8. Quality Assurance

Bart Draper • Tyler Jackson

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. This chapter provides a description of the QA program under which the data presented in this report are collected and analyzed. This section also describes the environmental analytical laboratories and waste management facilities utilized by Lawrence Livermore National Laboratory (LLNL) during 2020. Finally, this section describes how the detailed data tables in **Appendix A** were developed and the quality assurance measures in place to ensure the accuracy of this report.

8.1 Quality Assurance Program Description

The LLNL QA section of the Management Assurance System 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 development and assessment of the Environmental Monitoring Plan (EMP, Brunckhorst 2019) and this report. The Technical Services Department (TSD) implements the EMP.

The key requirement and implementing documents comprising 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.

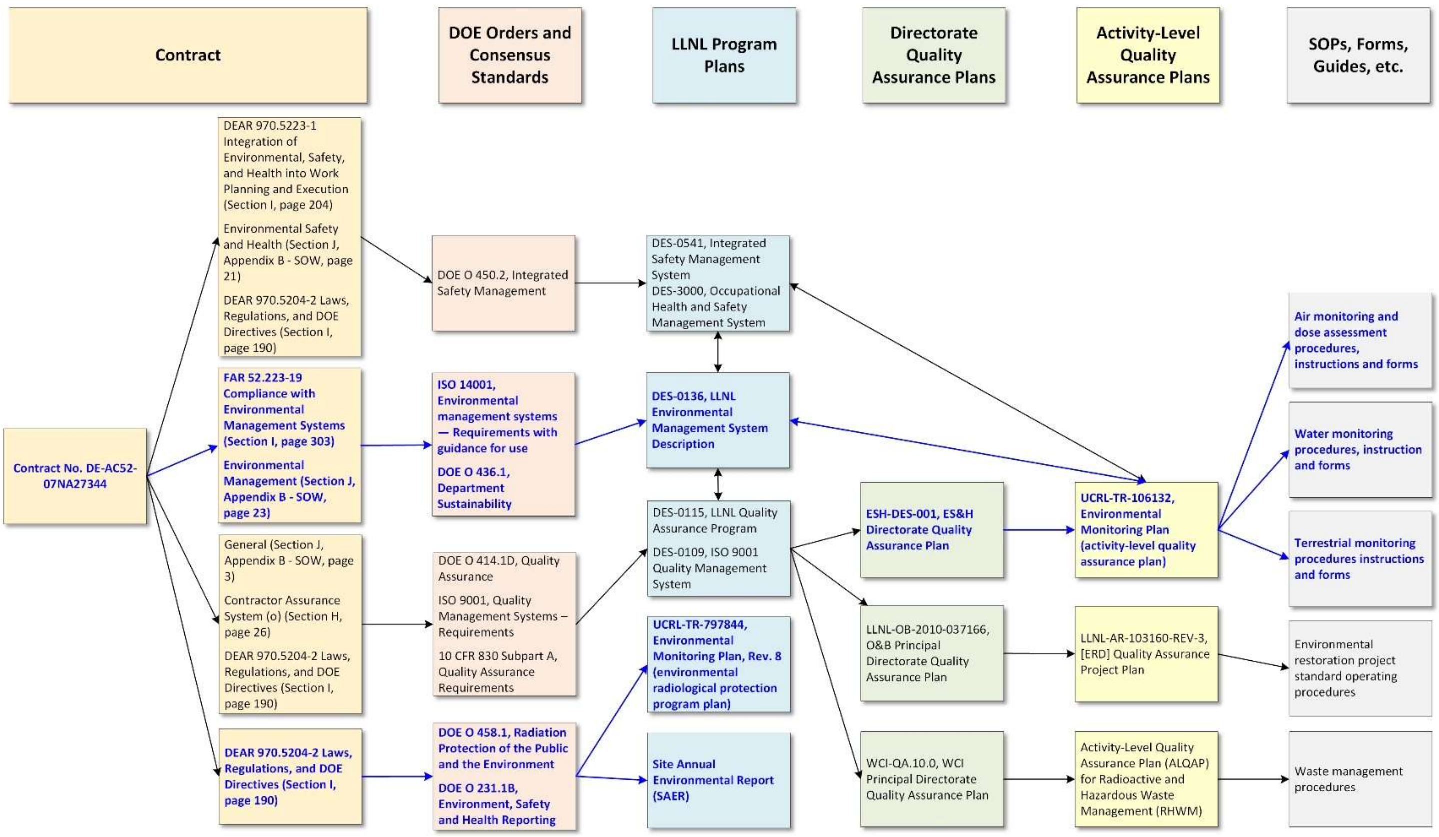

Figure 8.1. Quality assurance documents for SAER related work processes

The QAPP is designed around the Plan – Do – Check – Act model (**Figure 8.2**) consistent with the United States Environmental Protection Agency (EPA) quality policy (The Quality Policy CIO 2106.0) and its implementing procedure (CIO Procedure CIO 2106-P-01.0 *Procedure for Quality Policy*); and with both ISO 14001 and ISO 9001 international standards for environmental and quality management systems.

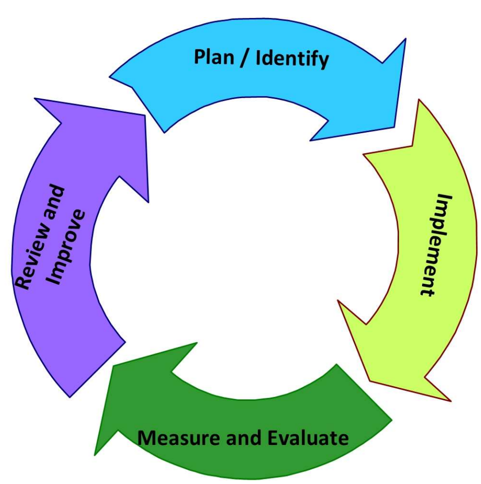

Figure 8.2. Plan – Do – Check – Act model

This cycle can be described as follows:

- Plan/Identify
  - Establish the objectives of EFA compliance and monitoring systems.
  - Assure the required resources are available to deliver results in accordance with Department of Energy (DOE) and stakeholder requirements and LLNL policies.
  - Identify and address risks and opportunities.
- Implement
  - Implement what was planned in accordance with established work control documents.
- Measure and Evaluate
  - Monitor and measure performance and the resulting work products and services against policies, objectives, requirements, and planned activities.
  - Report the results as, for example management self-assessments or management observations, inspections, or external assessments.
- Review and Improve
  - Take actions to improve performance, as necessary, 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 Issues 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 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 2020. 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 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.

The LLNL environmental data QA program is broadly consistent with the *Uniform Federal Policy (UFP) for Implementing Environmental Quality Systems* (March 2005) in that it 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* (February 2006). New studies, especially those related to site infrastructure improvements have plans informed by the data quality objectives process and the Visual Sample Plan (VSP) software tools.

8.2 Analytical Laboratories

LLNL addresses commercial analytical laboratory problems as they arise. Many of the 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.

In 2020, LLNL had Blanket Service Agreements (BSAs) with six commercial analytical laboratories. In addition, during 2020 LLNL secured commercial analytical laboratory services via purchase order and worked with three in-house LLNL laboratory organizations. **Table 8-1** identifies the scope of services provided by both the commercial and in-house laboratories during 2020.

Table 8-1. Commercial and on-site laboratories utilized in 2020.

Contract No.	Laboratory	Scope of Services
H100596	BC Laboratories, Inc. 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
H100676	Caltest Analytical Laboratory Napa, CA 94558	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 Fort Collins, CO 80524	Analysis of potentially radiologically contaminated environmental samples and radiological analysis of environmental samples
H100901	Eurofins Air Toxics, LLC Folsom, CA 95630	Analysis of non-radiologically contaminated 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

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 main industry standard, DOE, and State of California certifications and accreditations held by laboratories utilized by LLNL in 2020.

Table 8-2. Laboratory certifications and accreditations in 2020.

Laboratory	Certifications/Accreditations
BC Laboratories, Inc.	Interim 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 for Environmental Laboratories Version 5.3, May 2019
Eurofins TestAmerica - Denver	American Association for Laboratory Accreditation (A2LA) accredited for compliance with ISO/IEC 17025:2017, the 2009 TNI 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 5.3 of the DoD/DOE Quality System Manual for Environmental Laboratories (QSM) 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
Caltest Analytical Laboratory	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 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 Quality System Manual for Environmental Laboratories (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
ALS Environmental	Certificate of Environmental Accreditation, California ELAP Perry Johnson Laboratory Accreditation, Inc., accredited for meeting the requirements of ISO/IEC 17025:2005 "General Requirements for the competence of Testing and Calibration Laboratories" and the DOE Quality Systems Manual for Environmental Laboratories Version 5.1.1, February 2018 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 Colorado Department of Public Health & Environment, Radioactive Materials License

Table 8-2. Laboratory certifications and accreditations in 2020.

Laboratory	Certifications/Accreditations
Eurofins Air Toxics, LLC	ANSI National Accreditation Board Accreditation to ISO/IEC 17025:2017 and U.S. Department of Defense (DOD) Quality Systems Manual for Environmental Laboratories (DOD QSM V5.3)
ALAB	Certificate of Environmental Accreditation, California ELAP
EMRL	Certificate of Environmental Accreditation, California ELAP
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-comparison performance evaluation programs to identify and monitor trends in laboratory 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 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 laboratory inter-comparison programs. To obtain DOE Mixed Analyte Performance Evaluation Program (MAPEP) reports that include the results from all participating laboratories, see 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 three commercial laboratories that provide radiochemical analytical services to LLNL and for one in-house LLNL organization 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	ALS Environmental	EMRL
March 2020				
20-MaS42 - Mixed Analyte Soil Standard	Inorganics acceptable	Inorganics and radiological acceptable	Inorganics (Ag and ^{235}U) unacceptable and radiological acceptable	Radiological acceptable
20-MaW42 - Mixed Analyte Water Standard	Inorganics acceptable	Inorganics and radiological acceptable	Inorganics and radiological acceptable	Radiological acceptable
20-GrW42 - Gross alpha/beta water standard	No report	Radiological acceptable	No report	Radiological acceptable
20-XaW42 - Radiological I-129 Water Standard	No report	Radiological acceptable	Radiological acceptable	No report
20-RdF42 - Radiological Air Filter Standard	No report	Inorganics and Radiological acceptable	Radiological acceptable	Radiological acceptable
20-GrF42 - Gross alpha/beta air filter	No report	Radiological acceptable	No report	No report
20-RdV42 - Radiological Vegetation Standard	No report	Radiological acceptable	Radiological acceptable	No report
20-RaW42 - Radium Analytes in Water	No report	Uncertainty flags acceptable	No report	No report
20-XrM42 - Special Radiological Matrix	No report	Participated and Reported	No report	No report
August 2020				
20-MaS43 - Mixed Analyte Soil Standard	Inorganics acceptable	Inorganics and radiological acceptable	Inorganics and radiological acceptable	Radiological acceptable
20-MaW43 - Mixed Analyte Water Standard	Inorganics acceptable	Inorganics and radiological acceptable	Inorganics and radiological acceptable	Radiological acceptable
20-GrW43 - Gross alpha/beta water standard	No report	Radiological acceptable	No report	Radiological acceptable
20-RdF43 - Radiological Air Filter Standard	No report	Inorganics and radiological acceptable	Radiological acceptable	Radiological acceptable
20-GrF43 - Gross alpha/beta air filter	No report	Radiological acceptable	No report	No report
20-RdV43 - Radiological Vegetation Standard	No report	Radiological acceptable	Radiological acceptable	No report
20-XrM43 - Special Radiological Matrix	No report	Participated and reported	No report	No report

8.2.2 Analytical Laboratory Observations, Assessments, and/or Audits

LLNL monitors the DOECAP. 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.

In FY2020, the laboratories certified by the State of California operating at LLNL as government owned and contractor operated were not internally assessed but are subject to assessment by the State of California under the ELAP. **Table 8-4** summarized the results of assessment conducted during 2020.

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.

Table 8-4. 2020 Laboratory observations, assessments and/or audits.

Laboratory	Accrediting Body	Assessment Type	Results
BC Laboratories, Inc.	Perry Johnson Laboratory Accreditation, Inc.	Surveillance	0 Major nonconformance 4 Minor nonconformances 1 Observations
Eurofins TestAmerica - Denver	Not assessed in 2020	Not applicable	Not applicable
Alpha Analytical Laboratories	Not assessed in 2020	Not applicable	Not applicable
Caltest Analytical Laboratory	Not assessed in 2020	Not applicable	Not applicable
GEL Laboratories, LLC	Not assessed in 2020	Not applicable	Not applicable
ALS Environmental	Perry Johnson Laboratory Accreditation, Inc.	Reaccreditation and upgrade	0 Major nonconformance 5 Minor nonconformances 0 Observations
Eurofins Air Toxics, LLC	Not assessed in 2020	Not applicable	Not applicable
ALAB	Not assessed in 2020	Not applicable	Not applicable
EMRL	Not assessed in 2020	Not applicable	Not applicable
RML	Not assessed in 2020	Not applicable	Not applicable

LLNL reviews deficiencies and non-conformances and investigates corrective actions when they occur in fields of 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 in Sections 8.2.3.1 and 8.2.3.2 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 errors such as mislabeled samples or data entry errors. **Appendix E** presents summary statistics for collocated sample pairs, grouped by sample matrix and analyte. Samples from both the Livermore Site, Livermore Valley, and Site 300 are included. **Appendix E** is based on data pairs in which 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 with the same method.
- Both routine and duplicate sample values are detected above the reporting limit.
- There are no flags marking these as suspect or rejected results.

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

RPD values can represent differences because of real difference: a collocated sample just happened to have a high concentration in one container (this should be limited through standard sampling procedures), or through errors associated with the analytical method.

RPD values can represent differences because of error: sampling activities in the field introduced an error, or analytical laboratories introduced an error by methods of processing one of the samples. In a perfect environment with uniform media, one would expect an RPD of zero for collocated sampling.

LLNL calculates RPD:

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

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

In 2020, LLNL planned quality control sampling which resulted in 782 routine-duplicate analytical pairs to review. A total of 707 pairs were in control and signaled good quality results, while 75 pairs (9.6-percent) were out of control requiring further review. **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 correct normal conditions. **Appendix F** summarizes the percent complete for many of the data sets described in previous sections of this report and presented in **Appendix A**. The average completeness of data gathered for routine monitoring networks was 94 percent during 2020. For non-routine monitoring, the average completeness for 2020 was 37 percent. Lower percent completeness values are expected for non-routine monitoring because sampling and analysis for infrastructure projects may be planned but delayed or canceled. Event based sampling, for example, for rain and stormwater may be planned, but a qualifying storm may not occur.

8.3 Waste Management Facilities

Table 8-5 provides a list of waste management facilities utilized by LLNL during 2020.

Table 8-5. Waste management facilities.

Clean Harbors Aragonite, LLC 11600 North Aptus Road Aragonite, UT 84029	**Diversified Scientific Services, Inc.** 657 Gallaher Road Kingston, TN 37763
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	**US Ecology of Idaho, Inc.** 10.5 Miles Nw Highway 78 Grand View, ID 83624
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 US DOE Waste Management** Nevada Test Site Zone 2 Mercury, NV 89023
Demenno Kerdoon 2000 North Alameda St. Compton, CA 90222	

Three of the waste management facilities utilized by LLNL were assessed by the DOECAP during 2020. **Table 8-6** provides a summary of the types of assessments conducted and the results. Results considered priority I findings are factual statements resulting from the audit that document 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 during 2020.

Table 8-6. Waste management facility observations, assessments, and/or audits in 2020.

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 1 Priority II Findings 1 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 3 Priority II Findings 3 Observations
Clean Harbors Aragonite, LLC	DOECAP	Quality Assurance Management Systems Sampling and Analytical Data Quality Waste Operations Environmental Compliance and Permitting Industrial and Chemical Safety Transportation Management	0 Priority I Findings 0 Priority II Findings 5 Observations
Clean Harbors Deer Park, LLC	DOECAP	Quality Assurance Management Systems Waste Operations Environmental Compliance and Permitting Industrial and Chemical Safety	0 Priority I Findings 8 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, organize the data into rows and columns, and present a draft table. 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. 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.

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.

8.4.2 Non-radiological Data

Non-radiological data reported by the analytical laboratory as being below the analytical contract 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. The calculation of summary statistics may be affected by the presence of non-detections.

Adjustments to the calculation of the median and IQR for data sets that include such non-detections are described below:

- Data sets can fall into three categories: sets where all values in the dataset are detected values, sets where there is a mix of detections above the contract reporting limit and non-detections below a contract reporting limit, and sets that are comprised of only non-detect results.
- For data sets where all values are known, calculations for summary statistics follow standard calculation methods for the median and IQR.
- For data sets where there is a mix of non-detects and detect data, 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, we will report the median 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 data.
- For data sets that contain only non-detect data, 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 (i.e., the middle two 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 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 (two sigma) uncertainties. A ± 2σ uncertainty represents the range of results expected to occur approximately 95 percent 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 percent 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, 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). 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) and 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.

Comparing two or more sampling measurements to determine the difference is a common activity when analyzing environmental monitoring data. Uncertainty must be considered in these comparisons. Using an uncertainty interval lets us estimate with a degree of confidence that the "true" concentration is somewhere in the interval. When comparing sampling measurements with different reported measurements and the uncertainty intervals overlap, we cannot conclude that these measurements are different.

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 here.

Analytical laboratories send reports electronically, which are loaded directly into a 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 TSD Data Management Team (DMT) 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 environmental report's accuracy. In addition, EFA technical staff review the analytical laboratories' internal QC results to make sure that analytical QC standards have been met, and to identify potential errors. When necessary, analytical laboratories are asked to review results or reanalyze samples. Results that do not meet QC standards may be flagged as suspect or rejected.

As described in **Section 8.4**, computer scripts are used to pull data from the database directly into the format of the table, including unit conversion and summary statistic calculations. All the data tables contained in **Appendix A** were prepared 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 any summary calculations have been done correctly.

For this 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 report editor 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, 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 2019.