



Designation: **D5110–98 (Reapproved 2017) D5110 – 22**

Standard Practice for Calibration of Ozone Monitors and Certification of Ozone Transfer Standards Using Ultraviolet Photometry¹

This standard is issued under the fixed designation D5110; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers a means for calibrating ambient, workplace, or indoor ozone monitors, and for certifying transfer standards to be used for that purpose.

1.2 This practice describes means by which dynamic streams of ozone in air can be designated as primary ozone standards.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* See Section 8 for specific precautionary statements.

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

[ASTM D5110-22](#)

<https://standards.iteh.ai/catalog/standards/sist/9392c667-b1e9-4846-af93-f0284c19c432/astm-d5110-22>

2.1 ASTM Standards:²

[D1356 Terminology Relating to Sampling and Analysis of Atmospheres](#)

[D3195 Practice for Rotameter Calibration](#)

[D3249 Practice for General Ambient Air Analyzer Procedures](#)

[D3631 Test Methods for Measuring Surface Atmospheric Pressure](#)

[D5011 Practices for Calibration of Ozone Monitors Using Transfer Standards](#)

[E220 Test Method for Calibration of Thermocouples By Comparison Techniques](#)

[E591 Practice for Safety and Health Requirements Relating to Occupational Exposure to Ozone \(Withdrawn 1990\)](#)³

[E644 Test Methods for Testing Industrial Resistance Thermometers](#)

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, refer to Terminology [D1356](#).

3.2 *Definitions of Terms Specific to This Standard:*

¹ This practice is under the jurisdiction of ASTM Committee [D22](#) on Air Quality and is the direct responsibility of Subcommittee [D22.03](#) on Ambient Atmospheres and Source Emissions.

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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.

³ The last approved version of this historical standard is referenced on www.astm.org.

3.2.1 *primary standard, n*—a standard directly defined and established by some authority, against which all secondary standards are compared.

3.2.2 *secondary standard, n*—a standard used as a means of comparison, but checked against a primary standard.

3.2.3 *standard, n*—an accepted reference sample or device used for establishing measurement of a physical quantity.

3.2.4 *transfer standard, n*—a type of secondary standard. It is a transportable device or apparatus that, together with operational procedures, is capable of reproducing pollutant concentration or producing acceptable assays of pollutant concentrations.

3.2.5 *zero air, n*—purified air that does not contain ozone, and does not contain any other component that may interfere with the measurement (see 7.1).

4. Summary of Practice

4.1 This practice is based on the photometric assay of ozone (O_3) concentrations in a dynamic flow system. The concentration of O_3 in an absorption cell is determined from a measurement of the amount of 253.7 nm light absorbed by the sample. This determination requires knowledge of (1) the absorption coefficient of O_3 at 253.7 nm, (2) the optical path length through the sample, (3) the transmittance of the sample at a wavelength of 253.7 nm, and (4) the temperature and pressure of the sample. The transmittance is defined as the ratio:

$$I/I_o$$

where:

I = the intensity of light that passes through the cell and is sensed by the detector when the cell contains an O_3 sample, and
 I_o = the intensity of light that passes through the cell and is sensed by the detector when the cell contains zero air.

It is assumed that all conditions of the system, except for the contents of the absorption cell, are identical during measurements of I and I_o . The quantities defined above are related by the Beer-Lambert absorption law:

$$\text{Transmittance} = I/I_o = e^{-acd} \quad (1)$$

where:

a = absorption coefficient of O_3 at 253.7 nm, $(308 \pm 4) \times 10^{-6} \text{ ppm}^{-1} \text{ cm}^{-1}$ at 0°C and 101.3 kPa (1 atm) **(1-8)**,⁴
 a = absorption coefficient of O_3 at 253.7 nm, $(304.39 \pm 0.94) \times 10^{-6} \text{ ppm}^{-1} \text{ cm}^{-1}$ at 0°C and 101.3 kPa (1 atm) **(1-9)**,⁴
 c = O_3 concentration, ppm, and
 d = optical path length, cm.

4.1.1 In practice, a stable O_3 generator (see 6.1.4) is used to produce O_3 concentrations over the required range. Each O_3 concentration is determined from the measurement of the transmittance of the sample at 253.7 nm, and is calculated from the equation:

$$c = \frac{-\ln \frac{I}{I_o}}{(ad)} \quad (2)$$

The calculated O_3 concentrations must be corrected for O_3 losses, which may occur in the photometer, and for the temperature and pressure of the sample.

5. Significance and Use

5.1 The reactivity and instability of O_3 preclude the storage of O_3 concentration standards for any practical length of time, and precludes direct certification of O_3 concentrations as Standard Reference Materials (SRMs). Moreover, there is no available SRM that can be readily and directly adapted to the generation of O_3 standards analogous to permeation devices and standard gas cylinders for sulfur dioxide and nitrogen oxides. Dynamic generation of O_3 concentrations is relatively easy with a source of

⁴ The boldface numbers in parentheses refer to the references listed at the end of this practice.

ultraviolet (UV) radiation. However, accurately certifying an O₃ concentration as a primary standard requires assay of the concentration by a comprehensively specified analytical procedure, which must be performed every time a standard is needed (910).

5.2 This practice is not designed for the routine calibration of O₃ monitors at remote locations (see Practices D5011).

6. Apparatus

6.1 A typical complete UV calibration system consists of an O₃ generator, an output port or manifold, a photometer, a source of zero air, and other components as necessary. The configuration must provide a stable O₃ concentration at the system output and allow the photometer to assay accurately the output concentration to the precision specified for the photometer. Fig. 1 shows the system, and illustrates the calibration system. Ozone is highly reactive and subject to losses upon contact with surfaces. All components between the O₃ generator and the photometer absorption cell shall be of inert material, such as glass or TFE-fluorocarbon. Lines and interconnections shall be as short as possible, and all surfaces shall be chemically clean. For certification of transfer standards that provide their own source of O₃, the generator and possibly other components shown in Fig. 1 may not be required (see Practices D5011).

6.1.1 *UV Photometer*, consisting of a low-pressure mercury discharge lamp, collimation optics (optional), an absorption cell, a detector, and signal-processing electronics, as shown in Fig. 1. It shall be capable of measuring the transmittance, I/I_0 , at a wavelength of 253.7 nm with sufficient precision that the standard deviation of the concentration measurements does not exceed the greater of 0.005 ppm or 3 % of the concentration. It shall incorporate means to assure that no O₃ is generated in the cell by the UV lamp. This is generally accomplished by absorbing the 184.9 nm Hg line with a high silica window, or by isolating the

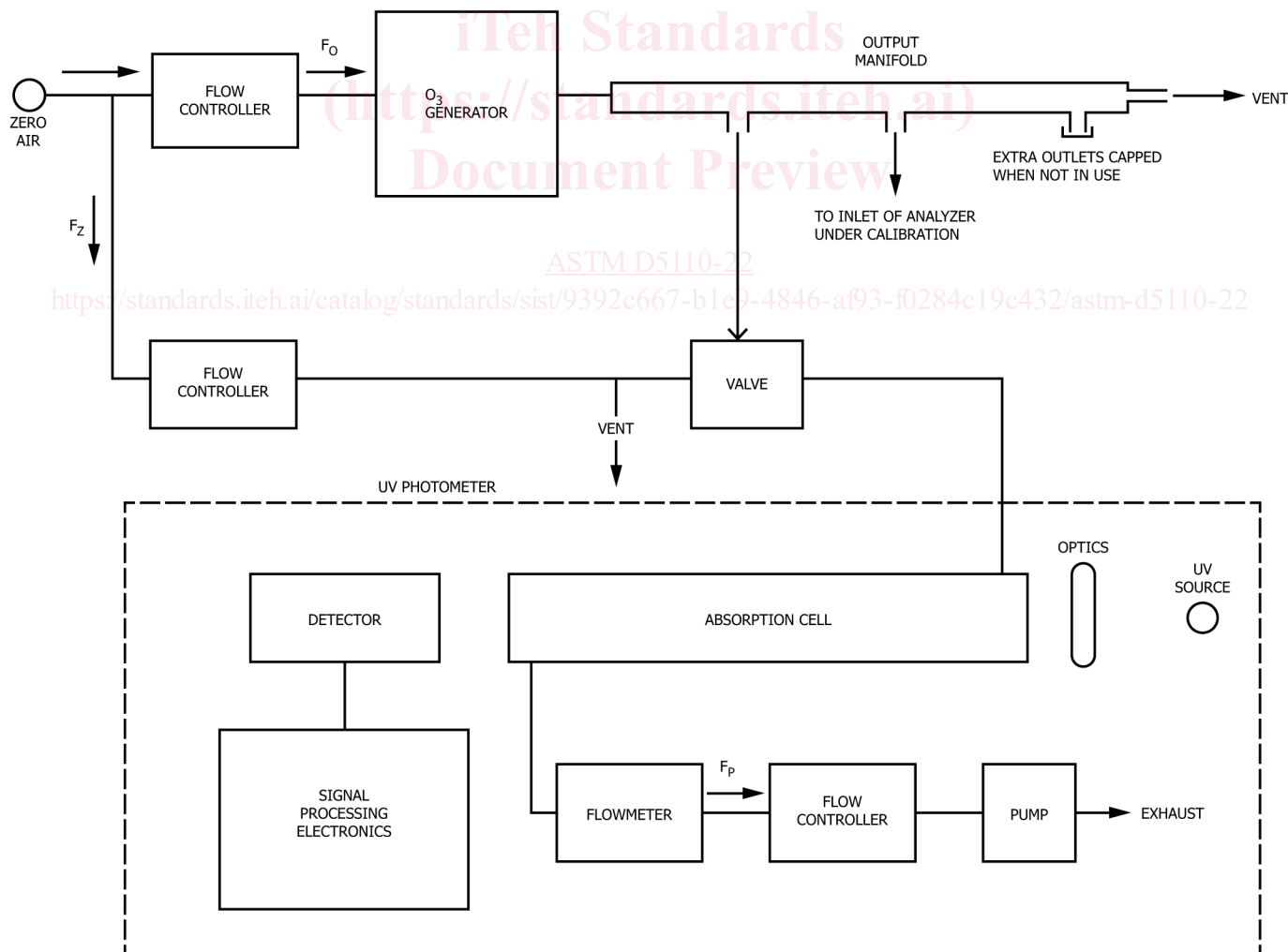


FIG. 1 Schematic Diagram of a Typical UV Photometric Calibration System

253.7 nm Hg line with an interference filter. In addition, at least 99.5 % of the radiation sensed by the detector shall be 253.7 nm. This is usually accomplished by using a solar blind photodiode tube. The length of the light path through the absorption cell shall be known with an accuracy of at least 0.5 %. In addition, the cell and associated plumbing shall be designed to minimize loss of O₃ from contact with surfaces (~~H11~~).

6.1.2 *Air Flow Controller*, capable of regulating air flows as necessary to meet the output stability and photometer precision requirements.

6.1.3 *Flowmeters*, calibrated in accordance with Practice **D3195**.

6.1.4 *Ozone Generator*, capable of generating stable levels of O₃ over the required concentration range. It shall be stable over short periods to facilitate the sequential photometric measurement of *I* and *I*_o, and to allow for stability of the monitor or transfer standard connected to the output manifold. Conventional UV-photolytic type generators may be adequate, but shall have line voltage and temperature regulation.

6.1.5 *Output Manifold*, constructed of glass, TFE-fluorocarbon, or other nonreactive material. It shall be of sufficient diameter to ensure a negligible pressure drop at the photometer connection and other output ports. The output manifold serves the function of providing an interface between the calibration system and other devices and systems that utilize the output O₃ concentrations. It shall have one or more ports for connection of the external instruments or systems, and shall be such that all ports provide the same O₃ concentrations. The vent, which exhausts excess gas flow from the system and insures that the manifold outlet ports are kept at atmospheric pressure for all flowrates, shall be large enough to avoid appreciable pressure drop, and shall be located downstream of the output ports to ensure that no ambient air enters the manifold due to eddy currents, back diffusion, and so forth.

6.1.6 *Three-Way Valve*, constructed of TFE-fluorocarbon, to switch the flow through the absorption cell from zero air (for the *I*_o measurement) to manifold gas (for the *I* measurement).

6.1.7 *Temperature Indicator*, accurate to ±1°C. This indicator is needed to measure the temperature of the gas in the photometric cell to calculate a temperature correction. In most photometers, particularly those whose cell is enclosed inside a case or housing with other electrical or electronic components, the cell operates at a temperature somewhat above ambient room temperature. Therefore, it is important to measure the temperature of the gas inside the cell, and not room temperature. A small thermocouple or thermistor, connected to an external readout device, may be attached to the cell wall or inserted through the cell wall to measure internal cell temperature. The point of temperature sensing shall be representative of the average cell temperature. The temperature sensing device shall be calibrated against a NIST certified thermometer initially, and at periodic intervals, subject to the laboratory quality control checks (~~H12~~). See Test Method **E220** or Test Methods **E644** for calibration procedures.

<https://standards.iteh.ai/catalog/standards/sist/9392e667-b1e9-4846-af93-f0284c19c432/astm-d5110-22>

6.1.8 *Barometer or Pressure Indicator*, accurate to 250 Pa (2 torr). The barometer or pressure indicator is used to measure the pressure of the gas in the cell to calculate a pressure correction. Most photometer cells operate at atmospheric pressure. If there are no restrictions between the cell and the output manifold, the cell pressure should be very nearly the same as the local barometric pressure. A certified local barometric pressure reading can then be used for the pressure correction. If the cell pressure is different from the local barometric pressure, some means of accurately measuring the cell pressure (manometer, pressure gauge, or pressure transducer) is required. This device shall be calibrated against a suitable pressure standard, in accordance with Test Methods **D3631**.

6.1.9 *Output Indicating Device*, such as continuous strip chart recorder or digital volt meter.

6.1.9.1 If a recorder is used, it shall have the following specifications:

Accuracy	±0.25 % of span
Chart width	no less than 150 mm
Time for full-scale travel	1 s

6.1.9.2 If a digital volt meter is used, it shall have an accuracy of ±0.25 % of range.

7. Reagents and Materials

7.1 *Zero Air*—Free of O₃ and any substance that by itself or whose decomposition products from the ozonizer might react with O₃, absorb 255.7 nm light, or undergo photolysis (for example NO, NO₂, ethylene, and particulate matter). The air shall be purified to remove such substances. Dirty air shall be precleaned to remove particulate matter, oil mist, liquid water, and so forth.

7.1.1 The following describes a system that has been used successfully: The air is dried with a membrane type dryer,⁵ followed by a column of indicating silica gel. The air is irradiated with a UV lamp to generate O₃, to convert NO to NO₂ and then passed through a column of activated charcoal (6 to 14 mesh) to remove NO₂, O₃, hydrocarbons, and various other substances, a column of molecular sieve (6 to 16 mesh, type 4A), and a final particulate filter (2 μm) to remove particulate matter. (**Warning**—An important requirement in photometer operation is that the zero air supplied to the photometer during the I_o measurement is from the same source as that used for the generation of O₃. The impurities present in zero air from different sources can significantly affect the transmittance of an air sample. This requirement presents no problem if the configuration shown in Fig. 1 is used. However, there may be a problem in certifying O₃ generator transfer standards that have their own source of zero air or O₃ (see Practices D5011). The zero air produced in 7.1.1 is very dry. The O₃ response of some measurement methods (for example, ethylene chemiluminescence, KI bubblers) is affected by changes in relative humidity. This dependence should be taken into account when reporting results.)

8. Hazards

8.1 *Safety Hazards*—See Practice D3249 for safety precautions on the use of monitors and electronic equipment.

8.1.1 Ozone is a toxic gaseous substance. See Practice E591 for biological effects, and for safety and health requirements.

8.1.2 The manifold vents and photometer and monitor exhausts must be vented to remove exhaust gases from the workplace. Care shall be taken to avoid a back pressure in the cell and manifold, and in the monitor or transfer standard being calibrated.

9. Preparation of Apparatus

9.1 *Conditioning*—The system shall be conditioned by flowing O₃ at maximum concentration for 10 to 30 min initially, and after periods of time while the system was not used, prior to reuse.

9.2 *General Operation*—A photometer used as a primary standard shall be dedicated exclusively to calibration service and specifically not used for ambient monitoring or as a transfer standard. The reason for this requirement is that the photometer must be intrinsically accurate and not exposed to outside effects. If it is used for other purposes, it will eventually become dirty and will be prone to O₃ losses and will give erratic readings. Reserving the photometer for use as a primary standard, where only clean, dry, filtered gas passes through the cell, will minimize loss of accuracy. A photometer used as a transfer standard will be subjected to environmental conditions, which may have an effect on its output.

9.3 *Photometer Verifications*—Since the accuracy of the calibration standards obtained by this practice depends entirely on the accuracy of the photometer, it is important to ensure that the photometer is operating properly and accurately.

9.3.1 A well designed and properly built photometer is a precision instrument; once shown to operate adequately, it is likely to continue to do so for some time, particularly if it is held stationary and used intermittently under laboratory conditions. Therefore, the performance checks may not necessarily have to be conducted every time the photometer is used. The actual frequency of the checks is a trade-off between confidence in the photometer performance and the cost and effort to conduct the checks. This is a matter of judgment, subject to the laboratory quality control checks (H12). One reasonable approach is to perform the checks very frequently with a new photometer, keeping a chronological record of each performance check, using the QA control chart, and to reduce the frequency as experience dictates. Even where the record shows excellent stability, the checks shall be performed at some minimum frequency (for example, once every 2 or 3 weeks) because the possibility of malfunction is always present. A regular schedule of checks will avoid the risk of losing long periods of data due to photometer malfunction.

9.4 *Instrument Manual*—If the photometer is commercially manufactured, it shall have been provided with an operation/instruction manual. The manual shall be studied thoroughly and its recommendations followed carefully and completely.

9.5 *System Check*—A visual inspection of the photometer system shall be conducted to verify that the system is in order. The configuration and plumbing connections shall be compared to the flow diagram. All connections shall be verified as being sound, and not restricting the flow. Any leaks shall be corrected. Cleanliness of cell, manifold, and lines shall be checked. A thorough leak

⁵ The sole source of supply of the apparatus known to the committee at this time is Perma Pure Inc., 8 Executive Drive, P.O. Box 2105, Toms River, NJ 08754. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

check is performed by blocking the output ports and measuring the inlet and exhaust flow rates with an external flowmeter. An alternate procedure is to measure the outlet flowrate and compare the reading against the system flowmeter reading. This procedure also checks the system flowmeter. The three-way valve shall be leak checked. Flowrates and vents shall be checked for lack of back pressure. The zero air supply components shall be checked to determine if the consumables require replacing.

9.6 Linearity Test—A linearity check is an indication of accuracy because the photometric measurement is a direct ratio measurement. The photometer operates over a very narrow range of absorbance, so nonlinearity is normally not a problem with properly functioning apparatus.

9.6.1 The linearity test is conducted by first generating and assaying an O₃ concentration near the upper range limit of the system. Then the concentration is diluted with a configuration similar to that shown in Fig. 2. A flow of zero air is added to the original generated concentration, and the mixture is passed through a mixing chamber to produce a homogeneous concentration at the output manifold. The dilution ratio shall be accurately known; hence the original and dilution flowrates shall be measured to ±2 %. To ensure sufficiently precise measurements of the ratio, the two flowmeters shall be of the same general type, and one shall be calibrated against the other. The dilution ratio is calculated as follows:

$$R = \frac{F_o}{(F_D + F_o)} \tag{3}$$

where:

- R = dilution ratio,
- F_O = flow of original concentration, and
- F_D = dilution flow.

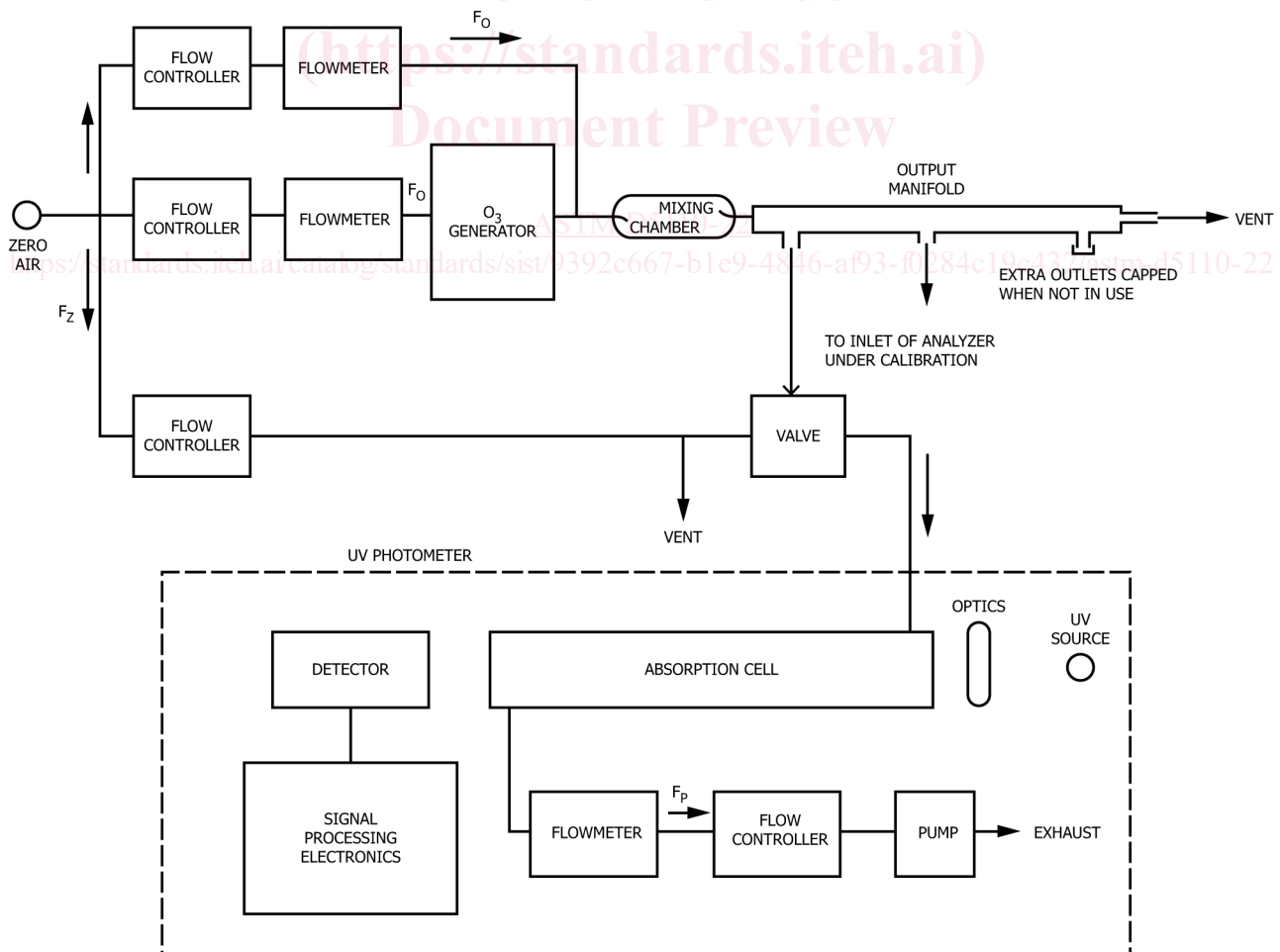


FIG. 2 Schematic Diagram of a Typical UV Photometric Calibration System (Option)

9.6.2 When the dilution flow has been adjusted and the dilution ratio has been calculated, the diluted concentration is measured with the photometer. The diluted concentration is then compared to the original undiluted concentration by calculating the percent linearity error in accordance with the following:

$$E = \frac{(A_1 - A_2/R)}{A_1} 100 \quad (4)$$

where:

- E = linearity error, %,
- A_1 = original concentration, ppm,
- A_2 = diluted concentration, ppm, and
- R = dilution ratio, from 9.6.1.

9.6.3 The linearity error shall be less than 5 %. It should be noted, however, that the result may not be a true linearity test because it includes possible errors in the flow measurements. If the error is greater than 5 % or exceeds previous determinations, the accuracy of the flow dilution shall be verified.

9.6.4 The linearity test shall be performed for at least five dilution ratios, and the mean linearity error calculated.

9.6.5 If the linearity error is excessive and is not due to flow measurement inaccuracy, the photometer system shall be checked for the following:

- Dirty or contaminated cell, lines or manifold
- Inadequate system conditioning
- Leaking three-way valve or system
- Contaminated zero air
- Nonlinear photometer detectors
- Faulty photometer electronics

9.7 *Intercomparison*—A good check on the overall accuracy of a photometer calibration system is an occasional comparison with O₃ standards from other (independent) organizations. Such comparisons can best be made with transfer standards (see Practices D5011). If both standards agree, it is likely that both are accurate; if they disagree, it is evident that one of them is inaccurate, and further investigations are necessary.

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9.8 *Ozone losses*—In spite of scrupulous cleaning and preconditioning, some O₃ may inevitably be lost upon contact with photometer cell walls and gas handling components. Any significant O₃ loss must be quantitatively determined and used to correct the output concentration assay accordingly. O₃ loss shall not exceed 3 % and shall be constant.

9.8.1 To determine O₃ loss, first calibrate a stable photometer with the UV calibration system, assuming no O₃ loss. An O₃ concentration is then generated and measured with the monitor as close as possible to the actual inlet of the photometer cell. Then the concentration is measured as closely as possible to the outlet of the cell. Each measurement shall be repeated several times, and at several O₃ concentrations, to obtain a reliable average. The concentrations at the output manifold shall also be measured. Some commercial photometers have access fittings permanently installed to facilitate frequent loss checks.

9.8.2 Since a continuous O₃ flow through the photometer system is required when making these loss checks, the three-way valve shall be in the “sample” mode. In making these measurements, it is important to avoid shock or damage to the photometer, and to reassemble the fittings and check for leaks if permanent fittings are not available. Also, any pressure differences at the measurement points may cause inaccurate measurements if the monitor is affected by pressure changes.

9.8.3 For the system in Fig. 1, the percent O₃ loss is calculated as follows:

$$\text{Percent O}_3 \text{ loss equals } \frac{c_m - \frac{(c_{in} + c_{out})}{2}}{c_m} 100 \quad (5)$$

where:

- c_{in} = O₃ concentration at the cell inlet,