

**USACE KANSAS CITY AND ST. LOUIS DISTRICT
RADIONUCLIDE DATA QUALITY EVALUATION GUIDANCE
FOR ALPHA AND GAMMA SPECTROSCOPY**

INTRODUCTION

This document is designed to offer guidance in laboratory data quality evaluation of radioanalytical data and is based on SAIC's laboratory validation guidelines (ref. 9). In some aspects, it is equivalent to a standard operating procedure (SOP). In more subjective areas, only general guidance is offered due to the complexities and uniqueness of data relative to specific samples.

Four terms are used throughout this document: shall indicates a requirement for the data validator, must indicates a requirement for the data, should indicates a recommendation. And may indicates an acceptable practice (neither a requirement nor a recommendation).

Those areas where specific SOPs are possible are primarily areas in which definitive performance requirements are established. These requirements are concerned with specifications that are not sample dependent; they specify performance requirements on matters that should be completely under a laboratory's control. These specific areas include blanks, calibration standards, calibration verification standards, laboratory control standards, and interference check standards. In particular, mistakes such as calculation and transcription errors must be rectified by submission of corrected data sheets.

In instances where a decision on the quality/acceptability of the data is difficult after implementation of this guidance, the reviewer is expected to request data in addition to the data specifically mentioned in this guidance.

At times, there may be an urgent need to use data that do not meet all contract requirements and technical criteria, Use of these data does not constitute either a new requirement standard or full acceptance of the data. Any decision to utilize data for which performance criteria have not been met is strictly to facilitate the progress of projects requiring the availability of the data. A laboratory submitting out-of-specification data shall be required to perform corrective actions (unless the client waives this requirement) and rerun or resubmit data depending on the nature of the corrective action even if the previously submitted data have been utilized due to urgent program needs. Data for which corrective actions were required and performed but failed to correct the problem are considered acceptable, regardless of their usability. The overriding concern is to obtain data that are technically valid and legally defensible.

RADIONUCLIDE PROCEDURE

The requirements to be checked in validation are listed below. Contractual requirements for these items are not always the same as the data review criteria).

1. Holding times (Lab holding times only)
2. Calibration
 - Initial
 - Continuing
3. Blanks
4. Sample specific chemical recovery
5. Laboratory control sample
6. Matrix spike

7. Field duplicates
8. Duplicate sample
9. Radionuclide quantitation and implied detection limits
10. Chemical separation specificity
11. Target radionuclide list identification -

I. HOLDING TIMES

A. Objective

The objective is to ascertain the validity of results based on the holding time of the sample from time of collection to time of analysis.

Note: The holding time is based on the date of collection (rather than verified time of sample receipt) and date of digestion/distillation. It is a technical evaluation rather than a contractual requirement

B. Criteria

The following technical requirements for sample holding times and preservation have only been established for water matrices. Due to limited information concerning holding times for soil samples, it is left to the professional judgment of the data reviewer whether to apply water holding time criteria to soil samples.

1. Tritium solutions: 6 months, with no preservative and stored in glass.
2. Iodine solutions: 6 months, with no preservatives.
3. Radon-222: 4 days, cool to 4°C and stored in glass with Teflon-lined septum.
4. Cesium: 6 months, when preserved to pH <2 in hydrochloric acid.
5. Plutonium: 6 months, when preserved in 2M nitric acid.
6. Other radionuclides: 6 months, when preserved to pH <2 in nitric or hydrochloric acid.

C. Evaluation Procedure

Actual holding times are established by comparing the sampling date on the sample traffic report with the dates of analysis found in the laboratory raw data (digestion logs and instrument run logs). Examine the digestion and/or distillation logs to determine if samples were preserved at the proper pH. Note: Physical characteristics and half-lives must also be considered when evaluating holding times (e.g., Tc-99 is volatile, or Rn-222 has a 4 day half-life).

Analyte Holding Times (days) = Analysis Date - Sampling Date

D. Action

1. If criteria for holding times and preservation are not met, qualify all results as estimated (J).

2. If holding times are exceeded, the reviewer shall use professional judgment to determine the reliability of the data and the effects of additional storage on the sample results. The expected bias would be low and the reviewer shall determine that results less than the MDA are unusable (R).
3. Due to limited information concerning holding times for soil samples, it is left to the professional judgment of the data reviewer whether to apply water holding time criteria to soil samples. If the data are qualified when water holding time criteria are applied to soil samples, it shall be clearly documented in the review.

II. BLANKS

A. Objective

Blank analysis results are assessed to determine the existence and magnitude of contamination problems. The criteria for evaluation of blanks applies to any blank associated with the samples. If problems with any blank exist, all data associated with the case shall be carefully evaluated to determine whether or not there is an inherent variability in the data for the case, or if the problem is an isolated occurrence not affecting other data.

B. Criteria

At least one blank must be analyzed for every matrix, every batch, or for every 20 samples (5% of samples), whichever is more frequent. The result of all blanks must be reported along with the sample results and should be plotted on a QC chart. Acceptable tolerances must be based on system performance and analytical requirements. Tolerance limits of ± 3 standard deviations are recommended.

When average blanks or instrument backgrounds are subtracted to determine net counts, the net blank result must be less than the associated uncertainty. Contamination shall be suspected when the net blank result is larger than the associated uncertainty.

C. Evaluation Procedures

Review the results reported on the Blank Summary (Form 2) and evaluate the blank control charts as well as the raw data for all blanks. Verify that the results were accurately reported and that tolerance limits were not exceeded. Verify that net blank results are less than the associated uncertainty.

D. Action

If the blank QC results fall outside the appropriate tolerance limits or if the net blank results are not less than the associated uncertainty, the following equation should be used in determining the effect of possible blank contamination on the sample results

$$\text{Normalized Absolute Difference}_{\text{MethodBlank}} = \frac{|Sample - Blank|}{\sqrt{(\sigma_{\text{Sample}})^2 + (\sigma_{\text{Blank}})^2}}$$

Where:

$\sigma_{\text{Sample}} = 2\sigma$ counting uncertainty of the sample

$\sigma_{\text{Blank}} = 2\sigma$ counting uncertainty of the blank

Normalized absolute difference	Qualification
> 2.58	None
$1.96 > x < 2.58$	J
$x < 1.96$	J or R*

* = Minimally the result should be qualified as estimated, J; however, if other quality indicators are deficient the validator may determine the result should be qualified as unusable, R.

III. SAMPLE SPECIFIC CHEMICAL RECOVERY

A. Objective

Laboratory performance on individual samples subject to chemical process and separation is established by means of spiking with tracer quantities of other radioisotopes of the same element or carrier quantities of the inactive isotope of the same or a chemically similar element. All samples are spiked prior to sample preparation.

Criteria:

1. Sample specific recoveries must be within limits as per applicable scope of work (SOW). Generally, recoveries of 50-100% are considered acceptable. Each chemical tracer percent recovery (CT %R) must be recorded and should be plotted on a QC chart for each radionuclide and method and fall within the prescribed limits.
2. The quantity of tracer material used must be adequate to provide a maximum uncertainty as specified by the SOW at the 95% confidence level in the measured recovery using the following equation:

$$2\sigma \text{ uncertainty} = \frac{1.96\sqrt{(C_s/t_s) + (C_b/t_b)}}{E \times Vol \times R \times 2.22}$$

Where:

C_s = Sample count rate, cpm

C_b = Background count rate, cpm

t_s = Sample count time, minutes

t_b = Background count time, minutes

E = Counting efficiency

Vol = Volume of sample (liters or grams)

R	=	Radiochemical recovery
2.22	=	Conversion factor from dpm to pCi

B. Evaluation Procedure

1. Review Form 3 and verify that sample specific recoveries fall within the control limits.
2. Check the raw data to verify that sample specific recoveries are accurately reported on Form 3. Recalculate up to 10% of the sample specific recoveries (CT %R) using the following equation:

$$CT \%R = (CT_{\text{Found}}/CT_{\text{True}})100$$

Where:

CT_{Found} = concentration (in pCi/L for aqueous; pCi/kg for solid) of each analyte measured in the analysis of LCS solution.

CT_{True} = concentration (in pCi/L for aqueous; pCi/kg for solid) of each analyte in the LCS source.

3. Check spike levels to verify that sufficient concentrations are used to provide adequate precision for recovery determination.
4. Evaluate recovery to verify that limits specified in SOW are met.

C. Action

For sample specific recoveries out of specification, the following approaches are suggested based on a review of all data from the case, especially considering the apparent complexity of the sample matrix:

1. for sample specific recoveries, qualify results for the appropriate radionuclides in all associated samples as follows:
 - a. 50-100%: acceptable for use
 - b. 100-150%: estimated (J) after corrective actions; otherwise R
 - c. 20-50%: estimated (J) after corrective actions; otherwise R
 - d. <20%: unacceptable (R)
 - e. >150%: unacceptable (R)
2. If significant errors are noted in the calculations, flag all affected results, specific to that sample, (R).

IV. LABORATORY CONTROL SAMPLE (applies to α spectroscopy except where noted)

A. Objective

The laboratory control sample (LCS) serves as a monitor of the overall accuracy and performance of all steps in the analysis, including the sample preparation. For the following limits to apply, the LCS must contain greater than 10 times the radionuclide's detection limit activity.

B. Criteria (for alpha and gamma)

1. At least one LCS must be analyzed for every matrix, every batch, or for every 20 samples (5% of samples), whichever is more frequent
2. All aqueous LCS results must fall within the control limits of 80-120% recovery of the standard value or laboratory derived limits.
3. All solid LCS results must fall within the control limits of 70-130% recovery of the standard value or laboratory derived limits.
4. All LCS results must be recorded and should be plotted on aQC chart according to sample type and radionuclide and fall within the prescribed limits.

C. Evaluation Procedure

1. Review Form 4 and verify that results fall within the control limits.
2. Check the raw data (counter printout, strip charts, bench sheets, etc.) to verify the reported recoveries on Form 4. Recalculate a few of the LCS percent recoveries (LCS %R).

D. Action

For gamma spectroscopy, reject all associated samples whose LCS falls outside the specified limits.

1. Aqueous LCS
 - a. If the LCS %R for any analyte falls within the range of 50-80%, or 120-150%, qualify results for that radionuclide in all associated samples as estimated (3).
 - b. If LCS %R are <50% or >150%, qualify results for that radionuclide in all associated samples as unusable (R).
2. Solid LCS
 - c. If the LCS %R for any analyte falls within the range of 40-70% or 130-160%, qualify results for that radionuclide in all associated samples as estimated (3).
 - d. If LCS %R are <40% or >160%, qualify results for that radionuclide in all associated samples as unusable CR).

V. MATRIX(SPIKE SAMPLE ANALYSIS (not applicable in γ -spectroscopy)

A. Objective

The matrix spike sample (MSS) analysis provides information about the effect of each sample matrix on the digestion and measurement methodology. MSSs are required when sample specific chemical recovery mechanisms are not available and the samples undergo a chemical process.

B. Criteria

1. At least one MSS must be analyzed for every matrix, every batch, or for every 20 samples (5% of samples), whichever is more frequent, when sample specific chemical recovery mechanisms are not available and the samples undergo a chemical process
 2. Samples identified as field blanks must not be used for spiked sample analysis.
 3. Matrix spike sample percent recovery (MSS %R) must be within the limits of 75-125% for aqueous matrix and 70-130% for solid matrix samples
 4. The MSS %R of the matrix spike must be recorded and should be plotted on a QC chart and fall within the prescribed limits.
- C. Evaluation Procedure
1. Review Form 5 and verify that results fall within the specified limits.
 2. Check raw data and recalculate, at a minimum, 10% of the %R using the following equation to verify that the results were correctly reported on Form 5.

$$MSS \%R = (SSR - SR)/SA * 100$$

Where:

SSR = Spiked Sample Result
 SR = Sample Result
 SA = Spike Added

3. Verify that the field blank was not used for spike analysis.

D. Action

Same as Section IV.

VI. DUPLICATE ANALYSIS SAMPLES

A. Objective

Duplicate analyses are indicators of laboratory precision based on each sample matrix.

B. Criteria

1. Samples identified as field blanks must not be used for duplicate sample analysis
2. At least one duplicate must be analyzed for every matrix. every batch. or for every 20 samples (5% of samples). whichever is more frequent.
3. The duplicate analyses results must be in agreement when the 2 standard deviations (95% confidence limit) uncertainties are considered, or if the RPD (relative percent difference) is within $\pm 35\%$ for solid samples and $\pm 25\%$ for water samples when the sample activities are $\geq 5x$ MDCs..

When the 95% confidence limit is considered, the Normalized Absolute Difference (NAD) as defined in the following equation must be less than ± 1.96 . The NAD must be recorded and should be plotted on QC charts with a control limit set at 1.96.

$$\text{Normalized absolute difference}_{\text{Duplicate}} = \frac{| \text{Sample} - \text{Duplicate} |}{\sqrt{(\sigma_{\text{Sample}})^2 + (\sigma_{\text{Duplicate}})^2}}$$

Where:

Sample	=	first sample value (original),
Duplicate	=	second sample value (duplicate),
σ_{Sample}	=	2σ counting uncertainty of the sample
$\sigma_{\text{Duplicate}}$	=	2σ counting uncertainty of the duplicate

C. Evaluation Procedure

1. Review Form 6 and verify that NAD results are less than 1.96.
2. Check one or more of the duplicate results and recalculate the NAD values or RPD if these calculations are in doubt.
3. Use the above equation to verify that NAD results have been correctly reported on Form 6.
4. Verify that the field blank was not used for duplicate analysis.

D. Action

1. If NAD for a particular radionuclide is greater than 1.96 but less than 3.92, qualify the results for that radionuclide in all associated samples of the same matrix as estimated (J). If NAD is greater than 3.92, qualify data in that batch as rejected.
2. If the field blank was used for duplicate analysis, all other QC data shall be carefully checked and professional judgment exercised when evaluating the data.

VII. FIELD REPLICATE ANALYSIS

A. Objective

Field duplicate samples shall be taken and analyzed as an indication of overall precision. Field replicates shall be blind to the lab. The replicate shall be prepared by thoroughly homogenizing the sample. The sample is then split and the splits sent to the lab, with one of the splits labeled such that it cannot be determined from which sample it was split. The replicate is therefore prepared in the same fashion as the laboratory prepares a duplicate, thus the criteria for agreement is the same as the criteria for a laboratory duplicate.

B. Criteria

There are no specific review criteria for field duplicate analyses comparability. However, both the NAD and the RPD can be used as an evaluation of the overall precision.

C. Evaluation Procedures

Samples that are field replicates should be identified using sample field sheets.

D. Action

The lack of agreement between the sample and its replicate should only be used as a verification that a quality problem exists as evidenced by at least one other QC indicator. Any evaluation of the field replicates should be provided with the validator's comments

VIII. RADIONUCLIDE QUANTITATION AND IMPLIED DETECTION LIMITS

A. Objective

The objective is to ensure that the reported quantitation results are accurate and that the required detection limits have been met. When detection limit requirements are not met; the data quality objectives may not have been met. All results shall be evaluated relative to the uncertainty associated with the analysis.

B. Criteria

1. Radionuclide quantitation must be calculated according to the appropriate procedures specified in the contractual SOW.
2. Detection limits specified in the specific procedures must be met unless other detection limits are specified in the SOW.
3. Analytical uncertainties must be reported with all results in order to qualify the data. Results and uncertainties must be reported for all required analyses regardless of the size or sign of the result. The reported uncertainty must include all uncertainties associated with the analysis. If the reported uncertainty only includes counting uncertainty, this fact must be documented in the case narrative.

E. Evaluation Procedures

1. The raw data shall be examined to verify the correct calculation of sample results reported on Form I by the laboratory.
 - a. Examine the raw data for any anomalies (i.e., omissions, legibility, etc.). Recalculate a few of the results if there is a suspicion the results have not been calculated properly. If calculation errors are found, (e.g., if sample results cannot be reproduced through manual calculations), contacting the laboratory may be necessary to resolve the problem. Qualifiers should be placed using professional judgment.
 - b. Verify that all analytical uncertainties have been propagate and reported or otherwise documented.

2. Verify that uncertainties (Form 1) have been reported for all results.
3. If there is doubt about detection limits, spot check the detection limits by verifying that, for blanks or any other samples that have an uncertainty greater than the result, the 2 sigma uncertainty multiplied by 1.65 is less than or equal to the specified detection limit.

Note: Net negative results that have uncertainties greater than their absolute value indicate the sample count was less than background. Net positive results that have uncertainties larger than the results indicate the sample count was less than the critical level or less than 95% confidence of positive detection.

D. Action

1. When significant errors are found in the calculations, flag all affected results as rejected.
2. For net negative results that have uncertainties smaller than their absolute value, flag the data as unusable (R). This is an indication of improper blank subtraction.
3. When analytical uncertainties are not reported, flag the results according to the above listed requirements.

If any discrepancies are found, the laboratory may be contacted by the designated representative to obtain additional information that could resolve any differences. If a discrepancy remains unresolved, the reviewer may determine that qualification of the data is warranted based on the reviewer's professional judgment.

IX. Chemical Separation Specificity

A. Objective

Chemical separation specificity the contract laboratory's ability to separate various radionuclides by chemical separation techniques. The chemical separation specificity can be verified for alpha spectroscopy measurements by observation of the alpha energy spectrum.

B. Criteria

Energy of the radionuclide of interest must be within 40 keV of the observed peak energy.

C. Evaluation

Randomly check that the energy of the observed peak of interest is within 40 keV of the energy for the radionuclide of interest.

D. Action

If the energy of the peak of interest is more than 40 keV from the energy for the radionuclide of interest, qualify the results as unusable (R).

X. TARGET RADIONUCLIDE LIST IDENTIFICATION (Gamma Spectroscopy)

A. Objective

The target radionuclide list (TRL) contains those radionuclides for which a quantitative analysis is required. Therefore, net quantitation with uncertainties must be provided for all TRL radionuclides (whether or not the radionuclide is identified in the peak search and identification). This is accomplished by determining the net area in the region associated with the radionuclide when the radionuclide is not detected by the computerized peak search routine. When a peak is detected for the radionuclide. Positive identification is achieved using the following criteria.

B. Criteria

The target radionuclide energy must be within 2 keV of the observed peak.

C. Evaluation Procedure

1. Check that the peak search algorithm of the instrument is set at 2 keV. of the standard library energy for the identified radionuclide.
2. Compare isotope concentrations with equilibrium concentrations. Unless enrichment is suspected, these concentrations should be comparable.

D. Action

Qualify the data according to the following:

For TRL radionuclide peaks that are detected but fail to meet the positive identification criteria, flag the data as rejected. (R)

If any discrepancies are found. The laboratory may be contacted by the designated representative to obtain additional information that may resolve any differences. If a discrepancy remains unresolved the reviewer shall decide which value is the best value. Under these circumstances, the reviewer may determine whether qualification of data is warranted

GLOSSARY A

Data Qualifier Definitions

- J - The associated numerical value is an estimated quantity.
- R - The data are unacceptable (radionuclide may or may not be present or quantitation is in serious doubt). Resampling and reanalysis is necessary for verification.
- U - Not Detected at the Detection limit listed.

GLOSSARY B

Additional Terms

Calibration Curve - An analytical curve based on the pulse energy, detector efficiency, energy absorbance or other measured characteristic obtained from standard sources and a reagent blank.

Calibration Source - A radionuclide source counted daily to verify the calibration of a counting system.

Case - A finite (usually predetermined) number of samples collected over a given time period for a particular site. A case consists of one or more sample delivery group(s).

Chemical Tracer - A trace quantity of a different radioisotope of the same element or a carrier quantity of an inactive isotope of the same or a chemically similar element

Critical Level (CL) - The net count rate that must be exceeded before there is a specific degree of confidence that the sample contains any measurable radioactive material above background.

Customer Required Detection Limit (CRDL) - The minimum concentration in a given matrix type that a customer will accept of a radionuclide that can be measured and reported with a specific degree of confidence that the radionuclide activity is greater than zero

Duplicate - Two aliquots taken from a homogenized sample and analyzed as individual samples. These are used to determine the precision of the method.

Duplicate Error Ratio - The ratio of the difference between the duplicate results to the sum of the two standard deviation uncertain ties for duplicate results.

Field Blank - A sample of radionuclide-free media which is taken to the field in sealed containers and transferred from one vessel to another at the sampling site and preserved with the appropriate reagents. This serves as a-check on reagent and environmental contamination. These blanks are treated as actual samples but may not be used for matrix spikes or sample duplicates.

Field Duplicate - Independent samples that are collected as close as possible to the same point in space and time. They are two separate samples taken from the same source, stored in separate containers, and analyzed independently. These duplicates are useful in documenting the precision of the sampling process.

Full Width at Half Maximum (FWHM) - the width of the distribution at a level that is half the maximum ordinate of the peak.

Holding Times - The time between the date of collection of sample and the date of sample analysis.

Laboratory Control Sample (LCS) - A control sample of known composition. Aqueous and solid laboratory control samples are analyzed using the same sample preparation, reagents and analytical methods employed for the unknown samples being analyzed. The results from the analysis of the controls are plotted and compared to control limits to determine the usability of the data.

Matrix Spike Sample (MSS) - An aliquot of sample spiked with a known concentration of target radionuclide(s). The spiking occurs prior to sample preparation and analysis. A matrix spike is used to document the bias of a method in a given sample matrix. (Some Federal Regulations require that data be corrected for spike recovery prior to reporting. Environmental Protection Agency recommends a minimum of 10 times the method detection Limit or 2 to 4 times the measured quantity.)

Method Blank - A radionuclide-free matrix to which all reagents are added in the same volumes or proportions as used in sample processing. The method blank is carried through the complete sample preparation and analytical procedure. The method blank is used to document contamination resulting from the analytical process and should not be used for matrix spikes or sample duplicates.

Method Detection Limit (MDL) - The minimum concentration of a radionuclide that can be measured and reported with a specific degree of confidence that the radionuclide's activity is greater than zero and is determined for analysis of a sample in a given matrix type. MDL is equivalent to LLD, MDA, etc.

Percent Recovery (%R) - The fractional amount of the known activity of the radionuclide of interest that was obtained in the analysis.

Quality Control (QC) - An aggregate of activities designed to ensure adequate quality of analytical data.

QC Chart - A graphic representation on which the values obtained on the analysis of backgrounds, blank, calibrations, and laboratory control samples are plotted sequentially. The chart usually consist of a central line and two control limit lines parallel to the central line. The distribution of the plotted values with respect to the control limits provide valuable visual and statistical information on the quality of the analyses.

Quench Curve - A plot of efficiency versus degree of quenching for quenched standards.

Quenching - A reduction in the pulse height from the output of the photomultiplier tube due to physical or chemical processes occurring during or after the deposition of energy by the ionizing particle in the scintillator. Quenching reduces the scintillation efficiency and hence produces a loss in counting efficiency.

Standard Operating Procedure (SOP) - Established or prescribed methods to be followed routinely for the performance of design ateo operations or in designated situations.

Statement of Work (SOW) - A detailed description of work to be performed by a contracted laboratory or facility.

Target Radionuclide List (TRL) - A listing of radionuclides for which a quantitative analysis is required Therefore net quantitation with uncertainties must be provided for all TRL radionuclides whether or not the radionuclide is identified in the computerized peak search and identification routine.

REFERENCES

- 1 American Society for Testing and Materials (ASTM), "Establishing a Quality Assurance Program for Analytical Chemistry Laboratories Within the Nuclear Industry," American Society for Testing and Materials C 1009-83. Philadelphia, PA, 1986.
- 2 Bleyler, Ruth, comp., Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analyses, (Draft), Hazardous Site Evaluation Division of the U.S. Environmental Protection Agency, 1988.
- 3 Bleyler, Ruth, comp., Laboratory Data Validation Functional Guidelines for Evaluating Organics Analyses, (Draft), Hazardous Site Evaluation Division of the U.S. Environmental Protection Agency, 1988.
- 4 Drinking Water Laboratory Certification Implementation Work Group, Manual for the Certification of Laboratories Analyzing Drinking Water, EPA-570/9-82-002, U.S. Environmental Protection Agency, Washington DC, October 1982.
- 5 National Primary Drinking Water Regulations; Radionuclides - Notice of Proposed Rulemaking, 40 CFR Parts 141, 142. U.S. Environmental Protection Agency. Federal Register, Volume 56, Number 138, July 18, 1991.
- 6 Gibson, J.A.B., "Modern Techniques for Measuring the Quenching Correction in a Liquid Scintillation Counter: A Critical Review," pp 153-172 in Liquid Scintillation Counting: Recent Applications and Development -Volume I Physical Aspects, ed. Chin-Tzu Peng, Donald L. Horrocks. And Edward L. Alpen. Academic Press, New York, 1980.
- 7 Institute of Nuclear Power Operations. Quality Control Program for Chemistry Instrumentation, INPO 83-016 (Revision 01) (CY-701), Institute of Nuclear Power Operations. Atlanta, GA, January 1986.
- 8 Lochamy, Joseph C., The Minimum Detectable Activity Concept. proceedings of the National Bureau of Standards 75th Anniversary Symposium. and EG&G Ortec System Applications Studies, PSD No.17, September 1981.
- 9 Rucker, Thomas L. and Johnson, C. Martin, Jr., Laboratory Data Validation Guidelines for Evaluating Radionuclide Analyses, Science Applications International Corporation (SAIC), Revision 05, 31 December 1992.