8. Quality Assurance

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Quality assurance (QA) is a system of activities and processes that ensure products or services meet or exceed customer specifications. Quality control (QC) consists of activities that verify deliverables are of acceptable quality and meet criteria established in the quality planning process. This chapter describes the QA program used when collecting and analyzing data in this report, lists the environmental analytical laboratories and waste management facilities Lawrence Livermore National Laboratory (LLNL) used in 2022, and describes how the data tables in **Appendix A** were developed.

8.1 Quality Assurance Program Description

The LLNL Institutional QA section of the Mission Assurance department is responsible for developing, implementing, and assessing the institutional aspects of the quality management system. The LLNL Environmental Functional Area (EFA) is responsible for developing, implementing, and assessing the institutional Environmental Management System (EMS). Within the EFA, the Water Resources and Environmental Planning (WREP) group is responsible for developing the Environmental Monitoring Plan (EMP, Brunckhorst 2019) and this report. The Technical Services Department (TSD) implements the EMP.

The key documents of the EFA quality management system are illustrated by the diagram in **Figure 8.1** and highlighted in bold blue font. The primary interaction between the EFA QA Project Plan (QAPP) and the institutional EMS relates to the EMP and this report. The EMS credits the EMP with implementing the monitoring, measurement, analysis, and evaluation requirements of International Organization for Standardization (ISO) 14001. The EMS also credits this report with implementing the external communication requirements of ISO 14001.

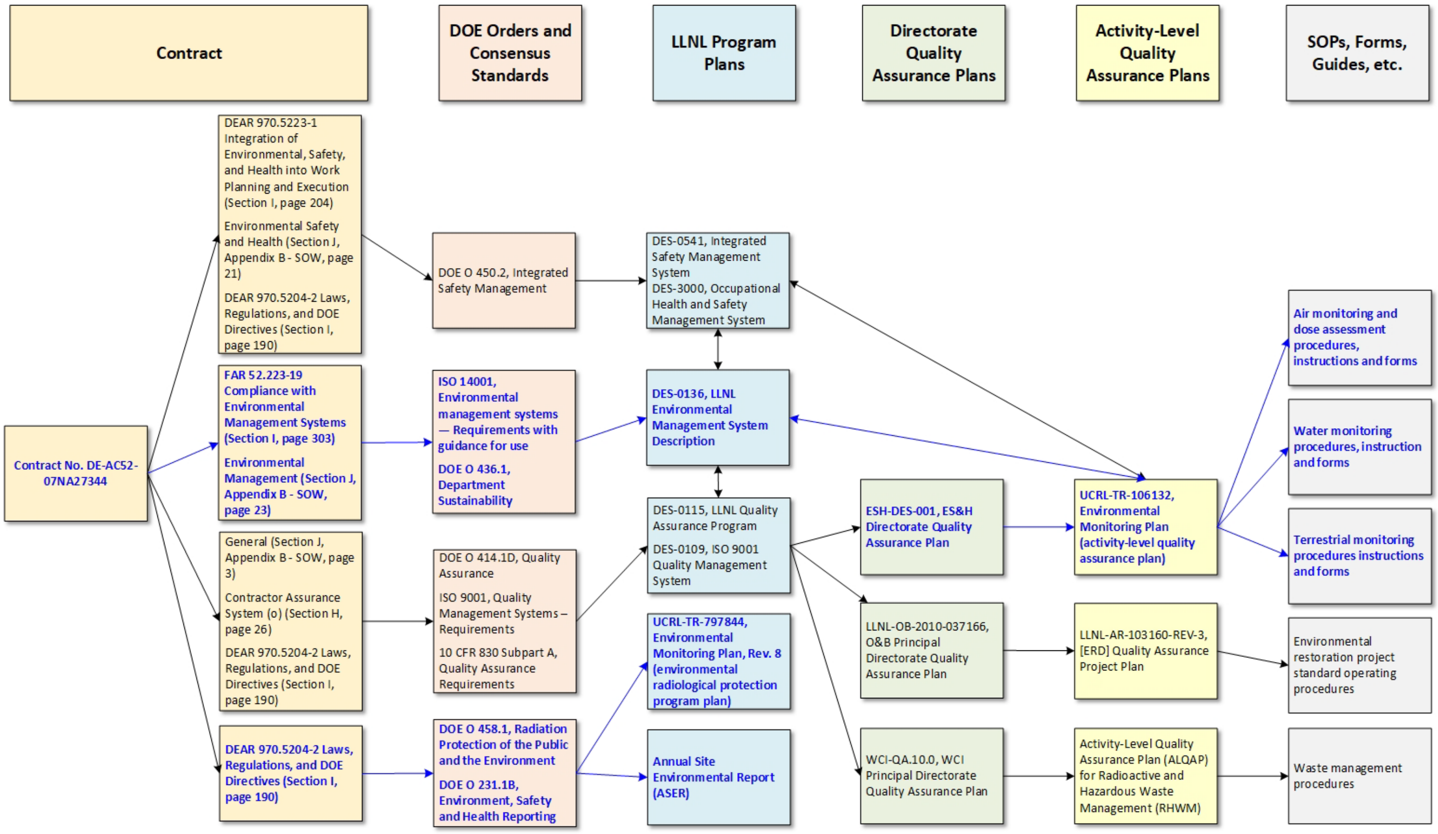

Figure 8.1. Quality Assurance Documents for ASER Work Processes

The QAPP is designed around the Plan – Do – Check – Act model (**Figure 8.2**) consistent with the United States Environmental Protection Agency (EPA) *Environmental Information Quality Policy* (CIO 2105.3) and its implementing procedure (CIO 2105-P-01.3), and with both ISO 14001 and ISO 9001 international standards for environmental and quality management systems.

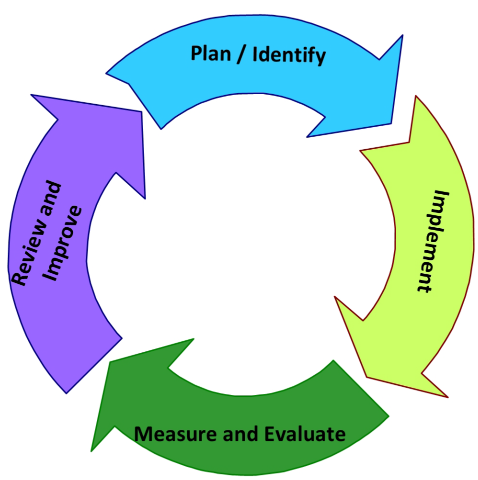

Figure 8.2. Plan – Do – Check – Act Model

This cycle can be described as follows:

- Plan and Identify
  - Establish the objectives of EFA compliance and monitoring systems.
  - Assure the required resources are available to deliver results in accordance with LLNL policies and Department of Energy (DOE) and stakeholder requirements.
  - Identify and address risks and opportunities.
- Implement
  - Implement what was planned in accordance with established work control documents.
- Measure and Evaluate
  - Monitor and compare the resulting work products and services against policies, objectives, requirements, and planned activities.
  - Report the results (e.g., management assessments, external assessments, or inspections.)
- Review and Improve
  - As needed, take actions to improve performance (e.g., revise and update plans and work control documents based on lessons learned.)

Nonconformance reporting and tracking is a formal process used to ensure that problems are identified, resolved, and prevented from recurring. The LLNL EFA tracks problems using the LLNL DevonWay Issues Tracking System (ITS). ITS items are initiated when potential compliance issues are identified.

Nonconformances identified by EFA are captured and used to provide trending information for environmental compliance evaluations. Many minor sampling or data problems are resolved without generating an ITS item. The LLNL QA 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 ITS.

LLNL avoids sampling problems by requiring formal and informal training on sampling procedures. Errors that occur during sampling generally do not result in lost samples. However, this may require extra work for laboratory, sampling, and data management personnel to correct sampling errors.

The LLNL environmental data QA program is generally consistent with the *Uniform Federal Policy (UFP) for Implementing Environmental Quality Systems* (2005) and is designed to ensure that:

- Environmental data are of known and documented quality and suitable for their intended uses.
- Environmental data collection and technology programs meet stated requirements.

Most of the monitoring networks described in this report were planned and developed prior to issuance of EPA QA/G-4, *Guidance on Systematic Planning Using the Data Quality Objectives Process* (2006). The data quality objectives process and the Visual

Sample Plan (VSP) software tools are used to develop new sampling plans, especially those related to site infrastructure improvements.

8.2 Analytical Laboratories

LLNL addresses commercial analytical laboratory problems as they arise. Many of the problems concern minor documentation errors and are corrected once 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 impact sample results.

In 2022, LLNL had Blanket Service Agreements (BSAs) with seven commercial analytical laboratories; five of these laboratories were utilized in 2022. Additionally, LLNL secured commercial analytical laboratory services via purchase order and worked with three in-house LLNL laboratory organizations in 2022. **Table 8-1** identifies the scope of services provided by both commercial and in-house laboratories in 2022.

Table 8-1. Commercial and On-Site Laboratories Utilized in 2022

Contract No.	Laboratory	Scope of Services
H100596	Pace Bakersfield Laboratory[1] Bakersfield, CA 93308	Analysis of non-radiologically contaminated environmental samples
H100621	Eurofins TestAmerica Arvada, CO 80002	Analysis of non-radiologically contaminated environmental samples
H100719	Alpha Analytical Laboratories Livermore, CA 94551	Analysis of non-radiologically contaminated environmental samples
H100570	GEL Laboratories, LLC Charleston, SC 29407	Analysis of potentially radiologically contaminated environmental samples and radiological analysis of environmental samples
H100571	ALS Environmental[2] Fort Collins, CO 80524	Analysis of potentially radiologically contaminated environmental samples and radiological analysis of environmental samples
In-house LLNL Organization	Analytical Laboratory (ALAB) Livermore, CA 94550	Analysis of non-radiologically contaminated environmental samples
In-house LLNL Organization	Environmental Monitoring Radiological Laboratory (EMRL) Livermore, CA 94550	Radiological analysis of environmental samples
In-house LLNL Organization	Radiological Measurements Laboratory (RML) Livermore, CA 94550	Radiological analysis of environmental samples

[1] BC Laboratories was acquired by Pace in 2022.

[2] ALS Environmental in Fort Collins, CO discontinued operations in 2022.

8.2.1 Analytical Laboratory Accreditations and Proficiency Demonstrations

All commercial 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. **Table 8-2** provides the certifications and accreditations held by laboratories used by LLNL in 2022.

Table 8-2. Laboratory Certifications and Accreditations in 2022

Laboratory	Certifications/Accreditations
Pace Analytical Services, LLC	Certificate of Environmental Accreditation, California State Environmental Laboratory Accreditation Program (ELAP) Certified to meet the requirements of Nevada Administrative Code, NAC 445A, by the State of Nevada Department of Conservation and Natural Resources Division of Environmental Protection Perry Johnson Laboratory Accreditation, Inc., accredited for meeting the requirements of ISO/International Electrotechnical Commission (IEC) 17025:2017 "General Requirements for the competence of Testing and Calibration Laboratories" and the DOE Quality Systems Manual (QSM) for Environmental Laboratories Version 5.4, October 2021
Eurofins TestAmerica - Denver	American Association for Laboratory Accreditation (A2LA) accredited for compliance with ISO/IEC 17025:2017, The NELAC Institute (TNI) 2009 and 2016 Environmental Testing Laboratory Standard, the requirements of the Department of Defense (DoD ELAP), and the requirements of the Department of Energy Consolidated Audit Program (DOECAP) as detailed in Version 5.4 of the DoD/DOE QSM for Environmental Laboratories Certificate of Environmental Accreditation, California ELAP Certified to meet the requirements of Nevada Administrative Code, NAC 445A, by the State of Nevada Department of Conservation and Natural Resources Division of Environmental Protection
Alpha Analytical Laboratories	Certificate of Environmental Accreditation, California ELAP
GEL Laboratories, LLC	Certificate of Environmental Accreditation, California ELAP A2LA accredited for compliance with ISO/IEC 17025:2017, the 2009 and 2016 TNI Environmental Testing Laboratory Standard, the requirements of the DoD ELAP, and the requirements of the DOECAP as detailed in Version 5.3 of the DoD/DOE QSM Certified to meet the requirements of Nevada Administrative Code, NAC 445A by the State of Nevada Department of Conservation and Natural Resources Division of Environmental Protection South Carolina Department of Health and Environmental Control Radioactive Material License
ALAB	Certificate of Environmental Accreditation, California ELAP
EMRL	Certificate of Environmental Accreditation, California ELAP

Table 8-2. (cont.) Laboratory Certifications and Accreditations in 2022

Laboratory	Certifications/Accreditations
RML	Not currently accredited. Accreditation is not required as data is used only for informational screening of weekly sewer samples not for compliance reporting. Monthly compliance samples are analyzed by EMRL.

LLNL uses the results of nationally recognized inter-laboratory comparison programs to identify and monitor trends in laboratory performance and to highlight any performance deficiencies. 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 a commercial laboratory continues to perform unacceptably or fails to prepare and implement acceptable corrective action responses, the LLNL Supply Chain Management Department formally notifies the laboratory of its unsatisfactory performance. If the problem persists, the commercial laboratory's BSA could be terminated for that test. If an in-house LLNL laboratory continues to perform unacceptably, use of that laboratory could be suspended until the problem is corrected.

Laboratories are required to participate in inter-laboratory comparison programs. DOE Mixed Analyte Performance Evaluation Program (MAPEP) reports that include the results from all participating laboratories can be found here: https://www.id.energy.gov/resl/mapep/mapepreports.html. MAPEP is a DOE program, and the results are publicly available from laboratories that choose to participate. **Table 8-3** provides an overview of the MAPEP results for the two commercial laboratories that provide radiochemical analytical services to LLNL and for one in-house LLNL laboratory. LLNL considers MAPEP results unacceptable when two or more analytes in a field of testing do not meet MAPEP acceptance criteria. Unacceptable results are investigated by LLNL.

Table 8-3. Laboratory Participation in the Mixed Analyte Performance Evaluation Program

Mixed Analyte Performance Evaluation Program	Eurofins TestAmerica – Denver	GEL Laboratories, LLC	EMRL
March 2022			
22-MaS46 – Mixed Analyte Soil Standard	No report	Inorganics acceptable except Sb and Se, radiological acceptable except ^{99}Tc and ^{55}Fe	Radiological acceptable except ^{238}Pu

Table 8-3. (cont.) Laboratory Participation in the Mixed Analyte Performance Evaluation Program

Mixed Analyte Performance Evaluation Program	Eurofins TestAmerica – Denver	GEL Laboratories, LLC	EMRL
22-MaW46 – Mixed Analyte Water Standard		Inorganics and radiological acceptable	Radiological acceptable except ^{3}H, ^{238}Pu, and $^{239/240}Pu$
22-GrW46 – Gross Alpha/Beta Water Standard	No report	Radiological acceptable	Radiological acceptable
22-RdF46 – Radiological Air Filter Standard	No report	Radiological acceptable	Radiological acceptable except ^{57}Co
22-GrF46 – Gross Alpha/Beta Air Filter	No report	Radiological acceptable	No report
22-RdV46 – Radiological Vegetation Standard	No report	Radiological acceptable except ^{90}Sr	No report
22-MaSU46 – Mixed Analyte Synthetic Urine Standard	No report	Radiological acceptable	No report
August 2022			
22-MaS47 – Mixed Analyte Soil Standard	No report	Inorganics acceptable except Sb; radiological acceptable except ^{234}U, ^{235}U, and ^{238}U	Radiological acceptable except ^{134}Cs, ^{57}Co, ^{54}Mn, ^{40}K, and ^{65}Zn
22-MaW47 – Mixed Analyte Water Standard	No report	Inorganics acceptable and radiological acceptable	Radiological acceptable except ^{65}Zn
22-GrW47 – Gross Alpha/Beta Water Standard	No report	Radiological acceptable	Radiological acceptable
22-RdF47 – Radiological Air Filter Standard	No report	Inorganics and radiological acceptable	Radiological acceptable
22-GrF47 – Gross Alpha/Beta Air Filter	No report	Radiological acceptable	No report
22-RdV47 – Radiological Vegetation Standard	No report	Radiological acceptable	No report
22-MaSF47 – Mixed Analyte Synthetic Fecal Standard	No report	Radiological (^{237}Np) unacceptable	No report

8.2.2 Analytical Laboratory Observations, Assessments, and/or Audits

LLNL monitors the DOECAP. All commercial laboratories used by LLNL are qualified vendors and are either certified by the National Environmental Laboratory Accreditation Program (NELAP) or accredited by the California Department of Health Services Environmental Laboratory. Audit reports, checklists, and Corrective Action Plans are maintained under the DOECAP program for commercial labs.

An external analytical laboratory provides the following services:

- 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

Table 8-4 summarizes the results of assessment conducted in 2022.

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

Table 8-4. Laboratory Observations, Assessments and/or Audits in 2022

Laboratory	Accrediting Body	Assessment Type	Results
BC Laboratories	Perry Johnson Laboratory Accreditation, Inc.	Surveillance assessment	0 Major finding 10 Minor findings 1 Observation
Eurofins TestAmerica – Denver	American Association for Laboratory Accreditation	Scope expansion	0 Major findings 7 Minor findings 0 Observations
Alpha Analytical Laboratories – Ukiah	International Accreditation Services	CA ELAP renewal and amendment application	10 Corrective action requests
Alpha Analytical Laboratories – Livermore	International Accreditation Services	ELAP assessment	5 Corrective action requests
GEL Laboratories, LLC	American Association for Laboratory Accreditation	Interim	0 Major findings 1 Minor finding 0 Observations
ALAB	Not third party assessed in 2022	Not applicable	Not applicable
EMRL	International Accreditation Service	External on-site	3 Corrective actions
RML	Not third party assessed in 2022	Not applicable	Not applicable

LLNL reviews deficiencies and non-conformances and investigates corrective actions when they occur in testing utilized by LLNL.

8.2.3 LLNL Environmental and Waste Characterization Program Performance

LLNL monitors the relative percent difference between the results of duplicate sample pairs and the number of completed sample analyses as a percentage of planned analyses. These measures of precision and completeness are described below.

8.2.3.1 Duplicates

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, matrix homogeneity, handling, shipping, storage, preparation, and analysis (U.S. EPA 1987). Collocated samples may also identify inconsistencies such as mislabeled samples or data entry errors. **Appendix E** presents summary statistics for collocated sample pairs from the Livermore Site, Livermore Valley, and Site 300, grouped by sample matrix and analyte. **Appendix E** is based on data pairs where both values are considered "detections." Pairs where relative percent difference (RPD) is calculated are determined by the following criteria:

- Sampled at the same location.
- Sampled at the same time.
- Analyzed for the same method.
- Both routine and duplicate sample values are detected above the reporting limit.
- There are no data flags.

LLNL uses a 30 percent RPD control limit as an indicator of an out-of-control duplicate pair. Therefore, RPD values above 30 percent indicate that there may be some degree of uncertainty regarding the analytical results.

RPD values can represent real differences. For example, a collocated sample had a high concentration in one container (this should be limited through standard sampling procedures) or there was error associated with the analytical method.

RPD values can also represent differences caused by error. For example, error was introduced during field sampling or analysis in the analytical laboratory. An RPD of zero is expected for collocated sampling in a perfect environment with uniform media.

LLNL calculates RPD:

$$RPD = \frac{|R - D|}{\left[\frac{(R + D)}{2}\right]} \, x \, 100$$

R is the routine sample result and D is the duplicate collocated sample result.

Appendix E summarizes the total percentage of in-control pairs for programs, media, and analytes.

8.2.3.2 Completeness

Completeness is a measure of the amount of valid data obtained from a measurement system compared to the amount that was expected to be obtained under normal conditions. **Appendix F** summarizes the percent completeness for many of the data sets described in this report and presented in **Appendix A**. Lower percent completeness values are expected for non-routine monitoring because sampling and analysis for infrastructure projects may be planned but delayed or canceled. For example, event-based stormwater sampling may be planned, but a qualifying storm may not occur.

8.3 Waste Management Facilities

Table 8-5. Waste Management Facilities Utilized by LLNL in 2022

Clean Harbors Aragonite, LLC 11600 North Aptus Road Aragonite, UT 84029	**Clean Harbors Wilmington, LLC** 1737 E. Denni Street Wilmington, CA 90744
Energy Solutions, LLC-UT Clive Disposal Facility 423 West 300 South, Suite 200 Salt Lake City, UT 84116	**Clean Harbors Grassy Mountain, LLC** Interstate 80, Exit 41 3mi. East, 7mi. North of Knolls Grassy Mountain, UT 84029
Perma-Fix Northwest, Inc. 2025 Battelle Blvd. Richland, WA 99354	**Evoqua Water Technologies, LLC** 2430 Rose Place Roseville, MN 55113
Clean Harbors Colfax, LLC 3763 Highway 471 Colfax, LA 71417	**US Ecology Nevada, Inc.** Highway 95, 11 Mi. South of Beatty Beatty, NV 89003
Kinsbursky Brothers, Inc. 1314 N. Lemon St. Anaheim, CA 92801	**Safety-Kleen of California, Inc.** 6880 Smith Ave Newark, CA 94560
Clean Harbors La Porte, L.P. 500 Independence Parkway South La Porte, TX 77581	**Clean Harbors Buttonwillow, LLC** 2500 West Lokern Road Buttonwillow, CA 93206
Clean Harbors, El Dorado LLC 309 American Circle El Dorado, AR 71730	**NNSS for U.S. DOE Waste Management** Nevada Test Site Zone 2 Mercury, NV 89023
Clean Harbors of San Jose, LLC 1021 Berryessa Road San Jose, CA 95133	**Nuclear Waste Partnership, LLC., on behalf of U.S. DOE** 30 Miles East of Carlsbad on Jal Highway Eddy County, NM 88221
Clean Harbors, Lone Mountain, LLC 40355 S. County Rd 236 Waynoka, OK 73860	

Four of the waste management facilities utilized by LLNL were assessed by the DOECAP in 2022. **Table 8-6** provides a summary of the types of assessments conducted and the results. Priority I findings are factual statements from the audit documenting a deficiency from a requirement that represents a substantial risk and liability to DOE. Priority II findings are factual statements that document a deviation from a requirement that could lead to a Priority I finding if not addressed and corrected. Observations document deviations from best management practices or opportunities for improvement. There were no Priority I findings for waste management facilities utilized by LLNL in 2022.

Table 8-6. Waste Management Facility Observations, Assessments, and/or Audits in 2022

Waste Management Facility	Accrediting Body	Assessment Type	Results
Energy Solutions, LLC-UT	DOECAP	• Quality Assurance Management Systems • Sampling and Analytical Data Quality • Waste Operations • Environmental Compliance and Permitting • Radiological Control • Industrial and Chemical Safety • Transportation Management	0 Priority I Findings 2 Priority II Findings 4 Observations
Perma-Fix Northwest, Inc.	DOECAP	• Quality Assurance Management Systems • Sampling and Analytical Data Quality • Waste Operations • Environmental Compliance and Permitting • Radiological Control • Industrial and Chemical Safety • Transportation Management	0 Priority I Findings 4 Priority II Findings 5 Observations
Clean Harbors Colfax, LLC	DOECAP	• Quality Assurance Management Systems • Sampling and Analytical Data Quality • Waste Operations • Environmental Compliance and Permitting • Industrial and Chemical Safety	0 Priority I Findings 0 Priority II Findings 5 Observations
Clean Harbors La Porte, LLC	DOECAP	• Quality Assurance Management Systems • Sampling and Analytical Data Quality • Waste Operations • Environmental Compliance and Permitting • Industrial and Chemical Safety	0 Priority I Findings 2 Priority II Findings 4 Observations

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 the data, and organize it into rows and columns. The tables are then reviewed by the responsible analyst before inclusion in **Appendix A**. Analytical laboratory data and values calculated from the data are normally displayed with two, or at most three, significant digits. Significant trailing zeros may be omitted.

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. The uncertainty value represents intrinsic variation in the measurement process, most of which is due to the random nature of radioactive decay (see **Section 8.6**). The uncertainty value is not used in summary statistic calculations.

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, resulting in a negative value. Such results are reported in the data tables and used in the calculation of summary statistics.

8.4.2 Non-radiological Data

Non-radiological data reported by the analytical laboratory as being below the analytical reporting limit is displayed in tables with a less-than symbol (<) and referred to as a “non-detection.” 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 (Brunckhorst 2019). 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. In this report, at least four values are required to calculate the median and at least six values are required to calculate the IQR.

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 percent 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.

Summary statistics are calculated from values that, if necessary, have already been rounded, such as when units have been converted from picocuries (pCi) to Becquerels (Bq) and are then rounded to an appropriate number of significant digits. Non-detections may impact the calculation of summary statistics.

Adjustments to the calculation of the median and IQR for data sets that include nondetections are described below:

- Data sets can fall into three categories: sets containing only detected values, sets where there is a mix of detections above the reporting limit and non-detections below the reporting limit, and sets containing only non-detections.
- For data sets where all values are known, calculations of summary statistics follow standard calculation methods for the median and IQR.
- For data sets where there is a mix of non-detections and detections, the reporting limit is substituted for non-detect data points in summary statistic calculations. The median is then calculated following the standard method with the distinction that if the result is a substituted reporting limit, the median will be reported with a less than (<) sign to indicate the median represents an upper bound. The IQR is only calculated when greater than 25 percent of the data set contains detections.
- For data sets that contain only non-detections, the calculation of the median and IQR is not appropriate.
- 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 when the values are sorted from smallest to largest. If both 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 non-detection or any value larger than the 25th percentile is a non-detection, the IQR cannot be calculated and is not reported.

8.6 Reporting Uncertainty in Data Tables

Measurement uncertainties associated with analytical laboratory results are represented in two ways. The first way is significant digits, which are derived 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, then 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 2.1 cm, which would indicate that the “true” length of the object is closer 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 and the implied uncertainty is ± 0.05 cm. A more precise measuring device may be able to measure an object to the nearest one-hundredth of a centimeter. In that case, a measurement of 2.12 cm would be reported. This value would have three significant digits and the implied uncertainty is ± 0.005 cm. A result reported as 3.0 cm has two significant digits. The trailing zero is significant and implies that the true length is closer to 3.0 than to 2.9 or 3.1 cm (i.e., between 2.95 and 3.05 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 (two sigma) uncertainties. A $\pm 2\sigma$ uncertainty represents the range of results expected to occur approximately 95 percent of the time if a sample were to be recounted repeatedly. For example, a radiological result of 2.6 ± 1.2 Bq/g would indicate with approximately 95 percent confidence that the true value ranges from 1.4 to 3.8 Bq/g (i.e., 2.6 – 1.2 = 1.4 and 2.6 + 1.2 = 3.8).

When necessary, radiological 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 x 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). The uncertainty is first rounded to the appropriate number of significant digits and then the result is rounded to the same number of decimal places. For example, after unit conversion the result is 0.1961 ± 0.05436 and the appropriate number of significant digits is two. First, 0.05436 is rounded to 0.054 (two significant digits). Since 0.054 has three decimal places, 0.1961 is then rounded to three decimal places (0.196). The data table would present the result 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 – round 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.

Sampling measurements are often compared when analyzing environmental monitoring data. Uncertainty must be considered in these comparisons. The uncertainty interval provides an estimate with a degree of confidence that the true concentration is within the interval. When comparing sampling measurements with different reported measurements and the uncertainty intervals overlap, it cannot be concluded that these measurements are different.

8.7 Quality Assurance Process for the Environmental Report

This section describes the actions that are taken to ensure the accuracy of this data-rich environmental report.

Analytical laboratories send reports electronically, which are loaded directly into an LLNL database. Since laboratory reporting is not perfect, the TSD Data Management Team (DMT) carefully checks incoming data throughout the year to ensure that electronic copies match printed laboratory reports. Additionally, EFA technical staff review the laboratory's internal QC results to identify potential errors and ensure that analytical QC standards are met. When necessary, analytical laboratories are asked to review results or reanalyze samples. Results that do not meet QC standards may be flagged or rejected.

As described in **Section 8.4**, computer scripts are used to pull data from the database into tables, including unit conversion and summary statistic calculations. All data tables in **Appendix A** were prepared in this manner. These tables are checked annually by the appropriate analyst. Analysts verify that the data tables match the data received from DMT and that summary calculations are correct.

LLNL staff also QC tables and figures in the body of the report. Staff check figure captions and table titles, data accuracy and completeness, figure labels and table headings, units, significant digits, and consistency with text. Any edits are incorporated into the ASER by the editor.

There are multiple levels of document review performed to ensure the accuracy and clarity of this report. Authors, scientific editors, and the DOE Livermore Field Office (LFO) all participate in multiple review cycles throughout document production.

8.8 Errata

Appendix D contains the protocol for errata in LLNL Environmental Reports and the errata for LLNL Site Annual Environmental Report 2021.

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