

**Old Church Rock Mine
Eastern Abandoned Uranium Mine Region**

**OCRM Removal Assessment
Appendix E
Gamma-Radium Correlation Report**

**Response, Assessment, and Evaluation Services
Contract No. EP-S9-17-03
Task Order 00035**

August 25, 2023

**Submitted to
U.S. Environmental Protection Agency**

**Submitted by
Tetra Tech, Inc.
1999 Harrison Street, Suite 500
Oakland, CA 94612**



TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
ACRONYMS AND ABBREVIATIONS	E-v
EXECUTIVE SUMMARY	E-ES-1
1.0 INTRODUCTION	E-1
1.1 PURPOSE	E-1
1.2 BACKGROUND	E-1
2.0 METHODS	E-3
2.1 PLOT SELECTION.....	E-3
2.2 WALKOVER GAMMA SCANNING	E-6
2.3 STATIC GAMMA COUNT RATE.....	E-7
2.4 GAMMA EXPOSURE RATE.....	E-7
2.5 SOIL CORRELATION COMPOSITE SAMPLING	E-8
3.0 DATA RESULTS AND QUALIFIERS	E-10
3.1 OVERVIEW	E-10
3.2 WALKOVER GAMMA SCANNING (UNSHIELDED)	E-12
3.3 WALKOVER GAMMA SCANNING (SHIELDED)	E-12
3.4 WALKOVER REGRESSION ANALYSIS	E-12
3.5 STATIC GAMMA COUNT RATE.....	E-21
3.6 UNSHIELDED WALKOVER AND STATIC GAMMA.....	E-21
3.7 HIGH-PRESSURE IONIZATION CHAMBER EXPOSURE RATE	E-25
3.8 STATIC GAMMA COUNT RATE VERSUS HPIC EXPOSURE RATE	E-25
3.9 SOIL CORRELATION LABORATORY ANALYSIS RESULTS.....	E-25
4.0 REGRESSION ANALYSIS	E-31
4.1 SUMMARY OF QUALIFIERS	E-31
4.2 UNSHIELDED WALKOVER AND RADIUM-226 RESULTS.....	E-31
4.3 SHIELDED WALKOVER AND RADIUM-226 RESULTS.....	E-36
5.0 MODEL DEVELOPMENT	E-38
5.1 OVERVIEW	E-38
5.2 MODEL 1: TRADITIONAL LINEAR REGRESSION WITH OCRM-CORR12 EXCLUDED	E-38
5.2.1 Overview of Model 1	E-38
5.2.2 Model 1 Estimated Extent of Ra-226 Contamination	E-43
5.3 MODEL 2: TRADITIONAL LINEAR REGRESSION WITH ONLY DATA PAIRS WITH LESS THAN 19,000 CPM INCLUDED	E-47
5.3.1 Overview of Model 2	E-47
5.3.2 Model 2 Estimated Extent of Ra-226 Contamination	E-51

6.0	MODEL SELECTION.....	E-55
6.1	MODEL COMPARISON ANALYSIS	E-55
6.1.1	Gamma Cutoff Analysis	E-55
6.1.2	Gamma Regression Analysis.....	E-55
6.1.3	Containment Analysis	E-57
6.2	FINAL SELECTION	E-59
7.0	CONCLUSIONS.....	E-61
8.0	REFERENCES	E-62

FIGURES

Figure E-1.	Old Church Rock Mine 2022 Gamma-Radium Correlation Study Plot Locations ..	E-5
Figure E-2.	Grid Scanning Pattern for Soil Correlation Plot (Blue Dashed Lines Indicate Scanning Data)	E-6
Figure E-3.	Photograph of HPIC Placement in Correlation Plot.....	E-7
Figure E-4.	Example Composite Soil Sampling Pattern within Correlation Plot (Black Hexagons represent aliquot samples collected within 0 to 6 inches bgs).....	E-8
Figure E-5.	Unshielded (x-axis) and Shielded (y-axis) Gamma Count Rate Regression Analysis	E-19
Figure E-6.	Unshielded (x-axis) and Shielded (y-axis) Gamma Count Rate Regression Analysis (Outliers Removed)	E-20
Figure E-7.	Unshielded Walkover (x-axis) and Static (y-axis) Gamma Count Rate Regression Analysis	E-23
Figure E-8.	Unshielded Walkover (x-axis) and Static (y-axis) Gamma Count Rate Regression Analysis (Outlier Removed).....	E-24
Figure E-9.	Static Gamma Count Rate (x-axis) and HPIC Gamma Exposure Rate (y-axis) Linear Regression.....	E-28
Figure E-10.	Static Gamma Count Rate (x-axis) and HPIC Gamma Exposure Rate (y-axis) Linear Regression (Outlier Removed, Final Model Used in Report).....	E-29
Figure E-11.	Linear Regression of Unshielded Walkover Gamma Count Rate and Ra-226 Soil Concentration (Full Dataset).....	E-33
Figure E-12.	Linear Regression of Unshielded Walkover Gamma Count Rate and Ra-226 Soil Concentration (OCRM-CORR12 Removed as Outlier)	E-34
Figure E-13.	Linear Regression of Unshielded Walkover Gamma Count Rate and Ra-226 Soil Concentration (Less than 19,000 cpm)	E-35
Figure E-14.	Shielded Gamma Count Rate versus Ra-226 Soil Concentration (Full Dataset) ..	E-37
Figure E-15.	Gamma-Radium Correlation, Linear Regression – Model 1	E-40
Figure E-16.	Estimated Ra-226 Soil Concentration Map (Model 1)	E-42
Figure E-17.	Areal Extent of Estimated Ra-226 Above 2 pCi/g (Model 1)	E-44
Figure E-18.	Areal Extent of Estimated Ra-226 Above 5 pCi/g (Model 1)	E-45

Figure E-19. Areal Extent of Estimated Ra-226 Above 15 pCi/g (Model 1)	E-46
Figure E-20. Gamma-Radium Correlation, Linear Regression – Model 2	E-48
Figure E-21. Estimated Ra-226 Soil Concentration Map (Model 2)	E-50
Figure E-22. Areal Extent of Estimated Ra-226 Above 2 pCi/g (Model 2)	E-52
Figure E-23. Areal Extent of Estimated Ra-226 Above 5 pCi/g (Model 2)	E-53
Figure E-24. Areal Extent of Estimated Ra-226 Above 15 pCi/g (Model 2)	E-54
Figure E-25. Gamma-Radium Correlation Model Regression Comparison	E-56
Figure E-26. Final Hybrid Model Selection (Red Dotted Line Shows Break Point Between Model 1 and Model 2	E-60

TABLES

Table E-1. Summary Information of Gamma-Radium Correlation Plots	E-4
Table E-2. Summary of Laboratory Analyses of Correlation Soil Samples	E-9
Table E-3. Summary of Qualifiers for Soil Correlation Plot Data	E-11
Table E-4. Summary Statistics of Unshielded Walkover Scanning Results	E-13
Table E-5. Unshielded Walkover Scanning Qualifier Analysis	E-14
Table E-6. Summary Statistics of Shielded Walkover Scanning Results	E-15
Table E-7. Unshielded Walkover Scanning Qualifier Analysis	E-16
Table E-8. Summary of Unshielded and Shielded Average Gamma Count Rate at Soil Correlation Plots	E-17
Table E-9. Unshielded and Shielded Regression Qualifier Analysis	E-18
Table E-10. Static Gamma Count Rate Data and Qualifiers	E-21
Table E-11. Unshielded Walkover and Static Gamma Count Rate and Qualifiers	E-22
Table E-12. Summary Statistics of High-Pressure Ionization Chamber Gamma Exposure Rate	E-26
Table E-13. Average Gamma Exposure Rate and Static Gamma Count Rate and Qualifiers...	E-27
Table E-14. Summary of Select Laboratory Analytes from the Soil Correlation Plots	E-30
Table E-15. Summary of Final Qualifiers for Soil Correlation Plots	E-31
Table E-16. Average Unshielded Gamma and Ra-226 Soil Concentration	E-32
Table E-17. Model 1 Traditional Linear Data Pair Inclusion/Exclusion	E-39
Table E-18. Summary of Model 1 Gamma Cutoff Values	E-41
Table E-19. Model 2 Traditional Linear Data Pair Inclusion/Exclusion	E-47
Table E-20. Summary of Model 2 Gamma Cutoff Values	E-49
Table E-21. Ra-226 Concentration Equivalent Gamma Cutoff Values	E-55
Table E-22. Containment Analysis at 2 pCi/g Ra-226	E-58
Table E-23. Containment Analysis at 5 pCi/g Ra-226	E-58
Table E-24. Containment Analysis at 15 pCi/g Ra-226	E-58
Table E-25. Summary of Ra-226 Estimates	E-61



ATTACHMENTS

Attachment E-1: Ludlum Collimator Design

Attachment E-2: SOP 003: Making an Exposure Rate Measurement Using an HPIC

Attachment E-3: Correlation Plot Statistics – Unshielded Gamma

Attachment E-4: Correlation Plot Statistics – Shielded Gamma

Attachment E-5: Correlation Plot Statistics – Exposure Rate

ACRONYMS AND ABBREVIATIONS

μR/hr	Microroentgens per hour
ags	Above ground surface
AUM	Abandoned Uranium Mine
bgs	Below ground surface
BTV	Background threshold value
CAS	Chemical Abstracts Service
cpm	Counts per minute
Energy Fuels	Energy Fuels Resources, Inc.
HPIC	High-Pressure Ionization Chamber
ID	Identification
K-40	Potassium-40
m ²	Square meter
MARLAP	<i>Multi-Agency Radiological Laboratory Analytical Protocols Manual</i>
MARSSIM	<i>Multi-Agency Radiological Site Survey Investigation Manual</i>
mg/kg	Milligram per kilogram
NAD	North American Datum
NaI	Sodium iodide
NORM	Naturally Occurring Radioactive Materials
NRC	United States Nuclear Regulatory Commission
OCRM	Old Church Rock Mine
pCi/g	Picocuries per gram
QA	Quality Assurance
QC	Quality Control
R ²	Coefficient of Variance
Ra-226	Radium-226
RPD	Relative Percent Difference
RSD	Relative Standard Deviation
SOP	Standard operating procedure



ACRONYMS AND ABBREVIATIONS (CONTINUED)

Tetra Tech	Tetra Tech, Inc.
Th-232	Thorium-232

USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency



EXECUTIVE SUMMARY

This report presents methodology and results of utilizing gamma radiation survey data as surrogate measurements of radium-226 (Ra-226) within surface soils of the Old Church Rock Mine (OCRM) site (the site). Ra-226 is a risk driver at abandoned uranium mines (AUM), and ability to understand the geospatial distribution of this radionuclide is important for cleanup decisions at a site. Within this report, Tetra Tech, Inc. (Tetra Tech) presents different models for predicting Ra-226 in surface soils using gamma radiation survey data. A strong gamma-radium model is useful for estimating cleanup and/or removal volumes, allows use of gamma radiation survey data as a real-time remedial survey tool for conducting mine cleanup operations, and can serve as a tool for verification purposes post-cleanup to support the final status survey.



1.0 INTRODUCTION

This Appendix B to the Old Church Rock Mine Removal Assessment Report (hereafter referred to as the main report) presents methodology, results, and data interpretation of the gamma-radium soil correlation study at Old Church Rock Mine (OCRM) within the Navajo Nation (the site).

1.1 PURPOSE

There is potential for a release, or a significant threat of a release at the site, based on results from this and previous investigations. Currently no documented action memorandum exists, and no current cleanup levels have been established for the site; however, radium-226 (Ra-226) is likely considered to be a risk driver at the site. Therefore, quantitation of the geospatial distribution of Ra-226 within the surface soils of the site is an important goal.

A relationship between gamma exposure rates and gamma emitting radionuclides exists at every site, but because of numerous manufacturing, geological, and geographic factors, as well as Natural Occurring Radioactive Material (NORM) such as thorium and potassium, a generalized relationship does not exist—thus need for development of a site-specific relationship. Upon development of a site-specific correlation, field staff will be able to readily estimate concentrations of gamma-emitting radionuclides, particularly Ra-226, by using handheld survey instrumentation (e.g., sodium iodide [NaI] scintillators), which are substantially less expensive, quicker, and enable coverage of greater area than alternative soil characterization methods such as laboratory analysis of soil samples.

No site-specific gamma-radium correlation study has been performed at the site to date. The purpose of the 2022 gamma-radium correlation study at the site was to determine the site-specific relationship between gamma radiation levels and Ra-226 soil concentrations.

1.2 BACKGROUND

Using gamma radiation to estimate radionuclides is a common approach at sites contaminated with windblown uranium tailings (such as at former uranium mills) and at abandoned uranium mines (Abelquist 2014; USEPA 2000; Johnson, Meyer, and Vidyasagar 2006; Whicker and others 2008). Attempts have been made to develop relationships between gamma exposure rate and soil Ra-226 concentrations, so that the less expensive gamma data—easily collected over large areas—can be used to predict Ra-226 concentrations in soil for remedial action. From as early as 1985 (Thomas and Kinnison 1985), this has been a common strategy at sites contaminated with windblown contamination near uranium tailings piles.

The principal method for accurately determining concentration of Ra-226 in soil or any given material typically is by way of gamma spectral analysis, which can be time consuming and costly. Analytical soil sampling is the only way to measure Ra-226 accurately, but is very costly, and return of results from a laboratory can take over a month because of sampling requirements for analyses for the daughter products (at least for the preferred gamma spectral analysis method). Analytical soil sampling likely always will occur to identify and confirm efficacy of cleanup actions at the site; however, one goal is to utilize gamma radiation survey data as a primary screening or indicator tool for effectively identifying whether the site has been

remediated or needs further remediation. Therefore, it is important to determine if a strong gamma-radium relationship exists at the site so that site-specific conversion and/or correlation factors can be established.

The correlation factor developed between gamma measurements and Ra-226 may provide the basis of an economical and effective method for estimating Ra-226 concentration over the entire site (Energy Fuels Resources, Inc. [Energy Fuels] 2014). Currently, no formal guidance or methodology for performing gamma-radium correlation studies or specifics on developing correlation factors are available within the primary U.S. agency guidance documents such as *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) (USEPA 2000) or *Multi-Agency Radiological Laboratory Analytical Protocols Manual* (MARLAP) (USEPA 2004). Literature from Johnson, Meyer, and Vidyasagar (2006) and Whicker and others (2008) presented methodology for performing correlations and developing these types of correlation factors, referred to here as a “gamma-radium correlation,” at uranium mills and uranium mines in the Western United States.

Tetra Tech has performed gamma-radium correlation studies at different uranium sites following approaches or variations of approaches from Johnson, Meyer, and Vidyasagar (2006) and Whicker and others (2008). Some examples include the previous project-wide correlation study at Riley Pass (Tetra Tech 2013, 2017b, 2019a; and United States Department of Agriculture [USDA] 2016). Additional correlation studies include those at the Red Bluff Uranium Mine in the Tonto National Forest (Tetra Tech 2017a) and at the Northern Agency Tronox Mines in the Navajo Nation (Tetra Tech 2019b), among others.

The intent of the gamma-radium correlation study during the 2022 field investigation at the site was to determine if a strong relationship exists between gamma radiation levels and soil Ra-226 concentrations and, if possible, develop statistical correlations that may be useful to estimate approximate soil Ra-226 concentrations across the entire site based on gamma survey results; the latter achievement would aid remediation design, remedial action surveys, and/or final verifications. The study was designed with an aim to incorporate lessons learned from the previous studies cited, and to improve data acquisition techniques and data evaluation approaches for the site. Some lessons learned include: (1) how to better identify and address outliers in gamma-radium correlation data pairs, and how to prevent those from occurring in the field; (2) the importance of utilizing data around the cleanup level and not data too far outside of range; and (3) not to use logarithmic regression models for gamma-radium conversion factors.

Quality assurance and quality control (QA/QC) was a priority throughout data collection and analysis tasks completed in support of the gamma-radium correlation. Specific QA/QC procedures were implemented to both minimize and evaluate potential sources of inaccuracy during sample collection and analysis. QA/QC procedures were designed to consider relevant guidance from USEPA, as well as MARSSIM and MARLAP. Data quality for in-field gamma measurements is presented in “Gamma Validation and Verification Report” (Appendix B to the main report). A detailed photographic log of gamma-radium correlation field activities is in Appendix A to the main report.

2.0 METHODS

This section discusses methodology of the gamma-radium correlation study during the 2022 field investigation of the site.

2.1 PLOT SELECTION

A “plot” refers to a “soil correlaton plot” or “sampling plot,” which is an area of land, selected by the lead radiation expert, to be (1) scanned for radiation, and (2) sampled via collections of composite soil samples for analyses for metals and radionuclide data. Data from the plots are used in the correlation study typically through linear or non-linear regression or multiple linear regression. Plot selection is crucial for a meaningful and successful correlation. Careful planning during plot selection is likely to be far more beneficial to the quality of the correlation results than other factors. As part of the plot selection process, Tetra Tech conducted a desktop study in the field during the initial stages of the 2022 field investigation utilizing already collected gamma walkover data. The goal was to identify ideal plot locations. An ideal set of correlation plots have the following characteristics:

- Plots contain a *homogenous* gamma radiation level and soil radionuclide concentrations, i.e., the gamma radiation field typically follows a normal, lognormal, or uniform parametric distribution.
- Plot shapes are typically square or rectangular.
- Plots should be located in a relatively flat area and generally be free of dense vegetation or uneven terrain.
- Plot size should generally be no smaller than 25 square meters (m²) and no larger than 200 m² in surface area.
- A minimum of 10 plots per correlation study is recommended, but the higher the number of plots selected, the more statistically sound the correlation will become.
- Gamma levels and soil concentrations across the range of plots selected will encompass a wide range ideally bounding the cleanup level for the site with regards to soil Ra-226 concentrations. Gamma levels and soil Ra-226 concentrations should be approximately evenly spaced across this range.

Initial correlation plots were selected by use of gamma radiation survey data collected in the field during November 2022. Plots were identified by the radiation team lead and were preliminarily scanned to determine if they would be appropriate for further analysis. Once the plots were determined to be suitable locations, the field team scanned them with backpack scan systems on November 19, 2022, led by the radiation expert. Plots were then altered, moved, or kept in place, as necessary in the field, for the gamma-radium correlation study.

[Table E-1](#) lists sampling information regarding each of the final soil correlation plot locations including field sample ID, laboratory sample number, sample date, sample time, geospatial coordinates, vertical elevation, and surface area of each plot. The plots ranged in size from 87 to 145 m². The following [Figure E-1](#) is a map showing soil correlation plot locations. Once the final

plots were selected, gamma scanning followed according to methods described in the next subsection.

Table E-1. Summary Information of Gamma-Radium Correlation Plots

Sample ID	Date	Northing (US Feet)	Easting (US Feet)	Surface Area of Correlation Plot (m ²)
OCRM-CORR01	11/19/2022	1,680,715	2,505,848	122
OCRM-CORR02	11/19/2022	1,680,755	2,506,291	114
OCRM-CORR03	11/19/2022	1,682,941	2,510,034	121
OCRM-CORR04	11/19/2022	1,682,864	2,509,924	109
OCRM-CORR05	11/19/2022	1,682,946	2,509,889	117
OCRM-CORR06	11/19/2022	1,680,563	2,506,350	123
OCRM-CORR07	11/19/2022	1,681,821	2,507,996	112
OCRM-CORR08	11/19/2022	1,681,873	2,508,192	101
OCRM-CORR09	11/19/2022	1,682,219	2,508,421	127
OCRM-CORR10	11/19/2022	1,682,131	2,508,640	89
OCRM-CORR11	11/19/2022	1,681,876	2,508,913	87
OCRM-CORR12	11/19/2022	1,682,332	2,508,717	113
OCRM-CORR13	11/19/2022	1,682,671	2,508,653	145
OCRM-CORR14	11/19/2022	1,682,600	2,508,589	141
OCRM-CORR15	11/19/2022	1,683,228	2,509,247	98

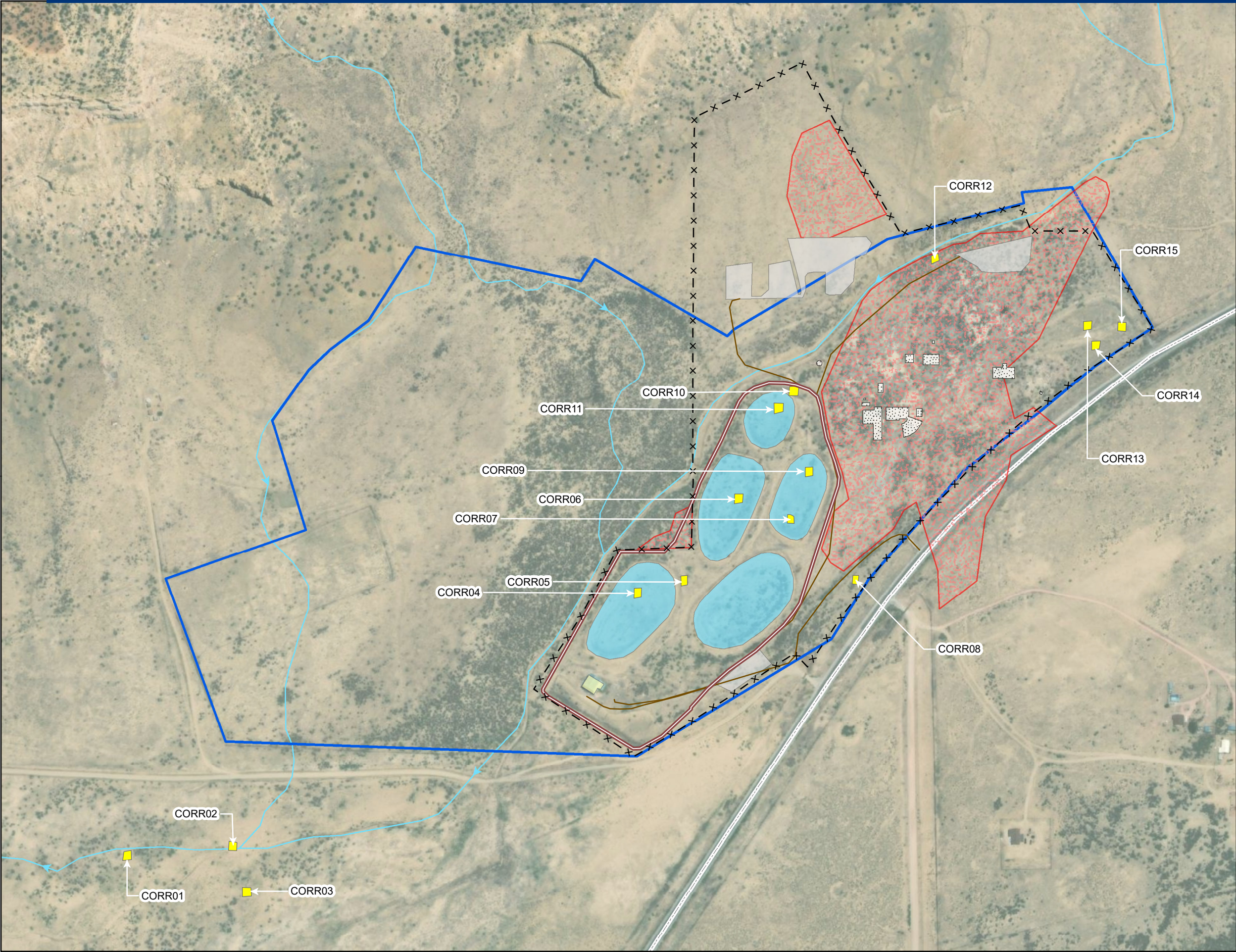
Notes:

Spatial coordinates are in NAD 1983 New Mexico West FIPS 4001 (US Feet), and represent centroid of the plot.

m² Square meter

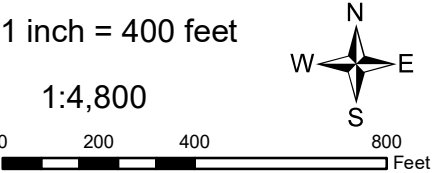
NAD North American Datum

US United States



- Correlation Plot
- 2007 USEPA Navajo AUM Atlas Polygon
- Features**
 - Berm
 - Fenced Boundary
 - Drill Road - Fall 2022
 - Concrete Pad
 - Former Pond
 - Ion Exchange Building
 - Laydown Areas - Fall 2022
 - Approximate Waste Disposal Area
 - Community Road
 - Surface Water Pathway¹

Notes:
¹All surface water pathways drain to the Puerco River.
AUM Abandoned uranium mine



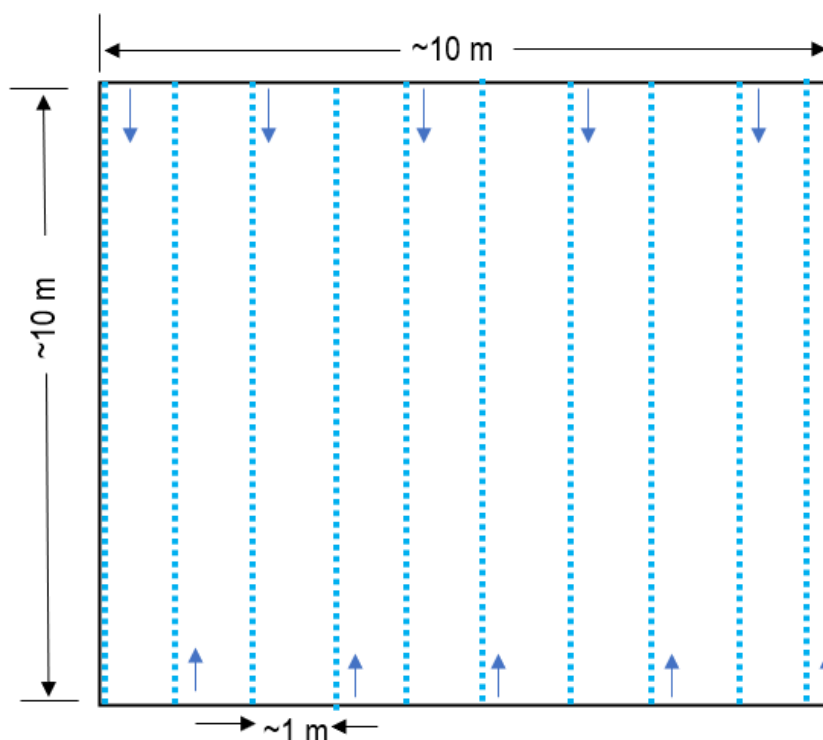
OLD CHURCH ROCK MINE
2022 CORRELATION STUDY
PLOT LOCATIONS

Prepared For: U.S. EPA Region 9	Prepared By:
	TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0035	Contract No.: EP-S9-17-03
Location: CHURCH ROCK CHAPTER NAVAJO NATION	Date: 8/21/2023
Coordinate System: NAD 1983 State Plane New Mexico West FIPS 3003 Feet Transverse	Figure No.: E-1

2.2 WALKOVER GAMMA SCANNING

After initial selection of plots from the desktop study, an initial scan in the field ensued to determine if the plot boundaries required adjustment based on the measured gamma radiation field, and to see if these were appropriate plots (i.e., met the criteria specified in [Section 2.1](#)). Once the plots were confirmed to meet the appropriate criteria set forth in [Section 2.1](#), high-density gamma radiation scanning (unshielded and shielded) was performed inside of the plot.

Gamma radiation scanning (walkover gamma scanning) occurred at a high density (1-meter transect spacing) within the boundary of the selected correlation plot. Prior to scanning, the field team had placed pin flags at corners of the correlation plot. Gamma scanning proceeded across the plot in a pattern similar to that shown on [Figure E-2](#). On this figure, the arrows represent the direction of scanning (scan lines are shown as blue dashed dots). Scanning was performed in either horizontal or vertical directions at approximately 1-meter transect spacing. Unshielded scanning occurred initially across the plot at a 1-meter height above ground surface (ags) followed by a lower height (1-foot) shielded scan involving application of a lead collimator. An engineering diagram of the lead shield (collimator) used for this study is in [Attachment E-1](#). One of the radiation instruments used for the soil correlation gamma radiation survey was the same as used for ground-based gamma radiation surveys. For this study, field staff used mobile scanning systems with Ludlum Model 44-10 (2- by 2-inch) sodium iodide (NaI) gamma scintillation detectors coupled to Ludlum Model 3000 ratemeters/scalers set in ratemeter mode. The detectors were coupled to ERG Model 105 Global Positioning System (GPS) units. The ERG Model 105 GPS unit consists of a Juniper Mesa 2 field computer and geode GPS receiver.



**Figure E-2. Grid Scanning Pattern for Soil Correlation Plot
(Blue Dashed Lines Indicate Scanning Data)**

2.3 STATIC GAMMA COUNT RATE

Following the walkover scanning, a pin flag was placed in the approximate centroid of the soil correlation plot. By use of the same radiation detection system, a 1-meter ags, static 60-second gamma count rate measurement occurred at the plot centroid. The 60-second average and standard deviation were recorded in the field logbook. Only an unshielded static measurement was taken for this project (not an accompanying shielded measurement).

2.4 GAMMA EXPOSURE RATE

Following the gamma radiation survey of the plot and measurement of the 60-second static gamma count rate, a high-pressure ionization chamber (HPIC) was placed in the approximate centroid of the soil correlation plot. For the exposure-rate correlation, an HPIC (GE Reuter-Stokes RSDetection, RS-S131-200) was used to take energy-independent measurements of exposure rates in accordance with Standard Operating Procedure (SOP) 003: Making Exposure Rate Measurements Using a HPIC (included as [Attachment E-2](#)). At each measurement location, gamma exposure rate measurements occurred at 1-minute integrated intervals over a duration of at least 10 minutes. The HPIC gamma exposure rate representing a grid is the average of the 1-minute integrated measurements, excluding the first minute of data acquisition during which the HPIC exhibits a startup pulse. The HPIC was centered within the correlation plot area at 1 meter ags. A single, project-wide correlation was determined. [Figure E-3](#) shows a photograph of the HPIC placement in a soil correlation plot.



Figure E-3. Photograph of HPIC Placement in Correlation Plot

2.5 SOIL CORRELATION COMPOSITE SAMPLING

Soil sampling followed completion of gamma scanning within the correlation plot. Grid based, nine-point composite samples of surface soil (0 to 6 inches below ground surface [bgs]) were collected and homogenized into a single sample to be sent for laboratory analysis. Soil sampling proceeded with collection of nine aliquot samples, each within a depth of 0 to 6 inches bgs, followed in turn by compositing the aliquots and then homogenizing them in a stainless steel bowl; removing organic matter, large rocks, and debris; and placing the composite soil sample into a plastic bag to be submitted for laboratory analysis. [Figure E-4](#) is a conceptual image of the soil sampling pattern followed at each grid: ideally the nine-aliquot samples are equally spaced across the correlation plot and adjusted as necessary to fit the final shape of the correlation plot. Sample locations in irregularly shaped correlation plots were distributed evenly across the area of the plot. Typically, the first team member selected the nine-aliquot samples and used a shovel or pickaxe to loosen the soil while the second team member collected the aliquot using a stainless steel shovel and placed it into a stainless steel bowl where the soil subsequently was homogenized. Soil samples were analyzed by GEL Laboratories LLC in Charleston, South Carolina, for Ra-226, thorium-232 (Th-232), and potassium-40 (K-40) via United States Environmental Protection Agency (USEPA) Method 901.1, and for other analytes listed in [Table E-2](#).

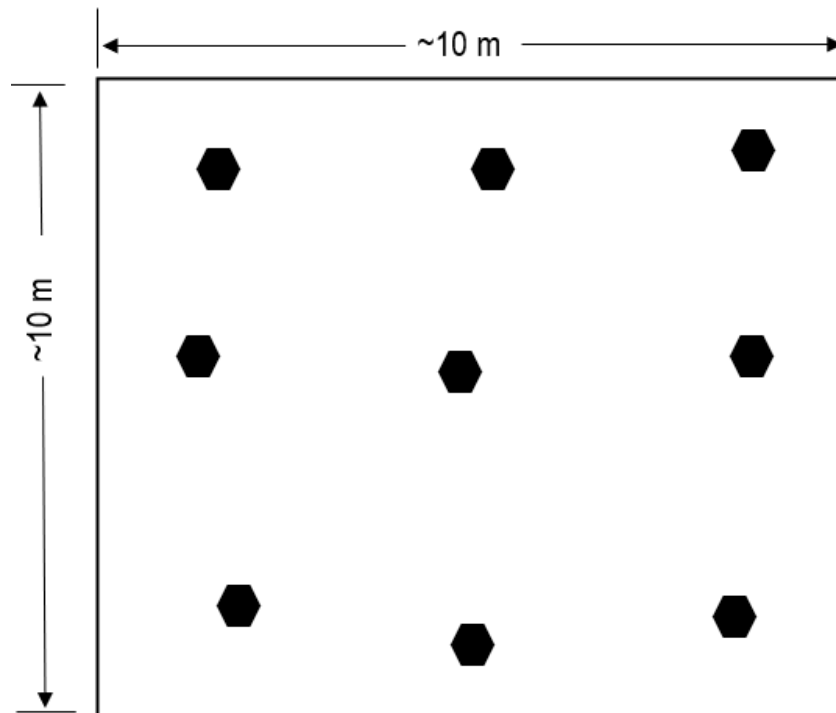


Figure E-4. Example Composite Soil Sampling Pattern within Correlation Plot (Black Hexagons represent aliquot samples collected within 0 to 6 inches bgs)

Table E-2. Summary of Laboratory Analyses of Correlation Soil Samples

Analytical Parameter	Abbreviation	CAS Number	Laboratory Method
Actinium-228	Ac-228	14331-83-0	EPA 901.1
Potassium-40	K-40	13966-00-2	EPA 901.1
Radium-226	Ra-226	13982-63-3	EPA 901.1
Thorium-228	Th-228	14274-82-9	HASL 300
Thorium-230	Th-230	14269-63-7	HASL 300
Thorium-232	Th-232	7440-63-7	HASL 300
Uranium-234	U-234	13966-29-5	HASL 300
Uranium-235	U-235	15117-96-1	HASL 300
Uranium-238	U-238	7440-61-1	HASL 300
Arsenic	As	7440-38-2	EPA SW-846 6020B
Thorium	Th	7440-29-1	EPA SW-846 6020B
Uranium	U	7440-61-1	EPA SW-846 6020B

Notes:

CAS

EPA 901.1

HASL 300

EPA SW-846 6020B

Chemical Abstracts Service

Gamma Spectrometry

Alpha Spectrometry

Inductively Coupled Plasma – Mass Spectrometry

3.0 DATA RESULTS AND QUALIFIERS

The following subsections present and discuss data obtained from soil correlation plots.

3.1 OVERVIEW

This section presents data acquired in the field within soil correlation plots, and a method for identifying potentially non-idealized soil correlation plots. The previous section presented methods and various data collected within the soil correlation plots, as part of the gamma-radium correlation study. In total, types of acquired data fell into five primary categories:

- Unshielded gamma count rate walkover data (1 meter ags)
- Shielded gamma count rate walkover data (1 foot ags)
- Static 1-meter ags gamma count rate (60-second average) in plot centroid
- Gamma exposure rate measured at 1 meter ags in plot centroid by use of HPIC
- Laboratory analytical data (radionuclides and metals).

[Section 2.1](#) presented an idealized situation of data from plots meeting specified criteria. Tetra Tech has developed a series of assessment metrics, some quantitative and some qualitative, useful to ascertain how well individual soil correlation plots meet the criteria. These metrics are used to “qualify” a correlation plot based on the criteria, based on evidence that the soil correlation plot may not be idealized (may not truly be homogenous). [Table E-3](#) summarizes the different potential qualifiers that may be applied to datasets. Applications of qualifiers to any soil correlation plots could provide suitable justification for a potential outlier exclusion analysis. Notably, in all cases, Tetra Tech evaluates the data with and without outliers, but typically removes only outliers deemed justifiable for removal.

All metrics identified in [Table E-3](#) are from datasets collected in the field. In theory, it is possible to analyze this information once the soil correlation plots have been scanned and to eliminate or add soil correlation plots based on findings. However, for some projects, this can be limited by budget, field schedule, or other constraints. It is strongly recommended to evaluate this information in the field and so no qualifiers are applied to any soil correlation plots (which rarely happens).

The following subsections present data distinguished by data types, and describes analysis appropriate for determination of qualifiers. The qualifiers are useful for model development.

Table E-3. Summary of Qualifiers for Soil Correlation Plot Data

Criterion	Data Type	Qualifier
RSD of plot data is > 10%	Unshielded Correlation Data Only	A
If the RPD between the mean and median of plot data is > 1.0%		B
Visual analysis of probability plots; any deviations from normal or lognormal		C
RSD of shielded plot data is > 20%	Shielded Correlation Data Only	D
If the RPD between the mean and median of plot data is > 2%		E
Visual analysis of probability plots; any deviations from normal or lognormal		F
The ratio of unshielded to shielded is > 5.0	Unshielded/Shielded	G
Visual outliers observed in the regression		H
RSD of static gamma count rate data is > 10%	Static Gamma Count Rate	I
The ratio of walkover to static < 0.90 or > 1.10	Walkover/Static Unshielded	J
Visual outliers observed in the regression		K
RSD of HPIC plot data is > 5%	HPIC Data Only	L
If the RPD between the mean and median of HPIC plot data is > 1%		M
Visual outliers observed in the regression	HPIC/Static Unshielded	N
Field observations – uneven terrain, heterogenous soil etc.	Field Logbook	O

Notes:

HPIC High-pressure ionization chamber
 RPD Relative percent difference (also can be equated to the coefficient of variation)
 RSD Relative standard deviation

3.2 WALKOVER GAMMA SCANNING (UNSHIELDED)

[Table E-4](#) lists summary statistics of the walkover unshielded gamma scanning data, per soil correlation plot. Average unshielded gamma count rate ranged between 11,474 cpm (OCRM-CORR03) and 37,722 cpm (OCRM-CORR13). The RSD ranged between 3.3 percent (OCRM-CORR07) and 9.8 percent (OCRM-CORR12); all plots were within the qualifying limits for RSD criteria. The Relative Percent Difference (RPD) between the mean and median of the correlation plot ranged from 0.1 percent (OCRM-CORR01) to 3.5 percent (OCRM-CORR12), with three plots exceeding the qualifying limit.

The qualifying criteria listed in [Table E-3](#) were applied to qualify the soil correlation plots based on unshielded walkover scanning results, and the summary of these results is in [Table E-5](#). One correlation plot (OCRM-CORR06) had at least one qualifier, one correlation plot had two qualifiers (OCRM-CORR08), and one correlation plot (OCRM-CORR12) had all three of the possible unshielded walkover qualifiers. [Attachment E-3](#) presents summary statistics and graphical analysis of the raw unshielded gamma count rate data in every soil correlation plot, including individual value plot, box plot, violin plot, probability plot, and histograms.

3.3 WALKOVER GAMMA SCANNING (SHIELDED)

[Table E-6](#) lists summary statistics of the walkover shielded gamma scanning data, per soil correlation plot. Average shielded gamma count rate ranged between 3,036 cpm (OCRM-CORR03) and 8,344 cpm (OCRM-CORR13), which matched the unshielded results. The RSD ranged between 3.4 percent (OCRM-CORR11) and 8.7 percent (OCRM-CORR12); all plots were within the qualifying limits for RSD criteria. The RPD between the mean and median of the correlation plot ranged from 0.05 percent (OCRM-CORR13) to 2.01 percent (OCRM-CORR14), with one plot (OCRM-CORR14) exceeding the qualifying limit.

The qualifying criteria listed in [Table E-3](#) were applied to qualify the soil correlation plots based on shielded walkover scanning results, and the summary of these results is in [Table E-7](#). Only one correlation plot (OCRM-CORR14) had at least one qualifier. [Attachment E-4](#) presents summary statistics and graphical analysis of the raw shielded gamma count rate data in every soil correlation plot, including individual value plot, box plot, violin plot, probability plot, and histograms.

3.4 WALKOVER REGRESSION ANALYSIS

An analysis compared the unshielded and shielded gamma count rate walkover data within each soil correlation plot. [Table E-8](#) lists unshielded and shielded average gamma count rate data, and the ratio of unshielded average to shielded average.

Table E-4. Summary Statistics of Unshielded Walkover Scanning Results

Correlation Plot ID	Count (n)	Minimum Unshielded Gamma Count Rate (cpm)	Maximum Unshielded Gamma Count Rate (cpm)	Average Unshielded Gamma Count Rate (cpm)	Standard Deviation (cpm)	Median (cpm)	RSD (%)	RPD of Mean/Median (%)
OCRM-CORR01	93	12,100	14,700	13,392	559	13,400	4.2%	0.1%
OCRM-CORR02	150	10,700	13,300	11,871	466	11,800	3.9%	0.6%
OCRM-CORR03	117	10,500	12,600	11,474	400	11,400	3.5%	0.6%
OCRM-CORR04	113	14,200	17,000	15,643	669	15,600	4.3%	0.3%
OCRM-CORR05	116	15,100	18,500	16,863	738	16,800	4.4%	0.4%
OCRM-CORR06	118	15,100	18,200	16,341	631	16,300	3.9%	0.2%
OCRM-CORR07	116	16,700	19,600	18,046	602	18,100	3.3%	0.3%
OCRM-CORR08	116	16,000	24,000	18,463	1,260	18,200	6.8%	1.4%
OCRM-CORR09	130	18,800	25,400	21,633	1,273	21,600	5.9%	0.2%
OCRM-CORR10	99	21,000	28,100	24,340	1,387	24,400	5.7%	0.2%
OCRM-CORR11	149	16,700	21,800	19,010	904	19,200	4.8%	1.0%
OCRM-CORR12	105	25,800	37,400	30,350	2,960	29,300	9.8%	3.5%
OCRM-CORR13	97	33,100	41,800	37,722	2,146	37,600	5.7%	0.3%
OCRM-CORR14	104	31,400	40,700	35,866	2,181	35,950	6.1%	0.2%
OCRM-CORR15	99	26,600	34,400	30,547	1,527	30,600	5.0%	0.2%

Notes:

Bold font indicates the value is above qualifying criterion for that correlation plot.

cpm Counts per minute

RPD Relative percent difference

RSD Relative standard deviation

Table E-5. Unshielded Walkover Scanning Qualifier Analysis

Correlation Plot ID	Qualifier A, B, or C
OCRM-CORR01	--
OCRM-CORR02	--
OCRM-CORR03	--
OCRM-CORR04	--
OCRM-CORR05	--
OCRM-CORR06	C
OCRM-CORR07	--
OCRM-CORR08	B, C
OCRM-CORR09	--
OCRM-CORR10	--
OCRM-CORR11	--
OCRM-CORR12	B, C
OCRM-CORR13	--
OCRM-CORR14	--
OCRM-CORR15	--

Notes:

- No qualifier
- A RSD of unshielded correlation plot greater than 10 percent
- B RPD between mean and median of unshielded plot data is greater than 1 percent
- C Visually identified deviations from normal or lognormal for the unshielded correlation plot
- RPD Relative percent difference
- RSD Relative standard deviation

Table E-6. Summary Statistics of Shielded Walkover Scanning Results

Correlation Plot ID	Count (n)	Minimum Shielded Gamma Count Rate (cpm)	Maximum Shielded Gamma Count Rate (cpm)	Average Shielded Gamma Count Rate (cpm)	Standard Deviation (cpm)	Median (cpm)	RSD (%)	RPD of Mean/Median (%)
OCRM-CORR01	83	3,510	4,260	3,965	157	4,000	4.0%	0.88%
OCRM-CORR02	112	3,110	3,680	3,456	128	3,460	3.7%	0.10%
OCRM-CORR03	95	2,570	3,280	3,036	131	3,030	4.3%	0.18%
OCRM-CORR04	102	3,560	4,420	3,851	161	3,815	4.2%	0.94%
OCRM-CORR05	105	4,100	4,930	4,414	167	4,390	3.8%	0.55%
OCRM-CORR06	122	3,720	4,920	4,247	206	4,220	4.9%	0.64%
OCRM-CORR07	98	4,270	5,100	4,594	159	4,580	3.5%	0.30%
OCRM-CORR08	100	3,850	4,950	4,406	192	4,410	4.4%	0.09%
OCRM-CORR09	118	4,550	5,960	5,104	300	5,085	5.9%	0.37%
OCRM-CORR10	96	4,520	5,760	5,186	285	5,180	5.5%	0.12%
OCRM-CORR11	134	4,020	4,860	4,513	155	4,505	3.4%	0.17%
OCRM-CORR12	105	4,860	7,280	5,943	516	5,830	8.7%	1.92%
OCRM-CORR13	76	6,990	9,530	8,344	667	8,340	8.0%	0.05%
OCRM-CORR14	77	7,110	9,870	8,223	705	8,060	8.6%	2.01%
OCRM-CORR15	80	5,980	8,040	6,959	528	6,880	7.6%	1.14%

Notes:

cpm Counts per minute
RPD Relative percent difference
RSD Relative standard deviation

Table E-7. Unshielded Walkover Scanning Qualifier Analysis

Correlation Plot ID	Qualifier D, E, or F
OCRM-CORR01	--
OCRM-CORR02	--
OCRM-CORR03	--
OCRM-CORR04	--
OCRM-CORR05	--
OCRM-CORR06	--
OCRM-CORR07	--
OCRM-CORR08	--
OCRM-CORR09	--
OCRM-CORR10	--
OCRM-CORR11	--
OCRM-CORR12	--
OCRM-CORR13	--
OCRM-CORR14	E
OCRM-CORR15	--

Notes:

--	No qualifier
D	RSD of shielded correlation plot greater than 20 percent
E	RPD between mean and median of shielded plot data is greater than 2 percent
F	Visually identified deviations from normal or lognormal for the shielded correlation plot
RPD	Relative percent difference
RSD	Relative standard deviation

Table E-8. Summary of Unshielded and Shielded Average Gamma Count Rate at Soil Correlation Plots

Correlation Plot ID	Unshielded Average Gamma Count Rate (cpm)	Shielded Average Gamma Count Rate (cpm)	Ratio of Unshielded to Shielded
OCRM-CORR01	13,392	3,965	3.4
OCRM-CORR02	11,871	3,456	3.4
OCRM-CORR03	11,474	3,036	3.8
OCRM-CORR04	15,643	3,851	4.1
OCRM-CORR05	16,863	4,414	3.8
OCRM-CORR06	16,341	4,247	3.8
OCRM-CORR07	18,046	4,594	3.9
OCRM-CORR08	18,463	4,406	4.2
OCRM-CORR09	21,633	5,104	4.2
OCRM-CORR10	24,340	5,186	4.7
OCRM-CORR11	19,010	4,513	4.2
OCRM-CORR12	30,350	5,943	5.1
OCRM-CORR13	37,722	8,344	4.5
OCRM-CORR14	35,866	8,223	4.4
OCRM-CORR15	30,547	6,959	4.4

Notes:

Bold font indicates the value is above qualifying criterion for that correlation plot.

cpm Counts per minute

By application of the qualifying criteria listed in [Table E-3](#), the relationship between unshielded and shielded average gamma count rate was used to qualify the soil correlation plots based on that criterion, and the summary of these results is in [Table E-9](#). Only one correlation plot had a “G” qualifier because the ratio of unshielded to shielded average gamma count rate exceeded a value of 5. [Figure E-5](#) shows a linear regression of all soil correlation plot data pairs for unshielded and shielded average gamma count rate. While the Coefficient of Variance (R^2) was high (0.96), three data pairs were identified as visual outliers, and those plots received an “H” qualifier and are shown as red on [Figure E-5](#). When the visual outliers are removed from the dataset, the linear regression results in an increased R^2 (0.99), as shown on [Figure E-6](#).

Table E-9. Unshielded and Shielded Regression Qualifier Analysis

Correlation Plot ID	Qualifier G or H
OCRM-CORR01	H
OCRM-CORR02	--
OCRM-CORR03	--
OCRM-CORR04	--
OCRM-CORR05	--
OCRM-CORR06	--
OCRM-CORR07	--
OCRM-CORR08	--
OCRM-CORR09	--
OCRM-CORR10	H
OCRM-CORR11	--
OCRM-CORR12	G, H
OCRM-CORR13	--
OCRM-CORR14	--
OCRM-CORR15	--

Notes:

-- No qualifier

G The ratio of unshielded to shielded is greater than 5

H Visual outliers identified in the regression between unshielded and shielded average gamma count rate

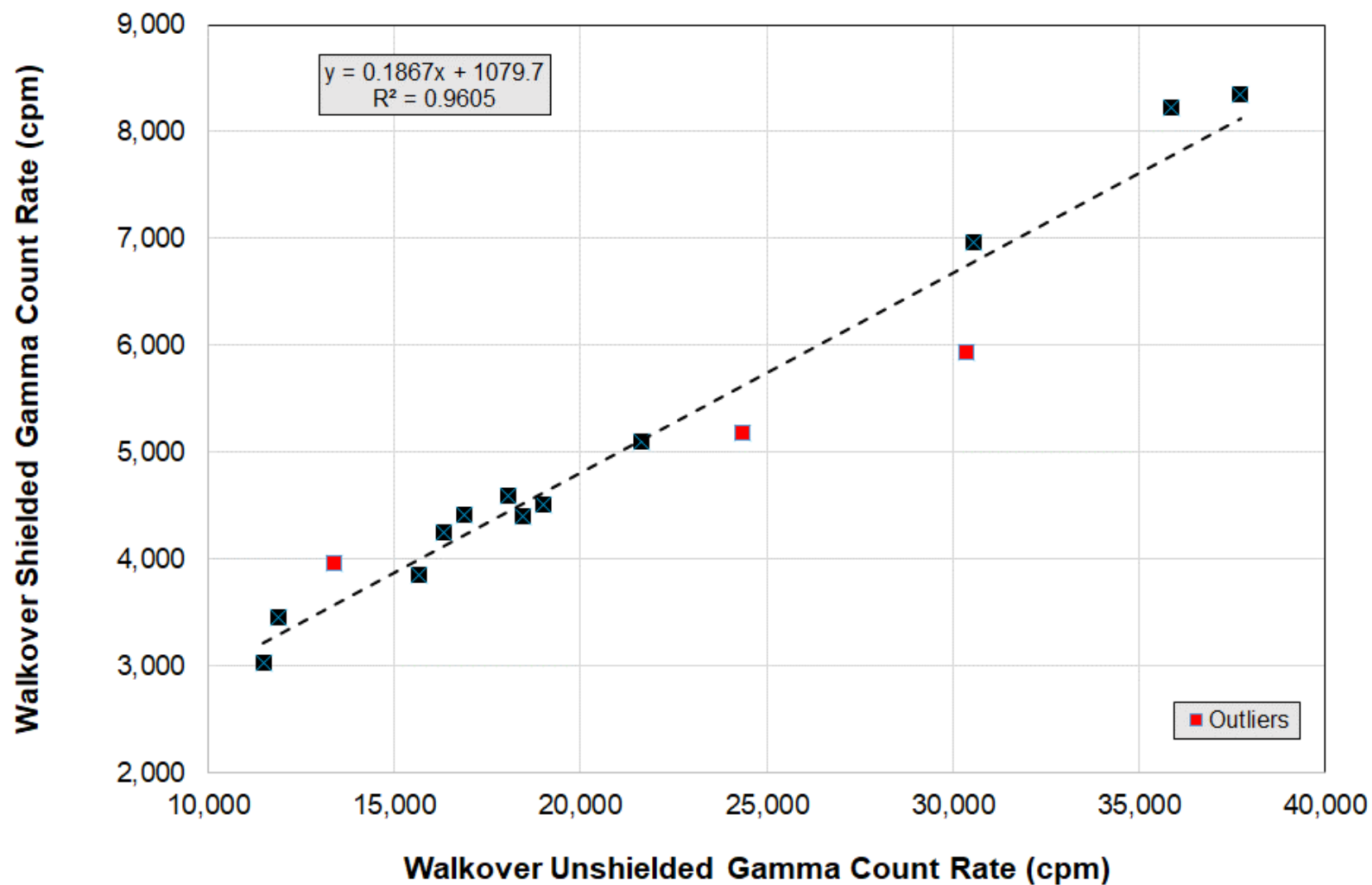


Figure E-5. Unshielded (x-axis) and Shielded (y-axis) Gamma Count Rate Regression Analysis

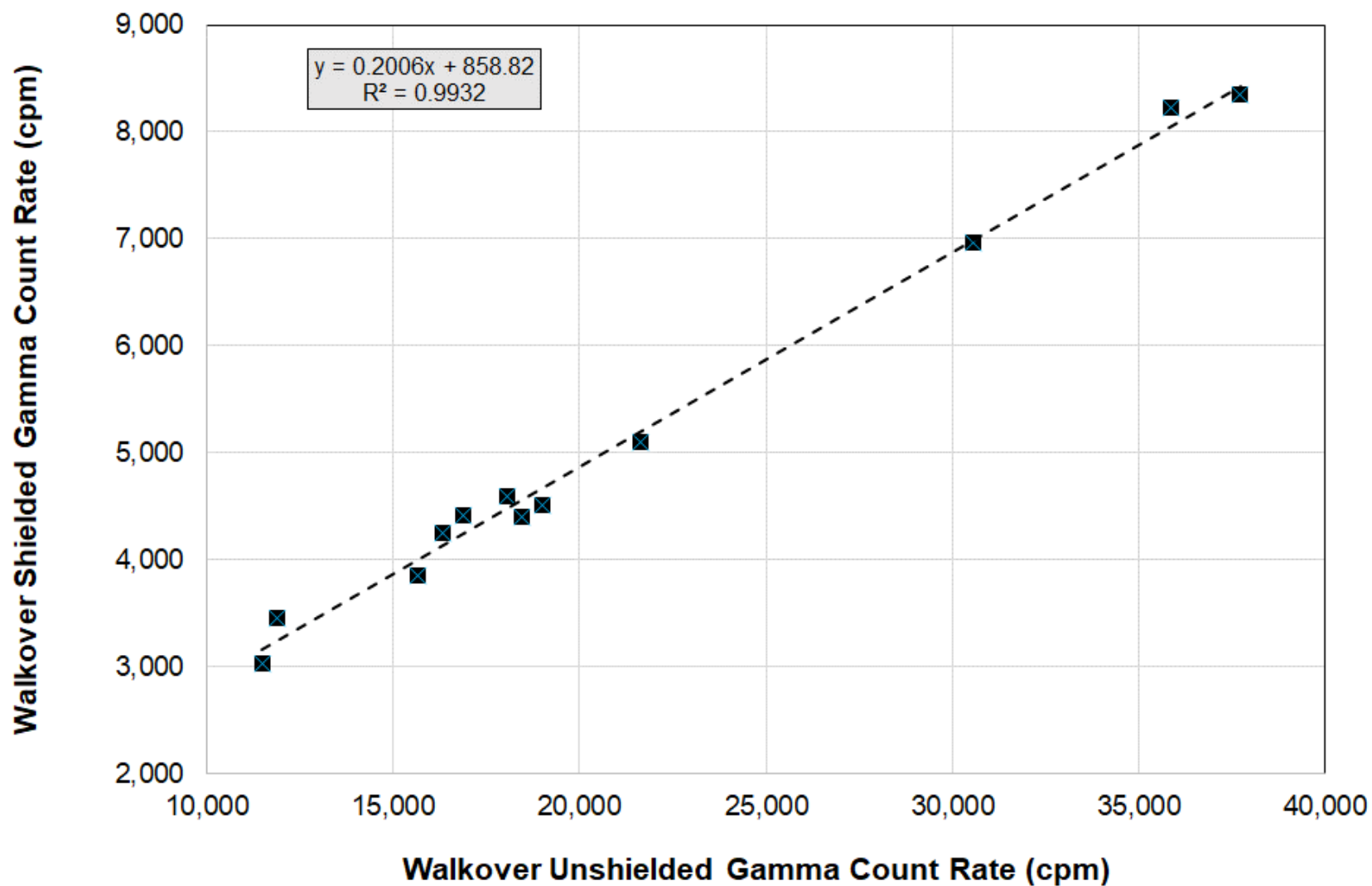


Figure E-6. Unshielded (x-axis) and Shielded (y-axis) Gamma Count Rate Regression Analysis (Outliers Removed)

3.5 STATIC GAMMA COUNT RATE

Table E-10 lists summary statistics of static gamma count rate data (unshielded at 1 meter ags detector height). No associated qualifiers were applied to the RSD (qualifier “I”)—all calculated RSDs were below 10 percent.

Table E-10. Static Gamma Count Rate Data and Qualifiers

Correlation Plot ID	Average Static Gamma Count Rate (cpm)	Standard Deviation (cpm)	Relative Standard Deviation	Qualifier (I)
OCRM-CORR01	14,299	920	6.4%	--
OCRM-CORR02	12,163	930	7.7%	--
OCRM-CORR03	11,313	796	7.0%	--
OCRM-CORR04	15,369	914	5.9%	--
OCRM-CORR05	16,119	1,112	6.9%	--
OCRM-CORR06	16,435	913	5.6%	--
OCRM-CORR07	17,852	1,032	5.8%	--
OCRM-CORR08	17,431	1,046	6.0%	--
OCRM-CORR09	23,286	1,301	5.6%	--
OCRM-CORR10	23,098	1,082	4.7%	--
OCRM-CORR11	18,219	1,063	5.8%	--
OCRM-CORR12	36,408	1,632	4.5%	--
OCRM-CORR13	38,311	1,641	4.3%	--
OCRM-CORR14	34,464	1,269	3.7%	--
OCRM-CORR15	31,050	1,241	4.0%	--

Notes:

-- No qualifier
 cpm Counts per minute
 I RSD of static gamma count rate data is >10 percent
 RSD Relative standard deviation

3.6 UNSHIELDED WALKOVER AND STATIC GAMMA

Table E-11 lists average 1-meter ags unshielded walkover and static gamma count rate data and associated qualifiers. One soil correlation plot (OCRM-CORR12) was qualified based on the ratio criterion. A linear regression between the average unshielded walkover and static gamma count rate data appears on Figure E-7. One soil correlation plot (OCRM-CORR12) was identified as a visual outlier and received a “K” qualifier, identified as red on Figure E-7. The R^2 of the full dataset is 0.96. The visual outlier was removed, and the linear regression was performed again, as shown on Figure E-8— R^2 increased to 0.99.

**Table E-11. Unshielded Walkover and Static Gamma Count Rate and Qualifiers**

Correlation Plot ID	Average Walkover Gamma Count Rate (cpm)	Average Static Gamma Count Rate (cpm)	Ratio of Walkover to Static	Qualifier J or K
OCRM-CORR01	13,392	14,299	0.94	--
OCRM-CORR02	11,871	12,163	0.98	--
OCRM-CORR03	11,474	11,313	1.01	--
OCRM-CORR04	15,643	15,369	1.02	--
OCRM-CORR05	16,863	16,119	1.05	--
OCRM-CORR06	16,341	16,435	0.99	--
OCRM-CORR07	18,046	17,852	1.01	--
OCRM-CORR08	18,463	17,431	1.06	--
OCRM-CORR09	21,633	23,286	0.93	--
OCRM-CORR10	24,340	23,098	1.05	--
OCRM-CORR11	19,010	18,219	1.04	--
OCRM-CORR12	30,350	36,408	0.83	J, K
OCRM-CORR13	37,722	38,311	0.98	--
OCRM-CORR14	35,866	34,464	1.04	--
OCRM-CORR15	30,547	31,050	0.98	--

Notes:

-- No qualifier

cpm Counts per minute

J The ratio of unshielded average walkover to static is <0.90 or >1.10

K Visual outliers identified in regression between unshielded walkover and static average gamma count rate

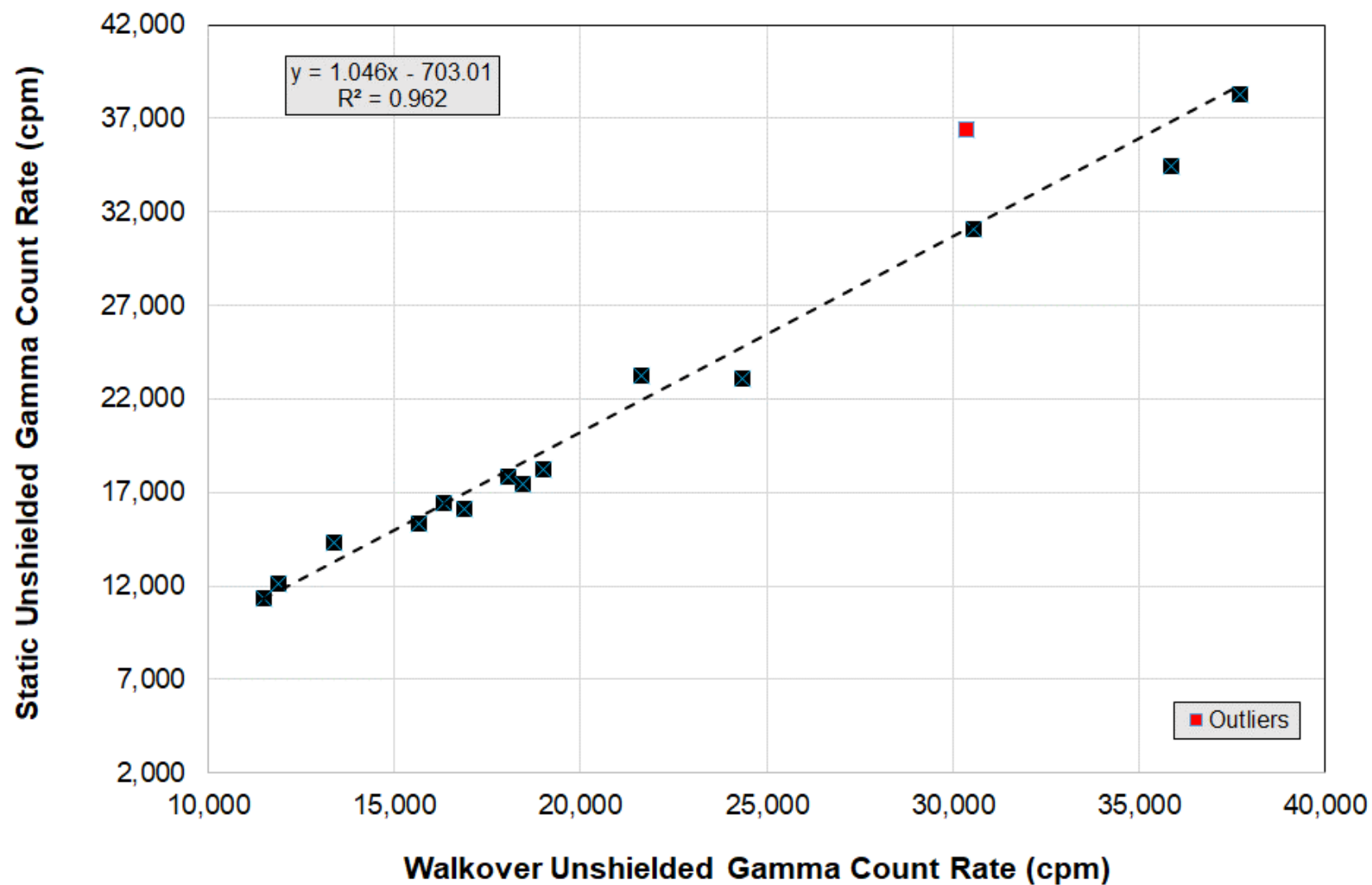


Figure E-7. Unshielded Walkover (x-axis) and Static (y-axis) Gamma Count Rate Regression Analysis

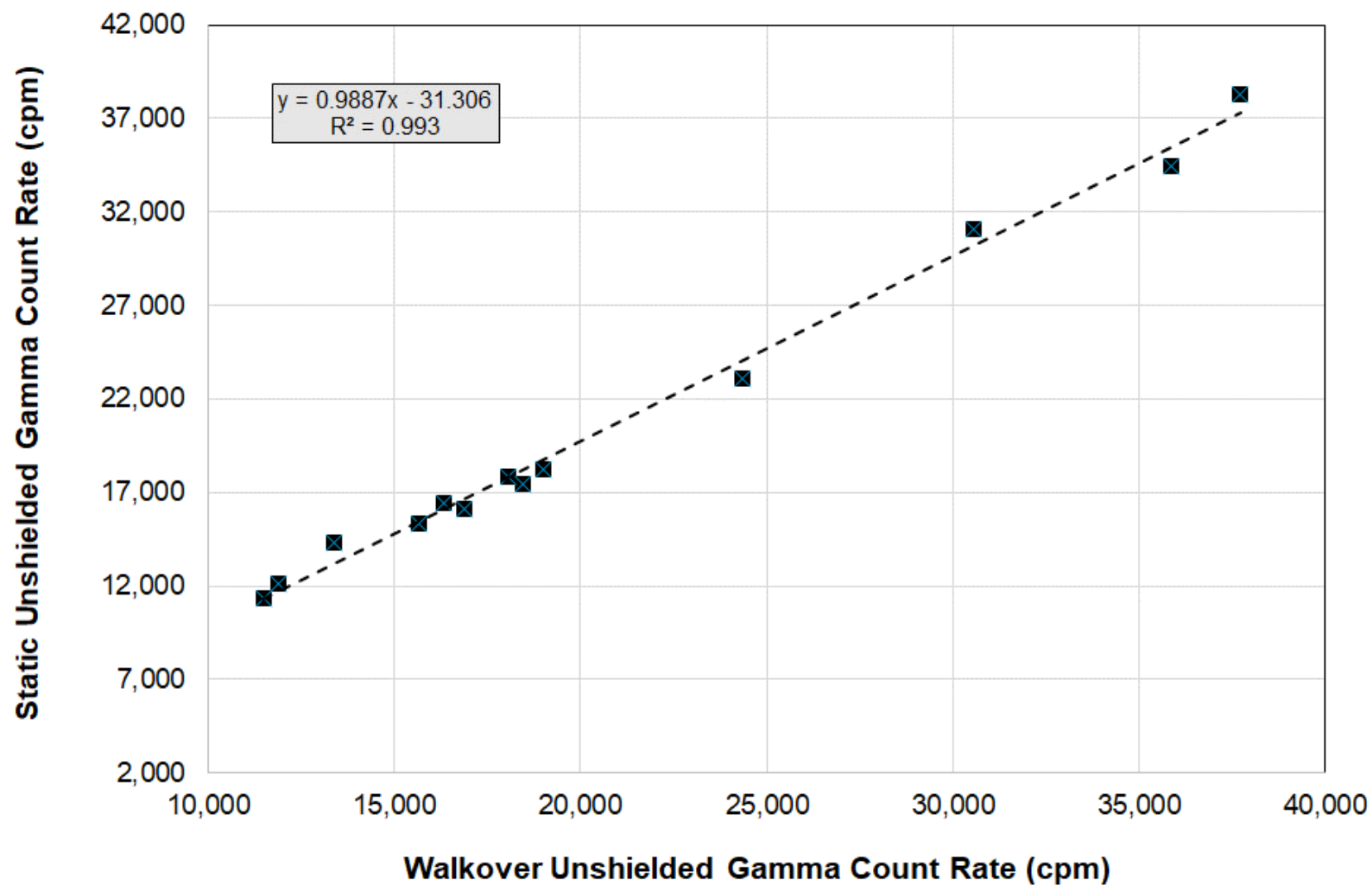


Figure E-8. Unshielded Walkover (x-axis) and Static (y-axis) Gamma Count Rate Regression Analysis (Outlier Removed)

3.7 HIGH-PRESSURE IONIZATION CHAMBER EXPOSURE RATE

Table E-12 lists summary statistics of HPIC exposure rate data collected at soil correlation plots. Measured average gamma exposure rate across all soil correlation plots ranged between 14.6 and 28.7 microrentgens per hour ($\mu\text{R/hr}$). The RSD ranged between 2 and 4 percent; all were below the qualifying criterion of 5 percent. The RPD between the mean and median ranged between 0.1 and 0.5 percent—all below the qualifying criterion of 1 percent. Therefore, no soil correlation plots qualified based on the HPIC exposure rate data. Attachment E-5 presents summary statistics and a graphical analysis of raw exposure rate data in every soil correlation plot, including individual value plot, box plot, violin plot, probability plot, and histograms.

3.8 STATIC GAMMA COUNT RATE VERSUS HPIC EXPOSURE RATE

Table E-13 lists average gamma exposure rates measured by use of the HPIC and 1-meter ags unshielded static gamma count rates. A linear regression on the full dataset appears on Figure E-9. The full dataset linear regression had an R^2 of 0.93. Two identified outliers (OCRM-CORR05 and OCRM-CORR12) are shown on Figure E-9 as red squares. Only OCRM-CORR12 was removed from the dataset, and a linear regression occurred again as shown on Figure E-10, with R^2 increasing from 0.93 to 0.98. While both OCRM-CORR05 and OCRM-CORR12 were qualified, only OCRM-CORR12 was determined to be an influential outlier that would significantly impact estimation of gamma exposure rate.

The final model was developed with the OCRM-CORR12 data pair removed. The final equation to be used for this project for estimating gamma exposure rate from gamma count rate is:

$$\text{Gamma Exposure } \left(\frac{\mu\text{R}}{\text{hr}} \right) = (0.000482 * [\text{Gamma Count Rate (cpm)}]) + 9.724779$$

3.9 SOIL CORRELATION LABORATORY ANALYSIS RESULTS

Table E-14 lists laboratory analytical results for Ra-226, K-40, and thorium.

Table E-12. Summary Statistics of High-Pressure Ionization Chamber Gamma Exposure Rate

Correlation Plot ID	Count (n)	Minimum (μR/hr)	Maximum (μR/hr)	Average (μR/hr)	Standard Deviation (μR/hr)	Median (μR/hr)	RSD (%)	RPD of Mean/Median	Qualifier L or M
OCRM-CORR01	90	15.7	18.4	16.6	0.56	16.6	3%	0.3%	--
OCRM-CORR02	90	15.0	17.6	16.0	0.56	15.9	4%	0.5%	--
OCRM-CORR03	90	13.4	15.9	14.6	0.45	14.5	3%	0.2%	--
OCRM-CORR04	90	15.9	17.8	16.9	0.39	16.9	2%	0.1%	--
OCRM-CORR05	90	17.2	20.3	18.6	0.52	18.6	3%	0.2%	--
OCRM-CORR06	90	16.9	18.6	17.5	0.39	17.5	2%	0.1%	--
OCRM-CORR07	90	17.0	20.1	18.4	0.54	18.4	3%	0.4%	--
OCRM-CORR08	90	16.9	19.7	18.4	0.57	18.4	3%	0.1%	--
OCRM-CORR09	90	19.0	21.8	20.0	0.53	19.9	3%	0.4%	--
OCRM-CORR10	90	19.4	21.8	20.8	0.53	20.8	3%	0.1%	--
OCRM-CORR11	90	17.0	20.2	18.7	0.58	18.6	3%	0.3%	--
OCRM-CORR12	90	21.6	25.3	23.4	0.72	23.5	3%	0.5%	--
OCRM-CORR13	90	26.8	30.5	28.7	0.75	28.8	3%	0.5%	--
OCRM-CORR14	90	24.8	27.8	26.5	0.73	26.5	3%	0.2%	--
OCRM-CORR15	90	22.6	25.6	24.1	0.65	24.0	3%	0.2%	--

Notes:

-- No qualifier
 μR/hr Microrentgens per hour
 HPIC High-pressure ionization chamber
 L If the RSD of HPIC data is >5 percent
 M If the RPD between the mean and median of HPIC data is > 1 percent
 RPD Relative percent difference
 RSD Relative standard deviation

Table E-13. Average Gamma Exposure Rate and Static Gamma Count Rate and Qualifiers

Correlation Plot ID	Average Gamma Exposure Rate (μ R/hr)	Average Static Gamma Count Rate (cpm)	Qualifier (N)
OCRM-CORR01	16.6	14,299	--
OCRM-CORR02	16.0	12,163	--
OCRM-CORR03	14.6	11,313	--
OCRM-CORR04	16.9	15,369	--
OCRM-CORR05	18.6	16,119	N
OCRM-CORR06	17.5	16,435	--
OCRM-CORR07	18.4	17,852	--
OCRM-CORR08	18.4	17,431	--
OCRM-CORR09	20.0	23,286	--
OCRM-CORR10	20.8	23,098	--
OCRM-CORR11	18.7	18,219	--
OCRM-CORR12	23.4	36,408	N
OCRM-CORR13	28.7	38,311	--
OCRM-CORR14	26.5	34,464	--
OCRM-CORR15	24.1	31,050	--

Notes:

-- No qualifier
 μ R/hr Microrentgens per hour
 cpm Counts per minute
 HPIC High-Pressure Ionization Chamber
 N Visual outliers observed in the regression of HPIC/Static

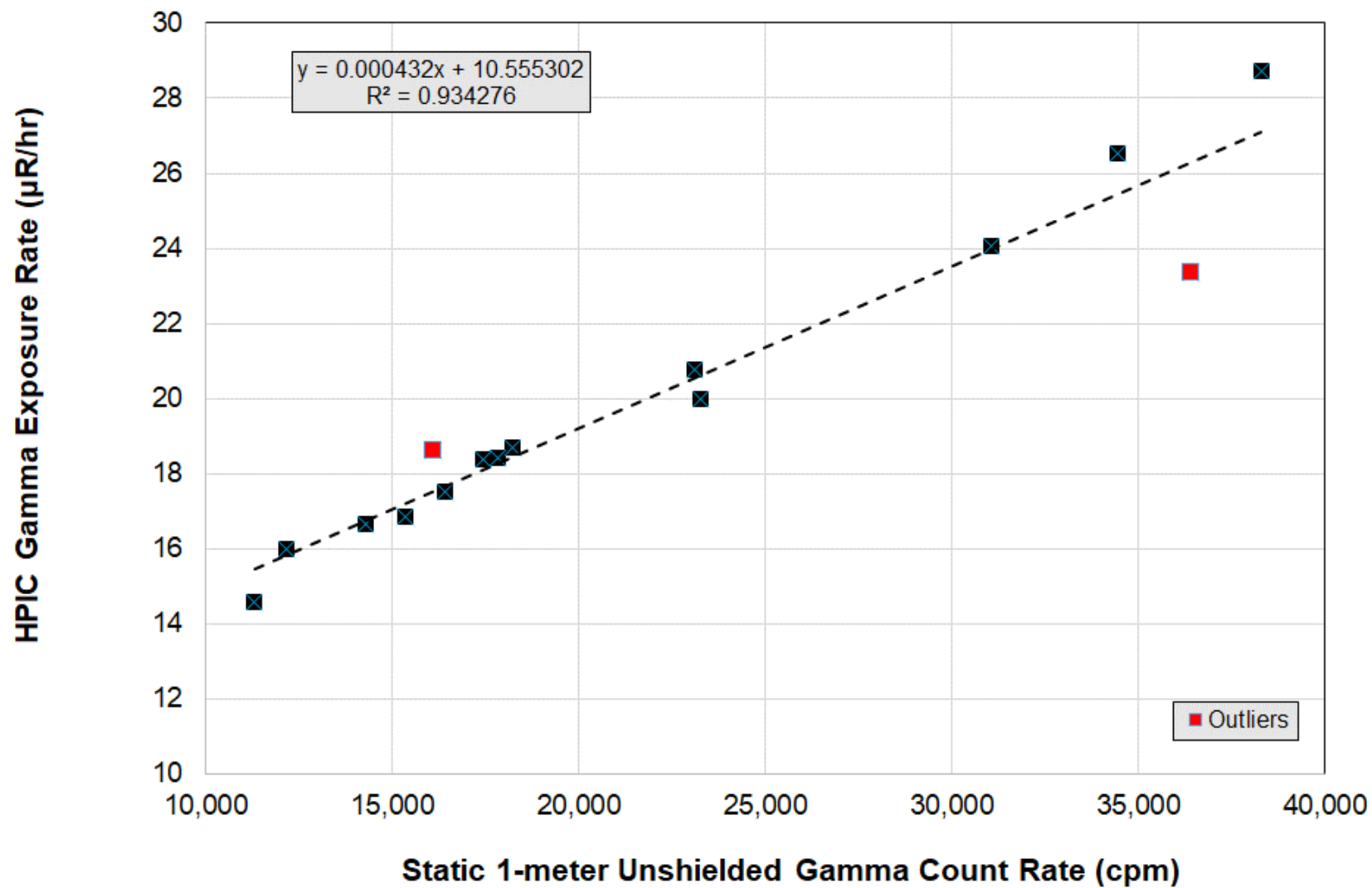


Figure E-9. Static Gamma Count Rate (x-axis) and HPIC Gamma Exposure Rate (y-axis) Linear Regression

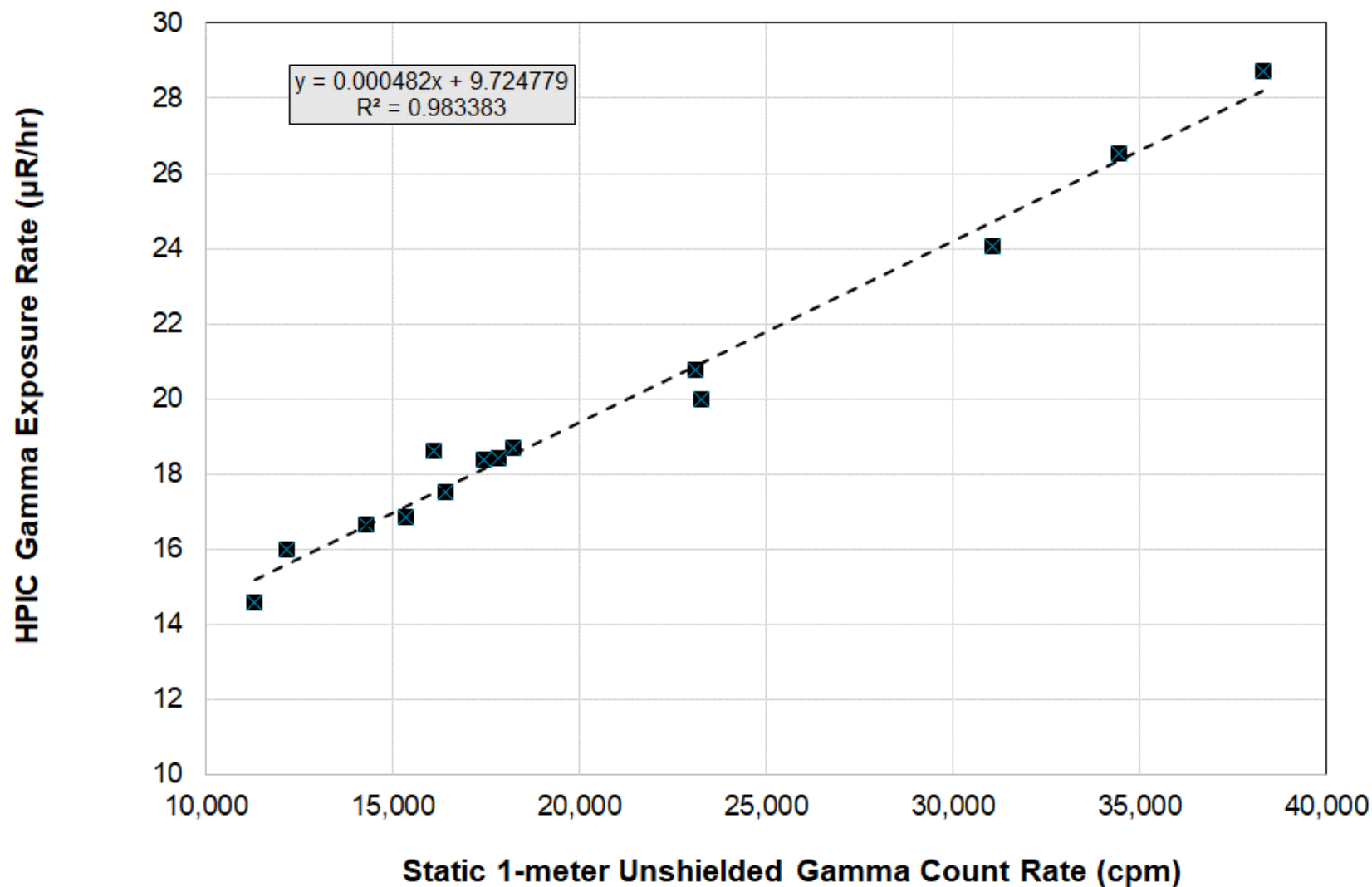


Figure E-10. Static Gamma Count Rate (x-axis) and HPIC Gamma Exposure Rate (y-axis) Linear Regression (Outlier Removed, Final Model Used in Report)

Table E-14. Summary of Select Laboratory Analytes from the Soil Correlation Plots

Sample ID	Radium-226 (pCi/g)	Qualifier	Measurement Uncertainty+/- (pCi/g)	K-40 (pCi/g)	Qualifier	Measurement Uncertainty+/- (pCi/g)	Thorium (mg/kg)	Qualifier
OCRM-CORR01-01-111922	1.51	--	0.19	22.0	--	2.38	8.51	--
OCRM-CORR02-01-111922	1.24	--	0.211	20.6	--	2.61	7.03	--
OCRM-CORR03-01-111922	1.12	--	0.209	16.0	--	2.2	4.29	--
OCRM-CORR04-01-111922	1.95	--	0.253	20.3	--	2.66	7.84	--
OCRM-CORR05-01-111922	3	--	0.35	20.2	--	2.53	8.3	--
OCRM-CORR06-01-111922	3.02	--	0.325	19.8	--	2.44	9.8	--
OCRM-CORR07-01-111922	3.53	--	0.37	19.6	--	2.45	8.24	--
OCRM-CORR08-01-111922	3.45	--	0.361	18.1	--	2.3	6.32	--
OCRM-CORR09-01-111922	2.75	--	0.335	20.9	--	2.67	7.2	--
OCRM-CORR10-01-111922	3.41	--	0.379	18.9	--	2.39	8.23	--
OCRM-CORR11-01-111922	1.6	--	0.215	20.6	--	2.51	7.92	--
OCRM-CORR12-01-111922	2.25	--	0.289	19.7	--	2.56	6.32	--
OCRM-CORR13-01-111922	17	--	1.67	19.6	--	2.74	4.87	--
OCRM-CORR14-01-111922	17.4	--	1.51	18.3	--	2.35	4.86	--
OCRM-CORR15-01-111922	10.7	--	1.04	19.9	--	2.59	5.83	--

Notes:

Qualifiers are based on laboratory reports from GEL

-- No qualifier

K-40 Potassium-40

mg/kg Milligram per kilogram

pCi/g Picocurie per gram

4.0 REGRESSION ANALYSIS

The following subsections discuss regression analysis.

4.1 SUMMARY OF QUALIFIERS

The preceding section presented a step-by-step qualifying analysis based on a number of factors and on criteria listed in [Table E-3](#). The qualifiers were then condensed for each soil correlation plot as listed in [Table E-15](#).

Table E-15. Summary of Final Qualifiers for Soil Correlation Plots

Correlation Plot ID	Final Qualifiers
OCRM-CORR01	H
OCRM-CORR02	--
OCRM-CORR03	--
OCRM-CORR04	--
OCRM-CORR05	N
OCRM-CORR06	C
OCRM-CORR07	--
OCRM-CORR08	B, C
OCRM-CORR09	--
OCRM-CORR10	H
OCRM-CORR11	--
OCRM-CORR12	B, C, G, H, J, K, N
OCRM-CORR13	--
OCRM-CORR14	E
OCRM-CORR15	--

Notes:

- No qualifiers
- A RSD of unshielded correlation plot greater than 10 percent
- B RPD between mean and median of unshielded plot data is greater than 1 percent
- C Visually identified deviations from normal or lognormal for the unshielded correlation plot
- D RSD of shielded correlation plot greater than 20 percent
- E RPD between mean and median of shielded plot data is greater than 2 percent
- F Visually identified deviations from normal or lognormal for the shielded correlation plot
- G The ratio of unshielded to shielded is greater than 5
- H Visual outliers identified in the regression between unshielded and shielded average gamma count rate
- I RSD of static gamma count rate data is >10 percent
- J The ratio of unshielded average walkover to static is <0.90 or >1.10
- K Visual outliers identified in regression between unshielded walkover and static average gamma count rate
- L If the RSD of HPIC data is >5 percent
- M If the RPD between the mean and median of HPIC data is > 1 percent
- N Visual outliers observed in the regression of HPIC/Static
- RSD Relative standard deviation

4.2 UNSHIELDED WALKOVER AND RADIUM-226 RESULTS

[Table E-16](#) lists average unshielded walkover gamma count rate data from and associated Ra-226 soil concentrations within all 15 soil correlation plots.

A linear regression analysis on the full dataset appears on [Figure E-11](#). The R^2 of the full dataset is 0.73. The low R^2 is likely associated with the OCRM-CORR12 outlier identified in a previous subsection. Therefore, a linear regression analysis on the dataset with removal of OCRM-CORR12 appears on [Figure E-12](#)—lowering R^2 to 0.88, which meets the project quality criterion for regression models for gamma-radium correlations.

[Figure E-12](#) shows that while OCRM-CORR12 was an influential outlier, the linear regression line still does not follow the lowest three soil correlation data pairs; therefore, the model may be slightly over predictive at lower concentrations.

Because of likely overprediction by application of the linear regression models, an additional analysis was performed on all data pairs where average gamma count rate was less than 19,000 cpm (which excluded seven data pairs). [Figure E-13](#) shows that the lower range dataset linear regression model yielded a resulting R^2 of 0.934 and extremely good mimic of lower Ra-226 concentrations; however, this model may not predict higher Ra-226 concentrations as accurately because of need to extrapolate to obtain higher estimates of Ra-226.

Table E-16. Average Unshielded Gamma and Ra-226 Soil Concentration

Correlation Plot ID	Average Unshielded Walkover Gamma Count Rate (cpm)	Radium-226 (pCi/g)
OCRM-CORR01	13,392	1.51
OCRM-CORR02	11,871	1.24
OCRM-CORR03	11,474	1.12
OCRM-CORR04	15,643	1.95
OCRM-CORR05	16,863	3
OCRM-CORR06	16,341	3.02
OCRM-CORR07	18,046	3.53
OCRM-CORR08	18,463	3.45
OCRM-CORR09	21,633	2.75
OCRM-CORR10	24,340	3.41
OCRM-CORR11	19,010	1.6
OCRM-CORR12	30,350	2.25
OCRM-CORR13	37,722	17
OCRM-CORR14	35,866	17.4
OCRM-CORR15	30,547	10.7

Notes:

cpm Counts per minute
pCi/g Picocurie per gram

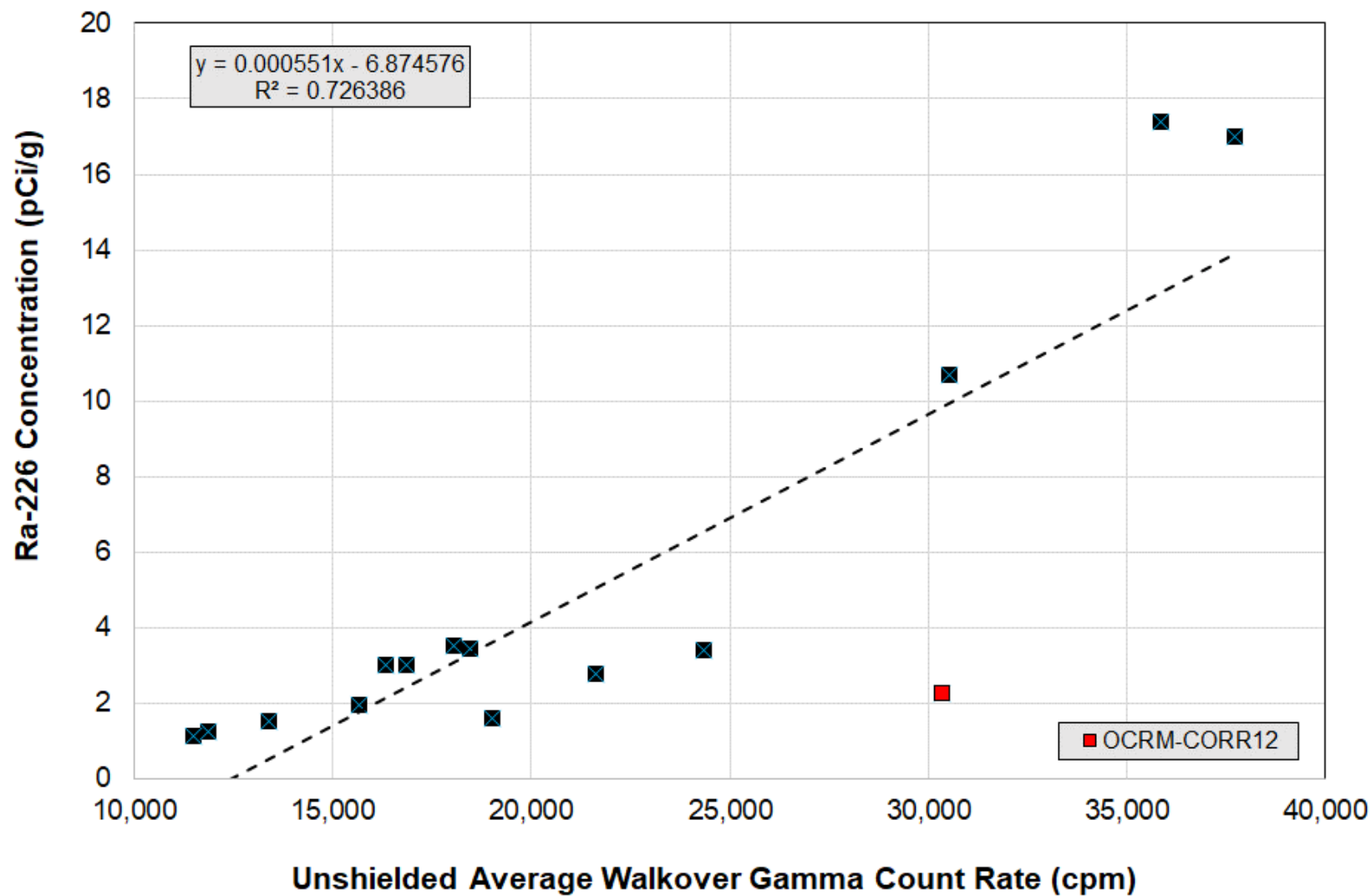


Figure E-11. Linear Regression of Unshielded Walkover Gamma Count Rate and Ra-226 Soil Concentration (Full Dataset)

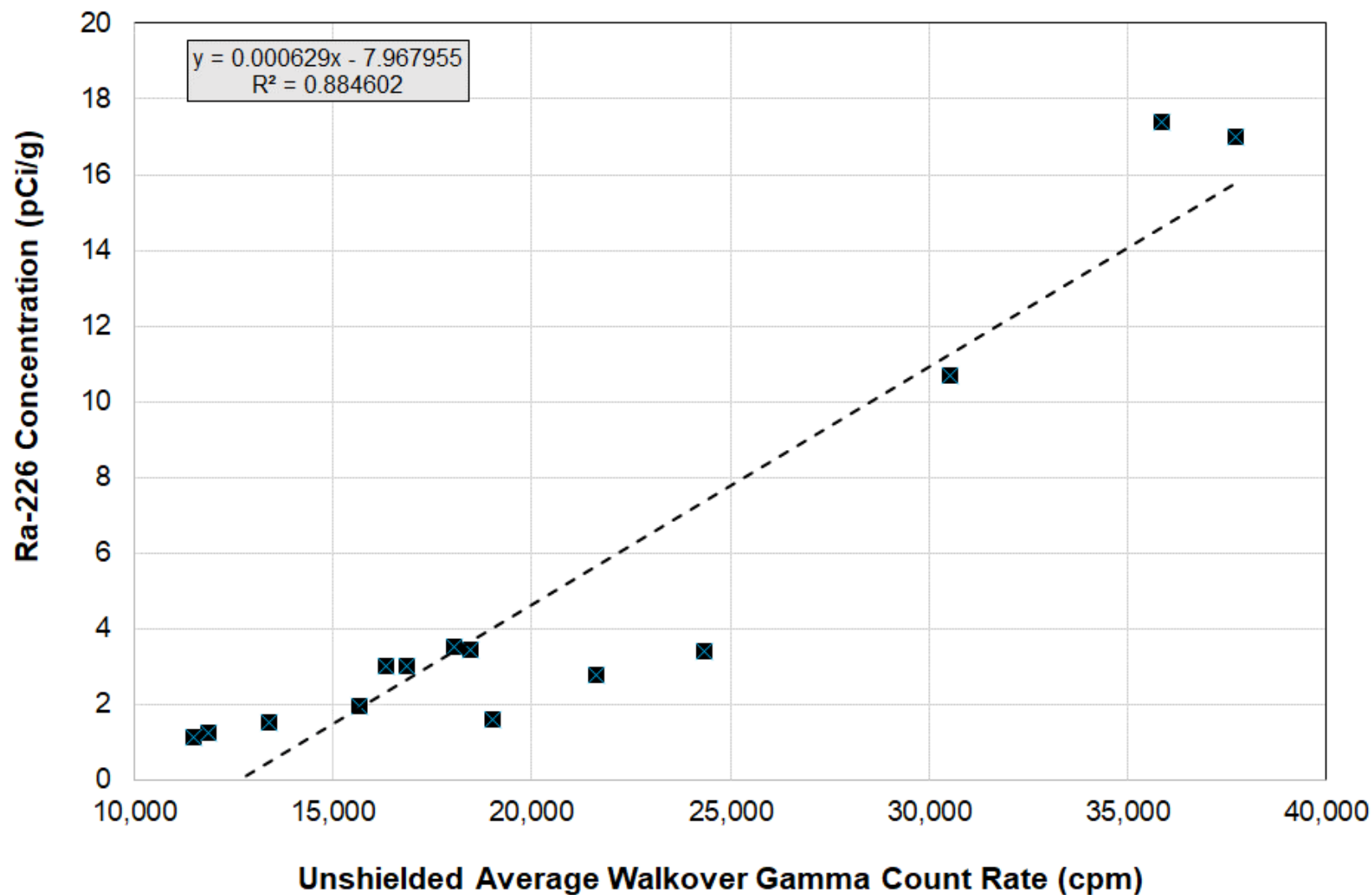


Figure E-12. Linear Regression of Unshielded Walkover Gamma Count Rate and Ra-226 Soil Concentration (OCRM-CORR12 Removed as Outlier)

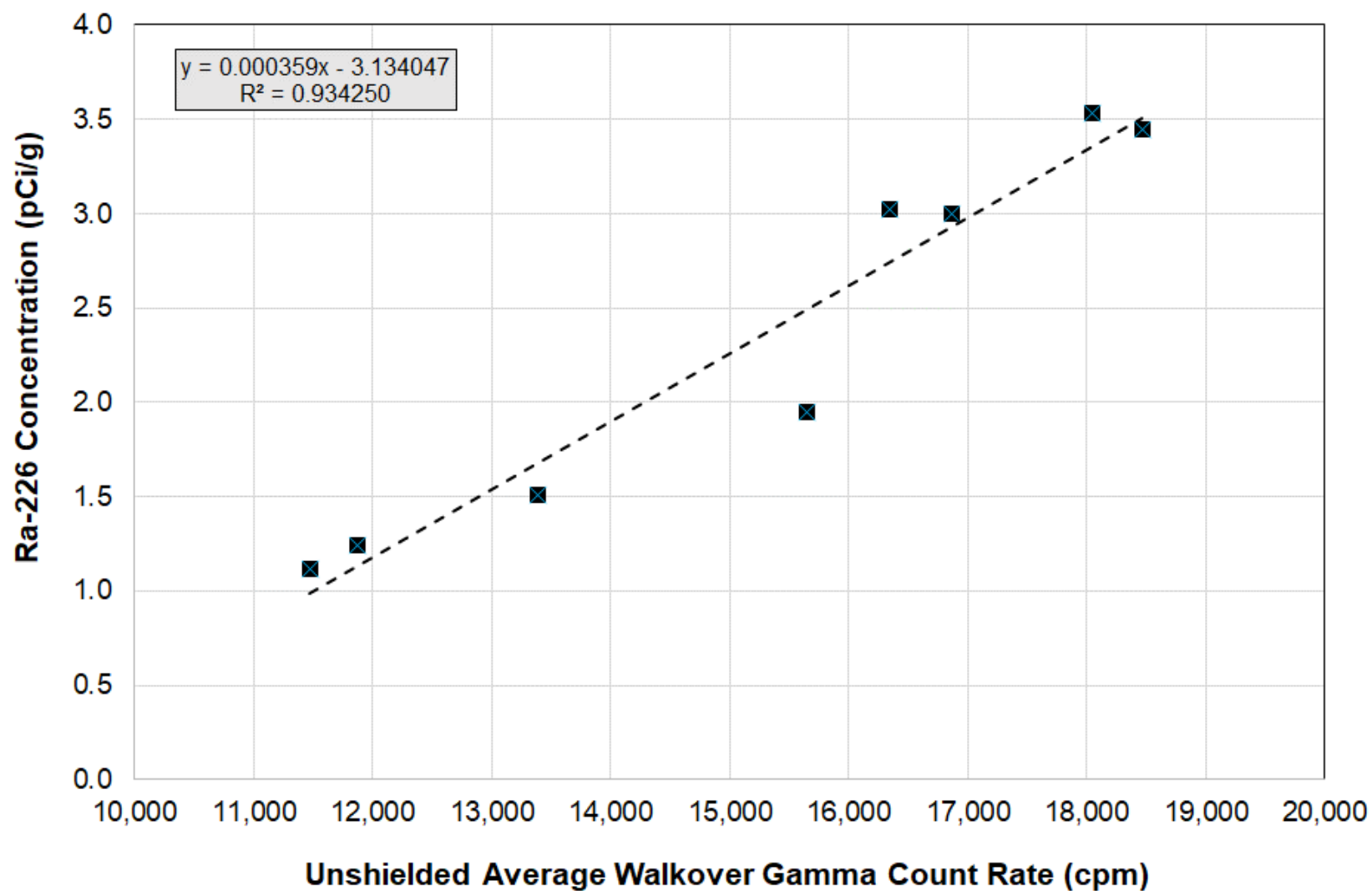


Figure E-13. Linear Regression of Unshielded Walkover Gamma Count Rate and Ra-226 Soil Concentration (Less than 19,000 cpm)



4.3 SHIELDED WALKOVER AND RADIUM-226 RESULTS

In certain instances, during remediation, it may be advantageous to utilize a collimated detection system for remedial action surveys (i.e., guiding remedial or removal action utilizing instrumentation). Therefore, an effort was made to ascertain the relationship between shielded gamma count rate and Ra-226 soil concentration. [Figure E-14](#) shows results of that effort.

The shielded gamma cutoff for 2 pCi/g of Ra-226 using the full dataset is 4,148 cpm, and the R^2 is 0.86. For 10 pCi/g, the shielded gamma cutoff is 6,699. Therefore, if a collimated detection system is to clean up the site for background and for 10 pCi/g, the shielded gamma cutoff to be used should be 4,100 and 6,700 cpm for 2 and 10 pCi/g, respectively.

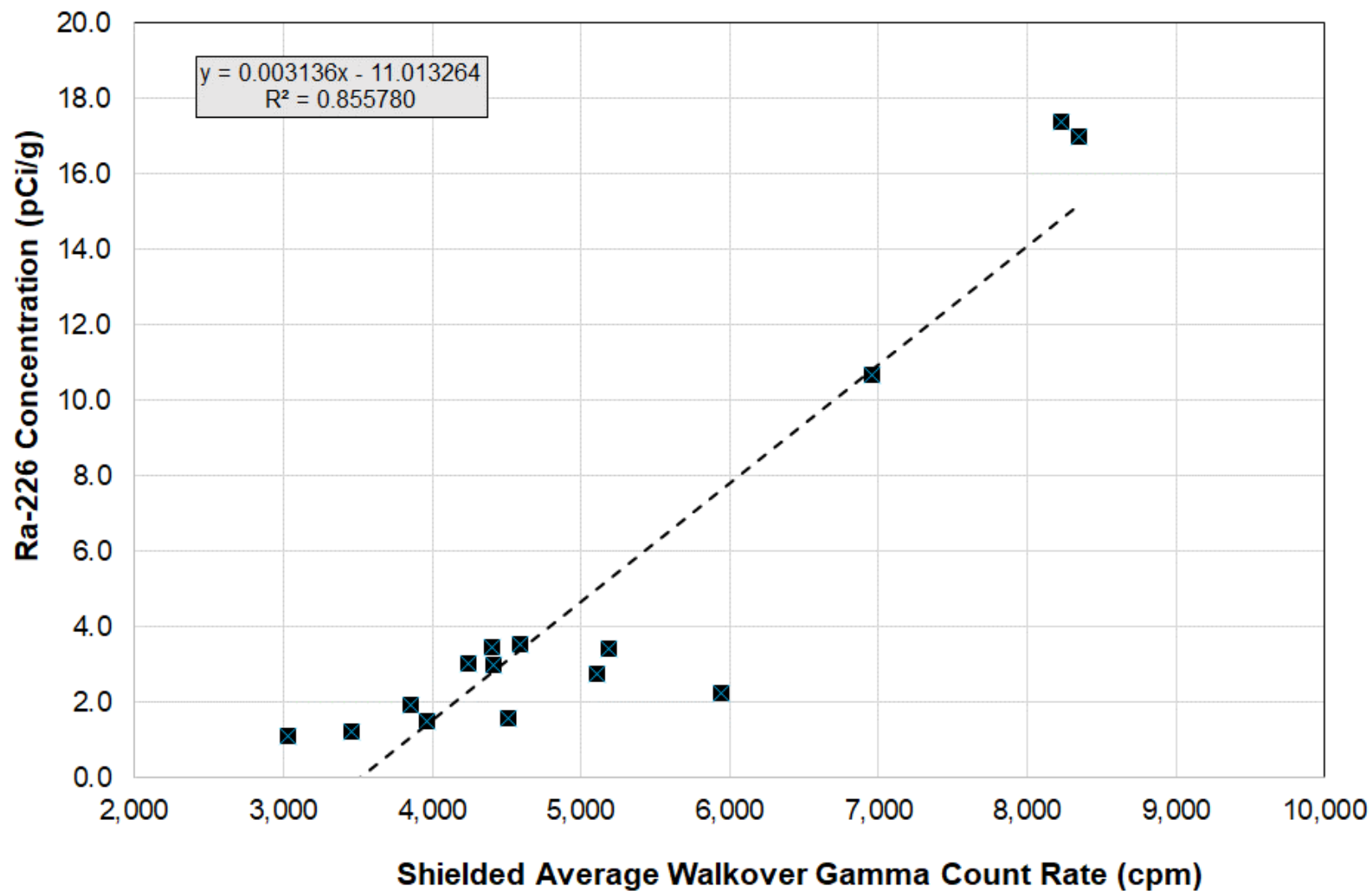


Figure E-14. Shielded Gamma Count Rate versus Ra-226 Soil Concentration (Full Dataset)

5.0 MODEL DEVELOPMENT

5.1 OVERVIEW

The preceding section presented an analysis of model development which lead to a linear correlation between unshielded gamma count rate and Ra-226 soil concentration as well as a linear correlation between unshielded gamma count rate and Ra-226 soil concentrations limited to a range less than 19,000 cpm. Additionally, a model was developed for shielded gamma count rate and Ra-226 soil concentration. The focus of this section is on final models selected for predicting estimated Ra-226 from unshielded gamma count rate data. Two models were selected for final analysis: Model 1 and Model 2, both forms of traditional models (i.e., gamma count rate versus Ra-226 soil concentration). The following subsections present information regarding both models.

These models were applied to the full validated dataset. For further analysis, a kriging boundary was developed across the site where appropriate, and the gamma survey data were buffered within 10 meters of the final kriged boundary. The final kriged boundary surrounded 236 acres. The final dataset used for kriging purposes was reduced from 260,946 to 238,185 measurements.

5.2 MODEL 1: TRADITIONAL LINEAR REGRESSION WITH OCRM-CORR12 EXCLUDED

The following subsections discuss Model 1.

5.2.1 Overview of Model 1

Model 1 is classified as a traditional linear model with one outlier removed (OCRMCORR12). The correlation plot OCRM-CORR12 was determined to be an influential outlier with numerous lines of evidence supporting and justifying removal and exclusion of the data pair from the initial correlation model. Therefore, no model was run using OCRM-CORR12 from the onset. [Table E-17](#) lists data pairs included in or excluded from Model 1. [Figure E-15](#) depicts the regression analysis that represents Model 1. The following equation was used to convert gamma count rate to Ra-226 for Model 1:

$$^{226}\text{Ra} \left(\frac{\text{pCi}}{\text{g}} \right) = (0.000629 * [\text{Gamma Count Rate (cpm)}]) - 7.967955$$

One issue with Model 1 is that negative values persist at lower gamma count rates. A total of 42,348 of 260,946 measurements were negative after the conversion, or 16 percent of the full dataset. For the dataset used for kriging, a total of 29,028 of 238,185 measurements were classified as negative. Any gamma count rate less than ~12,668 cpm was converted to a negative value. This is a common issue associated with linear regression models; furthermore, linear regression Model 1 evidently does not reflect the lower range of data pairs very well. Nonetheless, a common practice is to evaluate the full dataset in comparison to other models; however, this particular model does exclude the extreme outlier identified during the qualifying selection process (OCRMCORR12).

**Table E-17. Model 1 Traditional Linear Data Pair Inclusion/Exclusion**

Correlation Plot ID	Average Unshielded Walkover Gamma Count Rate (cpm)	Radium-226 (pCi/g)	Final Qualifiers	Model 1 Inclusion
OCRM-CORR01	13,392	1.51	H	Included
OCRM-CORR02	11,871	1.24	--	Included
OCRM-CORR03	11,474	1.12	--	Included
OCRM-CORR04	15,643	1.95	--	Included
OCRM-CORR05	16,863	3	N	Included
OCRM-CORR06	16,341	3.02	C	Included
OCRM-CORR07	18,046	3.53	--	Included
OCRM-CORR08	18,463	3.45	B, C	Included
OCRM-CORR09	21,633	2.75	--	Included
OCRM-CORR10	24,340	3.41	H	Included
OCRM-CORR11	19,010	1.6	--	Included
OCRM-CORR12	30,350	2.25	B, C, G, H, J, K, N	Excluded
OCRM-CORR13	37,722	17	--	Included
OCRM-CORR14	35,866	17.4	E	Included
OCRM-CORR15	30,547	10.7	--	Included

Notes:

-- No qualifier

cpm Counts per minute

pCi/g Picocurie per gram

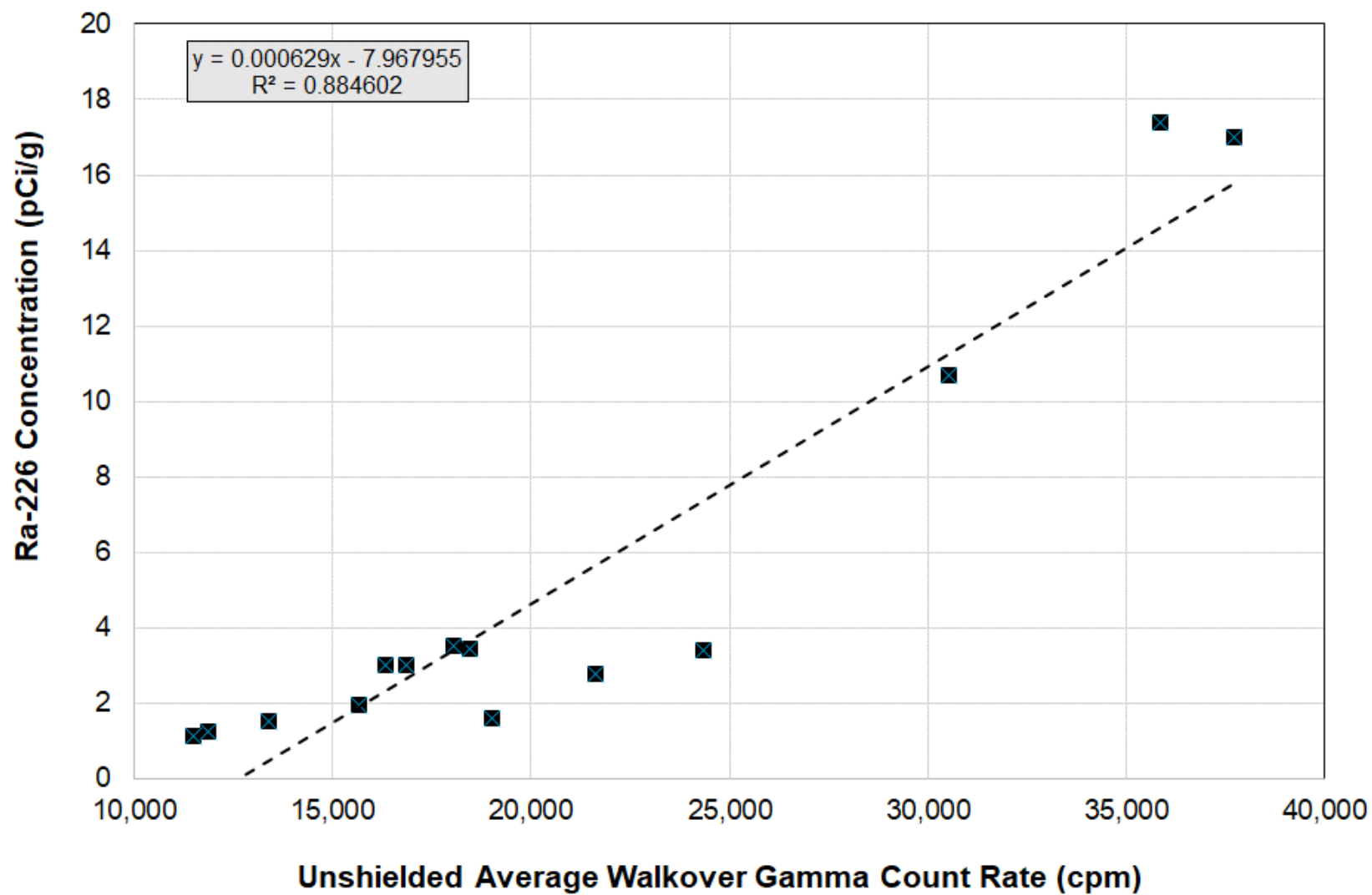


Figure E-15. Gamma-Radium Correlation, Linear Regression – Model 1

Table E-18 lists gamma cutoff values associated with various Ra-226 concentrations as derived from Model 1.

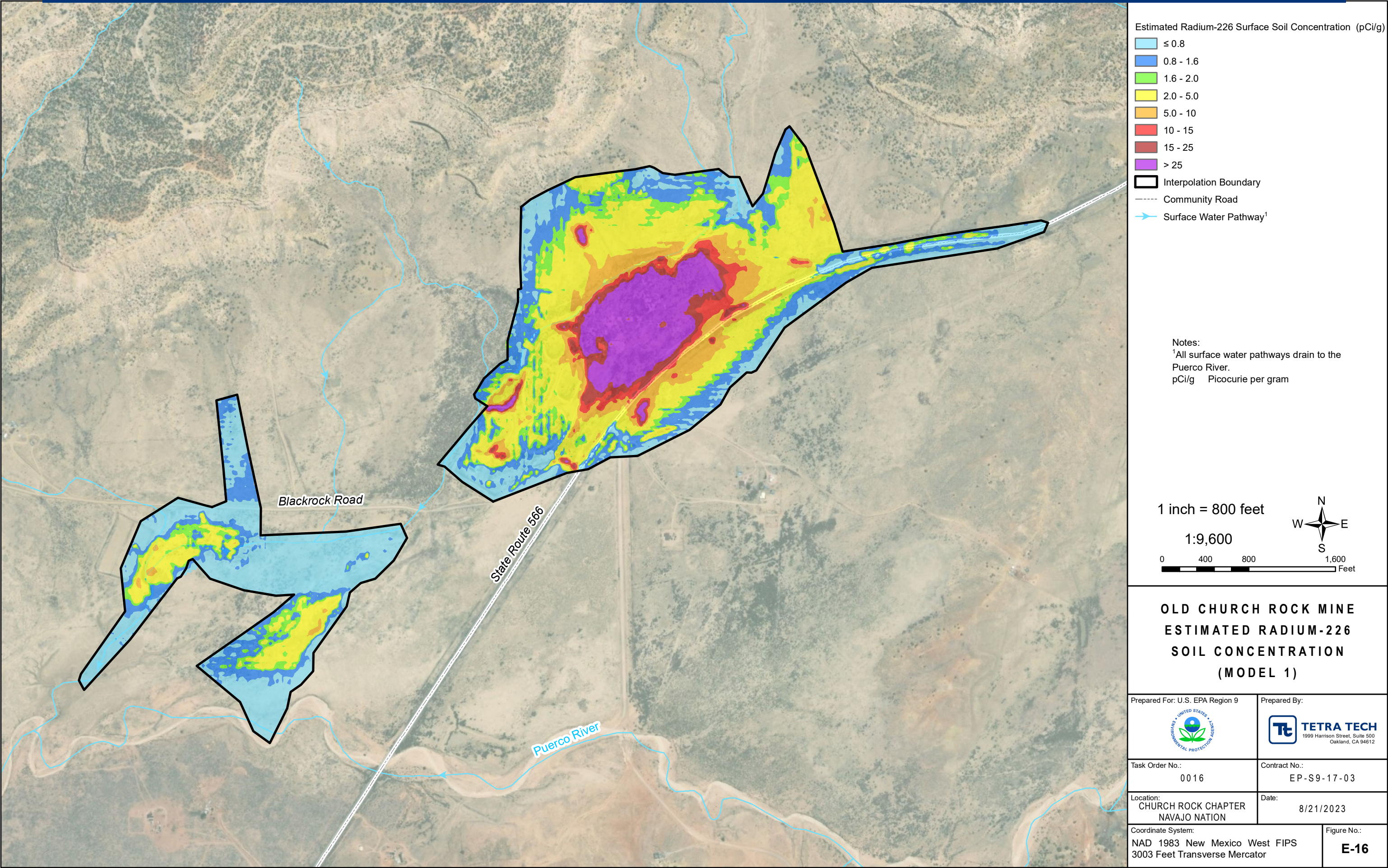
Table E-18. Summary of Model 1 Gamma Cutoff Values

Ra-226 Concentration (pCi/g)	Model 1 Cutoff Value (cpm)
2	15,847
5	20,617
10	28,566
15	36,515
25	52,413

Notes:

cpm Counts per minute
pCi/g Picocurie per gram

Figure E-16 shows an interpolated map of the gamma data collected at the site converted to an estimated Ra-226 concentration in pCi/g by application of Model 1.

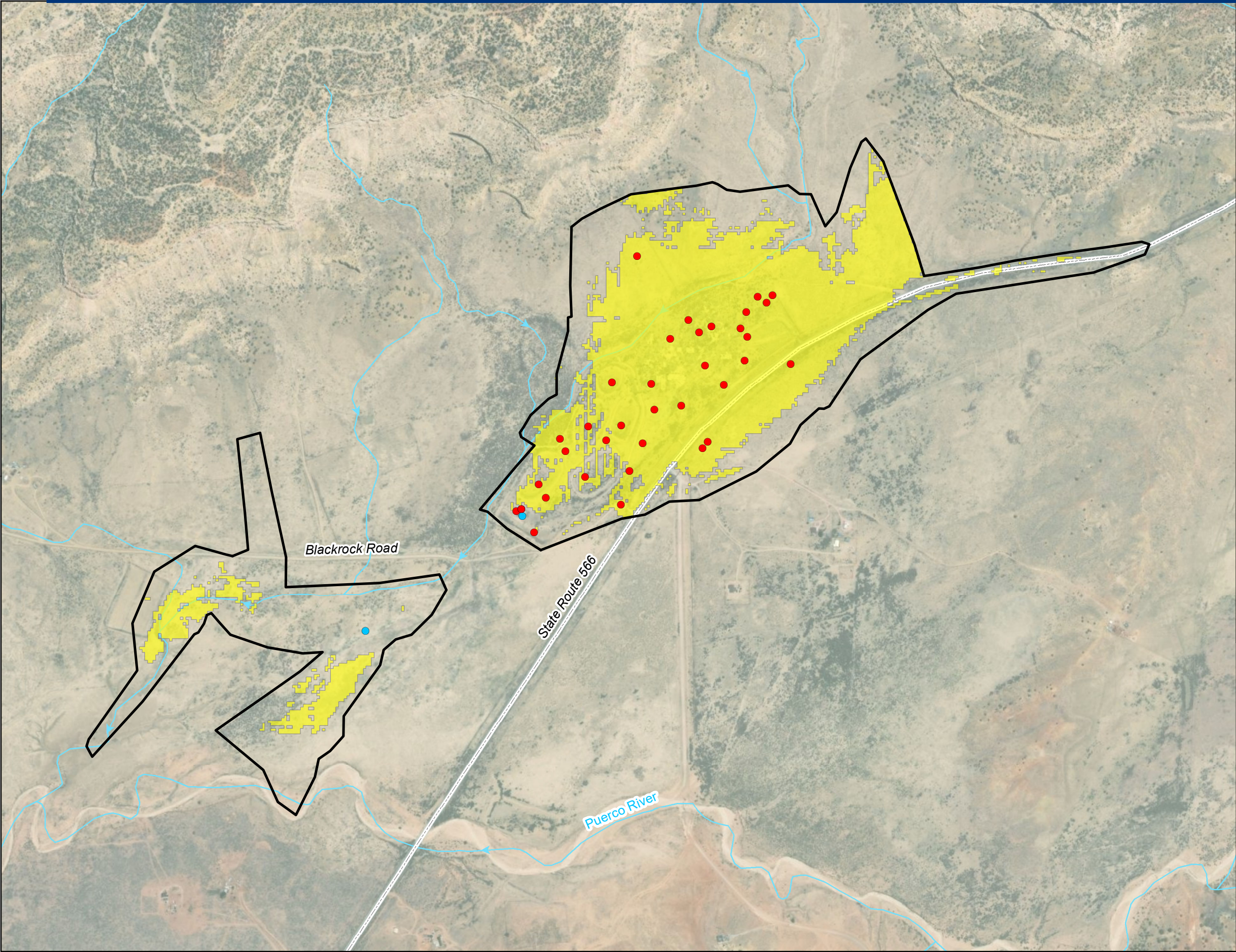


5.2.2 Model 1 Estimated Extent of Ra-226 Contamination

Total areal extent of estimated Ra-226 above 2 pCi/g by application of Model 1 is 125 acres. Both soil samples containing less than 2 pCi/g of Ra-226 were not within that areal extent (100 percent exclusion rate). Thirty-two of the 36 samples containing 2 pCi/g or greater of Ra-226 were within the footprint (89 percent containment rate). [Figure E-17](#) is a visual representation of these results.

Total areal extent of estimated Ra-226 above 5 pCi/g by application of Model 1 is 56 acres. Ten of the 11 soil samples containing less than 5 pCi/g of Ra-226 were outside the 5 pCi/g cleanup extent (91 percent exclusion rate). Twenty-five of the 27 samples containing 5 pCi/g or greater of Ra-226 were within the footprint (93 percent containment rate). [Figure E-18](#) is a visual representation of these results.

Total areal extent of estimated Ra-226 above 15 pCi/g by application of Model 1 is 29 acres. Thirteen of the 14 soil samples containing less than 15 pCi/g of Ra-226 were outside the 15 pCi/g cleanup extent (93 percent exclusion rate). Twenty-one the 24 samples containing 15 pCi/g or greater of Ra-226 were within the footprint (88 percent containment rate). [Figure E-19](#) is a visual representation of these results.



Observed Soil Radium-226 Validation Sample (pCi/g)

- ≤ 2.0
- > 2.0
- Predicted Removal Action Extent (≤ 2.0 pCi/g)
- ▭ Interpolation Boundary
- Community Road
- Surface Water Pathway¹

Notes:

¹All surface water pathways drain to the Puerco River.

pCi/g Picocurie per gram

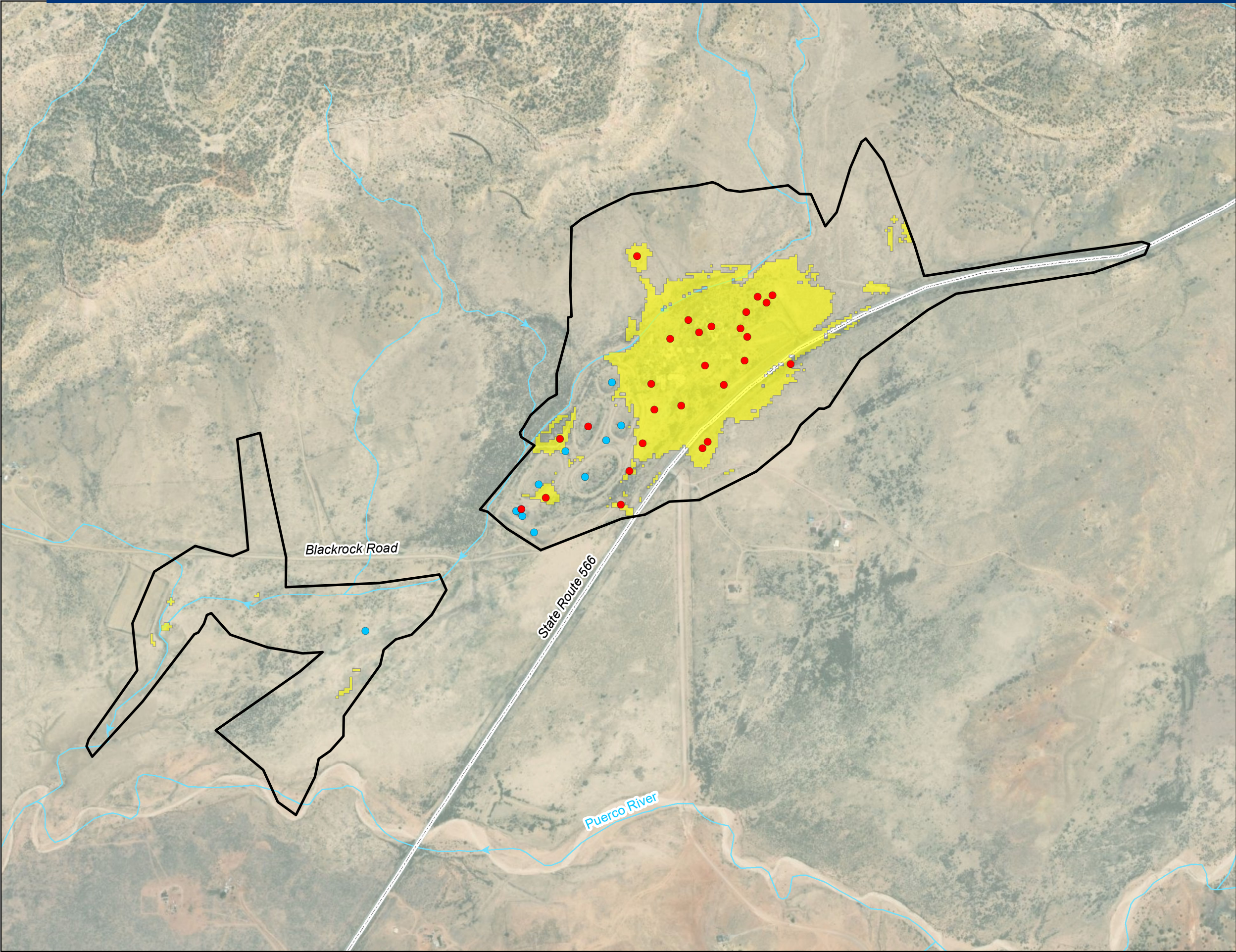
1 inch = 800 feet

1:9,600

0 400 800 1,600 Feet

**OLD CHURCH ROCK MINE
AREAL EXTENT OF
ESTIMATED RADIUM-226
ABOVE 2 pCi/g (MODEL 1)**

Prepared For: U.S. EPA Region 9 	Prepared By: TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: CHURCH ROCK CHAPTER NAVAJO NATION	Date: 8/21/2023
Coordinate System: NAD 1983 New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: E-17



Observed Soil Radium-226 Validation Sample (pCi/g)

- ≤ 5.0
- > 5.0
- Predicted Removal Action Extent (≤ 5.0 pCi/g)
- ▭ Interpolation Boundary
- Community Road
- Surface Water Pathway¹

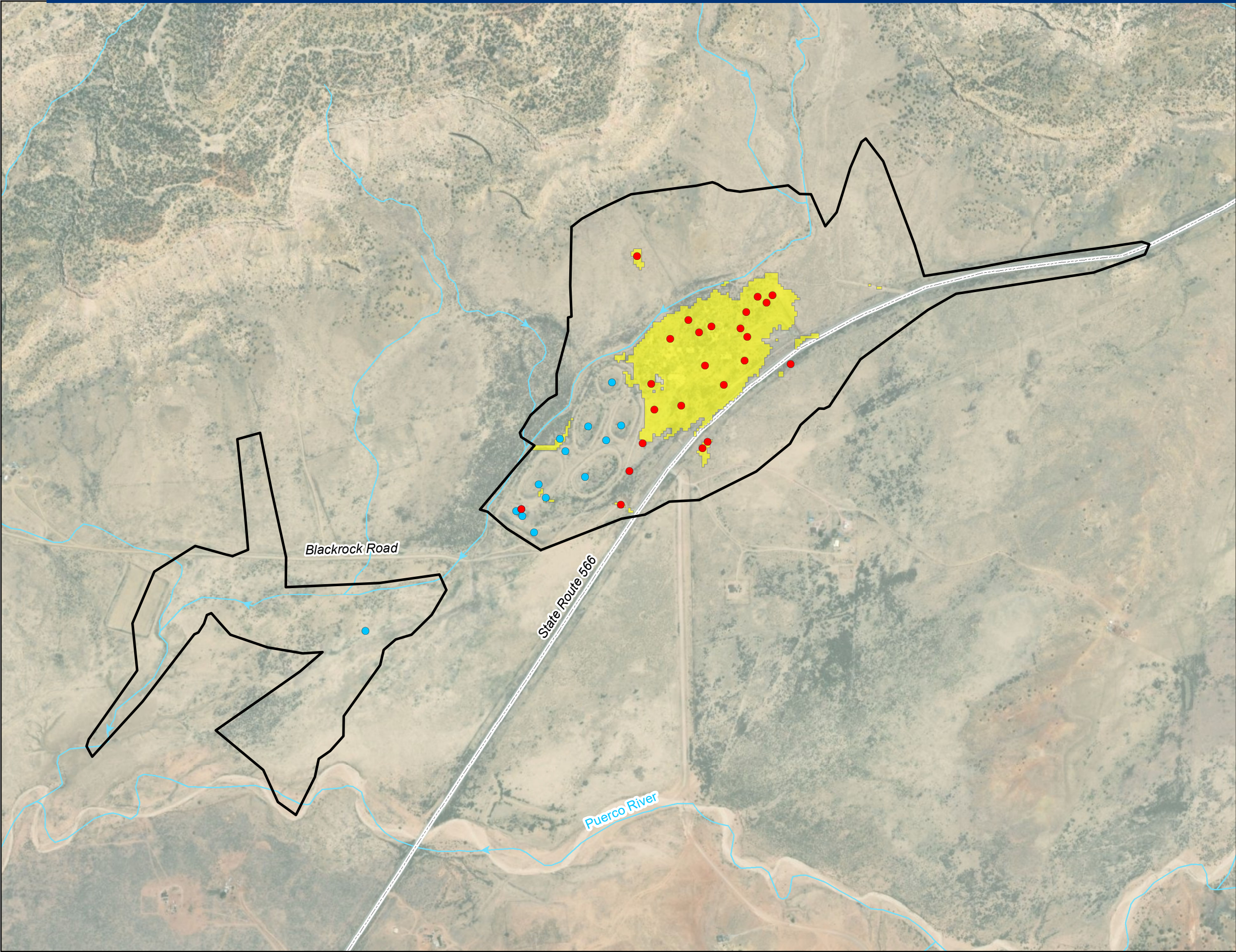
Notes:
¹All surface water pathways drain to the Puerco River.
pCi/g Picocurie per gram

1 inch = 800 feet
1:9,600

0 400 800 1,600 Feet

**OLD CHURCH ROCK MINE
AREAL EXTENT OF
ESTIMATED RADIUM-226
ABOVE 5 pCi/g (MODEL 1)**

Prepared For: U.S. EPA Region 9 	Prepared By: TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: CHURCH ROCK CHAPTER NAVAJO NATION	Date: 8/21/2023
Coordinate System: NAD 1983 New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: E-18



Observed Soil Radium-226 Validation Sample (pCi/g)

- ≤ 15
- > 15
- Predicted Removal Action Extent (≤ 15.0 pCi/g)
- ▭ Interpolation Boundary
- Community Road
- Surface Water Pathway¹

Notes:
¹All surface water pathways drain to the Puerco River.
pCi/g Picocurie per gram

1 inch = 800 feet
1:9,600

0 400 800 1,600 Feet

N
W E
S

**OLD CHURCH ROCK MINE
AREAL EXTENT OF
ESTIMATED RADIUM-226
ABOVE 15 pCi/g (MODEL 1)**

Prepared For: U.S. EPA Region 9 	Prepared By: TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: CHURCH ROCK CHAPTER NAVAJO NATION	Date: 8/21/2023
Coordinate System: NAD 1983 New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: E-19

5.3 MODEL 2: TRADITIONAL LINEAR REGRESSION WITH ONLY DATA PAIRS WITH LESS THAN 19,000 CPM INCLUDED

The following subsections discuss Model 2.

5.3.1 Overview of Model 2

Model 2 is classified as a traditional linear model with only data pairs where the average unshielded gamma count rate less than 19,000 cpm was included. [Table E-19](#) lists the data pairs included or excluded for Model 2. [Figure E-20](#) depicts the regression analysis that represents Model 2. The following equation was used to convert gamma count rate to Ra-226 for Model 2:

$$^{226}\text{Ra} \left(\frac{\text{pCi}}{\text{g}} \right) = (0.000359 * [\text{Gamma Count Rate (cpm)}]) - 3.134047$$

Table E-19. Model 2 Traditional Linear Data Pair Inclusion/Exclusion

Correlation Plot ID	Average Unshielded Walkover Gamma Count Rate (cpm)	Radium-226 (pCi/g)	Final Qualifiers	Model 2 Inclusion
OCRM-CORR01	13,392	1.51	H	Included
OCRM-CORR02	11,871	1.24	--	Included
OCRM-CORR03	11,474	1.12	--	Included
OCRM-CORR04	15,643	1.95	--	Included
OCRM-CORR05	16,863	3	N	Included
OCRM-CORR06	16,341	3.02	C	Included
OCRM-CORR07	18,046	3.53	--	Included
OCRM-CORR08	18,463	3.45	B, C	Included
OCRM-CORR09	21,633	2.75	--	Excluded
OCRM-CORR10	24,340	3.41	H	Excluded
OCRM-CORR11	19,010	1.6	--	Excluded
OCRM-CORR12	30,350	2.25	B, C, G, H, J, K, N	Excluded
OCRM-CORR13	37,722	17	--	Excluded
OCRM-CORR14	35,866	17.4	E	Excluded
OCRM-CORR15	30,547	10.7	--	Excluded

Notes:

-- No qualifier
 cpm Counts per minute
 pCi/g Picocurie per gram

The number of negative values resulting from application of Model 2 was significantly less than from application of Model 1. Via Model 2, all data less than ~8,729 cpm is converted to a negative Ra-226 value. This results in 682 of 260,946 measurements being converted to negative Ra-226 values for the full dataset, and 226 of 238,185 measurements converted to negative Ra-226 values from the dataset used for the kriging.

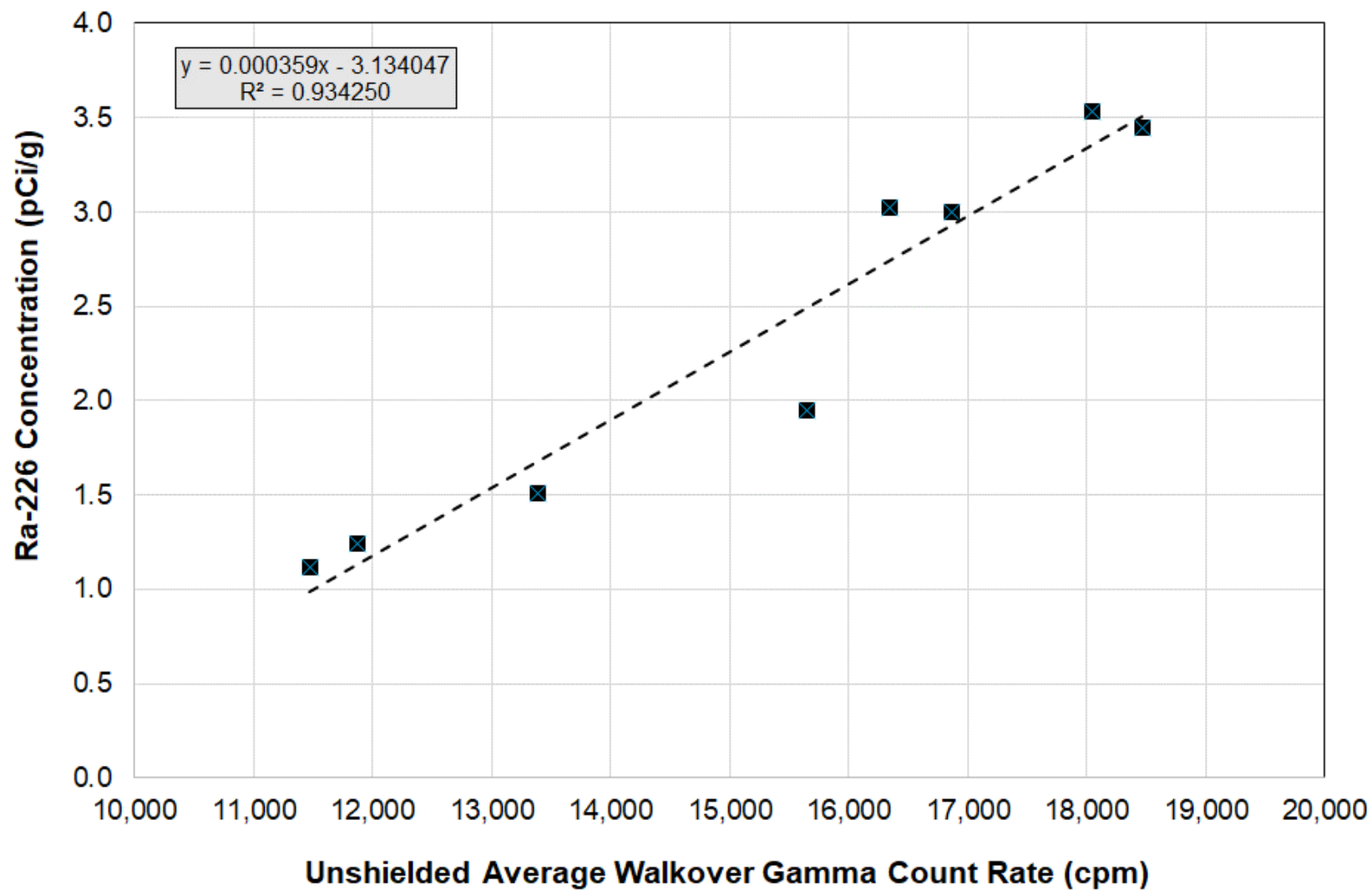


Figure E-20. Gamma-Radium Correlation, Linear Regression – Model 2

Table E-20 lists gamma equivalent values of Ra-226 concentrations as derived from Model 2.

Table E-20. Summary of Model 2 Gamma Cutoff Values

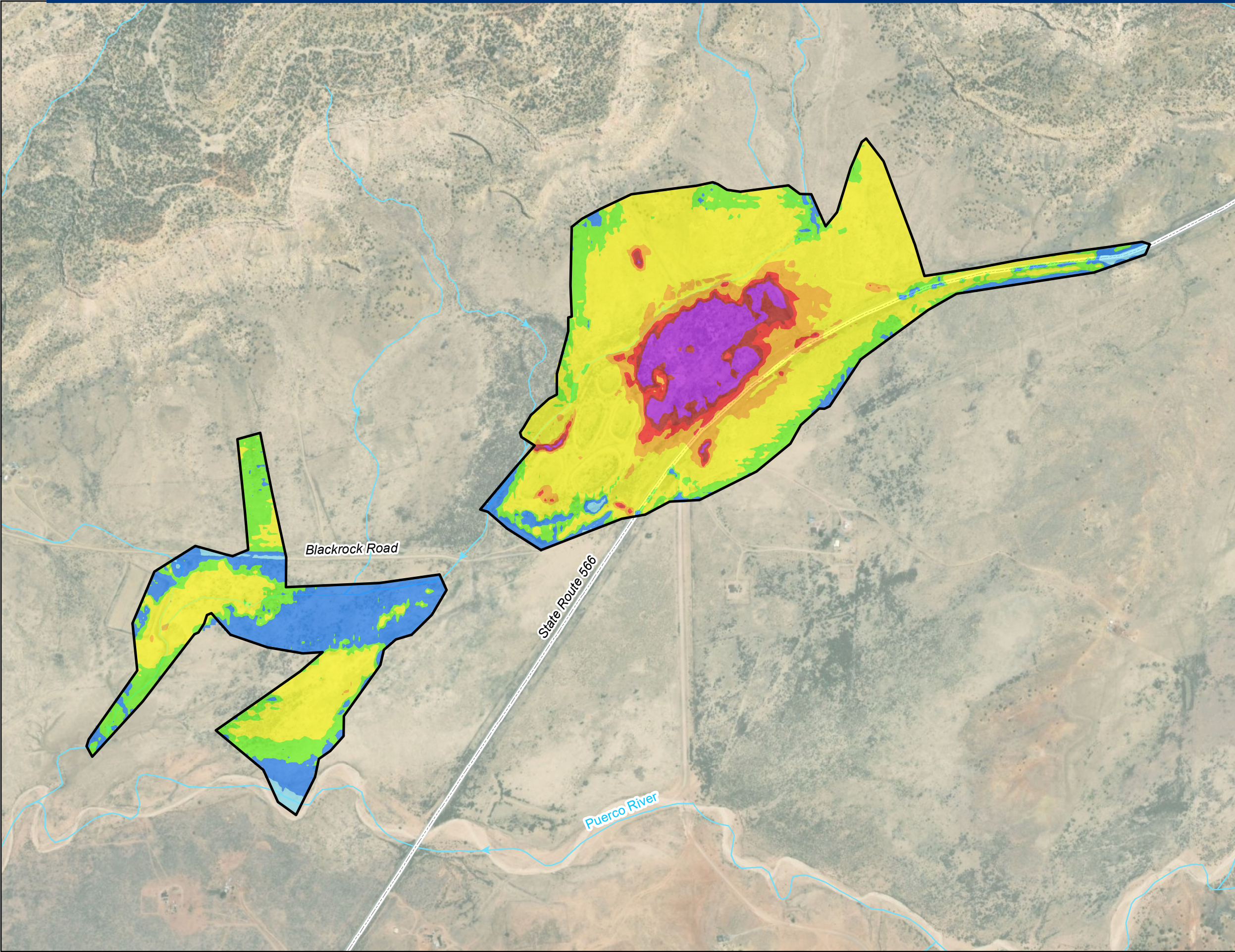
Ra-226 Concentration (pCi/g)	Model 2 Cutoff Value (cpm)
2	14,301
5	22,658
10	36,585
15	50,513
25	78,368

Notes:

cpm Counts per minute

pCi/g Picocuries per gram

Figure E-21 is an interpolated map of the gamma data collected at the site converted to estimated Ra-226 concentrations in pCi/g by application of Model 2.



Estimated Radium-226 Surface Soil Concentration (pCi/g)

- ≤ 0.8
- 0.8 - 1.6
- 1.6 - 2.0
- 2.0 - 5.0
- 5.0 - 10
- 10 - 15
- 15 - 25
- > 25

Interpolation Boundary

Community Road

Surface Water Pathway¹

Notes:

¹All surface water pathways drain to the Puerco River.

pCi/g Picocurie per gram

1 inch = 800 feet

1:9,600

0 400 800 1,600 Feet

**OLD CHURCH ROCK MINE
ESTIMATED RADIUM-226
SOIL CONCENTRATION
(MODEL 2)**

Prepared For: U.S. EPA Region 9

Prepared By:

TETRA TECH
1999 Harrison Street, Suite 500
Oakland, CA 94612

Task Order No.:
0016

Contract No.:
EP-S9-17-03

Location:
CHURCH ROCK CHAPTER
NAVAJO NATION

Date:
8/21/2023

Coordinate System:
NAD 1983 New Mexico West FIPS
3003 Feet Transverse Mercator

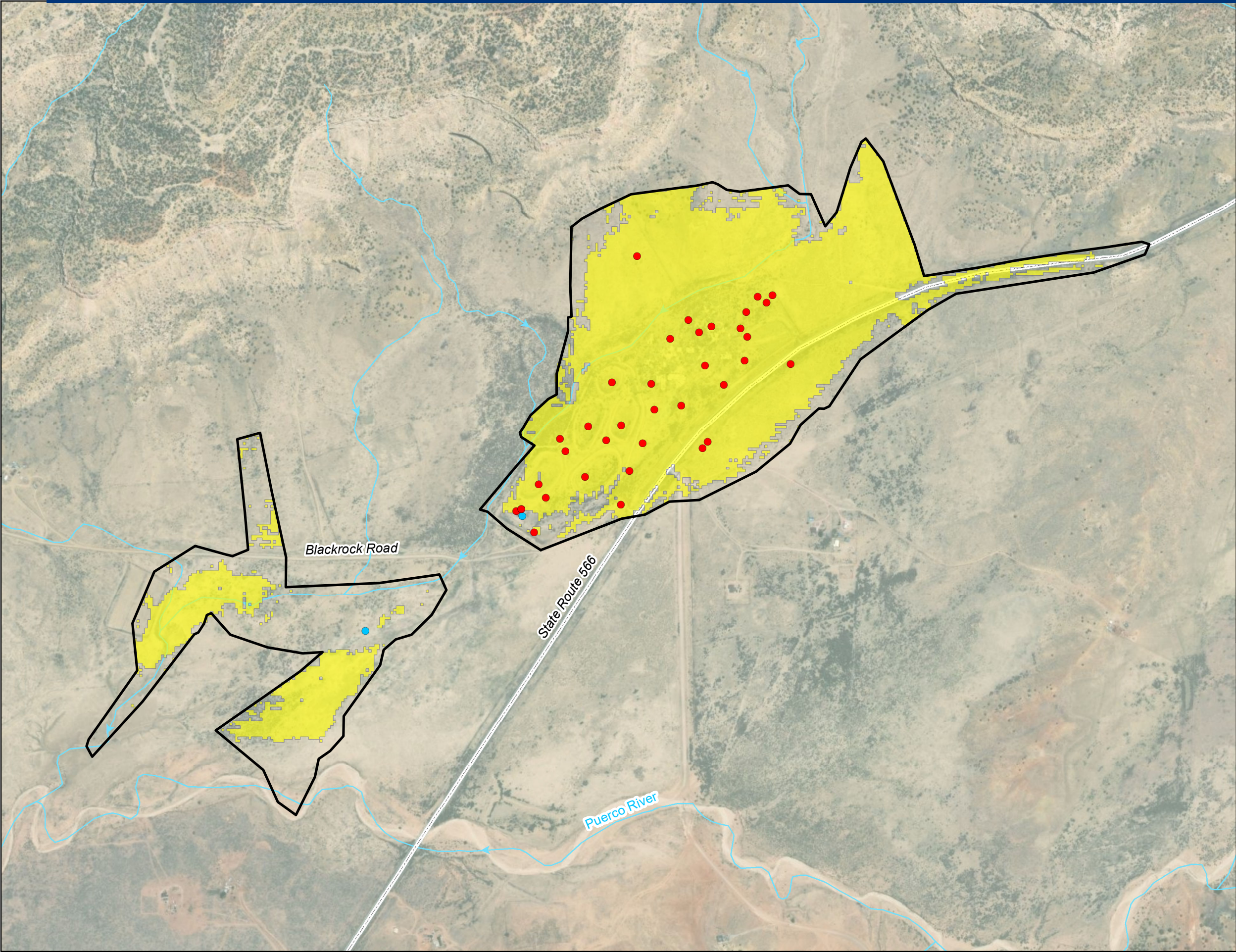
Figure No.:
E-21

5.3.2 Model 2 Estimated Extent of Ra-226 Contamination

Total areal extent of estimated Ra-226 above 2 pCi/g by application of Model 2 is 171 acres. Both soil samples containing less than 2 pCi/g of Ra-226 were not within the areal extent (100 percent exclusion rate). Thirty-five of the 36 samples containing 2 pCi/g or greater of Ra-226 were within the footprint (97 percent containment rate). [Figure E-22](#) is a visual representation of these results.

Total areal extent of estimated Ra-226 above 5 pCi/g by application of Model 2 is 46 acres. All 11 soil samples containing less than 5 pCi/g of Ra-226 were outside the 5 pCi/g cleanup extent (100 percent exclusion rate). Twenty-four of the 27 samples containing 5 pCi/g or greater of Ra-226 were within the footprint (89 percent containment rate). [Figure E-23](#) is a visual representation of these results.

Total areal extent of estimated Ra-226 above 15 pCi/g by application of Model 2 is 22 acres. Thirteen of the 14 soil samples containing less than 15 pCi/g of Ra-226 were outside the 15 pCi/g cleanup extent (93 percent exclusion rate). Twenty of the 24 samples containing 15 pCi/g or greater of Ra-226 were within the footprint (83 percent containment rate). [Figure E-24](#) is a visual representation of these results.



Observed Soil Radium-226 Validation Sample (pCi/g)

- ≤ 2.0
- > 2.0

■ Predicted Removal Action Extent (≤ 2.0 pCi/g)

▬ Interpolation Boundary

----- Community Road

→ Surface Water Pathway¹

Notes:

¹All surface water pathways drain to the Puerco River.

pCi/g Picocurie per gram

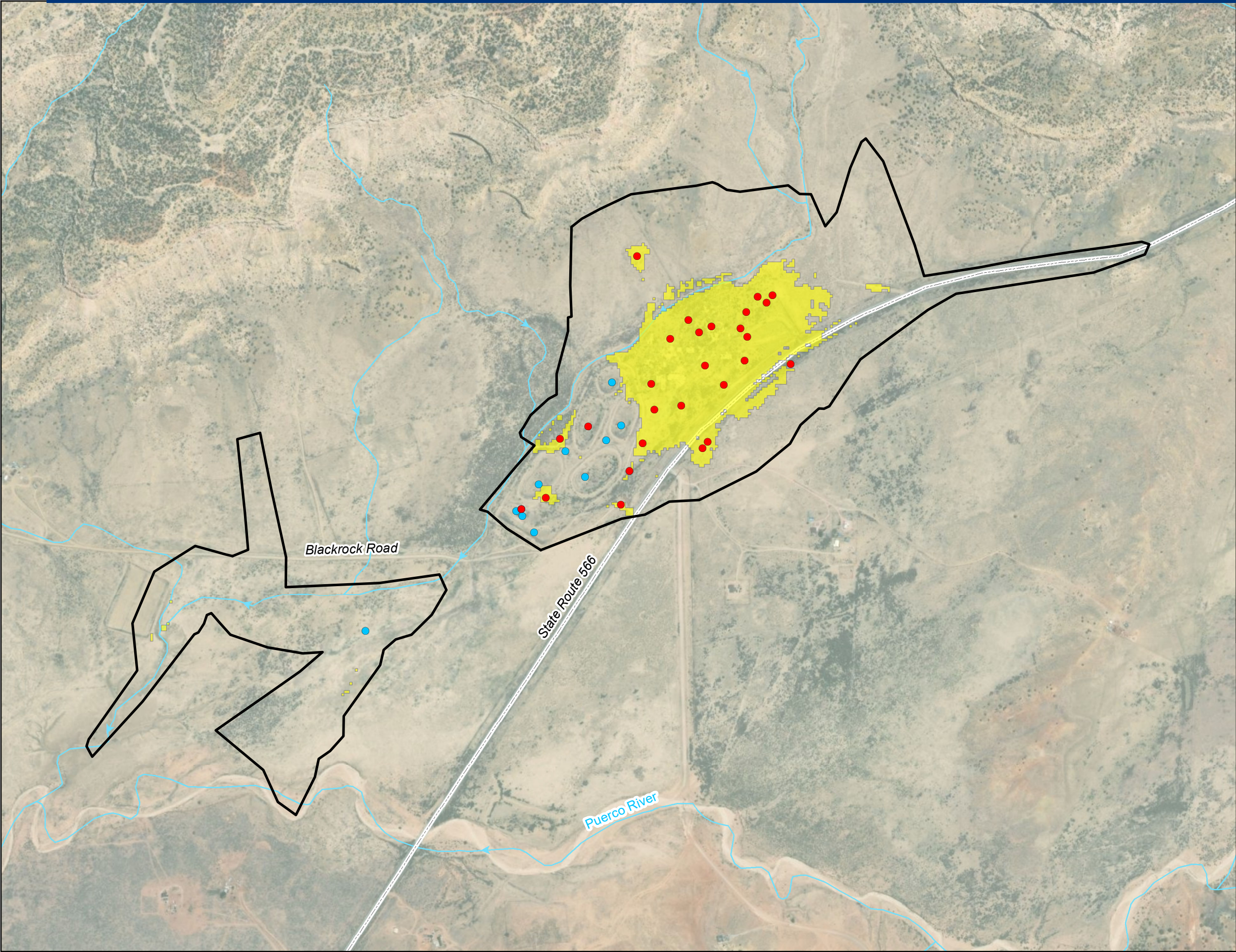
1 inch = 800 feet

1:9,600

0 400 800 1,600 Feet

**OLD CHURCH ROCK MINE
AREAL EXTENT OF
ESTIMATED RADIUM-226
ABOVE 2 pCi/g (MODEL 2)**

Prepared For: U.S. EPA Region 9	Prepared By:
	TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: CHURCH ROCK CHAPTER NAVAJO NATION	Date: 8/21/2023
Coordinate System: NAD 1983 New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: E-22



Observed Soil Radium-226 Validation Sample (pCi/g)

- ≤ 5.0
- > 5.0
- Predicted Removal Action Extent (≤ 5.0 pCi/g)
- ▭ Interpolation Boundary
- Community Road
- Surface Water Pathway¹

Notes:

¹All surface water pathways drain to the Puerco River.

pCi/g Picocurie per gram

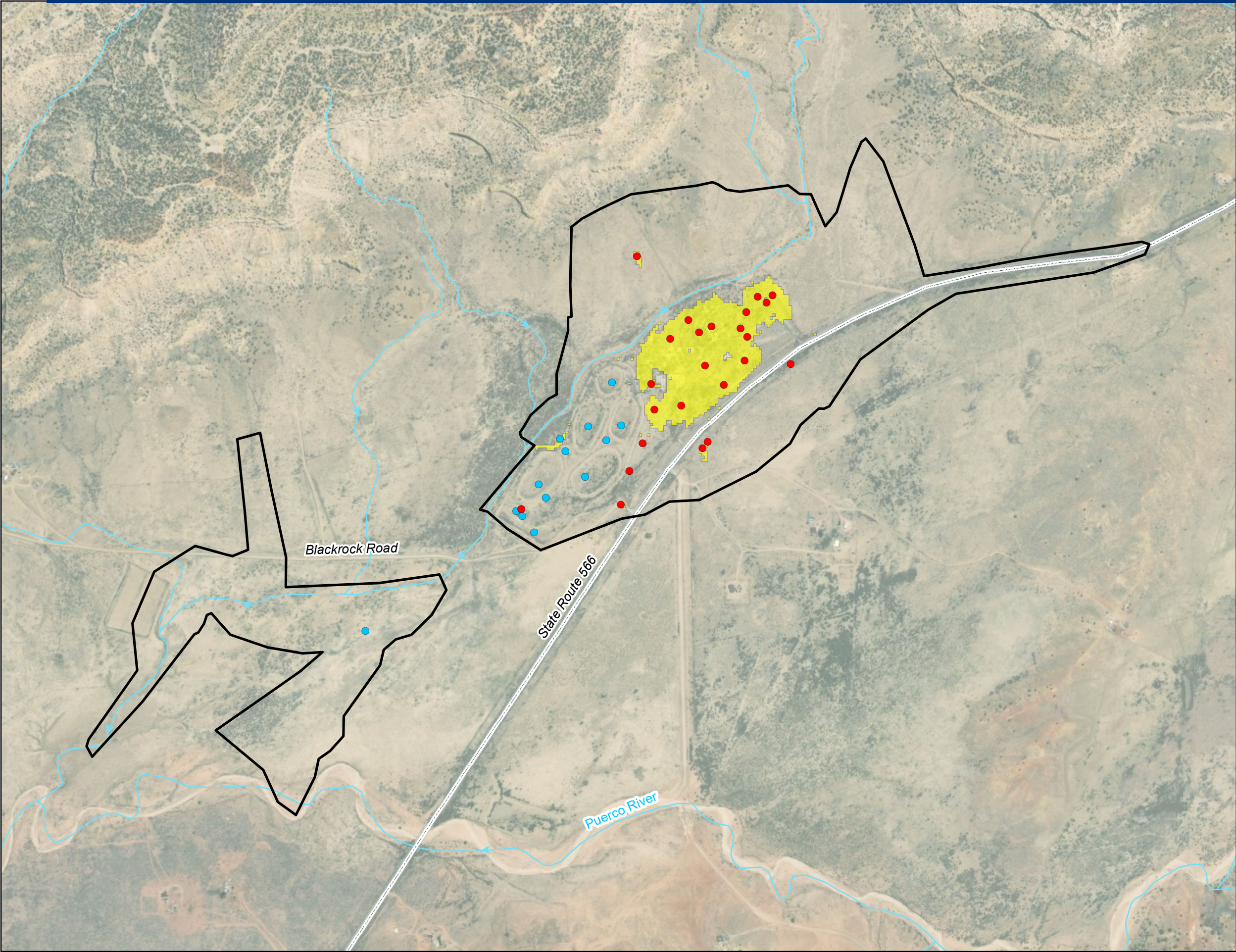
1 inch = 800 feet

1:9,600

0 400 800 1,600 Feet

**OLD CHURCH ROCK MINE
AREAL EXTENT OF
ESTIMATED RADIUM-226
ABOVE 5 pCi/g (MODEL 2)**

Prepared For: U.S. EPA Region 9 	Prepared By: TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: CHURCH ROCK CHAPTER NAVAJO NATION	Date: 8/21/2023
Coordinate System: NAD 1983 New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: E-23



Observed Soil Radium-226 Validation Sample (pCi/g)

- ≤ 15
- > 15
- Predicted Removal Action Extent (≤ 15.0 pCi/g)
- ▭ Interpolation Boundary
- Community Road
- Surface Water Pathway¹

Notes:
¹All surface water pathways drain to the Puerco River.
pCi/g Picocurie per gram

1 inch = 800 feet
1:9,600

0 400 800 1,600 Feet

**OLD CHURCH ROCK MINE
AREAL EXTENT OF
ESTIMATED RADIUM-226
ABOVE 15 pCi/g (MODEL 2)**

Prepared For: U.S. EPA Region 9 	Prepared By: TETRA TECH 1999 Harrison Street, Suite 500 Oakland, CA 94612
Task Order No.: 0016	Contract No.: EP-S9-17-03
Location: CHURCH ROCK CHAPTER NAVAJO NATION	Date: 8/21/2023
Coordinate System: NAD 1983 New Mexico West FIPS 3003 Feet Transverse Mercator	Figure No.: E-24

6.0 MODEL SELECTION

This section discusses determination whether Model 1 or Model 2 is a better fit for future use at the site.

6.1 MODEL COMPARISON ANALYSIS

This section compares Model 1 and Model 2 by analyzing gamma cutoff values and gamma regressions of each, and conducting a containment analysis of each model.

6.1.1 Gamma Cutoff Analysis

Table E-21 lists gamma equivalents for both models at various Ra-226 concentrations that may be useful for future cleanup efforts. Model 2 yields a lower gamma equivalent cutoff value only when estimated Ra-226 concentration is very low (close to background).

Table E-21. Ra-226 Concentration Equivalent Gamma Cutoff Values

Ra-226 Concentration (pCi/g)	Gamma Cutoff Value (cpm)	
	Model 1	Model 2
2	15,847	14,301
5	20,617	22,658
10	28,566	36,585
15	36,515	50,513
25	52,413	78,368

Notes:

cpm Counts per minute
pCi/g Picocurie per gram

6.1.2 Gamma Regression Analysis

Figure E-25 is a plot of both Model 1 and Model 2 regressions on the same axis. Confirming information conveyed in Section 6.1.1, Model 2 is a more conservative model, predicting a higher Ra-226 concentration when the gamma count rate is lower. The intersection point of the two Models is 17,903 cpm, at which both models estimate a Ra-226 concentration of 3.3 pCi/g. Above this point, for any given gamma count rate, Model 1 is more conservative and will estimate a higher Ra-226 concentration.

Visually, Model 1 is more accurate when estimating Ra-226 at higher concentrations. Model 2 on the other hand underpredicts Ra-226 at higher levels. The inverse is true for visual assessment of lower concentrations, with Model 1 estimating negative concentrations of Ra-226 when lab results indicate concentrations in the range of 1 pCi/g.

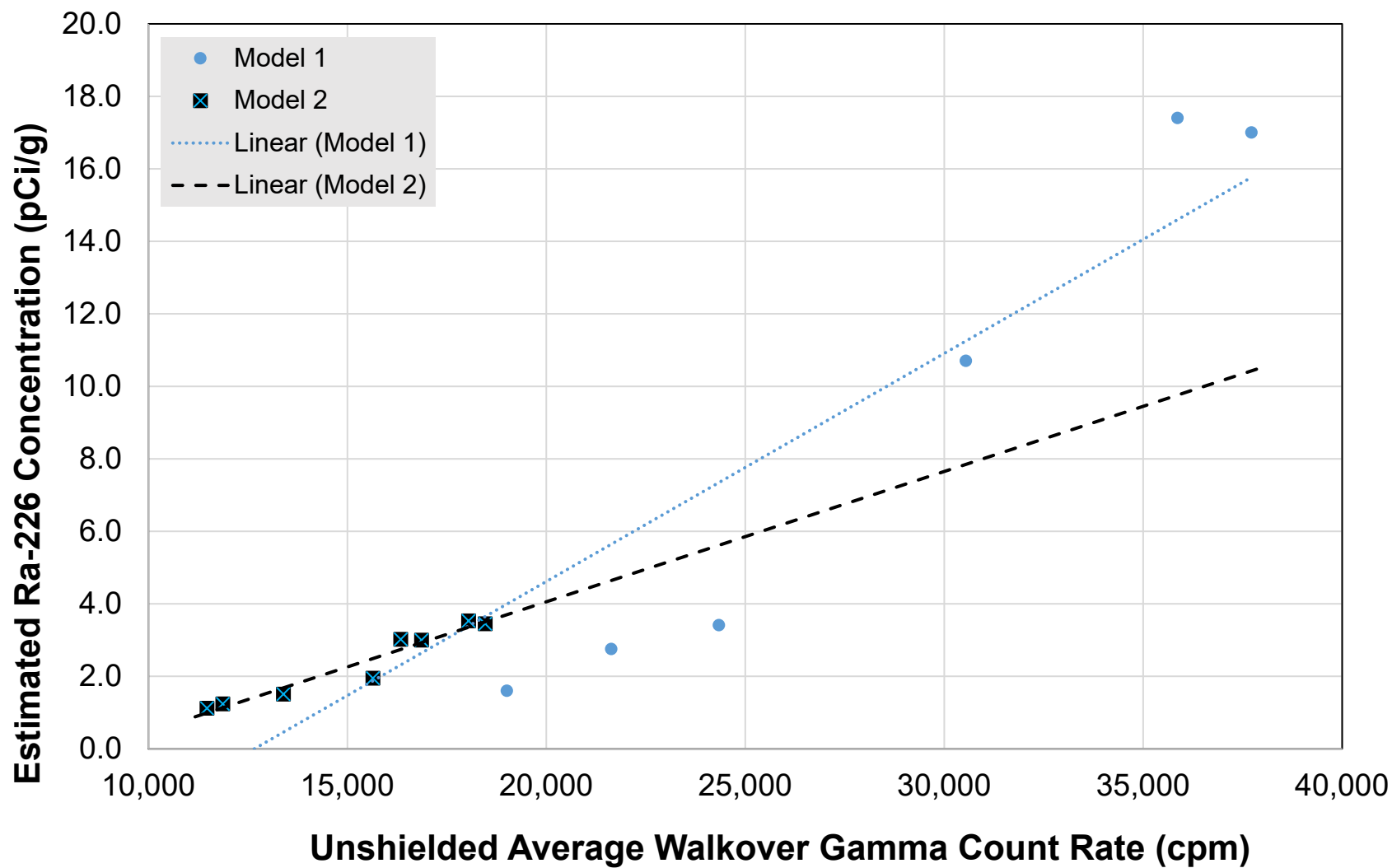


Figure E-25. Gamma-Radium Correlation Model Regression Comparison

6.1.3 Containment Analysis

Separate from the 15 correlation composite samples collected during the OCRM removal assessment, 38 soil samples were collected around the site and analyzed for Ra-226. Each of these samples was collected within an area for which walkover gamma data were available.

[Table E-22](#) through [Table E-24](#) summarize the containment analysis of site soil samples via applications of Model 1 and Model 2, as discussed in [Section 5.2.2](#) and [Section 5.3.2](#), respectively.

Model 2 yielded a greater containment rate of samples exceeding a threshold of 2 pCi/g, with only one sample being improperly contained (97 percent containment rate), whereas Model 1 yielded an 89 percent containment rate. Both Model 1 and Model 2 demonstrated a 100 percent exclusion rate of samples below a threshold of 2 pCi/g.

Model 1 yielded a greater containment rate of samples exceeding thresholds of 5 and 15 pCi/g, with containment rates of 93 percent and 88 percent, respectively. Model 2 yielded containment rates of 89 percent and 83 percent for the same thresholds. Model 2 demonstrated a slightly better exclusion rate of samples lower than 5 pCi/g (100 percent), with Model 1 improperly containing one sample, resulting in an exclusion rate of 93 percent at a threshold of 5 pCi/g. Both Models yielded a 100 percent exclusion rate of samples below a threshold of 15 pCi/g.

Table E-22. Containment Analysis at 2 pCi/g Ra-226

Model	Acres	# ≥ 2.0 pCi/g	# ≥ 2.0 pCi/g Contained	# ≥ 2.0 pCi/g Excluded	Contained %	# < 2.0 pCi/g	# < 2.0 pCi/g Contained	# < 2.0 pCi/g Excluded	Excluded %
Model 1	125	36	32	4	89%	2	0	2	100%
Model 2	171	36	35	1	97%	2	0	2	100%

Notes:

pCi/g Picocurie per gram

Ra-226 Radium-226

Table E-23. Containment Analysis at 5 pCi/g Ra-226

Model	Acres	# ≥ 5.0 pCi/g	# ≥ 5.0 pCi/g Contained	# ≥ 5.0 pCi/g Excluded	Contained %	# < 5.0 pCi/g	# < 5.0 pCi/g Contained	# < 5.0 pCi/g Excluded	Excluded %
Model 1	56	27	25	2	93%	11	1	10	91%
Model 2	46	27	24	3	89%	11	0	11	100%

Notes:

pCi/g Picocurie per gram

Ra-226 Radium-226

Table E-24. Containment Analysis at 15 pCi/g Ra-226

Model	Acres	# ≥ 15.0 pCi/g	# ≥ 15.0 pCi/g Contained	# ≥ 15 pCi/g Excluded	Contained %	# < 15.0 pCi/g	# < 15.0 pCi/g Contained	# < 15.0 pCi/g Excluded	Excluded %
Model 1	29	24	21	3	88%	14	1	13	93%
Model 2	22	24	20	4	83%	14	1	13	93%

Notes:

pCi/g Picocurie per gram

Ra-226 Radium-226

6.2 FINAL SELECTION

Two modeling approaches were considered to predict Ra-226 soil concentrations at the site, described in [Section 5.0](#) and compared in [Section 6.1](#). It is important to carefully consider selection of an appropriate model that better represents actual ground conditions to avoid both potential cost of unnecessary cleanup and potential hazards related to contamination left in place.

Model 2 demonstrated better capabilities than Model 1 of estimating Ra-226 at concentrations closer to background. Model 1 demonstrated better capabilities than Model 2 of estimating Ra-226 at concentrations above background. The two models shared an intersection point of 17,903 cpm, which equates to 3.3 pCi/g Ra-226.

Because both models demonstrate better performance in different regions of Ra-226 concentration, combining both models into a hybrid model would entail advantages of characteristic benefits from both models. To generate a continuous function, the point at which the hybrid model changes regressions should be set to the point at which the two models intersect, which is at 17,903 cpm.

This hybrid model can be implemented such that Model 2 is applied when estimating Ra-226 concentrations lower than 3.3 pCi/g, and Model 1 is applied when estimating Ra-226 concentrations greater than or equal to 3.3 pCi/g.

[Figure E-26](#) is a visual representation of the final hybrid model recommended for the site, including the breakpoint between Model 1 and Model 2.

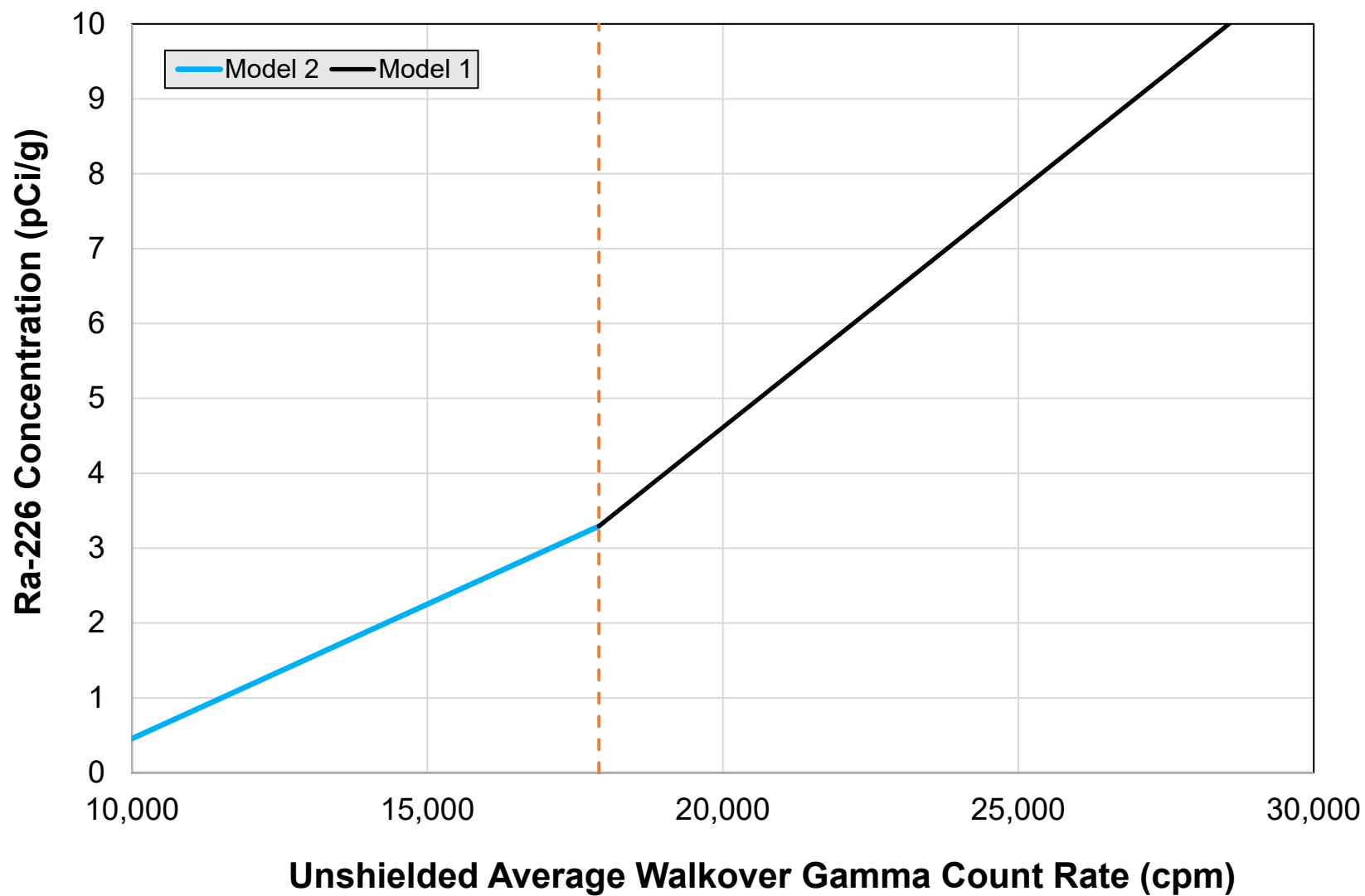


Figure E-26. Final Hybrid Model Selection (Red Dotted Line Shows Break Point Between Model 1 and Model 2)

7.0 CONCLUSIONS

Studies within 15 100-square-meter plots at the site included gamma walkover surveys, static gamma surveys co-located with HPIC surveys, visual observations, and composite soil sampling. One of the correlation plots was not used in development of all correlations.

From the remaining 14 correlation plots at the site, two models were developed correlating raw gamma radiation count measurements to Ra-226 analytical results. These models could be combined into a single hybrid model that changes regressions around the models' intersection point.

- Model 1 ($R^2 = 0.88$) is best used when estimating Ra-226 concentrations in areas of higher gamma radiation (greater than or equal to 17,903 cpm).

$$^{226}\text{Ra} \left(\frac{\text{pCi}}{\text{g}} \right) = (0.000629 * [\text{Gamma Count Rate (cpm)}]) - 7.967955$$

- Model 2 ($R^2 = 0.93$) is best used when estimating Ra-226 concentrations in areas of gamma radiation close to background (less than 17,903 cpm).

$$^{226}\text{Ra} \left(\frac{\text{pCi}}{\text{g}} \right) = (0.000359 * [\text{Gamma Count Rate (cpm)}]) - 3.134047$$

From the remaining 14 correlation plots at the site, a single model was developed correlating raw gamma radiation count measurements to exposure rate measurements ($R^2 = 0.98$).

$$\text{Gamma Exposure} \left(\frac{\mu\text{R}}{\text{hr}} \right) = (0.000482 * [\text{Gamma Count Rate (cpm)}]) + 9.724779$$

Table E-25 summarizes recommended gamma cutoff values by application of the appropriate Model for the given range, along with equivalent exposure rates.

Table E-25. Summary of Ra-226 Estimates

Ra-226 Concentration (pCi/g)	Recommended Gamma-Radium Model	Gamma Cutoff Value (cpm)	Exposure Rate (μR/hr)
2	Model 2	14,301	16.6
3.3	Model 1 & Model 2	17,903	18.4
5	Model 1	20,617	19.7
10	Model 1	28,566	23.5
15	Model 1	36,515	27.3
25	Model 1	52,413	35.0

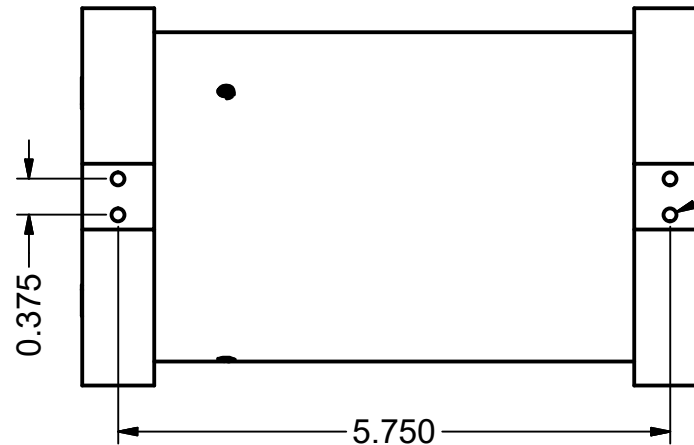
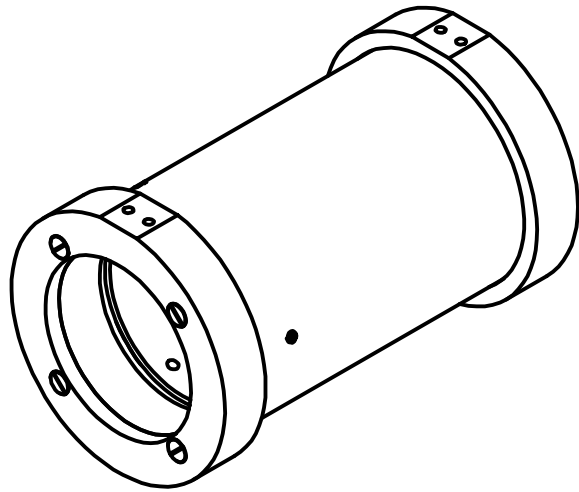
Notes:

μR/hr Microrentgen per hour
cpm Counts per minute
pCi/g Picocurie per gram

8.0 REFERENCES

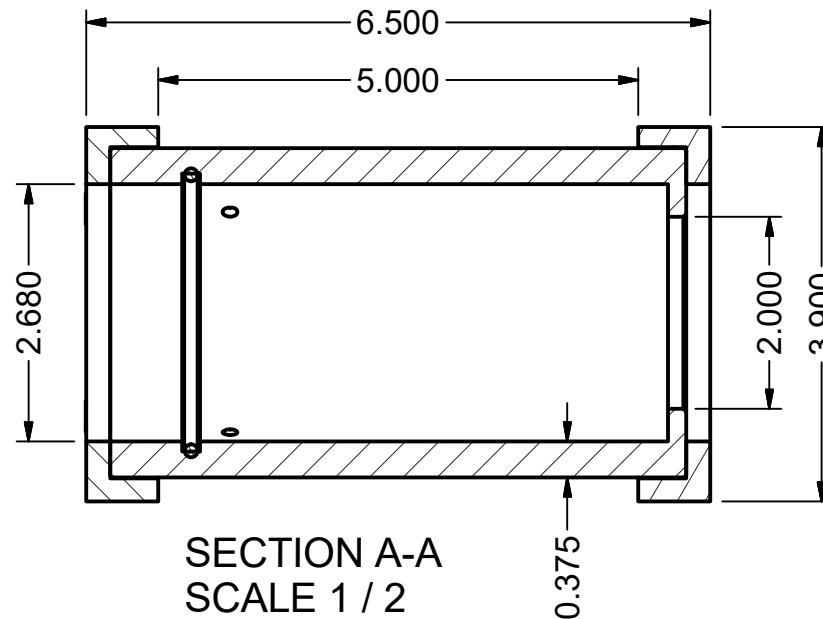
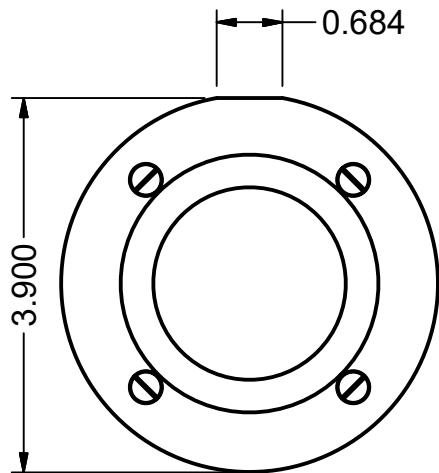
- Abelquist, Eric W. 2014. *Decommissioning Health Physics. A Handbook for MARSSIM Users. Second Edition.* 2014.
- Energy Fuels Resources Inc. (Energy Fuels). 2014. Evaluation of the Radiological Characteristics of Uranium Mine Waste Rock. March.
- Johnson, J.A., H.R. Meyer, and M. Vidyasagar. 2006. Characterization of Surface Soils at a Former Uranium Mill. *Health Physics* 90 (Suppl 1): S29-S32.
- Tetra Tech, Inc. (Tetra Tech). 2013. Tronox Bluff Waste Characterization Report, Riley Pass Abandoned Uranium Mines Site, North Cave Hills, Harding County, SD, Prepared for United States Department of Agriculture (USDA) Forest Service, Red Lodge, Montana.
- Tetra Tech. 2017a. Red Bluff Uranium Mine Radiological Investigation Report. Prepared for United States Forest Service, Tonto National Forest. April.
- Tetra Tech. 2017b. 2016 Riley Pass Abandoned Uranium Mine Verification Sampling Report Bluff F, Bluff G, and Bluff I. Prepared for United States Forest Service, Custer-Gallatin National Forest. August.
- Tetra Tech. 2019a. 2018 Riley Pass Abandoned Uranium Mine Waste Characterization Sampling Report Bluff A. Prepared for United States Forest Service, Custer-Gallatin National Forest. August.
- Tetra Tech. 2019b. Northern Agency Tronox Mines Removal Site Evaluation Report. Prepared for United States Environmental Protection Agency (EPA) Region 9. October.
- Thomas, V.W. and Kinnison, R.R. 1985. Recommended Sampling Strategies for Spatial Evaluation of Windblown Contamination Around Uranium Tailings Piles. Pacific Northwest Laboratory. Prepared for U.S. Nuclear Regulatory Commission (NRC). PNL-4830.
- United States Department of Agriculture (USDA). 2016. Action Memorandum – Riley Pass Uranium Mines Site Removal Action within the North Cave Hills Land Unit, Custer Gallatin National Forest – Sioux Ranger District, Harding County, South Dakota.
- United States Environmental Protection Agency (USEPA). 2000. *Multi-Agency Radiation Survey and Site Investigation Manual. (MARSSIM).* August.
- USEPA. 2004. *Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP).* July.
- Whicker R.P. and others. 2008. “Radiological Site Characterizations: Gamma Surveys, Gamma/Radium-226 Correlations, and Related Spatial Analysis Techniques.” *The Radiation Safety Journal* S180. November.

ATTACHMENT E-1: LUDLUM COLLIMATOR DESIGN

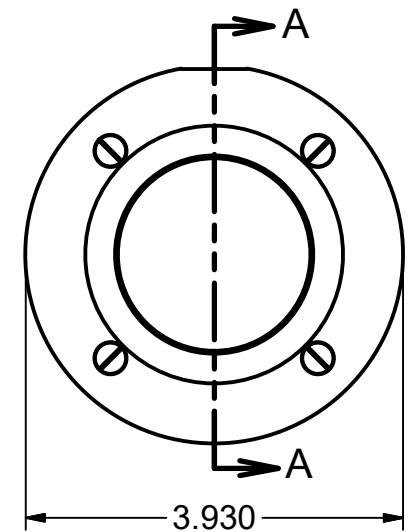


REVISION HISTORY			
REV	DESCRIPTION	DATE	BY
1	VALID	10/10/18	JWI

8-32 UNC X 0.500 DEEP
4 PLACES



SECTION A-A
SCALE 1 / 2



NOTES:
 DIMENSIONS SHOWN FOR 3/8" WALL DESIGN
 3/8" WALL DESIGN IS 9.6#
 1/2" WALL DESIGN IS 13.1#

DWN	DATE	CHK	DATE	APP	DATE
JWI	10/10/18				
DWG NUM: 4260-233				SCALE:	
TITLE M 44-10 COLLIMATOR ASSY					
LUDLUM MEASUREMENTS, INC. 501 OAK STREET SWEETWATER, TEXAS 79556		SERIES 260		SHEET 233	

**ATTACHMENT E-2: SOP 003: MAKING AN EXPOSURE RATE
MEASUREMENT USING AN HPIC**

Environmental Standard Operating Procedure

SOP No. 003

**Making Exposure Rate Measurements Using a
High Pressure Ionization Chamber (HPIC)**



Tetra Tech, Inc.

Environmental Restoration Group, Inc.



February 2018



CONTENTS

<u>Section</u>	<u>Page</u>
1.0 PURPOSE	1
2.0 PRECAUTIONS.....	1
3.0 EQUIPMENT AND MATERIALS	1
4.0 COMMUNICATION AND SETUP.....	1
4.1 COMMUNICATION	1
4.2 GENERAL SETTINGS.....	2
4.3 SENSOR CONFIGURATION.....	2
5.0 OPERATION	2
5.1 MAKE MEASUREMENT.....	2
5.2 VIEWING DATA IN REAL TIME.....	2
5.3 DOWNLOAD DATA	2



1.0 PURPOSE

This Standard Operating Procedure (SOP) describes a method for making exposure rate measurements using the GE-Energy Model RS-S131 High Pressure Ionization Chamber (HPIC), or similar.

An HPIC is a highly sensitive and stable detector for measuring gamma radiation exposure rates in air, in the unit milliroentgen per hour (mR/hr). These measurements often are made for comparison to, and/or correlation with, other gamma radiation detectors such as Ludlum Model 44-10 or Model 44-20 gamma scintillators.

To make project-related exposure rate measurements using an HPIC, personnel must be recognized on their ERG Training Qualification Form as qualified to perform this procedure.

2.0 PRECAUTIONS

- For shipping purposes the GE-Energy Model RS-S131 HPIC is considered Dangerous Goods, and must be shipped as such.

3.0 EQUIPMENT AND MATERIALS

The following equipment is required for making exposure rate measurements using a High Pressure Ionization Chamber (HPIC):

- A calibrated GE-Energy Model RSS-131 HPIC, or similar. NOTE: fully charge battery.
- Tripod
- Computer with Model RSS-131 software installed to communicate with HPIC.
- Cables, including USB to RS-232 cable, and others as necessary.

4.0 COMMUNICATION AND SETUP

Setup of the HPIC is an initial one-time step for a project. After setting this up on the computer it will not be necessary to perform again.

4.1 COMMUNICATION

1. Load the Model RS-S131 software on to the computer to be used with HPIC.
2. Connect the round 8-pin connector to COM2 on the HPIC and connect the 9-pin serial connector to COM1 on computer. *NOTE: A Serial to USB adaptor may be needed to make this connection since many computers have no serial port. It may be necessary to setup the Serial to USB adaptor as COM1 in the computer's Device Manager.*
3. Power on the HPIC using the ON/OFF toggle switch.
4. Open the Model RS-S131 Configuration Utility on the computer.
5. To change COM port settings select the **PC** menu, then **Serial Config...** option to open up the **Serial Setup** window. On the left side of the **Serial Setup** window is the **PC COM Port** options; choose



COM1. On the right side of the Serial Setup window is the **RS-S131 COM Port** Options; choose COM4. The **PC Baud rate** should be 9600 and **PC Parity** should be None.

6. When done with these settings click the **OK** button. Refer to the GE-Energy Model RS-S131 User's Manual for additional communication information.

4.2 GENERAL SETTINGS

To change the HPIC general use settings select the **Configuration** menu, then the **General...** option. The general use settings should be **Time Format** equal to mm/dd/yy, and **Radiation Label** equal to mR/hr.

4.3 SENSOR CONFIGURATION

If there is a need to adjust the recording interval of the HPIC measurements then select the **Configuration** menu, then the **Sensors** option to open the **Sensor Configuration** window. In the **Sensor Configuration** window select the **HPIC** tab and input the desired interval in the **Recording interval (sec)** box. *NOTE: The Sensor Configuration window is where the user may confirm that the Conversion factor set matches the unit's calibration sheet.*

5.0 OPERATION

The HPIC will log readings when powered on, regardless of whether it is connected to a computer. You may power the detector on/off as needed between locations.

5.1 MAKE MEASUREMENT

Power on the HPIC using the ON/OFF toggle switch. *NOTE: When the HPIC is powered on the exposure rate readings will be a dip, relative to the actual exposure rate. After approximately one minute the exposure rate readings will stabilize. The HPIC will continue to log exposure rate readings according to the logging settings as set in the Sensor Configuration. The project work plan may prescribe the measurement duration and/or logging interval, but if not then 5-minutes per location and an interval of 6-seconds is typically acceptable.* At each location where an HPIC measurement is made record the date, collection time, approximate measurement duration, and comments (any other pertinent information) in the logbook. When finished with making the measurement, power off the HPIC.

5.2 VIEWING DATA IN REAL TIME

Exposure rate readings can be viewed in real time through the RS-S131 Configuration Utility application. Select the **Online** menu, then the **Sensor Data...** option. The exposure rate in units of mR/hr will be displayed next to HPIC in the Sensor Values window. Another option for viewing data in real time is to select the **Online** menu, then the **Current Data...** option to open the **Current Data** window. When the **Current Data** window opens choose the HPIC in the Sensor drop down box and click the **Get Data** button. *NOTE: The exposure rate in mR/hr will be updated at the interval set in the Sensor Configuration.*

5.3 DOWNLOAD DATA

Upon completion of making measurements the data may be downloaded to the computer. From the **Online** menu select **Upload Sensor Data...** Option to open the Upload window. In the Upload window enter the **Start – Date** and **Time**, and the **End – Date** and **Time** in mm/dd/yyyy and hh:mm format. Do this

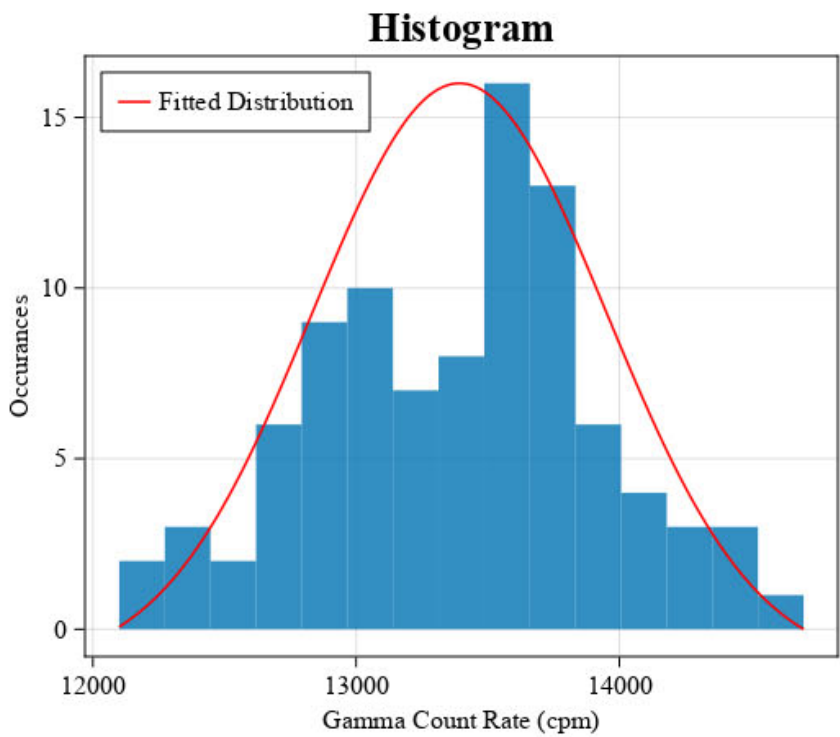
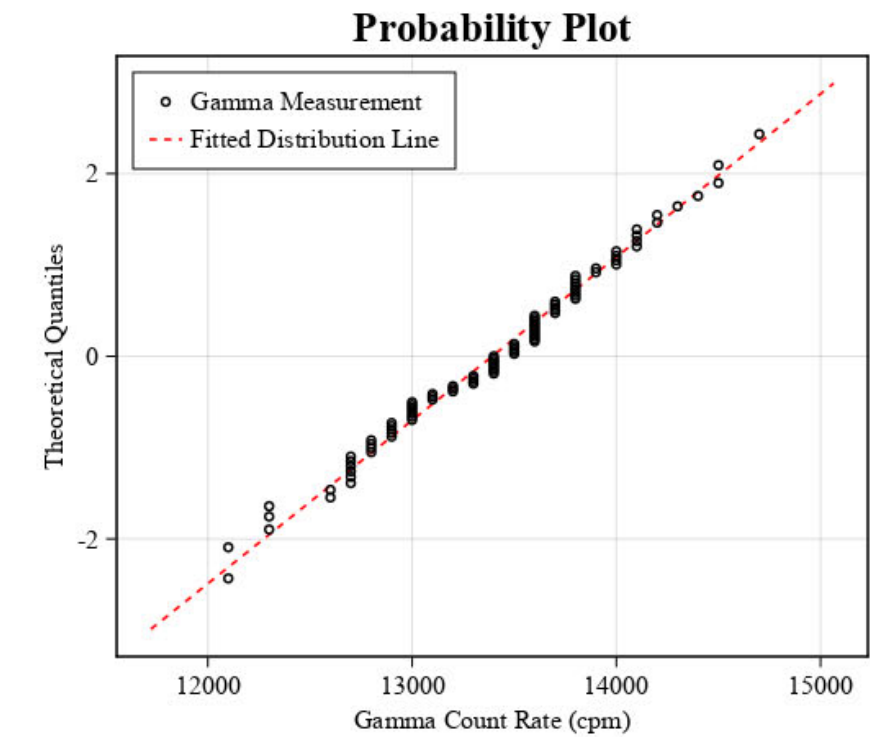
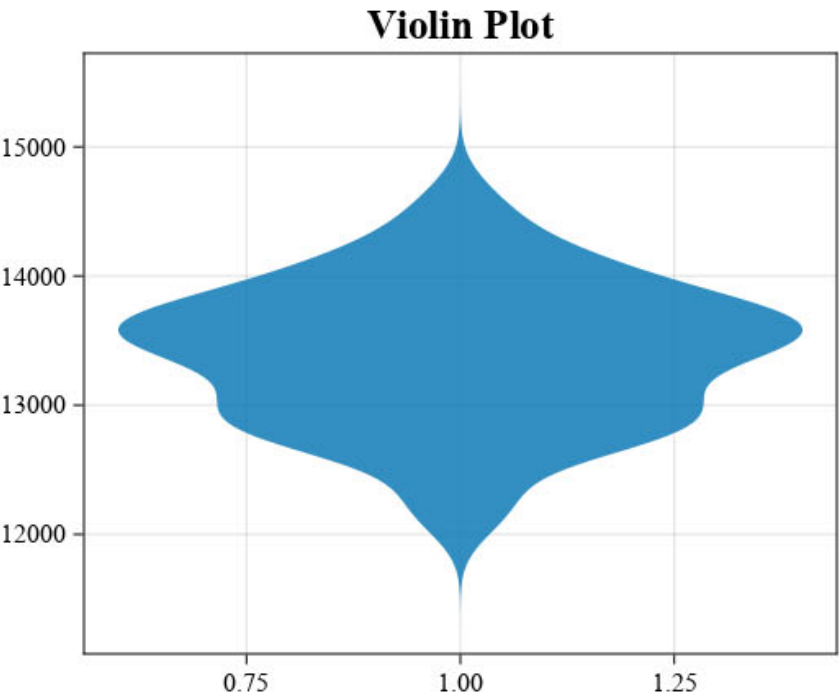
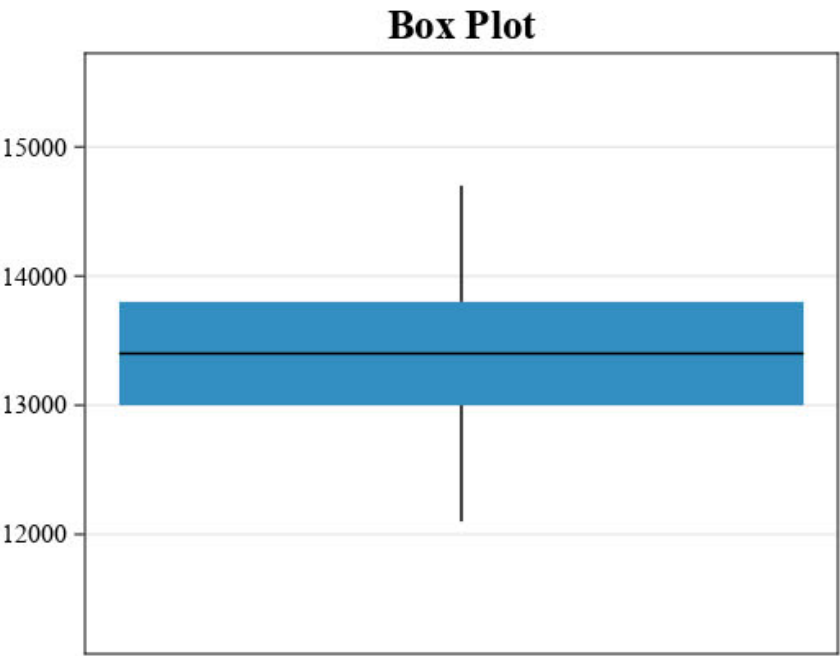
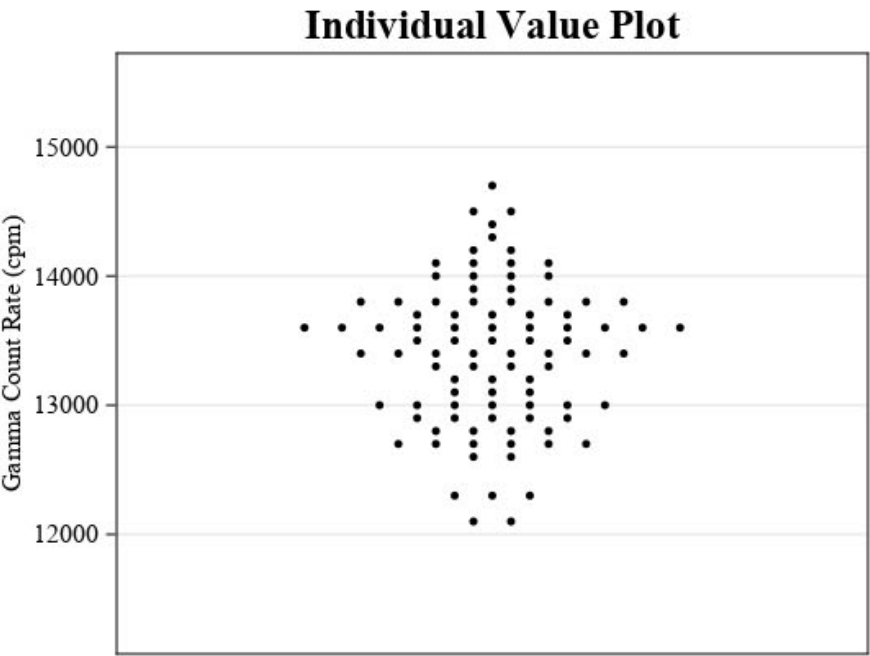


for the period of data to be saved then click the **OK** button. A **Save As** dialog window will open allowing the user to navigate to the location where the file is to be saved. Click on the Save button to save the file.

ATTACHMENT E-3: CORRELATION PLOT STATISTICS – UNSHIELDED GAMMA

Summary Statistics - Correlation Plots

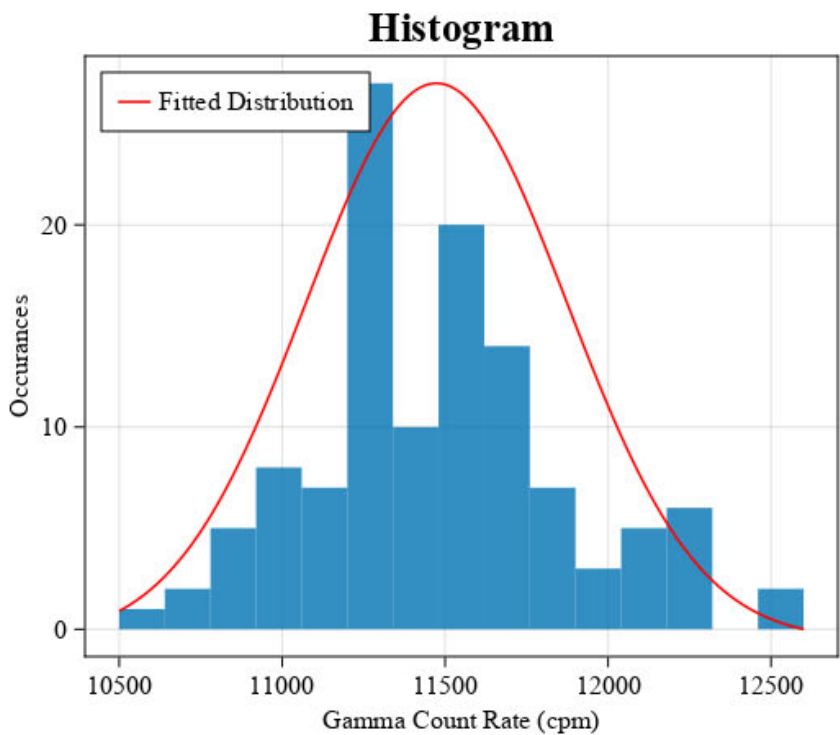
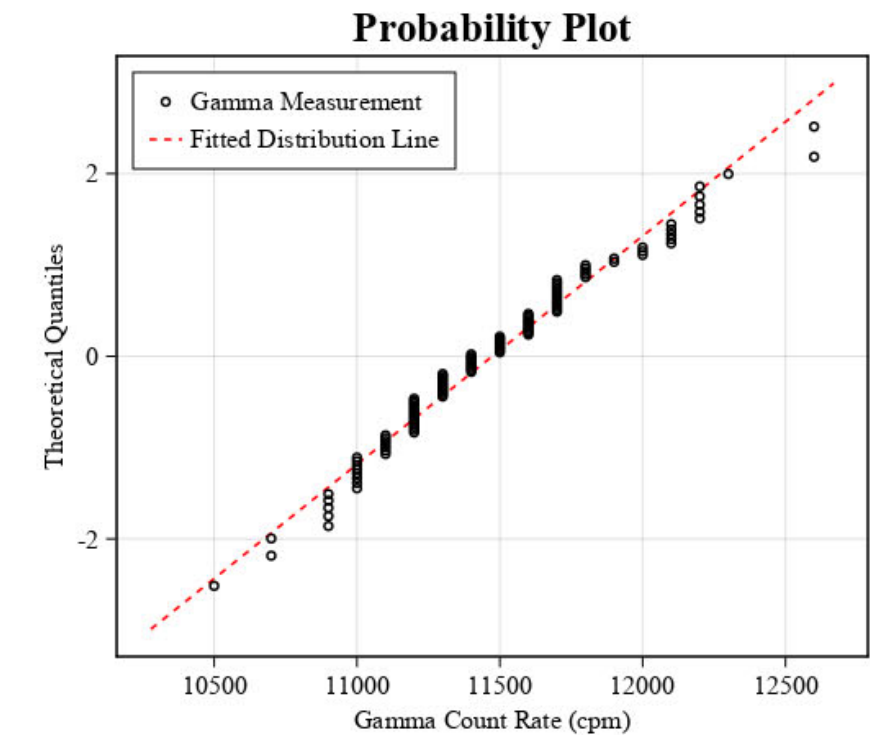
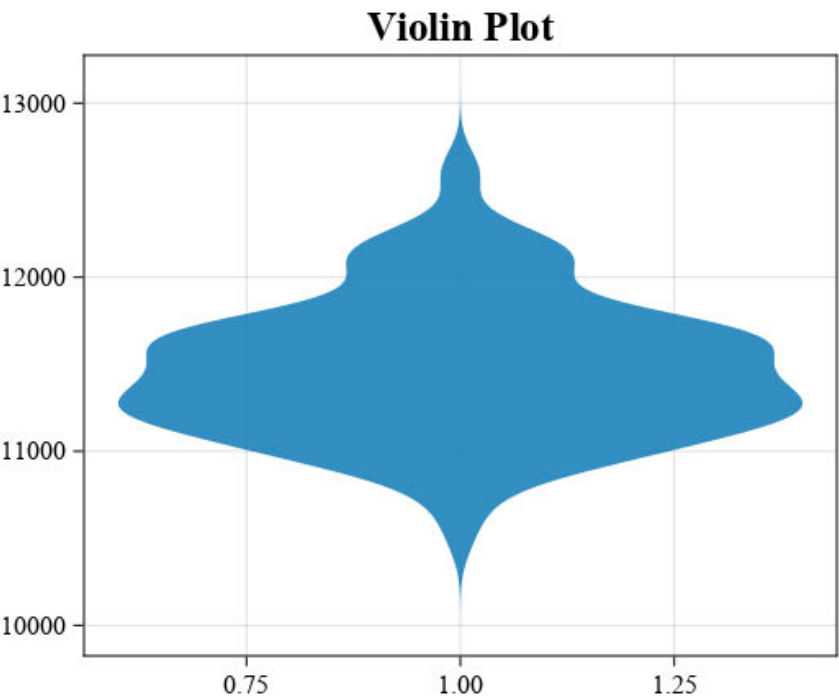
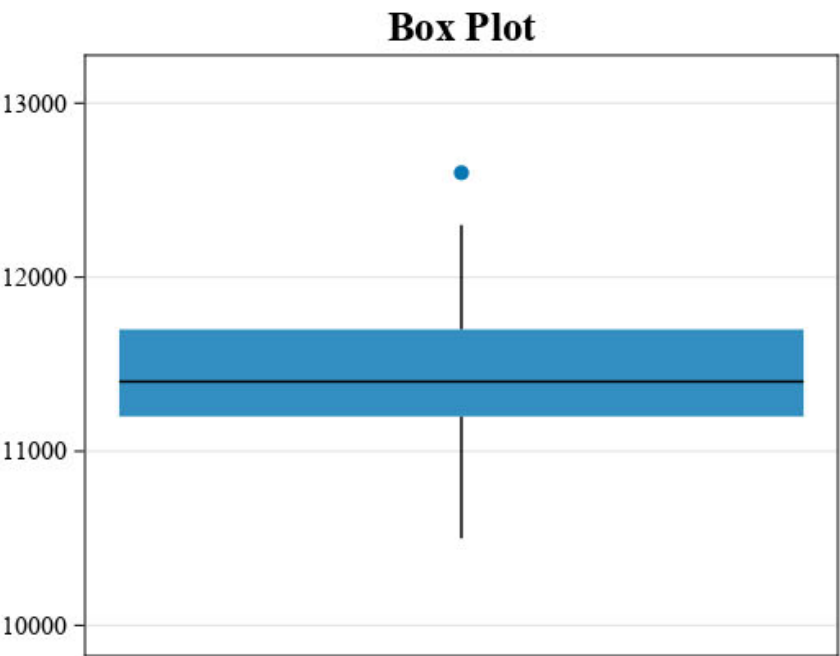
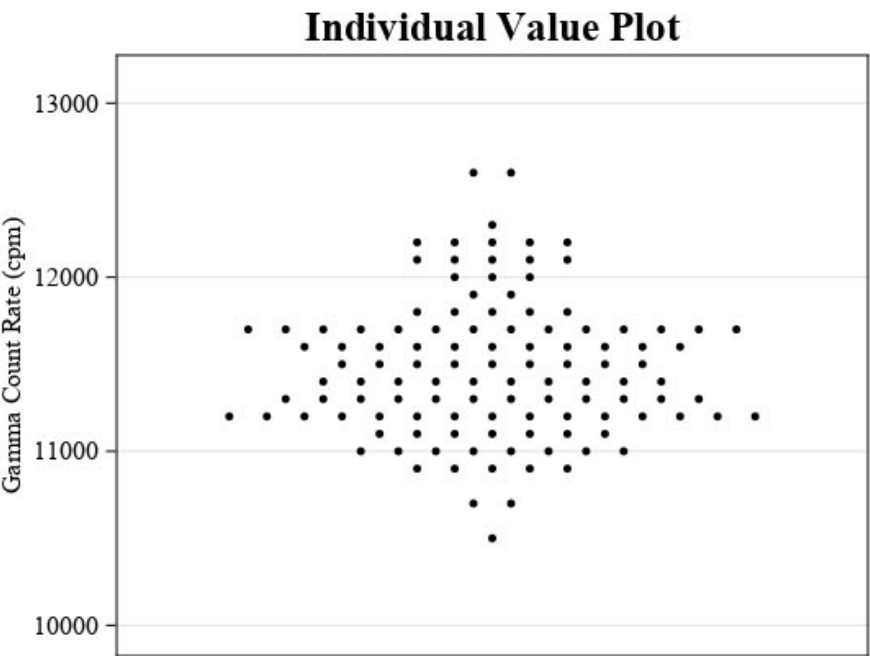
Site: OCRM Plot ID: CORR01 Type: Unshielded



Summary Statistics	
Count (n)	93
Minimum (cpm)	12,100
Maximum (cpm)	14,700
Average (cpm)	13,392
Median (cpm)	13,400
Standard Deviation (cpm)	559
Relative Standard Deviation	4.177%
RPD of Mean and Median	0.056%
90th Percentile (cpm)	14,100
95th Percentile (cpm)	14,300
99th Percentile (cpm)	14,700

Summary Statistics - Correlation Plots

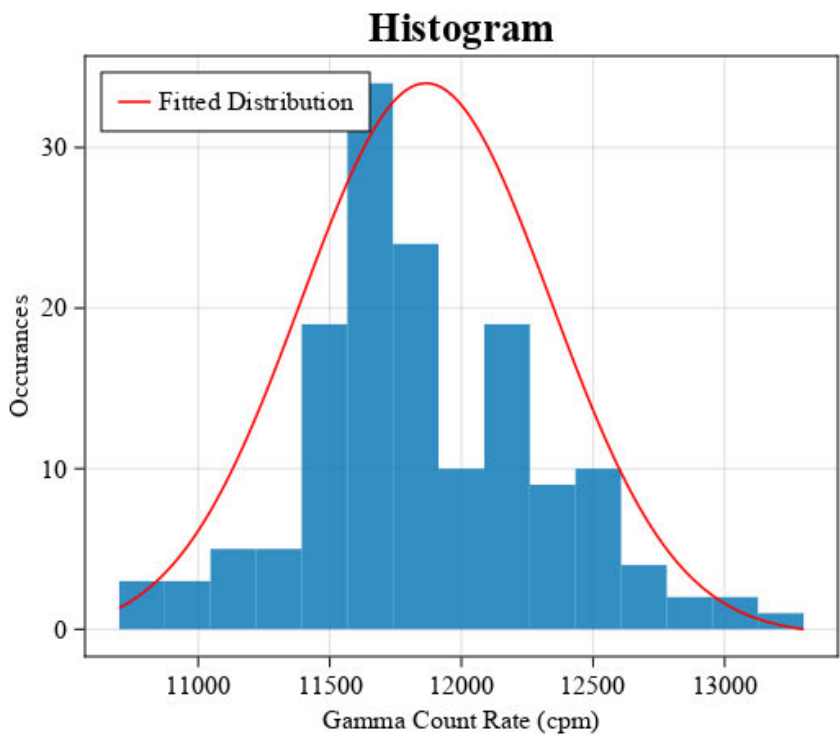
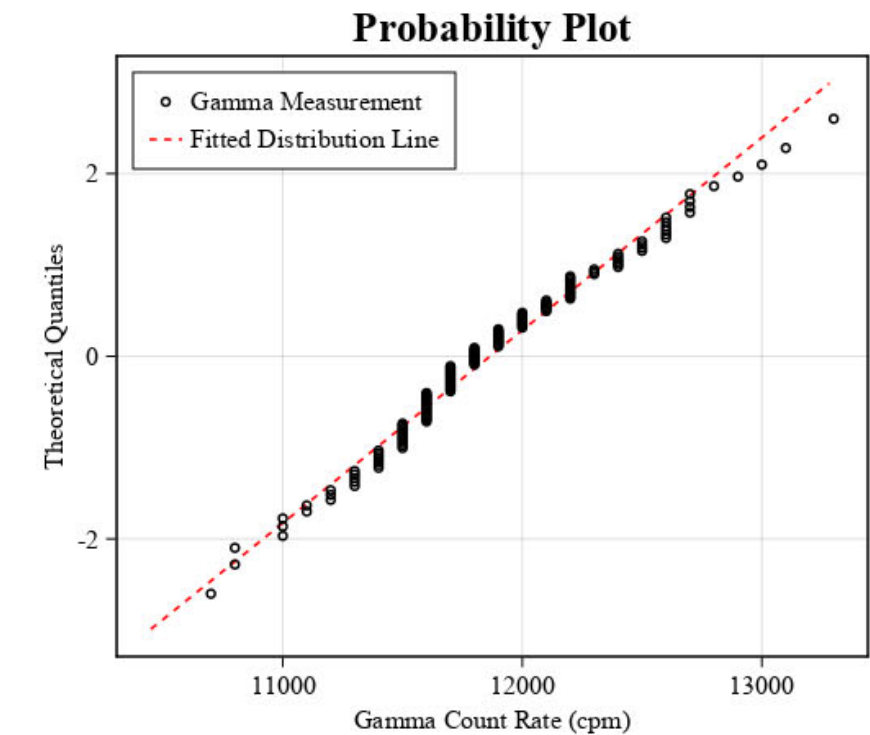
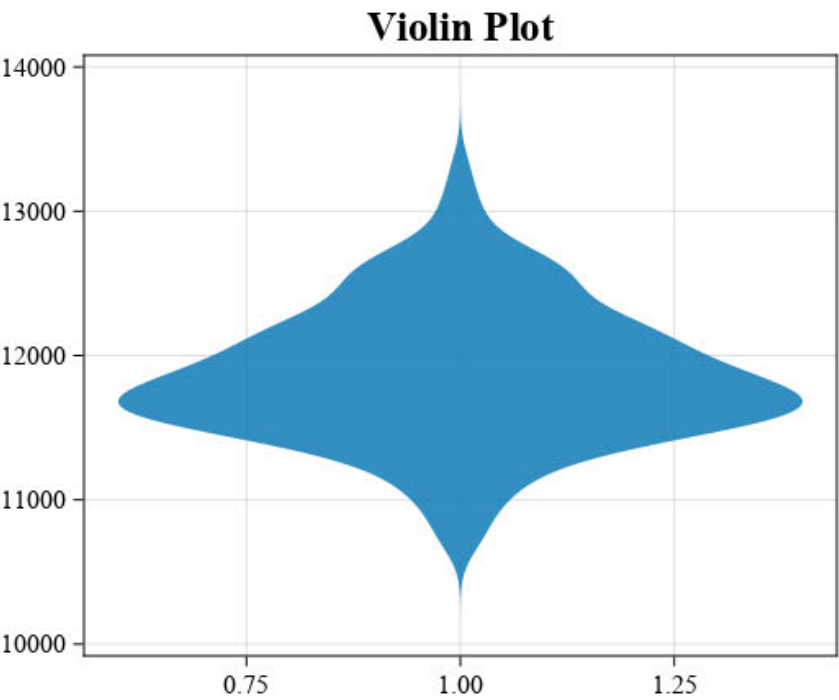
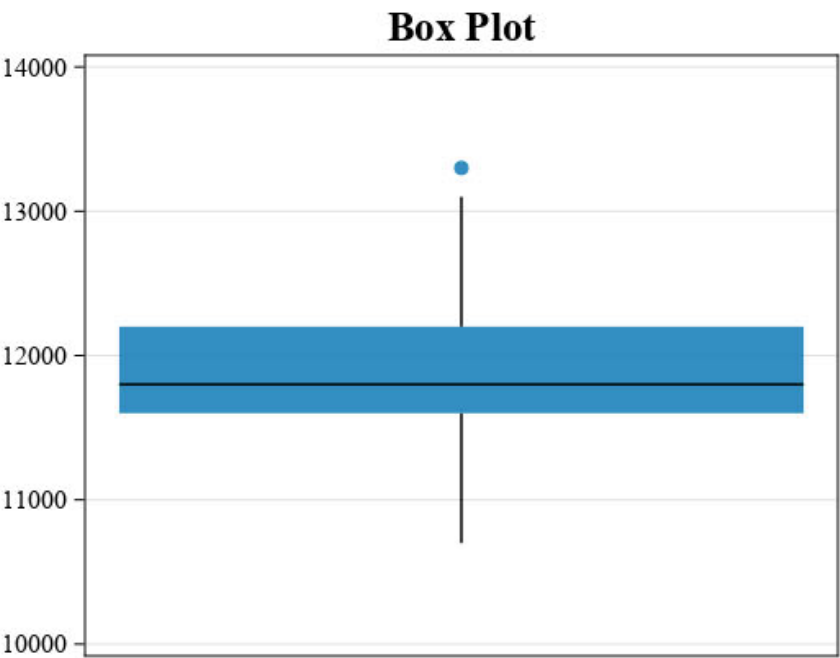
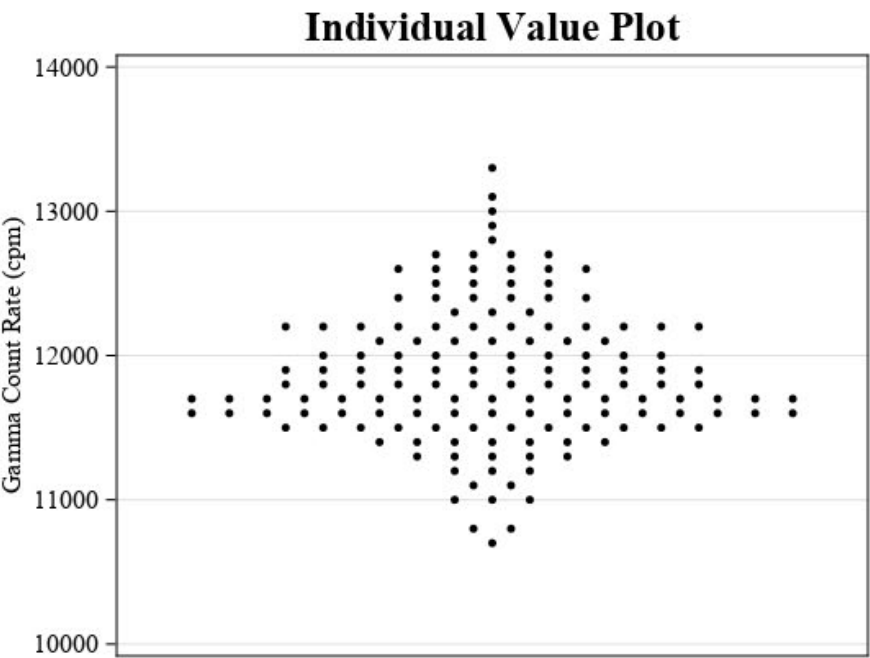
Site: OCRM Plot ID: CORR03 Type: Unshielded



Summary Statistics	
Count (n)	117
Minimum (cpm)	10,500
Maximum (cpm)	12,600
Average (cpm)	11,474
Median (cpm)	11,400
Standard Deviation (cpm)	400
Relative Standard Deviation	3.485%
RPD of Mean and Median	0.643%
90th Percentile (cpm)	12,100
95th Percentile (cpm)	12,200
99th Percentile (cpm)	12,600

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR02 Type: Unshielded

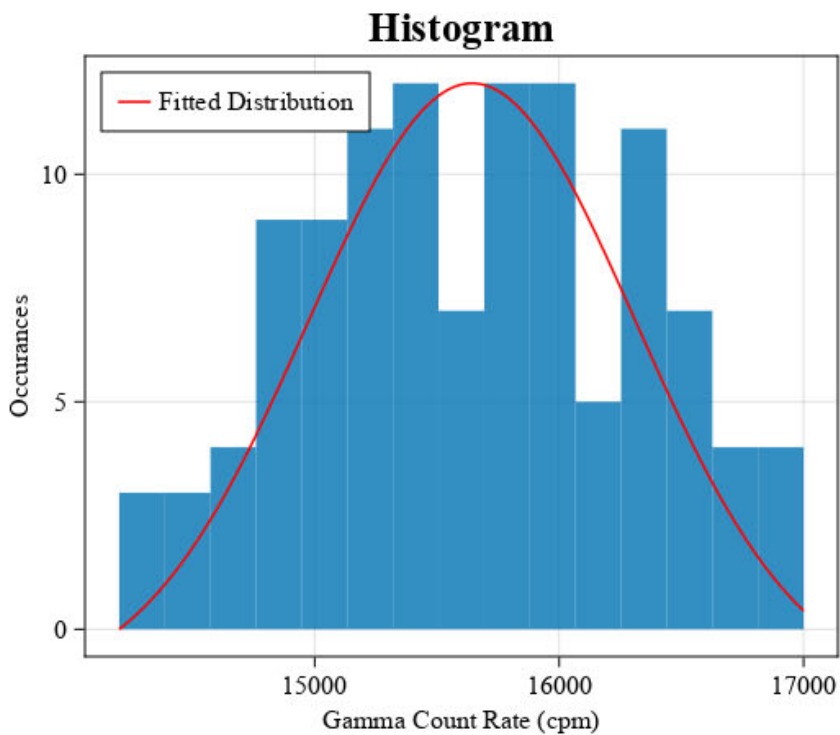
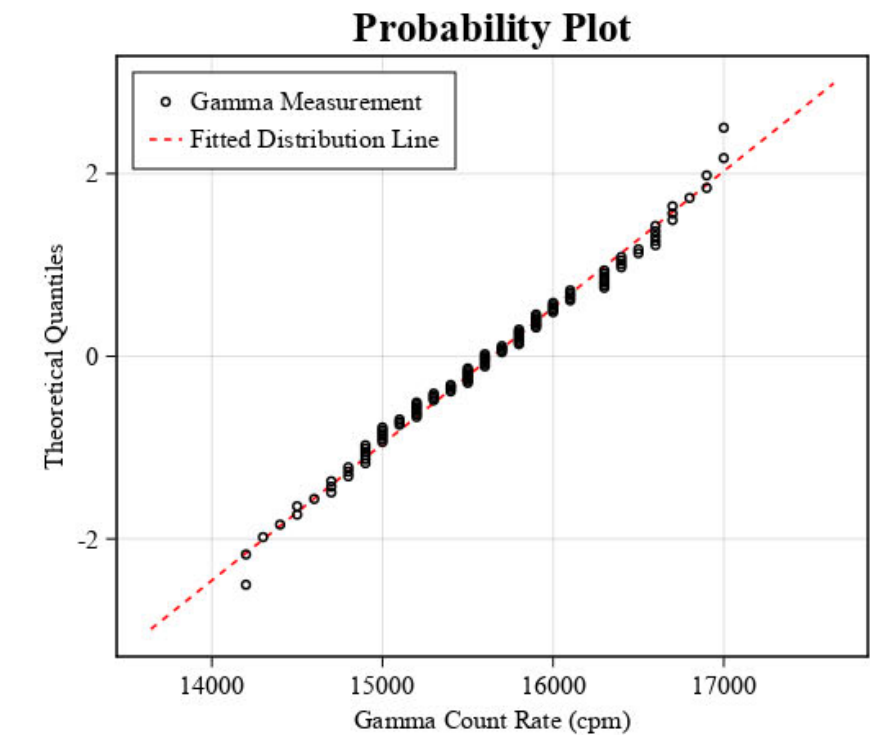
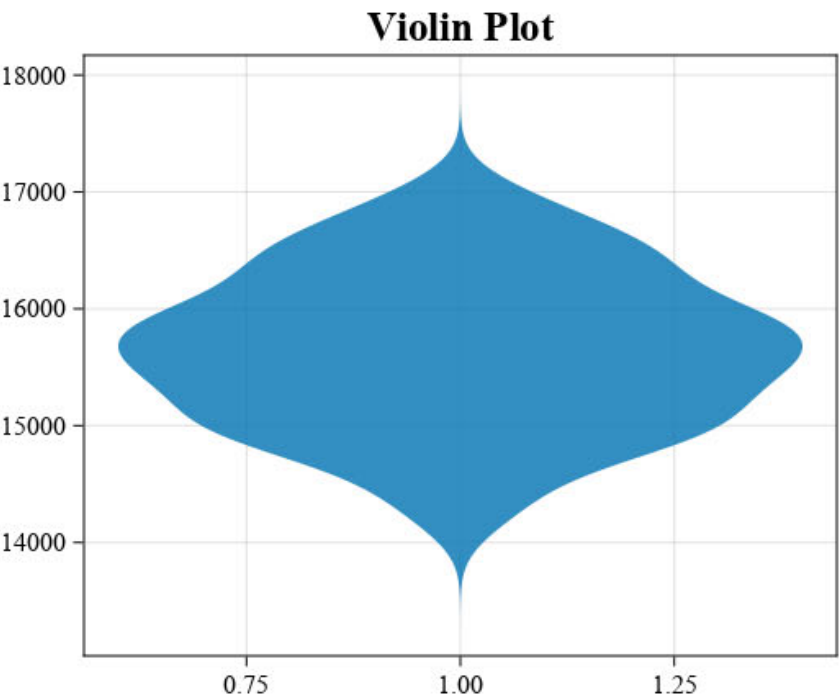
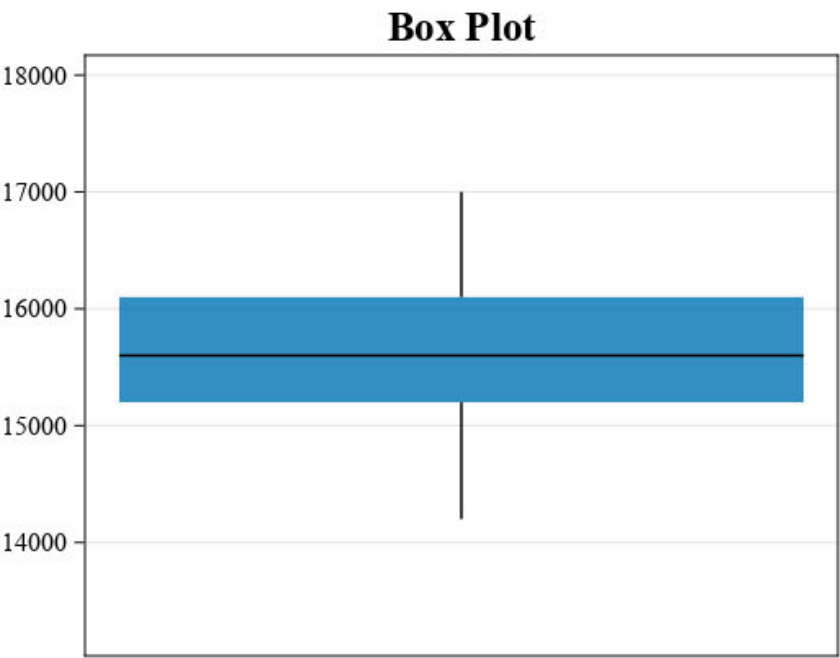
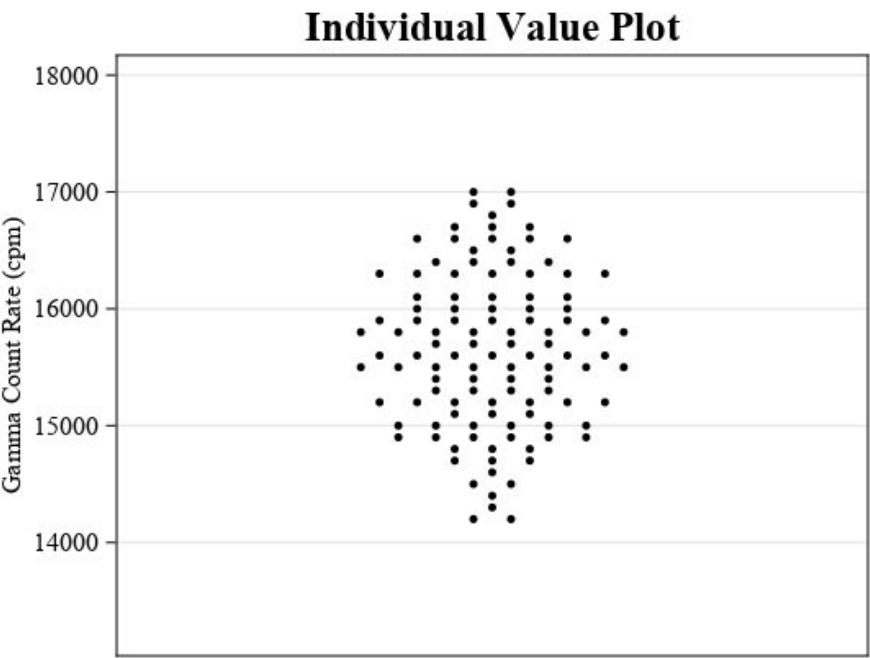


Summary Statistics

Count (n)	150
Minimum (cpm)	10,700
Maximum (cpm)	13,300
Average (cpm)	11,865
Median (cpm)	11,800
Standard Deviation (cpm)	474
Relative Standard Deviation	3.994%
RPD of Mean and Median	0.552%
90th Percentile (cpm)	12,600
95th Percentile (cpm)	12,700
99th Percentile (cpm)	13,100

Summary Statistics - Correlation Plots

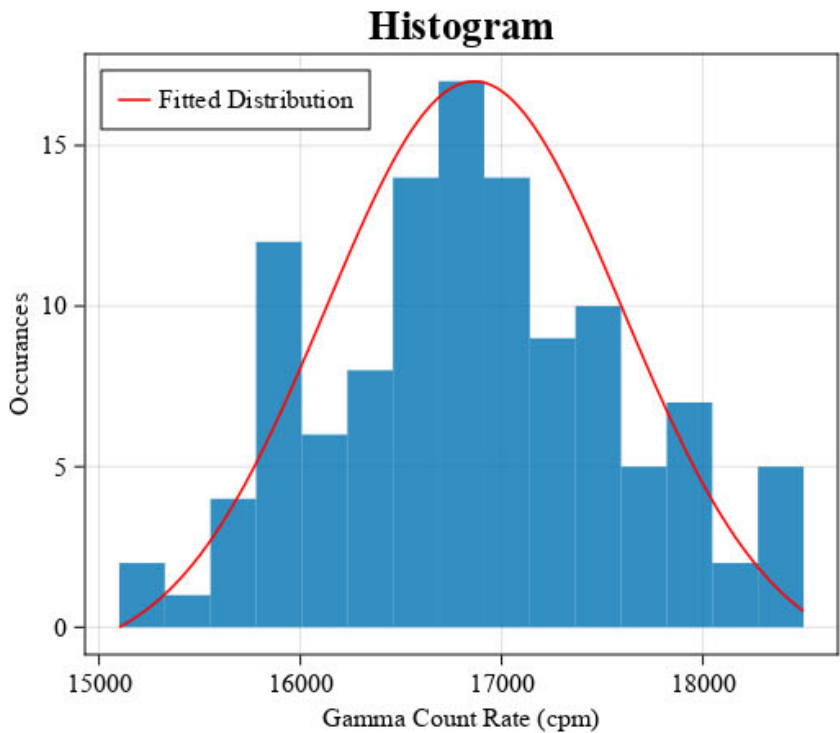
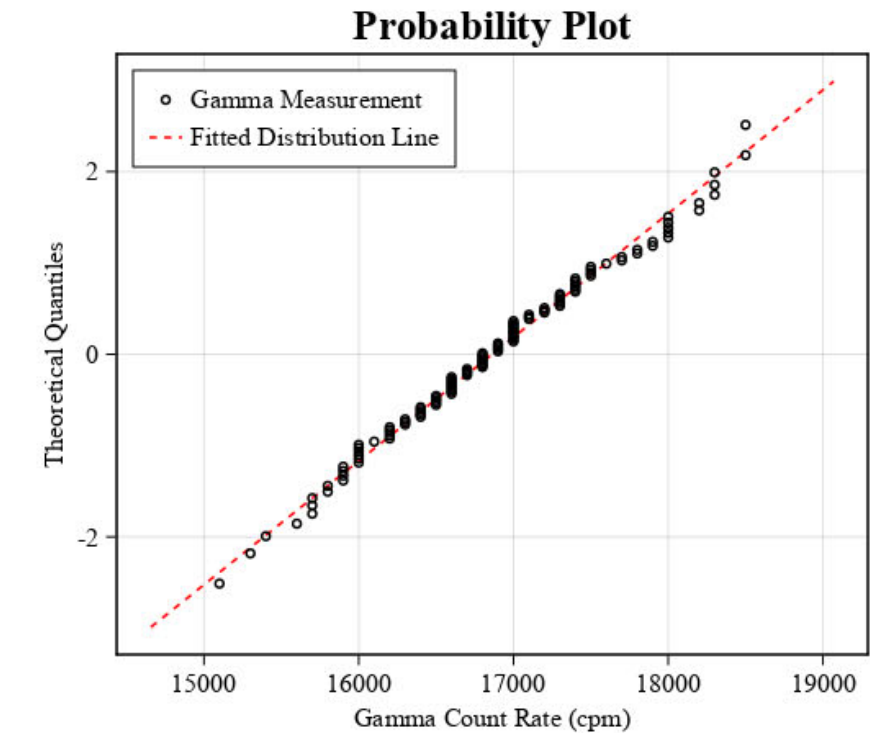
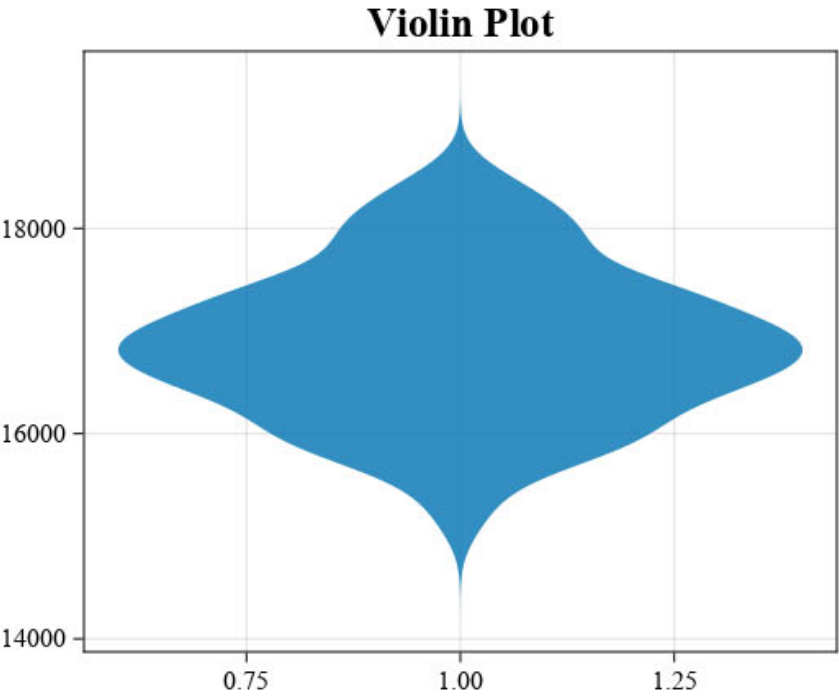
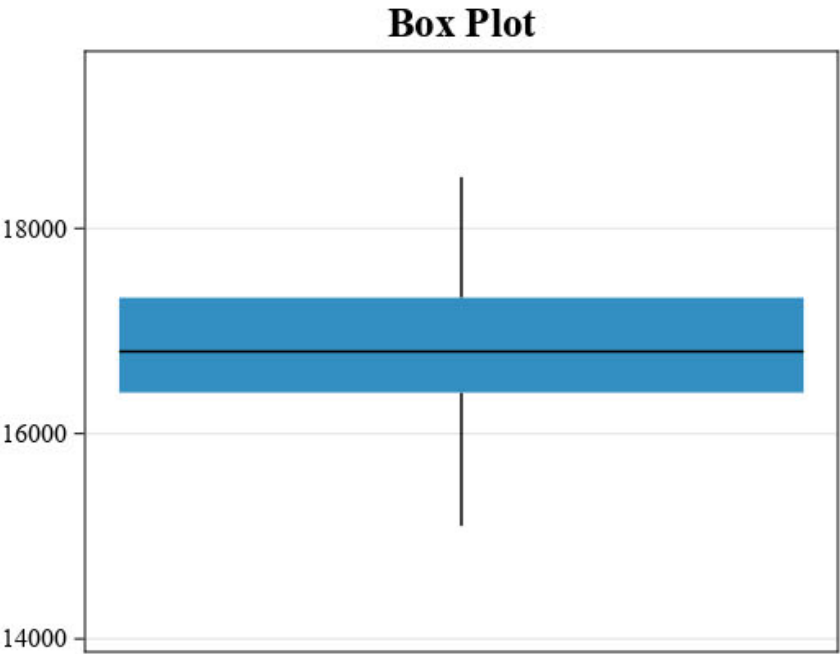
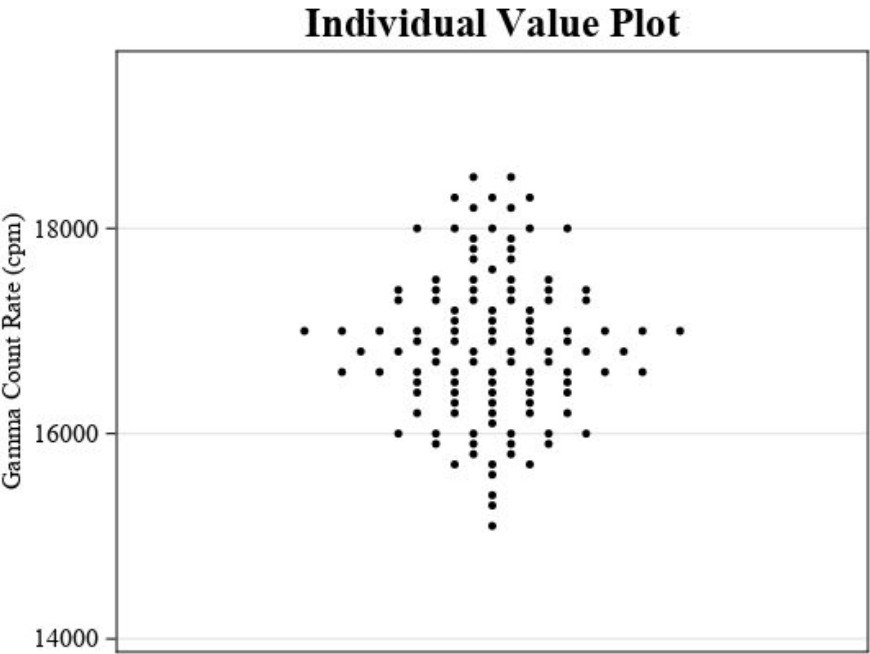
Site: OCRM Plot ID: CORR04 Type: Unshielded



Summary Statistics	
Count (n)	113
Minimum (cpm)	14,200
Maximum (cpm)	17,000
Average (cpm)	15,643
Median (cpm)	15,600
Standard Deviation (cpm)	669
Relative Standard Deviation	4.28%
RPD of Mean and Median	0.278%
90th Percentile (cpm)	16,600
95th Percentile (cpm)	16,700
99th Percentile (cpm)	17,000

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR05 Type: Unshielded

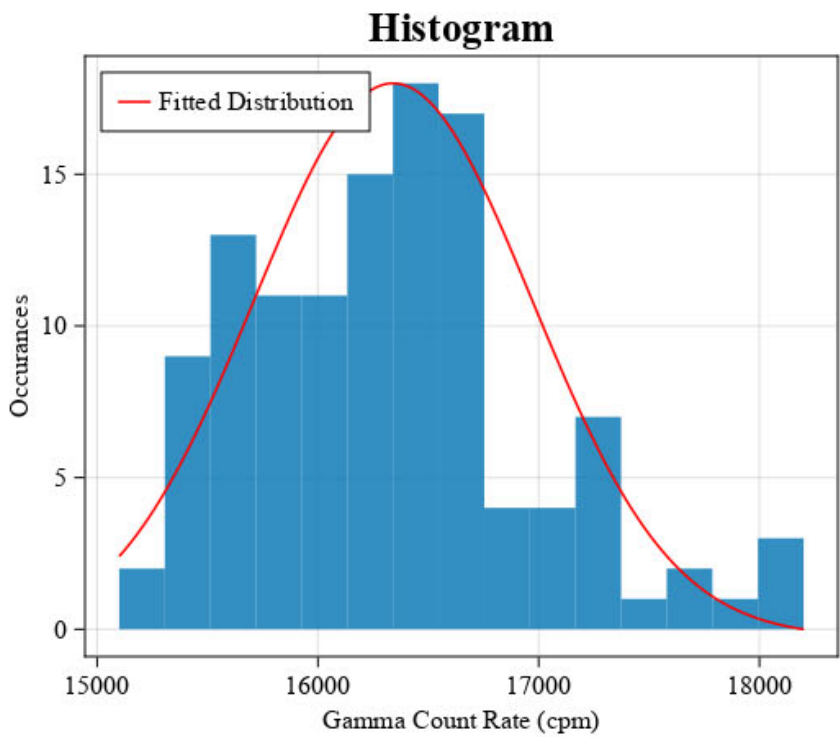
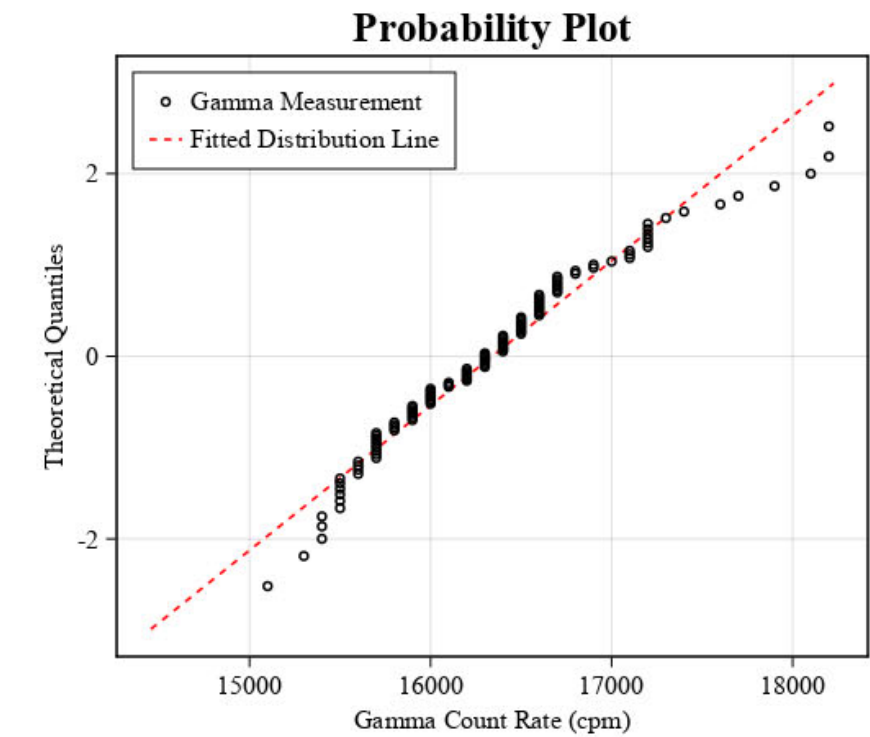
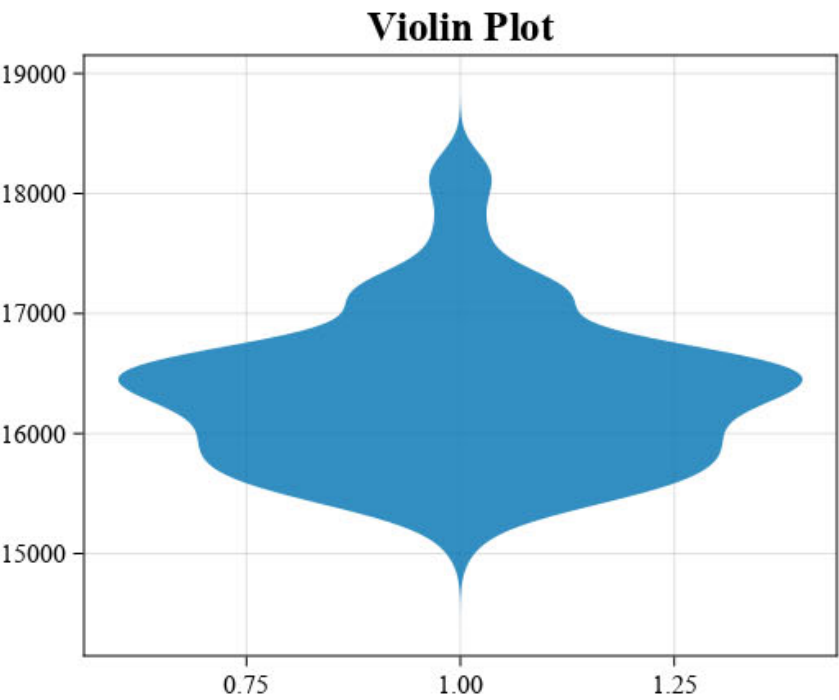
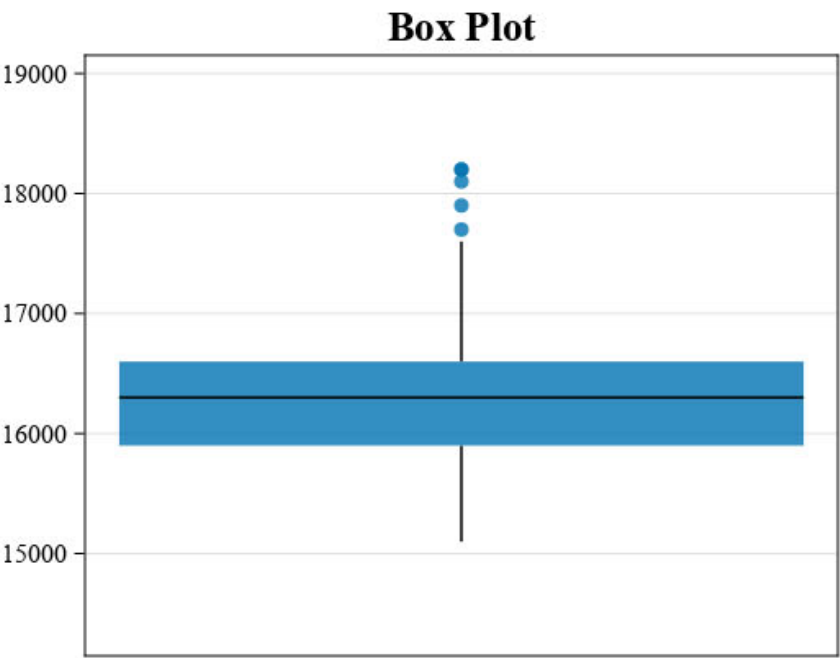
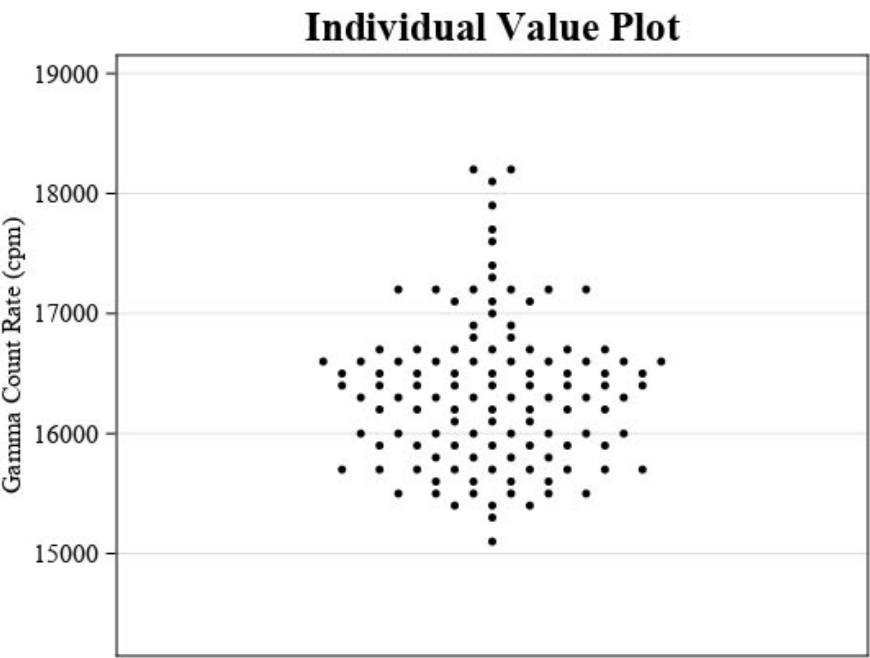


Summary Statistics

Count (n)	116
Minimum (cpm)	15,100
Maximum (cpm)	18,500
Average (cpm)	16,863
Median (cpm)	16,800
Standard Deviation (cpm)	738
Relative Standard Deviation	4.378%
RPD of Mean and Median	0.374%
90th Percentile (cpm)	18,000
95th Percentile (cpm)	18,200
99th Percentile (cpm)	18,500

Summary Statistics - Correlation Plots

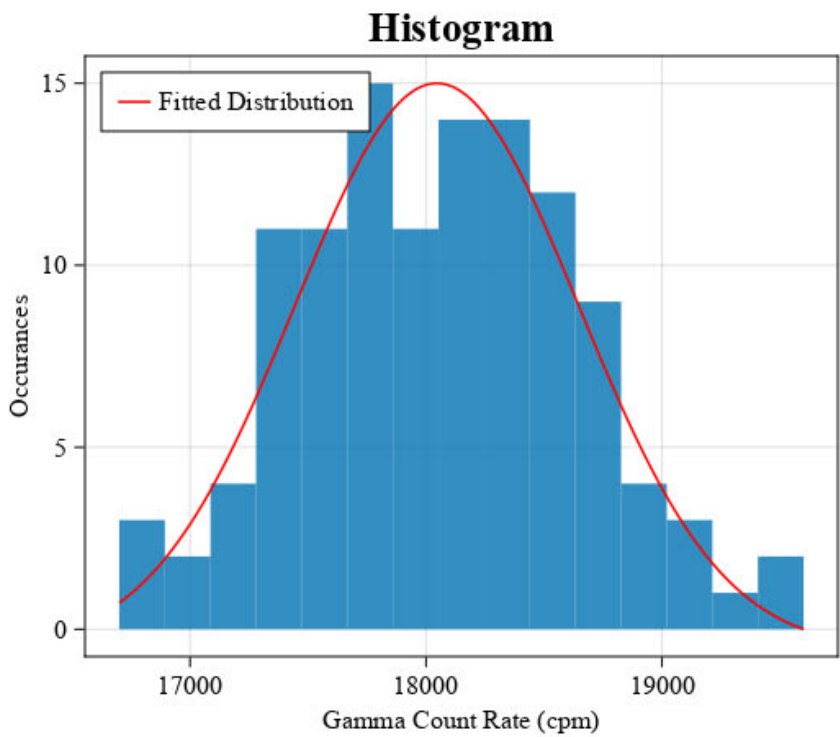
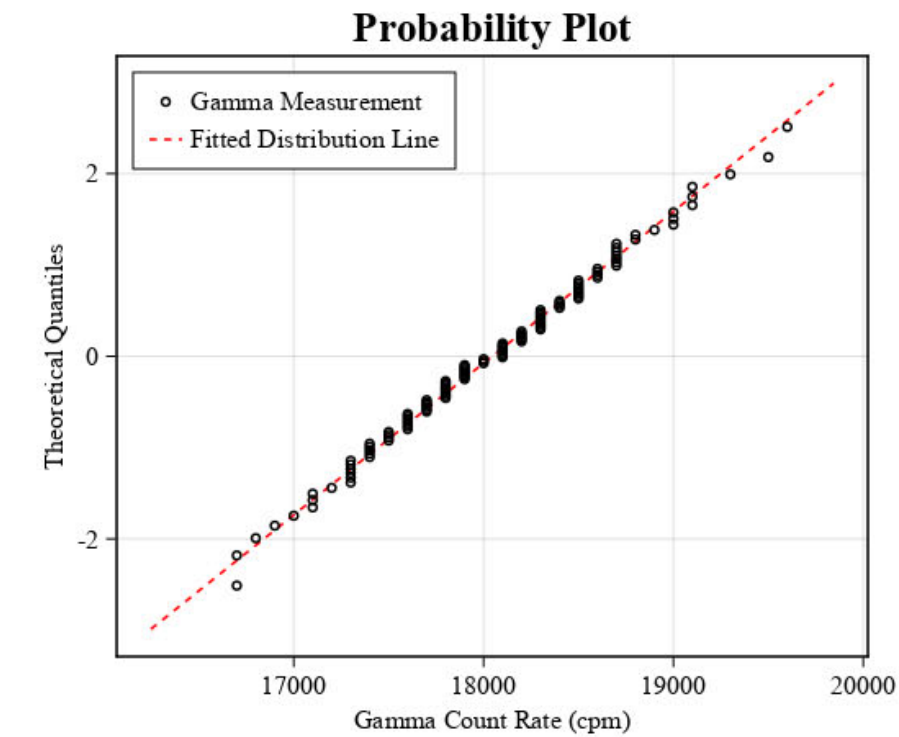
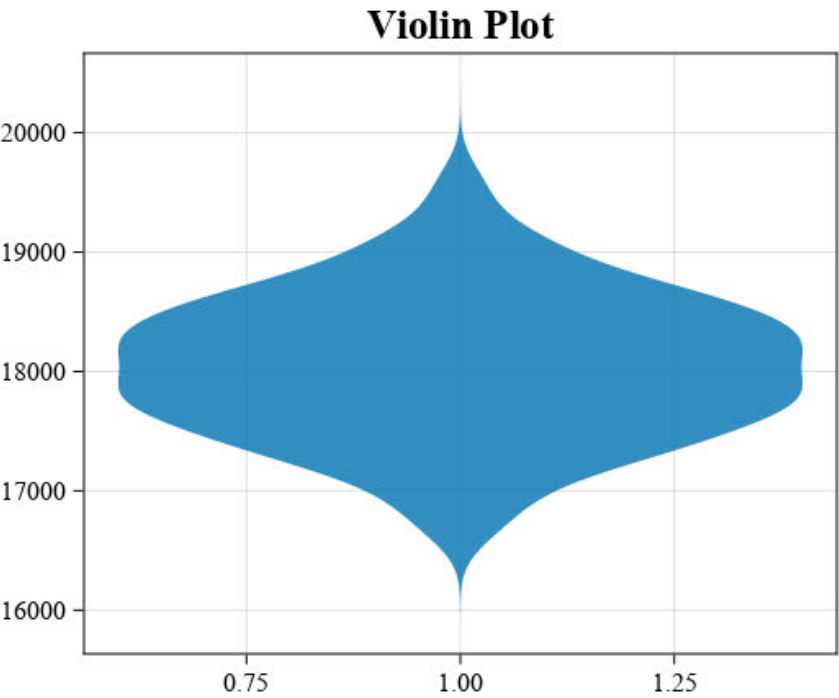
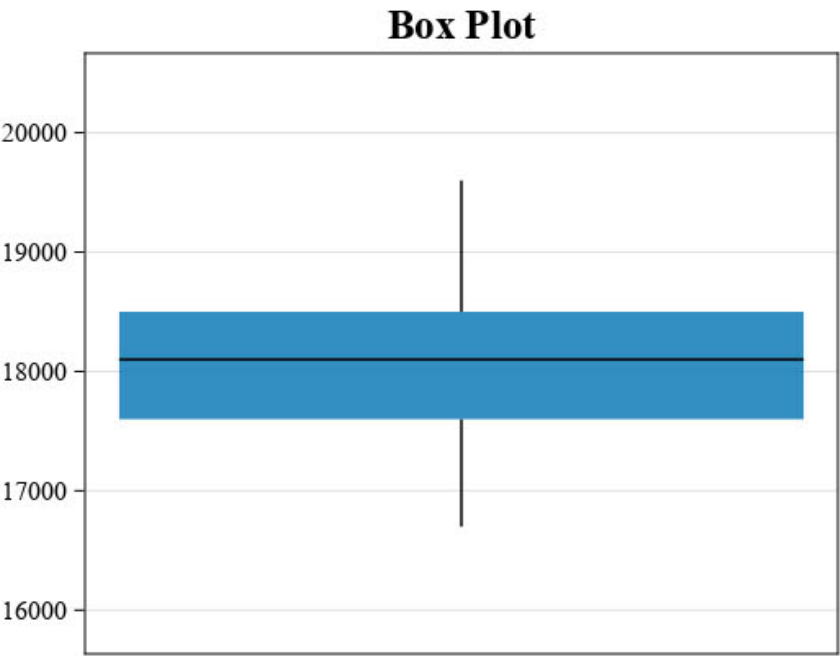
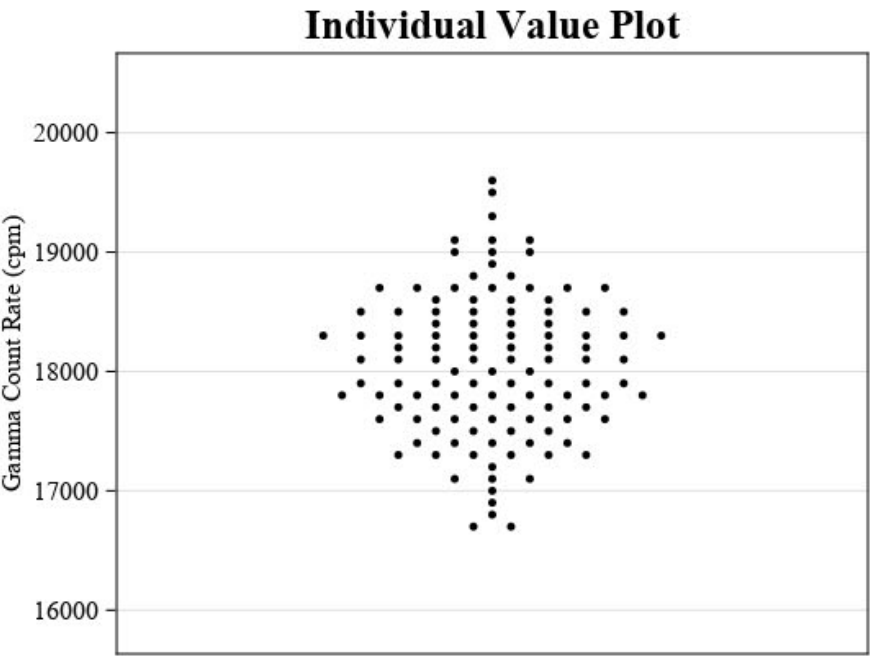
Site: OCRM Plot ID: CORR06 Type: Unshielded



Summary Statistics	
Count (n)	118
Minimum (cpm)	15,100
Maximum (cpm)	18,200
Average (cpm)	16,341
Median (cpm)	16,300
Standard Deviation (cpm)	631
Relative Standard Deviation	3.862%
RPD of Mean and Median	0.249%
90th Percentile (cpm)	17,200
95th Percentile (cpm)	17,600
99th Percentile (cpm)	18,200

Summary Statistics - Correlation Plots

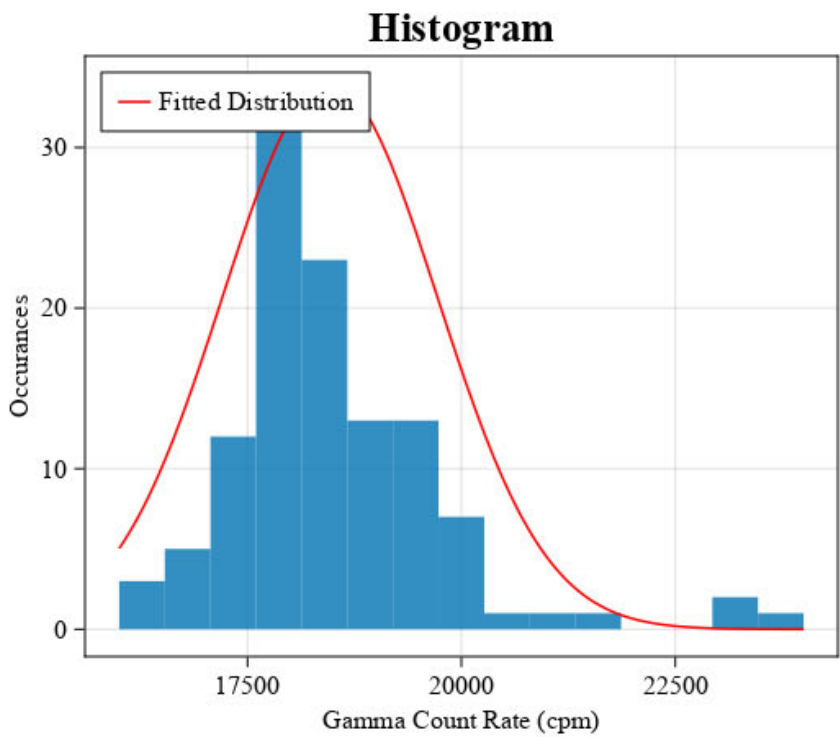
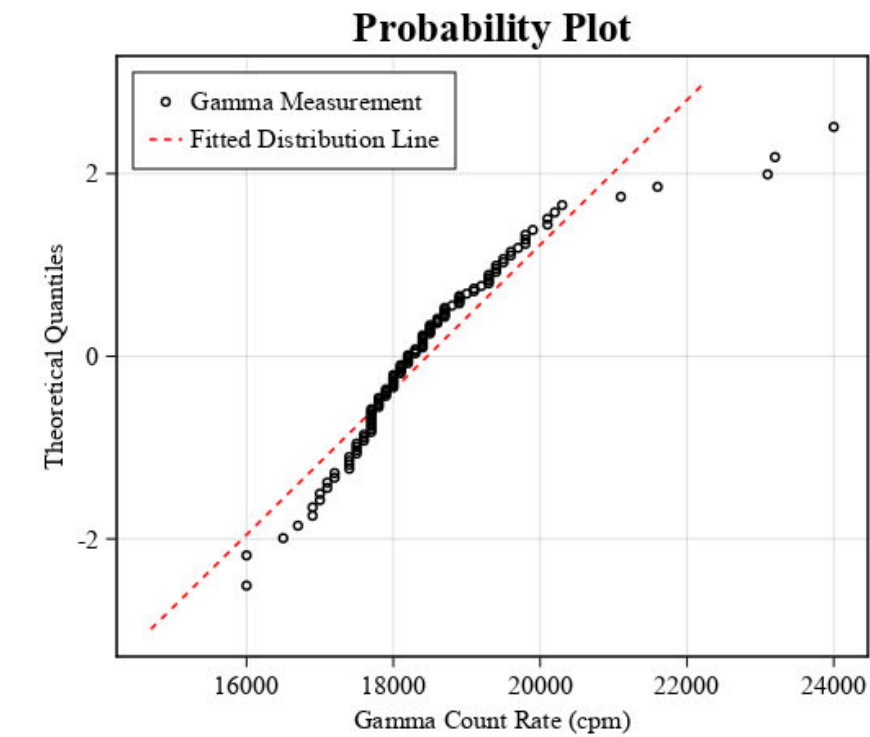
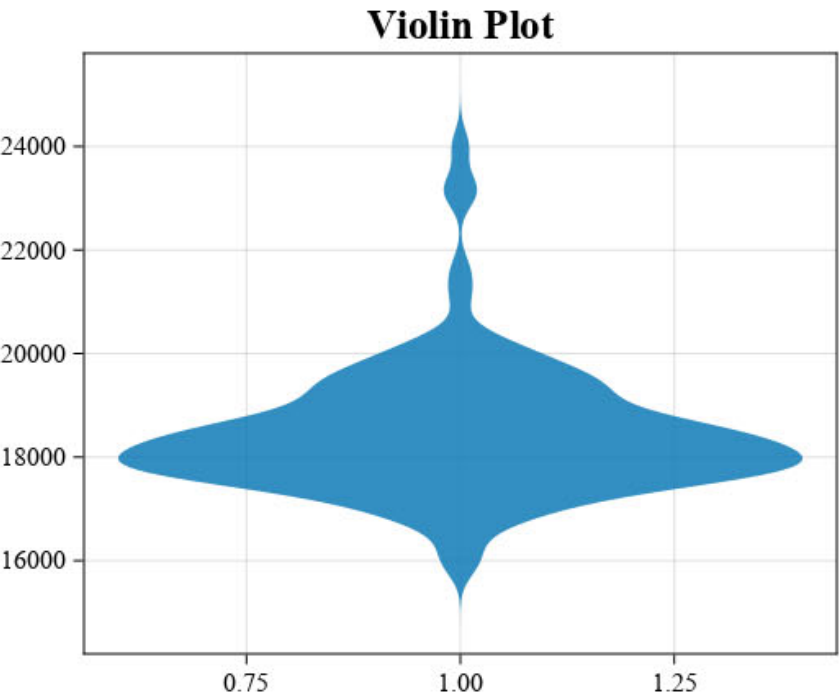
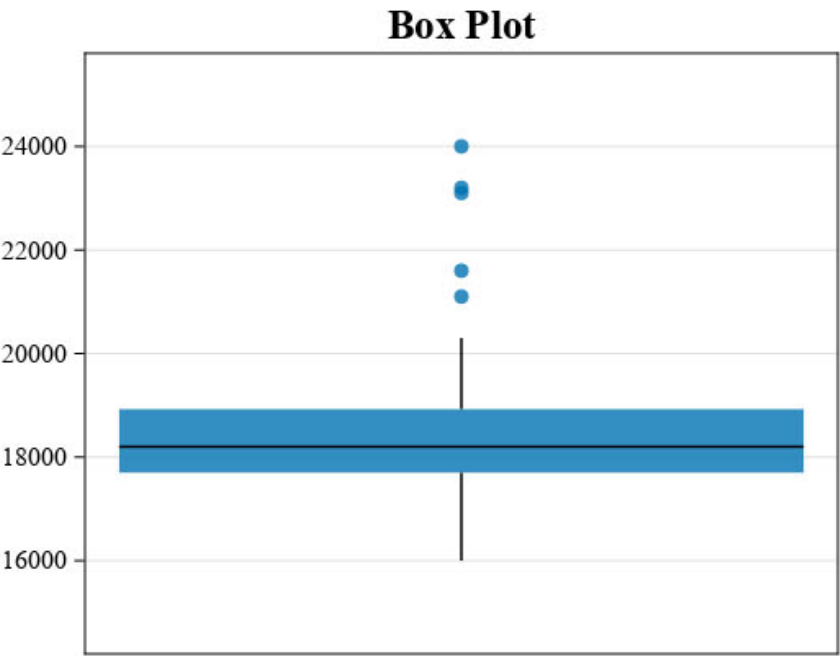
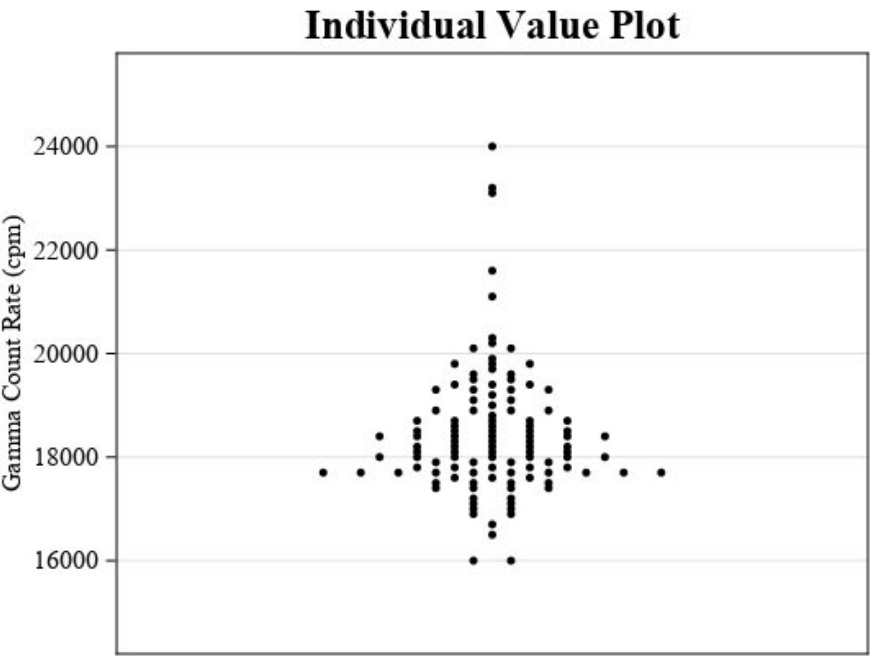
Site: OCRM Plot ID: CORR07 Type: Unshielded



Summary Statistics	
Count (n)	116
Minimum (cpm)	16,700
Maximum (cpm)	19,600
Average (cpm)	18,046
Median (cpm)	18,100
Standard Deviation (cpm)	602
Relative Standard Deviation	3.335%
RPD of Mean and Median	0.301%
90th Percentile (cpm)	18,800
95th Percentile (cpm)	19,100
99th Percentile (cpm)	19,500

Summary Statistics - Correlation Plots

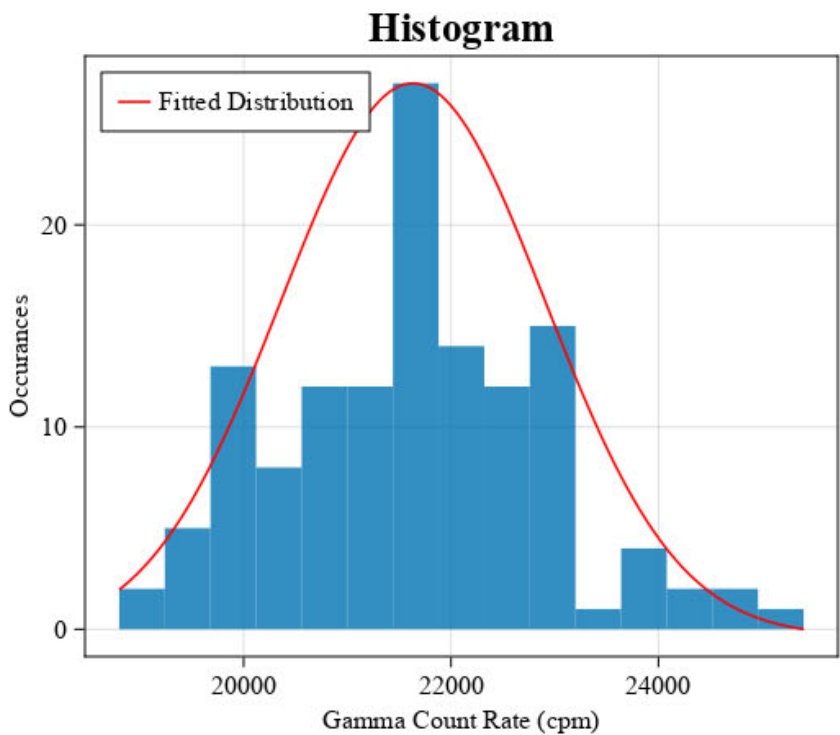
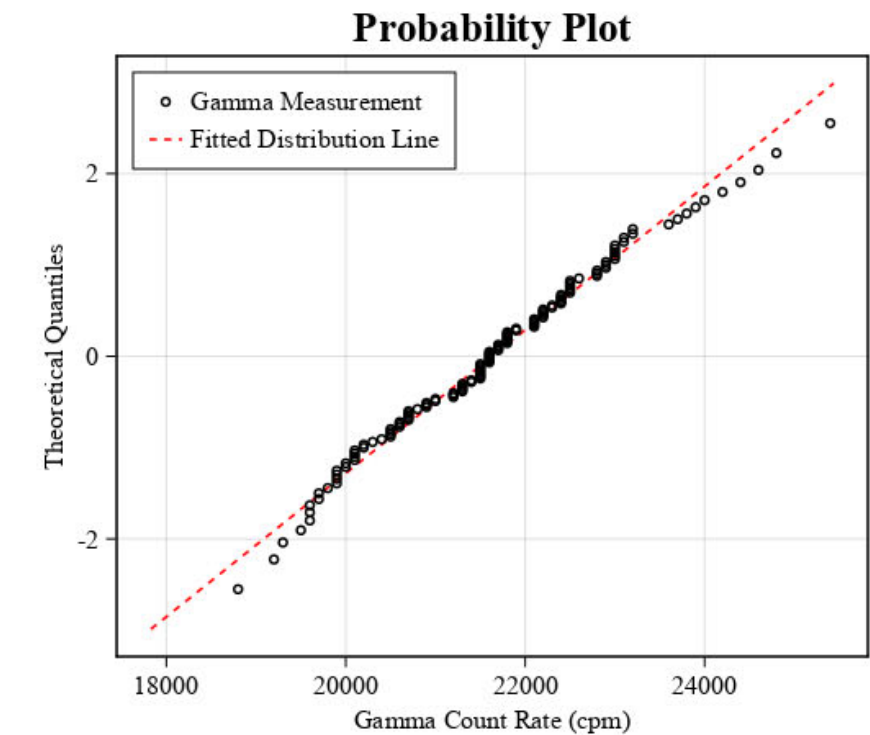
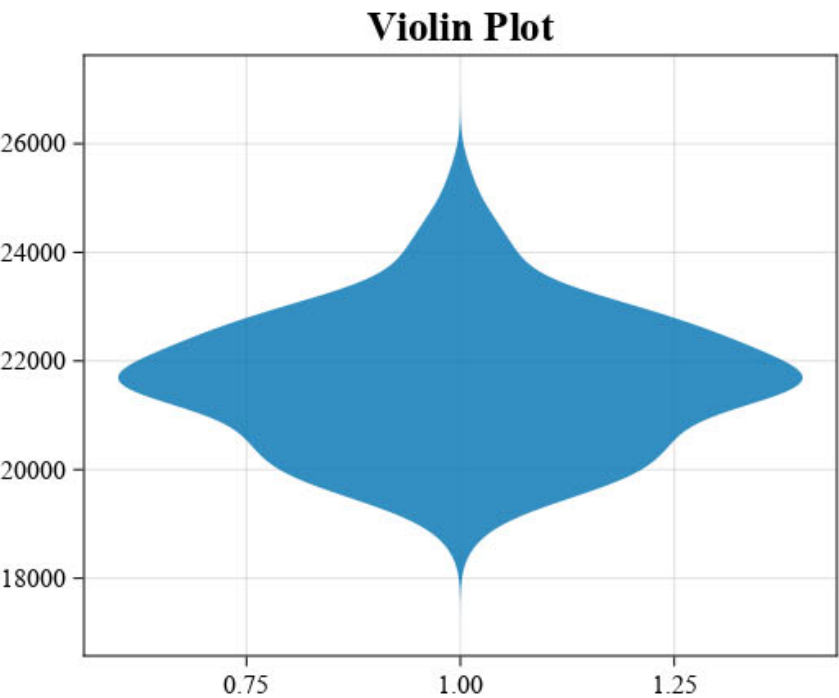
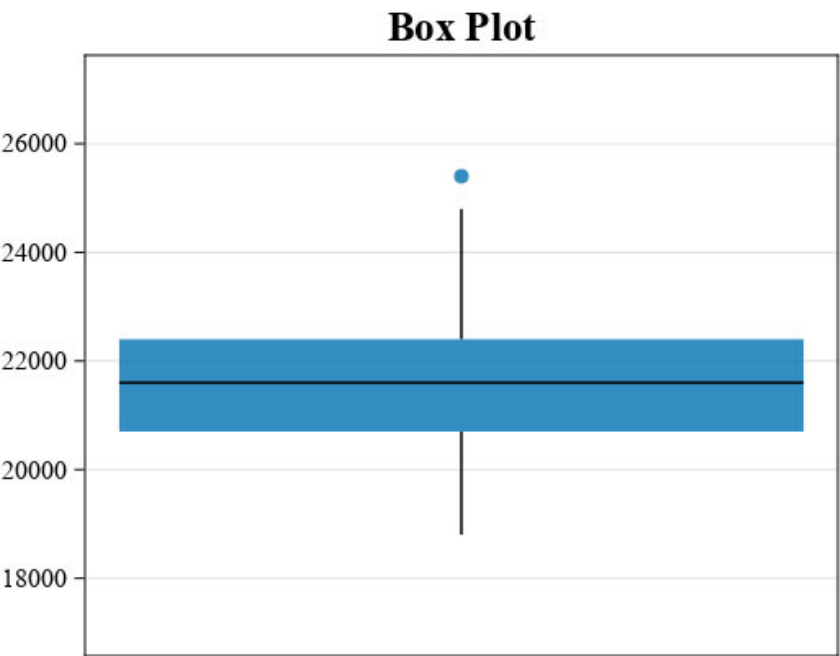
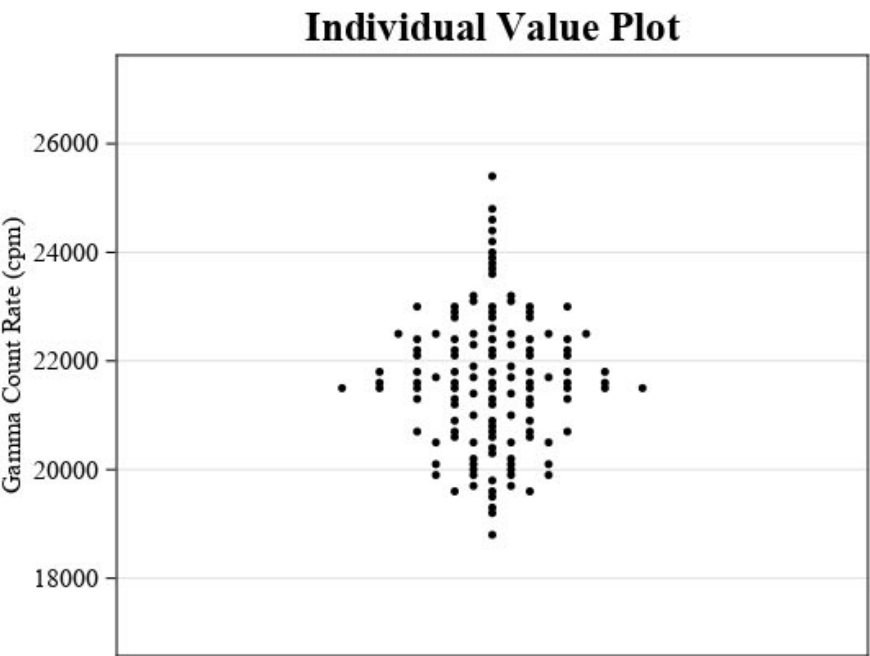
Site: OCRM Plot ID: CORR08 Type: Unshielded



Summary Statistics	
Count (n)	116
Minimum (cpm)	16,000
Maximum (cpm)	24,000
Average (cpm)	18,463
Median (cpm)	18,200
Standard Deviation (cpm)	1,260
Relative Standard Deviation	6.826%
RPD of Mean and Median	1.434%
90th Percentile (cpm)	19,800
95th Percentile (cpm)	20,300
99th Percentile (cpm)	23,200

Summary Statistics - Correlation Plots

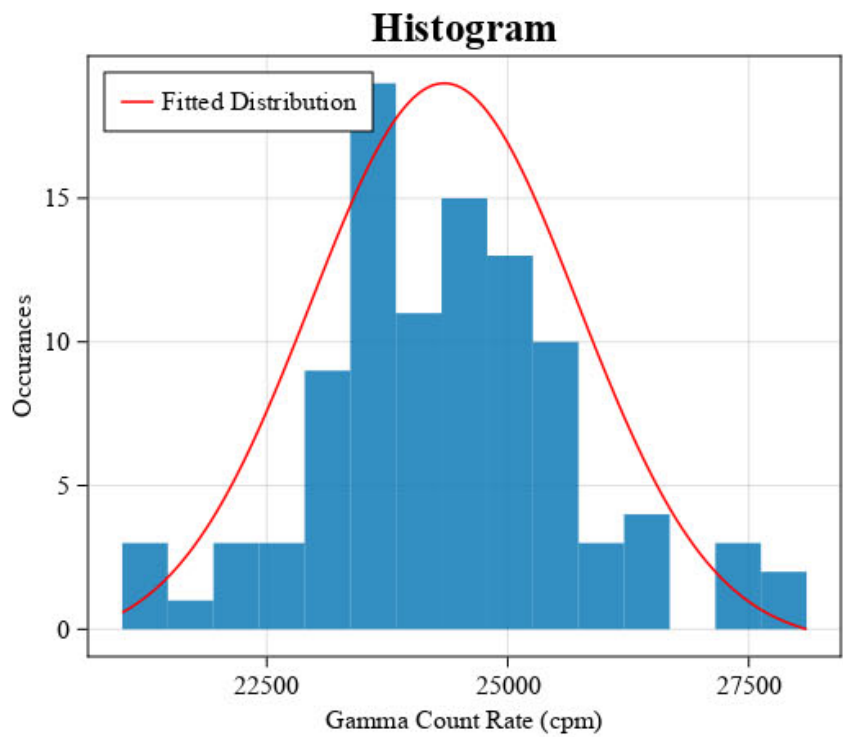
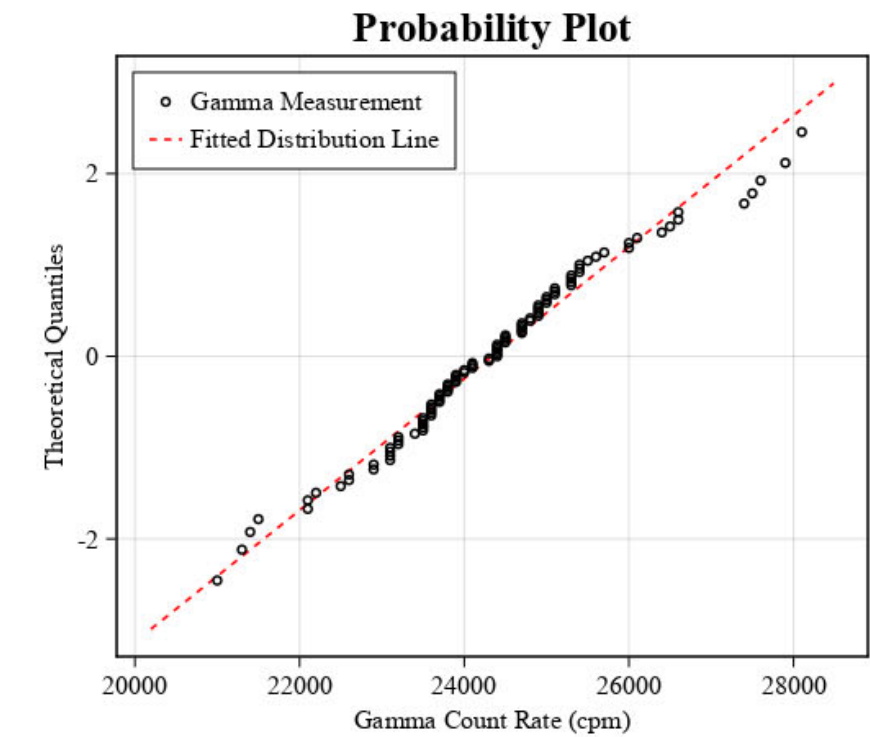
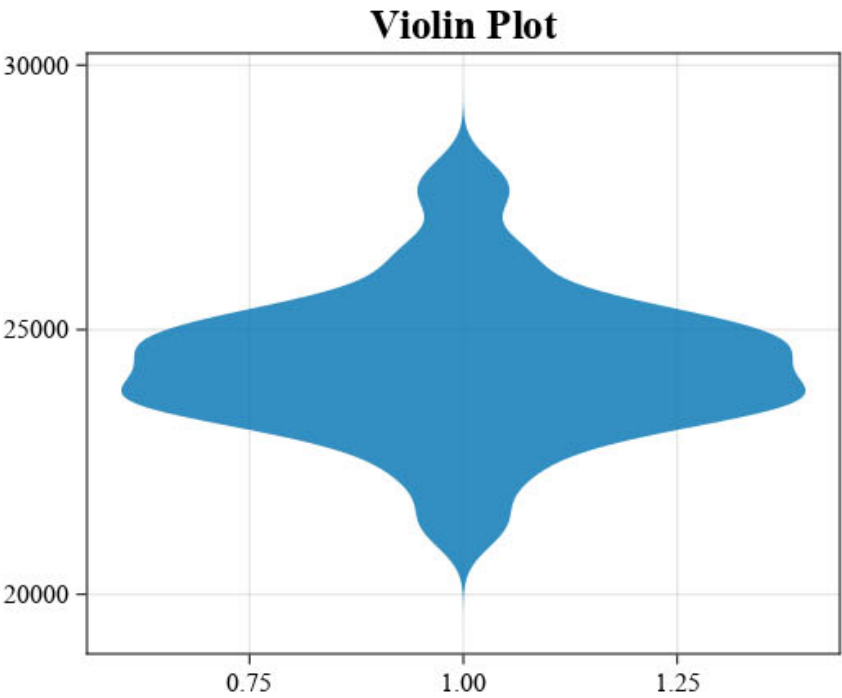
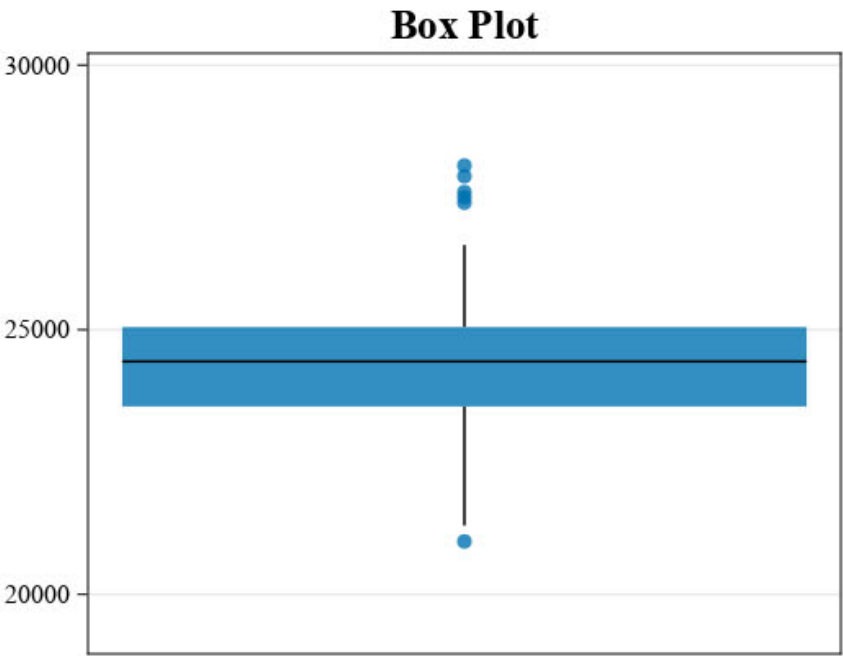
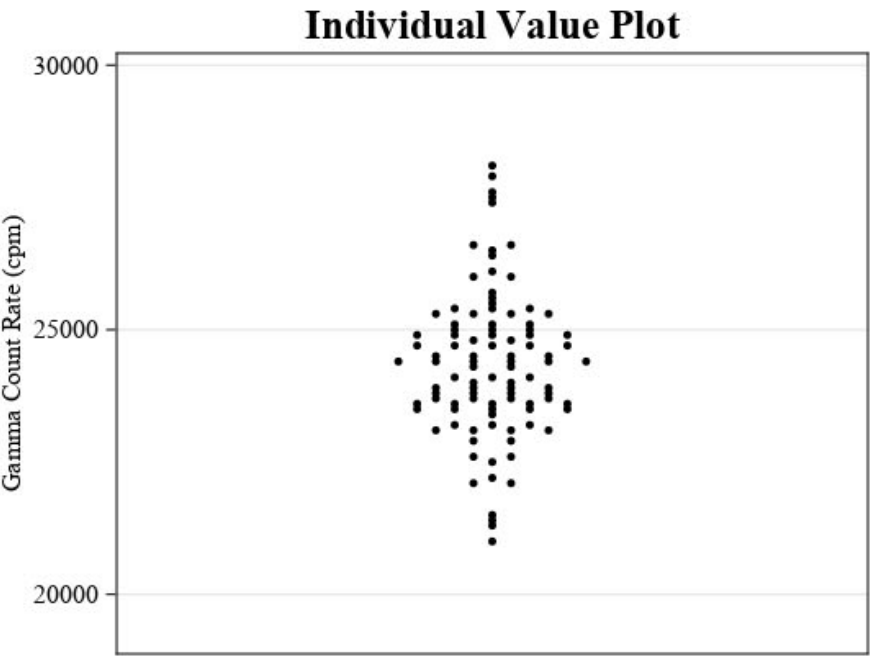
Site: OCRM Plot ID: CORR09 Type: Unshielded



Summary Statistics	
Count (n)	130
Minimum (cpm)	18,800
Maximum (cpm)	25,400
Average (cpm)	21,633
Median (cpm)	21,600
Standard Deviation (cpm)	1,273
Relative Standard Deviation	5.886%
RPD of Mean and Median	0.153%
90th Percentile (cpm)	23,100
95th Percentile (cpm)	23,900
99th Percentile (cpm)	24,800

Summary Statistics - Correlation Plots

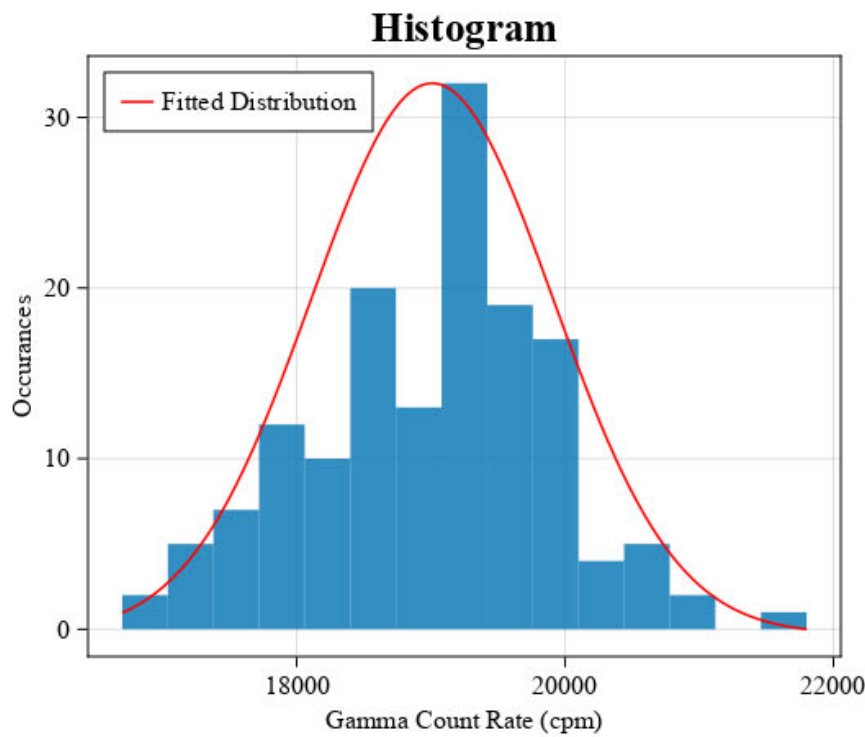
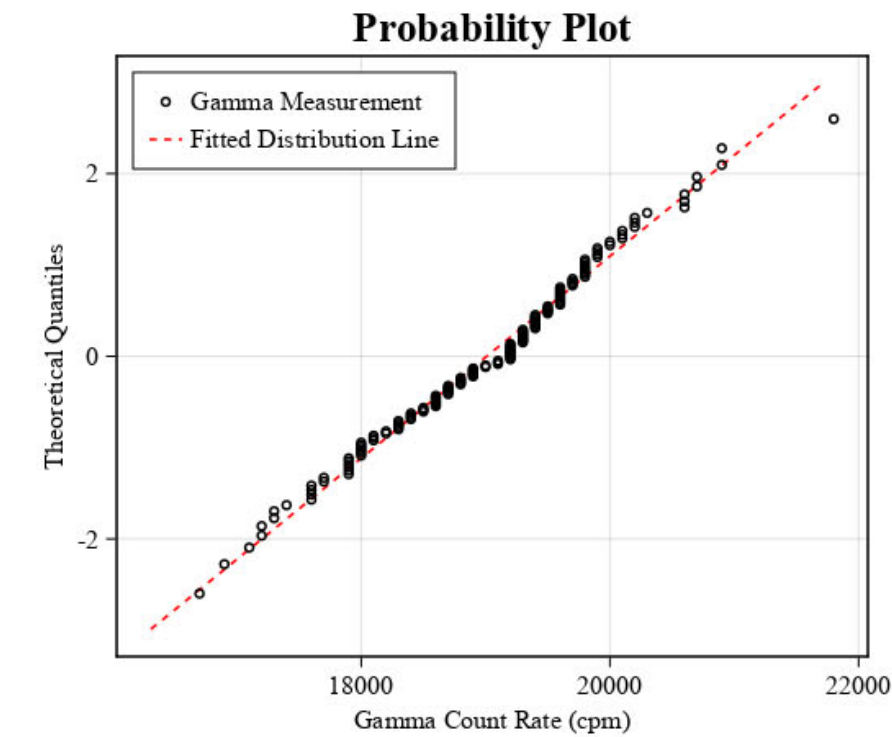
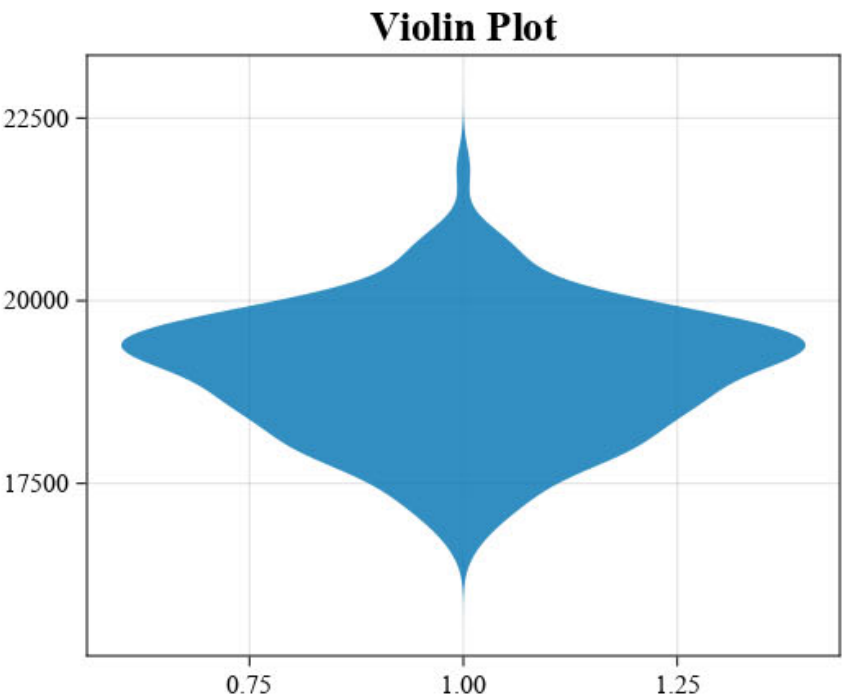
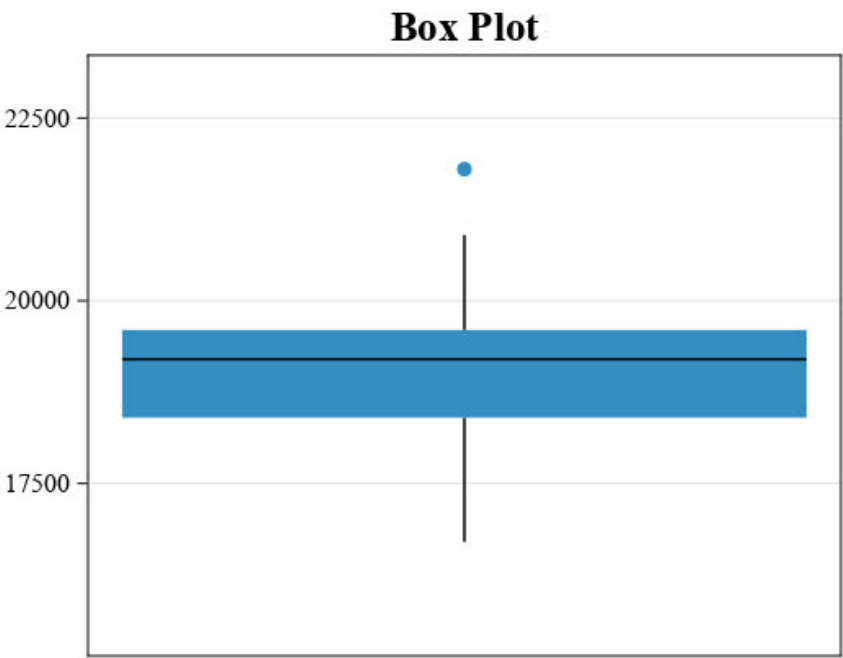
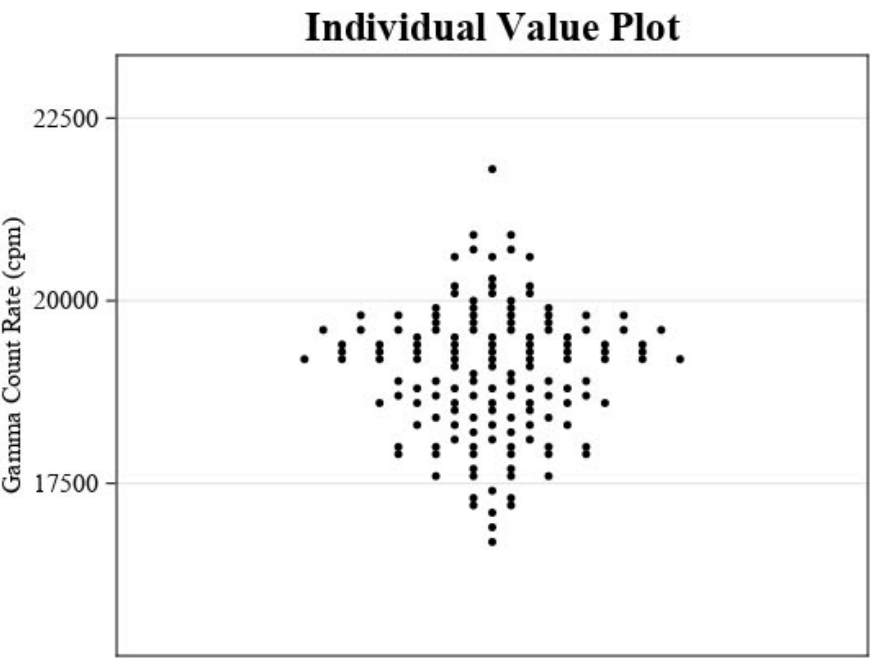
Site: OCRM Plot ID: CORR10 Type: Unshielded



Summary Statistics	
Count (n)	99
Minimum (cpm)	21,000
Maximum (cpm)	28,100
Average (cpm)	24,340
Median (cpm)	24,400
Standard Deviation (cpm)	1,387
Relative Standard Deviation	5.7%
RPD of Mean and Median	0.245%
90th Percentile (cpm)	26,100
95th Percentile (cpm)	27,400
99th Percentile (cpm)	28,100

Summary Statistics - Correlation Plots

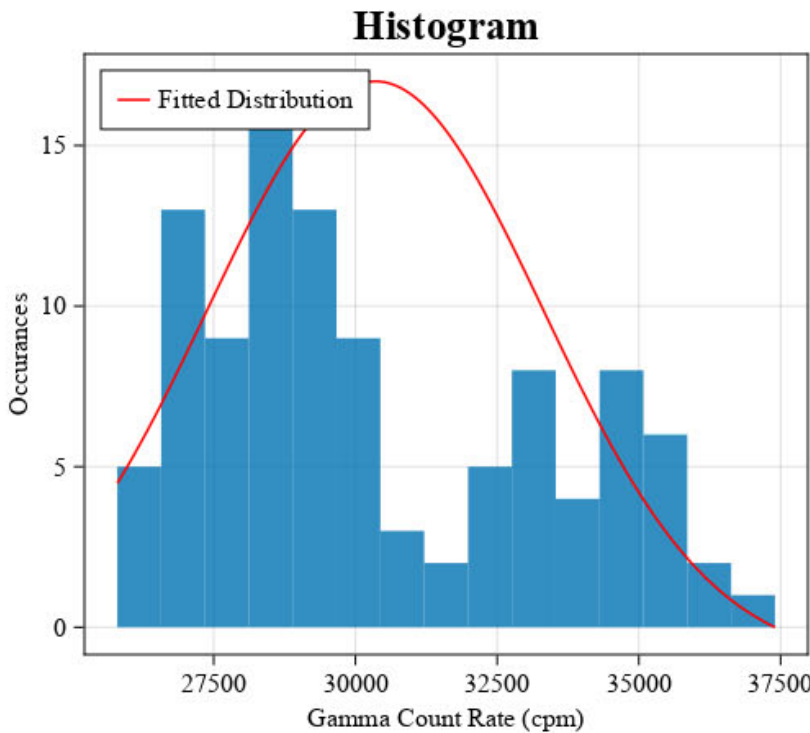
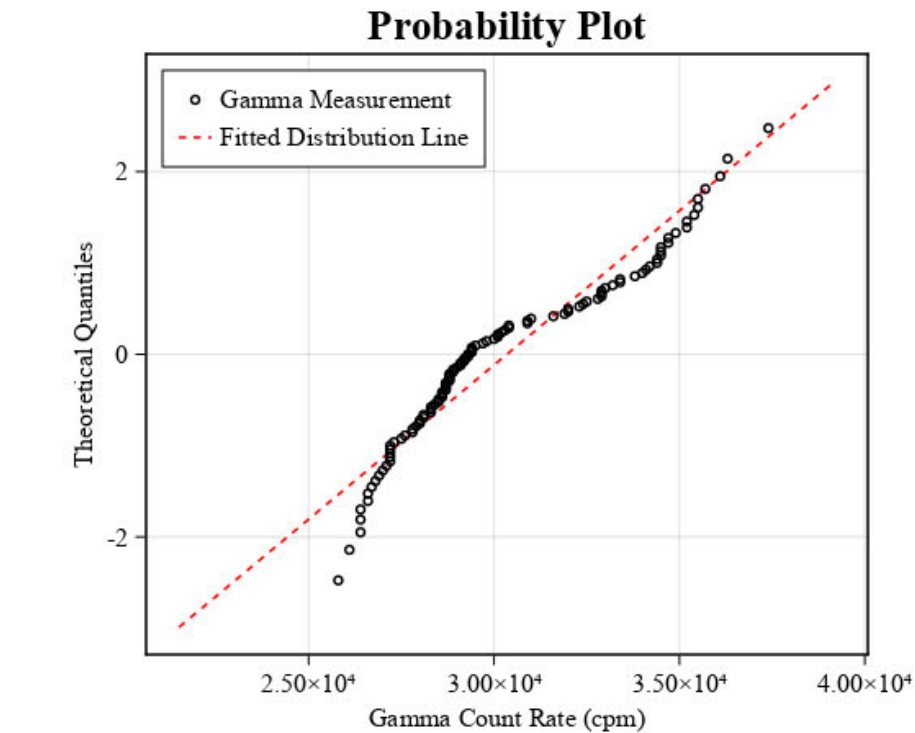
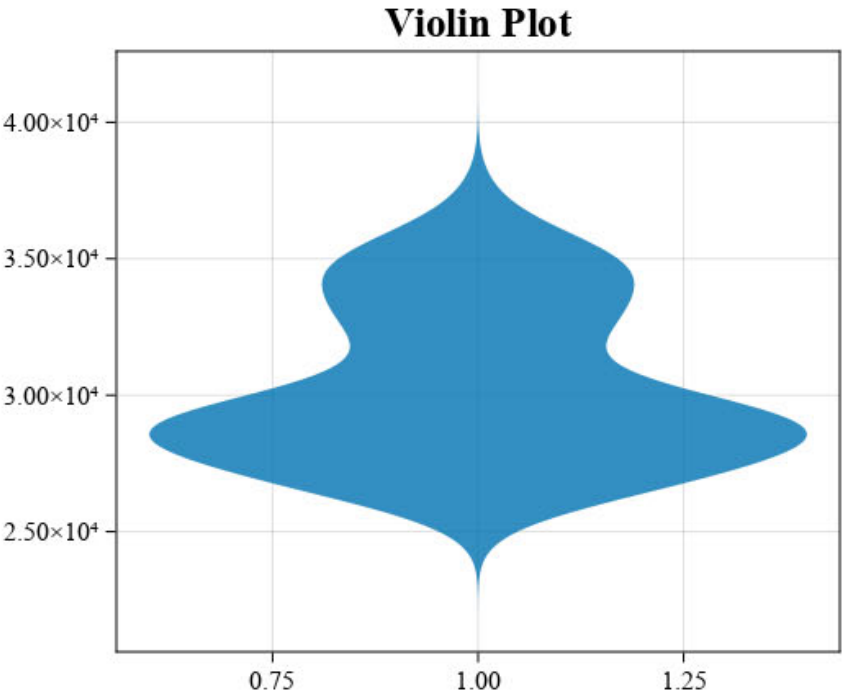
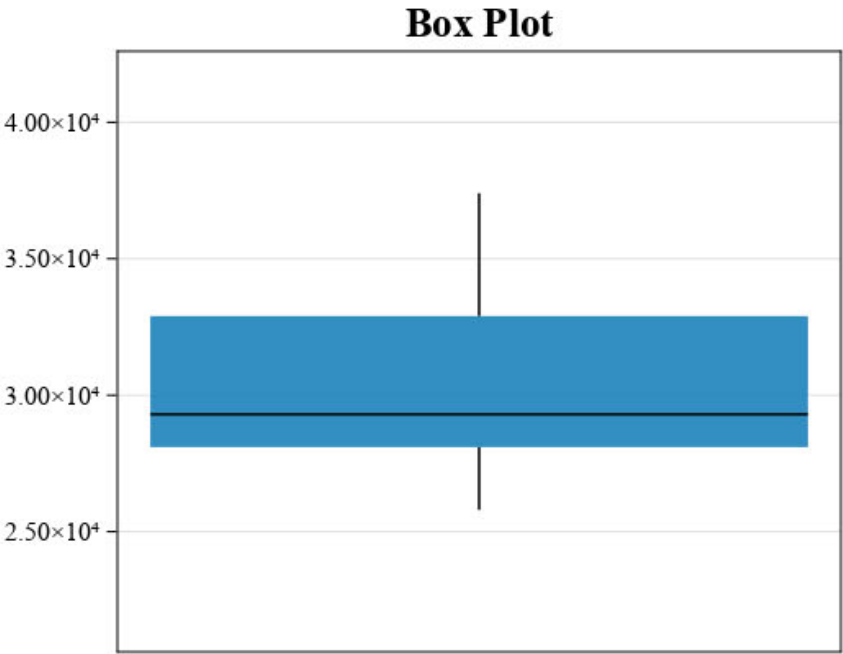
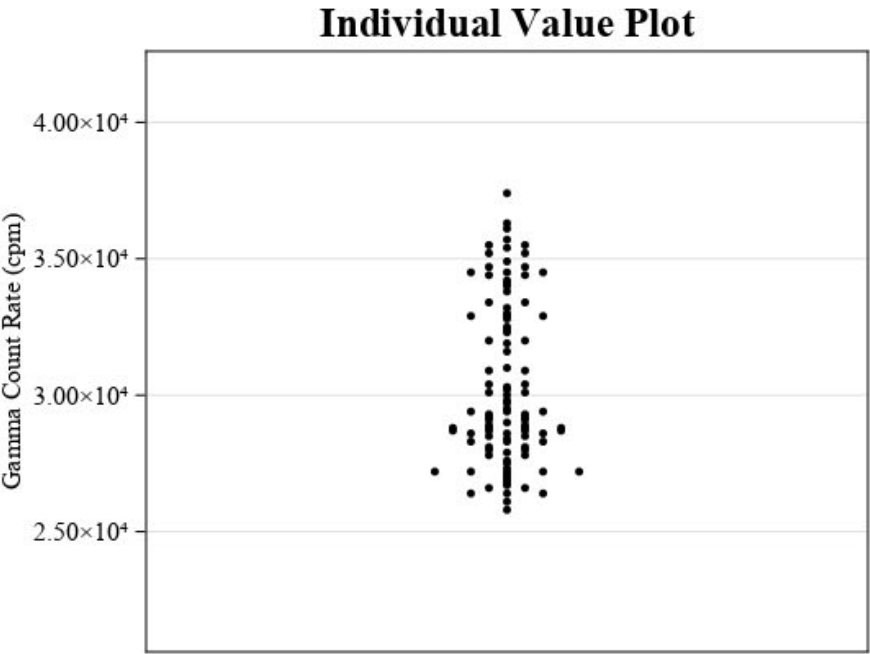
Site: OCRM Plot ID: CORR11 Type: Unshielded



Summary Statistics	
Count (n)	149
Minimum (cpm)	16,700
Maximum (cpm)	21,800
Average (cpm)	19,010
Median (cpm)	19,200
Standard Deviation (cpm)	904
Relative Standard Deviation	4.755%
RPD of Mean and Median	0.994%
90th Percentile (cpm)	20,100
95th Percentile (cpm)	20,600
99th Percentile (cpm)	20,900

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR12 Type: Unshielded

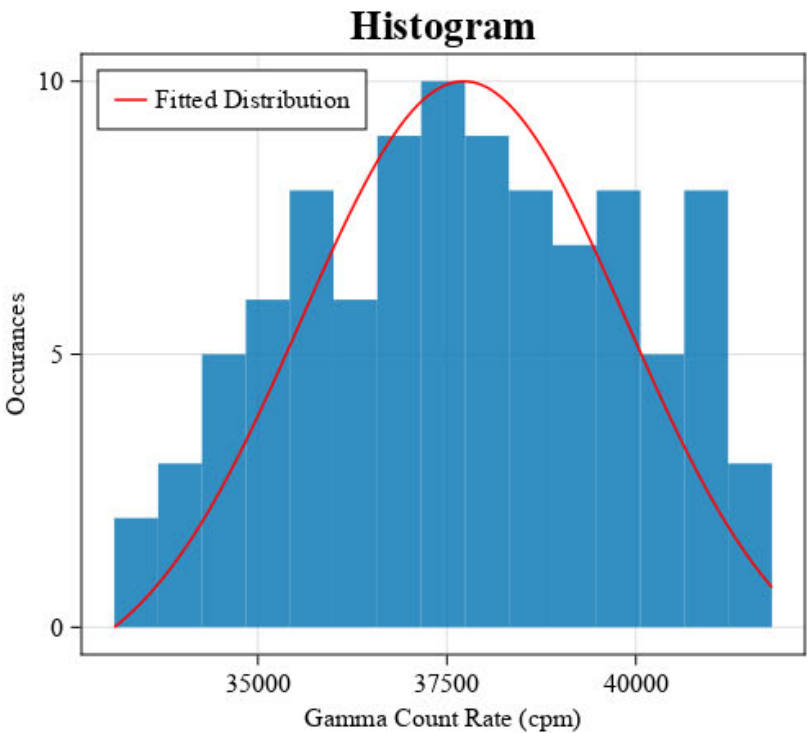
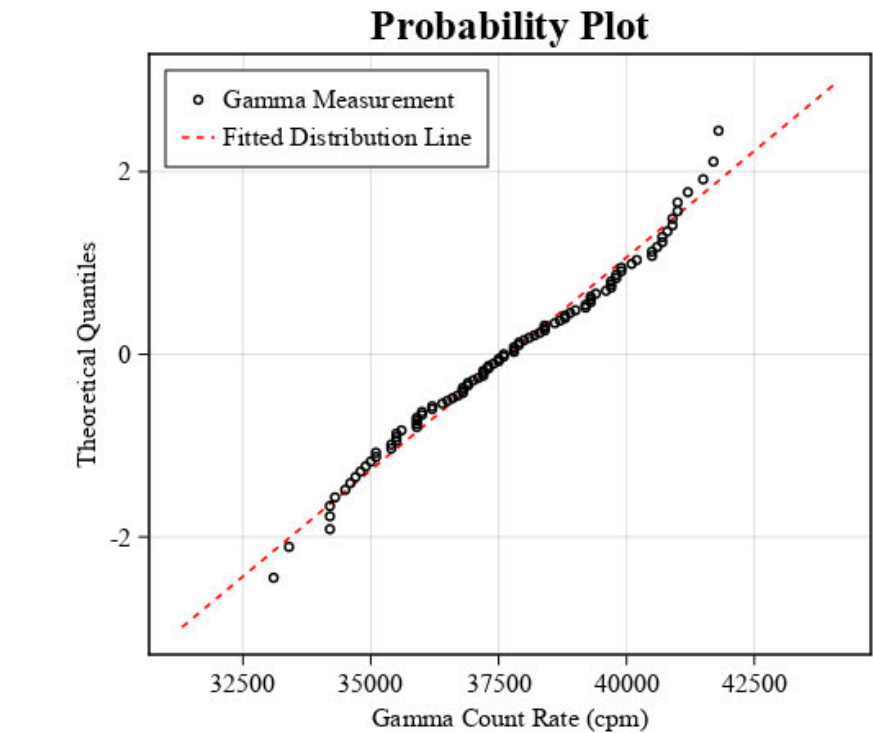
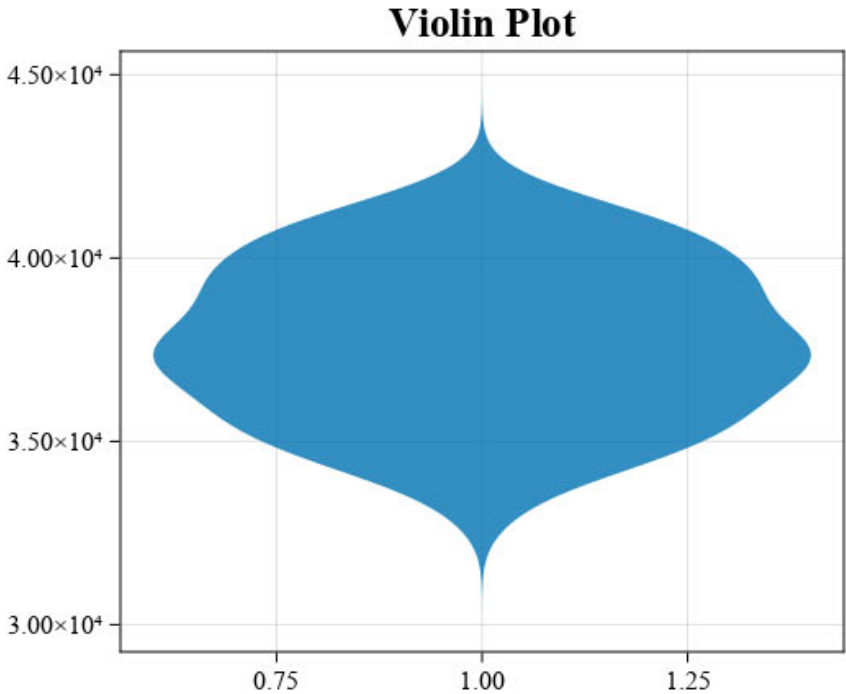
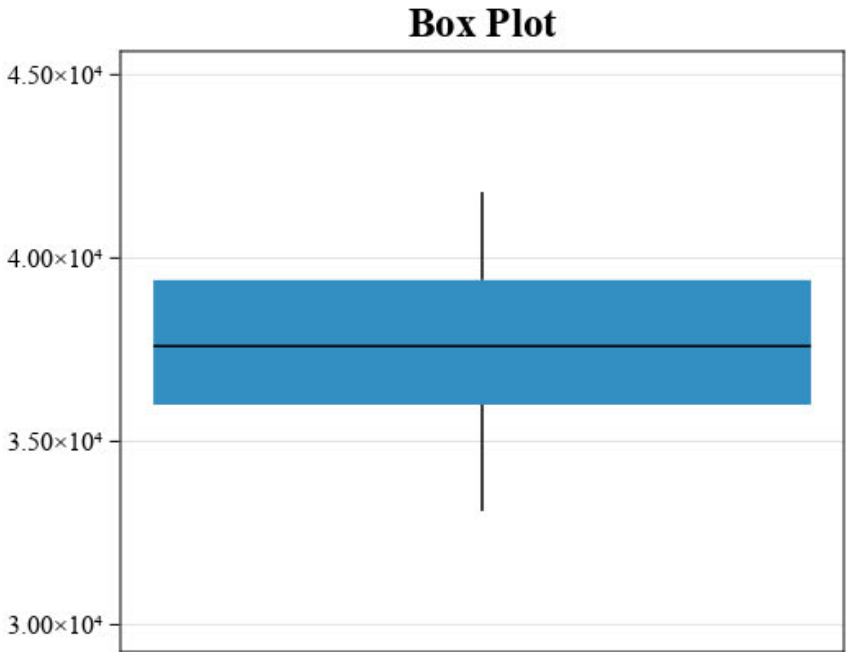
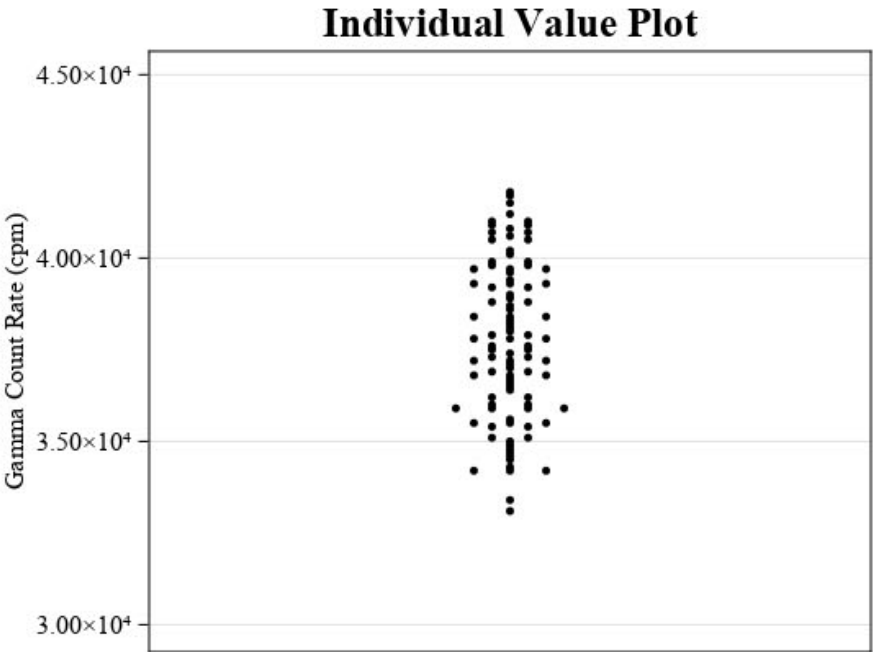


Summary Statistics

Count (n)	105
Minimum (cpm)	25,800
Maximum (cpm)	37,400
Average (cpm)	30,350
Median (cpm)	29,300
Standard Deviation (cpm)	2,960
Relative Standard Deviation	9.754%
RPD of Mean and Median	3.519%
90th Percentile (cpm)	34,700
95th Percentile (cpm)	35,500
99th Percentile (cpm)	36,300

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR13 Type: Unshielded

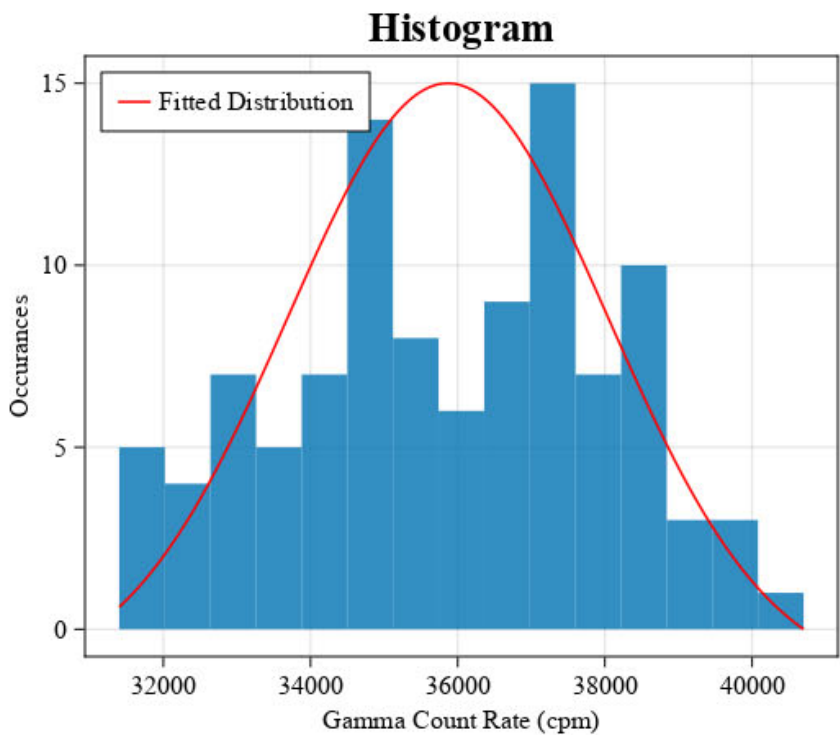
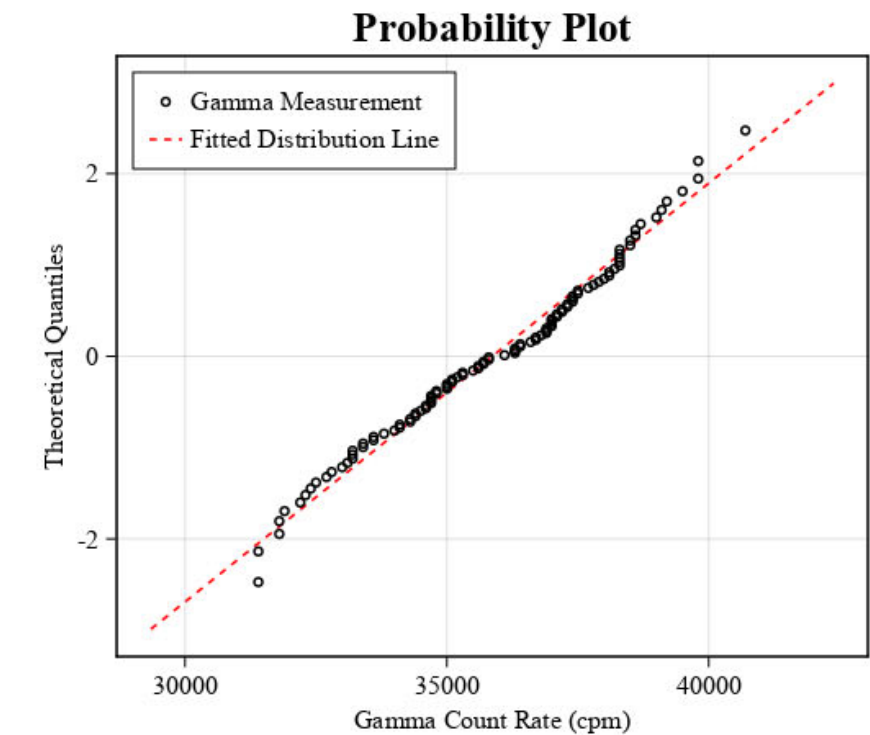
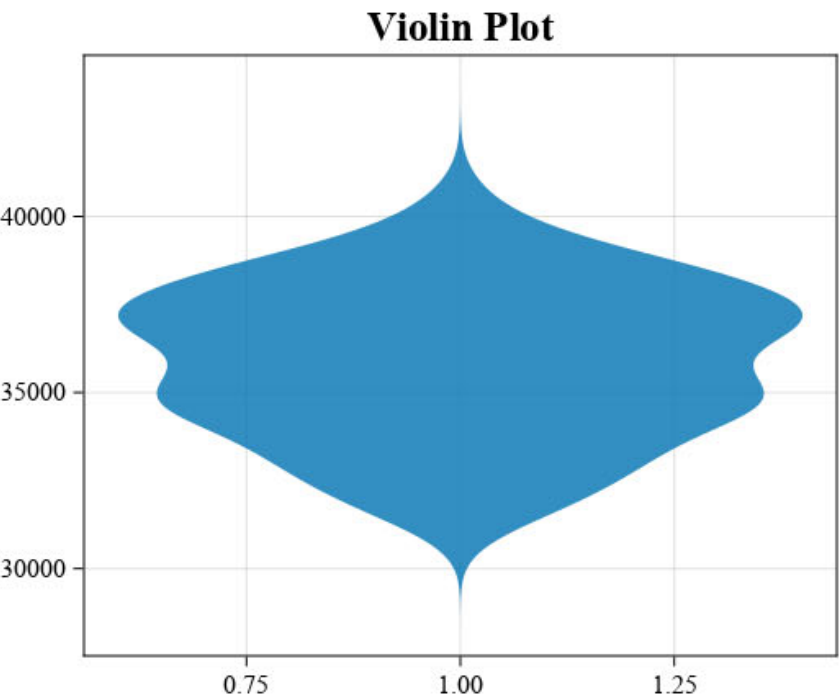
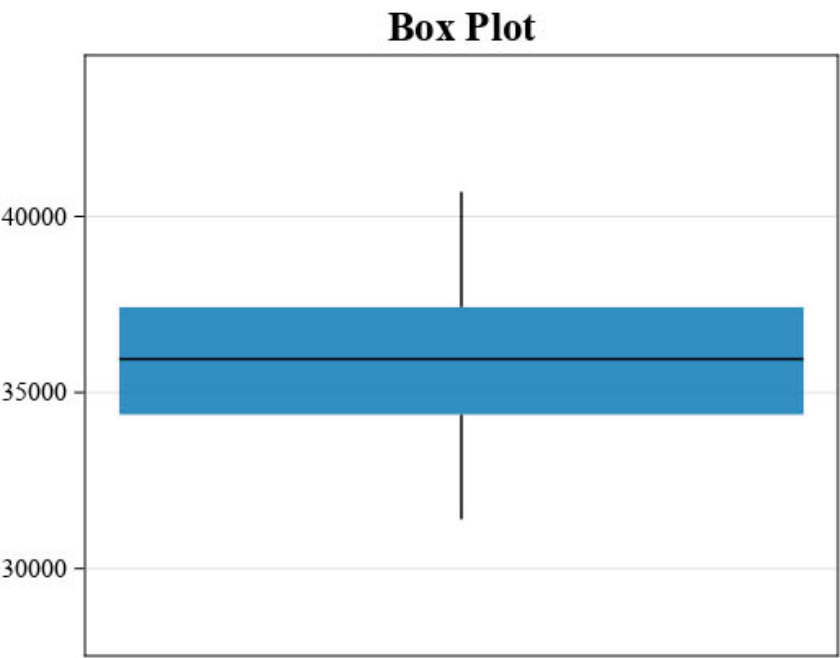
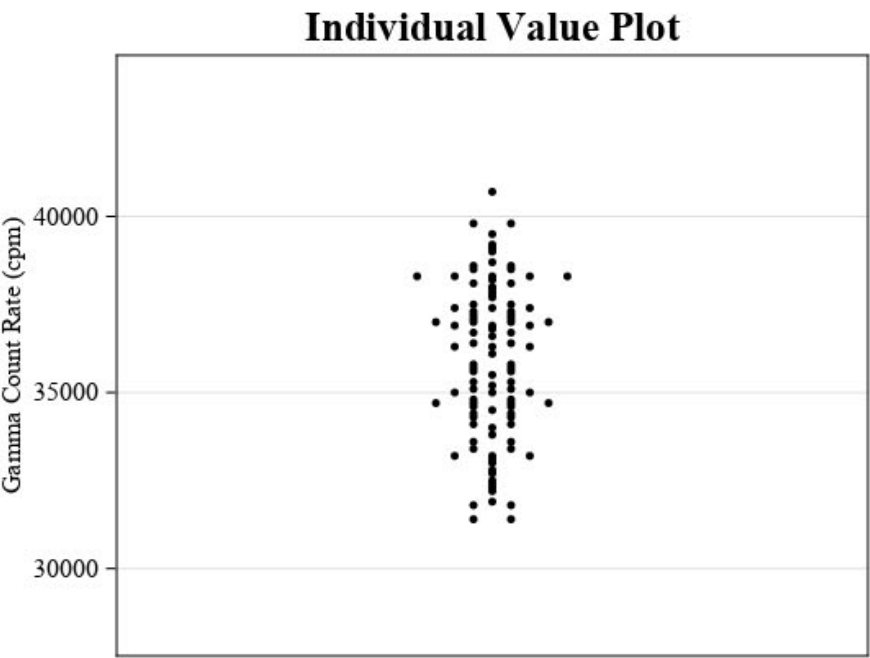


Summary Statistics

Count (n)	97
Minimum (cpm)	33,100
Maximum (cpm)	41,800
Average (cpm)	37,722
Median (cpm)	37,600
Standard Deviation (cpm)	2,146
Relative Standard Deviation	5.69%
RPD of Mean and Median	0.323%
90th Percentile (cpm)	40,700
95th Percentile (cpm)	41,000
99th Percentile (cpm)	41,800

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR14 Type: Unshielded

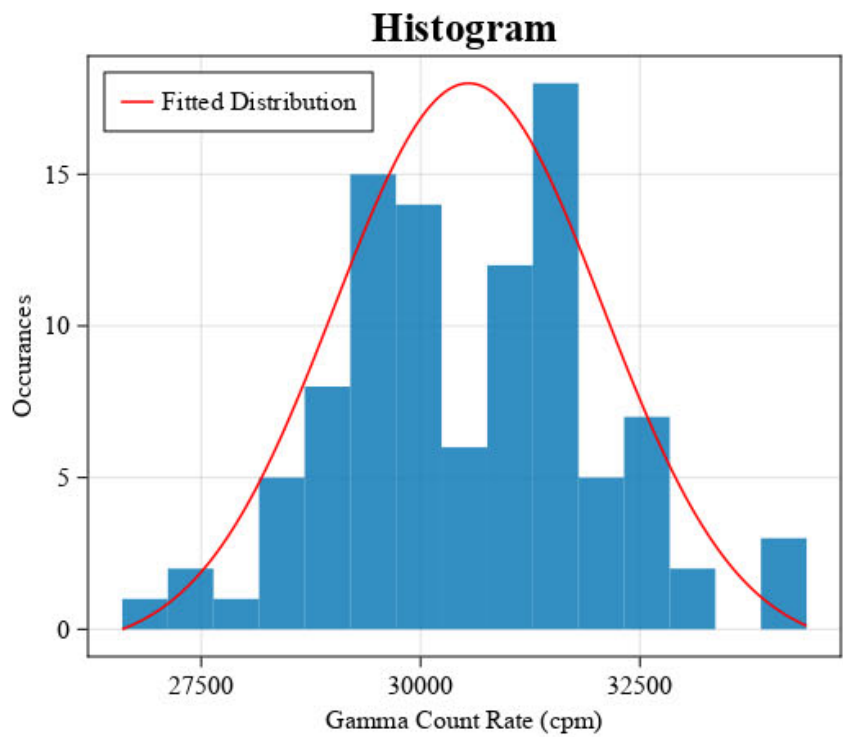
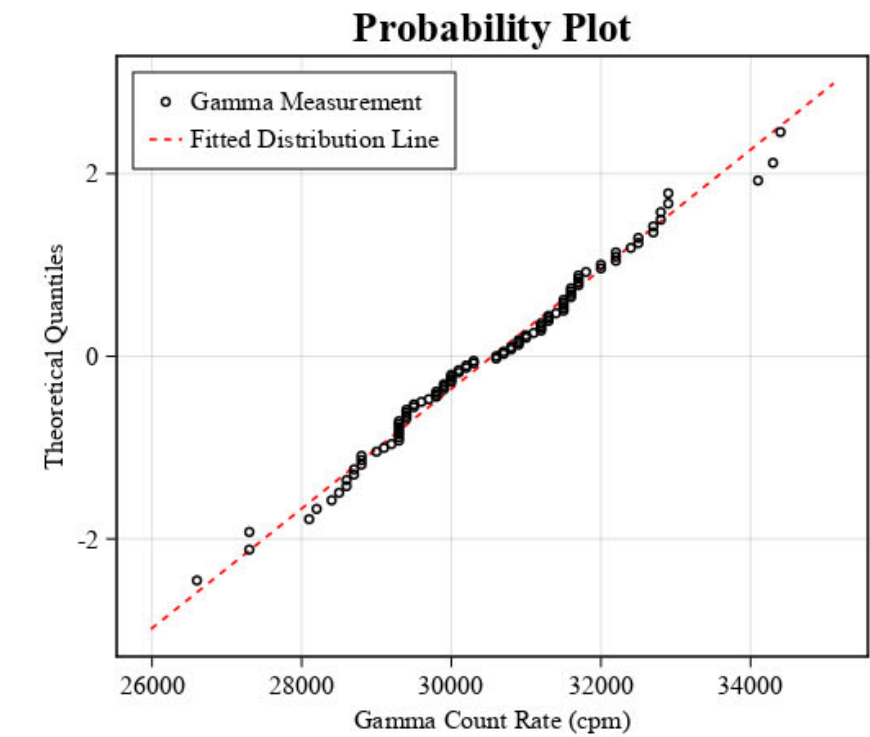
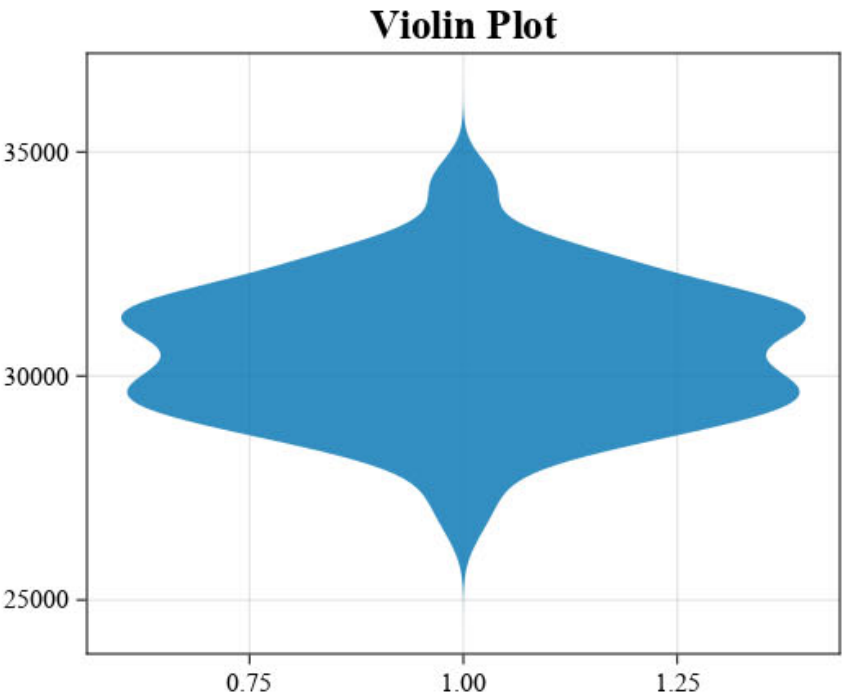
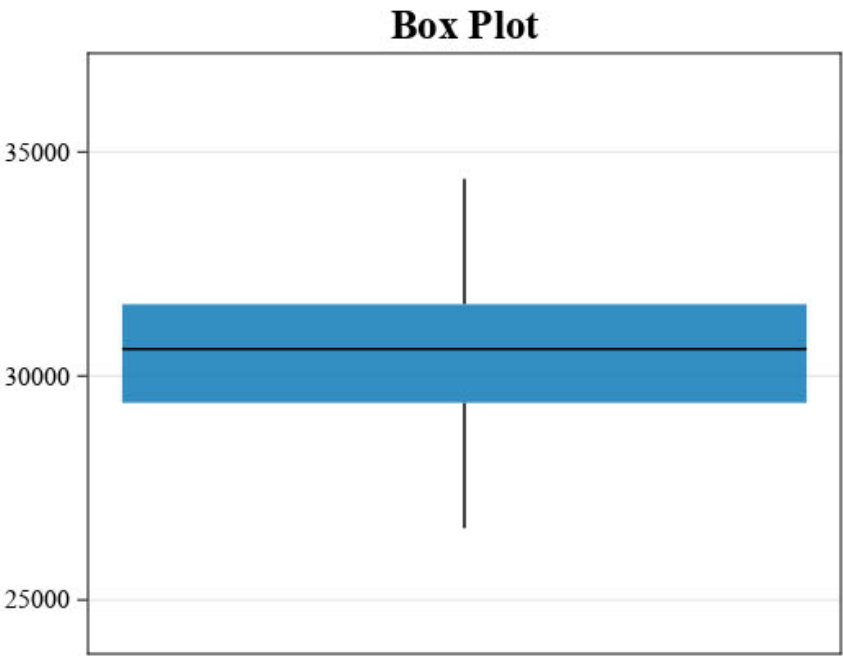
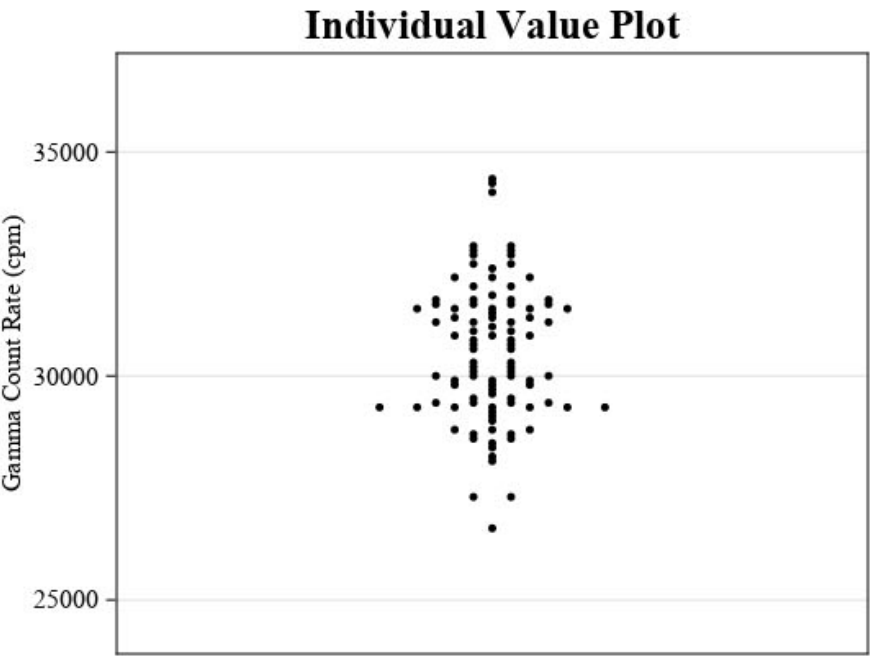


Summary Statistics

Count (n)	104
Minimum (cpm)	31,400
Maximum (cpm)	40,700
Average (cpm)	35,866
Median (cpm)	35,950
Standard Deviation (cpm)	2,181
Relative Standard Deviation	6.082%
RPD of Mean and Median	0.233%
90th Percentile (cpm)	38,500
95th Percentile (cpm)	39,100
99th Percentile (cpm)	39,800

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR15 Type: Unshielded



Summary Statistics

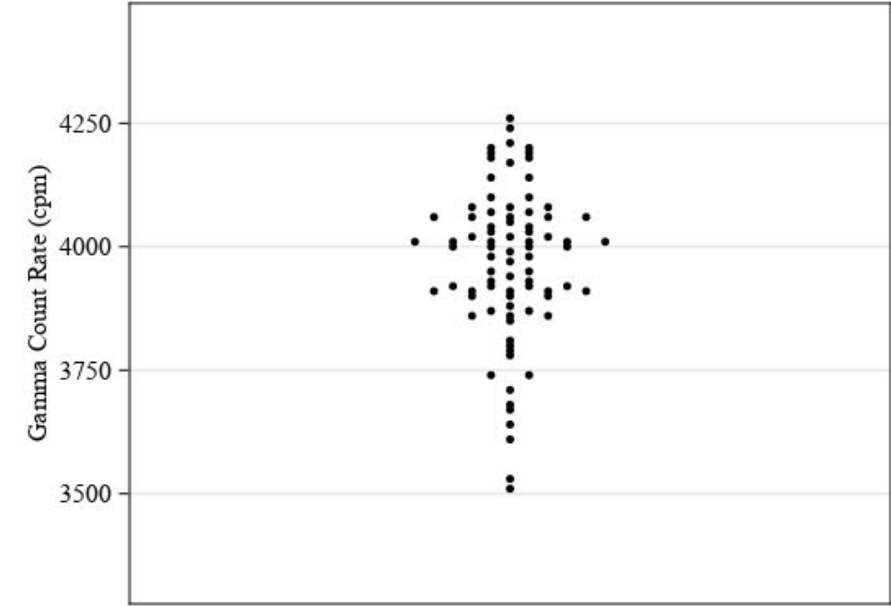
Count (n)	99
Minimum (cpm)	26,600
Maximum (cpm)	34,400
Average (cpm)	30,547
Median (cpm)	30,600
Standard Deviation (cpm)	1,527
Relative Standard Deviation	4.998%
RPD of Mean and Median	0.172%
90th Percentile (cpm)	32,500
95th Percentile (cpm)	32,900
99th Percentile (cpm)	34,400

ATTACHMENT E-4: CORRELATION PLOT STATISTICS – SHIELDED GAMMA

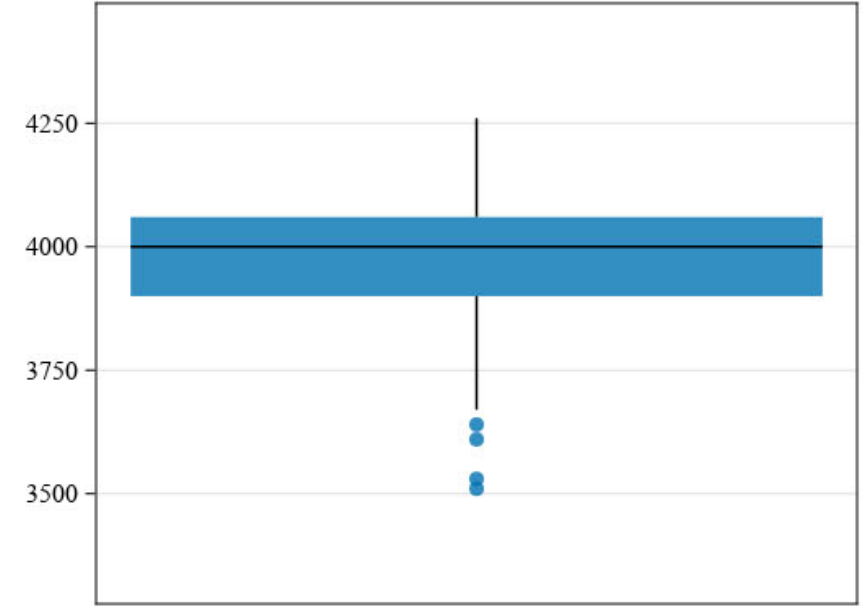
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR01 Type: Shielded

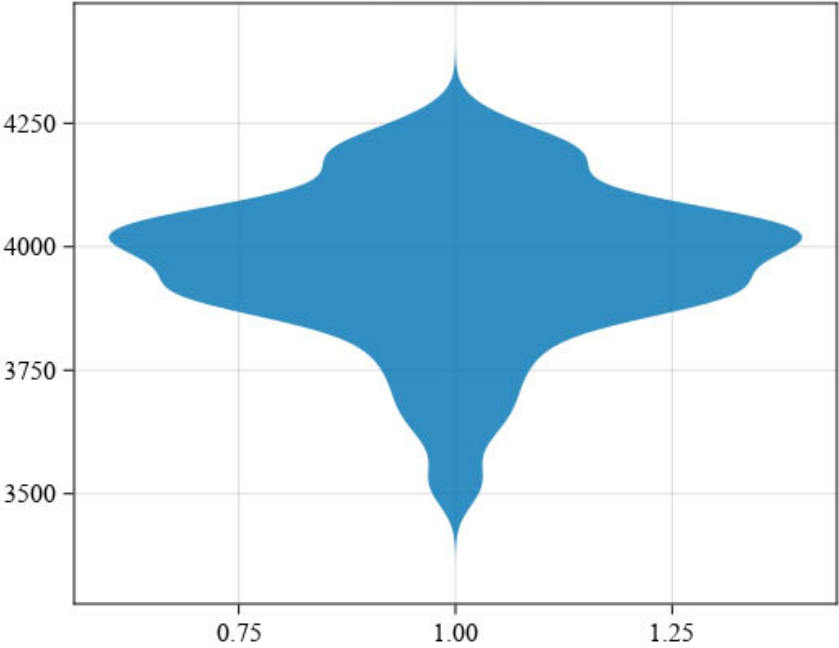
Individual Value Plot



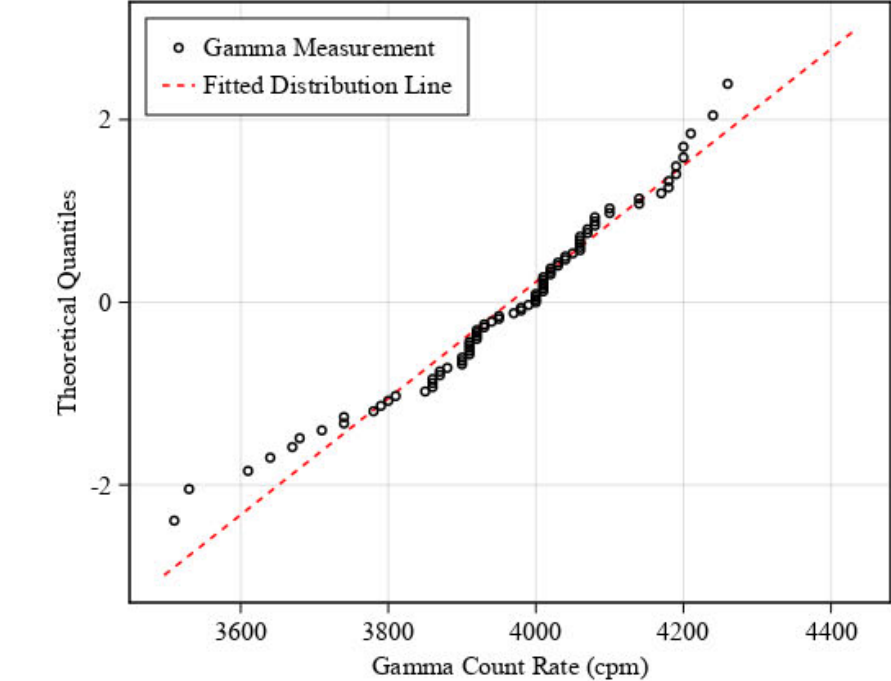
Box Plot



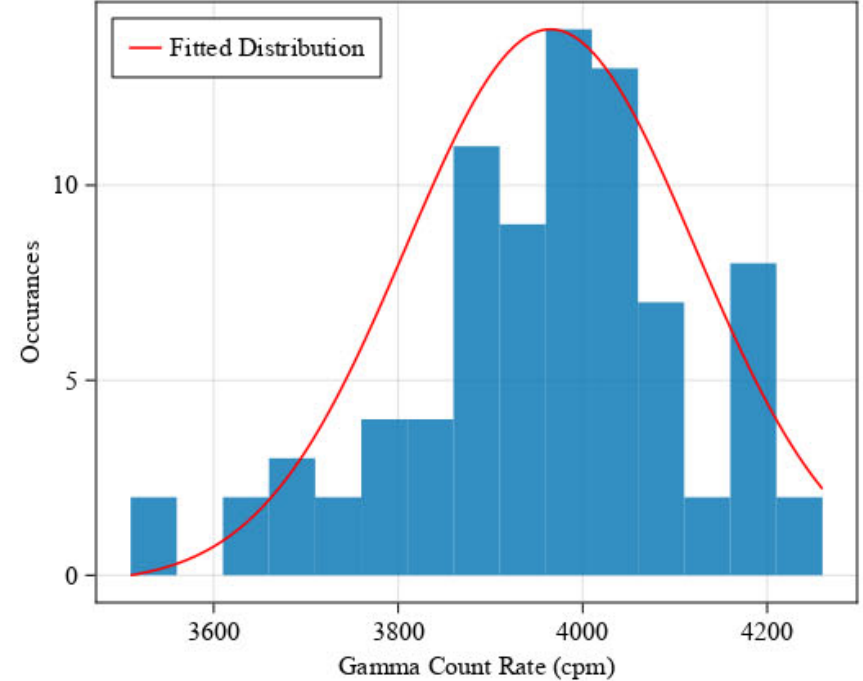
Violin Plot



Probability Plot



Histogram



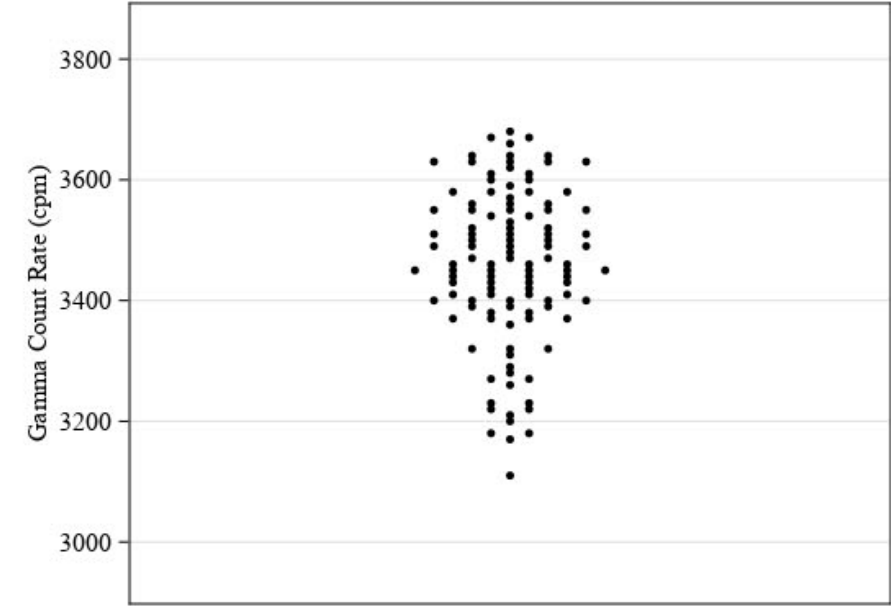
Summary Statistics

Count (n)	83
Minimum (cpm)	3,510
Maximum (cpm)	4,260
Average (cpm)	3,965
Median (cpm)	4,000
Standard Deviation (cpm)	157
Relative Standard Deviation	3.956%
RPD of Mean and Median	0.877%
90th Percentile (cpm)	4,180
95th Percentile (cpm)	4,200
99th Percentile (cpm)	4,260

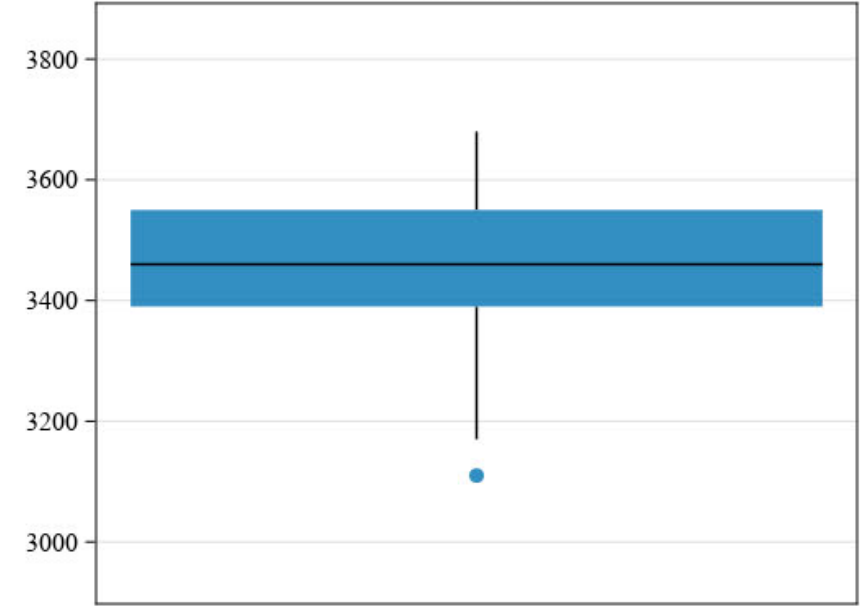
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR02 Type: Shielded

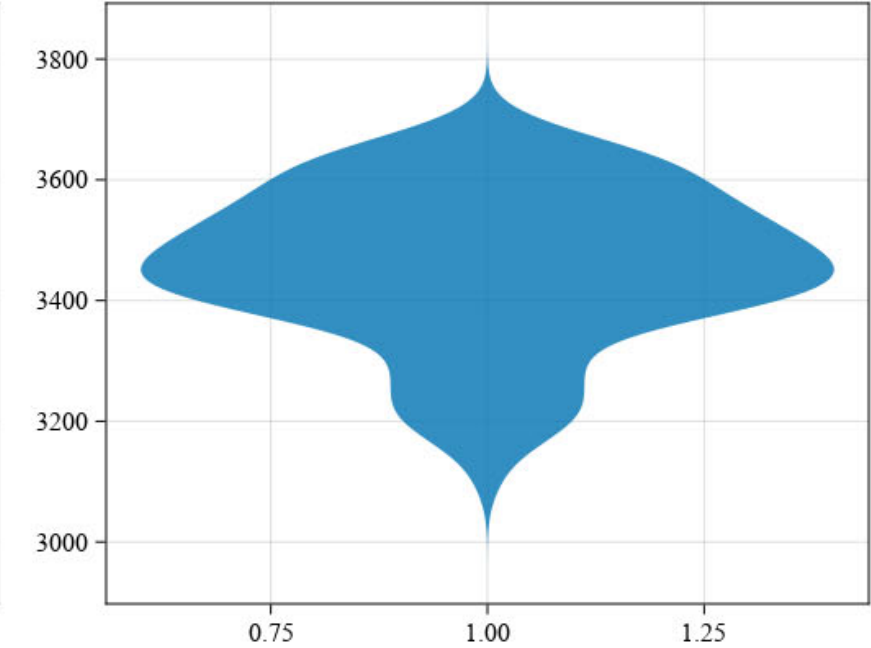
Individual Value Plot



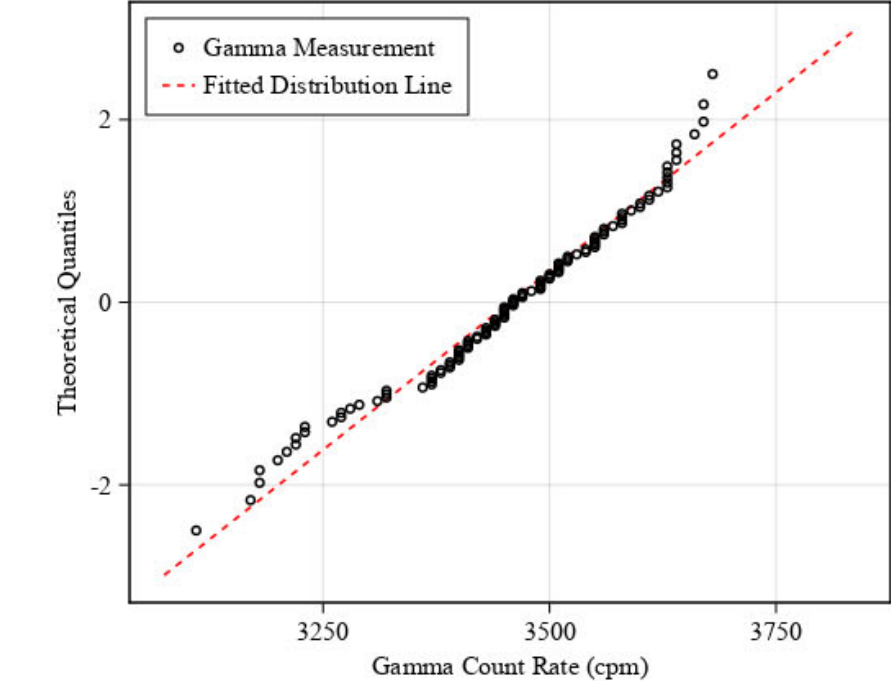
Box Plot



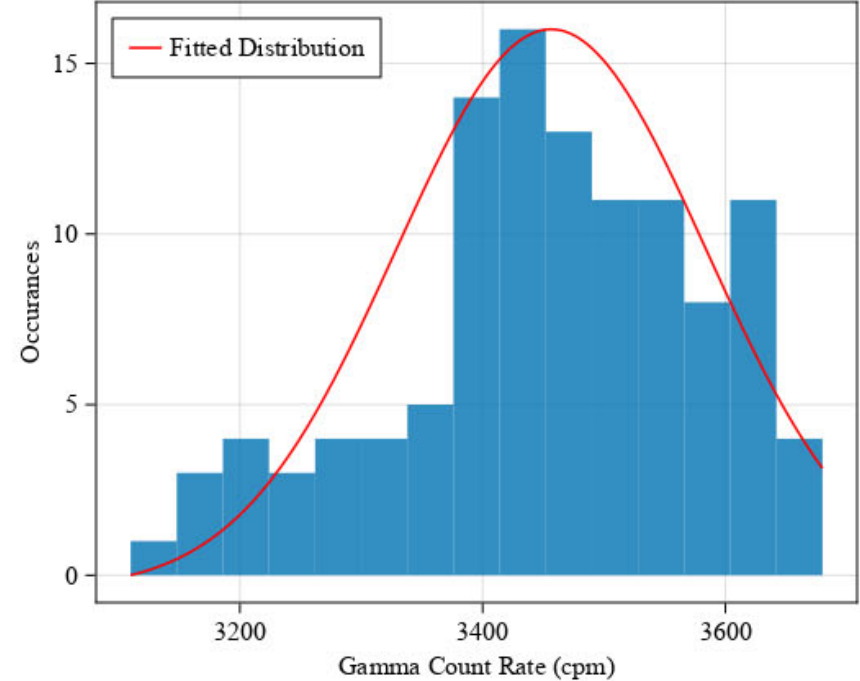
Violin Plot



Probability Plot



Histogram



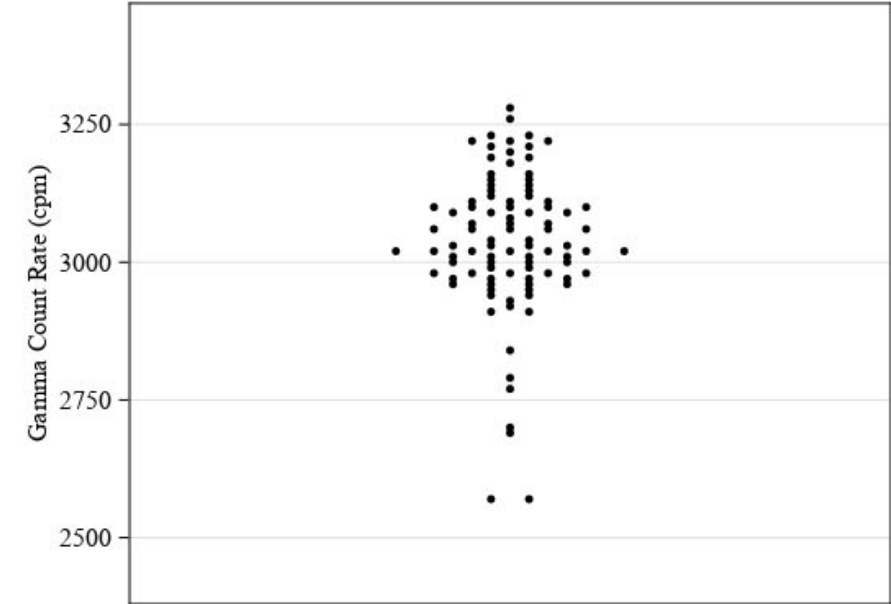
Summary Statistics

Count (n)	112
Minimum (cpm)	3,110
Maximum (cpm)	3,680
Average (cpm)	3,456
Median (cpm)	3,460
Standard Deviation (cpm)	128
Relative Standard Deviation	3.695%
RPD of Mean and Median	0.103%
90th Percentile (cpm)	3,630
95th Percentile (cpm)	3,640
99th Percentile (cpm)	3,670

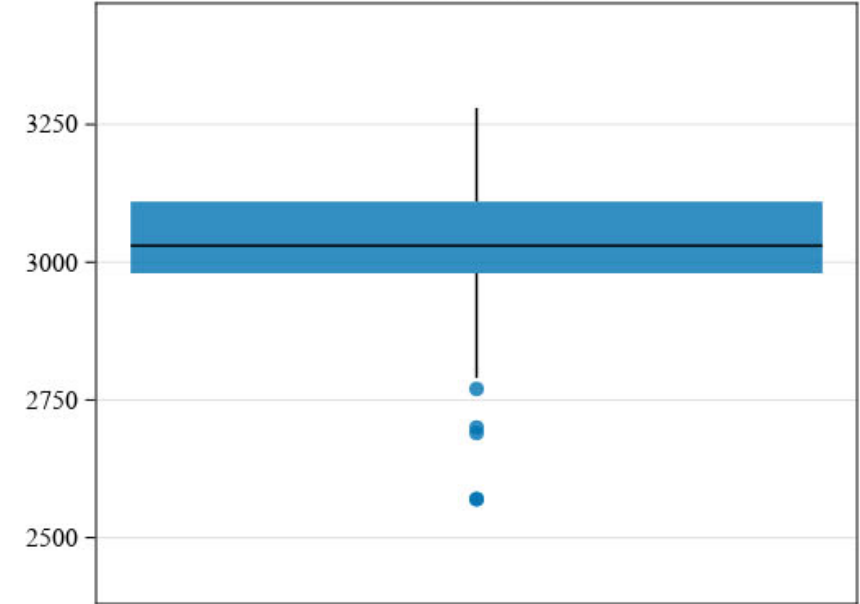
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR03 Type: Shielded

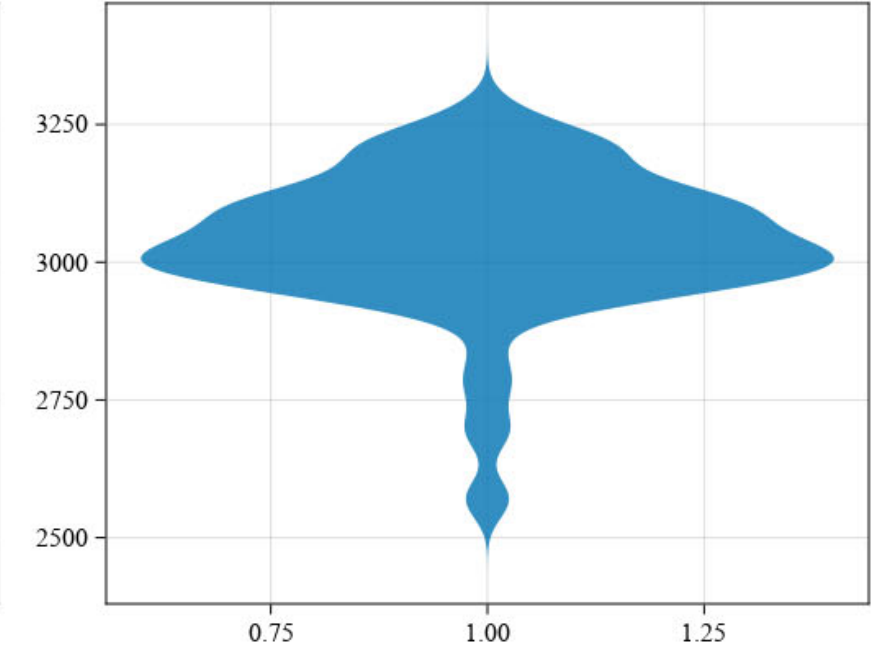
Individual Value Plot



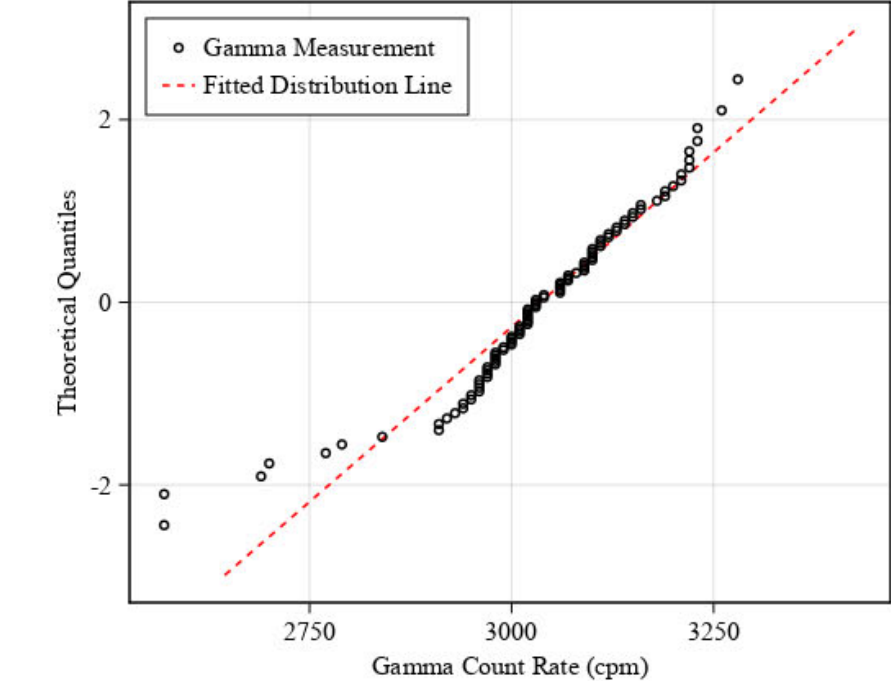
Box Plot



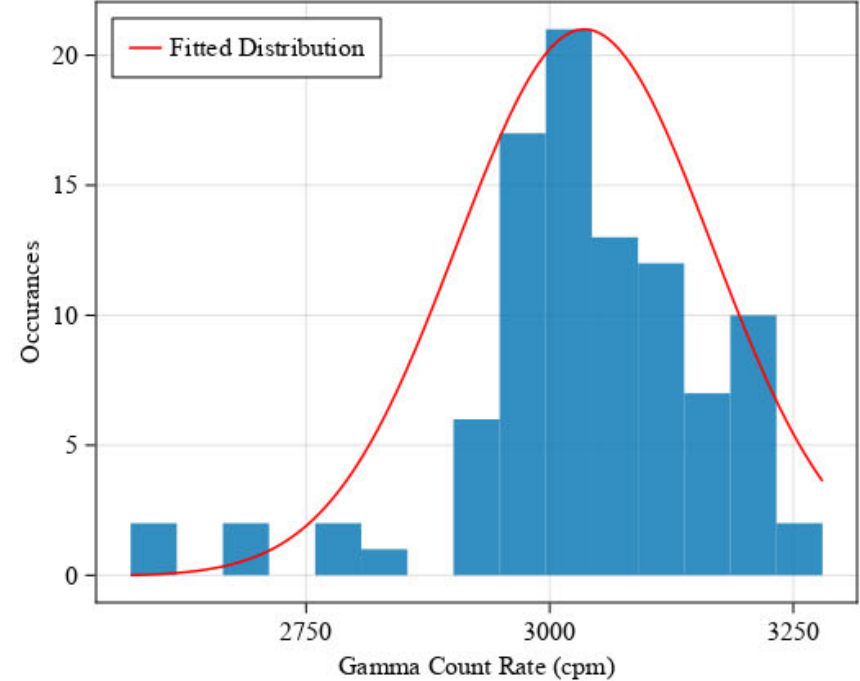
Violin Plot



Probability Plot



Histogram

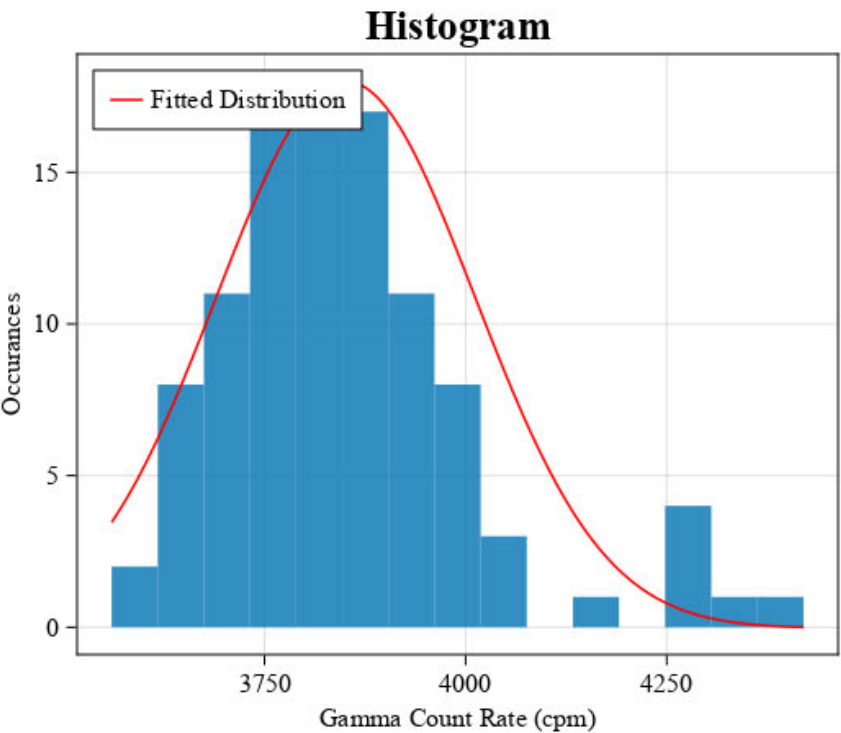
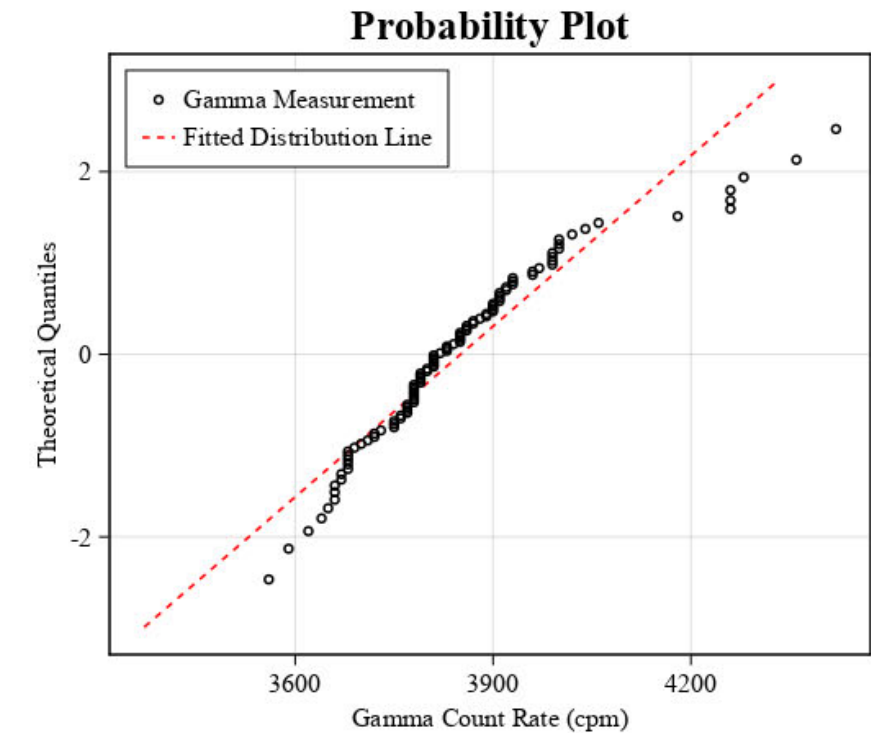
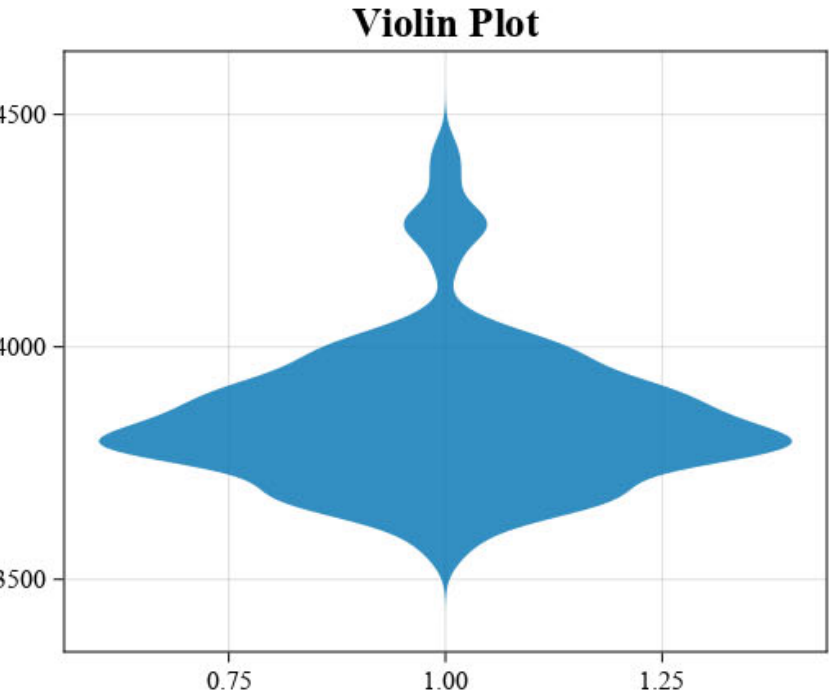
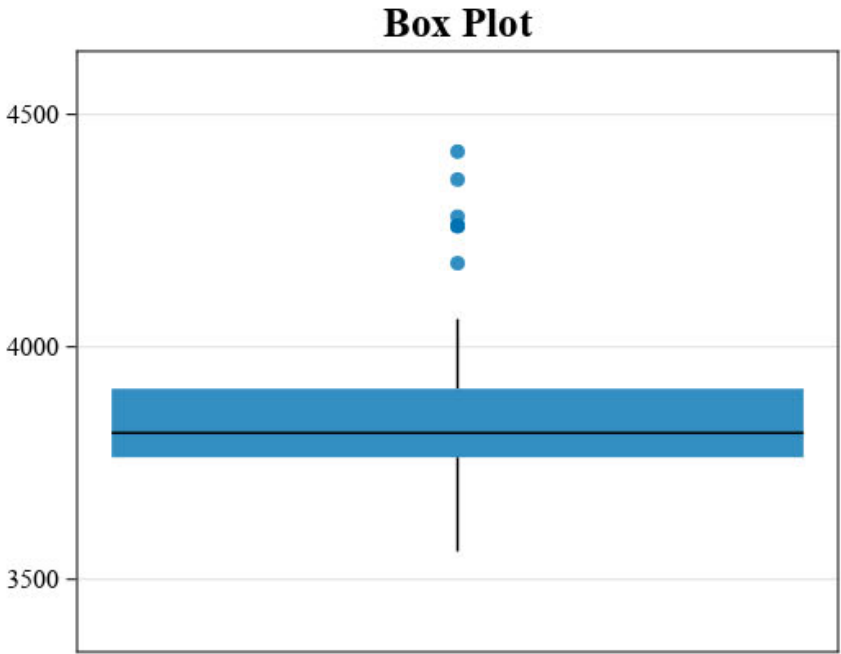
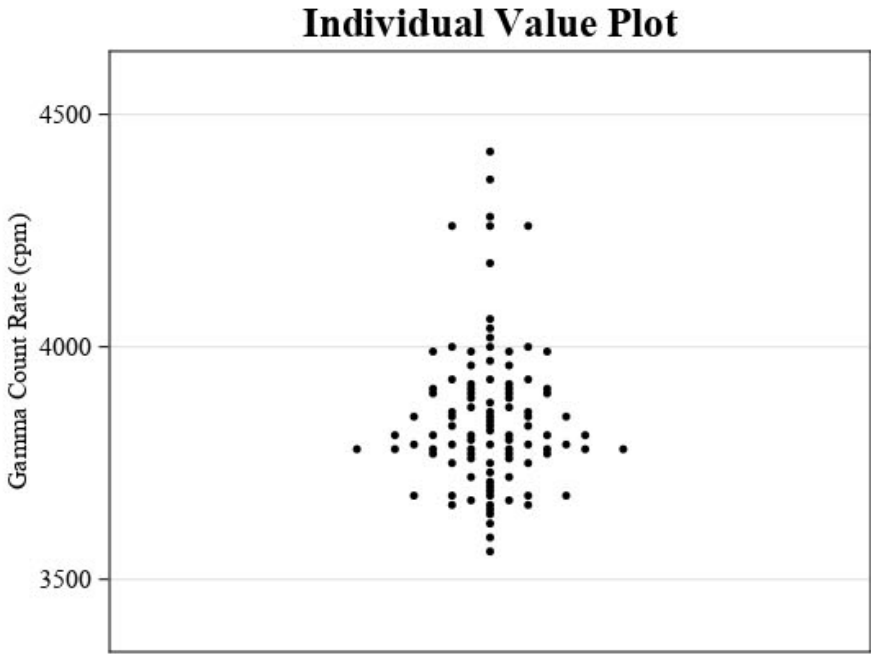


Summary Statistics

Count (n)	95
Minimum (cpm)	2,570
Maximum (cpm)	3,280
Average (cpm)	3,036
Median (cpm)	3,030
Standard Deviation (cpm)	131
Relative Standard Deviation	4.306%
RPD of Mean and Median	0.184%
90th Percentile (cpm)	3,200
95th Percentile (cpm)	3,220
99th Percentile (cpm)	3,280

Summary Statistics - Correlation Plots

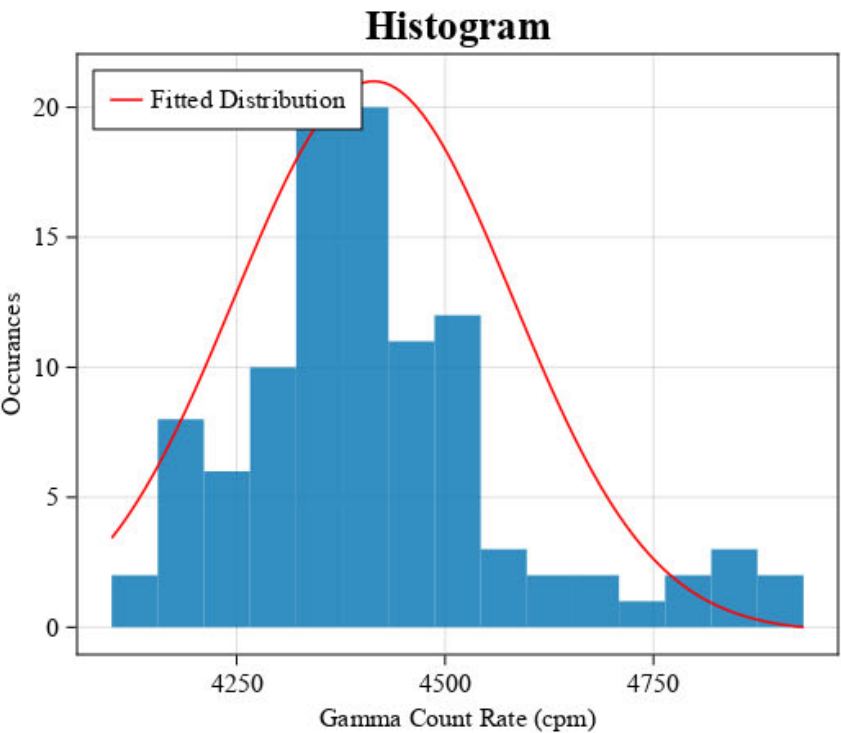
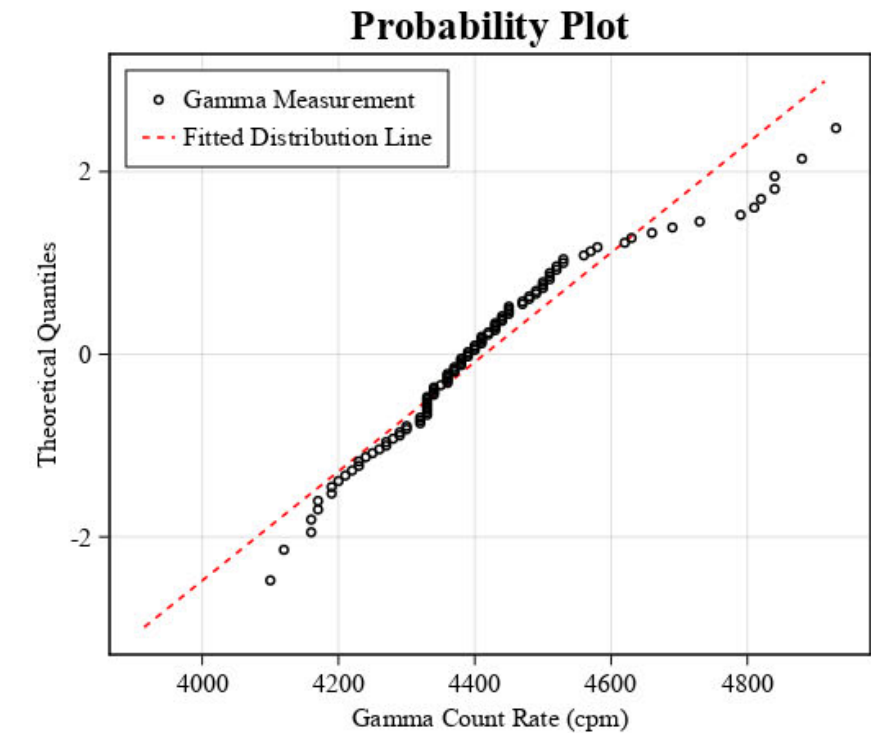
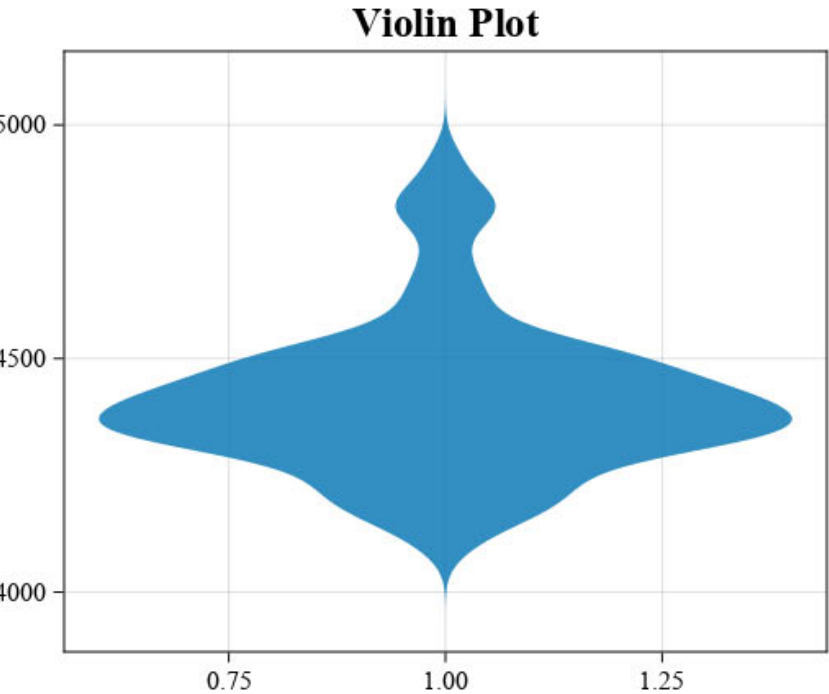
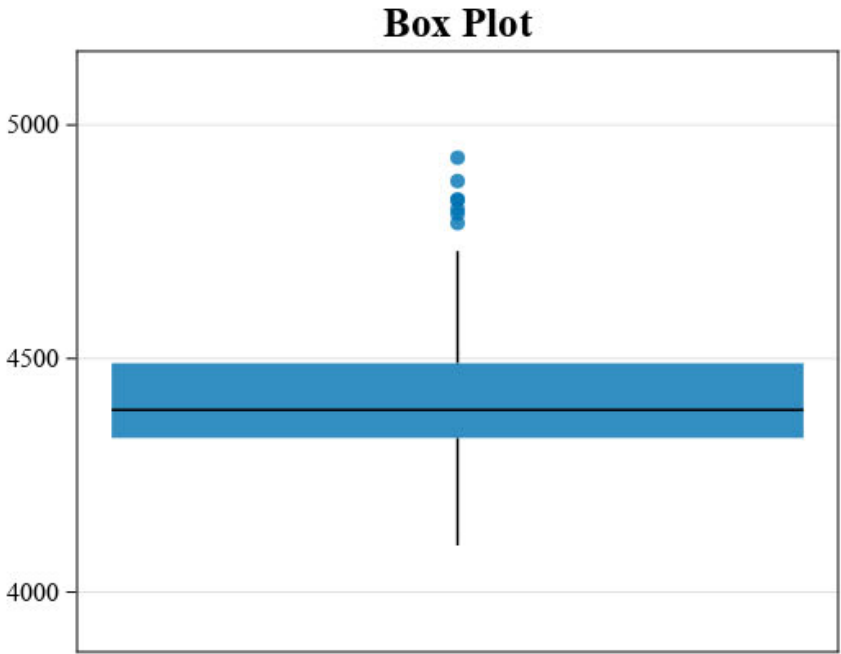
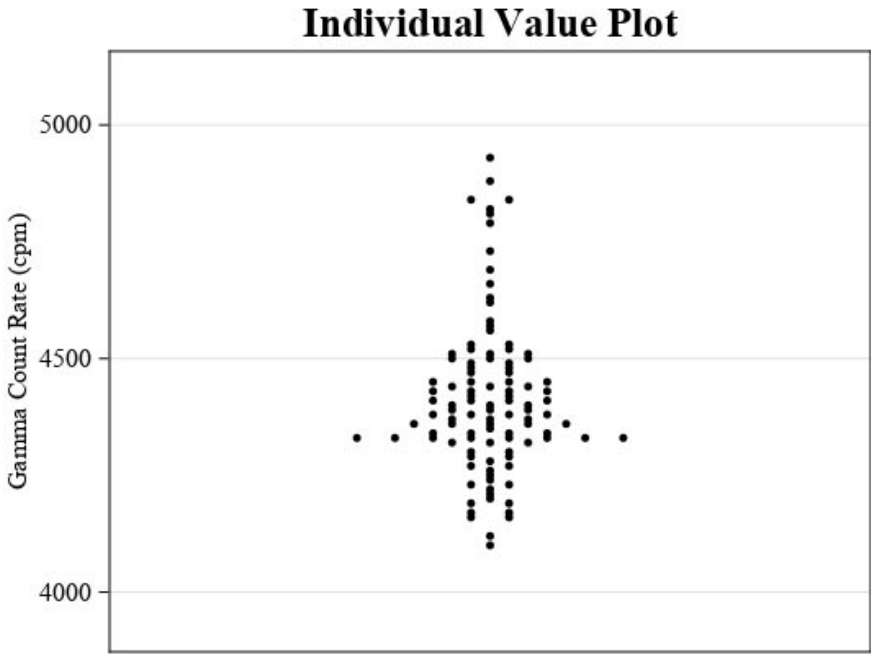
Site: OCRM Plot ID: CORR04 Type: Shielded



Summary Statistics	
Count (n)	102
Minimum (cpm)	3,560
Maximum (cpm)	4,420
Average (cpm)	3,851
Median (cpm)	3,815
Standard Deviation (cpm)	161
Relative Standard Deviation	4.169%
RPD of Mean and Median	0.936%
90th Percentile (cpm)	4,000
95th Percentile (cpm)	4,260
99th Percentile (cpm)	4,360

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR05 Type: Shielded



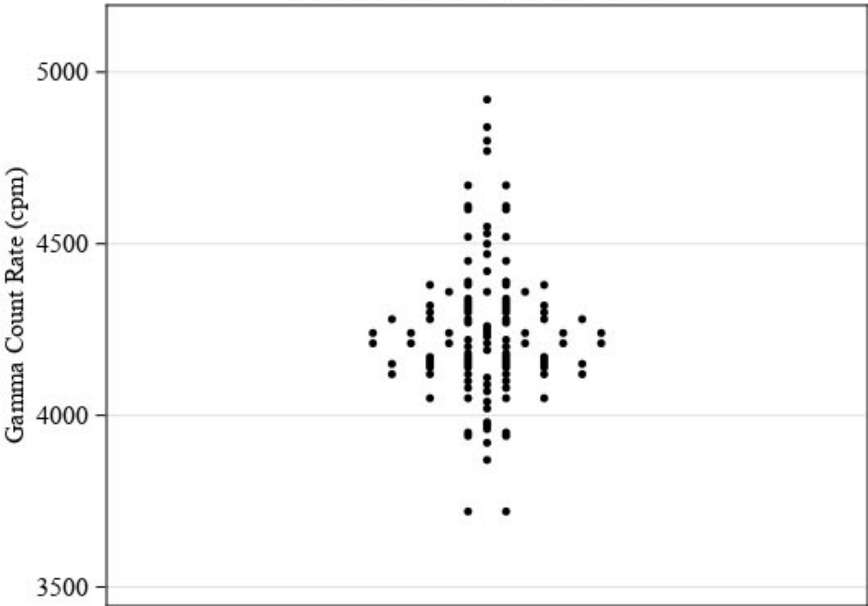
Summary Statistics

Count (n)	105
Minimum (cpm)	4,100
Maximum (cpm)	4,930
Average (cpm)	4,414
Median (cpm)	4,390
Standard Deviation (cpm)	167
Relative Standard Deviation	3.784%
RPD of Mean and Median	0.55%
90th Percentile (cpm)	4,630
95th Percentile (cpm)	4,810
99th Percentile (cpm)	4,880

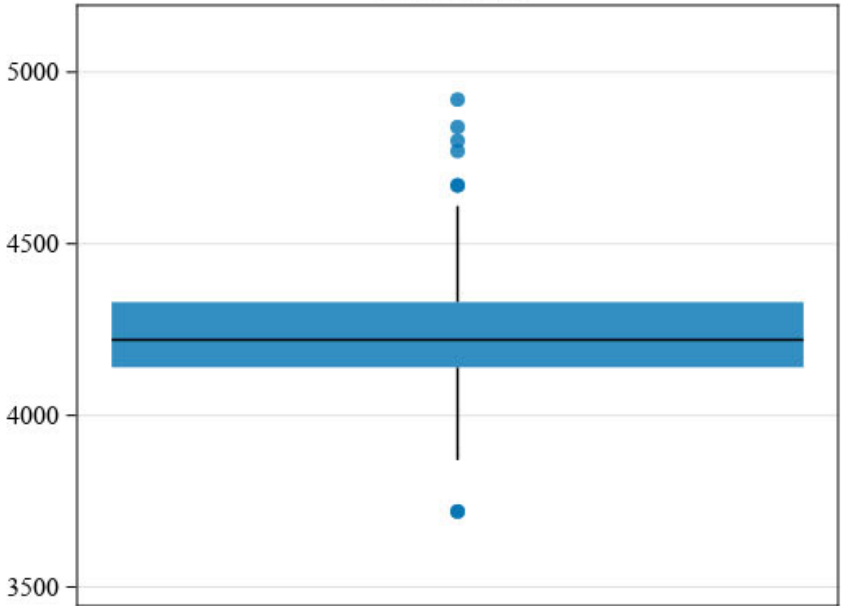
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR06 Type: Shielded

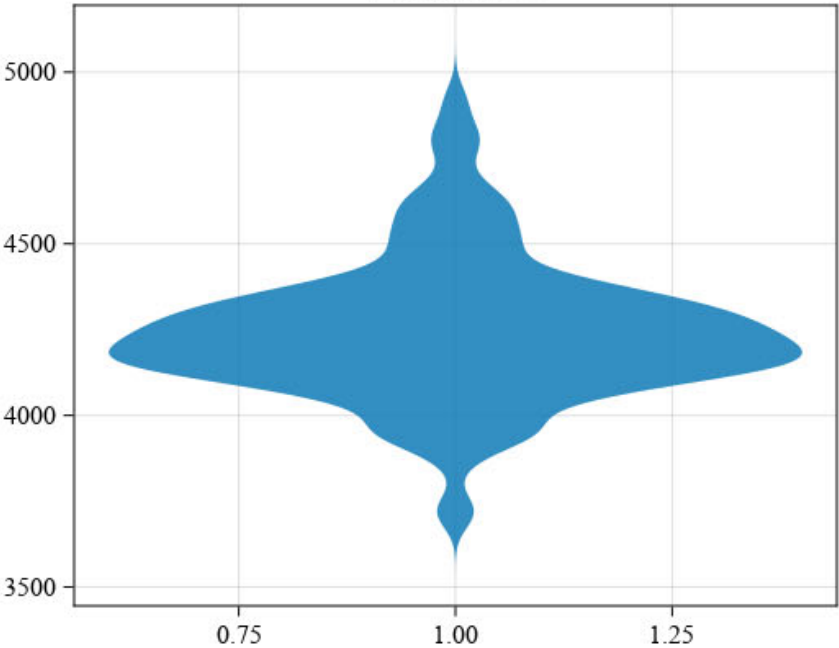
Individual Value Plot



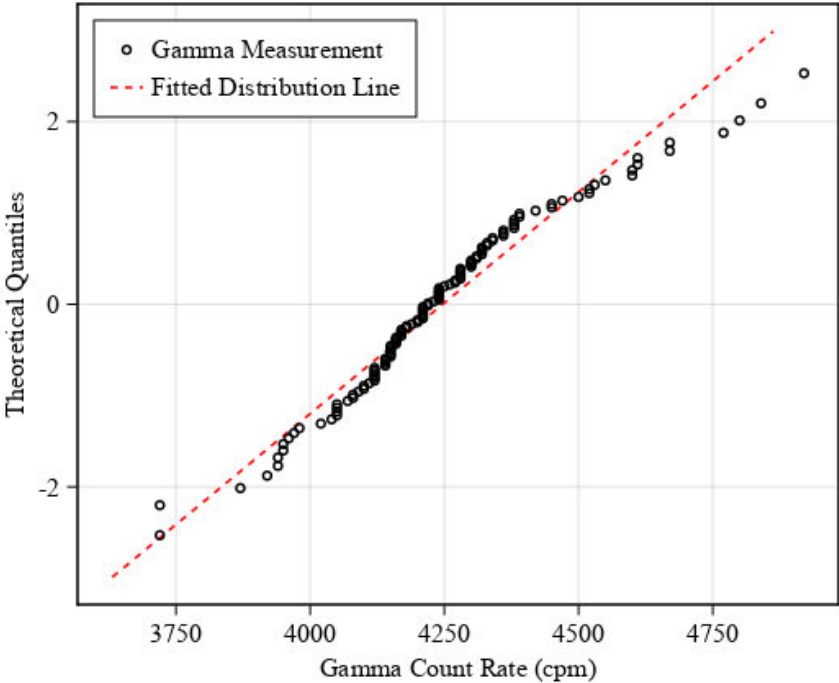
Box Plot



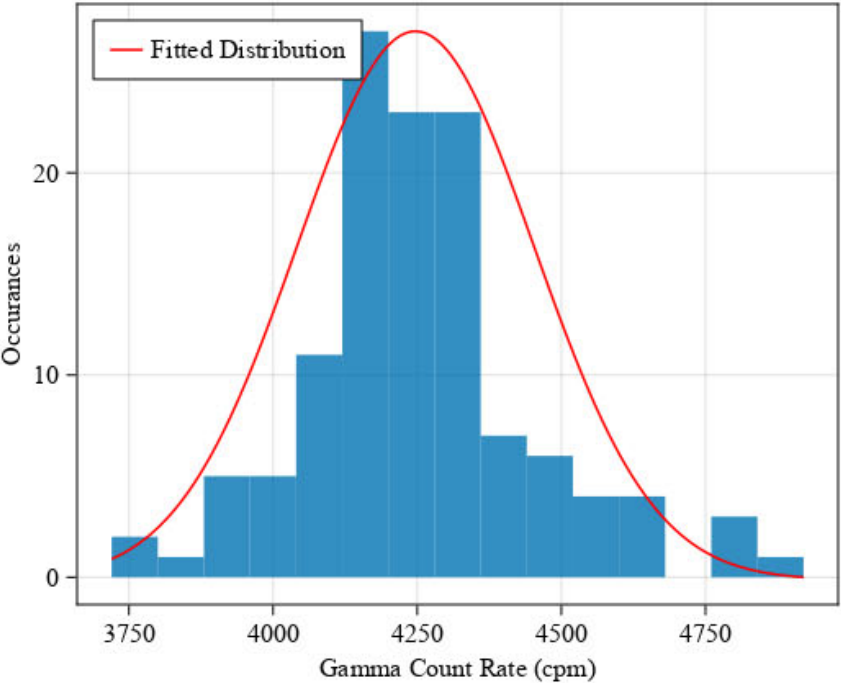
Violin Plot



Probability Plot



Histogram



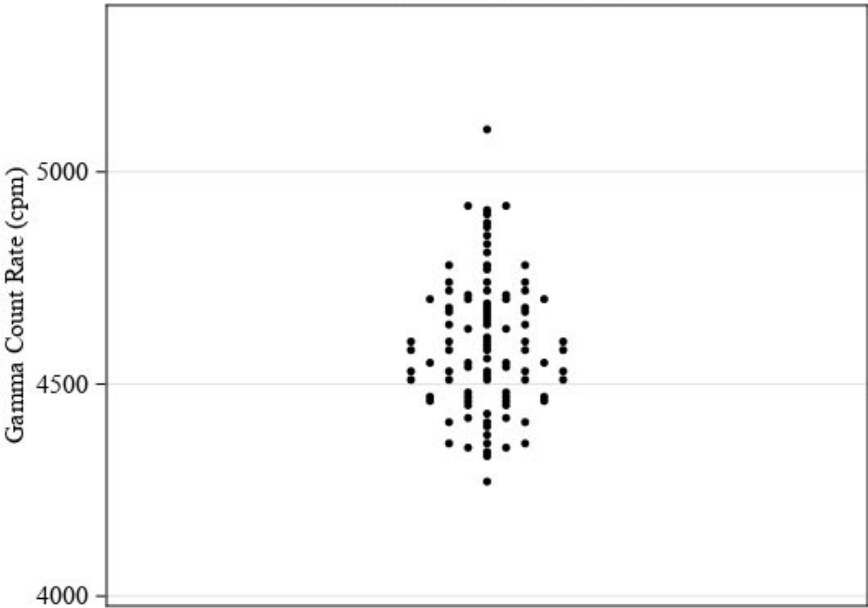
Summary Statistics

Count (n)	122
Minimum (cpm)	3,720
Maximum (cpm)	4,920
Average (cpm)	4,247
Median (cpm)	4,220
Standard Deviation (cpm)	206
Relative Standard Deviation	4.851%
RPD of Mean and Median	0.637%
90th Percentile (cpm)	4,520
95th Percentile (cpm)	4,610
99th Percentile (cpm)	4,840

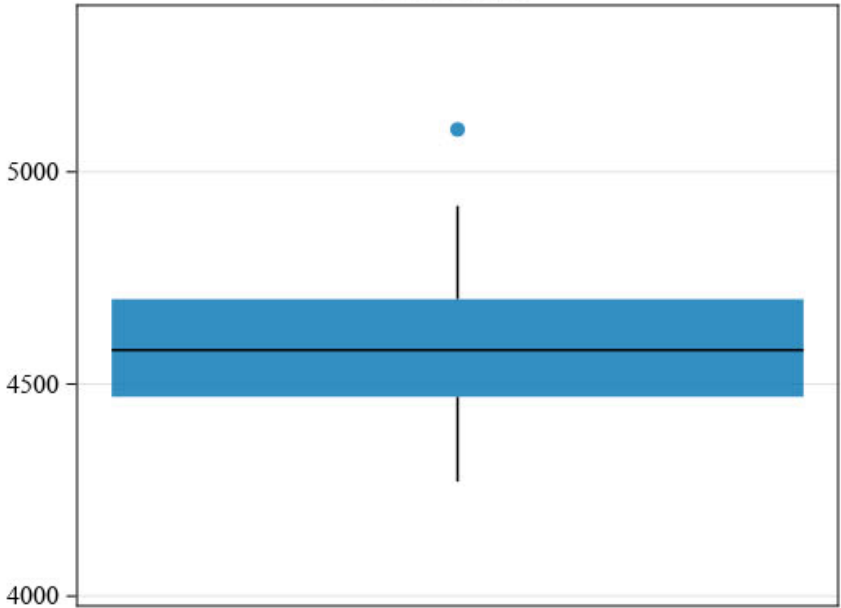
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR07 Type: Shielded

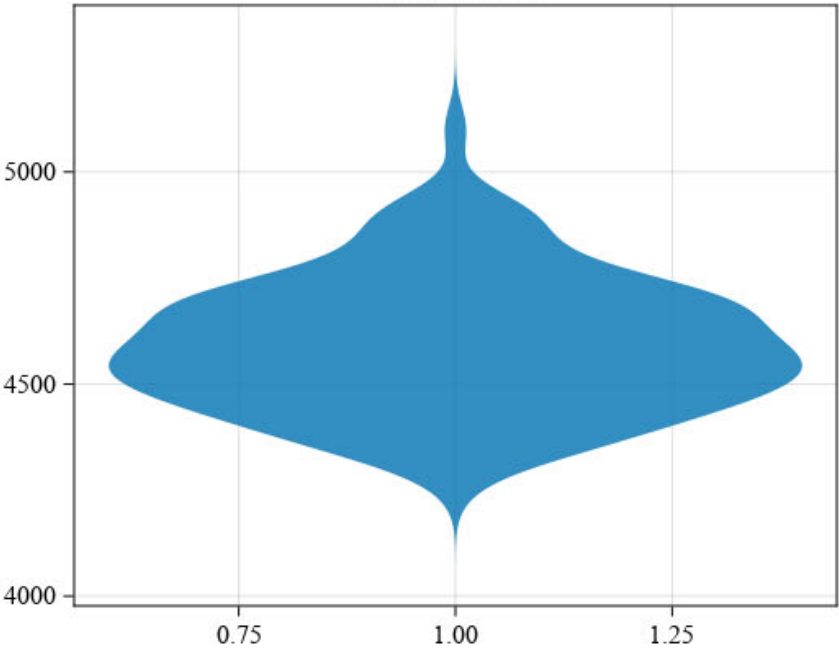
Individual Value Plot



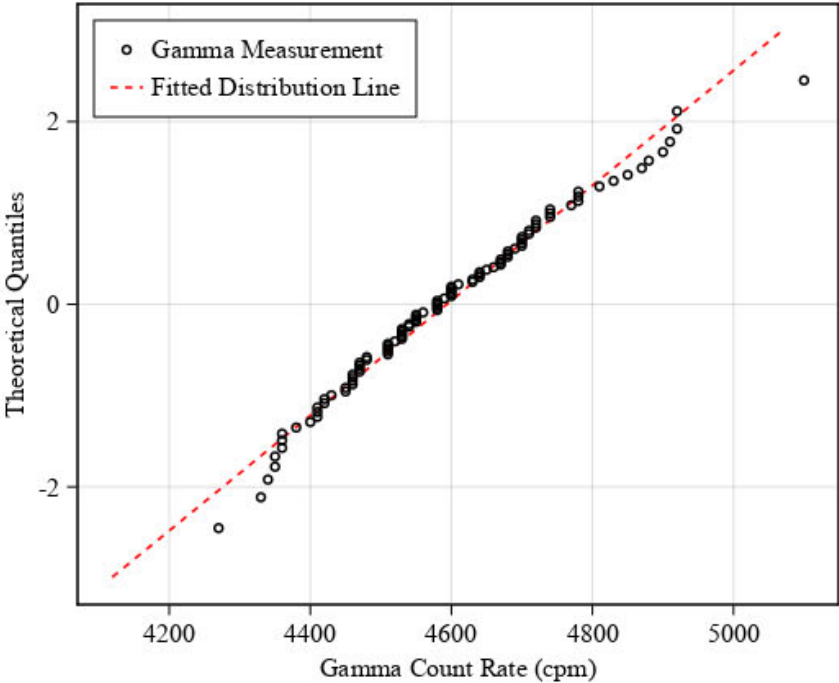
Box Plot



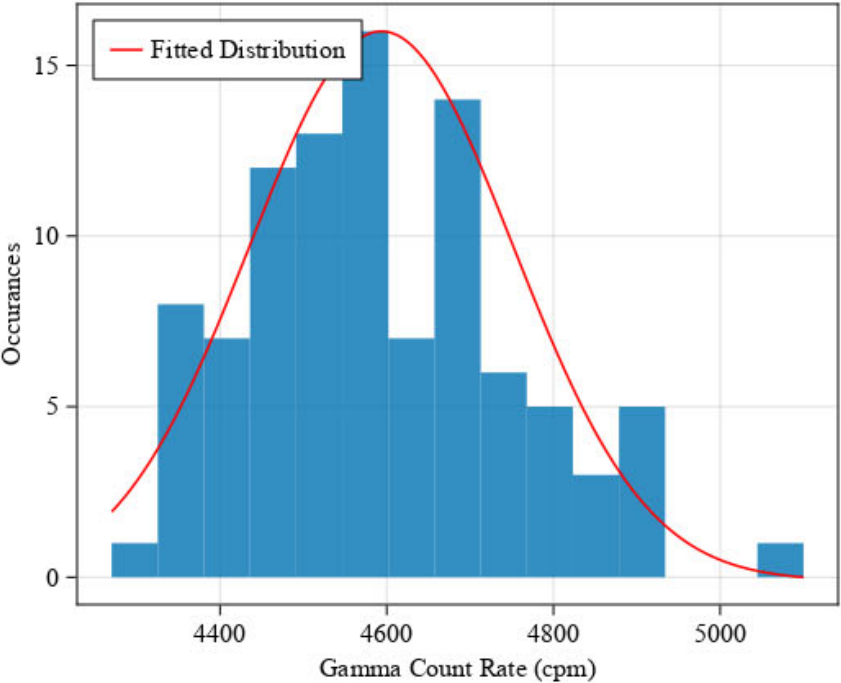
Violin Plot



Probability Plot



Histogram

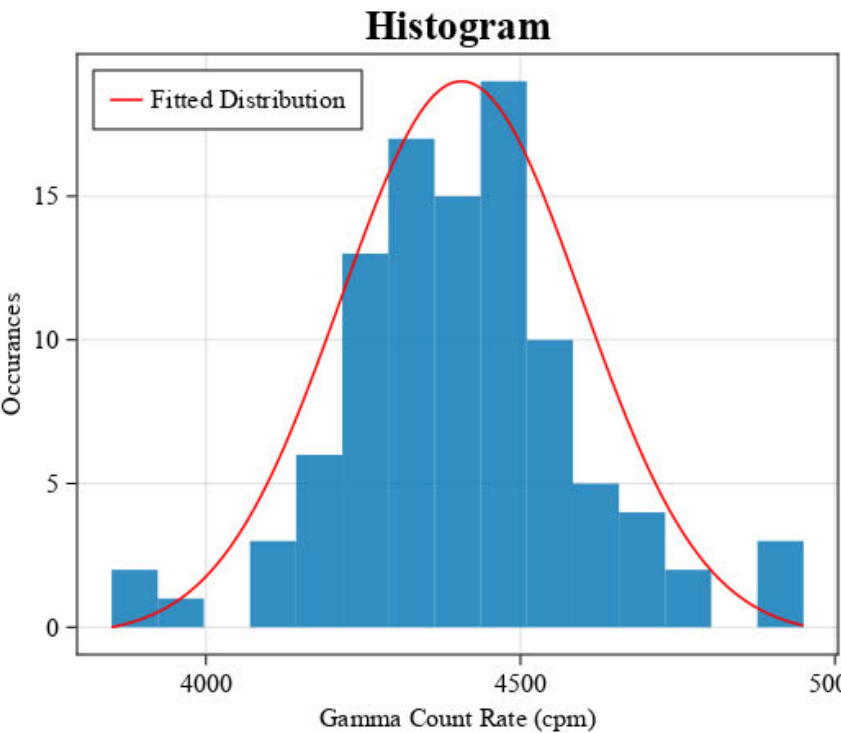
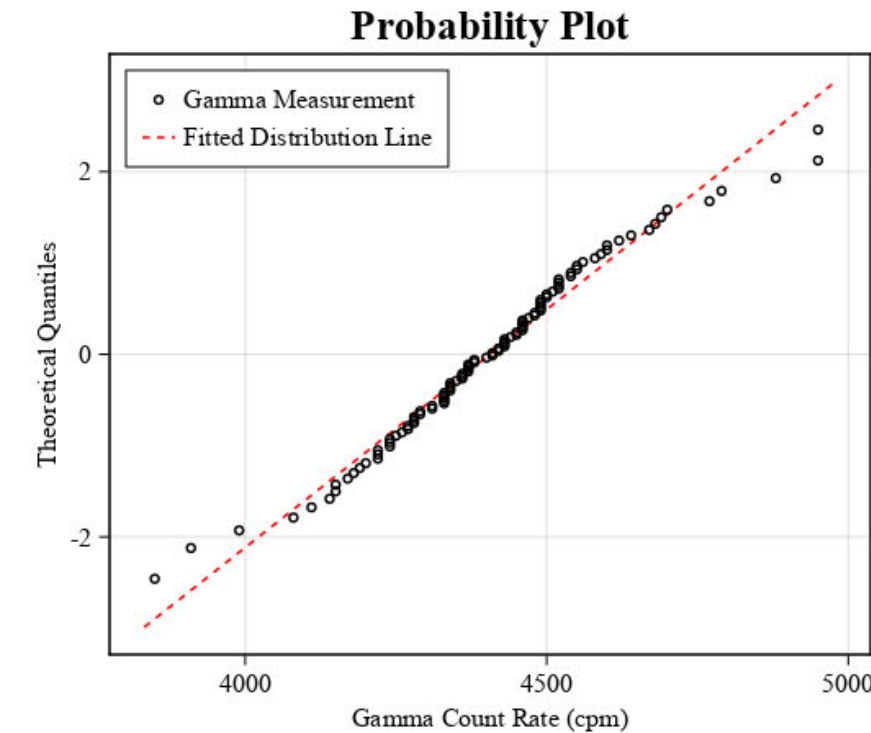
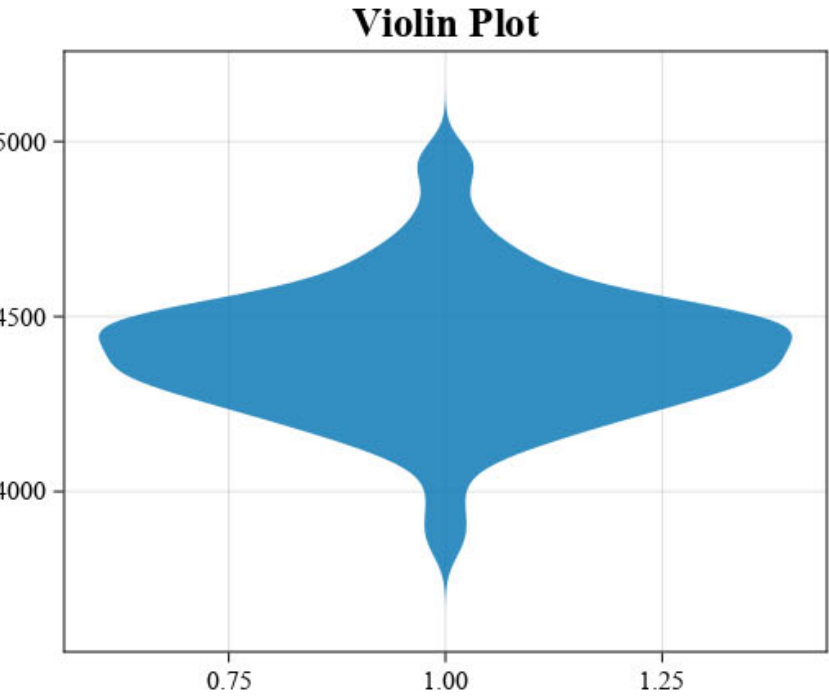
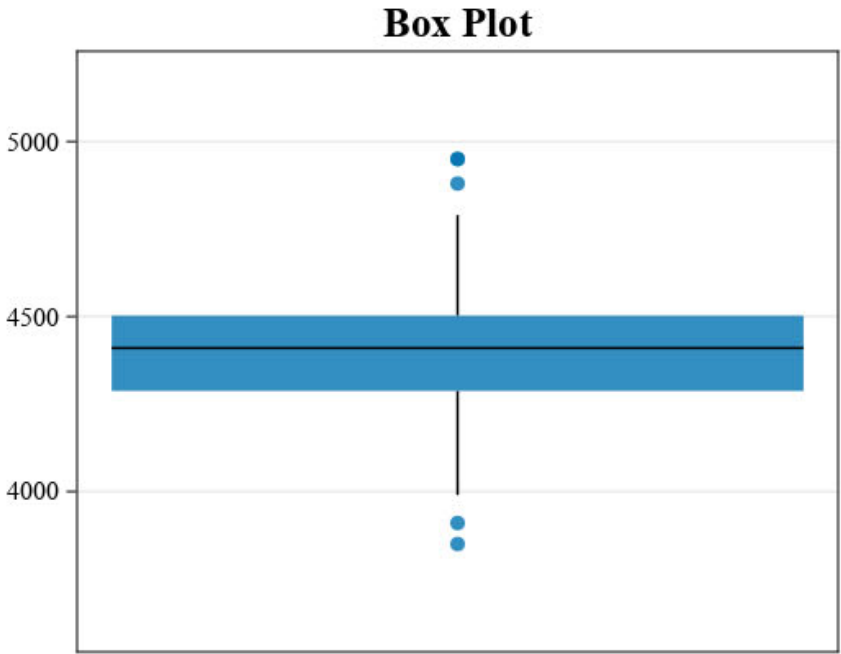
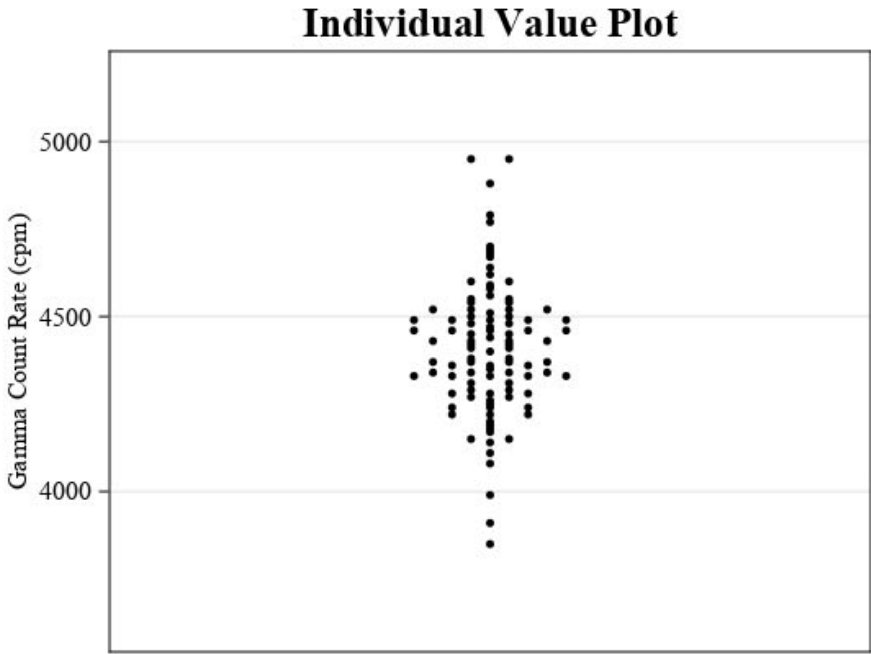


Summary Statistics

Count (n)	98
Minimum (cpm)	4,270
Maximum (cpm)	5,100
Average (cpm)	4,594
Median (cpm)	4,580
Standard Deviation (cpm)	159
Relative Standard Deviation	3.456%
RPD of Mean and Median	0.296%
90th Percentile (cpm)	4,810
95th Percentile (cpm)	4,900
99th Percentile (cpm)	5,100

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR08 Type: Shielded



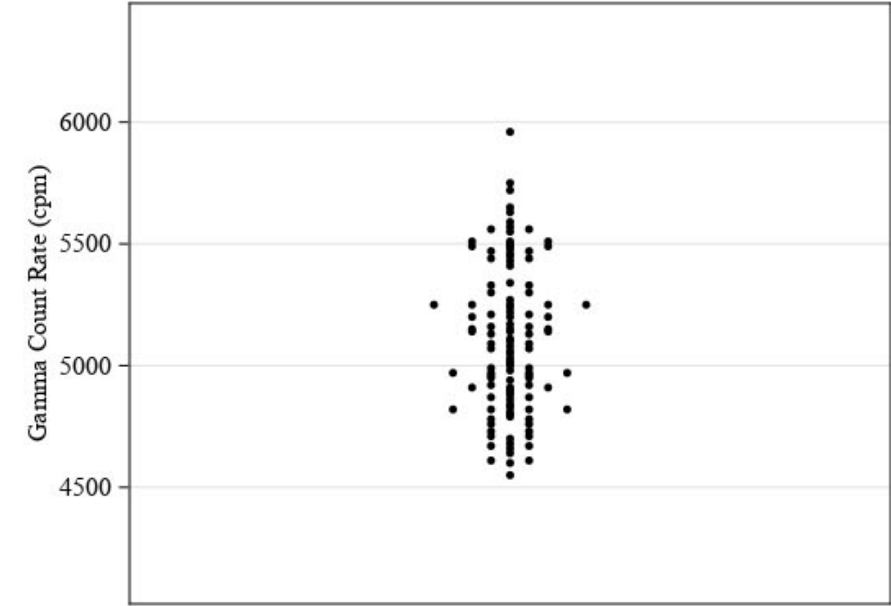
Summary Statistics

Count (n)	100
Minimum (cpm)	3,850
Maximum (cpm)	4,950
Average (cpm)	4,406
Median (cpm)	4,410
Standard Deviation (cpm)	192
Relative Standard Deviation	4.356%
RPD of Mean and Median	0.088%
90th Percentile (cpm)	4,620
95th Percentile (cpm)	4,700
99th Percentile (cpm)	4,950

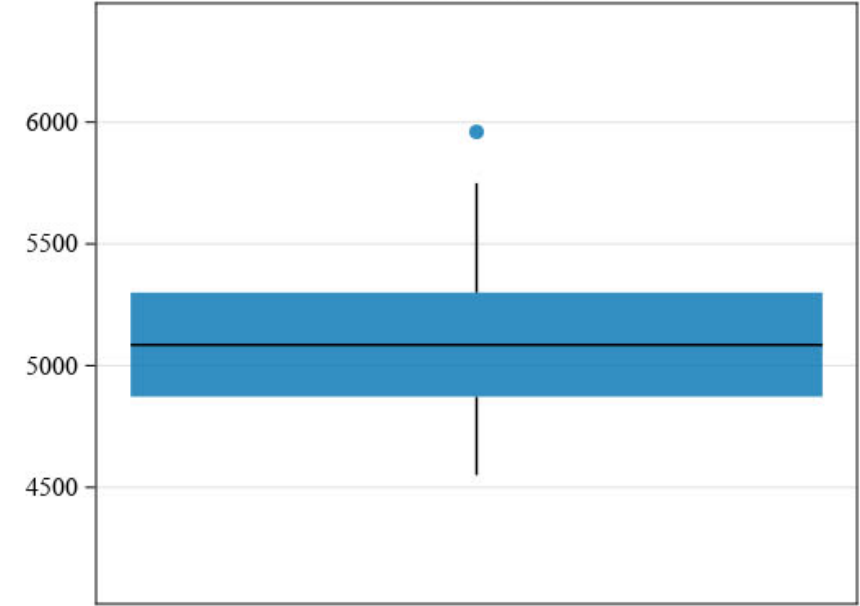
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR09 Type: Shielded

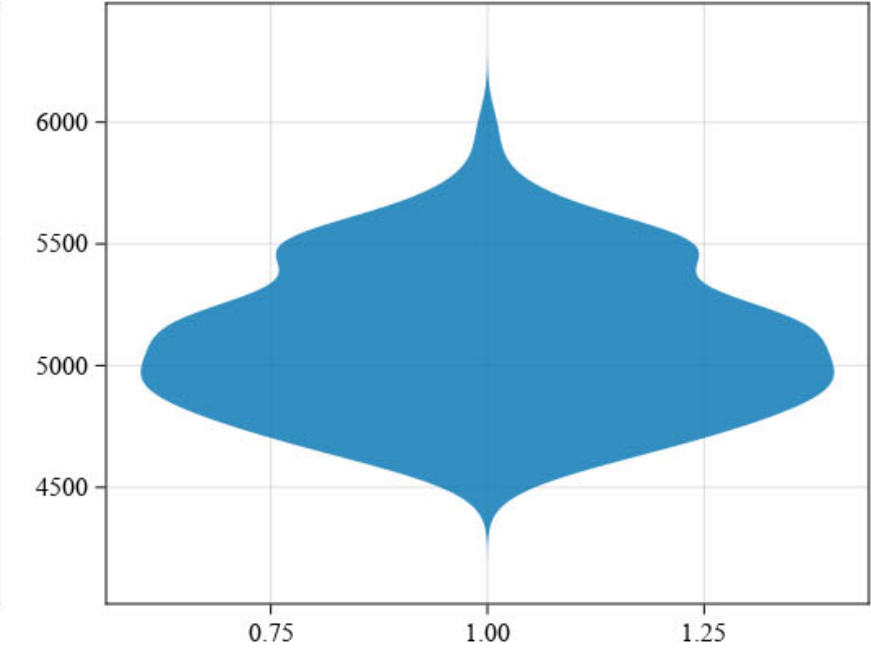
Individual Value Plot



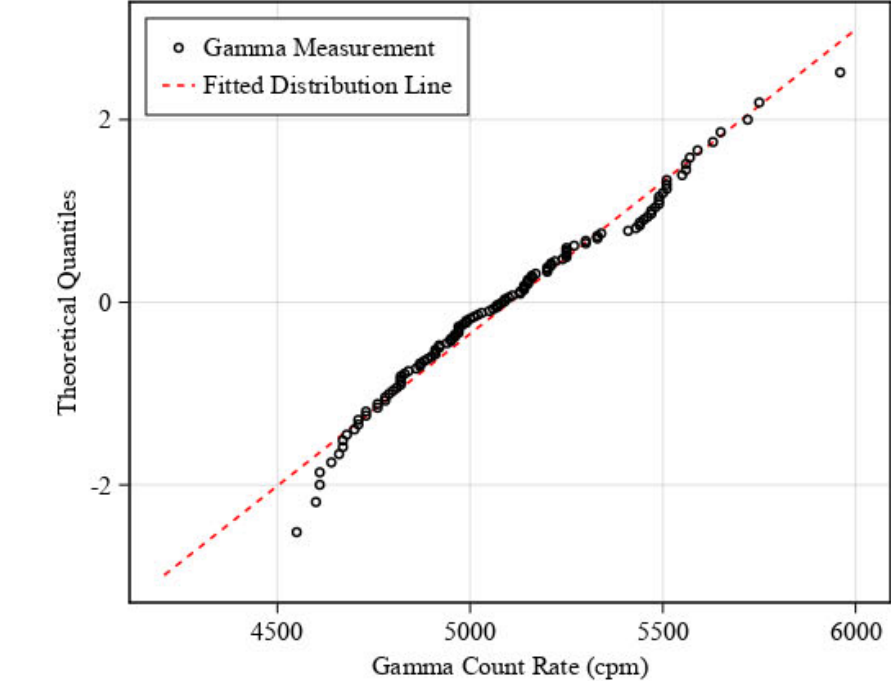
Box Plot



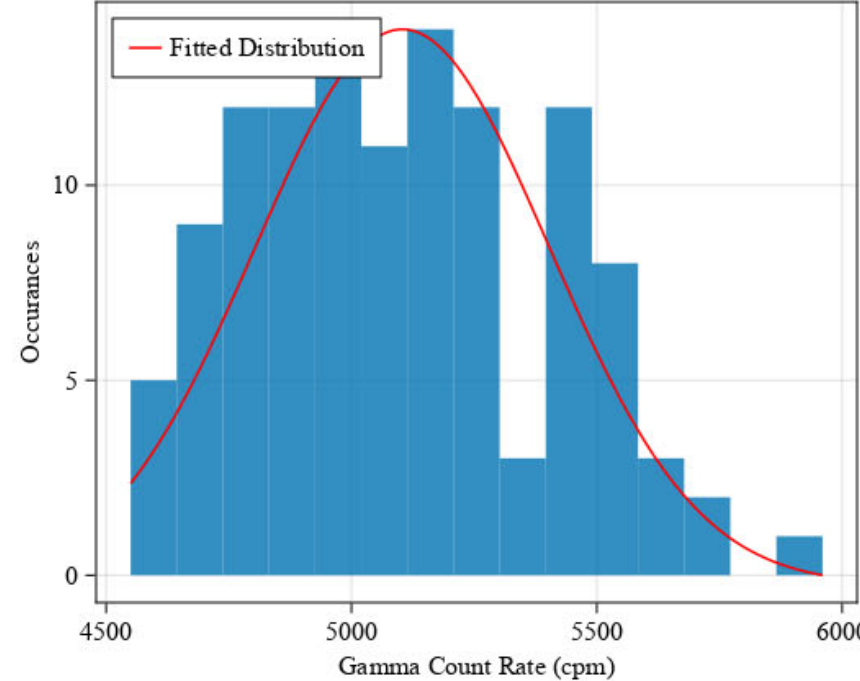
Violin Plot



Probability Plot



Histogram



Summary Statistics

Count (n)	118
Minimum (cpm)	4,550
Maximum (cpm)	5,960
Average (cpm)	5,104
Median (cpm)	5,085
Standard Deviation (cpm)	300
Relative Standard Deviation	5.882%
RPD of Mean and Median	0.366%
90th Percentile (cpm)	5,510
95th Percentile (cpm)	5,590
99th Percentile (cpm)	5,750

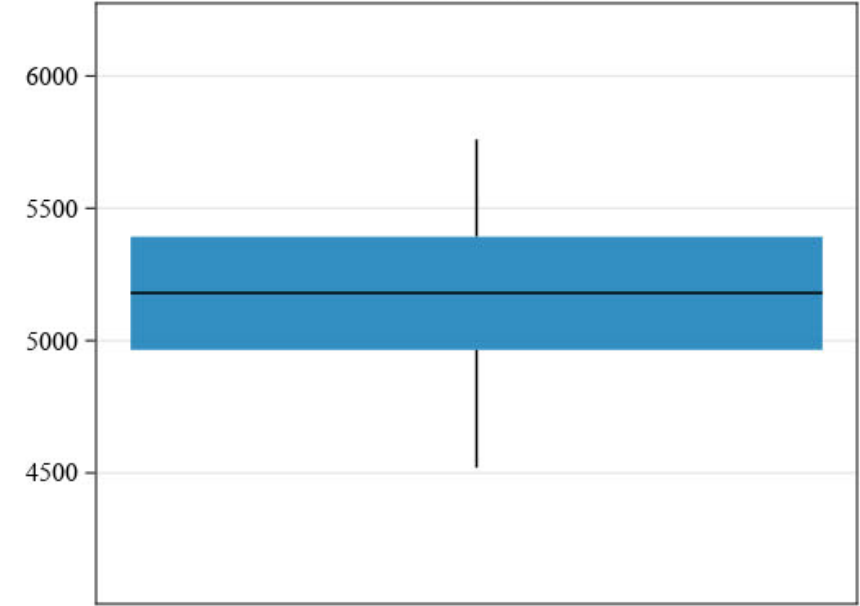
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR10 Type: Shielded

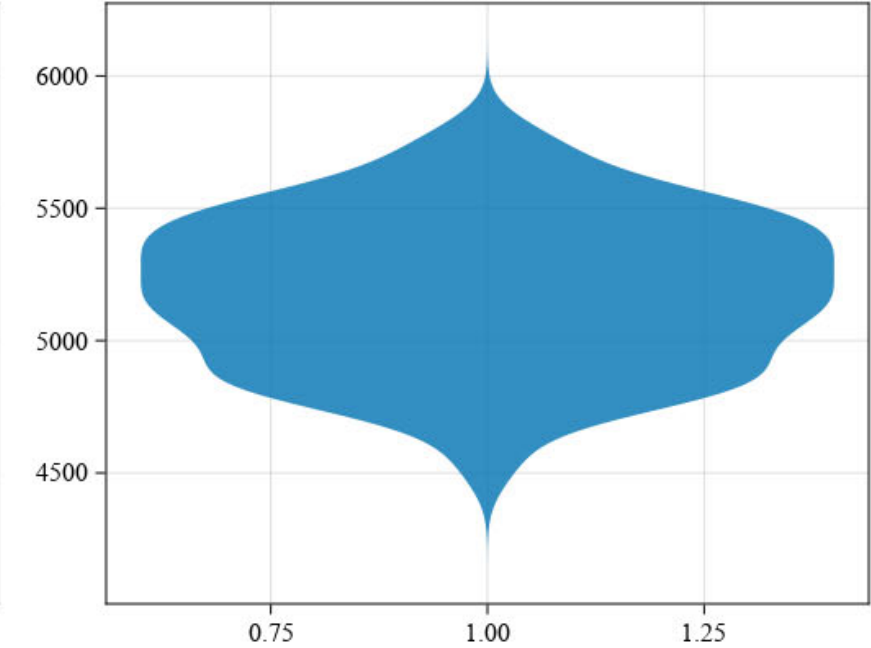
Individual Value Plot



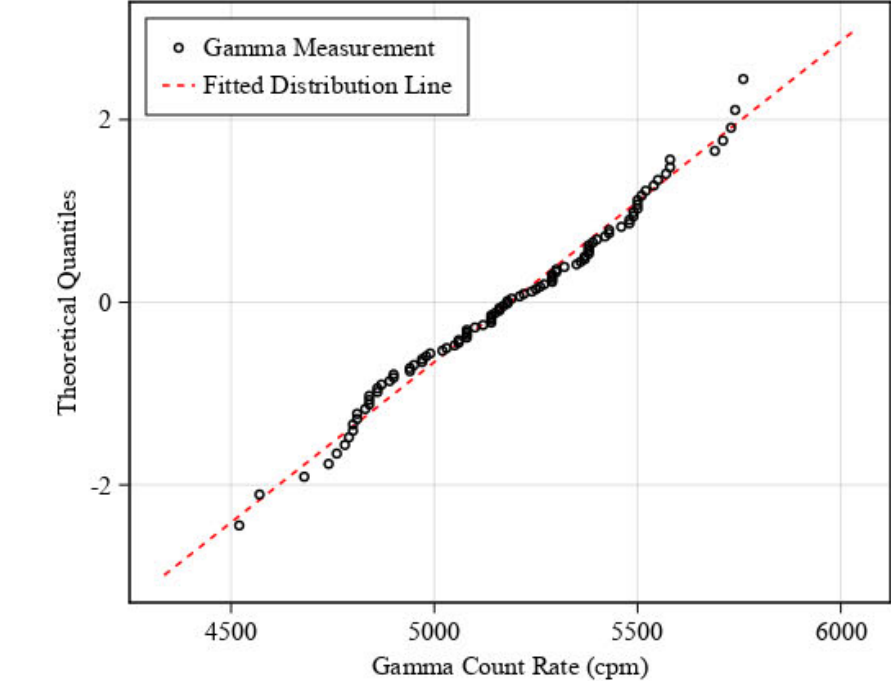
Box Plot



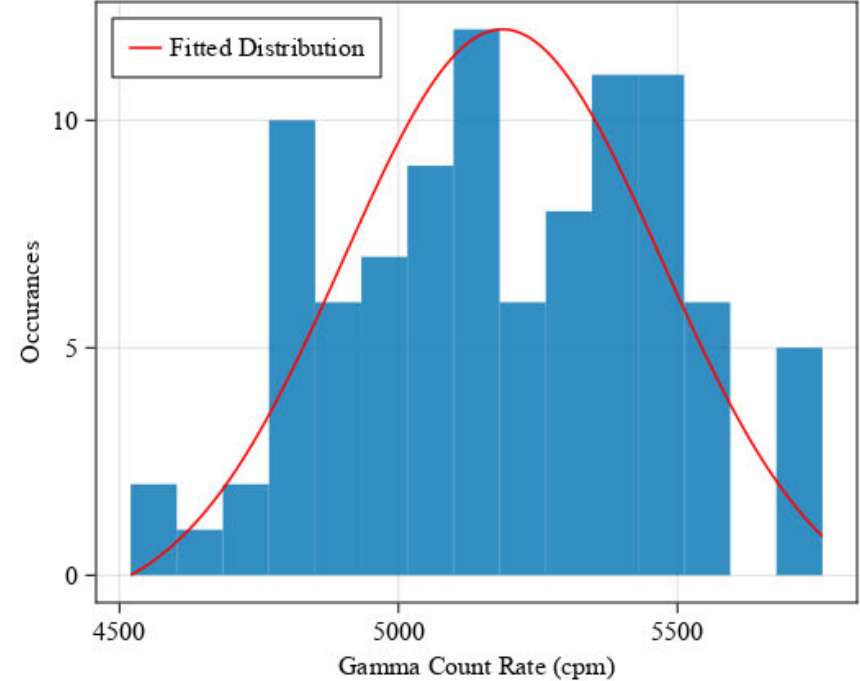
Violin Plot



Probability Plot



Histogram



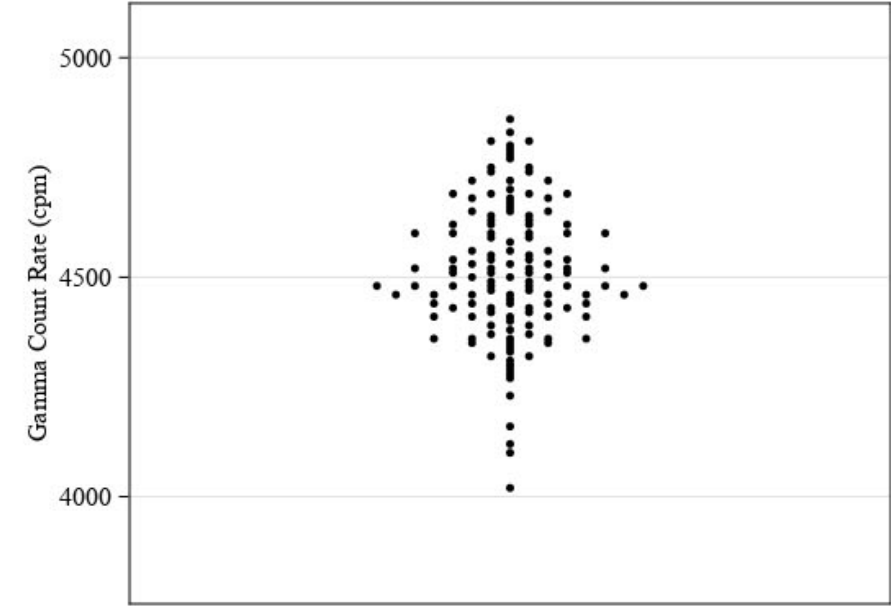
Summary Statistics

Count (n)	96
Minimum (cpm)	4,520
Maximum (cpm)	5,760
Average (cpm)	5,186
Median (cpm)	5,180
Standard Deviation (cpm)	285
Relative Standard Deviation	5.489%
RPD of Mean and Median	0.123%
90th Percentile (cpm)	5,540
95th Percentile (cpm)	5,690
99th Percentile (cpm)	5,760

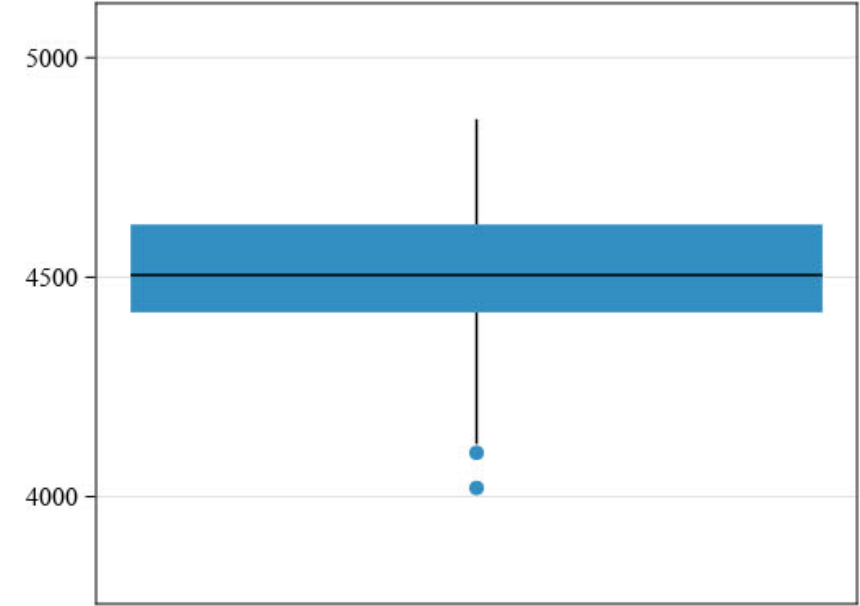
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR11 Type: Shielded

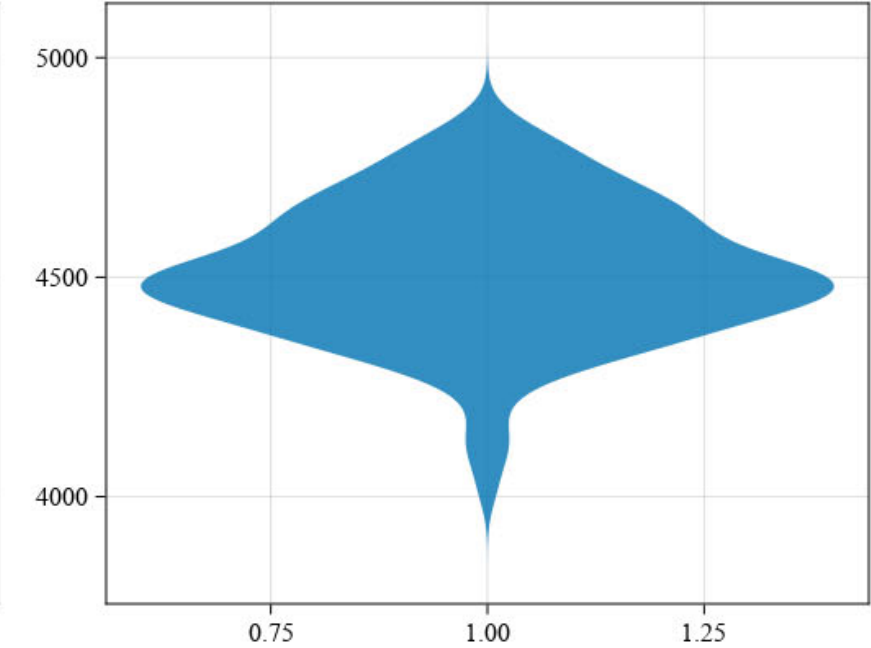
Individual Value Plot



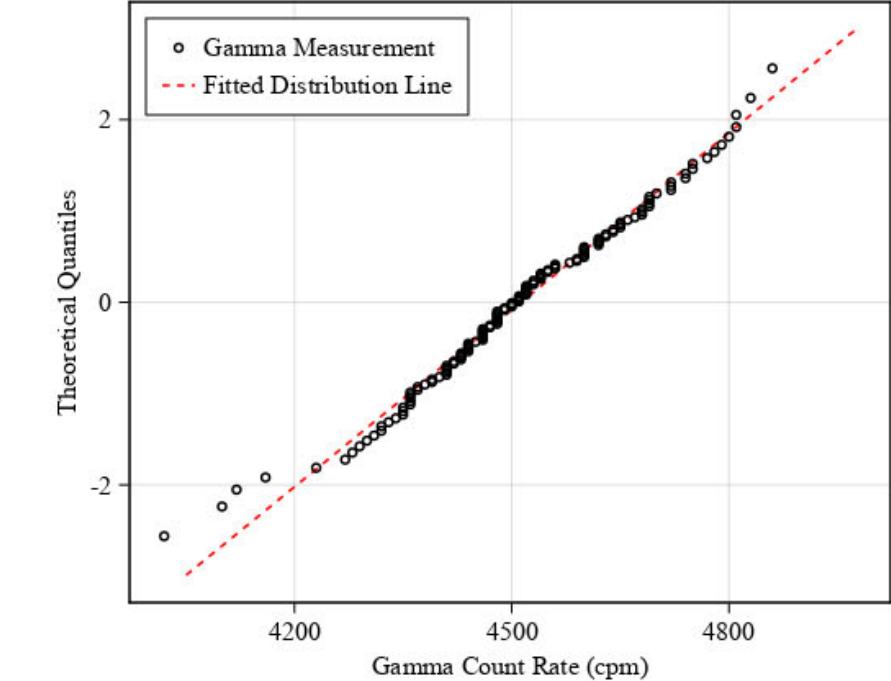
Box Plot



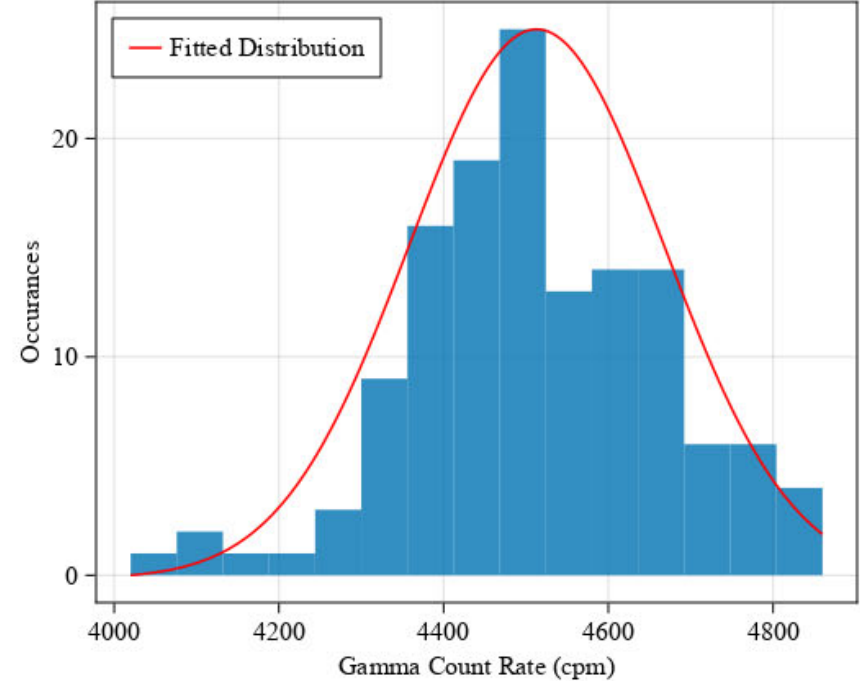
Violin Plot



Probability Plot



Histogram



Summary Statistics

Count (n)	134
Minimum (cpm)	4,020
Maximum (cpm)	4,860
Average (cpm)	4,513
Median (cpm)	4,505
Standard Deviation (cpm)	155
Relative Standard Deviation	3.429%
RPD of Mean and Median	0.174%
90th Percentile (cpm)	4,720
95th Percentile (cpm)	4,780
99th Percentile (cpm)	4,830

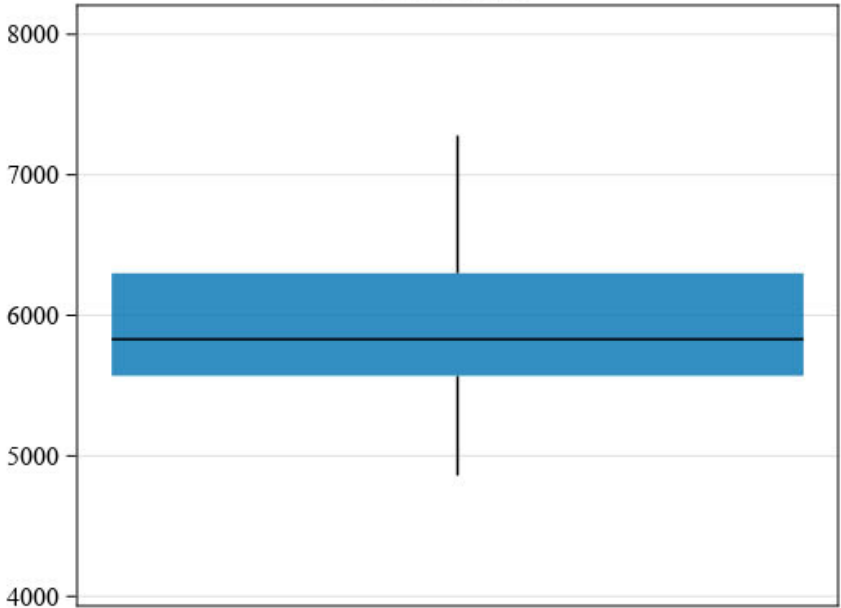
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR12 Type: Shielded

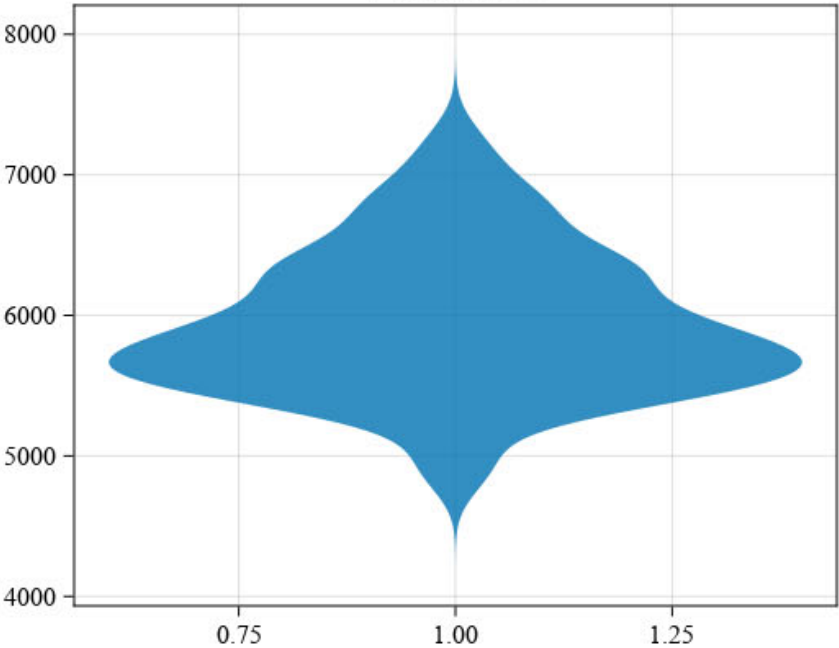
Individual Value Plot



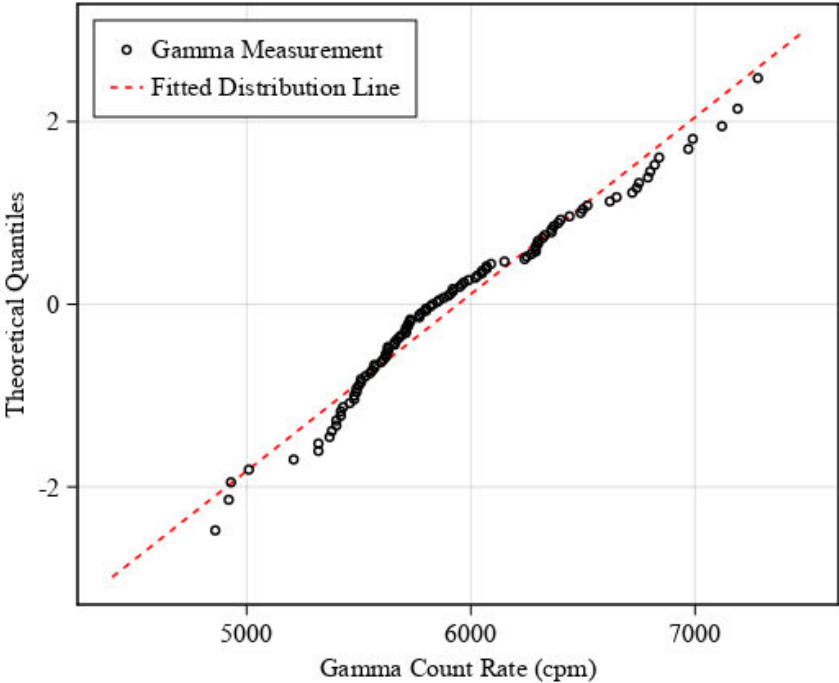
Box Plot



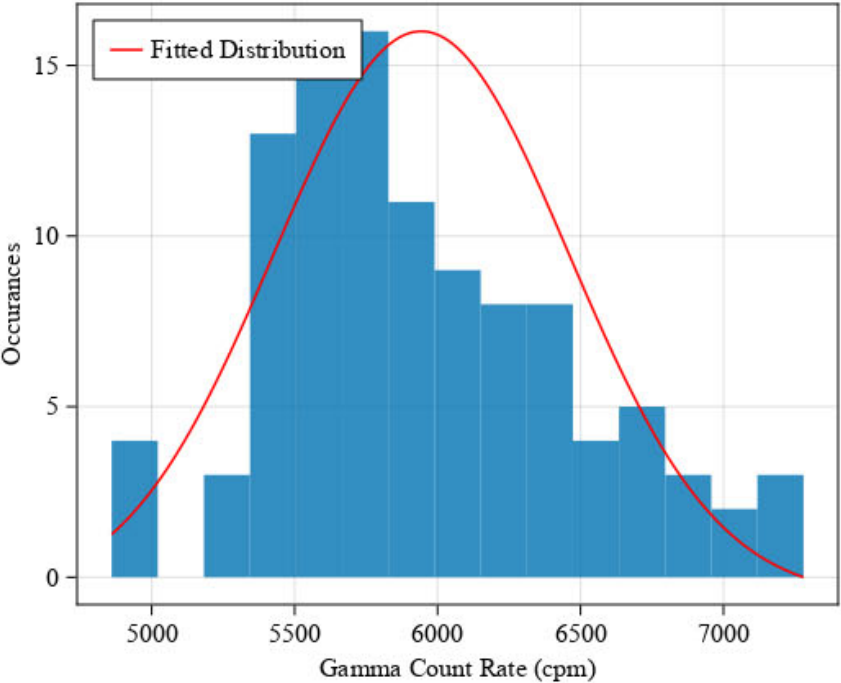
Violin Plot



Probability Plot



Histogram

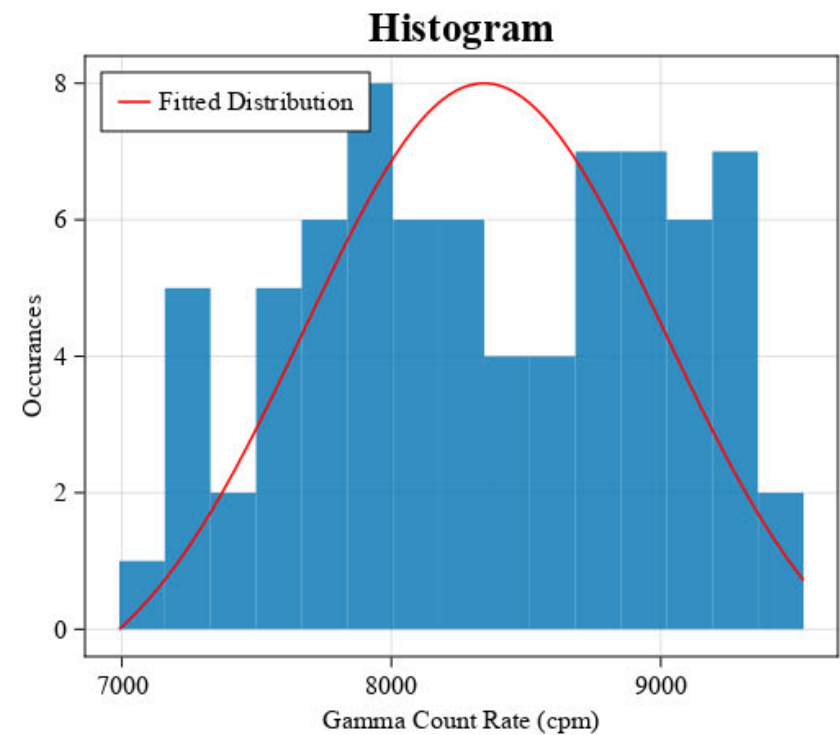
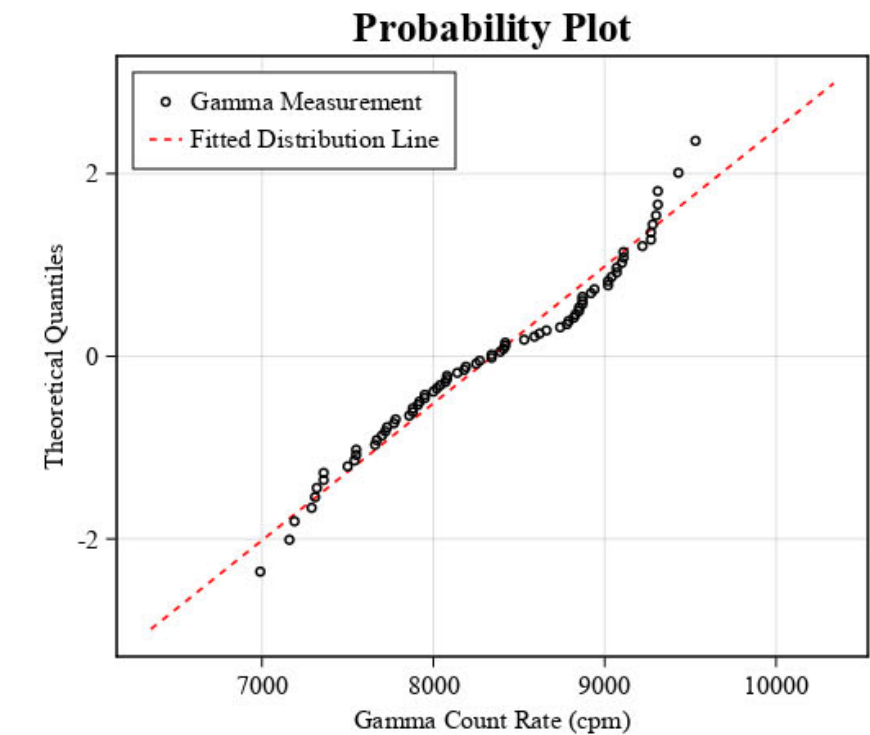
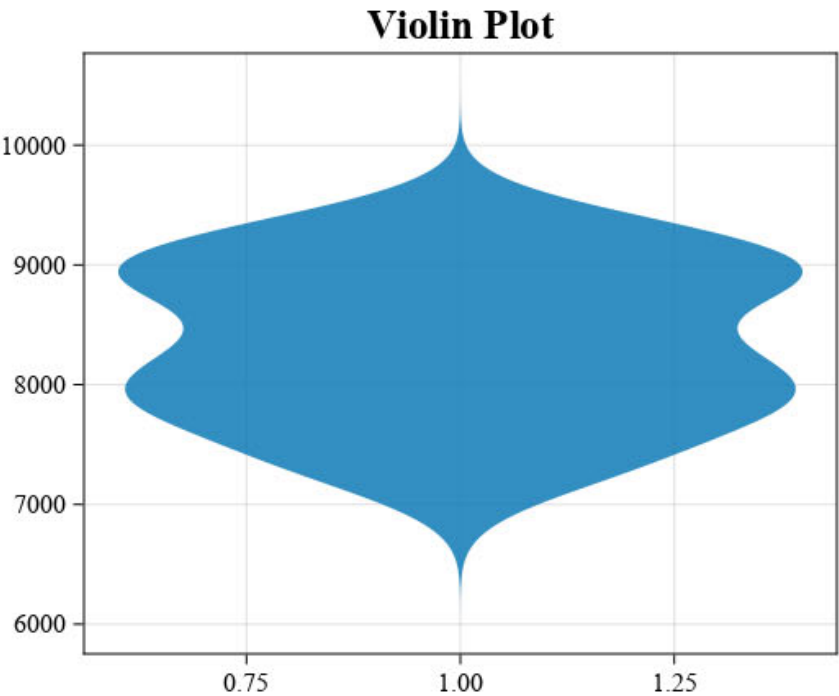
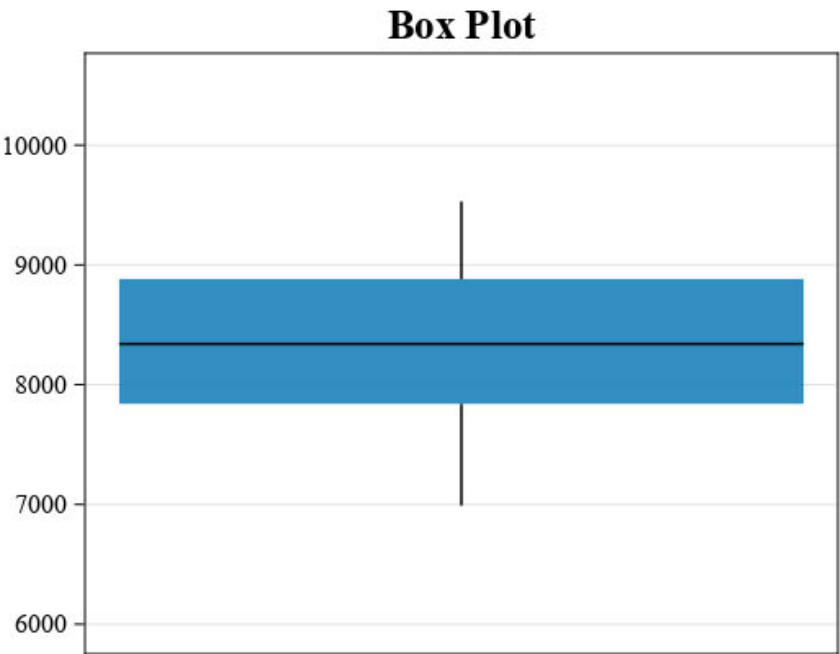
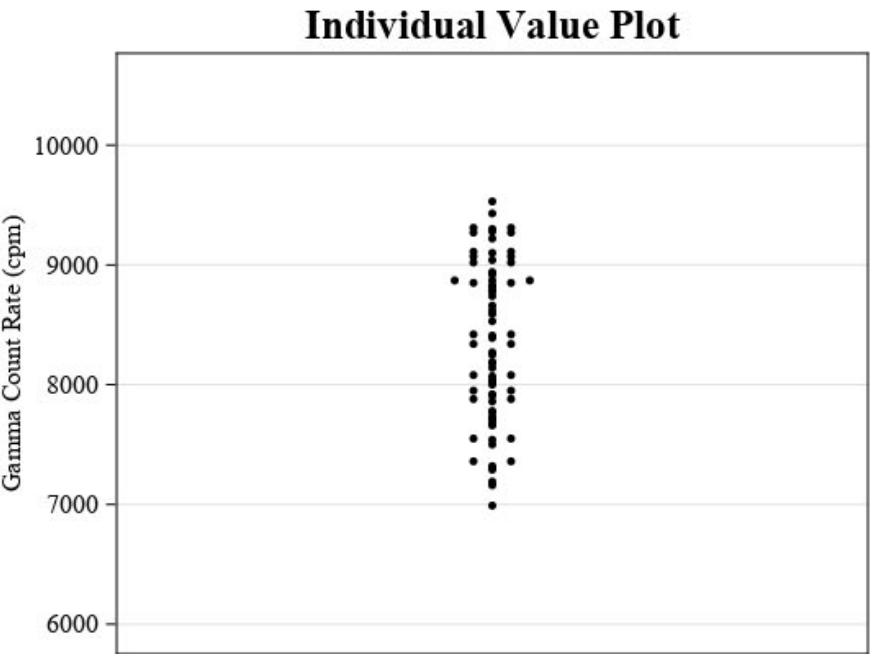


Summary Statistics

Count (n)	105
Minimum (cpm)	4,860
Maximum (cpm)	7,280
Average (cpm)	5,943
Median (cpm)	5,830
Standard Deviation (cpm)	516
Relative Standard Deviation	8.686%
RPD of Mean and Median	1.92%
90th Percentile (cpm)	6,740
95th Percentile (cpm)	6,840
99th Percentile (cpm)	7,190

Summary Statistics - Correlation Plots

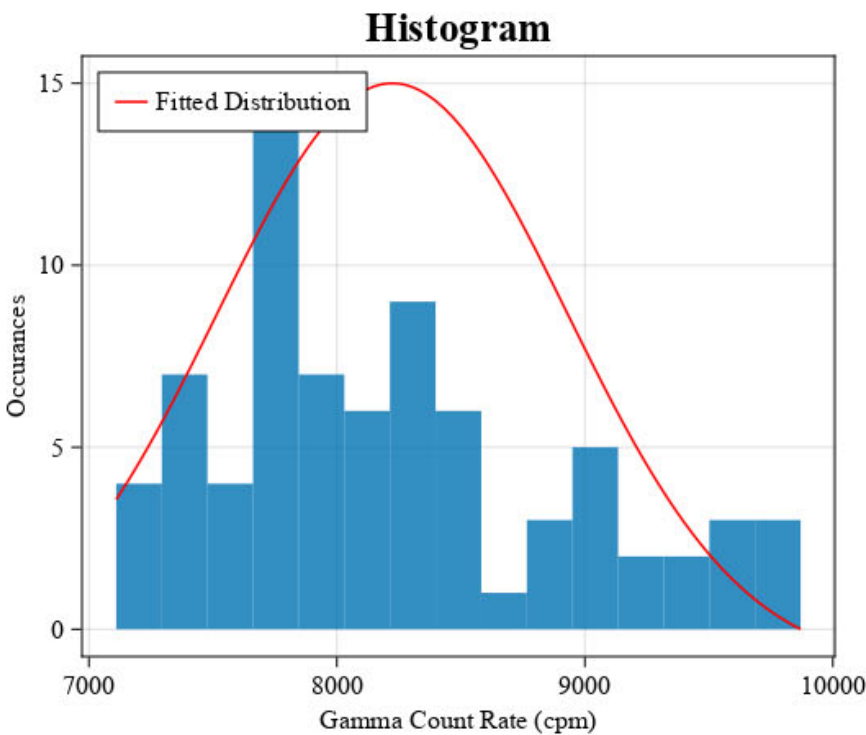
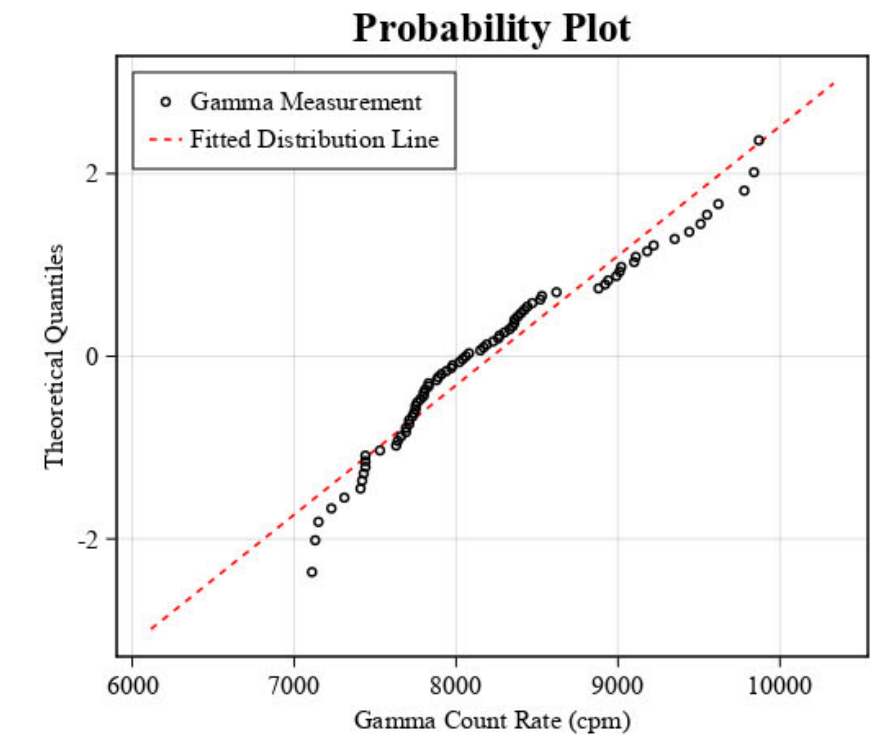
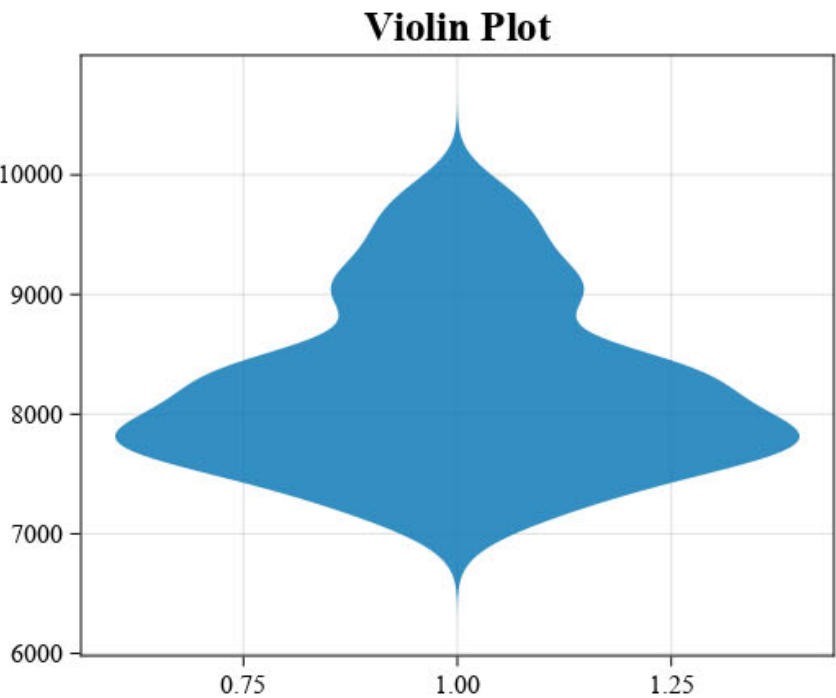
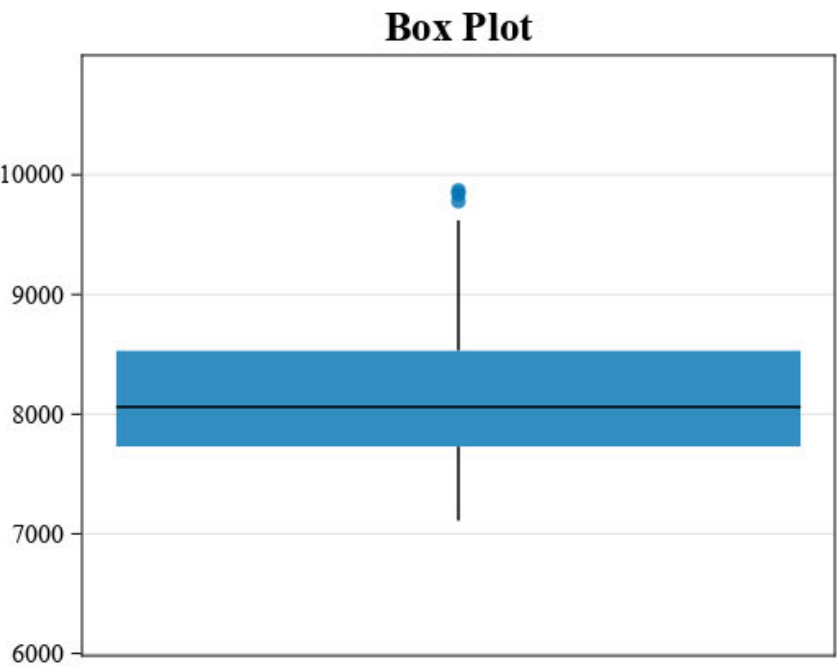
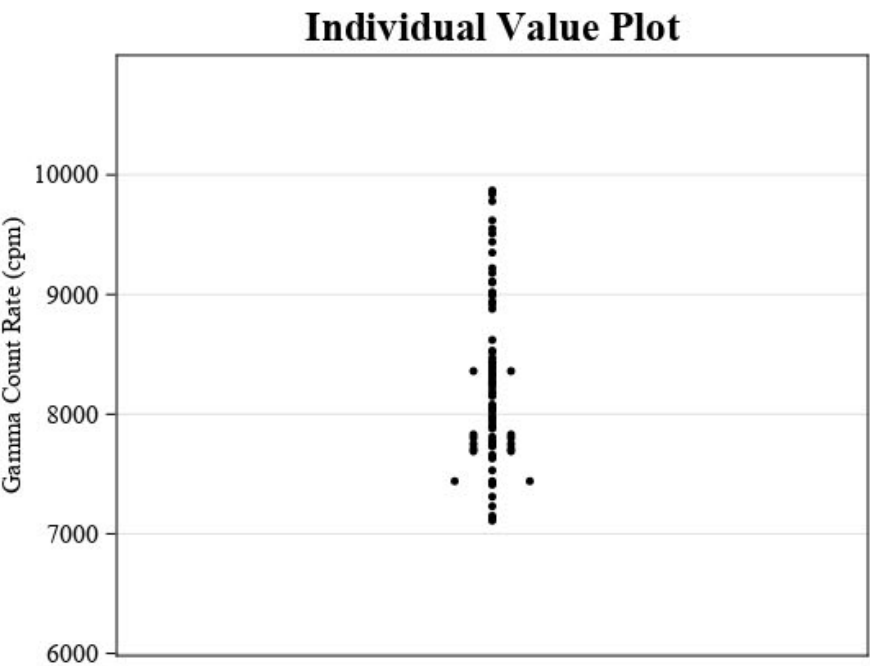
Site: OCRM Plot ID: CORR13 Type: Shielded



Summary Statistics	
Count (n)	76
Minimum (cpm)	6,990
Maximum (cpm)	9,530
Average (cpm)	8,344
Median (cpm)	8,340
Standard Deviation (cpm)	667
Relative Standard Deviation	7.99%
RPD of Mean and Median	0.046%
90th Percentile (cpm)	9,270
95th Percentile (cpm)	9,310
99th Percentile (cpm)	9,530

Summary Statistics - Correlation Plots

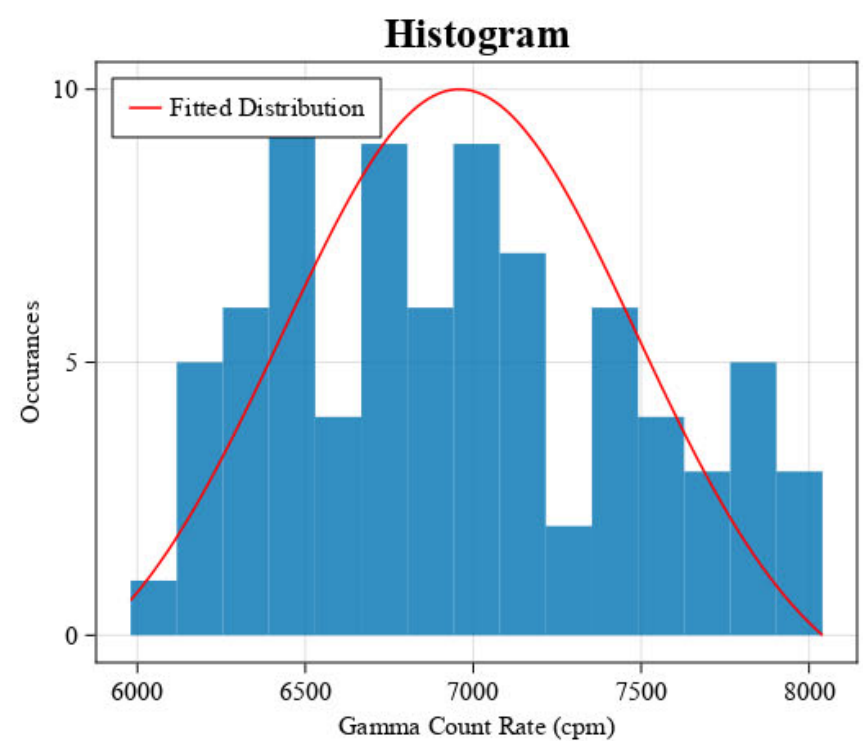
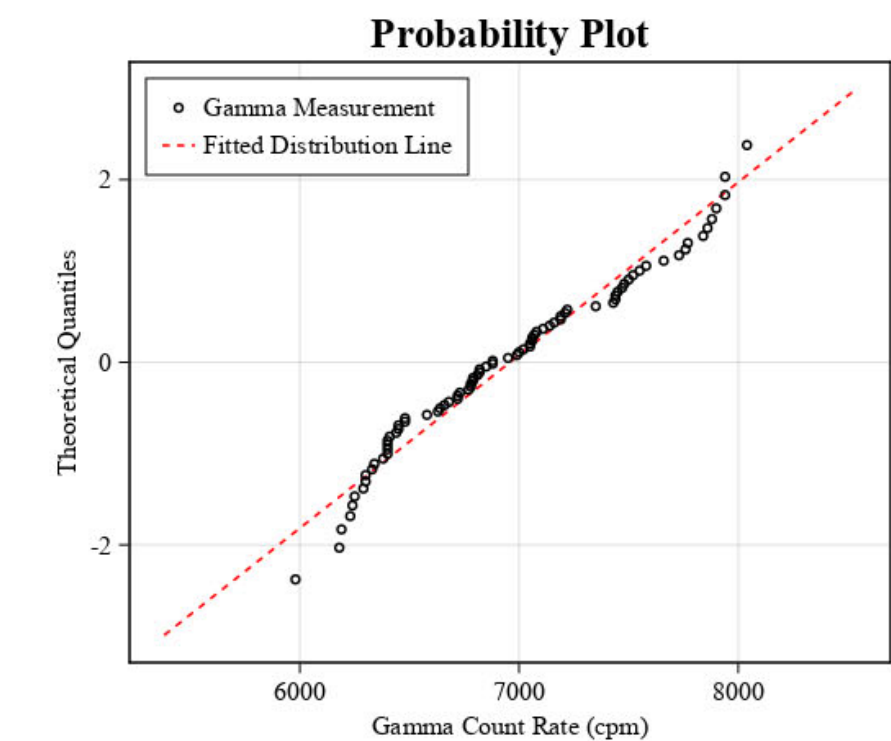
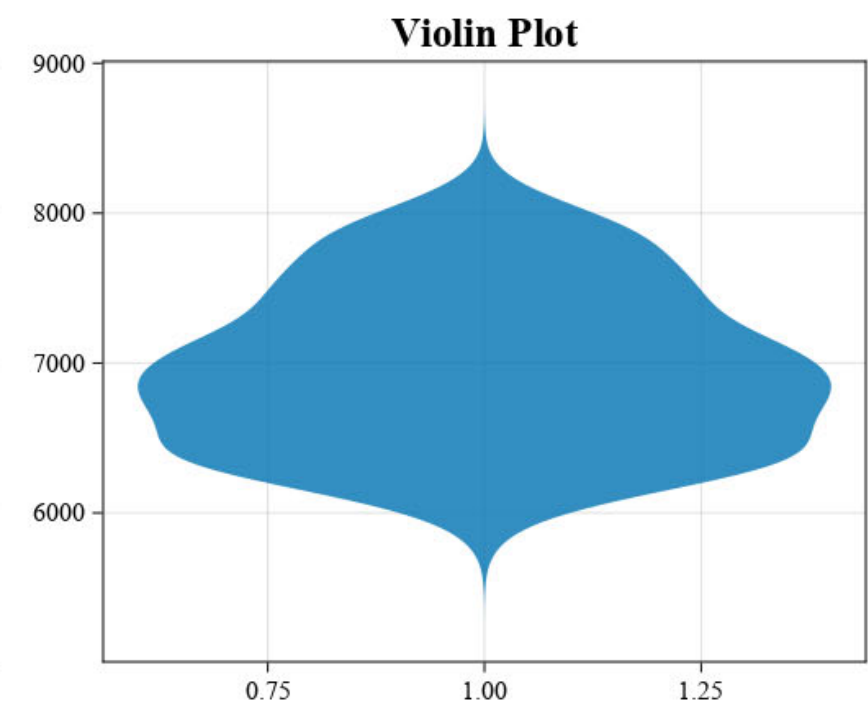
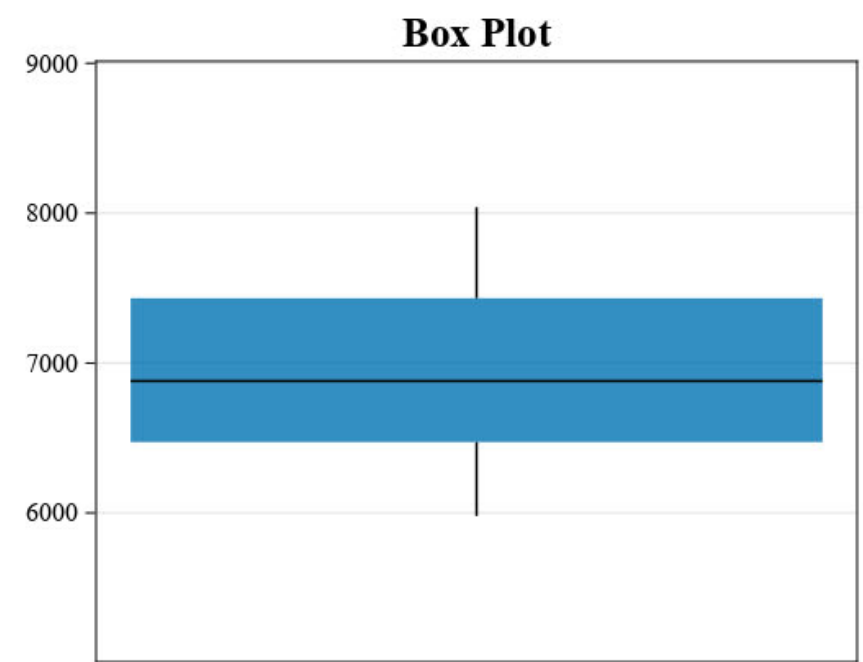
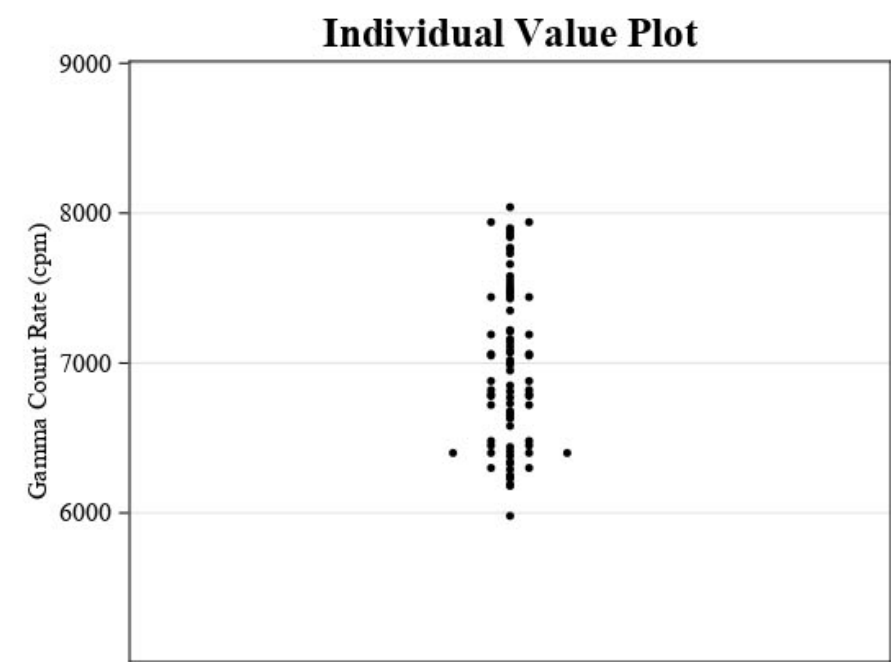
Site: OCRM Plot ID: CORR14 Type: Shielded



Summary Statistics	
Count (n)	77
Minimum (cpm)	7,110
Maximum (cpm)	9,870
Average (cpm)	8,223
Median (cpm)	8,060
Standard Deviation (cpm)	705
Relative Standard Deviation	8.579%
RPD of Mean and Median	2.007%
90th Percentile (cpm)	9,350
95th Percentile (cpm)	9,620
99th Percentile (cpm)	9,870

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR15 Type: Shielded



Summary Statistics

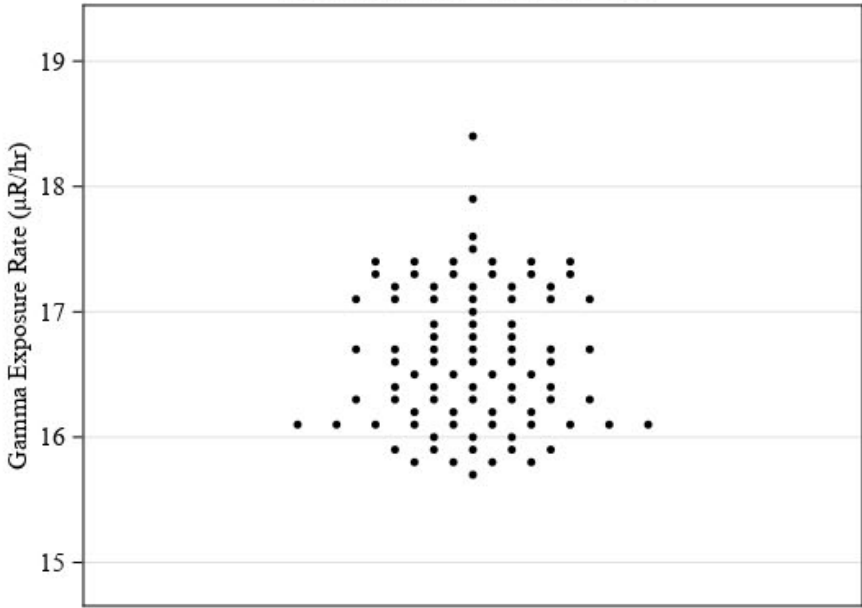
Count (n)	80
Minimum (cpm)	5,980
Maximum (cpm)	8,040
Average (cpm)	6,959
Median (cpm)	6,880
Standard Deviation (cpm)	528
Relative Standard Deviation	7.587%
RPD of Mean and Median	1.143%
90th Percentile (cpm)	7,770
95th Percentile (cpm)	7,900
99th Percentile (cpm)	8,040

ATTACHMENT E-5: CORRELATION PLOT STATISTICS – EXPOSURE RATE

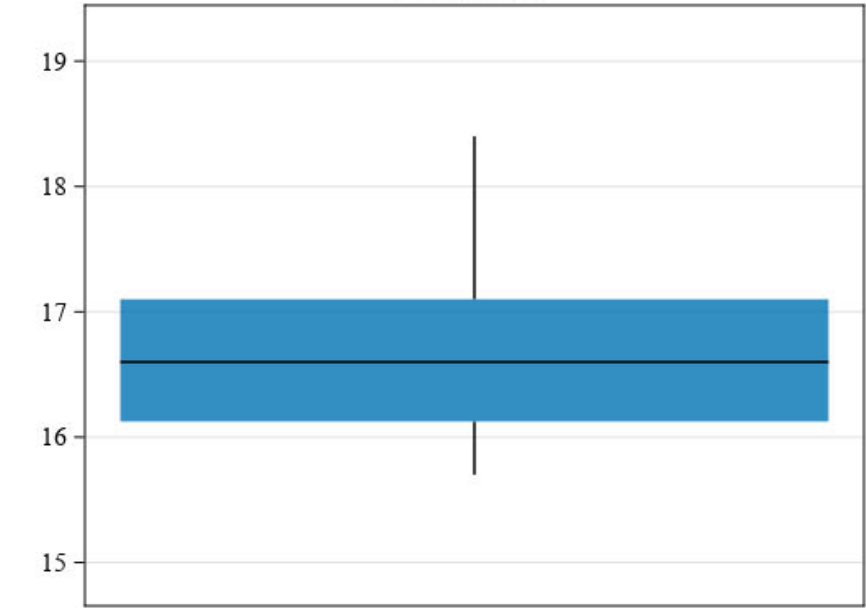
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR01 Type: High Pressure Ionization Chamber

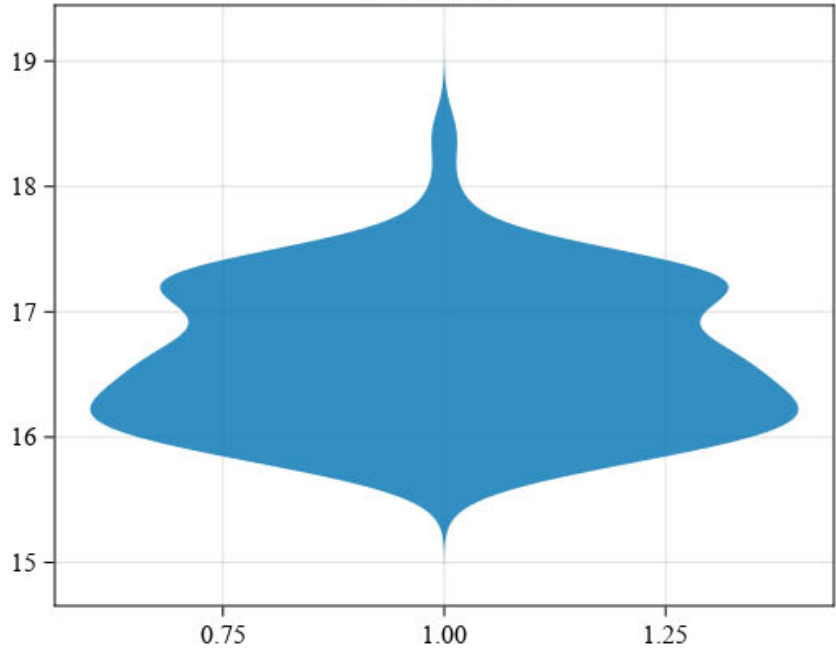
Individual Value Plot



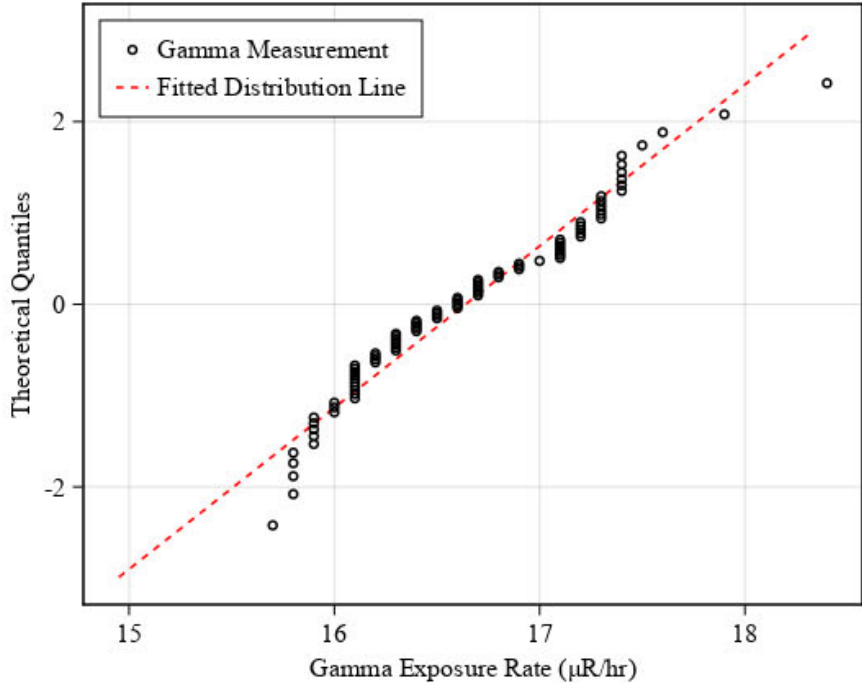
Box Plot



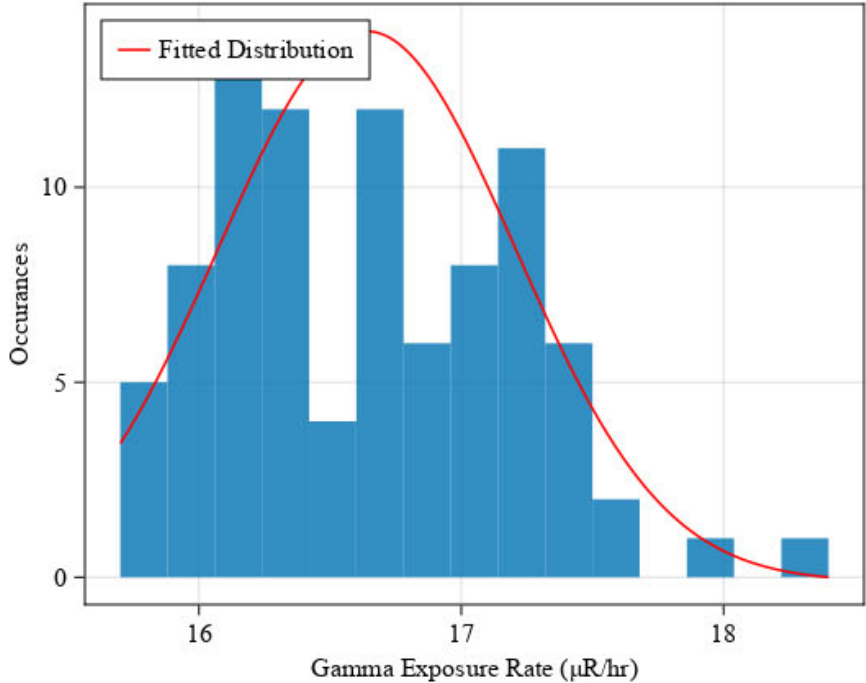
Violin Plot



Probability Plot



Histogram

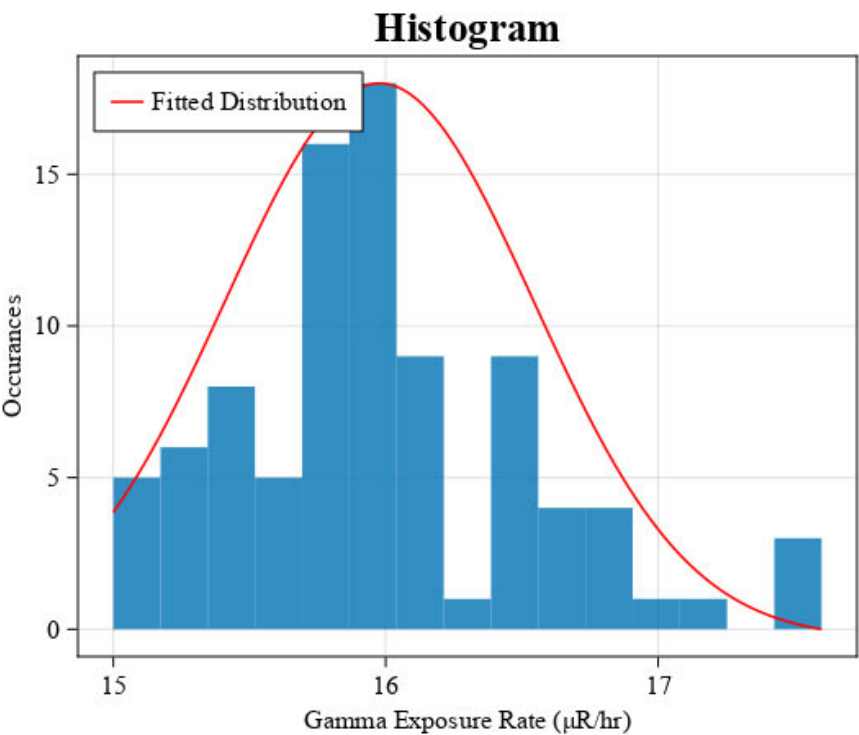
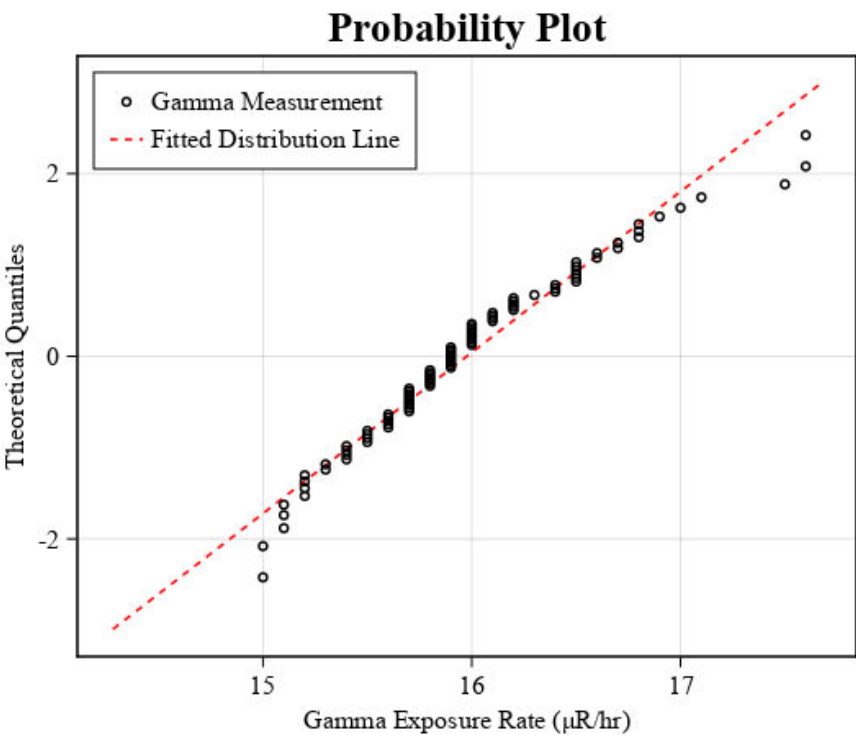
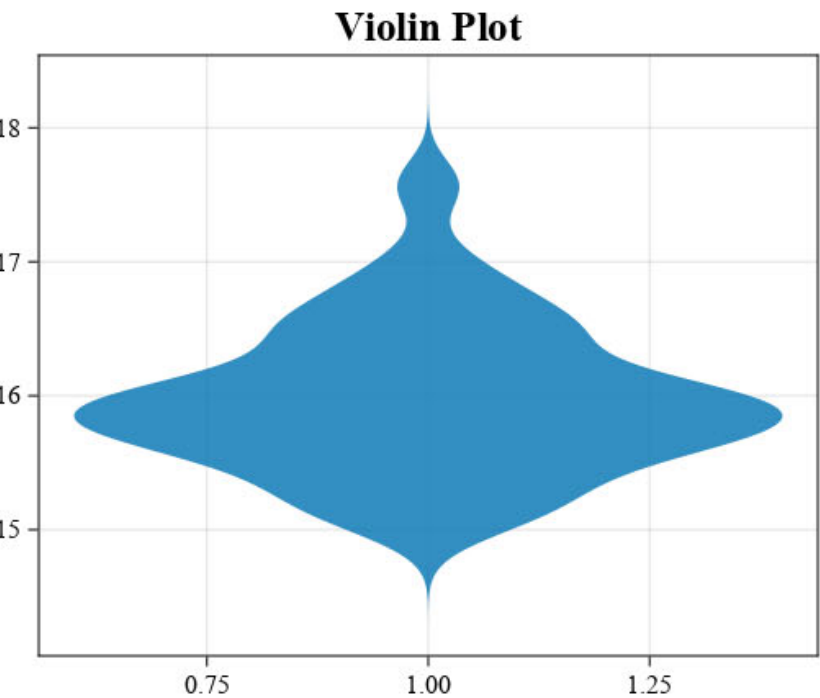
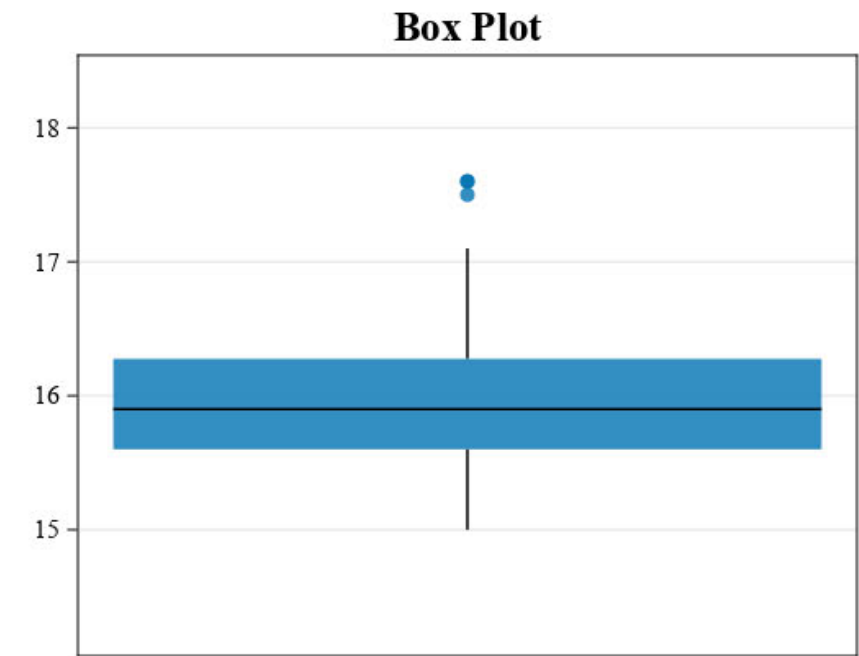
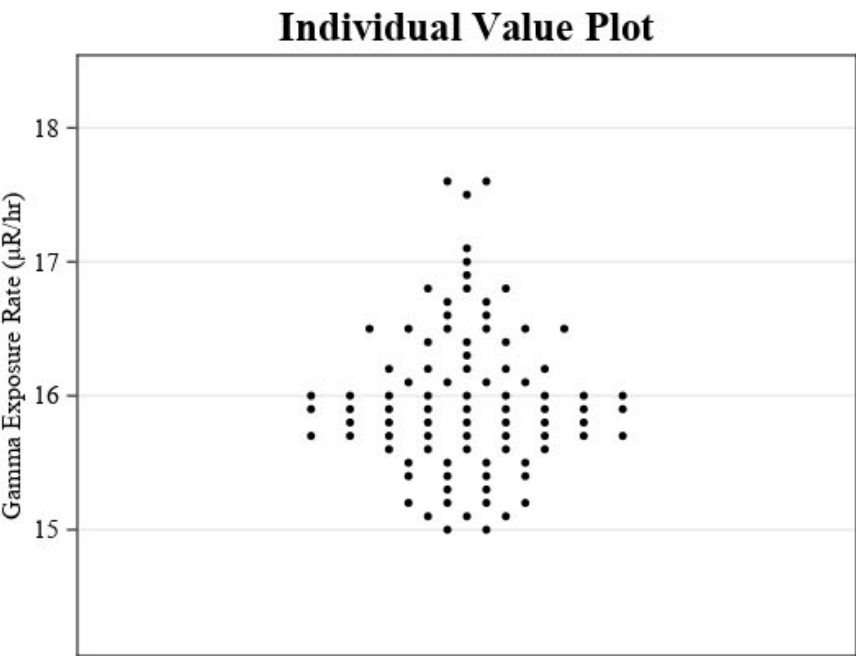


Summary Statistics

Count (n)	90
Minimum (µR/hr)	15.7
Maximum (µR/hr)	18.4
Average (µR/hr)	16.6
Median (µR/hr)	16.6
Standard Deviation (µR/hr)	0.57
Relative Standard Deviation	3.398%
RPD of Mean and Median	0.241%
90th Percentile (µR/hr)	17.4
95th Percentile (µR/hr)	17.4
99th Percentile (µR/hr)	18.4

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR02 Type: High Pressure Ionization Chamber

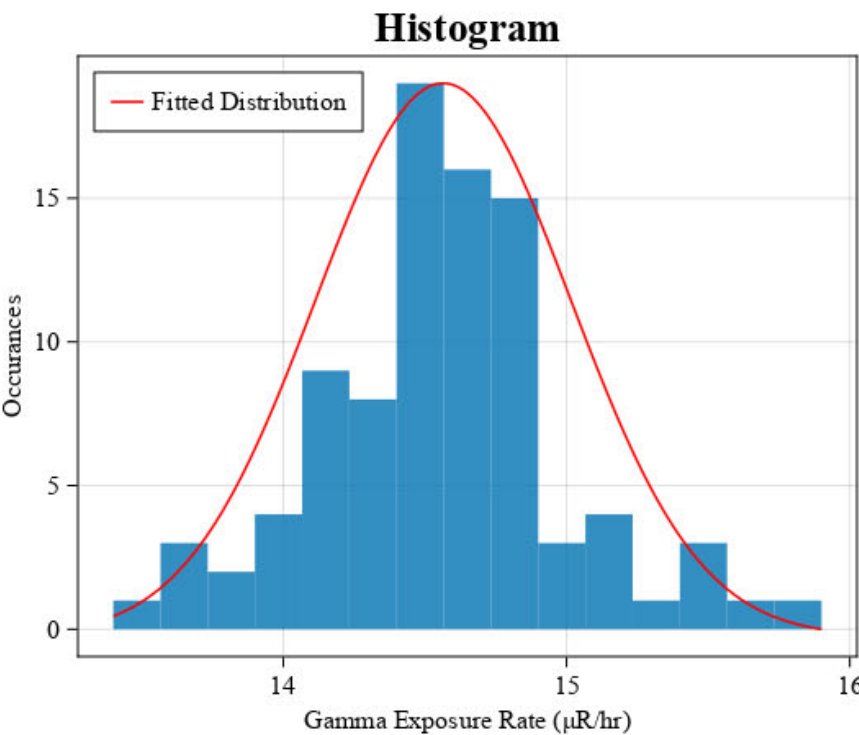
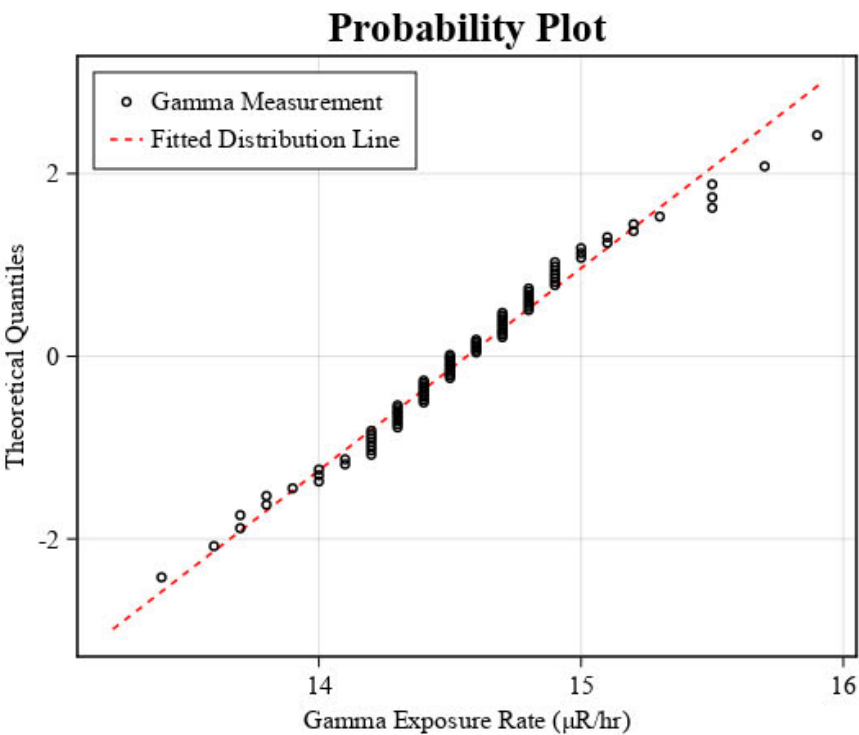
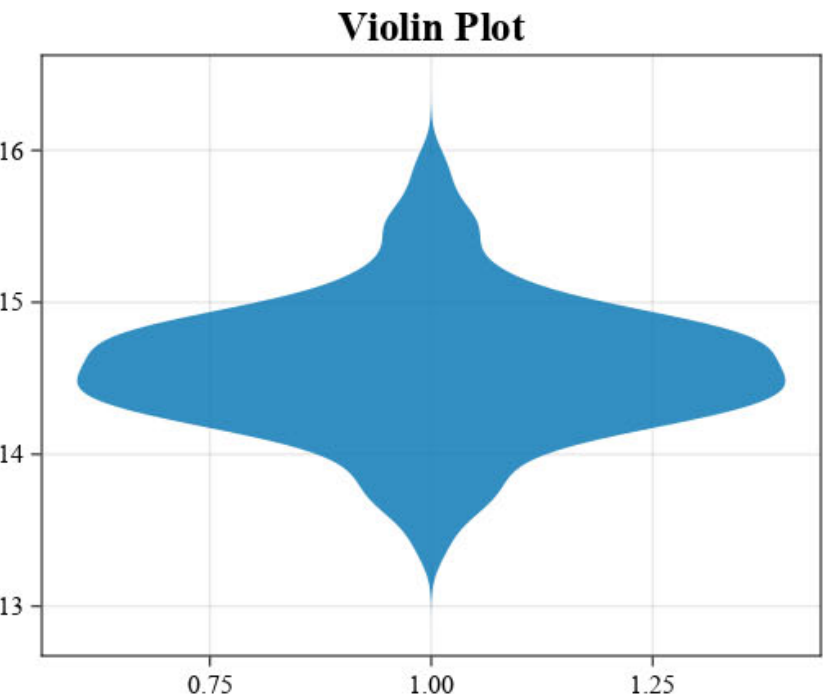
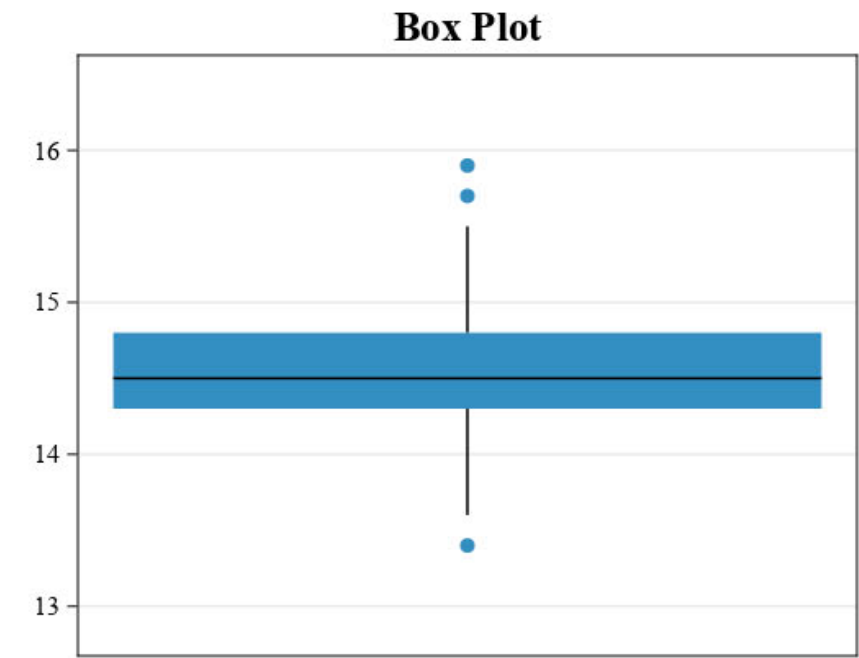
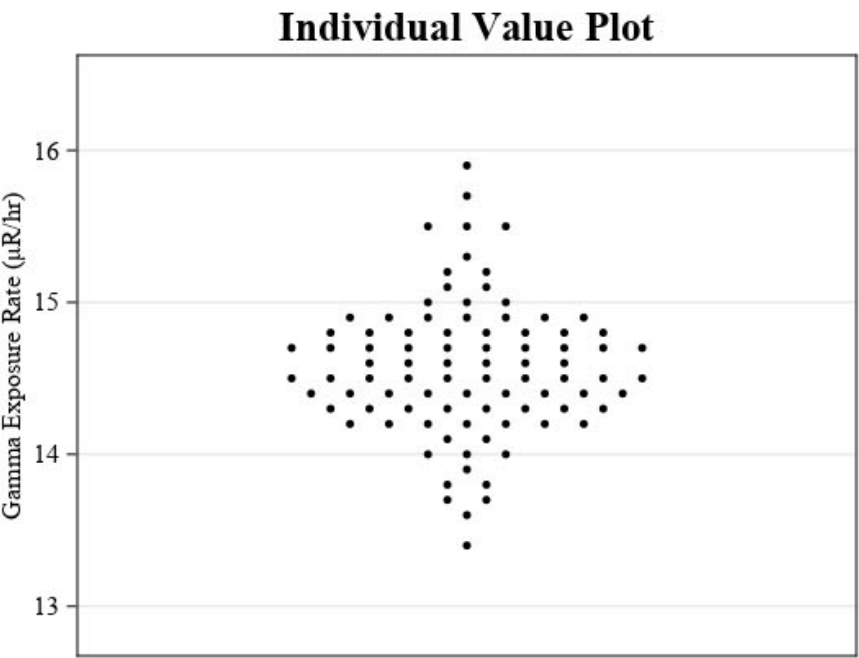


Summary Statistics

Count (n)	90
Minimum (µR/hr)	15.0
Maximum (µR/hr)	17.6
Average (µR/hr)	16.0
Median (µR/hr)	15.9
Standard Deviation (µR/hr)	0.57
Relative Standard Deviation	3.552%
RPD of Mean and Median	0.481%
90th Percentile (µR/hr)	16.7
95th Percentile (µR/hr)	17.0
99th Percentile (µR/hr)	17.6

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR03 Type: High Pressure Ionization Chamber

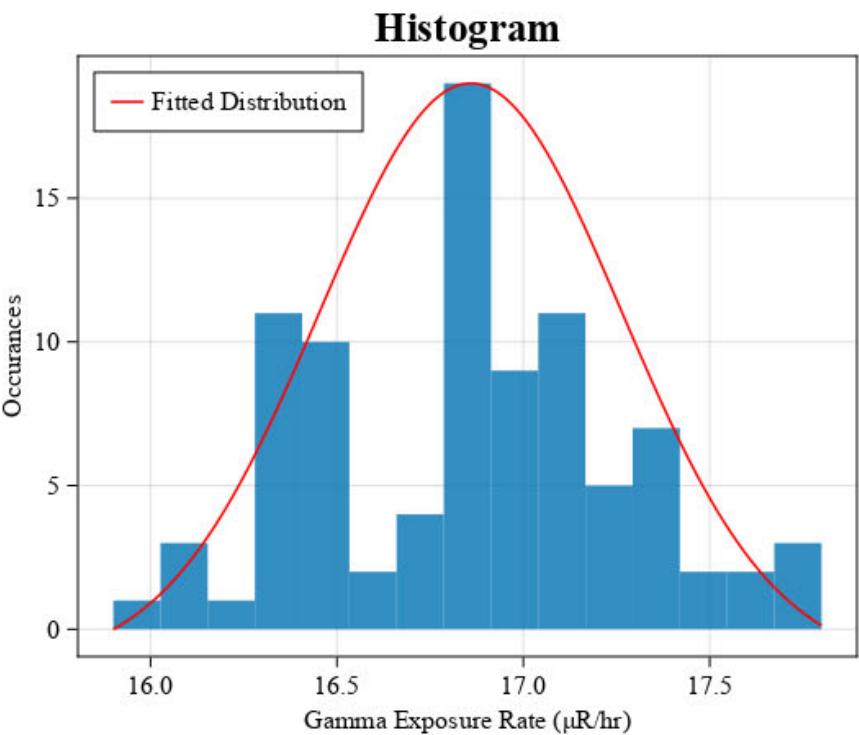
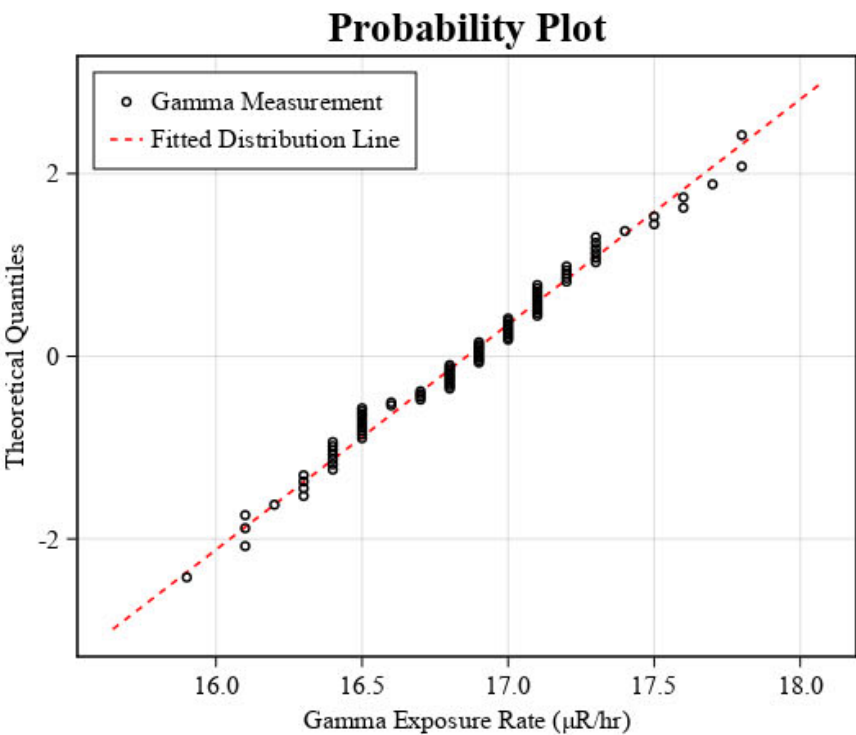
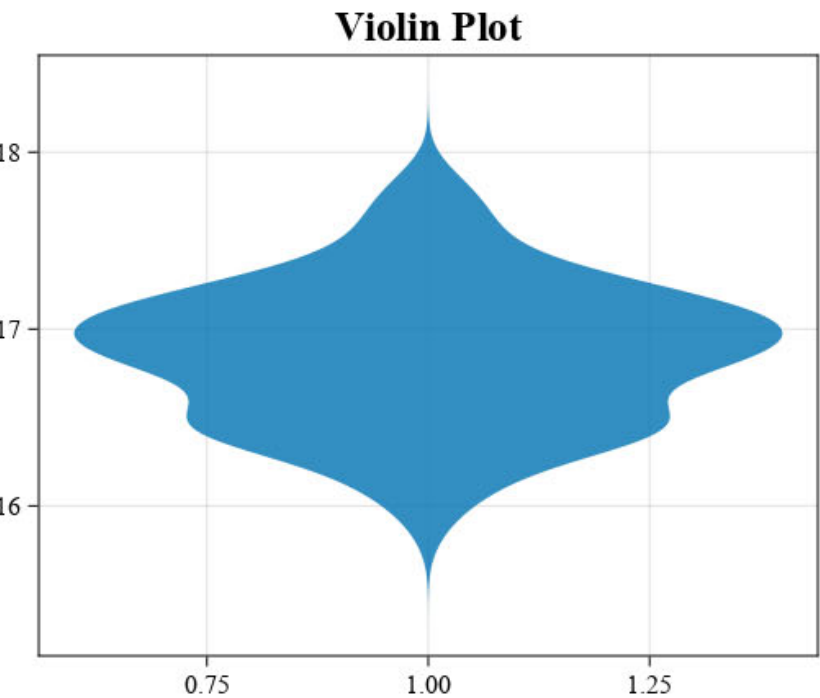
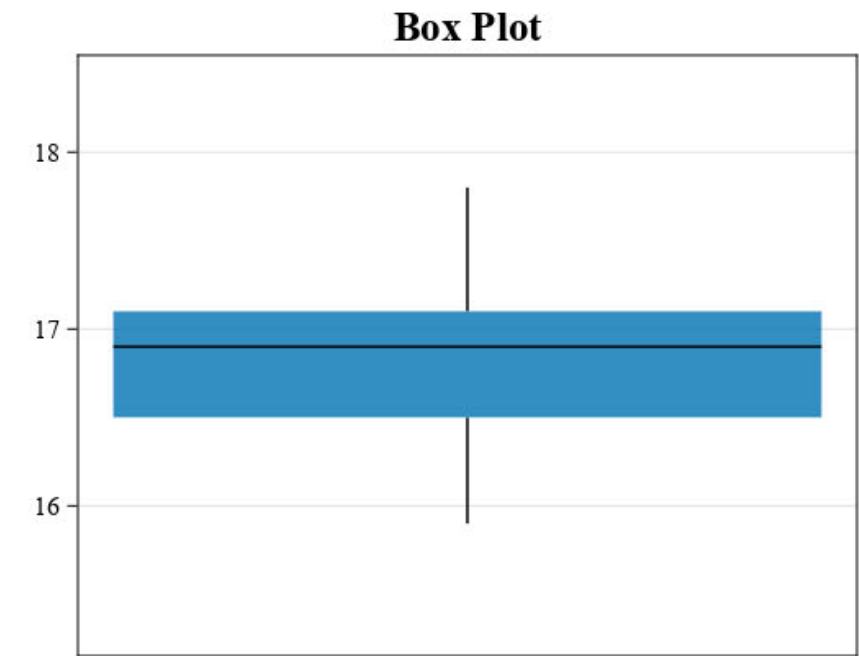
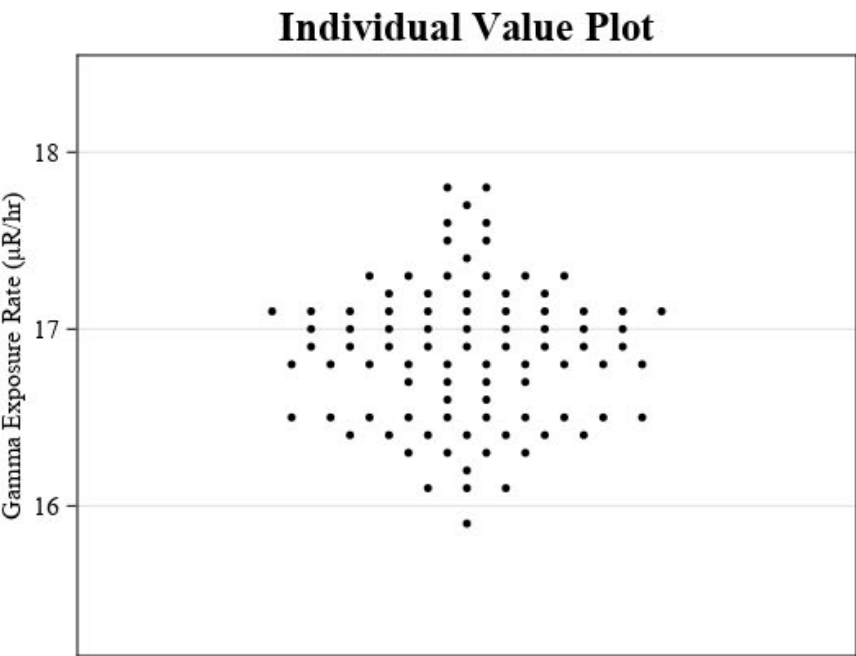


Summary Statistics

Count (n)	90
Minimum (µR/hr)	13.4
Maximum (µR/hr)	15.9
Average (µR/hr)	14.6
Median (µR/hr)	14.5
Standard Deviation (µR/hr)	0.45
Relative Standard Deviation	3.102%
RPD of Mean and Median	0.443%
90th Percentile (µR/hr)	15.1
95th Percentile (µR/hr)	15.5
99th Percentile (µR/hr)	15.9

Summary Statistics - Correlation Plots

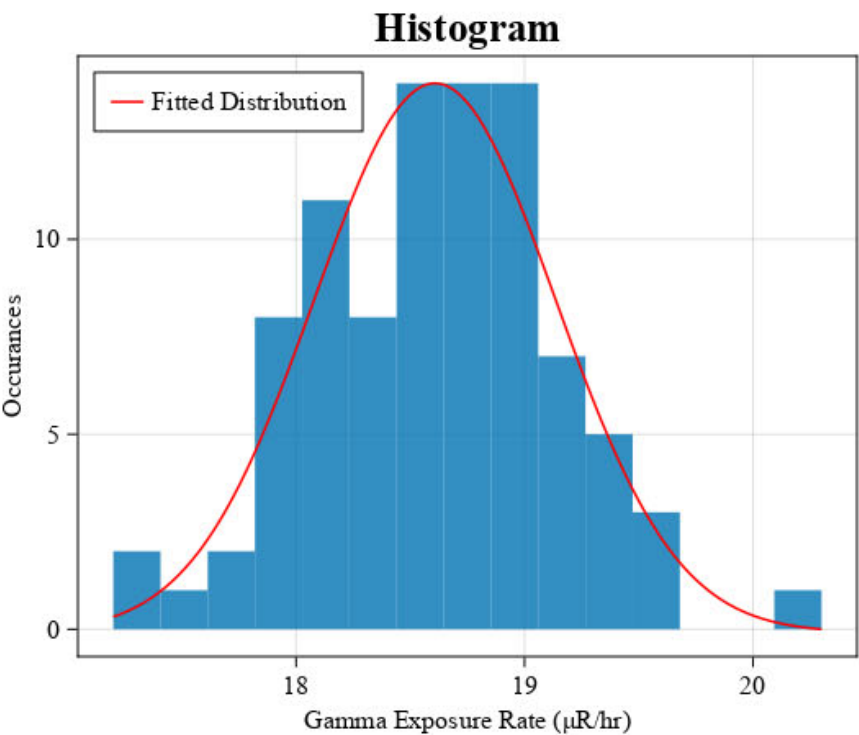
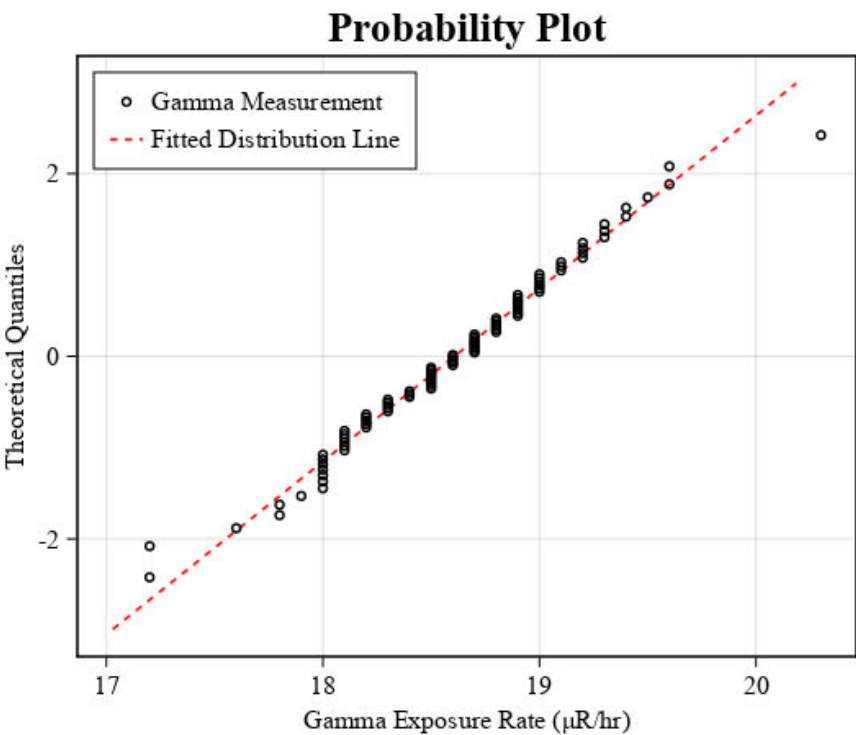
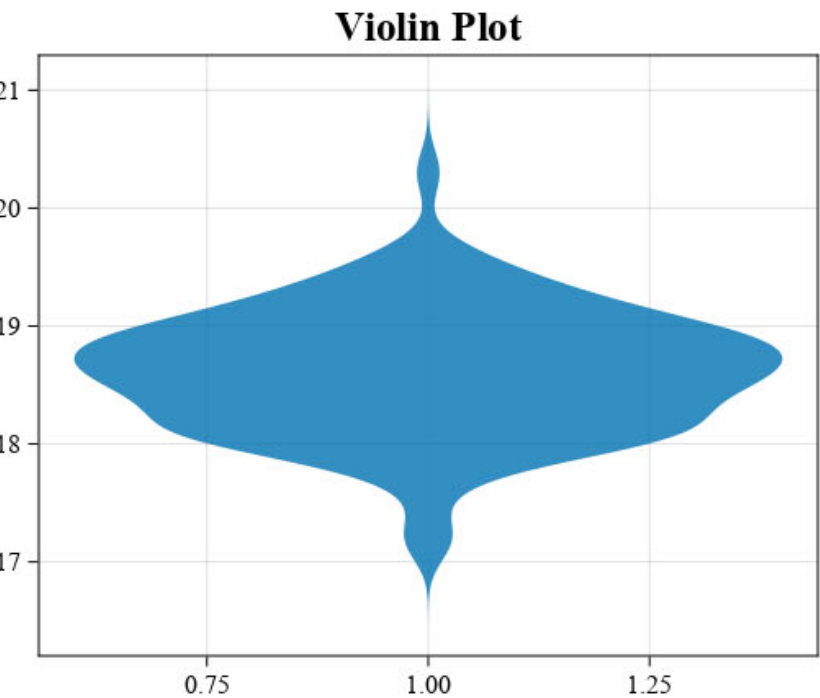
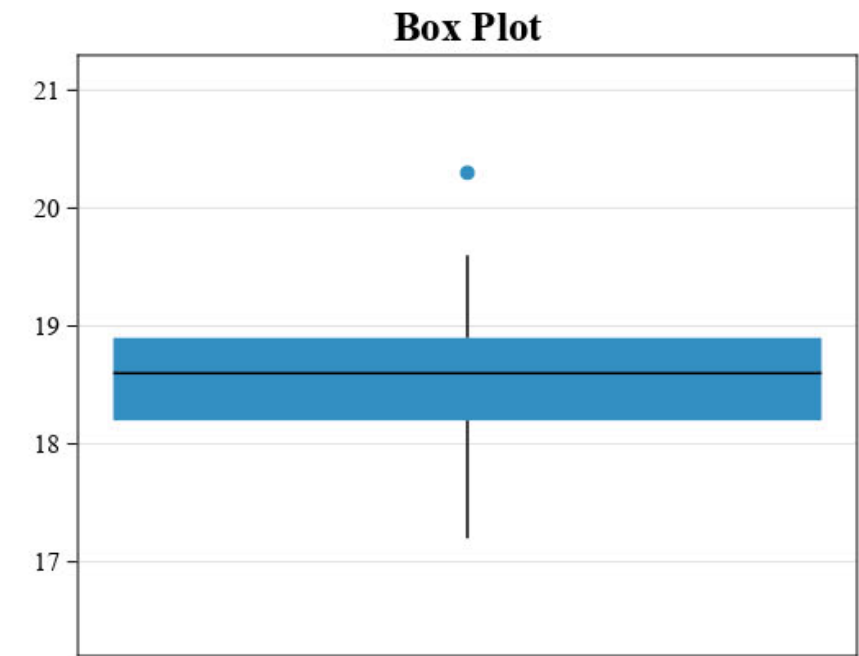
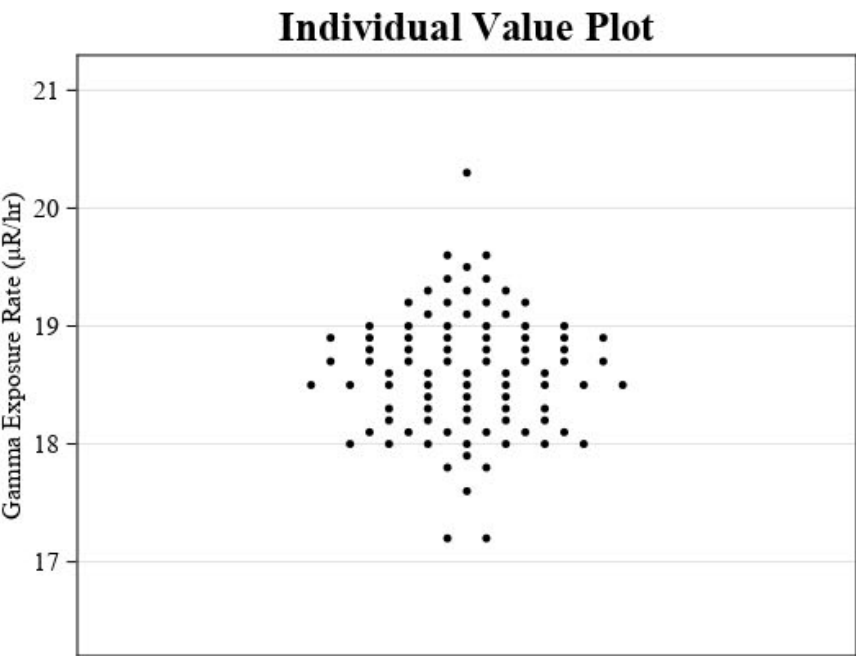
Site: OCRM Plot ID: CORR04 Type: High Pressure Ionization Chamber



Summary Statistics	
Count (n)	90
Minimum (µR/hr)	15.9
Maximum (µR/hr)	17.8
Average (µR/hr)	16.9
Median (µR/hr)	16.9
Standard Deviation (µR/hr)	0.41
Relative Standard Deviation	2.406%
RPD of Mean and Median	0.244%
90th Percentile (µR/hr)	17.3
95th Percentile (µR/hr)	17.6
99th Percentile (µR/hr)	17.8

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR05 Type: High Pressure Ionization Chamber

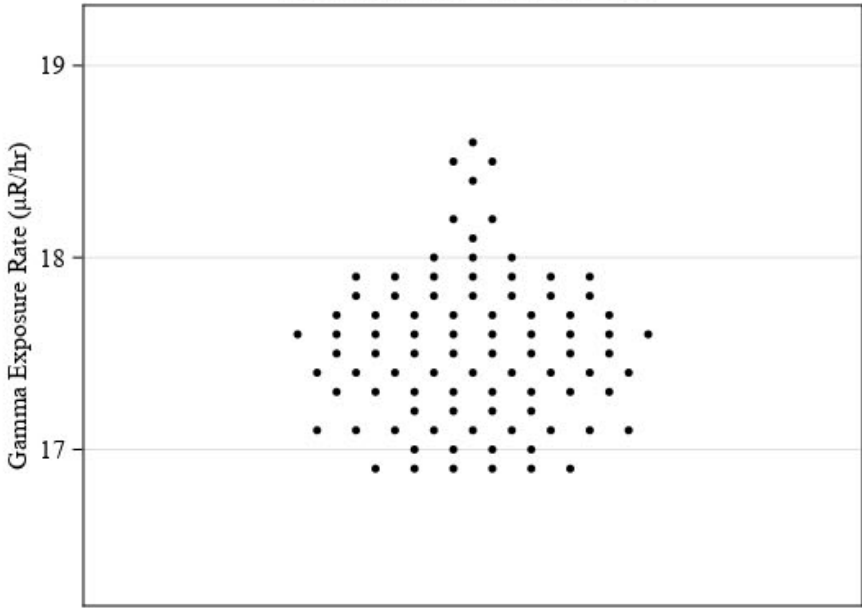


Summary Statistics	
Count (n)	90
Minimum (µR/hr)	17.2
Maximum (µR/hr)	20.3
Average (µR/hr)	18.6
Median (µR/hr)	18.6
Standard Deviation (µR/hr)	0.53
Relative Standard Deviation	2.837%
RPD of Mean and Median	0.042%
90th Percentile (µR/hr)	19.3
95th Percentile (µR/hr)	19.4
99th Percentile (µR/hr)	20.3

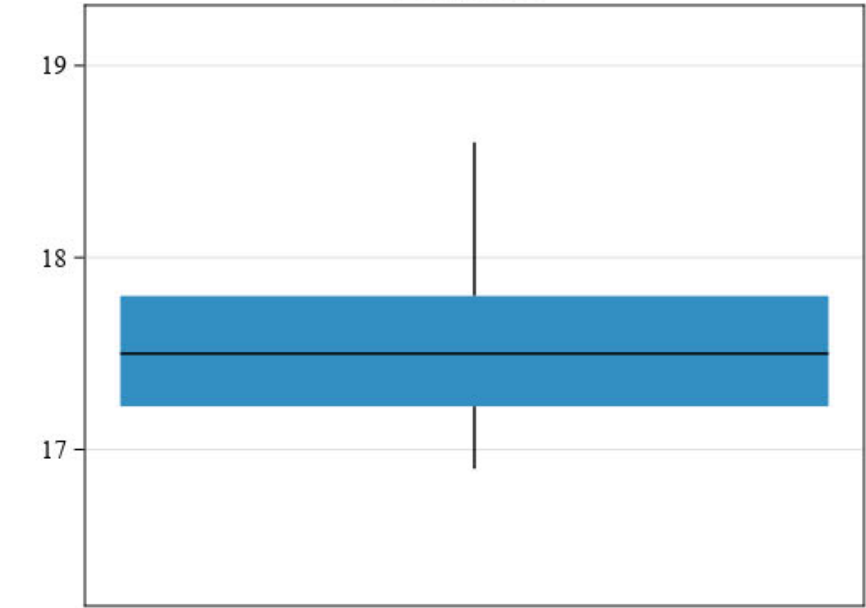
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR06 Type: High Pressure Ionization Chamber

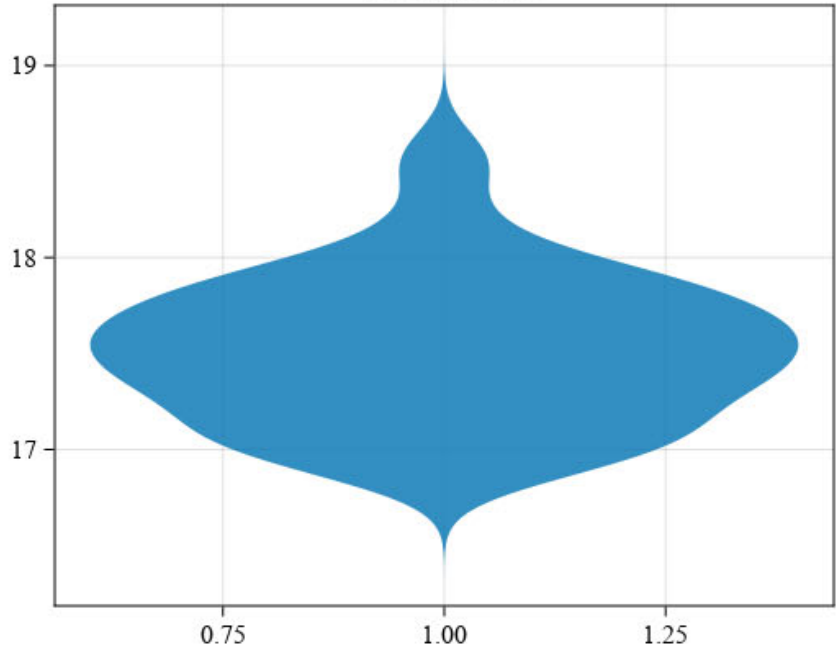
Individual Value Plot



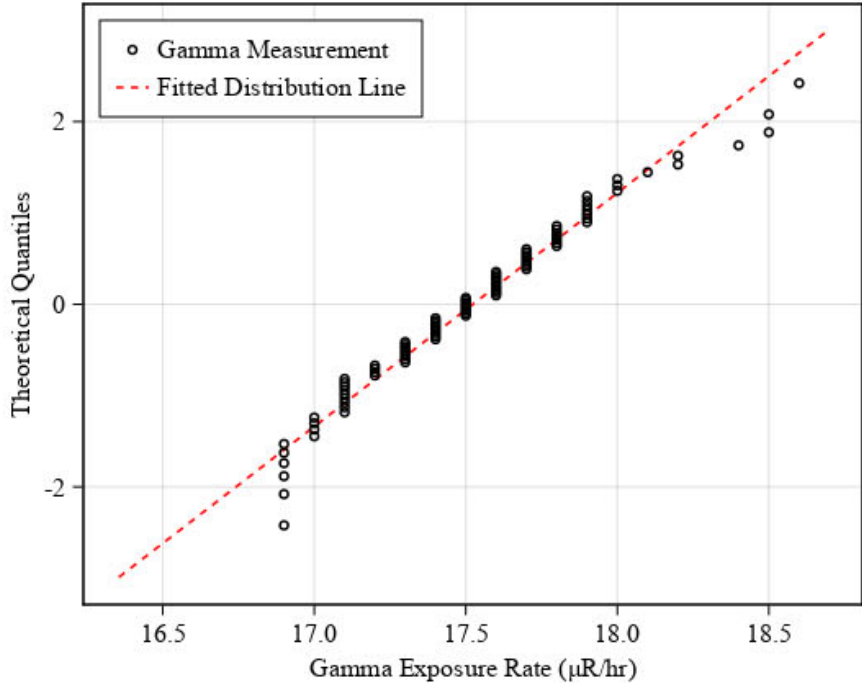
Box Plot



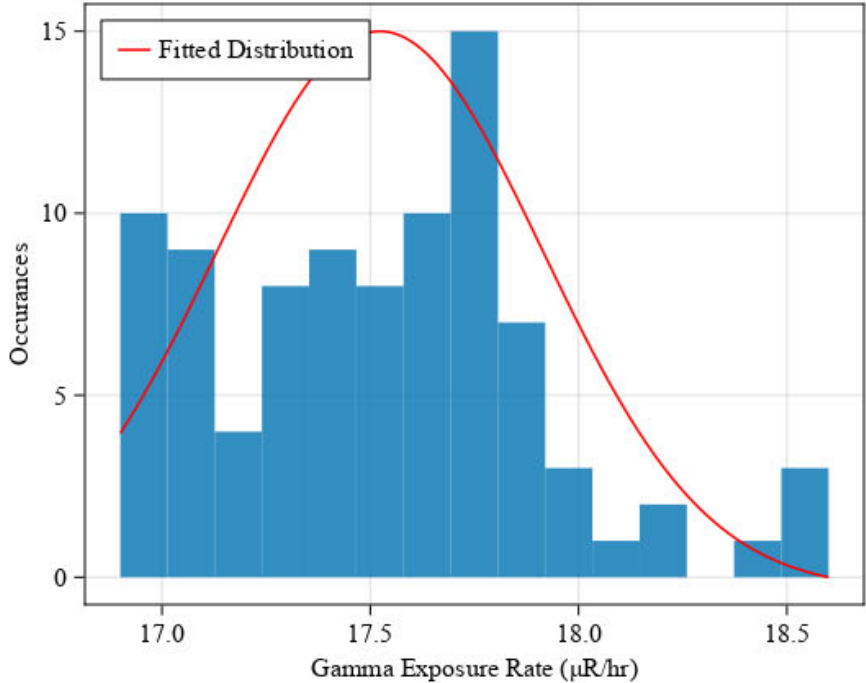
Violin Plot



Probability Plot



Histogram

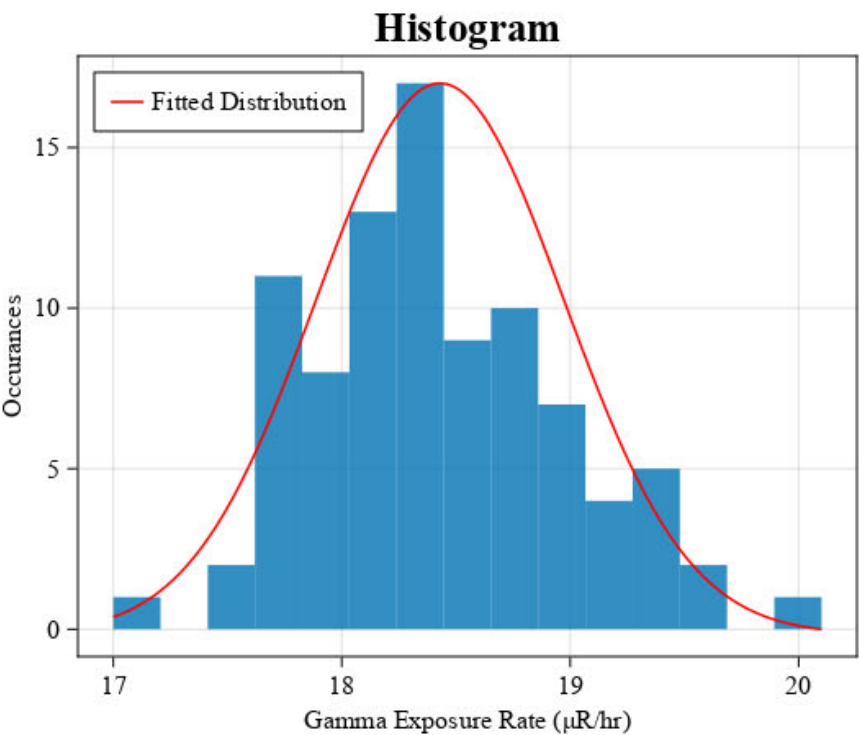
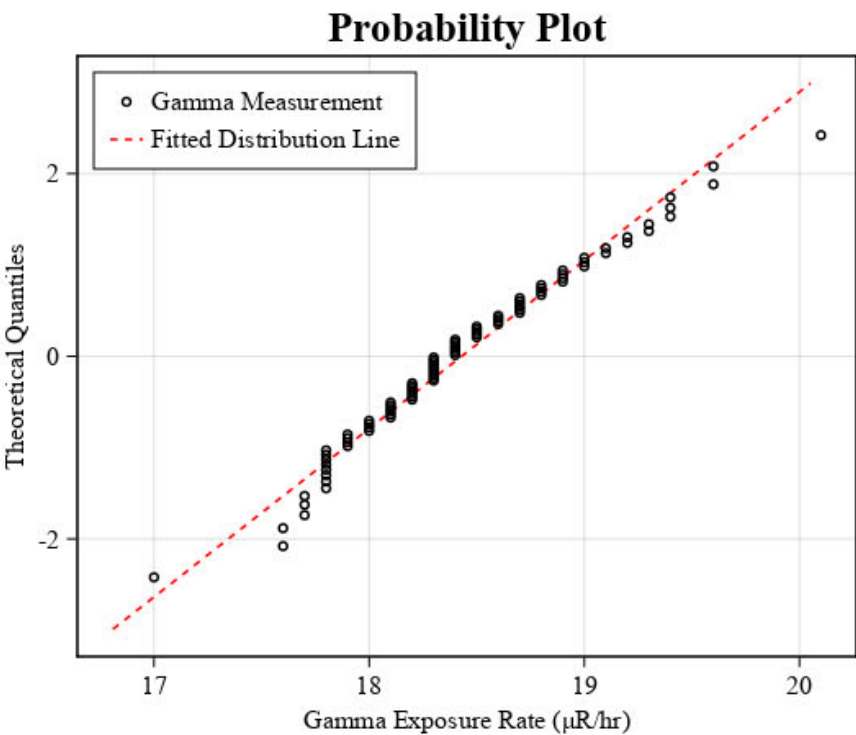
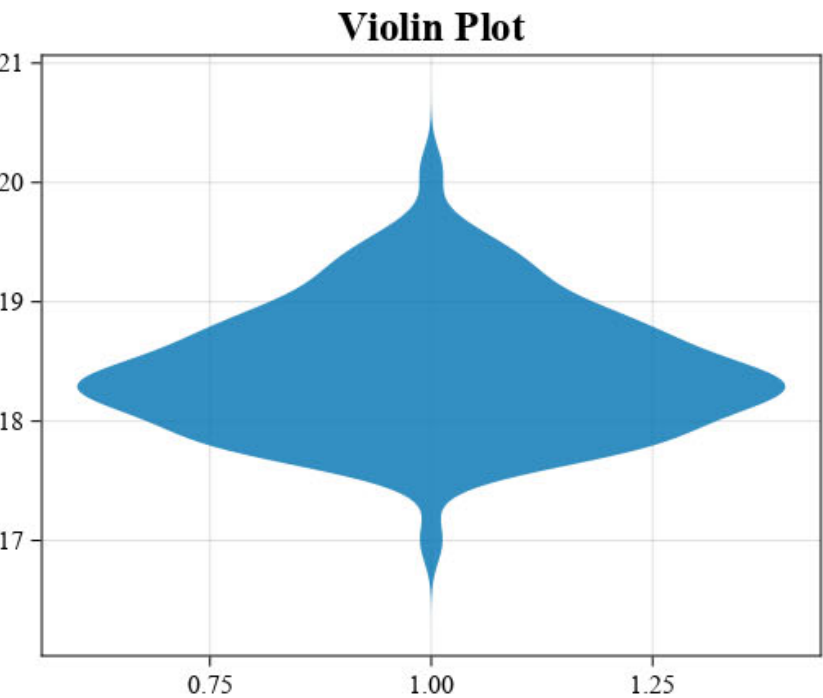
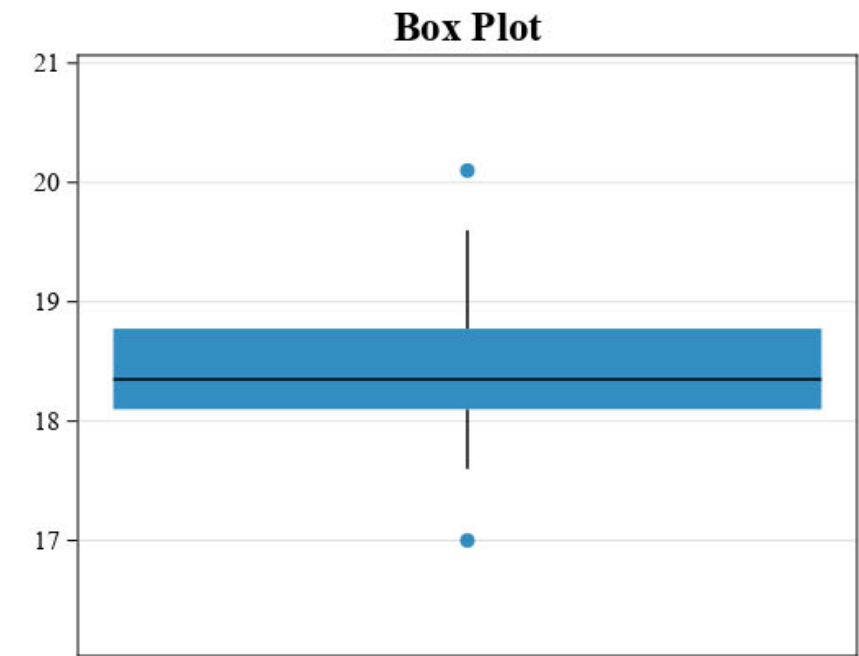
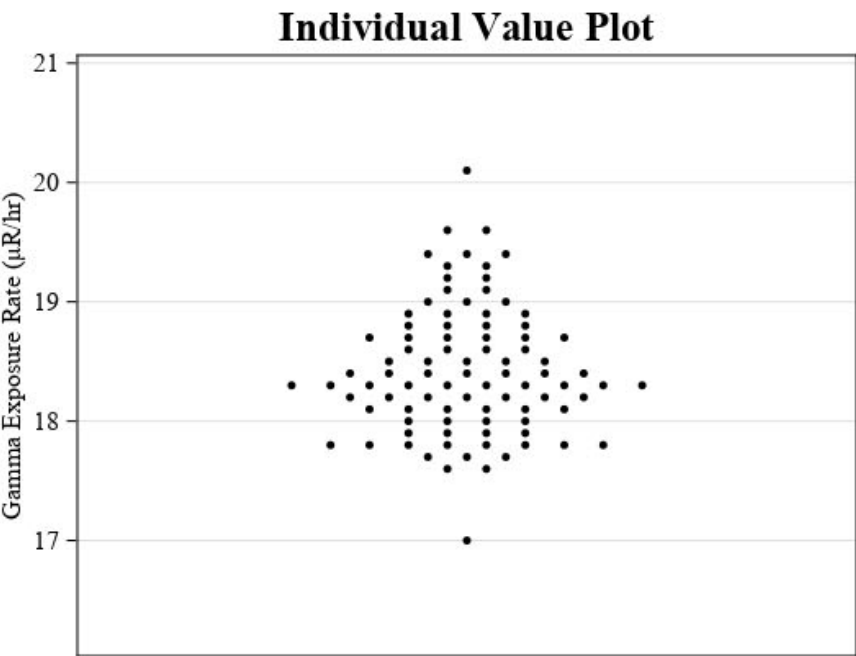


Summary Statistics

Count (n)	90
Minimum (µR/hr)	16.9
Maximum (µR/hr)	18.6
Average (µR/hr)	17.5
Median (µR/hr)	17.5
Standard Deviation (µR/hr)	0.39
Relative Standard Deviation	2.231%
RPD of Mean and Median	0.133%
90th Percentile (µR/hr)	18.0
95th Percentile (µR/hr)	18.2
99th Percentile (µR/hr)	18.6

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR07 Type: High Pressure Ionization Chamber

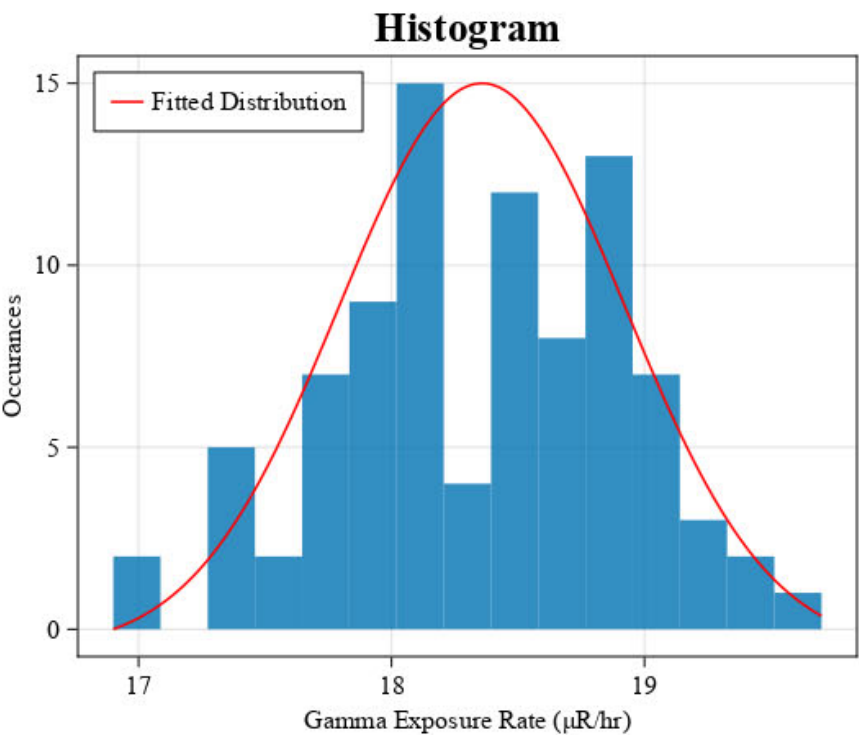
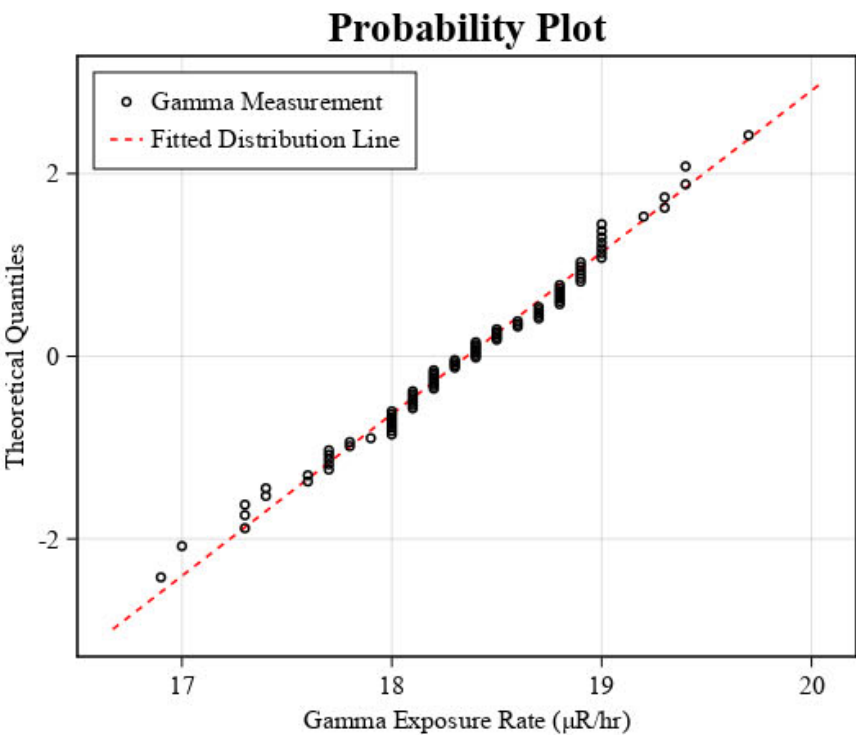
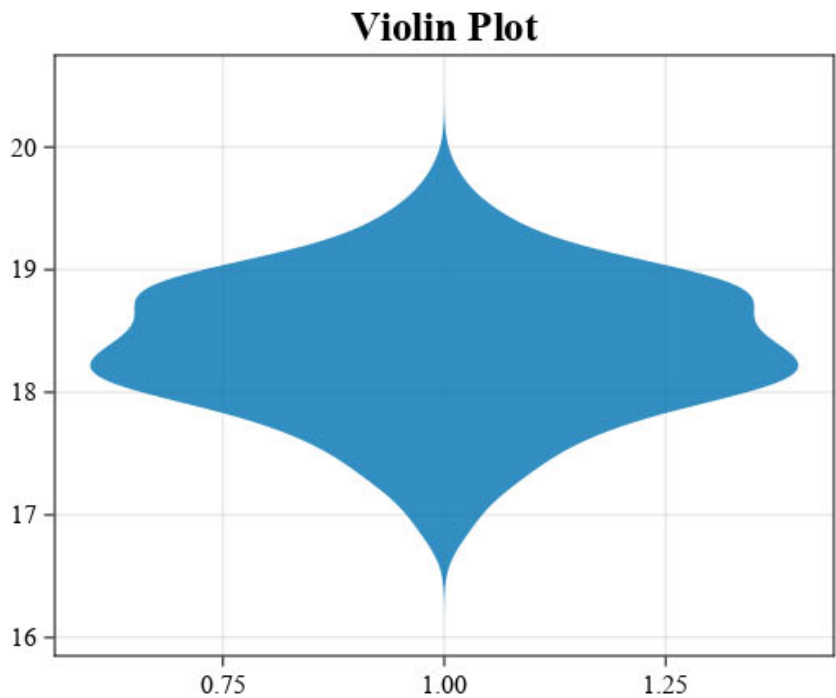
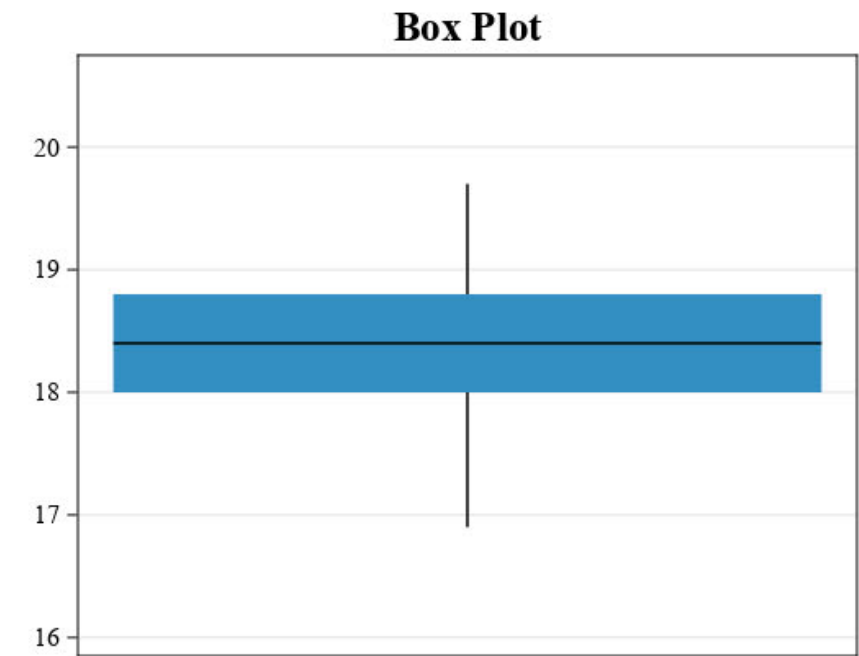
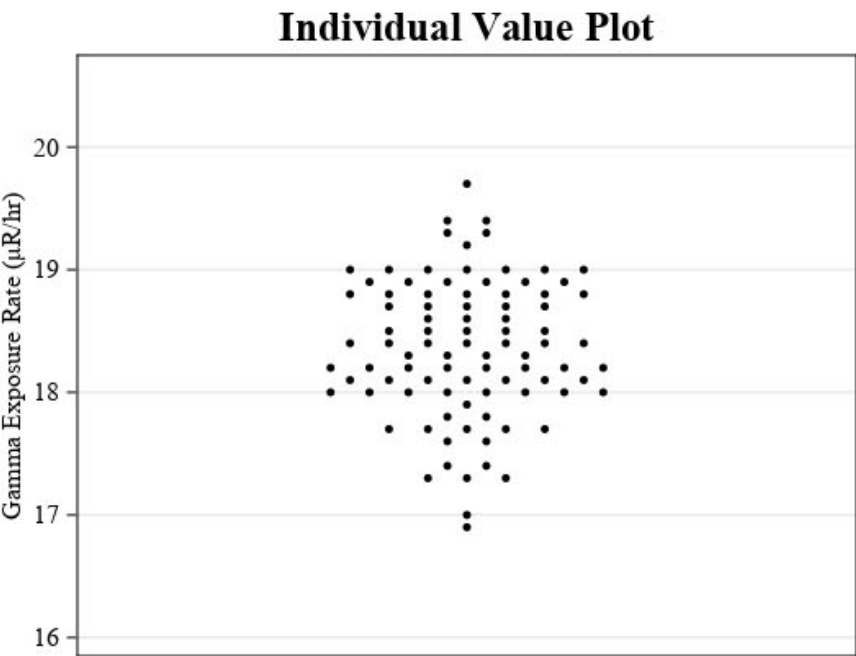


Summary Statistics

Count (n)	90
Minimum (µR/hr)	17.0
Maximum (µR/hr)	20.1
Average (µR/hr)	18.4
Median (µR/hr)	18.4
Standard Deviation (µR/hr)	0.54
Relative Standard Deviation	2.943%
RPD of Mean and Median	0.435%
90th Percentile (µR/hr)	19.2
95th Percentile (µR/hr)	19.4
99th Percentile (µR/hr)	20.1

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR08 Type: High Pressure Ionization Chamber

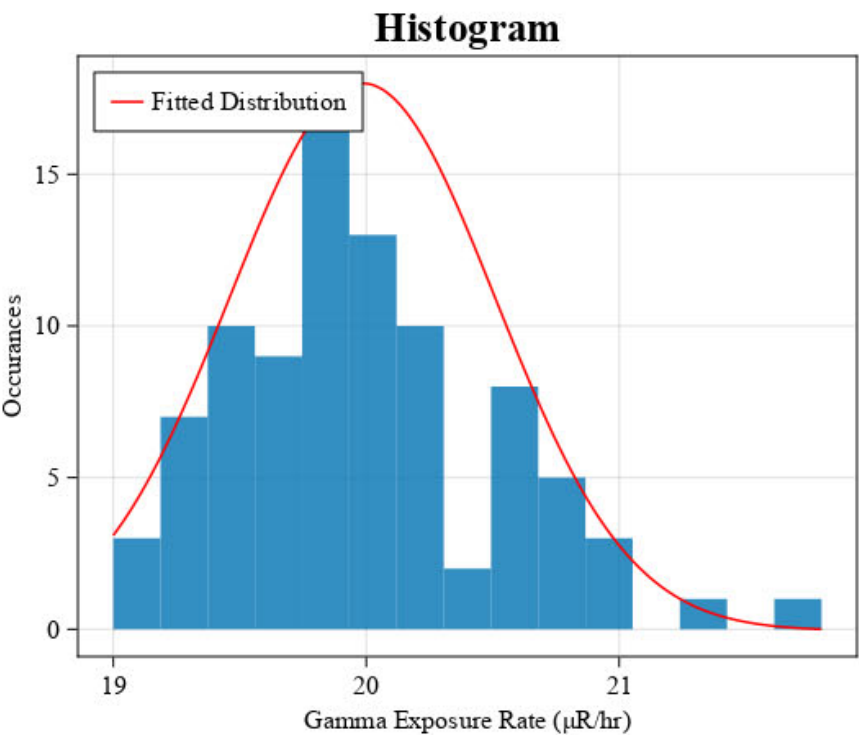
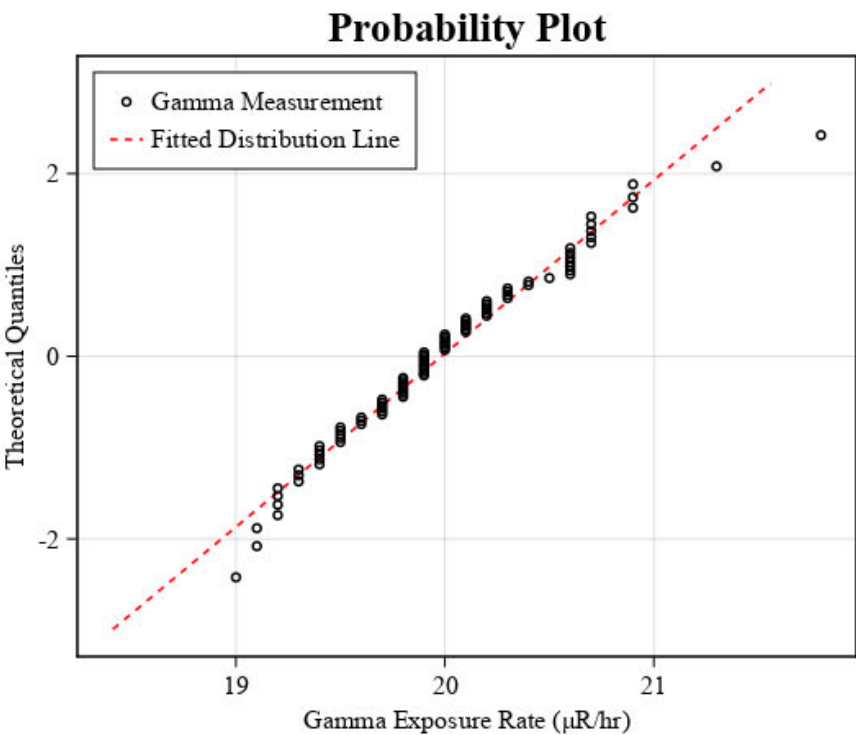
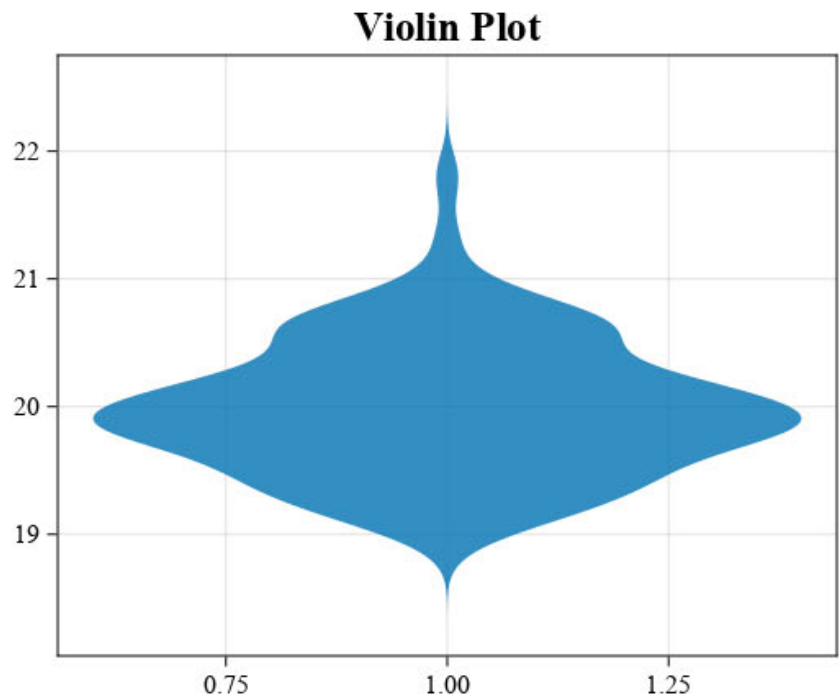
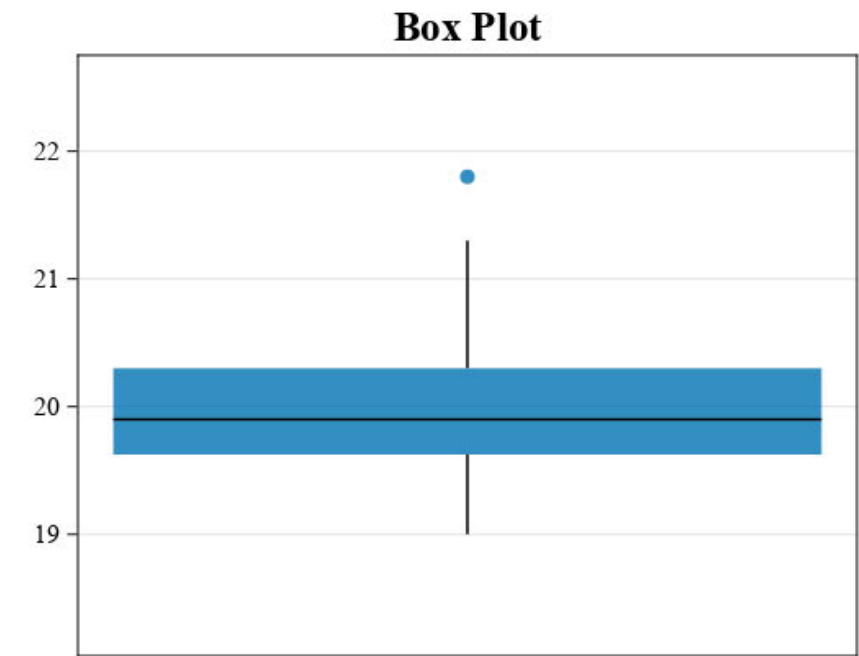
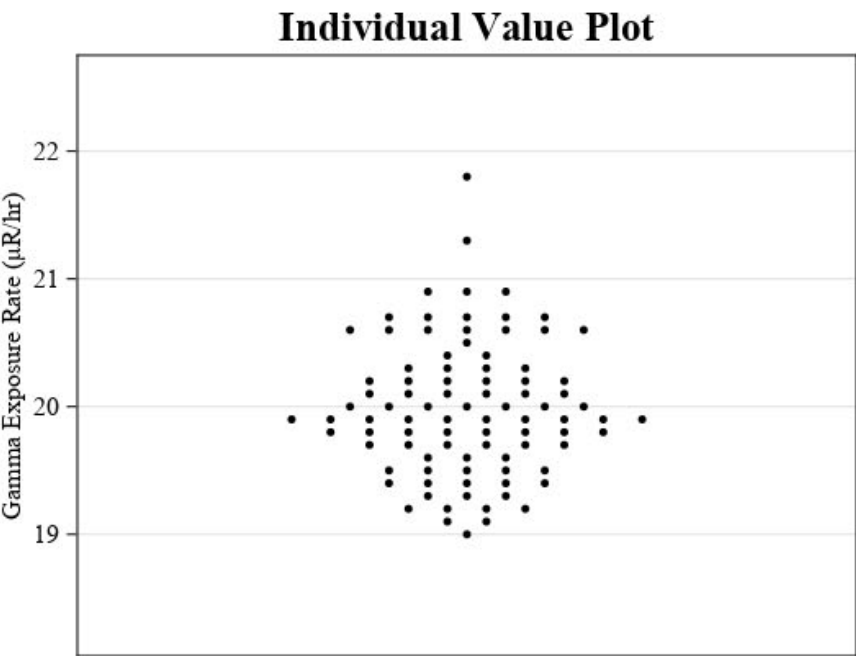


Summary Statistics

Count (n)	90
Minimum (µR/hr)	16.9
Maximum (µR/hr)	19.7
Average (µR/hr)	18.4
Median (µR/hr)	18.4
Standard Deviation (µR/hr)	0.56
Relative Standard Deviation	3.075%
RPD of Mean and Median	0.23%
90th Percentile (µR/hr)	19.0
95th Percentile (µR/hr)	19.3
99th Percentile (µR/hr)	19.7

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR09 Type: High Pressure Ionization Chamber



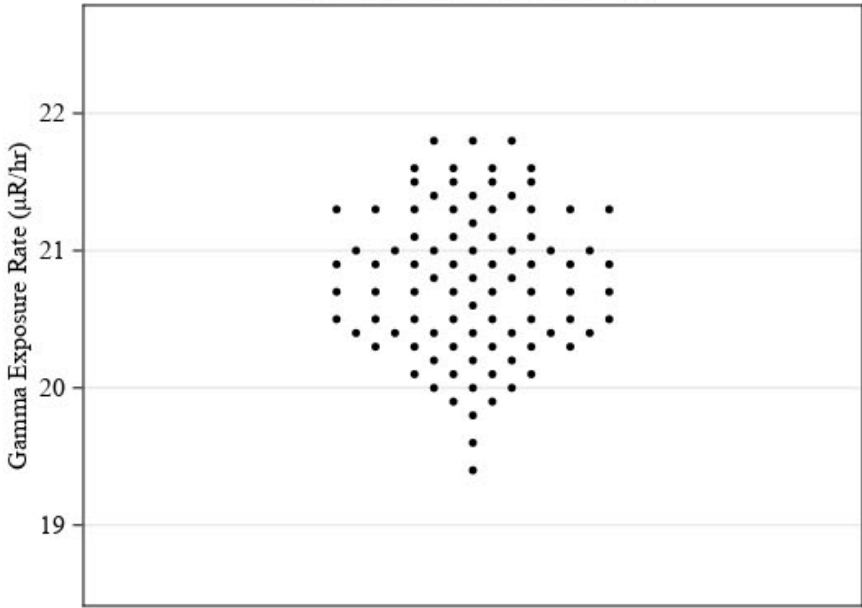
Summary Statistics

Count (n)	90
Minimum (µR/hr)	19.0
Maximum (µR/hr)	21.8
Average (µR/hr)	20.0
Median (µR/hr)	19.9
Standard Deviation (µR/hr)	0.53
Relative Standard Deviation	2.635%
RPD of Mean and Median	0.423%
90th Percentile (µR/hr)	20.7
95th Percentile (µR/hr)	20.9
99th Percentile (µR/hr)	21.8

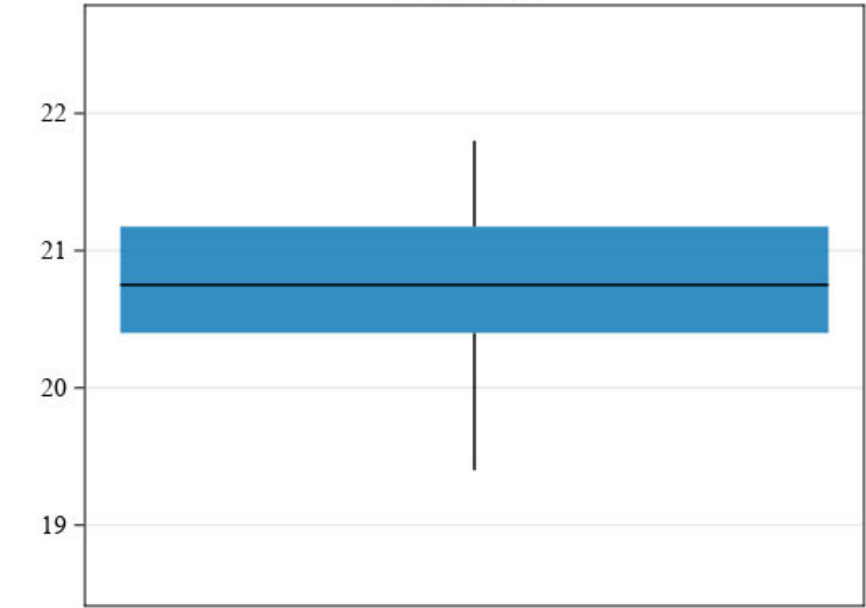
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR10 Type: High Pressure Ionization Chamber

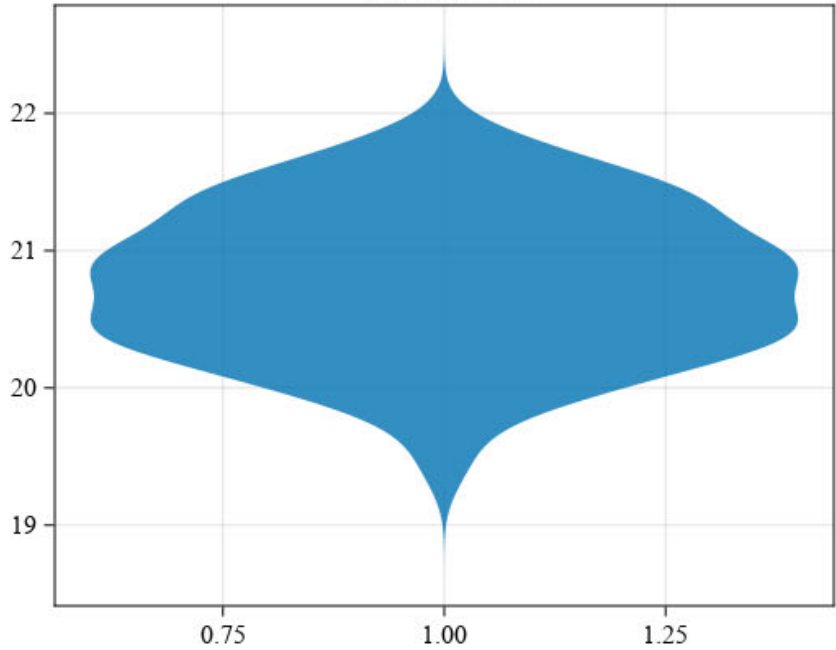
Individual Value Plot



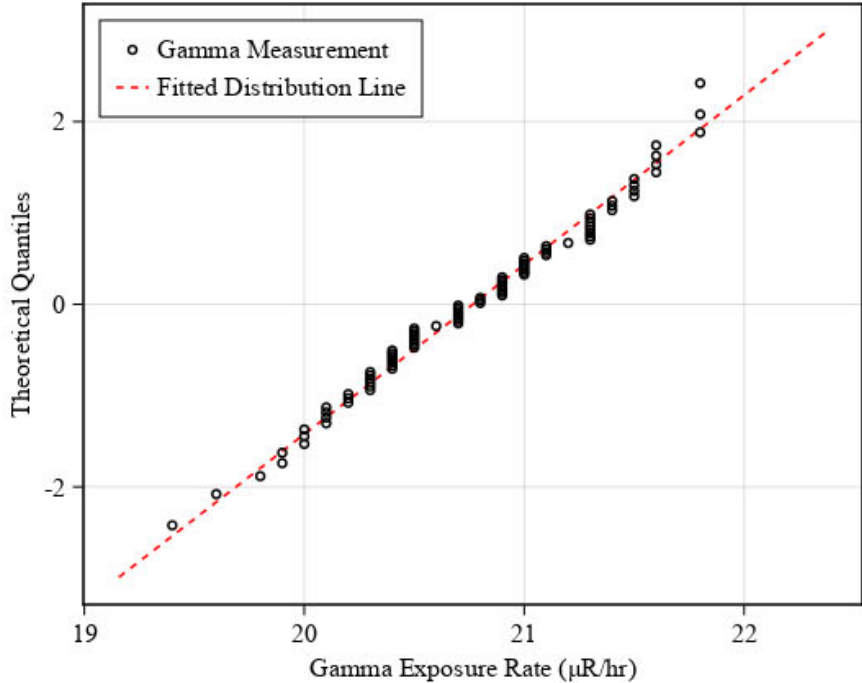
Box Plot



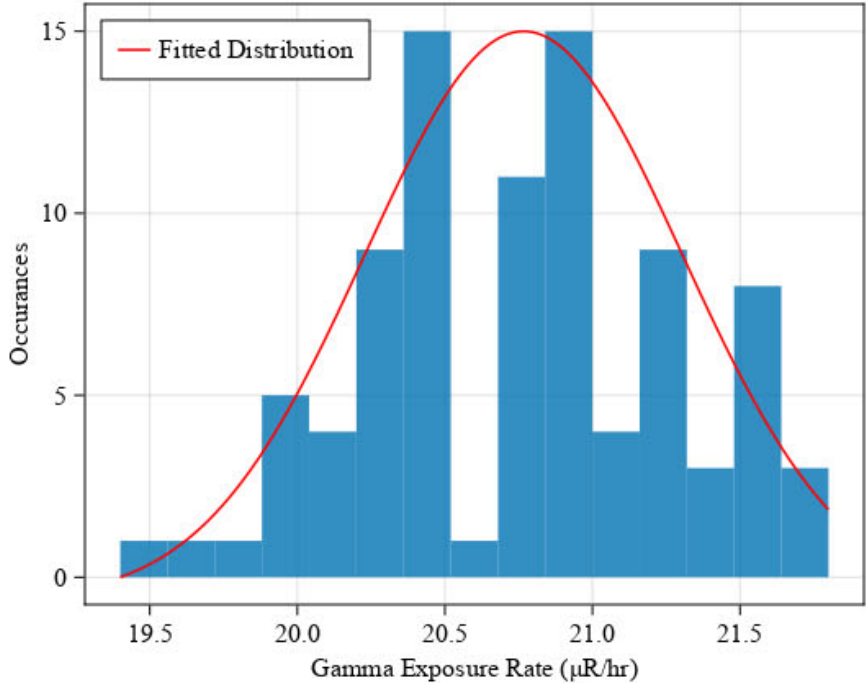
Violin Plot



Probability Plot



Histogram

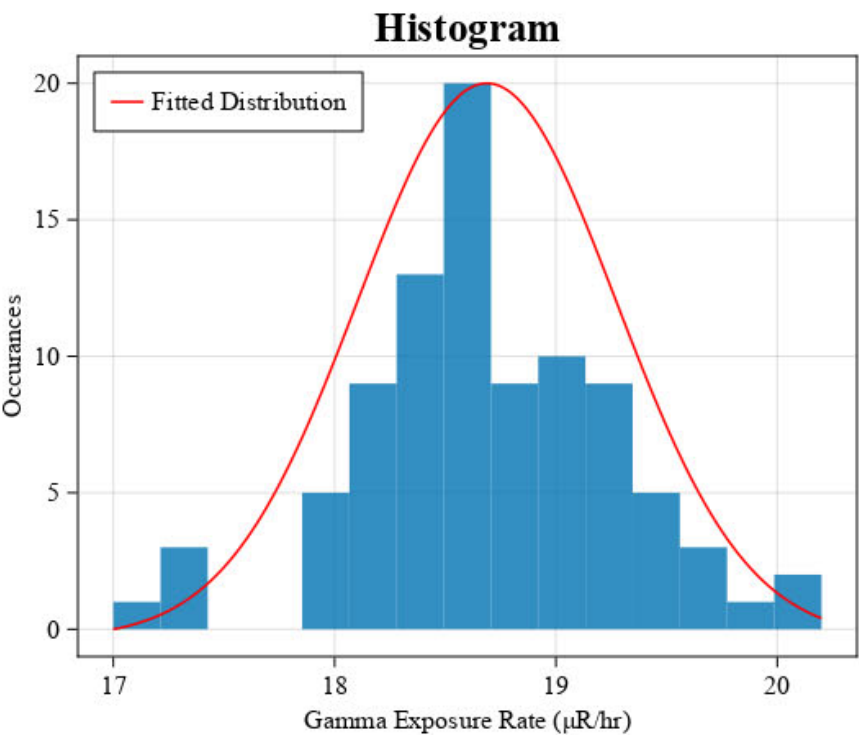
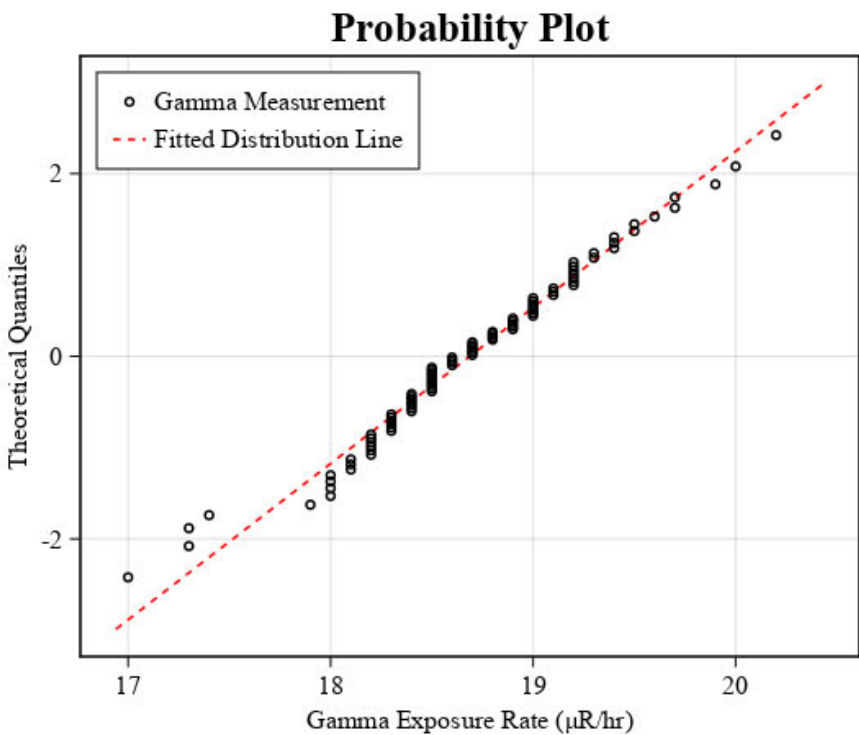
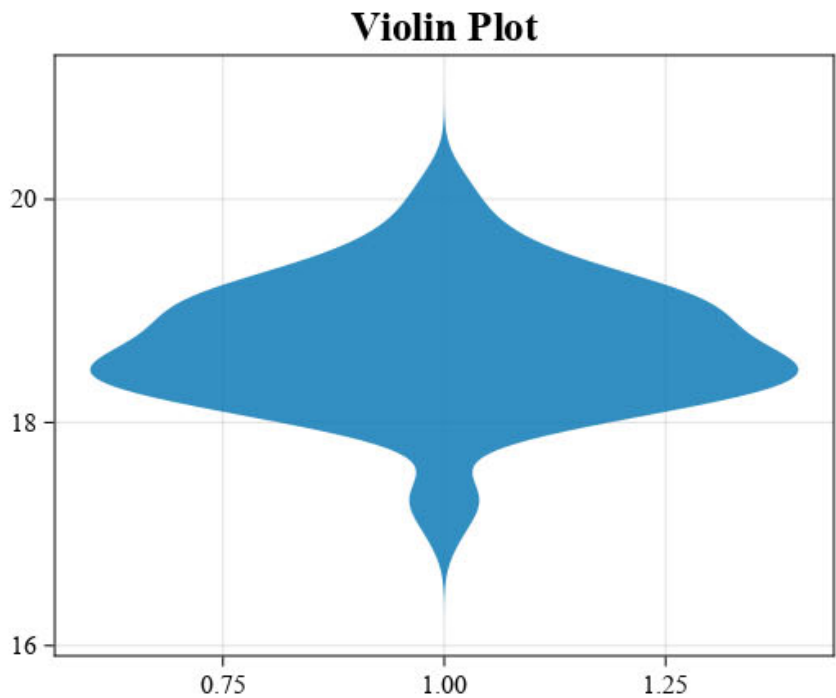
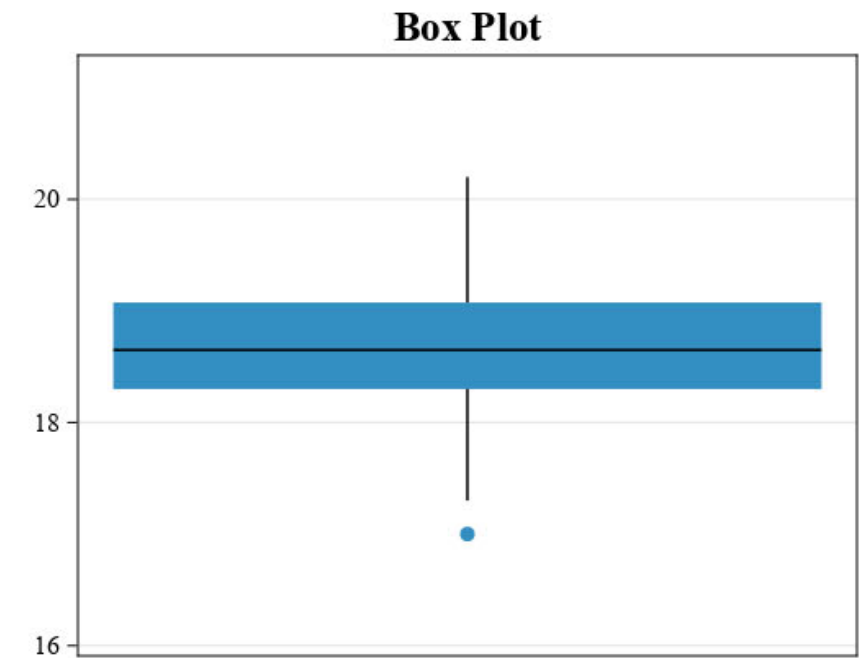
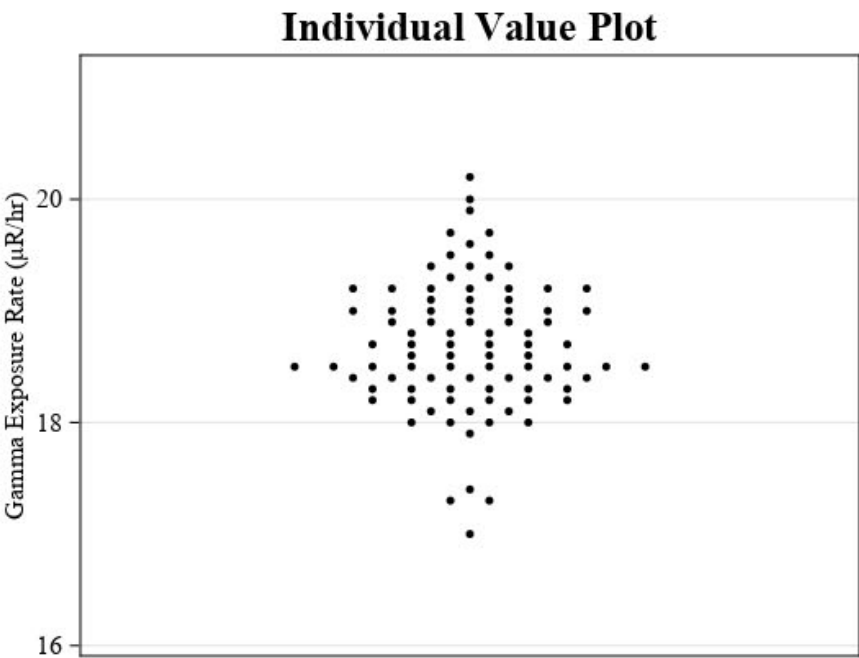


Summary Statistics

Count (n)	90
Minimum (µR/hr)	19.4
Maximum (µR/hr)	21.8
Average (µR/hr)	20.8
Median (µR/hr)	20.8
Standard Deviation (µR/hr)	0.54
Relative Standard Deviation	2.594%
RPD of Mean and Median	0.08%
90th Percentile (µR/hr)	21.5
95th Percentile (µR/hr)	21.6
99th Percentile (µR/hr)	21.8

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR11 Type: High Pressure Ionization Chamber



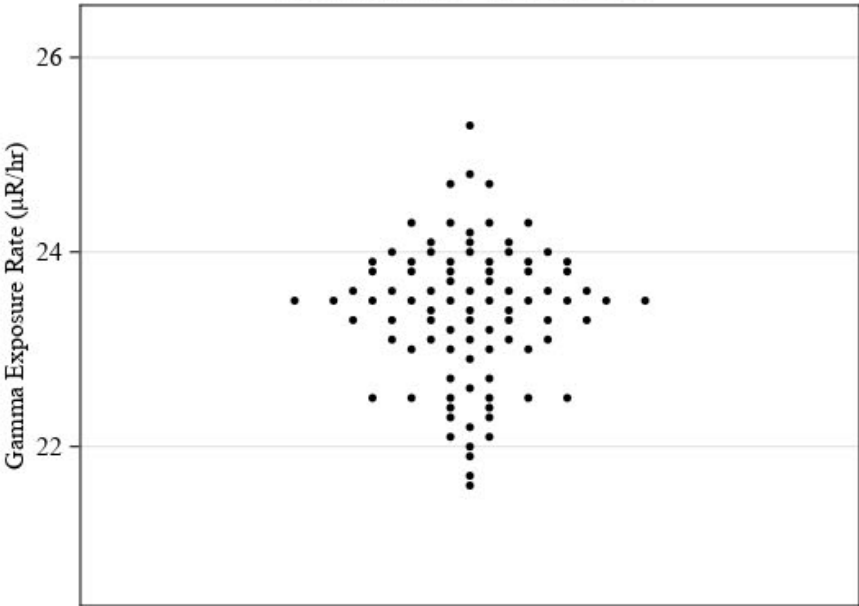
Summary Statistics

Count (n)	90
Minimum (µR/hr)	17.0
Maximum (µR/hr)	20.2
Average (µR/hr)	18.7
Median (µR/hr)	18.6
Standard Deviation (µR/hr)	0.58
Relative Standard Deviation	3.13%
RPD of Mean and Median	0.202%
90th Percentile (µR/hr)	19.4
95th Percentile (µR/hr)	19.7
99th Percentile (µR/hr)	20.2

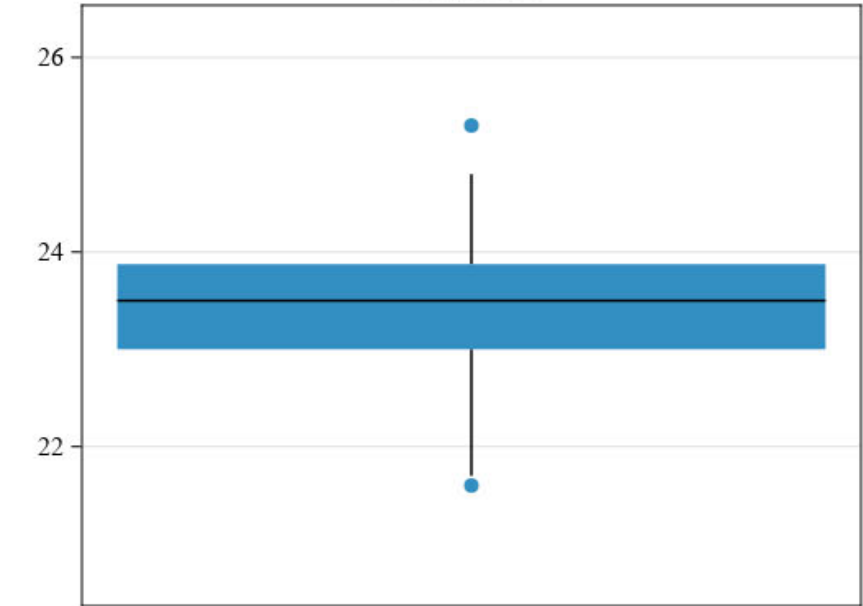
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR12 Type: High Pressure Ionization Chamber

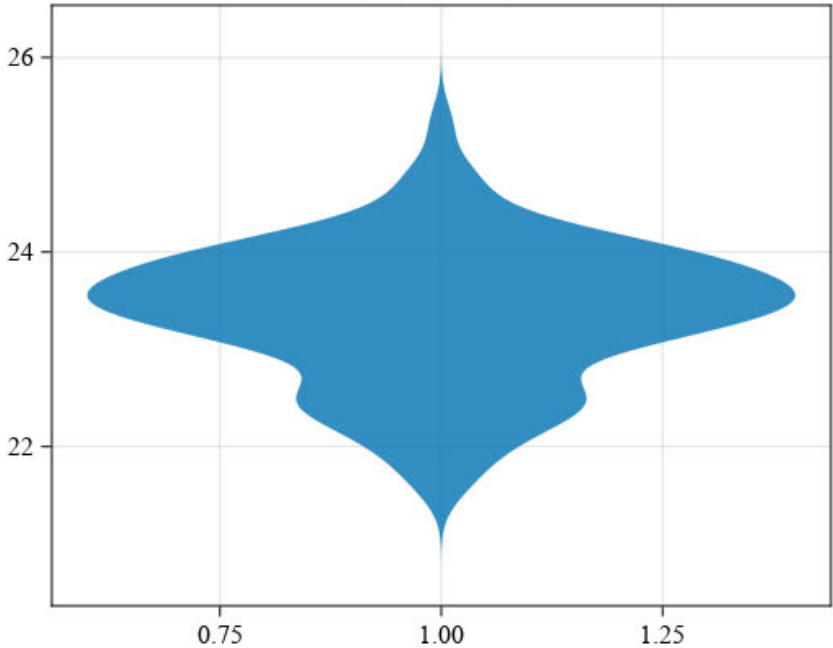
Individual Value Plot



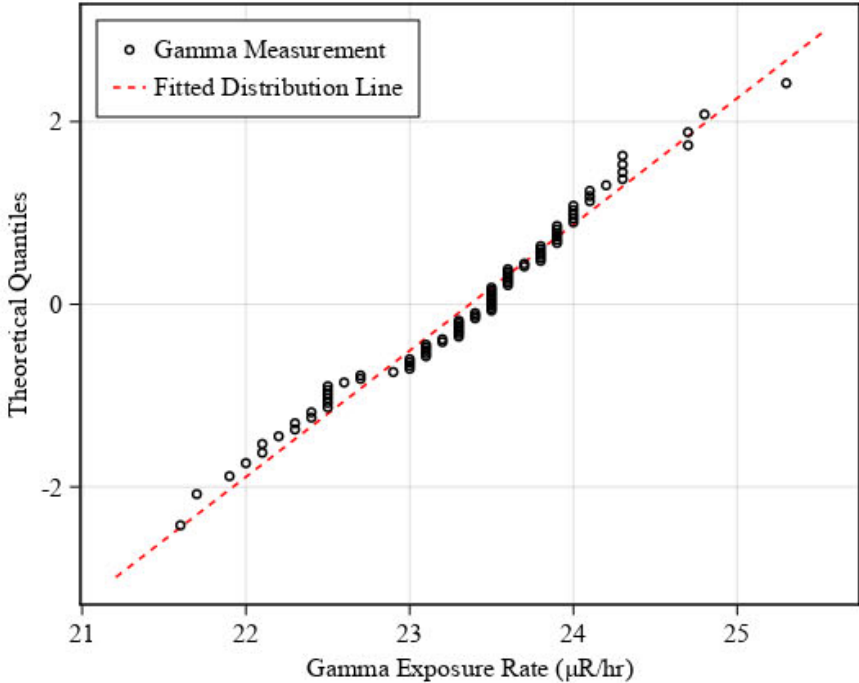
Box Plot



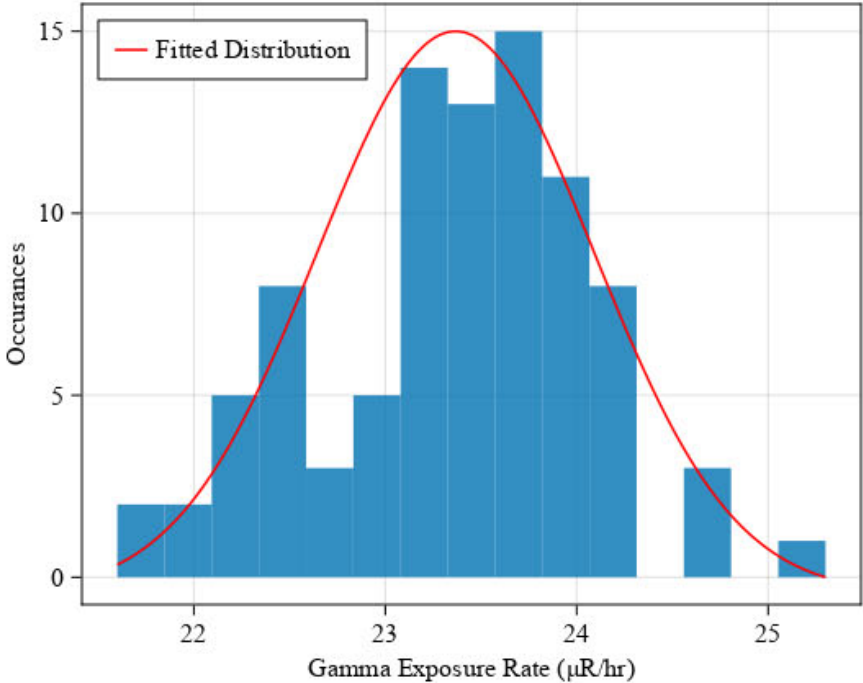
Violin Plot



Probability Plot



Histogram



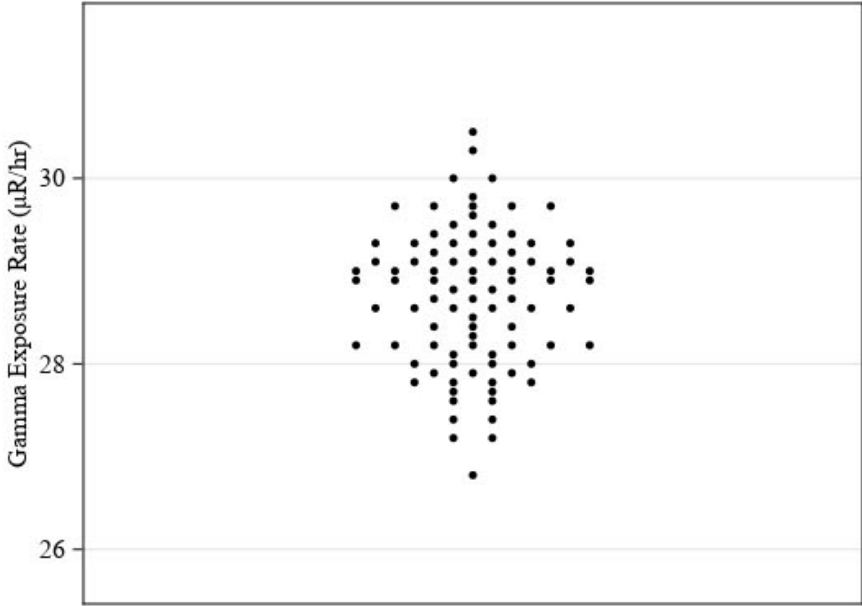
Summary Statistics

Count (n)	90
Minimum (µR/hr)	21.6
Maximum (µR/hr)	25.3
Average (µR/hr)	23.4
Median (µR/hr)	23.5
Standard Deviation (µR/hr)	0.72
Relative Standard Deviation	3.096%
RPD of Mean and Median	0.564%
90th Percentile (µR/hr)	24.2
95th Percentile (µR/hr)	24.3
99th Percentile (µR/hr)	25.3

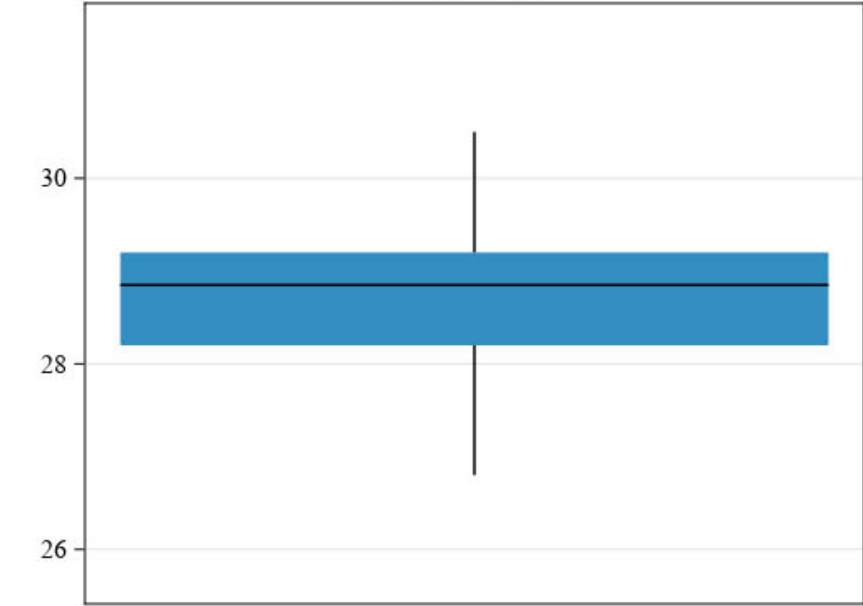
Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR13 Type: High Pressure Ionization Chamber

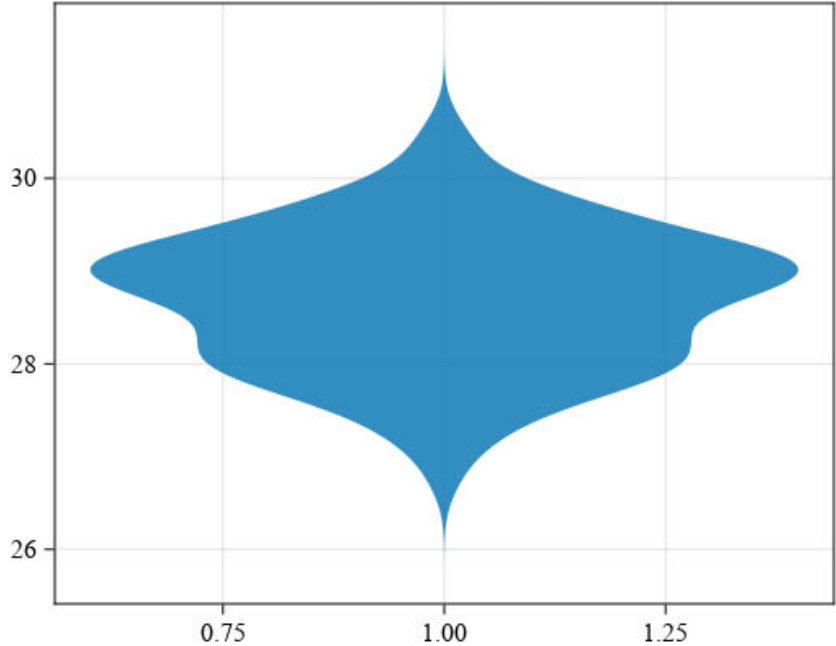
Individual Value Plot



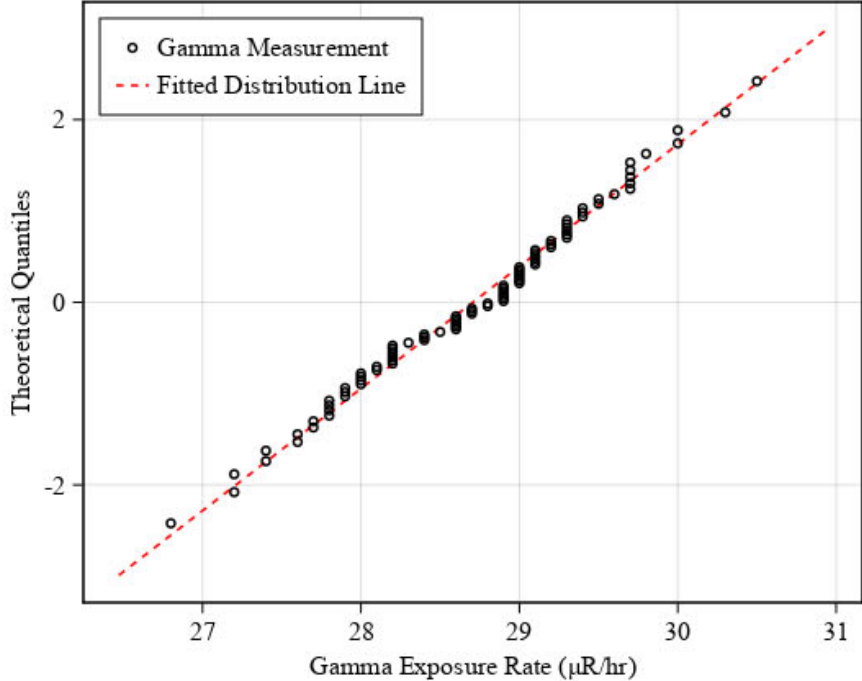
Box Plot



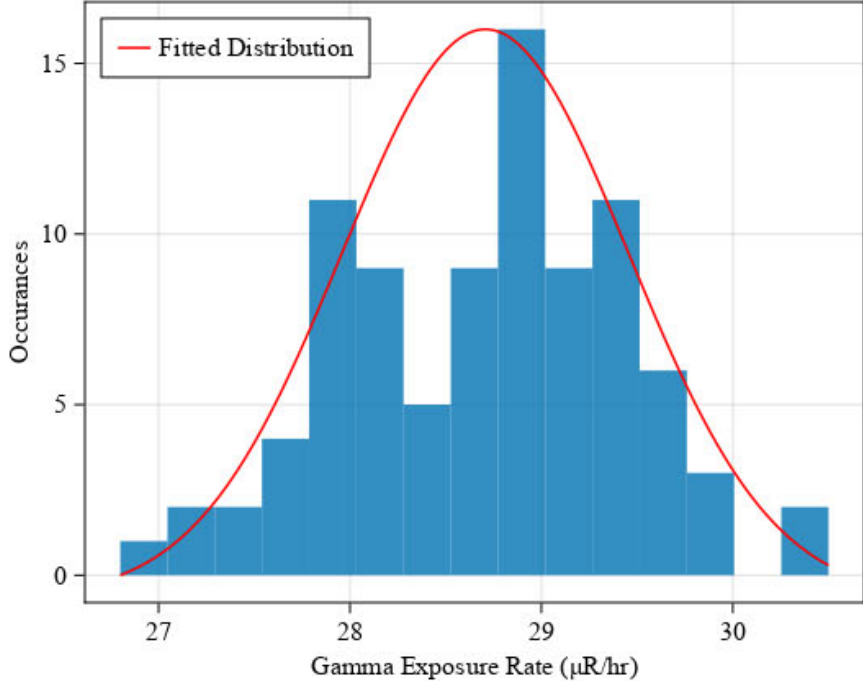
Violin Plot



Probability Plot



Histogram

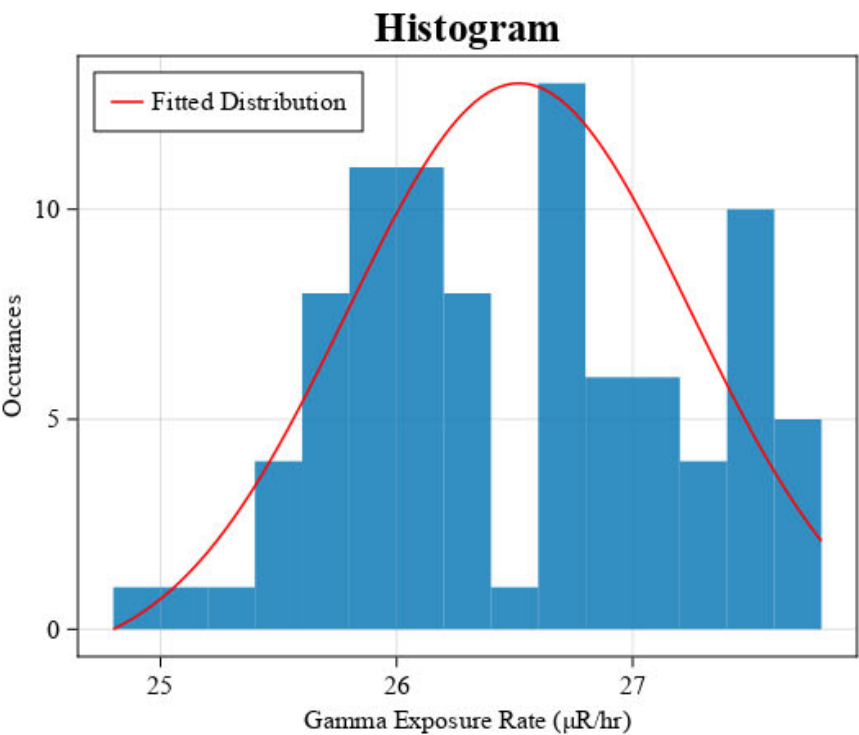
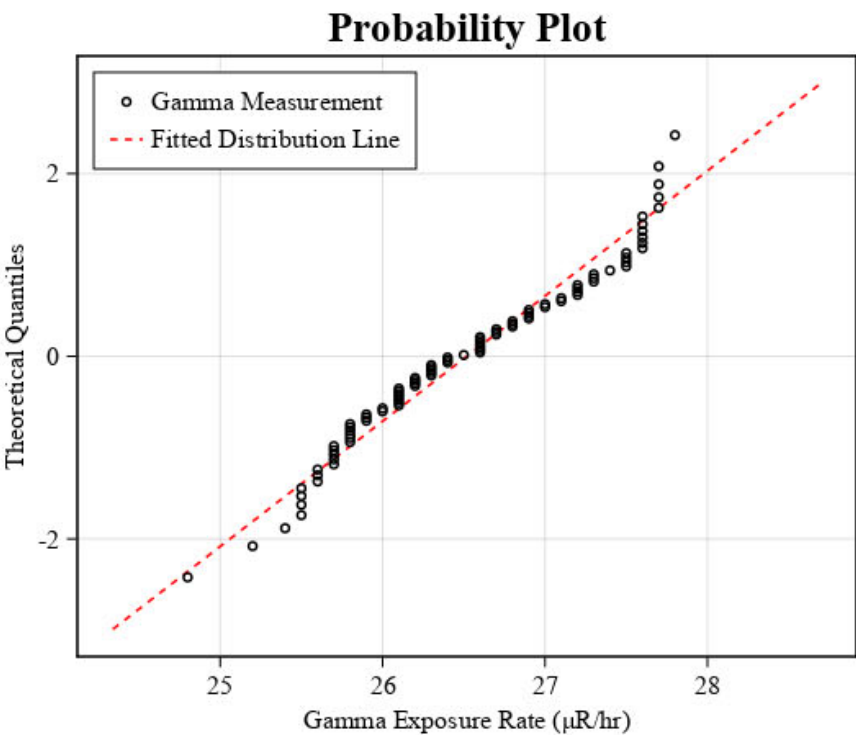
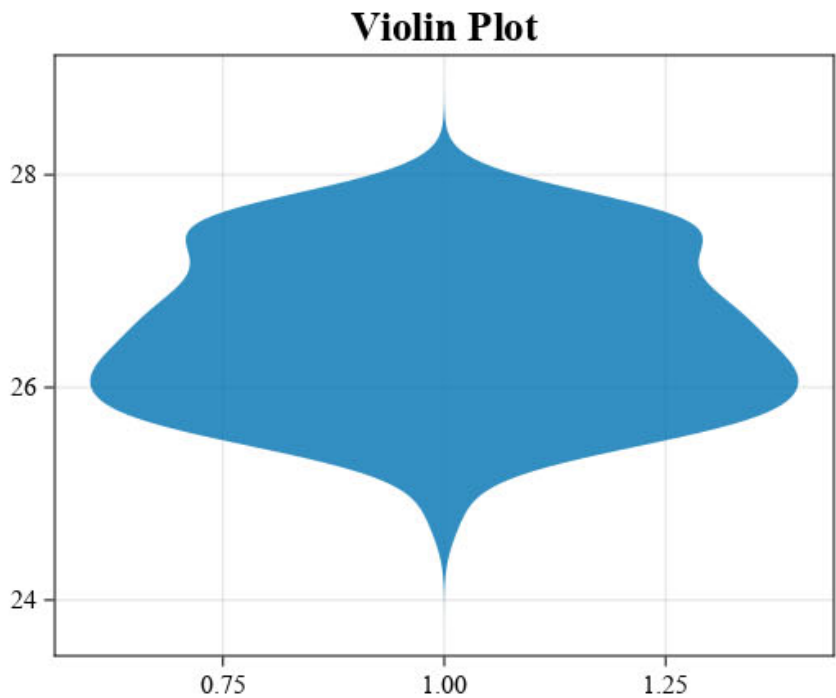
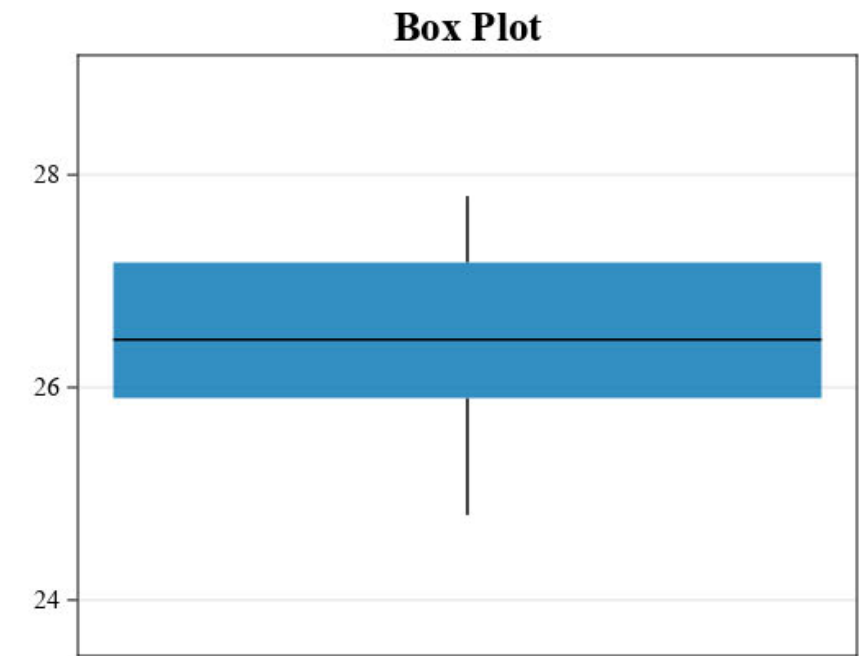
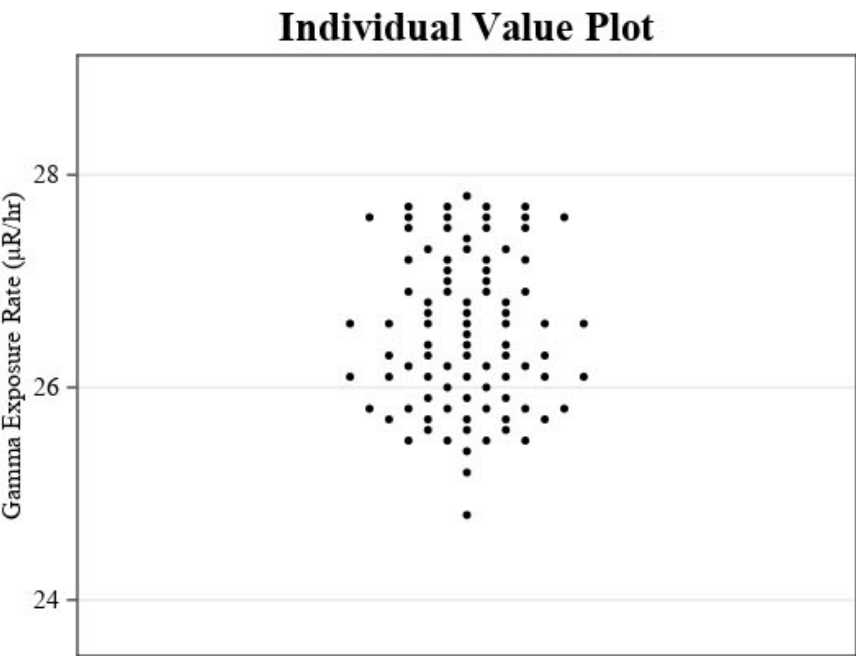


Summary Statistics

Count (n)	90
Minimum (µR/hr)	26.8
Maximum (µR/hr)	30.5
Average (µR/hr)	28.7
Median (µR/hr)	28.8
Standard Deviation (µR/hr)	0.75
Relative Standard Deviation	2.605%
RPD of Mean and Median	0.498%
90th Percentile (µR/hr)	29.7
95th Percentile (µR/hr)	29.8
99th Percentile (µR/hr)	30.5

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR14 Type: High Pressure Ionization Chamber

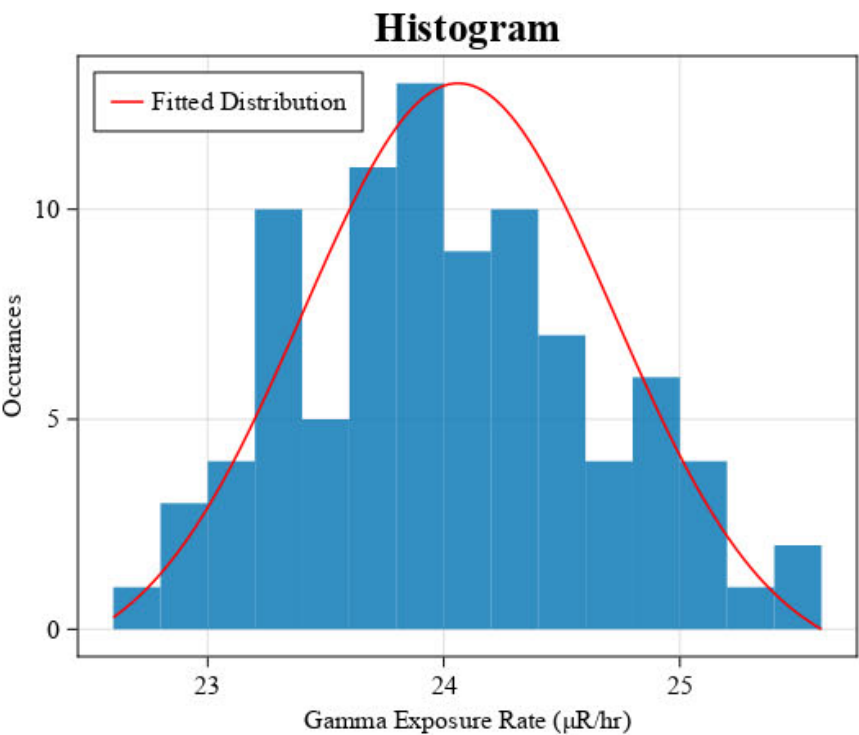
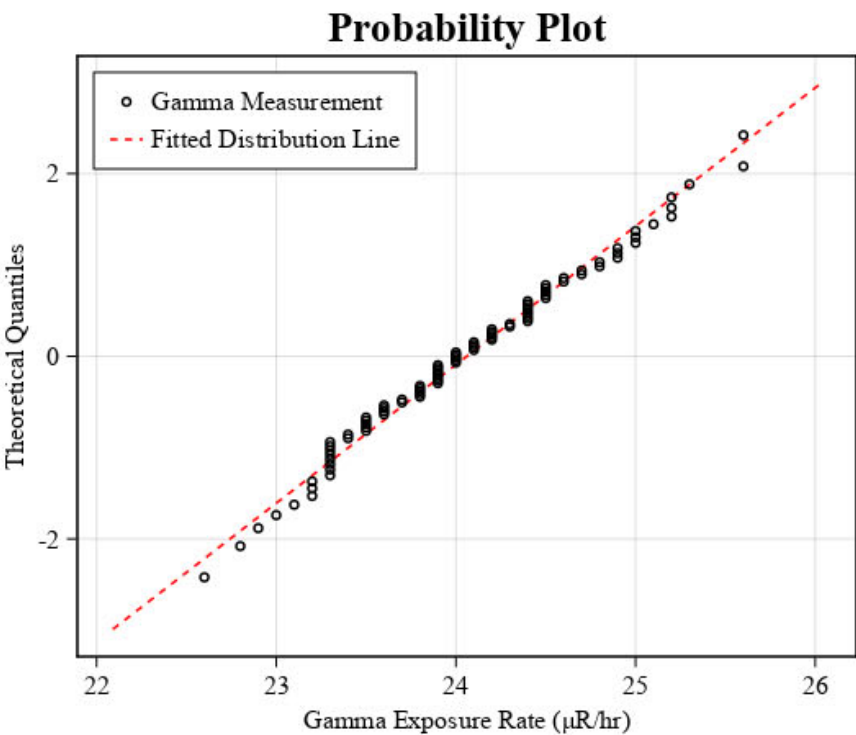
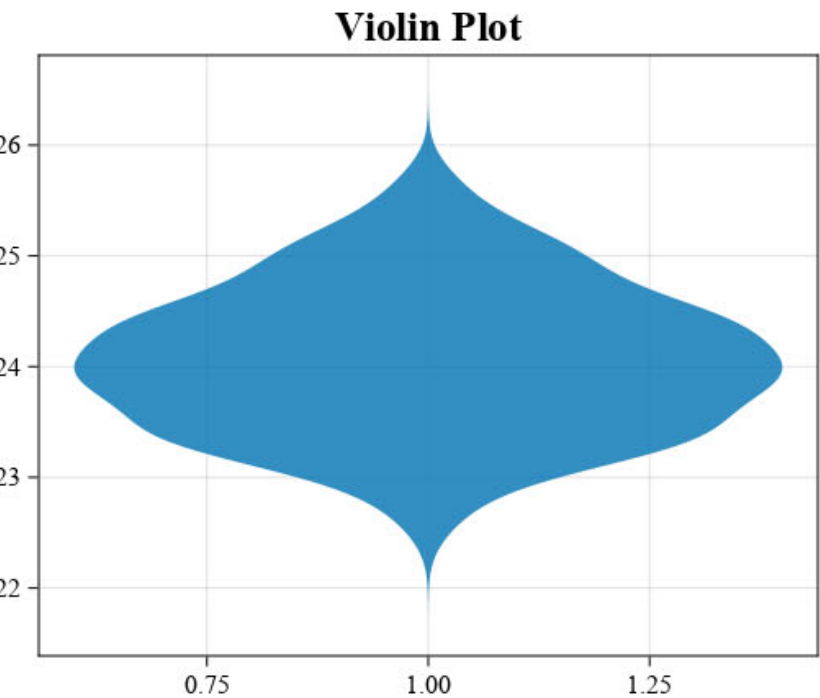
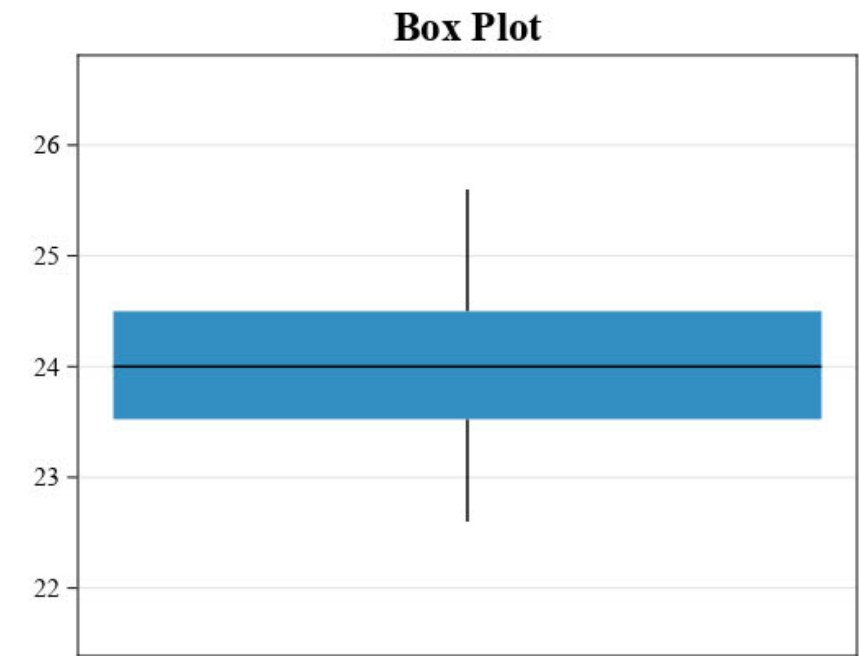
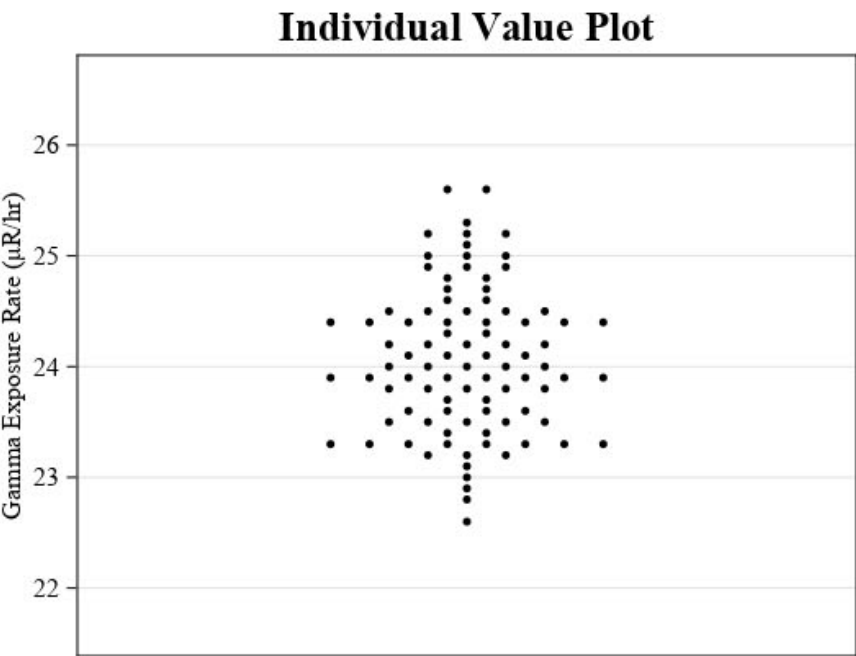


Summary Statistics

Count (n)	90
Minimum (µR/hr)	24.8
Maximum (µR/hr)	27.8
Average (µR/hr)	26.5
Median (µR/hr)	26.4
Standard Deviation (µR/hr)	0.73
Relative Standard Deviation	2.75%
RPD of Mean and Median	0.26%
90th Percentile (µR/hr)	27.6
95th Percentile (µR/hr)	27.7
99th Percentile (µR/hr)	27.8

Summary Statistics - Correlation Plots

Site: OCRM Plot ID: CORR15 Type: High Pressure Ionization Chamber



Summary Statistics

Count (n)	90
Minimum (µR/hr)	22.6
Maximum (µR/hr)	25.6
Average (µR/hr)	24.1
Median (µR/hr)	24.0
Standard Deviation (µR/hr)	0.66
Relative Standard Deviation	2.74%
RPD of Mean and Median	0.254%
90th Percentile (µR/hr)	25.0
95th Percentile (µR/hr)	25.2
99th Percentile (µR/hr)	25.6