radionuclides, but excellent resolution in alpha spectroscopy requires use of membrane-type filters, which are front-surface collectors.

Decisions on upgrading to more modern filter media should include additional considerations, such as the potential loss of continuity between historical and future sampling results, potential impacts on vacuum system performance, requirements for analyzer retesting and re-qualification, requirements for revision and approval of documentation, retraining requirements for workers, and potential impacts on secondary uses of the filter samples, such as periodic chemical analyses for process control. However, some filter media date back many decades and their continued use is not justified simply because of historical precedents.

When filter media are used, a backup support that produces negligible pressure drop should be used behind the filter to prevent filter distortion or deterioration. The sample holder shall provide adequate structural support while not damaging the filter, shall prevent sampled air from bypassing the filter, should facilitate changing of the filter, and should facilitate decontamination. If gaskets are used to seal the filter to the backing plate, the gasket should be in contact with the filter along the entire circumference to ensure a good fit. Periodically, inspections of the gasket should be performed to detect degradation and eliminate buildup of dust or filter material, which could result in sampled air bypassing the filter.

To reduce the uncertainty associated with collection efficiency, filters that are used for sampling airborne radioactive particles should have a minimum efficiency of 95%. Efficiency values shall be applicable to the conditions of use. For example, the collection efficiency of a Whatman 41 cellulose fiber filter is 99.5% for 0.3 μm aerodynamic diameter when the face velocity is 124 cm/s, but drops to only 72% at a face velocity of 16.9 cm/s (Liu et al. 1983).

If published or manufacturer's data on filter collection efficiency are not available for the particle sizes of interest, then the efficiency shall be determined by the user. This can be done by placing a highly efficient membrane or glass fiber filter behind the filter of interest and then comparing the mass penetrating to the backup filter to the total mass collected on the both filters (see Hickey et al. 1991). If a filter with an efficiency lower than 95% is required to meet the overall sampling objectives, then a correction for efficiency shall be made. Because filter efficiency is a function of air flowrate, care shall be taken to maintain a sample flowrate that is adequate to achieve the desired collection efficiency.

If penetration of radioactive material into the collection media or self-absorption of radiation by the material collected would reduce the count rate by more than 5%, a correction factor should be used. A dual filter method can also be used to measure efficiency absorption in the filter medium (Hickey et al. 1991). Evaluation of self-absorption in the material collected may require separate radiochemical analyses.

Annex D illustrates the type of information that is useful in selecting an appropriate filter for sampling airborne radioactive particles. This includes physical and performance characteristics of a number of typical coarse-fiber, fine-fiber, and membrane-type filters.

6.7 Collection of gas and vapor samples

Airborne radioactive volatile materials and noble gases (e.g., krypton) are frequently present in nuclear facility effluents. Their sampling and collection require techniques and methods that are different than those used in particle sampling. This topic may be divided into two general methods of sampling: 1) sampling with retention of specific constituents of the airstream, and 2) sampling without constituent separation. Annexes C and H provide further guidance specific for radioiodine and tritium.

6.7.1 Sampling with retention of specific constituents

Sampling with removal and collection of specific constituents requires a detailed knowledge of the

chemical and physical properties of the radioactive material of interest, including possible interfering materials such as particulate matter and accompanying non-radioactive gases (e.g., acids and organic chemicals). The many possible combinations of the properties of the constituents to be measured and the accompanying airborne materials require careful study to select the optimum collector. Gases and vapor components may be soluble in water, may be highly reactive with certain solutions, may dissolve in specific non-aqueous solvents, or may be retained on specific solid adsorbents or other specifically prepared media. In general, continuous or extended samples are taken when separation and removal of a constituent is required. Sampling rates shall be established to ensure adequate sensitivity for the selected radioassay method and shall be compatible with the collector performance characteristics. Avoiding sample breakthrough should also be considered when choosing the sampling rate and duration. The principal collection methods include solid adsorbents (such as carbon, zeolites, silica gel, and metal beds), condensation, gas absorption, and catalytic or chemical reaction. More detailed descriptions can be found in Brown and Woebkenberg (1989).

6.7.2 Sampling without constituent separation

In some instances a sample of air containing gaseous radioactive constituents may be desired for measurement of trends or relative levels of airborne materials. Examples are noble gas isotopes, tritium, and activated gases near a reactor. Volume collection and flow-through detectors are the two principal methods for total gas sampling or monitoring.

Because the constituent radioactive materials of interest may not be concentrated with a particular flow-through or volumetric collection device, insufficient sensitivity of detection may limit or preclude their use. Each situation will have to be evaluated individually to determine the feasibility of the gross sample measurement.

Volume collection methods include the following:

a. using an evacuated container that can be valved open to the stream of interest, then sealed and returned to a laboratory for measurement of gross radioactivity or of individual constituents;

b. passing the stream through the sample vessel until the vessel is completely purged, then closing the inlet and outlet valves;

c. pumping the sample stream into deflated bags (of a non-adsorbing material) for later compression and analysis

d. compressing the sample stream into a vessel for realtime or subsequent analysis.;

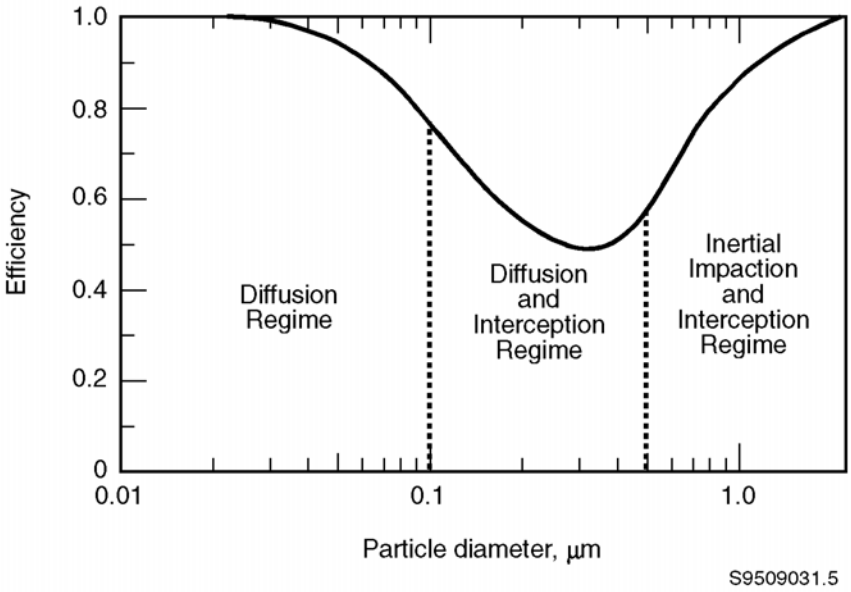

Figure 3 – Schematic of filter efficiency vs. particle size illustrating the different filtration regimes (Lee and Ramamurthi 1993)

A flow-through sample vessel may also be an ion chamber whose ion current reflects the relative radioactivity of material in the gas. Care shall be taken to keep the gas well above its dewpoint in the sampling system and ionization chamber. A gradual buildup of contamination in the chamber should be expected. The effect will be manifest by a gradually increasing response with clean air in the chamber.

Flow-through chamber samplers may be similarly monitored by gamma-ray scintillation crystal counters or other detectors held adjacent to or inserted in a well in the chamber wall. An increased background from contamination is to be expected in these samplers, and the chamber shall be periodically decontaminated to avoid errors from this source. Prior filtration of the airstream will assist in keeping the chamber clean when gaseous constituents alone are to be measured. A flow-through sampling system, which is frequently used at power reactors for acci

dent monitoring, involves placement of a high- or wide-range detector mounted directly inside or outside the effluent stack or duct.

6.8 Sample volume measurement

The volume of the sampled air is a key parameter in determining emission rates and dose levels. Because sample volume depends on the density of air, a standard density value should be selected for all data that are used to represent or report sample volume data at a facility. It is recommended that the standard density be based on dry air at a pressure of 101.3 kPa (760 mm Hg) and a temperature of 25°C (298 K). The total sampled volume at these standard conditions is represented by the symbol $Q_{T,std}$. Other pressure and temperature values may be employed in use of the data for calculating exposure levels; however, the density would be nonstandard and shall be so reported.

For record sampling, if the stack or duct is PIC 1 of table 2, measurement and control of the sample flowrate shall be used and the sample flowrate

shall be varied in proportion to the flowrate through the stack or duct. For other PICs of table 2, or when CAMs are used with PIC 1 sources, the sample flowrate may be held constant; however, this reduces the accuracy of the quantity of emitted radioactivity.

6.8.1 Basic considerations

The flowrate through a sampling system shall be measured and an indication of the value shall be displayed. However, if the flowrate is controlled at a set value (e.g., for PIC 2 and 3 systems of table 2), the display can be an error signal that the control system is out of compliance. The flow detector shall be placed in the flow system in such a manner that it does not cause losses of aerosol particles or reactive radioactive gases. As a consequence, the flow sensor is generally located downstream of the collector or analyzer. This sensor location generally causes the pressure at the point of measurement to be less than that in the stack or duct. Also, temperature at the point of measurement may differ from that in the stack, duct, or chamber from which samples are being removed.

6.8.2 Volume of air sampled

If the sampling flowrate will not vary by more than ±20% over the sampling period, as a minimum it should be recorded at the start and the end of a sampling period. For such a case, the total volume sampled, Q_T, may be calculated from

$$Q_T = \frac{q_1 + q_2}{2}\,\Theta \qquad (8)$$

where: q_1 (liter/min) is the volumetric flowrate indicated by the flowmeter at the start of the sampling period;

q_2 (liter/min) is the volumetric flowrate at the end of the period;

Θ (min) is the time period over which sampling is performed.

Continuous flow measurement control shall be used for all stacks and ducts where significant emissions could occur (PIC 1 of table 2), or if the flowrate can vary by more than ±20% during the sampling period. When continuous flow measurement is employed, the flowrate should be recorded at intervals not to exceed 10 minutes. The total volume of sampled air is based on integration of flow over the entire sampling period. If the time interval between recordings is Δt (min), and the flowrate during the interval (either the true average in the interval, the average of the initial and final values in the interval, or the value at the interval midpoint) is q_i (liter/min), the total volume of air sampled (liter) is calculated from

$$Q_T = \sum_{i=1}^{N} q_i \Delta t \qquad (9)$$

where N is the number of intervals. Other integration schemes may be used if the numerically induced errors do not exceed those implicit in eqn (9). The total sample volume, Q_T, is based on the flowrate indicated by the flowmeter. For many flowmeters, the indicated flowrate is not based on standard conditions, and appropriate corrections shall be made to the resulting data.

6.8.3 Flowrate control

If sampling is performed with constant sample flowrate conditions, where a controller is used to maintain constancy of flowrate, the flow controller shall maintain the flowrate within ±15% over conditions that correspond to an initial pressure drop across the collector (usually a filter) or analyzer to a value that is twice the initial pressure drop. The vacuum source used during a test of the controller shall have similar characteristics to the vacuum source used to draw air through the system in the field application. If the source is PIC 1 of table 2, a controller shall be used to maintain the ratio between sample flowrate and effluent flowrate within ±20% of a predetermined value.

6.9 Leak checks

A sampling system shall be inspected for leaks at the time of installation and at any time when either significant maintenance is performed or during an annual inspection. If the sampling system is used with a PIC 2 or 3 source (table 2), an inspection of the system is satisfactory provided the methodology used for inspection is documented. For sampling systems used on PIC 1 sources, the system shall be tested for assurance that leakage does not exceed an acceptable rate. One approach is to block flow through the nozzle, then apply a vacuum to the transport line and measure the leakage rate. For example, a mass flow meter could be attached downstream of the collector or monitor and the vacuum source connected to downstream side of the mass flow meter. The pressure level in the tubing between the collector or monitor and vacuum source would be adjusted to the nominal value encountered during sampling (typically about 4 kPa or 15" H_20 for sampling systems that involve use of collection filters) by bleeding air into the line downstream of the flowmeter. If the measured flow rate through the mass flow meter exceeds 5% of the nominal sample flow rate, the leakage is unacceptable. Other approaches can be used to demonstrate the leakage flow rate is acceptable provided the method allows the leak rate to be quantified and the leakage rate does not exceed 5% of the nominal sampling flow rate. Methodology used to quantify the leakage flow rate must be documented.

6.10 Optimization and upgrading of new and existing system

Even with complete awareness of the many conditions that contribute to obtaining a representative sample, the design will frequently be a compromise between the best location of the nozzle from a technical standpoint and safety and logistical considerations. Arriving at a suitable solution requires optimization among competing factors. Guidance on the process of optimization for radiological protection has been provided by the International Commission on Radiological Protection (ICRP 1989).

6.10.1 Defining the scope of the study

Optimization studies may address design issues covering all sampled and monitored stacks in a certain category (e.g., the use of a certain type of transport line and detector for all tritium stacks), or it may apply to specific stacks that require special treatment. If the design process is a prelude to new construction, it is usually easier to apply optimization globally to stacks in the same category. Retrofit of old facility stacks is more likely to involve stack-specific concerns and treatments. Once the scope of the optimization study is defined, it is necessary to specify radiological protection factors, constraints on access, applicability of certain options to achieve good mixing, and many other factors and limitations.

6.10.2 Identifying options and their consequences

A number of options will have to be considered in each case, with the implications of their adoption considered with respect to their contribution (or detriment) to representative sampling performance, consequences for workers' safety, and other factors affecting the decision. In some cases it may be advisable to conduct computational, laboratory, and/or field studies in support of the decision-making process. For example, it may be that a sample withdrawal location in an existing facility stack is unacceptable due to poor mixing, but is optimal in terms of accessibility, short transport lines, and worker safety and can be utilized if a simple, easily installed mixing system could be introduced. Computational fluids modeling, physical scale modeling, and *in-situ* measurements may provide effective solutions to complete the design of an optimized system.

6.10.3 Use of decision-aiding techniques

In many cases the results of an optimization study and a comparison among the options identified can be carried out qualitatively using straightforward prioritization and ranking techniques. But in some cases quantitative techniques may have to be applied to balance dose implications and other factors such as occupational safety, existing facility constraints, and others. Adequacy of documentation and reliability of any estimation and prioritization procedures used shall be a major concern in either case and should enter into the record of decision.

6.10.4 Upgrading and retrofit of existing stacks

Many existing nuclear facilities have stack sampling systems built during the 1960's through 1980s, which have isokinetic sampling with multiple small-diameter nozzles. In addition, many facilities have flow systems that are fitted with flow straighteners, which serve the purpose of making the velocity profile uniform, but which impede mixing of contaminant mass in the flow stream. It is now known that if an aerosol contaminant is not well mixed, and a multitude of poorly designed, small diameter nozzles are deployed, seriously nonrepresentative samples may result. Attempts to salvage existing multi-nozzle sampling systems, or designing such systems for new installations, have the potential to create severe deficiencies from the perspective of representative sampling of particulate matter in accident conditions. With the obvious exception of instances where the contaminant is gaseous (tritium or noble gases) and gas mixing is complete, it is difficult to continue to defend the use of isokinetic, multi-nozzle sampling systems without demonstrating their compliance with this standard.

7 Quality assurance and quality control

The purposes of a Quality Assurance (QA) program are to provide assurance to facility management teams, regulatory agencies, and the public of the validity of air sampling data, and to identify any deficiencies in the sampling equipment and procedures so that corrective action can be taken. The tools used to accomplish these objectives include documentation, maintenance, inspection, and calibration.

7.1 Quality assurance plan

Every facility that conducts radiological air emissions sampling shall have a QA Program that addresses the quality-related activities of the air sampling program. A specific QA Plan may be developed and implemented. As the minimum, the QA Program shall address the quality aspects of the air sampling program in the following areas:

a. organizational responsibilities;

b. personnel qualifications;

c. administrative controls;

d. means for identification of sources;

e. basis for the selection of sampling points. The methodology for verification of compliance with mixing requirements shall be documented;

f. basis for selection of sampling and monitoring systems. The methodology for demonstrating compliance with performance requirements shall be documented;

g. sample collection and tracking procedures;

h. calibration methods and calibration standards;

i. system operating procedures;

j. maintenance and inspection procedures;

k. procedure qualification;

l. data quality objectives and how they are accomplished;

m. audit and surveillance procedures;

n. corrective action program;

o. reporting and notification system;

p. program documentation requirements;

q. data analysis;

r. inspection status and disposition of deficient items and conditions.

7.2 Documentation

Documentation is an integral part of any QA program. The record keeping system shall ensure that all results are well documented and retrievable for analyses, audits, and archival purposes. The storage of data is as important as the collection of data. It should have an index arranged by storage files in a manner that will provide ready access. A copy of all documentation shall be maintained at a location remote from the principal data storage area.

Documents affecting the quality of air sampling data shall be prepared and reviewed by qualified personnel. The distribution of such documents shall be controlled.

A records system shall be established by the responsible organization that recognizes internal, external, and regulatory requirements. Such a records system shall designate records, their storage requirements, retention period, legibility requirements, identification, and retrievability.

7.3 System characterization and documentation

The quality assurance program shall assure that the air sampling system and its components are characterized and documented.

7.3.1 Source term

Drawings of the ventilation system serving each sampled stack shall be maintained. Modifications to the system performed during construction or anytime thereafter shall be described in detail. This includes changes to the ventilation system or changes to processes that might effect the effluent. The nature of the processes serving each stack shall be identified, including information about the identity of the radionuclides as well as their chemical and physical forms. The air cleaning systems associated with each stack shall be identified as well as the probable nature of releases resulting from the possible failure of these systems.

7.3.2 Effluent flow characterization

The results of studies to characterize the flow conditions of the effluents shall be documented (e.g., spatial and temporal variations in velocity across the stack or duct, checks for cyclonic flow, estimates of particle size distributions, etc.). The documentation shall include or list all procedures employed, times and dates of the measurements, individuals involved, equipment used, and any pertinent information regarding facility operations.

7.3.3 Design and construction

Documentation that describes the objectives of each stack sampling system, and includes or lists all radionuclides and their physical and chemical forms, shall be available. If a particular component is present but not sampled, the reasons should be discussed.

The rationale and any supporting evidence for sampling at a particular location along the duct or stack shall be documented. Similarly, the rationale for sampling at a particular point(s) within (across) the stack or duct shall be documented. Documentation that explains the rationale for the design of the sampling system shall be available. This includes documentation regarding the choice of the transport system, the material, diameter and configuration of the sampling lines, the choice of filters or absorbers, the selection of flowmeters, etc. Also, there should be a means for allowing verification that the installed sampling equipment is that described in the documentation. This can be accomplished by identification marks on the installed components. An evaluation of particulate losses in the sampling lines shall be documented. Other design documents that shall be maintained include engineering change control documents, equipment manuals, and vendor supplied information.

7.4 Training

Individuals involved in system operation, inspection, audits, surveillance, and calibrations shall receive training in these commensurate with their nature. Training requirements shall be determined by the responsible management organization and documented.

7.5 Maintenance and inspection requirements

The requirements for maintenance and inspection depend upon the nature of the sampling equipment. Routine maintenance should be performed as described in the manufacturer's equipment manuals. Non-routine maintenance should also be performed as indicated by the results of inspections.

Inspection and maintenance activities shall be described in procedures. Checklists should be employed as part of inspection protocols, and, after use, a checklist should become a part record of the inspection. The inspection and maintenance records shall include the nature of the inspection or maintenance, reasons for the inspection or maintenance, names of the individuals involved, times and dates, identity of the equipment employed, and a description of any replacement parts or materials. All deficiencies identified during scheduled and unscheduled inspections shall be dispositioned. A summary of recommended maintenance and inspection requirements is given in table 5.

Regularly scheduled inspections shall be performed at least once a year, possibly concurrent with calibrations. Ideally, the same individuals responsible for the calibrations should also be responsible for the inspections. The inspections should include but not be limited to:

a. checks of nozzle position and orientation;

b. the measurements of the nozzle opening and checks for dust accumulation;

c. functional checks of instrumentation;

d. visual inspections for corrosion, physical damage, or dust loading to the sampling lines and equipment;

e. checks to ensure the tightness of all fittings and connections;

e. leak tests.

7.5.1 Sampling system flowmeter inspections

Mass flowmeters should be checked at least quarterly with a secondary or transfer standard, where a transfer standard is typically a calibrated mass flowmeter placed in series with the unit to be tested. Unscheduled calibrations may be needed if any maintenance to the sampling system has been conducted that could affect the performance of the flowmeter. The flowrate at which the mass flowmeter is checked shall be at a level that is within ±25% of the nominal design sampling rate of the system. If the flowrate, q_{std}, of the flow meter being tested differs by more than 10% from the value indicated by a secondary standard, the flowmeter shall be removed from service for maintenance and calibration.

Flow through critical flow venturis should be checked at the start of each sampling period by observing the values of ΔP_m (differential pressure across the meter) and ΔP_f (differential pressure across the filter). If the value ΔP_m is less than that needed for critical flow, the vacuum system shall be checked to determine the cause. If the value of ΔP_f is less than 70% of that normally observed when the particular filter or collector is used, the critical flowmeter shall be inspected for blockage, or the sampling system shall be checked for other possible problems. The critical flowmeter shall be removed from service for cleaning and re-calibration if it is the cause of the erroneous reading. If the value of ΔP_f is greater than 130% of that normally observed, the filter or collector should be inspected for possible problems. Rotameters may not need to be checked in the field with secondary standards unless any maintenance or changes have been made to the sampling system that could affect its accuracy. A rotameter should be inspected at the start of each sampling interval for assurance that no foreign matter has been deposited on inside surfaces in the measurement tube. If foreign matter is visible, the rotameter shall be removed from service, cleaned, and re-calibrated.

7.5.2 Continuous effluent flow measurement apparatus

On a quarterly basis, response checks should be made of the flowrate readings from in-stack equipment through use of a reference Prandtl-type pitot-static tube. If a thermal anemometer or pitot tube is used in the stack or duct, the reference pitot tube should be placed in the vicinity of the in-stack device at a point where, based on previous measurements (e.g., EPA Method 2 measurements on an EPA Method 1 grid [40 CFR 60, Appendix A]), the velocity reading is either the same as that of the in-stack device or a known correction factor can be applied to provide a ratio of the two velocity readings. If the in-stack sensor is a pitot tube, the velocities calculated from use of the two tubes should be within ±10% (after taking into account any correction factors). If the in-stack sensor is a thermal anemometer, the velocity determined from use of the reference pitot tube, V, should be converted to the equivalent velocity at standard conditions, V_{std}, through use of:

$$V_{std} = V \frac{T_{std}}{T} \frac{p}{p_{std}} \qquad (10)$$

For the performance of the thermal anemometer to be acceptable, the ratio of the velocity at standard conditions indicated by the in-stack sensor and the reference sensor should be within ±10%.

If the velocity value from either an in-stack pitot tube or thermal anemometer is outside of the specified range, the cause of the difference shall be determined. The device may need to be recalibrated. Also, if a sensor requires maintenance that could affect the calibration, the device shall be recalibrated.

If the flow sensor is a pitot tube, response checks shall be made at least quarterly to verify the functionality of any pressure gauges used in conjunction with the pitot tube readout. This check may be a simple test to show the application of a pressure differential causes an appropriate output of the gauge.

If an acoustic flowmeter is used as the in-stack equipment, at least quarterly performance checks should be made by comparing the average velocity determined with the acoustic flowmeter to the velocity at a reference point determined with a Prandtl-type pitot-static tube. Based on EPA Method 2 measurements taken during calibration of the acoustic flowmeter, a ratio can be established between the average velocity and the velocity at the selected reference point. The

Table 5 – Summary of maintenance, calibration, and field check requirements

Item	Frequency or Criterion	Subclause Where Referenced
Cleaning of thermal anemometer elements.	As required by application	6.2.2.1
Inspect pitot tubes for contaminant deposits.	At least annually	6.2.2.2
Inspect pitot tube systems for leaks.	At least annually	6.2.2.2
Inspect sharp-edged nozzles for damage.	At least annually or after maintenance that could cause damage	6.3.4.5
Check nozzles for alignment, presence of deposits, or other potentially degrading factors.	Annually	6.3.4.8
Check transport lines of HEPA-filtered applications to determine if cleaning is required.	Annually	6.4.6
Clean transport lines.	Visible deposits for HEPA-filtered applications. Surface density of 1 g/cm^3 for other applications	6.4.6
Inspect or test the sample transport system for leaks.	At least annually	6.9
Check mass flow meters of sampling systems with a secondary or transfer standard.	At least quarterly	7.5.1
Check sampling flow rate through critical flow venturis.	At the start of each sampling period	7.5.1
Inspect rotameters of sampling systems for presence of foreign matter.	At the start of each sampling period	7.5.1
Check response of stack flow rate systems.	At least quarterly	7.5.2
Calibration of flow meters of sampling systems.	At least annually	7.6.1
Calibration of effluent flow measurement devices.	At least annually	7.6.2
Calibration of timing devices.	At least annually	7.6.3

velocity measured with the acoustic flow meter should agree within ±10% of the single point pitot tube measurement when the latter is corrected with the velocity ratio. If this criterion is not met, necessary evaluation, repair, maintenance, and calibration procedures should be used to solve any problems.

7.6 Calibration

Measurement and test equipment shall be calibrated using standards whose calibration is traceable to NIST (or other nationally recognized standards) or derived from accepted values of natural physical constants. The principal calibration activities on a sampling system involve the verification of sample flowrate, sampling time, and effluent flowrate. The suggested calibration frequency is annually for systems operated under normal or controlled environmental conditions. For systems used under extreme conditions, the calibrations should be conducted more frequently, e.g., every six months.

The methods used in calibrating all equipment and systems shall be clearly described in procedures. The results of all calibrations shall be recorded. This includes flowmeter and timer calibrations. The records shall include the names of the individuals involved, times and dates, and the types and serial numbers of the calibration equipment.

7.6.1 Calibration of sampling system flowmeters

The goal of the flowmeter calibration is to help ensure that the uncertainty in the measurement of the total volume of air sampled is ±10%. Annex E describes a number of considerations for uncertainty analysis. All flowmeters shall be calibrated at least annually against devices that are either based on first principles (bubble meters or proof meters) or that are traceable to NIST.

The internal sensing region of a flowmeter shall be inspected before calibration. If there is any indication of surface deposits, the internal components of the flowmeter shall be cleaned or replaced.

Mass flowmeters should be calibrated at conditions corresponding to 40%, 70%, 100%, 130%, and 170% of the nominal flowrate in terms of standard conditions. Other values may be used; however, technical justification shall be documented to show that the use of the selected points will provide calibration data equivalent to, or superior to, the recommended points. If the flowrate through the sampling system could, under normal conditions or anticipated or accident conditions, exceed the limits recommended herein for flow calibration, additional calibration points shall be used to encompass the possible operating range.

Critical venturi flowmeters may need only to be calibrated at a single point that corresponds to operating conditions with a sufficient pressure differential across the meter such that the velocity at the throat of the meter is sonic. The temperature at the entrance of the critical flowmeter during calibration should be within ±5°C of the average temperature anticipated at that same location during sampling. The absolute pressure at the entrance of the critical flow meter should be within ±2% of the average absolute pressure anticipated at that location.

Rotameters shall be calibrated at flowrate conditions that correspond to the average anticipated flowrate during sampling, and at 75% and 125% of the anticipated sampling flowrate.

The following approach, described in U.S. Nuclear Regulatory Commission (NRC) Guide 8.25 (US NRC 1992), can be employed to calculate the total uncertainty in the volume of air (E_{QT}):

$$E_{QT}^2 = \left(\mathrm{F_k}\,\mathrm{E_s}\right)^2 + \mathrm{E_c^2} + \mathrm{E_t^2} \qquad (11)$$

where: E_s is the error (dimensionless) in reading the flowmeter scale. This can be estimated by dividing one-half the value of the smallest scale division by the indicated flowrate.