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Standard Practice for Validation of the Performance of Process Stream Analyzer Systems¹

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~~^{ε1}Note—Updated Fig. 5 editorially in November 2006.~~

INTRODUCTION

Operation of a process stream analyzer system typically involves four sequential activities. (1) **Analyzer Calibration**—When an analyzer is initially installed, or after major maintenance has been performed, diagnostic testing is performed to demonstrate that the analyzer meets the manufacturer's specifications and historical performance standards. These diagnostic tests may require that the analyzer be adjusted so as to provide predetermined output levels for certain reference materials. (2) **Correlation**—Once the diagnostic testing is completed, process stream samples are analyzed using the analyzer system. For application where the process analyzer system results are required to agree with results produced from an independent (primary) test method (PTM), a mathematical function is derived that relates the analyzer results to the primary test method results (PTMR). The application of this mathematical function to an analyzer result produces a predicted primary test method result (PPTMR). (3) **Probationary Validation**—After the correlation relationship between the analyzer results and primary test method results has been established, a probationary validation is performed using an independent but limited set of materials that were not part of the correlation activity. This probationary validation is intended to demonstrate that the PPTMRs agree with the PTMRs to within user-specified requirements for the analyzer system application. (4) **General and Continual Validation**—After an adequate amount of PPTMRs and PTMRs have been accrued on materials that were not part of the correlation activity, a comprehensive statistical assessment is performed to demonstrate that the PPTMRs agree with the PTMRs to within the tolerances established from the correlation activities. Subsequent to a successful general validation, quality assurance control chart monitoring of the differences between PPTMR and PTMR is conducted during normal operation of the process analyzer system to demonstrate that the agreement between the PPTMRs and PTMRs established in the General Validation is maintained. This practice deals with the third and fourth of these activities.

1. Scope

1.1 This practice describes procedures and methodologies based on the statistical principles of Practice D 6708 to validate whether the degree of agreement between the results produced by a total analyzer system (or its subsystem), versus the results produced by an independent test method that purports to measure the same property, meets user-specified requirements. This is a performance-based validation, to be conducted using a set of materials that are not used a priori in the development of any correlation between the two measurement systems under investigation. A result from the independent test method is herein referred to as a Primary Test Method Result (PTMR).

1.2 This practice assumes any correlation necessary to mitigate systemic biases between the analyzer system and PTM have been applied to the analyzer results.

1.3 This practice requires that both the primary method against which the analyzer is compared to, and the analyzer system under investigation, are in statistical control. Practices described in Practice D 6299 should be used to ensure this condition is met.

¹ This practice is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.25 on Performance Assessment and Validation of Process Stream Analyzer Systems for Petroleum and Petroleum Products.

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1.4 This practice applies if the process stream analyzer system and the primary test method are based on the same measurement principle(s), or, if the process stream analyzer system uses a direct and well-understood measurement principle that is similar to the measurement principle of the primary test method. This practice also applies if the process stream analyzer system uses a different measurement technology from the primary test method, provided that the calibration protocol for the direct output of the analyzer does not require use of the PTMRs (see Case 1 in Note 1).

1.5 This practice does not apply if the process stream analyzer system utilizes an indirect or mathematically modeled measurement principle such as chemometric or multivariate analysis techniques where PTMRs are required for the chemometric or multivariate model development. Users should refer to Practice D 6122 for detailed validation procedures for these types of analyzer systems (see Case 2 in Note 1).

NOTE 1—For example, for the measurement of benzene in spark ignition fuels, comparison of a Mid-Infrared process analyzer system based on Test Method D 6277 to a Test Method D 3606 gas chromatography primary test method would be considered Case 1, and this practice would apply. For each sample, the Mid-Infrared spectrum is converted into a single analyzer result using methodology (Test Method D 6277) that is independent of the primary test method (Test Method D 3606). However, when the same analyzer uses a multivariate model to correlate the measured Mid-Infrared spectrum to Test Method D 3606 reference values using the methodology of Practice E 1655, it is considered Case 2 and Practice D 6122 applies. In this case 2 example, the direct output of the analyzer is the spectrum, and the conversion of this multivariate output to an analyzer result require use of Practice D 6122, hence it is not independent of the primary test method.

1.6 Performance Validation is conducted by calculating the precision and bias of the differences between results from the analyzer system (or subsystem) after the application of any necessary correlation, (such results are herein referred to as Predicted Primary Test Method Results (PPTMRs)), versus the PTMRs for the same sample set. Results used in the calculation are for samples that are not used in the development of the correlation. The calculated precision and bias are statistically compared to user-specified requirements for the analyzer system application.

1.6.1 For analyzers used in product release or product quality certification applications, the precision and bias requirement for the degree of agreement are typically based on the site or published precision of the Primary Test Method.

NOTE 2—In most applications of this type, the PTM is the specification-cited test method.

1.6.2 This practice does not describe procedures for establishing precision and bias requirements for analyzer system applications. Such requirements must be based on the criticality of the results to the intended business application and on contractual and regulatory requirements. The user must establish precision and bias requirements prior to initiating the validation procedures described herein.

1.7 Two procedures for validation are described: the line sample procedure and the validation reference material (VRM) injection procedure.

1.8 Only the analyzer system or subsystem downstream of the VRM injection point or the line sample extraction point is being validated by this practice.

1.9 The line sample procedure is limited to applications where material can be safely withdrawn from the sampling point of the analyzer unit without significantly altering the property of interest.

1.10 Validation information obtained in the application of this practice is applicable only to the type and property range of the materials used to perform the validation.

1.11 Two types of validation are described: General Validation, and Level Specific Validation. These are typically conducted at installation or after major maintenance once the system mechanical fitness-for-use has been established.

1.11.1 General Validation is based on the statistical principles and methodology of Practice D 6708. In most cases, General Validation is preferred, but may not always be possible if the variation in validation materials is insufficient. General Validation will validate analyzer operation over a wider operating range than Level Specific Validation.

1.11.2 When the variation in available validation materials is insufficient to satisfy the requirements of Practice D 6708, a Level Specific Validation is done to validate analyzer operation over a limited range.

1.11.3 The validation outcome are considered valid only within the range covered by the validation material Data from several different Validations (general or level-specific) can potentially be combined for use in a General Validation.

1.12 Procedures for the continual validation of system performance are described. These procedures are typically applied at a frequency commensurate with the criticality of the application.

1.13 This practice does not address procedures for diagnosing causes of validation failure.

1.14 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

- D 1265 Practice for Sampling Liquefied Petroleum (LP) Gases, Manual Method
 - D 3606 Test Method for Determination of Benzene and Toluene in Finished Motor and Aviation Gasoline by Gas Chromatography
 - D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products
 - D 4177 Practice for Automatic Sampling of Petroleum and Petroleum Products
 - D 5842 Practice for Sampling and Handling of Fuels for Volatility Measurement
 - D 6122 Practice for Validation of the Performance of Multivariate Process Infrared Spectrophotometer Based Analyzer Systems
 - D 6277 Test Method for Determination of Benzene in Spark-Ignition Engine Fuels Using Mid Infrared Spectroscopy
 - D 6299 Practice for Applying Statistical Quality Assurance and Control Charting Techniques to Evaluate Analytical Measurement System Performance
 - D 6708 Practice for Statistical Assessment and Improvement of Expected Agreement Between Two Test Methods that Purport to Measure the Same Property of a Material
 - E 456 Terminology Relating to Quality and Statistics
 - E 1655 Practices for Infrared Multivariate Quantitative Analysis
 - F 307 Practice for Sampling Pressurized Gas for Gas Analysis
- 2.2 *ASTM Adjuncts:*
 Software Program CompTM, adjunct to Practice D 6708³

3. Terminology

3.1 Definitions:

3.1.1 *accepted reference value (ARV), n*—a value that serves as an agreed-upon reference for comparison, and which is derived as: (1) a theoretical or established value, based on scientific principles, (2) an assigned or certified value, based on experimental work of some national or international organization, or (3) a consensus or certified value, based on collaborative experimental work under the auspices of a scientific or engineering group. **E 456**

3.1.2 *cross-method reproducibility (R_{XY}), n*—a quantitative expression of the random error associated with the difference between two results obtained by different operators using different apparatus and applying the two methods *X* and *Y*, respectively, each obtaining a single result on an identical test sample, when the methods have been assessed and an appropriate bias-correction has been applied in accordance with this practice; it is defined as the 95 % confidence limit for the difference between two such single and independent results. **D 6708**

3.1.2.1 *Discussion*—Within the context of this practice, R_{XY} is interpreted to be the 95 % confidence limit for the prediction deviation between any single Primary Test Method Result (PTMR) and the Predicted Primary Test Method Result (PPTMR) produced by the analyzer system that is deemed acceptable on the assumption that both the analyzer system and primary test method are in statistical control, and that the correlation relationship applied to the analyzer results to produce the PPTMR is fit-for-purpose. **E 456**

3.1.3 *precision, n*—the closeness of agreement between independent test results obtained under stipulated conditions. **E 456**

3.1.4 *repeatability conditions, n*—conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time. **E 456**

3.1.5 *reproducibility conditions, n*—conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment. **E 456**

3.1.6 *site precision conditions, n*—conditions under which test results are obtained by one or more operators in a single site location practicing the same test method on a single measurement system using test specimens taken at random from the same sample of material, over an extended period of time spanning at least a 15 day interval. **D 6299**

3.1.6.1 *Discussion*—A measurement system may comprise multiple instruments being used for the same test method.

3.1.7 *site precision, n*—2.77 times the standard deviation of results obtained under site precision conditions. **D 6299**

3.2 Definitions of Terms Specific to This Standard:

3.2.1 Analyzer System Items:

3.2.1.1 *analyzer output, n*—a signal (pneumatic, electrical, or digital), proportional to the property being measured that is suitable for readout or control instrumentation external to the analyzer system.

3.2.1.2 *analyzer system result, n*—the measured property reading, in the accepted property measurement units, that is displayed by the analyzer unit readout instrumentation or transmitted to end user of the analyzer system.

3.2.1.3 *analyzer unit, n*—the instrumental equipment necessary to automatically measure the physical or chemical property of a process or product stream sample using either an intermittent or a continuous technique.

3.2.1.4 *analyzer unit repeatability, n*—2.77 times the standard deviation of results obtained from repetitive analysis of the same material directly injected into the analyzer unit under repeatability conditions.

3.2.1.5 *continuous analyzer unit, n*—an analyzer that measures the property value of a process or product stream on a continuous basis and dynamically displays the instantaneously updated analyzer output.

³ Available from ASTM International Headquarters. Order Adjunct No. ADJD6708. Original adjunct produced in 2005.

3.2.1.6 *intermittent analyzer unit, n*—a cyclic type analyzer that performs a measurement sequence on samples from a process or product stream and displays a new analyzer output at the conclusion of each cycle.

3.2.1.7 *total analyzer system, n*—the complete analyzer system inclusive of the sample loop, sample conditioning unit, analyzer unit, readout instrumentation, and excess sample return system (see Fig. 1).

3.2.1.8 *line sample, n*—an aliquot of material taken from the process stream that is intended to be used to perform analyzer system validation as per this standard.

3.2.2 *Time Unit Items—General Terms:*

3.2.2.1 *analyzer unit cycle time, n*—for intermittent analyzers, the time interval between successive updates of the analyzer output.

3.2.2.2 *analyzer unit dead time, n*—the time interval between the introduction of a step change in property characteristic at the inlet of the analyzer unit and the initial indication of analyzer response to this change.

(1) *Discussion*—For intermittent analyzers, if the analyzer dead time is less than one analyzer unit cycle time, the analyzer unit dead time cannot be directly measured.

3.2.2.3 *analyzer unit response time, n*—(see Fig. 2) the time interval between the introduction of a step change in property characteristic at the inlet of the analyzer unit and when the analyzer output indicates a value corresponding to 99.5 % of the subsequent change in analyzer results.

(1) *Discussion*—For continuous and intermittent analyzers with sufficiently short cycle times, the total analyzer response time is the analyzer dead time plus three times the analyzer unit time constant. For intermittent analyzers with long cycle times, the analyzer unit response time is effectively equal to the analyzer unit cycle time. For intermittent analyzers with intermediate cycle times, the analyzer unit response time should be defined as the multiple of the analyzer unit cycle time needed to exceed 99.5 % response.

3.2.2.4 *analyzer unit time constant, n*—(see Fig. 2) the time interval between the initial response of the analyzer unit to a step change in property characteristic and when the analyzer output indicates a value corresponding to 63 % of the subsequent change in analyzer results.

(1) *Discussion*—For intermittent analyzers, if the analyzer unit time constant is less than one analyzer unit cycle time, the analyzer time constant cannot be directly measured.

3.2.2.5 *lag time, n*—the time required for material to travel from Point A to Point B in the total analyzer system (Points A and B are user-defined).

(1) *Discussion*—Lag time is a function of an analyzer system design parameters such as length and diameter of lines, number of fittings, flow restrictions, and the flow rate of the material (process or product stream) through the analyzer system (see Figs. 2 and 1).

3.2.2.6 *sample conditioning unit lag time, n*—the time required for material to travel from the start of the sample conditioning unit to the analyzer unit inlet.

3.2.2.7 *sample loop lag time, n*—the time required for material to travel from the process takeoff point of the sample loop to start of the sample conditioning unit.

3.2.2.8 *total analyzer system response time, n*—(see Fig. 2) The time interval between when a step change in property characteristic at the sample loop inlet and when the analyzer output indicates a value *c* corresponding to the 99.5 % of the subsequent change in analyzer results; the total analyzer system response time is the sum of the sample loop lag time, the same

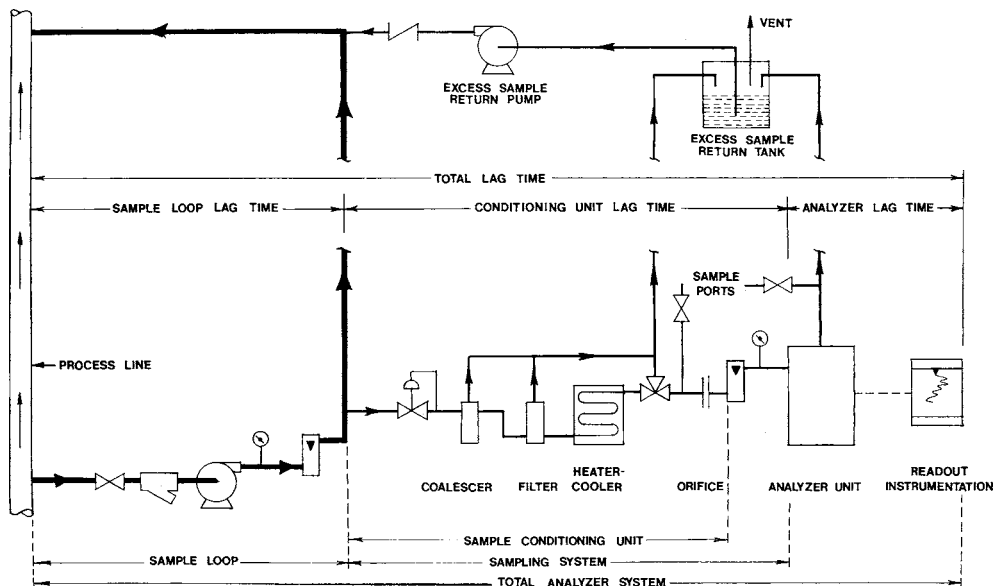


FIG. 1 Total Analyzer System

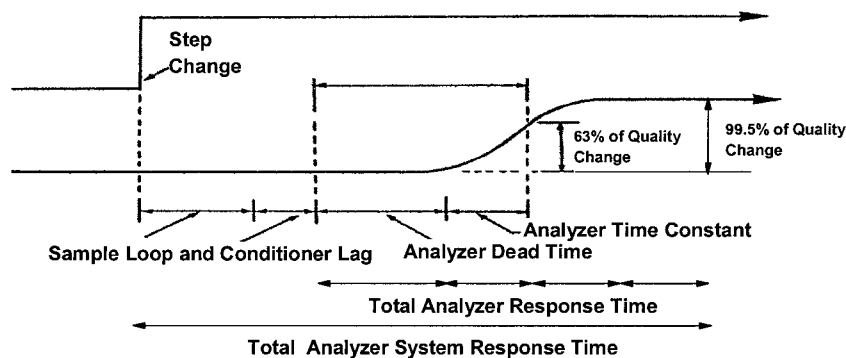


FIG. 2 Analyzer Time Units

conditioning loop lag time, and the total analyzer response time.

3.2.3 General Terms:

3.2.3.1 *composition-specific VRM, n*—a validation reference material consisting of a single, pure compound, or a known, reproducible mixture of compounds for which an accepted reference value or site assigned value can be calculated or measured.

(1) *Discussion*—A composition-specific VRM may be a commercial standard reference material (SRM) having a certified accepted reference value.

3.2.3.2 *continual validation, n*—the quality assurance process by which the bias and precision performance determined during initial validation are shown to be sustained.

3.2.3.3 *direct measurement, n*—a quantitative measurement result obtained using a principle or principles that express the characteristic property of interest in its defining units.

3.2.3.4 *indirect measurement, n*—a correlated quantitative measurement result obtained using a measurement principle that produces values that do not express the desired characteristic property but which can be modified empirically, using mathematical modeling techniques, to estimate the necessary defining units of the property of interest.

(1) *Discussion*—Methods that utilize chemometric or multivariate analysis are indirect measurements for generating correlative characteristic property measurement results.

3.2.3.5 *line sample, n*—process material that can be safely withdrawn from a sample port and associated facilities located anywhere in the total analyzer system without significantly altering the property of interest.

3.2.3.6 *prediction deviations (Δ), n*—calculated differences (including algebraic sign) between predicted primary test method result and primary test result, defined as (PPTMR – PTMR).

(1) *Discussion*—This is also referred to as prediction residuals in Practice D 6708.

3.2.3.7 *primary test method results (PTMR), n*—test results produced from an ASTM or other established standard test method that are accepted as the reference measure of a property.

3.2.3.8 *predicted Primary Test Method Results (PPTMR), n*—results from the analyzer system, after application of any necessary correlation, that is interpreted as predictions of what the primary test method results would have been, if it was conducted on the same material.

3.2.3.9 *process-derived VRM, n*—a validation reference material derived from an isolated batch of process or product stream material with chemical or physical characteristics, or both, that is suitable for determination of an accepted reference value or site assigned value for the property of interest.

3.2.3.10 *site assigned value (SAV), n*—a property value of a reference material that is based on multiple results from either the analyzer unit or a primary test method, obtained under site precision conditions.

3.2.3.11 *validation, n*—the statistically quantified judgment that the analyzer system or subsystem, in conjunction with any correlation applied, can produce acceptable precision and bias performance on the prediction deviations (Δ) for materials that were not used to develop the correlation.

3.2.3.12 *validation reference material (VRM), n*—for validation and quality assurance testing, a material having an accepted reference value or site assigned value for the property of interest.

4. Summary of Practice

4.1 PPTMRs from the total analyzer system or its subsystem are compared to the corresponding PTMRs on at least 15 materials. PPTMR and PTMR are statistically assessed relative to each other using the methodology of Practice D 6708, recognizing that this is only a preliminary Practice D 6708 assessment. Precision and bias statistics on the prediction deviations (Δ) are generated and the bias is assessed against pre-specified performance criteria. The system or subsystem performance is considered to be probationary validated for materials and property ranges representative of those used in the validation if the prediction deviations are in statistical control, and bias performance statistic meets pre-specified criterion.

4.2 After probationary validation is achieved, continued statistical quality control chart monitoring and analyses on Δ are carried out with new production samples to ensure on-going prediction performance of the PPTMR meets the levels established from the probationary validation.

4.3 Once the total number of samples with completed datasets (PPTMR , PTMR , Δ) from probationary and continual validation reaches 30, a general validation is conducted using the statistical methodology of Practice D 6708. The objective of the general validation is to demonstrate performance with at least 30 samples over a wider operating envelope, or, to confirm outcome from probationary validation with more accrued data.

4.4 If the variation among the 30 samples is inadequate to conduct the Practice D 6708 assessment, a level specific validation may be performed to validate the agreement between PPTMR and PTMR over a narrow operating range. As additional (PPTMR / PTMR / Δ) datasets are collected covering a wider operating range, the general validation may again be attempted.

4.5 After general validation has been achieved, continue to monitor Δ using statistical quality control charts at a frequency commensurate with the criticality of the application.

5. Significance and Use

5.1 This practice can be used to quantify the performance of a process stream analyzer system or its subsystem in terms of precision and bias relative to those of a primary test method for the property of interest.

5.2 This practice provides developers or manufacturers of process stream analyzer systems with useful procedures for evaluating the capability of newly designed systems for industrial applications that require reliable prediction of measurements of a specific property by a primary test method of a flowing component or product.

5.3 This practice provides purchasers of process stream analyzer systems with some reliable options for specifying acceptance test requirements for process stream analyzer systems at the time of commissioning to ensure the system is capable of making the desired property measurement with the appropriate precision or bias specifications, or both.

5.4 PPTMR from Analyzer Systems validated in accordance with this practice can be used to predict, with a specified confidence, what the PTMR would be, to within a specified tolerance, if the actual primary test method was conducted on the materials that are within the validated property range and type.

5.5 This practice provides the user of a process stream analyzer system with useful information from on-going quality control charts to monitor the variation in Δ over time, and trigger update of correlation relationship between the analyzer system and primary test method in a timely manner.

5.6 Validation information obtained in the application of this practice is applicable only to the material type and property range of the materials used to perform the validation. Selection of the property levels and the compositional characteristics of the samples must be suitable for the application of the analyzer system. This practice allows the user to write a comprehensive validation statement for the analyzer system including specific limits for the validated range of application. This practice does not recommend extrapolation of validation results beyond the material type and property range used to obtain these results. In addition, users are cautioned that for measurement systems that show matrix dependencies, bias information determined from pure compounds or simple mixtures of pure compounds may not be representative of that achieved on actual process or product samples.

6. System Components

6.1 Fig. 1 illustrates a total analyzer system incorporating a selection and arrangement of components that are typical but not specific for any particular analyzer system. A total analyzer system design addresses the chemical and physical properties of the process or product stream to be measured, provides a representative sample, and handles it without adversely affecting the value of the specific property of interest. Included are a sample loop, piping, hardware, a sampling port, sample conditioning devices, an analyzer unit instrumentation, any data analysis computer hardware and software, and a readout display.

6.2 *Sample Loop*—Piping connected to the main process stream to deliver a portion of the stream to a location close to the analyzer system with minimum lag time and return the unused material to the main process stream.

6.3 *Sampling System*—Sample probes, valves, lines, containers, pressure regulator, and gages that constitute the equipment employed to obtain a proper sample from the sample loop and introduce either it or a validation standard sample to the analyzer.

6.4 *Sample Conditioning Unit*—A collection of devices to properly treat a portion of the sample from the sample loop so that it meets the requirements for testing by the process analyzer. These components can incorporate temperature or pressure adjustment, change of state (liquid, vapor), or removal of contaminants.

6.5 *Inlet Port*—Appropriate piping with selector valve(s) for placement either at the inlet to the analyzer unit or, when dictated by the measurement specifications, at the inlet to the sample conditioning unit. The purpose of this inlet port is to allow injection of validation standards or other calibration material into the analyzer system with quick switching between these typically containerized materials and the flowing process stream.

6.5.1 For many analyzer systems the inlet port requires a manifold arrangement for validation or quality assurance studies. Such a manifold, with suitable valving, provides a means to use a containerized supply of standby material when a flowing process stream is not available for the purpose. It also permits quick switching between different validation standards when that is desirable.

6.6 *Sample Port*—An appropriate probe or fitting in the piping to permit collection of representative samples for laboratory analyses using a primary test method.

6.7 *Analyzer Unit*—Instrumentation designed to automatically measure the chemical or physical property of a process or product stream sample and provide either an intermittent or a continuous output signal representing the measurement result.