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RELATIVE BIOAVAILABILITY OF ARSENIC AND LEAD IN THE NIST 2710A SOIL STANDARD

Prepared for:

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EXECUTIVE SUMMARY

A study using juvenile swine as test animals was performed to measure the gastrointestinal absorption of arsenic and lead from a sample of NIST 2710a soil. NIST 2710a is a National Institute of Standards and Technology (NIST) certified standard reference material consisting of contaminated Montana soil collected near Silver Bow Creek that is blended with lead oxide. Arsenic and lead concentrations (mean±SD) of the soil are 1540±100 mg/kg and 5520±30 mg/kg, respectively.

The relative oral bioavailability of arsenic and lead in NIST 2710a was assessed by comparing the absorption of arsenic or lead from NIST 2710a ("test material") to that of a reference material, either sodium arsenate or lead acetate. Groups of five swine were given oral doses of a reference material or the test material twice a day for 14 days. A group of three non-treated swine served as a control for both the arsenic and lead test groups.

The amount of arsenic absorbed by each animal was evaluated by measuring the amount of arsenic excreted in the urine (collected over 48-hour periods beginning on days 6, 9, and 12). The urinary excretion fraction (UEF) is the ratio of the amount excreted per 48 hours divided by the dose given per 48 hours. UEF was calculated for each test material and the sodium arsenate using simultaneous weighted linear regression. The relative bioavailability (RBA) of arsenic in the test material compared to sodium arsenate was calculated as follows:

$$RBA = \frac{UEF(test\ soil)}{UEF(sodium\ arsenate)}$$

The amount of lead absorbed by each animal was evaluated by measuring the amount of lead in the blood (measured on days 0, 2, 4, 8, 11, and 15) and the amount of lead in liver, kidney, and bone (measured on day 15 at study termination). Because equal absorbed doses of lead will produce equal responses in tissue concentrations regardless of the source or nature of the ingested lead, the RBA of a test material is calculated as the ratio of doses (test material and reference material) that produce equal increases in lead concentration in the body compartment. Thus, the basic data reduction task to calculate a lead RBA for the test material was to fit mathematical equations to the dose-response data for both the test material and the reference material, and then solve the equations to find the ratio of doses that would be expected to yield equal responses.

Estimated arsenic RBA values (mean and 90% confidence interval) are as follows:

Collection Interval	Estimated Arsenic RBA (90% Confidence Interval)
Days 6/7	0.43 (0.39–0.47)
Days 9/10	0.41 (0.37–0.44)
Days 12/13	0.42 (0.38–0.46)
All Days	**0.42 (0.40–0.44)**

Estimated lead RBA values (mean and 90% confidence interval) are as follows:

Measurement Endpoint	Estimated Lead RBA (90% Confidence Interval)
Blood Lead AUC	0.49 (0.38–0.68)
Liver Lead	0.75 (0.57–0.99)
Kidney Lead	0.52 (0.38–0.71)
Femur Lead	0.53 (0.44–0.63)
Point Estimate	**0.57 (0.39–0.84)**

The best fit point estimates for arsenic and lead RBAs for the NIST 2710a soil are 42 and 57% for arsenic and lead, respectively.

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ACRONYMS AND ABBREVIATIONS

ABA	Absolute bioavailability
AUC	Area under the curve
AF_o	Oral absorption fraction
As^{+3}	Trivalent inorganic arsenic
As^{+5}	Pentavalent inorganic arsenic
CDC	Centers for Disease Control and Prevention
D	Ingested dose
DMA	Dimethyl arsenic
EDTA	Ethylenediaminetetra-acetic acid
g	Gram
GLP	Good Laboratory Practices
ICP MS	Inductively coupled plasma mass spectrometry
kg	Kilogram
K_u	Fraction of absorbed arsenic which is excreted in urine
mL	Milliliter
MMA	Monomethyl arsenic
N	Number of data points
ng	Nanogram
NIST	National Institute of Standards and Technology
PE	Performance evaluation
ppb	Parts per billion
ppm	Parts per million
QC	Quality control
RBA	Relative bioavailability
ref	Reference material
RfD	Reference dose
RPD	Relative percent difference
SD	Standard deviation
SF	Slope factor
SRM	Standard reference material
TM	Test material
UEF	Urinary excretion fraction
USEPA	United States Environmental Protection Agency
µg	Microgram
µm	Micrometer
°C	Degrees Celsius
°F	Degrees Fareinheit

1.0 INTRODUCTION

1.1 Overview of Bioavailability

Reliable analysis of the potential hazard to humans from ingestion of a chemical depends upon accurate information on a number of key parameters, including the concentration of the chemical in environmental media (e.g., soil, dust, water, food, air, paint), intake rates of each medium, and the rate and extent of absorption ("bioavailability") of the chemical by the body from each ingested medium. The amount of a chemical that actually enters the body from an ingested medium depends on the physical-chemical properties of the chemical and of the medium. For example, some metals in soil may exist, at least in part, as poorly water-soluble minerals, and may also exist inside particles of inert matrix such as rock or slag of variable size, shape, and association. These chemical and physical properties may influence (usually decrease) the absorption (bioavailability) of the metals when ingested. Thus, equal ingested doses of different forms of a chemical in different media may not be of equal health concern.

Bioavailability of a chemical in a particular medium may be expressed either in absolute terms (absolute bioavailability) or in relative terms (relative bioavailability):

> Absolute bioavailability (ABA) is the ratio of the amount of the chemical absorbed to the amount ingested:
>
> $$ABA = \frac{Absorbed\ \ Dose}{Ingested\ \ Dose}$$
>
> This ratio is also referred to as the oral absorption fraction (AF_o).
>
> Relative bioavailability (RBA) is the ratio of the AF_o of the chemical present in some test material (*test*) to the AF_o of the chemical in some appropriate reference material (*ref*), such as the chemical dissolved in water or a solid form that is expected to fully dissolve in the stomach:
>
> $$RBA(test\ vs\ ref) = \frac{AF_o(test)}{AF_o(ref)}$$

For example, if 100 micrograms (μg) of a chemical dissolved in drinking water were ingested and a total of 50 μg were absorbed into the body, the AF_o would be 50/100, or 0.50 (50%). Likewise, if 100 μg of the same chemical contained in soil were ingested and 30 μg were absorbed into the body, the AF_o for this chemical in soil would be 30/100, or 0.30 (30%). If the chemical dissolved in water were used as the frame of reference for describing the relative bioavailability of the same chemical in soil, the RBA would be 0.30/0.50, or 0.60 (60%).

For additional discussion about the concept and application of bioavailability, see Gibaldi and Perrier (1982), Goodman et al. (1990), and/or Klaassen et al. (1996).

1.2 Using RBA Data to Improve Risk Calculations

When reliable data are available on the RBA of a chemical in a site medium (e.g., soil), the information can be used to improve the accuracy of exposure and risk calculations at that site. RBA data can be used to adjust default oral toxicity values (reference dose and slope factor) to account for differences in absorption between the chemical ingested in water and the chemical ingested in site media, assuming the toxicity factors are based on a readily soluble form of the chemical.

1.2.1 Arsenic

For non-cancer effects, the default reference dose ($RfD_{default}$) can be adjusted ($RfD_{adjusted}$) as follows:

$$RfD_{adjusted} = \frac{RfD_{default}}{RBA}$$

For potential carcinogenic effects, the default slope factor ($SF_{default}$) can be adjusted ($SF_{adjusted}$) as follows:

$$SF_{adjusted} = SF_{default} \cdot RBA$$

Alternatively, it is also acceptable to adjust the dose (rather than the toxicity factors) as follows:

$$Dose_{adjusted} = Dose_{default} \cdot RBA$$

This dose adjustment is mathematically equivalent to adjusting the toxicity factors as described above.

1.2.2 Lead

Based on available information on lead absorption in humans and animals, the U.S. Environmental Protection Agency (USEPA) estimates that the absolute bioavailability of lead from water and other fully soluble forms of lead is usually about 50% in children (USEPA 1991) and about 20% in adults (USEPA 2003). Thus, when a reliable site-specific lead RBA value for soil is available, it may be used to estimate a site-specific absolute bioavailability in that soil, as follows:

$$ABA_{soil}\ (child) = 50\% \cdot RBA_{soil}$$

$$ABA_{soil}\ (adult) = 20\% \cdot RBA_{soil}$$

The default lead RBA used by USEPA for lead in soil and dust compared to lead in water is 60% for both children and adults. When the measured RBA in soil or dust at a site is found to be less than 60% compared to some fully soluble form of lead, it may be concluded that exposures to and hazards from lead in these media at that site are probably lower than the typical default

assumptions. If the measured RBA is higher than 60%, absorption of and hazards from lead in these media may be higher than usually assumed.

1.3 Purpose of this Study

The objective of this study was to use juvenile swine as a test system in order to determine the RBA of arsenic and lead in a standard soil reference material (NIST 2710a) compared to soluble forms of arsenic (sodium arsenate) and lead (lead acetate).

2.0 STUDY DESIGN

The test and reference materials were administered to groups of five juvenile swine at three different dose levels for 14 days. The study included a non-treated group of three animals to serve as a control for determining background arsenic and lead levels. Study design details are presented in Table 2-1. All doses were administered orally. The study was performed as nearly as possible within the spirit and guidelines of Good Laboratory Practices (GLP: 40 CFR 792).

Table 2-1. Study Design and Dosing Information

Group	Dose Material Administered	Number of Swine in Group	Arsenic Dose (µg/kg BW-day)		Lead Dose (µg/kg BW-day)	
			Target Dose	Actual Dose[a]	Target Dose	Actual Dose[b]
1	Lead acetate	5	0	0	75	76
2	Lead acetate	5	0	0	150	160
3	Lead acetate	5	0	0	300	314
4	NIST 2710a	5	40	41	143	147
5	NIST 2710a	5	60	62	215	219
6	NIST 2710a	5	120	121	430	440
7	Sodium arsenate	5	25	26	0	0
8	Sodium arsenate	5	50	52	0	0
9	Sodium arsenate	5	100	105	0	0
10	None (negative control)	3	0	0	0	0

[a] Calculated as the administered daily dose divided by the measured or extrapolated daily body weight, averaged over days 6/7, 9/10, and 12/13 for each animal and each group.
[b] Calculated as the administered daily dose divided by the measured or extrapolated daily body weight, averaged over days 0–15 for each animal and each group.
Doses were administered in two equal portions given at 9:00 AM and 3:00 PM each day. Doses were adjusted upwards every 3 days during the exposure interval based on measured group mean weights.

2.1 Test Materials

2.1.1 Sample Description

The test soil used in this investigation was a sample of National Institute of Standards and Technology (NIST) Standard Reference Material® (SRM) 2710a ("NIST 2710a"). NIST 2710a consists of soil collected from land along Silver Bow Creek approximately 5 miles west of Butte,

Montana. The collection site is approximately nine miles east of Anaconda and 6.5 miles south of settling ponds that feed the creek (NIST 2009).

2.1.2 Sample Preparation and Analysis

All preparation and analysis of the bulk material was conducted by NIST, with no further processing before administration to swine. As described in NIST (2009), NIST 2710a was prepared by air drying at room temperature. The material was then deaggregated and sieved to remove coarse (≥2 mm) material. Material remaining on the screen was ground in a ball mill together with enough lead oxide to achieve a 0.55% mass fraction of lead in the final product. The ball-milled batch of soil was transferred to a cross-flow V-blender for mixing. The blended soil was radiation sterilized, then split into containers using a spinning riffler, used to apportion approximately 50 g into each pre-cleaned bottles. Homogeneity assessments were performed on every 100th bottle and results indicated that additional processing was needed to achieve optimum homogeneity. Therefore, material from all bottles was combined, and then ground in batches between stainless steel plates for a time sufficient to produce a powder of which ≥95%, by mass, passed through a 200 mesh (74 μm) sieve. The resulting powder was blended, and 50 g portions were dispensed into bottles using the spinning riffler. Homogeneity assessments on the re-blended material were acceptable.

This prepared soil as provided by NIST was used *as is* for the bioavailability study, without further preparation. The NIST-certified arsenic and lead concentrations of the NIST 2710a sample are 1540±100 mg/kg and 5520±30 mg/kg, respectively.

2.2 Experimental Animals

Juvenile swine were selected for use because they are considered to be a good physiological model for gastrointestinal absorption in children (Weis and LaVelle 1991; Casteel et al. 1996). The animals were intact males of the Pig Improvement Corporation genetically defined Line 26, and were purchased from Chinn Farms, Clarence, Missouri.

The number of animals purchased for the study was several more than required by the protocol. These animals were purchased at an age of about 5–6 weeks (weaning occurs at age 3 weeks) and housed in individual stainless steel cages. The animals were then held under quarantine for one week to observe their health before beginning exposure to dosing materials. Each animal was examined by a certified veterinary clinician (swine specialist) and any animals that appeared to be in poor health during this quarantine period were excluded from the study. To minimize weight variations among animals and groups, extra animals most different in body weight (either heavier or lighter) five days prior to exposure (day-5) were also excluded from the study. The remaining animals were assigned to dose groups at random (group assignments are presented in Appendix A).

When exposure began (day 0), the animals were about 6–7 weeks old. The animals were weighed at the beginning of the study and every three days during the course of the study. In each study, the rate of weight gain was comparable in all dosing groups. Body weight data are presented in Appendix B.

All animals were examined daily by an attending veterinarian while on study and were subjected to detailed examination at necropsy by a certified veterinary pathologist in order to assess overall animal health.

2.3 Diet

Animals were weaned onto standard swine chow (purchased from MFA Inc., Columbia, Missouri) by the supplier. In order to minimize lead exposure from the diet, all animals were gradually transitioned from the MFA feed to a special purified low-lead feed (purchased from TestDiet®, Richmond, Indiana) several days before dosing began, and this feed was maintained for the duration of the study. The feed was nutritionally complete and met all requirements of the National Institutes of Health–National Research Council (NRC 1988). The ingredients and nutritional profile of the feed are presented in Appendix C. Arsenic and lead concentrations in a randomly selected feed sample measured <0.1 μg/g.

Beginning 5 days before the first day of dosing, each animal was given a daily amount of feed equal to 4.0% of the mean body weight of all animals on study. Feed was reduced to 3.7% body weight starting on day 8 of the study. Feed amounts were adjusted every three days, when animals were weighed. Feed was administered in two equal portions, at 11:00 AM and 5:00 PM daily.

Drinking water was provided *ad libitum* via self-activated watering nozzles within each cage. Arsenic and lead concentrations of five water samples from randomly selected drinking water nozzles were <0.6 μg/L.

2.4 Dosing

Animals were exposed to dosing materials for 14 days, with the dose for each day being administered in two equal portions beginning at 9:00 AM and 3:00 PM (two hours before feeding). Swine were dosed two hours before feeding to ensure that they were in a semi-fasted state. To facilitate dose administration, dosing materials were placed in a small depression in a ball of dough consisting of moistened feed (typically about 5 g) and the dough was pinched shut. This was then placed in the feeder at dosing time.

Target arsenic and lead doses (expressed as μg of metal per kg of body weight per day) for animals in each group are shown in the study design (see Table 2-1). The actual administered doses were calculated based on the arsenic content of the material administered and the measured group mean body weights. Specifically, doses of arsenic for the three days following each weighing were based on the group mean body weight adjusted by the addition of 1 kg to account for the expected weight gain over the time interval. After completion of the study, body weights were estimated by interpolation for those days when measurements were not collected and the actual administered doses were calculated for each day and then averaged across all days. The actual mean doses for each dosing group are included in Table 2-1.

2.5 Collection and Preservation of Urine Samples

Samples of urine were collected from each animal for 48-hour periods on days 6 to 7 (U-1), 9 to 10 (U-2), and 12 to 13 (U-3) of the study. Collection began at 8:00 AM and ended 48 hours

later. The urine was collected in a plastic bucket placed beneath each cage, which was emptied into a plastic storage bottle. Aluminum screens were placed under the cages to minimize contamination with feces or spilled food. Due to the length of the collection period, collection containers were emptied periodically (typically twice daily) into separate plastic bottles to ensure that there was no loss of sample due to overflow.

At the end of each collection period, the total urine volume for each animal was measured (see Appendix D) and three 60-mL portions were removed and acidified with 0.6 mL concentrated nitric acid. All samples were refrigerated. Two of the aliquots were archived and one aliquot was sent for arsenic analysis. Refrigeration was maintained until arsenic analysis.

2.6 Collection and Preservation of Blood Samples

Samples of blood were collected from each animal on the first day of exposure (day 0) and on days 2, 4, 8, 11, and 15 following the start of exposure. All blood samples were collected by vena-puncture of the anterior vena cava, and samples were immediately placed in purple-top Vacutainer® tubes containing EDTA (ethylenediaminetetra-acetic acid) as anticoagulant. Blood samples were collected each sampling day beginning at 8:00 AM, approximately one hour before the first of the two daily exposures to lead on the sampling day and 17 hours after the last lead exposure the previous day. This blood collection time was selected because the rate of change in blood lead resulting from the preceding exposures is expected to be relatively small after this interval (LaVelle et al. 1991; Weis et al. 1993), so the exact timing of sample collection relative to the last dosing is not likely to be critical.

2.7 Collection and Preservation of Tissue and Bone Samples

Following collection of the final blood sample on day 15, all animals were humanely euthanized and samples of liver, kidney, and bone (the right femur, defleshed) were removed and stored at -80°C in lead-free plastic bags for lead analysis.

2.8 Preparation and Analysis

All biological samples were assigned random chain-of-custody tag numbers and submitted to the analytical laboratory for analysis in a blind fashion. The samples were analyzed for arsenic or lead by L.E.T., Inc. (Columbia, Missouri).

Subsamples of all the biological samples collected were archived in order to allow for reanalysis and verification of lead or arsenic levels, if needed.

2.8.1 Urine Sample Preparation and Analysis

Urine samples (25 mL) were digested by refluxing and then heating to dryness in the presence of magnesium nitrate and concentrated nitric acid. Following magnesium nitrate digestion, samples were transferred to a muffle furnace and ashed at 500°C. The digested and ashed residue was dissolved in hydrochloric acid and analyzed by the hydride generation technique using a Perkin Elmer 3100 atomic absorption spectrometer. Previous tests of this method established that each of the different forms of arsenic that may occur in urine, including trivalent inorganic arsenic

(As^{+3}), pentavalent inorganic arsenic (As^{+5}), monomethyl arsenic (MMA), and dimethyl arsenic (DMA) are all recovered with high efficiency.

Analytical results for the urine samples are presented in Appendix D.

2.8.2 Blood Sample Preparation

One milliliter of whole blood was removed from the purple-top Vacutainer® tube and added to 9.0 mL of "matrix modifier", a solution recommended by the Centers for Disease Control and Prevention (CDC) for analysis of blood samples for lead. The composition of matrix modifier is 0.2% (v/v) ultrapure nitric acid, 0.5% (v/v) Triton X-100, and 0.2% (w/v) dibasic ammonium phosphate in deionized distilled water.

2.8.3 Liver and Kidney Sample Preparation

One gram of soft tissue (liver or kidney) was placed in a lead-free screw-cap Teflon container with 2 mL of concentrated (70%) nitric acid and heated in an oven to 90°C overnight. After cooling, the digestate was transferred to a clean lead-free 10 mL volumetric flask and diluted to volume with deionized distilled water.

2.8.4 Bone Sample Preparation

The right femur of each animal was defleshed, broken, and dried at 100°C overnight. The dried bones were then placed in a muffle furnace and dry-ashed at 450°C for 48 hours. Following dry ashing, the bone was ground to a fine powder using a lead-free mortar and pestle, and 200 mg was removed and dissolved in 10.0 mL of 1:1 (v:v) concentrated nitric acid/water. After the powdered bone was dissolved and mixed, 1.0 mL of the acid solution was removed and diluted to 10.0 mL in deionized distilled water.

2.8.5 Lead Sample Analysis

Samples of blood, liver, kidney, and bone and other materials (e.g., food, water, reagents, solutions) were analyzed for lead by graphite furnace atomic absorption using a Perkin Elmer Analyst 800 high-performance atomic absorption spectrometer.

All analytical results were reported in units of μg Pb/L (ng/mL) of prepared sample. The quantitation limit was defined as three-times the standard deviation of a set of seven replicates of a low-lead sample (typically about 2–5 μg/L). The standard deviation was approximately 0.3 μg/L, therefore the quantitation limit was approximately 0.9–1.0 μg/L. For prepared blood samples (diluted 1/10), this corresponds to a quantitation limit of 10 μg/L (1 μg/dL). For soft tissues (liver and kidney, diluted 1/10), the corresponding quantitation limit is 10 μg/kg (10 ng/g) wet weight, and for bone (diluted 1/500) the corresponding quantitation limit is 0.5 μg/g (50 ng/g) ashed weight. All responses below the quantitation limit were evaluated at one-half the quantitation limit. Lead analytical results for study samples are presented in Appendix E.

2.9 Quality Control

A number of quality control (QC) steps were taken during this project to evaluate the accuracy of the analytical procedures. The results for QC samples are presented in Appendix F and are summarized below.

Blind Duplicates (Sample Preparation Replicates)

A random selection of about 8% of all urine samples, 9% of all blood samples, and 3 samples each for kidney, liver, and femur samples generated during the study were prepared for laboratory analysis in duplicate and submitted to the laboratory in a blind fashion. Results are shown in Appendix F (see Table F-1 and Figures F-1 and F-2). There was generally good agreement between results for the duplicate pairs.

Spike Recovery

During analysis, one feed and water sample and every tenth urine, blood, bone, or tissue sample was spiked with known amounts of arsenic (sodium arsenate) or lead (lead acetate) and the recovery of the added arsenic or lead was measured. Results (see Table F-2) show that mean arsenic and lead concentrations recovered from spiked samples were typically within 10% of actual concentrations.

Laboratory Duplicates

During analysis, every tenth sample was analyzed in duplicate. Duplicate results for urine and lead samples (see Table F-3) typically agreed within 10% relative percent difference (RPD).

Laboratory Control Standards

Several NIST standard reference materials (SRMs), for which certified concentrations of specific analytes has been established, were tested periodically during sample analysis. Recovery of arsenic and lead from these standards was generally good and within the acceptable range (see Table F-4).

Performance Evaluation Samples for Arsenic

A number of Performance Evaluation (PE) samples (urine samples of known arsenic concentration) were submitted to the laboratory in a blind fashion. The PE samples included varying concentrations (20, 100, or 400 µg/L) each of four different types of arsenic (As^{+3}, As^{+5}, MMA, and DMA). The results for the PE samples are shown in Table F-5 and Figure F-3. All sample results were close to the expected values, indicating that there was good recovery of the arsenic in all cases.

CDC Samples for Lead

The CDC provides a variety of blood lead "check samples" for use in quality assurance programs for blood lead studies. Several CDC check samples of different concentrations were provided to the analytical laboratory in a blind fashion, to be analyzed periodically during blood sample

analysis. The results are summarized in Table F-6 and Figure F-4. Sample results were slightly lower than expected values; however, this same relationship has been observed in lead studies in the past, and therefore the relationship is interpreted as normal and expected for blood lead samples.

Laboratory Blanks

Laboratory blank samples were run along with each batch of samples at a rate of about 10%. Blanks never yielded a measurable level of arsenic (all results <1 µg/L) and only one sample, a blank sample associated with the water samples, yielded a measureable level of lead (Blank-1 = 1 ng/mL). Results are shown in Table F-7.

Summary of QC Results

Based on the results of all of the QC samples and steps described above, it is concluded that the analytical results are of sufficient quality for derivation of reliable estimates of arsenic and lead absorption from the test materials.

3.0 DATA ANALYSIS FOR ARSENIC

3.1 Overview

Figure 3-1 shows a conceptual model for the toxicokinetic fate of ingested arsenic. Key points of this model are as follows:

- In most animals (including humans), absorbed arsenic is excreted mainly in the urine over the course of several days. Thus, the urinary excretion fraction (UEF), defined as the amount excreted in the urine divided by the amount given, is usually a reasonable approximation of the AF_o or ABA. However, this ratio will underestimate total absorption, because some absorbed arsenic is excreted in the feces via the bile, and some absorbed arsenic enters tissue compartments (e.g., skin, hair) from which it is cleared very slowly or not at all. Thus, the UEF should not be equated with the absolute absorption fraction.

- The RBA of two orally administered materials (i.e., a test material and reference material) can be calculated from the ratio of the UEF of the two materials. This calculation is independent of the extent of tissue binding and of biliary excretion:

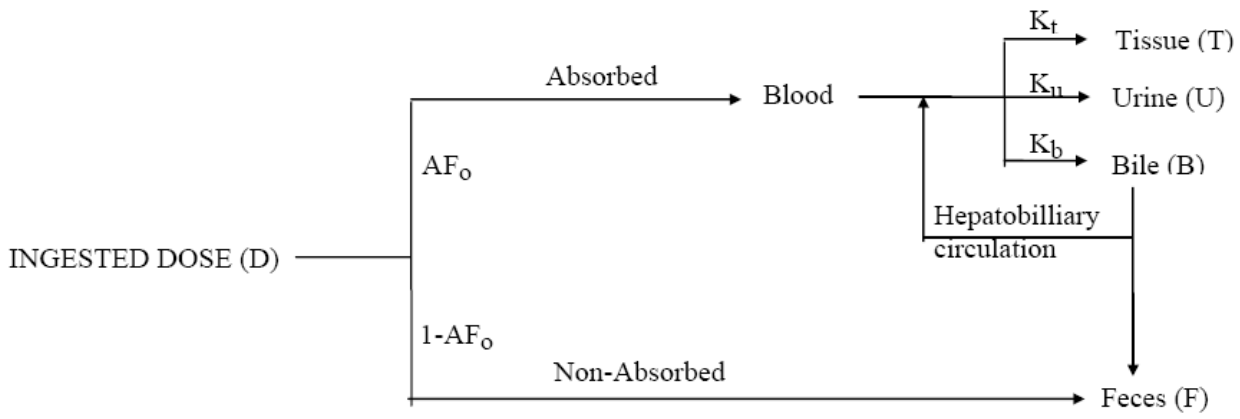
$$RBA(test\ vs\ ref) = \frac{AF_o(test)}{AF_o(ref)} = \frac{D \cdot AF_o(test) \cdot K_u}{D \cdot AF_o(ref) \cdot K_u} = \frac{UEF(test)}{UEF(ref)}$$

where:

D = ingested dose (µg)

K_u = fraction of absorbed arsenic that is excreted in the urine

Figure 3-1. Conceptual Model for Arsenic Toxicokinetics



where:

AF_o = Oral Absorption Fraction

K_t = Fraction of absorbed arsenic which is retained in tissues

K_u = Fraction of absorbed arsenic which is excreted in urine

K_b = Fraction of absorbed arsenic which is excreted in the bile

BASIC EQUATIONS:

Amount in Urine

$$U_{oral} = D \bullet AF_o \bullet K_u$$

Urinary Excretion Fraction (UEF)

$$UEF_{oral} = \frac{U_{oral}}{D_{oral}} = AF_o \bullet K_u$$

Relative Bioavailability

$$RBA_{(x\ vs.\ y)} = \frac{UEF_{x,oral}}{UEF_{y,oral}} = \frac{AF_{O(x)} \bullet K_u}{AF_{O(y)} \bullet K_u} = \frac{AF_{O(x)}}{AF_{O(y)}}$$

Based on the conceptual model above, the basic method used to estimate the RBA of arsenic in a particular test material compared to arsenic in a reference material (sodium arsenate) is as follows:

1. Plot the amount of arsenic excreted in the urine (μg per 48 hours) as a function of the administered amount of arsenic (μg per 48 hours), both for reference material and for test material.

2. Find the best fit linear regression line through each data set. The slope of each line (μg per 48 hours excreted per μg per 48 hours ingested) is the best estimate of the UEF for each material.

3. Calculate RBA for each test material as the ratio of the UEF for test material compared to UEF for reference material:

$$RBA(test\ vs\ ref) = \frac{UEF(test)}{UEF(ref)}$$

A detailed description of the curve-fitting methods and rationale and the methods used to quantify uncertainty in the arsenic RBA estimates for a test material are summarized below. All model fitting was performed in Microsoft Excel® using matrix functions.

3.2 Arsenic Dose-Response Model

Simultaneous Regression

The techniques used to derive linear regression fits to the dose-response data are based on the methods recommended by Finney (1978). As noted by Finney (1978), when the data to be analyzed consist of two dose-response curves (the reference material and the test material), it is obvious that both curves must have the same intercept, since there is no difference between the curves when the dose is zero. This requirement is achieved by combining the two dose response equations into one and solving for the parameters simultaneously, as follows:

Separate models:

$$\mu_r(i) = a + b_r \cdot x_r(i)$$

$$\mu_t(i) = a + b_t \cdot x_t(i)$$

Combined model:

$$\mu(i) = a + b_r \cdot x_r(i) + b_t \cdot x_t(i)$$

where $\mu(i)$ indicates the expected mean response of animals exposed at dose $x(i)$, and the subscripts r and t refer to reference and test material, respectively. The coefficients of this combined model are derived using multivariate regression, with the understanding that the combined data set is restricted to cases in which one (or both) of x_r and x_t are zero (Finney 1978).

Weighted Regression

Regression analysis based on ordinary least squares assumes that the variance of the responses is independent of the dose and/or the response (Draper and Smith 1998). It has previously been shown that this assumption is generally not satisfied in swine-based RBA studies, where there is a tendency toward increasing variance in response as a function of increasing dose (heteroscedasticity) (USEPA 2007). One method for dealing with heteroscedasticity is through the use of weighted least squares regression (Draper and Smith 1998). In this approach, each observation in a group of animals is assigned a weight that is inversely proportional to the variance of the response in that group:

$$w_i = \frac{1}{\sigma_i^2}$$

where:

w_i = weight assigned to all data points in dose group *i*

σ_i^2 = variance of responses in animals in dose group *i*

When the distributions of responses at each dose level are normal, weighted regression is equivalent to the maximum likelihood method.

There are several alternative strategies for assigning weights. The method used in this study estimates the value of σ_i^2 using an "external" variance model based on an analysis of the relationship between variance and mean response using data consolidated across many different swine-based arsenic RBA studies. The data used to derive the variance model are shown in Figure 3-2. As seen, log-variance increases as an approximately linear function of log-mean response:

$$\ln(s_i^2) = k1 + k2 \cdot \ln(\bar{y}_i)$$

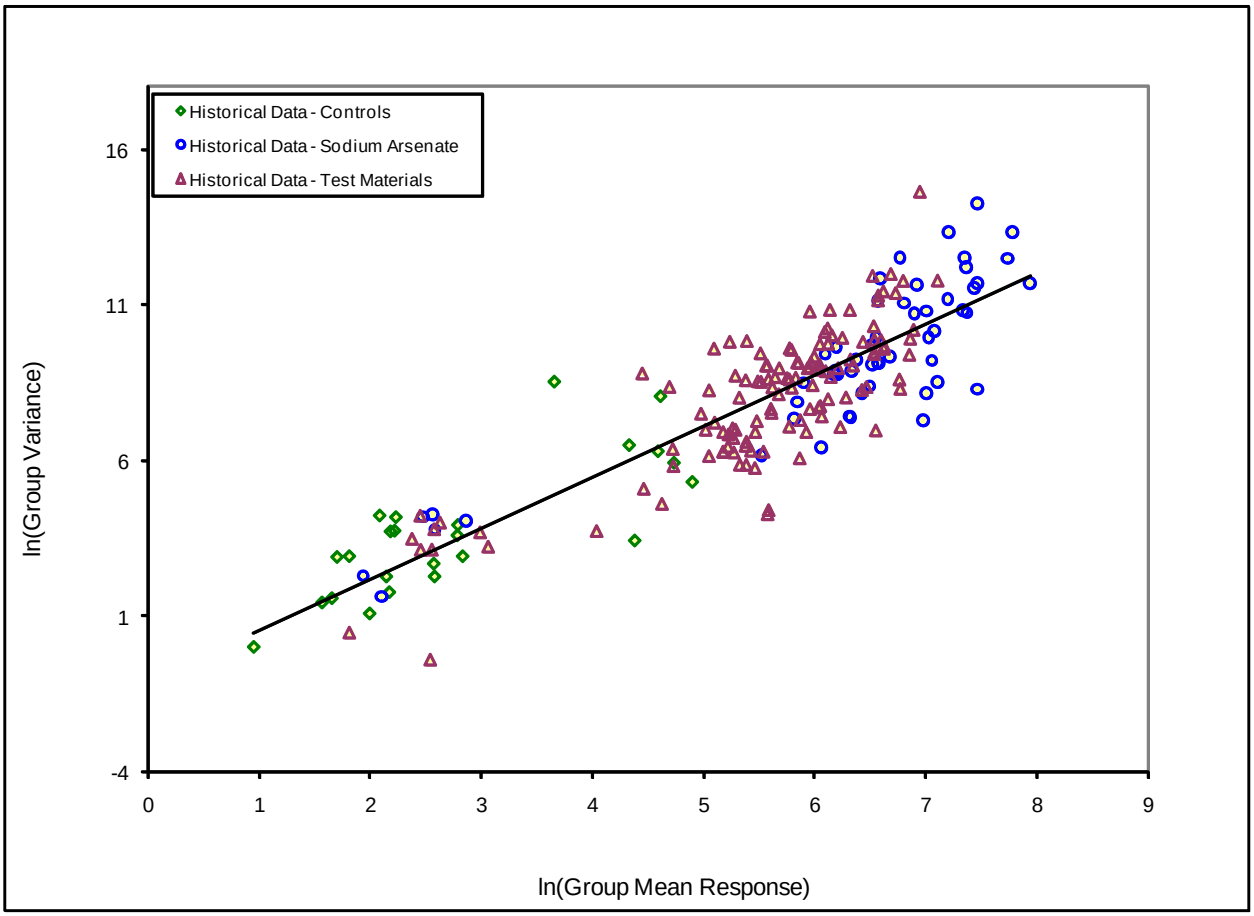
where:

s_i^2 = observed variance of responses of animals in dose group *i*

$\bar{y}_i$ = mean observed response of animals in dose group *i*

Based on these data, values of *k*1 and *k*2 were derived using ordinary least squares minimization. The resulting values were -1.10 for *k*1 and 1.64 for *k*2.

Figure 3-2. Urinary Arsenic Variance Model



Goodness-of-Fit

The goodness-of-fit of each dose-response model was assessed using the F test statistic and the adjusted coefficient of multiple determination (Adj R^2) as described by Draper and Smith (1998). A fit is considered acceptable if the p-value is less than 0.05.

Data Assessment

Arsenic data were assessed in two parts. First, the urine volumes and arsenic concentrations were reviewed. A large volume of urine is typically indicative that a swine spilled its drinking water into the urine collection trays. In these instances, the arsenic concentration in the diluted urine will become very small and difficult to measure with accuracy. Furthermore, because the response of the swine to arsenic dose is calculated from the product of urine concentration and volume, the result becomes highly uncertain when the concentration is multiplied by a volume that is not representative of the total urine volume. For this reason, in cases where total urine volume per 24-hour period was more than 5 liters (more than twice the average urine output of swine) and the measured urine concentration of arsenic was at or below the quantitation limit

(<2 µg/L), the samples were judged to be unreliable and were excluded from the quantitative analysis.

Once samples with a high urine volume to arsenic concentration were removed, the remaining data set was modeled. The modeled data set was then analyzed for individual measured responses that appeared atypical compared to the responses from other animals in the same dose group. Responses that yielded standardized weighted residuals greater than 3.5 or less than -3.5 were considered to be potential outliers (Canavos 1984).

3.3 Calculation of Arsenic RBA Estimates

The arsenic RBA values were calculated as the ratio of the slope term for the test material data set (b_t) and the reference material data set (b_r):

$$RBA = \frac{b_t}{b_r}$$

The uncertainly range about the RBA ratio was calculated using Fieller's Theorem as described by Finney (1978).

4.0 DATA ANALYSIS FOR LEAD

4.1 Overview

The basic approach for measuring lead absorption *in vivo* is to administer an oral dose of lead to test animals and measure the increase in lead level in one or more body compartments (e.g., blood, soft tissue, bone). In order to calculate the RBA value of a test material, the increase in lead in a body compartment is measured both for that test material and a reference material (lead acetate). Because equal absorbed doses of lead (as Pb^{+2}) will produce equal responses (i.e., equal increases in concentration in tissues) regardless of the source or nature of the ingested lead, the RBA of a test material is calculated as the ratio of doses (test material and reference material) that produce equal increases in lead concentration in the body compartment. Thus, the basic data reduction task required to calculate an RBA for a test material is to fit mathematical equations to the dose-response data for both the test material and the reference material, and then solve the equations to find the ratio of doses that would be expected to yield equal responses.

Some biological responses to lead exposure may be non-linear functions of dose (i.e., tending to flatten out or plateau as dose increases). The cause of this non-linearity is uncertain but might be due either to non-linear absorption kinetics and/or to non-linear biological response per unit dose absorbed. However, the principal advantage of the approach described above is that it is not necessary to understand the basis for a non-linear dose response curve (non-linear absorption and/or non-linear biological response) in order to derive valid RBA estimates; the approach yields reliable results for both non-linear and linear responses.

A detailed description of the curve-fitting methods and rationale, along with the methods used to quantify uncertainty in the RBA estimates for the test material, are presented in USEPA (2007) and are summarized below.

4.2 Description of Measurement Endpoints for Lead

Four independent measurement endpoints were evaluated based on the concentration of lead observed in blood, liver, kidney, and bone (femur). For liver, kidney, and bone, the measurement endpoint was simply the concentration in the tissue at the time of sacrifice (day 15). The measurement endpoint used to quantify the blood lead response was the area under the curve (AUC) for blood lead vs. time (days 0–15). AUC was selected because it is the standard pharmacokinetic index of chemical uptake into the blood compartment, and is relatively insensitive to small variations in blood lead level by day. The AUC was calculated using the trapezoidal rule to estimate the AUC between each time point that a blood lead value was measured:

$$AUC(d_i \text{ to } d_j) = 0.5 \cdot (r_i + r_j) \cdot (d_j - d_i)$$

where:

d = day number

r = response (blood lead value) on day i (r_i) or day j (r_j)

The areas were then summed across all time intervals in the study to yield the final AUC for each animal.

4.3 Lead Dose-Response Models

Basic Equations

Nearly all blood lead AUC data sets can be well-fit using an exponential equation (USEPA 2007) and most tissue (liver, kidney, and bone) lead data can be well-fit using a linear equation, as follows:

Linear (liver, kidney, bone): $\text{Response} = a + b \cdot \text{Dose}$

Exponential (blood lead AUC): $\text{Response} = a + b \cdot [1 - \exp(-c \cdot \text{Dose})]$

Simultaneous Regression

Because the data to be analyzed consist of two dose-response curves for each endpoint and there is no difference between the curves when the dose is zero, both curves for a given endpoint must have the same intercept. This requirement is achieved by combining the two dose response equations into one and solving for the parameters simultaneously, resulting in the following equations:

Linear: $y = a + b_r \cdot x_r + b_t \cdot x_t$

Exponential: $y = a + b \cdot [\ (1-\exp(-c_r \cdot x_r)) + (1-\exp(-c_t \cdot x_t))\ ]$

where:

y = response
x = dose
a, b, c = empirical coefficients for the reference material (r) and test material (t).

All linear model fitting was performed in Microsoft® Office Excel using matrix functions. Exponential model fitting was performed using JMP® version 3.2.2, a commercial software package developed by SAS®.

Weighted Regression

An "external" variance model was used to estimate the value of σ_i^2 for lead based on an analysis of the relationship between variance and mean response using data consolidated across many different swine-based lead RBA studies. The data used to derive the variance models for each endpoint are shown in Figure 4-1. Values of k1 and k2 were derived for each endpoint using ordinary least squares minimization, and the resulting values are shown below:

Endpoint	k1	k2
Blood AUC	-1.3226	1.5516
Liver	-2.6015	2.0999
Kidney	-1.8499	1.9557
Femur	-1.9713	1.6560

Goodness-of-Fit

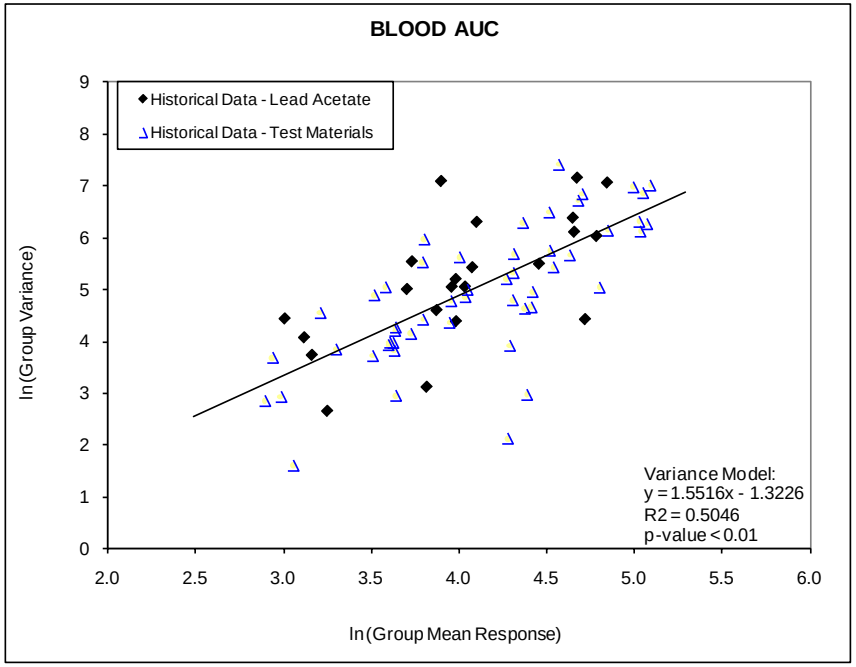
The goodness-of-fit of each dose-response model was assessed using the F test statistic and the adjusted coefficient of multiple determination (Adj R^2) as described by Draper and Smith (1998). A fit is considered acceptable if the p-value is less than 0.05.

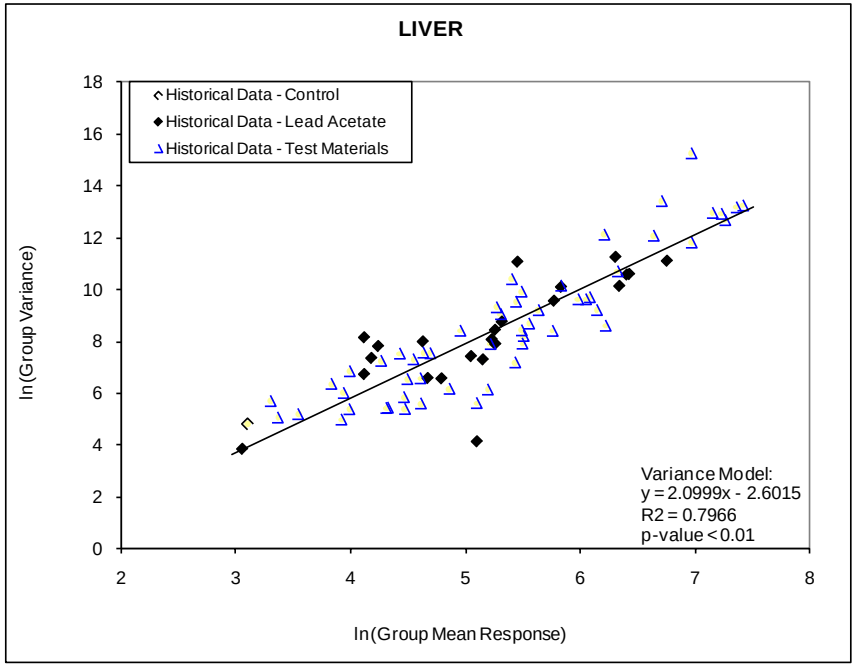
Data Assessment

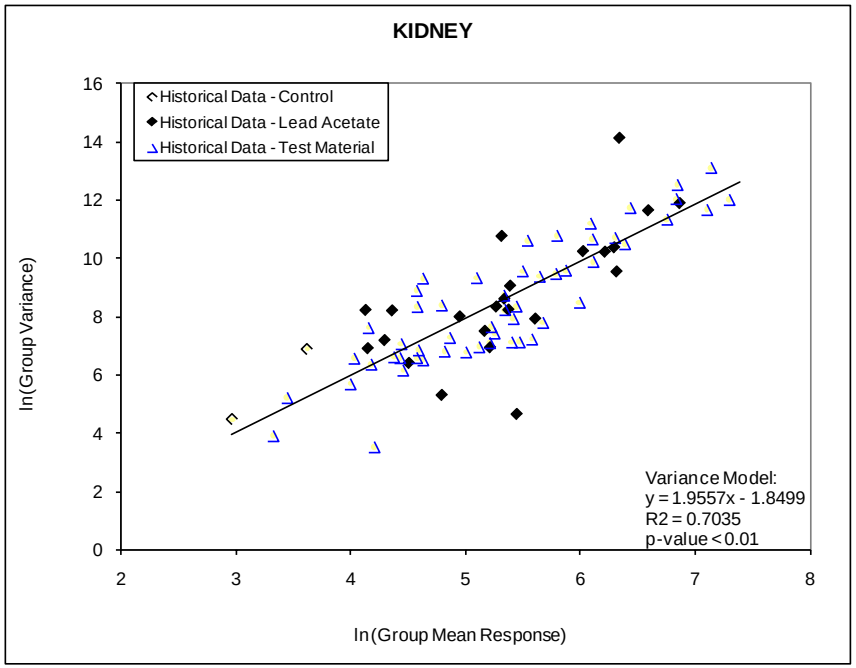
Lead data were assessed in two parts. First, blood lead data were reviewed. Occasionally, blood lead values are obtained that are clearly different than expected. Blood lead values that were more than a factor of 1.5 above or below the group mean for any given day were flagged as potentially unreliable data points. Each data point identified in this way was reviewed and professional judgment was used to decide if the value should be retained or excluded. In order to avoid inappropriate biases, blood lead exclusion designations are restricted to values that are clearly aberrant from a time-course and/or dose-response perspective. Once individual unreliable blood lead data points were removed, AUC was determined and this data set was modeled.

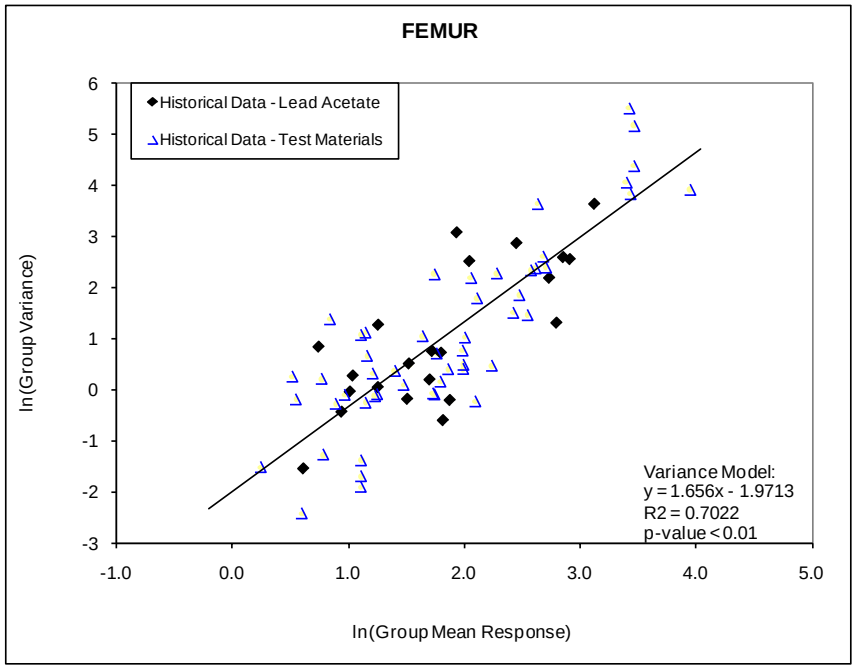
The modeled data set, including AUC, liver, kidney, and femur data was then analyzed for individual measured responses that appeared atypical compared to the responses from other animals in the same dose group. Responses that yielded standardized weighted residuals greater than 3.5 or less than -3.5 were considered to be potential outliers (Canavos 1984).

Figure 4-1. Variance Models for Lead Endpoints









4.4 Calculation of Lead RBA Estimates

Endpoint-Specific RBA Estimates

Lead RBA values were estimated using the basic statistical techniques recommended by Finney (1978). Each endpoint-specific RBA value was calculated as the ratio of a model coefficient for the reference material data set and for the test material data set:

Linear endpoints: $RBA_t = b_t / b_r$

Exponential endpoint: $RBA_t = c_t / c_r$

The uncertainly range about the RBA ratio was calculated using Fieller's Theorem as described by Finney (1978).

RBA Point Estimate

Because there are four independent estimates of RBA (one from each measurement endpoint) for a given test material, the final RBA estimate for a test material involves combining the four endpoint-specific RBA values into a single value (point estimate) and estimating the uncertainty around that point estimate. As described in USEPA (2007), analysis of data from multiple studies suggests that the four endpoint-specific RBA values are all approximately equally reliable (as reflected in the average coefficient of variation in RBA values derived from each endpoint). Therefore, the RBA point estimate for the test material was calculated as the simple mean of all four endpoint-specific RBA values.

The uncertainty bounds around this point estimate were estimated using Monte Carlo simulation. Values for RBA were drawn from the uncertainty distributions for each endpoint with equal frequency. Each endpoint-specific uncertainty distribution was assumed to be normal, with the mean equal to the best estimate of RBA and the standard deviation estimated from Fieller's Theorem (Finney 1978). The uncertainty in the point estimate was characterized as the range from the 5^{th} to the 95^{th} percentile of the mean across endpoints.

5.0 RESULTS

5.1 Clinical Signs

The doses of arsenic and lead administered in this study are below a level that is expected to cause toxicological responses in swine. No clinical signs of toxicity were noted in any of the animals used in the studies. Four swine received 1 cc Naxcel once per day for several days during the study (Table 5-1) to treat a systemic bacterial infection (swine were found with fever ≥104°F).

Table 5-1. NAXCEL Treatments

Swine Number	Days of Treatment
647	0–2
659	0–2
649	3–4
646	5–7

5.2 Dosing Deviations

Missed doses are summarized in Table 5-2. Most missed doses occurred on the first four days of dosing and were not specific to any particular group.

Table 5-2. Missed Dose Consumption

Swine Number	Study Day	% Dose Ingested		
		AM	PM	Combined
659	0	100	0	50
649	2	100	0	50
	3	0	0	0
	4	100	50	75
682	2	0	0	0
695	2	0	100	50
	3	100	50	75
	7	100	50	75
657	3	100	50	75
687	3	100	50	75
646	7	100	0	50
656	7	75	50	63

5.3 Background Arsenic and Lead

Measured values for urinary arsenic, tissue, and bone lead levels, and blood lead AUC for control animals are shown in Table 5-3. Urinary arsenic concentration (mean±SD) for all control animals combined across days 6 to 13 was 14.8±9.6 µg/L. Tissue and bone lead levels were typically less than detection limits, and blood lead AUC was 7.5 for all swine (after excluding the outlier for swine 685, day 8; see Table 5-5). The urinary arsenic and blood, bone and tissue lead values observed in the control animals were within the range of typical endogenous background levels reported from other studies (see Figures 3-2 and 4-1). Therefore, the background data support the view that the animals were not exposed to any significant exogenous sources of arsenic or lead throughout the study.

Table 5-3. Background Urinary Arsenic and Blood and Tissue Lead Levels

Analyte	Period of Collection	Measure	Swine Number		
			645	684	685
Arsenic	Days 6 and 7	Total As excreted (µg/48 hours)	10.41	15.9	10.04
	Days 9 and 10	Total As excreted (µg/48 hours)	34	4.46	13.62
	Days 12 and 13	Total As excreted (µg/48 hours)	25.93	5.61	12.8
Lead	Days 0, 2, 4, 8, 11, and 15	Blood AUC	7.5	7.5	7.5
	Day 15	Femur lead (ng/g)	<300	<300	<300
	Day 15	Liver lead (ng/g)	<10	<10	220
	Day 15	Kidney lead (ng/g)	<10	<10	30

5.4 Variance Data

As discussed in Sections 3.2 and 4.3, urinary arsenic and lead endpoint dose-response data are analyzed using weighted least squares regression and the weights are assigned using "external" variance models. To ensure that the variance models are valid, the variance values from each of the dose groups were superimposed on the historic data sets (Figures 5-1 and 5-2). As shown, the variances of the urinary arsenic and lead endpoint data from this study are consistent with the data used to generate the variance model.

Figure 5-1. NIST 2710a Data Compared to Urinary Arsenic Variance Model

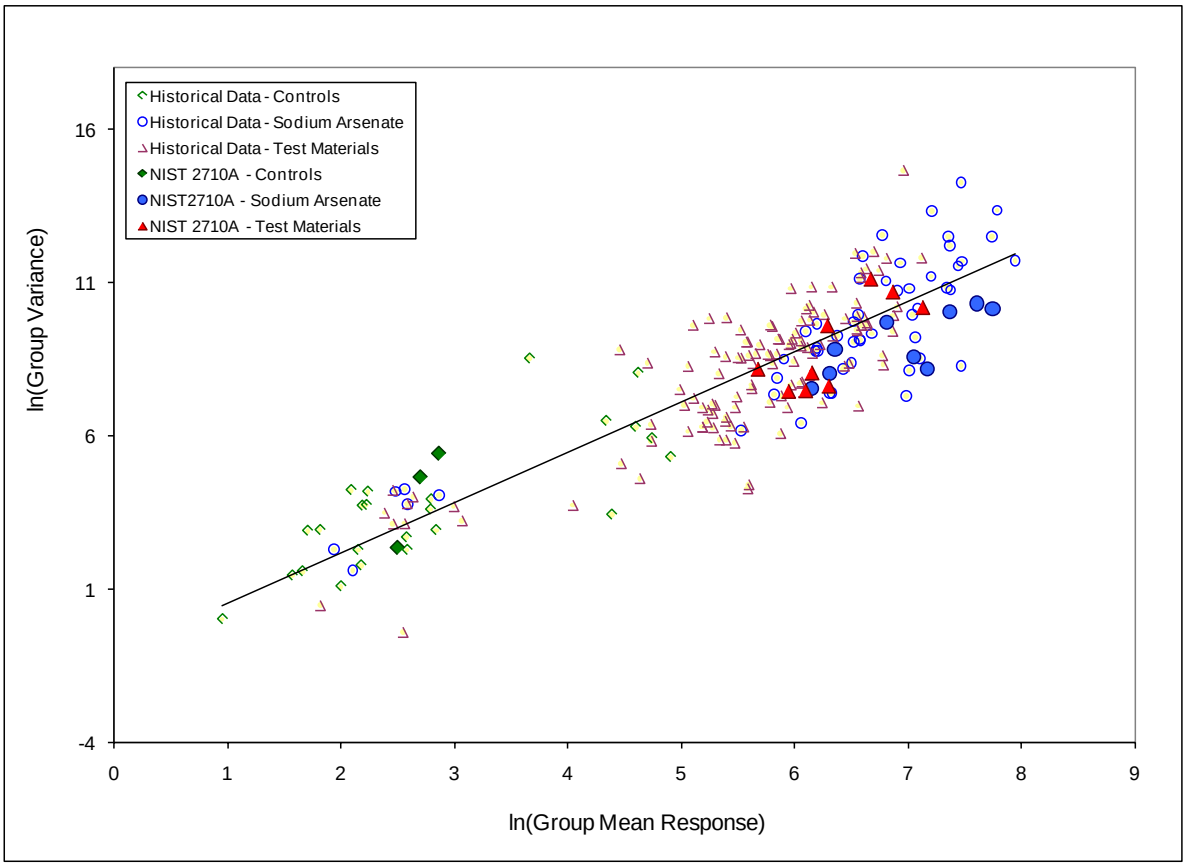
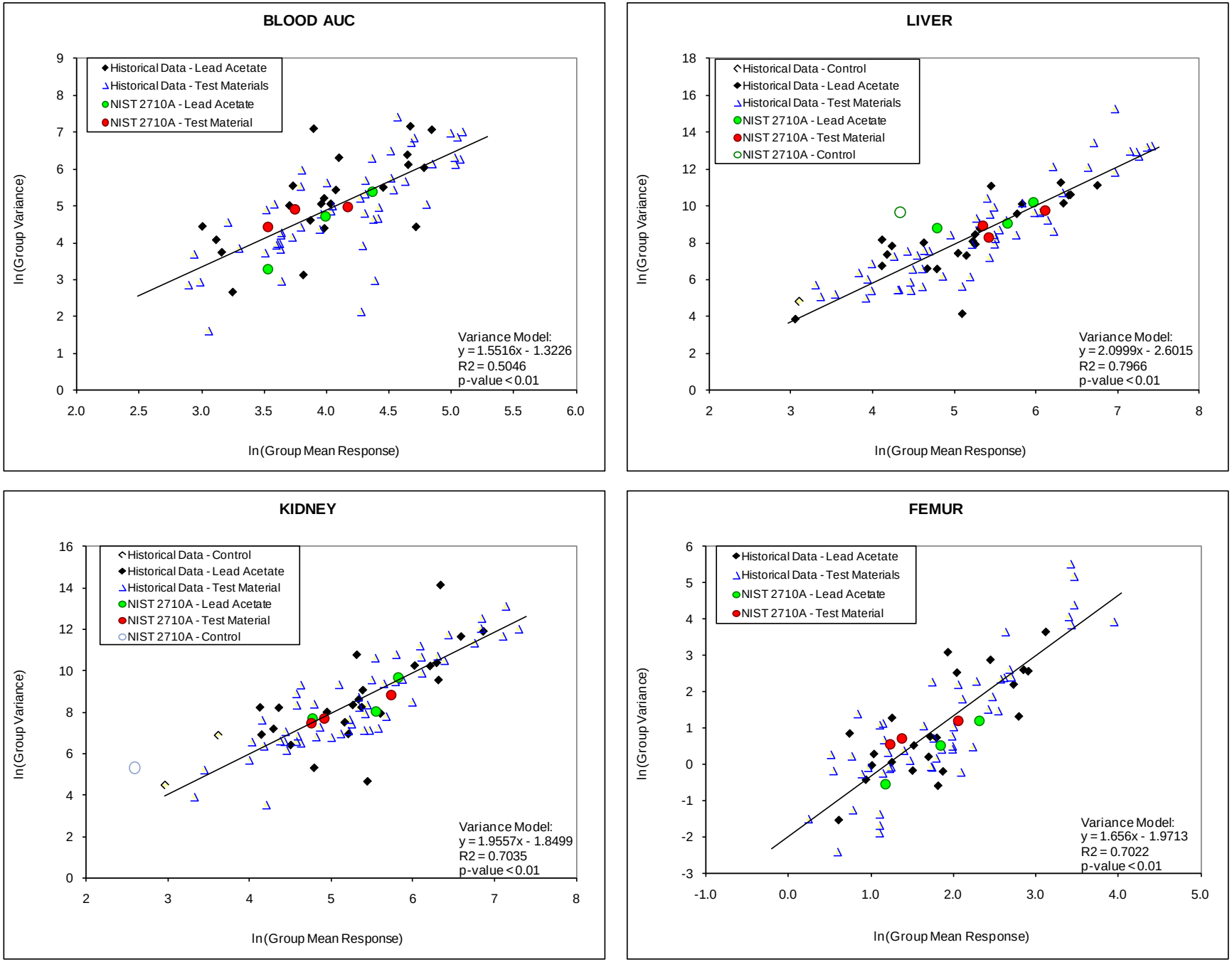


Figure 5-2. NIST 2710a Data Compared to Lead Variance Models



5.5 Dose-Response Modeling

5.5.1 Arsenic

Four urine samples were excluded due to high volume and low arsenic concentrations (see Section 3.2). This included swine 645 (all days) and swine 684 (days 6/7). Both swine were from the control group.

Once samples with a high urine volume to arsenic concentration were removed, the remaining data set was analyzed (Figures 5-3 through 5-6). No samples were identified as outliers (see Section 3.2).

All of the dose-response curves were approximately linear, with the slope of the best fit straight line being equal to the best estimate of the UEF. The resulting slopes (UEF estimates) for the final fittings of the test material and corresponding reference material are shown in Table 5-4.

Table 5-4. Urine Excretion Fraction (UEF) Estimates

Urine Collection Period (days)	Outliers Excluded	Slopes (UEF Estimates)	
		b_r	b_{t1}
Days 6/7	0	1.46	0.63
Days 9/10	0	1.67	0.68
Days 12/13	0	1.72	0.72
All Days	0	1.61	0.67

b_r = slope for reference material (sodium arsenate)
b_{t1} = slope for test material 1 (NIST 2710a)

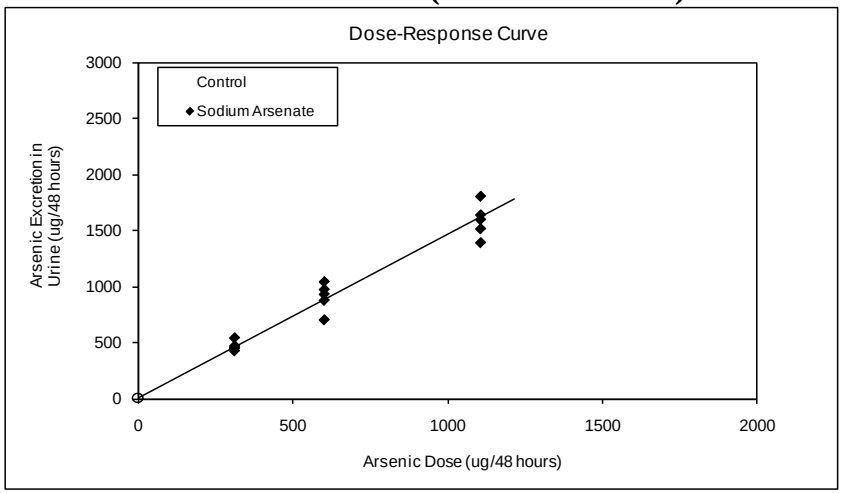
5.5.2 Lead

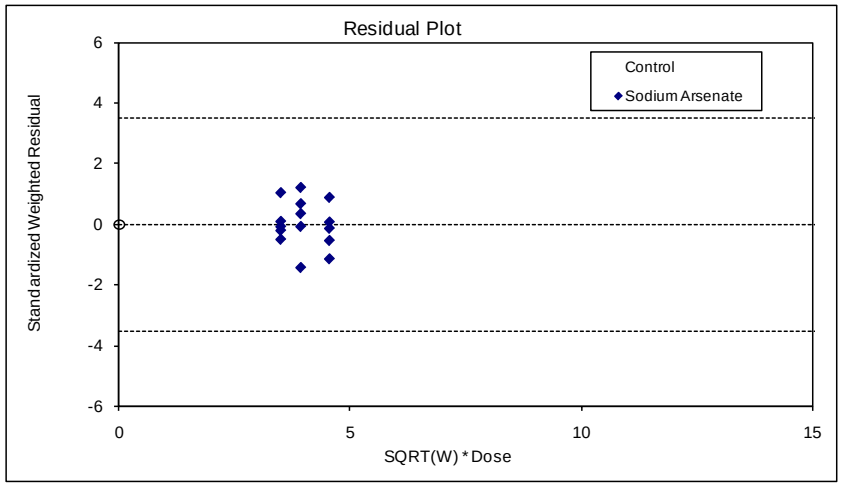
Group mean blood lead data for all swine are plotted by day in Figure 5-7 (Panel A). In this study, three values were judged as unreliable data points as described in Section 4.3 (see Table 5-5). These lead values were excluded from calculations of AUC, and the missing values were replaced by values interpolated from the preceding and following values from the same animal. Figure 5-7 (Panel B) shows the group mean blood lead data plotted by day based on the interpolated values for these three measurements. The AUC determinations for days 0–15 are presented in Table 5-6.

The blood lead AUC data were then modeled using an exponential equation. The results of this fitting are shown in Figure 5-8. The dose-response data for lead in liver, kidney, and bone (measured at sacrifice on day 15) were modeled using a linear equation. The results of these fittings are shown in Figures 5-9a (liver), 5-10 (kidney), and 11 (femur). One outlier was identified in the liver control group (as indicated in Figure 5-9a) and was excluded from the final evaluation for lead RBA (see Figure 5-9b). No other outliers were identified for any of the endpoints.

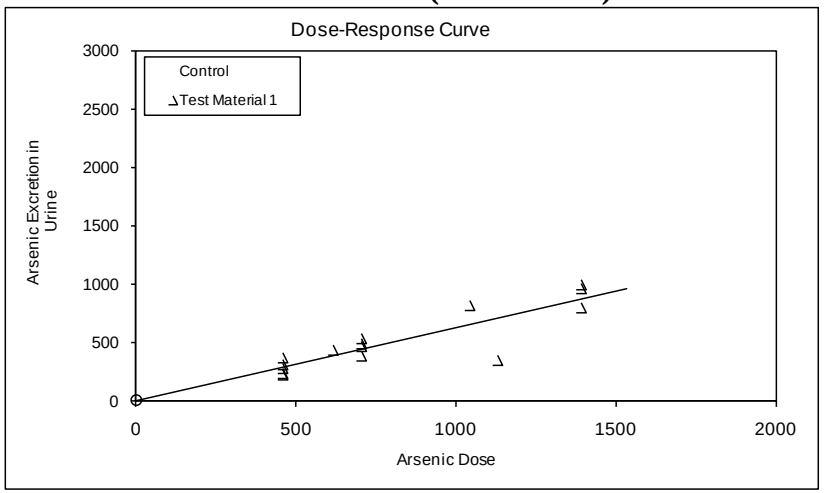
Figure 5-3. NIST 2710a Urinary Excretion of Arsenic: Days 6/7 (All Data)

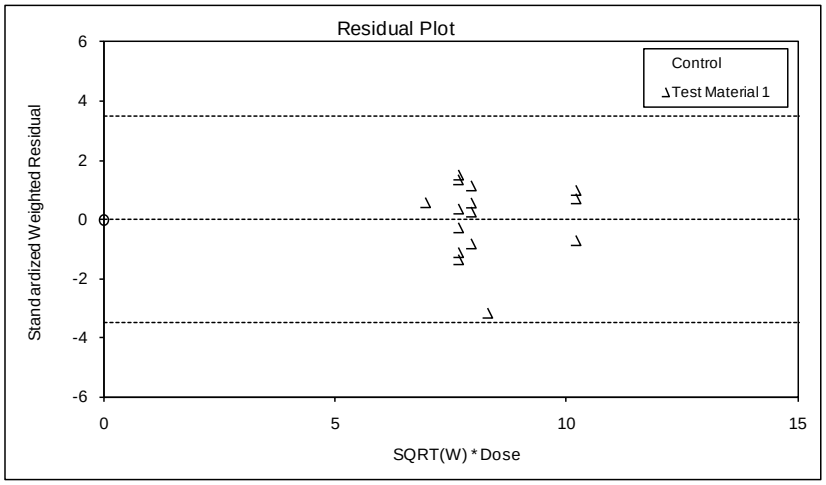
Reference Material (Sodium Arsenate)





Test Material 1 (NIST 2710a)





Summary of Fitting [a]

Parameter	Estimate	Standard Error
a	10.1	3.3
b_r	1.46	0.06
b_{t1}	0.63	0.03
Covariance (b_r,b_{t1})	0.0168	–
Degrees of Freedom	29	–

[a] $y = a + b_r*x_r + b_{t1}*x_{t1} + b_{t2}*x_{t2}$
where r = Reference Material, t1 = Test Material 1

ANOVA

Source	SSE	DF	MSE
Fit	888.35	2	444.18
Error	21.35	28	0.76
Total	909.71	30	30.32

Statistic	Estimate
F	582.478
P	<0.001
Adjusted R^2	0.9749

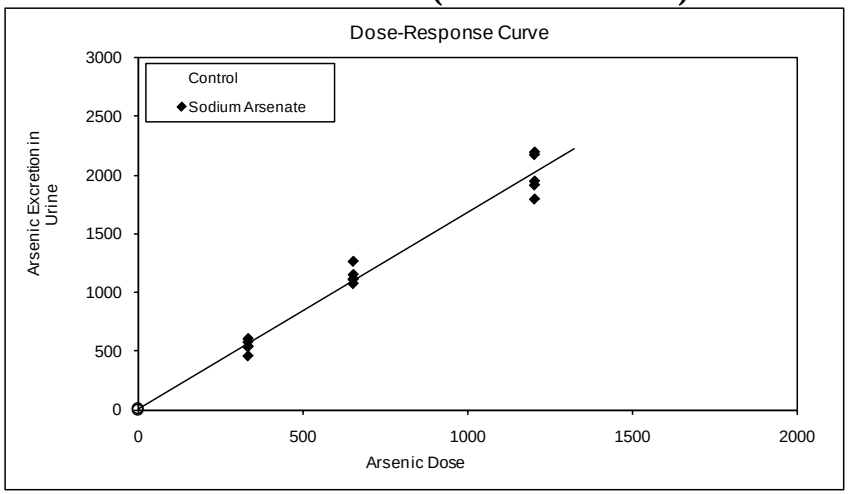
RBA and Uncertainty

	Test Material 1
RBA	0.43
Lower bound [c]	0.39
Upper bound [c]	0.47
Standard Error [c]	0.025

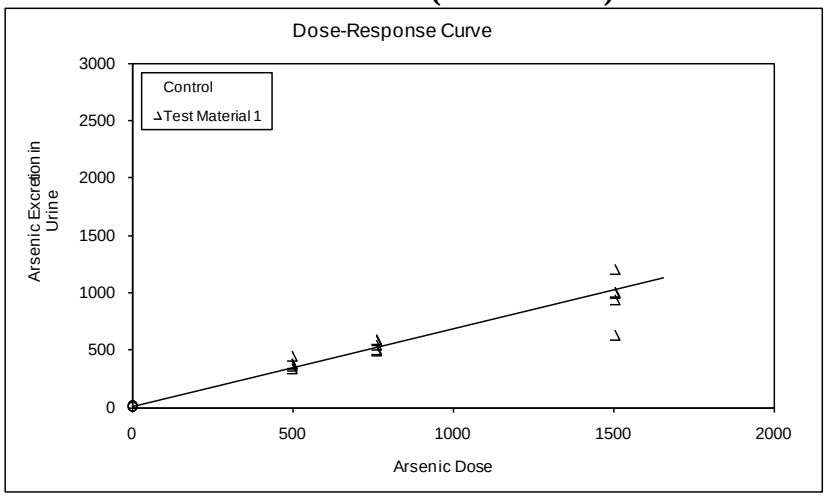
[c] 90% confidence interval calculated using Fieller's theorem

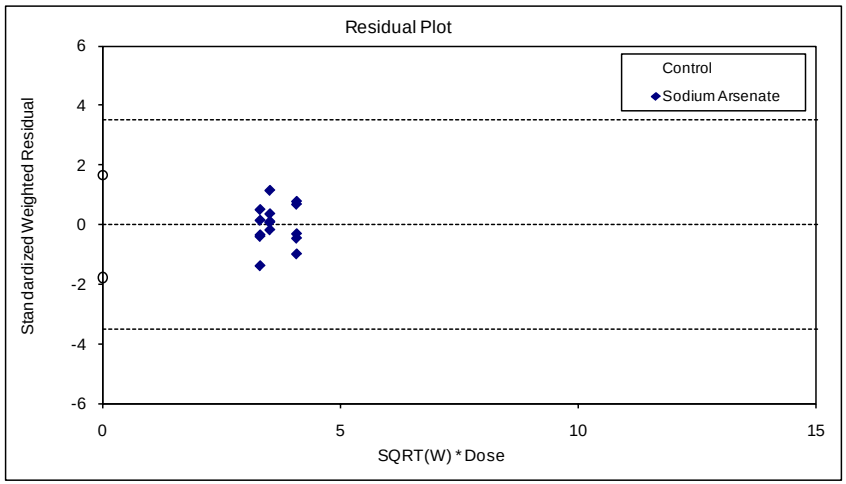
Figure 5-4. NIST 2710a Urinary Excretion of Arsenic: Days 9/10

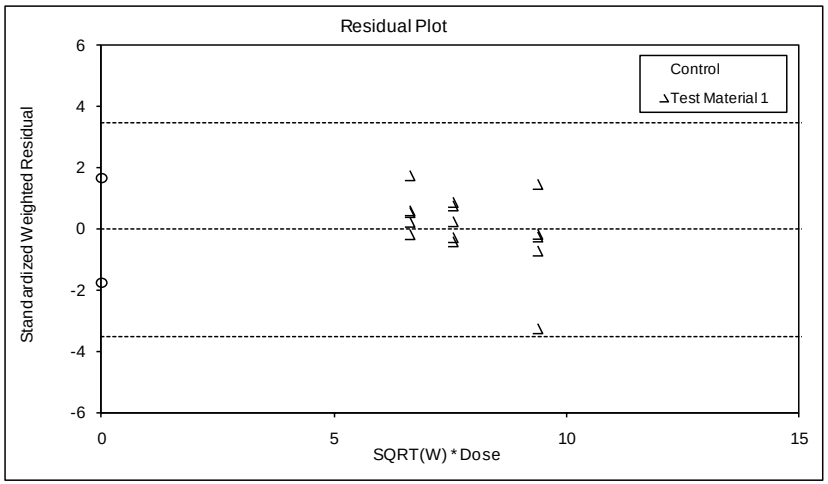
Reference Material (Sodium Arsenate)



Test Material 1 (NIST 2710a)







Summary of Fitting [a]

Parameter	Estimate	Standard Error
a	9.2	2.0
b_r	1.67	0.06
b_{t1}	0.68	0.03
Covariance (b_r,b_{t1})	0.0051	–
Degrees of Freedom	30	–

[a] $y = a + b_r*x_r + b_{t1}*x_{t1} + b_{t2}*x_{t2}$
where r = Reference Material, t1 = Test Material 1

ANOVA

Source	SSE	DF	MSE
Fit	983.49	2	491.75
Error	18.10	29	0.62
Total	1001.60	31	32.31

Statistic	Estimate
F	787.693
P	<0.001
Adjusted R^2	0.9807

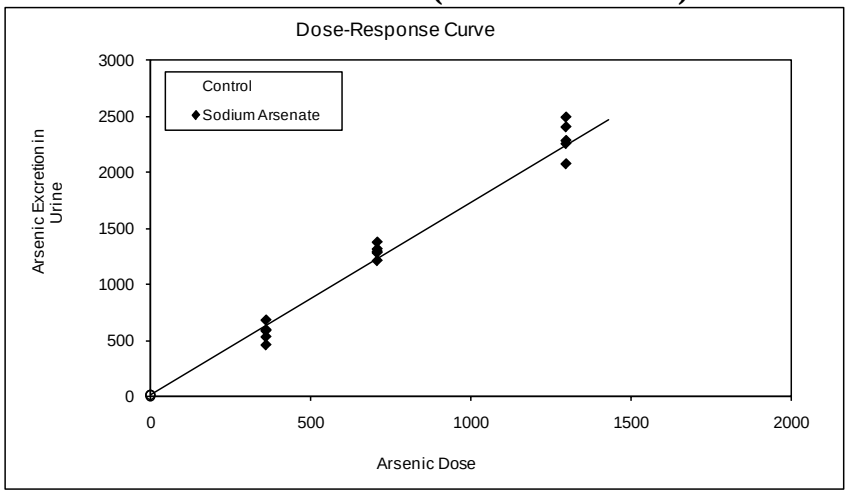
RBA and Uncertainty

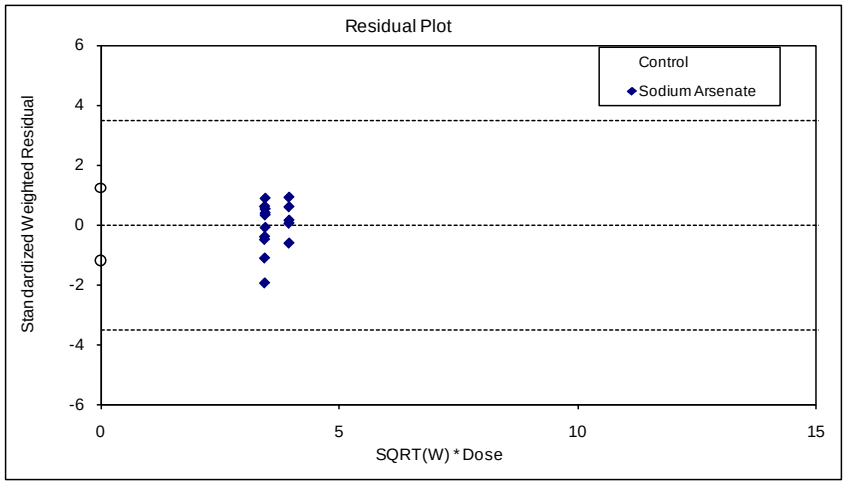
	Test Material 1
RBA	0.41
Lower bound [c]	0.37
Upper bound [c]	0.44
Standard Error [c]	0.021

[c] 90% confidence interval calculated using Fieller's theorem

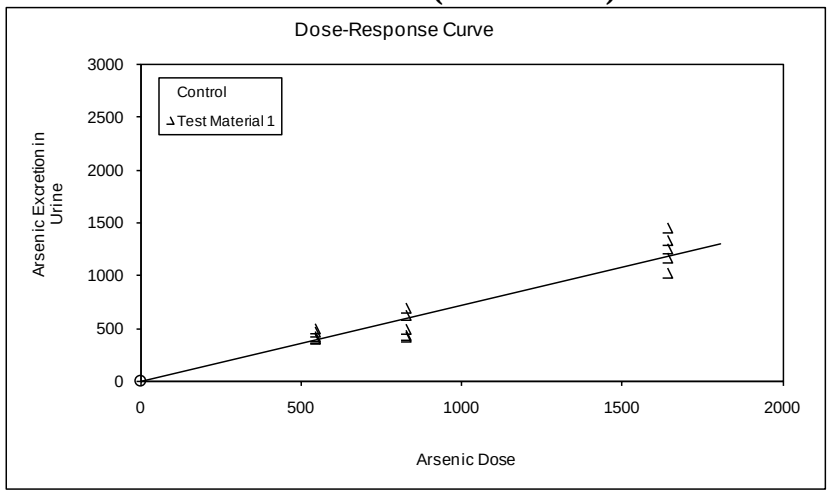
Figure 5-5. NIST 2710a Urinary Excretion of Arsenic: Days 12/13

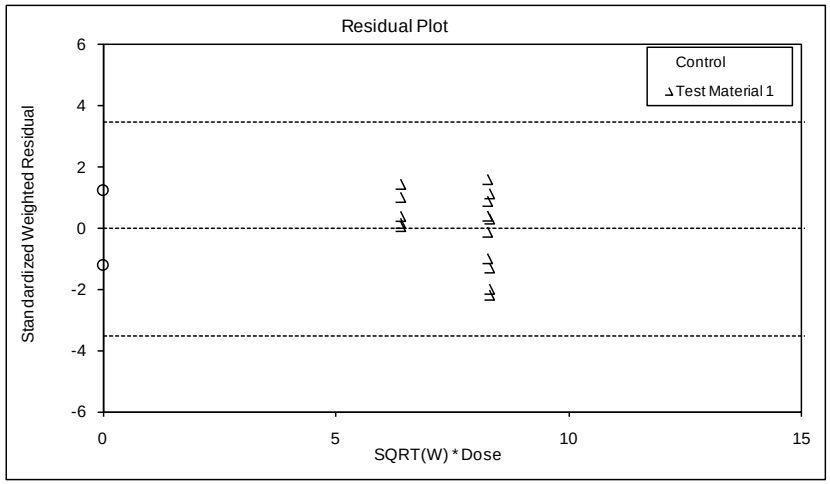
Reference Material (Sodium Arsenate)





Test Material 1 (NIST 2710a)





Summary of Fitting [a]

Parameter	Estimate	Standard Error
a	9.1	2.2
b_r	1.72	0.06
b_{t1}	0.72	0.03
Covariance (b_r,b_{t1})	0.0046	–
Degrees of Freedom	30	–

[a] $y = a + b_r*x_r + b_{t1}*x_{t1} + b_{t2}*x_{t2}$
where r = Reference Material, t1 = Test Material 1

ANOVA

Source	SSE	DF	MSE
Fit	1029.17	2	514.58
Error	21.36	29	0.74
Total	1050.52	31	33.89

Statistic	Estimate
F	698.767
P	<0.001
Adjusted R^2	0.9783

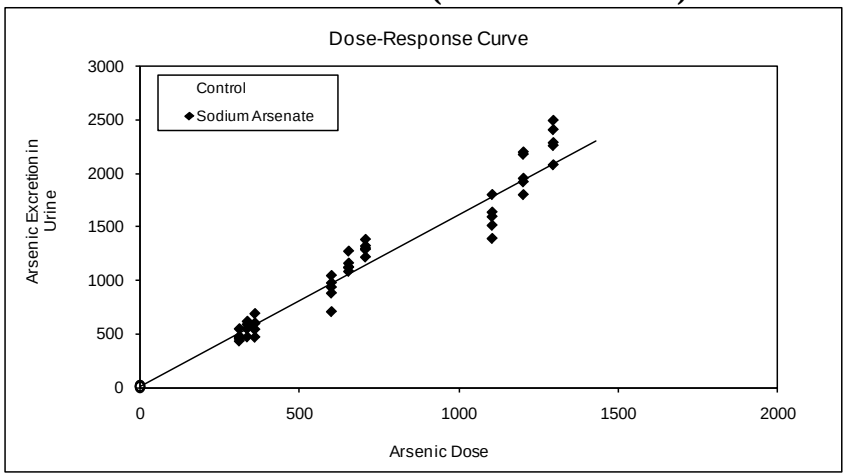
RBA and Uncertainty

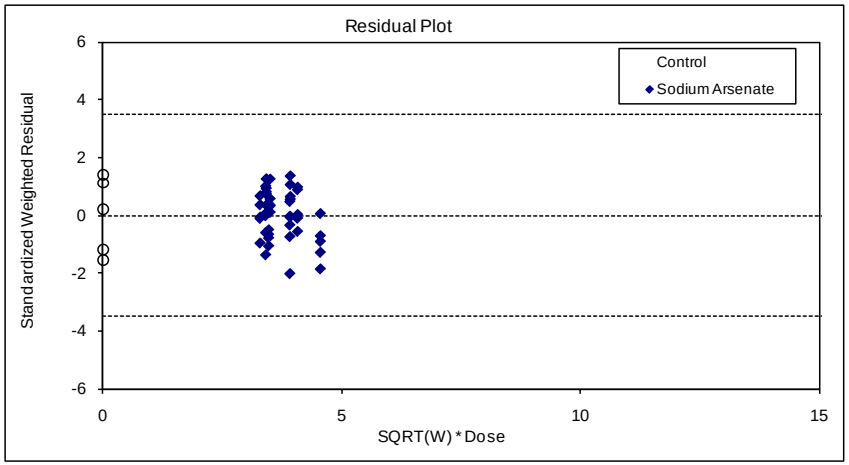
	Test Material 1
RBA	0.42
Lower bound [c]	0.38
Upper bound [c]	0.46
Standard Error [c]	0.022

[c] 90% confidence interval calculated using Fieller's theorem

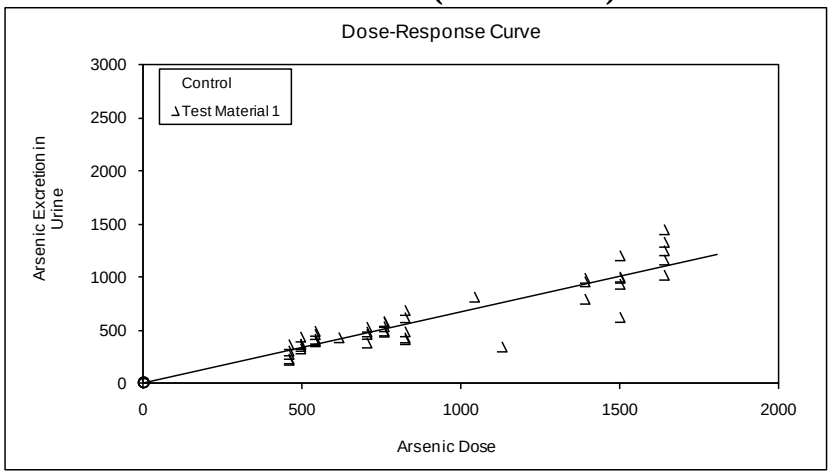
Figure 5-6. NIST 2710a Urinary Excretion of Arsenic: All Days

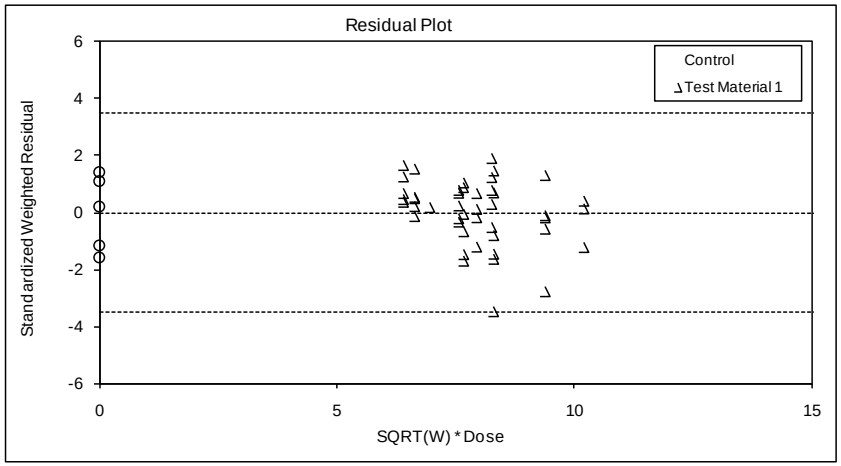
Reference Material (Sodium Arsenate)





Test Material 1 (NIST 2710a)





Summary of Fitting [a]

Parameter	Estimate	Standard Error
a	9.3	1.4
b_r	1.61	0.04
b_{t1}	0.67	0.02
Covariance (b_r,b_{t1})	0.0069	–
Degrees of Freedom	93	–

[a] $y = a + b_r*x_r + b_{t1}*x_{t1} + b_{t2}*x_{t2}$
where r = Reference Material, t1 = Test Material 1

ANOVA

Source	SSE	DF	MSE
Fit	2899.63	2	1449.82
Error	73.60	92	0.80
Total	2973.23	94	31.63

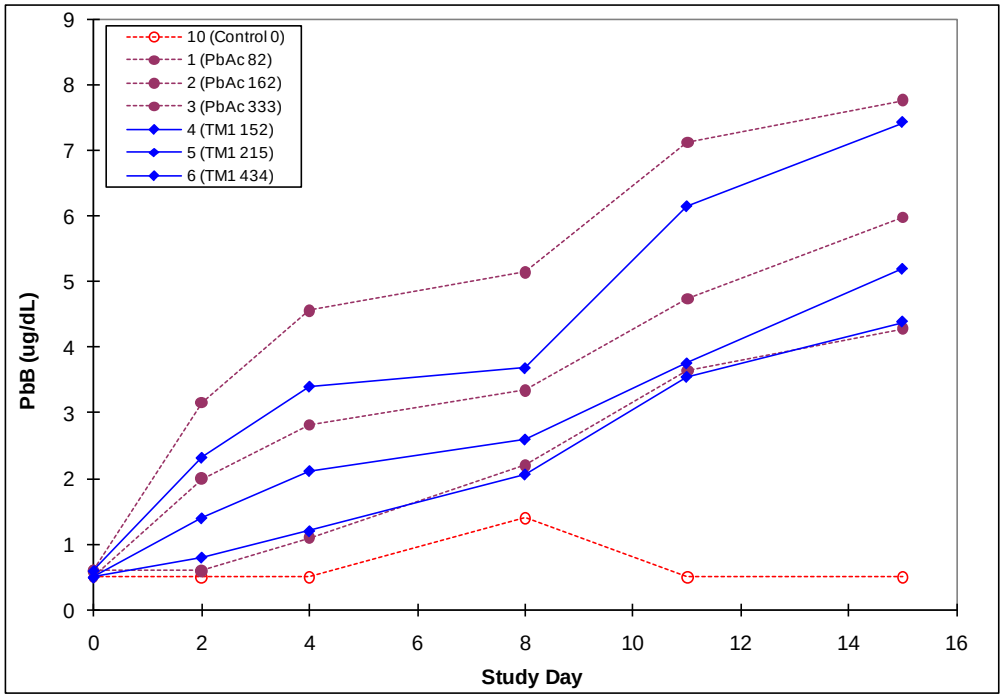
Statistic	Estimate
F	1812.252
P	<0.001
Adjusted R^2	0.9747

RBA and Uncertainty

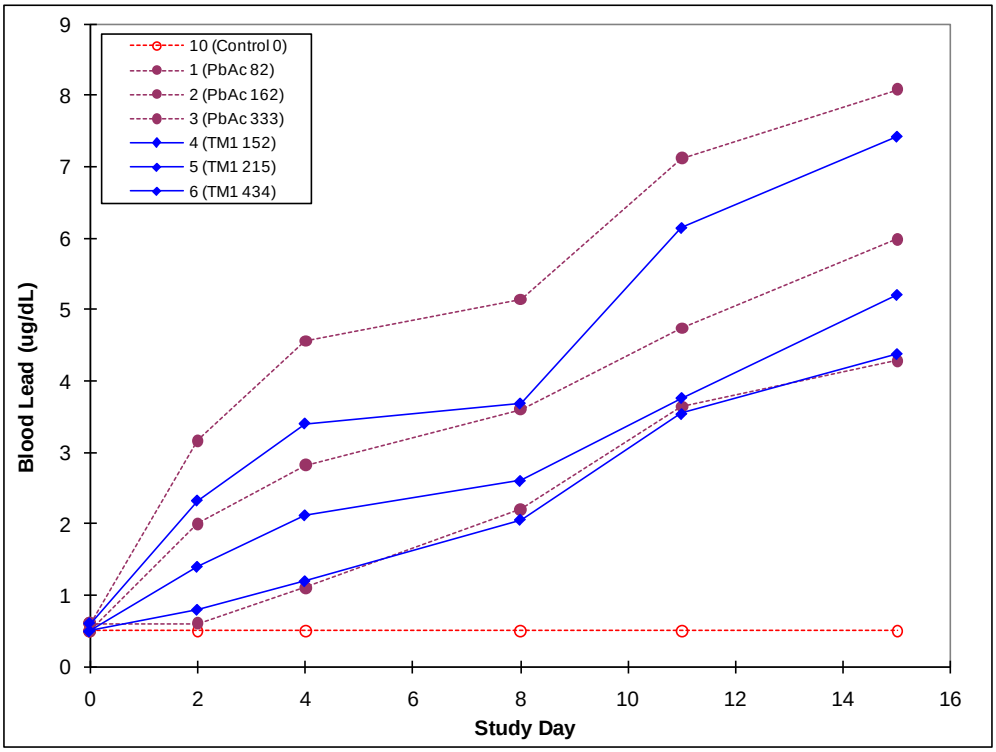
	Test Material 1
RBA	0.42
Lower bound [c]	0.40
Upper bound [c]	0.44
Standard Error [c]	0.014

[c] 90% confidence interval calculated using Fieller's theorem

Figure 5-7. Group Mean Blood Lead by Day



Panel A: All Data



Panel B: Outliers Excluded

Table 5-5. Blood Lead Outlier Identification

Group	Swine Number	Blood Lead by Day (µg/dL)					
		0	2	4	8	11	15
1	664	1	1	1	2	3	4.1
1	669	0.5	0.5	1	2	3.2	3.6
1	682	0.5	0.5	0.5	3	4.9	5.3
1	686	0.5	0.5	1	2	3	3.9
1	692	0.5	0.5	2	2	4.1	4.5
2	648	0.5	2	2	3.3	3.9	5.7
2	658	0.5	3	3	3.5	4.7	5.8
2	662	0.5	1	2	2[a]	4.3	6
2	676	0.5	3	4.1	4.8	6.3	7.3
2	690	0.5	1	3	3.1	4.5	5.1
3	665	0.5	2	2	3.7	6.9	7.5
3	666	1	5.1	7.2	6.2	8.2	9.8
3	667	0.5	3.6	4.4	4.7	6.3	8.5
3	681	0.5	2	3.4	5.8	8.1	7.7
3	691	0.5	3.1	5.8	5.3	6.1	5.3[b]
4	650	0.5	1	2	1	3	5.4
4	657	0.5	0.5	0.5	0.5	2	3.5
4	670	0.5	1	1	3.5	3.8	4.2
4	673	0.5	1	2	3.3	4.1	4
4	687	0.5	0.5	0.5	2	4.8	4.8
5	655	0.5	2	3	4	4.8	6.1
5	674	0.5	2	3.1	3	3.9	5.4
5	677	0.5	2	2	2	3.5	4.5
5	695	0.5	0.5	0.5	3	4.6	6.2
5	697	0.5	0.5	2	1	2	3.8
6	646	1	2	5.4	4.7	7.4	7.3
6	652	0.5	3	3.5	4.2	7.9	7.9
6	654	0.5	3.1	3.1	3.3	4.8	6.6
6	656	0.5	3	2	2	4.2	7.5
6	694	0.5	0.5	3	4.2	6.4	7.8
10	645	0.5	0.5	0.5	0.5	0.5	0.5
10	684	0.5	0.5	0.5	0.5	0.5	0.5
10	685	0.5	0.5	0.5	3.2[c]	0.5	0.5

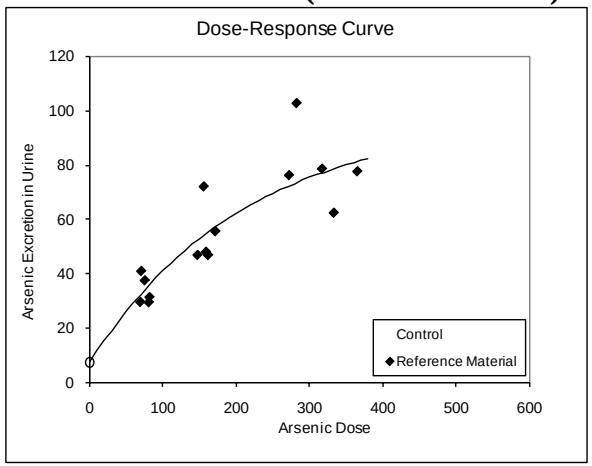
[a] Result was excluded as an outlier; a value of 3.3 was interpolated from previous and following results.
[b] Result was excluded as an outlier; a value of 6.9 was determined by taking the mean increase in daily blood lead levels.
[c] Result was excluded as an outlier; a value of 0.5 was interpolated from previous and following results.

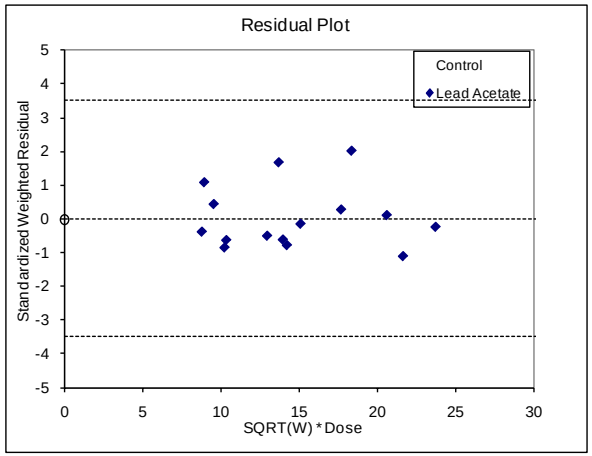
Table 5-6. Area Under Curve Determinations

Group	Swine Number	AUC (µg/dL-days) for Time Interval Shown					AUC Total (µg/dL-days)
		0–2	2–4	4–8	8–11	11–15	
1	664	2.00	2.00	6.00	7.50	14.20	31.70
1	669	1.00	1.50	6.00	7.80	13.60	29.90
1	682	1.00	1.00	7.00	11.85	20.40	41.25
1	686	1.00	1.50	6.00	7.50	13.80	29.80
1	692	1.00	2.50	8.00	9.15	17.20	37.85
2	648	2.50	4.00	10.60	10.80	19.20	47.10
2	658	3.50	6.00	13.00	12.30	21.00	55.80
2	662	1.50	3.00	10.62	11.42	20.60	47.14
2	676	3.50	7.10	17.80	16.65	27.20	72.25
2	690	1.50	4.00	12.20	11.40	19.20	48.30
3	665	2.50	4.00	11.40	15.90	28.80	62.60
3	666	6.10	12.30	26.80	21.60	36.00	102.80
3	667	4.10	8.00	18.20	16.50	29.60	76.40
3	681	2.50	5.40	18.40	20.85	31.60	78.75
3	691	3.60	8.90	22.20	17.10	26.00	77.80
4	650	1.50	3.00	6.00	6.00	16.80	33.30
4	657	1.00	1.00	2.00	3.75	11.00	18.75
4	670	1.50	2.00	9.00	10.95	16.00	39.45
4	673	1.50	3.00	10.60	11.10	16.20	42.40
4	687	1.00	1.00	5.00	10.20	19.20	36.40
5	655	2.50	5.00	14.00	13.20	21.80	56.50
5	674	2.50	5.10	12.20	10.35	18.60	48.75
5	677	2.50	4.00	8.00	8.25	16.00	38.75
5	695	1.00	1.00	7.00	11.40	21.60	42.00
5	697	1.00	2.50	6.00	4.50	11.60	25.60
6	646	3.00	7.40	20.20	18.15	29.40	78.15
6	652	3.50	6.50	15.40	18.15	31.60	75.15
6	654	3.60	6.20	12.80	12.15	22.80	57.55
6	656	3.50	5.00	8.00	9.30	23.40	49.20
6	694	1.00	3.50	14.40	15.90	28.40	63.20
10	645	1.00	1.00	2.00	1.50	2.00	7.50
10	684	1.00	1.00	2.00	1.50	2.00	7.50
10	685	1.00	1.00	2.00	1.50	2.00	7.50

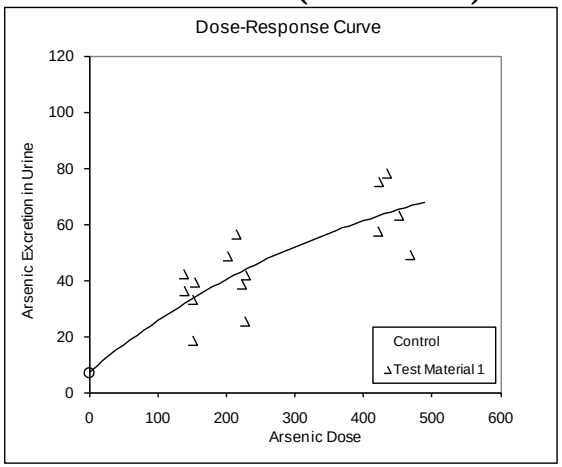
Figure 5-8. Blood Lead AUC Dose-Response

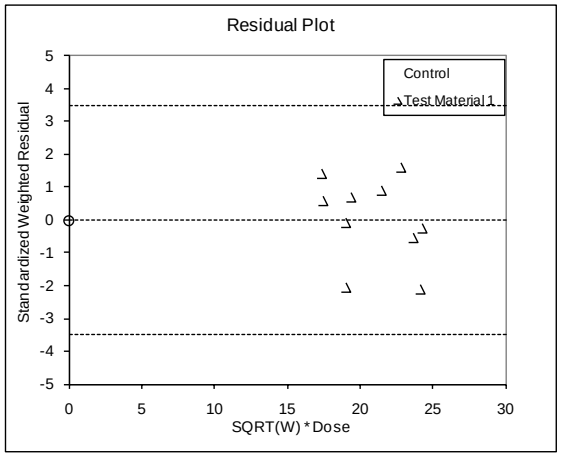
Reference Material (Sodium Arsenate)





Test Material 1 (NIST 2710a)





Summary of Fitting [a]

Parameter	Estimate	Standard Error
A	7.54E+00	1.38E+00
B	9.00E+01	1.91E+01
c_r	4.69E-03	1.63E-03
c_{t1}	2.28E-03	7.24E-04
Covariance (c_r,c_{t1})	0.9161	–
Degrees of Freedom	29	–

[a] $y = a + b\cdot(1-\exp(-c_r\cdot x_r)) + b\cdot(1-\exp(-c_{t1}\cdot x_{t1}))$
where r = Reference Material, t1 = Test Material 1

ANOVA

Source	MSE
Fit	154.08
Error	0.93
Total	10.50

Statistic	Estimate
F	166.559
P	<0.001
Adjusted R^2	0.9119

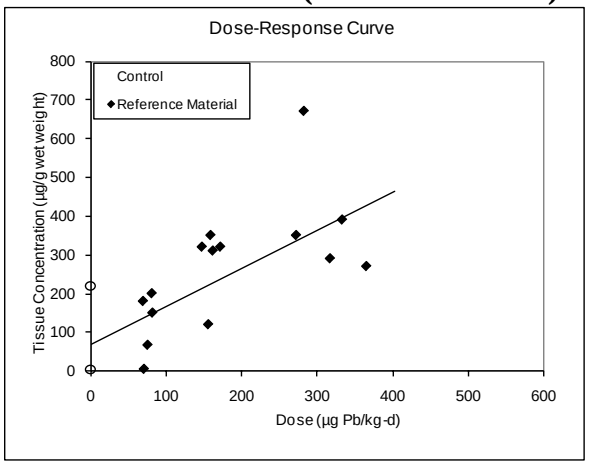
RBA and Uncertainty

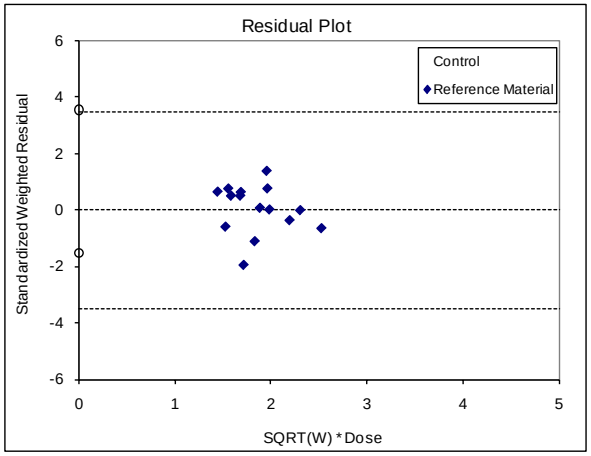
	Test Material 1
RBA	0.49
Lower bound [c]	0.38
Upper bound [c]	0.68
Standard Error [c]	0.065

[c] 90% confidence interval calculated using Fieller's theorem

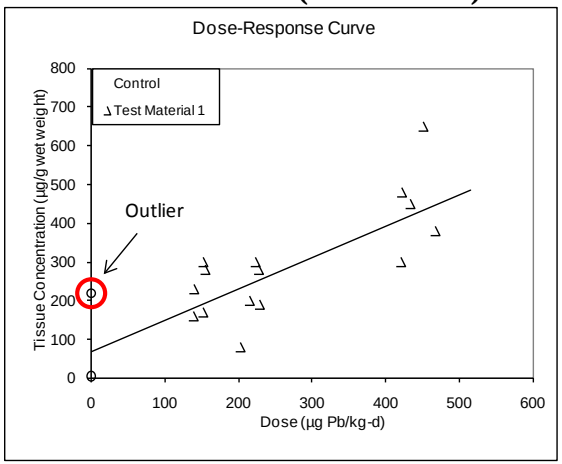
Figure 5-9a. Liver Lead Dose-Response (All Data)

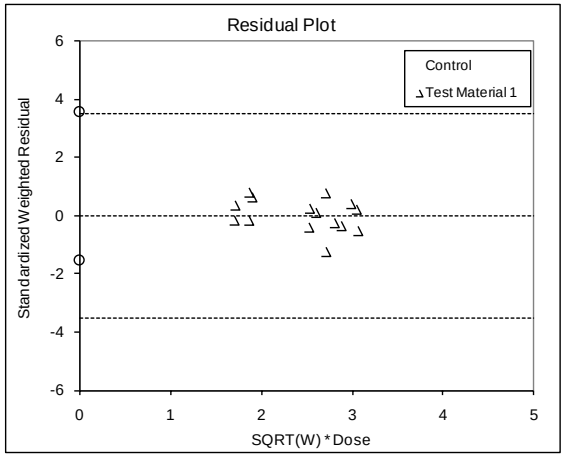
Reference Material (Sodium Arsenate)





Test Material 1 (NIST 2710a)





Summary of Fitting [a]

Parameter	Estimate	Standard Error
a	6.90E+01	2.24E+01
b_r	9.81E-01	2.80E-01
b_{t1}	8.09E-01	1.96E-01
Covariance (b_r,b_{t1})	0.2611	–
Degrees of Freedom	30	–

[a] $y = a + b_r \cdot x_r + b_{t1} \cdot x_{t1}$

ANOVA

Source	MSE
Fit	33.19
Error	2.85
Total	4.74

Statistic	Estimate
F	11.652
P	<0.001
Adjusted R^2	0.3997

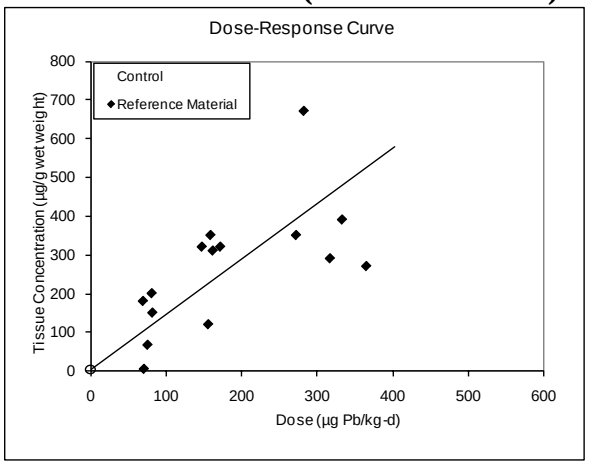
RBA and Uncertainty

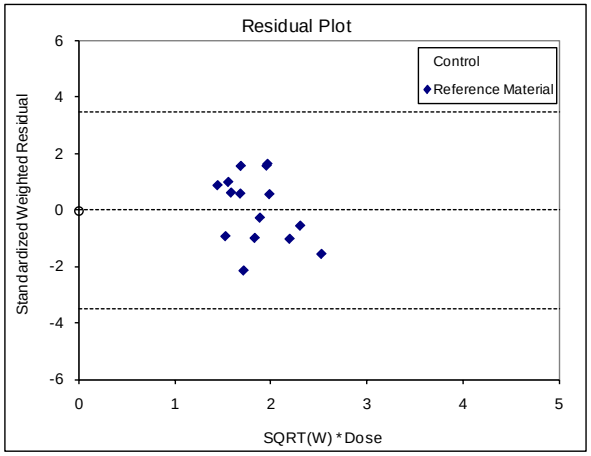
	Test Material 1
RBA	0.83
Lower bound [c]	0.47
Upper bound [c]	1.58
Standard Error [c]	0.266*

[c] 90% confidence interval calculated using Fieller's theorem
* g ≥0.05, estimate is uncertain

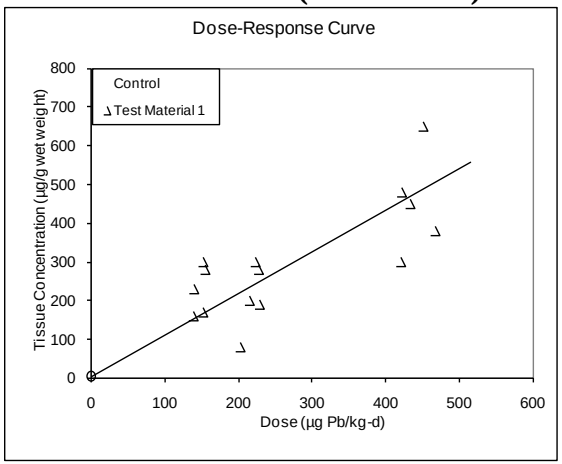
Figure 5-9b. Liver Lead Dose-Response (Outlier Excluded)

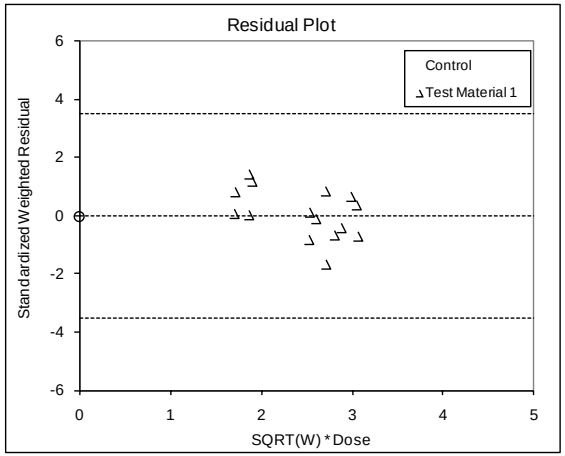
Reference Material (Sodium Arsenate)





Test Material 1 (NIST 2710a)





Summary of Fitting [a]

Parameter	Estimate	Standard Error
a	5.05E+00	1.23E+00
b_r	1.43E+00	1.62E-01
b_{t1}	1.07E+00	1.21E-01
Covariance (b_r,b_{t1})	0.0022	–
Degrees of Freedom	29	–

[a] $y = a + b_r \cdot x_r + b_{t1} \cdot x_{t1}$

ANOVA

Source	MSE
Fit	107.77
Error	1.38
Total	8.24

Statistic	Estimate
F	78.023
P	<0.001
Adjusted R^2	0.8325

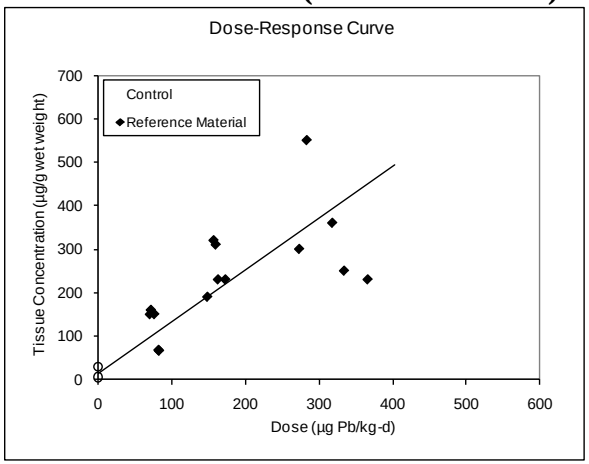
RBA and Uncertainty

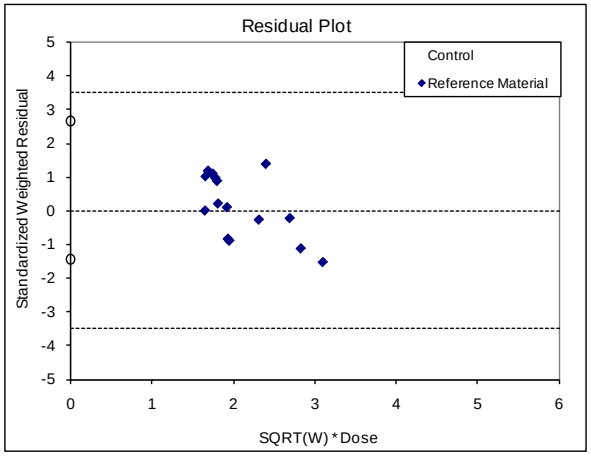
	Test Material 1
RBA	0.75
Lower bound [c]	0.57
Upper bound [c]	0.99
Standard Error [c]	0.120

[c] 90% confidence interval calculated using Fieller's theorem

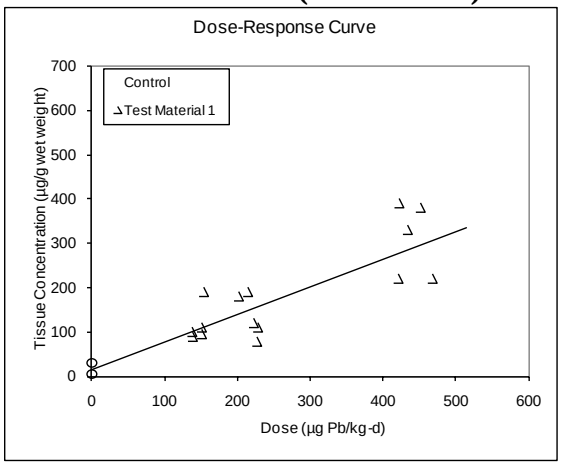
Figure 5-10. Kidney Lead Dose-Response

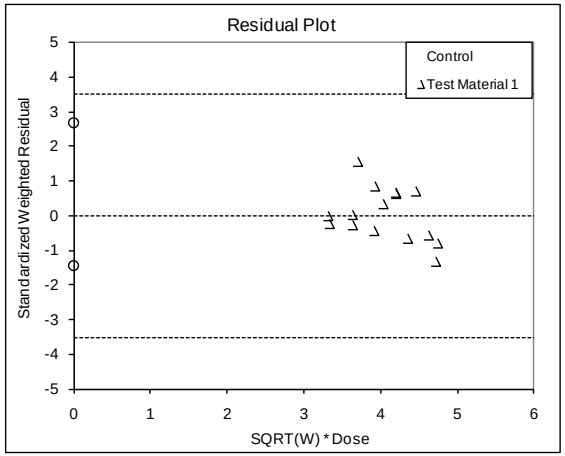
Reference Material (Sodium Arsenate)





Test Material 1 (NIST 2710a)





Summary of Fitting [a]

Parameter	Estimate	Standard Error
a	1.38E+01	3.60E+00
b_r	1.20E+00	1.54E-01
b_{t1}	6.27E-01	8.11E-02
Covariance (b_r,b_{t1})	0.0281	–
Degrees of Freedom	30	–

[a] $y = a + b_r \cdot x_r + b_{t1} \cdot x_{t1}$

ANOVA

Source	MSE
Fit	92.41
Error	1.58
Total	7.26

Statistic	Estimate
F	58.434
P	<0.001
Adjusted R^2	0.7821

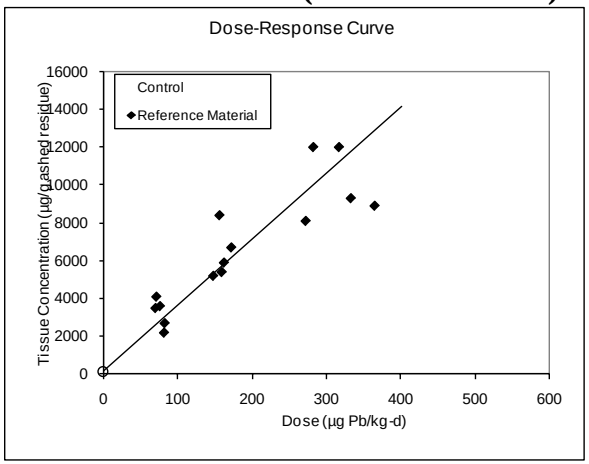
RBA and Uncertainty

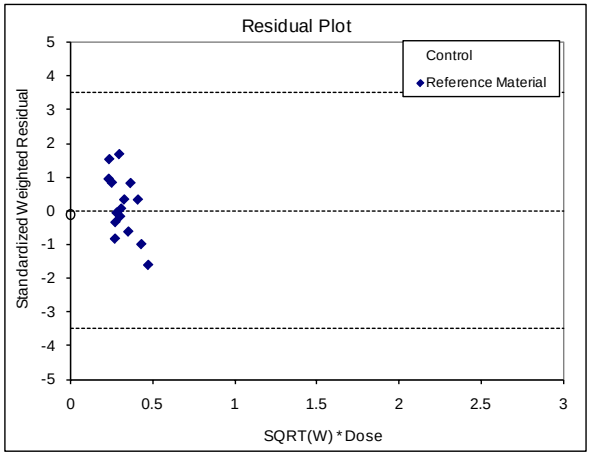
	Test Material 1
RBA	0.52
Lower bound [c]	0.38
Upper bound [c]	0.71
Standard Error [c]	0.094

[c] 90% confidence interval calculated using Fieller's theorem

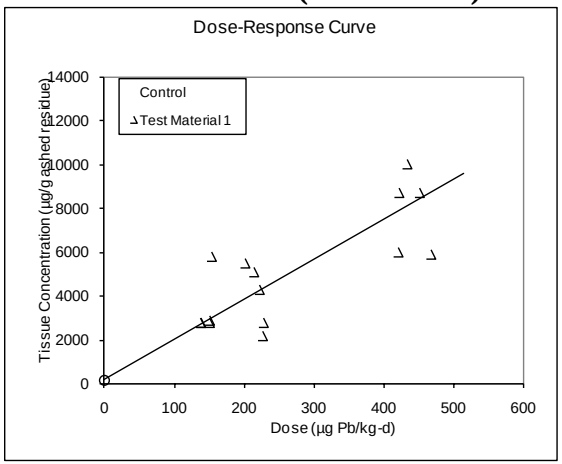
Figure 5-11. Femur Lead Dose-Response

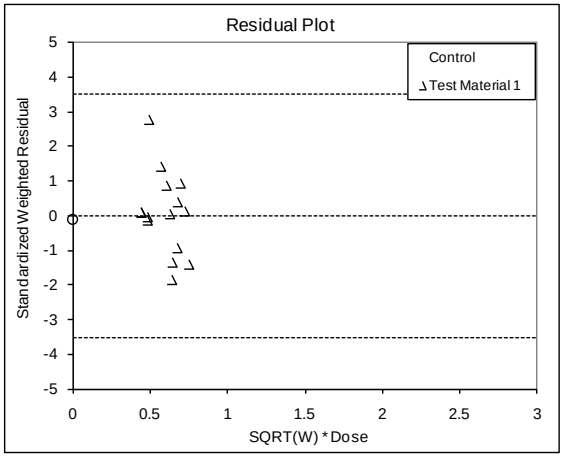
Reference Material (Sodium Arsenate)





Test Material 1 (NIST 2710a)





Summary of Fitting [a]

Parameter	Estimate	Standard Error
a	1.58E+02	4.52E+01
b_r	3.49E+01	2.61E+00
b_{t1}	1.83E+01	1.43E+00
Covariance (b_r,b_{t1})	0.0130	–
Degrees of Freedom	30	–

[a] $y = a + b_r \cdot x_r + b_{t1} \cdot x_{t1}$

ANOVA

Source	MSE
Fit	1861.27
Error	11.03
Total	126.67

Statistic	Estimate
F	168.808
P	<0.001
Adjusted R^2	0.9130

RBA and Uncertainty

	Test Material 1
RBA	0.53
Lower bound [c]	0.44
Upper bound [c]	0.63
Standard Error [c]	0.057

[c] 90% confidence interval calculated using Fieller's theorem

5.6 Calculated RBA Values

Estimated arsenic and lead RBA values (mean and 90% confidence interval) are shown in Tables 5-7 and 5-8. The best fit point estimate arsenic and lead RBAs for NIST 2710a soil are 42% and 57% for arsenic and lead, respectively.

Table 5-7. Estimated Arsenic RBA for NIST 2710a Soil

Urine Collection Period (days)	Estimated RBA (90% Confidence Interval)
Days 6/7	0.43 (0.39–0.47)
Days 9/10	0.41 (0.37–0.44)
Days 12/13	0.42 (0.38–0.46)
All Days	0.42 (0.40–0.44)

Table 5-8. Estimated Lead RBA for NIST 2710a Soil

Endpoint	Estimated RBA (90% Confidence Interval)
Blood lead AUC	0.49 (0.38–0.68)
Liver lead	0.75 (0.57–0.99)
Kidney lead	0.52 (0.38–0.71)
Femur lead	0.53 (0.44–0.63)
Point estimate	0.57 (0.39–0.84)

5.7 Uncertainty

The bioavailability estimates above are subject to uncertainty that arises from several different sources. One source of uncertainty is the inherent biological variability between different animals in a dose group, which in turn causes variability in the amount of arsenic or lead absorbed by the exposed animals. The between-animal variability results in statistical uncertainty in the best fit dose-response curves and, hence, uncertainty in the calculated values of RBA. Such statistical uncertainty is accounted for by the statistical models used above and is characterized by the uncertainty range around the RBA estimates.

However, there is also uncertainty in the extrapolation of RBA values measured in juvenile swine to young children or adults, and this uncertainty is not included in the statistical confidence bounds above. Even though the immature swine is believed to be a useful and meaningful animal model for gastrointestinal absorption in humans, it is possible that there are differences in physiological parameters that may influence RBA. Therefore, RBA values in swine may not be identical to values in children. In addition, RBA may depend on the amount and type of food in the stomach, since the presence of food can influence stomach pH, holding time, and possibly other factors that may influence solubilization and absorption of arsenic or lead. RBA values measured in this study are based on animals that have little or no food in their

stomach at the time of exposure and, hence, are likely to yield high-end values of RBA. Thus, these RBA values may be somewhat conservative for humans who ingest the site soils along with food. The magnitude of this bias is not known.

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APPENDIX A: GROUP ASSIGNMENTS FOR THE NIST 2710A ARSENIC AND LEAD RBA STUDY – DECEMBER 2009

Table A-1. Group Assignments for the NIST 2710a Arsenic and Lead RBA Study – December 2009

Swine Number	Group	Treatment	Target Arsenic Dose (µg/kg BW-day)	Target Lead Dose (µg/kg BW-day)
664 669 682 686 692	1	PbAc	0	75
648 658 662 676 690	2	PbAc	0	150
665 666 667 681 691	3	PbAc	0	300
650 657 670 673 687	4	TM1	40	143
655 674 677 695 697	5	TM1	60	215
646 652 654 656 694	6	TM1	120	430
668 671 672 679 688	7	NaAs	25	0
647 651 659 663 683	8	NaAs	50	0
649 678 680 689 693	9	NaAs	100	0
645 684 685	10	Control	0	0

APPENDIX B: BODY WEIGHTS

Table B-1. Body Weights

Group	Swine No.	Weight (kg)													
		Day -5 12/2/09	Group MBW	Day -1 12/6/09	Group MBW	Day 2 12/9/09	Group MBW	Day 5 12/12/09	Group MBW	Day 8 12/15/09	Group MBW	Day 11 12/18/09	Group MBW	Day 14 12/21/09	Group MBW
1 PbAc 75	664	7.8		8.9		9.5		10.3		11.0		12.3		13.6	
	669	9.8		10.5		11.2		12.1		13.3		14.4		15.5	
	682	9.2		9.3		10.4		11.1		12.1		13.2		14.6	
	686	8.8		8.7		9.5		10.5		11.3		12.3		13.9	
	692	8.7	8.86±0.73	9.3	9.34±0.70	10.1	10.14±0.71	11.3	11.06±0.71	12.3	12.00±0.91	13.2	13.08±0.86	14.7	14.46±0.74
2 PbAc 150	648	8.4		8.9		9.6		10.7		12.1		13.1		14.2	
	658	8.2		9.2		9.3		10.2		11.1		11.8		13.5	
	662	8.9		9.8		10.9		12.0		12.9		14.2		15.3	
	676	8.7		9.4		10.4		11.1		12.3		13.3		14.7	
	690	8.3	8.50±0.29	9.2	9.30±0.33	10.0	10.04±0.63	11.0	11.00±0.66	12.0	12.08±0.65	13.3	13.14±0.86	14.4	14.42±0.66
3 PbAc 300	665	7.8		8.1		9.1		10.0		11.0		11.6		12.5	
	666	9.1		9.6		10.7		11.5		12.8		14.0		15.1	
	667	9.6		10.4		11.2		12.1		13.3		14.0		15.6	
	681	8.1		8.3		9.3		10.5		11.3		12.4		14.0	
	691	8.0	8.52±0.79	8.6	9.00±0.97	8.8	9.82±1.06	9.2	10.66±1.16	9.6	11.60±1.48	10.0	12.40±1.70	11.2	13.68±1.83
4 TM1 40 (As)	650	7.7		8.6		9.4		10.2		11.1		12.4		13.8	
	657	7.9		8.2		9.2		10.1		10.9		12.2		13.6	
	670	7.7		8.1		9.4		10.1		11.0		11.9		13.5	
	673	9.3		9.9		10.4		11.3		12.2		13.3		14.6	
	687	9.2	8.36±0.82	9.7	8.90±0.85	10.3	9.74±0.56	10.8	10.50±0.53	11.9	11.42±0.59	13.0	12.56±0.58	14.5	14.00±0.51
5 TM1 60 (As)	655	8.5		9.5		10.0		11.0		12.2		13.2		14.8	
	674	8.9		9.7		10.7		12.1		12.7		13.9		15.7	
	677	8.9		8.5		9.8		10.8		11.6		12.9		14.1	
	695	8.0		8.4		9.0		9.7		10.5		11.5		12.8	
	697	8.7	8.60±0.37	9.7	9.16±0.65	9.8	9.86±0.61	10.2	10.76±0.91	11.3	11.66±0.84	12.3	12.76±0.91	13.8	14.24±1.09

Table B-1. Body Weights

Group	Swine No.	Weight (kg)													
		Day -5 12/2/09	Group MBW	Day -1 12/6/09	Group MBW	Day 2 12/9/09	Group MBW	Day 5 12/12/09	Group MBW	Day 8 12/15/09	Group MBW	Day 11 12/18/09	Group MBW	Day 14 12/21/09	Group MBW
6 TM1 120 (As)	646	8.3		8.8		9.6		10.4		11.4		12.5		14.2	
	652	8.9		9.5		10.2		11.1		12.1		13.3		14.9	
	654	8.8		9.3		10.2		11.2		12.3		13.3		14.8	
	656	8.2		8.9		9.3		10.0		10.4		11.7		13.2	
	694	8.5	8.54±0.30	8.6	9.02±0.37	9.5	9.76±0.42	10.3	10.60±0.52	11.4	11.52±0.75	12.6	12.68±0.66	14.0	14.22±0.69
7 NaAs 25	668	8.5		9.4		10.3		11.5		12.5		13.3		15.1	
	671	8.3		8.7		9.6		10.7		11.8		12.8		14.4	
	672	9.2		10.0		10.4		11.3		12.0		13.0		14.1	
	679	8.9		10.1		10.6		11.7		12.7		13.7		15.3	
	688	9.1	8.80±0.39	10.1	9.66±0.61	11.1	10.40±0.54	12.1	11.46±0.52	13.3	12.46±0.59	14.3	13.42±0.60	15.6	14.90±0.63
8 NaAs 50	647	8.1		8.7		9.3		10.1		11.2		12.2		13.9	
	651	8.8		9.8		10.7		11.6		12.7		13.9		15.4	
	659	8.1		9.4		9.9		10.9		12.1		13.0		14.6	
	663	7.9		9.2		10.1		11.0		12.0		13.1		15.0	
	683	9.0	8.38±0.49	9.7	9.36±0.44	10.6	10.12±0.57	11.5	11.02±0.60	12.5	12.10±0.58	13.6	13.16±0.65	15.1	14.80±0.58
9 NaAs 100	649	8.0		8.2		8.8		9.4		10.4		11.2		13.1	
	678	7.9		8.4		9.4		10.0		11.1		12.4		13.7	
	680	8.3		7.9		8.6		8.7		9.6		10.2		11.3	
	689	8.9		9.3		9.7		10.8		11.6		12.5		14.0	
	693	8.9	8.40±0.48	9.7	8.70±0.76	10.6	9.42±0.79	11.4	10.06±1.08	12.5	11.04±1.11	13.6	11.98±1.31	15.1	13.44±1.40
10 Control 0	645	8.7		9.0		9.3		10.0		10.9		11.7		13.1	
	684	8.3		8.6		10.0		10.4		11.4		12.6		14.3	
	685	8.1	8.37±0.31	8.9	8.83±0.21	9.9	9.73±0.38	10.8	10.40±0.40	11.3	11.20±0.26	12.5	12.27±0.49	14.1	13.83±0.64

Group MBW = means and standard deviations of each group's body weight.

APPENDIX C: TYPICAL FEED COMPOSITION

Appendix C. Typical Feed Composition

Purina TestDiet® 5TXP: Porcine Grower Purified Diet with Low Lead[a]

INGREDIENTS			
Corn Starch, %	25.2	Potassium Phosphate, %	0.87
Sucrose, %	20.9648	Calcium Carbonate, %	0.7487
Glucose, %	16	Salt, %	0.501
Soy Protein Isolate, %	14.9899	Magnesium Sulfate, %	0.1245
Casein - Vitamin Free, %	8.5	DL-Methionine, %	0.0762
Powdered Cellulose, %	6.7208	Choline Chloride, %	0.0586
Corn Oil, %	3.4046	Vitamin/Mineral Premix, %	0.0577
Dicalcium Phosphate, %	1.7399	Sodium Selenite, %	0.0433

NUTRITIONAL PROFILE[b]				
Protein, %	**21**	**Fat, %**		**3.5**
Arginine, %	1.42	Cholesterol, ppm		0
Histidine, %	0.61	Linoleic Acid, %		1.95
Isoleucine, %	1.14	Linolenic Acid, %		0.03
Leucine, %	1.95	Arachidonic Acid, %		0
Lysine, %	1.56	Omega-3 Fatty Acids, %		0.03
Methionine, %	0.49	Total Saturated Fatty Acids, %		0.43
Cystine, %	0.23	Total Monounsaturated Fatty Acids, %		0.82
Phenylalanine, %	1.22	Polyunsaturated Fatty Acids, %		1.98
Tyrosine, %	1.03			
Threonine, %	0.88	**Fiber (max), %**		**6.8**
Tryptophan, %	0.32			
Valine, %	1.16	**Carbohydrates, %**		**62.2**
Alanine, %	0.95			
Aspartic Acid, %	2.33	**Energy (kcal/g) [c]**		**3.62**
Glutamic Acid, %	4.96	*From:*	*kcal*	*%*
Glycine, %	0.79	Protein	0.84	23.1
Proline, %	1.83	Fat (ether extract)	0.315	8.7
Serine, %	1.25	Carbohydrates	2.487	68.3
Taurine, %	0			
Minerals		**Vitamins**		
Calcium, %	0.8	Vitamin A, IU/g		1.7
Phosphorus, %	0.72	Vitamin 0-3 (added), IU/g		0.2
Phosphorus (available), %	0.4	Vitamin E, IU/kg		11
Potassium, %	0.27	Vitamin K (as menadione), ppm		0.52
Magnesium, %	0.04	Thiamin Hydrochloride, ppm		1
Sodium, %	0.3	Ribonavin, ppm		3.1
Chlorine, %	0.31	Niacin, ppm		13
Fluorine, ppm	0	Pantothenic Acid, ppm		9
Iron, ppm	82	Folic Acid, ppm		0.3
Zinc, ppm	84	Pyridoxine, ppm		1.7
Manganese, ppm	3	Biotin, ppm		0.1
Copper, ppm	4.9	Vitamin B-12, mcg/kg		15
Cobalt, ppm	0.1	Choline Chloride, ppm		410
Iodine, ppm	0.15	Ascorbic Acid, ppm		0
Chromium, ppm	0			
Molybdenum, ppm	0.01			
Selenium, ppm	0.26			

[a] This special purified diet was originally developed for lead RBA studies.
[b] Based on the latest ingredient analysis information. Since nutrient composition of natural ingredients varies, analysis will differ accordingly. Nutrients expressed as percent of ration on an arsenic fed basis except where otherwise indicated.
[c] Energy (kcal/gm) – sum of decimal fractions of protein, fat, and carbohydrate × 4, 9, and 4 kcal/g, respectively.

APPENDIX D: URINARY ARSENIC ANALYTICAL RESULTS AND URINE VOLUMES FOR NIST 2710A STUDY SAMPLES

Table D-1. Urinary Arsenic Analytical Results and Urine Volumes for NIST 2710a Study Samples

Group	Material	Collection Period (days)	Sample ID	Swine Number	Urinary Arsenic Concentration (µg/L)	Urine Volume (mL)
4	TM1	6/7	NISTa-573	650	69	3320
			NISTa-618	657	59	4090
			NISTa-627	670	28	13380
			NISTa-594	673	31	10200
			NISTa-608	687	34	8350
		9/10	NISTa-646	650	120	3140
			NISTa-667	657	38	10000
			NISTa-642	670	27	12420
			NISTa-666	687	36	12380
			NISTa-669	673	54	6640
		12/13	NISTa-719	650	79	5940
			NISTa-732	657	44	11350
			NISTa-721	670	29	14675
			NISTa-729	673	39	10320
			NISTa-695	687	49	8360
5	TM1	6/7	NISTa-605	655	120	4480
			NISTa-592	674	25	18840
			NISTa-596	677	190	2600
			NISTa-619	695	140	3140
			NISTa-607	697	49	7960
		9/10	NISTa-660	655	140	4220
			NISTa-658	674	60	8200
			NISTa-653	677	150	3880
			NISTa-638	695	160	3140
			NISTa-652	697	69	7860
		12/13	NISTa-694	695	79	5540
			NISTa-733	677	130	4820
			NISTa-736	697	28	15065
			NISTa-722	655	140	4960
			NISTa-710	674	66	7500
6	TM1	6/7	NISTa-611	656	60	5880
			NISTa-600	646	130	6300
			NISTa-621	654	76	10520
			NISTa-583	694	88	10940
			NISTa-599	652	210	4740
		9/10	NISTa-639	646	130	7660
			NISTa-649	652	471	2560
			NISTa-659	654	270	3480
			NISTa-631	656	110	5720
			NISTa-681	694	74	13600
		12/13	NISTa-728	646	180	7400
			NISTa-693	652	464	2700
			NISTa-715	654	240	4860
			NISTa-731	656	160	6400
			NISTa-708	694	93	15585

Table D-1. Urinary Arsenic Analytical Results and Urine Volumes for NIST 2710a Study Samples

Group	Material	Collection Period (days)	Sample ID	Swine Number	Urinary Arsenic Concentration (µg/L)	Urine Volume (mL)
7	NaAs	6/7	NISTa-576	668	210	2580
			NISTa-580	671	110	4280
			NISTa-597	672	130	3280
			NISTa-595	679	95	4720
			NISTa-586	688	95	4820
		9/10	NISTa-663	671	110	4920
			NISTa-628	672	110	4220
			NISTa-650	668	190	3220
			NISTa-680	679	69	8460
			NISTa-641	688	96	5680
		12/13	NISTa-702	668	200	3420
			NISTa-690	671	81	7360
			NISTa-724	672	100	5340
			NISTa-720	679	97	6060
			NISTa-716	688	97	4760
8	NaAs	6/7	NISTa-622	663	190	5480
			NISTa-591	683	230	4045
			NISTa-624	647	85	8260
			NISTa-612	651	170	5720
			NISTa-623	659	300	2920
		9/10	NISTa-647	647	57	22280
			NISTa-634	651	220	5260
			NISTa-635	659	360	3100
			NISTa-630	663	250	4320
			NISTa-668	683	250	4480
		12/13	NISTa-712	651	230	5280
			NISTa-697	647	93	13940
			NISTa-704	659	531	2420
			NISTa-711	663	200	6900
			NISTa-707	683	140	9420
9	NaAs	6/7	NISTa-581	678	100	16360
			NISTa-572	680	380	4740
			NISTa-616	689	240	6640
			NISTa-582	693	450	3360
			NISTa-606	649	310	4480
		9/10	NISTa-636	649	573	3840
			NISTa-656	678	150	12000
			NISTa-655	680	440	4440
			NISTa-665	693	558	3440
			NISTa-675	689	220	9900
		12/13	NISTa-700	649	469	4820
			NISTa-709	678	170	13460
			NISTa-730	680	421	4940
			NISTa-738	689	160	15060
			NISTa-734	693	550	4540

Table D-1. Urinary Arsenic Analytical Results and Urine Volumes for NIST 2710a Study Samples

Group	Material	Collection Period (days)	Sample ID	Swine Number	Urinary Arsenic Concentration (µg/L)	Urine Volume (mL)
10	Control	6/7	NISTa-617	684	1	15900
			NISTa-609	685	2	5020
			NISTa-604	645	0.5	20820
		9/10	NISTa-651	645	2	17000
			NISTa-657	685	3	4540
			NISTa-676	684	0.5	8920
		12/13	NISTa-713	645	1	25930
			NISTa-698	684	1	5610
			NISTa-723	685	2	6400

APPENDIX E: LEAD ANALYTICAL RESULTS FOR NIST 2710A STUDY SAMPLES

Table E-1. Lead Analytical Results for NIST 2710a Study Samples

Group	Material	Sample ID	Collection Day	Swine Number	Sample Type	Lead Concentration	Units
1	PbAc	NISTa-126	0	664	Blood	10	ng/mL
1	PbAc	NISTa-123	0	669	Blood	<10	ng/mL
1	PbAc	NISTa-140	0	682	Blood	<10	ng/mL
1	PbAc	NISTa-141	0	686	Blood	<10	ng/mL
1	PbAc	NISTa-131	0	692	Blood	<10	ng/mL
1	PbAc	NISTa-196	2	664	Blood	10	ng/mL
1	PbAc	NISTa-179	2	669	Blood	<10	ng/mL
1	PbAc	NISTa-195	2	682	Blood	<10	ng/mL
1	PbAc	NISTa-199	2	686	Blood	<10	ng/mL
1	PbAc	NISTa-154	2	692	Blood	<10	ng/mL
1	PbAc	NISTa-209	4	664	Blood	10	ng/mL
1	PbAc	NISTa-259	4	669	Blood	10	ng/mL
1	PbAc	NISTa-226	4	682	Blood	<10	ng/mL
1	PbAc	NISTa-248	4	686	Blood	10	ng/mL
1	PbAc	NISTa-212	4	692	Blood	20	ng/mL
1	PbAc	NISTa-265	8	664	Blood	20	ng/mL
1	PbAc	NISTa-302	8	669	Blood	20	ng/mL
1	PbAc	NISTa-304	8	682	Blood	30	ng/mL
1	PbAc	NISTa-312	8	686	Blood	20	ng/mL
1	PbAc	NISTa-282	8	692	Blood	20	ng/mL
1	PbAc	NISTa-282	8	692	Blood	3000	ng/mL
1	PbAc	NISTa-336	11	664	Blood	30	ng/mL
1	PbAc	NISTa-336	11	664	Blood	31	ng/mL
1	PbAc	NISTa-318	11	669	Blood	32	ng/mL
1	PbAc	NISTa-364	11	682	Blood	49	ng/mL
1	PbAc	NISTa-319	11	686	Blood	30	ng/mL
1	PbAc	NISTa-319	11	686	Blood	30	ng/mL
1	PbAc	NISTa-340	11	692	Blood	41	ng/mL
1	PbAc	NISTa-399	15	664	Blood	41	ng/mL
1	PbAc	NISTa-413	15	669	Blood	36	ng/mL
1	PbAc	NISTa-383	15	682	Blood	53	ng/mL
1	PbAc	NISTa-388	15	686	Blood	39	ng/mL
1	PbAc	NISTa-418	15	692	Blood	45	ng/mL
2	PbAc	NISTa-113	0	648	Blood	<10	ng/mL
2	PbAc	NISTa-146	0	658	Blood	<10	ng/mL
2	PbAc	NISTa-118	0	662	Blood	<10	ng/mL
2	PbAc	NISTa-149	0	676	Blood	<10	ng/mL
2	PbAc	NISTa-119	0	690	Blood	<10	ng/mL
2	PbAc	NISTa-186	2	648	Blood	20	ng/mL
2	PbAc	NISTa-205	2	658	Blood	30	ng/mL
2	PbAc	NISTa-163	2	662	Blood	10	ng/mL
2	PbAc	NISTa-163	2	662	Blood	2500	ng/mL
2	PbAc	NISTa-178	2	676	Blood	30	ng/mL
2	PbAc	NISTa-159	2	690	Blood	10	ng/mL
2	PbAc	NISTa-250	4	648	Blood	20	ng/mL
2	PbAc	NISTa-250	4	648	Blood	20	ng/mL
2	PbAc	NISTa-213	4	658	Blood	30	ng/mL
2	PbAc	NISTa-213	4	658	Blood	2500	ng/mL
2	PbAc	NISTa-249	4	662	Blood	20	ng/mL

Table E-1. Lead Analytical Results for NIST 2710a Study Samples

Group	Material	Sample ID	Collection Day	Swine Number	Sample Type	Lead Concentration	Units
2	PbAc	NISTa-247	4	676	Blood	41	ng/mL
2	PbAc	NISTa-234	4	690	Blood	30	ng/mL
2	PbAc	NISTa-264	8	648	Blood	33	ng/mL
2	PbAc	NISTa-261	8	658	Blood	35	ng/mL
2	PbAc	NISTa-276	8	662	Blood	20	ng/mL
2	PbAc	NISTa-266	8	676	Blood	48	ng/mL
2	PbAc	NISTa-269	8	690	Blood	31	ng/mL
2	PbAc	NISTa-322	11	648	Blood	39	ng/mL
2	PbAc	NISTa-365	11	658	Blood	49	ng/mL
2	PbAc	NISTa-365	11	658	Blood	47	ng/mL
2	PbAc	NISTa-314	11	662	Blood	43	ng/mL
2	PbAc	NISTa-346	11	676	Blood	63	ng/mL
2	PbAc	NISTa-348	11	690	Blood	45	ng/mL
2	PbAc	NISTa-369	15	648	Blood	57	ng/mL
2	PbAc	NISTa-379	15	658	Blood	58	ng/mL
2	PbAc	NISTa-405	15	662	Blood	60	ng/mL
2	PbAc	NISTa-389	15	676	Blood	73	ng/mL
2	PbAc	NISTa-372	15	690	Blood	51	ng/mL
2	PbAc	NISTa-372	15	690	Blood	2550	ng/mL
3	PbAc	NISTa-152	0	665	Blood	<10	ng/mL
3	PbAc	NISTa-106	0	666	Blood	10	ng/mL
3	PbAc	NISTa-106	0	666	Blood	<10	ng/mL
3	PbAc	NISTa-129	0	667	Blood	<10	ng/mL
3	PbAc	NISTa-114	0	681	Blood	<10	ng/mL
3	PbAc	NISTa-108	0	691	Blood	<10	ng/mL
3	PbAc	NISTa-166	2	665	Blood	20	ng/mL
3	PbAc	NISTa-191	2	666	Blood	51	ng/mL
3	PbAc	NISTa-176	2	667	Blood	36	ng/mL
3	PbAc	NISTa-164	2	681	Blood	20	ng/mL
3	PbAc	NISTa-180	2	691	Blood	31	ng/mL
3	PbAc	NISTa-207	4	665	Blood	20	ng/mL
3	PbAc	NISTa-207	4	665	Blood	30	ng/mL
3	PbAc	NISTa-253	4	666	Blood	72	ng/mL
3	PbAc	NISTa-208	4	667	Blood	44	ng/mL
3	PbAc	NISTa-218	4	681	Blood	34	ng/mL
3	PbAc	NISTa-221	4	691	Blood	56	ng/mL
3	PbAc	NISTa-221	4	691	Blood	58	ng/mL
3	PbAc	NISTa-279	8	665	Blood	37	ng/mL
3	PbAc	NISTa-299	8	666	Blood	62	ng/mL
3	PbAc	NISTa-283	8	667	Blood	47	ng/mL
3	PbAc	NISTa-263	8	681	Blood	58	ng/mL
3	PbAc	NISTa-263	8	681	Blood	58	ng/mL
3	PbAc	NISTa-275	8	691	Blood	53	ng/mL
3	PbAc	NISTa-275	8	691	Blood	51	ng/mL
3	PbAc	NISTa-356	11	665	Blood	69	ng/mL
3	PbAc	NISTa-327	11	666	Blood	82	ng/mL
3	PbAc	NISTa-327	11	666	Blood	2400	ng/mL
3	PbAc	NISTa-343	11	667	Blood	63	ng/mL
3	PbAc	NISTa-343	11	667	Blood	2630	ng/mL

Table E-1. Lead Analytical Results for NIST 2710a Study Samples

Group	Material	Sample ID	Collection Day	Swine Number	Sample Type	Lead Concentration	Units
3	PbAc	NISTa-345	11	681	Blood	81	ng/mL
3	PbAc	NISTa-313	11	691	Blood	61	ng/mL
3	PbAc	NISTa-313	11	691	Blood	2400	ng/mL
3	PbAc	NISTa-382	15	665	Blood	75	ng/mL
3	PbAc	NISTa-396	15	666	Blood	98	ng/mL
3	PbAc	NISTa-400	15	667	Blood	85	ng/mL
3	PbAc	NISTa-400	15	667	Blood	2630	ng/mL
3	PbAc	NISTa-384	15	681	Blood	77	ng/mL
3	PbAc	NISTa-403	15	691	Blood	53	ng/mL
4	TM1	NISTa-134	0	650	Blood	<10	ng/mL
4	TM1	NISTa-102	0	657	Blood	<10	ng/mL
4	TM1	NISTa-116	0	670	Blood	<10	ng/mL
4	TM1	NISTa-144	0	673	Blood	<10	ng/mL
4	TM1	NISTa-144	0	673	Blood	2500	ng/mL
4	TM1	NISTa-144	0	673	Blood	<10	ng/mL
4	TM1	NISTa-147	0	687	Blood	<10	ng/mL
4	TM1	NISTa-206	2	650	Blood	10	ng/mL
4	TM1	NISTa-189	2	657	Blood	<10	ng/mL
4	TM1	NISTa-171	2	670	Blood	10	ng/mL
4	TM1	NISTa-169	2	673	Blood	10	ng/mL
4	TM1	NISTa-169	2	673	Blood	10	ng/mL
4	TM1	NISTa-184	2	687	Blood	<10	ng/mL
4	TM1	NISTa-229	4	650	Blood	20	ng/mL
4	TM1	NISTa-229	4	650	Blood	2400	ng/mL
4	TM1	NISTa-220	4	657	Blood	<10	ng/mL
4	TM1	NISTa-255	4	670	Blood	10	ng/mL
4	TM1	NISTa-239	4	673	Blood	20	ng/mL
4	TM1	NISTa-236	4	687	Blood	<10	ng/mL
4	TM1	NISTa-286	8	650	Blood	10	ng/mL
4	TM1	NISTa-310	8	657	Blood	<10	ng/mL
4	TM1	NISTa-294	8	670	Blood	35	ng/mL
4	TM1	NISTa-281	8	673	Blood	33	ng/mL
4	TM1	NISTa-260	8	687	Blood	20	ng/mL
4	TM1	NISTa-347	11	650	Blood	30	ng/mL
4	TM1	NISTa-315	11	657	Blood	20	ng/mL
4	TM1	NISTa-359	11	670	Blood	38	ng/mL
4	TM1	NISTa-359	11	670	Blood	2610	ng/mL
4	TM1	NISTa-361	11	673	Blood	41	ng/mL
4	TM1	NISTa-351	11	687	Blood	48	ng/mL
4	TM1	NISTa-351	11	687	Blood	46	ng/mL
4	TM1	NISTa-368	15	650	Blood	54	ng/mL
4	TM1	NISTa-411	15	657	Blood	35	ng/mL
4	TM1	NISTa-386	15	670	Blood	42	ng/mL
4	TM1	NISTa-386	15	670	Blood	2560	ng/mL
4	TM1	NISTa-404	15	673	Blood	40	ng/mL
4	TM1	NISTa-376	15	687	Blood	48	ng/mL
5	TM1	NISTa-112	0	655	Blood	2400	ng/mL
5	TM1	NISTa-112	0	655	Blood	<10	ng/mL
5	TM1	NISTa-117	0	674	Blood	<10	ng/mL

Table E-1. Lead Analytical Results for NIST 2710a Study Samples

Group	Material	Sample ID	Collection Day	Swine Number	Sample Type	Lead Concentration	Units
5	TM1	NISTa-117	0	674	Blood	<10	ng/mL
5	TM1	NISTa-135	0	677	Blood	<10	ng/mL
5	TM1	NISTa-135	0	677	Blood	<10	ng/mL
5	TM1	NISTa-107	0	695	Blood	<10	ng/mL
5	TM1	NISTa-115	0	697	Blood	<10	ng/mL
5	TM1	NISTa-198	2	655	Blood	20	ng/mL
5	TM1	NISTa-183	2	674	Blood	20	ng/mL
5	TM1	NISTa-172	2	677	Blood	20	ng/mL
5	TM1	NISTa-175	2	695	Blood	2500	ng/mL
5	TM1	NISTa-175	2	695	Blood	<10	ng/mL
5	TM1	NISTa-170	2	697	Blood	<10	ng/mL
5	TM1	NISTa-230	4	655	Blood	30	ng/mL
5	TM1	NISTa-223	4	674	Blood	31	ng/mL
5	TM1	NISTa-245	4	677	Blood	20	ng/mL
5	TM1	NISTa-245	4	677	Blood	2400	ng/mL
5	TM1	NISTa-224	4	695	Blood	<10	ng/mL
5	TM1	NISTa-222	4	697	Blood	20	ng/mL
5	TM1	NISTa-273	8	655	Blood	40	ng/mL
5	TM1	NISTa-272	8	674	Blood	30	ng/mL
5	TM1	NISTa-262	8	677	Blood	20	ng/mL
5	TM1	NISTa-287	8	695	Blood	30	ng/mL
5	TM1	NISTa-280	8	697	Blood	10	ng/mL
5	TM1	NISTa-335	11	655	Blood	48	ng/mL
5	TM1	NISTa-362	11	674	Blood	39	ng/mL
5	TM1	NISTa-330	11	677	Blood	35	ng/mL
5	TM1	NISTa-358	11	695	Blood	46	ng/mL
5	TM1	NISTa-325	11	697	Blood	20	ng/mL
5	TM1	NISTa-416	15	655	Blood	61	ng/mL
5	TM1	NISTa-409	15	674	Blood	54	ng/mL
5	TM1	NISTa-377	15	677	Blood	45	ng/mL
5	TM1	NISTa-366	15	695	Blood	62	ng/mL
5	TM1	NISTa-385	15	697	Blood	38	ng/mL
6	TM1	NISTa-104	0	646	Blood	10	ng/mL
6	TM1	NISTa-145	0	652	Blood	<10	ng/mL
6	TM1	NISTa-150	0	654	Blood	<10	ng/mL
6	TM1	NISTa-150	0	654	Blood	<10	ng/mL
6	TM1	NISTa-142	0	656	Blood	<10	ng/mL
6	TM1	NISTa-139	0	694	Blood	<10	ng/mL
6	TM1	NISTa-202	2	646	Blood	20	ng/mL
6	TM1	NISTa-168	2	652	Blood	30	ng/mL
6	TM1	NISTa-203	2	654	Blood	31	ng/mL
6	TM1	NISTa-158	2	656	Blood	30	ng/mL
6	TM1	NISTa-181	2	694	Blood	<10	ng/mL
6	TM1	NISTa-181	2	694	Blood	10	ng/mL
6	TM1	NISTa-258	4	646	Blood	54	ng/mL
6	TM1	NISTa-258	4	646	Blood	2300	ng/mL
6	TM1	NISTa-244	4	652	Blood	35	ng/mL
6	TM1	NISTa-243	4	654	Blood	31	ng/mL
6	TM1	NISTa-257	4	656	Blood	20	ng/mL

Table E-1. Lead Analytical Results for NIST 2710a Study Samples

Group	Material	Sample ID	Collection Day	Swine Number	Sample Type	Lead Concentration	Units
6	TM1	NISTa-241	4	694	Blood	30	ng/mL
6	TM1	NISTa-307	8	646	Blood	46	ng/mL
6	TM1	NISTa-307	8	646	Blood	47	ng/mL
6	TM1	NISTa-290	8	652	Blood	42	ng/mL
6	TM1	NISTa-267	8	654	Blood	33	ng/mL
6	TM1	NISTa-308	8	656	Blood	20	ng/mL
6	TM1	NISTa-303	8	694	Blood	42	ng/mL
6	TM1	NISTa-331	11	646	Blood	74	ng/mL
6	TM1	NISTa-355	11	652	Blood	79	ng/mL
6	TM1	NISTa-329	11	654	Blood	48	ng/mL
6	TM1	NISTa-360	11	656	Blood	42	ng/mL
6	TM1	NISTa-337	11	694	Blood	64	ng/mL
6	TM1	NISTa-387	15	646	Blood	73	ng/mL
6	TM1	NISTa-371	15	652	Blood	79	ng/mL
6	TM1	NISTa-395	15	654	Blood	66	ng/mL
6	TM1	NISTa-393	15	656	Blood	75	ng/mL
6	TM1	NISTa-393	15	656	Blood	75	ng/mL
6	TM1	NISTa-402	15	694	Blood	78	ng/mL
10	Control	NISTa-111	0	645	Blood	<10	ng/mL
10	Control	NISTa-128	0	684	Blood	3000	ng/mL
10	Control	NISTa-128	0	684	Blood	<10	ng/mL
10	Control	NISTa-130	0	685	Blood	<10	ng/mL
10	Control	NISTa-190	2	645	Blood	<10	ng/mL
10	Control	NISTa-185	2	684	Blood	<10	ng/mL
10	Control	NISTa-174	2	685	Blood	<10	ng/mL
10	Control	NISTa-231	4	645	Blood	<10	ng/mL
10	Control	NISTa-251	4	684	Blood	<10	ng/mL
10	Control	NISTa-238	4	685	Blood	<10	ng/mL
10	Control	NISTa-238	4	685	Blood	<10	ng/mL
10	Control	NISTa-268	8	645	Blood	2400	ng/mL
10	Control	NISTa-268	8	645	Blood	<10	ng/mL
10	Control	NISTa-271	8	684	Blood	<10	ng/mL
10	Control	NISTa-311	8	685	Blood	32	ng/mL
10	Control	NISTa-317	11	645	Blood	<10	ng/mL
10	Control	NISTa-342	11	684	Blood	<10	ng/mL
10	Control	NISTa-326	11	685	Blood	<10	ng/mL
10	Control	NISTa-398	15	645	Blood	<10	ng/mL
10	Control	NISTa-381	15	684	Blood	<10	ng/mL
10	Control	NISTa-381	15	684	Blood	<10	ng/mL
10	Control	NISTa-414	15	685	Blood	2540	ng/mL
10	Control	NISTa-414	15	685	Blood	<10	ng/mL
1	PbAc	NISTa-569	15	664	Femur	2700	ng/g
1	PbAc	NISTa-540	15	669	Femur	3500	ng/g
1	PbAc	NISTa-548	15	682	Femur	4100	ng/g
1	PbAc	NISTa-536	15	686	Femur	2200	ng/g
1	PbAc	NISTa-557	15	692	Femur	3600	ng/g
2	PbAc	NISTa-531	15	648	Femur	5900	ng/g
2	PbAc	NISTa-566	15	658	Femur	6700	ng/g
2	PbAc	NISTa-566	15	658	Femur	6700	ng/g

Table E-1. Lead Analytical Results for NIST 2710a Study Samples

Group	Material	Sample ID	Collection Day	Swine Number	Sample Type	Lead Concentration	Units
2	PbAc	NISTa-533	15	662	Femur	5200	ng/g
2	PbAc	NISTa-562	15	676	Femur	8400	ng/g
2	PbAc	NISTa-571	15	690	Femur	5400	ng/g
3	PbAc	NISTa-525	15	665	Femur	9300	ng/g
3	PbAc	NISTa-534	15	666	Femur	12000	ng/g
3	PbAc	NISTa-534	15	666	Femur	130000	ng/g
3	PbAc	NISTa-568	15	667	Femur	8100	ng/g
3	PbAc	NISTa-524	15	681	Femur	12000	ng/g
3	PbAc	NISTa-521	15	691	Femur	8900	ng/g
4	TM1	NISTa-558	15	650	Femur	2800	ng/g
4	TM1	NISTa-545	15	657	Femur	2900	ng/g
4	TM1	NISTa-545	15	657	Femur	124000	ng/g
4	TM1	NISTa-543	15	670	Femur	5800	ng/g
4	TM1	NISTa-530	15	673	Femur	2800	ng/g
4	TM1	NISTa-539	15	687	Femur	2800	ng/g
4	TM1	NISTa-539	15	687	Femur	2800	ng/g
5	TM1	NISTa-561	15	655	Femur	5100	ng/g
5	TM1	NISTa-544	15	674	Femur	5500	ng/g
5	TM1	NISTa-532	15	677	Femur	4300	ng/g
5	TM1	NISTa-556	15	695	Femur	2900	ng/g
5	TM1	NISTa-556	15	695	Femur	2800	ng/g
5	TM1	NISTa-565	15	697	Femur	2200	ng/g
6	TM1	NISTa-537	15	646	Femur	10000	ng/g
6	TM1	NISTa-523	15	652	Femur	8700	ng/g
6	TM1	NISTa-560	15	654	Femur	6000	ng/g
6	TM1	NISTa-560	15	654	Femur	129000	ng/g
6	TM1	NISTa-552	15	656	Femur	5900	ng/g
6	TM1	NISTa-527	15	694	Femur	8400	ng/g
6	TM1	NISTa-527	15	694	Femur	8700	ng/g
10	Control	NISTa-535	15	645	Femur	<300	ng/g
10	Control	NISTa-549	15	684	Femur	<300	ng/g
10	Control	NISTa-538	15	685	Femur	<300	ng/g
1	PbAc	NISTa-484	15	664	Kidney	66	ng/g
1	PbAc	NISTa-484	15	664	Kidney	69	ng/g
1	PbAc	NISTa-519	15	669	Kidney	150	ng/g
1	PbAc	NISTa-505	15	682	Kidney	160	ng/g
1	PbAc	NISTa-517	15	686	Kidney	68	ng/g
1	PbAc	NISTa-512	15	692	Kidney	150	ng/g
2	PbAc	NISTa-474	15	648	Kidney	230	ng/g
2	PbAc	NISTa-510	15	658	Kidney	230	ng/g
2	PbAc	NISTa-492	15	662	Kidney	190	ng/g
2	PbAc	NISTa-492	15	662	Kidney	690	ng/g
2	PbAc	NISTa-491	15	676	Kidney	320	ng/g
2	PbAc	NISTa-520	15	690	Kidney	310	ng/g
3	PbAc	NISTa-515	15	665	Kidney	250	ng/g
3	PbAc	NISTa-515	15	665	Kidney	740	ng/g
3	PbAc	NISTa-507	15	666	Kidney	550	ng/g
3	PbAc	NISTa-509	15	667	Kidney	300	ng/g
3	PbAc	NISTa-495	15	681	Kidney	360	ng/g

Table E-1. Lead Analytical Results for NIST 2710a Study Samples

Group	Material	Sample ID	Collection Day	Swine Number	Sample Type	Lead Concentration	Units
3	PbAc	NISTa-477	15	691	Kidney	230	ng/g
3	PbAc	NISTa-477	15	691	Kidney	670	ng/g
4	TM1	NISTa-493	15	650	Kidney	110	ng/g
4	TM1	NISTa-486	15	657	Kidney	95	ng/g
4	TM1	NISTa-478	15	670	Kidney	190	ng/g
4	TM1	NISTa-472	15	673	Kidney	100	ng/g
4	TM1	NISTa-482	15	687	Kidney	89	ng/g
5	TM1	NISTa-488	15	655	Kidney	190	ng/g
5	TM1	NISTa-513	15	674	Kidney	180	ng/g
5	TM1	NISTa-506	15	677	Kidney	120	ng/g
5	TM1	NISTa-508	15	695	Kidney	630	ng/g
5	TM1	NISTa-508	15	695	Kidney	110	ng/g
5	TM1	NISTa-499	15	697	Kidney	77	ng/g
5	TM1	NISTa-499	15	697	Kidney	78	ng/g
6	TM1	NISTa-516	15	646	Kidney	330	ng/g
6	TM1	NISTa-480	15	652	Kidney	390	ng/g
6	TM1	NISTa-479	15	654	Kidney	220	ng/g
6	TM1	NISTa-518	15	656	Kidney	220	ng/g
6	TM1	NISTa-518	15	656	Kidney	230	ng/g
6	TM1	NISTa-497	15	694	Kidney	380	ng/g
10	Control	NISTa-511	15	645	Kidney	<10	ng/g
10	Control	NISTa-511	15	645	Kidney	<10	ng/g
10	Control	NISTa-489	15	684	Kidney	<10	ng/g
10	Control	NISTa-502	15	685	Kidney	30	ng/g
1	PbAc	NISTa-430	15	664	Liver	150	ng/g
1	PbAc	NISTa-430	15	664	Liver	680	ng/g
1	PbAc	NISTa-463	15	669	Liver	180	ng/g
1	PbAc	NISTa-433	15	682	Liver	<10	ng/g
1	PbAc	NISTa-427	15	686	Liver	200	ng/g
1	PbAc	NISTa-434	15	692	Liver	67	ng/g
2	PbAc	NISTa-426	15	648	Liver	310	ng/g
2	PbAc	NISTa-435	15	658	Liver	310	ng/g
2	PbAc	NISTa-435	15	658	Liver	320	ng/g
2	PbAc	NISTa-443	15	662	Liver	320	ng/g
2	PbAc	NISTa-443	15	662	Liver	830	ng/g
2	PbAc	NISTa-462	15	676	Liver	120	ng/g
2	PbAc	NISTa-453	15	690	Liver	350	ng/g
2	PbAc	NISTa-453	15	690	Liver	360	ng/g
3	PbAc	NISTa-469	15	665	Liver	380	ng/g
3	PbAc	NISTa-469	15	665	Liver	390	ng/g
3	PbAc	NISTa-436	15	666	Liver	670	ng/g
3	PbAc	NISTa-445	15	667	Liver	350	ng/g
3	PbAc	NISTa-455	15	681	Liver	290	ng/g
3	PbAc	NISTa-425	15	691	Liver	270	ng/g
4	TM1	NISTa-428	15	650	Liver	170	ng/g
4	TM1	NISTa-450	15	657	Liver	300	ng/g
4	TM1	NISTa-419	15	670	Liver	280	ng/g
4	TM1	NISTa-454	15	673	Liver	160	ng/g
4	TM1	NISTa-457	15	687	Liver	230	ng/g

Table E-1. Lead Analytical Results for NIST 2710a Study Samples

Group	Material	Sample ID	Collection Day	Swine Number	Sample Type	Lead Concentration	Units
5	TM1	NISTa-424	15	655	Liver	200	ng/g
5	TM1	NISTa-424	15	655	Liver	200	ng/g
5	TM1	NISTa-444	15	674	Liver	80	ng/g
5	TM1	NISTa-421	15	677	Liver	300	ng/g
5	TM1	NISTa-437	15	695	Liver	190	ng/g
5	TM1	NISTa-439	15	697	Liver	280	ng/g
6	TM1	NISTa-461	15	646	Liver	450	ng/g
6	TM1	NISTa-420	15	652	Liver	480	ng/g
6	TM1	NISTa-441	15	654	Liver	300	ng/g
6	TM1	NISTa-423	15	656	Liver	380	ng/g
6	TM1	NISTa-458	15	694	Liver	650	ng/g
6	TM1	NISTa-458	15	694	Liver	3000	ng/g
10	Control	NISTa-449	15	645	Liver	<10	ng/g
10	Control	NISTa-432	15	684	Liver	<10	ng/g
10	Control	NISTa-456	15	685	Liver	220	ng/g

APPENDIX F: ANALYTICAL RESULTS FOR QUALITY CONTROL SAMPLES

Table F-1. Blind Duplicate Samples

Blind Duplicate Sample ID	Sample Type	Swine Number	Collection Days	Original Sample Concentration	Duplicate Sample Concentration	Sample Units	RPD
NISTa-587	Urine	688	6/7	95	98	µg/L	3%
NISTa-584	Urine	651	6/7	170	180	µg/L	6%
NISTa-789	Urine	684	6/7	1	<1	µg/L	67%
NISTa-790	Urine	687	9/10	36	37	µg/L	3%
NISTa-791	Urine	659	9/10	360	360	µg/L	0%
NISTa-868	Urine	672	9/10	110	110	µg/L	0%
NISTa-699	Urine	652	12/13	464	457	µg/L	2%
NISTa-684	Urine	689	12/13	160	160	µg/L	0%
NISTa-792	Urine	679	12/13	97	100	µg/L	3%
NISTa-109	Blood	666	0	10	<10	µg/L	67%
NISTa-187	Blood	676	2	30	31	µg/L	3%
NISTa-194	Blood	673	2	10	10	µg/L	0%
NISTa-201	Blood	684	2	<10	<10	µg/L	0%
NISTa-214	Blood	665	4	20	30	µg/L	40%
NISTa-246	Blood	657	4	<10	30	µg/L	143%
NISTa-288	Blood	652	8	42	48	µg/L	13%
NISTa-289	Blood	669	8	20	20	µg/L	0%
NISTa-293	Blood	695	8	30	30	µg/L	0%
NISTa-354	Blood	655	11	48	51	µg/L	6%
NISTa-406	Blood	656	15	75	77	µg/L	3%
NISTa-408	Blood	685	15	<10	<10	µg/L	0%
NISTa-801	Blood	664	0	10	<10	µg/L	67%
NISTa-802	Blood	691	0	<10	<10	µg/L	0%
NISTa-803	Blood	645	4	<10	<10	µg/L	0%
NISTa-804	Blood	646	11	74	69	µg/L	7%
NISTa-805	Blood	670	11	38	45	µg/L	17%
NISTa-806	Blood	691	15	53	59	µg/L	11%
NISTa-542	Femur	654	15	6000	5600	ng/g	7%
NISTa-814	Femur	676	15	8400	8400	ng/g	0%
NISTa-559	Femur	695	15	2800	3000	ng/g	7%
NISTa-813	Kidney	658	15	230	230	ng/g	0%
NISTa-810	Kidney	667	15	300	290	ng/g	3%
NISTa-470	Kidney	697	15	78	73	ng/g	7%
NISTa-807	Liver	650	15	170	190	ng/g	11%
NISTa-464	Liver	658	15	320	320	ng/g	0%
NISTa-431	Liver	670	15	280	300	ng/g	7%

RPD = relative percent difference
One-half the detection limit was used to calculate RPD in cases where one value was detected and the other was not.

Table F-2. Laboratory Spikes

Spike Sample ID	Sample Type	Original Sample Concentration (ppb)	Added Spike Concentration (ppb)	Measured Sample Concentration (ppb)	Recovered Spike (ppb)	Recovery (%)
NISTa-586	Urine	95	200	290	195	98%
NISTa-600	Urine	130	200	320	190	95%
NISTa-617	Urine	1	200	200	199	100%
NISTa-627	Urine	28	200	220	192	96%
NISTa-641	Urine	96	200	320	224	112%
NISTa-654	Urine	400	200	600	200	100%
NISTa-666	Urine	36	200	260	224	112%
NISTa-698	Urine	1	200	210	209	105%
NISTa-711	Urine	200	200	415	215	108%
NISTa-724	Urine	100	200	320	220	110%
NISTa-737	Urine	2	200	220	218	109%
NISTa-791	Urine	360	200	590	230	115%
NISTa-112	Blood	<10	2500	2400	2395	96%
NISTa-128	Blood	<10	2500	3000	2995	120%
NISTa-144	Blood	<10	2500	2500	2495	100%
NISTa-163	Blood	10	2500	2500	2490	100%
NISTa-175	Blood	<10	2500	2500	2495	100%
NISTa-187	Blood	31	2500	2600	2569	103%
NISTa-201	Blood	<10	2500	2500	2495	100%
NISTa-213	Blood	30	2500	2500	2470	99%
NISTa-229	Blood	20	2500	2400	2380	95%
NISTa-245	Blood	20	2500	2400	2380	95%
NISTa-258	Blood	54	2500	2300	2246	90%
NISTa-268	Blood	<10	2500	2400	2395	96%
NISTa-282	Blood	20	2500	3000	2980	119%
NISTa-295	Blood	34	2500	2400	2366	95%
NISTa-313	Blood	61	2500	2400	2339	94%
NISTa-327	Blood	82	2500	2400	2318	93%
NISTa-343	Blood	63	2500	2630	2567	103%
NISTa-359	Blood	38	2500	2610	2572	103%
NISTa-372	Blood	51	2500	2550	2499	100%
NISTa-386	Blood	42	2500	2560	2518	101%
NISTa-400	Blood	85	2500	2630	2545	102%
NISTa-414	Blood	5	2500	2540	2535	101%
NISTa-806	Blood	59	2500	2540	2481	99%
NISTa-534	Femur	12000	126000	130000	118000	94%
NISTa-545	Femur	2900	123000	124000	121100	98%
NISTa-560	Femur	6000	122000	129000	123000	101%
NISTa-814	Femur	8400	123000	130000	121600	99%
NISTa-477	Kidney	230	490	670	440	90%
NISTa-492	Kidney	190	526	690	500	95%
NISTa-508	Kidney	110	476	630	520	109%
NISTa-515	Kidney	250	481	740	490	102%
NISTa-810	Kidney	290	481	760	470	98%
NISTa-430	Liver	150	505	680	530	105%
NISTa-443	Liver	320	505	830	510	101%
NISTa-458	Liver	650	2500	3000	2350	94%

Table F-3. Laboratory Duplicates

Duplicate Sample ID	Sample Type	Original Sample Concentration (ppb)	Duplicate Concentration (ppb)	RPD	Absolute Difference
NISTa-580	Urine	110	120	9%	10
NISTa-594	Urine	31	32	3%	1
NISTa-608	Urine	34	34	0%	0
NISTa-622	Urine	190	190	0%	0
NISTa-634	Urine	220	230	4%	10
NISTa-649	Urine	471	470	0%	1
NISTa-659	Urine	270	280	4%	10
NISTa-676	Urine	<0.5	1	67%	0.5
NISTa-691	Urine	443	415	7%	28
NISTa-706	Urine	110	99	11%	11
NISTa-719	Urine	79	78	1%	1
NISTa-732	Urine	44	43	2%	1
NISTa-796	Urine	<0.5	<0.5	0%	0
NISTa-793	Urine	0.2	0.1	67%	0.1
NISTa-106	Blood	10	<10	67%	5
NISTa-117	Blood	<10	<10	0%	0
NISTa-135	Blood	<10	<10	0%	0
NISTa-150	Blood	<10	<10	0%	0
NISTa-169	Blood	10	10	0%	0
NISTa-181	Blood	<10	10	67%	5
NISTa-194	Blood	10	20	67%	10
NISTa-207	Blood	20	30	40%	10
NISTa-221	Blood	58	56	4%	2
NISTa-238	Blood	<10	<10	0%	0
NISTa-250	Blood	20	20	0%	0
NISTa-263	Blood	58	58	0%	0
NISTa-275	Blood	53	51	4%	2
NISTa-289	Blood	20	20	0%	0
NISTa-307	Blood	47	46	2%	1
NISTa-319	Blood	30	30	0%	0
NISTa-336	Blood	30	31	3%	1
NISTa-351	Blood	48	46	4%	2
NISTa-365	Blood	47	49	4%	2
NISTa-381	Blood	<10	<10	0%	0
NISTa-393	Blood	75	75	0%	0
NISTa-406	Blood	77	77	0%	0
NISTa-802	Blood	<10	20	120%	15
NISTa-527	Femur	8700	8400	4%	300
NISTa-539	Femur	2800	2800	0%	0
NISTa-556	Femur	2800	2900	4%	100
NISTa-566	Femur	6700	6700	0%	0
NISTa-484	Kidney	66	69	4%	3
NISTa-499	Kidney	78	77	1%	1
NISTa-511	Kidney	<10	<10	0%	0
NISTa-518	Kidney	220	230	4%	10
NISTa-424	Liver	200	200	0%	0
NISTa-435	Liver	320	310	3%	10
NISTa-453	Liver	350	360	3%	10

Table F-3. Laboratory Duplicates

Duplicate Sample ID	Sample Type	Original Sample Concentration (ppb)	Duplicate Concentration (ppb)	RPD	Absolute Difference
NISTa-469	Liver	390	380	3%	10
NISTa-818	Feed	1	1	0%	0
NISTa-821	Water	<40	<50	22%	10

RPD = relative percent difference

Table F-4. Laboratory Quality Control Standards

Sample ID	Associated Sample Type	LET Number	Analyte Measured	Measured Concentration	Units	Detection Limit (ppb)	Reference Material ID	Certified Mean±Standard Deviation	Recovery
QC-1	Urine	L10010126	Arsenic	6	ng/mL	3	NIST 2670a-L	3	200%
QC-2	Urine	L10010150	Arsenic	220	ng/mL	10	NIST 2670a-H	220±10	100%
QC-3	Urine	L10010174	Arsenic	230	ng/mL	10	NIST 2670a-H	220±10	105%
QC-4	Urine	L10010198	Arsenic	230	ng/mL	10	NIST 2670a-H	220±10	105%
QC-5	Urine	L10010222	Arsenic	230	ng/mL	10	NIST 2670a-H	220±10	105%
QC-6	Urine	L10010246	Arsenic	230	ng/mL	10	NIST 2670a-H	220±10	105%
QC-7	Urine	L10010258	Arsenic	55	ng/mL	1	NIST 1643e	58.98±0.7	93%
QC-8	Urine	L10010264	Arsenic	7.7	µg/g	0.2	NIST 1566b	7.65±0.65	101%
QC-1	Blood	V10020022	Lead	28	ng/mL	2	NIST 1640	26.7±0.41	105%
QC-10	Blood	V10020238	Lead	30	ng/mL	2	NIST 1640	26.7±0.41	112%
QC-11	Blood	V10020262	Lead	30	ng/mL	2	NIST 1640	26.7±0.41	112%
QC-12	Blood	V10020274	Lead	29	ng/mL	2	NIST 1640	26.7±0.41	109%
QC-2	Blood	V10020046	Lead	26	ng/mL	2	NIST 1640	26.7±0.41	97%
QC-3	Blood	V10020070	Lead	28	ng/mL	2	NIST 1640	26.7±0.41	105%
QC-4	Blood	V10020094	Lead	28	ng/mL	2	NIST 1640	26.7±0.41	105%
QC-5	Blood	V10020118	Lead	27	ng/mL	2	NIST 1640	26.7±0.41	101%
QC-6	Blood	V10020142	Lead	28	ng/mL	2	NIST 1640	26.7±0.41	105%
QC-7	Blood	V10020166	Lead	28	ng/mL	2	NIST 1640	26.7±0.41	105%
QC-8	Blood	V10020190	Lead	27	ng/mL	2	NIST 1640	26.7±0.41	101%
QC-9	Blood	V10020214	Lead	29	ng/mL	2	NIST 1640	26.7±0.41	109%
QC-2	Feed	V10030011	Lead	0.44	µg/g	1	NRCC Dolt-3	0.319±0.045	138%
QC-1	Femur	V10020386	Lead	8.7	ng/g	30	NIST 1400	9.07±0.12	96%
QC-2	Femur	V10020406	Lead	9.3	ng/g	30	NIST 1400	9.07±0.12	103%
QC-1	Tissue	V10020299	Lead	0.38	ng/g	10	NRCC TORT-2	0.35±0.13	109%
QC-2	Tissue	V10020322	Lead	0.23	ng/g	10	NRCC Dolt-3	0.319±0.045	72%
QC-3	Tissue	V10020346	Lead	0.32	ng/g	10	NRCC TORT-2	0.35±0.13	91%
QC-4	Tissue	V10020362	Lead	0.17	ng/g	10	NRCC Dolt-3	0.319±0.045	53%
QC-1	Water	V10030010	Lead	26	ng/g	1	NIST 1640	9.07±0.12	97%

Table F-5. Arsenic Performance Evaluation Samples

Sample ID	PE ID	PE Standard	PE Concentration	Sample Concentration	Adjusted Concentration	RPD
NISTa-643	as3.100	Sodium arsenite	100	110	108	8%
NISTa-687	as3.20	Sodium arsenite	20	23	21	7%
NISTa-593	as3.400	Sodium arsenite	400	390	388	3%
NISTa-620	as5.100	Sodium arsenate	100	110	108	8%
NISTa-662	as5.20	Sodium arsenate	20	22	20	2%
NISTa-735	as5.400	Sodium arsenate	400	441	439	9%
NISTa-737	ctrl	Control urine	0	2	0	0%
NISTa-625	ctrl	Control urine	0	1	0	0%
NISTa-678	dma100	Disodium methylarsenate	100	100	98	2%
NISTa-626	dma20	Disodium methylarsenate	20	22	20	2%
NISTa-691	dma400	Disodium methylarsenate	400	443	441	10%
NISTa-706	mma100	Dimethyl arsenic acid	100	110	108	8%
NISTa-577	mma20	Dimethyl arsenic acid	20	21	19	3%
NISTa-654	mma400	Dimethyl arsenic acid	400	400	398	0%

PE = performance evaluation. Sample concentration adjusted by subtracting mean of background arsenic (~1.5 µg/L) from sample concentration.
RPD = relative percent difference

Table F-6. Lead CDC Samples

Sample ID	Sample Type	CDC Sample	CDC Concentration (µg/dL)	Sample Concentration	RPD
NISTa-105	Blood	CDC BLLRS sample 294	1.9	1	45%
NISTa-219	Blood	CDC BLLRS sample 294	1.9	1	45%
NISTa-320	Blood	CDC BLLRS sample 294	1.9	1	45%
NISTa-391	Blood	CDC BLLRS sample 294	1.9	1	45%
NISTa-101	Blood	CDC BLLRS sample 199	5.5	3.6	95%
NISTa-192	Blood	CDC BLLRS sample 199	5.5	3.4	105%
NISTa-295	Blood	CDC BLLRS sample 199	5.5	3.4	105%
NISTa-341	Blood	CDC BLLRS sample 199	5.5	3.8	85%
NISTa-165	Blood	CDC BLLRS sample 592	13.9	12	95%
NISTa-210	Blood	CDC BLLRS sample 592	13.9	12	95%
NISTa-292	Blood	CDC BLLRS sample 592	13.9	12	95%
NISTa-373	Blood	CDC BLLRS sample 592	13.9	13	45%

RPD = relative percent difference

Table F-7. Blanks

Sample ID	Associated Sample Type	Analyte Measured	Measured Concentration	Detection Limit	Units
Blank-8	Feed	Arsenic	<0.1	0.1	µg/g
Blank-1	Urine	Arsenic	<1	1	ng/mL
Blank-2	Urine	Arsenic	<1	1	ng/mL
Blank-3	Urine	Arsenic	<1	1	ng/mL
Blank-4	Urine	Arsenic	<1	1	ng/mL
Blank-5	Urine	Arsenic	<1	1	ng/mL
Blank-6	Urine	Arsenic	<1	1	ng/mL
Blank-7	Urine	Arsenic	<1	1	ng/mL
Blank-1	Water	Arsenic	1	1	ng/mL
Blank-1	Blood	Lead	<10	10	ng/mL
Blank-2	Blood	Lead	<10	10	ng/mL
Blank-3	Blood	Lead	<10	10	ng/mL
Blank-4	Blood	Lead	<10	10	ng/mL
Blank-5	Blood	Lead	<10	10	ng/mL
Blank-6	Blood	Lead	<10	10	ng/mL
Blank-7	Blood	Lead	<10	10	ng/mL
Blank-8	Blood	Lead	<10	10	ng/mL
Blank-9	Blood	Lead	<10	10	ng/mL
Blank-10	Blood	Lead	<10	10	ng/mL
Blank-11	Blood	Lead	<10	10	ng/mL
Blank-12	Blood	Lead	<10	10	ng/mL
Blank-1	Femur	Lead	<300	300	ng/g
Blank-2	Femur	Lead	<300	300	ng/g
Blank-1	Tissue	Lead	<10	10	ng/g
Blank-2	Tissue	Lead	<10	10	ng/g
Blank-3	Tissue	Lead	<10	10	ng/g
Blank-4	Tissue	Lead	<10	10	ng/g

Figure F-1. Urinary Arsenic Blind Duplicates

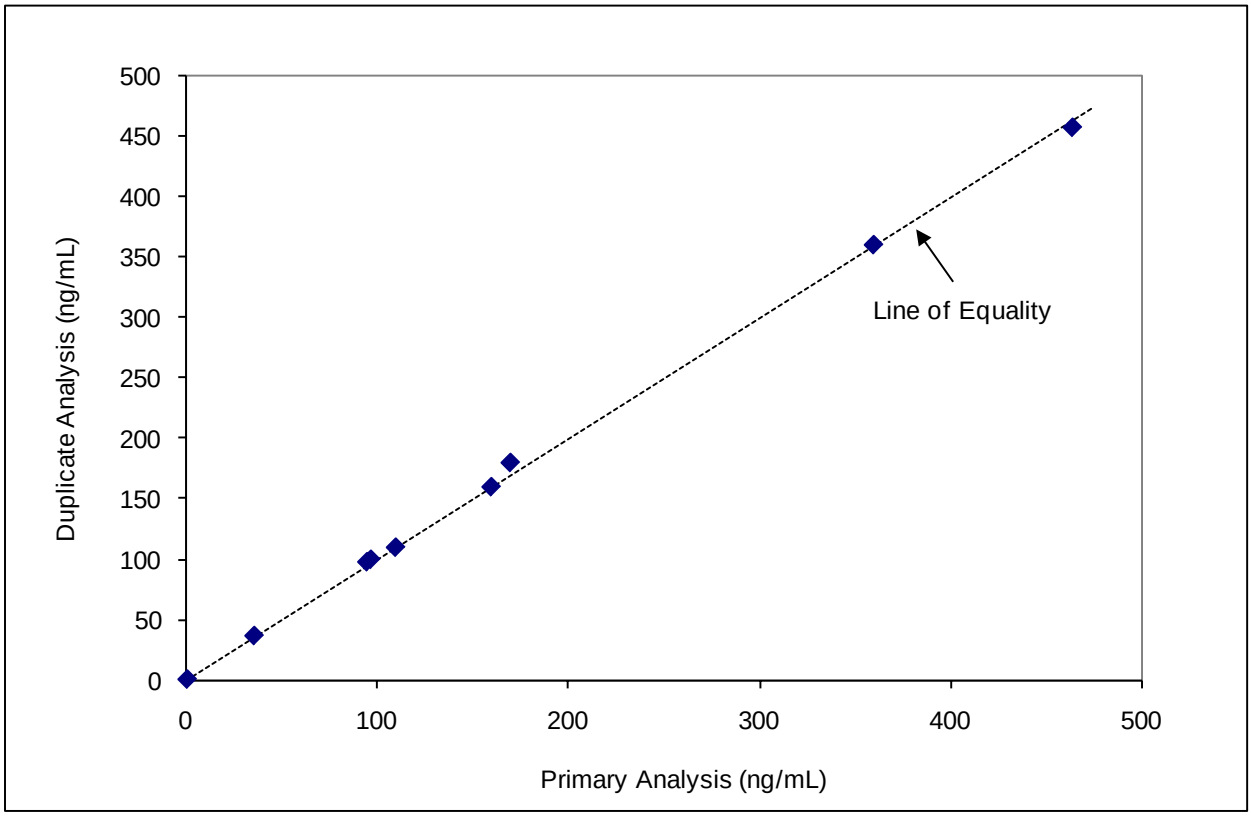
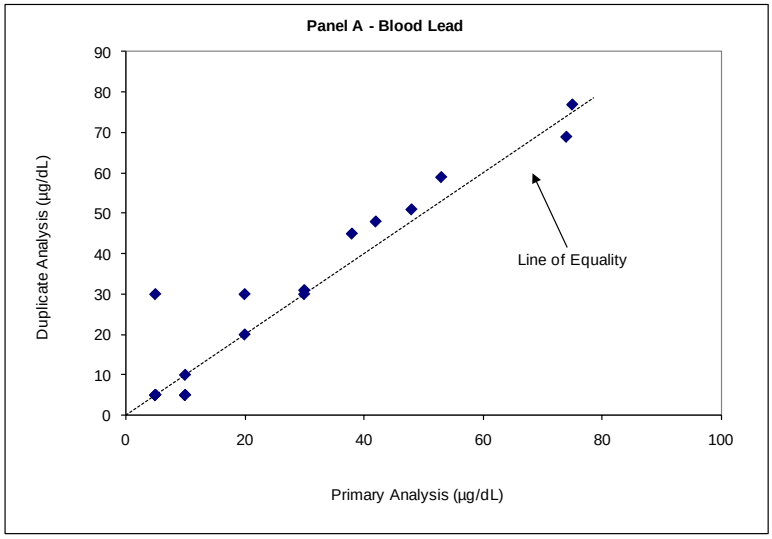
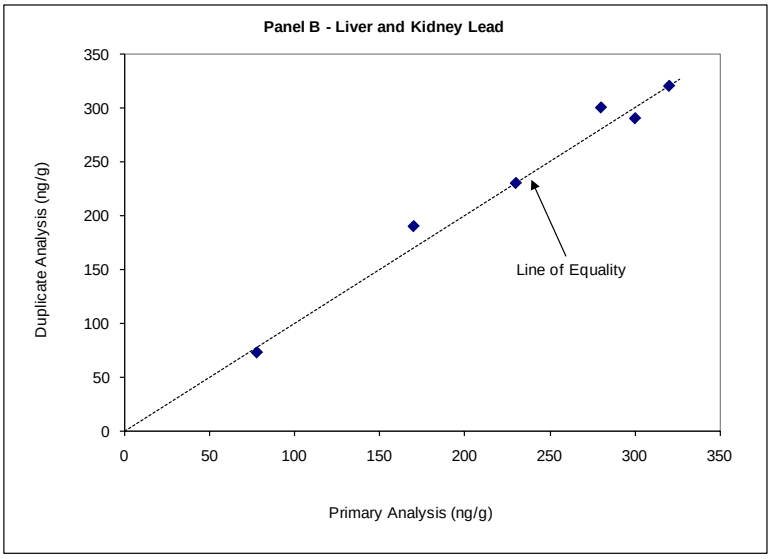


Figure F-2. Lead Blind Duplicates





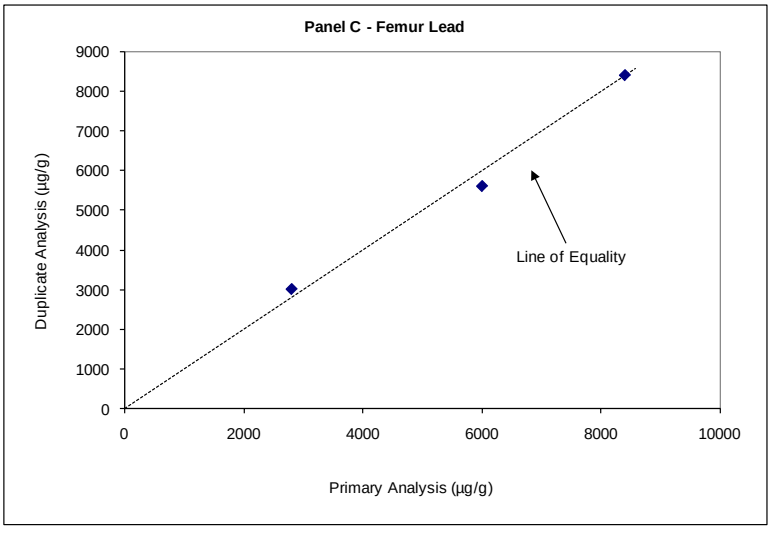


Figure F-3. Performance Evaluation Samples

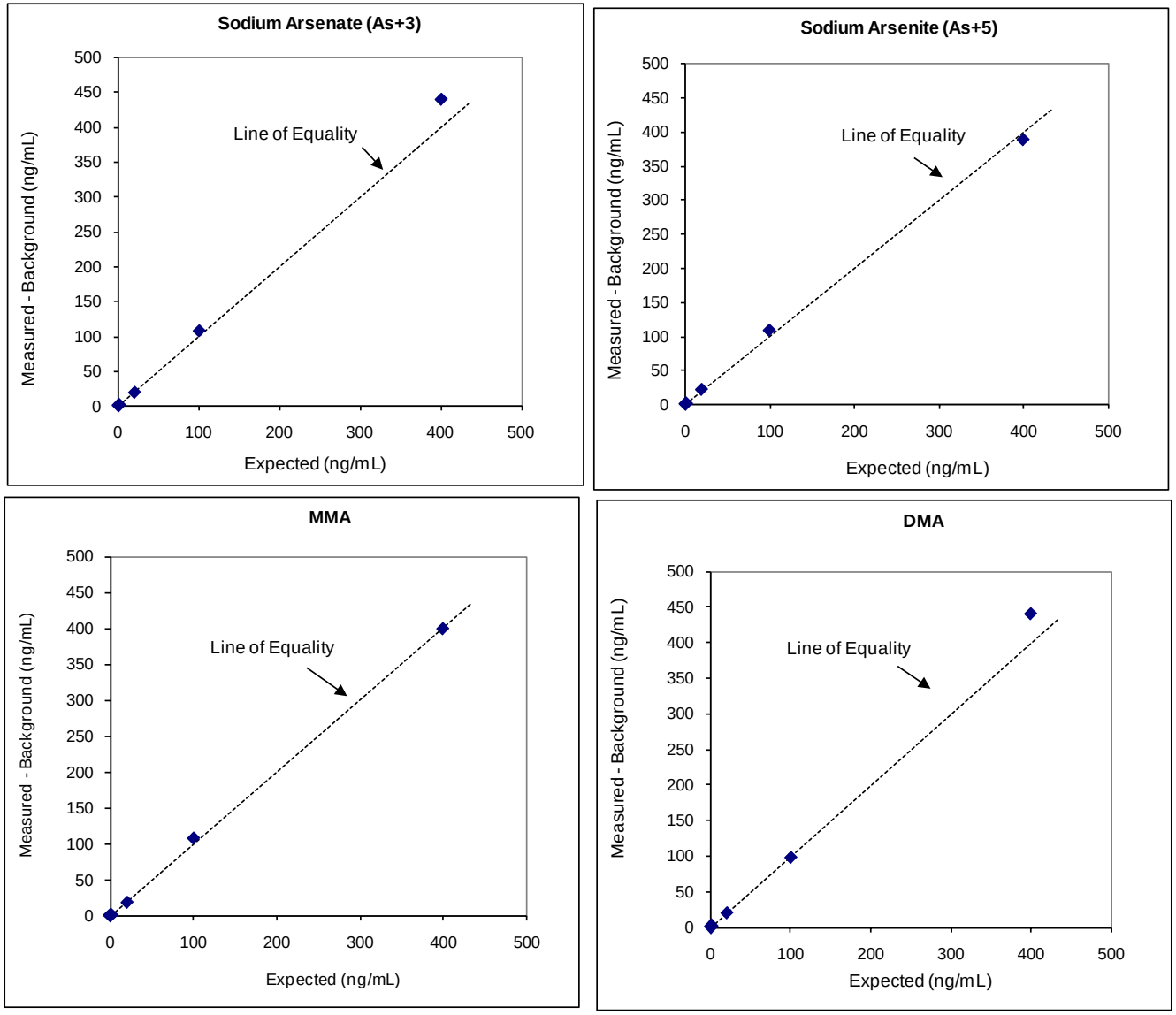


Figure F-4. CDC Blood Lead Check Sample