrates Corrected and Uncorrected), Classified Using Threshold Values Reported in the XRF Performance Characteristic Sheet For Instruments Sold Or Serviced After June 26, 1995 and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard for Data Taken From Testing Archived Building Components in July 1995.

SUBSTRATE	THRESHOLD VALUES	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	1.0	0.0% (0/1)	0.0% (0/2)	0.0%
Concrete	1.0	0.0% (0/2)	(0/0)	0.0%
Drywall	1.0	0.0% (0/14)	(0/0)	0.0%
Metal	0.9	0.0% (0/27)	0.0% (0/11)	0.0%
Plaster	1.0	3.5% (1/29)	11.1% (1/9)	0.0%
Wood	1.0	5.0% (2/40)	8.7% (2/23)	0.0%
Metal (Uncorrected)	0.9 to 1.2	0.0% (0/27)	0.0% (0/11)	10.5% (4/38)
TOTAL*		2.7% (3/113)	6.7% (3/45)	0.0%

*Total results are for values reported in PCS.

Table D-24. Classification Results For Radiation Monitoring Device LPA-1 Quick Mode Readings (Uncorrected), Classified Using Inconclusive Ranges and Threshold Values Reported in the XRF Performance Characteristic Sheet For Instruments Sold Or Serviced After June 26, 1995 and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken From Testing Archived Building Components in July 1995.

SUBSTRATE	INCONCLUSIVE RANGE OR THRESHOLD	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	1.0	0.0% (0/1)	0.0% (0/2)	0.0% (0/3)
Concrete	1.0	0.0% (0/2)	(0/0)	0.0% (0/2)
Drywall	1.0	0.0% (0/14)	(0/0)	0.0% (0/14)
Metal	0.9 to 1.3	3.7% (1/27)	0.0% (0/11)	13.2% (5/38)
Plaster	0.9 to 1.0	3.5% (1/29)	0.0% (0/9)	0.0% (0/38)
Wood	1.0	5.0% (2/40)	8.7% (2/23)	0.0% (0/63)
TOTAL		3.5% (4/113)	4.4% (2/45)	3.2% (5/158)

Table D-25. Classification Results For Radiation Monitoring Device LPA-1 30-Second Readings (Metal and Wood Substrates Corrected and Uncorrected), Classified Using Threshold Values Reported

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in the XRF Performance Characteristic Sheet For Instruments That Were Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995 and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken From Testing Archived Building Components in March and September 1995.

SUBSTRATE	THRESHOLD VALUES	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.8	0.0% (0/1)	0.0% (0/2)	0.0%
Concrete	0.8	0.0% (0/2)	(0/0)	0.0%
Drywall	0.7	0.0% (0/14)	(0/0)	0.0%
Metal	0.8	3.7% (1/27)	0.0% (0/11)	0.0%
Plaster	0.8	3.5% (1/29)	11.1% (1/9)	0.0%
Wood	0.9	5.1% (2/39)	8.7% (2/23)	0.0%
Metal (Uncorrected)	0.4	3.7% (1/27)	0.0% (0/11)	0.0% (0/38)
Wood (Uncorrected)	0.8	5.0% (2/40)	8.7% (2/23)	0.0% (0/63)
TOTAL*		3.5% (4/113)	6.7% (3/45)	0.0%

*Total results are for values reported in PCS.

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Table D-26. Classification Results For Radiation Monitoring Device LPA-1 20-Second Readings (Metal and Wood Substrates Corrected and Uncorrected), Classified Using Threshold Values Reported in the XRF Performance Characteristic Sheet For Instruments That Were Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995 and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken From Testing Archived Building Components in March and September 1995.

SUBSTRATE	THRESHOLD VALUES	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.7	0.0% (0/2)	0.0% (0/4)	0.0%
Concrete	0.7	0.0% (0/4)	(0/0)	0.0%
Drywall	0.7	0.0% (0/28)	(0/0)	0.0%
Metal	0.9	5.6% (3/54)	0.0% (0/22)	0.0%
Plaster	0.8	3.5% (2/58)	7.1% (1/14)	0.0%
Wood	0.8	6.3% (5/80)	13.0% (6/46)	0.0%
Metal (Uncorrected)	0.4	9.3% (5/54)	0.0% (0/22)	0.0% (0/76)
Wood (Uncorrected)	0.7	6.3% (5/80)	10.9% (5/46)	0.0% (0/126)
TOTAL*		4.4% (10/226)	8.1% (7/86)	0.0%

*Total results are for values reported in PCS.

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Table D-27. Classification Results For Radiation Monitoring Device LPA-1 Quick Mode Readings (Metal and Wood Substrates Corrected and Uncorrected), Classified Using Inconclusive Ranges Reported in the XRF Performance Characteristic Sheet For Instruments That Were Sold Prior to June 26, 1995 and Have Not Been Serviced Since June 26, 1995 and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken From Testing Archived Building Components in March and September 1995.

SUBSTRATE	INCONCLUSIVE RANGE	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.7 to 0.8	0.0% (0/2)	0.0% (0/4)	0.0% (0/6)
Concrete	0.7 to 0.8	0.0% (0/4)	(0/0)	0.0% (0/4)
Drywall	0.6 to 0.8	0.0% (0/28)	(0/0)	0.0% (0/28)
Metal	0.9 to 1.0	1.9% (1/54)	4.6% (1/22)	0.0% (0/76)
Plaster	0.7 to 0.8	3.5% (2/58)	7.1% (1/14)	0.0% (0/72)
Wood	0.7 to 0.8	3.8% (3/80)	13.0% (6/46)	0.8% (1/126)
Metal (Uncorrected)	0.3 to 0.4	0.0% (0/54)	4.6% (1/22)	0.0% (0/76)
Wood (Uncorrected)	0.7 to 0.8	3.9% (3/80)	13.0% (6/46)	0.0% (0/126)
TOTAL[a]		2.7% (6/226)	9.3% (8/86)	0.3% (1/312)

[a]Total results are for values reported in PCS.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

D.4 XRF Performance Characteristic Sheet for the Scitec MAP-3 and Related Results

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP-3

EFFECTIVE DATE: August 24, 1995 **EDITION NO.**: 1

MANUFACTURER AND MODEL:

Make: *Scitec Corporation*
Model: *MAP-3*
Source: Co^{57}
Note: This sheet supersedes all previous sheets for the XRF instrument of the make, model, and source shown above.

EVALUATION DATA SOURCE AND DATE:

This sheet is supplemental information to be used in conjunction with Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* ("HUD Guidelines"). Performance parameters shown on this sheet are calculated from evaluation data collected during the EPA/HUD field evaluation study conducted from March through October 1993. The data were collected from four instruments at approximately 1,200 15-second test locations and 300 60-second test locations. One instrument had a January 1993 source and the other three instruments had July 1993 sources. All four instruments had sources with 40 mCi initial strengths. The results of this study are reported in *A Field Test of Lead-Based Paint Testing Technologies: Technical Report*, EPA 747-R-95-002b, May 1995.

FIELD OPERATION GUIDANCE

OPERATING PARAMETERS:

Performance parameters shown in this sheet are applicable only when operating the instrument under the same conditions as the evaluation testing and using the procedures described in Chapter 7 of the HUD Guidelines. Operating parameters include:

- Manufacturer-recommended warm-up and quality control procedures
- Use the Multifamily Decision Flowchart for determining the presence of lead on a component type in multifamily housing
- Nominal 15-second or nominal 60-second readings on three locations per component for single-family housing and one location per component for multifamily housing
- Calibration checks are taken using the red (1.02 mg/cm^2) NIST Standard Reference Material (SRM No. 2579) paint film
- Readings for determining the substrate correction values are taken on bare substrate covered with red (1.02 mg/cm^2) NIST SRM paint film
- Lead-based paint is defined as paint with lead equal to or in excess of 1.0 mg/cm^2.

Figure D-3. XRF Performance Characteristic Sheet for the Scitec Corporation MAP-3.

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XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP-3

XRF CALIBRATION CHECK:

Chapter 7 of the HUD Guidelines recommends using a calibration check procedure to determine the operating condition of the XRF instrument. If the observed calibration check average minus 1.02 mg/cm^2 is greater than the positive (plus) calibration check tolerance value, or less than the negative (minus) calibration check tolerance value, then the instructions provided by the manufacturer should be followed in order to bring the instrument back into control before any more XRF testing is done. This calibration check is estimated to produce an incorrect result (that is, a finding that the instrument is out of calibration) very infrequently - once out of every 200 times this procedure is followed.

15-SECOND READINGS	60-SECOND READINGS
minus value = -0.6 mg/cm^2 plus value = +0.3 mg/cm^2	minus value = -0.4 mg/cm^2 plus value = +0.1 mg/cm^2

FOR XRF RESULTS BELOW 4.0 mg/cm^2, SUBSTRATE CORRECTION RECOMMENDED FOR:

Metal and Wood

SUBSTRATE CORRECTION NOT RECOMMENDED FOR:

Brick, Concrete, Drywall, and Plaster

SUBSTRATE CORRECTION VALUE COMPUTATION:

Chapter 7 of the HUD Guidelines provides guidance on correcting XRF results for substrate bias. Supplemental guidance for using the red (1.02 mg/cm^2) NIST SRM paint film for substrate correction is provided below.

XRF results are corrected for substrate bias by subtracting from each XRF result a correction value determined separately in each house for single-family housing or in each development for multifamily housing, for each substrate. The correction value is an average of XRF readings taken over red NIST SRM (1.02 mg/cm^2) paint films at test locations that had been scraped clean of their paint covering. Compute the correction values as follows:

- Using the same XRF instrument, take three readings on a bare substrate area covered with the red NIST SRM (1.02 mg/cm^2) paint film. Repeat this procedure by taking three more readings on a second bare substrate area of the same substrate covered with the red NIST SRM (1.02 mg/cm^2) paint film.
- Compute the correction value for each substrate type by computing the average of all six readings as shown below.

Figure D-3 continued. XRF Performance Characteristic Sheet for the Scitec Corporation MAP-3.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP-3

For each substrate type:

$$\text{Correction Value} \left\{ \frac{1^{st} \quad 2^{nd} \quad 3^{rd} \quad 4^{th} \quad 5^{th} \quad 6^{th} \text{ Reading}}{6} \right. \quad 1.02 mg/cm^2$$

- Repeat this procedure for each substrate tested in the house or housing development.

INCONCLUSIVE RANGE:

XRF results are classified as positive if they are greater than or equal to the upper limit of the inconclusive range, and negative if they are less than or equal to the lower limit of the inconclusive range. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. For computing the XRF result, use all digits that are reported by the instrument. Inconclusive ranges were determined for comparing results to the 1.0 mg/cm^2 standard. For a listing of laboratories recommended by the EPA National Lead Laboratory Accreditation Program (NLLAP) for the analysis of samples to resolve an inconclusive XRF result or additional confirmational analysis, call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

15-SECOND READING DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)
Results corrected for substrate bias for 15-second readings on metal and wood substrates only	Brick	0.0 to 1.5
	Concrete	0.0 to 1.5
	Drywall	0.9 to 1.0
	Metal	0.9 to 1.3
	Plaster	0.3 to 1.3
	Wood	0.9 to 1.3

60-SECOND READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)	INCONCLUSIVE RANGE (mg/cm^2)
Readings corrected for substrate bias for 60-second readings on metal and wood substrates only	Brick	None	0.3 to 0.9
	Concrete	None	0.3 to 0.9
	Drywall	None	0.6 to 0.8
	Metal	None	0.9 to 1.2
	Plaster	None	0.2 to 0.9
	Wood	1.0	None

INSTRUCTIONS FOR EVALUATING XRF TESTING:

Chapter 7 of the HUD Guidelines recommends several options for evaluating XRF testing. Among those options is the following procedure which may be used after XRF testing has been completed. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily

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Figure D-3 continued. XRF Performance Characteristic Sheet for the Scitec Corporation MAP-3.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP-3

housing, an XRF result is a single reading taken on a testing combination. If a multifamily housing development is being retested, randomly select two units from within the development from which the ten testing combinations should be randomly selected.

Randomly select ten testing combinations for retesting from each house or from the two selected units.

Conduct XRF retesting at the ten testing combinations selected for retesting.

Determine if the XRF testing in the units or house passed or failed the test by applying the steps below.

Compute the Retest Tolerance Limit by the following steps:

Determine XRF results for the original and retest XRF readings. Do not correct the original or retest results for substrate bias. In single-family housing a result is defined as the average of three readings. In multifamily housing, a result is a single reading. Therefore, there will be ten original and ten retest XRF results for each house or for the two selected units.

Compute the average of the original and re-test result for each of the ten testing combinations.

Square the average for each testing combination.

Add the ten squared averages together. Call this quantity C.

Multiply the number C by 0.0072. Call this quantity D.

Add the number 0.032 to D. Call this quantity E.

Take the square root of E. Call this quantity F.

Multiply F by 1.645. The result is the Retest Tolerance Limit.

Compute the overall average of all ten retest XRF results over all ten testing combinations selected for retesting.

Take the difference of the overall average of the ten original XRF results and the overall average of the ten retest XRF results. If the difference is negative, drop the negative sign.

If the difference of the overall averages is less than the Retest Tolerance Limit, the inspection has passed the retest. If the difference of the overall averages equals or exceeds the Retest Tolerance Limit, this procedure should be repeated with ten new testing combinations. If the difference of the overall averages is equal to or greater than the Retest Tolerance Limit a second time, then the inspection should be considered deficient.

Use of this procedure is estimated to produce a spurious result approximately 1% of the time. That is, results of this procedure will call for further examination when no examination is warranted in approximately 1 out of 100 dwelling units tested.

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Figure D-3 continued. XRF Performance Characteristic Sheet for the Scitec Corporation MAP-3.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP-3

BIAS AND PRECISION:

Do not use these bias and precision data to correct for substrate bias. These bias and precision data were computed without substrate correction from samples with reported laboratory results less than 4.0 mg/cm^2 lead. There were 124 15-second testing locations with a laboratory reported result equal to or greater than 4.0 mg/cm^2 lead. Of these, none had XRF readings less than 1.0 mg/cm^2. For the 60-second testing locations, 34 had laboratory reported results equal to or greater than 4.0 mg/cm^2 lead, with 2 of those having XRF readings less than 1.0 mg/cm^2. These data are for illustrative purposes only. Actual bias must be determined on the site. Inconclusive ranges provided above already account for bias and precision. Units are in mg/cm^2.

15-SECOND READING MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	PRECISION* (mg/cm^2)
0.0 mg/cm^2	Brick	-0.7	0.9
	Concrete	-0.7	0.9
	Drywall	0.0	0.4
	Metal	0.3	0.3
	Plaster	-0.7	0.8
	Wood	-0.1	0.5
0.5 mg/cm^2	Brick	-0.5	1.0
	Concrete	-0.5	1.0
	Drywall	-0.1	0.4
	Metal	0.4	0.5
	Plaster	-0.6	0.8
	Wood	0.2	0.6
1.0 mg/cm^2	Brick	-0.4	1.0
	Concrete	-0.4	1.0
	Drywall	-0.1	0.4
	Metal	0.5	0.6
	Plaster	-0.4	0.9
	Wood	0.4	0.7
2.0 mg/cm^2	Brick	-0.1	1.2
	Concrete	-0.1	1.2
	Drywall	-0.3	0.4
	Metal	0.6	0.7
	Plaster	-0.2	0.9
	Wood	0.8	0.8

*Precision at 1 standard deviation.

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Figure D-3 continued. XRF Performance Characteristic Sheet for the Scitec Corporation MAP-3.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP-3

60-SECOND READING MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	PRECISION* (mg/cm^2)
0.0 mg/cm^2	Brick	-0.8	0.7
	Concrete	-0.8	0.7
	Drywall	0.0	0.3
	Metal	0.3	0.2
	Plaster	-0.9	0.5
	Wood	-0.2	0.4
0.5 mg/cm^2	Brick	-0.7	0.7
	Concrete	-0.7	0.7
	Drywall	-0.2	0.3
	Metal	0.4	0.3
	Plaster	-0.7	0.7
	Wood	0.1	0.4
1.0 mg/cm^2	Brick	-0.7	0.7
	Concrete	-0.7	0.7
	Drywall	-0.4	0.3
	Metal	0.6	0.4
	Plaster	-0.5	0.8
	Wood	0.3	0.5
2.0 mg/cm^2	Brick	-0.6	0.7
	Concrete	-0.6	0.7
	Drywall	-0.8	0.3
	Metal	0.8	0.6
	Plaster	-0.1	1.0
	Wood	0.8	0.6

*Precision at 1 standard deviation.

A document titled *Methodology for XRF Performance Characteristic Sheets* provides an explanation of the statistical methodology used to construct the data in the sheets and provides empirical results from using the recommended inconclusive ranges or thresholds for specific XRF instruments. For a copy of this document call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

This XRF Performance Characteristic Sheet is a joint product of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD). The issuance of this sheet does not constitute rulemaking. The information provided here is intended solely as guidance to be used in conjunction with Chapter 7 of the *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. EPA and HUD reserve the right to revise this guidance. Please address questions and comments on this sheet to: Director, Office of Lead-Based Paint Abatement and Poisoning Prevention, U.S. Department of Housing and Urban Development, Room B-133, 451 Seventh St, S.W., Washington, DC 20410.

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Figure D-3 continued. XRF Performance Characteristic Sheet for the Scitec Corporation MAP-3.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-28. Inconclusive Ranges For Scitec MAP-3 15-Second K-Shell Readings Where Substrate Correction Is Not Performed, But Substrate Correction Is Recommended.

15-SECOND READING DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)
Readings not corrected for substrate bias on any substrate	Metal Wood	0.9 to 1.6 0.9 to 1.6

Table D-29. Inconclusive Ranges or Thresholds For Scitec MAP-3 K-Shell 60-Second Readings Where Substrate Correction Is Not Performed, But Substrate Correction Is Recommended.

60-SECOND READING DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)
Readings not corrected for substrate bias on any substrate	Metal Wood	0.9 to 1.6 0.9 to 1.3

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-30. Bias Estimates, and Their Standard Errors, of Scitec MAP-3 K-Shell 15-Second Readings.

15-SECOND READING MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR FOR BIAS
0.0 mg/cm^2	No	Brick	-0.7	0.06
		Concrete	-0.7	0.06
		Drywall	0.0	0.04
		Metal	0.3	0.04
		Plaster	-0.7	0.07
		Wood	-0.1	0.04
	Yes	Metal	-0.1	0.04
		Wood	-0.3	0.04
0.5 mg/cm^2	No	Brick	-0.5	0.07
		Concrete	-0.5	0.07
		Drywall	-0.1	0.09
		Metal	0.4	0.04
		Plaster	-0.6	0.07
		Wood	0.2	0.04
	Yes	Metal	0.0	0.04
		Wood	-0.1	0.04
1.0 mg/cm^2	No	Brick	-0.4	0.12
		Concrete	-0.4	0.12
		Drywall	-0.1	0.20
		Metal	0.5	0.06
		Plaster	-0.4	0.14
		Wood	0.4	0.06
	Yes	Metal	0.1	0.06
		Wood	0.1	0.06
2.0 mg/cm^2	No	Brick	-0.1	0.25
		Concrete	-0.1	0.25
		Drywall	-0.3	0.41
		Metal	0.6	0.12
		Plaster	-0.2	0.30
		Wood	0.8	0.13
	Yes	Metal	0.3	0.12
		Wood	0.5	0.12

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-31. Bias Estimates, and Their Standard Errors, of Scitec MAP-3 K-Shell 60-Second Readings.

60-SECOND READING MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR FOR BIAS
0.0 mg/cm^2	No	Brick	-0.8	0.13
		Concrete	-0.8	0.13
		Drywall	0.0	0.07
		Metal	0.3	0.05
		Plaster	-0.9	0.10
		Wood	-0.2	0.06
	Yes	Metal	0.0	0.05
		Wood	-0.3	0.06
0.5 mg/cm^2	No	Brick	-0.7	0.12
		Concrete	-0.7	0.12
		Drywall	-0.2	0.21
		Metal	0.4	0.05
		Plaster	-0.7	0.10
		Wood	0.1	0.06
	Yes	Metal	0.1	0.05
		Wood	-0.2	0.06
1.0 mg/cm^2	No	Brick	-0.7	0.22
		Concrete	-0.7	0.22
		Drywall	-0.4	0.44
		Metal	0.6	0.10
		Plaster	-0.5	0.21
		Wood	0.3	0.10
	Yes	Metal	0.2	0.09
		Wood	0.0	0.10
2.0 mg/cm^2	No	Brick	-0.6	0.48
		Concrete	-0.6	0.48
		Drywall	-0.8	0.91
		Metal	0.8	0.19
		Plaster	-0.1	0.46
		Wood	0.8	0.20
	Yes	Metal	0.4	0.18
		Wood	0.3	0.19

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-32. Precision Estimates, and Their Standard Errors, of Scitec MAP-3 K-Shell 15-Second Readings.

15-SECOND READING MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	Brick	0.9	0.04
		Concrete	0.9	0.04
		Drywall	0.4	0.03
		Metal	0.3	0.03
		Plaster	0.8	0.05
		Wood	0.5	0.03
	Yes	Metal	0.4	0.03
		Wood	0.6	0.04
0.5 mg/cm^2	No	Brick	1.0	0.06
		Concrete	1.0	0.06
		Drywall	0.4	0.03
		Metal	0.5	0.03
		Plaster	0.8	0.06
		Wood	0.6	0.04
	Yes	Metal	0.5	0.03
		Wood	0.7	0.04
1.0 mg/cm^2	No	Brick	1.0	0.10
		Concrete	1.0	0.10
		Drywall	0.4	0.03
		Metal	0.6	0.05
		Plaster	0.9	0.10
		Wood	0.7	0.06
	Yes	Metal	0.6	0.05
		Wood	0.8	0.06
2.0 mg/cm^2	No	Brick	1.2	0.17
		Concrete	1.2	0.17
		Drywall	0.4	0.03
		Metal	0.7	0.08
		Plaster	0.9	0.19
		Wood	0.8	0.10
	Yes	Metal	0.8	0.07
		Wood	0.9	0.10

*Precision at 1 standard deviation

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-33. Precision Estimates, and Their Standard Errors, of Scitec MAP-3 K-Shell 60-Second Readings.

60-SECOND READING MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	Brick	0.7	0.09
		Concrete	0.7	0.09
		Drywall	0.3	0.05
		Metal	0.2	0.04
		Plaster	0.5	0.07
		Wood	0.4	0.05
	Yes	Metal	0.3	0.04
		Wood	0.4	0.04
0.5 mg/cm^2	No	Brick	0.7	0.09
		Concrete	0.7	0.09
		Drywall	0.3	0.05
		Metal	0.3	0.06
		Plaster	0.7	0.10
		Wood	0.4	0.06
	Yes	Metal	0.3	0.05
		Wood	0.5	0.05
1.0 mg/cm^2	No	Brick	0.7	0.09
		Concrete	0.7	0.09
		Drywall	0.3	0.05
		Metal	0.4	0.10
		Plaster	0.8	0.16
		Wood	0.5	0.11
	Yes	Metal	0.3	0.10
		Wood	0.5	0.09
2.0 mg/cm^2	No	Brick	0.7	0.09
		Concrete	0.7	0.09
		Drywall	0.3	0.05
		Metal	0.6	0.16
		Plaster	1.0	0.27
		Wood	0.6	0.20
	Yes	Metal	0.3	0.19
		Wood	0.6	0.15

*Precision at 1 standard deviation

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-34. Classification Results For Scitec MAP-3 K-Shell 15-Second Readings (Metal and Wood Corrected and Uncorrected), Classified Using the Inconclusive Ranges Reported in the XRF Performance Characteristic Sheet and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken During the EPA/HUD Field Study.

SUBSTRATE	INCONCLUSIVE RANGE	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.0 to 1.5	1.4% (2/143)	0.0% (0/42)	20.5% (38/185)
Concrete	0.0 to 1.5	2.9% (11/382)	1.9% (3/54)	29.6% (129/436)
Drywall	0.9 to 1.0	3.5% (8/226)	(0/0)	0.9% (2/226)
Metal	0.9 to 1.3	1.7% (5/290)	1.1% (1/88)	6.1% (23/378)
Plaster	0.3 to 1.3	2.0% (8/392)	11.5% (6/52)	15.5% (69/444)
Wood	0.9 to 1.3	3.2% (16/499)	7.5% (15/199)	4.6% (32/698)
Metal (Uncorrected)	0.9 to 1.6	1.7% (5/290)	1.1% (1/88)	16.9% (64/378)
Wood (Uncorrected)	0.9 to 1.6	4.0% (20/499)	5.5% (11/199)	8.5% (59/698)
TOTAL*		2.6% (50/1932)	5.8% (25/435)	12.4% (293/2367)

*Total results are for values reported in PCS.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-35. Classification Results For Scitec MAP-3 K-Shell 60-Second Readings (Metal and Wood Corrected and Uncorrected), Classified Using the Inconclusive Ranges and Threshold Value Reported in the XRF Performance Characteristic Sheet and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken During the EPA/HUD Field Study.

SUBSTRATE	INCONCLUSIVE RANGE OR THRESHOLD	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.3 to 0.9	5.9% (2/34)	0.0% (0/8)	4.8% (1/42)
Concrete	0.3 to 0.9	5.8% (6/103)	7.1% (1/14)	12.0% (14/117)
Drywall	0.6 to 0.8	5.0% (3/60)	(0/0)	0.0% (0/60)
Metal	0.9 to 1.2	2.7% (2/74)	3.6% (1/28)	5.9% (6/102)
Plaster	0.2 to 0.9	0.0% (0/107)	5.9% (1/17)	8.1% (10/124)
Wood	1.0	1.9% (2/106)	5.8% (3/52)	0.0% (0/158)
Metal (Uncorrected)	0.9 to 1.6	2.7% (2/74)	0.0% (0/28)	15.7% (16/102)
Wood (Uncorrected)	0.9 to 1.3	1.9% (2/107)	0.0% (0/51)	7.0% (11/158)
TOTAL*		3.1% (15/484)	5.0% (6/119)	5.1% (31/603)

*Total results are for values reported in PCS.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

D.5 XRF Performance Characteristic Sheet for the Scitec MAP 4 and Related Results

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP 4

EFFECTIVE DATE: June 26, 1996 **EDITION NO.**: 1

MANUFACTURER AND MODEL:

Make: *Scitec Corporation*
Model: *MAP 4*
Source: Co^{57}
Note: This sheet supersedes all previous sheets for the XRF instrument of the make, model, and source shown above.

EVALUATION DATA SOURCE AND DATE:

This sheet is supplemental information to be used in conjunction with Chapter 7 of the HUD *Guidelines* for the Evaluation and Control of Lead-Based Paint Hazards in Housing ("HUD Guidelines"). Performance parameters shown on this sheet are calculated from an EPA/HUD evaluation using archived building components. Testing was conducted on approximately 150 test locations. All of the test locations were tested in February 1996 using two different instruments. One instrument had a new source installed in July 1994 and its strength at the time of testing was calculated as 10.1 mCi. The other instrument had a new source installed in September 1994 and its strength at the time of testing was calculated as 11.5 mCi.

FIELD OPERATION GUIDANCE

OPERATING PARAMETERS:

Performance parameters shown in this sheet are applicable only when operating the instrument under the same conditions as the evaluation testing and using the procedures described in Chapter 7 of the HUD Guidelines. Operating parameters include:

- Manufacturer-recommended warm-up and quality control procedures.
- Use the Multifamily Decision Flowchart for determining the presence of lead on a component type in multifamily housing.
- Take readings on three locations per component for single-family housing and one location per component for multifamily housing.
- Calibration checks are taken in TEST mode while using the red (1.02 mg/cm^2) NIST Standard Reference Material (SRM No. 2579) paint film.
- Readings for determining the substrate correction values are taken on bare substrate covered with red (1.02 mg/cm^2) NIST SRM paint film.
- Lead-based paint is defined as paint with lead equal to or in excess of 1.0 mg/cm^2.

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Figure D-4. XRF Performance Characteristic Sheet for Scitec MAP 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP 4

XRF CALIBRATION CHECK:

Chapter 7 of the HUD Guidelines recommends using a calibration check procedure to determine the operating condition of the XRF instrument. For this instrument, calibration checks should be taken in TEST mode. If the observed calibration check average minus 1.02 mg/cm^2 is greater than the positive (plus) calibration check tolerance value, or less than the negative (minus) calibration check tolerance value, then the instructions provided by the manufacturer should be followed in order to bring the instrument back into control before any more XRF testing is done. This calibration check is estimated to produce an incorrect result (that is, a finding that the instrument is out of calibration) very infrequently - once out of every 200 times this procedure is followed.

minus value = -0.4 mg/cm^2
plus value = +0.2 mg/cm^2

WHEN USING UNLIMITED MODE, SUBSTRATE CORRECTION RECOMMENDED FOR:

None

WHEN USING UNLIMITED MODE, SUBSTRATE CORRECTION NOT RECOMMENDED FOR:

Brick, Concrete, Drywall, Metal, Plaster, and Wood

WHEN USING SCREEN OR TEST MODE, FOR XRF RESULTS BELOW 4.0 mg/cm^2, SUBSTRATE CORRECTION RECOMMENDED FOR:

Drywall, Metal, and Wood

WHEN USING SCREEN OR TEST MODE, SUBSTRATE CORRECTION NOT RECOMMENDED FOR:

Brick, Concrete, and Plaster

SUBSTRATE CORRECTION VALUE COMPUTATION:

Chapter 7 of the HUD Guidelines provides guidance on correcting XRF results for substrate bias. Supplemental guidance for using the red (1.02 mg/cm^2) NIST SRM paint film for substrate correction is provided below.

XRF results are corrected for substrate bias by subtracting from each XRF result a correction value determined separately in each house for single-family housing or in each development for multifamily housing, for each substrate. The correction value is an average of XRF readings taken over red NIST SRM (1.02 mg/cm^2) paint films at test locations that had been scraped clean of their paint covering. Compute the correction values as follows:

- Using the same XRF instrument, take three readings on a bare substrate area covered with the red NIST SRM (1.02 mg/cm^2) paint film. Repeat this procedure by taking three more readings on a second bare substrate area of the same substrate covered with the red NIST SRM (1.02 mg/cm^2) paint film.

- Compute the correction value for each substrate type by computing the average of all six readings as shown below.

Figure D-4 continued. XRF Performance Characteristic Sheet for the Scitec Map 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP 4

For each substrate type:

$$\text{Correction Value} \Big\} \quad \frac{1^{st} \quad 2^{nd} \quad 3^{rd} \quad 4^{th} \quad 5^{th} \quad 6^{th} \text{ Reading}}{6} \quad 1.02 mg/cm^2$$

- Repeat this procedure for each substrate tested in the house or housing development.

INCONCLUSIVE RANGE OR THRESHOLD:

XRF results are classified using either the threshold or the inconclusive range. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. For computing the XRF result, use all digits that are reported by the instrument. For the threshold, results are classified as positive if they are greater than or equal to the threshold, and negative if they are less than the threshold. There is no inconclusive classification when using the threshold. For the inconclusive range, results are classified as positive if they are greater than or equal to the upper limit of the inconclusive range, and negative if they are less than or equal to the lower limit of the inconclusive range. Thresholds and inconclusive ranges were determined for comparing results to the 1.0 mg/cm^2 standard. For a listing of laboratories recommended by the EPA National Lead Laboratory Accreditation Program (NLLAP) for the analysis of samples to resolve an inconclusive XRF result or additional confirmational analysis, call the National Lead Information Center Clearinghouse on 1-800-424-LEAD.

UNLIMITED MODE READING DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)
Results not corrected for substrate bias for unlimited mode readings	Brick	0.9 to 1.2
	Concrete	0.9 to 1.2
	Drywall	0.9 to 1.2
	Metal	0.9 to 1.2
	Plaster	0.9 to 1.2
	Wood	0.9 to 1.2

SCREEN MODE READING DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)
Results corrected for substrate bias for screen mode readings on drywall, metal, and wood substrates only	Brick	0.9 to 1.1
	Concrete	0.9 to 1.1
	Drywall	0.9 to 1.4
	Metal	0.9 to 1.2
	Plaster	0.9 to 1.1
	Wood	0.9 to 1.3

Figure D-4 continued. XRF Performance Characteristic Sheet for the Scitec Map 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP 4

TEST MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)	INCONCLUSIVE RANGE (mg/cm^2)
Readings corrected for substrate bias for test mode readings on drywall, metal, and wood substrates only	Brick	0.9	None
	Concrete	0.9	None
	Drywall	None	0.9 to 1.4
	Metal	None	0.9 to 1.1
	Plaster	0.9	None
	Wood	None	0.9 to 1.3

INSTRUCTIONS FOR EVALUATING XRF TESTING:

Chapter 7 of the HUD Guidelines recommends several options for evaluating XRF testing. Among those options is the following procedure which may be used after XRF testing has been completed. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. If a multifamily housing development is being retested, randomly select two units from within the development from which the ten testing combinations should be randomly selected. Use either 15-second readings or 60-second readings.

Randomly select ten testing combinations for retesting from each house or from the two selected units.

Conduct XRF retesting at the ten testing combinations selected for retesting.

Determine if the XRF testing in the units or house passed or failed the test by applying the steps below.

Compute the Retest Tolerance Limit by the following steps:

Determine XRF results for the original and retest XRF readings. Do not correct the original or retest results for substrate bias. In single-family housing a result is defined as the average of three readings. In multifamily housing, a result is a single reading. Therefore, there will be ten original and ten retest XRF results for each house or for the two selected units.

Compute the average of the original and re-test result for each of the ten testing combinations.

Square the average for each testing combination.

Add the ten squared averages together. Call this quantity C.

Multiply the number C by 0.0072. Call this quantity D.

Add the number 0.032 to D. Call this quantity E.

Take the square root of E. Call this quantity F.

Multiply F by 1.645. The result is the Retest Tolerance Limit.

Figure D-4 continued. XRF Performance Characteristic Sheet for the Scitec Map 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP 4

Compute the overall average of all ten retest XRF results over all ten testing combinations selected for retesting.

Take the difference of the overall average of the ten original XRF results and the overall average of the ten retest XRF results. If the difference is negative, drop the negative sign.

If the difference of the overall averages is less than the Retest Tolerance Limit, the inspection has passed the retest. If the difference of the overall averages equals or exceeds the Retest Tolerance Limit, this procedure should be repeated with ten new testing combinations. If the difference of the overall averages is equal to or greater than the Retest Tolerance Limit a second time, then the inspection should be considered deficient.

Use of this procedure is estimated to produce a spurious result approximately 1% of the time. That is, results of this procedure will call for further examination when no examination is warranted in approximately 1 out of 100 dwelling units tested.

TESTING TIMES:

For screen, test, and confirm modes, the MAP 4 instrument tests until a K-shell result is obtained relative to a level of precision. A result is "positive", "negative" or "retest" as displayed by indicator lights. For the unlimited mode, the MAP 4 instrument tests until a K-shell result is indicated relative to an action level (1.0 mg/cm^2 for archive testing) and the current precision, or until the reading is terminated by releasing the trigger. A few unlimited mode readings were terminated because they exceeded the two-minute limit used for archive testing. The following tables provide testing time information for three testing modes. Insufficient information is available to provide this information for confirm mode. All times have been scaled to match an initial 12 mCi source. Note that source strength and factors such as substrate may affect testing times.

UNLIMITED MODE TESTING TIMES (Seconds)

SUBSTRATE*	ALL DATA			MEDIAN FOR LABORATORY-MEASURED LEAD LEVELS (mg/cm^2)		
	25th Percentile	Median	75th Percentile	Pb < 0.25	0.25	1.0
Wood Drywall	3	4	6	4	13	3
Metal	3	4	8	4	9	3
Brick Concrete Plaster	4	5	8	6	6	3

* The general calibration was used for wood, drywall, brick, concrete, plaster. Steel calibration was used for metal. (There are no aluminum samples in the archive facility).

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Figure D-4 continued. XRF Performance Characteristic Sheet for the Scitec Map 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP 4

TESTING TIMES (continued):

SCREEN MODE TESTING TIMES (Seconds)						
SUBSTRATE*	**ALL DATA**			**MEDIAN FOR LABORATORY-MEASURED LEAD LEVELS (mg/cm^2)**		
	25th Percentile	**Median**	**75th Percentile**	**Pb < 0.25**	**0.25**	**1.0**
Wood Drywall	4	6	7	5	6	7
Metal	4	5	6	5	5	5
Brick Concrete Plaster	11	11	13	11	11	11

* The general calibration was used for wood, drywall, brick, concrete, plaster. Steel calibration was used for metal. (There are no aluminum samples in the archive facility).

TEST MODE TESTING TIMES (Seconds)						
SUBSTRATE*	**ALL DATA**			**MEDIAN FOR LABORATORY-MEASURED LEAD LEVELS (mg/cm^2)**		
	25th Percentile	**Median**	**75th Percentile**	**Pb < 0.25**	**0.25**	**1.0**
Wood Drywall	17	22	27	21	20	28
Metal	13	20	23	20	20	20
Brick Concrete Plaster	41	42	52	41	46	43

* The general calibration was used for wood, drywall, brick, concrete, plaster. Steel calibration was used for metal. (There are no aluminum samples in the archive facility).

Figure D-4 continued. XRF Performance Characteristic Sheet for the Scitec Map 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP 4

BIAS AND PRECISION:

Do not use these bias and precision data to correct for substrate bias. These bias and precision data were computed without substrate correction from samples with laboratory-measured lead levels less than 4.0 mg/cm^2 lead. There were 15 testing locations taken in the screen mode with laboratory-measured lead levels equal to or greater than 4.0 mg/cm^2 lead. None of these had XRF readings less than 1.0 mg/cm^2. There were 15 testing locations taken in the test mode with laboratory-measured lead levels equal to or greater than 4.0 mg/cm^2 lead. None of these had XRF readings less than 1.0 mg/cm^2. There were not any testing locations taken in the confirm mode with a laboratory-measured lead levels equal to or greater than 4.0 mg/cm^2 lead. There were 15 testing locations taken in the unlimited mode with laboratory-measured lead levels equal to or greater than 4.0 mg/cm^2 lead. None of these had XRF readings less than 1.0 mg/cm^2. All testing was done in February 1996 with two different instruments. The following data are for illustrative purposes only. Actual bias must be determined on the site. Inconclusive ranges provided above already account for bias and precision. Units are in mg/cm^2.

SCREEN MODE READING MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	PRECISION* (mg/cm^2)
0.0 mg/cm^2	Brick	-0.1	0.3
	Concrete	-0.1	0.3
	Drywall	0.1	0.2
	Metal	0.1	0.3
	Plaster	-0.1	0.3
	Wood	0.0	0.2
0.5 mg/cm^2	Brick	0.0	0.3
	Concrete	0.0	0.3
	Drywall	0.3	0.4
	Metal	0.2	0.3
	Plaster	0.0	0.3
	Wood	0.2	0.4
1.0 mg/cm^2	Brick	0.1	0.4
	Concrete	0.1	0.4
	Drywall	0.5	0.6
	Metal	0.3	0.3
	Plaster	0.1	0.4
	Wood	0.4	0.6
2.0 mg/cm^2	Brick	0.4	0.5
	Concrete	0.4	0.5
	Drywall	0.9	0.8
	Metal	0.5	0.3
	Plaster	0.4	0.5
	Wood	0.7	0.8

*Precision at 1 standard deviation

Figure D-4 continued. XRF Performance Characteristic Sheet for the Scitec Map 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Scitec Corporation; MAP 4

BIAS AND PRECISION (continued):

TEST MODE READING MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	PRECISION* (mg/cm^2)
0.0 mg/cm^2	Brick	-0.1	0.2
	Concrete	-0.1	0.2
	Drywall	0.1	0.1
	Metal	0.1	0.2
	Plaster	-0.1	0.2
	Wood	0.0	0.1
0.5 mg/cm^2	Brick	-0.1	0.3
	Concrete	-0.1	0.3
	Drywall	0.3	0.4
	Metal	0.2	0.2
	Plaster	-0.1	0.3
	Wood	0.2	0.4
1.0 mg/cm^2	Brick	-0.1	0.3
	Concrete	-0.1	0.3
	Drywall	0.5	0.6
	Metal	0.3	0.2
	Plaster	-0.1	0.3
	Wood	0.4	0.6
2.0 mg/cm^2	Brick	0.0	0.4
	Concrete	0.0	0.4
	Drywall	1.0	0.8
	Metal	0.5	0.2
	Plaster	0.0	0.4
	Wood	0.8	0.8

*Precision at 1 standard deviation

A document titled *Methodology for XRF Performance Characteristic Sheets* provides an explanation of the statistical methodology used to construct the data in the sheets and provides empirical results from using the recommended inconclusive ranges or thresholds for specific XRF instruments. For a copy of this document call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

This XRF Performance Characteristic Sheet is a joint product of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD). The issuance of this sheet does not constitute rulemaking. The information provided here is intended solely as guidance to be used in conjunction with Chapter 7 of the *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. EPA and HUD reserve the right to revise this guidance. Please address questions and comments on this sheet to: Director, Office of Lead-Based Paint Abatement and Poisoning Prevention, U.S. Department of Housing and Urban Development, Room B-133, 451 Seventh St, S.W., Washington, DC 20410.

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Figure D-4 continued. XRF Performance Characteristic Sheet for the Scitec Map 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-36. Bias Estimates, and Their Standard Errors, of Scitec MAP 4 K-Shell **SCREEN** Mode Readings.

15-SECOND SCREEN MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR
0.0 mg/cm^2	No	Brick	-0.1	0.08
		Concrete	-0.1	0.08
		Drywall	0.1	0.07
		Metal	0.1	0.06
		Plaster	-0.1	0.08
		Wood	0.0	0.05
	Yes	Drywall	0.0	0.07
		Metal	0.0	0.07
		Wood	-0.1	0.07
0.5 mg/cm^2	No	Brick	0.0	0.07
		Concrete	0.0	0.07
		Drywall	0.3	0.09
		Metal	0.2	0.05
		Plaster	0.0	0.07
		Wood	0.2	0.06
	Yes	Drywall	0.1	0.09
		Metal	0.1	0.06
		Wood	0.0	0.07
1.0 mg/cm^2	No	Brick	0.1	0.13
		Concrete	0.1	0.13
		Drywall	0.5	0.14
		Metal	0.3	0.08
		Plaster	0.1	0.13
		Wood	0.4	0.11
	Yes	Drywall	0.3	0.14
		Metal	0.2	0.09
		Wood	0.2	0.12
2.0 mg/cm^2	No	Brick	0.4	0.30
		Concrete	0.4	0.30
		Drywall	0.9	0.26
		Metal	0.5	0.16
		Plaster	0.4	0.30
		Wood	0.7	0.24
	Yes	Drywall	0.7	0.26
		Metal	0.3	0.17
		Wood	0.6	0.24

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-37. Bias Estimates, and Their Standard Errors, of Scitec MAP 4 K-Shell **TEST** Mode Readings.

15-SECOND TEST MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR
0.0 mg/cm^2	No	Brick	-0.1	0.06
		Concrete	-0.1	0.06
		Drywall	0.1	0.05
		Metal	0.1	0.06
		Plaster	-0.1	0.06
		Wood	0.0	0.04
	Yes	Drywall	0.0	0.06
		Metal	-0.1	0.07
		Wood	-0.2	0.06
0.5 mg/cm^2	No	Brick	-0.1	0.05
		Concrete	-0.1	0.05
		Drywall	0.3	0.07
		Metal	0.2	0.05
		Plaster	-0.1	0.05
		Wood	0.2	0.06
	Yes	Drywall	0.2	0.08
		Metal	0.0	0.06
		Wood	0.0	0.07
1.0 mg/cm^2	No	Brick	-0.1	0.11
		Concrete	-0.1	0.11
		Drywall	0.5	0.13
		Metal	0.3	0.08
		Plaster	-0.1	0.11
		Wood	0.4	0.12
	Yes	Drywall	0.4	0.13
		Metal	0.1	0.09
		Wood	0.2	0.12
2.0 mg/cm^2	No	Brick	0.0	0.24
		Concrete	0.0	0.24
		Drywall	1.0	0.25
		Metal	0.5	0.17
		Plaster	0.0	0.24
		Wood	0.8	0.24
	Yes	Drywall	0.8	0.25
		Metal	0.3	0.17
		Wood	0.6	0.24

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-38. Precision Estimates, and Their Standard Errors, of Scitec MAP 4 K-Shell **SCREEN** Mode Readings.

15-SECOND SCREEN MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR
0.0 mg/cm^2	No	Brick	0.3	0.05
		Concrete	0.3	0.05
		Drywall	0.2	0.04
		Metal	0.3	0.04
		Plaster	0.3	0.05
		Wood	0.2	0.04
	Yes	Drywall	0.2	0.04
		Metal	0.3	0.03
		Wood	0.2	0.04
0.5 mg/cm^2	No	Brick	0.3	0.06
		Concrete	0.3	0.06
		Drywall	0.4	0.07
		Metal	0.3	0.04
		Plaster	0.3	0.06
		Wood	0.4	0.07
	Yes	Drywall	0.4	0.07
		Metal	0.3	0.03
		Wood	0.4	0.07
1.0 mg/cm^2	No	Brick	0.4	0.10
		Concrete	0.4	0.10
		Drywall	0.6	0.10
		Metal	0.3	0.04
		Plaster	0.4	0.10
		Wood	0.6	0.10
	Yes	Drywall	0.6	0.10
		Metal	0.3	0.03
		Wood	0.6	0.10
2.0 mg/cm^2	No	Brick	0.5	0.16
		Concrete	0.5	0.16
		Drywall	0.8	0.15
		Metal	0.3	0.04
		Plaster	0.5	0.16
		Wood	0.8	0.15
	Yes	Drywall	0.8	0.15
		Metal	0.3	0.03
		Wood	0.8	0.15

*Precision at 1 standard deviation.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-39. Precision Estimates, and Their Standard Errors, of Scitec MAP 4 K-Shell **TEST** Mode Readings.

15-SECOND TEST MODE READING MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR
0.0 mg/cm^2	No	Brick	0.2	0.04
		Concrete	0.2	0.04
		Drywall	0.1	0.03
		Metal	0.2	0.04
		Plaster	0.2	0.04
		Wood	0.1	0.03
	Yes	Drywall	0.1	0.3
		Metal	0.3	0.4
		Wood	0.1	0.3
0.5 mg/cm^2	No	Brick	0.3	0.05
		Concrete	0.3	0.05
		Drywall	0.4	0.07
		Metal	0.2	0.04
		Plaster	0.3	0.05
		Wood	0.4	0.07
	Yes	Drywall	0.4	0.6
		Metal	0.3	0.4
		Wood	0.4	0.6
1.0 mg/cm^2	No	Brick	0.3	0.08
		Concrete	0.3	0.08
		Drywall	0.6	0.10
		Metal	0.2	0.04
		Plaster	0.3	0.08
		Wood	0.6	0.10
	Yes	Drywall	0.6	0.10
		Metal	0.3	0.04
		Wood	0.6	0.10
2.0 mg/cm^2	No	Brick	0.4	0.12
		Concrete	0.4	0.12
		Drywall	0.8	0.14
		Metal	0.2	0.04
		Plaster	0.4	0.12
		Wood	0.8	0.14
	Yes	Drywall	0.8	0.14
		Metal	0.3	0.04
		Wood	0.8	0.14

*Precision at 1 standard deviation.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-40. Classification Results For Scitec MAP 4 K-Shell **UNLIMITED** Mode Readings (Uncorrected), Classified Using the Inconclusive Ranges Reported in the XRF Performance Characteristic Sheet and Compared to Laboratory-Measured Lead Levels in mg/cm^2 Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken From Testing Archived Building Components in February 1996.

SUBSTRATE	INCONCLUSIVE RANGE	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.9 to 1.2	0.0% (0/2)	0.0% (0/4)	0.0% (0/6)
Concrete	0.9 to 1.2	0.0% (0/4)	(0/0)	0.0% (0/4)
Drywall	0.9 to 1.2	3.6% (1/28)	(0/0)	14.3% (4/28)
Metal	0.9 to 1.2	3.7% (2/54)	0.0% (0/22)	5.3% (4/76)
Plaster	0.9 to 1.2	3.4% (2/58)	0.0% (0/18)	1.3% (1/76)
Wood	0.9 to 1.2	11.3% (9/80)	0.0% (0/46)	5.6% (7/126)
TOTAL		6.2% (14/226)	0.0% (0/90)	5.1% (16/316)

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-41. Classification Results For Scitec MAP 4 K-Shell **SCREEN** Mode Readings (Drywall, Metal, and Wood Corrected and Uncorrected), Classified Using the Inconclusive Ranges Reported in the XRF Performance Characteristic Sheet and Compared to Laboratory-Measured Lead Levels in mg/cm^2 Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken From Testing Archived Building Components in February 1996.

SUBSTRATE	INCONCLUSIVE RANGE	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.9 to 1.1	0.0% (0/2)	0.0% (0/4)	0.0% (0/6)
Concrete	0.9 to 1.1	0.0% (0/4)	(0/0)	0.0% (0/4)
Drywall	0.9 to 1.4	0.0% (0/28)	(0/0)	7.1% (2/28)
Metal	0.9 to 1.2	1.9% (1/54)	0.0% (0/22)	3.9% (3/76)
Plaster	0.9 to 1.1	3.4% (2/58)	0.0% (0/18)	0.0% (0/76)
Wood	0.9 to 1.3	10.0% (8/80)	0.0% (0/46)	4.8% (6/126)
Drywall (Uncorrected)	0.9 to 1.5	0.0% (0/28)	(0/0)	17.9% (5/28)
Metal (Uncorrected)	0.9 to 1.3	1.9% (1/54)	0.0% (0/22)	7.9% (6/76)
Wood (Uncorrected)	0.9 to 1.4	10.0% (8/80)	0.0% (0/46)	7.9% (10/126)
TOTAL*		4.9% (11/226)	0.0% (0/90)	3.5% (11/316)

*Total results are for values reported in PCS.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-42. Classification Results For Scitec MAP 4 K-Shell **TEST** Mode Readings (Drywall, Metal, and Wood Corrected), Classified Using the Inconclusive Ranges and Threshold Value Reported in the XRF Performance Characteristic Sheet and Compared to Laboratory-Measured Lead Levels in mg/cm^2 Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken From Testing Archived Building Components in February 1996.

SUBSTRATE	INCONCLUSIVE RANGE OR THRESHOLD	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.9	0.0% (0/2)	0.0% (0/4)	0.0% (0/6)
Concrete	0.9	0.0% (0/4)	(0/0)	0.0% (0/4)
Drywall	0.9 to 1.4	0.0% (0/28)	(0/0)	10.7% (3/28)
Metal	0.9 to 1.1	1.9% (1/54)	0.0% (0/22)	1.3% (1/76)
Plaster	0.9	3.4% (2/58)	0.0% (0/18)	0.0% (0/76)
Wood	0.9 to 1.3	8.8% (7/80)	2.2% (1/46)	7.9% (10/126)
Drywall (Uncorrected)	0.9 to 1.5	0.0% (0/28)	(0/0)	17.9% (5/28)
Metal (Uncorrected)	0.9 to 1.3	1.9% (1/54)	0.0% (0/22)	5.3% (4/76)
Wood (Uncorrected)	0.9 to 1.4	8.8% (7/80)	0.0% (0/46)	8.7% (11/126)
TOTAL*		4.4% (10/226)	1.1% (1/90)	4.4% (14/316)

*Total results are for values reported in PCS.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-43. Misclassification of Indicated Positive and Negative Results and Retest Percentages For Scitec MAP 4 K-Shell Readings (Uncorrected), Taken in **UNLIMITED**, **SCREEN**, and **TEST** Modes and **SCREEN-TEST-CONFIRM** Mode Sequence Compared to Laboratory-Measured Lead Levels in mg/cm^2 Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken From Testing Archived Building Components in February 1996 Obtained From Archive Testing Without Applying Substrate Correction Procedures, Inconclusive Ranges, or Thresholds. (These results can be compared to the corresponding percentages in Tables D-40, D-41, and D-42).

TESTING MODE	FALSE POSITIVE PERCENTAGE	FALSE NEGATIVE PERCENTAGE	RETEST PERCENTAGE
Unlimited mode	7.1%	0.0%	3.8%
Screen mode	5.1%	0.0%	15.8%
Test mode	6.6%	0.0%	7.0%
Screen-Test-Confirm mode sequence*	7.1%	0.0%	3.2%

*As indicated by the Operations Manual for the instrument: First, a screen mode reading was taken. If the result of the screen mode result was positive or negative, testing stopped and the screen mode result was the final reading. Otherwise, a test mode reading was taken. If the test mode result was positive or negative, then testing stopped, and the test mode result was the final reading. Otherwise, a confirm mode reading was taken. If the confirm mode result was positive or negative, the confirm mode result was the final reading. If the confirm mode result was indicated as "RETEST", the testing was terminated, and the final result was designated as "RETEST".

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

D.6 XRF Performance Characteristic Sheet for the Warrington Microlead I Revision 4 and Related Results

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Warrington, Inc.; Microlead I revision 4

EFFECTIVE DATE: September 25, 1995 **EDITION NO.**: 1

MANUFACTURER AND MODEL:

Make: *Warrington, Inc.*
Model: *Microlead I revision 4*
Source: Co^{57}
Note: This sheet supersedes all previous sheets for the XRF instrument of the make, model, and source shown above

EVALUATION DATA SOURCE AND DATE:

This sheet is supplemental information to be used in conjunction with Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* ("HUD Guidelines"). Performance parameters shown on this sheet are calculated from evaluation data collected during the EPA/HUD field evaluation study conducted from March through October 1993. The data were collected from approximately 1,200 test locations using five instruments with source dates ranging from March 1993 to October 1993. All five instruments had sources with 10 mCi initial strengths. The results of this study are reported in *A Field Test of Lead-Based Paint Testing Technologies: Technical Report*, EPA 747-R-95-002b, May 1995.

FIELD OPERATION GUIDANCE

OPERATING PARAMETERS:

Performance parameters shown in this sheet are applicable only when operating the instrument under the same conditions as the evaluation testing and using the procedures described in Chapter 7 of the HUD Guidelines. Operating parameters include:

- Manufacturer-recommended warm-up and quality control procedures
- Use the Multifamily Decision Flowchart for determining the presence of lead on a component type in multifamily housing
- Nominal 15-second readings on three locations per component for single-family housing and one location per component for multifamily housing
- Calibration checks are taken using the red (1.02 mg/cm^2) NIST Standard Reference Material (SRM No. 2579) paint film
- Readings for determining the substrate correction values are taken on bare substrate covered with red (1.02 mg/cm^2) NIST SRM paint film
- Lead-based paint is defined as paint with lead equal to or in excess of 1.0 mg/cm^2.

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Figure D-5. XRF Performance Characteristic Sheet for the Warrington Microlead I revision 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Warrington, Inc.; Microlead I revision 4

XRF CALIBRATION CHECK:

Chapter 7 of the HUD Guidelines recommends using a calibration check procedure to determine the operating condition of the XRF instrument. If the observed calibration check average minus 1.02 mg/cm^2 is greater than the positive (plus) calibration check tolerance value, or less than the negative (minus) calibration check tolerance value, then the instructions provided by the manufacturer should be followed in order to bring the instrument back into control before any more XRF testing is done. This calibration check is estimated to produce an incorrect result (that is, a finding that the instrument is out of calibration) very infrequently - once out of every 200 times this procedure is followed.

minus value = -0.6 mg/cm^2
plus value = +0.6 mg/cm^2

FOR XRF RESULTS BELOW 4.0 mg/cm^2, SUBSTRATE CORRECTION RECOMMENDED FOR:

Brick, Concrete, Drywall, Metal, and Wood.

SUBSTRATE CORRECTION NOT RECOMMENDED FOR:

Plaster.

SUBSTRATE CORRECTION VALUE COMPUTATION:

Chapter 7 of the HUD Guidelines provides guidance on correcting XRF results for substrate bias. Supplemental guidance for using the red (1.02 mg/cm^2) NIST SRM paint film for substrate correction is provided below.

XRF results are corrected for substrate bias by subtracting from each XRF result a correction value determined separately in each house for single-family housing or in each development for multifamily housing, for each substrate. The correction value is an average of XRF readings taken over red NIST SRM (1.02 mg/cm^2) paint films at test locations that had been scraped clean of their paint covering. Compute the correction values as follows:

- Using the same XRF instrument, take three readings on a bare substrate area covered with the red NIST SRM (1.02 mg/cm^2) paint film. Repeat this procedure by taking three more readings on a second bare substrate area of the same substrate covered with the red NIST SRM (1.02 mg/cm^2) paint film.
- Compute the correction value for each substrate type by computing the average of all six readings as shown below.

  For each substrate type:

$$\text{Correction Value} = \frac{1^{st} + 2^{nd} + 3^{rd} + 4^{th} + 5^{th} + 6^{th}\ \text{Reading}}{6} - 1.02 mg/cm^2$$

- Repeat this procedure for each substrate tested in the house or housing development.

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Figure D-5 continued. XRF Performance Characteristic Sheet for the Warrington Microlead I revision 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Warrington, Inc.; Microlead I revision 4

INCONCLUSIVE RANGE:

XRF results are classified as positive if they are greater than or equal to the upper limit of the inconclusive range, and negative if they are less than or equal to the lower limit of the inconclusive range. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. For computing the XRF result, use all digits that are reported by the instrument. Inconclusive ranges were determined for comparing results to the 1.0 mg/cm^2 standard. For a listing of laboratories recommended by the EPA National Lead Laboratory Accreditation Program (NLLAP) for the analysis of samples to resolve an inconclusive XRF result or additional confirmational analysis, call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE in mg/cm^2
Results corrected for substrate bias on all substrates except plaster	Brick	0.8 to 1.3
	Concrete	0.5 to 1.4
	Drywall	0.9 to 1.1
	Metal	0.9 to 1.4
	Plaster	0.7 to 1.6
	Wood	0.9 to 1.6

INSTRUCTIONS FOR EVALUATING XRF TESTING:

Chapter 7 of the HUD Guidelines recommends several options for evaluating XRF testing. Among those options is the following procedure which may be used after XRF testing has been completed. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. If a multifamily housing development is being retested, randomly select two units from within the development from which the ten testing combinations should be randomly selected.

Randomly select ten testing combinations for retesting from each house or from the two selected units.

Conduct XRF retesting at the ten testing combinations selected for retesting.

Determine if the XRF testing in the units or house passed or failed the test by applying the steps below.

Compute the Retest Tolerance Limit by the following steps:

Determine XRF results for the original and retest XRF readings. Do not correct the original or retest results for substrate bias. In single-family housing a result is defined as the average of three readings. In multifamily housing, a result is a single reading. Therefore, there will be ten original and ten retest XRF results for each house or for the two selected units.

Compute the average of the original and re-test result for each of the ten testing combinations.

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Figure D-5 continued. XRF Performance Characteristic Sheet for the Warrington Microlead I revision 4

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Warrington, Inc.; Microlead I revision 4

Square the average for each testing combination.

Add the ten squared averages together. Call this quantity C.

Multiply the number C by 0.0072. Call this quantity D.

Add the number 0.032 to D. Call this quantity E.

Take the square root of E. Call this quantity F.

Multiply F by 1.645. The result is the Retest Tolerance Limit.

Compute the overall average of all ten retest XRF results over all ten testing combinations selected for retesting.

Take the difference of the overall average of the ten original XRF results and the overall average of the ten retest XRF results. If the difference is negative, drop the negative sign.

If the difference of the overall averages is less than the Retest Tolerance Limit, the inspection has passed the retest. If the difference of the overall averages equals or exceeds the Retest Tolerance Limit, this procedure should be repeated with ten new testing combinations. If the difference of the overall averages is equal to or greater than the Retest Tolerance Limit a second time, then the inspection should be considered deficient.

Use of this procedure is estimated to produce a spurious result approximately 1% of the time. That is, results of this procedure will call for further examination when no examination is warranted in approximately 1 out of 100 dwelling units tested.

BIAS AND PRECISION:

Do not use these bias and precision data to correct for substrate bias. These bias and precision data were computed without substrate correction from samples with reported laboratory results less than 4.0 mg/cm^2 lead. There were 143 test locations with a laboratory reported result equal to or greater than 4.0 mg/cm^2 lead. Of these, 1 had an XRF reading less than 1.0 mg/cm^2. These data are for illustrative purposes only. Actual bias must be determined on the site. Inconclusive ranges provided above already account for bias and precision. Bias and precision ranges are provided whenever significant variability was found between machines of the same model. Units are in mg/cm^2.

Figure D-5 continued. XRF Performance Characteristic Sheet for the Warrington Microlead I revision 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Warrington, Inc.; Microlead I revision 4

MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	BIAS RANGE (mg/cm^2)	PRECISION* (mg/cm^2)	PRECISION RANGE (mg/cm^2)
0.0 mg/cm^2	Brick	0.1	-	0.6	-
	Concrete	0.3	(0.0, 0.9)	0.6	(0.5, 1.2)
	Drywall	0.0	(0.0, 0.7)	0.3	(0.3, 0.5)
	Metal	-0.3	(-0.4, 1.1)	0.5	(0.3, 0.8)
	Plaster	0.1	(-0.3, 0.2)	0.5	(0.3, 0.6)
	Wood	0.4	(0.0, 0.5)	0.6	(0.5, 0.8)
0.5 mg/cm^2	Brick	0.4	-	0.5	-
	Concrete	0.3	(0.1, 1.1)	0.6	(0.5, 1.3)
	Drywall	0.1	(0.1, 1.3)	0.3	(0.3, 0.5)
	Metal	-0.2	(-0.3, 1.2)	0.6	(0.5, 0.8)
	Plaster	0.1	(-0.3, 0.1)	0.6	(0.4, 0.8)
	Wood	0.7	(0.2, 0.7)	0.7	(0.6, 0.8)
1.0 mg/cm^2	Brick	-0.3	-	0.6	-
	Concrete	0.3	(0.2, 1.2)	0.7	(0.6, 1.4)
	Drywall	0.2	(0.2, 1.9)	0.3	(0.3, 0.5)
	Metal	-0.1	(-0.1, 1.4)	0.6	(0.5, 0.8)
	Plaster	0.1	(-0.3, 0.3)	0.7	(0.5, 1.0)
	Wood	1.0	(0.3, 1.0)	0.7	(0.6, 0.8)
2.0 mg/cm^2	Brick	0.7	-	0.5	-
	Concrete	0.2	(0.2, 1.5)	0.8	(0.7, 1.7)
	Drywall	0.4	(0.1, 3.1)	0.3	(0.3, 0.5)
	Metal	0.2	(0.1, 1.7)	0.7	(0.5, 0.8)
	Plaster	0.2	(-0.3, 0.7)	0.9	(0.6, 1.2)
	Wood	1.6	(0.6, 1.7)	0.8	(0.7, 0.8)

*Precision at 1 standard deviation

A document titled *Methodology for XRF Performance Characteristic Sheets* provides an explanation of the statistical methodology used to construct the data in the sheets and provides empirical results from using the recommended inconclusive ranges or thresholds for specific XRF instruments. For a copy of this document call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

This XRF Performance Characteristic Sheet is a joint product of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD). The issuance of this sheet does not constitute rulemaking. The information provided here is intended solely as guidance to be used in conjunction with Chapter 7 of the *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. EPA and HUD reserve the right to revise this guidance. Please address questions and comments on this sheet to: Director, Office of Lead-Based Paint Abatement and Poisoning Prevention, U.S. Department of Housing and Urban Development, Room B-133, 451 Seventh St, S.W., Washington, DC 20410.

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Figure D-5 continued. XRF Performance Characteristic Sheet for the Warrington Microlead I revision 4.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-44. Inconclusive Ranges For Warrington Microlead I Revision 4 Readings Where Substrate Correction Is Not Performed, But Substrate Correction Is Recommended.

DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)
Results not corrected for substrate bias on any substrate	Brick	0.9 to 1.7
	Concrete	0.9 to 1.8
	Drywall	0.9 to 1.2
	Metal	0.9 to 1.3
	Wood	0.9 to 2.3

Table D-45. Bias Estimates, and Their Standard Errors, of Warrington Microlead I Revision 4 Readings.

MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERRORS FOR BIAS
0.0 mg/cm^2	No	Brick*	0.1	-
		Concrete	0.3	0.06
		Drywall	0.0	0.05
		Metal	-0.3	0.06
		Plaster	0.1	0.06
		Wood	0.4	0.07
	Yes	Brick*	-‡	-
		Concrete	-0.1	0.05
		Drywall	-0.1	0.05
		Metal	-0.2	0.06
		Wood	-0.3	0.07
0.5 mg/cm^2	No	Brick*	0.4	-
		Concrete	0.3	0.05
		Drywall	0.1	0.11
		Metal	-0.2	0.05
		Plaster	0.1	0.05
		Wood	0.7	0.06
	Yes	Brick*	-0.2	-
		Concrete	-0.1	0.05
		Drywall	0.0	0.11
		Metal	-0.1	0.05
		Wood	0.0	0.06
1.0 mg/cm^2	No	Brick*	-0.3	-
		Concrete	0.3	0.09
		Drywall	0.2	0.23
		Metal	-0.1	0.07
		Plaster	0.1	0.11
		Wood	1.0	0.09
	Yes	Brick*	-0.2	-
		Concrete	-0.2	0.10
		Drywall	0.1	0.23
		Metal	0.1	0.07
		Wood	0.2	0.08
2.0 mg/cm^2	No	Brick*	0.7	-
		Concrete	0.2	0.20
		Drywall	0.4	0.47
		Metal	0.2	0.14
		Plaster	0.2	0.25
		Wood	1.6	0.18
	Yes	Brick*	-0.2	-
		Concrete	-0.2	0.21
		Drywall	0.3	0.48
		Metal	0.4	0.15
		Wood	0.7	0.17

*Nonparametric estimation used.
‡A reliable estimate at 0.0 mg/cm^2 could not be obtained.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-46. Precision Estimates, and Their Standard Errors, of Warrington Microlead I Revision 4 Readings.

MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	Brick†	0.6	-
		Concrete	0.6	0.04
		Drywall	0.3	0.03
		Metal	0.5	0.04
		Plaster	0.5	0.04
		Wood	0.6	0.05
	Yes	Brick†	-**	-
		Concrete	0.8	0.04
		Drywall	0.5	0.03
		Metal	0.7	0.03
		Wood	0.9	0.04
0.5 mg/cm^2	No	Brick†	0.5	-
		Concrete	0.6	0.05
		Drywall	0.3	0.03
		Metal	0.6	0.03
		Plaster	0.6	0.06
		Wood	0.7	0.05
	Yes	Brick†	0.7	-
		Concrete	0.8	0.05
		Drywall	0.5	0.03
		Metal	0.7	0.03
		Wood	0.9	0.04
1.0 mg/cm^2	No	Brick†	0.6	-
		Concrete	0.7	0.07
		Drywall	0.3	0.03
		Metal	0.6	0.03
		Plaster	0.7	0.10
		Wood	0.7	0.09
	Yes	Brick†	0.7	-
		Concrete	0.9	0.06
		Drywall	0.5	0.03
		Metal	0.8	0.04
		Wood	0.9	0.04
2.0 mg/cm^2	No	Brick†	0.5	-
		Concrete	0.8	0.13
		Drywall	0.3	0.03
		Metal	0.7	0.03
		Plaster	0.9	0.16
		Wood	0.8	0.17
	Yes	Brick†	0.7	-
		Concrete	0.9	0.11
		Drywall	0.5	0.03
		Metal	0.8	0.06
		Wood	0.9	0.04

*Precision at 1 standard deviation.
†Nonparametric estimation used.
**A reliable estimate at 0.0 mg/cm^2 could not be obtained.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-47. Classification Results For Warrington Microlead I Revision 4 Readings (All Substrate Corrected and Uncorrected Except For Plaster Which is Uncorrected), Classified Using the Inconclusive Ranges Reported in the XRF Performance Characteristic Sheet and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken During the EPA/HUD Field Study.

SUBSTRATE	INCONCLUSIVE RANGE	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.8 to 1.3	4.2% (6/144)	0.0% (0/42)	10.8% (20/186)
Concrete	0.5 to 1.4	4.9% (19/388)	5.4% (3/56)	27.3% (121/444)
Drywall	0.9 to 1.1	2.1% (5/237)	(0/0)	1.3% (3/237)
Metal	0.9 to 1.4	5.4% (17/314)	3.3% (3/92)	5.9% (24/406)
Plaster	0.7 to 1.6	1.5% (6/404)	5.1% (3/59)	17.1% (79/463)
Wood	0.9 to 1.6	4.6% (24/519)	8.6% (19/220)	8.5% (63/739)
Brick (Uncorrected)	0.9 to 1.7	2.8% (4/144)	2.4% (1/42)	15.1% (28/186)
Concrete (Uncorrected)	0.9 to 1.8	6.4% (25/388)	1.8% (1/56)	17.8% (79/444)
Drywall (Uncorrected)	0.9 to 1.2	11.4% (27/237)	(0/0)	6.3% (15/237)
Metal (Uncorrected)	0.9 to 1.3	11.2% (35/314)	2.2% (2/92)	6.9% (28/406)
Wood (Uncorrected)	0.9 to 2.3	4.8% (25/519)	3.6% (8/220)	20.6% (152/739)
TOTAL*		3.8% (77/2006)	6.6% (28/427)	12.5% (310/2475)

*Total results are for values reported in PCS.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

D.7 XRF Performance Characteristic Sheet for the TN Technologies Pb Analyzer and Related Results

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
TN Technologies (TN Spectrace); Pb Analyzer

EFFECTIVE DATE: October 31, 1995 **EDITION NO.**: 1

MANUFACTURER AND MODEL:

Manufacturer:	*TN Technologies, Inc. (TN Spectrace)*
Make:	*Pb Analyzer*
Model:	*9292*
Source:	Cd^{109}
Note:	This sheet supersedes all previous sheets for the XRF instrument of the make, model, and source shown above.

EVALUATION DATA SOURCE AND DATE:

This sheet is supplemental information to be used in conjunction with Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* ("HUD Guidelines"). Performance parameters shown on this sheet are calculated from evaluation data collected during the EPA/HUD field evaluation study conducted from March through October 1993 and from data collected during testing on the EPA/HUD archived building components in January 1995 and in September 1995. The field evaluation data were collected from approximately 1,200 test locations using two instruments both with radiation sources installed in April 1993. The results of this study are reported in *A Field Test of Lead-Based Paint Testing Technologies: Technical Report*, EPA 747-R-95-002b, May 1995. The archive testing data were collected from approximately 150 test locations using two instruments. The instrument that was used in January had a radiation source installed in July 1994 and the instrument that was used in September 1995 had a radiation source installed in January 1995. All of the aforementioned instruments had 30 mCi initial strengths.

FIELD OPERATION GUIDANCE

OPERATING PARAMETERS:

Performance parameters shown in this sheet are applicable only when operating the instrument under the same conditions as the evaluation testing and using the procedures described in Chapter 7 of the HUD Guidelines. Operating parameters include:

- Manufacturer-recommended warm-up and quality control procedures
- Use the Multifamily Decision Flowchart for determining the presence of lead on a component type in multifamily housing
- Nominal 15-second readings on three locations per component for single-family housing and one location per component for multifamily housing
- Calibration checks are taken using the red (1.02 mg/cm^2) NIST Standard Reference Material (SRM No. 2579) paint film
- Lead-based paint is defined as paint with lead equal to or in excess of 1.0 mg/cm^2.

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Figure D-6. XRF Performance Characteristic Sheet for the TN Technologies Pb Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
TN Technologies (TN Spectrace); Pb Analyzer

XRF CALIBRATION CHECK:

Chapter 7 of the HUD Guidelines recommends using a calibration check procedure to determine the operating condition of the XRF instrument. If the observed calibration check average minus 1.02 mg/cm^2 is greater than the positive (plus) calibration check tolerance value, or less than the negative (minus) calibration check tolerance value, then the instructions provided by the manufacturer should be followed in order to bring the instrument back into control before any more XRF testing is done. This calibration check is estimated to produce an incorrect result (that is, a finding that the instrument is out of calibration) very infrequently - once out of every 200 times this procedure is followed.

minus value = -0.3 mg/cm^2
plus value = +0.4 mg/cm^2

FOR XRF RESULTS BELOW 4.0 mg/cm^2, SUBSTRATE CORRECTION RECOMMENDED FOR:

None

SUBSTRATE CORRECTION NOT RECOMMENDED FOR:

Brick, Concrete, Drywall, Metal, Plaster, and Wood

INCONCLUSIVE RANGE OR THRESHOLD:

XRF results are classified using the inconclusive range. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. For computing the XRF result, use all digits that are reported by the instrument. For the inconclusive range, results are classified as positive if they are greater than or equal to the upper limit of the inconclusive range, and negative if they are less than or equal to the lower limit of the inconclusive range. Inconclusive ranges were determined for comparing results to the 1.0 mg/cm^2 standard. For a listing of laboratories recommended by the EPA National Lead Laboratory Accreditation Program (NLLAP) for the analysis of samples to resolve an inconclusive XRF result or additional confirmational analysis, call the National Lead Information Center Clearinghouse on 1-800-424-LEAD.

DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE in mg/cm^2	
		LOWER BOUND	UPPER BOUND
Results not corrected for substrate bias	Brick	0.9	1.2
	Concrete	0.9	1.2
	Drywall	0.9	1.2
	Metal	0.9	1.2
	Plaster	0.9	1.1
	Wood	0.9	1.3

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Figure D-6 continued. XRF Performance Characteristic Sheet for the TN Technologies Pb Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
TN Technologies (TN Spectrace); Pb Analyzer

INSTRUCTIONS FOR EVALUATING XRF TESTING:

Chapter 7 of the HUD Guidelines recommends several options for evaluating XRF testing. Among those options is the following procedure which may be used after XRF testing has been completed. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. If a multifamily housing development is being retested, randomly select two units from within the development from which the ten testing combinations should be randomly selected.

Randomly select ten testing combinations for retesting from each house or from the two selected units.

Conduct XRF retesting at the ten testing combinations selected for retesting.

Determine if the XRF testing in the units or house passed or failed the test by applying the steps below.

Compute the Retest Tolerance Limit by the following steps:

Determine XRF results for the original and retest XRF readings. Do not correct the original or retest results for substrate bias. In single-family housing a result is defined as the average of three readings. In multifamily housing, a result is a single reading. Therefore, there will be ten original and ten retest XRF results for each house or for the two selected units.

Compute the average of the original and re-test result for each of the ten testing combinations.

Square the average for each testing combination.

Add the ten squared averages together. Call this quantity C.

Multiply the number C by 0.0072. Call this quantity D.

Add the number 0.032 to D. Call this quantity E.

Take the square root of E. Call this quantity F.

Multiply F by 1.645. The result is the Retest Tolerance Limit.

Compute the overall average of all ten retest XRF results over all ten testing combinations selected for retesting.

Take the difference of the overall average of the ten original XRF results and the overall average of the ten retest XRF results. If the difference is negative, drop the negative sign.

If the difference of the overall averages is less than the Retest Tolerance Limit, the inspection has passed the retest. If the difference of the overall averages equals or exceeds the Retest Tolerance Limit, this procedure should be repeated with ten new testing combinations. If the difference of the overall averages is equal to or greater than the Retest Tolerance Limit a second time, then the inspection should be considered deficient.

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Figure D-6 continued. XRF Performance Characteristic Sheet for the TN Technologies Pb Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
TN Technologies (TN Spectrace); Pb Analyzer

Use of this procedure is estimated to produce a spurious result approximately 1% of the time. That is, results of this procedure will call for further examination when no examination is warranted in approximately 1 out of 100 dwelling units tested.

BIAS AND PRECISION:

These bias and precision data were computed without substrate correction from samples with reported laboratory results less than 4.0 mg/cm^2 lead. There were 88 test locations with a laboratory reported result equal to or greater than 4.0 mg/cm^2 lead. Of these, none had XRF readings less than 1.0 mg/cm^2. These data are for illustrative purposes only. Substrate correction is not recommended for this XRF instrument. Bias and precision ranges are provided to show the variability found between machines of the same model. Units are in mg/cm^2.

MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	BIAS RANGE* (mg/cm^2)	PRECISION† (mg/cm^2)	PRECISION RANGE* (mg/cm^2)
0.0 mg/cm^2	Brick	0.0	(0.0, 0.0)	0.1	(0.1, 0.1)
	Concrete	0.0	(0.0, 0.0)	0.1	(0.1, 0.1)
	Drywall	0.0	(0.0, 0.0)	0.1	(0.1, 0.1)
	Metal	0.0	(-0.1, 0.1)	0.1	(0.1, 0.1)
	Plaster	0.0	(-0.1, 0.0)	0.1	(0.1, 0.1)
	Wood	0.0	(0.0, 0.0)	0.1	(<0.1, 0.1)
0.5 mg/cm^2	Brick	0.1	(0.0, 0.2)	0.3	(0.3, 0.3)
	Concrete	0.1	(0.0, 0.2)	0.3	(0.2, 0.3)
	Drywall	0.1	(0.0, 0.2)	0.3	(0.1, 0.3)
	Metal	0.1	(0.0, 0.3)	0.3	(0.3, 0.3)
	Plaster	0.0	(-0.1, 0.2)	0.3	(0.1, 0.3)
	Wood	0.1	(0.1, 0.2)	0.3	(0.3, 0.3)
1.0 mg/cm^2	Brick	0.2	(0.0, 0.4)	0.4	(0.4, 0.5)
	Concrete	0.2	(0.0, 0.4)	0.4	(0.3, 0.5)
	Drywall	0.2	(0.1, 0.4)	0.4	(0.2, 0.5)
	Metal	0.2	(0.0, 0.5)	0.4	(0.4, 0.5)
	Plaster	0.1	(-0.1, 0.3)	0.4	(0.1, 0.5)
	Wood	0.3	(0.1, 0.4)	0.4	(0.4, 0.5)
2.0 mg/cm^2	Brick	0.4	(0.0, 0.7)	0.6	(0.5, 0.6)
	Concrete	0.3	(0.0, 0.7)	0.5	(0.4, 0.6)
	Drywall	0.5	(0.3, 0.7)	0.5	(0.3, 0.6)
	Metal	0.4	(0.0, 0.8)	0.6	(0.5, 0.6)
	Plaster	0.2	(-0.3, 0.7)	0.5	(0.1, 0.6)
	Wood	0.5	(0.3, 0.7)	0.6	(0.5, 0.6)

*Ranges are provided to show the variability between machines of the same model.
†Precision at 1 standard deviation.

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Figure D-6 continued. XRF Performance Characteristic Sheet for the TN Technologies Pb Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
TN Technologies (TN Spectrace); Pb Analyzer

A document titled *Methodology for XRF Performance Characteristic Sheets* provides an explanation of the statistical methodology used to construct the data in the sheets, and provides empirical results from using the recommended inconclusive ranges or thresholds for specific XRF instruments. For a copy of this document call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

This XRF Performance Characteristic Sheet is a joint product of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD). The issuance of this sheet does not constitute rulemaking. The information provided here is intended solely as guidance to be used in conjunction with Chapter 7 of the *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. EPA and HUD reserve the right to revise this guidance. Please address questions and comments on this sheet to: Director, Office of Lead-Based Paint Abatement and Poisoning Prevention, U.S. Department of Housing and Urban Development, Room B-133, 451 Seventh St, S.W., Washington, DC 20410.

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Figure D-6 continued. XRF Performance Characteristic Sheet for the TN Technologies Pb Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-48. Bias Estimates, and Their Standard Errors, of TN Technologies Pb Analyzer K-Shell 15-Second Readings.

MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR FOR BIAS
0.0 mg/cm^2	No	Brick	0.0	0.03
		Concrete	0.0	0.03
		Drywall	0.0	0.03
		Metal	0.0	0.03
		Plaster	0.0	0.04
		Wood	0.0	0.03
0.5 mg/cm^2	No	Brick	0.1	0.05
		Concrete	0.1	0.03
		Drywall	0.1	0.05
		Metal	0.1	0.04
		Plaster	0.0	0.04
		Wood	0.1	0.03
1.0 mg/cm^2	No	Brick	0.2	0.10
		Concrete	0.2	0.06
		Drywall	0.2	0.09
		Metal	0.2	0.06
		Plaster	0.1	0.06
		Wood	0.3	0.06
2.0 mg/cm^2	No	Brick	0.4	0.20
		Concrete	0.3	0.12
		Drywall	0.5	0.17
		Metal	0.4	0.12
		Plaster	0.2	0.11
		Wood	0.5	0.12

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-49. Precision Estimates, and Their Standard Errors, of TN Technologies Pb Analyzer K-Shell 15-Second Readings.

MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	Brick	0.1	0.02
		Concrete	0.1	0.01
		Drywall	0.1	0.02
		Metal	0.1	0.02
		Plaster	0.1	0.01
		Wood	0.1	0.02
0.5 mg/cm^2	No	Brick	0.3	0.05
		Concrete	0.3	0.03
		Drywall	0.3	0.03
		Metal	0.3	0.03
		Plaster	0.3	0.03
		Wood	0.3	0.03
1.0 mg/cm^2	No	Brick	0.4	0.07
		Concrete	0.4	0.04
		Drywall	0.4	0.05
		Metal	0.4	0.04
		Plaster	0.4	0.04
		Wood	0.4	0.04
2.0 mg/cm^2	No	Brick	0.6	0.10
		Concrete	0.5	0.06
		Drywall	0.5	0.07
		Metal	0.6	0.06
		Plaster	0.5	0.07
		Wood	0.6	0.06

*Precision at 1 standard deviation.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-50. Classification Results For TN Technologies Pb Analyzer K-Shell 15-Second Readings (Uncorrected), Classified Using Inconclusive Ranges Reported in the XRF Performance Characteristic Sheet and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken During the EPA/HUD Field Study and From Testing Archived Building Components in January 1995 and in September 1995.

SUBSTRATE	INCONCLUSIVE RANGE	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.9 to 1.2	0.0% (0/74)	0.0% (0/25)	2.0% (2/99)
Concrete	0.9 to 1.2	1.0% (2/195)	11.1% (3/27)	1.4% (3/222)
Drywall	0.9 to 1.2	0.7% (1/140)	(0/0)	0.0% (0/140)
Metal	0.9 to 1.2	3.5% (7/199)	7.6% (5/66)	3.0% (8/265)
Plaster	0.9 to 1.1	1.6% (4/254)	2.5% (1/40)	0.3% (1/294)
Wood	0.9 to 1.3	4.5% (15/335)	4.7% (7/148)	4.6% (22/483)
TOTAL		2.4% (29/1197)	5.2% (16/306)	2.4% (36/1503)

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

D.8 XRF Performance Characteristic Sheet for the Princeton Gamma-Tech XK-3 and Related Results

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Princeton Gamma-Tech, Inc.; XK-3

EFFECTIVE DATE: September 25, 1995 **EDITION NO.**: 1

MANUFACTURER AND MODEL:

Make: *Princeton Gamma-Tech, Inc.*
Model: *XK-3*
Source: Co^{57}
Note: This sheet supersedes all previous sheets for the XRF instrument of the make, model, and source shown above

EVALUATION DATA SOURCE AND DATE:

This sheet is supplemental information to be used in conjunction with Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* ("HUD Guidelines"). Performance parameters shown on this sheet are calculated from evaluation data collected during the EPA/HUD field evaluation study conducted from March through October 1993. The data were collected from approximately 1,200 test locations using three instruments. One instrument had a March 1993 source and the other two instruments had April 1993 sources. All three instruments had sources with 10 mCi initial strengths. The results of this study are reported in *A Field Test of Lead-Based Paint Testing Technologies: Technical Report*, EPA 747-R-95-002b, May 1995.

FIELD OPERATION GUIDANCE

OPERATING PARAMETERS:

Performance parameters shown in this sheet are applicable only when operating the instrument under the same conditions as the evaluation testing and using the procedures described in Chapter 7 of the HUD Guidelines. Operating parameters include:

- Manufacturer-recommended warm-up and quality control procedures
- Use the Multifamily Decision Flowchart for determining the presence of lead on a component type in multifamily housing
- Nominal 15-second readings on three locations per component for single-family housing and one location per component for multifamily housing
- Calibration checks are taken using the red (1.02 mg/cm^2) NIST Standard Reference Material (SRM No. 2579) paint film
- Readings for determining the substrate correction values are taken on bare substrate covered with red (1.02 mg/cm^2) NIST SRM paint film
- Lead-based paint is defined as paint with lead equal to or in excess of 1.0 mg/cm^2.

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Figure D-7. XRF Performance Characteristic Sheet for the Princeton Gamma-Tech XK-3.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Princeton Gamma-Tech, Inc.; XK-3

XRF CALIBRATION CHECK:

Chapter 7 of the HUD Guidelines recommends using a calibration check procedure to determine the operating condition of the XRF instrument. For this instrument, calibration check readings should be taken on wood. If the observed calibration check average minus 1.02 mg/cm^2 is greater than the positive (plus) calibration check tolerance value, or less than the negative (minus) calibration check tolerance value, then the instructions provided by the manufacturer should be followed in order to bring the instrument back into control before any more XRF testing is done. Testing must cease for those instruments with readings that exceed the calibration check tolerance limits in accordance with manufacturer's specifications. This calibration check is estimated to produce an incorrect result (that is, a finding that the instrument is out of calibration) very infrequently - once out of every 200 times this procedure is followed.

minus value = -0.5 mg/cm^2
plus value = +1.3 mg/cm^2

(Operators may choose to use the limits in the manufacturer's instruction manual for this calibration check. The rate of an incorrect result if the limits in the manufacturer's instruction manual are followed may be different from the rate of an incorrect result stated here).

FOR XRF RESULTS BELOW 4.0 mg/cm^2, SUBSTRATE CORRECTION RECOMMENDED FOR:

Brick, Concrete, Drywall, Metal, Plaster, and Wood.

SUBSTRATE CORRECTION NOT RECOMMENDED FOR:

None.

SUBSTRATE CORRECTION VALUE COMPUTATION:

Chapter 7 of the HUD Guidelines provides guidance on correcting XRF results for substrate bias. Supplemental guidance for using the red (1.02 mg/cm^2) NIST SRM paint film for substrate correction is provided below.

XRF results are corrected for substrate bias by subtracting from each XRF result a correction value determined separately in each house for single-family housing or in each development for multifamily housing, for each substrate. The correction value is an average of XRF readings taken over red NIST SRM (1.02 mg/cm^2) paint films at test locations that had been scraped clean of their paint covering. Compute the correction values as follows:

- Using the same XRF instrument, take three readings on a bare substrate area covered with the red NIST SRM (1.02 mg/cm^2) paint film. Repeat this procedure by taking three more readings on a second bare substrate area of the same substrate covered with the red NIST SRM (1.02 mg/cm^2) paint film.
- Compute the correction value for each substrate type by computing the average of all six readings as shown below.

Figure D-7 continued. XRF Performance Characteristic Sheet for the Princeton Gamma-Tech XK-3.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Princeton Gamma-Tech, Inc.; XK-3

For each substrate type:

$$\text{Correction Value} = \frac{1^{st} + 2^{nd} + 3^{rd} + 4^{th} + 5^{th} + 6^{th}\ \text{Reading}}{6} - 1.02 mg/cm^2$$

- Repeat this procedure for each substrate tested in the house or housing development.

INCONCLUSIVE RANGE OR THRESHOLD:

XRF results are classified using either the threshold or the inconclusive range. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. For computing the XRF result, use all digits that are reported by the instrument. For the threshold, results are classified as positive if they are greater than or equal to the threshold, and negative if they are less than the threshold. There is no inconclusive classification when using the threshold. For the inconclusive range, results are classified as positive if they are greater than or equal to the upper limit of the inconclusive range, and negative if they are less than or equal to the lower limit of the inconclusive range. Thresholds and inconclusive ranges were determined for comparing results to the 1.0 mg/cm^2 standard. For a listing of laboratories recommended by the EPA National Lead Laboratory Accreditation Program (NLLAP) for the analysis of samples to resolve an inconclusive XRF result or additional confirmational analysis, call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)	INCONCLUSIVE RANGE (mg/cm^2)
Readings corrected for substrate bias on all substrates	Brick	None	0.9 to 1.3
	Concrete	None	0.8 to 1.7
	Drywall	1.0	None
	Metal	None	0.4 to 1.8
	Plaster	None	0.7 to 1.4
	Wood	None	0.9 to 1.4

INSTRUCTIONS FOR EVALUATING XRF TESTING:

Chapter 7 of the HUD Guidelines recommends several options for evaluating XRF testing. Among those options is the following procedure which may be used after XRF testing has been completed. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. If a multifamily housing development is being retested, randomly select two units from within the development from which the ten testing combinations should be randomly selected.

Randomly select ten testing combinations for retesting from each house or from the two selected units.

Conduct XRF retesting at the ten testing combinations selected for retesting.

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Figure D-7 continued. XRF Performance Characteristic Sheet for the Princeton Gamma-Tech XK-3.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Princeton Gamma-Tech, Inc.; XK-3

Determine if the XRF testing in the units or house passed or failed the test by applying the steps below.

Compute the Retest Tolerance Limit by the following steps:

Determine XRF results for the original and retest XRF readings. Do not correct the original or retest results for substrate bias. In single-family housing a result is defined as the average of three readings. In multifamily housing, a result is a single reading. Therefore, there will be ten original and ten retest XRF results for each house or for the two selected units.

Compute the average of the original and re-test result for each of the ten testing combinations.

Square the average for each testing combination.

Add the ten squared averages together. Call this quantity C.

Multiply the number C by 0.0072. Call this quantity D.

Add the number 0.032 to D. Call this quantity E.

Take the square root of E. Call this quantity F.

Multiply F by 1.645. The result is the Retest Tolerance Limit.

Compute the overall average of all ten retest XRF results over all ten testing combinations selected for retesting.

Take the difference of the overall average of the ten original XRF results and the overall average of the ten retest XRF results. If the difference is negative, drop the negative sign.

If the difference of the overall averages is less than the Retest Tolerance Limit, the inspection has passed the retest. If the difference of the overall averages equals or exceeds the Retest Tolerance Limit, this procedure should be repeated with ten new testing combinations. If the difference of the overall averages is equal to or greater than the Retest Tolerance Limit a second time, then the inspection should be considered deficient.

Use of this procedure is estimated to produce a spurious result approximately 1% of the time. That is, results of this procedure will call for further examination when no examination is warranted in approximately 1 out of 100 dwelling units tested.

BIAS AND PRECISION:

Do not use these bias and precision data to correct for substrate bias. These bias and precision data were computed without substrate correction from samples with reported laboratory results less than 4.0 mg/cm^2 lead. There were 143 testing locations with a laboratory reported result equal to or greater than 4.0 mg/cm^2 lead. Of these, 1 had an XRF reading less than 1.0 mg/cm^2. These data are for illustrative purposes only. Actual bias must be determined on the site. Inconclusive ranges provided above already account for

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Figure D-7 continued. XRF Performance Characteristic Sheet for the Princeton Gamma-Tech XK-3.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Princeton Gamma-Tech, Inc.; XK-3

bias and precision. Bias and precision ranges are provided whenever significant variability was found between machines of the same model. Units are in mg/cm^2.

MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	BIAS RANGE (mg/cm^2)	PRECISION* (mg/cm^2)	PRECISION RANGE (mg/cm^2)
0.0 mg/cm^2	Brick	0.9	-	0.6	-
	Concrete	1.3	(0.6, 1.9)	0.6	(0.2, 0.6)
	Drywall	-0.1	(-0.3, 0.2)	0.3	(0.2, 0.3)
	Metal	0.9	(0.5, 1.4)	0.5	(0.4, 0.5)
	Plaster	0.8	(0.4, 1.7)	0.5	(0.4, 0.5)
	Wood	0.2	(-0.1, 1.0)	0.4	(0.3, 0.5)
0.5 mg/cm^2	Brick	0.9	-	0.6	-
	Concrete	1.3	(0.7, 1.9)	0.6	(0.5, 0.7)
	Drywall	0.0	(-0.2, 0.2)	0.4	(0.3, 0.4)
	Metal	1.1	(0.7, 1.6)	0.8	(0.4, 0.9)
	Plaster	0.8	(0.2, 1.6)	0.6	(0.4, 0.6)
	Wood	0.4	(0.1, 1.1)	0.6	(0.3, 0.9)
1.0 mg/cm^2	Brick	0.9	-	0.6	-
	Concrete	1.3	(0.7, 2.0)	0.7	(0.6, 0.8)
	Drywall	0.0	(-0.1, 0.2)	0.4	(0.4, 0.5)
	Metal	1.3	(0.9, 1.7)	1.0	(0.5, 1.1)
	Plaster	0.8	(0.0, 1.6)	0.6	(0.4, 0.7)
	Wood	0.6	(0.3, 1.3)	0.7	(0.3, 1.2)
2.0 mg/cm^2	Brick	0.9	-	0.6	-
	Concrete	1.3	(0.7, 2.0)	0.8	(0.6, 0.9)
	Drywall	0.1	(0.1, 0.2)	0.6	(0.5, 0.6)
	Metal	1.7	(1.4, 2.1)	1.4	(0.6, 1.6)
	Plaster	0.7	(-0.3, 1.6)	0.7	(0.4, 0.8)
	Wood	1.0	(0.8, 1.5)	0.9	(0.3, 1.7)

*Precision at 1 standard deviation

A document titled *Methodology for XRF Performance Characteristic Sheets* provides an explanation of the statistical methodology used to construct the data in the sheets and provides empirical results from using the recommended inconclusive ranges or thresholds for specific XRF instruments. For a copy of this document call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

This XRF Performance Characteristic Sheet is a joint product of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD). The issuance of this sheet does not constitute rulemaking. The information provided here is intended solely as guidance to be used in conjunction with Chapter 7 of the *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. EPA and HUD reserve the right to revise this guidance. Please address questions and comments on this sheet to: Director, Office of Lead-Based Paint Abatement and Poisoning Prevention, U.S. Department of Housing and Urban Development, Room B-133, 451 Seventh St, S.W., Washington, DC 20410.

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Figure D-7 continued. XRF Performance Characteristic Sheet for the Princeton Gamma-Tech XK-3.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-51. Inconclusive Ranges For Princeton Gamma-Tech XK-3 Readings Where Substrate Correction Is Not Performed, But Substrate Correction Is Recommended.

DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)
Results not corrected for substrate bias on any substrate	Brick Concrete Drywall Metal Plaster Wood	0.9 to 2.4 0.9 to 2.9 0.9 to 1.1 0.9 to 2.9 0.9 to 2.2 0.9 to 1.8

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-52. Bias Estimates, and Their Standard Errors, of Princeton Gamma-Tech XK-3 Readings.

MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR FOR BIAS
0.0 mg/cm^2	No	Brick	0.9	0.06
		Concrete	1.3	0.05
		Drywall	-0.1	0.03
		Metal	0.9	0.06
		Plaster	0.8	0.05
		Wood	0.2	0.03
	Yes	Brick	0.1	0.05
		Concrete	0.2	0.05
		Drywall	-0.2	0.03
		Metal	-0.2	0.06
		Plaster	0.1	0.05
		Wood	-0.2	0.03
0.5 mg/cm^2	No	Brick	0.9	0.10
		Concrete	1.3	0.05
		Drywall	0.0	0.10
		Metal	1.1	0.06
		Plaster	0.8	0.05
		Wood	0.4	0.03
	Yes	Brick	0.0	0.09
		Concrete	0.2	0.05
		Drywall	-0.1	0.09
		Metal	0.0	0.06
		Plaster	0.0	0.05
		Wood	0.0	0.04
1.0 mg/cm^2	No	Brick	0.9	0.22
		Concrete	1.3	0.10
		Drywall	0.0	0.21
		Metal	1.3	0.10
		Plaster	0.8	0.09
		Wood	0.6	0.06
	Yes	Brick	0.0	0.19
		Concrete	0.2	0.09
		Drywall	0.0	0.19
		Metal	0.2	0.10
		Plaster	0.0	0.09
		Wood	0.2	0.06
2.0 mg/cm^2	No	Brick	0.9	0.47
		Concrete	1.3	0.21
		Drywall	0.1	0.43
		Metal	1.7	0.20
		Plaster	0.7	0.21
		Wood	1.0	0.13
	Yes	Brick	-0.1	0.40
		Concrete	0.1	0.20
		Drywall	0.2	0.39
		Metal	0.7	0.20
		Plaster	-0.2	0.21
		Wood	0.6	0.13

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-53. Precision Estimates, and Their Standard Errors, of Princeton Gamma-Tech XK-3 Readings.

MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	Brick	0.6	0.04
		Concrete	0.6	0.04
		Drywall	0.3	0.03
		Metal	0.5	0.05
		Plaster	0.5	0.04
		Wood	0.4	0.03
	Yes	Brick	0.5	0.03
		Concrete	0.6	0.04
		Drywall	0.3	0.02
		Metal	0.6	0.05
		Plaster	0.6	0.03
		Wood	0.5	0.03
0.5 mg/cm^2	No	Brick	0.6	0.04
		Concrete	0.6	0.04
		Drywall	0.4	0.09
		Metal	0.8	0.06
		Plaster	0.6	0.04
		Wood	0.6	0.04
	Yes	Brick	0.5	0.03
		Concrete	0.7	0.04
		Drywall	0.4	0.04
		Metal	0.8	0.05
		Plaster	0.6	0.04
		Wood	0.6	0.04
1.0 mg/cm^2	No	Brick	0.6	0.04
		Concrete	0.7	0.07
		Drywall	0.4	0.16
		Metal	1.0	0.09
		Plaster	0.6	0.07
		Wood	0.7	0.06
	Yes	Brick	0.5	0.03
		Concrete	0.7	0.07
		Drywall	0.4	0.06
		Metal	1.0	0.08
		Plaster	0.7	0.06
		Wood	0.8	0.06
2.0 mg/cm^2	No	Brick	0.6	0.04
		Concrete	0.8	0.12
		Drywall	0.6	0.26
		Metal	1.4	0.13
		Plaster	0.7	0.13
		Wood	0.9	0.09
	Yes	Brick	0.5	0.03
		Concrete	0.8	0.12
		Drywall	0.4	0.11
		Metal	1.3	0.13
		Plaster	0.7	0.11
		Wood	1.0	0.09

*Precision at 1 standard deviation

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-54. Classification Results For the Princeton Gamma-Tech XK-3 K-shell 15-Second Readings (Corrected and Uncorrected), Classified Using the Inconclusive Ranges and Threshold Value Reported in the XRF Performance Characteristic Sheet and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken During the EPA/HUD Field Study.

SUBSTRATE	INCONCLUSIVE RANGE OR THRESHOLD	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE
Brick	0.9 to 1.3	6.3% (9/144)	2.4% (1/42)	4.8% (9/186)
Concrete	0.8 to 1.7	2.6% (10/388)	3.6% (2/56)	20.5% (91/444)
Drywall	1.0	2.1% (5/237)	(0/0)	0.0% (0/237)
Metal	0.4 to 1.8	2.2% (7/314)	12.0% (11/92)	25.1% (102/406)
Plaster	0.7 to 1.4	4.0% (16/403)	6.8% (4/59)	19.3% (89/462)
Wood	0.9 to 1.4	3.5% (18/519)	7.1% (16/224)	6.1% (45/743)
Brick (Uncorrected)	0.9 to 2.4	6.3% (9/144)	2.4% (1/42)	36.0% (67/186)
Concrete (Uncorrected)	0.9 to 2.9	5.4% (21/388)	1.8% (1/56)	56.5% (251/444)
Drywall (Uncorrected)	0.9 to 1.1	3.0% (7/237)	--	2.1% (5/237)
Metal (Uncorrected)	0.9 to 2.9	4.5% (14/314)	5.4% (5/92)	46.1% (187/406)
Plaster (Uncorrected)	0.9 to 2.2	8.2% (33/403)	1.7% (1/59)	35.3% (163/462)
Wood (Uncorrected)	0.9 to 1.8	4.2% (22/519)	4.0% (9/224)	12.9% (96/743)
TOTAL*		3.2% (65/2005)	7.2% (34/473)	13.6% (336/2478)

*Total results are for values reported in PCS.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

D.9 XRF Performance Characteristic Sheet for the Niton XL-309 Spectrum Analyzer and Related Results

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Niton Corporation; XL-309 Spectrum Analyzer

EFFECTIVE DATE: August 24, 1995 **EDITION NO.**: 1

MANUFACTURER AND MODEL:

Make: *Niton Corporation*
Model: *XL-309 Spectrum Analyzer*
Source: Cd^{109}
Note: This sheet supersedes all previous sheets for the XRF instrument of the make, model, source, and software versions shown above.

EVALUATION DATA SOURCE AND DATE:

This sheet is supplemental information to be used in conjunction with Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* ("HUD Guidelines"). Performance parameters shown on this sheet are calculated from the EPA/HUD evaluation using archived building components. Testing was conducted March 1995 on approximately 150 test locations using a single instrument with an October 1994 source at 10 mCi initial strength while running software version 1.2C. These results supersede the 1993 testing of XL prototypes reported in the document titled: *A Field Test of Lead-Based Paint Testing Technologies*.

FIELD OPERATION GUIDANCE

OPERATING PARAMETERS:

Performance parameters shown in this sheet are applicable only when operating the instrument under the same conditions as the evaluation testing and using the procedures described in Chapter 7 of the HUD Guidelines. Operating parameters include:

- Manufacturer-recommended warm-up and quality control procedures
- Use the Multifamily Decision Flowchart for determining the presence of lead on a component type in multifamily housing
- Nominal 20-second readings for L-shell results or 120-second readings for K-shell results on three locations per component for single-family housing and one location per component for multifamily housing
- Calibration checks are taken using the red (1.02 mg/cm^2) NIST Standard Reference Material (SRM No. 2579) paint film
- Lead-based paint is defined as paint with lead equal to or in excess of 1.0 mg/cm^2.

XRF CALIBRATION CHECK:

Chapter 7 of the HUD Guidelines recommends using a calibration check procedure to determine the operating condition of the XRF instrument. If the observed calibration check average minus 1.02 mg/cm^2 is greater than the positive (plus) calibration check tolerance value, or less than the negative (minus) calibration check tolerance value, then the instructions provided by the manufacturer should be followed in order to bring

Figure D-8. XRF Performance Characteristic Sheet for the Niton XL-309 Spectrum Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Niton Corporation; XL-309 Spectrum Analyzer

the instrument back into control before any more XRF testing is done. This calibration check is estimated to produce an incorrect result (that is, a finding that the instrument is out of calibration) very infrequently - once out of every 200 times this procedure is followed.

minus value = -0.1 mg/cm^2
plus value = +0.1 mg/cm^2

FOR XRF RESULTS BELOW 4.0 mg/cm^2, SUBSTRATE CORRECTION RECOMMENDED FOR:

None

SUBSTRATE CORRECTION NOT RECOMMENDED FOR:

Brick, Concrete, Drywall, Metal, Plaster, and Wood

HOW TO CLASSIFY READINGS:

This section describes how to apply the readings and other information displayed by this instrument to determine the presence or absence of lead in paint using the procedures recommended in Chapter 7 of the HUD Guidelines. These guidelines recommend classifying XRF results as positive, negative, or inconclusive compared to the 1.0 mg/cm^2 standard. But because this instrument displays readings and ancillary information useful for classification purposes, an algorithmic procedure is described that makes use of not only the XRF reading but some of the other displayed information as well.

As detailed below, the algorithm for classifying results is first applied to 20-second nominal L-shell readings followed by 120-second nominal K-shell readings to resolve inconclusive results and laboratory analysis of paint-chip samples, if necessary. For a listing of laboratories recommended by the EPA National Lead Laboratory Accreditation Program (NLLAP) for the analysis of samples to perform additional confirmational analysis, call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

XRF results are classified using threshold values. For the XL-309, threshold values are the only values provided for classifying results. Results are classified as positive if they are greater than or equal to the threshold, and as negative if they are less than the threshold. There is no inconclusive classification when using threshold values. However, inconclusive results still may be obtained regardless of whether decisions are based on L-shell readings, K-shell readings, or both, as described below. Use all digits that are reported by the instrument. Threshold values, which were determined for comparing results to the 1.0 mg/cm^2 standard, are provided in the following table.

Figure D-8 continued. XRF Performance Characteristic Sheet for the Niton XL-309 Spectrum Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Niton Corporation; XL-309 Spectrum Analyzer

DESCRIPTION	SUBSTRATE	THRESHOLD* (mg/cm^2)
Results not corrected for substrate bias	Brick	1.0
	Concrete	1.0
	Drywall	1.0
	Metal	1.0
	Plaster	1.0
	Wood	1.0

* Application of the decision making methodology recommended in this PCS can result in inconclusive results regardless of whether decisions are based on L-shell readings, K-shell readings, or both.

This instrument displays its lead-based paint measurements as both L-shell and K-shell readings based on the corresponding L-shell and K-shell X-ray fluorescence (refer to Chapter 7 of the HUD Guidelines for more details). The L-shell readings (or L-readings) are displayed as a numerical result alone, or as a numerical result preceded by either one greater-than symbol (">") or preceded by two greater-than symbols (">>"). The two greater-than symbols will only be displayed when the detected lead level is greater than 5.0 mg/cm^2. Since the maximum lead level reported by this instrument is 5.0 mg/cm^2, lead levels greater than 5.0 mg/cm^2 are displayed as ">>5.0". Other examples of how L-readings can be displayed (in mg/cm^2 units) are "0.6" and ">0.9". The numerical display alone implies that the instrument measured the lead in the paint at the displayed level using L-shell X-ray fluorescence; 0.6 mg/cm^2 in the example. A number preceded by a single greater-than symbol indicates that the measurable lead is deeply buried in the paint and the detected lead level is greater than the displayed value. In the example, >0.9 indicates that the instrument detected lead deeply buried in paint at a level greater than 0.9 mg/cm^2. K-shell readings (or K-readings) are displayed in one of two ways: 1) as a single K-reading plus and minus a "precision" value or 2) as an upper K-reading and lower K-reading.

The algorithm used for testing in multifamily housing differs slightly from that used in single-family housing. This is because the recommended number of readings per testing combination varies between the two types of housing. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, the HUD Guidelines recommend taking a single XRF reading on a testing combination. In single-family housing, three XRF readings are recommended on each testing combination.

MULTIFAMILY HOUSING XRF RESULT CLASSIFICATIONS:

A. Take a single 20-second nominal reading on each testing combination.

B. Classify the L-reading based on the type of information displayed.

<u>If two greater-than symbols are displayed then</u>:

- Classify the >>5.0 L-reading as POSITIVE

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Figure D-8 continued. XRF Performance Characteristic Sheet for the Niton XL-309 Spectrum Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Niton Corporation; XL-309 Spectrum Analyzer

If one greater-than symbol is displayed then:

- Classify the L-reading as POSITIVE if the numerical result that follows the greater than symbol is equal to or greater than 1.0.
- Classify the L-reading as INCONCLUSIVE if the numerical result that follows the greater than symbol is less than 1.0.

If the numerical L-reading is displayed alone (that is, without any preceding greater-than symbols) then:

- Classify the L-reading as POSITIVE if the numerical result is equal to or greater than 1.0.
- Classify the L-reading as NEGATIVE if the numerical result is less than 1.0.

C. Resolution of results classified as inconclusive.

All results classified as inconclusive above require further investigation. Take a 120-second nominal XRF reading and use the K-shell reading. In multifamily housing, resolve the inconclusive classification with a single K-shell reading or laboratory analysis as described below.

- Classify the result as POSITIVE if either the K-reading minus the displayed precision value or the lower K-reading is equal to or greater than 1.0.
- Classify the result as NEGATIVE if either the K-reading plus the displayed precision value or the upper K-reading is less than 1.0.
- Classify the result as INCONCLUSIVE if neither of the above decision rules using the K-reading provided a classification which can occur when the upper K-reading is equal to or greater than 1.0 or the lower K-reading is less than 1.0.
- To resolve a remaining INCONCLUSIVE classification, remove a paint-chip sample and have it analyzed in a laboratory as described in Chapter 7 of the HUD Guidelines.

SINGLE-FAMILY HOUSING XRF RESULT CLASSIFICATIONS:

D. Take three 20-second nominal readings on each testing combination.

E. Classify each L-reading using the methodology described in item A under Multifamily Housing XRF Result Classifications.

F. Classification of the XRF result for a given testing combination is obtained by combining the individual results of the three L-shell readings as follows:

- A POSITIVE classification is obtained if at least two of the three individual L-readings are classified as positive.

Figure D-8 continued. XRF Performance Characteristic Sheet for the Niton XL-309 Spectrum Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Niton Corporation; XL-309 Spectrum Analyzer

- A NEGATIVE classification is obtained if at least two of the three individual L-readings are classified as negative.

- An INCONCLUSIVE classification is obtained if at least two of the three individual L-readings are classified as inconclusive or if one L-reading is classified as positive, another is classified as negative, and the third is classified as inconclusive.

G. Resolution of results classified as inconclusive.

Any results classified as inconclusive require further investigation in the same manner as described above for multifamily housing with one exception. Take three 120-second nominal K-readings instead of a single one. Obtain a classification by combining the individual results of the three K-readings. Resolve the inconclusive classification by classifying the combined K-shell readings or with laboratory analysis as described below.

- A POSITIVE classification is obtained if at least two of the three individual K-readings where classified as positive.

- A NEGATIVE classification is obtained if at least two of the three individual K-readings where classified as negative.

- An INCONCLUSIVE classification is obtained if at least two of the three individual K-readings where classified as inconclusive.

- To resolve a remaining INCONCLUSIVE classification, remove a paint-chip sample and have it analyzed in a laboratory as described in Chapter 7 of the HUD Guidelines.

INSTRUCTIONS FOR EVALUATING XRF TESTING:

Chapter 7 of the HUD Guidelines recommends several options for evaluating XRF testing. Among those options is the following procedure which may be used after XRF testing has been completed. In single-family housing, an XRF result is the average of three readings taken on a testing combination. (A testing combination is a location on a painted surface as defined in Chapter 7 of the HUD Guidelines). In multifamily housing, an XRF result is a single reading taken on a testing combination. If a multifamily housing development is being retested, randomly select two units from within the development from which the ten testing combinations should be randomly selected.

Randomly select ten testing combinations for retesting from each house or from the two selected units.

Conduct XRF retesting at the ten testing combinations selected for retesting.

Determine if the XRF testing in the units or house passed or failed the test by applying the steps below.

Compute the Retest Tolerance Limit by the following steps:

Determine XRF results for the original and retest XRF readings. Do not correct the original or

Figure D-8 continued. XRF Performance Characteristic Sheet for the Niton XL-309 Spectrum Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
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retest results for substrate bias. In single-family housing a result is defined as the average of three readings. In multifamily housing, a result is a single reading. Therefore, there will be ten original and ten retest XRF results for each house or for the two selected units.

Compute the average of the original and re-test result for each of the ten testing combinations.

Square the average for each testing combination.

Add the ten squared averages together. Call this quantity C.

Multiply the number C by 0.0072. Call this quantity D.

Add the number 0.032 to D. Call this quantity E.

Take the square root of E. Call this quantity F.

Multiply F by 1.645. The result is the Retest Tolerance Limit.

Compute the overall average of all ten retest XRF results over all ten testing combinations selected for retesting.

Take the difference of the overall average of the ten original XRF results and the overall average of the ten retest XRF results. If the difference is negative, drop the negative sign.

If the difference of the overall averages is less than the Retest Tolerance Limit, the inspection has passed the retest. If the difference of the overall averages equals or exceeds the Retest Tolerance Limit, this procedure should be repeated with ten new testing combinations. If the difference of the overall averages is equal to or greater than the Retest Tolerance Limit a second time, then the inspection should be considered deficient.

Use of this procedure is estimated to produce a spurious result approximately 1% of the time. That is, results of this procedure will call for further examination when no examination is warranted in approximately 1 out of 100 dwelling units tested.

BIAS AND PRECISION:

These bias and precision data were computed without substrate correction using the using 20-second L-shell readings from samples with reported laboratory results less than 4.0 mg/cm^2 lead. Readings reported by the instrument in the "*>x*" or "*>>x*" format were not used in the computation. There were 15 test locations with a laboratory reported result equal to or greater than 4.0 mg/cm^2 lead. Of these, 12 readings were reported in the "*>x*" or "*>>x*" format, but of the 3 remaining, 1 had an XRF reading less than 1.0 mg/cm^2. These data are for illustrative purposes only. Substrate correction is not recommended for this XRF instrument. Units are in mg/cm^2.

Figure D-8 continued. XRF Performance Characteristic Sheet for the Niton XL-309 Spectrum Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

XRF PERFORMANCE CHARACTERISTIC SHEET
Niton Corporation; XL-309 Spectrum Analyzer

MEASURED AT	SUBSTRATE	BIAS (mg/cm^2)	PRECISION* (mg/cm^2)
0.0 mg/cm^2	All	0.0	<0.1
0.5 mg/cm^2	All	0.0	0.2
1.0 mg/cm^2	All	0.0	0.3
2.0 mg/cm^2	All	-0.1	0.5

*Precision at 1 standard deviation

A document titled *Methodology for XRF Performance Characteristic Sheets* provides an explanation of the statistical methodology used to construct the data in the sheets and provides empirical results from using the recommended inconclusive ranges or thresholds for specific XRF instruments. For a copy of this document call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

This XRF Performance Characteristic Sheet is a joint product of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD). The issuance of this sheet does not constitute rulemaking. The information provided here is intended solely as guidance to be used in conjunction with Chapter 7 of the *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. EPA and HUD reserve the right to revise this guidance. Please address questions and comments on this sheet to: Director, Office of Lead-Based Paint Abatement and Poisoning Prevention, U.S. Department of Housing and Urban Development, Room B-133, 451 Seventh St, S.W., Washington, DC 20410.

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Figure D-8 continued. XRF Performance Characteristic Sheet for the Niton XL-309 Spectrum Analyzer.

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-55. Bias Estimates, and Their Standard Errors, of Niton XL-309 Spectrum Analyzer Readings.

MEASURED AT	CORRECTED?	SUBSTRATE	BIAS (mg/cm^2)	STANDARD ERROR FOR BIAS
0.0 mg/cm^2	No	All	0.0	0.06
0.5 mg/cm^2	No	All	0.0	0.03
1.0 mg/cm^2	No	All	0.0	0.05
2.0 mg/cm^2	No	All	-0.1	0.12

Table D-56. Precision Estimates, and Their Standard Errors, of Niton XL-309 Spectrum Analyzer.

MEASURED AT	CORRECTED?	SUBSTRATE	PRECISION* (mg/cm^2)	STANDARD ERROR FOR PRECISION
0.0 mg/cm^2	No	All	<0.1	0.00
0.5 mg/cm^2	No	All	0.2	0.02
1.0 mg/cm^2	No	All	0.3	0.03
2.0 mg/cm^2	No	All	0.5	0.04

*Precision at 1 standard deviation

APPENDIX D: XRF PERFORMANCE CHARACTERISTIC SHEETS AND RELATED RESULTS

Table D-57. Classification Results For the Niton XL-309 20-Second L-Shell Readings (Uncorrected) and 120-Second K-Shell Readings (Uncorrected), Classified Using the Threshold Values and Methodology Reported in the XRF Performance Characteristic Sheet and Compared to Laboratory Results in mg/cm^2 Lead Classified Using the 1.0 mg/cm^2 Lead Federal Standard For Data Taken From Archive Testing.

SUBSTRATE	THRESHOLD	FALSE POSITIVE RATE	FALSE NEGATIVE RATE	INCONCLUSIVE RATE*
Brick	1.0	0.0% (0/1)	0.0% (0/2)	0.0% (0/3)
Concrete	1.0	0.0% (0/2)	(0/0)	0.0% (0/2)
Drywall	1.0	0.0% (0/14)	(0/0)	21.4% (3/14)
Metal	1.0	0.0% (0/27)	9.1% (1/11)	5.3% (2/38)
Plaster†	1.0	0.0% (0/29)	40.0% (2/5)	11.8% (4/34)
Wood	1.0	5.0% (2/40)	0.0% (0/23)	14.3% (9/63)
TOTAL		1.8% (2/113)	7.3% (3/41)	11.7% (18/154)

*For this table, readings were classified following the procedures stated in the PCS for this instrument. The inconclusive rate was defined as the percentage of samples tested which were classified as inconclusive after both a 20-second L-shell reading and a 120-second K-shell reading. However, in the testing of this instrument, 18 samples were classified as inconclusive when tested by the 20-second L-shell reading, and none of these 18 samples were resolved (classified) by the 120-second K-shell reading.

†Testing of four additional plaster samples was completed at the National Institute of Standards and Technology with the same instrument that was used for testing at the archive site. The inclusion of these four additional plaster samples has the following affect in the table. The false negative rate for plaster decreased to 33.3% (3 out of 9) and the overall false negative rate increased to 8.9% (4 out of 45). The false positive and inconclusive rates are unchanged. Specifically, one L-shell reading classified a sample as negative that had a laboratory ICP result greater than 1.0 mg/cm^2 lead and another L-shell reading correctly classified a second sample as positive. The two remaining samples were classified by the 20-second L-shell readings as inconclusive, which, in turn, were correctly classified as positive by 120-second K-shell readings.

APPENDIX E: XRF PERFORMANCE CHARACTERISTIC SHEET: AN EXAMPLE

E.1 Introduction

The XRF Performance Characteristic Sheets (PCSs) currently available from the National Lead Information Center (1-800-424-LEAD) are duplicated in appendix D. In this appendix, an example XRF Performance Characteristic Sheet illustrates the minimal amount of information needed to test for lead-based paint according to Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. The information provided in this example PCS is strictly for illustrative purposes only and is not intended to be used as a PCS for field testing. The model in this appendix is proposed as a possible new format for the XRF Performance Characteristic Sheets after publication of this report.

E.2 Example

The example PCS is shown on the following pages.

APPENDIX E: XRF PERFORMANCE CHARACTERISTIC SHEET: AN EXAMPLE

XRF PERFORMANCE CHARACTERISTIC SHEET (PCS)
ABC Company, Inc.; XRF I

EFFECTIVE DATE: May 1, 1997 **EDITION NO.**: 1

MANUFACTURER AND MODEL:

Make: *ABC Company, Inc.*
Model: *XRF I*
Source: Co^{57}
Note: This sheet supersedes all previous sheets for the XRF instrument of the make, model, and source shown above.

USE AND EVALUATION DATA SOURCE:

This sheet is supplemental information to be used in conjunction with Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* ("HUD Guidelines"). It is important that the user of this sheet be familiar with Chapter 7 of the HUD Guidelines. Performance parameters shown in this sheet are based on EPA/HUD evaluation using archived building components.

OPERATING PARAMETERS AND INSTRUCTIONS:

Performance parameters shown in this PCS are applicable only if the instrument is operated under the same conditions as in the evaluation testing and using the procedures described in Chapter 7 of the HUD Guidelines:

- XRF results, as defined in Chapter 7 of the HUD Guidelines, should be calculated using all digits that are reported by the instrument
- XRF results obtained in quick mode, and in standard mode with either nominal 20-second or 30-second reading times, are addressed by this sheet
- Calibration checks are performed using nominal 20-second standard mode readings and the red (1.02 mg/cm^2) NIST Standard Reference Material (SRM No. 2579) paint film
- Substrate correction values are calculated from XRF readings obtained on bare substrate covered with red (1.02 mg/cm^2) NIST SRM paint film
- XRF results obtained using these parameters can be applied to the Multifamily Decision Flowchart for determining the presence of lead on a component type in multifamily housing

This XRF Performance Characteristic Sheet is a joint product of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Housing and Urban Development (HUD). The issuance of this sheet does not constitute rulemaking. The information provided here is intended solely as guidance to be used in conjunction with Chapter 7 of the *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. EPA and HUD reserve the right to revise this guidance. Please address questions and comments on this sheet to: Director, Office of Lead-Based Paint Abatement and Poisoning Prevention, U.S. Department of Housing and Urban Development, Room B-133, 451 Seventh St, S.W., Washington, DC 20410.

Figure E-1. Example PCS.

APPENDIX E: XRF PERFORMANCE CHARACTERISTIC SHEET: AN EXAMPLE

XRF PERFORMANCE CHARACTERISTIC SHEET (PCS)
ABC Company, Inc.; XRF I

INSTRUMENT CALIBRATION CHECK:

Calibration check readings are taken in standard mode with nominal 20-second reading times. If the observed calibration check average minus 1.02 mg/cm^2 is greater than the PLUS VALUE, or less than the MINUS VALUE, the manufacturer's instructions should be followed to bring the instrument into control before additional testing is done. This calibration check is designed to minimize the chance of rejecting a properly calibrated instrument: only about one out of every 200 times this procedure is followed.

MINUS VALUE = -0.4 mg/cm^2
PLUS VALUE = +0.2 mg/cm^2

SUBSTRATE CORRECTION:

For XRF results below 4.0 mg/cm^2, substrate correction is recommended for:

- Metal and Wood

Substrate correction is **not** recommended for:

- Brick, Concrete, Drywall, and Plaster

Substrate correction value computation:

XRF results are corrected for substrate bias by subtracting from each XRF result a correction value determined separately for each house (single-family housing) or for each development (multifamily housing) for each substrate type. The correction values are computed as follows:

- Using the same XRF instrument, take three readings on a bare substrate area covered with the red NIST SRM (1.02 mg/cm^2) paint film. Repeat this procedure by taking three more readings on a second bare substrate area, of the same substrate, covered with the red NIST SRM (1.02 mg/cm^2) paint film.
- Compute the correction value for each substrate type that requires substrate correction by computing the average of all six readings as shown below.

  For each substrate type:

$$\textit{Correction Value} = \frac{1^{st} + 2^{nd} + 3^{rd} + 4^{th} + 5^{th} + 6^{th}\ \textit{Reading}}{6} - 1.02 mg/cm^2$$

Figure E-1 continued. Example PCS.

XRF PERFORMANCE CHARACTERISTIC SHEET (PCS)
ABC Company, Inc.; XRF I

LBP CLASSIFICATION USING INCONCLUSIVE RANGES AND THRESHOLD VALUES:

XRF results are classified using either a threshold or an inconclusive range. With an inconclusive range, XRF results are classified as positive if they are greater than or equal to the upper bound of the inconclusive range, as negative if they are less than or equal to the lower bound, and as inconclusive otherwise. With a threshold, XRF results are classified as positive if they are greater than or equal to the threshold, and as negative if they are less than the threshold. There is no inconclusive classification with a threshold. If substrate correction is recommended, always correct XRF results before using the inconclusive ranges and thresholds shown below.

QUICK MODE READING DESCRIPTION	SUBSTRATE	INCONCLUSIVE RANGE (mg/cm^2)	
		LOWER BOUND	UPPER BOUND
Results corrected for substrate bias on metal and wood substrates only	Brick	0.8	0.9
	Concrete	0.8	0.9
	Drywall	0.7	0.9
	Metal	0.8	0.9
	Plaster	0.8	0.9
	Wood	0.8	0.9

20-SECOND OR 30-SECOND STANDARD MODE READING DESCRIPTION	SUBSTRATE	THRESHOLD (mg/cm^2)
Results corrected for substrate bias on metal and wood substrates only	Brick	0.8
	Concrete	0.8
	Drywall	0.8
	Metal	0.9
	Plaster	0.9
	Wood	0.9

ADDITIONAL INFORMATION:

For a listing of laboratories recommended by the EPA National Lead Laboratory Accreditation Program (NLLAP) or for the document titled *Methodology for XRF Performance Characteristic Sheets*, which describes the statistical methodology used to construct the data in the sheets and provides empirical results from using the recommended inconclusive ranges or thresholds for specific XRF instruments, call the National Lead Information Center Clearinghouse at 1-800-424-LEAD.

Figure E-1 continued. Example PCS.

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16. Abstract (Limit: 200 words)

Information collected from an EPA/HUD field study conducted in 1993 provided background for Chapter 7 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*. A primary conclusion of the field study is that testing by K-shell XRF instruments, with laboratory confirmation of inconclusive XRF results, and with substrate correction in cases where this is effective in reducing bias, is a viable way to test for lead-based paint. This approach can produce satisfactory results for classifying the paint on architectural components using the federal threshold of 1.0 mg/cm^2. This information is included in Chapter 7. Since it was anticipated that there would be ongoing improvements XRF instrumentation as the demand for testing for lead-based paint increased, Chapter 7 was written to defer to easily updated documents for providing testing guidance for specific instruments called *XRF Performance Characteristic Sheets (PCSs)*. This report describes the methodology used to develop the *PCSs*.

17. Document Analysis a. Descriptors

Lead-based paint, lead-based paint testing, field evaluation, archive testing, recommendations for testing for lead in paint, XRF Performance Characteristic Sheets, PCS, PCSs.

b. Identifiers/Open-Ended Terms

X-ray fluorescence instrument, XRF instrument, portable XRF, inductively coupled plasma-atomic emission spectrometry, ICP-AES, ICP

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