Direct-Reading Methods

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Contents

Introduction

This guideline provides a uniform and practical means for validating direct-reading monitor methods for workplace exposure of hazardous chemicals by the Occupational Safety and Heath Administration's (OSHA) Salt Lake Technical Center (SLTC). It defines required laboratory tests and statistical calculations with acceptance criteria for determining usability of direct-reading monitors. This guideline replaces a previous method validation guideline used by OSHA[1] and harmonizes validation tests, statistical calculations, terms, and definitions with the OSHA laboratory based sampling and analytical method guideline[2]. This guideline also explains how OSHA will evaluate and report sources of uncertainty using the approach outlined in ISO 20581:2016.[3] Unique methods and procedures that do not fit within the framework of this guideline may be developed to fulfill the needs of the agency using other appropriate tests and procedures.

Before approval and use, all validated methods will be reviewed by technical experts, and found to demonstrate that the method is clearly written using standardized language, that terms and numerical data are correctly used and presented, and that the validation requirements of this guideline have been met. All traceability documentation and data associated with a method must be stored in a standardized format and made accessible during the process of development and review, and future reference.

1 Preliminary Considerations

Review the literature, regulatory standards, and other appropriate sources of information to determine how and where the chemical substance is used in workplaces and how it is or may be regulated. Identify other common chemicals present in those workplaces that could cause monitoring interferences.

Consider basic requirements needed for field operations, such as working range, resolution, calibration setup, wearability/portability, battery life, etc. Compare working principles, specifications, and ease of use among various types of commercially available direct-reading monitors and explore ways to use common instrumentation aligned with other direct-reading methods.

1.1 Target Concentration Selection

Determine the concentration of the chemical substance at which the validation will be performed. This value, referred to as the target concentration (T_C), may be an OSHA Permissible Exposure Limit (PEL), an American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV), or some other occupational exposure limit (OEL) for which there is a basis for selection. The method can be validated at more than one concentration if the chemical substance has multiple exposure limits such as an 8-hour time weighted average (TWA), ceiling, peak, short-term exposure limit (STEL), action level, and immediately dangerous to life or health (IDLH) exposure level.

1.2 Testing Technique

The use of a dynamically generated controlled test atmosphere is the preferred technique for testing direct-reading monitors when air contaminants are encountered in the gas or vapor phase. When safety concerns or other problems prevent the use of a dynamically generated system, consider the use of static test atmospheres such as those prepared in gas-sampling bags. All test atmospheres generated must be non-condensing. Generate test atmospheres using either dry or humid air as specified in Section 2. Generate humid test atmospheres using a relative humidity and temperature that provides an absolute humidity of 15.7 ± 3.0 milligrams of water per liter of air, and dry test atmospheres at an absolute humidity of 3.92 ± 1.6 milligrams of water per liter of air. For example, 15.7 milligrams of water per liter of air is generated in a test atmosphere at 80% relative humidity and 22.2 °C, and 3.92 milligrams of water per liter of air is generated in a test atmosphere at 20% relative humidity and 22.2 °C. Generate test atmospheres at levels equivalent to the T_C at 25 °C and 760 mmHg, except as specified in Section 2. Also, for diffusive monitors, generate test atmospheres at a velocity of 0.5 m/s with flow directed across the sampling interface, except as specified in Sections 2.6 and 2.7.

1.3 Interference

The effect of water vapor on direct-reading monitors must always be considered. OSHA's experience is that water will usually have a detrimental effect on results, so testing is mostly done using humid air; however, testing is also done using dry air as in some cases this has also been shown to be detrimental.

Besides the effect of water, test other potential interferences as needed. Select representative interferences that are possibly present as air contaminants simultaneously with the target analyte(s) and are known or suspected to be problematic for the direct-reading monitor used.

2 Validation Testing

Validation tests are presented in logical order; however, the order in which tests are completed is not important. If possible, all validation tests should be performed using three distinct direct-reading monitors of the same type and manufacturer. Use an appropriate datalogging collection frequency based on the data storage capacity of the monitor and the recommended monitoring time specified in the final method. All reference and calibration materials should be accredited to ISO 17034:2016[4] and traceable to National Institute of Standards and Technology (NIST) or equivalent national or international standards, where possible. Use reagents of acceptable purity (e.g., reagent grade or better). Ensure that supplier information (including lot numbers) for reagents, standards, and expiration dates are captured in the traceability system used to document method development activities. Evaluate and respect expiration dates for standards and reagents. Validation testing instrumentation must be properly maintained and must be verified to be performing properly. Record all needed details regarding monitor performance and maintenance status, traceability, and testing details to allow evaluation and re-creation of all tests completed. Ensure that all relevant testing is documented, whether successful or not, to leave a data trail that may be important for future method development work. Compliance with these traceability and documentation requirements will result in a digitized data packet for validation work. Complete all final validation tests of record using the conditions described in the final method.

2.1 Time of Response

Determine the response time to attain 63% of the final steady-state measured value (t_{63})[5,6] for each direct-reading monitor using the following procedure:

1. Expose each monitor to test atmospheres at the proposed on-site method calibration concentration level and the midpoint concentration of the manufacturer-listed measurement range. Set test atmospheres to concentrations based on local temperature and pressure. The difference of relative

humidity of the test atmosphere between inside and outside shall be within ±5%. For example, if the relative humidity outside the test atmosphere is 40%, the relative humidity inside the test atmosphere should be within 35%-45%. Use 75% of the maximum manufacturer-listed working range concentration when the method calibration level is at or above the midpoint of the working range. Calibrate monitors in the test atmosphere at the level tested.

2. Allow monitor readings to stabilize outside the test atmosphere and then quickly place them into the test atmosphere. After the reading has stabilized quickly remove the monitors from the test atmosphere. Repeat this cycle six times at each concentration level.

3. Calculate $t_{63(rise)}$ for each exposure cycle using the five consecutive monitor readings nearest 50% of the exposure level during signal rise. For example, select the five monitor readings nearest 50 ppm when the test atmosphere concentration is 100 ppm. Plot $\ln(Y_{atm} - X_t)$ vs time for the five readings, where Y_{atm} is the test atmosphere concentration and X_t is the monitor reading at time t. Obtain the ordinary least squares (OLS) regression line equation and calculate $t_{63(rise)}$using Equation 1:

$$t_{63(rise)} = (m_{rise})^{-1} \tag{1}$$

where m_{rise} is the slope. Calculate the mean $t_{63(\mathrm{rise})}$ and percent coefficient of variation (%CV) for each monitor and exposure level.

4. Calculate $t_{63(decay)}$ for each exposure cycle using the five consecutive monitor readings nearest 50% of the exposure level during signal decay. Plot $\ln(X_t)$ vs time for the five reading, where X_t is the monitor reading at time t. Obtain the OLS regression line equation and calculate $t_{63(decay)}$ using Equation 2:

$$t_{63(decay)} = (m_{decay})^{-1} \tag{2}$$

where m_{decay} is the slope. Calculate the mean $t_{63(decay)}$ and %CV for each monitor and exposure level.

5. Calculate the mean t_{63} by combining $t_{63(rise)}$ and $t_{63(decay)}$ at both levels for each monitor. If the %CV for an individual monitor at a calibration level is greater than 25%, increase the method calibration level and return to Step 1. Use the highest mean t_{63} to obtain stable readings for the remaining validation tests.

2.2 Calibration

Calibrate direct-reading monitors using a 2-point calibration procedure as follows:

1. Zero-calibrate monitor with zero or clean air.

2. Span-calibrate monitor with the on-site calibration level that leads to an acceptable %CV (see Section 2.1 Step 5).

2.3 Limit of Detection and Reporting Limit

Determine the limit of detection (LOD) using the following procedure:

1. Calibrate three monitors using the calibration procedure determined in Section 2.2.

2. Expose each monitor to six evenly spaced humid test atmosphere levels from clean/zero air to the level producing a response approximately five times the monitor resolution. Generate test atmospheres without correcting concentrations for temperature and pressure (i.e., 25 °C and 760 mmHg).

3. Expose each monitor at each level for a monitoring time greater than or equal to 10× t_{63} determined in Section 2.1 to obtain a stable reading.

4. Plot response versus concentration and determine the slope (m) from an OLS linear regression line equation.

5. Calculate the standard error of estimate using Equation 3

$$S_{y/x} = \sqrt{\frac{\sum(y_i - \hat{y})^2}{n - k}} \tag{3}$$

   where $S_{y/x}$ is the standard error of estimate; y_i is the observed response; $\hat{y}$ is the calculated response from the line equation, n is the number of levels tested (six); and k is 2 for linear regression.

6. Calculate the LOD using Equation 4:

$$LOD = \frac{3.3 \times S_{y/x}}{m} \tag{4}$$

   where LOD is the limit of detection in terms of air concentration; $S_{y/x}$ is the standard error of estimate; and m is the slope. Equation 4 assumes that the probability of a false positive and of a false negative are both 5%, and results are not blank corrected.[7–11] Calculate the LOD as the average limit of detection of all monitors tested.

7. Designate the reporting limit (RL) as the nearest tested concentration to the LOD with a percent recovery within ±25% for all three monitors.

2.4 Working Range

Determine the working range using the following procedure:

1. Calibrate three monitors using the calibration procedure determined in Section 2.2.

2. Expose each monitor to ten evenly spaced humid test atmosphere levels with concentrations ranging from the reporting limit to 90% of the maximum manufacturer-listed measurement value. Generate test atmospheres without correcting concentrations for temperature and pressure (i.e., 25 °C and 760 mmHg).

3. Expose each monitor at each level for a monitoring time greater than or equal to 10× t_{63} determined in Section 2.1 to obtain a stable reading.

4. Calculate the percent recovery of each monitor at each level.

5. Calculate the mean percent recovery at each level.

6. Define the working range by including the reporting limit and all levels in sequence above the reporting limit for which the recoveries are within ±10%.

2.5 Method Precision and Bias

2.5.1 TWA Monitoring

Determine the method precision and bias of TWA monitoring (e.g., PEL, STEL) using the following procedure:

1. Calibrate three monitors using the calibration procedure determined in Section 2.2.

2. Expose each monitor to five levels (i.e., 0.1, 0.5, 1.0, 2.0 and 5.0× the T_C) using a humid test atmosphere and the recommended monitoring time. If 0.1× T_C is < RL, then use the RL as the lowest testing level. If the T_C is ≥ 20% of the maximum working range determined in the Section 2.4, set five reasonable levels for testing.

3. Calculate the percent recovery of each monitor at each level.

4. Calculate the mean recovery and variance at each level.

5. Apply a Dixon Q test for possible mean recovery outlier values and a Cochran C test for within-level variance outliers across the five levels tested (both at the 95% confidence level).[12] A difference in variance between levels, or a mean recovery outlier, should be investigated to determine if it is due to the testing procedure or monitor performance.

2.5.2 Transient Monitoring

Determine the method precision and bias of transient monitoring (e.g., ceiling, peak, IDLH) using the following procedure:

1. Calibrate three monitors using the calibration procedure determined in Section 2.2.

2. Expose each monitor to five levels (i.e., 0.75, 0.9, 1.0, 1.1 and 1.25× the T_C) using a humid test atmosphere and a monitoring time greater than or equal to 10× t_{63} determined in Section 2.1 to obtain a stable reading.

3. Calculate the percent recovery of each monitor at each level.

4. Calculate the mean percent recovery and variance at each level.

5. Apply a Dixon Q test for possible mean recovery outlier values and a Cochran C test for within-level variance outliers across the five levels tested (both at the 95% confidence level).[12] A difference in variance between levels, or a mean recovery outlier, should be investigated to determine if it is due to the testing procedure or monitor performance.

2.6 Effect of Face Velocity

Determine the effect of face velocity for diffusive monitors using the following procedure:

1. Calibrate three monitors using the calibration procedure determined in Section 2.2.

2. Expose each monitor to a 1.0× T_C humid test atmosphere at five different face velocities (i.e., 0.1, 0.3, 0.5, 0.7 and 1.0 m/s) using a monitoring time greater than or equal to 10× t_{63} determined in Section 2.1 to obtain a stable reading.

3. Calculate the percent recovery of each monitor at each level.

4. Calculate the mean percent recovery at each level.

5. Calculate the effect of face velocity (Δ_v) as the absolute difference between the highest and lowest mean recoveries. If Δ_v is > 10%, consider changes to the sampling procedure to reduce variation (i.e., convert the diffusive monitor into an active monitor by installing an external pump).

2.7 Effect of Orientation

Determine the effect of orientation for diffusive monitors using the following procedure:

1. Calibrate three monitors using the calibration procedure determined in Section 2.2.

2. Expose each monitor to a 1.0× T_C humid test atmosphere with two orientations (e.g., 0° and 90° to gas flow direction) using a monitoring time greater than or equal to 10× t_{63} determined in Section 2.1 to obtain a stable reading. Set the face velocity to 0.5 m/s for both orientations.

3. Calculate the percent recovery of each monitor at each orientation.

4. Calculate the mean percent recovery at each orientation.

5. Calculate the effect of orientation (Δ_o) as the absolute difference of the mean recoveries between the orientations. If Δ_o is > 10%, consider changes to the sampling procedure to reduce variation (i.e., convert the diffusive monitor into an active monitor by installing an external pump).

2.8 Effect of Humidity

Determine the effect of humidity using the following procedure:

1. Calibrate three monitors using the calibration procedure determined in Section 2.2.

2. Expose each monitor to a dry test atmosphere at 1.0× T_C in the same manner used in Section 2.5.

3. Calculate the percent recovery of each monitor.

4. Calculate the dry mean percent recovery.

5. Calculate the effect of humidity (Δ_h) as the absolute difference between the dry mean recovery and the humid mean recovery from the 1.0× T_C precision test determined in Section 2.5.

2.9 Effect of Interferents

Prioritize potential interferents by assessing possible field scenarios combined with the cross-sensitivities of known interferents provided by the manufacturer. Determine the effect of interferents using the following procedure:

1. Calibrate three monitors using the calibration procedure determined in Section 2.2.

2. Expose each monitor to a 1.0× T_C humid test atmosphere combined with 1.0× T_C of the interferent in the same manner used in Section 2.5.

3. Calculate the percent recovery of each monitor.

4. Calculate the mean percent recovery.

5. Calculate the effect of the interferent (Δ_i) as the absolute difference between the mean recovery with the interferent and the mean recovery determined in Section 2.5.

2.10 Effect of Intermittent Exposure

Determine the effect of intermittent exposure on TWA monitoring using the following procedure:

1. Calibrate three monitors using the calibration procedure determined in Section 2.2.

2. Perform an intermittent exposure cycle test by exposing each monitor to a 1.0× T_C test atmosphere for an exposure time equivalent to 2.3× t_{63} determined in Section 2.1, followed by zero or clean air for the same exposure time. Continuously repeat the above exposure cycle ten times. Set the relative humidity of the test atmosphere as close as possible to the relative humidity used in Section 2.1.

3. Perform a steady exposure test by exposing each monitor to the above 1.0× T_C test atmosphere for an exposure time equivalent to 23× t_{63} determined in Section 2.1.

4. Determine the total exposure time for each test from the initial monitor response to the final monitor response.

5. Calculate the percent recovery of each monitor based on the total exposure time for each test.

6. Calculate the mean percent recovery for each test.

7. Calculate the effect of intermittent exposure (Δ_{ie}) as the absolute difference between the mean TWA recovery from intermittent exposure and the mean TWA recovery from the steady exposure.

2.11 Effect of Temperature

Determine the effect of temperature using the following procedure:

1. Calibrate three monitors at the ambient temperature using the calibration procedure determined in Section 2.2.

2. Equilibrate all monitors at ambient temperature, 5 °C and 50 °C for 1 hour, respectively.

3. Exposure each monitor equilibrated at each temperature to a 1.0× T_C humid test atmosphere levels using a monitoring time greater than or equal to 10× t_{63} determined in Section 2.1 to obtain a stable reading.

4. Calculate the percent recovery of each monitor at each temperature.

5. Calculate the mean percent recovery at each temperature.

6. Calculate the effect of temperature (Δ_T) as the absolute difference between the highest mean recovery and lowest mean recovery.

2.12 Effect of Oversaturation

Determine the effect of oversaturation using the following procedure:

1. Calibrate three monitors using the calibration procedure determined in Section 2.2.

2. Expose each monitor to a humid test atmosphere at 2.0× the maximum manufacturer-listed measurement value for 10 minutes.

3. Expose each oversaturated monitor to the air outside the test atmosphere for 60 minutes.

4. Expose each monitor to a span gas at the concentration of the calibration gas used in Section 2.2 using a monitoring time greater than or equal to 10× t_{63} determined in Section 2.1 to obtain a stable

reading. If monitors do not match within ±5% of the concentration of span gas, suspected oversaturated exposure events should be recorded during field operations.

2.13 Reproducibility

Determine if the direct-reading procedure is reproducible using the following procedure:

1. Provide three monitors and accessories to the SLTC Production Team for monitoring along with a complete draft copy of the proposed method. The analyst will conduct the direct-reading measurement relying solely on the draft method for guidance.

2. Request the analyst to monitor a humid test atmosphere set at 1.0× T_C.

3. No individual monitoring result may deviate from the calculated value by more than the expanded uncertainty determined in Section 3.2. If excess deviation occurs, steps must be taken to determine and eliminate the error (e.g., lack of clarity in the method instructions provided in the draft copy), followed by a repeat of the test.

3 Estimation of Method Uncertainty

3.1 Uncertainty Components

3.1.1 Calibration Standard

Determine the uncertainty components associated with the concentration of the calibration standard. These components depend on how the calibration standard is made and can include the following:

- purity of the starting material (e.g., purity >99.0%);
- uncertainty associated with measuring the starting material (e.g., weighing, pipetting);
- uncertainty associated with diluting;
- laboratory temperature and pressure.

Calculate the relative standard uncertainty for the calibration standard (u_{cs}) by propagation of errors using the appropriate uncertainty components. Examples of the calculation of u_{cs} can be found in Eurachem's *Quantifying Uncertainty in Analytical Measurement* guide.[13]

3.1.2 Precision

Calculate the uncertainty associated with method precision as described in Section C.6.2 of ISO/DIS 22065:2018[14],using Equation 5:

$$u_{mp} = \sqrt{(CV_m)^2 + \left(1 - \frac{1}{n}\right)(CV_{pl})^2} \tag{5}$$

where u_{mp} is the percent relative standard uncertainty of method precision, CV_m is coefficient of variation of the means of the five levels tested in Section 2.5 (expressed as percent), n is the number of replicate samples tested per level (three), CV_{pl} is the pooled coefficient of variation of the five levels tested in Section 2.5 (expressed as percent), calculated using Equation 6:

$$CV_{pl} = \sqrt{\frac{(CV_1)^2 + (CV_2)^2 + \cdots + (CV_5)^2}{5}} \tag{6}$$

where CV_1, through CV_5 are the coefficients of variation of the five levels tested expressed as percent values.

3.1.3 Bias

Calculate the uncertainty associated with method bias using Equation 7:

$$u_{mb} = \sqrt{\left(\frac{B_{mb}}{\sqrt{3}}\right)^2 + \left(\frac{CV_{mb}}{\sqrt{n}}\right)^2 + (u_{rc})^2} \tag{7}$$

where u_{mb} is the percent relative standard uncertainty of the method bias, B_{mb} is the absolute difference between the mean percent recovery of the fifteen method precision samples analyzed in Section 2.5 and the calculated 100% recovery value, CV_{mb} is the percent coefficient of variation of the recovery of the fifteen samples analyzed in Section 2.5, n is fifteen, and u_{rc} is the percent relative standard uncertainty of the reference concentration sampled. For gas and vapor dynamic test atmosphere generation, use an estimated u_{rc} value of 3% as suggested in ISO/DIS 22065:2018.[14]

3.1.4 Effect of Face Velocity

Calculate the uncertainty associated with face velocity, assuming a rectangular probability distribution, using Equation 8:

$$u_v = \frac{\Delta_v}{\sqrt{3}} \tag{8}$$

where u_v is the percent relative standard uncertainty of the effect of face velocity, and Δ_v is the effect of face velocity difference calculated in Section 2.6, expressed as percent.

3.1.5 Effect of Orientation

Calculate the uncertainty associated with orientation, assuming a rectangular probability distribution, using Equation 9:

$$u_o = \frac{\Delta_o}{\sqrt{3}} \tag{9}$$

where u_o is the percent relative standard uncertainty of the effect of orientation, and Δ_o is the effect of orientation difference calculated in Section 2.7, expressed as percent.

3.1.6 Effect of Humidity

Calculate the uncertainty associated with humidity, assuming a rectangular probability distribution, using Equation 10:

$$u_h = \frac{\Delta_h}{\sqrt{3}} \tag{10}$$

where u_h is the percent relative standard uncertainty of the effect of humidity, and Δ_h is the effect of humidity difference calculated in Section 2.8, expressed as percent.

3.1.7 Effect of Interferents

Calculate the uncertainty associated with an interferent, assuming a rectangular probability distribution, using Equation 11:

$$u_i = \frac{\Delta_i}{\sqrt{3}} \tag{11}$$

where u_i is the percent relative standard uncertainty of the effect of an interferent, and Δ_i is the effect of an interferent difference calculated in Section 2.9, expressed as percent.

3.1.8 Effect of Intermittent Exposure

Calculate the uncertainty associated with intermittent exposure, assuming a rectangular probability distribution, using Equation 12:

$$u_{ie} = \frac{\Delta_{ie}}{\sqrt{3}} \tag{12}$$

where u_{ie} is the percent relative standard uncertainty of the effect of intermittent exposure, and Δ_{ie} is the effect of intermittent exposure difference calculated in Section 2.10, expressed as percent.

3.1.9 Effect of Temperature

Calculate the uncertainty associated with temperature, assuming a rectangular probability distribution, using Equation 13:

$$u_T = \frac{\Delta_T}{\sqrt{3}} \tag{13}$$

where u_T is the percent relative standard uncertainty of the effect of temperature, and Δ_T is the effect of temperature difference calculated in Section 2.11, expressed as percent.

3.1.10 Effect of Resolution

Calculate the uncertainty associated with resolution, assuming a rectangular probability distribution, using Equation 14:

$$u_{res} = \frac{Res}{2 \times \sqrt{3} \times T_c} \times 100\% \tag{14}$$

where u_{res} is the percent relative standard uncertainty of the effect of resolution, and Res is the resolution at the T_C.

3.1.11 Monitor Response Drift

Calculate the uncertainty associated with monitor response drift, assuming a rectangular probability distribution, using Equation 15:

$$u_{dr} = \frac{d_{max}}{\sqrt{3}} \tag{15}$$

where u_{dr} is the percent relative standard uncertainty of the instrument response drift, and d_{max} is the percent maximum allowed instrument response drift of a continuing calibration standard.

3.2 Combined Standard Uncertainty and Expanded Uncertainty

Calculate the combined uncertainty using Equation 16:

$$u = \sqrt{\sum_{i=1}^{n} (u_i)^2} \tag{16}$$

where u is the combined percent relative standard uncertainty, u_i is the relevant uncertainty components calculated in Section 3.1, and n is the number of relevant uncertainty components.

Calculate the expanded uncertainty using Equation 17:

$$U = k \times u \tag{17}$$

where U is the percent expanded uncertainty of the procedure, u is the combined relative standard uncertainty, and k is the coverage factor. For a two-sided 95% confidence interval use a coverage factor of 2.

4 Preparation of Written Method

Include the following sections in OSHA methods for direct-reading monitors:

- Cover Page

- Introduction
- Monitoring Procedure
- Data Processing Procedure
- Method Validation and Estimation of Measurement Uncertainty
- References

The following information will be included in the header of every page: version number, state, date, method number, and title. The cover page will include, CAS No., OSHA PEL, type(s) of PEL (e.g., "general industry," "construction," and/or "shipyard" as applicable), other appropriate OEL values, a brief description of the monitoring procedure, recommended monitoring time, RL, working range, uncertainty, any special requirements, and author. A version number beginning with 1 will be assigned to new methods and incremented by 1 for any change. When a method is updated and approved, the new approval date will be in the header of the document and a description of the changes will be included in the Introduction. All methods with a reported combined uncertainty will be considered validated.

In the Introduction section, include relevant historical information regarding previous methods and procedures used or tested by OSHA, along with any informative information from the literature. In the Monitoring Procedure and Data Processing Procedure sections, describe the materials and procedures used for performing monitoring and data processing. In the Validation section, describe the results from the validation tests performed and include a description of the testing procedures. For the Estimation of Measurement Uncertainty, list the monitoring uncertainty component values. Include comments to ensure clarity on how values were determined and the expanded uncertainty value with the coverage factor.

Present experimentally derived data with appropriate significant figures. Report percentages to one decimal place, unless the value is less than 1%, then report two or more decimal places. Report uncertainty and expanded uncertainty using two significant figures. Report RL in accordance with precision of the resolution.

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