8. Quality Assurance

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Quality assurance (QA) is a system of activities and processes put in place to ensure that products or services meet or exceed customer specifications. Quality control (QC) consists of activities used to verify that deliverables are of acceptable quality and meet criteria established in the quality planning process.

8.1 Quality Assurance Activities

Nonconformance reporting and tracking is a formal process used to ensure that problems are identified, resolved, and prevented from recurring. The LLNL Environmental Functional Area (EFA) and Environmental Restoration Department (ERD) track problems using the LLNL Institutional Tracking System (ITS). ITS items are initiated when items or activities are identified that do not comply with procedures or other documents that specify requirements for EFA operations or that cast doubt on the quality of regulatory reports, integrity of samples, or data, and that are not covered by other reporting or tracking mechanisms. Nonconformances involving the EFA are captured and used to provide trending information for environmental compliance evaluations. There were no laboratory data nonconformances affecting the quality of data used for reporting purposes documented in 2013. Many minor sampling or data problems are resolved without generating an ITS item. The LLNL quality assurance requirements stipulate that laboratories generating data must have a formal nonconformance program to track and document issues in their analyses. Such programs are separate from the LLNL Institutional Tracking System.

LLNL averts sampling problems by requiring formal and informal training on sampling procedures. Errors that occur during sampling generally do not result in lost samples but may require extra work on the part of laboratory or sampling and data management personnel to correct the errors.

LLNL addresses commercial analytical laboratory problems as they arise. Many of the documented problems concern minor documentation errors and are corrected soon after they are identified. Other problems, such as missed holding times, late analytical results, incorrect analysis and typographical errors on data reports, account for the remaining issues and are not tracked as nonconformances. These problems are corrected by the commercial laboratory reissuing reports or correcting paperwork and do not affect associated sample results.

LLNL participates in the Department of Energy Consolidated Auditing Program (DOECAP). Annual on-site visits to commercial laboratories under contract to LLNL are part of the auditing program to ensure that accurate and defensible data are generated. The audit program is based on DOECAP requirements under The NELAC Institute (TNI). All commercial laboratories used by LLNL are LLNL-qualified vendors and are National Environmental Laboratory Accreditation Program (NELAP) certified or California Department of Health Services Environmental laboratory accredited. Audit reports, checklists, and Corrective Action Plans are maintained under the DOECAP program for commercial labs.

The following six areas pertain to the services provided by a particular external analytical laboratory:

- QA management systems and general laboratory practices
- Organic analyses
- Inorganic and wet chemistry analyses
- Radiochemical analyses
- Laboratory information management systems and electronic deliverables
- Hazardous and radioactive materials management

LLNL has qualified auditors under the national DOECAP program in the areas of quality assurance, organic chemistry, inorganic chemistry, laboratory information management, and hazardous material management.

In FY2013, the laboratories certified by the State of California operating at LLNL as government owned and contractor operated were not internally assessed, but are by the State of California under the Environmental Laboratory Accreditation Program (ELAP).

Analytical laboratories routinely perform QC tests to document and assess the quality and validity of their sample results. Each set of data received from the analytical laboratory is systematically evaluated and compared to establish measurement-quality objectives before the results can be authenticated and accepted into the monitoring database. Categories of measurement quality objectives include accuracy, precision, and comparability. When possible, quantitative criteria are used to define and assess data quality.

8.2 Analytical Laboratories and Laboratory Intercomparison Studies

In 2013, LLNL had Blanket Service Agreements (BSAs) with seven commercial analytical laboratories. All analytical laboratory services used by LLNL are provided by facilities certified by the State of California. LLNL works closely with these analytical laboratories to minimize problems and ensure that QA/QC objectives are maintained.

LLNL uses the results of nationally recognized intercomparison performance evaluation program data to identify and monitor trends in performance and to draw attention to the need to improve laboratory performance. If a laboratory performs unacceptably for a particular test in two consecutive performance evaluation studies, LLNL may stop work and select another laboratory to perform the affected analyses until the original laboratory has demonstrated that the problem has been corrected. If an off-site laboratory continues to perform unacceptably or fails to prepare and implement acceptable corrective action responses, the LLNL Procurement Department formally notifies the laboratory of its unsatisfactory performance. If the problem persists, the off-site laboratory’s BSA could be terminated for that test. If an on-site laboratory continues to perform unacceptably, use of that laboratory could be suspended until the problem is corrected. In

2013, all contracted commercial labs were successful in participation in performance evaluation studies and where there were individual failures to perform, the commercial labs were verified to have corrective actions in place.

Although laboratories are also required to participate in laboratory intercomparison programs, permission to publish their accreditation results for comparison purposes was not granted for 2013. To obtain DOE Mixed Analyte Performance Evaluation Program (MAPEP) reports that include the results from all participating laboratories, see http://www.inl.gov/resl/mapep/reports.html. MAPEP is a DOE program and the results are publicly available from laboratories that choose to participate.

8.3 Duplicate Analyses

Duplicate (collocated) samples are distinct samples of the same matrix collected as closely as possible to the same point in space and time. Collocated samples that are processed and analyzed by the same laboratory provide information about the precision of the entire measurement system, including sampling, homogeneity, handling, shipping, storage, preparation, and analysis. Collocated samples that are processed and analyzed by different laboratories provide information about the precision of the entire measurement system that also captures interlaboratory variation (U.S. EPA 1987). Collocated samples may also identify errors such as mislabeled samples or data entry errors. **Tables 8-1**, **8-2**, and **8-3** present summary statistics for collocated sample pairs, grouped by sample matrix and analyte. Samples from both the Livermore Site and Site 300 are included. **Tables 8-1** and **8-2** are based on data pairs in which both values are above the analytical contract reporting limit (referred to as "detections"); see **Section 8.4**). **Table 8-3** is based on data pairs in which either or both values are below the analytical contract reporting limit (referred to as nondetections).

Table 8-1. Quality assurance collocated sampling: Summary statistics for analytes with more than eight pairs in which both results were above the reporting limit.

Media	Analyte	N [a]	%RSD [b]	Slope	r^2 [c]	Intercept
Air	Gross alpha [d]	18	27.2	0.737	0.26	1.46×10^{-5} Bq/m^3
Air	Gross beta	52	14.7	0.881	0.85	3.17×10^{-5} Bq/m^3
Air	Beryllium	16	11.2	1.21	0.93	-1.08 pg/m^3
Air	Uranium 235 by mass measurement	12	4.25	1.13	1	-1.4×10^{-8} µg/m^3
Air	U238 by mass	12	5.35	1.13	1	-1.84×10^{-6} µg/m^3
Air	Tritium	26	24.2	0.895	0.83	0.00107 Bq/m^3
Direct radiation	90 day Rad dose	32	3.56	1	0.89	0.108 mrem
Groundwater	Gross alpha [d]	12	31	0.72	0.55	0.043 Bq/L
Groundwater	Gross beta [d]	35	39.1	0.627	0.49	0.136 Bq/L
Groundwater	Total Alkalinity (as $CaCO_3$)	9	0	1.02	0.99	-4.96 mg/L
Groundwater	Arsenic	30	17.6	1.11	0.96	-0.0014 mg/L
Groundwater	Barium	15	2.85	1	1	-0.0012 mg/L
Groundwater	Calcium	10	1.39	1	1	-0.0883 mg/L
Groundwater	Chloride	15	0	0.999	1	0.2 mg/L
Groundwater	cis-1,2-Dichloroethene [e]	16	11	1.68	0.98	-16.5 µg/L

Table 8-1(cont.). Quality assurance collocated sampling: Summary statistics for analytes with more than eight pairs in which both results were above the reporting limit.

Media	Analyte	N (a)	%RSD (b)	Slope	r^2 (c)	Intercept
Groundwater	1,2-Dichloroethene (total) (e)	13	17.5	1.7	0.99	-23.1 µg/L
Groundwater	Fluoride	16	5.42	0.984	0.99	-0.00451 mg/L
Groundwater	Magnesium	10	1.22	1.02	1	-0.264 mg/L
Groundwater	Nitrate (as NO3)	72	11.2	1.02	0.99	-0.0344 mg/L
Groundwater	Perchlorate	23	6.27	1.05	0.99	-0.943 µg/L
Groundwater	pH	13	0.808	0.986	0.92	0.103 Units
Groundwater	Potassium	15	1.28	1.06	0.99	-0.421 mg/L
Groundwater	Selenium	10	14.6	1.28	0.86	-0.000537 mg/L
Groundwater	Sodium	16	1.89	1.01	0.99	-1.58 mg/L
Groundwater	TDS	10	4.97	0.907	0.97	69.5 mg/L
Groundwater	Specific Conductance	13	1	0.985	1	17.2 µmhos/cm
Groundwater	Sulfate	15	0	0.999	1	0.325 mg/L
Groundwater	Total Hardness (as CaCO3)	9	1.4	1.01	1	-1.25 mg/L
Groundwater	Trichloroethene	70	8.57	1.1	1	-55.1 µg/L
Groundwater	Tritium	26	6.88	1.03	1	-2.78 Bq/L
Groundwater	U234+U233	21	10.4	0.887	1	0.0101 Bq/L
Groundwater	U235	14	36.8	0.991	0.9	0.00168 Bq/L
Groundwater	U238	21	10.7	0.911	1	0.00414 Bq/L
Sewer	Gross beta (d)	12	18	0.549	0.18	0.000256 Bq/mL

(a) Number of collocated pairs included in regression analysis.

(b) 75th percentile of percent relative standard deviations (%RSD) where $\%RSD = \left(\frac{200}{\sqrt{2}}\right)\frac{|x_1 - x_2|}{x_1 + x_2}$ and x_1 and x_2 are the reported concentrations of each routine–collocated pair.

(c) Coefficient of determination.

(d) Outside acceptable range of slope or r^2 because of high variability.

(e) Outside acceptable range of slope or r^2 because of outliers.

Table 8-2. Quality assurance collocated sampling: Summary statistics for selected analytes with eight or fewer pairs in which both results were above the reporting limit.

Media	Analyte	N (a)	Minimum ratio	Maximum ratio
Aqueous	Gross alpha	1	0.94	0.94
Aqueous	Gross beta	1	1.2	1.2
Aqueous	Uranium 234 and Uranium 233	1	0.55	0.55
Aqueous	Uranium 235 and Uranium 236	1	0.68	0.68
Aqueous	Uranium 238	1	0.68	0.68
Groundwater	Radium 226	2	0.95	1
Groundwater	Uranium 235 by mass measurement	2	1	1
Groundwater	Uranium 238 by mass measurement	2	1	1
Other water	Gross beta	1	0.98	0.98
Runoff (from rain)	Gross alpha	2	1.7	3.6
Runoff (from rain)	Gross beta	3	0.36	3.4
Runoff (from rain)	Tritium	1	1.4	1.4
Soil	Cesium 137	3	0.86	1
Soil	Potassium 40	3	0.94	1
Soil	Plutonium 239+240	2	1	2
Soil	Radium 226	3	0.95	1
Soil	Radium 228	3	0.94	0.98
Soil	Thorium 228	3	0.87	1

Table 8-2 (cont.). Quality assurance collocated sampling: Summary statistics for selected analytes with eight or fewer pairs in which both results were above the reporting limit.

Media	Analyte	N [(a)]	Minimum ratio	Maximum ratio
Soil	Uranium 235	3	0.7	0.93
Soil	Uranium 238	2	0.79	0.92
Sewer	Tritium	5	0.78	1.2
Vegetation	Tritium	4	0.62	1.6

(a) Number of collocated pairs used in ratio calculations.

Table 8-3. Quality assurance collocated sampling: Summary statistics for analytes with at least four pairs in which one or both results were below the reporting limit.

Media	Analyte	Number of inconsistent pairs [(a)]	Number of pairs	Percent of in-consistent pairs
Air	Gross alpha	1	35	2.9
Groundwater	Barium	1	26	3.8
Groundwater	Nitrate (as NO3)	1	75	1.3
Groundwater	Perchlorate	1	126	0.79
Groundwater	RDX	1	66	1.5
Groundwater	Trichlorofluoromethane	2	223	0.9
Groundwater	Uranium 235 and Uranium 236	2	22	9.1
Groundwater	Uranium 235 and Uranium 236	2	22	9.1

(a) Inconsistent pairs are those for which one of the results is more than twice the reporting limit of the other.

When there were nine or more data pairs with both results in each pair considered detections, precision and regression analyses were performed; those results are presented in **Table 8-1**. When there were eight or fewer data pairs with both results considered detections, the ratios of the individual data pairs for selected analytes were calculated; the minimum and maximum ratios are given in **Table 8-2**. When either of the results in a pair is considered a nondetection, the other result should be a nondetection or less than two times the reporting limit. **Table 8-3** identifies the sample media and analytes for which at least one pair failed this criterion. Media and analytes with fewer than four pairs are omitted from the table.

Precision is measured by the percent relative standard deviation (%RSD); see the EPA's *Data Quality Objectives for Remedial Response Activities: Development Process*, Section 4.6 (U.S. EPA 1987). Acceptable values for %RSD vary greatly with matrix, analyte, and analytical method; however, lower values represent better precision. The results for %RSD given in **Table 8-1** are the 75th percentile of the individual precision values. Routine and collocated sample results show good %RSD—90% of the pairs have %RSD of 24% or better.

Regression analysis consists of fitting a straight line to the collocated sample pairs. Good agreement is indicated when the data lie close to a line with a slope equal to 1 and an intercept equal to 0, as illustrated in **Figure 8-1**. Allowing for normal analytical and environmental variation, the slope of the fitted line should be between 0.7 and 1.3, and the absolute value of the intercept should be less than the detection limit. The coefficient of determination (r^2) should be greater than 0.8. These criteria apply to pairs in which both results are considered above the detection limit.

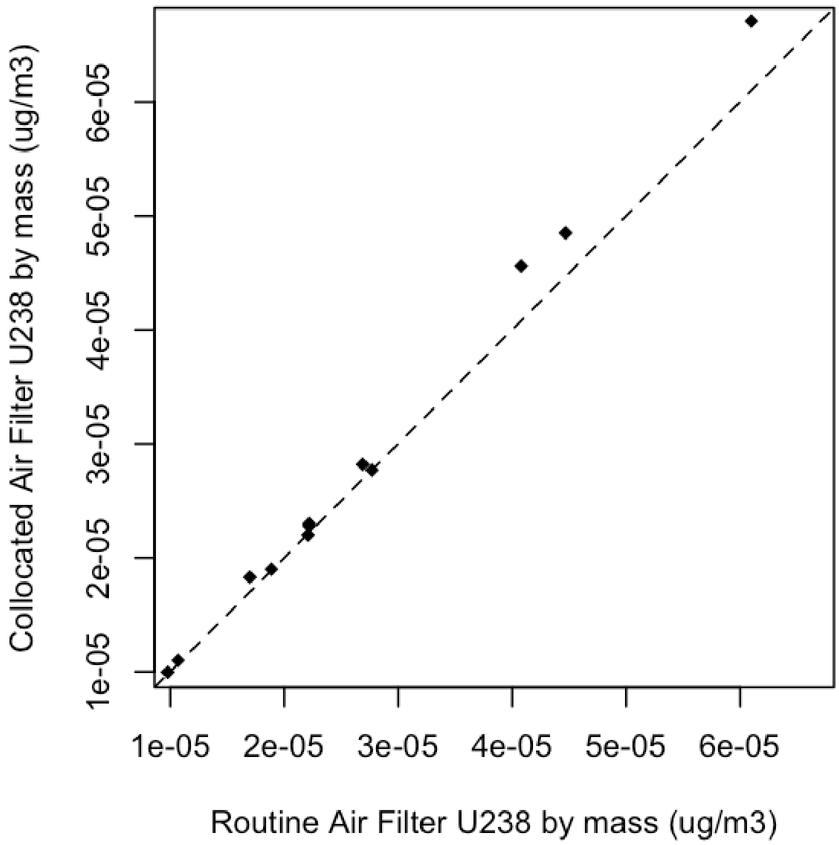

Figure 8-1. Example of good agreement between collocated sample results using uranium-238 concentrations in air.

Collocated sample comparisons are more variable when the members of the pair are analyzed by different methods or with different criteria for analytical precision. For example, radiological analyses using different counting times or different laboratory aliquot sizes will have different amounts of variability. Different criteria are rarely, if ever, used with collocated sample pairs in LLNL environmental monitoring sampling. Different criteria are sometimes used in special studies if more than one agency is involved and each sets its own analytical criteria.

Data sets that do not meet LLNL regression analysis criteria fall into one of two categories: outliers and high variability. Outliers can occur because of data transcription errors, measurement errors, or real but anomalous results. Of the 34 data sets reported in **Table 8-1**, two did not meet the criterion for acceptability because of outliers. **Figure 8-2** illustrates a set of collocated pairs with one outlier.

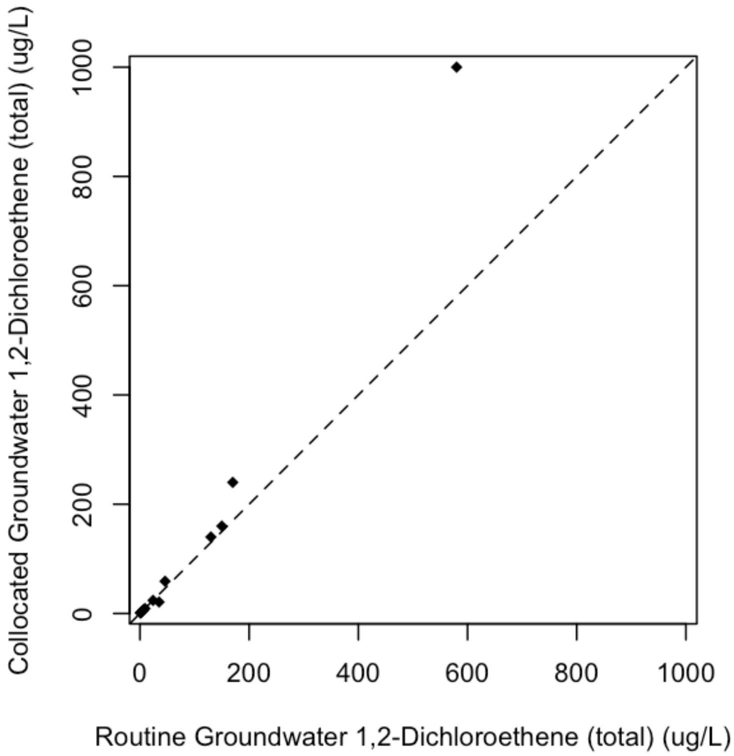

Figure 8-2. Example of data with one outlier using collocated air filter groundwater total 1,2-DCE concentrations.

The second category, high variability, occurs when the measurement process inherently has substantial variability (see **Figure 8-3** for an example). It tends to occur at extremely low environmental concentrations. Low concentrations of radionuclides on particulates in air highlight this effect because a small change in the number of radionuclide-containing particles on an air filter can significantly affect results. Analyses of total organic carbon and total organic halides in water are particularly difficult to control. Of the 34 data sets listed in **Table 8-1**, four show sufficient variability in the results to make them fall outside the acceptable range.

8.4 Data Presentation

The data tables in **Appendix A** were created using computer scripts that retrieve data from a database, convert the data into Système International (SI) units when necessary, calculate summary statistics, format data as appropriate, organize the data into rows and columns, and present a draft table. The tables are then reviewed by the responsible analyst before inclusion in the Appendix. Analytical laboratory data and the values calculated from the data are normally displayed with two, or at most three, significant digits. Significant trailing zeros may be omitted.

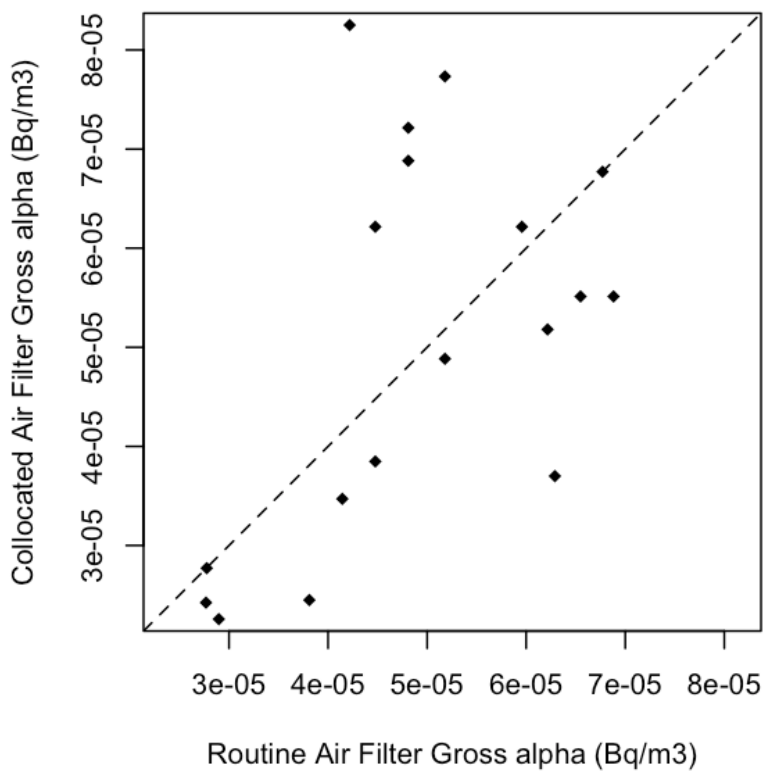

Figure 8-3. Example of high variability using collocated air filter gross alpha concentrations.

8.4.1 Radiological Data

Most of the data tables in **Appendix A** that have radiological data display the result plus or minus (±) an associated 2σ (two sigma) uncertainty. This measure of uncertainty represents intrinsic variation in the measurement process, most of which is due to the random nature of radioactive decay (see **Section 8.6**). The uncertainties are not used in summary statistic calculations. Any radiological result exhibiting a 2σ uncertainty greater than or equal to 100% of the result is considered a nondetection.

Some radiological results are derived from the number of sample counts minus the number of background counts inside the measurement apparatus. In such cases, samples with a concentration at or near background sometimes have more background counts than sample counts, and thus a negative value. Such results are reported in the data tables and used in the calculation of summary statistics and statistical comparisons.

Some data tables provide a limit-of-sensitivity value instead of an uncertainty when the radiological result is below the detection criterion. Such results are displayed with the limit-of-sensitivity value in parentheses.

8.4.2 Nonradiological Data

Nonradiological data reported by the analytical laboratory as being below the reporting limit is displayed in tables with a less-than symbol (<). Reporting limit values are used in the calculation of summary statistics, as explained below.

8.5 Statistical Comparisons and Summary Statistics

Standard statistical comparison techniques such as regression analysis, *t*-tests, and analysis of variance are used where appropriate to determine the statistical significance of trends or differences between means. When a statistical comparison is made, the results are described as either “statistically significant” or “not statistically significant.” Other uses of the word “significant” in this report do not imply that statistical tests have been performed but relate to the concept of practical significance and are based on professional judgment.

Summary statistics are calculated according to Gallegos (2012). The usual summary statistics are the median, which is a measure of central tendency, and interquartile range (IQR), which is a measure of dispersion (variability). However, data tables may present other measures at the discretion of the analyst.

The median indicates the middle of the data set (i.e., half of the measured results are above the median, and half are below). The IQR is the range that encompasses the middle 50% of the data set. The IQR is calculated by subtracting the 25th percentile of the data set from the 75th percentile of the data set. When necessary, the percentiles are interpolated from the data. Different software vendors may use slightly different formulas for calculating percentiles. Radiological data sets that include values less than zero may have an IQR greater than the median. In this report, at least four values are required to calculate the median and at least six values are required to calculate the IQR.

Summary statistics are calculated from values that, if necessary, have already been rounded, such as when units have been converted from picocuries to Becquerels (Bqs), and are then rounded to an appropriate number of significant digits. The calculation of summary statistics may be affected by the presence of nondetections. A nondetection of the form “less than the reporting limit” indicates that no specific measured value is available; instead, the best information available is that the actual value is less than the contract reporting limit. Adjustments to the calculation of the median and IQR for data sets that include such nondetections are described below.

For data sets with all measurements above the reporting limit and radiological data sets that include reported values below the reporting limit, all reported values, including any below the reporting limit, are included in the calculation of summary statistics.

For data sets that include one or more values reported as “less than the reporting limit,” the reporting limit is used as an upper bound value in the calculation of summary statistics.

If the number of values is odd, the middle value (when sorted from smallest to largest) is the median. If the middle value and all larger values are detections, the middle value is reported as the median. Otherwise, the median is assigned a less-than (<) sign.

If the number of values is even, the median is halfway between the middle two values (i.e., the middle two when the values are sorted from smallest to largest). If both of the middle two values and all larger values are detections, the median is reported. Otherwise, the median is assigned a less-than (<) sign.

If any value used to calculate the 25th percentile is a nondetection, or any value larger than the 25th percentile is a nondetection, the IQR cannot be calculated and is not reported.

The median and the IQR are not calculated for data sets with no detections.

8.6 Reporting Uncertainty in Data Tables

Measurement uncertainties associated with results from analytical laboratories are represented in two ways. The first of these, significant digits, derives from the resolution of the measuring device. For example, if an ordinary household ruler with a metric scale is used to measure the length of an object in centimeters, and the ruler has tick marks every one-tenth of a centimeter, the length can reliably and consistently be measured to the nearest tenth of a centimeter (i.e., to the nearest tick mark). An attempt to be more precise is not likely to yield reliable or reproducible results because it would require a visual estimate of a distance between tick marks. The appropriate way to report a measurement using this ruler would be, for example, 2.1 cm, which would indicate that the "true" length of the object is nearer to 2.1 cm than to 2.0 cm or 2.2 cm (i.e., between 2.05 and 2.15 cm). A measurement of 2.1 cm has two significant digits. Although not stated, the uncertainty is considered to be ± 0.05 cm. A more precise measuring device might be able to measure an object to the nearest one-hundredth of a centimeter; in that case a value such as "2.12 cm" might be reported. This value would have three significant digits and the implied uncertainty would be ± 0.005 cm. A result reported as "3.0 cm" has two significant digits. That is, the trailing zero is significant and implies that the true length is between 2.95 and 3.05 cm—closer to 3.0 than to 2.9 or 3.1 cm.

When performing calculations with measured values that have significant digits, all digits are used. The number of significant digits in the calculated result is the same as that of the measured value with the fewest number of significant digits.

Most unit conversion factors do not have significant digits. For example, the conversion from milligrams to micrograms requires multiplying by the fixed (constant) value of 1,000. The value 1,000 is exact; it has no uncertainty and therefore the concept of significant digits does not apply.

The second method of representing uncertainty is based on random variation. For radiological measurements, there is variation due to the random nature of radioactive decay. As a sample is measured, the number of radioactive decay events is counted and the reported result is calculated from the number of decay events that were observed. If the sample is recounted, the number of decay events will almost always be different because radioactive decay events occur randomly. Uncertainties of this type are reported as 2σ uncertainties. A 2σ uncertainty represents the range of results expected to occur approximately 95% of the time if a sample were to be recounted many times. A radiological result reported as, for example, "2.6 ± 1.2 Bq/g," would indicate that with approximately 95% confidence, the "true" value is in the range of 1.4 to 3.8 Bq/g (i.e., 2.6 – 1.2 = 1.4 and 2.6 + 1.2 = 3.8). When necessary, results are converted from pCi to Bq by multiplying by 0.037; this introduces additional digits that are not significant and should not be shown in data tables (for example, 5.3 pCi/g × 0.037 Bq/pCi = 0.1961 Bq/g). The initial value, 5.3, has two significant digits, so the value 0.1961 would be rounded to two significant digits, that is, 0.20.

However, the rounding rule changes when there is a radiological uncertainty associated with a radiological result. In this case, data are presented according to the method recommended in Multi-Agency Radiological Laboratory Analytical Protocols (MARLAP) Section 19.3.7 (U.S. NRC/U.S. EPA 2004). First the uncertainty is rounded to the appropriate number of significant digits, after which the result is rounded to the same number of decimal places. For example, suppose a result and uncertainty after unit conversion are 0.1961 ± 0.05436, and the appropriate number of significant digits is two. First, 0.05436 is rounded to 0.054 (two significant digits). 0.054 has three decimal places, so 0.1961 is then rounded to three decimal places, i.e., 0.196. These would be presented in the data tables as 0.196 ± 0.054.

When rounding a value with a final digit of "5," the software used to prepare the data tables implements the ISO/IEC/IEEE 60559:2011 rule, which is "go to the even digit." For example, 2.45 would be rounded down to 2.4, and 2.55 would be rounded up to 2.6.

The software that prepares the data tables pays careful attention to the details of rounding for significant digits. It should be noted, however, that these details are of little practical significance. For example, if a result of 5.6 is incorrectly rounded to 5.5 or 5.7, the introduced "error" is less than 2% (0.1/5.6 = 0.018). Such an error will rarely have any impact on the interpretation of the data with respect to human health or environmental impact.

8.7 Quality Assurance Process for the Environmental Report

Unlike the preceding sections, which focused on standards of accuracy and precision in data acquisition and reporting, this section describes the actions that are taken to ensure the accuracy of this data-rich environmental report, the preparation of which involves many operations and many people. The key elements that are used to ensure accuracy are described below.

Analytical laboratories send reports electronically, which are loaded directly into the database. This practice should result in perfect agreement between the database and data in printed reports from the laboratories. In practice, however, laboratory reporting is not perfect, so the EFA and ERD Data Management Teams (DMTs) carefully check incoming data throughout the year to make sure that electronic and printed reports from the laboratories agree. This aspect of QC is essential to the report's accuracy. Because of this ongoing QC of incoming data, data stored in the database and used to prepare the annual environmental report tables are unlikely to contain errors.

As described in **Section 8.4**, scripts are used to pull data from the database directly into the format of the table, including unit conversion and summary statistic calculations. All of the data tables contained in **Appendix A** were prepared for this report in this manner. For these tables, it is the responsibility of the appropriate analyst to check each year that the table is up-to-date (e.g., new locations/analytes added, old ones removed), that the data agree with the data he or she has received from DMT, and that the summary calculations have been done correctly.

For this 2013 environmental report, LLNL staff checked tables and figures in the body of the report. Forms to aid in the QC of tables and figures were distributed along with the appropriate figure, table, and text, and a coordinator kept track of the process. Items that were checked included clarity and accuracy of figure captions and table titles; data accuracy and completeness; figure labels and table headings; units; significant digits; and consistency with text. Completed QC forms and the corrected figures or tables were returned to the report editor, who, in collaboration with the responsible author, ensured that corrections were made.

There are multiple levels of document review performed to ensure the accuracy and clarity of this report. Authors, technical and scientific editors and DOE LSO all participate in multiple review cycles throughout document production.

8.8 Errata

Appendix E contains the protocol for errata in LLNL *Environmental Reports* and the errata for *LLNL Site Annual Environmental Report 2012*.