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Performance Testing of Radiobioassay Laboratories: In Vivo Measurements, Final Report

J. A. MacLellan
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April 1990

Prepared for the U.S. Department of Energy
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PERFORMANCE TESTING OF RADIOBIOASSAY LABORATORIES: IN VIVO MEASUREMENTS, FINAL REPORT

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ABSTRACT

A study of two rounds of in vivo laboratory performance testing was undertaken by Pacific Northwest Laboratory (PNL) to determine the appropriateness of the in vivo performance criteria of draft American National Standards Institute (ANSI) standard ANSI N13.30, "Performance Criteria for Bioassay." The draft standard provides guidance to in vivo counting facilities regarding the sensitivity, precision, and accuracy of measurements for certain categories of commonly assayed radionuclides and critical regions of the body.

This report concludes the testing program by presenting the results of the Round Two testing. The previous pilot round of testing was reported by Robinson et al. (1986). The two rounds of testing are compared in this report, which cites the gains made over the previous study.

Testing involved two types of measurements: chest counting for radionuclide detection in the lung, and whole body counting for detection of uniformly distributed material. Each type of measurement was further divided into radionuclide categories as defined in the draft standard.

The appropriateness of the draft standard criteria by measuring a laboratory's ability to attain them were judged by the results of both Round One and Round Two testing. The testing determined that performance criteria are set at attainable levels, and the majority of in vivo monitoring facilities passed the criteria when complete results were submitted. The single minimum detectable amount (MDA) calculation was determined to be unsatisfactory for use with an accreditation program because; 1) reporting a proper value of (s_b) for appropriate blanks was not possible for some automated counting systems; 2) the MDA statistic must be tailored to the laboratory's particular system of measurement and data analysis in order for proper baseline determinations to be made; and 3) each laboratory's quality control data should be used in lieu of the small set of test background measurements to identify important blank spectra characteristics that will affect the MDA calculation.

SUMMARY

This report concludes a series of documents based on a performance testing program that was developed for U.S. Department of Energy (DOE) bioassay testing laboratories (and other radiobioassay testing laboratories that participated) in order to evaluate their performance in analyzing and reporting in vivo radioactivity concentrations. The work was based on the DOE Laboratory Accreditation Program (DOELAP), whereby laboratories were tested to determine their conformance to the applicable standards in the proposed American National Standards Institute (ANSI) Standard N13.30, "Performance Criteria for Bioassay".[a] A pilot round of testing was performed and reported in 1986. The final (Round Two) testing results are reported here and compared with the pilot testing results of 1986; details of phantom preparation and testing radionuclide solution preparation are included, as is a summary of laboratory performance with recommendations for revisions to the draft ANSI N13.30.

Of 23 separate facilities originally contacted for the study, 11 of them reported results to the testing program after changes in the scope of the program were concluded. Among these 11 facilities, several had multiple analysis laboratories or systems to test, which raised the total number of responses to 27 participating in one or more testing category.

One of the most critical elements determined by the testing program was the choice of valid formulae used to determine the minimum detectable amount (MDA) of a particular counting system. The results of Round Two testing have required the use of several methods of determining the MDA of a facility, based on the quality of the reported background and testing blank data that were furnished.

Results indicate that for the MDA criteria more than 50% of the reporting laboratories did not include information on blank results, and with few exceptions it was not possible to determine their MDAs in proper accordance with the draft standard. Thus, they were not included in the passing

(a) Copies of the published draft are available from the Office of the Health Physics Society Executive Secretary, 800 Westpark Drive, Suite 400, McLean, VA 22101.

statistic. It was determined that a calculation of the MDA based on results of non-blank samples gave an imprecise measure of each laboratories' performance capability. For those laboratories that had an MDA calculated in accordance with the draft standard there was only an 8% failure rate overall.

Bias and precision measurement results were dependent on the radionuclide and interferences present. Cerium-144 lung counting results showed improved performance when compared with the pilot round whole body counting of ^{144}Ce, but overall only 7 of 21 facilities passed all of the criteria. Similar results were obtained for the second fission/activiation product testing nuclide, ^{54}Mn, although a fair amount of respondents misidentified the radionuclide. For the uranium and ^{238}Pu lung counting categories, all three facilities that sent results passed the precision criteria with a wide margin of success. However, 50% of ^{238}Pu results exceeded the bias performance criterion. For ^{238}U all laboratories passed the bias criterion. A potential fault in the realistic phantom could have caused the low bias results in plutonium lung counting.

In the whole body counting categories, only 4 of 11 facilities passed all of the criteria for ^{137}Cs, although the failure in achieving the MDA was only 9% as compared with 38% in the previous pilot test. Again, not reporting the blank counting data was the largest cause of not passing the MOA criterion. For ^{134}Cs, only 2 of 10 facilities passed all of the performance criteria.

A large diversity in the performance of bioassay laboratories is still evident, in spite of the fact that there have been several gains since the previous testing round. Lung counting for fission products improved by a factor of about 3, and the results of transuranic and natural uranium counting continued to be very good. Gains were not made in whole body fission-product counting, but the difference in the radionuclide matrix of the Round Two test phantoms and the phantoms used in the pilot testing made this comparison less valid. The most significant observation of Round Two is the necessity for obtaining actual background and blank counting data from the analysis equipment, because without these data no valid MDA can be calculated. The attempt to use derived background counting data from phantoms with test radionuclides greater than the acceptable minimum detectable amount (AMDA), in lieu of blank counting data that were not submitted, consistently caused failure of the MDA

criterion. All multi-channel counting systems should have the ability to manually remove count data in specified regions of interest.

Several concepts used in this report differ from the current draft ANSI N13.30. The determination of a confidence interval for the MDA statistic was introduced to characterize random and systematic errors that can cause uncertainty in the MDA estimate. This allowed for a comparison to be made of passing the MDA criterion using the MDA itself or using the lower 5% bound of the confidence limit of the MDA. The confidence limit of the MDA statistic was based on the use of a chi-square distribution for the standard deviation.

Due to the long duration of the testing program, some of the testing phantoms had radioactively decayed to less than 10 times the AMDA of activity before the testing program was complete. Thus, bias and precision results for some categories could not be evaluated in accordance with the draft standard. Even so, in many instances laboratory performance at activities below the specified AMDA itself was still well within limits. In only a few cases was it possible to conclude from the analyses of the data that a failure of precision or bias was due to excess random counting error from low-activity (less than 10 AMDA) phantoms.

Four reasons for laboratory failure of the MDA performance criterion were noted. Two reasons were due to improper or missing counting data for blank and background spectra. The inability to detect radioactivity at the specified AMDA was noted; and one due to failure to consider the uncertainty in the MDA estimate.

Recommendations from this testing round include: 1) the use of tailored MDA equations, based on the analysis and calculational methods of the procedure evaluated; 2) the use of a laboratory's own quality control data to determine baseline spectra in lieu of the small set of measurements received from performance testing; and 3) the use of procedures for revising the MDA calculation when Poisson statistics are rejected by appropriate statistical testing.

ACRONYMS

ALI	annual limit on intake
AMDA	acceptable minimum detectable amount
ANSI	American National Standards Institute
BOMAB	bottle-manikin-absorption (phantom)
B_r	relative bias
DOE	U.S. Department of Energy
DOELAP	Department of Energy Laboratory Accreditation Program
HPS	Health Physics Society
ICRP	International Commission on Radiological Protection
LLNL	Lawrence Livermore National Laboratory
MDA	minimum detectable amount
MDC	minimum detectable count
NCRP	National Council on Radiation Protection and Measurements
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
PNL	Pacific Northwest Laboratory
QA	quality assurance
QC	quality control
S_A	relative precision (formula A)
S_B	relative precision (formula B)
TQ	testing quantity

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INTRODUCTION

In the early 1980s, the U.S. Department of Energy (DOE) embarked on a process of evaluating and upgrading performance at DOE and DOE contractor facilities to ensure that their measurements of occupational radiation exposure are accurate. DOE's approach has been to encourage the development of performance standards by national consensus standards organizations, to evaluate the feasibility and technical appropriateness of the standards for application in DOE operations, and to develop and implement a routine performance testing program. These steps were completed for personnel dosimetry with the establishment of the Department of Energy Laboratory Accreditation Program (DOELAP) in 1986. DOE is now focusing on programs for radiation protection radiobioassay, internal dosimetry, and instrumentation.

Radiobioassay procedures are used to estimate the amount of radionuclides inside the body. One type of bioassay procedure, in vitro analysis involves measuring radioactivity in samples of body excreta. Another type, in vivo analysis, involves measuring radioactive emissions from the body (x- or gamma rays) using radiation detectors positioned close to the body. Accurate bioassay measurements are necessary to assess a worker's internal dose following an intake of radioactivity.

Significant differences exist in the techniques and instrumentation used for bioassay. However, any effectively managed bioassay program will be concerned with quality control, so that accurate determinations are made without bias caused by the procedure used in making the measurement.

PREPARATION OF DRAFT ANSI N13.30

The Health Physics Society (HPS) Working Group 2.5[a] was formed in 1979 to address the concern about accurate measurements. This group prepared the draft American National Standards Institute (ANSI) Standard ANSI N13.30 (ANSI 1989), which defined the criteria for analytical measurement performance of radiobioassay laboratories. The primary concern of the Working Group was that bioassay service laboratories, both commercial and institutional, must provide

(a) The current chairman of Health Physics Society Working Group 2.5 is Roscoe Hall, Savannah River Plant, Aiken, SC 29801.

accurate results for the analyses performed. The following factors may contribute to internal dosimetry inaccuracies resulting from in vivo bioassay measurements (Traub and Robinson 1987):

- undetected dose from intake of radioactive material that is removed from the body prior to the radiobioassay
- random and systematic errors in the measurement process
- errors in the mathematical model used to estimate excretion and retention
- uncertainty in the date of the intake and the subsequent fraction of the intake excreted prior to the bioassay
- variation in organ mass among individuals
- variations in the fraction of energy emitted from a source organ and later deposited in a target organ due to relative positions, organ size, shape, etc.
- variations from assumptions in the metabolic model.

Estimation of internal dose is a two-step process. First, the quantity of radioactivity present in an organ or the whole body of an individual is estimated from a physical measurement. Next, the dose is estimated using mathematical models for the metabolism of the radionuclide and energy deposition of emitted radiations. The performance criteria of draft ANSI N13.30 and the measurements discussed in this report only address the random and systematic errors in the first step.

The draft standard specifies numerical values by nuclide for acceptable minimum detectable amount (AMDA), relative bias (B_r), and relative precision (S_A, S_B). The standard also includes guidelines to be used by accrediting laboratories to test whether bioassay service laboratories conform to the quantitative performance criteria as well as to standard quality control procedures, such as might be required in a test for laboratory accreditation. The current draft standard has been accepted by ANSI Committee N13 for trial use, but has not been approved by ANSI as an accepted standard.

TECHNICAL EVALUATION OF DRAFT ANSI N13.30

Occupational radiation protection is a major area of research at Pacific Northwest Laboratory (PNL)[a] and technical evaluation of draft ANSI N13.30 has been one aspect of PNL's research under a project titled "Technical Evaluation of Draft ANSI Standard N13.30, 'Performance Criteria for Radiobioassay'" (ANSI 1989). The purpose of this project was to evaluate the appropriateness of the draft standard by conducting a bioassay performance intercomparison study. At completion of the first draft standard, the following seven objectives of the project were formulated:

- Establish test procedures for evaluating bioassay laboratories in accordance with the draft standard.
- Set up the necessary laboratory equipment and facilities to conduct preliminary testing of bioassay laboratory performance.
- Conduct two rounds of intercomparison testing.
- Compile results and compare the performance of bioassay laboratories with the draft standard performance criteria.
- Analyze the data to determine sources of error.
- Recommend any necessary revisions to the draft standard.
- Prepare a procedures manual for a laboratory to follow in conducting an ongoing performance-testing program for bioassay laboratory accreditation.

This research project involved three major phases: 1) develop testing procedures and establish laboratory facilities for preparing test samples and in vivo phantoms, 2) conduct a pilot intercomparison study with a small number of voluntarily participating in vitro and in vivo laboratories, and 3) conduct a second-round intercomparison study with a larger number of participating laboratories. The development of a set of procedures manuals was included in the third phase.

In support of evaluation of the draft standard, PNL has conducted performance tests of bioassay laboratories at DOE facilities, DOE contractor facilities, and other facilities throughout the United States. The results of

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(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

these studies were used to verify the appropriateness of the criteria selected by the HPS Committee.

The previous PNL studies evaluated bioassay laboratory performance as follows:

- two rounds of analysis of radioactivity in an artificial urine matrix (Robinson, Fisher, and Hadley 1984; MacLellan, Fisher, and Traub 1988)
- a single round of testing using artificial fecal samples (MacLellan 1988)
- a pilot test of laboratories that perform direct measurements (in vivo bioassay) of radioactive material in occupationally exposed individuals (Robinson et al. 1986).

The project has also investigated the effect of using discrete versus uniform source distributions in testing phantoms (Scherpelz and MacLellan 1987), and it provided the recommended procedures manuals for the proposed DOE accreditation laboratory (Fenrick and MacLellan 1988a; Fenrick and MacLellan 1988b; MacLellan and Traub 1988).

This report, on the second round of in vivo testing, completes PNL's evaluation phase of the project. It includes a description of the two rounds of in vivo testing, a discussion of the results of those rounds, and recommendations for future revisions of draft ANSI N13.30. The results from this and previous PNL reports and future PNL work will greatly assist in the establishment and design of a bioassay laboratory accreditation program at the DOE Radiological and Environmental Sciences Laboratory at the Idaho National Engineering Laboratory in Idaho Falls, Idaho.

QUALITY ASSURANCE

This research project conformed with PNL's internal quality assurance (QA) guidelines and with draft ANSI N13.30. As the testing laboratory, PNL was bound by the same QA requirements as the participating laboratories.

At PNL, all equipment and laboratory procedures or evaluations were documented in laboratory notebooks and records books. All radionuclide solutions used for spikes were obtained from the National Institute of Standards and Technology (NIST) or a supplier with calibrations traceable to NIST.

Participating laboratories were guided by QA instructions presented in Section 5 of the draft standard.

METHODS

Round One of in vivo testing was conducted by PNL using volunteer bioassay laboratories. Three types of phantoms (i.e., whole body bottle phantom, torso phantom with interchangeable lung sets, and thyroid phantom) were distributed in a round-robin fashion to the participating laboratories. Round Two involved a larger number of laboratories and different test radionuclides, but used only torso and whole body phantoms.

LABORATORY PARTICIPATION

Invitations to participate in the two-round intercomparison study were initially extended during the 27th Conference on Bioassay, Analytical, and Environmental Chemistry in 1981. Announcements about the opportunity to participate in the study were also published at various times in the HPS Newsletter. Invitations to participate and details of the Round One testing process were mailed to about 40 bioassay laboratories that had responded to the announcement and to other potential participants. With each invitation was a response form and this information:

- Participation would be entirely voluntary.
- All costs pertaining to the measurement of samples or phantoms would be borne by the participating laboratory.
- All laboratory names, categories of participation, and the identification of individual results would be strictly confidential to allow uninhibited participation.

In vivo counting facilities that indicated their desire to participate were then contacted by telephone. Further information and instructions regarding the study were sent to each interested participant.

For Round Two, letters of inquiry were sent to the previous participants and other facilities that had indicated interest in participating. The instructions and information provided were similar to Round One.

Round One Pilot Study

Five in vivo measurement categories with seven test radionuclides were offered during the first round of testing:

- lung measurements for ^{241}Am
- lung measurements for ^{235}U
- lung measurements for ^{60}Co
- whole body measurements for ^{60}Co, ^{137}Cs, ^{144}Ce
- thyroid measurements for ^{131}I

Table 1 shows the test radionuclides and activity ranges for in vivo performance testing that were chosen for the first-round intercomparison study. The radionuclides were selected from a list provided in an early version of draft ANSI N13.30. Strontium-90 and/or ^{40}K were added to the phantom to provide an intentional background "interference" to more closely represent the actual counting of human subjects. The acceptable test ranges given in Table 1 were changed in later versions of draft ANSI N13.30.

TABLE 1. Round One Test Radionuclides, Organs, and Activity Ranges for In Vivo Performance Testing (from the 1982 draft of ANSI N13.30)

Category	Organ	Radionuclide(s)	Activity Test Ranges (nCi)
Photons with energy $\leq$ 60 keV	Lung	^{241}Am(a)	1.0-10.0
Photons with energy 100-200 keV	Lung	^{235}U(a)	0.75-7.5
Photons with energy > 200 keV	Lung	^{60}Co(a)	40.0-400
Uniformly distributed fission and products	Whole body	^{60}Co ^{137}Cs ^{144}Ce(b)	200-2000 250-2500 300-3000
Radionuclides in the thyroid	Thyroid	^{131}I	40.0-400

(a) With ^{40}K present.

(b) With ^{40}K and ^{90}Sr present.

Fifteen facilities participated in one or more of the five categories of lung and whole body counting. These included five national laboratories, one university, one fuel fabrication facility, and eight reactor sites. Each facility was given the option of performing measurements in any or all of the above categories, depending on their need and interest. In general, the DOE-contractor laboratories performed measurements in all categories, whereas facilities regulated by the U.S. Nuclear Regulatory Commission (NRC) were primarily interested in measurements involving fission and activation products.

Round Two Testing

Four different in vivo measurement categories were offered during Round Two testing:

- lung measurements for ^{238}Pu
- lung measurements for natural uranium
- lung measurements for fission/activation products (i.e., ^{54}Mn and ^{144}Ce)
- whole body measurements for ^{134}Cs and ^{137}Cs.

Table 2 shows the test radionuclides and activity ranges for in vivo performance testing that were chosen for the second-round intercomparison study. All phantoms contained ^{40}K to provide an intentional background "interference" to more closely represent the actual counting of human subjects. The phantoms also contained specific interference radionuclides; the fission product lung phantom contained ^{134}Cs and ^{137}Cs and the whole body phantom contained ^{54}Mn and ^{60}Co. In accordance with draft ANSI N13.30, these radionuclides were present for interference but were not used for testing. The acceptable test ranges given in Table 2 are from the latest version of the standard.

Twenty-seven facilities participated in one or more of the four lung and whole body counting categories. These included five national laboratories, one nuclear vendor, two DOE contractors, one non-DOE federal facility, and eleven commercial reactor sites. Each facility was given the option of performing measurements in any or all of the above categories, depending on their need and interest. Again, the DOE laboratories performed measurements

TABLE 2. Round Two Test Radionuclides, Organs, and Activity Ranges for In Vivo Performance Testing (from August 1987 draft of ANSI N13.30)

Category Number	Category	Organ	Radionuclide[a]	Testing Activity Ranges, μCi
I	Measurement of transuranium elements via L x-rays	Lung	^{238}Pu	0.05 to 5
III	Measurement of ^{234}Th	Lung	Natural uranium	0.03 to 3
V	Measurement of fission and activation products	Lung	^{54}Mn and ^{144}Ce[b]	0.02 to 2 0.2 to 20
VI	Measurement of fission and activation products	Whole body	^{134}Cs and ^{137}Cs[c]	0.02 to 2 0.02 to 2

(a) In addition to the specified test radionuclide(s), ^{40}K shall be present with an activity in the range of 0.05 to 0.10 μCi for lung categories, and in the range of 0.08 to 0.16 μCi for the total body category.
(b) ^{134}Cs and ^{137}Cs shall be present as interference nuclides (0.02 to 2 μCi each).
(c) ^{54}Mn and ^{60}Co shall be present as interference nuclides (0.02 to 2 μCi each).

in all categories, whereas NRC-regulated facilities were primarily interested in measurements involving fission and activation products. All participating facilities received an in vivo measurements report form (see sample in Appendix A). Table 3 lists the AMDAs for the test radionuclides used in Round Two testing, as determined by the 1987 draft ANSI N13.30.

PREPARATION OF IN VIVO PHANTOMS

Phantom preparation procedures for Round One of this study were described by Robinson et al. (1986). For Round Two, all lung and BOMAB phantoms were prepared by PNL. The foaming polyurethane used in Round One for lung phantoms was not available in small batches from the original supplier, so a new

TABLE 3. Acceptable Minimum Detectable Amounts for Nuclides Used in Round Two Testing (from the 1987 draft ANSI N13.30)

Category Number	Category Description	Organ	Radionuclide	AMDA (nCi)
I	Measurement of trans-uranium elements via L-x rays	Lung	^{238}Pu	46
III	Measurement of ^{234}Th	Lung	U_{nat}	3
V	Measurement of fission and activation products	Lung	^{54}Mn	20
V	Measurement of fission and activation products	Lung	^{144}Ce	185
VI	Measurement of fission and activation products	Total body	^{137}Cs	24
VI	Measurement of fission and activation products	Total body	^{134}Cs	21

supplier was used,[a] which allowed pre-mixed batches of the identical lung material to be molded into lungs according to the original Lawrence Livermore National Laboratory (LLNL) lung formulation. All radionuclide solutions were obtained either directly from NIST or from suppliers with calibrations directly traceable to NIST. Propagation of error in radionuclides incorporated into the phantoms is detailed in Appendix B.

Two types of phantoms were prepared. The first type of phantom is an appropriate blank as described in draft ANSI N13.30. This phantom contained only ^{40}K. The second type of phantom, a test phantom, was identical to the blank phantom except for the addition of the test radionuclides. The purpose of the blank phantom was to allow for estimation of the minimum detectable amount (MDA) of the service laboratory. The test phantom was used to estimate the bias and precision of the service laboratory. Lung phantoms with activities less than 10 times the AMDA were also used to evaluate the performance of the service laboratory near the AMDA for the given procedure, and for verification of the MDA calculations. The service laboratory was requested to

(a) The new supplier of foaming polyurethane was Radiological Support Services, Long Beach, California.

make five replicate analyses of each phantom, removing and repositioning the phantom after each analysis.

Whole Body Phantom Preparation

Draft ANSI N13.30 requires that the whole body phantom used for testing purposes be commercially available and that the activity be uniformly distributed throughout the phantom. A BOMAB[(a)] whole body bottle phantom, consisting of 10 sturdy polyethylene circular or elliptical right cylinders, was used for this study. Each cylinder was fitted with a screw-cap to accommodate filling. The bottles of the phantom were of various sizes and volumes that approximated the whole body proportions of an adult male of average stature. The dimensions and volumes of the phantom are given in Table 4.

Each of the bottles of the phantom were filled with a solution that contained the appropriate quantity of radionuclides and ^{40}K in a gelatin solution. The purpose of the gelatin was to stabilize the radionuclide solution and to reduce leakage if a segment was dropped and broken. The potassium included in the phantom approximated the potassium content of an adult, giving the approximate ^{40}K body burden of 120 nCi.

Preparation of Whole Body Phantom Spike Solutions

The radionuclide spike solutions were prepared at PNL according to the methods developed in the previous pilot testing study (Robinson et al. 1986). According to the current ANSI N13.30 draft, the quantity of radionuclide placed in the whole body phantom for purposes of testing relative precision and relative bias must exceed 10 times the AMDA for the particular radionuclide. A solution containing 0.444 nCi/g of ^{54}Mn, 0.352 nCi/g of ^{134}Cs, 0.440 nCi/g of ^{137}Cs, and 0.252 nCi/g of ^{60}Co was prepared to form a stock solution. During the preparation of the stock solution, the dilutions of individual radionuclides did not exceed a factor of about 1:1000. During dilution of the radionuclides, precautions were taken to ensure that the radionuclide did not adhere to the surface of the container; the radionuclide solution was diluted with nitric acid. Aliquants of the phantom

(a) The BOMAB (bottle-manikin-absorption) whole body bottle phantom is manufactured by Atlantech, Inc., Roswell, Georgia, and NE Tech, Inc., Mammouth Junction, New Jersey.

TABLE 4. Dimensions of Phantom Bottles Representing Human Body Parts

Part	Shape	Cross Section (cm)	Length (cm)	Volume (mL)	Percent of Total
Head	Ellipse	19 x 17	20	3,244	5.8
Neck	Circle	13	10	900	1.6
Thorax	Ellipse	30 x 20	40	16,370	29.1
Abdomen	Ellipse	36 x 20	20	9,118	16.2
Arms (2)	Circle	10	60	7,305	13.0
Thighs (2)	Circle	15	40	11,970	21.3
Legs (2)	Circle	12	40	7,362	13.0
Total				56,269	100.0

stock, in proportion to the "percent of total" column in Table 4, were pre-weighed into plastic containers; one for each phantom segment.

Preparation of Whole Body Phantom Body Parts

BOMAB phantom body parts were prepared at PNL according to the following procedure. A warm gelatin mixture was prepared by dissolving 300 g of gelatin in 2.5 L of water. The gelatin solution was poured into each phantom section until the section was about half full. The pre-weighed radionuclide solution was neutralized with an appropriate volume of KOH solution and poured into the phantom segment. The radionuclide bottle was rinsed several times and the rinse solution was poured into the body segment. Benzalkonium chloride (16 mL/L of a 17% solution) was added to the phantom segment to inhibit the growth of microorganisms, and sodium metabisulfate (5 g/L) was added to retard the oxidation of the gelatin. The phantom segments were tilted back and forth until the solution was completely mixed. Food coloring was added to the segment prior to the mixing process, and the distribution of the food coloring was used to gauge the degree of mixing achieved.

Draft ANSI N13.30 states that the phantom shall contain ^{40}K in an amount equivalent to that contained in a person of average stature (0.08-0.16 μCi). Enriched ^{40}K was not available, so the requisite activity was obtained using 270 g of KCl (an isotopic abundance of 0.0118% for ^{40}K in potassium was assumed). The 120 nCi of ^{40}K was distributed among the phantom segments in proportion to the "percent of total" column of Table 4.

The phantom segments were filled by adding gelatin solution in small increments, and the contents were mixed after each addition. When the segment was filled and well mixed, it was placed in a refrigerator to cool and solidify. The total activity of each radionuclide in the whole body phantom is shown in Table 5. Only the cesium isotopes were intended to be quantified by the participating laboratories.

A "blank" phantom was also prepared for use in estimating the MDA. This phantom was identical to the phantom that contained the test radionuclides, except that no spike solution or interference radionuclides were added. The ^{40}K content was the same as that of the test phantom. Different colors of food coloring were used to distinguish between the blank and test phantoms, but they were not identified as to which was which.

Lung Phantom Preparation

The lung phantom specified by draft ANSI N13.30 is a realistic simulation of the torso, skeleton, and lungs of a man of average stature. According to the 1987 draft ANSI N13.30, the phantom should have a chest wall over the lungs that simulates muscle tissue with a thickness in the range of 1.4 to 1.7 cm. The simulated tissues of the phantom should have transmission and scatter characteristics for low-energy photons that closely approximate those for normal tissue. The torso phantom should have interchangeable pairs of simulated lungs in which the test radionuclide is uniformly distributed.

The torso phantom used during intercomparison testing was a "Realistic Phantom" developed at LLNL and marketed commercially by the Humanoid Systems,

TABLE 5. Total Activity of Test and Interference Radionuclides in the BOMAB Whole Body Bottle Phantom

Radionuclide	Total Activity (nCi)
^{134}Cs	299 ± 8
^{137}Cs	374 ± 5
^{54}Mn	377 + 10 - 8
^{60}Co	214 ± 5

Inc. (now Radiological Support Services, in Long Beach, California).[a] The phantom was constructed of tissue-equivalent plastic materials and plastic bone. The phantom contains interchangeable pairs of simulated lungs with a density of 0.3 g/cm^3, which were produced at PNL from kits supplied by the manufacturer.

For the final round of the intercomparison study, kits were obtained from the phantom manufacturer that allowed custom fabrication of lung sets. The kit material consisted of two parts: a black urethane plastic and a catalyst. The radionuclide solution was mixed with the plastic component prior to polymerization. Addition of the catalyst causes polymerization and foaming of the urethane material. After the lungs were formed they were sealed with a polyurethane coating. The final product was a lung-shaped object that contained a uniform distribution of radioactivity, the total quantity of which was well characterized.

Preparation of the Lung Spike Solutions

Draft ANSI N13.30 states that for testing the bias and precision of the service laboratory, the radionuclides shall be in the lungs in a quantity that is at least 10 times the AMDA for the particular radionuclide and within the range of activity listed in Table 3 of the current draft standard. The testing quantity can be any quantity chosen by the performance-testing laboratory within the range of 10 to 100 times the AMDA. In accordance with the performance testing procedures (MacLellan and Traub 1988), this quantity is called the TQ.

A solution containing the TQ of each radionuclide was prepared to form a phantom stock solution. During the preparation of the phantom stock solution the dilutions of individual radionuclides did not exceed a factor of about 1:1000. Nitric acid was added to the solution to ensure that the radionuclide did not adhere to the surface of the container.

(a) Reference to a company or product name does not imply approval, recommendation, or endorsement by Pacific Northwest Laboratory or the U.S. Department of Energy to the exclusion of other companies or products that may be suitable.

The TQ was partitioned between the right and the left lung in proportion to the relative mass of each lung. These quantities will be referred to as TQ-R and TQ-L, respectively, and are determined as follows:

$$TQ\text{-}R = 0.56\ TQ \quad (1)$$

$$TQ\text{-}L = 0.44\ TQ. \quad (2)$$

The test solutions were prepared using gravimetric means rather than volumetric means, because Standard Reference Materials are calibrated for gravimetric dispensing and gravimetric methods avoid the necessity of temperature corrections for the volumes. The balances used were calibrated with weights traceable to NIST.

In addition to the test phantoms that contained 10 to 100 times the AMDA quantity, one set of blank lungs with only the added KCl and one set of lungs with added activity near the AMDA were also prepared for each category.

^{238}Pu Solutions. Standard Reference Materials solutions of ^{238}Pu were ordered from NIST. The solutions were packaged by NIST so that the desired quantity for each lung was in a separate vial. The vials were opened, weighed, emptied into the lung material, and then reweighed. The material dispensed into the lung material was assumed to equal the loss in mass of the vial.

Activation/Fission Product Solutions. The lungs for the activation/fission product phantoms contained four radionuclides; two test radionuclides (^{54}Mn and ^{144}Ce) and two interference radionuclides (^{134}Cs and ^{137}Cs). Each radionuclide was diluted so that TQ-L and TQ-R were in a volume from 0.12 mL to no more than 1.2 mL. The solutions were prepared so that the TQ was in the smallest possible volume. The ^{54}Mn and ^{144}Ce solutions were obtained from a commercial vendor with demonstrated traceability to NIST. The stock solutions contained 2.629 μCi/g of ^{54}Mn and 4.373 μCi/g of ^{144}Ce.

Natural Uranium Solutions. Standard Reference Materials of natural uranium metal were obtained from the New Brunswick Laboratory, in Argonne, Illinois. To prepare the metal as a solution the metal chip was dipped in 1:1 HNO_3 for about 10 minutes to remove the surface oxide on the metal, rinsed in distilled water, then etched in 1:3 HCl for 5 minutes. The metal was then

rinsed thoroughly in distilled water, patted dry with a lint-free wiper, and placed in a vacuum desiccator for one-half hour to accelerate removal of surface moisture and retard re-oxidation of the metal. After about 30 minutes, the chip was periodically reweighed until a constant weight was achieved. Only clean stainless steel forceps were used to handle the metal and the weighing was done on a calibrated balance.

After a constant weight was achieved for the uranium metal it was placed in a tared Pyrex™ flask and enough 1:1 HNO_3/3N HCl was added to dissolve the metal. After the metal was dissolved, the flask was reweighed. The formula for the concentration of the uranium solution (CUS) is:

$$CUS = \frac{\text{mass of uranium chip}}{F2 - F1} \tag{3}$$

where F2 is the mass of the flask including the uranium and dissolving solution and F1 is the flask tare weight. The solution activity was determined to be 0.0607 g-U(nat)/g. with an assay error of ± 0.017%. The formula for the quantity of the solution placed into each lung was:

$$\text{Mass of solution for left lung} = (TQ\text{-}L)/CUS \tag{4}$$

$$\text{Mass of solution for right lung} = (TQ\text{-}R)/CUS. \tag{5}$$

Preparation of Lung Phantoms

Lung phantoms are prepared using lung molds and plastic lung material. The lung molds were prepared by first cleaning them with acetone and then lubricating them with a silicone grease (Dow Corning #4 silicone grease). The lung material used was obtained as a two-component kit. One component is a black plastic, the other is a clear catalyst (isocyanate) that promotes the reaction of the foam. Only a very small volume of the radionuclide solution can be incorporated into the plastic component. (The manufacturer recommends that the volume be less than 0.5 mL, although PNL has incorporated up to 5 mL of radionuclide solution at PNL without significant loss of viscoelasticity of the plastic.)

™ Pyrex is a registered trademark of Dow-Corning Glass Works, Corning, New York.

The first step in the preparation of the lung phantoms, was to record the mass of the black plastic material in the mixing container. Then, the radionuclide solution was added to the plastic component. Although human lung actually contain very little potassium, draft ANSI N13.30 specifies that KCl also be added to the lung material. The lungs themselves had a total of 3.8 g KCl added to them, with the remaining 152 g (which equates to approximately 70 nCi of ^{40}K) added to the phantom cavity. The phantom cavity contained 42 g located in the heart cavity and 110 g located in plugs throughout the abdominal block. This distribution was chosen as an approximation of the K distribution in organs as noted in ICRP 23. The plastic component was then thoroughly mixed with a paint stirrer attached to a hand-held power drill.

The catalyst component was mixed well, then drawn into two 50-mL syringes with luer fittings. The luer fittings have a smaller orifice and produce more force for the catalyst injection than catheter fittings. After the syringes had been filled with catalyst material, their mass was recorded.

Next, one individual mixed the black plastic component using the hand-held drill with its attached paint stirrer. The second person added the catalyst, emptying the two syringes simultaneously. The streams from the syringes were moved back and forth to aid in the mixing of the catalyst.

After the catalyst was injected into the black plastic, the mass of the catalyst syringes was recorded. The plastic and catalyst were mixed for about 10 seconds and then the mixture was poured into the bottom half of the lung mold. The remaining mixture was scraped from the mixing container into the bottom half of the lung mold with a tongue depressor. When all of the lung material was transferred, the top of the lung mold was clamped into place. The vent hole at the top of the lung mold was closed with a stopper when plastic material began to exude from the hole.

The lung phantom was then allowed to set for at least 1 hour before removing it from the mold. Once removed from the mold, the mold was cleaned with acetone. After trimming off all of the material that leaked out between the two halves of the lung mold, the lung was weighed to determine its mass. Finally, the lung was painted with a polyurethane coating material (as a sealant) and identifying marks were applied using white model paint.

Test Lung Radionuclide Activity

The radionuclide concentration (C) in the lung material was calculated using the following equation:

$$C = \frac{A_r}{(M_B + M_C + M_R + M_K)} \quad (6)$$

where M_B = Mass of black plastic (the mass of the material placed into the mixing container)

A_r = Activity of added test radionuclide solution in nanocuries

M_C = Mass of catalyst (the mass of the full catalyst syringes minus the mass of the emptied catalyst syringes)

M_R = Mass of the radionuclide solution

M_K = Mass of KCl.

The activity in the lung material (AL) was determined using the following equation:

$$A_L = M_L \times C \quad (7)$$

where M_L equals the mass of the lungs after trimming off the excess material and before applying the sealant. The activities of each test radionuclide are shown in Table 6.

TABLE 6. Round Two Performance Test Lung Activities

Category Number	Category	Radionuclide	Calibration Date	Phantom Activity (nCi)	
				Test Lungs	MDA Lungs
I	Measurement of transuranics via L x-rays	^{238}Pu	July 21, 1986	374 ± 8	32 ± 1
III	Measurement of ^{234}Th	U_{nat}	June 30, 1986	33 ± 1	3.5 ± 0.1
V	Measurements of fission and activation products	^{54}Mn	June 27, 1986	663 + 18 - 14	65 ± 1
		^{144}Ce	June 27, 1986	1926 ± 60	223 ± 7

PHANTOM IDENTIFICATION AND SHIPMENT TO PARTICIPATING LABORATORIES

The primary marking on the lung phantoms was of the type "nnnnn-xx," where nnnnn was the laboratory notebook number and xx was the page number of the notebook that contained the data recorded during the manufacture of the lung material. The lungs were coded with a nuclide identifier and a random number designation (1 through 3) for the spike level (i.e., test level, MDA level, or blank).

The test radionuclide activity levels qualified under the "limited quantity" designation of 49 CFR 173. The sample containers were packaged and labeled in compliance with federal regulations for packaging and shipping and they were shipped by surface carrier. The shipping of "limited quantity" activity levels does not require any external radiation labeling on the box.

DATA EVALUATION

Following the receipt of analysis data for all samples sent to the service laboratories, the test statistics for the performance report were calculated in accordance with draft ANSI N13.30 and the recommended procedures for the performance testing (MacLellan and Traub 1988). The performance criteria included the relative bias (B_r), relative precision (S_A and S_B), and the MDA for each test nuclide analyzed by the service laboratory. Additional confidence intervals were calculated for these criteria according to methods described in the section "Confidence Intervals for the Performance Criteria."

DRAFT ANSI N13.30 PERFORMANCE CRITERIA

The performance criteria as they are currently specified in the latest (August 1987) draft of ANSI N13.30 were used in the analyses of the in vivo counting data. Additionally, methods of introducing confidence intervals based on Poisson statistics were developed and introduced to determine the outer bounds of the various performance criteria statistics. A discussion of the current criteria and the basis for them is provided here.

Relative Bias

The relative bias (B_r) was calculated from the analysis data reported by the service laboratory using the following equations:

$$B_{ri} = \frac{A_i - A_{ai}}{A_{ai}} \tag{8}$$

$$B_r = \sum_{i=1}^{N} B_{ri} \; / \; N \tag{9}$$

where B_{ri} = the relative bias of the ith sample in the activity category

B_r = the mean relative bias of all replicates in the activity category

A_i = the reported result in the ith activity category

A_{ai} = the true activity for the ith activity category

N = the number of samples or replicates per activity category.

Relative Precision

The relative precision estimators (S_A and S_B) were also calculated from the analysis data reported by the service laboratory using the following equations:

$$S_A = \left[\sum_{i=1}^{N} [(A_i/\bar{A})-1]^2/(N-1) \right]^{\frac{1}{2}} \quad (10)$$

$$S_B = \left[\sum_{i=1}^{N} (B_{ri}-B_r)^2/(N-1) \right]^{\frac{1}{2}} \quad (11)$$

where $\bar{A}$ is the mean reported result for all N samples or replicates in the i^{th} activity category, and the rest of the terms are the same as those defined above for the Equations (8) and (9). The above equations for relative precision (S_A and S_B) are analogous to equations used in the August 1987 draft ANSI N13.30. The rationale for using two different relative precision equations is provided in Appendix B of the August 1987 draft standard.

Minimum Detectable Amount

Estimation of the MDA requires the evaluation of the variability observed in the measurement of the appropriate blanks. The specific form of the MDA equation will depend on the assumptions made about the count distribution. If the performance test identifies a relative bias for the reported analysis data, the calculated MDA should be multiplied by $1/(1+B_r)$ to obtain the bias-corrected MDA, for purposes of comparison with the AMDA.

When each sample measurement is paired with an appropriate blank, the non-Poisson errors may be considered to cancel out and a Poisson distribution may be assumed. The measurement procedures tested in this performance test may be considered to be paired observations because the baseline of the gamma spectrum is subtracted from the peak to obtain the net counts. The MDA was therefore calculated using the following equation, which is equivalent to the equation in Section 3.4.1.2 of draft ANSI N13.30.

$$MDA = \frac{[3.29\ s_o + 2\ \Delta_B B + 3]}{KT\ (1 + \Delta_K)} \qquad (12)$$

where K = the calibration factor supplied by the service laboratory for the measurement process in counts per minute per nanocurie

Δ_K = the estimated fractional systematic error in the calibration factor K. The upper 95% bound of the performance test estimate of B_r should be used for this factor (Brodsky 1986)

B = the baseline count for the spectrum in the region of interest, including any interference nuclide counts

Δ_B = the estimated fractional systematic error in determining the baseline count B (assumed to have an upper bound of ±5% when no higher energy interference nuclides are present and ±1% when higher energy nuclides are present)

$s_o = s_b(h) = (\bar{x})^{\frac{1}{2}}(h)$, the standard deviation of the net blank count

T = the sample count time.

The term $(3.29s_o)$ evolves from the argument from Currie (1984) and the equation deviation is explained by MacLellan (1989). When the standard deviation of the sample measurement is known and constant up to the MDA value, the a priori minimum detectable count (MDC) is just twice the minimum count that will be considered significantly greater than a blank count with 95% probability. Assuming a normal distribution for the blank data, the MDC is $2(1.645)s_o$ or $3.29s_o$ and the MDA would be determined by dividing the result by the appropriate calibration factors. For most measurement systems, the baseline standard deviation is not constant and additional terms are required in the MDA equation numerator. The "$2\ \Delta_B B$" term estimates the upper bound for systematic (non-random) errors in the baseline estimate and the "3" term accounts for the Poisson-related increase in the standard deviation at the MDA value.

The value of s_o may be calculated from the product of the background standard deviation (s_b) multiplied by a factor (h), where (h) equals the square root of (1+1/b) and (b) is the ratio of the background to sample counting times. The MDA equations then reduce to

$$MDA = (3.29(h)s_b + 0.10B + 3)/KT\ (1 + \Delta_K) \qquad (13)$$

when no interference nuclides are present and the use of a "well-known blank" is used to compare the background and net count spectra, and

$$MDA = (3.29(h)s_b + 0.02B + 3)/KT\ (1 + \Delta_K) \quad (14)$$

when interference nuclides are present. For paired observations (each sample compared with a single not "well-known blank"), the respective equations reduce further to

$$MDA = (4.65\ s_b + 0.10\ B + 3)/KT\ (1 + \Delta_K) \quad (15)$$

and

$$MDA = (4.65\ s_b + 0.02\ B + 3)/KT\ (1 + \Delta_K) \quad (16)$$

The calibration factor, K, is equal to the product of the detector counting efficiency, sample volume, and the physical conversion factor for nuclear transformations in the region of interest per unit activity (i.e., decays per minute per nanocurie). This value should be supplied by the service laboratory.

CONFIDENCE INTERVALS FOR THE PERFORMANCE CRITERIA

Because the performance criteria results were based on a small sample size, it is important to calculate their confidence intervals. The bias is assumed to be normally distributed so that its estimated value follows the t-distribution. The confidence interval will therefore be

$$B_r \pm t\ (S_B/\sqrt{n}) \quad (17)$$

where n is the performance test sample size, S_B is the relative precision estimator, and t is listed in Table 7 for the 90% confidence level.

TABLE 7. Student's t Statistic at 90% Confidence Level ($n \leq 30$)

Sample Size (n)	t
1	-
2	6.314
3	2.920
4	2.353
5	2.132
6	2.015
7	1.943
8	1.895
9	1.860
10	1.833
15	1.751
20	1.729

Since the performance criteria estimates may be based on as few as five replicates, it is important to calculate their confidence intervals. The random variable $(n-1)s^2/\sigma^2$ follows the chi-square distribution with n-1 degrees of freedom (Remington and Schork 1970). To obtain the 5% lower bound and 95% upper bound for any standard deviation related term, the (s_b) term should be divided by the value from the third and fifth columns of Table 8, respectively. These boundary values should then be used in the appropriate MDA equation to obtain the 90% confidence interval.

The null hypothesis (that the true MDA is less than or equal to the acceptable MDA) should be accepted if the lower 5% bound for the interval is less than or equal to the acceptable MDA of draft ANSI N13.3D. If the null hypothesis is accepted, the service laboratory should not be failed in the MDA criterion. The acceptable values for bias and precision were established with testing variability in mind and therefore have a built-in confidence interval.

TABLE 8. Factors for MDA Confidence Interval Estimation

Replicates, n	$\chi^2_{0.95}$	$[\chi^2/(n-1)]$	$\chi^2_{0.05}$	$[\chi^2/(n-1)]$
2	3.841	1.96	0.0393	0.063
3	5.991	1.73	0.103	0.227
4	7.815	1.61	0.352	0.343
5	9.488	1.54	0.711	0.422
6	11.070	1.49	1.145	0.479
7	12.592	1.45	1.635	0.522
8	14.067	1.42	2.167	0.556
9	15.507	1.39	2.733	0.584
10	16.919	1.37	3.325	0.608

Source: Remington and Schork (1970).

Confidence Interval for the Estimated Minimum Detectable Amount

Since the estimate of the sample population was assumed to be Poisson distributed, both the mean and variance of the net count were assumed to follow the Poisson distribution, which approximates the normal distribution for mean values greater than 20. The 5% lower bound for the s_b term was calculated using the following equation:

$$s_{b.05} = \sqrt{(B-1.645\sqrt{B})} \qquad (18)$$

The lower 5% bound for the confidence interval of the true MDA value was obtained by substituting $s_{b.05}$ for s_b in Equation (13).

Service Laboratory Estimated Minimum Detectable Amount

Each service laboratory was asked to furnish their estimate of the MDA of each radiobioassay procedure it completed. This estimate was compared with the testing laboratory (PNL) results to identify laboratories that may be underestimating the precision of their analyses.

LABORATORY PERFORMANCE SUMMARY

The laboratory performance criteria results for both Round One and Round Two testing are summarized in Table 9. They are included together in order to more easily contrast the results of each testing round. It should be remembered that the formulae that were used for MDA are not the same in Round Two as those used in Round One. The S_A criterion was not added to the standard until after Round One testing was complete. The comparison of the two differently formulated results is only done to judge how changes have affected the performance of the service laboratories.

TABLE 9. Summary of In Vivo Performance Test Results - Rounds One and Two

Round One

Category	Radionuclide	Number of Respondents	Number of Respondents Failing Criterion: Bias	Precision S_B	MDA	Not Reported(a)
Lung	^{241}Am	4	0	0	2(50%)	1(25%)
Lung	^{235}U	5	1(20%)	0	2(40%)	2(40%)
Lung	^{60}Co	13	8(62%)	0	2(15%)	3(23%)
Whole body	^{60}Co	13	5(38%)	1(8%)	5(38%)	3(23%)
Whole body	^{137}Cs	13	2(15%)	0	5(38%)	2(15%)
Subtotal		48	16(33%)	1(2%)	16(33%)	11(23%)
Whole body	^{144}Ce	13	7(58%)	5(42%)	4(33%)	3(25%)
Total		60	23(38%)	6(10%)	20(33%)	14(23%)

Round Two

Category	Radionuclide	Number of Respondents	Number of Respondents Failing Criterion: Bias	Precision S_A	Precision S_B	MDA	Not Reported(a)
Lung	^{238}Pu	3	1(33%)	0	0	0	0
Lung	^{238}U	3	0	0	0	0	0
Lung	^{54}Mn	22	6(27%)	0	1(5%)	1(5%)	12(55%)
Lung	^{144}Ce	21	8(38%)	0	1(5%)	0	10(48%)
Whole body	^{137}Cs	11	2(18%)	1(9%)	0	1(9%)	6(55%)
Whole body	^{134}Cs	10	4(40%)	0	0	1(10%)	5(50%)
Total		70	21(30%)	1(1%)	2(3%)	3(4%)	33(47%)

(a) Facilities failing to provide replicate background counts.

Performance test results are arranged by radionuclide category and summarized in Tables 10 through 15. Companion Figures 1 through 18 are graphs of the results of testing in each radionuclide category. These scatter diagrams include the limits of the performance criteria as the solid vertical line(s), and any results that lie outside of the limits are considered to have failed the criteria. Horizontal lines are included at the true activity levels for AMDA and 10 times the AMDA to reference laboratory response to the suggested testing level for 10 times the AMDA. The graphs do not show the confidence intervals for the performance criteria estimates. There were only two instances where applying $MOA_{0.05}$ instead of MDA resulted in additional laboratories passing the MDA criterion. The performance criteria results with respective confidence intervals are listed for each nuclide and laboratory code in Appendix C.

The performance of the three laboratories that reported results for ^{238}Pu is detailed in Table 10 and diagrammed in Figures 1 through 3. Two of the three passed the relative bias criterion, all three passed the relative precision criteria (S_A) and (S_B), and all three passed the MDA criterion. Two of the three facilities had noticeably low bias (negative), which prompted an investigation of the chest wall thickness of the phantom used in the study. It should be noted that the TQ of the AMOA lung set for ^{238}Pu was below the specified AMDA.

While the Humanoid test phantom was at the PNL whole body counter, PNL personnel compared the transmission properties of ^{238}Pu x-rays through the phantom with those transmission properties through an original LLNL torso phantom. Based on the ratio of counts between the two phantoms and assuming the specified chest wall thickness of the LLNL phantom is correct, the Humanoid test phantom chest wall thickness was calculated to be closer to 1.6 cm rather than the 1.42 cm given in the technical specification from the manufacturer. The physical thickness of the chest wall was subsequently measured with calipers and by computerized tomography. The estimates showed some differences in physical thickness from the manufacturer's specification but do not provide information on the density of the phantom material. Therefore, we can only presume at this point that the physical thickness specified by the manufacturer for the Humanoid phantom chest wall may be incorrect, and

TABLE 10. ^{238}Pu Lung In Vivo Intercomparison Testing Results (AMDA = 46 nCi)

Laboratory Code	(nCi) Activity	(nCi) Assay	Relative Bias	Precision (S_A)	Precision (S_B)	MDA (nCi)	Activity >10 x AMDA	System Type	Pass
A	31.94	23.0	-0.28	0.08	0.06	8.2	No	Phoswich/	No
A	367.66	245.3	-0.33	0.02	0.01		No	Vault	No
K	32.38	20.5	-0.37	0.16	0.10	24	No	Multi.HPGe	No
K	372.71	289.1	-0.22	0.04	0.03		No	Vault	Yes
M	31.82	29.0	-0.09	0.28	0.26	26	No	Mult.HPGe	Yes
M	366.31	376.0	0.03	0.05	0.05		No	Vault	Yes

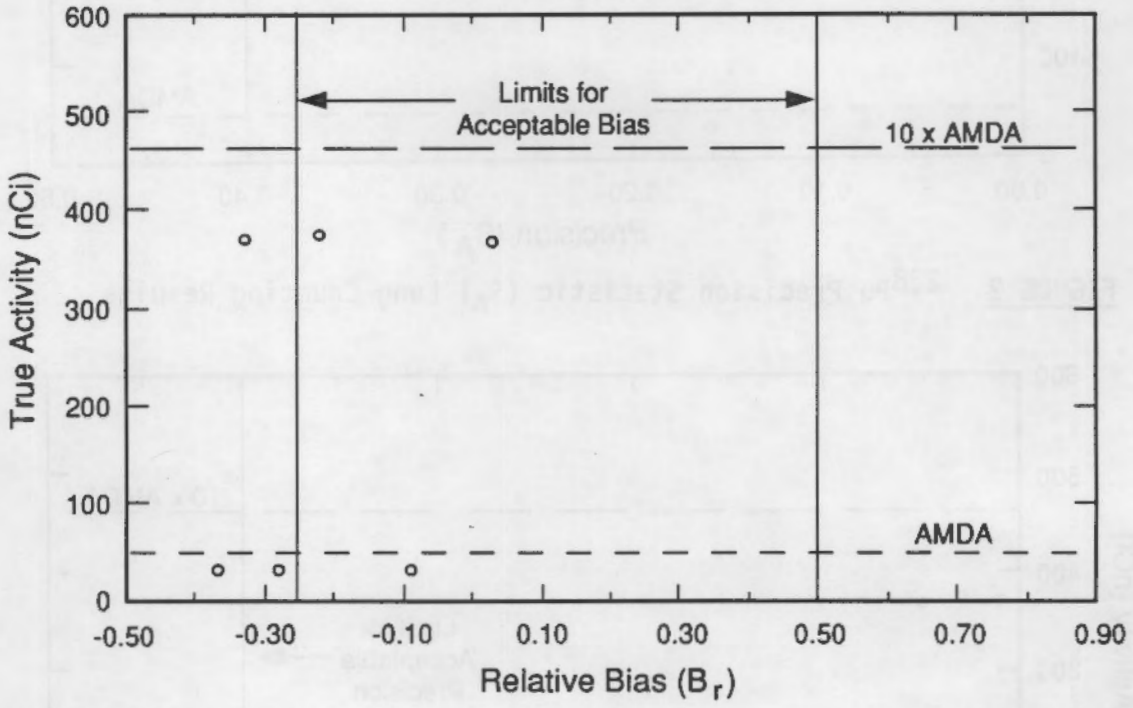

FIGURE 1. ^{238}Pu Bias Statistic (B_r) Lung Counting Results

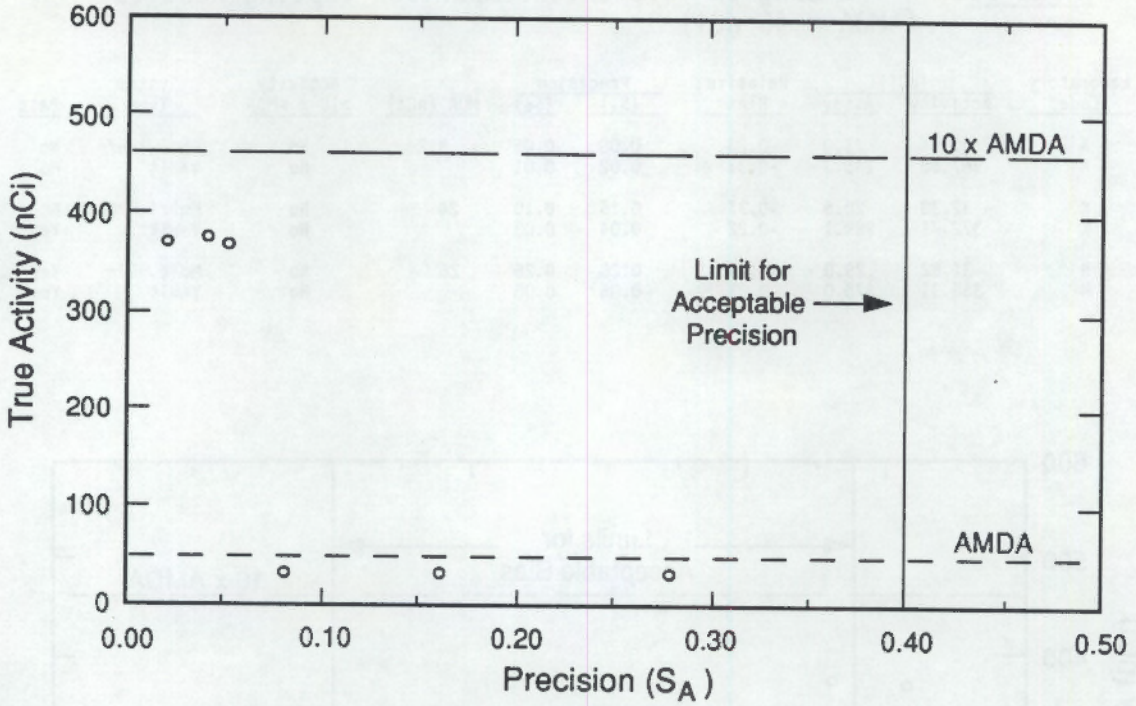

FIGURE 2. ^{238}Pu Precision Statistic (S_A) Lung Counting Results

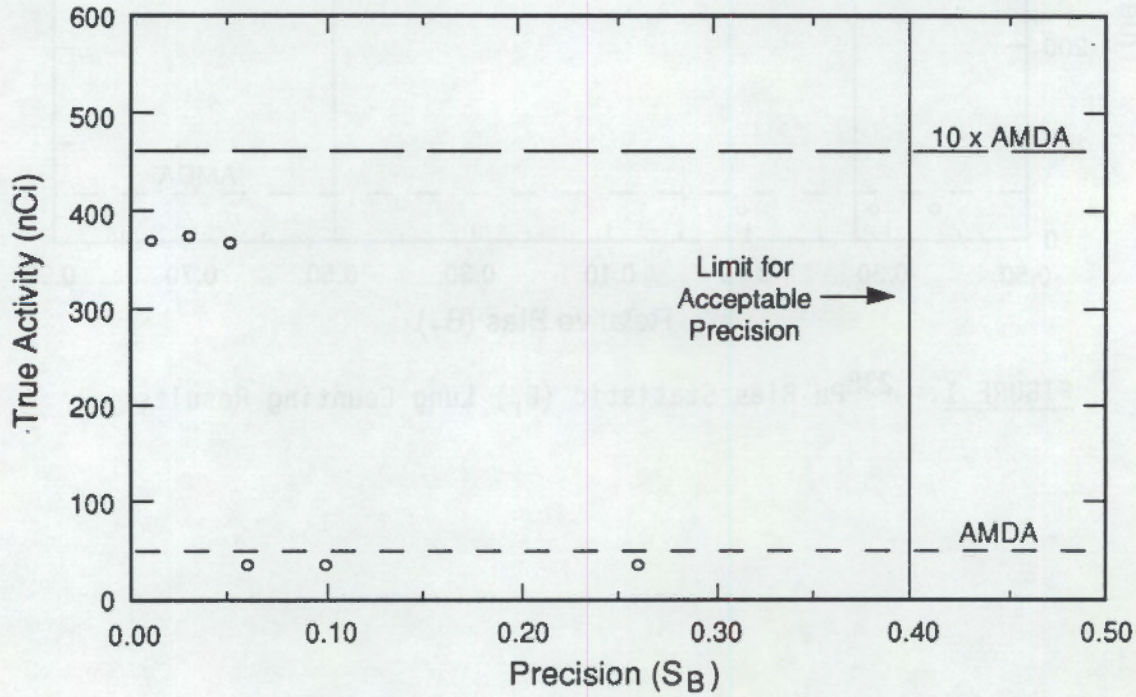

FIGURE 3. ^{238}Pu Precision Statistic (S_B) Lung Counting Results

TABLE 11. ^{238}U Lung In Vivo Intercomparison Testing Results (AMAD = 3 nCi)

Laboratory Code	(nCi) Activity	(nCi) Assay	Relative Bias	Precision (S_A)	Precision (S_B)	MDA (nCi)	Activity >10 x AMDA	System Type	Pass
A	3.51	5.0	0.42	0.03	0.04	0.97	No	Phoswich/	Yes
A	33.07	33.7	0.02	0.02	0.02		Yes	Vault	Yes
K	3.51	2.65	-0.24	0.17	0.13	1.5	No	Mult.HPGe/	Yes
K	33.07	29.8	-0.10	0.04	0.03		Yes	Vault	Yes
N	3.51	3.7	0.05	0.13	0.14	0.90	No	Mult.HPGe/	Yes
N	33.07	32.0	-0.03	0.00(a)	0.07		Yes	Vault	Yes

(a) Actual result 0.002, chi-square test passed.

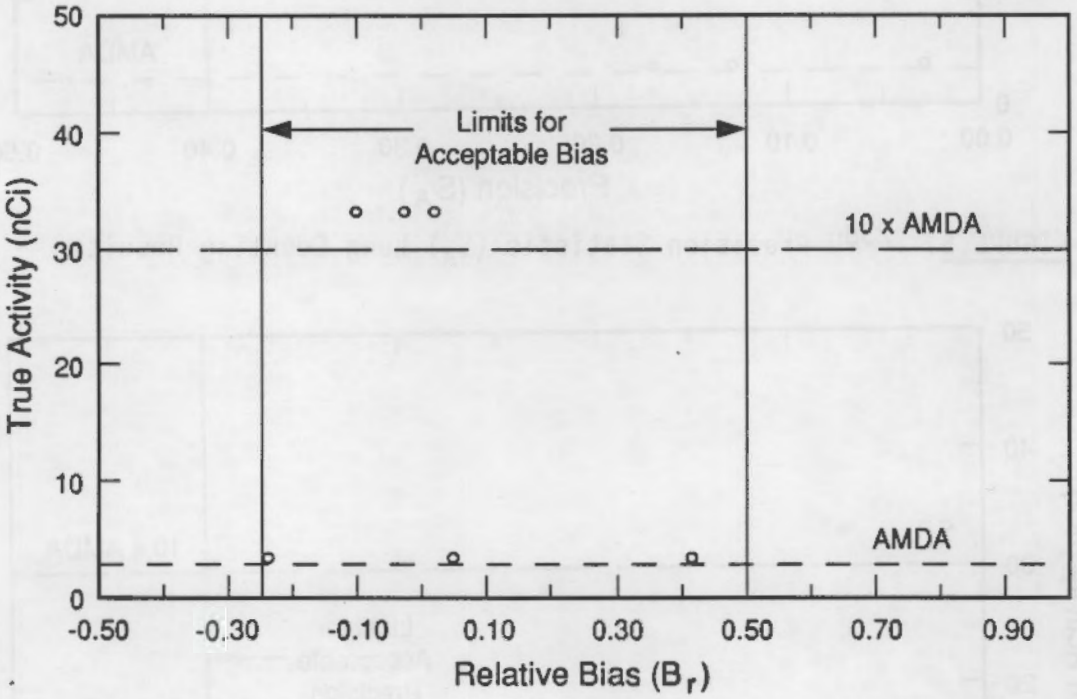

FIGURE 4. ^{238}U Bias Statistic (B_r) Lung Counting Results

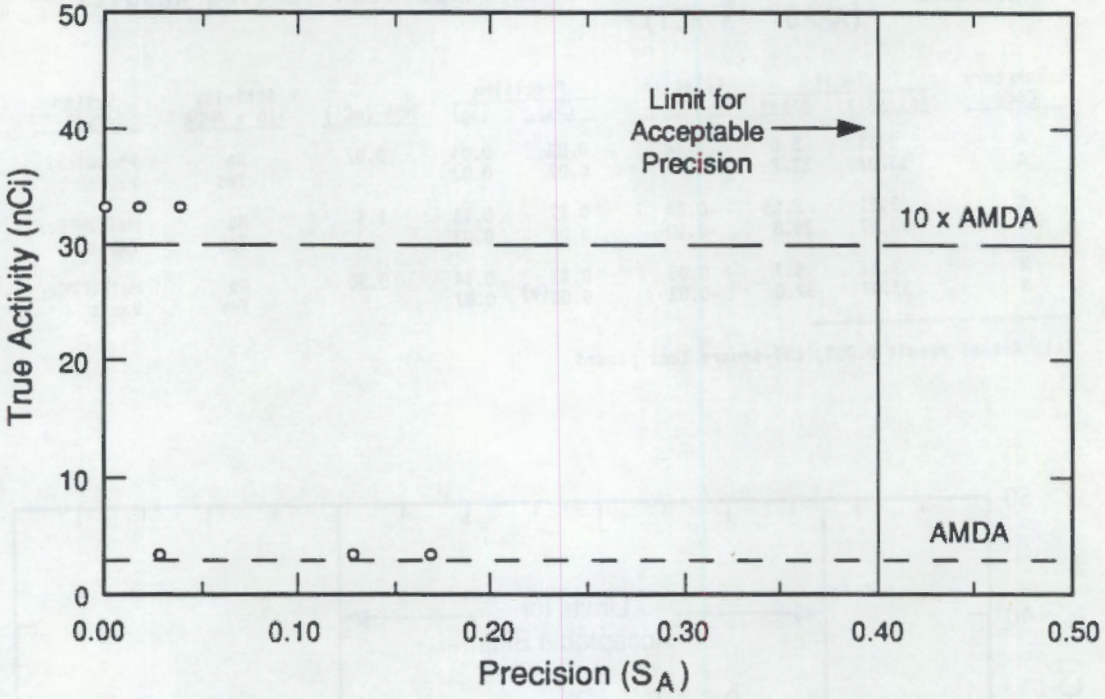

FIGURE 5. ^{238}U Precision Statistic (S_A) Lung Counting Results

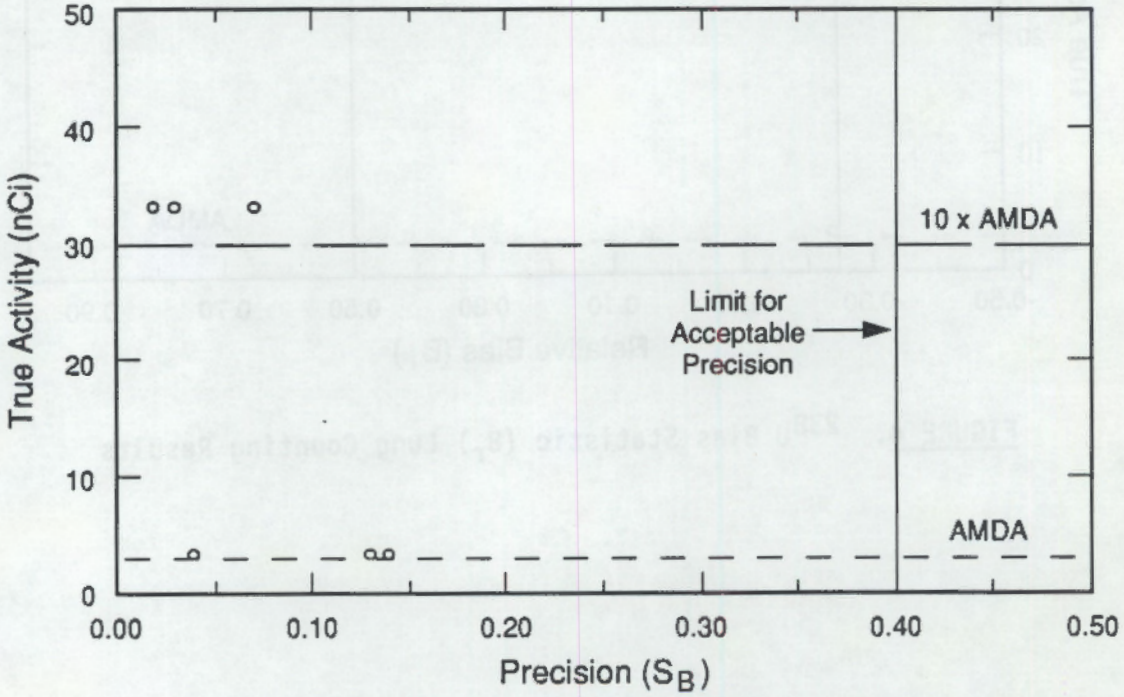

FIGURE 6. ^{238}U Precision Statistic (S_B) Lung Counting Results

TABLE 12. ^{54}Mn Lung In Vivo Intercomparison Testing Results (AMDA = 20 nCi)

Laboratory Code	(nCi) Activity	(nCi) Assay	Relative Bias	Precision (S_A)	Precision (S_B)	MDA (nCi)	Activity >10 x AMDA	System Type	Pass
A	10.6	7.0	-0.34	0.12	0.08	NC[a]	No	Phoswich/	No
A	107.7	121.7	0.13	0.00	0.01	NC	No	Vault	No
B2	247.8	499.8	1.02	0.23	0.47	9.9[b]	Yes	(2)NAI/ Chair[c]	No
B1	247.8	316.5	0.28	0.09	0.11	7.9[b]	Yes	NAI/Bed	Yes
C	185.7	108.4	-0.42	0.23	0.13	3.0	No	NAI/Bed	Yes
C	226.2	196.6	-0.13	0.08	0.07		Yes	"	Yes
D1	23.6	15.4	-0.35	0.13	0.09	NC	No	NAI/Bed	No
D1	240.2	230.0	-0.04	0.02	0.02	NC	Yes	"	Yes
D2	23.5	134.2	4.71	0.01	0.06	NC	No	(2)NAI/	No[d]
D2	238.2	336.2	0.41	0.02	0.02	NC	Yes	Chair	No
D3	23.3	144.7	5.21	0.02	0.14	NC	No	(2)NAI/	No[d]
D3	236.6	370.3	0.57	0.02	0.04	NC	Yes	Chair	No
D4	23.0	25.6	0.11	0.16	0.18	13[b]	No	HPGe	Yes
D4	234.0	218.1	-0.07	0.03	0.03		Yes	HPGe	Yes
D5	23.0	26.7	0.16	0.20	0.24	33[b]	No	HPGe	Yes
D5	233.9	256.8	0.10	0.03	0.03		Yes	HPGe	Yes
D6	22.9	126.3	4.51	0.03	0.18	5.3[b]	No	NAI/	No
D6	232.9	304.8	0.31	0.03	0.04		Yes	Chair	Yes
I	27.9	46.1	0.65	0.13	0.21	NC	No	NAI/	No
I	283.7	453.1	0.60	0.01	0.02	NC	Yes	Chair	No
J1	246.0	445.3	0.81	0.13	0.24	7.4	Yes	(2)NAI/	No
J2	246.0	583.1	1.37	0.10	0.36	5.1	Yes	Chair	No
J3	202.0	569.5	0.87	0.09	0.25	6.7	Yes	"	No
J3	246.0	705.0	1.86	0.23	0.65		Yes	"	No
K	255.5	210.2	-0.18	0.05	0.04	0.66	Yes	(2)GeLi/	Yes
K	209.7	100.2	-0.52	0.02	0.01		Yes	ShadowSh	No
M1	263.1	319.1	0.21	0.05	0.06	NC	Yes	NAI/Bed	Yes
M2	25.8	125.4					No	Mult.NAI/	No[d]
M2	262.5	329.0	0.25	0.01	0.01	NC	Yes	Chair	Yes
M3	25.8	130.8					No	Mult.NAI/	No[d]
M3	262.5	367.4	0.4	0.01	0.02	NC	Yes	Chair	Yes
M4	25.5	140.0					No	MultiNAI/	No[d]
M4	259.1	366.6	0.41	0.01	0.01	NC	Yes	Chair	Yes
M5	25.5	133.4					No	Multi.NAI/	No[d]
M5	259.1	265.6	0.03	0.29	0.30	NC	Yes	Chair	Yes
M6	25.7	123.0					No	Multi.NAI/	No[d]
M6	261.9	330.2	0.26	0.01	0.02	NC	Yes	Chair	Yes
M7	25.7	125.0					No	Multi.NAI/	No[d]
M7	261.9	351.6	0.34	0.01	0.01	NC	Yes	Chair	Yes

(a) NC = not calculated due to insufficient data.
(b) No blank counting data returned; MDA calculated from AMDA-level phantom.
(c) Lung detector viewing from back.
(d) Misidentified as ^{58}Co.

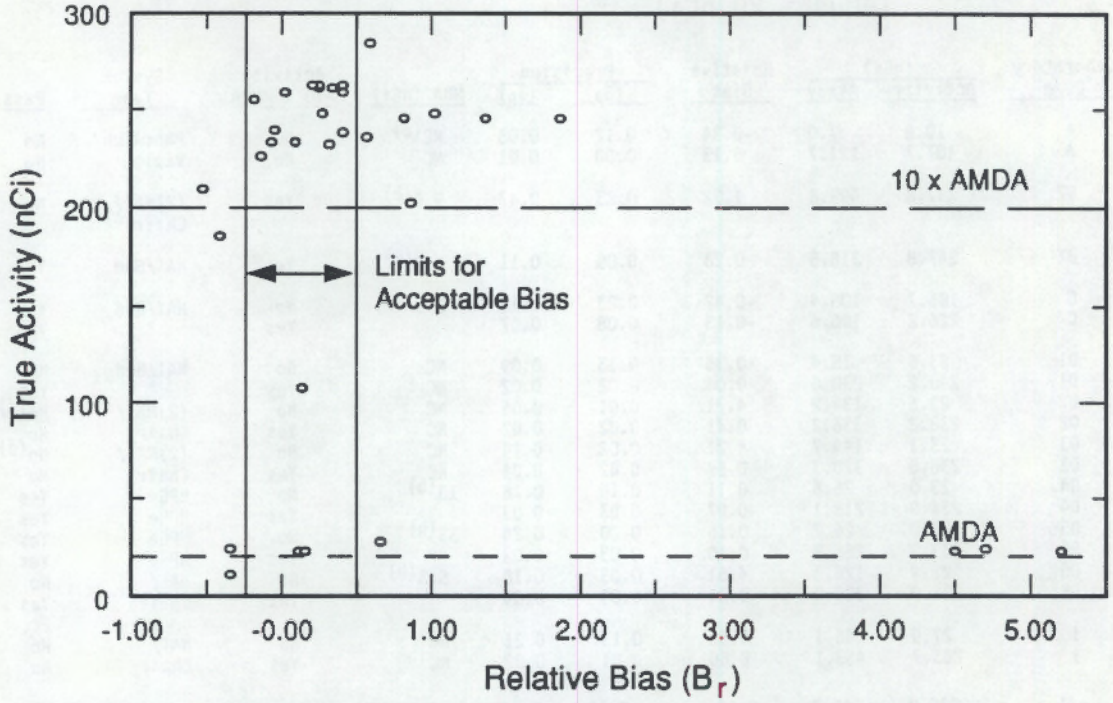

FIGURE 7. ^{54}Mn Bias Statistic (B_r) Lung Counting Results

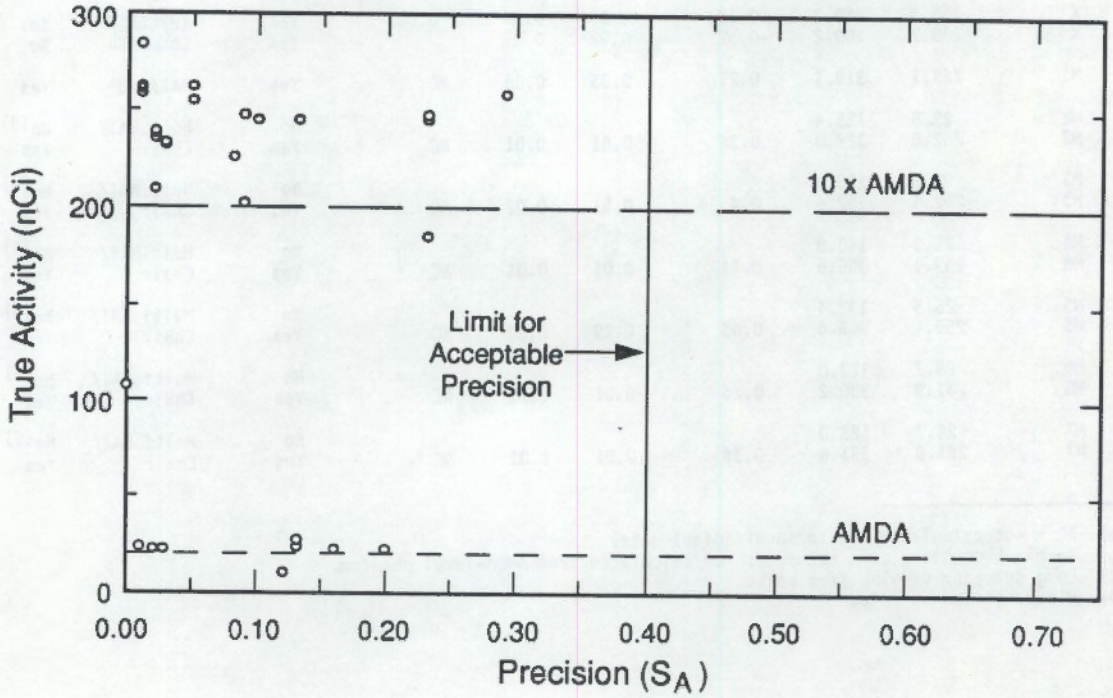

FIGURE 8. ^{54}Mn Precision Statistic (S_A) Lung Counting Results

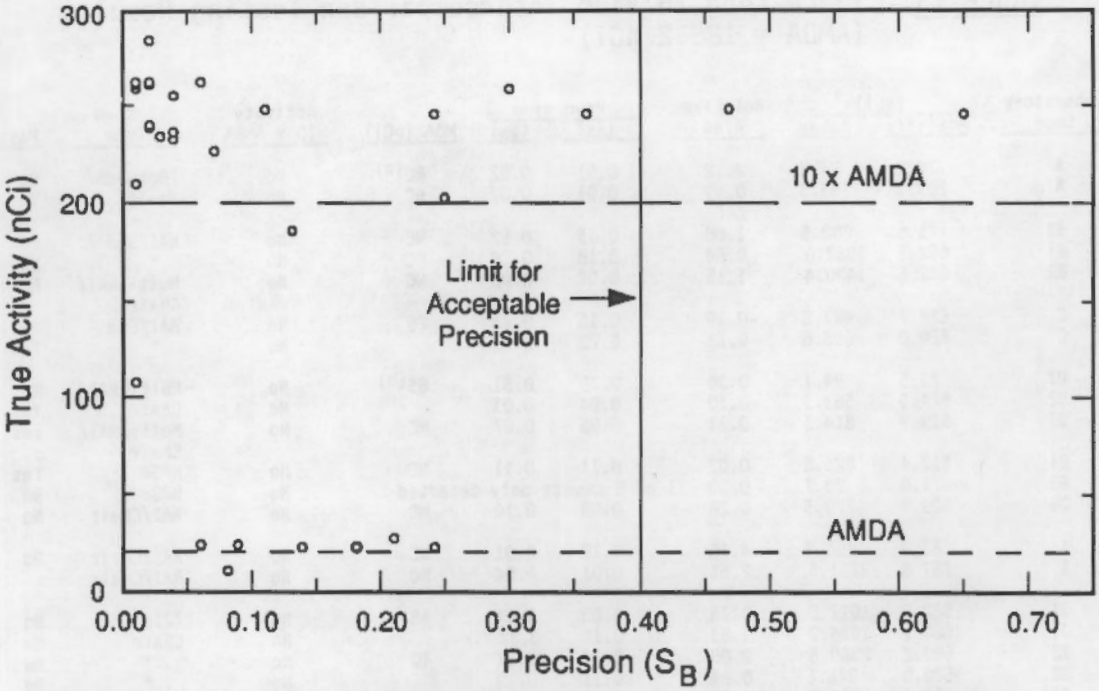

FIGURE 9. ^{54}Mn Bias Statistic (S_B) Lung Counting Results

TABLE 13. ^{144}Ce Lung In Vivo Intercomparison Testing Results (AMDA = 185.2 nCi)

Laboratory Code	(nCi) Activity	(nCi) Assay	Relative Bias	Precision (S_A)	Precision (S_B)	MDA (nCi)	Activity >10 x AMDA	System Type	Pass
A	30.2	94.3	2.12	0.01	0.02	NC[a]	No	Phoswich/	No
A	260.9	388.3	0.49	0.01	0.02	NC	No	Vault	Yes
B1	75.6	202.5	1.68	0.35	0.92	NC	No	NAI/Bed	No
B1	652.5	1067.0	0.64	0.18	0.29	NC	No	"	No
B2	652.5	1400.4	1.15	0.04	0.08	NC	No	Multi.NAI/ Chair	No
C	528.7	427.6	-0.19	0.16	0.13	26	No	NAI/Bed	Yes
C	620.0	698.6	0.13	0.20	0.23		No	"	Yes
D2	75.5	94.1	0.30	0.39	0.51	65[b]	No	Multi.NAI/	No
D2	624.5	563.3	-0.10	0.04	0.03		No	Chair	Yes
D3	619.9	814.3	0.31	0.06	0.07	NC	No	Multi.NAI/ Chair	Yes
D4	612.4	625.8	0.02	0.11	0.11	NC	No	HPGe	Yes
D5	71.0	70.7	0.00	1 of 5 counts only detected			No	HPGe	No
D6	609.4	779.5	0.28	0.08	0.10	NC	No	NAI/Chair	No
I	87.9	456.2	4.18	0.18	0.91	NC	No	NAI/Chair	No
I	757.8	2731.6	2.61	0.01	0.04	NC	No	NAI/Chair	
J1	580.0	1017.6	0.75	0.08	0.14	48	No	(2)NAI/	No
J1	680.2	1924.2	1.83	0.11	0.32		No	Chair	No
J2	680.2	2080.6	2.06	0.12	0.37	40	No	"	No
J2	580.0	948.6	0.64	0.11	0.19		No	"	No
J3	680.2	1799.8	1.65	0.09	0.25	65	No	"	No
J3	580.0	881.4	0.52	0.12	0.18		No	"	No
K	604.57	312.8	-0.48	0.02	0.01	7.9	No	(2)GeLi/	No
K	709.07	570.8	-0.20	0.07	0.05		No	ShadowSh	Yes
M1	80.79	226.3	1.80	0.25	0.71	NC	No	NAI/Bed	No
M1	696.95	1565.2	1.25	0.03	0.08	NC	No	"	No
M2	80.5	110.3	0.37	0.51	0.69	43[b]	No	Multi.NAI/	No
M2	695.25	790.6	0.14	0.08	0.09		No	Chair	Yes
M3	80.59	87.3	0.08	0.59	0.64	45[b]	No	Multi.NAI/	No
M3	695.25	531.8	-0.24	0.06	0.04		No	Chair	Yes
M4	685.15	864.4	0.26	0.36	0.46	NC	No	"	No
M5	79.42	70.7	-0.11	0.17	0.15	66[b]	No	MultiNAI/	Yes
M5	685.15	668.0	-0.03	0.07	0.07		No	Chair	Yes
M6	80.40	97.7	0.21	0.39	0.47	46[b]	No	MultiNAI/	No
M6	693.56	487.8	-0.30	0.08	0.05		No	Chair	No
M7	80.40	63.0	-0.22	0.26	0.21	55	No	MultiNAI/	Yes
M7	693.56	654.8	-0.06	0.10	0.10		No	Chair	Yes

(a) NC = Not calculated due to insufficient data.
(b) No blank count information given, MDA calculated from low spike lung set.

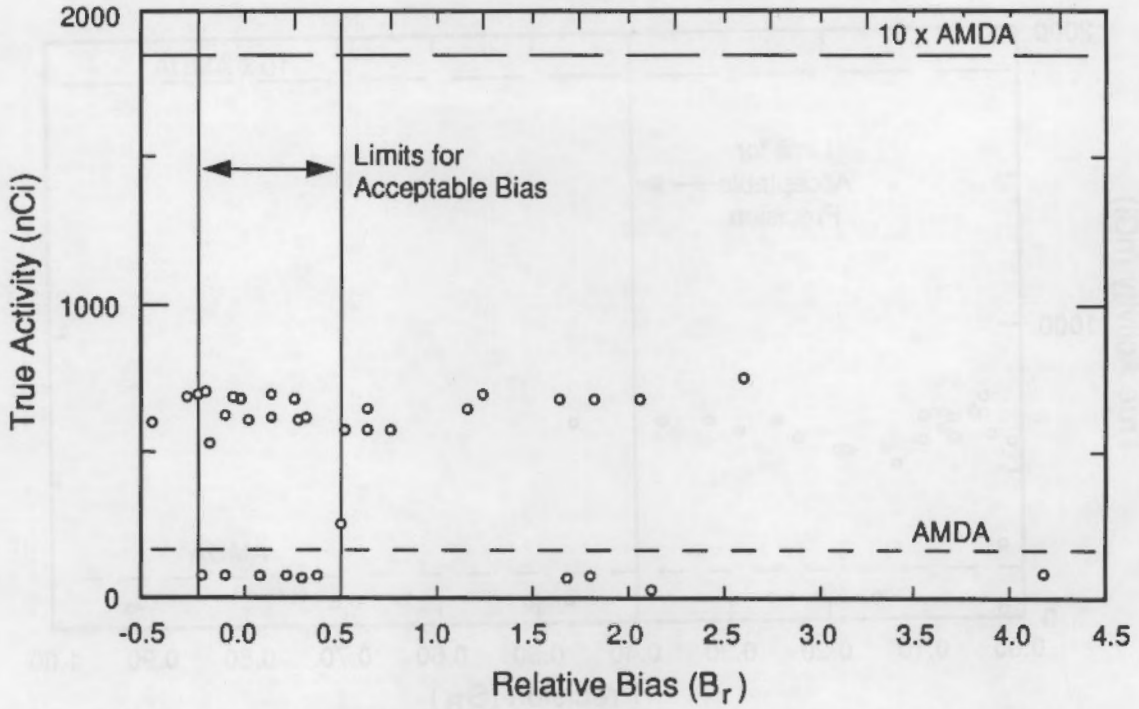

FIGURE 10. ^{144}Ce Bias Statistic (B_r) Lung Counting Results

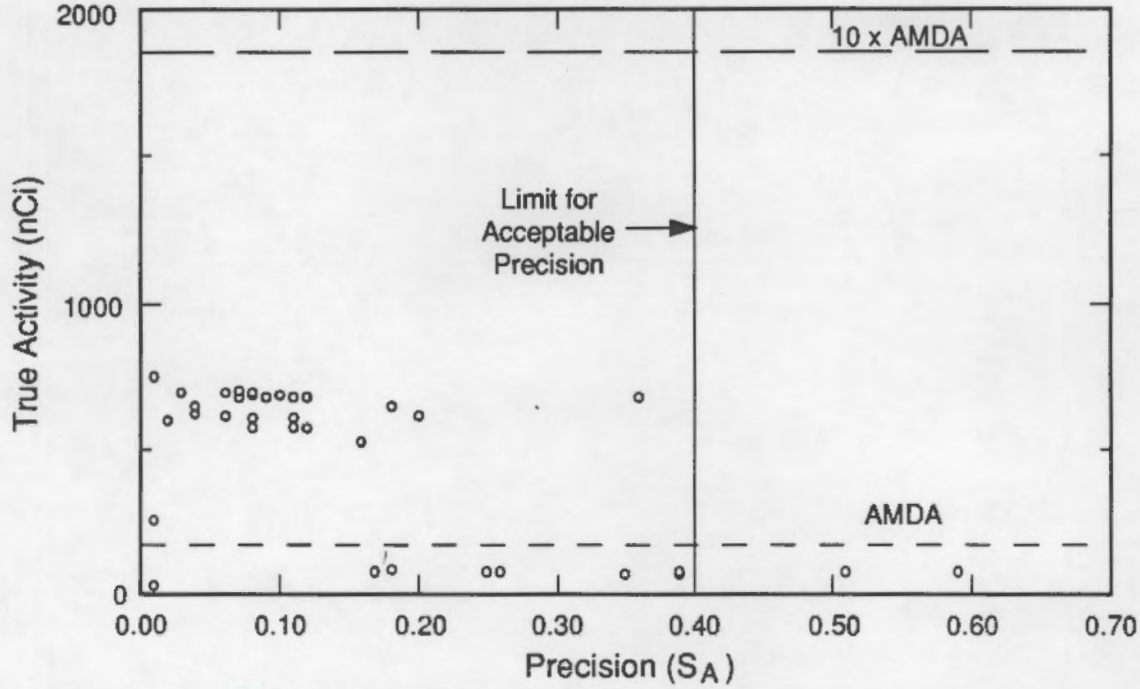

FIGURE 11. ^{144}Ce Precision Statistic (S_A) Lung Counting Results

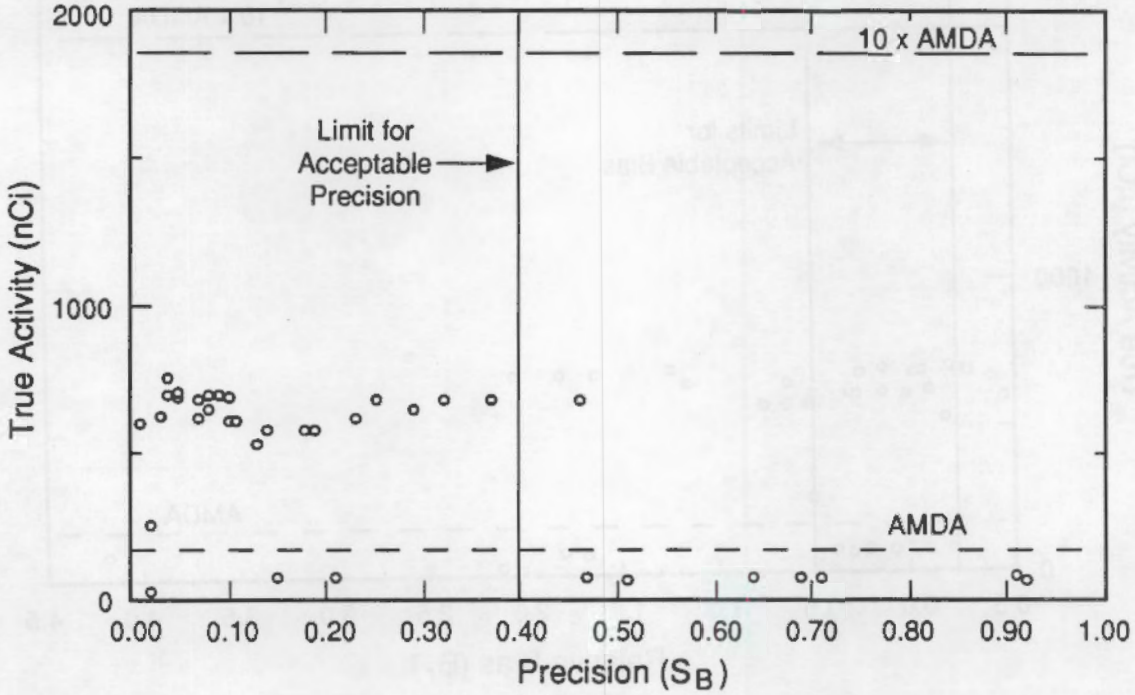

FIGURE 12. ^{144}Ce Precision Statistic (S_B) Lung Counting Results

TABLE 14. ^{137}Cs Whole Body In Vivo Intercomparison Testing Results (AMDA = 24 nCi)

Laboratory Code	(nCi) Activity	(nCi) Assay	Relative Bias	Precision (S_A)	Precision (S_B)	MDA (nCi)	Activity >10 x AMDA	System Type	Pass
A	343.77	261.8	-0.24	0.06	0.04	NC(a)	Yes	(2)NAI	Yes
B1	354.56	412.6	0.16	0.08	0.10	NC	Yes	NAI/bed	Yes
B2	354.56	238.8	-0.33	0.07	0.11	NC	Yes	(3)NAI/ Chair	No
G	350.67	349.0	-0.00	0.01	0.01	4.5	Yes	NAI/Chair	Yes
G1	350.67	336.8	-0.04	0.01	0.01	NC	Yes	"	Yes
I	355.20	454.2	0.28	0.08	0.10	NC	Yes	NAI/Chair	Yes
J1	358.5	417.2	0.16	0.04	0.05	14	Yes	(2)NAI/ Chair	Yes
J2	358.5	284.0	-0.21	0.41	0.32	21	Yes	"	No
J3	358.5	233.7	-0.35	0.11	0.07	29	Yes	"	No
L	340.71	348.0	0.02	0.09	0.09	14.	Yes	CoaxGeLi/ Chair	Yes
M1	354.18	386.3	0.08	0.03	0.04	NC	Yes	NAI/Bed	Yes

(a) NC = Not calculated due to insufficient data.

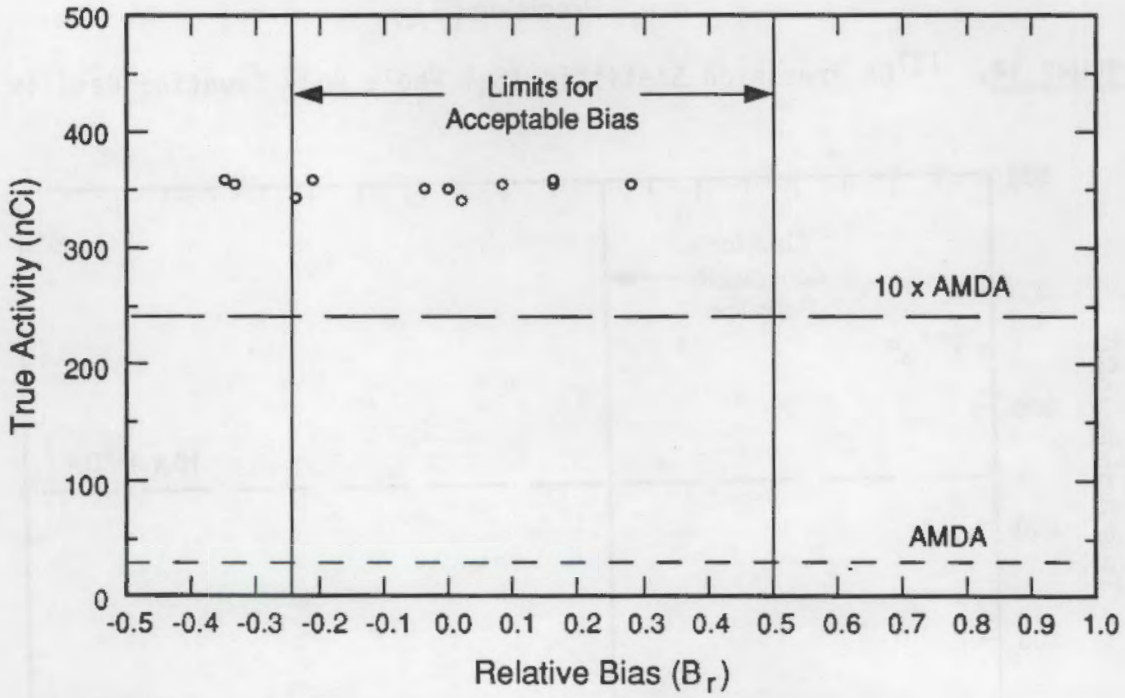

FIGURE 13. ^{137}Cs Bias Statistic (B_r) Whole Body Counting Results

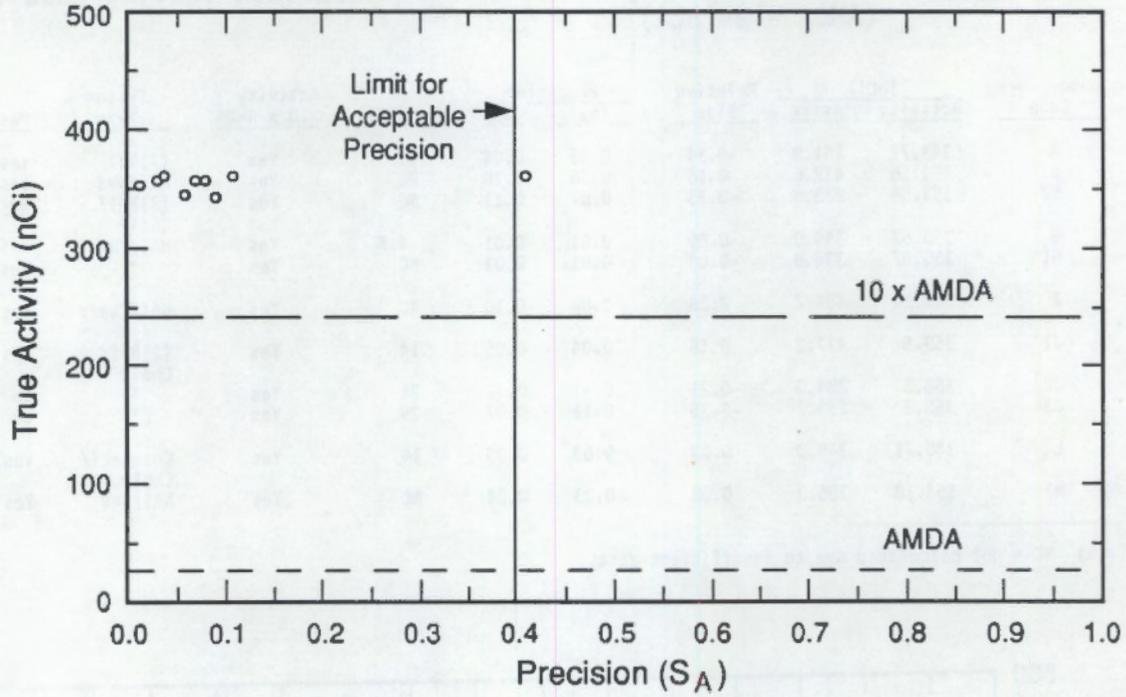

FIGURE 14. ^{137}Cs Precision Statistic (S_A) Whole Body Counting Results

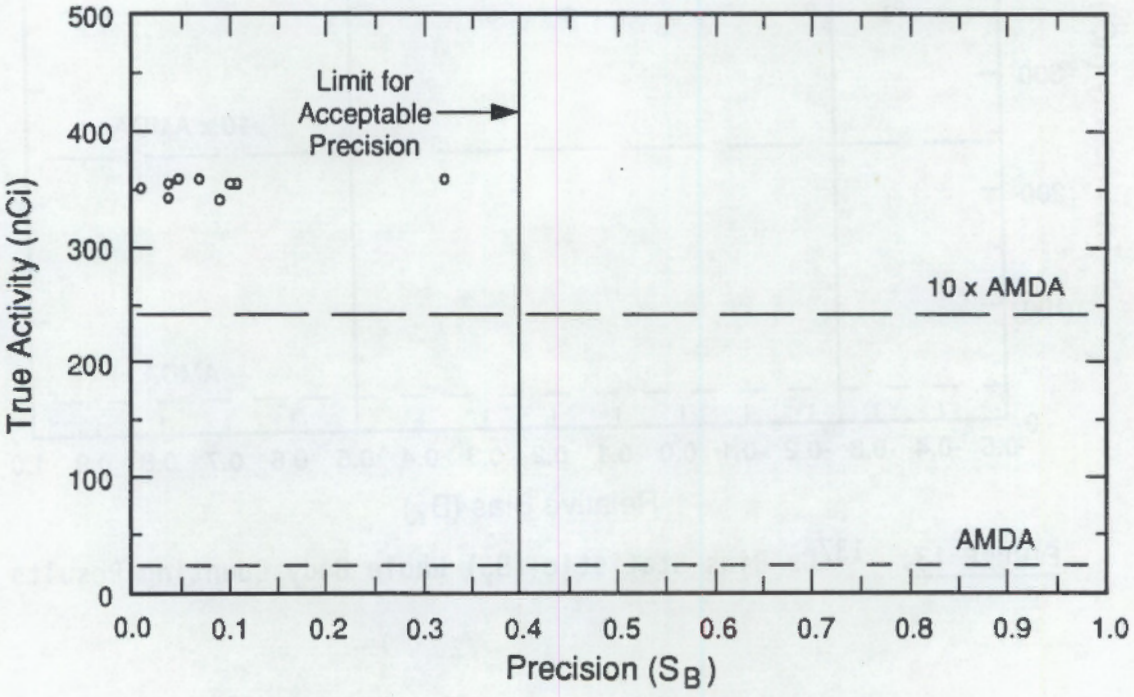

FIGURE 15. ^{137}Cs Precision Statistic (S_B) Whole Body Counting Results

TABLE 15. ^{134}Cs Whole Body In Vivo Intercomparison Testing Results (AMDA = 21 nCi)

Laboratory Code	(nCi) Activity	(nCi) Assay	Relative Bias	Precision (S_A)	Precision (S_B)	MDA (nCi)	Activity >10 x AMDA	System Type	Pass
A	147.59	118.0	-0.20	0.04	0.04	NC[a]	No	(2)NAI	Yes
B1	231.99	254.8	0.10	0.08	0.09	NC	Yes	NAI/Bed	Yes
B2	231.99	143.6	-0.38	0.17	0.11	NC	Yes	(3)NAI/ Chair	No
G	197.45	143.2	-0.27	0.02	0.01	4.4	No	NAI/Chair	No
I	238.27	248.8	0.04	0.10	0.10	NC	Yes	NAI/Chair	Yes
J1	272.81	352.5	0.29	0.26	0.34	12	Yes	(2)NAI/ Chair	Yes
J2						20			No
J3	272.81	177.7	-0.35	0.18	0.11	26	Yes	"	No
L	129.38	134.0	0.04	0.09	0.09	11	No	CoaxGeLi/ Chair	Yes
M1	228.38	209.9	-0.08	0.03	0.03	NC	Yes	NAI/Bed	Yes

(a) NC = Not calculated due to insufficient data.

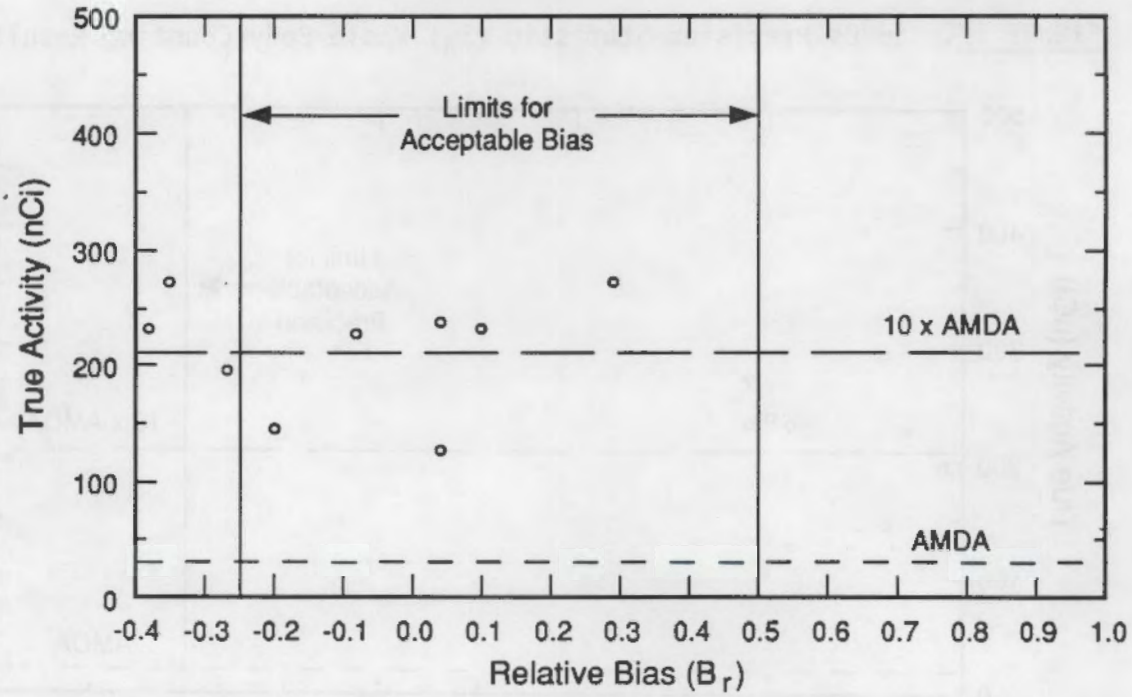

FIGURE 16. ^{134}Cs Bias Statistic (B_r) Whole Body Counting Results

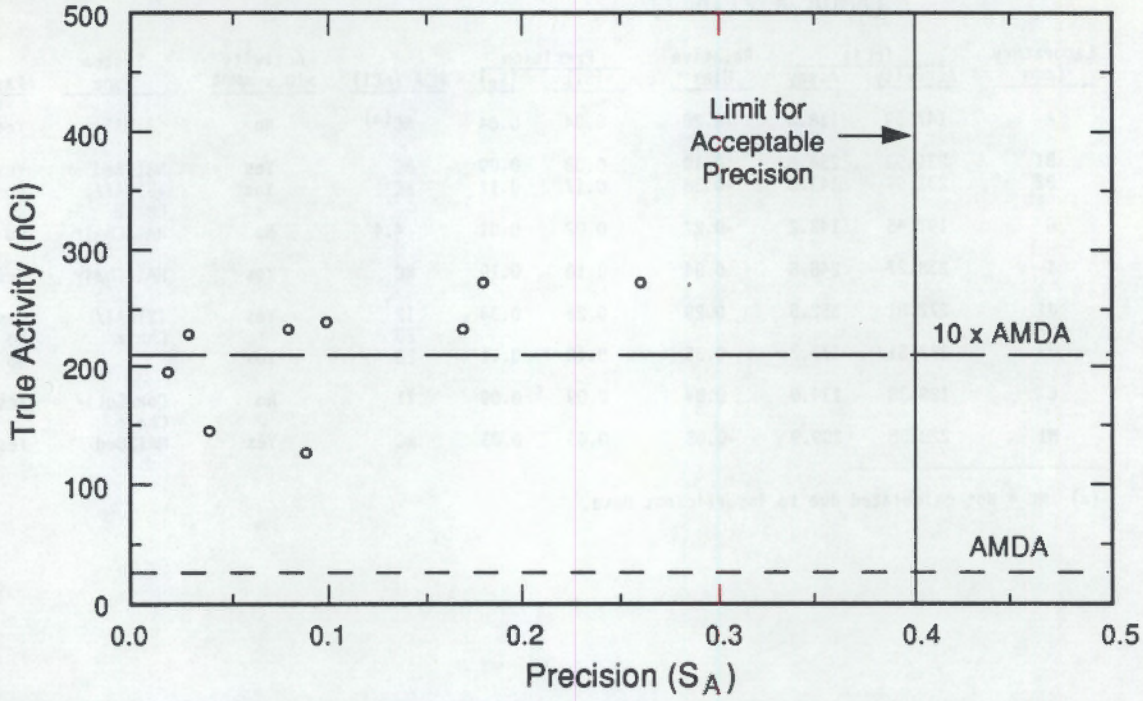

FIGURE 17. ^{134}Cs Precision Statistic (S_A) Whole Body Counting Results

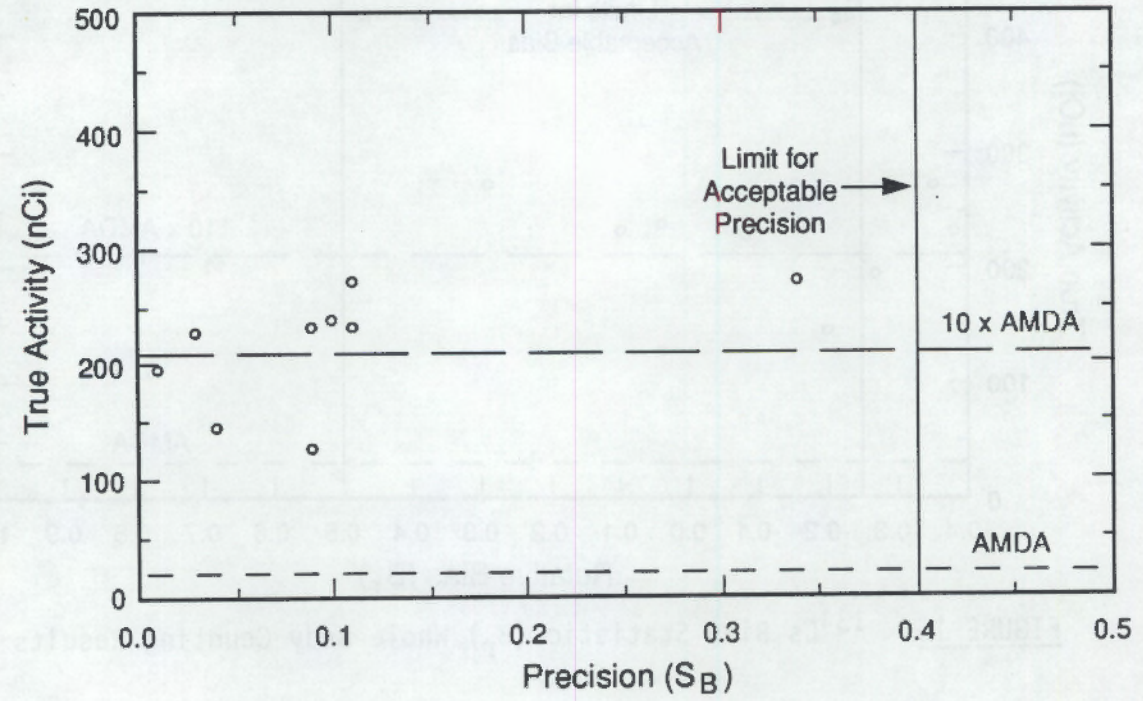

FIGURE 18. ^{134}Cs Precision Statistic (S_B) Whole Body Counting Results

the effective attenuation for the two phantoms is different. The inconsistencies in phantoms was assumed to be the cause of the negative ^{238}Pu measurements bias for two laboratories.

The measurement of ^{238}U (by ^{234}Th) in lungs was successfully passed by all three participating labs for all performance criteria. The MDAs of the facilities were in the range of 30% to 50% of the AMDA listed in the current draft ANSI N13.30. As in the previous round of testing, laboratories that need to detect transuranic radionuclides and uranium had analytical facilities, which included custom-built detector systems in shielded vaults. This allowed for substantially lower backgrounds and increased detection capabilities for low-energy, low-level sources. Based on the observed MDAs, the current state-of-the-art detection capability is below the AMDA, thus they are set at an attainable level.

It is not within the scope of this report to determine whether the AMDA is set appropriately with respect to the MDA required to detect a certain effective dose equivalent. The variability of the parameters of intake form, duration of intake, and frequency of bioassay monitoring all combine to make judgment on a single acceptable AMDA value difficult. If a 1.0 nCi MDA of natural uranium is consistently attainable (as two of the three results determined), then, based on ICRP 30 (1978) methodology, an acute exposure of 15% of an annual limit on intake (ALI) of class Y natural uranium would be detectable 30 days after intake. This may be satisfactory for some facilities but could potentially cause substantial missed dose in other situations, especially those with annual or biannual lung counting frequencies.

The lung measurements of ^{54}Mn in the fission product lung sets were less successful. The fission product lung sets included two test radionuclides, ^{54}Mn and ^{144}Ce, and two interference nuclides that were not meant to be quantitatively measured, ^{134}Cs and ^{137}Cs. For many of the NaI(Tl)-based detection systems, the resolution was not sufficient for accurate determinations of the test radionuclides to be made in the presence of the interferences. Several facilities misidentified the nuclide as ^{58}Co and, as mentioned previously, only 5 of 22 facilities returned data on the blank lung set. This meant no MDA could be calculated. However, in the specific case of ^{54}Mn, an estimated MDA was calculated for several facilities on the basis of background data returned from the low-level test lung set, because

the amount of radionuclide in this set of lungs had decayed to the AMDA level. This allowed an estimate of (s_b), the standard deviation of the sample near the MDA, to be made with a fair degree of accuracy. Notably, four of the five facilities passed the MDA criterion by this method. The failure percentage for the bias criteria, the precision statistics, and the MDA values are given in the Round Two section of Table 9.

For the measurement of ^{144}Ce, the interference nuclides seemed to reduce the passing rate again. In the case of ^{144}Ce, neither lung set at the time of initial shipment had a TQ of radionuclide greater than 10 times the AMDA, so the requirements of draft ANSI N13.30 were not met in testing precision and bias. In spite of this, only one facility failed the precision criterion S_B, and none failed the S_A criterion. However, due to improper quantitative determinations of the interference nuclides large errors were noted in the activity and the bias statistic for ^{144}Ce.

The whole body test phantom (BOMAB) results are listed in Tables 14 and 15 for ^{137}Cs and ^{134}Cs, respectively. The TQ was above 10 times the AMDA for both radionuclides, but in the case of ^{134}Cs the bias results again show a failure rate that resulted from poor quantification or identification of the interference radionuclides ^{54}Mn and ^{60}Co.

The passing rate for the bias and precision criteria for the ^{137}Cs whole body category was similar to Round One testing, with the significant exception that many more laboratories did not report background spectral data--55% for Round Two versus 15% for Round One. Nevertheless, overall passing of the MDA criterion had increased. Cesium-134 was not included as a whole body test radionuclide in Round One, but the increase in passing both the bias statistic and the precision statistic is dramatic when compared with the other Round One test radionuclide, ^{144}Ce. Results for both rounds of in vivo testing are summarized in Table 9. The test radionuclide, ^{144}Ce, was deleted from the whole body category following Round One testing because it was determined to be more appropriately placed in the lung-counting category. When these results are similarly deleted from Round One data, the overall percentage of respondents failing the criteria in Round One and Round Two are similar for both relative bias and relative precision. However, the number of laboratories failing the MDA criterion decreased significantly.

The decrease in the percentage of laboratories failing the MDA criterion was due to a change in methods used to calculate the MDA. In Round One, the MDA was calculated using a replicate-based estimate of the baseline standard deviation (Robinson et al. 1986). But, the baseline count in a spectrum is assumed to be a continuum and the baseline under a peak is estimated by the baseline count near the peak. Any between-measurement changes in the baseline will therefore affect the peak baseline and its near-peak estimate equally. The use of a replicate-based estimate of the baseline standard deviation will therefore overestimate the true value of the baseline standard deviation. A Poisson-based estimate of the standard deviation was therefore thought to be more appropriate and Round One estimates are thought to be biased high.

Another complication in the MDA calculation is the critical level (L_C) used by the bioassay laboratory to determine a positive result. For our calculations we have assumed a 5% level for false identification (i.e., α error). When an automated peak search program scans a spectrum, assuming a 5% α error for each region of interest results in a large cumulative probability for at least one false identification for each analysis. Many in vivo laboratories compensate for this by decreasing the sensitivity factor of the detection criterion. If a critical level of $3\sigma_0$ is used instead of the assumed $1.645\sigma_0$, the MDA may be increased up to 41%. The participating laboratories were not requested to provide their critical level and the calculated MDA may therefore underestimate the true MDA that a laboratory will have when the use of an automated peak search program is wholly depended upon. This may explain why some laboratories failed to detect activity near their calculated MDA. (See Table 13 and Appendix C.)

Some mention must be made of the different participatory status of some of the laboratories that returned results to the testing program. Not all of the equipment that was used to count the various phantoms was in a calibrated and cross-checked operational status. Some members of the study found it useful to attempt calibration of new or unused in vivo counting systems or intercomparisons between instrument systems at the same facility. These results are also listed in the section "Attainability of Performance Criteria." These "experimental" data were many times reported along with data from operational and well-calibrated in vivo counting systems, although they were removed from the calculations upon which conclusions were based. Because

an objective of these intercomparison studies was to survey the overall capabilities of the industry and DOE in particular, these data were determined to be of value and were included in the results.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this study are based on the type and quality of reported results and the ability of an in vivo testing laboratory to perform measurements within the guidelines specified by the current draft standard. This study attempted to minimize errors that might affect one type of counting system more than another, but, with the variability of in vivo counting systems throughout the United States, some reported results were due to reasons other than inability to repeatedly detect and accurately quantify the test radionuclides.

The increases in performance from Round One to Round Two are somewhat due to the large changes in both the calculation of the performance criteria and the relaxed limits for passing. The appropriateness of the current limits and recommended revisions to draft ANS1 N13.3D are discussed below.

LABORATORY ATTAINMENT OF PERFORMANCE CRITERIA

The performance criteria of draft ANSI N13.30, as they have been set in the latest version (August 1987), are discussed here in light of the ability of each criterion to be used to identify satisfactory bioassay laboratory performance. The conclusions are based solely on the results reported to PNL and permutations of the data that were undertaken by PNL to test the results.

The bias statistic criterion, which measures a laboratory's overall tendency of deviation from the true known activity of a sample or phantom, is discussed first.

Using the K factor test for tolerance intervals from Report No. 58 of the National Council on Radiation Protection and Measurements (NCRP 1978), the service laboratories results for the relative bias criterion were tested to determine a population passing rate. Using only results from greater-than-10-AMDA-level test lungs, a population of normally distributed bias results would have a mean of $B_r = 0.18$ with a standard deviation of ± 0.45. Based on the current boundaries of the relative bias statistic of -0.25 to +0.5, approximately 60% of service laboratories would be expected to pass.

The assumption of normality may not be appropriate here due to factors in some laboratories' bias results from interferences and calculational errors.

Because several laboratories misidentified nuclides, this tolerance level statistic is not appropriate in determining whether the bias criterion is set at an appropriate or attainable level.

However, when outlying data are removed that were due to 1) misidentification of nuclide, 2) miscalculations of either activity or interference, or 3) uncalibrated counting systems, the change in overall performance is dramatic. The mean bias of all laboratory results is now 0.084 with a standard deviation of $\pm$ 0.308. Thus, the current bias range of -0.25 to +0.50 would include approximately 80% of a population of laboratory results.

It can therefore be said that the bias statistic is set at a satisfactory level and that failures are due to gross forms of error that can be corrected for by training and upgrading laboratory QC ability.

The relative precision criteria were surpassed in only three results from the population of laboratories tested in Round Two. The use of a one-sided t-factor table results in more than 95% of a population of tested facilities being expected to pass the current criteria of relative precision, (S_B) or (S_A), assuming a normal distribution with a mean of 0.102 and a standard deviation of 0.128. By itself, it can be concluded that the relative precision statistic is set at an attainable level.

Although the performance criteria could be lowered without significantly increasing the number of failures, the cumulative probability of passing all criteria must be considered. The apparent looseness of the criteria is discussed in Appendix C of draft ANSI N13.30. The criteria were set so that a good laboratory could expect to pass all three criteria with a reasonably high probability. If the criteria are independent, the probability of passing all three is the product of the probabilities of passing each criterion. If a laboratory had a 95% probability of passing each criterion, its overall probability of passing a test category would be (0.95)•(0.95)•(0.95) or 0.86. Therefore, the laboratory would need better than a 98% probability of passing each category in order to have an overall 95% probability of passing a complete test category. Considering the cumulative effect of multiple test criteria, none of the criteria is overly restrictive.

The MDA criterion was the most prevalent cause of failure for participating laboratories. There are four possible causes for the large number of laboratories failing the MDA criterion:

- The measurement systems for these laboratories were truly incapable of detecting radioactivity at the level specified in draft ANSI N13.30.
- The MDA was calculated using an improper estimate of the standard deviation of the net blank count.
- The evaluation of the calculated MDA failed to consider the uncertainty in the MDA estimate.
- The analysis laboratory's automated counting system did not have the capability of giving blank or background counting information, and none was submitted to the testing laboratory (PNL).

The first three of these causes are discussed in detail by MacLellan (1989).

Analysis procedures that are incapable of detecting radioactivity at the required level should fail the performance test, but the second and third causes of failure are related to the procedures used by the testing laboratory to evaluate the performance test data. The final reason, by far the most frequent reason for failure in this study, should be noted for future efforts in developing computer software for automated counting systems. The inability of many systems to allow for the removal of raw counting data or manual options that can quantify regions of interest of multi-channel spectra will severely inhibit any standardization of laboratories. The current trend of only allowing identification of spectral peaks above certain confidence intervals and not allowing user-set regions of interest to be quantified for background and blank spectral data will inhibit the ability of a testing laboratory to adequately perform accreditation testing. The use of a facility's QC data, which may include calculated MDAs generated by software packages, should be treated with caution. The necessary confidence must first be obtained in both the software analysis system that the laboratory has chosen and the proper input of information by the user of the software. Any analysis software packages used in an accredited program should have mandatory manual capabilities, and all algorithms used in calculational steps should be documented precisely.

RECOMMENDED REVISIONS TO DRAFT ANSI N13.30

The MDA criteria were based on previously published criteria from other standards and advisory groups and the capabilities of bioassay laboratories reported in their procedures manuals. Primary sources were the derived investigation levels from publications such as Publication 10 of the International Commission of Radiological Protection (ICRP 1960). In the future, regulations will be based on dose calculations done with ICRP 30 (1978) methodology.

The AMOA values were established with the sometimes conflicting objectives of: 1) adequate worker protection from radionuclides, 2) reasonable levels attainable without expending unnecessary resources, and 3) state-of-the-art detection limits; thus, it is often difficult to determine where an AMDA should be set. Current AMDA values are in some cases too high to enable detection of internal radioactivity at desired levels. In these cases, new AMDA levels should be set each time it becomes obvious that the state of the art allows for further reductions and worker protection requires further reductions.

The current settings of the tested AMDAs (for Round Two) were attainable by most of the tested service laboratories, and in some instances 10% of the AMDA was the norm. Other service laboratories with poorly calibrated and inexpensive detection systems failed bias and precision criteria, but still passed the AMOA.

Attempting to relate AMDA performance of Round One to Round Two is clouded by the use of an entirely different set radionuclides. If comparison is made of similar radionuclides in the same nuclide category, then it is obvious that advances were made. Overall only 9% of service laboratories failed the AMDA criteria, compared with 38% in Round One.

The calculations of MOA used in draft ANSI N13.30 should take into account the potential errors involved in a facility's analysis system and apply confidence intervals to the calculated MOA. The most accurate method of determining this criteria would be from a laboratory's own QC data.

The statistics for simple counting systems are reasonably well defined, but some commercial in vivo counting systems do not allow for inspection of the raw spectral data and often report only "less than" values when they are

less than the MDA calculated by the software. It is impossible to verify compliance of these systems with the draft standard MDA criterion.

It is often necessary to examine the QC data to identify important characteristics of the blank distribution that will affect the MDA calculation (MacLellan 1989). Characteristics such as unequal variances of detectors, unstable electronics, and paired samples must all be considered. The MDA equation must be based on the analysis and calculational methods of the procedure evaluated. No single MDA equation will be appropriate for all analyses.

Even when the correct MDA equation is applied, the MDA calculated may have a relatively large confidence interval when relatively few replicates are used to estimate the standard deviation. At least 13 replicates are needed to limit the ratio of the upper-to-lower bound of the 90% confidence interval to 2 (Currie 1984). For this reason, a relatively precise estimate of the MDA is generally only available when Poisson statistics may be applied.

With the above performance test limitations in mind, the following recommendations are made for determination of the MDA in conjunction with draft ANSI N13.30 performance testing:

- The bioassay laboratory's own QC data should be used for the MDA calculation in preference to the small data set available from performance testing.
- The MDA equation should be designed specifically for the measurement process being evaluated. If generic MDA equations are developed, the assumptions used should be verified whenever one is applied.
- Poisson statistics should be assumed for the MDA calculation whenever the Poisson distribution is not rejected for the available data.
- If Poisson statistics are rejected, the standard deviation should be estimated from replicates and a confidence interval should be calculated for the MDA. The laboratory should not be failed if the lower 5% bound of the confidence interval is less than the MDA criterion of draft ANSI N13.30. This approach is recommended because of the inherent uncertainty of the replicate-based MDA estimate.

The premise common to all the above recommendations is that performance testing alone cannot provide all of the information necessary to make an accurate estimate of the measurement process MDA. Review of the laboratory's QC data and the entire measurement procedure will be necessary.

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APPENDIX A

IN VIVO MEASUREMENTS REPORT FORM

APPENDIX A

IN VIVO MEASUREMENTS REPORT FORM

Laboratory Name: _____ Phantom Type: ____ Lung
____ Whole Body
____ Thyroid

Address: _____

_____ Nuclide (s): _____

Contact Person: _____ Phone: _____

Date of Phantom Receipt: _____ Date(s) of Analysis: _____

Brief description of counting equipment (shielding. detection. geometry):

_____

_____

_____

_____

Type of appropriate blank used for the Analysis: _____

_____

Count No.[a]	Total Counts[b]	Counting Time (min)	Background Count Rate[c]	Counting Efficiency[d]	Assay (nCi)[e]	Estimated Error
1						
2						
3						
4						
5						

(a) Remove and reposition phantom after each count.
(b) Region of interest, total counts.
(c) Region of interest, count rate.
(d) Count rate per unit activity in the phantom (cpm/nCi).
(e) Report calculated assay, including negative values and values < MDA.

Estimated Minimum Detectable Activity (MDA); nCi

Please return this form to: Jay MacLellan
Pacific Northwest Laboratory
P.O. Box 999
Richland, Washington 99352
(509) 375-2626

APPENDIX B

PROPAGATION OF ERROR IN SPIKED IN VIVO PHANTOMS

APPENDIX B

PROPAGATION OF ERROR IN SPIKED IN VIVO PHANTOMS

The sources of error in the preparation of the whole body and lung phantoms used in this study are documented Table B.1 below. These include a quantification of the potential measurement errors in the various gravimetric and volumetric procedures that were followed to develop the spiked phantoms.

All the errors in the development of lung phantoms are common to every phantom with the exception of the calibration uncertainty of each radionuclide standard incorporated into the lungs. This source of error has also been included in the overall errors listed in Tables 5 and 6 in the text.

The standard deviations used in Table 5 and 6 assume linear propagation of errors in the various that are traceable to NIST standards and the above volumetric and gravimetric errors. All propagated error was less than a maximum of 3.5%.

TABLE B.1. Errors Associated with Phantom Preparation

Errors	Whole Body Phantom	Lung Phantom
Weighing	± 0.15%	± 0.5%
Volumetric	± 0.20%	NA
Stock solution preparation	± 1%	± 1%
Radionuclide calibration	± 0.5-2%	+ 0.5-2%

APPENDIX C

IN VIVO BIOASSAY COUNTING RESULTS

APPENDIX C

IN VIVO BIOASSAY COUNTING RESULTS

TABLE C.1. In Vivo Bioassay Counting Results

LAB CODE	PHANTOM TYPE[a]	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)[b]	TRUE SPIKE
A	W1-CS134	1	8 - 20 - 88	120.00	4.00	147.59
A	W1-CS134	2	8 - 20 - 88	119.00	4.00	147.59
A	W1-CS134	3	8 - 20 - 88	123.00	4.00	147.59
A	W1-CS134	4	8 - 20 - 88	120.00	4.00	147.59
A	W1-CS134	5	8 - 20 - 88	108.00	4.00	147.59
A	W1-CS134	6	8 - 20 - 88	118.00	4.00	147.59

MEAN = 118.0 Lab Est. Rel. Error = 0.04

BR (5%) =	-0.23	BR =	-0.20	BR (95%) =	-0.17
SA (5%) =	0.03	SA =	0.04	SA (95%) =	0.09
SB (5%) =	0.02	SB =	0.04	SB (95%) =	0.07

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
A	W1-CS137	1	8 - 20 - 88	267.00	4.00	343.77
A	W1-CS137	2	8 - 20 - 88	257.00	4.00	343.77
A	W1-CS137	3	8 - 20 - 88	290.00	4.00	343.77
A	W1-CS137	4	8 - 20 - 88	254.00	4.00	343.77
A	W1-CS137	5	8 - 20 - 88	251.00	4.00	343.77
A	W1-CS137	6	8 - 20 - 88	252.00	4.00	343.77

MEAN = 261.8 Lab Est. Rel. Error = 0.04

BR (5%) =	-0.27	BR =	-0.24	BR (95%) =	-0.20
SA (5%) =	0.04	SA =	0.06	SA (95%) =	0.12
SB (5%) =	0.03	SB =	0.04	SB (95%) =	0.09

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
A	M2-MN54	1	9 - 24 - 88	6.20	1.00	10.60
A	M2-MN54	2	9 - 24 - 88	6.90	1.00	10.60
A	M2-MN54	3	9 - 24 - 88	7.80	1.00	10.60

MEAN = 7.0 Lab Est. Rel. Error = 0.01

BR (5%) =	-0.47	BR =	-0.34	BR (95%) =	-0.22
SA (5%) =	0.07	SA =	0.12	SA (95%) =	0.51
SB (5%) =	0.04	SB =	0.08	SB (95%) =	0.33

(a) Phantom type: W = Whole body, M = lung/mixed fission product, U = lung/uranium, P = lung/^{238}Pu, 1-3 = coded activity levels.
(b) % error reported by laboratory as estimated error on reporting form.

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
A	M1-MN54	1	9 - 24 - 88	121.00	1.00	107.69
A	M1-MN54	2	9 - 24 - 88	122.00	1.00	107.69
A	M1-MN54	3	9 - 24 - 88	122.00	1.00	107.69

MEAN =	121.7	Lab Est. Rel. Error =	0.01		
BR (5%) =	0.12	BR = 0.13	BR (95%) =	0.14	
SA (5%) =	0.00	SA = 0.00	SA (95%) =	0.02	
SB (5%) =	0.00	SB = 0.01	SB (95%) =	0.02	

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
A	M2-CE144	1	9 - 24 - 88	95.00	30.00	30.25
A	M2-CE144	2	9 - 24 - 88	94.00	29.00	30.25
A	M2-CE144	3	9 - 24 - 88	94.00	29.00	30.25

MEAN =	94.3	Lab Est. Rel. Error =	0.29		
BR (5%) =	2.09	BR = 2.12	BR (95%) =	2.15	
SA (5%) =	0.00	SA = 0.01	SA (95%) =	0.03	
SB (5%) =	0.01	SB = 0.02	SB (95%) =	0.08	

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
A	M1-CE144	1	9 - 24 - 88	385.00	13.00	260.92
A	M1-CE144	2	9 - 24 - 88	395.00	11.00	260.92
A	M1-CE144	3	9 - 24 - 88	385.00	11.00	260.92

MEAN =	388.3	Lab Est. Rel. Error =	0.12		
BR (5%) =	0.45	BR = 0.49	BR (95%) =	0.53	
SA (5%) =	0.01	SA = 0.01	SA (95%) =	0.07	
SB (5%) =	0.01	SB = 0.02	SB (95%) =	0.10	

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
A	U3-U238	1	10 - 1 - 88	5.10	1.00	3.51
A	U3-U238	2	10 - 1 - 88	4.90	1.00	3.51

MEAN =	5.0	Lab Est. Rel. Error =	0.01		
BR (5%) =	0.24	BR = 0.42	BR (95%) =	0.60	
SA (5%) =	0.01	SA = 0.03	SA (95%) =	0.45	
SB (5%) =	0.02	SB = 0.04	SB (95%) =	0.64	

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
A	U1-U238	1	10 - 1 - 88	33.00	1.00	33.07
A	U1-U238	2	10 - 1 - 88	34.00	1.00	33.07
A	U1-U238	3	10 - 1 - 88	34.00	1.00	33.07

MEAN = 33.7 Lab Est. Rel. Error = 0.01
BR (5%) = -0.01 BR = 0.02 BR (95%) = 0.05
SA (5%) = 0.01 SA = 0.02 SA (95%) = 0.08
SB (5%) = 0.01 SB = 0.02 SB (95%) = 0.08

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
A	U2-U238	1	13609	30.0	147.8	2.0000
A	U2-U238	2	13933	30.0	133.2	2.3000
A	U2-U238	3	13946	30.0	161.5	1.9000

MEAN = 13829 s^2/MEAN = 2.636 (ACCEPT < 3 WHEN N = 3)
BIAS(5%) = -0.01 BIAS = 0.02 BIAS(95%) = 0.05
MDA(POISSON 5%) = 0.92 MDA(POISSON) = 0.97 MDA(POISSON 95%) = 1.02
LAB ESTIMATED MDA = 2.2 nCi

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
A	P2-PU238	1	9 - 30 - 88	24.00	1.00	31.94
A	P2-PU238	2	9 - 30 - 88	25.00	1.00	31.94
A	P2-PU238	3	9 - 30 - 88	22.00	1.00	31.94
A	P2-PU238	4	9 - 30 - 88	21.00	1.00	31.94

MEAN = 23.0 Lab Est. Rel. Error = 0.01
BR (5%) = -0.35 BR = -0.28 BR (95%) = -0.21
SA (5%) = 0.05 SA = 0.08 SA (95%) = 0.23
SB (5%) = 0.04 SB = 0.06 SB (95%) = 0.17

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
A	P3-PU238	1	9 - 30 - 88	245.00	1.00	367.66
A	P3-PU238	2	9 - 30 - 88	245.00	1.00	367.66
A	P3-PU238	3	9 - 30 - 88	250.00	1.00	367.66
A	P3-PU238	4	9 - 30 - 88	241.00	1.00	367.66

MEAN = 245.3 Lab Est. Rel. Error = 0.01
BR (5%) = -0.34 BR = -0.33 BR (95%) = -0.32
SA (5%) = 0.01 SA = 0.02 SA (95%) = 0.04
SB (5%) = 0.01 SB = 0.01 SB (95%) = 0.03

BLANK PHANTOM RESULTS

LAB COOE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
A	P1-PU238	1	255	30.0	0.482	0.6200
A	P1-PU238	2	235	30.0	0.482	-0.8300
A	P1-PU238	3	264	30.0	0.482	1.2400

s^2/MEAN = 0.877 (ACCEPT < 3 WHEN N = 3)

BIAS(5%) = -0.34 BIAS = -0.33 BIAS(95%) = -0.32

MDA(POISSON 5%) = 7.671 MDA(POISSON) = 8.214 MDA(POISSON 95%) = 8.756

LAB ESTIMATED MDA = 17.00

LAB COOE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B2	M1-CE144	1	9 - 14 - 87	1411.00	4.30	652.55
B2	M1-CE144	2	9 - 14 - 87	1424.00	4.60	652.55
B2	M1-CE144	3	9 - 14 - 87	1466.00	4.30	652.55
B2	M1-CE144	4	9 - 14 - 87	1363.00	5.10	652.55
B2	M1-CE144	5	9 - 14 - 87	1338.00	4.60	652.55

MEAN = 1400.4 Lab Est. Rel. Error = 0.05

BR (5%) = 1.07 BR = 1.15 BR (95%) = 1.22

SA (5%) = 0.02 SA = 0.04 SA (95%) = 0.09

SB (5%) = 0.05 SB = 0.08 SB (95%) = 0.18

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B1	W1-CS134	1	4 - 17 - 87	289.00	5.40	231.99
B1	W1-CS134	2	4 - 17 - 87	229.00	5.00	231.99
B1	W1-CS134	3	4 - 17 - 87	249.00	5.70	231.99
B1	W1-CS134	4	4 - 17 - 87	254.00	5.40	231.99
B1	W1-CS134	5	4 - 17 - 87	253.00	5.60	231.99

MEAN = 254.8 Lab Est. Rel. Error = 0.05

BR (5%) = 0.01 BR = 0.10 BR (95%) = 0.19

SA (5%) = 0.06 SA = 0.08 SA (95%) = 0.20

SB (5%) = 0.06 SB = 0.09 SB (95%) = 0.22

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B1	W1-CS137	1	4 - 17 - 87	369.00	3.80	354.56
B1	W1-CS137	2	4 - 17 - 87	466.00	3.30	354.56
B1	W1-CS137	3	4 - 17 - 87	415.00	3.70	354.56
B1	W1-CS137	4	4 - 17 - 87	403.00	4.10	354.56
B1	W1-CS137	5	4 - 17 - 87	410.00	3.60	354.56

MEAN = 412.6 Lab Est. Rel. Error = 0.04

BR (5%) = 0.07 BR = 0.16 BR (95%) = 0.26

SA (5%) = 0.05 SA = 0.08 SA (95%) = 0.20

SB (5%) = 0.06 SB = 0.10 SB (95%) = 0.23

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B2	W1-CS134	1	4 - 17 - 87	42.00	6.60	231.99
B2	W1-CS134	2	4 - 17 - 87	74.00	5.80	231.99
B2	W1-CS134	3	4 - 17 - 87	63.00	5.40	231.99
B2	W1-CS134	4	4 - 17 - 87	79.00	5.30	231.99
B2	W1-CS134	5	4 - 17 - 87	59.00	6.30	231.99

MEAN = 63.4 Lab Est. Rel. Error = 0.06
BR (5%) = -0.79 BR = -0.73 BR (95%) = -0.67
SA (5%) = 0.15 SA = 0.23 SA (95%) = 0.54
SB (5%) = 0.04 SB = 0.06 SB (95%) = 0.15

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B2	W1-CS137	1	4 - 17 - 87	77.00	4.50	354.56
B2	W1-CS137	2	4 - 17 - 87	89.00	4.90	354.56
B2	W1-CS137	3	4 - 17 - 87	108.00	4.20	354.56
B2	W1-CS137	4	4 - 17 - 87	76.00	5.30	354.56
B2	W1-CS137	5	4 - 17 - 87	110.00	3.80	354.56

MEAN = 92.0 Lab Est. Rel. Error = 0.05
BR (5%) = -0.78 BR = -0.74 BR (95%) = -0.70
SA (5%) = 0.12 SA = 0.18 SA (95%) = 0.42
SB (5%) = 0.03 SB = 0.05 SB (95%) = 0.11

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B2	W1-CS134	1	4 - 17 - 87	70.00	4.40	231.99
B2	W1-CS134	2	4 - 17 - 87	108.00	5.00	231.99
B2	W1-CS134	3	4 - 17 - 87	78.00	5.20	231.99
B2	W1-CS134	4	4 - 17 - 87	68.00	4.90	231.99
B2	W1-CS134	5	4 - 17 - 87	77.00	5.20	231.99

MEAN = 80.2 Lab Est. Rel. Error = 0.05
BR (5%) = -0.72 BR = -0.65 BR (95%) = -0.59
SA (5%) = 0.13 SA = 0.20 SA (95%) = 0.48
SB (5%) = 0.05 SB = 0.07 SB (95%) = 0.16

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B2	W1-CS137	1	4 - 17 - 87	130.00	3.70	354.56
B2	W1-CS137	2	4 - 17 - 87	119.00	4.40	354.56
B2	W1-CS137	3	4 - 17 - 87	150.00	3.60	354.56
B2	W1-CS137	4	4 - 17 - 87	170.00	3.50	354.56
B2	W1-CS137	5	4 - 17 - 87	155.00	3.40	354.56

MEAN = 144.8 Lab Est. Rel. Error = 0.04
BR (5%) = -0.65 BR = -0.59 BR (95%) = -0.54
SA (5%) = 0.09 SA = 0.14 SA (95%) = 0.33
SB (5%) = 0.04 SB = 0.06 SB (95%) = 0.14

LAB COOE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B1	M2-CE144	1	9 - 14 - 87	159.00	20.30	75.64
B1	M2-CE144	2	9 - 14 - 87	305.00	14.50	75.64
B1	M2-CE144	3	9 - 14 - 87	157.00	22.70	75.64
B1	M2-CE144	4	9 - 14 - 87	189.00	22.00	75.64

MEAN = 202.5 Lab Est. Rel. Error = 0.20

BR (5%) = 0.59 BR = 1.68 BR (95%) = 2.76

SA (5%) = 0.21 SA = 0.35 SA (95%) = 1.01

SB (5%) = 0.57 SB = 0.92 SB (95%) = 2.69

LAB COOE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B1	M1-CE144	1	9 - 14 - 87	1219.00	8.90	652.55
B1	M1-CE144	2	9 - 14 - 87	793.00	14.50	652.55
B1	M1-CE144	3	9 - 14 - 87	967.00	9.80	652.55
B1	M1-CE144	4	9 - 14 - 87	1091.00	8.90	652.55
B1	M1-CE144	5	9 - 14 - 87	1265.00	8.60	652.55

MEAN = 1067.0 Lab Est. Rel. Error = 0.10

BR (5%) = 0.35 BR = 0.64 BR (95%) = 0.92

SA (5%) = 0.12 SA = 0.18 SA (95%) = 0.43

SB (5%) = 0.19 SB = 0.29 SB (95%) = 0.70

LAB CODE	PHANTOM TYPE	COUNT NO.	OATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B2	M1-CE144	1	9 - 14 - 87	1411.00	4.30	652.55
B2	M1-CE144	2	9 - 14 - 87	1424.00	4.60	652.55
B2	M1-CE144	3	9 - 14 - 87	1466.00	4.30	652.55
B2	M1-CE144	4	9 - 14 - 87	1363.00	5.10	652.55
B2	M1-CE144	5	9 - 14 - 87	1338.00	4.60	652.55

MEAN = 1400.4 Lab Est. Rel. Error = 0.05

BR (5%) = 1.07 BR = 1.15 BR (95%) = 1.22

SA (5%) = 0.02 SA = 0.04 SA (95%) = 0.09

SB (5%) = 0.05 SB = 0.08 SB (95%) = 0.18

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B2	M1-MN54	1	9 - 14 - 87	575.00	1.10	247.86
B2	M1-MN54	2	9 - 14 - 87	362.00	1.30	247.86
B2	M1-MN54	3	9 - 14 - 87	382.00	1.40	247.86
B2	M1-MN54	4	9 - 14 - 87	595.00	1.00	247.86
B2	M1-MN54	5	9 - 14 - 87	585.00	1.00	247.86

MEAN = 499.8 Lab Est. Rel. Error = 0.01

BR (5%) = 0.57 BR = 1.02 BR (95%) = 1.47

SA (5%) = 0.15 SA = 0.23 SA (95%) = 0.56

SB (5%) = 0.31 SB = 0.47 SB (95%) = 1.12

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
B1	M1-MN54	1	9 - 14 - 87	333.00	2.40	247.86
B1	M1-MN54	2	9 - 14 - 87	348.00	2.40	247.86
B1	M1-MN54	3	9 - 14 - 87	294.00	3.00	247.86
B1	M1-MN54	4	9 - 14 - 87	291.00	2.90	247.86

MEAN = 316.5 Lab Est. Rel. Error = 0.03
BR (5%) = 0.14 BR = 0.28 BR (95%) = 0.41
SA (5%) = 0.06 SA = 0.09 SA (95%) = 0.26
SB (5%) = 0.07 SB = 0.11 SB (95%) = 0.33

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
C	M1-CE144	1	3 - 17 - 87	383.00	25.00	528.71
C	M1-CE144	2	3 - 17 - 87	402.00	25.00	528.71
C	M1-CE144	3	3 - 17 - 87	507.00	25.00	528.71
C	M1-CE144	4	3 - 17 - 87	356.00	25.00	521.03
C	M1-CE144	5	3 - 17 - 87	490.00	25.00	521.03

MEAN = 427.6 Lab Est. Rel. Error = 0.25
BR (5%) = -0.31 BR = -0.19 BR (95%) = -0.06
SA (5%) = 0.10 SA = 0.16 SA (95%) = 0.37
SB (5%) = 0.08 SB = 0.13 SB (95%) = 0.30

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
C	M2-CE144	1	3 - 11 - 87	788.00	25.00	620.09
C	M2-CE144	2	3 - 11 - 87	574.00	25.00	620.09
C	M2-CE144	3	3 - 11 - 87	881.00	25.00	620.09
C	M2-CE144	4	3 - 11 - 87	544.00	25.00	620.09
C	M2-CE144	5	3 - 11 - 87	706.00	25.00	620.09

MEAN = 698.6 Lab Est. Rel. Error = 0.25
BR (5%) = -0.09 BR = 0.13 BR (95%) = 0.35
SA (5%) = 0.13 SA = 0.20 SA (95%) = 0.48
SB (5%) = 0.15 SB = 0.23 SB (95%) = 0.54

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
C	M3-CE144	1	7092	10.0	1.486	27.5000
C	M3-CE144	2	6977	10.0	1.486	21.3000
C	M3-CE144	3	7162	10.0	1.486	17.6000
C	M3-CE144	4	6843	10.0	1.486	18.2000
C	M3-CE144	5	7218	10.0	1.486	35.1000

s^2/MEAN = 3.200 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -0.09 BIAS = 0.13 BIAS(95%) = 0.35
MDA(POISSON 5%) = 23.035 MDA(POISSON) = 25.62 MDA(POISSON 95%) = 34.68
LAB ESTIMATED MDA = 40.00

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
C	M1-MN54	1	3 - 11 - 87	107.00	15.00	185.70
C	M1-MN54	2	3 - 11 - 87	114.00	15.00	185.70
C	M1-MN54	3	3 - 11 - 87	120.00	15.00	185.70
C	M1-MN54	4	3 - 11 - 87	68.00	15.00	185.70
C	M1-MN54	5	3 - 11 - 87	133.00	15.00	185.70

MEAN = 108.4 Lab Est. Rel. Error = 0.15
BR (5%) = -0.54 BR = -0.42 BR (95%) = -0.29
SA (5%) = 0.15 SA = 0.23 SA (95%) = 0.54
SB (5%) = 0.09 SB = 0.13 SB (95%) = 0.31

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
C	M2-MN54	1	3 - 11 - 87	198.00	15.00	226.21
C	M2-MN54	2	3 - 11 - 87	202.00	15.00	226.21
C	M2-MN54	3	3 - 11 - 87	218.00	15.00	226.21
C	M2-MN54	4	3 - 11 - 87	183.00	15.00	226.21
C	M2-MN54	5	3 - 11 - 87	182.00	15.00	226.21

MEAN = 196.6 Lab Est. Rel. Error = 0.15
BR (5%) = -0.19 BR = -0.13 BR (95%) = -0.07
SA (5%) = 0.05 SA = 0.08 SA (95%) = 0.18
SB (5%) = 0.04 SB = 0.07 SB (95%) = 0.16

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
C	M3-MN54	1	654	10.0	11.840	-0.2500
C	M3-MN54	2	591	10.0	11.840	-0.0600
C	M3-MN54	3	623	10.0	11.840	0.1000
C	M3-MN54	4	526	10.0	11.840	0.3200
C	M3-MN54	5	568	10.0	11.840	0.3000

s^2/MEAN = 4.109 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -0.19 BIAS = -0.13 BIAS(95%) = -0.07
MDA(POISSON 5%) = 2.73 MDA(POISSON) = 3.02 MDA(POISSON 95%) = 3.35
LAB ESTIMATED MDA = 5.00

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D1	M2-MN54	1	9 - 28 - 87	15.00	33.80	23.66
D1	M2-MN54	2	9 - 28 - 87	17.00	35.40	23.66
D1	M2-MN54	3	9 - 28 - 87	12.00	48.60	23.66
D1	M2-MN54	4	9 - 28 - 87	16.00	29.80	23.66
D1	M2-MN54	5	9 - 28 - 87	17.00	32.40	23.66

MEAN = 15.4 Lab Est. Rel. Error = 0.36
BR (5%) = -0.43 BR = -0.35 BR (95%) = -0.27
SA (5%) = 0.09 SA = 0.13 SA (95%) = 0.32
SB (5%) = 0.06 SB = 0.09 SB (95%) = 0.21

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D1	M1-MN54	1	9 - 28 - 87	230.00	9.00	240.29
D1	M1-MN54	2	9 - 28 - 87	237.00	9.00	240.29
D1	M1-MN54	3	9 - 28 - 87	230.00	8.90	240.29
D1	M1-MN54	4	9 - 28 - 87	226.00	9.00	240.29
D1	M1-MN54	5	9 - 28 - 87	227.00	9.00	240.29

MEAN = 230.0 Lab Est. Rel. Error = 0.09
BR (5%) = -0.06 BR = -0.04 BR (95%) = -0.03
SA (5%) = 0.01 SA = 0.02 SA (95%) = 0.04
SB (5%) = 0.01 SB = 0.02 SB (95%) = 0.04

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D2	M2-CE144	1	10 - 1 - 87	50.12	27.80	72.57
D2	M2-CE144	2	10 - 1 - 87	76.42	18.50	72.57
D2	M2-CE144	3	10 - 1 - 87	117.30	14.20	72.57
D2	M2-CE144	4	10 - 1 - 87	144.50	12.60	72.57
D2	M2-CE144	5	10 - 1 - 87	82.14	17.20	72.57

MEAN = 94.1 Lab Est. Rel. Error = 0.18
BR (5%) = -0.19 BR = 0.30 BR (95%) = 0.78
SA (5%) = 0.26 SA = 0.39 SA (95%) = 0.93
SB (5%) = 0.33 SB = 0.51 SB (95%) = 1.21

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D2	M1-CE144	1	10 - 2 - 87	534.00	5.50	624.53
D2	M1-CE144	2	10 - 2 - 87	572.60	3.70	624.53
D2	M1-CE144	3	10 - 2 - 87	570.10	5.10	624.53
D2	M1-CE144	4	10 - 2 - 87	547.50	4.40	624.53
D2	M1-CE144	5	10 - 2 - 87	587.20	3.60	624.53

MEAN = 562.3 Lab Est. Rel. Error = 0.04
BR (5%) = -0.13 BR = -0.10 BR (95%) = -0.07
SA (5%) = 0.02 SA = 0.04 SA (95%) = 0.09
SB (5%) = 0.02 SB = 0.03 SB (95%) = 0.08

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D2	M2-MN54	1	10 - 1 - 87	134.20	1.60	23.50
D2	M2-MN54	2	10 - 1 - 87	133.00	1.40	23.50
D2	M2-MN54	3	10 - 1 - 87	136.60	1.40	23.50
D2	M2-MN54	4	10 - 1 - 87	133.00	1.60	23.50
D2	M2-MN54	5	10 - 1 - 87	134.30	1.60	23.50

MEAN = 134.2 Lab Est. Rel. Error = 0.02
BR (5%) = 4.65 BR = 4.71 BR (95%) = 4.77
SA (5%) = 0.01 SA = 0.01 SA (95%) = 0.03
SB (5%) = 0.04 SB = 0.06 SB (95%) = 0.15

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D2	M1-MN54	1	10 - 2 - 87	345.10	1.00	238.17
D2	M1-MN54	2	10 - 2 - 87	333.30	1.00	238.17
D2	M1-MN54	3	10 - 2 - 87	334.00	1.00	238.17
D2	M1-MN54	4	10 - 2 - 87	330.90	1.00	238.17
D2	M1-MN54	5	10 - 2 - 87	337.50	1.00	238.17

MEAN = 336.2 Lab Est. Rel. Error = 0.01
BR (5%) = 0.39 BR = 0.41 BR (95%) = 0.43
SA (5%) = 0.01 SA = 0.02 SA (95%) = 0.04
SB (5%) = 0.02 SB = 0.02 SB (95%) = 0.06

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D3	M2-MN54	1	10 - 5 - 87	142.90	0.60	23.29
D3	M2-MN54	2	10 - 5 - 87	146.20	0.60	23.29
D3	M2-MN54	3	10 - 5 - 87	147.50	0.60	23.29
D3	M2-MN54	4	10 - 5 - 87	147.40	0.60	23.29
D3	M2-MN54	5	10 - 5 - 87	139.70	0.60	23.29

MEAN = 144.7 Lab Est. Rel. Error = 0.01
BR (5%) = 5.08 BR = 5.21 BR (95%) = 5.35
SA (5%) = 0.02 SA = 0.02 SA (95%) = 0.06
SB (5%) = 0.09 SB = 0.14 SB (95%) = 0.34

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D3	M1-MN54	1	10 - 5 - 87	374.00	1.00	236.59
D3	M1-MN54	2	10 - 5 - 87	364.50	1.00	236.59
D3	M1-MN54	3	10 - 5 - 87	383.20	1.00	236.59
D3	M1-MN54	4	10 - 5 - 87	362.90	1.00	236.59
D3	M1-MN54	5	10 - 5 - 87	367.00	1.00	236.59

MEAN = 370.3 Lab Est. Rel. Error = 0.01
BR (5%) = 0.53 BR = 0.57 BR (95%) = 0.60
SA (5%) = 0.01 SA = 0.02 SA (95%) = 0.05
SB (5%) = 0.02 SB = 0.04 SB (95%) = 0.08

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D3	M1-CE144	1	10 - 5 - 87	737.90	6.50	619.98
D3	M1-CE144	2	10 - 5 - 87	831.60	5.60	619.98
D3	M1-CE144	3	10 - 5 - 87	815.80	6.50	619.98
D3	M1-CE144	4	10 - 5 - 87	861.50	6.80	619.98
D3	M1-CE144	5	10 - 5 - 87	824.80	6.50	619.98

MEAN = 814.3 Lab Est. Rel. Error = 0.06
BR (5%) = 0.24 BR = 0.31 BR (95%) = 0.38
SA (5%) = 0.04 SA = 0.06 SA (95%) = 0.13
SB (5%) = 0.05 SB = 0.07 SB (95%) = 0.18

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D4	M2-MN54	1	10 - 10 - 87	29.30	6.00	23.03
D4	M2-MN54	2	10 - 10 - 87	27.00	4.00	23.03
D4	M2-MN54	3	10 - 10 - 87	25.60	3.00	23.03
D4	M2-MN54	4	10 - 10 - 87	27.30	4.00	23.03
D4	M2-MN54	5	10 - 10 - 87	18.70	4.00	23.03

MEAN = 25.6 Lab Est. Rel. Error = 0.04
BR (5%) = -0.06 BR = 0.11 BR (95%) = 0.28
SA (5%) = 0.10 SA = 0.16 SA (95%) = 0.38
SB (5%) = 0.11 SB = 0.18 SB (95%) = 0.42

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D4	M1-MN54	1	10 - 10 - 87	216.50	8.70	233.98
D4	M1-MN54	2	10 - 10 - 87	212.70	8.70	233.98
D4	M1-MN54	3	10 - 10 - 87	227.50	9.00	233.98
D4	M1-MN54	4	10 - 10 - 87	209.90	9.20	233.98
D4	M1-MN54	5	10 - 10 - 87	223.90	8.40	233.98

MEAN = 218.1 Lab Est. Rel. Error = 0.09
BR (5%) = -0.10 BR = -0.07 BR (95%) = -0.04
SA (5%) = 0.02 SA = 0.03 SA (95%) = 0.08
SB (5%) = 0.02 SB = 0.03 SB (95%) = 0.08

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D4	M1-CE144	1	10 - 10 - 87	707.00	10.30	612.47
D4	M1-CE144	2	10 - 10 - 87	558.00	10.80	612.47
D4	M1-CE144	3	10 - 10 - 87	569.00	10.50	612.47
D4	M1-CE144	4	10 - 10 - 87	687.00	8.90	612.47
D4	M1-CE144	5	10 - 10 - 87	608.00	9.70	612.47

MEAN = 625.8 Lab Est. Rel. Error = 0.10
BR (5%) = -0.08 BR = 0.02 BR (95%) = 0.13
SA (5%) = 0.07 SA = 0.11 SA (95%) = 0.26
SB (5%) = 0.07 SB = 0.11 SB (95%) = 0.26

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D5	M2-MN54	1	10 - 10 - 87	19.20	18.20	23.03
D5	M2-MN54	2	10 - 10 - 87	32.80	10.40	23.03
D5	M2-MN54	3	10 - 10 - 87	28.40	12.30	23.03
D5	M2-MN54	4	10 - 10 - 87	23.30	17.20	23.03
D5	M2-MN54	5	10 - 10 - 87	30.00	12.70	23.03

MEAN = 26.7 Lab Est. Rel. Error = 0.14
BR (5%) = -0.06 BR = 0.16 BR (95%) = 0.39
SA (5%) = 0.13 SA = 0.20 SA (95%) = 0.48
SB (5%) = 0.15 SB = 0.24 SB (95%) = 0.56

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D5	M1-MN54	1	10 - 10 - 87	247.00	3.90	233.98
D5	M1-MN54	2	10 - 10 - 87	250.00	3.90	233.98
D5	M1-MN54	3	10 - 10 - 87	260.00	3.80	233.98
D5	M1-MN54	4	10 - 10 - 87	260.00	3.80	233.98
D5	M1-MN54	5	10 - 10 - 87	267.00	3.70	233.98

MEAN = 256.8 Lab Est. Rel. Error = 0.04
BR (5%) = 0.06 BR = 0.10 BR (95%) = 0.13
SA (5%) = 0.02 SA = 0.03 SA (95%) = 0.08
SB (5%) = 0.02 SB = 0.03 SB (95%) = 0.08

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D5	M2-CE144	1	10 - 10 - 87	71.00	36.62	71.00

MEAN = 71.0 Lab Est. Rel. Error = 0.37

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D5	M1-CE144	1	10 - 10 - 87	688.00	9.70	612.47
D5	M1-CE144	2	10 - 10 - 87	679.00	13.10	612.47
D5	M1-CE144	3	10 - 10 - 87	775.00	8.50	612.47
D5	M1-CE144	4	10 - 10 - 87	602.00	17.90	612.47
D5	M1-CE144	5	10 - 10 - 87	741.00	9.00	612.47

MEAN = 697.0 Lab Est. Rel. Error = 0.12
BR (5%) = 0.04 BR = 0.14 BR (95%) = 0.24
SA (5%) = 0.06 SA = 0.09 SA (95%) = 0.22
SB (5%) = 0.07 SB = 0.11 SB (95%) = 0.26

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D6	M2-MN54	1	10 - 12 - 87	124.10	4.00	22.93
D6	M2-MN54	2	10 - 12 - 87	129.40	3.90	22.93
D6	M2-MN54	3	10 - 12 - 87	130.10	3.80	22.93
D6	M2-MN54	4	10 - 12 - 87	127.70	3.90	22.93
D6	M2-MN54	5	10 - 12 - 87	120.20	4.20	22.93

MEAN = 126.3 Lab Est. Rel. Error = 0.04
BR (5%) = 4.34 BR = 4.51 BR (95%) = 4.68
SA (5%) = 0.02 SA = 0.03 SA (95%) = 0.08
SB (5%) = 0.12 SB = 0.18 SB (95%) = 0.43

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D6	M1-MN54	1	10 - 12 - 87	296.1D	2.40	232.95
D6	M1-MN54	2	10 - 12 - 87	322.20	2.20	232.95
D6	M1-MN54	3	10 - 12 - 87	303.90	2.30	232.95
D6	M1-MN54	4	10 - 12 - 87	298.10	2.30	232.95
D6	M1-MN54	5	10 - 12 - 87	303.60	2.30	232.95

MEAN = 304.8 Lab Est. Rel. Error = 0.02
BR (5%) = 0.27 BR = 0.31 BR (95%) = 0.35
SA (5%) = 0.02 SA = 0.03 SA (95%) = 0.08
SB (5%) = 0.03 SB = 0.04 SB (95%) = 0.10

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
D6	M1-CE144	1	10 - 12 - 87	826.70	6.40	609.49
D6	M1-CE144	2	10 - 12 - 87	773.30	6.50	609.49
D6	M1-CE144	3	10 - 12 - 87	823.30	6.40	609.49
D6	M1-CE144	4	1D - 12 - 87	794.20	5.20	609.49
D6	M1-CE144	5	10 - 12 - 87	680.00	7.90	609.49

MEAN = 779.5 Lab Est. Rel. Error = 0.06
BR (5%) = D.19 BR = D.28 BR (95%) = 0.37
SA (5%) = 0.05 SA = 0.08 SA (95%) = 0.18
SB (5%) = 0.06 SB = 0.10 SB (95%) = 0.23

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTEO	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
G	W1-CS134	1	10 - 9 - 87	147.00	5.00	197.45
G	W1-CS134	2	10 - 9 - 87	141.00	5.00	197.45
G	W1-CS134	3	10 - 9 - 87	144.00	5.00	197.45
G	W1-CS134	4	10 - 9 - 87	140.00	5.00	197.45
G	W1-CS134	5	10 - 9 - 87	144.00	5.00	197.45

MEAN = 143.2 Lab Est. Rel. Error = 0.05
BR (5%) = -0.29 BR = -0.27 BR (95%) = -0.26
SA (5%) = 0.01 SA = 0.02 SA (95%) = 0.05
SB (5%) = 0.01 SB = 0.01 SB (95%) = 0.03

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
G	W2-CS134	1	22999	15.0	19.680	-2.0700
G	W2-CS134	2	23281	15.0	19.680	-1.1500
G	W2-CS134	3	23241	15.0	19.680	-1.2500
G	W2-CS134	4	23312	15.0	19.680	-1.0000
G	W2-CS134	5	23035	15.0	19.680	-1.9500

s^2/MEAN = 0.916 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -0.29 BIAS = -0.27 BIAS(95%) = -0.26
MDA(POISSON 5%) = 4.305 MDA(POISSON) = 4.403 MDA(POISSON 95%) = 4.504
LAB ESTIMATED MDA = 2.50

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
G	W1-CS137	1	10 - 9 - 87	348.00	5.00	350.67
G	W1-CS137	2	10 - 9 - 87	343.00	5.00	350.67
G	W1-CS137	3	10 - 9 - 87	355.00	5.00	350.67
G	W1-CS137	4	10 - 9 - 87	352.00	5.00	350.67
G	W1-CS137	5	10 - 9 - 87	347.00	5.00	350.67

MEAN = 349.0 Lab Est. Rel. Error = 0.05
BR (5%) = -0.02 BR = -0.00 BR (95%) = 0.01
SA (5%) = 0.01 SA = 0.01 SA (95%) = 0.03
SB (5%) = 0.01 SB = 0.01 SB (95%) = 0.03

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
G1	W1-CS137	1	10 - 9 - 87	338.0	1.8	350.67
G1	W1-CS137	2	10 - 9 - 87	335.0	1.8	350.67
G1	W1-CS137	3	10 - 9 - 87	337.0	1.8	350.67
G1	W1-CS137	4	10 - 9 - 87	339.0	1.8	350.67
G1	W1-CS137	5	10 - 9 - 87	335.0	1.8	350.67

MEAN = 336.8 Lab. Est. Rel. Error = 0.02
BR = -0.04
No Data SA = 0.01 No Data
SB = 0.01

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
G	W2-CS137	1	18120	15.0	12.27	-1.5000
G	W2-CS137	2	18467	15.0	12.27	0.4200
G	W2-CS137	3	18347	15.0	12.27	-0.2400
G	W2-CS137	4	18357	15.0	12.27	-0.1800
G	W2-CS137	5	18407	15.0	12.27	0.0900

s^2/MEAN = 0.945 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) =-0.02 BIAS = -0.00 BIAS(95%) = 0.01
MDA(POISSON 5%) = 4.45 MDA(POISSON) = 4.53 MDA(POISSON 95%) = 4.61
LAB ESTIMATED MDA = 3.40

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
I	W1-CS134	1	3 - 19 - 87	242.80	27.60	238.27
I	W1-CS134	2	3 - 19 - 87	262.60	26.60	238.27
I	W1-CS134	3	3 - 19 - 87	275.30	6.90	238.27
I	W1-CS134	4	3 - 19 - 87	212.20	29.80	238.27
I	W1-CS134	5	3 - 19 - 87	251.20	26.80	238.27

MEAN = 248.8 Lab Est. Rel. Error = 0.24
BR (5%) = -0.05 BR = 0.04 BR (95%) = 0.14
SA (5%) = 0.06 SA = 0.10 SA (95%) = 0.23
SB (5%) = 0.06 SB = 0.10 SB (95%) = 0.24

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
I	W1-CS137	1	3 - 19 - 87	450.20	8.70	355.20
I	W1-CS137	2	3 - 19 - 87	450.10	9.10	355.20
I	W1-CS137	3	3 - 19 - 87	509.00	8.20	355.20
I	W1-CS137	4	3 - 19 - 87	405.00	9.90	355.20
I	W1-CS137	5	3 - 19 - 87	456.90	9.80	355.20

MEAN =	454.2	Lab Est. Rel. Error =		0.09	
BR (5%) =	0.18	BR =	0.28	BR (95%) =	0.38
SA (5%) =	0.05	SA =	0.08	SA (95%) =	0.19
SB (5%) =	0.07	SB =	0.10	SB (95%) =	0.25

LAB CODE	PHANTOM TYPE	COUNT NO.	OATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
I	M2-CE144	1	7 - 14 - 87	524.90	39.80	87.99
I	M2-CE144	2	7 - 14 - 87	355.00	33.20	87.99
I	M2-CE144	3	7 - 14 - 87	487.70	22.70	87.99
I	M2-CE144	4	7 - 14 - 87	387.10	28.60	87.99
I	M2-CE144	5	7 - 14 - 87	526.30	25.60	87.99

MEAN =	456.2	Lab Est. Rel. Error =		0.30	
BR (5%) =	3.32	BR =	4.18	BR (95%) =	5.05
SA (5%) =	0.11	SA =	0.18	SA (95%) =	0.42
SB (5%) =	0.59	SB =	0.91	SB (95%) =	2.16

LAB CODE	PHANTOM TYPE	COUNT NO.	OATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
I	M1-CE144	1	7 - 15 - 87	2731.00	5.50	757.18
I	M1-CE144	2	7 - 15 - 87	2713.00	5.50	757.18
I	M1-CE144	3	7 - 15 - 87	2698.00	5.50	757.18
I	M1-CE144	4	7 - 15 - 87	2765.00	5.50	757.18
I	M1-CE144	5	7 - 15 - 87	2751.00	5.50	757.18

MEAN =	2731.6	Lab Est. Rel. Error =		0.06	
BR (5%) =	2.57	BR =	2.61	BR (95%) =	2.64
SA (5%) =	0.01	SA =	0.01	SA (95%) =	0.02
SB (5%) =	0.02	SB =	0.04	SB (95%) =	0.09

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
I	M2-MN54	1	7 - 15 - 87	42.00	11.00	27.94
I	M2-MN54	2	7 - 15 - 87	50.25	21.00	27.94

MEAN =	46.1	Lab Est. Rel. Error =		0.16	
BR (5%) =	-0.28	BR =	0.65	BR (95%) =	1.58
SA (5%) =	0.06	SA =	0.13	SA (95%) =	2.01
SB (5%) =	0.11	SB =	0.21	SB (95%) =	3.31

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
I	M1-MN54	1	7 - 15 - 87	456.70	4.00	283.76
I	M1-MN54	2	7 - 15 - 87	456.90	4.10	283.76
I	M1-MN54	3	7 - 15 - 87	451.80	4.20	283.76
I	M1-MN54	4	7 - 15 - 87	455.70	2.40	283.76
I	M1-MN54	5	7 - 15 - 87	444.20	3.60	283.76

MEAN = 453.1 Lab Est. Rel. Error = 0.04
BR (5%) = 0.58 BR = 0.60 BR (95%) = 0.61
SA (5%) = 0.01 SA = 0.01 SA (95%) = 0.03
SB (5%) = 0.01 SB = 0.02 SB (95%) = 0.04

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J1	M2-CE144	1	2 - 1 - 87	2095.00	5.70	680.29
J1	M2-CE144	2	2 - 1 - 87	2164.00	5.70	680.29
J1	M2-CE144	3	2 - 1 - 87	1910.00	6.40	680.29
J1	M2-CE144	4	2 - 1 - 87	1616.00	6.70	680.29
J1	M2-CE144	5	2 - 1 - 87	1836.00	5.90	680.29

MEAN = 1924.2 Lab Est. Rel. Error = 0.06
BR (5%) = 1.52 BR = 1.83 BR (95%) = 2.13
SA (5%) = 0.07 SA = 0.11 SA (95%) = 0.27
SB (5%) = 0.21 SB = 0.32 SB (95%) = 0.76

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J1	M1-CE144	1	2 - 1 - 87	1108.00	10.00	580.03
J1	M1-CE144	2	2 - 1 - 87	885.00	11.40	580.03
J1	M1-CE144	3	2 - 1 - 87	1040.00	9.70	580.03
J1	M1-CE144	4	2 - 1 - 87	1023.00	10.50	580.03
J1	M1-CE144	5	2 - 1 - 87	1032.00	9.70	580.03

MEAN = 1017.6 Lab Est. Rel. Error = 0.10
BR (5%) = 0.62 BR = 0.75 BR (95%) = 0.89
SA (5%) = 0.05 SA = 0.08 SA (95%) = 0.19
SB (5%) = 0.09 SB = 0.14 SB (95%) = 0.33

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LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
J	M3-CE144	1	4206	10.0	0.240	23.3300
J	M3-CE144	2	3079	10.0	0.240	24.5800
J	M3-CE144	3	3850	10.0	0.240	12.5000

s^2/MEAN = 89.417 (ACCEPT < 3 WHEN N = 3)
BIAS(5%) = 1.52 BIAS = 1.83 BIAS(95%) = 2.13
MDA(POISSON 5%) = 42.490 MDA(POISSON) = 47.641 MDA(POISSON 95%) = 54.030
LAB ESTIMATED MDA = 0.00

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J1	M2-MN54	1	2 - 1 - 87	512.00	2.30	246.09
J1	M2-MN54	2	2 - 1 - 87	424.00	2.50	246.09
J1	M2-MN54	3	2 - 1 - 87	400.00	2.00	246.09

MEAN = 445.3 Lab Est. Rel. Error = 0.02
BR (5%) = 0.41 BR = 0.81 BR (95%) = 1.21
SA (5%) = 0.08 SA = 0.13 SA (95%) = 0.58
SB (5%) = 0.14 SB = 0.24 SB (95%) = 1.06

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
J	M3-MN54	1	943	10.0	1.160	3.7100
J	M3-MN54	2	889	10.0	1.260	0.7100
J	M3-MN54	3	1094	10.0	1.330	1.0500

s^2/MEAN = 11.576 (ACCEPT < 3 WHEN N = 3)
BIAS(5%) = 0.41 BIAS = 0.81 BIAS(95%) = 1.21
MDA(POISSON 5%) = 5.569 MDA(POISSON) = 6.984 MDA(POISSON 95%) = 9.206
LAB ESTIMATED MDA = 0.00

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J2	M2-MN54	1	2 - 1 - 87	944.00	1.50	246.09
J2	M2-MN54	2	2 - 1 - 87	942.00	2.20	246.09
J2	M2-MN54	3	2 - 1 - 87	788.00	1.70	246.09
J2	M2-MN54	4	2 - 1 - 87	793.00	2.60	246.09
J2	M2-MN54	5	2 - 1 - 87	770.00	1.70	246.09

MEAN = 847.4 Lab Est. Rel. Error = 0.02
BR (5%) = 2.10 BR = 2.44 BR (95%) = 2.78
SA (5%) = 0.07 SA = 0.10 SA (95%) = 0.25
SB (5%) = 0.23 SB = 0.36 SB (95%) = 0.84

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J2	M1-MN54	1	2 - 1 - 87	628.00	1.80	202.03
J2	M1-MN54	2	2 - 1 - 87	593.00	2.00	202.03
J2	M1-MN54	3	2 - 1 - 87	540.00	2.80	202.03
J2	M1-MN54	4	2 - 1 - 87	517.00	2.10	202.03

MEAN = 569.5 Lab Est. Rel. Error = 0.02
BR (5%) = 1.53 BR = 1.82 BR (95%) = 2.11
SA (5%) = 0.05 SA = 0.09 SA (95%) = 0.26
SB (5%) = 0.15 SB = 0.25 SB (95%) = 0.73

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J2	M2-CE144	1	2 - 1 - 87	2341.00	5.30	680.29
J2	M2-CE144	2	2 - 1 - 87	2375.00	5.30	680.29
J2	M2-CE144	3	2 - 1 - 87	1898.00	5.30	680.29
J2	M2-CE144	4	2 - 1 - 87	1909.00	6.10	680.29
J2	M2-CE144	5	2 - 1 - 87	1880.00	6.20	680.29

MEAN = 2080.6 Lab Est. Rel. Error = 0.06
BR (5%) = 1.70 BR = 2.06 BR (95%) = 2.41
SA (5%) = 0.08 SA = 0.12 SA (95%) = 0.29
SB (5%) = 0.24 SB = 0.37 SB (95%) = 0.88

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J2	M1-CE144	1	2 - 1 - 87	1093.00	10.60	580.03
J2	M1-CE144	2	2 - 1 - 87	811.00	11.20	580.03
J2	M1-CE144	3	2 - 1 - 87	938.00	11.90	580.03
J2	M1-CE144	4	2 - 1 - 87	1009.00	10.90	580.03
J2	M1-CE144	5	2 - 1 - 87	892.00	11.50	580.03

MEAN = 948.6 Lab Est. Rel. Error = 0.11
BR (5%) = 0.46 BR = 0.64 BR (95%) = 0.81
SA (5%) = 0.07 SA = 0.11 SA (95%) = 0.27
SB (5%) = 0.12 SB = 0.19 SB (95%) = 0.44

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J3	M2-MN54	1	2 - 1 - 87	850.00	1.60	246.09
J3	M2-MN54	2	2 - 1 - 87	561.00	1.60	246.09
J3	M2-MN54	3	2 - 1 - 87	806.00	1.60	246.09
J3	M2-MN54	4	2 - 1 - 87	804.00	1.60	246.09
J3	M2-MN54	5	2 - 1 - 87	504.00	1.70	246.09

MEAN = 705.0 Lab Est. Rel. Error = 0.02
BR (5%) = 1.25 BR = 1.86 BR (95%) = 2.48
SA (5%) = 0.15 SA = 0.23 SA (95%) = 0.54
SB (5%) = 0.42 SB = 0.65 SB (95%) = 1.54

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J3	M1-MN54	1	2 - 1 - 87	628.00	1.80	202.03
J3	M1-MN54	2	2 - 1 - 87	593.00	2.00	202.03
J3	M1-MN54	3	2 - 1 - 87	540.00	2.80	202.03
J3	M1-MN54	4	2 - 1 - 87	517.00	2.10	202.03

MEAN = 569.5 Lab Est. Rel. Error = 0.02
BR (5%) = 1.53 BR = 1.82 BR (95%) = 2.11
SA (5%) = 0.05 SA = 0.09 SA (95%) = 0.26
SB (5%) = 0.15 SB = 0.25 SB (95%) = 0.73

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J3	M2-CE144	1	2 - 1 - 87	2058.00	5.70	680.29
J3	M2-CE144	2	2 - 1 - 87	1806.00	5.60	680.29
J3	M2-CE144	3	2 - 1 - 87	1841.00	5.90	680.29
J3	M2-CE144	4	2 - 1 - 87	1654.00	5.30	680.29
J3	M2-CE144	5	2 - 1 - 87	1640.00	5.60	680.29

MEAN = 1799.8 Lab Est. Rel. Error = 0.06
BR (5%) = 1.41 BR = 1.65 BR (95%) = 1.88
SA (5%) = 0.06 SA = 0.09 SA (95%) = 0.22
SB (5%) = 0.16 SB = 0.25 SB (95%) = 0.59

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J3	M1-CE144	1	2 - 1 - 87	852.00	9.80	580.03
J3	M1-CE144	2	2 - 1 - 87	1041.00	9.30	580.03
J3	M1-CE144	3	2 - 1 - 87	869.00	9.30	580.03
J3	M1-CE144	4	2 - 1 - 87	901.00	9.80	580.03
J3	M1-CE144	5	2 - 1 - 87	744.00	11.20	580.03

MEAN = 881.4 Lab Est. Rel. Error = 0.10
BR (5%) = 0.34 BR = 0.52 BR (95%) = 0.70
SA (5%) = 0.08 SA = 0.12 SA (95%) = 0.29
SB (5%) = 0.12 SB = 0.18 SB (95%) = 0.44

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J3	W1-CS134	1	10 - 23 - 86	206.00	6.70	272.81
J3	W1-CS134	2	10 - 23 - 86	183.00	6.50	272.81
J3	W1-CS134	3	10 - 23 - 86	144.00	6.90	272.81

MEAN = 177.7 Lab Est. Rel. Error = 0.07
BR (5%) = -0.54 BR = -0.35 BR (95%) = -0.16
SA (5%) = 0.10 SA = 0.18 SA (95%) = 0.78
SB (5%) = 0.07 SB = 0.11 SB (95%) = 0.51

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LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
J3	W2-CS134	1	2749	10.0	1.500	15.0000
J3	W2-CS134	2	2076	10.0	1.500	27.0000
J3	W2-CS134	3	2049	10.0	1.500	5.0000
J3	W2-CS134	4	1759	10.0	1.500	4.0000
J3	W2-CS134	5	2767	10.0	1.500	5.0000

s^2/MEAN = 90.301 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -0.54 BIAS = -0.35 BIAS(95%) = -0.16
MDA(POISSON 5%) = 19.250 MDA(POISSON) = 25.370 MDA(POISSON 95%) = 36.662
LAB ESTIMATED MDA = 0.00

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J3	W1-CS137	1	10 - 23 - 86	213.00	5.70	358.50
J3	W1-CS137	2	10 - 23 - 86	226.00	5.30	358.50
J3	W1-CS137	3	10 - 23 - 86	262.00	5.00	358.50

MEAN = 233.7 Lab Est. Rel. Error = 0.05
BR (5%) = -0.47 BR = -0.35 BR (95%) = -0.23
SA (5%) = 0.06 SA = 0.11 SA (95%) = 0.48
SB (5%) = 0.04 SB = 0.07 SB (95%) = 0.31

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
J3	W2-CS137	1	2749	10.0	1.310	17.5000
J3	W2-CS137	2	2076	10.0	1.310	31.0000
J3	W2-CS137	3	2049	10.0	1.310	5.0000
J3	W2-CS137	4	1759	10.0	1.310	5.0000
J3	W2-CS137	5	2767	10.0	1.310	5.0000

s^2/MEAN = 90.301 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -0.47 BIAS = -0.35 BIAS(95%) = -0.23
MDA(POISSON 5%) = 24.151 MDA(POISSON) = 29.026 MDA(POISSON 95%) = 36.077
LAB ESTIMATED MDA = 0.00

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J1	W1-CS137	1	10 - 23 - 86	416.70	4.60	358.50
J1	W1-CS137	2	10 - 23 - 86	402.00	4.50	358.50
J1	W1-CS137	3	10 - 23 - 86	443.00	4.30	358.50
J1	W1-CS137	4	10 - 23 - 86	407.00	4.30	358.50
J1	W1-CS137	5	10 - 23 - 86	146.00	6.90	358.50

MEAN = 362.9 Lab Est. Rel. Error = 0.05
BR (5%) = -0.31 BR = 0.01 BR (95%) = 0.34
SA (5%) = 0.22 SA = 0.34 SA (95%) = 0.80
SB (5%) = 0.22 SB = 0.34 SB (95%) = 0.81

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LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
J1	W2-CS137	1	1454	10.0	1.150	4.7000
J1	W2-CS137	2	1418	10.0	1.150	10.3000
J1	W2-CS137	3	1497	10.0	1.150	3.2000
J1	W2-CS137	4	1489	10.0	1.150	9.5000
J1	W2-CS137	5	1433	10.0	1.150	2.9000

s^2/MEAN = 0.810 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -0.31 BIAS = 0.01 BIAS(95%) = 0.34
MDA(POISSON 5%) = 10.89 MOA(POISSON) = 14.68 MOA(POISSON 95%) = 22.05
LAB ESTIMATED MDA = 0.00

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J1	W1-CS134	1	10 - 23 - 86	287.00	6.30	272.81
J1	W1-CS134	2	10 - 23 - 86	418.00	4.70	272.81

MEAN = 352.5 Lab Est. Rel. Error = 0.06
BR (5%) = -1.22 BR = 0.29 BR (95%) = 1.81
SA (5%) = 0.13 SA = 0.26 SA (95%) = 4.17
SB (5%) = 0.17 SB = 0.34 SB (95%) = 5.39

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
J1	W2-CS134	1	1454	10.0	1.230	4.4000
J1	W2-CS134	2	1418	10.0	1.230	9.6000
J1	W2-CS134	3	1497	10.0	1.230	3.0000
J1	W2-CS134	4	1489	10.0	1.230	8.9000
J1	W2-CS134	5	1433	10.0	1.230	2.7000

s^2/MEAN = 0.810 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -1.22 BIAS = 0.29 BIAS(95%) = 1.81
MDA(POISSON 5%) = 5.54 MDA(POISSON) = 12.28 MDA(POISSON 95%) = -72.27
LAB ESTIMATED MDA = 23.4 nCi

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
J2	W1-CS137	1	10 - 23 - 86	185.00	6.50	358.50
J2	W1-CS137	2	10 - 23 - 86	185.00	5.20	358.50
J2	W1-CS137	3	10 - 23 - 86	356.00	4.60	358.50
J2	W1-CS137	4	10 - 23 - 86	410.00	4.50	358.50

MEAN = 284.0 Lab Est. Rel. Error = 0.05
BR (5%) = -0.59 BR = -0.21 BR (95%) = 0.17
SA (5%) = 0.25 SA = 0.41 SA (95%) = 1.20
SB (5%) = 0.20 SB = 0.32 SB (95%) = 0.95

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LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
J2	W2-CS137	1	1379	10.0	1.150	25.1000
J2	W2-CS137	2	1383	10.0	1.150	14.2000
J2	W2-CS137	3	1332	10.0	1.150	11.5000

s^2/MEAN = 0.589 (ACCEPT < 3 WHEN N = 3)
BIAS(5%) = -0.59 BIAS = -0.21 BIAS(95%) = 0.17
MDA(POISSON 5%) = 13.666 MDA(POISSON) = 20.683 MDA(POISSON 95%) = 40.760
LAB ESTIMATED MDA = 23.50

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
J2	W2-CS134	1	1379	10.0	1.230	23.5000
J2	W2-CS134	2	1383	10.0	1.230	13.3000
J2	W2-CS134	3	1332	10.0	1.230	10.7000

s^2/MEAN = 0.589 (ACCEPT < 3 WHEN N = 3)

BIAS(5%) = -0.59 BIAS = -D.21 BIAS(95%) = 0.17

MDA(POISSON 5%) = 12.777 MDA(POISSON) = 19.53 MDA(POISSON 95%) = 38.109

LAB ESTIMATED MDA = 23.50

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
K	P2-PU238	1	1 - 9 - 87	18.10	0.00	32.38
K	P2-PU238	2	1 - 9 - 87	24.80	0.00	32.38
K	P2-PU238	3	1 - 9 - 87	23.20	0.00	32.38
K	P2-PU238	4	1 - 9 - 87	17.30	D.00	32.38
K	P2-PU238	5	1 - 9 - 87	19.20	0.00	32.38

MEAN = 20.5 Lab Est. Rel. Error = 0.00

BR (5%) = -0.46 BR = -0.37 BR (95%) = -0.27

SA (5%) = 0.10 SA = 0.16 SA (95%) = 0.38

SB (5%) = 0.07 SB = 0.10 SB (95%) = 0.24

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
K	P3-PU238	1	1 - 9 - 87	290.90	0.00	372.71
K	P3-PU238	2	1 - 9 - 87	285.00	0.00	372.71
K	P3-PU238	3	1 - 9 - 87	301.60	0.00	372.71
K	P3-PU238	4	1 - 9 - 87	294.90	0.00	372.71
K	P3-PU238	5	1 - 9 - 87	272.90	0.00	372.71

MEAN = 289.1 Lab Est. Rel. Error = 0.00

BR (5%) = -0.25 BR = -0.22 BR (95%) = -0.20

SA (5%) = 0.02 SA = 0.04 SA (95%) = 0.09

SB (5%) = 0.02 SB = 0.03 SB (95%) = 0.07

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
K	P1-PU238	1	149	33.3	0.098	-2.7000
K	P1-PU238	2	137	33.3	0.098	-7.7000
K	P1-PU238	3	169	33.3	0.098	3.9000
K	P1-PU238	4	140	33.3	0.098	-7.1000
K	P1-PU238	5	135	33.3	0.098	-8.7000

s^2/MEAN = 1.329 (ACCEPT < 2.37 WHEN N = 5)

BIAS(5%) = -0.25 BIAS = -0.22 BIAS(95%) = -0.20

MDA(POISSON 5%) = 21.620 MDA(POISSON) = 23.962 MDA(POISSON 95%) = 26.370

LAB ESTIMATED MDA = 6.80

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
K	U3-U238	1	1 - 6 - 87	2.74	0.00	3.51
K	U3-U238	2	1 - 6 - 87	2.29	0.00	3.51
K	U3-U238	3	1 - 6 - 87	2.09	0.00	3.51
K	U3-U238	4	1 - 6 - 87	3.17	0.00	3.51
K	U3-U238	5	1 - 6 - 87	2.95	0.00	3.51

MEAN =	2.6	Lab Est. Rel. Error =	0.00		
BR (5%) =	-0.37	BR =	-0.25	BR (95%) =	-0.12
SA (5%) =	0.11	SA =	0.17	SA (95%) =	0.40
SB (5%) =	0.08	SB =	0.13	SB (95%) =	0.30

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
K	U1-U238	1	1 - 2 - 87	30.10	0.00	33.07
K	U1-U238	2	1 - 2 - 87	29.80	0.00	33.07
K	U1-U238	3	1 - 2 - 87	31.30	0.00	33.07
K	U1-U238	4	1 - 2 - 87	28.20	0.00	33.07
K	U1-U238	5	1 - 2 - 87	29.80	0.00	33.07

MEAN =	29.8	Lab Est. Rel. Error =	0.00		
BR (5%) =	-0.13	BR =	-0.10	BR (95%) =	-0.07
SA (5%) =	0.02	SA =	0.04	SA (95%) =	0.09
SB (5%) =	0.02	SB =	0.03	SB (95%) =	0.08

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
K	U2-U238	1	191	33.3	1.540	-0.2190
K	U2-U238	2	192	33.3	1.540	0.2480
K	U2-U238	3	188	33.3	1.540	-0.0380
K	U2-U238	4	168	33.3	1.540	-0.3950
K	U2-U238	5	200	33.3	1.540	0.2290

s^2/MEAN = 0.757 (ACCEPT < 2.37 WHEN N = 5)

BIAS(5%) = -0.13 BIAS = -0.10 BIAS(95%) = -0.07

MDA(POISSON 5%) = 1.350 MDA(POISSON) = 1.483 MDA(POISSON 95%) = 1.620

LAB ESTIMATED MDA = 1.24

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
K	M2-CE144	1	1 - 15 - 87	607.00	0.00	709.07
K	M2-CE144	2	1 - 15 - 87	587.00	0.00	709.07
K	M2-CE144	3	1 - 15 - 87	522.00	0.00	709.07
K	M2-CE144	4	1 - 15 - 87	540.00	0.00	709.07
K	M2-CE144	5	1 - 15 - 87	598.00	0.00	709.07

MEAN =	570.8	Lab Est. Rel. Error =	0.00		
BR (5%) =	-0.25	BR =	-0.20	BR (95%) =	-0.14
SA (5%) =	0.04	SA =	0.07	SA (95%) =	0.16
SB (5%) =	0.03	SB =	0.05	SB (95%) =	0.13

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
K	M1-CE144	1	1 - 15 - 87	306.00	0.00	604.57
K	M1-CE144	2	1 - 15 - 87	310.00	0.00	604.57
K	M1-CE144	3	1 - 15 - 87	317.00	0.00	604.57
K	M1-CE144	4	1 - 15 - 87	309.00	0.00	604.57
K	M1-CE144	5	1 - 15 - 87	322.00	0.00	604.57

MEAN = 312.8 Lab Est. Rel. Error = 0.00
BR (5%) = -0.49 BR = -0.48 BR (95%) = -0.47
SA (5%) = 0.01 SA = 0.02 SA (95%) = 0.05
SB (5%) = 0.01 SB = 0.01 SB (95%) = 0.03

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
K	M3-CE144	1	213	10.0	1.200	1.1700
K	M3-CE144	2	240	10.0	1.200	4.8300
K	M3-CE144	3	209	10.0	1.200	0.7500
K	M3-CE144	4	240	10.0	1.200	3.5800
K	M3-CE144	5	242	10.0	1.200	0.5800

s^2/MEAN = 1.166 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -0.25 BIAS = -0.20 BIAS(95%) = -0.14
MDA(POISSON 5%) = 6.98 MOA(POISSON) = 7.89 MDA(POISSON 95%) = 8.76
LAB ESTIMATED MDA = 5.52

LAB CODE	PHANTOM TYPE	COUNT NO.	OATE COUNTEO	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
K	M2-MN54	1	1 - 15 - 87	221.00	0.00	255.54
K	M2-MN54	2	1 - 15 - 87	219.00	0.00	255.54
K	M2-MN54	3	1 - 15 - 87	196.00	0.00	255.54
K	M2-MN54	4	1 - 15 - 87	200.00	0.00	255.54
K	M2-MN54	5	1 - 15 - 87	215.00	0.00	255.54

MEAN = 210.2 Lab Est. Rel. Error = 0.00
BR (5%) = -0.22 BR = -0.18 BR (95%) = -0.13
SA (5%) = 0.04 SA = 0.05 SA (95%) = 0.13
SB (5%) = 0.03 SB = 0.04 SB (95%) = 0.11

LAB COOE	PHANTOM TYPE	COUNT NO.	OATE COUNTEO	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
K	M1-MN54	1	1 - 15 - 87	99.00	0.00	209.79
K	M1-MN54	2	1 - 15 - 87	101.00	0.00	209.79
K	M1-MN54	3	1 - 15 - 87	101.00	0.00	209.79
K	M1-MN54	4	1 - 15 - 87	103.00	0.00	209.79
K	M1-MN54	5	1 - 15 - 87	97.00	0.00	209.79

MEAN = 100.2 Lab Est. Rel. Error = 0.00
BR (5%) = -0.53 BR = -0.52 BR (95%) = -0.51
SA (5%) = 0.01 SA = 0.02 SA (95%) = 0.05
SB (5%) = 0.01 SB = 0.01 SB (95%) = 0.03

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
K	M3-MN54	1	15	10.D	3.750	0.0600
K	M3-MN54	2	15	10.0	3.750	-0.0200
K	M3-MN54	3	12	10.0	3.750	0.0000
K	M3-MN54	4	16	10.0	3.750	0.1000
K	M3-MN54	5	12	10.0	3.750	-0.0200

s^2/MEAN = 0.250 (ACCEPT < 2.37 WHEN N = 5)

BIAS(5%) = -0.22 BIAS = -0.18 BIAS(95%) = -0.13

MDA(POISSON 5%) = 0.498 MDA(POISSON) = 0.666 MDA(POISSON 95%) = 0.821

LAB ESTIMATED MDA = 0.45

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
L	W1-CS134	1	1 - 10 - 89	130.00	4.30	129.38
L	W1-CS134	2	1 - 10 - 89	150.00	3.70	129.38
L	W1-CS134	3	1 - 10 - 89	140.00	4.70	129.38
L	W1-CS134	4	1 - 10 - 89	120.00	4.10	129.38
L	W1-CS134	5	1 - 10 - 89	130.00	4.00	129.38

MEAN = 134.0 Lab Est. Rel. Error = 0.04

BR (5%) = -0.05 BR = 0.04 BR (95%) = 0.12

SA (5%) = 0.06 SA = 0.09 SA (95%) = 0.20

SB (5%) = 0.06 SB = 0.09 SB (95%) = 0.21

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
L	W2-CS134	1	367	33.3	0.249	0.0000
L	W2-CS134	2	367	33.3	0.251	0.0000
L	W2-CS134	3	300	33.3	0.257	-7.7800
L	W2-CS134	4	367	33.3	0.258	0.0000
L	W2-CS134	5	433	33.3	0.255	7.7800

s^2/MEAN = 6.028 (ACCEPT < 2.37 WHEN N = 5)

BIAS(5%) = -0.05 BIAS = 0.04 BIAS(95%) = 0.12

MDA(POISSON 5%) = 9.686 MDA(POISSON) = 10.918 MDA(POISSON 95%) = 12.346

LAB ESTIMATED MDA = 1.00

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
L	W1-CS134	1	1 - 10 - 89	130.00	4.10	129.38
L	W1-CS134	2	1 - 10 - 89	150.00	3.60	129.38
L	W1-CS134	3	1 - 10 - 89	140.00	3.80	129.38
L	W1-CS134	4	1 - 10 - 89	120.00	4.30	129.38
L	W1-CS134	5	1 - 10 - 89	130.00	3.80	129.38

MEAN = 134.0 Lab Est. Rel. Error = 0.04

BR (5%) = -0.05 BR = 0.04 BR (95%) = 0.12

SA (5%) = 0.06 SA = 0.09 SA (95%) = 0.20

SB (5%) = 0.06 SB = 0.09 SB (95%) = 0.21

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
L	W2-CS134	1	633	33.3	0.189	10.6000
L	W2-CS134	2	633	33.3	0.196	10.2000
L	W2-CS134	3	400	33.3	0.217	-23.0000
L	W2-CS134	4	567	33.3	0.195	0.0000
L	W2-CS134	5	600	33.3	0.194	5.0000

s^2/MEAN = 16.630 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -0.05 BIAS = 0.04 BIAS(95%) = 0.12
MDA(POISSON 5%) = 15.609 MDA(POISSON) = 17.444 MDA(POISSON 95%) = 19.583
LAB ESTIMATED MDA = 1.00

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
L	W1-CS137	1	1 - 10 - 89	320.00	2.30	340.71
L	W1-CS137	2	1 - 10 - 89	380.00	2.10	340.71
L	W1-CS137	3	1 - 10 - 89	380.00	2.20	340.71
L	W1-CS137	4	1 - 10 - 89	320.00	2.30	340.69
L	W1-CS137	5	1 - 10 - 89	340.00	2.20	340.69

MEAN = 348.0 Lab Est. Rel. Error = 0.02
BR (5%) = -0.06 BR = 0.02 BR (95%) = 0.11
SA (5%) = 0.06 SA = 0.09 SA (95%) = 0.21
SB (5%) = 0.06 SB = 0.09 SB (95%) = 0.21

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
L	W2-CS137	1	400	33.3	0.231	-6.0600
L	W2-CS137	2	400	33.3	0.228	-6.1400
L	W2-CS137	3	700	33.3	0.229	33.1900
L	W2-CS137	4	467	33.3	0.229	2.6200
L	W2-CS137	5	237	33.3	0.227	-23.7900

s^2/MEAN = 63.938 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -0.06 BIAS = 0.02 BIAS(95%) = 0.11
MDA(POISSON 5%) = 11.988 MDA(POISSON) = 13.56 MDA(POISSON 95%) = 15.232
LAB ESTIMATED MDA = 1.20

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M1	W1-CS134	1	5 - 4 - 87	213.90	4.70	228.38
M1	W1-CS134	2	5 - 4 - 87	207.70	4.80	228.38
M1	W1-CS134	3	5 - 4 - 87	208.80	5.30	228.38
M1	W1-CS134	4	5 - 4 - 87	200.20	4.50	228.38
M1	W1-CS134	5	5 - 4 - 87	219.10	4.60	228.38

MEAN = 209.9 Lab Est. Rel. Error = 0.05
BR (5%) = -0.11 BR = -0.08 BR (95%) = -0.05
SA (5%) = 0.02 SA = 0.03 SA (95%) = 0.08
SB (5%) = 0.02 SB = 0.03 SB (95%) = 0.07

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M1	W1-CS137	1	5 - 4 - 87	373.60	2.00	354.18
M1	W1-CS137	2	5 - 4 - 87	387.90	1.80	354.18
M1	W1-CS137	3	5 - 4 - 87	377.90	2.10	354.18
M1	W1-CS137	4	5 - 4 - 87	404.90	1.80	354.18
M1	W1-CS137	5	5 - 4 - 87	373.90	2.10	354.18

MEAN = 383.6 Lab Est. Rel. Error = 0.02
BR (5%) = 0.05 BR = 0.08 BR (95%) = 0.12
SA (5%) = 0.02 SA = 0.03 SA (95%) = 0.08
SB (5%) = 0.02 SB = 0.04 SB (95%) = 0.09

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LA8 ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M1	M2-CE144	1	8 - 18 - 87	184.50	23.30	80.79
M1	M2-CE144	2	8 - 18 - 87	313.10	23.00	80.79
M1	M2-CE144	3	8 - 18 - 87	248.40	19.50	80.79
M1	M2-CE144	4	8 - 18 - 87	216.40	24.30	80.79
M1	M2-CE144	5	8 - 18 - 87	169.10	23.80	80.79

MEAN = 226.3 Lab Est. Rel. Error = 0.23
BR (5%) = 1.12 BR = 1.80 BR (95%) = 2.48
SA (5%) = 0.16 SA = 0.25 SA (95%) = 0.60
SB (5%) = 0.46 SB = 0.71 SB (95%) = 1.68

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M1	M1-CE144	1	8 - 18 - 87	1601.80	49.70	696.95
M1	M1-CE144	2	8 - 18 - 87	1616.00	34.70	696.95
M1	M1-CE144	3	8 - 18 - 87	1588.80	35.70	696.95
M1	M1-CE144	4	8 - 18 - 87	1493.90	37.30	696.95
M1	M1-CE144	5	8 - 18 - 87	1525.50	37.40	696.95

MEAN = 1565.2 Lab Est. Rel. Error = 0.39
BR (5%) = 1.17 BR = 1.25 BR (95%) = 1.32
SA (5%) = 0.02 SA = 0.03 SA (95%) = 0.08
SB (5%) = 0.05 SB = 0.08 SB (95%) = 0.18

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M1	M1-MN54	1	8 - 18 - 87	314.40	11.20	263.15
M1	M1-MN54	2	8 - 18 - 87	327.00	10.80	263.15
M1	M1-MN54	3	8 - 18 - 87	338.60	11.20	263.15
M1	M1-MN54	4	8 - 18 - 87	321.70	10.90	263.15
M1	M1-MN54	5	8 - 18 - 87	294.00	5.60	263.15

MEAN =	319.1	Lab Est. Rel. Error =		0.10	
BR (5%) =	0.15	BR =	0.21	BR (95%) =	0.27
SA (5%) =	0.03	SA =	0.05	SA (95%) =	0.12
SB (5%) =	0.04	SB =	0.06	SB (95%) =	0.15

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M2	M2-CE144	1	8 - 19 - 87	170.00	15.00	80.59
M2	M2-CE144	2	8 - 19 - 87	59.00	36.50	80.59
M2	M2-CE144	3	8 - 19 - 87	102.00	21.00	80.59

MEAN =	110.3	Lab Est. Rel. Error =		0.24	
BR (5%) =	-0.80	BR =	0.37	BR (95%) =	1.54
SA (5%) =	0.29	SA =	0.51	SA (95%) =	2.23
SB (5%) =	0.40	SB =	0.69	SB (95%) =	3.06

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M2	M1-CE144	1	8 - 19 - 87	830.00	7.00	695.25
M2	M1-CE144	2	8 - 19 - 87	737.00	7.00	695.25
M2	M1-CE144	3	8 - 19 - 87	877.00	5.00	695.25
M2	M1-CE144	4	8 - 19 - 87	728.00	6.00	695.25
M2	M1-CE144	5	8 - 19 - 87	781.00	7.00	695.25

MEAN =	790.6	Lab Est. Rel. Error =		0.06	
BR (5%) =	0.05	BR =	0.14	BR (95%) =	0.22
SA (5%) =	0.05	SA =	0.08	SA (95%) =	0.19
SB (5%) =	0.06	SB =	0.09	SB (95%) =	0.21

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M2	M2-MN54	1	8 - 19 - 87	127.00	2.00	25.85
M2	M2-MN54	2	8 - 19 - 87	124.00	2.00	25.85
M2	M2-MN54	3	8 - 19 - 87	126.00	2.00	25.85
M2	M2-MN54	4	8 - 19 - 87	125.00	2.00	25.85
M2	M2-MN54	5	8 - 19 - 87	125.00	2.00	25.85

MEAN =	125.4	Lab Est. Rel. Error =	0.02		
BR (5%) =	3.81	BR =	3.85	BR (95%) =	3.89
SA (5%) =	0.01	SA =	0.01	SA (95%) =	0.02
SB (5%) =	0.03	SB =	0.04	SB (95%) =	0.10

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M2	M1-MN54	1	8 - 19 - 87	329.00	3.30	262.57
M2	M1-MN54	2	8 - 19 - 87	327.00	3.30	262.57
M2	M1-MN54	3	8 - 19 - 87	334.00	3.30	262.57
M2	M1-MN54	4	8 - 19 - 87	327.00	3.30	262.57
M2	M1-MN54	5	8 - 19 - 87	328.00	3.30	262.57

MEAN =	329.0	Lab Est. Rel. Error =	0.03		
BR (5%) =	0.24	BR =	0.25	BR (95%) =	0.26
SA (5%) =	0.01	SA =	0.01	SA (95%) =	0.02
SB (5%) =	0.01	SB =	0.01	SB (95%) =	0.03

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M3	M2-CE144	1	8 - 19 - 87	56.00	26.50	80.59
M3	M2-CE144	2	8 - 19 - 87	39.00	30.50	80.59
M3	M2-CE144	3	8 - 19 - 87	155.00	10.50	80.59
M3	M2-CE144	4	8 - 19 - 87	99.00	15.50	80.59

MEAN =	87.3	Lab Est. Rel. Error =	0.21		
BR (5%) =	-0.67	BR =	0.08	BR (95%) =	0.84
SA (5%) =	0.37	SA =	0.59	SA (95%) =	1.73
SB (5%) =	0.40	SB =	0.64	SB (95%) =	1.87

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M3	M1-CE144	1	8 - 19 - 87	522.00	7.50	695.25
M3	M1-CE144	2	8 - 19 - 87	543.00	6.50	695.25
M3	M1-CE144	3	8 - 19 - 87	565.00	6.50	695.25
M3	M1-CE144	4	8 - 19 - 87	487.00	7.00	695.25
M3	M1-CE144	5	8 - 19 - 87	542.00	5.50	695.25

MEAN =	531.8	Lab Est. Rel. Error =	0.07		
BR (5%) =	-0.28	BR =	-0.24	BR (95%) =	-0.19
SA (5%) =	0.04	SA =	0.06	SA (95%) =	0.13
SB (5%) =	0.03	SB =	0.04	SB (95%) =	0.10

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M3	M2-MN54	1	8 - 19 - 87	128.00	2.00	25.85
M3	M2-MN54	2	8 - 19 - 87	121.00	3.00	25.85
M3	M2-MN54	3	8 - 19 - 87	134.00	2.00	25.85
M3	M2-MN54	4	8 - 19 - 87	133.00	3.00	25.85
M3	M2-MN54	5	8 - 19 - 87	138.00	2.00	25.85

MEAN =	130.8	Lab Est. Rel. Error =			0.02
BR (5%) =	3.82	BR =	4.06	BR (95%) =	4.30
SA (5%) =	0.03	SA =	0.05	SA (95%) =	0.12
SB (5%) =	0.16	SB =	0.25	SB (95%) =	0.60

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M3	M1-MN54	1	8 - 19 - 87	359.00	1.00	262.57
M3	M1-MN54	2	8 - 19 - 87	370.00	1.00	262.57
M3	M1-MN54	3	8 - 19 - 87	371.00	1.00	262.57
M3	M1-MN54	4	8 - 19 - 87	365.00	1.00	262.57
M3	M1-MN54	5	8 - 19 - 87	372.00	1.00	262.57

MEAN =	367.4	Lab Est. Rel. Error =			0.01
BR (5%) =	0.38	BR =	0.40	BR (95%) =	0.42
SA (5%) =	0.01	SA =	0.01	SA (95%) =	0.03
SB (5%) =	0.01	SB =	0.02	SB (95%) =	0.05

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M4	M1-CE144	1	8 - 25 - 87	615.00	7.00	685.15
M4	M1-CE144	2	8 - 25 - 87	751.00	7.00	685.15
M4	M1-CE144	3	8 - 25 - 87	864.00	5.50	685.15
M4	M1-CE144	4	8 - 25 - 87	691.00	6.50	685.15
M4	M1-CE144	5	8 - 25 - 87	1401.00	3.50	685.15

MEAN =	864.4	Lab Est. Rel. Error =			0.06
BR (5%) =	-0.17	BR =	0.26	BR (95%) =	0.70
SA (5%) =	0.24	SA =	0.36	SA (95%) =	0.86
SB (5%) =	0.30	SB =	0.46	SB (95%) =	1.08

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M4	M2-MN54	1	8 - 25 - 87	139.00	2.00	25.51
M4	M2-MN54	2	8 - 25 - 87	141.00	2.00	25.51
M4	M2-MN54	3	8 - 25 - 87	141.00	2.00	25.51
M4	M2-MN54	4	8 - 25 - 87	143.00	2.00	25.51
M4	M2-MN54	5	8 - 25 - 87	136.00	2.00	25.51

MEAN =	140.0	Lab Est. Rel. Error =			0.02
BR (5%) =	4.39	BR =	4.49	BR (95%) =	4.59
SA (5%) =	0.01	SA =	0.02	SA (95%) =	0.04
SB (5%) =	0.07	SB =	0.10	SB (95%) =	0.25

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M4	M1-MN54	1	8 - 25 - 87	367.00	1.00	259.10
M4	M1-MN54	2	8 - 25 - 87	367.00	1.00	259.10
M4	M1-MN54	3	8 - 25 - 87	366.00	1.00	259.10
M4	M1-MN54	4	8 - 25 - 87	363.00	1.00	259.10
M4	M1-MN54	5	8 - 25 - 87	370.00	1.00	259.10

MEAN = 366.6 Lab Est. Rel. Error = 0.01
BR (5%) = 0.41 BR = 0.41 BR (95%) = 0.42
SA (5%) = 0.00 SA = 0.01 SA (95%) = 0.02
SB (5%) = 0.01 SB = 0.01 SB (95%) = 0.02

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M5	M2-CE144	1	8 - 25 - 87	57.00	32.50	79.42
M5	M2-CE144	2	8 - 25 - 87	79.00	21.00	79.42
M5	M2-CE144	3	8 - 25 - 87	76.00	21.50	79.42

MEAN = 70.7 Lab Est. Rel. Error = 0.25
BR (5%) = -0.36 BR = -0.11 BR (95%) = 0.14
SA (5%) = 0.10 SA = 0.17 SA (95%) = 0.74
SB (5%) = 0.09 SB = 0.15 SB (95%) = 0.66

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M5	M1-CE144	1	8 - 25 - 87	637.00	5.50	685.15
M5	M1-CE144	2	8 - 25 - 87	658.00	5.50	685.15
M5	M1-CE144	3	8 - 25 - 87	627.00	8.00	685.15
M5	M1-CE144	4	8 - 25 - 87	671.00	7.00	685.15
M5	M1-CE144	5	8 - 25 - 87	747.00	5.00	685.15

MEAN = 668.0 Lab Est. Rel. Error = 0.06
BR (5%) = -0.09 BR = -0.03 BR (95%) = 0.04
SA (5%) = 0.05 SA = 0.07 SA (95%) = 0.17
SB (5%) = 0.04 SB = 0.07 SB (95%) = 0.16

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M5	M2-MN54	1	8 - 25 - 87	134.00	2.00	25.51
M5	M2-MN54	2	8 - 25 - 87	133.00	2.00	25.51
M5	M2-MN54	3	8 - 25 - 87	134.00	2.00	25.51
M5	M2-MN54	4	8 - 25 - 87	134.00	2.00	25.51
M5	M2-MN54	5	8 - 25 - 87	132.00	2.00	25.51

MEAN = 133.4 Lab Est. Rel. Error = 0.02
BR (5%) = 4.20 BR = 4.23 BR (95%) = 4.26
SA (5%) = 0.00 SA = 0.01 SA (95%) = 0.02
SB (5%) = 0.02 SB = 0.04 SB (95%) = 0.08

LAB COOE	PHANTOM TYPE	COUNT NO.	DATE COUNTEO	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M5	M1-MN54	1	8 - 25 - 87	182.00	1.50	259.10
M5	M1-MN54	2	8 - 25 - 87	346.00	1.00	259.10
M5	M1-MN54	3	8 - 25 - 87	228.00	1.00	259.10
M5	M1-MN54	4	8 - 25 - 87	224.00	1.50	259.10
M5	M1-MN54	5	8 - 25 - 87	348.00	1.00	259.10

MEAN	= 265.6	Lab Est. Rel. Error =		0.01	
BR (5%)	= -0.26	BR =	0.03	BR (95%) =	0.31
SA (5%)	= 0.19	SA =	0.29	SA (95%) =	0.68
SB (5%)	= 0.19	SB =	0.30	SB (95%) =	0.70

LAB COOE	PHANTOM TYPE	COUNT NO.	OATE COUNTEO	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M6	M2-CE144	1	8 - 20 - 87	97.00	20.50	80.40
M6	M2-CE144	2	8 - 20 - 87	60.00	26.00	80.40
M6	M2-CE144	3	8 - 20 - 87	136.00	10.55	80.40

MEAN	= 97.7	Lab Est. Rel. Error =		0.19	
BR (5%)	= -0.58	BR =	0.21	BR (95%) =	1.01
SA (5%)	= 0.22	SA =	0.39	SA (95%) =	1.71
SB (5%)	= 0.27	SB =	0.47	SB (95%) =	2.08

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M6	M1-CE144	1	8 - 20 - 87	515.00	5.50	693.56
M6	M1-CE144	2	8 - 20 - 87	484.00	6.00	693.56
M6	M1-CE144	3	8 - 20 - 87	450.00	6.00	693.56
M6	M1-CE144	4	8 - 20 - 87	455.00	6.00	693.56
M6	M1-CE144	5	8 - 20 - 87	535.00	5.50	693.56

MEAN	= 487.8	Lab Est. Rel. Error =		0.06	
BR (5%)	= -0.35	BR =	-0.30	BR (95%) =	-0.25
SA (5%)	= 0.05	SA =	0.08	SA (95%) =	0.18
SB (5%)	= 0.03	SB =	0.05	SB (95%) =	0.13

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M6	M2-MN54	1	8 - 20 - 87	124.00	2.00	25.79
M6	M2-MN54	2	8 - 20 - 87	122.00	2.00	25.79
M6	M2-MN54	3	8 - 20 - 87	124.00	2.00	25.79
M6	M2-MN54	4	8 - 20 - 87	122.00	2.00	25.79
M6	M2-MN54	5	8 - 20 - 87	123.00	2.00	25.79

MEAN	= 123.0	Lab Est. Rel. Error =		0.02	
BR (5%)	= 3.73	BR =	3.77	BR (95%) =	3.81
SA (5%)	= 0.01	SA =	0.01	SA (95%) =	0.02
SB (5%)	= 0.03	SB =	0.04	SB (95%) =	0.09

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M6	M1-MN54	1	8 - 20 - 87	328.00	1.00	261.99
M6	M1-MN54	2	8 - 20 - 87	332.00	1.00	261.99
M6	M1-MN54	3	8 - 20 - 87	324.00	1.00	261.99
M6	M1-MN54	4	8 - 20 - 87	337.00	1.00	261.99
M6	M1-MN54	5	8 - 20 - 87	330.00	1.00	261.99

MEAN = 330.2 Lab Est. Rel. Error = 0.01
BR (5%) = 0.24 BR = 0.26 BR (95%) = 0.28
SA (5%) = 0.01 SA = 0.01 SA (95%) = 0.03
SB (5%) = 0.01 SB = 0.02 SB (95%) = 0.04

LAB CODE	PHANTOM TYPE	COUNT NO.	OATE COUNTEO	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M7	M2-CE144	1	8 - 20 - 87	77.00	25.50	80.40
M7	M2-CE144	2	8 - 20 - 87	70.00	27.50	80.40
M7	M2-CE144	3	8 - 20 - 87	39.00	39.50	80.40
M7	M2-CE144	4	8 - 20 - 87	66.00	29.50	80.40

MEAN = 63.0 Lab Est. Rel. Error = 0.31
BR (5%) = -0.46 BR = -0.22 BR (95%) = 0.03
SA (5%) = 0.16 SA = 0.26 SA (95%) = 0.77
SB (5%) = 0.13 SB = 0.21 SB (95%) = 0.60

LAB CODE	PHANTOM TYPE	COUNT NO.	OATE COUNTEO	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M7	M1-CE144	1	8 - 20 - 87	621.00	6.50	693.56
M7	M1-CE144	2	8 - 20 - 87	719.00	5.50	693.56
M7	M1-CE144	3	8 - 20 - 87	594.00	7.50	693.56
M7	M1-CE144	4	8 - 20 - 87	603.00	7.00	693.56
M7	M1-CE144	5	8 - 20 - 87	737.00	6.00	693.56

MEAN = 654.8 Lab Est. Rel. Error = 0.07
BR (5%) = -0.15 BR = -0.06 BR (95%) = 0.04
SA (5%) = 0.07 SA = 0.10 SA (95%) = 0.25
SB (5%) = 0.06 SB = 0.10 SB (95%) = 0.23

LAB CODE	PHANTOM TYPE	COUNT NO.	OATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M7	M2-MN54	1	8 - 20 - 87	129.00	2.00	25.79
M7	M2-MN54	2	8 - 20 - 87	122.00	2.00	25.79
M7	M2-MN54	3	8 - 20 - 87	123.00	2.50	25.79
M7	M2-MN54	4	8 - 20 - 87	127.00	2.00	25.79
M7	M2-MN54	5	8 - 20 - 87	124.00	2.00	25.79

MEAN = 125.0 Lab Est. Rel. Error = 0.02
BR (5%) = 3.74 BR = 3.85 BR (95%) = 3.95
SA (5%) = 0.02 SA = 0.02 SA (95%) = 0.06
SB (5%) = 0.07 SB = 0.11 SB (95%) = 0.27

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
M7	M1-MN54	1	8 - 20 - 87	346.00	1.50	261.99
M7	M1-MN54	2	8 - 20 - 87	355.00	1.00	261.99
M7	M1-MN54	3	8 - 20 - 87	351.00	1.00	261.99
M7	M1-MN54	4	8 - 20 - 87	352.00	1.00	261.99
M7	M1-MN54	5	8 - 20 - 87	354.00	1.00	261.99

MEAN = 351.6 Lab Est. Rel. Error = 0.01
BR (5%) = 0.33 BR = 0.34 BR (95%) = 0.35
SA (5%) = 0.01 SA = 0.01 SA (95%) = 0.02
SB (5%) = 0.01 SB = 0.01 SB (95%) = 0.03

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
N	P2-PU238	1	3 - 30 - 89	23.00	35.00	31.82
N	P2-PU238	2	3 - 30 - 89	29.00	31.00	31.82
N	P2-PU238	3	3 - 30 - 89	23.00	35.00	31.82
N	P2-PU238	4	3 - 30 - 89	43.00	21.00	31.82
N	P2-PU238	5	3 - 30 - 89	27.00	30.00	31.82

MEAN = 29.0 Lab Est. Rel. Error = 0.30
BR (5%) = -0.34 BR = -0.09 BR (95%) = 0.16
SA (5%) = 0.18 SA = 0.28 SA (95%) = 0.67
SB (5%) = 0.17 SB = 0.26 SB (95%) = 0.61

LAB CODE	PHANTOM TYPE	COUNT NO.	DATE COUNTED	LAB ASSAY (nCi)	ERROR(%)	TRUE SPIKE
N	P3-PU238	1	3 - 19 - 89	398.00	12.00	366.31
N	P3-PU238	2	3 - 19 - 89	375.00	11.00	366.31
N	P3-PU238	3	3 - 19 - 89	391.00	12.00	366.31
N	P3-PU238	4	3 - 19 - 89	366.00	12.00	366.31
N	P3-PU238	5	3 - 19 - 89	350.00	12.00	366.31

MEAN = 376.0 Lab Est. Rel. Error = 0.12
BR (5%) = -0.02 BR = 0.03 BR (95%) = 0.08
SA (5%) = 0.03 SA = 0.05 SA (95%) = 0.12
SB (5%) = 0.03 SB = 0.05 SB (95%) = 0.12

BLANK PHANTOM RESULTS

LAB CODE	PHANTOM TYPE	COUNT NO.	BACKGROUND COUNTS	COUNT TIME	EFFICIENCY (CPM/nCi)	ACTIVITY (nCi)
N	P1-PU238	1	1178	120.0	0.056	-2.0000
N	P1-PU238	2	1292	120.0	0.056	-3.0000
N	P1-PU238	3	1201	120.0	0.056	3.0000
N	P1-PU238	4	1232	120.0	0.056	6.0000
N	P1-PU238	5	1149	120.0	0.056	-6.0000

s^2/MEAN = 2.485 (ACCEPT < 2.37 WHEN N = 5)
BIAS(5%) = -0.02 BIAS = 0.03 BIAS(95%) = 0.08
MDA(POISSON 5%) = 23.914 MDA(POISSON) = 25.643 MDA(POISSON 95%) = 27.537

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