may include time to purge an instrument and time to account for its response.

(5) Sample and record values for 30 seconds, record the arithmetic mean, $\bar{y}_i$, and record the standard deviation, σ_i, of the recorded values. Refer to § 1065.602 for an example of calculating arithmetic mean and standard deviation.

(6) Also, if the reference quantity is not absolutely constant, which might be the case with a reference flow, sample and record values of y_{refi} for 30 seconds and record the arithmetic mean of the values, $\bar{y}_{ref}$. Refer to § 1065.602 for an example of calculating arithmetic mean.

(7) Subtract the reference value, y_{ref} (or $\bar{y}_{ref}$), from the arithmetic mean, $\bar{y}_i$. Record this value as the error, ε_i.

(8) Repeat the steps specified in paragraphs (d)(2) through (6) of this section until you have ten arithmetic means ($\bar{y}_1$, $\bar{y}_2$, $\bar{y}_i$,. . . $\bar{y}_{10}$), ten standard deviations, (σ_1, σ_2, σ_i,. . .σ_{10}), and ten errors (ε_1, ε_2, ε_i,. . .ε_{10}).

(9) Use the following values to quantify your measurements:

(i) *Accuracy*. Instrument accuracy is the absolute difference between the reference quantity, y_{ref} (or $\bar{y}_{ref}$), and the arithmetic mean of the ten $\bar{y}_i$, $\bar{y}$ values. Refer to the example of an accuracy calculation in § 1065.602. We recommend that instrument accuracy be within the specifications in Table 1 of § 1065.205.

(ii) *Repeatability*. Repeatability is two times the standard deviation of the ten errors (that is, repeatability = $2 \cdot \sigma_\varepsilon$). Refer to the example of a standard-deviation calculation in § 1065.602. We recommend that instrument repeatability be within the specifications in Table 1 of § 1065.205.

(iii) *Noise*. Noise is two times the root-mean-square of the ten standard deviations (that is, noise = $2 \cdot rms_\sigma$) when the reference signal is a zero-quantity signal. Refer to the example of a root-mean-square calculation in § 1065.602. We recommend that instrument noise be within the specifications in Table 1 of § 1065.205. Use this value in the noise correction specified in § 1065.657.

(10) You may use a measurement instrument that does not meet the accuracy, repeatability, or noise specifications in Table 1 of § 1065.205, as long as you meet the following criteria:

(i) Your measurement systems meet all the other required calibration, verification, and validation specifications in subparts D, F, and J of this part, as applicable.

(ii) The measurement deficiency does not adversely affect your ability to demonstrate compliance with the applicable standards.

§ 1065.307 Linearity verification.

(a) *Scope and frequency*. Perform a linearity verification on each measurement system listed in Table 1 of this section at least as frequently as indicated in the table, consistent with measurement system manufacturer recommendations and good engineering judgment. Note that this linearity verification may replace requirements we previously referred to as ''calibrations''. The intent of a linearity verification is to determine that a measurement system responds proportionally over the measurement range of interest. A linearity verification generally consists of introducing a series of at least 10 reference values to a measurement system. The measurement system quantifies each reference value. The measured values are then collectively compared to the reference values by using a least squares linear regression and the linearity criteria specified in Table 1 of this section.

(b) *Performance requirements*. If a measurement system does not meet the applicable linearity criteria in Table 1 of this section, correct the deficiency by re-calibrating, servicing, or replacing components as needed. Before you may use a measurement system that does not meet linearity criteria, you must demonstrate to us that the deficiency does not adversely affect your ability to demonstrate compliance with the applicable standards.

(c) *Procedure*. Use the following linearity verification protocol, or use good engineering judgment to develop a different protocol that satisfies the intent of this section, as described in paragraph (a) of this section:

(1) In this paragraph (c), we use the letter ''*y*'' to denote a generic measured quantity, the superscript over-bar

to denote an arithmetic mean (such as $\bar{y}$), and the subscript ''$_{ref}$'' to denote the known or reference quantity being measured.

(2) Operate a measurement system at its specified temperatures, pressures, and flows. This may include any specified adjustment or periodic calibration of the measurement system.

(3) Zero the instrument as you would before an emission test by introducing a zero signal. Depending on the instrument, this may be a zero-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a zero gas that meets the specifications of § 1065.750 and introduce it directly at the analyzer port.

(4) Span the instrument as you would before an emission test by introducing a span signal. Depending on the instrument, this may be a span-concentration gas, a reference signal, a set of reference thermodynamic conditions, or some combination of these. For gas analyzers, use a span gas that meets the specifications of § 1065.750 and introduce it directly at the analyzer port.

(5) After spanning the instrument, check zero with the same signal you used in paragraph (c)(3) of this section. Based on the zero reading, use good engineering judgment to determine whether or not to rezero and or re-span the instrument before proceeding to the next step.

(6) Use instrument manufacturer recommendations and good engineering judgment to select at least 10 reference values, y_{refi}, that are within the range from zero to the highest values expected during emission testing. We recommend selecting a zero reference signal as one of the reference values of the linearity verification.

(7) Use instrument manufacturer recommendations and good engineering judgment to select the order in which you will introduce the series of reference values. For example you may select the reference values randomly to avoid correlation with previous measurements, you may select reference values in ascending or descending order to avoid long settling times of reference signals, or as another example you may select values to ascend and then descend which might incorporate the effects of any instrument hysteresis into the linearity verification.

(8) Generate reference quantities as described in paragraph (d) of this section. For gas analyzers, use gas concentrations known to be within the specifications of § 1065.750 and introduce them directly at the analyzer port.

(9) Introduce a reference signal to the measurement instrument.

(10) Allow time for the instrument to stabilize while it measures the reference value. Stabilization time may include time to purge an instrument and time to account for its response.

(11) At a recording frequency of at least *f* Hz, specified in Table 1 of § 1065.205, measure the reference value for 30 seconds and record the arithmetic mean of the recorded values, $\bar{y}_i$. Refer to § 1065.602 for an example of calculating an arithmetic mean.

(12) Repeat steps in paragraphs (c)(9) through (11) of this section until all reference quantities are measured.

(13) Use the arithmetic means $\bar{y}_i$, and reference values, y_{refi}, to calculate least-squares linear regression parameters and statistical values to compare to the minimum performance criteria specified in Table 1 of this section. Use the calculations described in § 1065.602.

(d) *Reference signals.* This paragraph (d) describes recommended methods for generating reference values for the linearity-verification protocol in paragraph (c) of this section. Use reference values that simulate actual values, or introduce an actual value and measure it with a reference-measurement system. In the latter case, the reference value is the value reported by the reference-measurement system. Reference values and reference-measurement systems must be NIST-traceable. We recommend using calibration reference quantities that are NIST-traceable within 0.5% uncertainty, if not specified otherwise in other sections of this part 1065. Use the following recommended methods to generate reference values or use good engineering judgment to select a different reference:

(1) *Engine speed.* Run the engine or dynamometer at a series of steady-state speeds and use a strobe, a photo tachometer, or a laser tachometer to record reference speeds.

(2) *Engine torque.* Use a series of calibration weights and a calibration lever arm to simulate engine torque. You may instead use the engine or dynamometer itself to generate a nominal torque that is measured by a reference load cell or proving ring in series with the torque-measurement system. In this case use the reference load cell measurement as the reference value. Refer to § 1065.310 for a torque-calibration procedure similar to the linearity verification in this section.

(3) *Electrical work.* Use a controlled source of current and a watt-hour standard reference meter. Complete calibration systems that contain a current source and a reference watt-hour meter are commonly used in the electrical power distribution industry and are therefore commercially available.

(4) *Fuel rate.* Operate the engine at a series of constant fuel-flow rates or recirculate fuel back to a tank through the fuel flow meter at different flow rates. Use a gravimetric reference measurement (such as a scale, balance, or mass comparator) at the inlet to the fuel-measurement system. Use a stopwatch or timer to measure the time intervals over which reference masses of fuel are introduced to the fuel measurement system. The reference fuel mass divided by the time interval is the reference fuel flow rate.

(5) *Flow rates—inlet air, dilution air, diluted exhaust, raw exhaust, or sample flow.* Use a reference flow meter with a blower or pump to simulate flow rates. Use a restrictor, diverter valve, a variable-speed blower or a variable-speed pump to control the range of flow rates. Use the reference meter's response as the reference values.

(i) *Reference flow meters.* Because the flow range requirements for these various flows are large, we allow a variety of reference meters. For example, for diluted exhaust flow for a full-flow dilution system, we recommend a reference subsonic venturi flow meter with a restrictor valve and a blower to simulate flow rates. For inlet air, dilution air, diluted exhaust for partial-flow dilution, raw exhaust, or sample flow, we allow reference meters such as critical flow orifices, critical flow venturis, laminar flow elements, master mass flow standards, or Roots meters. Make sure the reference meter is calibrated by the flow-meter manufacturer and its calibration is NIST-traceable. If you use the difference of two flow measurements to determine a net flow rate, you may use one of the measurements as a reference for the other.

(ii) *Reference flow values.* Because the reference flow is not absolutely constant, sample and record values of $\dot{n}_{refi}$ for 30 seconds and use the arithmetic mean of the values, $\bar{\dot{n}}_{ref}$, as the reference value. Refer to § 1065.602 for an example of calculating arithmetic mean.

(6) *Gas division.* Use one of the two reference signals: (i) At the outlet of the gas-division system, connect a gas analyzer that meets the linearity verification described in this section and has not been linearized with the gas divider being verified. For example, verify the linearity of an analyzer using a series of reference analytical gases directly from compressed gas cylinders that meet the specifications of § 1065.750. We recommend using a FID analyzer or a PMD/MPD O_2 analyzer because of their inherent linearity. Operate this analyzer consistent with how you would operate it during an emission test. Connect a span gas to the gas-divider inlet. Use the gas-division system to divide the span gas with purified air or nitrogen. Select gas divisions that you typically use. Use a selected gas division as the measured value. Use the analyzer response divided by the span gas concentration as the reference gas-division value. Because the instrument response is not absolutely constant, sample and record values of x_{refi} for 30 seconds and use the arithmetic mean of the values $\bar{x}_{ref}$, as the reference value. Refer to § 1065.602 for an example of calculating arithmetic mean.

(ii) Using good engineering judgment and gas divider manufacturer recommendations, use one or more reference flow meters to verify the measured flow rates of the gas divider.

(7) *Continuous constituent concentration*. For reference values, use a series of gas cylinders of known gas concentration or use a gas-division system that is known to be linear with a span gas. Gas cylinders, gas-division systems, and span gases that you use for reference values must meet the specifications of § 1065.750.

Table 1 of §1065.307–Measurement systems that require linearity verifications

Measurement System	Quantity	Minimum verification frequency[a]	Linearity Criteria			
			$\lvert a_0 \rvert$[b]	a_1[c]	SEE[b]	r^2
Engine speed	f_n	Within 370 days before testing	$\leq 0.05\ \% \cdot f_{max}$	0.98-1.02	$\leq 2\ \% \cdot f_{max}$	≥ 0.990
Engine torque	T	Within 370 days before testing	$\leq 1\ \% \cdot T_{max}$	0.98-1.02	$\leq 2\ \% \cdot T_{max}$	≥ 0.990
Electrical work	W	Within 370 days before testing	$\leq 1\ \% \cdot W_{max}$	0.98-1.02	$\leq 2\ \% \cdot W_{max}$	≥ 0.990
Fuel flow rate	$\dot{m}$	Within 370 days before testing[d]	$\leq 1\ \% \cdot \dot{m}_{max}$	0.98-1.02[e]	$\leq 2\ \% \cdot \dot{m}_{max}$	≥ 0.990
Intake-air flow rate	$\dot{n}$	Within 370 days before testing[d]	$\leq 1\ \% \cdot \dot{n}_{max}$	0.98-1.02[e]	$\leq 2\ \% \cdot \dot{n}_{max}$	≥ 0.990
Dilution air flow rate	$\dot{n}$	Within 370 days before testing[d]	$\leq 1\ \% \cdot \dot{n}_{max}$	0.98-1.02	$\leq 2\ \% \cdot \dot{n}_{max}$	≥ 0.990
Diluted exhaust flow rate	$\dot{n}$	Within 370 days before testing[d]	$\leq 1\ \% \cdot \dot{n}_{min}$	0.98-1.02	$\leq 2\ \% \cdot \dot{n}_{max}$	≥ 0.990
Raw exhaust flow rate	$\dot{n}$	Within 185 days before testing[d]	$\leq 1\ \% \cdot \dot{n}_{max}$	0.98-1.02[e]	$\leq 2\ \% \cdot \dot{n}_{max}$	≥ 0.990
Batch sampler flow rates	$\dot{n}$	Within 370 days before testing[d]	$\leq 1\ \% \cdot \dot{n}_{max}$	0.98-1.02	$\leq 2\ \% \cdot \dot{n}_{max}$	≥ 0.990
Gas dividers	x	Within 370 days before testing	$\leq 0.5\ \% \cdot x_{max}$	0.98-1.02	$\leq 2\ \% \cdot x_{max}$	≥ 0.990
All gas analyzers	x	Within 35 days before testing	$\leq 0.5\ \% \cdot x_{max}$	0.99-1.01	$\leq 1\ \% \cdot x_{max}$	≥ 0.998
PM balance	m	Within 370 days before testing	$\leq 1\ \% \cdot m_{max}$	0.99-1.01	$\leq 1\ \% \cdot m_{max}$	≥ 0.998
Stand-alone pressures	p	Within 370 days before testing	$\leq 1\ \% \cdot p_{max}$	0.99-1.01	$\leq 1\ \% \cdot p_{max}$	≥ 0.998
Stand-alone temperatures	T	Within 370 days before testing	$\leq 1\ \% \cdot T_{max}$	0.99-1.01	$\leq 1\ \% \cdot T_{max}$	≥ 0.998

[a] Perform a linearity verification more frequently if the instrument manufacturer recommends it or based on good engineering judgment.

[b] "max" refers to the maximum value expected during a test—the maximum value used for the linearity verification.

[c] The specified ranges are inclusive. For example, a specified range of 0.98-1.02 for a_1 means $0.98 \leq a_1 \leq 1.02$.

[d] These linearity verifications are not required for systems that pass the flow-rate verification for diluted exhaust as described in §1065.341 (the propane check) or for systems that agree within ±2 % based on a chemical balance of carbon or oxygen of the intake air, fuel, and exhaust.

[e] a_0 and a_1 for these quantities are required only if the actual value of the quantity is required, as opposed to a signal that is only linearly proportional to the actual value.

§ 1065.308 Continuous gas analyzer system-response and updating-recording verification.

(a) *Scope and frequency*. Perform this verification after installing or replacing a gas analyzer that you use for continuous sampling. Also perform this verification if you reconfigure your system in a way that would change system response. For example, perform