

QUALITY ASSURANCE/QUALITY CONTROL

Reviewed by Standard Methods Committee, 2010. Editorial revisions, 2022. Joint Task Group: Robin S. Parnell (chair), Rodger B. Baird, Andrew D. Eaton, William C. Lipps.

5020 A. INTRODUCTION

Quality assurance (QA) is a laboratory operations program that specifies the measures required to produce defensible data with known precision and accuracy. This program is defined in a QA manual, written procedures, work instructions, and records. The manual should include a policy that defines the statistical level of confidence used to express data precision and bias, as well as method detection levels (MDLs) and reporting limits.

The overall system includes all QA policies and quality control (QC) processes needed to demonstrate the laboratory's competence and to ensure and document the quality of its analytical data. Quality systems are essential for laboratories seeking accreditation under state or federal laboratory certification programs. Refer to Section 1020 for details on establishing a Quality Assurance Plan.

As described in Part 1000, essential QC measures may include

- method calibration;
- reagent preparation and standardization;
- assessment of each analyst's capabilities;
- analysis of blind check samples;
- determination of the method's sensitivity [method detection level (MDL), limit of detection (LOD), level of quantification (LOQ), or minimum reporting level (MRL)]; and
- daily evaluation of bias, precision, and laboratory contamination or other analytical interference.

Some methods in Part 5000 include specific QC procedures, frequencies, and acceptance criteria. These are considered the minimum QCs needed to perform the method successfully. When the words *may* or *preferably* are used, the QC is suggested but not required; when *must* is used, the QC is required. Some regulatory programs may require additional QC or have alternative acceptance limits. In those cases, the laboratory must follow the more stringent requirements.

The QC program consists of at least the following elements, as applicable to specific methods:

- calibration,
- continuing calibration verification (CCV),
- operational range and MDL determination,
- initial demonstration of capability (IDC),
- ongoing demonstration of capability,
- method blank or reagent blank,
- laboratory-fortified blank (LFB),
- laboratory-fortified matrix (LFM),
- duplicate sample/laboratory-fortified matrix duplicate (LFMD),
- verification of MDL and MRL,
- QC calculations,
- control charts,
- corrective action,
- frequency of QC,
- QC acceptance criteria, and
- definitions of prep and analytical batches.

Sections 1010 and 1030 describe calculations for evaluating data quality.

5020 B. QUALITY CONTROL PRACTICES

At a minimum, analysts must use the QC practices specified here unless a method specifies alternative, more stringent practices. Laboratories may save time and money by purchasing premade standards, titrants, and reagents, but they still must perform the QC checks on these materials required by the analytical methods.

1. Calibration

a. Instrument calibration (not applicable to noninstrumental methods): Perform both instrument calibration and maintenance according to the manufacturer's instructions and recommendations. Conduct instrument-performance checks according to method or standard operating procedure (SOP) instructions.

b. Initial calibration: Perform initial calibration using

- at least 3 concentrations of standards and 1 blank (for linear calibrations),
- at least 5 concentrations of standards and 1 blank (for nonlinear calibrations), or
- as many concentrations as the method specifies.

The lowest concentration must be at or below the MRL, and the highest concentration should be at the upper end of the calibration range. Make sure the calibration range encompasses the concentrations expected in method samples or required dilutions. For the most accurate results, choose calibration standard concentrations no more than one order of magnitude apart. Some methods and instruments respond better to more orders of magnitude between concentrations.

Apply response-factor, linear, or quadratic-curve-fitting statistics (depending on what the method allows) to analyze the concentration-instrument response relationship. If the relative standard deviation (RSD) of the response factors is $\leq 15\%$, then the average response factor may be used. Otherwise, use a regression equation. The appropriate linear or nonlinear correlation coefficient for standard concentration-to-instrument response should be 0.995 for linear calibrations and ≥ 0.990 for quadratic

calibrations. Weighting factors (e.g., $1/x$ or $1/x^2$) may be used to give more weight to the lower concentration points of the calibration. Depending on the method, calibration curves may be

- linear through the origin,
- linear not through the origin,
- nonlinear through the origin, or
- nonlinear not through the origin.

Some nonlinear functions can be linearized via mathematical transformations (e.g., log). The following acceptance criteria are recommended for various calibration functions.

Compare each calibration point to the curve and recalculate its concentration. If any recalculated values are not within the method's acceptance criteria— ≤ 3 times the MRL $\pm 50\%$; between 3 and 5 times the MRL $\pm 20\%$; or > 5 times the MRL $\pm 10\%$, unless otherwise specified in individual methods—identify the source of any outliers and correct before sample quantitation.

Note: Do not use the correlation coefficient to verify a calibration's accuracy. However, many methods require verification of the correlation.

Verify the initial calibration by analyzing a standard prepared from a different stock standard than that used to create the calibration curve. Its concentration should be near the midpoint of the calibration range. The analytical results for this second-source midrange standard must be within 10% of its true value. If not, determine the cause of the error, and take corrective action.

Use the initial calibration to quantitate analytes of interest in samples. Use CCV (§ c below) only for calibration checks, not for sample quantitation. Perform initial calibration when the instrument is set up and whenever CCV criteria are not met.

c. Continuing calibration verification: In CCV, analysts periodically use a calibration standard to confirm that instrument performance has not changed since the initial calibration. Base the CCV interval on the number of samples analyzed (e.g., after every 10 samples and at least once per batch). Verify calibration by analyzing one standard whose concentration is at or near the

midpoint of the calibration range. The results must be within allowable deviations from either initial-calibration values or specific points on the calibration curve. If the CCV is out of control, then take corrective action—including reanalysis of any samples analyzed since the last acceptable CCV.

Refer to the method for CCV frequency and acceptance criteria; if not specified, use the criteria given here. Other concentrations (e.g., one near the MRL) may be used, but be aware that the acceptance criteria may vary depending on the standard's concentration.

2. Operational Range and MDL Determination

Before using a new method or instrument, determine its operational (calibration) range (upper and lower limits). Calibrate according to 5020 B.1, or verify the calibration by analyzing prepared standard solutions ranging from low to high concentrations. Determine the maximum concentration that can be measured within 10% of its true value based on the calibration curve: this is the *limit of linearity*. All samples that have concentrations above the limit of linearity or the highest calibration point, whichever is lower, must be diluted.

If reporting results < MRL, initially estimate the MDL as a concentration about 3 to 5 times lower than the minimum calibration standard. The method for determining the MDL is based on the procedure outlined by the US EPA.¹

To determine an MDL, prepare and analyze at least 7 portions of a solution spiked at or near the minimum calibration concentration and an equal number of blanks. Analysts should prepare and analyze the spikes and blanks over 3 d rather than performing them all in one batch. If one MDL will be used for multiple instruments, then the MDL analysis must be performed across all of them (however, it is unnecessary to analyze all samples on all instruments). Analysts must prepare and analyze at least 2 spikes and 2 blanks on different calendar dates for each instrument. If evaluating more than 3 instruments, then 1 set of spikes and blanks can be analyzed on multiple instruments, as long as at least 7 sets of spikes and blanks total are used. Alternatively, determine instrument-specific MDLs.

Calculate the estimated sample standard deviation, s_s , of the 7 replicates, and multiply by 3.14 to compute the MDL_s . Calculate MDL_b (MDL based on method blanks) using the following procedure.

If none of the method blanks give a numerical result (positive or negative), then MDL_b is not applicable, and $MDL = MDL_s$. If some give numerical results, then MDL_b equals the highest method blank result. If all of the method blanks give numerical results, calculate MDL_b as

$$MDL_b = X + 3.14S_b$$

where:

X = mean of blank results (set negative values to 0) and

S_b = standard deviation of blank results.

The MDL then equals whichever is greater: MDL_s or MDL_b .

If using more than 7 replicates, adjust the t value from 3.14 using Student t tables with $n-1$ degrees of freedom.

For methods in this section, spike recovery for MDL determinations must be within 50% to 150%, with an RSD of <20%.

If it does not meet these criteria, the MRL spiking level and calculated MDL are too low and must be repeated at a higher concentration.

3. Initial Demonstration of Capability

Each analyst in the laboratory should conduct an IDC at least once before analyzing any sample to demonstrate proficiency in performing the method and obtaining acceptable results for each analyte. The IDC also is used to demonstrate that a laboratory's modifications to a method produces results as precise and accurate as those produced by the reference method. As a minimum, include a reagent blank and at least 4 LFBs at a concentration between 1 to 10 times the MDL and the midpoint of the calibration curve (or other level specified in the method). Run the IDC after analyzing all required calibration standards. Ensure that the reagent blank does not contain any analyte of interest at a concentration greater than half the lowest calibration point (or other level specified in the method). Ensure that precision and accuracy (percent recovery) calculated for LFBs are within the acceptance criteria listed in the method of choice or generated by the laboratory (if there are no established mandatory criteria).

To establish laboratory-generated accuracy and precision limits, calculate the upper and lower control limits from the mean and standard deviation of percent recovery for 20 data points:

$$\text{Upper control limit} = \text{mean} + 3(\text{standard deviation})$$

$$\text{Lower control limit} = \text{mean} - 3(\text{standard deviation})$$

In the absence of established mandatory criteria, use laboratory-generated acceptance criteria for the IDC or else obtain acceptance criteria from a proficiency testing (PT) provider on PT studies and translate the data to percent recovery limits per analyte and method of choice. Ensure that lab-generated criteria are at least as tight as PT-study criteria, which are typically based on multiple laboratory results.

4. Ongoing Demonstration of Capability

The ongoing demonstration of capability, sometimes called a *laboratory control sample* (LCS), *laboratory control standard*, *QC check sample*, or *laboratory-fortified blank*, is used to ensure that the laboratory analysis remains in control while samples are analyzed and separates laboratory performance from method performance on the sample matrix. This standard should be preserved in accordance with method requirements and carried through the entire procedure, including any digestions, extraction, or filtration. Purchase an external QC standard (if available) from a reputable supplier and use the certified acceptance limits as the laboratory acceptance criteria.

Acceptance criteria vary depending on the method, matrix, and concentration. The concentration range may be either near the middle of the calibration range or near the maximum contaminant level (MCL), whichever is lower. Alternatively, prepare your own QC standard and calculate acceptance limits as ± 2 standard deviations based on analysis of ≥ 20 replicates, unless the method specifies acceptance limits.

Table 5020:1. Minimum Quality Control for Methods in Part 5000

| Section | Analyte | Method Blank | LFB | LFM and LFMD |
|---------------------|--|--------------|-----|--------------|
| 5210 B | BOD ^{a,b,c} | — | — | — |
| 5210 C | | — | — | — |
| 5210 D | | — | — | — |
| 5220 B | COD ^{a,b,c} | • | • | • |
| 5220 C | | • | • | • |
| 5220 D | | • | • | • |
| 5310 B | TOC ^{a,b,c} | • | • | • |
| 5310 C | | • | • | • |
| 5310 E | | • | • | • |
| 5320 B | Dissolved Organic Halogen ^{a,b,c} | • | • | • |
| 5510 B | Aquatic Humic Substances ^{a,b,c} | • | • | • |
| 5510 C | | • | • | • |
| 5520 B | Oil and Grease ^{a,b,c} | • | • | • |
| 5520 C | | • | • | • |
| 5520 D | | • | • | • |
| 5520 E | | • | • | • |
| 5520 F | | • | • | • |
| 5520 G | | • | • | • |
| 5530 B ^d | Phenols ^{a,b,c} | • | • | • |
| 5530 C | | • | • | • |
| 5530 D | | • | • | • |
| 5540 B ^d | Surfactants ^{a,b,c} | • | • | • |
| 5540 C | | • | • | • |
| 5540 D | | • | • | • |
| 5550 B | Tannin and Lignin ^{a,b,c} | • | • | • |
| 5560 B ^d | Organic/Volatile Acids ^{a,b,c} | • | • | • |
| 5560 C ^d | | • | • | • |
| 5560 D | | • | • | • |
| 5710 B | THMs and DBPs ^{a,b,c} | — | — | — |
| 5710 C | | — | — | — |
| 5710 D | | — | — | — |
| 5910 B | UV-Absorbing Organic Constituents ^{a,b,c} | • | — | — |

LFB = Laboratory-fortified blank; LFM = Laboratory-fortified matrix; LFMD = Laboratory-fortified matrix duplicate.

• indicates that a QC type is required for the method.

— indicates that a QC type is not required for the method.

^a Additional QC guidelines are in the method.

^b Duplicates or LFMD of the sample will be run.

^c Refer to 5020 B for further QC requirements.

^d A sample-preparation technique that is normally combined with a subsequent determinative technique

Note: This table is not comprehensive; refer to the specific method and 5020 B for further details.

5. Reagent Blank

A *reagent blank* (method blank) consists of reagent water (see Section 1080) and all reagents (including preservatives) that normally are in contact with a sample during the entire analytical procedure. The reagent blank is used to determine whether and how much reagents and the preparative analytical steps contribute to measurement uncertainty. As a minimum, include one reagent

blank with each sample set (batch) or on a 5% basis, whichever is more frequent. Analyze a blank after the initial CCV standard and before analyzing samples. Evaluate reagent-blank results for contamination; if contamination levels are unacceptable, identify and eliminate the source.

Positive sample results are suspect if analytes in the reagent blank are > 1/2 MRL, unless the method specifies otherwise. Samples analyzed with a contaminated blank must be reprepared

and reanalyzed unless concentrations are ≥ 10 times those of the blank, concentrations are nondetect, or data user will accept qualified data. See the method for specific reagent-blank acceptance criteria. General guidelines for qualifying sample results with regard to reagent-blank quality are as follows:

- If reagent blank is $< \text{MDL}$ and sample results are $> \text{MRL}$, then no qualification is required.
- If reagent blank is $> 1/2 \text{ MRL}$ but $< \text{MRL}$ and sample results are $> \text{MRL}$, then qualify results to indicate that analyte was detected in the reagent blank.
- If reagent blank is $> \text{MRL}$, then further corrective action and qualification is required.

6. Laboratory-Fortified Blank

A *laboratory-fortified blank* (LFB) is a reagent-water sample (with associated preservatives) to which a known concentration of the analytes of interest have been added. The LFB may be used as the LCS (5020 B.4) if the method requires a preliminary sample extraction or digestion.

An LFB is used to evaluate laboratory performance and analyte recovery in a blank matrix. Ideally, the concentration is high enough to be measured precisely, but not high enough to be irrelevant to measured environmental concentrations. As a minimum, include one LFB with each sample set (batch) or on a 5% basis, whichever is more frequent. (The definition of a batch is typically project-specific.)

Process the LFB through all sample preparation and analysis steps. Use an added concentration of at least $10 \times \text{MDL}$, at or below the midpoint of the calibration curve, a method-specified level, or a level specified in a project plan's data quality objectives. Ideally, the LFB concentration is less than the MCL (if the contaminant has one). Depending on method requirements, prepare the addition solution from either the same reference source used for calibration or an independent source. Evaluate the LFB for percent recovery of the added analytes by comparing results to method-specified limits, control charts, or other approved criteria. If LFB results are out of control, take corrective action, including re-preparation and reanalysis of associated samples if required. Use LFB results to evaluate batch performance, calculate recovery limits, and plot control charts.

7. Laboratory-Fortified Matrix

A *laboratory-fortified matrix* (LFM) is an additional portion of a sample to which a known amount of the analytes of interest is added before sample preparation. Some analytes are not appropriate for LFM analysis; see Table 5020:1 and specific methods for guidance on when an LFM is relevant.

The LFM is used to evaluate analyte recovery in a sample matrix. If an LFM is feasible and the method does not specify LFM frequency requirements, then include at least one LFM with each sample set (batch) or on a 5% basis, whichever is more frequent. Add a concentration that is at least $10 \times \text{MRL}$, less than or equal to the midpoint of the calibration curve, or method-specified level to the selected samples. Use the same concentration as for LFB (5020 B.6) to allow analysts to separate the matrix's effect from laboratory performance. Prepare LFM from

the same reference source used for LFB. Make the addition such that sample background levels do not adversely affect recovery (preferably adjust LFM concentrations if the known sample is more than 5 times the background level). For example, if the sample contains the analyte of interest, then add approximately as much analyte to the LFM sample as the concentration found in the known sample.

Evaluate LFM results for percent recovery; if they are not within control limits, then take corrective action to rectify the matrix effect, use another method, use the method of standard addition, or flag the data if reported. See the method for specific LFM-acceptance criteria until the laboratory develops statistically valid, laboratory-specific performance criteria. If the method does not provide limits, use the calculated preliminary limits from the IDC (5020 B.3). The LFM control limits may be wider than for LFB or LCS, and batch acceptance generally is not contingent upon LFM results.

8. Duplicate Sample and Laboratory-Fortified Matrix Duplicate

Duplicate samples are analyzed to estimate precision. If an analyte is rarely detected in a matrix type, use an LFM duplicate. An *LFM duplicate* is a second portion of the sample described in 5020 B.7 to which a known amount of the analytes of interest are added before sample preparation. If a sufficient sample volume is collected, this second portion of sample is added and processed in the same way as the LFM. As a minimum, include 1 duplicate sample or 1 LFM duplicate with each sample set (batch) or on a 5% basis, whichever is more frequent, and process it independently through the entire sample preparation and analysis.

Evaluate LFM duplicate results for precision and accuracy (precision alone for duplicate samples). If LFM duplicate results are out of control, then take corrective action to rectify the matrix effect, use another method, use the method of standard addition, or flag the data if reported. If duplicate results are out of control, then re-prepare and reanalyze the sample and take additional corrective action, as needed. When the value of one or both duplicate samples is $5 \times \text{MRL}$, the laboratory may use the MRL as the control limit, and the duplicate results are not used. See the method for specific acceptance criteria for LFM duplicates or duplicate samples until the laboratory develops statistically valid, laboratory-specific performance criteria. If the method does not provide limits, use the calculated preliminary limits from the IDC. In general, batch acceptance is not contingent upon LFM duplicate results.

9. Verification of MDL and MRL

With each analytical batch, analyze a reagent-water sample spiked at MRL and ensure that it meets MRL acceptance criteria (generally $\pm 50\%$). If not, reanalyze the entire batch or flag results for all samples in the batch.

If reporting to the MDL, then verify the MDL at least quarterly by analyzing a sample spiked at the same level used to determine the MDL and ensure that the result is positive. If 2 consecutive MDL-verification samples do not produce positive results, then recalculate the MDL using the most recent set of at least 7 blanks and MRL level spikes, following the protocols outlined in 5020 B.2.

10. QC Calculations

The following is a compilation of equations frequently used in QC calculations.

- a. Initial calibration:* See Section 1020 B.12a.
- b. Calibration verification:* See Section 1020 B.12b.
- c. Laboratory-fortified blank recovery:* See Section 1020 B.12c.
- d. Laboratory-fortified matrix:* See Section 1020 B.12e.
- e. Relative percent deviation:* See Section 1020 B.12f
- f. Standard additions:* See Section 1020 B.12g.

11. Control Charts

See Section 1020 B.13.

Reference

1. U.S. Environmental Protection Agency. III.H. Changes to method detection limit (MDL) procedure. In: Clean Water Act Methods Update Rule for the Analysis of Effluent. 2016. 40 CFR 136.